2008

Integration of Analysis and Deliberation to Evaluate Biodiesel Occupational and Environmental Exposures

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Integration of analysis and deliberation to evaluate biodiesel occupational and environmental exposures

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Defense Date September 20, 2007

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INTEGRATION OF ANALYSIS AND DELIBERATION TO EVALUATE BIODIESEL OCCUPATIONAL AND ENVIRONMENTAL EXPOSURES

By

Nora M. Traviss

A dissertation submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy
Environmental Studies

at

Antioch University New England

(2008)

Dedication

To my beautiful son Jake,
for opening my eyes as well as my heart.

Acknowledgements

There are so many people to acknowledge that have helped me along this journey. Five years ago, I was motoring along in my job as an Environmental Health and Safety (EHS) Coordinator for Keene State College, capping off 12 years working in the chemical process industries as either an engineer or EHS manager. It was during these varied work experiences I became fascinated with how private organizations, regulatory agencies, and individuals made decisions about risk. I recalled how employees would ask me directly "is this safe?" when working with a new chemical and how I struggled with the answer: "OSHA says it's safe, but I don't know about EPA, then there's NIOSH, CDC…" I remembered a (nameless) environmental agency representative informing me he could "care less about the safety" of my workers in cleaning up a toxic release, but only cared about the environment.

These and other scenarios challenged my thinking in how risk is conceptualized, communicated, and ultimately reconciled in some organizational, local or regulatory decision. While I had always enjoyed the hands-on problem solving aspect of my career, in the back of my mind, I wanted to understand more. More specifically, I wanted to know the "why" and "how" of risk decision-making. As an EHS practitioner it was becoming increasingly harder to answer a deceptively simple employee question such as "will I get cancer from working with this solvent?" Digging into this question started me on the PhD journey.

So first, I want to thank the dozens of workers and colleagues I learned from while an EHS professional. There are simply too many to name here, but I would be remiss not to acknowledge their contribution to my development as a person and professional. When I first met Dr. Melinda Treadwell, I knew I had found someone similarly engaged by the challenges facing EHS professionals. I became intrigued with her passion for education and her research demonstrating the impact of diesel exhaust on worker exposures. To me, diesel exhaust exposure seemed like the public health crisis few cared about, an interesting paradox of how risk is conceptualized and managed. She seemed likewise intrigued with my practical risk management experience in industry, and actually believed I had something to offer academia. Soon we began a wonderful collaborative relationship that eventually started me on a new career as a college professor, and toward an examination of biodiesel and risk. Her faith in me gave me the courage to take the PhD plunge. Her mentorship helped me transition from engineer to scientist (well, she did the best she could do). Her encouragement was critical in believing I could finish. Her expertise and guidance during the exposure assessment were invaluable. Finally, we were able to pursue this work because of the financial resources of her National Institute of Health grant (# P20RR018787). I have enjoyed our collaborative research immensely and look forward to many more years working together at Keene State College.

Dr. Tom Webler also opened up a world to me that was unknown before Antioch. I was simply unaware of the vast literature and scholarship relating to risk and risk decision-making. He was my navigator in this area, and challenged me enormously in my thinking and writing. I became especially intrigued with the ideas of analysis and deliberation upon which I based this dissertation research. The whole time he was supportive as I formulated my approach, but I had no idea of the level of his expertise in this area. So imagine my surprise as I am putting together my dissertation proposal to see his name –literally – as a technical consultant in the National Research Council report *Understanding Risk*. I almost had a panic attack! I thought about how modest Tom is regarding his vast intellect and impressive body of scholarly work and his generosity of spirit in helping me navigate such new and unfamiliar terrain to me, but obviously very familiar to him. He let me find my own way, not forcing his way, which is really a sign of a great teacher. I will be forever grateful and I look forward to future collaborations.

Dr. Rachel Thiet was also an incredible support and resource. Her eye for detail and ability to articulate what worked in my dissertation and what didn't were invaluable. Her familiarity with both social science and natural science approaches was especially critical for my work. I also am eternally grateful for her constructive feedback and her personal support during those times in the process that were just overwhelming.

I would also like to acknowledge Dr. Robert McCormick, of the National Renewable Energy Laboratory, with whom I connected during the last few months of writing the dissertation. Bob very patiently helped me better understand the science behind emissions tailpipe testing, sending me and discussing with me key literature on biodiesel emissions. Thanks also for taking an interest in our exposure work here at Keene State College. I am very much looking forward to the next few years working with you and your excellent staff.

This work would not have been possible and was directly supported by my EPA STAR (Science to Achieve Results) Fellowship #FP916576. The fellowship program allowed me to take a leave of absence from my teaching duties at Keene State College and devote a full year to research, data analysis and writing. It was a lifeline of support not only to me but many other doctoral students around the country. From the amazing research I saw at the 2006 Fellows conference, I would like to tell EPA it is money well spent.

To Steve Russell: who knew that you asking me about biodiesel air monitoring in 2004 would lead to all this? I have learned so much from you, and most of all how one person can make a difference just by taking that first, scary step into the unknown. All this biodiesel work really did start with you and your keen observations. I look forward to working with you talking about biodiesel and your story far into the future.

To Duncan Watson, the Keene Recycling Center staff, as well as other members in the City of Keene organization: thank you for all your openness, candor, and help during this project. I hope I made you feel your contributions were invaluable, because they were.

To Bud Winsor, Mary Jensen, Mike Fuller and the rest of the Keene State College Grounds Crew staff – talk about making a difference, you are all environmental leaders quietly doing what needs to be done. How exciting that to your team, biodiesel, even using B100, is old news, and you are now implementing the next sustainability initiative. Thank you for your insight, sharing, support and always being available to talk about biodiesel (and other fun stuff!)

To the wonderful Keene State College students and research assistants: Brendan McDuffee, Conor Hobbs, Kelly McGovern, Nikki Landry, Nolan Masse, Derec LeClerc, Shanel Aliano, Irissa Plouff, Joe DiFraia, Andrew Denley, Mike Grotton, Corey Tremblay, Matt Atwood, Mike LeSage, Jaime Ingalls and Chris Langille. Thanks for all the hard work you put into the exposure assessment and other biodiesel research projects, your amazing enthusiasm, and the great conversations about biodiesel and assorted sundry topics. I feel like the future is going to be just fine with you leading the way. Thanks to Jaime Ingalls for being an instrumentation whiz during the exposure assessment and keeping all the field work activities (and students) organized. Thanks to Chris Langille for his passion about biodiesel and in helping make the Monadnock Biodiesel Collaborative come together.

A special thank you to Michael LeSage: Thank you for transforming my chicken scratch and back of the envelope diagrams into works of art as well as science. Thanks for helping me organize mountains of data as well as other unglamorous tasks too numerous to mention. Figuring out End Note comes to mind. I might not remember every single job, but I remember you never complained once. Well, maybe once, but I am sure after a buffalo chicken sandwich you were happy again. Your dedication, intelligence and commitment to the biodiesel research elevated this dissertation work as well as all those conference posters and presentations. I couldn’t have done it without you. You are exceptionally gifted, and a simply exceptional person. (P.S. – Go to grad school!)

To my family and friends: there are just not enough words to thank you for the support and belief you sustained in me over these past five years. To my girls at Antioch:

Melissa, LuAnne, Nicole, Vikke, Marion, Ella, Gabriela, Twyla, Randi and Mary Lou. Thanks for listening and being there through some very, very difficult times; I hope I can somehow repay the favor, and I cherish each of you.

I thank my friends, for the lunches and listening. Listening and more listening. Kathi, Vicki, Trish, Leslie. A friendship with someone going through a PhD program tends to be very one sided. You know who you are. Thanks for waiting for me. A relationship with someone in a PhD program is an oxymoron.

To my brother Jeff: we may not talk everyday, but my life is so blessed to have you in it. I feel like I hit the genetic lottery. You are the sweetest person and I appreciate how you supported me during these past five years (and longer). Thanks for all the gut busting laughs, when I really needed them. And of course, thanks for Chim-Chim. I love you.

To my mom: there are not enough “thank you’s” in the world I could say, but I will at least try. Without your support (and the dozens and dozens of loads of laundry, meals cooked, and hours watching Jake), I would never have made it. Just when I thought I would give up, you would come to my rescue and I would make it through a few more weeks. It means so much to me that you are proud – thanks for telling me a million times. Thanks also for putting up with countless hours of listening to my tales of woe, and pretty much all of 2007 and much of 2008 of me being a major crab. You are an amazing, giving person and I love you very, very much.

And finally, to my son Jake, I did this for you, in the shared hope that many parents around the world have…that maybe, in some way, I will somehow help make the planet a little better for you to inherit. If I could, I would give you a perfect world, but instead I will give you all the love I have. I thank God for sending you to me for I am truly blessed.   P.S. - I miss you, Daddy. I wish you were here so I could tell you thanks and I love you, too.

Abstract

Many U.S. organizations interested in a renewable and domestic source of energy are considering switching from petroleum diesel to biodiesel blends for transportation and heavy-duty equipment use. Biodiesel is a fuel made from vegetable oils or waste grease. While there is a considerable body of evidence on the negative health effects of petroleum diesel exhaust exposures in occupational and urban settings, there has been little research examining the impact of biodiesel fuel on occupational and environmental exposures. This dissertation combined a collaborative exposure assessment of B20 (20% soy-based biodiesel/80% diesel) at a rural recycling center with a policy intervention to deliberate the results of this analysis and potential policy outcomes. I applied the National Research Council's (1996) analytic-deliberative model to connect the collaborative exposure assessment with a Biodiesel Working Group, which catalyzed policy decisions about the manufacture and use of biodiesel in Keene, NH.

Researchers and undergraduate students from Keene State College and employees from the City of Keene Department of Public Works quantitatively estimated diesel and biodiesel exposure profiles for particulate matter (< 2.5 microns diameter), elemental carbon, organic carbon, and nitrogen dioxide using standard occupational and environmental air monitoring methods. I collected qualitative data to examine the genesis, evolution and outcomes of the Biodiesel Working Group. Integrating analysis and deliberation led to a number of positive outcomes related to local use of B20 in nonroad engines. Particulate matter and elemental carbon concentrations were significantly reduced (60% and 22% respectively) during B20 use at the field site. Organic carbon levels were significantly higher

(370%) during B20 use. Although NO_2 levels were 19% higher, this increase was not statistically significant. Connecting the analysis with deliberation improved the quality of the exposure assessment, increased dissemination of the research results in the local community, and catalyzed novel policy outcomes, including the development of a unique public/private partnership to manufacture biodiesel locally from waste grease.

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Introduction

1.1 An Overview of the Problem of Diesel Exhaust in the U.S. Today

1.1.1 Use of Petroleum Diesel in the U.S. Today

1.1.1.a Who Uses Diesel?

Petroleum diesel fuel is the lifeblood of the American economy. Although the vast majority of passenger cars in the U.S. are fueled by gasoline, diesel engines are used in almost all heavy duty trucks, buses, railway engines, marine vessels, as well as countless other industrial and commercial applications. These applications range from the obvious, such as the use of diesel engines to power front loaders and bulldozers at construction sites, to the more obscure, such the use of diesel engines to power air compressors to make snow in New England ski resorts. Decker et al. (2003) effectively illustrate how diesel engines are embedded in the U.S. economy by describing the journey of a shipment of grain from a farm to international export. First, diesel tractors and diesel combines till, plant and harvest the grain, with diesel powered pumps providing irrigation water. Diesel trucks bring the grain to storage silos; from there, diesel powered trains bring the grain to shipping ports where it is loaded onto ocean ships by diesel powered equipment, with diesel electrical generators providing backup power as necessary (Decker et al. 2003). Simply put, diesel engines are the backbone of both the production and transportation of goods and people in this country.

There are about 6 million diesel engines on the road in the U.S. and almost 6 million non road engines in tractors, forklifts, locomotives, construction equipment and other applications (Weinhold 2002). In the U.S. trucking fleet, almost all Class 7 and Class 8 trucks (heavy heavy-duty or more than 26,000 pounds gross vehicle weight) utilize diesel engines, and an increasing number of light heavy-duty, medium duty, and light duty diesel trucks were sold in the 1990's (EPA 2002a). In 2004, there were approximately 2.7 million trucks registered in Class 8 alone, and 2006 marked a new all time sales record for Class 8 trucks with over 284,000 sold in the U.S. (American Trucking Association 2007). Most of the 600,000 school buses in the U.S. that transport nearly 24 million children daily are powered by diesel fuel (Wargo et al. 2002).

These diesel engines rely on enormous quantities of petroleum diesel fuel. Figure 1.1 shows the rising trend in distillate fuel oil consumption in the U.S., averaging almost 4 million barrels per day in 2006 (Energy Information Association 2007). Approximately 68% of all petroleum was used in the transportation sector in 2006, and 45% of this transportation petroleum is gasoline (Energy Information Administration 2007). While gasoline is clearly the primary petroleum product for the U.S. passenger vehicle fleet, over half of distillate fuel oil – more than 2 million barrels per day – is used as highway diesel fuel. Additionally, the annual gallons of diesel fuel consumed have been steadily increasing – from 29 billion gallons in 1996 to 35 billion in 2000, with annual increases of 2% per year expected into the foreseeable future (Weinhold 2002).

1.1.1.b Benefits of Diesel Engines

Gas and diesel engines operate differently and so require different types of fuel. The gas powered internal combustion engine in a typical U.S. car operates by capturing the energy from a spark induced reaction in a cylinder to move a piston. Diesel engines operate by compressing an air and fuel mixture in a cylinder and more efficiently capturing this energy to do useful work. Diesel engines are much more efficient than gas engines (45% versus 30%) (Weinhold 2002).

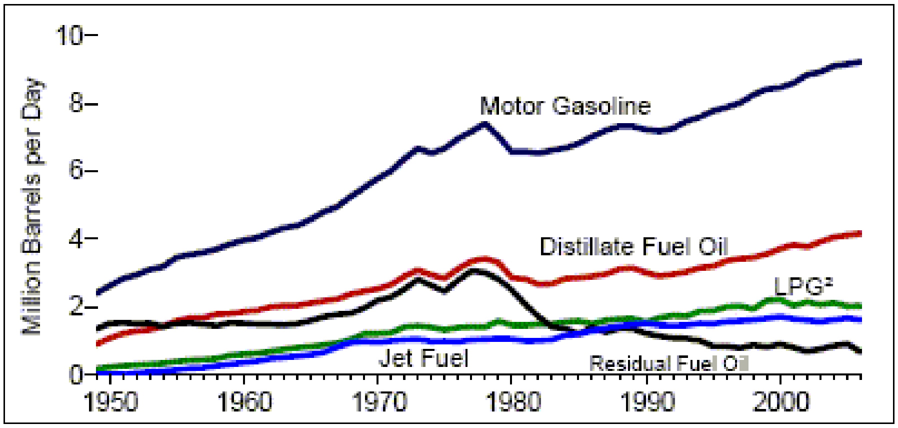


Figure 1.1: **Petroleum Consumption by Selected Product**
Source: EIA, 2007 (Available at: http://www.eia.doe.gov/emeu/aer/txt/ptb0511.html)

Increased efficiency means that diesel vehicles typically get better miles per gallon (MPG) when compared to equivalent gasoline vehicles. For example, a diesel powered 4 cylinder 2003 Volkswagen Jetta gets 40 MPG on the highway compared to 27 MPG for a similar sized gasoline powered Jetta (Department of Energy 2008).

Since diesel engines compress air to much higher pressures than gasoline engines, the cylinders in a diesel engine are designed to be more rugged and durable. Due to their better fuel efficiency, power, and engine durability, diesel engines are critical for heavy-duty applications. Many Class 8 engines can go to 1,000,000 miles before their first rebuild, and can be rebuilt several times (EPA 2002a). In addition to transportation applications, these powerful diesel engines have been adapted to a wide variety of non-road applications, such as construction and surface mining.

Due to emerging concerns regarding greenhouse gas emissions and climate change, the potential for diesel engines to get better mileage has focused attention on the difference between gasoline and diesel fuel. In 2003, the transportation sector accounted for about 27 percent of total U.S. greenhouse gas emissions, up from 24.8 percent in 1990 (EPA 2006).

Although diesel engines are more fuel efficient, emissions of carbon dioxide are greater from combustion of diesel fuel than from gasoline. According to EPA (2007b), 22 pounds of carbon dioxide is emitted per gallon of diesel fuel, compared to 19.4 pounds per gallon of gasoline. It is not clear whether the higher carbon dioxide output offsets the higher efficiency of diesel engines as a way to reduce overall greenhouse gas emissions.

1.1.2 What are the Hazardous Components of Diesel Exhaust?

Although diesel engines have many attractive qualities, the environmental and occupational health effects caused by exposure to petroleum diesel exhaust are daunting. There is substantial scientific evidence of negative health effects associated with exposure to the whole mixture of diesel exhaust, as well as negative health effects associated with exposure to the separate components of diesel exhaust. These health effects range from asthma exacerbation to lung cancer. In this section, I will review the hazardous components that make up diesel exhaust and in subsequent sections examine the literature on health effects associated with exposure.

Diesel exhaust is a complex mixture of over 450 components in vapor and particulate form. The main approach to better understanding the impact of diesel exhaust mixtures on human health has been to focus on the individual components in the mixture and their associated human health impacts. Figure 1.2 illustrates the materials that exit the tailpipe of a diesel vehicle: combusted fuel and lubricating oil, and unburned fuel and lubricating oil. These burned and unburned products are released as gases or in particulate phase form. The vapor phase consists of carbon dioxide, carbon monoxide, nitrogen oxides (NO_x), other inorganic gases, and numerous vapor phase hydrocarbon compounds like benzene and formaldehyde. Besides these gases, particles are emitted from the tailpipe. Primary particulate matter is emitted directly from the tailpipe and secondary particulate matter can form from the gaseous constituents transforming into particles (EPA 2002a).

Particles consist of an insoluble fraction and soluble fraction. The insoluble fraction is the elemental carbon core (EC) or soot and associated metals or ash that can't be dissolved in an organic solution. When diesel exhaust cools as it exits the tailpipe, the unburned fuel and oil condenses or adsorbs to the insoluble particle phase, forming a soluble organic fraction layer on the particle base (HEI 1995). The soluble organic fraction (SOF) is somewhat similar to the organic carbon content (OC) although SOF and OC are measured via different methods. The particles can undergo further atmospheric chemical processes such as oxidation or nitration, however there is limited knowledge on diesel exhaust's chemical and physical transformations in the atmosphere or the toxicological impact of these changes (EPA 2002a).

The detailed speciation of vapor phase, particle phase, and soluble organic carbon is more easily understood by examining Figure 1.3 below. Inorganic and organic gases such as vapor phase hydrocarbons are not attached to the particulate matter and form their own hazard category. Then the DPM (diesel particulate matter) phase consists of two main fractions: insoluble and soluble. The insoluble components of diesel particulate matter include mainly solid carbon spheres or the aforementioned elemental carbon (EC), with some metals, sulfates, and other unknowns. EC is carbon that is stripped of its hydrogen; EC content can range from 50-75% of DPM mass, depending on fuel, engine operation, and other characteristics (EPA 2002a). Adsorbed to EC is the soluble organic fraction (SOF), or the organic portion of DPM that can be extracted from the particle matrix into solution (EPA

2002a). While SOF and OC represent the adsorbed/condensed material on the solid carbon core, measurement of SOF and OC are by very different methods. Each of the components in Figure 1.3 – as well as the total mixture of the components - may be associated with significant health effects as described in the next two sections.

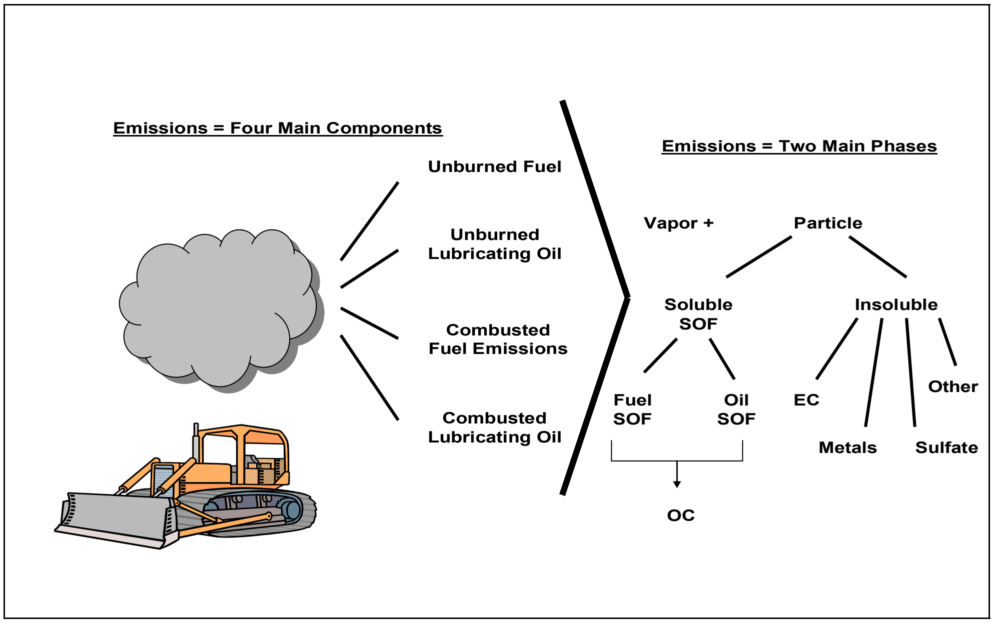
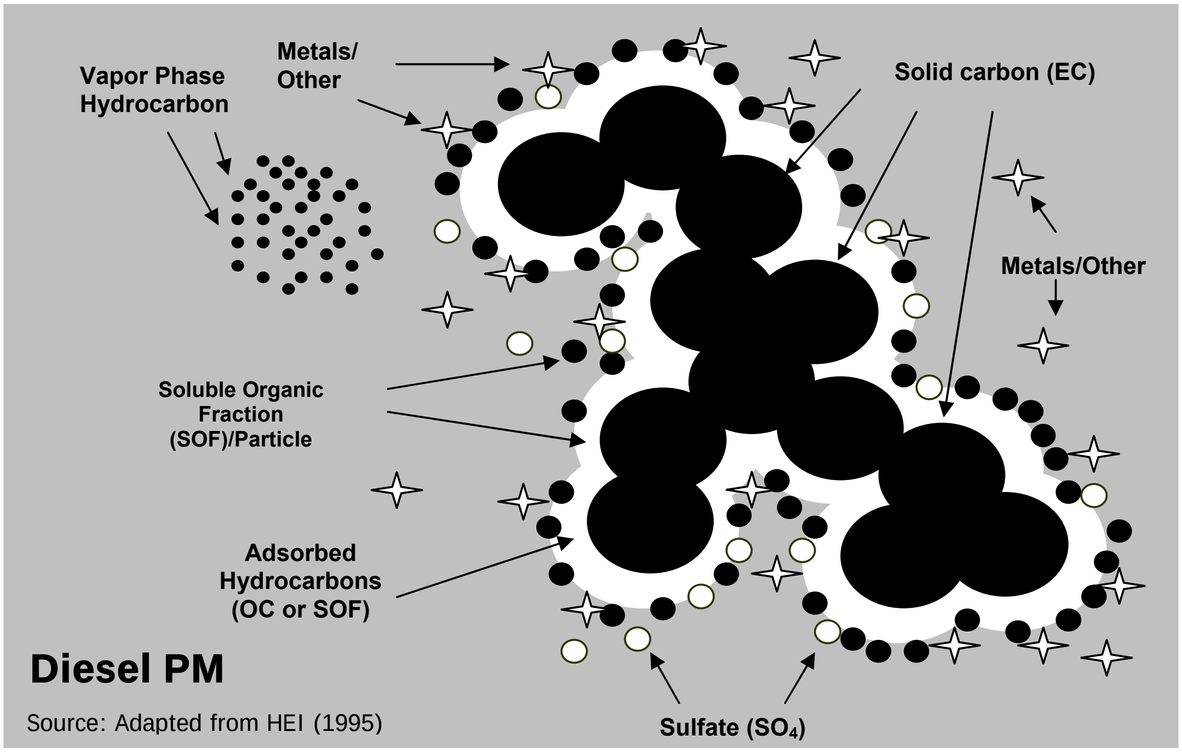


Figure 1.2: <u>General Composition of Tailpipe Diesel Emissions (Source: HEI 1995) (SOF = soluble organic fraction; EC = elemental carbon; OC = organic carbon)</u>



Source: Adapted from HEI (1995)

Figure 1.3: Details of Diesel Particulate Matter Speciation (Source: HEI 1995)

1.1.2a Main Focus of this Study: PM $_{2.5}$, NO_2, and EC/OC

Although diesel exhaust mixtures are chemically and physically complex and may vary due to engine type, load, operation, and chemical transformation in the atmosphere, there are critical components of diesel exhaust such as fine particulate matter and nitrogen oxides considered by public health scientists to be of primary health concern. This guided the selection of the air contaminants measured in this study. The key species measured were fine particulate matter (or particulate matter less than 2.5 micron in aerodynamic diameter), nitrogen dioxide, elemental carbon, and organic carbon. Fine particulate matter includes the soluble and insoluble fraction (solid carbon) of diesel particulate matter as shown in Figure 1.3. These air contaminants were selected due to their environmental and occupational health policy relevance and the local expertise and resources available at Keene State College for this study. To demonstrate the health policy relevance, first I will review the scale of the problem of diesel engine emissions' contribution to total PM $_{2.5}$ and NO_x inventories. Then I will summarize the major literature on human health effects from each pollutant.

1.1.2.b Scale of the Problem of Diesel Exhaust: Contribution of $PM_{2.5}$, NO_x, EC/OC to Ambient Air Pollution

Due to the widespread use of diesel engines, the scale of the problem of associated PM and NO_x emissions is significant. Diesel particulate matter is estimated to contribute up to 35% of total annual levels of $PM_{2.5}$ in some urban areas (EPA 2002a). As shown in Figure 1.4 below, approximately 90% of 2001 $PM_{2.5}$ emissions from all mobile sources came from onroad and nonroad diesel engines (Decker et al. 2003). The graph shows 64% of $PM_{2.5}$ came from nonroad diesel engines. By 2006, the total amount of $PM_{2.5}$ emitted by all mobile sources decreased slightly, but the percent contribution of nonroad engines to the total $PM_{2.5}$ emissions inventory increased to 69% (EPA 2007a). The majority of $PM_{2.5}$ from nonroad engines comes from construction, surface mining, and farm equipment sources, as indicated in Figure 1.5 below.

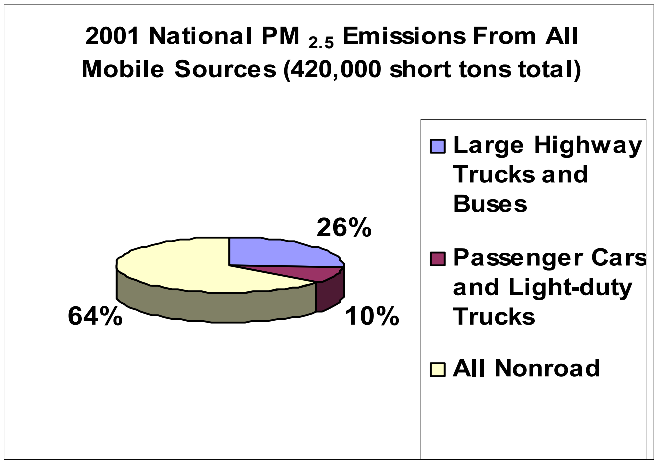


Figure 1.4: <u>2001 Emissions of $PM_{2.5}$ From All Mobile Sources (Source: Decker et al. 2003)</u>

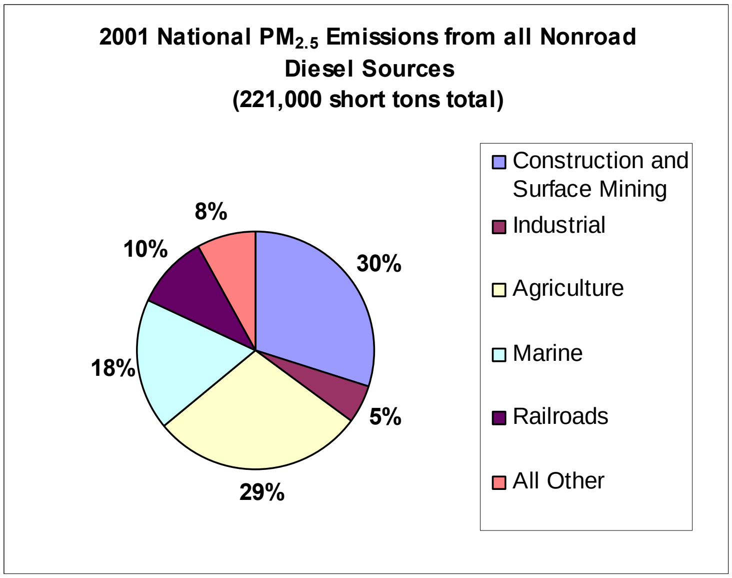


Figure 1.5: **2001 Emissions of $PM_{2.5}$ From Nonroad Diesel Sources (Source: Decker et al. 2003)**

Diesel engines are also large contributors to regional and national NO_x pollution. As shown in Figure 1.6 below, onroad and nonroad diesel engines accounted for 38% of national NO_x emissions totals in 2001 (Decker et al. 2003). Combining both onroad and nonroad diesel engines into one category results in the single largest source of NO_x. In 2006, over 1.5 million short tons of NO_x were emitted by diesel engines (EPA 2007a).

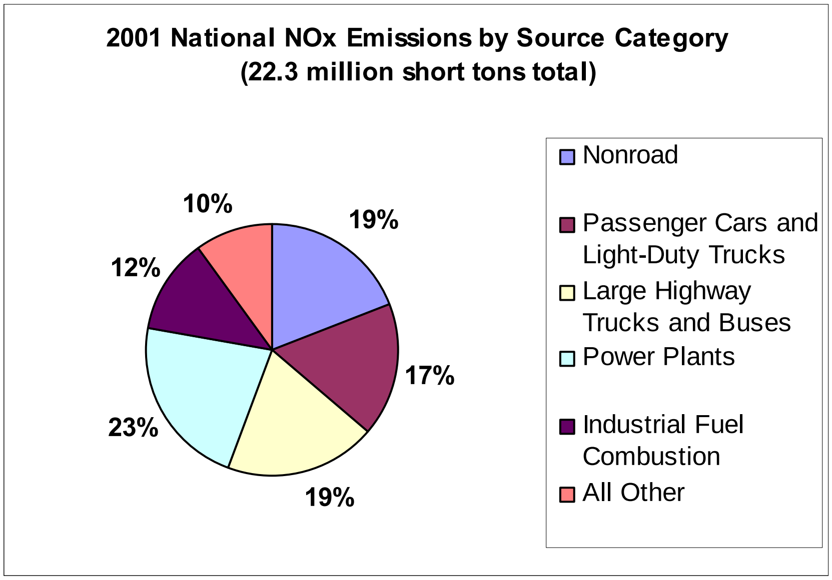


Figure 1.6: **2001 Emissions of NO_x From All Sources (Source: Decker et al. 2003)**

Determining national inventories of elemental or organic carbon or sources contributing these inventories is not possible at this time. Since $PM_{2.5}$ and NO_x are considered criteria air pollutants regulated by the Clean Air Act, there is extensive monitoring and inventory data available for these contaminants. Elemental and organic carbon represent the components of diesel particulate matter as shown in Figure 1.3, but are not required to be measured by any regulating authority. Elemental and organic carbon data (EC and OC) have been measured by researchers at local scales like the workplace and community. For example, a study of air quality in Harlem neighborhoods determined local EC levels ranging from 1.5 to 6.2 $\mu g/m^3$ (Kinney et al. 2000). EC can account for up to 90% of total DPM mass (HEI 2002), although in general EC accounts for about 50%-75% of the mass of DPM (EPA 2002a; Ramachadran and Watts 2003). Since most elemental carbon from vehicles is linked to diesel exhaust and not gasoline exhaust, EC is often considered a surrogate measure of total diesel particulate matter, especially in the workplace in the absence of other combustion sources (Cantrell and Watts 1997; Ramachandran and Watts 2003).

1.1.2.c Why Are These Components Hazardous? Summary of Human Health Effects of Diesel Exhaust, $PM_{2.5}$, NO_x, and EC/OC

U.S. regulatory agencies have determined that petroleum diesel exhaust is a "potential occupational carcinogen" (NIOSH 1988), and "likely to be carcinogenic to humans by inhalation" from environmental exposures (EPA 2002a). The extensive Multiple Air Toxics Exposure study (also known as MATES-II) conducted in southern California determined that 70% of the air pollution cancer risk for residents of the Los Angeles area was due to diesel particulate emissions (South Coast Air Quality Management District 2000). Exposure to diesel exhaust is also associated with a number of acute and chronic non-cancer health effects, ranging from nasal/eye irritation, decreased lung function, and increased cough to symptoms of bronchitis, chronic inflammation of lung tissue and reduced resistance to infection (SCAQMD 2000; EPA 2002a).

A number of researchers have suggested that diesel exhaust may contribute to allergic responses and asthma (Wade and Newman, 1993; Mauderly 2000; Pandya et al. 2002; EPA 2002a). Incidence of asthma has more than doubled from the 1978 to 1998 time period, affecting over 17 million people and highlighting the concern about possible associations between asthma and combustion related products such as diesel exhaust (EPA 2002c). A recent study of asthma rates in New England, which are consistently higher than the rest of the country, indicated 475,000 New England children (14%) and 1.62 million New England adults (15%) have been diagnosed with asthma in their lifetimes (Asthma Regional Council 2006). Asthma rates for New England children in the lowest income group were almost twice as high as asthma rates for New England children in the highest income group, and rates across all groups have been increasing (ARC 2006). There are a number of hypotheses for these increasing rates, including the impact of air pollution in urban areas. Diesel particulate matter may promote immunologic responses associated with asthma, which may help explain why some epidemiologic studies show an increased risk between children living near trucking routes and asthma (Pandya et al. 2000). EPA (2002a) has noted that children, the elderly, and people with existing heart and lung diseases like asthma are especially susceptible to the effects of whole diesel exhaust exposure.

The carcinogenic potential of whole diesel exhaust presents a major occupational and environmental health challenge. Although mutagenic and carcinogenic species have been identified in the organic carbon part of diesel particulate matter, there remains significant controversy regarding the strength of the association between environmental or ambient diesel exhaust exposures and lung cancer risk for the general public. Occupational exposures to diesel exhaust seem to indicate elevated lung cancer risk. The reported relative risks of long-term diesel emissions exposure in occupational settings range from 1.2 to 1.5, which indicates a 20 to 50% increased risk of developing lung cancer (HEI 1995). There have been at least forty epidemiological studies looking at lung cancer risk from diesel exposure (Mauderly 2000). However, though many of these epidemiological studies seemed to support a connection between lung cancer and human exposure, there has been such variety in methodological approaches – such as how smoking among study participants was addressed or whether exposures were directly quantified or instead estimated – that there continues to be a lack of scientific consensus regarding interpretation of the results and controversy regarding the findings (HEI 1995; EPA 2002a). In the next sections, I will review the health effects for each of the major components of diesel measured in this study.

1.1.3 Individual Hazardous Components: Health Effects

1.1.3.a Fine Particulate Matter ($PM_{2.5}$)

Diesel exhaust is an important source of fine particulate matter (PM), or particulate matter less than 2.5 micron in mean aerodynamic diameter. As 80 to 95% of DPM mass is less than 1.0 micron in diameter (with a mean particle diameter of 0.2 micron), almost all DPM is less than 2.5 micron in diameter (EPA 2002a). Fine particulate matter's main hazard is its ability to penetrate into the deep lung during inhalation. Particulate matter at this size is associated with numerous negative health effects including but not limited to increased mortality, direct lung injury (i.e., increased inflammation), cardiovascular effects (i.e., increased risk of arrhythmia in people with heart disease) and other organ effects (Lippmann et al. 2003).

Fine particulate matter exposure is especially problematic for certain groups within the national population. Health researchers have shown an association between the incidence of cardiovascular death and disease among postmenopausal women and long term exposure to $PM_{2.5.}$ Miller et al. (2007) studied over 65,000 postmenopausal women without history of heart disease in 36 U.S. urban areas with an estimated mean exposure to $PM_{2.5}$ of 13.5 ug/m^3. These researchers determined (with a 6 year median followup) that each increase in 10 ug/m^3 was associated with a 24% increase in the risk of a cardiovascular event, and a 76% increase in the risk of death from cardiovascular disease (Miller et al. 2007).

Sensitive subpopulations, such as older adults, children, and those with preexisting heart or lung disease are at increased risk from particle exposure and their associated health impacts (EPA 2003b; Pope 2000). Although the elderly, infants, and people with chronic diseases like asthma are more likely to experience death or serious illness from acute elevated fine PM exposures, the larger population is susceptible to the cumulative effects of chronic low level exposures, resulting in a predicted reduced life expectancy in areas with high particulate matter pollution (Pope 2000). More recently, particulate matter from all sources including diesel exhaust has been linked to reproductive problems and diabetes (Weinhold 2002). These and other studies support that $PM_{2.5}$ exposures are an occupational and environmental health policy problem.

1.1.3.b Elemental Carbon (EC) and Organic Carbon (OC)

Elemental carbon (EC) or the solid carbon core portion of diesel particulate matter is considered an especially potent component of the diesel exhaust mixture. These carbon particles can cause lung irritation and inhibit lung clearance mechanisms in animals, similar to other dusts like talc or silica (HEI 1995). As mentioned, EC makes up from 50-90% of DPM. The small size of the EC particle (typically less than 1.0 micron) also means it is reasonable to associate the health effects of $PM_{2.5}$ described in the previous section with DPM or EC (EPA 2002a). However, another important health concern for EC is related to its high specific surface area. The combination of small EC diameter size and high surface area means that EC is an effective carrier of adsorbed chemicals that can reach the deepest portions of the respiratory tract (EPA 2002a). EC is also strongly correlated with combustion of diesel fuel rather than other combustion sources. While EC is not 'one-to-one' measure of DPM, at this time EC is considered the best available "diesel signature" (HEI 2002).

The organic carbon content of DPM can range from 19 to 43% (EPA 2002a). Organic carbon is mostly unburned fuel and lubricating oil but also may contain PAH's and nitro-PAH's of key health concern. Many of the PAH's and nitro-PAH's identified in the organic carbon or soluble organic fraction of DPM are considered mutagenic or carcinogenic (EPA 2002a; HEI 2002). These mutagenic and carcinogenic organic compounds adsorb or condense on the elemental carbon core. The EC acts as a velcro-like platform, the OC sticks to the EC, and the combination becomes an advanced inhalation delivery system of toxics to the lungs.

1.1.3.c Nitrogen Oxides (NO_x)

Diesel engines also contribute large amounts of vapor phase NO_x to regional airsheds. NO_x is both a health concern from direct health effects such as lung irritation and an environmental concern due to the role of NO_x in ground level ozone formation. The main oxides of nitrogen include nitric oxide and nitrogen dioxide. Nitrogen dioxide was measured in this study and will be reviewed here.

Nitrogen dioxide is a severe respiratory irritant, with changes in pulmonary function noted at levels of 2 to 3 ppm, progressing to symptoms such as painful breathing as levels increase and leading to fatal lung injury at levels in excess of 50 ppm (OSHA 1991). Nitrogen dioxide symptoms can be delayed up to 12 hours after exposure (OSHA 1991).

Nitric oxide and nitrogen dioxide exposures tend to exist concurrently since NO is rapidly oxidized to nitrogen dioxide, with interconversion between species. While NO_x can come from natural sources such as volcanic activity and lightning, manmade production of NO_x comes mostly from combustion of fossil fuels, mainly in the form of NO from internal combustion engines (Manahan 2000). NIOSH has experimentally approximated a ratio of 35% NO_2 /65% NO in industrial settings where diesel exhaust is a primary source of exposure (NIOSH 1976). Although NO_x from diesel engines is primarily emitted in the form of NO, nitrogen dioxide is more harmful to human health at lower levels, and as such is a criteria air pollutant under the Clean Air Act.

Nitrogen dioxide's potential to photodissociate (or split into NO and O) in sunlight means it plays a critical role in ground level ozone formation with associated serious environmental and health impacts. Both nitric oxide and nitrogen dioxide contribute to smog formation by increasing ground level ozone, a respiratory irritant and major contributor to poor visibility or environmental haze. Ozone can cause lung and throat irritation, make breathing more difficult, and aggravate asthma (EPA 2003a). When nitric oxide emitted from diesel engines is converted to nitrogen dioxide, the subsequent photodissociation in sunlight starts a series of chain reactions contributing to ground level ozone and smog. Smog increases susceptibility to adverse health effects such as lung tissue damage, decrease in lung function, asthma, and negatively impacts crop yields/vegetation (EPA 2008b). NO_x emissions cause other problems such as acid rain, water quality deterioration, the formation of toxic chemicals in our atmosphere, and decreased visibility (EPA 2008b). Thus any source of NO_x, including those from diesel engines is an environmental and human health concern.

1.1.3.d The Particulate Matter/Nitrogen Oxide Tradeoff

EPA has regulated NO_x emissions from heavy duty diesel engines since 1985, with allowable emissions decreasing since that time. However, a further technical and policy complication is the PM/NO_x tradeoff in diesel engines: high combustion temperatures are needed to combust PM fully, yet these same high temperatures will lead to increased NO_x formation in the exhaust (HEI 1995). Lower temperatures or poor air/fuel mixing – indicators of poor combustion – will lead to lower NO_x emissions but higher PM emissions. The inverse relationship of NO_x/PM is the main barrier to lowering diesel emissions (Yanowitz et al. 2000). Since both PM and NO_x are undesired emissions, engine designers attempt to balance the undesired outputs against engine performance. The PM/NO_x tradeoff is also a challenge for alternative fuel considerations because oxygenated fuels like biodiesel may decrease PM but increase NO_x.

1.1.4 Environmental and Occupational Health Concerns of Diesel Exhaust

As defined by the World Health Organization (1993), environmental health "refers to the theory and practice of assessing, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations." Occupational health is defined as the "multidisciplinary approach to the recognition, diagnosis, treatment, and prevention and control of work-related diseases, injuries, and other conditions" (Levy and Wegman 2000). With respect to chemical exposures, occupational health examines the relationship between disease and workplace exposure, and environmental health examines the relationship between disease and a human populations' exposure to risk factors in the environment. Environmental health typically looks at disease/exposure relationships at a regional or global scale compared to a facility or organizational scale for occupational health.

Diesel exhaust exposures present both an environmental health and occupational health problem. As shown in the previous sections, the scale and volume of diesel exhaust emissions such as the contribution of diesel emissions to ambient background levels of $PM_{2.5}$ and NO_2 is significant. $PM_{2.5}$ impacts are of special environmental health concern, as numerous studies have consistently shown elevated fine particulate matter levels are correlated with increased hospital admissions and emergency room visits (EPA 2007c).

These environmental health impacts may also be disproportionate depending on socioeconomic status. Concerned about rising asthma rates in Harlem neighborhoods, a community based research study determined that DPM exposures in urban Harlem neighborhoods were elevated near diesel sources like bus depots (Kinney et al. 2000). DPM has been identified as having a key role in enhancing inflammatory and allergic responses in the lung (Diaz-Sanchez 1997; EPA 2002a). Environmental justice advocates maintain that incidence of asthma – and the link to diesel sources - disproportionately occurs in poorer neighborhoods (Kinney et al. 2000; Corburn 2005).

Diesel exhaust also poses an occupational health concern, as NIOSH (1988) has estimated over 1 million people are occupationally exposed to diesel emissions. Occupational exposures pose numerous noncancer health risks like lung inflammation, bronchitis, and asthma. A spectrum of epidemiological studies has indicated an increased risk of lung cancer associated with diesel exposure. For example, a detailed cohort study of railroad workers with occupational exposure to diesel exhaust indicated elevated lung cancer mortality (Garshick et al. 2004). However, EPA’s (2002a) meta-review of the epidemiological literature of occupational exposure to diesel exhaust in various jobs (such as trucking, mining, construction, and railroad workers) indicated a moderately increased relative risk of lung cancer but numerous methodological problems. Main points of controversy were correction (or lack thereof) for the impact of smoking on lung cancer cases, lack of a clearly identifiable diesel signature or singular marker for diesel exposure, and the use of surrogates for exposure (such as job title) due to the lack of measured, quantitative exposure data (EPA 2002a). These issues of scientific uncertainty have prevented development of a definitive dose-response curve for human exposure.

Diesel exhaust exposures remain a health concern for workers because occupational diseases like lung cancer may take decades to manifest, and external variables (such as high ambient background air pollution) make causality difficult to prove. In addition, certain work scenarios can result in combined environmental and occupational health impacts. Emissions from construction equipment can create unique microenvironments of elevated diesel exhaust levels, posing an increased health risk for equipment operators. Long term construction projects can create hazards for not only workers but nearby residents as the construction site becomes a semi-permanent source of air pollution in the local community. A recent exposure assessment performed for Northeast States Coordinated Air Use Management (NESCAUM) measured construction and industrial worker $PM_{2.5}$ exposures ranging from 1 to 16 times greater than background levels (Treadwell et al. 2003). The report estimated that as many as 200,000 workers may be exposed to harmful levels of diesel exhaust from nonroad equipment in the northeast (Treadwell et al. 2003).

In summary, in both the environmental and occupational health context, diesel exhaust poses a daunting challenge. In the next section, I will discuss the current regulatory approaches to manage risk from diesel exhaust exposure in the environment and workplace.

1.1.5 Current Regulatory Approaches for Managing Diesel Exhaust Exposures

1.1.5.a The Environmental Protection Agency's Regulatory Approach

EPA's main regulatory approach to manage diesel exhaust exposures has been two fold: requiring enhanced engine technology in new engines to reduce emissions, and reduction in sulfur content of highway diesel fuel from 500 ppm to 15 ppm. This ultralow sulfur diesel (ULSD) has been phased in since 2006, and as of 2007, new model heavy duty on road engines are required to meet stringent tailpipe emissions requirements that will significantly reduce PM and NO_x by as much as 90%. The emissions standards are based on new catalytic emissions control devices or other technology improvements, and are expected to reduce annual emissions of NO_x and PM by 2.6 million tons and 109,000 tons, respectively, by the year 2030 (EPA 2000). When fully implemented by 2030, the emissions reductions are expected to prevent over 8000 premature deaths, 9500 hospitalizations, and 1.5 million lost work days an annual basis (EPA 2000). Similar regulatory schemes will apply to nonroad engines, although emissions controls will not be required until 2014, and smaller engines do not have to meet the stringent emissions requirements of larger ones (EPA 2004). Nonroad diesel fuel sulfur content will be reduced to 500 ppm by 2007 and to 15 ppm by 2010.

EPA has also initiated a number of voluntary programs to encourage the replacement of existing engines with cleaner ones or place new retrofit emissions control technologies (such as oxidation catalysts) onto existing tailpipes. EPA provides technical and financial assistance through its voluntary National Clean Diesel Campaign for those eligible fleets that work towards reducing emissions. The Clean School Bus USA program encourages a number of strategies such as particulate filters, cleaner fuels (such as biodiesel) and anti-idling programs.

States have also tried to implement different policies and in some cases laws to reduce diesel exhaust pollution. In the Northeast, Connecticut, Massachusetts, and New Hampshire have anti-idling regulations (EPA 2008a). For example, New Hampshire has codified at Env-A 1101.5 that diesel engines may not idle for more than 5 minutes when the outdoor temperature is above freezing.

Finally, EPA has established a reference concentration (R_fC) of 5 $\mu g/m^3$ as an acceptable diesel exhausts exposure. This value is averaged over a 24 hour period, everyday for a lifetime, and is based on noncancer health effects only. The reference concentration of $5 \mu g/m^3$ is considered sufficiently protective of the general population for a lifetime of exposure without experiencing adverse respiratory effects like lung inflammation. However, the reference concentration mainly provides policy guidance for determining if air quality is acceptable from a health standpoint; there is no compliance or action-forcing provision if R_fC is exceeded.

In contrast, although not specific to diesel exhaust, EPA does have other health-based regulatory programs in place to control exposure to the components of diesel, such as the Clean Air Act's National Ambient Air Quality Standards for $PM_{2.5}$ and NO_2 levels. In 2006, in response to the growing body of knowledge of public health impacts from particulate matter, EPA lowered the National Ambient Air Quality Standard, commonly thought of as the "safe level" of exposure, from 65 to 35 $\mu g/m^3$ for a 24 hour average (EPA 2007c). The NAAQS for nitrogen dioxide has remained at 100 $\mu g/m^3$ average for an annual period. Under the Clean Air Act, states are required to submit State Implementation Plans to reduce air pollution and monitor air quality to ensure pollution is controlled. If air quality exceeds the NAAQS, the state could face sanctions from the federal government. States try to control sources of air pollution within their borders via permits and programs in order to ensure ambient air quality stays in attainment of NAAQS.

1.1.5.b The Occupational Safety and Health Administration's Regulatory Approach

The Occupational Health and Safety Administration does not regulate whole diesel exhaust exposure in the workplace. There is no Occupational Safety and Health Association permissible exposure limit (PEL) for diesel exhaust or diesel particulate matter. Although not legally binding, a DPM level of 150 $\mu g/m^3$ was proposed by the ACGIH (American Council of Governmental Industrial Hygienists) in 1995-1996. The proposed DPM exposure level was reduced to 50 $\mu g/m^3$ until the ACGIH withdrew the DPM listing in 2003. There is no legally binding standard other than in mines where MSHA limits average workday DPM exposure to 160 $\mu g/m^3$. Outside of mines, any reductions to diesel exposures in the workplace such as ventilation controls or "no idling" policies result from voluntary actions by employers.

With respect to the components of diesel exhaust, under the broader category of particulate matter exposure (which includes non-diesel sources of particles such as dusts), OSHA's permissible exposure limit is 5000 $\mu g/m^3$ compared to EPA's level of 35 $\mu g/m^3$. The OSHA PEL is an 8 hour time weighted average, as opposed to EPA's 24 hour time weighted average exposure limit. OSHA considers a PEL to be the allowable exposure for a worker that will not result in adverse health impacts if that worker were exposed 8 hours a day, 40 hours a week, over an entire career. OSHA's PEL for nitrogen dioxide is a 9000 $\mu g/m^3$ ceiling limit that cannot be exceeded during a workshift compared to 100 $\mu g/m^3$ averaged over a year. While OSHA does have diesel exhaust listed on its website as a safety and health topic, the information and links are mainly educational and point out the individual component PEL's and regulatory actions taken by EPA to manage the risk of diesel exhaust.

1.1.5.c The Insufficiency of Current Regulatory Approaches

There are a number of reasons why current regulatory approaches are insufficient. Ironically, one need not go any further than EPA's own National Clean Diesel Campaign (2007b) website to find justification for the need for faster action to reduce diesel exhaust exposures:

> Even with more stringent heavy-duty highway engine standards set to take effect over the next decade, over the next twenty years millions of diesel engines already in use will continue to emit large amounts of nitrogen oxides and particulate matter, both of which contribute to serious public health problems. These problems are manifested by thousands of instances of premature mortality, hundreds of thousands of asthma attacks, millions of lost work days, and numerous other health impacts.

In short, due to the durability and longevity of onroad and nonroad diesel engines and vehicles, EPA's main regulatory approach will not fully produce human health dividends until 10 to 20 years from now. New engines will very slowly replace existing diesel engines in current fleet inventories. Another generation of children, the elderly, workers and the general public will continue to be exposed to harmful levels of diesel exhaust. The public health concern is more critical in urban areas, such as in Los Angeles, Boston and New York City. Data from a community air quality study in Harlem, New York City (Kinney et al. 2000) indicated that locations with high diesel vehicle counts exceeded the 5 $\mu g/m^3$ reference concentration set by EPA to protect against lung impacts.

The current regulatory approach focuses mainly on PM and NO_x, not on the carcinogenic potential of diesel exhaust. Due to the scientific uncertainty regarding the association of diesel exhaust exposure with carcinogenic effects like lung or bladder cancer, it is unlikely stronger or faster regulatory action will occur. EPA's (2002a) weight of evidence approach in the Health Assessment Document concluded that diesel exhaust could only be classified as a B1 probable human carcinogen by inhalation at lower level environmental exposures due to numerous uncertainties. The uncertainties cited by EPA included a lack of understanding of diesel exhaust's cancer causing mechanism in humans, lack of scientific consensus regarding the relationship between occupational exposures and lung cancer, and expected changes in future engine and fuel technologies which would change future diesel exhaust exposures (EPA 2002a).

However, due to the identification of mutagens and carcinogens in diesel exhaust, and belief that no safe exposure threshold for mutagens and carcinogens exists, many scientists and advocates remain concerned that EPA's B1 assessment of diesel exhaust does not adequately protect public health. Typically EPA will advance regulatory options when the risk of cancer is at a 1 in 1,000,000 level (one excess cancer case per million people exposed). Although risk estimates from diesel exposure were not listed in the Health Assessment Document, other EPA policy documents put the risk estimate at 1 in 1,000 to 1 in 100,000 (Weinhold 2002). Although not enough to change its overall risk assessment, EPA allowed that evidence of mutagenic potential meant “a cancer hazard is presumed possible” at lower or environmental exposure levels (EPA 2002a).

Although EPA followed the steps to risk assessment outlined by the National Research Council (1983) report in developing its Health Assessment Document, there were major departures from typical EPA policy. Usually, the end product of a risk assessment is a quantitative estimate of excess unit cancer risk, sometimes also called the slope factor or potency estimate. Many researchers felt the mechanism that appeared to cause cancer in rats (via “lung overload”) was not specific to diesel exhaust exposure and not expected to occur in humans (EPA 2002a). Due to scientific uncertainty EPA (2002a) did not develop a definitive dose-response curve or slope factor for diesel exhaust.

The practical impact of not having a slope factor or cancer unit risk estimate is limited federal action to reduce diesel exposures via health protective emissions controls (Treadwell 2005). In other words, EPA completed a quantitative risk assessment, without ever finalizing an actual quantitative level of risk from exposure to diesel exhaust. Without an estimated level of risk, it is difficult to implement a cohesive regulatory approach to reduce diesel exposures to levels protective of human health. In contrast, maximum achievable control technology is required for carcinogenic air toxics emissions from industrial sources. Without a potency estimate, diesel exhaust exposures continue because they are not considered urgent enough for immediate and stringent control. It is also worth noting that the scientific discussion and review necessary to complete the EPA Health Assessment Document took over 10 years to finalize, due to ongoing debate between stakeholders and regulators, including the desire to review the latest science at each meeting (Treadwell 2005). It took over 10 years of debate in scientific and policy making circles to issue a nonbinding reference concentration value. With this background context, attempting to reconcile significant scientific uncertainty for more rapid implementation of emissions controls seems highly improbable.

Due to their proximity to sources of diesel emissions, workers as a subpopulation experience even higher exposures and have little to no regulatory protection. Occupational exposures to diesel exhaust tend to be much higher than environmental or ambient air exposures, posing increased risk to workers such as mechanics, miners and railroad employees (Cantrell and Watts 1997). In their seminal research study, Zaebst et al. (1991) found diesel mechanics and diesel forklift operators had diesel exposures significantly higher than background levels. A more recent diesel exposure assessment determined elevated levels of $PM_{2.5}$ and EC at sites that use nonroad equipment such as construction, farming, and a rural lumber yard (Treadwell et al. 2003). Treadwell and colleagues (2003) found workers at construction or similar sites were exposed to near field and in-cabin levels of $PM_{2.5}$ ranging from 2 to 660 $\mu g/m^3$, levels that were 1 to 16 times higher than background ambient levels.

The main way OSHA protects workers from chemical exposure risk is through enforceable permissible exposure limits (PEL's). As mentioned, there is no PEL for diesel exhaust, even though EPA (2002a) concluded "available human evidence shows a lung cancer hazard at occupational exposure levels" and NIOSH (1988) – the research arm of OSHA – concluded that diesel exhaust was a probable occupational carcinogen.

Additionally, although there are existing PEL's for diesel exhaust components such as particulate matter, these "safe" levels are orders of magnitude higher than EPA "safe" limits for the same chemical (5000 $\mu g/m^3$ [OSHA] vs. 35 $\mu g/m^3$ [EPA]). Treadwell (2005) points out even when the different averaging times are considered in the calculations (OSHA averages the exposure over an 8 hour workshift versus EPA's 24 hour day), workers can be exposed to daily particulate matter levels below occupational health limits but far above acceptable environmental health limits. Due to the discrepancies in EPA/OSHA health protective values, assuming a 5 $\mu g/m^3$ background $PM_{2.5}$ exposure, workers could theoretically experience the dose equivalent of about 48 EPA "unhealthy air" days in a single workshift. In a relatively short time, workers could experience a lifetime equivalent exposure in scenarios that would be considered completely unacceptable for a resident just outside the facility fence.

Diesel exhaust is an example of a chemical exposure risk vigorously debated in the environmental health sphere but not considered a priority risk in the workplace. "Acceptable" chemical exposure levels vary depending on whether one is standing inside or outside the facility fence. Some scholars consider the difference between the higher chemical exposure levels allowed by OSHA compared to EPA a manifestation of a hidden "ideological hazard" that considers worker health protection differently from the general public (Kasperson and Kasperson 1991). A "double standard" exists as a result of an ideological view that emphasizes the power of private business in the United States, and underscores the general reluctance of government to interfere with business operations. This lack of a health protective PEL also raises questions of environmental justice. Workers are more at-risk than the public due to higher exposure levels yet there is no workplace regulation. In summary, the case of diesel exhaust illustrates a disconnect between environmental and occupational health with respect to management of chemical exposures. Some of the possible reasons for the discrepancies will be discussed in the next section.

1.2 How the Problem of Diesel Exhaust Highlights a Disconnect Between Environmental and Occupational Health Risk Management

As mentioned, NIOSH (1988) identified diesel exhaust 20 years ago as a potential occupational carcinogen, estimating at the time that over 1,000,000 workers were exposed to diesel exhaust. The EPA Health Assessment Document noted the occupational data were "strongly supportive" of a diesel exposure–lung cancer link but did not regulate as a carcinogen and instead issued a reference concentration of 5 $\mu g/m^3$ to protect the public from noncancer health effects (EPA 2002a). No OSHA PEL exists for diesel exhaust. The PEL's that do exist for components of diesel – such as nitrogen dioxide and particulate matter – are 10 to 40 plus times higher than allowable EPA recommended limits. Why do such discrepancies between protection of environmental/public health and protection of occupational health persist? Though referring to other workplace hazards and not specifically to diesel exhaust, Shrader-Frechette (2002) argues the increased risk many workers face in the U.S. today is a clear example of environmental injustice. According to Shrader-Frechette (2002), if environmental justice is concerned with equalizing the burden of pollution across all segments of society, then environmental injustice occurs when one group bears a disproportionate risk, has less opportunity to participate in decision-making or has less access to environmental goods. Workers exposed to diesel exhaust appear to experience a disproportionate risk of exposure to diesel exhaust and also appear to have less opportunity to participate in decision making.

Both Shrader-Frechette (2002) and Kasperson and Kasperson (1991) suggest that the OSHA and EPA discrepancies in chemical exposure standards exist due to embedded societal beliefs including the following: job selection is considered a voluntary, individual choice, workers are both well compensated and well informed of the risks, and workers' compensation programs exist to pay for work-related injuries and illnesses. Shrader-Frechette's (2002) detailed analysis debunks many of these societal beliefs, showing for example, that workers in high hazard industries often do not earn better pay, nor are they well informed of the risks. Her arguments are compelling and outline important societal and ethical questions as to the fairness of different 'safe' exposure limits between agencies. However, there are also a number of other, arguably more structural barriers that impede progress toward an integrated chemical risk management approach protective of both environmental and occupational health. In the following sections, these barriers will be reviewed.

1.2.1 EPA vs. OSHA: Mandates

There are several explanations for why the discrepancy between EPA and OSHA safe exposure limits exists. Embedded within the broader environmental justice argument are a number of regulatory and institutional barriers that foster a separation between environmental and occupational health practice. Ironically, early research in the risk analysis field identified the workplace as a key source of present and future environmental risks and suggested that the workplace was an ideal hazard monitoring system, because exposures could be easily identified, monitored and effects on employees documented (Fischhoff et al. 1981). This viewpoint saw the workplace as the proverbial canary in the coal mine for environmental health risks and also that workplaces were clearly situated in the outside environment creating environmental health risks. Yet the swift passage of numerous environmental laws in the 1970's led to the emergence and evolution of dramatically different legislative mandates and agency cultures that helped create an artificial divide between the workplace and outside environment.

The divergent agency mandates of EPA and OSHA lead to significant regulatory barriers. EPA has responsibility to develop and enforce regulations for over 30 environmental laws, such as the Clean Air Act and Clean Water Act, while OSHA has responsibility for only one law, the Occupational Health and Safety Act (OSH Act). Environmental chemical hazards may be present as pesticide residues, new chemicals entering into commerce, or sources of air pollution from industrial sources. How EPA regulates chemical exposure risk depends on the environmental law as EPA is only authorized to take those actions specified within each law. Depending on the statute, EPA may or may not have to consider the economic or technological feasibility of compliance. Under the Clean Air Act (CAA), EPA does not have to consider economic or technological feasibility in developing health protective standards for the criteria pollutants (such as particulate matter), but must consider such feasibility in promulgating maximum achievable control technologies for chemicals identified as hazardous air pollutants (such as benzene). As another example, under the Toxic Substances Control Act (TSCA), EPA must balance risk to human health against the benefits of the chemical (to consumers and manufacturers) in order to make a determination of “unreasonable risk” (Cranor 1993). Per TSCA the burden of proof is on EPA to prove that a chemical is unsafe or that an extremely large number of people will be exposed in order to compel a company to perform additional toxicity testing.

These varying mandates set up a complex web of regulations that requires administration by technical experts in both the agency and the regulated industries, often setting up an adversarial relationship between experts over the finer points of regulatory interpretation and implementation. Other regulatory and institutional barriers have evolved since the 1970's. Environmental regulations are categorized by media (air, water, and soil), rely heavily on intense judicial review, focus narrowly on compliance rather than prevention, and center mainly on "end-of-pipe" controls (Fiorino 2006). In addition, environmental regulation, with its reliance on technical expertise, legal interpretation, and politically neutral managers, is also an excellent example of bureaucratic rationality (Fiorino 2006). However, there is a common thread throughout much of the environmental regulations that pertain to managing chemical exposure risk: EPA as an institution relies on quantitative risk assessment as an analytic tool to help meet statutory requirements and justify regulatory actions.

OSHA manages chemical exposure risk mainly through adoption and enforcement of permissible exposure limits. OSHA can initiate a new standard on its own or on petition from any other interested party, usually with input from an advisory committee (Ashford 2000). OSHA must also consider the economic and technological feasibility of the proposed standard. As such, setting health protective chemical exposure standards has been difficult for OSHA to implement in practice. OSHA has not updated the vast majority of its PEL's since the initial adoption in 1971 and most of these PEL's consider only noncancer health effects. The reasons why are related to OSHA's institutional use of risk assessment and are reviewed next.

1.2.2 EPA vs. OSHA: Institutional Culture of Risk Assessment

EPA uses quantitative risk assessment as a tool to characterize risks posed by chemical hazards much more frequently compared to OSHA. Although EPA utilized quantitative risk assessment techniques since its inception, in the 1980's returning EPA

Administrator William Ruckelshaus more fully embraced the National Research Council's (1983) risk assessment/risk management paradigm (Graham 1995). Ruckelshaus emphasized that much of the language in environmental laws contained "pious hope" that could not be met in practice and more pragmatic goals of risk management were needed (Ruckelshaus 1985). Under Ruckelshaus, EPA increasingly relied on risk assessment to meet evidentiary requirements within environmental statutes, especially to help determine acceptable risk levels for carcinogenic chemical exposures. Quantitative risk assessment provided a defensible basis for agency decision-making, or what Jasanoff (1991) refers to as "a lifeline to legitimacy."

Depending on the statute, EPA typically begins risk management policy deliberations at a risk level of 1 in 1,000,000 (one excess cancer case per 1,000,000 people exposed). Risk is typically defined in technocratic terms, as the probability of a hazardous injury/illness occurring. Simplify a very complex process, inhalation cancer risk is ultimately calculated by the equation: risk = exposure X toxicity, where exposure is the concentration of the chemical in air and toxicity is represented by the slope factor or unit cancer risk value. Exposures are then regulated via risk management policy decisions to ensure these risk levels are not exceeded. Since its inception, the benefits to EPA of risk assessment as an analytical tool soon became clear: allowable pollutant emissions levels could be standardized, clean-up standards at contaminated sites could be specified, acceptable levels of exposure could be determined, and enforcement mechanisms could be developed in a straightforward manner (Ginsburg 1997).

In summary, EPA's use of risk assessment increased dramatically during the 1980's as the scientific underpinning of regulatory decisions. Per the NRC (1983) paradigm, the more scientific risk assessment process was kept separate from - but fed information into - agency risk management or risk decision-making functions. The NRC (1983) paradigm is still prominent today, as exemplified by the recent diesel health assessment document.

In contrast, regulation of occupational chemical hazards is generally limited to the smaller universe of those chemicals common in the workplace. Unlike EPA, OSHA did not formally use risk assessment in the 1970's. At the time, OSHA did not consider risk assessment to be a necessary step in setting health standards under the OSH Act (Jasanoff 1986). OSHA viewed risk assessment as a potential tool to prioritize among risks but not to determine regulatory exposure levels (Cranor 1993). OSHA relied more on it's expertise and it's authority under the OSH Act in making decisions. In 1971, OSHA adopted as consensus standards the 1968 ACGIH (American Conference of Governmental Industrial Hygienists) threshold limit values (TLV's) for 450 chemicals, renaming them permissible exposure limits (PEL's). The PEL's are the centerpiece of OSHA's approach to chemical health risk management – employers are expected to keep workplace exposures below these limits, with penalties for non-compliance. PEL's are mainly protective against noncancer effects, and are based on a threshold concept, or that a threshold of exposure exists for most people below which adverse health effects are not expected to occur.

While many toxicologists do support the concept of a threshold for noncancer effects, many do not believe the threshold concept applies to carcinogens (Graham 1995). Many scientists believe there is theoretically no safe exposure threshold for a carcinogen because any exposure is associated with an increased cancer risk. OSHA was so concerned about exposure to workplace carcinogens that it proposed a generic carcinogen standard in 1977 that would regulate exposures to the lowest feasible levels (Graham 1995). Risk assessment wasn't needed by OSHA to establish a safe level or "acceptable" exposure level for carcinogens, as the goal was best practicable control to the lowest possible exposure level. With the proposed generic carcinogen standard, OSHA tried to avoid case-by-case, individual chemical risk assessments. Individual risk assessments can take 5 or more years to complete and are resource intensive (Cranor 1993).

However, industrial interests argued that risk assessment should be used to determine if the size of the carcinogenic risk was significant and to estimate health benefits in a cost benefit analysis of regulatory alternatives (Graham 1995). Some industrial legal challenges went all the way to the Supreme Court. In 1980, the "*Benzene*" case (Industrial Union Department AFL-CIO vs. American Petroleum Institute [448 U.S. 607]) became one of the most influential cases regarding OSHA's authority to issue health standards. OSHA had proposed to reduce the existing permissible exposure limit (PEL) of benzene, a known human carcinogen, from 10 ppm to 1 ppm, which was considered a feasible level. A majority of the Court ruled that OSHA did not provide substantial evidence that there was a "significant health risk" to workers at the present exposure level. OSHA was directed by the Court to use appropriate quantitative methods such as risk assessment to show workers were at significant risk at the present exposure level and that that risk would be reduced by the proposed standard (Jasanoff 1986). In short, agency expertise was not considered sufficient, and OSHA was directed to use quantitative techniques to evaluate risk.

After the "*Benzene*" decision, OSHA began conducting quantitative risk assessments for carcinogens and suspended the generic carcinogen standard (Jasanoff 1986). In addition, OSHA selected the lower range of the Court's suggested risk spectrum, and considered those occupational exposures that posed an excess cancer risk greater than 1 in 1000 as a starting point for further regulatory attention. Going forward, the 1 in 1000 value became OSHA's "bright line" decision rule for unacceptable risk. But there was a large universe of chemicals beyond carcinogens that posed health risks to workers. In 1989, OSHA proposed updating the bulk of the 1971 PEL's list to add new chemicals and to reflect more recent scientific information on existing chemicals. These updated PEL's were vacated in 1992 by the Eleventh Circuit Court of Appeals (*AFL-CIO v. OSHA*, 965 F.2d 962 [11th Cir. 1992]), which indicated that OSHA needed to determine significant risk existed for each substance, as required by the "*Benzene*" decision (Ashford 2000). In other words, OSHA needed to perform individual risk assessments on over 400 chemicals. These legal interpretations of OSHA's authority have severely constrained OSHA's ability to issue exposure limits to protect worker health.

OSHA has also adhered to a 1 in 1000 acceptable risk level compared to EPA's 1 in 1,000,000 acceptable risk level to trigger regulatory action. Most PEL's today still reflect the 1968 ACGIH values. These crucial court cases and policy decision rules meant the practice of risk assessment to protect human health and the environmental had now been opened to public and judicial critique. The science that informs the practice of risk assessment was also often critiqued, in what Fischer (2000) describes as an emerging politics of expertise and counterexpertise. In the next sections, I will more fully discuss the traditional risk assessment/risk management paradigm outlined by the NRC (1983), and take a closer look at the role of science in risk decision-making.

1.2.3 Risk Assessment vs. Risk Management: The 1983 Red Book Approach

An emerging theme from the above analysis is the prominence of quantitative risk assessment in agency decision making and the role of science in the risk assessment process. According to Jasanoff (1986), after the "Benzene" decision and publication of the NRC (1983) report, agencies like OSHA and EPA almost immediately incorporated the NRC's (1983) recommendations into their rule-making practices. In the NRC's (1983) risk assessment/risk management paradigm, risk assessment consists of four steps: hazard identification, dose-response assessment, exposure assessment and risk characterization. The output of the risk characterization is typically a quantitative estimate of risk, such as the excess risk of cancer that may result from inhaling a chemical at a specified concentration. Various scientific methodologies can be used to develop a risk assessment, including but not limited to epidemiology, toxicology, environmental science, statistics, industrial hygiene, and environmental engineering. While risk assessment may determine a quantitative estimate of risk, it does not determine whether that risk level is acceptable. Acceptability is considered the domain of risk management. Risk management refers to the evaluation of regulatory options to control risk, which includes the identification of associated public health, economic, social, and political consequences (NRC 1983).

Figure 1.7 shows how risk characterization was initially viewed as the end product of the risk assessment process - a quantitative estimate calculated by combining information from the exposure and dose-response assessment steps. Experts in risk assessment often relied on "uniform guidelines" to standardize "judgments", ultimately communicating risk estimates to the agency risk manager, who would develop and evaluate regulatory options. During the risk management phase, values associated with various options would be considered. Options would be deliberated by experts, with public participation where required by law. Although the NRC (1983) did recommend communication between assessment and management functions, in practice risk assessment and risk management became essentially divided.

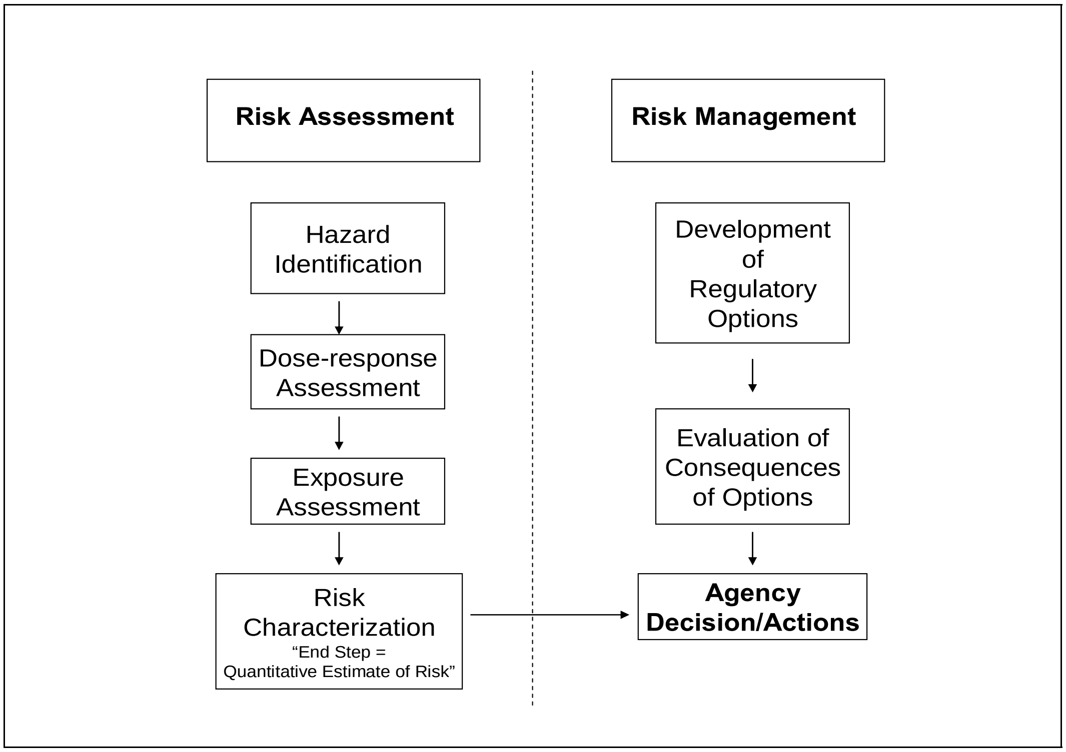


Figure 1.7: <u>Traditional Conceptualization of the Risk Decision-Making Process: The Risk Assessment/Risk Management Paradigm per the NRC's (1983) *Risk Assessment in the Federal Government*</u>

Risk assessment came to be seen as embodying more of the "science or facts" and risk management came to be seen more as the "policy or values" part of the decision-making process. Although the traditional paradigm frames risk assessment as a scientific process and risk management as the policy-oriented dimension of decision-making, in practice the two are very much intertwined. Risk assessment over the past thirty years has become institutionalized in EPA and OSHA. In numerous cases – such as the proposed ban on urea formaldehyde foam insulation - judicial review has emphasized the need for risk assessment and even critiqued agency risk assessment results (Graham 1995). The tangled relationship between risk assessment and risk management has resulted in multiple controversies and public erosion of trust in agency decision making.

Jasanoff (1986) describes the controversy over EPA's risk assessment of formaldehyde as prototypical of problems created by the facts vs. values dichotomy. In the early 1980's, an industry sponsored study showing a connection between formaldehyde exposure and increased risk of nasal cancer in rats prompted EPA to recommend a priority review under the Toxic Substance Control Act. While the rat data was considered reliable, and the doses used in the study comparable to human exposures, the available epidemiological evidence in humans was considered less certain, due to a lack of nasal cancer cases noted in human populations (although other cancers were noted). Industry scientists argued that the nasal cancer results observed in the rat study were specific only to rats, and not expected to occur in humans. The technical arguments and counterarguments revolving around EPA's risk assessment of formaldehyde ultimately led to the agency's reversal of a decision to more stringently evaluate formaldehyde's toxicity and prevalence of human exposure (Jasanoff 1991). Scientific uncertainty was exploited in a competing fashion by different experts to influence policy – pro-regulation scientists supported the rat studies as sufficiently conclusive to regulate, and pro-industry scientists argued regulation was premature as the data was too uncertain.

When viewed through the above lens, the diesel exhaust controversy shares many similarities with the formaldehyde case. While the animal studies indicated high concentrations of diesel exhaust can cause lung tumors in rats, EPA (2002b) pointed out the lung overload response observed in rats was not expected to occur in humans at environmental or occupational exposure levels. Similar to the formaldehyde risk assessment process, the diesel exhaust epidemiological studies were considered weaker and less reliable, due to issues of uncertainty. There have also been other technical issues: the Health Effects Institute's (2002) comprehensive report on risk from diesel exhaust expressed concern with both the methodological uncertainty associated with existing and proposed exposure assessments and the lack of an identifiable, specific diesel signature. While many scientists have argued for more regulation to reduce the health risk from diesel exhaust (Decker et al. 2003; Wargo et. al. 2001; Treadwell 2005), ultimately the regulatory approach has been cautious and incremental. For both the formaldehyde and diesel exhaust cases, scientific uncertainty in risk assessment appears to be a key point of political and scientific conflict in the risk decision-making process. Depending on one's worldview, scientific uncertainty can be used as an argument to either increase or postpone regulation of chemical exposures.

1.2.4 The Epistemiological Dimension: Policy vs. Normal Science

The appropriate role of science in risk decision-making and how to handle scientific uncertainty continues to challenge policy makers, agency experts, researchers and the public. Jasanoff (1986, 1991) states many risk controversies occur in the U.S. as a result of the desire to eliminate uncertainty by further refinement of quantitative techniques. As EPA has to justify its decision to both the public and regulated entities, risk policy has evolved to emphasize risk numbers upon which to base decisions. Yet, risk assessment debates can allow new kinds of uncertainty to come to the forefront, as shown in the formaldehyde case.

In the diesel exhaust case, the desire to incorporate evolving science to reduce uncertainty led to extensive delay and limited regulatory action. Ultimately, additional science did not resolve the contentious issues in both cases, but instead just brought more or new technical issues into the deliberations. These examples lay bare the policy conundrum of wanting a scientific basis for a policy decision, but coming up against the realization that not all questions are capable of being answered by science. Even if science determines an answer, often scientific inquiry creates new, relevant questions.

Part of the debate regarding the implications of scientific uncertainty may have more to do with competing epistemological understandings of science. "Mainstream" or "normal" science adheres to a reductionist philosophy that assumes systems can be taken apart, studied, and then put back together (Ravetz 2004). This idea of science builds on Kuhn's (1970) description of "normal" scientific research as a puzzle solving activity, intending to add to the foundation of existing scientific knowledge. Mayo (1991) asserts adherents to "normal" science believe that pure, value-free science exists as a kind of ultimate truth. Personal values must be kept separate from the objective fact-finding process of scientific investigation. Via this epistemology, one uses science to pursue a solution to the policy problem, believing that with enough research, a "best" solution will emerge from among alternatives. In both the formaldehyde and diesel exhaust cases, "normal" science did help make progress on total understanding of the exposure risk, but this progress was incremental, slow, and resulting regulatory action considered insufficient. "Normal" science is by its nature slow and incremental – but policy science needs facts quickly because decisions are often urgent, and policy makers regularly must make decisions without the desired ideal level of understanding.

Normal science is challenged by a social constructivist view of science in which facts and values interact (Fischer 2000). This viewpoint suggests science and policy are interconnected in ways not immediately obvious, even to scientists. Examples of science/policy interaction include when scientists decide to use certain statistical tests of significance, or the process of peer review. Science does not occur in a vacuum, segregated from the problem, nor is one "true" or "best" solution emphasized. While science is acknowledged as necessary to inform the policy process, the decision-maker at some point must cut the "knot of uncertainty" and the decision may not be improved by more quantitative analysis (Jasanoff 1991). Science by itself cannot solve many policy dilemmas simply because reasonable people (including scientists) disagree how to interpret information as well as decide which information is most important in making decisions (Stern 2005).

In closing, traditional risk decision making views science via a "normal" science lens, separate from policy, or that "science = facts" and "policy = values". The "facts" vs. "values" separation is comparable to the separation of risk assessment and risk management functions that has taken root in institutional cultures here in the U.S. (Jasanoff 1986; 1991). Attempting to separate science and policy by adhering to the "facts vs. values" dichotomy perpetuates a politics of expertise vs. counterexpertise (Fischer 2000). Yet the scientific method is itself a social process: scientific "facts" emerge often after a complex process of formal and informal peer review. Peer review, in essence, debates facts, because there is no one objective standard of "good" science. Since scientific expertise is thus interpreted, technical or expert judgment should not be the sole basis of policy decisions (Fischer 2000).

In summary, the regulatory, institutional and epistemological barriers outlined in this essay are formidable. Looking at the barriers separately invites speculation on regulatory or institutional solutions. But the cases in this chapter show that it is highly unlikely institutional or regulatory solutions will advance how scientific uncertainty is addressed in contemporary risk decision-making processes. Although not emphasized thus far, there are other uncertainties equally as challenging to risk decision-making as scientific uncertainty. For example, competing stakeholder and public values will also impact the risk decision-making process. Additionally, there are uncertainties in the level of trust stakeholders and citizens may have in regulatory institutions. Rayner and Cantor (1987) suggest that the conflict surrounding many risk management decisions has more to do with the lack of attention paid to issues of equity, trust and liability than issues of certainty of the estimates of probability of harm. Novel approaches to risk decision-making are needed to address these multiple dimensions.

1.3 How Risk Decision-Making has Changed: Moving from the NRC (1983) to the NRC (1996) Report

By the 1990's, it became clear new approaches to risk decision making were needed. Many scientists and environmental advocates had become frustrated with quantitative risk assessment's role in risk decision making. Some even considered risk assessment "ethically repugnant" and anti-democratic as it allows people to be exposed to toxic substances against their will, and legitimizes premeditated murder via chemical exposure (O'Brien 1997). Various calls for risk reform were made. Some critics of risk policy-making argued more broadly implemented cost/benefit analysis techniques could best guide regulatory agencies (Sunstein 2002). Others suggested a focus on democratic rather than technocratic improvements by expanding citizen participation in environmental decision making (Fischer 2000; Renn et al. 1995).

One view of policy-making is that policy emerges from shared understandings or knowledge. The critiques identified above may highlight the frustration with quantitative risk assessment (QRA), but it is arguably how risk assessment is used in decision-making that is at the root of the frustration. Ozonoff (1998:49) summarizes this view clearly:

> What gets environmentalists riled up about QRA has little to do with its use as an assessment device, but its use as a decision justification device. The agency/industry/policy maker has shot the arrow, and the risk assessment obligingly paints the target around it, preferably with sophisticated paint using an abundance of integral signs and capital sigmas to make it look infallible.

Fischer (2000) has recommended approaches to policy-making that incorporate a constructivist understanding of knowledge with a deliberative framework that reflects both scientific inquiry and local knowledge in an “evolving conversation.” Facts and values should not be kept artificially separate, and citizens and technical experts should work together. Improving risk decision-making in general - and integrating environmental and occupational health risk management more specifically - requires increased attention to the initial problem formulation stages, as well as ways to incorporate changes in understanding. One promising model that may lead to more informed risk decision-making is the NRC (1996) analytic-deliberative (A-D) model, which will be reviewed next.

1.3.1 Detailed Description of the A-D Framework

In the 1980’s and through the 1990’s, quantitative risk assessment had become the predominant frame for U.S. regulatory policy-making managing chemical exposure risk in the workplace and environment. However, the NRC (1996) acknowledged a fundamental deficit in the final risk characterization step in the QRA process: its emphasis on accurate translation of risk numbers for policy makers at the expense of missing the broader decision context and public concerns. The risk characterization step's focus on numbers and risk communication efforts to educate the public led to agency decisions – such as those regarding cleanup actions at contaminated hazardous waste sites – that resulted in controversy, public outrage, litigation, and overall increased public mistrust of agency decision-making processes. Yet the NRC committee realized during its work that the core issue was not improving QRA as a tool but how to best inform risk decision-making in a way that reflected the multidimensional nature of risk (Stern 1998). The scope of the problem was broader than deficiencies in one analytic tool.

Recognizing risk characterization as a complex nexus of science and judgment, the National Research Council (1996) undertook a broader look at this step and recommended that risk characterization be reconceptualized as decision-driven activity oriented towards solving problems. Risk characterization is performed via an iterative process of analysis and deliberation. Analysis refers to the use of "rigorous, replicable" methods from a wide variety of disciplines such as the physical sciences, law and mathematics to "arrive at answers to factual questions" (NRC 1996 p. 3 - 4). Deliberation refers to "formal or informal" communication processes where participants "discuss, ponder, exchange observations and views, reflect upon information and judgments…and attempt to persuade each other" as typical in consideration of issues of collective interest (NRC 1996, p.4). The NRC (1996) is careful to point out that the concept of "deliberation" is broader than "public participation" as it focuses on improving the understanding of a risk situation, especially in its initial stages preceding agency action.

Ideally, analysis and deliberation feed into each other at each step of the decision-making process, as outlined in Figure 1.8. Analysis informs deliberation, and deliberation frames analysis (NRC 1996).

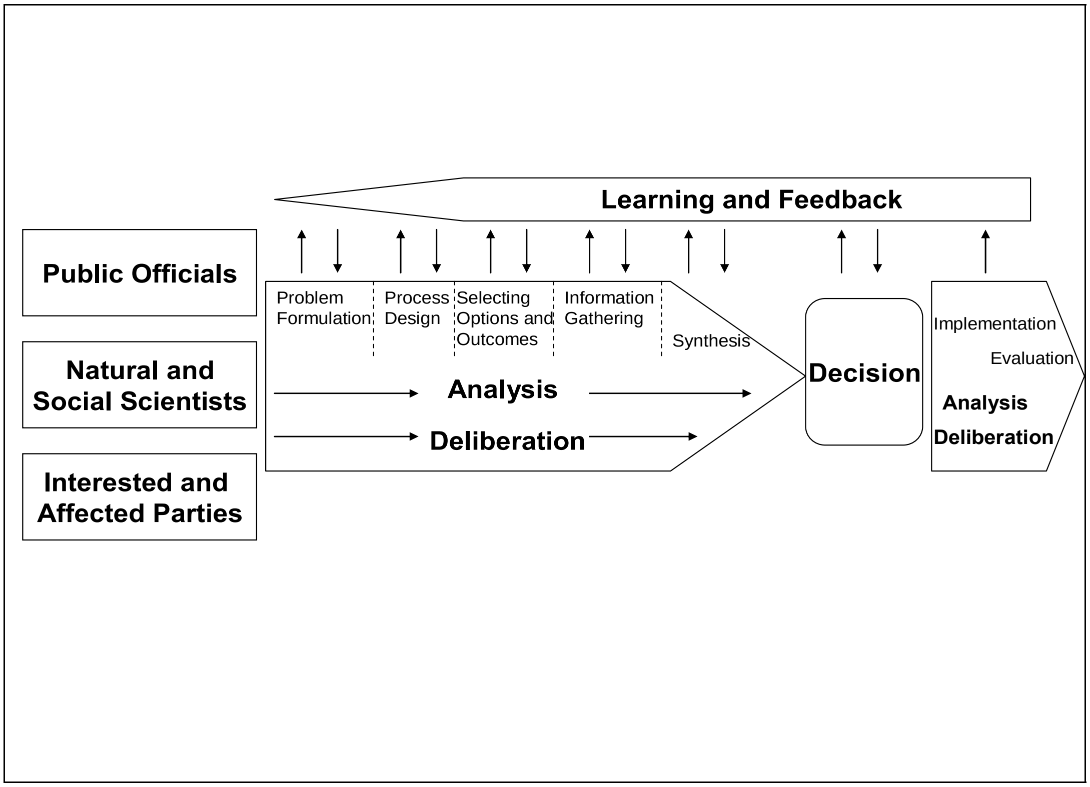


Figure 1.8: <u>Reconceptualization of the Risk Decision Making Process via the Analytic-Deliberative Framework per the NRC (1996) Report Understanding Risk</u>

As shown in Figure 1.8 above, participants, such as public officials, natural and social scientists, and other interested/affected parties participate in several key steps oriented towards making a decision: problem formulation, process design, selection of options/outcomes, and information gathering. Analysis and deliberation occurs at each step, ideally in an iterative process of task performance and feedback that fosters participant learning. The goal is a more useful synthesis of information (an enhanced risk characterization) that addresses the concerns of interested and affected parties. The report (and Figure 1.8) highlights how the NRC's (1996) conceptualization of risk decision making has changed since 1983 - moving from a clear demarcation between risk assessment/risk management (Figure 1.7) to recognition of the roles analysis and deliberation play in collaborative decision-making. In the NRC (1996) conceptualization, there is no separation of assessment and management functions, analytic-deliberative processes may vary at each step, and participation in any step may include scientists, public officials, and interested and affected parties. The benefits of this new approach are the anticipated improved quality and acceptability of the final decision.

Although the NRC (1996) is careful to point out risk decision making in practice may follow a different order than that outlined in Figure 1.8, typically problem formulation is the first step in the A-D approach. The attention given to the problem formulation stage is significant: comprehensive diagnostic questions are suggested to survey the risk decision landscape to ensure the knowledge base is as complete as possible and issues (like legislative mandates that may constrain agency decision-making in practice) are identified early. A key point of the NRC (1996) report is that interested and affected parties as well as experts should also be part of deliberative processes that occur in the early problem definition stage, when the risk problem is being defined or diagnosed, to help direct performance of necessary analysis. This focus on the problem formulation stage – the stage where risk is defined and knowledge gaps identified – and the recursive nature of the interaction between analysis and deliberation appear especially well suited to the goal of defining occupational and environmental health risks concurrently. This made the A-D model attractive for application to this study.

The next step is process design, or the identification of interested and affected parties and how participation will occur. Deliberative processes should be broadly based, involving not only decision-makers or experts but also interested and affected parties. In arguing for inclusion of interested and affected parties in analysis and deliberation, the NRC (1996) refers to Fiorino's (1990) three rationales justifying broadly based public participation in risk decision-making: normative, substantive, and instrumental. The normative rationale refers to the rights of citizens in a democratic society to participate in governmental decisions that may affect them. The substantive rationale explains that experts do not have exclusive domain over knowledge relating to a risk decision. The instrumental rationale for participation emphasizes the potential to legitimize agency regulatory decisions. Ideally, increasing the legitimacy of decisions would reduce conflict and controversy.

Since a wide literature already existed on analytic techniques, the NRC (1996) report focused on drawing out the role of deliberation. But understanding how to "do" deliberation, and do it well, remains a key challenge today. There is limited knowledge about how best to integrate analysis and deliberation. How to deliberate, who to involve, and what should be deliberated remain critical questions. While the attributes of various deliberative processes, such as citizen advisory boards and public hearings are discussed in the report, the NRC (1996) does not specify which types of risk problems should be matched with which deliberative processes. Instead, the NRC (1996) suggests an analytic-deliberative framework should meet the following objectives: getting the science right, getting the right science, getting the right participation, getting the participation right, and developing an accurate, balanced, and informative synthesis of the risk scenario. These criteria are meant to guide the analytic-deliberation processes that inform the overall risk decision making process.

While helpful to point policy-makers in the right direction, these criteria are relatively vague and may not be especially helpful for any given risk decision. From a practical standpoint, regulatory agencies and participating organizations need “how to” guidance to be able to increase the quantity and quality of deliberative processes.

For deliberative processes may hold promise to improve risk decision making, but there are also numerous challenges. First, opening the decision-making process up to interested and affected parties in early stages requires a commitment of time and resources that can significantly delay a decision. Second, making participation more “open” does not necessarily mean an equal playing field between participants, especially when there is a discrepancy in technical expertise. As Fischer (2000) makes clear, whenever discussions take place on experts’ “intellectual turf”, citizens are disadvantaged in the debate. Unequal power dynamics can add fuel to the fire of a controversial decision situation. Third, there are important ethical considerations that become apparent in expanding deliberations. U.S. society is made up of numerous value systems and worldviews, challenging risk managers in how to determine whose values to select as legitimate (Renn 1999). While acknowledging citizens can bring important knowledge to bear on a risk decision, technical expertise is still a necessary component in the evaluation of hazards. Finally, recommendations resulting from deliberation may still be rejected by the ultimate decision-maker, consensus may not be attainable via deliberative processes, and legal mandates may prescribe certain agency actions regardless of the views of interested and affected parties (NRC 1996). In short, broadly based deliberation can be expensive, time intensive, ethically charged, and offers no guarantee of success. In fact, success in itself can be a difficult variable to define.

While there is no cookbook formula to match deliberative processes to specific types of risk decisions, there is a body of literature that can be reviewed to help guide those interested in implementing participatory processes. Chess (2000)'s review of recent case studies guides environmental health professionals in how to "get the participation right" when involving the public in environmental decision-making. Successful participation can be defined by participants in different ways: consensus, reaching a desired decision outcome (i.e., accept or reject an agency proposal), improvement in environmental quality, an evaluation of the participatory process itself, or some combination thereof (Chess 2000). Similar to the NRC (1996) report, Chess (2000) emphasizes that evaluation and feedback of the process are important, and participation processes may need to be adapted in response to this feedback. Additional critical process design considerations include transparency, giving participants ownership of the process, creating a "safe" setting for dialogue, and creating a process where people feel like they can make a difference (Webler and Tuler 1999).

Deliberation is also critical in the next step in the A-D model: selection of options and outcomes. Webler and Tuler (1999) explain that selecting management outcomes and options gets at a number of key questions in the decision-making process: what do people care about, what should people care about, and what are good indicators for characterizing and ranking problems, options and outcomes? Deliberation about these criteria may identify the need for more analysis. In suggesting how this can happen in watershed management planning, Webler and Tuler (1999) explain that selection of a management option like tax breaks to prevent extensive shoreline development may trigger the need for an economic feasibility analysis. Analysis and deliberation feed into each other, directing future steps and action.

The development of options and outcomes requires the need to gather and interpret information. This is the next step in the A-D model, the place where analysis as conceptualized under a "normal science" paradigm is often located. In order to assess the viability of options and outcomes, data are needed. For example, in trying to establish the health risk from a chemical exposure at a hazardous waste site, health effects data from animal toxicology or epidemiological studies are traditionally reviewed. Yet, other types of analytical data may also be useful: other techniques to gather health effects data include worker health surveys or focus groups of affected community members. Affected parties may feel it is critical to gather their own health data as the local context may be unique or poorly researched. Corburn (2005) cites an example of an EPA health risk assessment in Brooklyn that overlooks the impact of subsistence fishing from polluted waters on a typical urban diet.

These types of research projects on health and exposure risk have traditionally been the domain of technical experts. Experts feed research results into deliberation processes regarding which options and outcomes are appropriate or if new ones are needed. Participation mechanisms like citizen advisory councils or other ad-hoc panels rely heavily on outside presentations of scientific data to inform their decision. Some researchers have critiqued the privileged role of technical expertise in gathering information to inform deliberative processes. A focus on deliberation of data primarily provided by scientific experts results in limited opportunities for the public to participate in activities that influence the analytic process (Judd et al. 2005). Fischer (2000) also critiques the NRC's (1996) focus on deliberation as leaving science squarely in the domain of experts, diminishing nonexpert participation in analysis. Since the NRC (1996)'s report adheres to a positivist (or "normal") conception of science, Fischer (2000) argues that scientific evidence remains the preferred type of evidence in environmental decision-making, and current institutional structures limit citizen involvement mainly to deliberation, not analysis.

I highlight these critiques at this point because this study had a community participation focus that attempted to expand and extend the idea of analysis beyond normal science. Other researchers have also recently begun using an expanded A-D framework to solve environmental problems. While most cases in the literature have focused on citizen participation in environmental decision-making, there are a small but growing number of cases where citizens have worked more actively within analysis as well as deliberation. Judd et al. (2005) applied the A-D model to increase community deliberations to frame scientific analysis in three cases. In each case, health risks related to chemically contaminated seafood were a major concern to the local community. Prior to the research, the typical way the risk of contaminated seafood was managed in the community was the issuance of fish advisories – a one way risk communication process. Many questioned the effectiveness of fish advisories due to language barriers. Another critique was that this process did not provide any feedback for safe management of contaminated fisheries. Researchers and community organizations worked together to come up with ways to better understand local consumption patterns of contaminated seafood, both from community markets and subsistence fishing, and helped set up local monitoring capability. While each case had a unique context, researcher and community collaboration led to similar benefits: enhanced research that met the needs of the community, community performance of the analysis and interpretation of data, better understanding of exposure risk, and building capacity among tribal groups to do their own risk management (Judd et al. 2005). A key result in each case was that community framing and participation in scientific activities led to better characterizations of risk from contaminated seafood (Judd et al 2005). The data collected was more easily integrated and synthesized into local decision-making process as well as associated educational processes due to the enhanced legitimacy that resulted from community participation.

Synthesis of information is the last step in the NRC (1996) A-D framework. The gathering of information step and the synthesis of information are closely related. This synthesis can take many forms: quantitative or qualitative, policy recommendation or management plan, recommendation for regulation or educational programs. As in the other steps, analysis and deliberation interact and the synthesis of information to address an initial problem may naturally lead to new problem formulations. For example, a watershed management plan would be the synthesis product from a watershed management process, but this process - and the associated plan - will likely evolve over time as conditions change. Webler and Tuler (1999) recommend that the final synthesis documents the uncertainties, assumptions, and information in a way accessible to interested and affected parties.

The previous explication of the A-D framework shows how the thinking regarding risk decision making has progressed since the 1970's and 1980's. Compared to the NRC (1983) risk assessment/risk management paradigm, the NRC (1996) report represents a more flexible and collaborative approach to risk decision-making. The A-D approach is detailed enough to provide guidance yet open and adaptive enough to be suitable to a number of environmental applications at the federal, regional, and local level. At a theoretical level, the NRC (1996) report is important and noteworthy because it provides a way to replace the traditional facts/values and science/policy dichotomy with a framework that is more consistent with how people actually make decisions (Webler 1998). Scientists and policy-makers each do analysis and deliberation naturally but just might not do it reflectively. For example, the scientific research process emphasizes objectivity in the discovery and analysis of facts, but the process also requires deliberation: scientists analyze facts, but often deliberate these facts at conferences and in other forums like peer reviewed articles. Another key contribution of the NRC (1996) report is highlighting how analysis includes more than traditional quantitative risk assessment or scientific hypothesis testing and deliberation includes more than traditional public participation mechanisms (Webler 1998). This broader conceptualization of analysis and deliberation is especially important when local knowledge may offer significant insight into environmental problem solving. The NRC (1996) report acknowledges that different ways of knowing should be respected and integrated to best inform decision making.

1.3.2 How the A-D Framework Can Be a Good Fit for the Problem of Diesel Exhaust

The above cases and review of the A-D model formed a rationale or basis for selection and application in this study. The problem of diesel exhaust is significant, and at a federal level, agency action to reduce exposures and associated health risk is limited or moving forward glacially at best. There is no federal action to prevent workplace exposures to whole diesel exhaust. The regulatory examination and evaluation of diesel exhaust risk (EPA 2002a) has mainly followed the NRC (1983) traditional paradigm. The Health Assessment Document followed this 4 step risk assessment process. EPA's regulatory approach with its emphasis on risk assessment vs. risk management has become relatively stuck on the point of scientific uncertainty regarding animal and human health studies. One could argue enough science has been done and the regulatory decisions have been motivated by politics and not existing scientific evidence.

However, the NRC (1983) risk assessment/risk management process is not well suited to the complexity of the diesel exhaust problem such as the evolving technology, widespread use, and variability in application of diesel engines. The multidimensionality of the problem of diesel exhaust exposes the weaknesses of the traditional paradigm. There are also multiple scales of exposure that overlap: workplace, community, regional and national. While public concern is somewhat limited, many environmental/occupational health scientists, and EPA itself on its website, recognize the significant contribution of diesel exhaust to ambient levels of air pollution and local elevated levels in the workplace. The known negative health effects of components of diesel exhaust – such as fine particulate matter - are substantial. Emerging knowledge supports that other components have their own unique health hazards. A new approach to the problem of diesel exhaust outside the traditional paradigm is needed.

The A-D framework presents one possible approach to understanding risk and one suitable to the unique local context of this study. This study applied the analytic-deliberative (A-D) model to a collaborative exposure assessment research project that evaluated the impact of biodiesel fuel – as a risk reduction alternative to petroleum diesel – on environmental and occupational exposures. Biodiesel use is growing in popularity in the U.S. for a number of reasons which will be discussed below. My research interest was the potential of biodiesel as a risk reduction intervention to reduce exposures to petroleum diesel emissions such as particulate matter, EC/OC, and nitrogen dioxide in both the workplace and local environment. Instead of following a more traditional risk assessment approach to inform development of a biodiesel potency estimate, I was interested in performing a real world, comparative study to assess the concurrent impact of switching to a 20% biodiesel blend (B20) on both occupational and environmental exposures. My initial research questions were inspired and informed by observations from the community and informal conversations with both City of Keene and Keene State College employees that indicated dramatic improvements in workplace air occurred soon after biodiesel was introduced in local fleets. I worked with these community members, technical experts and students from KSC to develop and implement a collaborative exposure assessment, an analytic process that measures levels of air contaminants in workplace and local ambient air. To connect analysis with deliberation I also organized and set up a local Biodiesel Working Group as a deliberative forum for dialogue, information exchange, and a place for analysis and deliberation to interact. More detail on the specific research questions and application of the A-D model to this study will be reviewed in Section 1.6.3. First I will discuss the basics of biodiesel and why it is considered a green alternative to diesel. In the next sections, I provide a brief background on biodiesel, its potential as an alternative to diesel fuel, and review the literature on biodiesel emissions, exposures and associated health impacts.

1.4 Introducing Biodiesel

1.4.1 Biodiesel: What Is It? How's It Made? Who's Using It?

Biodiesel is an alternative fuel made from vegetable oil, animal fat, or waste grease. While relatively recent in the U.S., biodiesel has been widely available and used in western European countries such as Germany for at least the last 10-15 years (Pahl 2005). In contrast to the US close to half of the European passenger vehicle fleet utilizes diesel engines. Over 1,900 public filling stations in Germany currently offer biodiesel, and officials there believe national biodiesel production capacity could displace almost 12% of that country's petroleum diesel by the end of 2008 (Bockey 2005). In the U.S., there are about 800 retail pumps nationwide, and 11 in New Hampshire (NBB 2008).

While rapeseed is the primary feedstock for German-made biodiesel, the most popular feedstock in the U.S. is soybean oil (Pahl 2005). Since the soybeans that make up this virgin oil feedstock are grown domestically, biodiesel is often referred to as a sustainable or renewable fuel. Researchers in the U.S. are examining other feedstocks such as mustard seed, rapeseed and even algae to increase oil yield and opportunity for farmers and other oil producers to enter into the biodiesel economy (Pahl 2005). Biodiesel is not the chemical equivalent to pure vegetable oil or grease; rather it is the mono-alkyl esters that remain after oil or grease undergoes a transesterification reaction.

Most biodiesel in the U.S. is made via base catalyzed transesterfication (Pahl 2005). In this chemical process, oil or grease is reacted with methanol (or ethanol) in the presence of a sodium hydroxide (or potassium hydroxide) catalyst to make mono alkyl esters (biodiesel) and glycerine as a by-product. When 100 pounds of oil are mixed with 10 pounds of methanol (plus necessary catalyst) approximately 100 pounds of biodiesel and 10 pounds of glycerine are produced (DOE 2004). Although this process is the most common in the U.S., there are other methods of biodiesel production, such as acid catalyzed transesterification, and research continues into new, more efficient methods to manufacture biodiesel from various feedstocks.

In terms of physical characteristics of the fuels, biodiesel and diesel fuel differ in many respects. Biodiesel has a higher cetane number than petroleum diesel fuel. The cetane number is a measure of a fuel's ability to autoignite. A higher cetane value is preferred in compression-ignition engines as this indicates the fuel will ignite more quickly. Other key differences: biodiesel has a higher boiling point and flash point than diesel, which means it is safer to transport as it is even less likely to combust than diesel. However, B100 has significant cold weather problems due to its high cloud point (or the temperature at which the fuel begins to cloud or crystals appear). B100 will start to cloud at around 36 ºF and will begin to gel at 28 ºF (DOE 2004). This limits B100's suitability in colder areas of the U.S. As a result, in the U.S. marketplace, diesel is often added to biodiesel. B20 blends have cloud and gel points almost identical to 100% petroleum diesel blends for similar performance in winter climates. Most biodiesel in the US is sold as B20 or a 20% soybased biodiesel and 80% petroleum diesel blend (DOE 2002). BXX is used to refer to the percentage of biodiesel in the blend; B10 would equal 10% biodiesel and 90% petroleum diesel.

Many U.S. organizations interested in a renewable and domestic source of energy are considering switching from 100% petroleum diesel to biodiesel/petroleum diesel blends for transportation and heavy-duty equipment use. According to the National Biodiesel Board, over 800 fleets in the United States are using biodiesel blends (NBB 2008). These fleets include municipal and government fleets located across the country, such as public works vehicles in the city of San Franscisco, CA and the city of Keene, NH. School buses from Medford, NJ to Clark County, NV run on B20 (NBB 2008).

The volume of biodiesel consumed nationwide is steadily increasing. Approximately 200 million gallons of biodiesel blended fuel were sold in 2006, and one blue-sky scenario predicts 1.5 billion gallons production capacity for 2007 (Schmidt 2007). Although the U.S. consumed more than 40 billion gallons of petroleum diesel in 2005 alone, some experts believe biodiesel could someday displace up to 25% of the current volumes of diesel fuel used in the U.S. (Schmidt 2007). The use of biodiesel is expected to continue to rise.

Cost is another key area where diesel and biodiesel differ. Petroleum markets continue to be widely volatile, making price comparisons between B20 and 100% petroleum diesel difficult. There are also tax subsidies supporting biodiesel at the federal and state levels which may or may not be reflected in the final price at the pump. Howerever, B20 blends are typically more expensive than petro-diesel, varying between 5 to 20 cents more per gallon. At the end of 2005, B20 blends averaged 10 cents more per gallon, and B100 blends averaged 59 cents more per gallon (Methanol Institute/International Fuel Quality Center 2006). This differential cost may be a key deterrent in market expansion of pure biodiesel. The lower cost differential and similar cold weather properties of B20 to diesel may help explain why B20 is the most popular blend in the U.S.

1.4.2 Advantages of Biodiesel

1.4.2.a Biodiesel as an Alternative to Petroleum

A key benefit of biodiesel is that no major engine modifications are necessary to existing diesel engines prior to use. The only recommended adjustment is replacement of rubber seals with synthetic materials in pre-1993 fuel systems if B100 is used as B100 has solvent properties that can degrade pure rubber (DOE 2002). Biodiesel, especially B20 blends, can be immediately introduced into existing distribution infrastructures and diesel engine applications. There are numerous case histories (such as from the municipal fleet in Keene, NH) testifying to smooth and beneficial integration into existing fleets. Although some documentation indicates biodiesel use will result in lower miles per gallon (DOE

2002), others report B20 use resulted in increased mileage efficiency. Wayne Hettler, Head Mechanic of St. Johns Public Schools, St. Johns, Michigan reports:

> We have experienced very positive results with B20…We now extend our oil services another 10 percent. Our buses don't have the exhaust soot on the back that needs to be scrubbed off. The fleet average fuel mileage has increased from 8.1 to 8.8 miles per gallon. When all of these things are added up, **we are seeing about $7500 savings per year. When we take out the cost difference in the price of the B20, we still see about $3000 per year savings** (USDA, undated publication).

Biodiesel offers a number of political, economic, and operational benefits. A fuel that can be domestically sourced is politically attractive. The growth of the biodiesel industry has resulted in new jobs and new revenues for soybean farmers, who for many years had a glut of surplus soybean oil (Pahl 2005). Biodiesel fuel is also biodegradable, low toxicity, and has high lubricity characteristics which may help extend engine life (DOE 2004). Biodiesel also has key industry support: most diesel engine manufacturers will not void warranties for burning up to a B20 blend as long as the fuel is ASTM (American Society for Testing and Materials) certified (Pahl 2005). Biodiesel has a slight solvent effect, cleaning out engine deposits – but this may help improve engine performance. At the same time, biodiesel increases lubricity in the engine compared to diesel fuel. This can have enormous benefit as sulfur content, the traditional lubricant in petroleum diesel, has been recently reduced in EPA mandated ultra low sulfur diesel fuel. The combination of cleaning and lubricity benefits can extend engine life. Adding just low levels or 1 to 2% biodiesel to ULSD is expected to improve overall lubricity (DOE 2004).

Biodiesel has a number of environmental benefits in addition to low toxicity that make it an attractive alternative to petroleum diesel. Compared to petroleum diesel use, biodiesel is more energy efficient, and reduces net carbon dioxide emissions. A joint study performed by the United States Department of Agriculture and the United States Department of Energy determined that over its life cycle of production and use, biodiesel yields 3.2 units of fuel product energy for every unit of fossil fuel energy that goes into making it (Sheehan et al. 1998). By contrast, petroleum diesel has a ratio of 0.83 units of fuel product energy yield per unit of fossil fuel energy consumed, or a net loss of energy over its entire life cycle. Another way of understanding this relationship is that, on a per gallon basis, soy based biodiesel provides 69% more energy than the fossil fuel energy that went into making it. The same study also found that use of soybean-based 100% biodiesel in an urban bus reduced net carbon dioxide emissions by 78% and B20 reduced CO2 by almost 16% (Sheehan, et al. 1998). Hill et al. (2006) performed a more recent life cycle accounting and determined that soy based biodiesel provides 93% more energy than the fossil fuel energy invested in its production, and reduces greenhouse gases by 41% compared to diesel (Hill et al. 2006).

Additional benefits of biodiesel relate to human health and the environment. Burning biodiesel vs. petroleum diesel results in reduced tailpipe emissions of carbon monoxide, particulate matter, and hydrocarbons (EPA 2002b). These reductions are shown in Table 1.1 below. B20 use results in an average 10% reduction in particulate matter (less than 10 micron diameter) but a corresponding average 2 percent increase in NO_x (EPA 2002b). In the next sections I will review the environmental benefits as reported by two fleets and review the scientific literature on biodiesel emissions studies.

POLLUTANT	B100	B20
Hydrocarbons	-80-90%	-21%
CO	-40%	-11%
Particulate Matter	-30-50%	-10%
NO_x	+12%	+2%

Table 1.1: <u>Biodiesel Reductions in Regulated Tailpipe Emissions Compared to 100% Petroleum Diesel, Source: EPA 2002b</u>

1.4.2.b Is Biodiesel a Carbon-Neutral or Carbon-Reduced Fuel? Stories from the Field

An examination of the biodiesel policy discourse identifies a number of political, economic, and health (both human health and environmental health) arguments driving increased biodiesel use. The political argument focuses on the domestic production of biodiesel as a way to lessen U.S. dependence on foreign petroleum imports. The economic argument states an increase in domestic production of biodiesel fuel would lead to an increase in U.S. jobs and a stronger economy. The human health-based argument points to existing scientific evidence indicating burning biodiesel fuel may present less risk to the environment and human health. Finally there is an argument for the environmental benefits suggested by widespread use of biodiesel as a renewable, plant based fuel. These benefits include reducing carbon in the form of carbon dioxide released into the atmosphere. Since biodiesel is made from plant sources, these plants can capture carbon dioxide during the cycle where feedstock plants are grown. Use of waste grease for making biodiesel fuel is even more beneficial, as the feedstock is a waste, but the pure oil used in cooking was initially made from plant materials.

For these reasons and others, many cities are adopting biodiesel as a way to improve environmental quality and reduce their overall carbon footprint. In the paragraphs that follow, I will discuss two city's stories: San Francisco, CA and Keene, NH.

In 2006, Mayor Gavin Newsom of San Francisco issued an executive directive that all municipal diesel vehicles use B20 by the end of 2007 as part of a city wide effort to reduce petroleum consumption, improve air quality, and reduce greenhouse gases (Newson 2006). This directive also initiated a Biodiesel Task Force to streamline regulations and encourage private sector biodiesel use. At the end of 2007, all of the City's 1500 diesel vehicles were powered by B20, making it one of the nation's largest green fleets (Marshall 2007). This equates to a displacement of approximately 1.2 million gallons of diesel fuel per year. In addition to use of biodiesel, San Francisco's Public Utilities Commission is setting up a program to collect waste grease from restaurants for free and sell this material for processing to local biodiesel manufacturers. City officials believe this could be a win-win for the restaurants and the City, because dumping of waste grease is a problem in local sewers, and costs the City $3.5 million a year to clear grease blockages in sewer lines (Cohen 2007). Since the City of San Francisco also uses B20 in its fleets, the hope is to move from using soy-based B20 to waste grease-based B20.

In the City of Keene, NH, the story behind the use of biodiesel is similar yet unique. Since the City of Keene's relationship with biodiesel provides important background for this study, I will present the local biodiesel story in more detail. Keene is a small city of approximately 22,000 people located in southwestern New Hampshire. With respect to environmental awareness, Keene could be considered a community more concerned about protection of the environment than most. In 2000, Keene signed the Cities for Climate

Protection Campaign, administered by the International Council for Local Environmental Initiatives (City of Keene 2007). The Cities for Climate Protection (CCP) Campaign focuses on local solutions to global warming, primarily by reducing emissions of greenhouse gases at the municipal level. Keene has signed on to reduce emissions of carbon dioxide and methane by 10% of 1995 levels by 2015, but the City municipal departments have committed to a 20% goal. To meet this goal, a number of environmental projects have been initiated, such as installing a methane recovery system at the local landfill, and implementing energy conservation measures in municipal buildings. Although biodiesel use is listed on the City's 2004 Local Action Plan (City of Keene 2007), the decision to use biodiesel happened concurrently and outside the formal CCP process, at least initially (Russell 2006).

The initial decision to use biodiesel in the City of Keene fleet originated with Department of Public Works Fleet Manager Steve Russell. Others interviewed as part of this study all point to Russell as being the critical component of the decision to use B20 in Keene. As Duncan Watson, Assistant Director of Public Works, and currently Russell's supervisor, puts it, "Steve Russell really took the initiative to get biodiesel into the fleet. Steve was the primary driver on this." (Watson 2006). Russell himself has acknowledged becoming a kind of biodiesel expert in the area, "I guess I'm the biodiesel king" (Cleary 2005). The city has been using B20 in its fleet since 2002.

However, there were a number of key steps in the decision that happened before B20 was finally implemented. In 2001, Russell attended a Granite State Clean Cities meeting at Antioch New England Graduate School (now Antioch University) where the question of biodiesel use came up. At the meeting, he offered to try the alternative fuel in his municipal fleet, but stated his budget could not allow for the extra 35 cents per gallon cost for B20. The next day he received a call from the New Hampshire Governor's Office of Energy offering a small $2500 grant to offset the cost differential to purchase B20. At that point, Russell recalls, "I started doing my homework" (Russell 2006). He developed a list of biodiesel's positives and negatives, particularly warranty issues. At the time, some engine manufacturers were taking a negative stance towards biodiesel, stating that use of the fuel could void the warranty. This meant that any problems with an engine subsequent to trying the fuel could be challenged. However, Russell researched the language in the engine warranties in his fleet and determined that engine warranties specifically cover workmanship of parts. If he used a quality certified biodiesel fuel the engine manufacturers had to stand by their commitment to correct any engine defects.

Yet, instead of immediately placing the order for a B20 delivery, Russell spent the next six months meeting with department heads across the City's organization in a long process of education and advocacy to address concerns and build support to try the fuel. When the $2500 from the initial grant ran out, Russell kept using B20 in the fleet, wondering if this would result in problems for him later:

> I kept it going for a while, and then I thought when my budget goes over, and they start asking questions, I am going to be in trouble. I said, I'll take the chance. I noticed it was doing good things for the fleet. I noticed the air was cleaner, the mechanics noticed it. There were a lot of positives (Russell 2006).

B20 is distributed to most of the Keene municipal fleet from the city's central underground storage tank system. B20 is used in fire engines, dump trucks and diesel trucks. Fleet nonroad vehicles at remote locations (that can't access the UST) do not use B20 due to lack of availability and higher cost for special delivery. As of 2007, the City of Keene DPW has used over 200,000 gallons of B20 in their centralized fleet.

1.5 Is Biodiesel a Promising Technical Solution to the Problem of Diesel Exhaust Exposure? A Review of the Air Quality Impacts & Associated Health Risks

A review of existing scientific evidence on biodiesel tailpipe emissions suggests biodiesel may indeed provide an attractive alternative to petroleum diesel with respect to air quality. For example, numerous studies have shown burning biodiesel reduces harmful particulate matter from tailpipe exhaust (EPA 2002b; Graboski and McCormick 1998; Bagley et al. 1998; Durbin et al. 2000; Wang et al. 2000). This scientific evidence indicates biodiesel fuel may hold promise as a technical solution to the problem of diesel exhaust with respect to its impact on particulate matter emissions.

However, while much about biodiesel is known, there is also much that is unknown. There are multiple dimensions to the study of biodiesel tailpipe emissions that have implications for risk decision-making. Most of the studies in the literature have focused on laboratory based tailpipe emissions from heavy duty on road diesel engines. There is limited data from nonroad engines on biodiesel tailpipe emissions (EPA 2002b). There is also limited data on 'real world' (compared to laboratory-based) biodiesel tailpipe emissions. There is almost no data on biodiesel exposures in the workplace, with only one regulatory study identified at the time of this writing. The next sections identify what is currently known about biodiesel, identifies data gaps in the literature, and discusses the challenges in the use of biodiesel as an alternative to petroleum.

1.5.1 EPA's Regulatory Review of Biodiesel and the EPA (2002b) Draft Technical Report on Biodiesel Emissions

Biodiesel is the only alternative fuel that has passed the EPA Clean Air Act Tier I and II testing requirements for health effects. Unlike straight vegetable oil, biodiesel is legally registered as a fuel for sale and distribution in the U.S.; for registration, EPA's Tier I and Tier II tests are required by the 1990 Clean Air Act amendments for any fuel or fuel additive sold in the U.S.

The Tier I test is a series of tailpipe emissions tests and the Tier II test is a 90 day (or subchronic) inhalation rat study where the animals are exposed to varying levels of biodiesel exhaust. The emissions testing for the Tier I requirements followed a series of protocols (CFR Title 40 Part 79), including detailed tailpipe emissions characterizations with the fuel burning on one or more diesel engines. These engines were operated according to specific test requirements (Federal Testing Protocol CFR Title 40 Part 86 Subpart N) that span the engine's torque capabilities and operating speed (Sharp et al 2000a). The Tier I tests were performed in a lab controlled environment, characterizing regulated emissions of particulate matter, total hydrocarbons, NO_x, and carbon monoxide as well as unregulated emissions of aldehydes, PAH's, and nitro-PAH's. Emissions levels are reported as grams/horsepower*hour or mass per unit of work, not in units of concentration such as $\mu g/m^3$. The Tier I test results found B100 and B20 emissions of PM, total hydrocarbon, and carbon monoxide were reduced when compared to petroleum diesel, although NO_x levels increased (Sharp et al. 2000a). B100 and B20 emissions of aldehydes, PAH's and n-PAH's also were reduced relative to diesel emissions (Sharp et al. 2000b). For both regulated and unregulated emissions, the B100 emissions profiles showed more dramatic reductions of measured emissions vs. diesel than B20, except for NO_x, where B100 use resulted in higher emissions than B20.

In the Tier II animal study, rats were exposed to 100% soy-based biodiesel exhaust (at three levels represented by exhaust concentrations diluted to 5, 25, or 50 ppm NO_x. After the 90 day test period, Finch et al. (2002) determined only modest adverse effects at the highest exposure level. The inhalation exposures for the rats resulted in a dose-related increase in particle-containing alveolar macrophages; however, this observation was similar to that seen in similar petroleum diesel exhaust rat exposure studies (Finch et al. 2002).

In addition to the regulatory Tier I and Tier II requirements EPA also completed a draft technical report studying biodiesel emissions. EPA's study (2002b) analyzed and consolidated data from numerous published studies and concluded that B20 would reduce particulate matter (PM) by approximately 10%. The report also found B100 could reduce PM by as much as 50% compared to petroleum diesel. Most of the EPA (2002b) reviewed studies found increased NO_x levels in biodiesel exhaust compared to diesel exhaust (2% increase in NO_x for a B20 blend); however, the impact of biodiesel on NO_x has been controversial and will be discussed in the next section.

The EPA (2002b) reported biodiesel use resulted in reductions in total hydrocarbon (vapor phase) and carbon monoxide as summarized in Table 1.1. The EPA (2002b) report recommended additional research was needed to fill in a number of data gaps including: more data from nonroad engines, from newer heavy duty engine models, from light duty diesel engines, and more air toxics data, especially on toxics of public health concern such as benzene and 1,3-butadiene.

1.5.2 Additional Literature on Biodiesel Tailpipe Emissions

1.5.2a Particulate Matter and Nitrogen Oxides

Most of the research literature on biodiesel tailpipe emissions indicates particulate matter (usually 10 micron diameter and lower) levels are reduced by burning pure biodiesel or biodiesel blends (EPA 2002b; Graboski and McCormick 1998; Bagley et al. 1998; Durbin et al. 2000; Wang et al. 2000; Sharp 2000a; McCormick et al. 2001). A more recent study that employed both urban and freeway driving cycles to compare petroleum diesel/B20 tailpipe emissions for heavy duty engines reported average PM reductions of 16% from B20 use (McCormick et al. 2006). Most research in the U.S. has indicated biodiesel use lowers PM emissions compared to petroleum diesel, with B100 use resulting in greater PM reductions than B20 use. However, due to the PM/NO_x tradeoff, lower PM levels are expected to result in higher NO_x levels.

There have been conflicting research results regarding the impact of biodiesel on NO_x tailpipe levels, with some studies indicating an increase, and others no significant change. The contradictory evidence regarding biodiesel's impact on NO_x levels has prompted some states like Texas to consider – though not yet implement - a ban on biodiesel (Schmidt 2007). EPA's (2002b) report indicated use of B20 would result in a 2% increase in NO_x emissions, with increasing levels of NO_x associated with each percentage increase in the biodiesel/petroleum diesel blend ratio. However, researchers from the National Renewable Energy Laboratory (NREL) team recently challenged these findings. McCormick et al. (2006) examined NO_x emissions from eight heavy duty diesel vehicles and concluded that while NO_x levels were highly variable, there was no statistically significant difference in NO_x emissions between B20 or petroleum diesel use. When they expanded the review to include other engine and vehicle studies they found the net average overall NO_x effect from B20 was ± 0.5 % (McCormick et al. 2006). McCormick et al. (2006) point out almost half of the NO_x data in EPA's (2002a) draft technical report came from engines from a single engine manufacturer, potentially biasing the NO_x predictions when considering the engine variety in the national fleet. Since NO_x contributes to ground level ozone, and many areas in the country exceed National Ambient Air Quality Standards for ozone, these types of scientific inconsistencies have left local state air regulators and other policy makers unsure about how to regulate biodiesel as the market expands.

In other relevant literature on diesel vs. biodiesel PM comparisons, Shi et al. (2005) showed B20 use reduced particulate matter emissions 17 to 34% compared to pure diesel. Chen and Wu (2002) found that burning B100 reduced the total number concentration of ultrafine particles (less than 1.0 micron in diameter) by 24 to 42% and the total mass concentration by 40 to 49%. Ultrafine particles have been identified as a potential health concern since they are smaller than fine particulate matter, and may penetrate into even deeper regions of the lung (HEI 2002). Jung et al. (2006) found burning B100 resulted in decreased particle size (80 nanometer to 62 nanometer diameter), number (by 38%), and volume (by 82%). Although the decreased number and volume of particles are beneficial, the smaller particle diameter appears to indicate the biodiesel particle may be morphologically different than diesel, which can be associated with negative health effects.

1.5.2.b Elemental Carbon/Organic Carbon

There is little data characterizing elemental and organic carbon levels in biodiesel emissions. Organic carbon levels for both B100 and B20 blends were higher when compared to a California diesel and synthetic diesel blend; alternately, elemental carbon levels were lower for B100 in the same study (Durbin et al. 2000). More typically, SOF or soluble organic fraction is measured. Here the database is limited but research is beginning to provide a clearer picture of biodiesel emission profiles. The level of soluble organic fraction (SOF) of particulate matter has been found to be higher in biodiesel exhaust compared to diesel exhaust (Graboski and McCormick 1998). However, polycyclic aromatic hydrocarbons (PAH's), which are organic species of primary human health concern due to their potential mutagenicity and carcinogenicity are generally reduced when biodiesel emissions are compared against petroleum diesel (Bagley et al. 1998; Durbin et al. 2002; Sharp et al. 2000b; Correa and Arbilla 2006). Bagley et al. (1998) found that both particle phase and vapor phase PAH's were lower with B100 compared to diesel fuel exhaust from nonroad equipment used in mines. Correa and Arbilla (2006) determined in their study of heavy-duty bus engines that reductions in PAH levels correlated with the percentage of biodiesel in the blend, with an average reduction of 2.7% for B2, 6.3% for B5 and 17.2% for B20.

1.5.2.c Air Toxics and Other Research Needs

Also relatively unstudied are the levels of air toxics (such as formaldehyde and acrolein) in biodiesel exhaust and the size distribution of particulate matter (fine particles vs. ultrafine particles). While Sharp et al (2000b) showed biodiesel reduced formaldehyde and other carbonyl levels, Turrio-Baldassarri et al. (2004) determined significantly higher formaldehyde emissions in B20 exhaust compared to diesel exhaust. More research is needed to better understand the composition of toxic gases in biodiesel exhaust as well as the impact of biodiesel on particle size distribution (McCormick 2007).

1.5.2.d Other Literature: Biodiesel Emissions Health Effects Testing

While the literature on biodiesel emissions characterizations is growing, there has been limited research examining biodiesel emissions' impact on human health via *in vivo* or *in vitro* tests. Epidemiological studies are not available, likely due to the relative newness of biodiesel in the U.S. The primary biodiesel exhaust animal study (*in vivo*) was the rat inhalation study by Finch et al. (2002) described previously, which indicated no major adverse health effects associated with subchronic exposure. In an *in vitro* study, Bagley et al. (1998) determined no vapor phase mutagenicity with soy based B100, and suggested that use of biodiesel is not expected to increase toxic health effects (associated with particle bound PAH's) compared to diesel emissions. Bunger et al. (2000a) found that particles from both rapeseed and soy based biodiesel exhaust contained lower levels of black carbon and total PAH's than diesel fuel, with less mutagenic potential. Kado and Kuzmicky (2003) found higher mutagenicity rates for canola based biodiesel exhaust compared to soy, but both were lower than mutagenicity rates associated with petroleum diesel exhaust. Researchers who studied both mutagenic and cytotoxic effects of diesel and rapeseed based biodiesel determined lower mutagenic potency for the biodiesel but higher cytotoxic effects on mouse fibroblasts (Bunger et al 2000b).

Contradictory results for biodiesel's impact on health effects have been reported in the literature. Mutagenicity tests performed in a more recent study on biodiesel (B20) and diesel exhaust from a heavy duty bus engine indicated no statistical difference between both fuels (Turrio-Baldassarri et al. 2004). While Kado and Kuzmicky (2003) reported lower total mutagenicity emission rates from biodiesel exhaust due to the lower particle mass emission rate, they found higher mutagenic activity per particle mass for biodiesel fuels. Other researchers point out long term human health effects from biodiesel emissions have not been given "due diligence" especially as biodiesel appears to increase the soluble organic fraction of particulate matter (Swanson et al. 2007). Swanson et al. (2007) recommend study of the potential for increased oxidative stress from biodiesel exhaust due to its higher soluble organic fraction. Composition of the soluble organic fraction remains relatively uncharacterized as most tailpipe studies have focused on regulated pollutants such as total particulate matter and NO_x, and not the speciation of the soluble organic fraction (SOF). Finally, the rat inhalation study of Finch et al. (2002) used subchronic (i.e., less than 90 days) animal testing protocols. Long term health effects may be missed and exposure data are needed from multiple and varied end-uses of biodiesel to ensure humans exposures are similar to the doses used in animal health effects testing (Swanson et al. 2007). These research gaps emphasize the need for multiple biodiesel exposure assessment studies from "real world" applications.

1.5.3 Emissions vs. Exposure

The literature above briefly summarizes the tailpipe emissions characterizations for biodiesel, as well as the emerging health effects literature. The tailpipe emissions literature is growing rapidly as economic and political forces expand the biodiesel market. However, as others have noted (Swanson et al. 2007; McCormick 2007; EPA 2002b), more research on biodiesel emissions and health effects are needed to fill in the following gaps: understanding changes in tailpipe emissions profiles from different types of engines (such as potential changes in particle size, organic composition and organic fraction), characterizing air toxics in biodiesel exhaust, quantifying exposures from different applications, and evaluating potential long term health effects.

In addition to tailpipe emissions testing, a critical need exists for the characterization of exposure profiles in real world applications. While tailpipe emissions data inform environmental decision-making regarding the composition of exhaust emissions and aggregate mobile source contributions to air shed inventories, exposure data are necessary to inform decision-making regarding the impact of emissions on human health and the environment. Exposure - or human contact with the components of tailpipe emissions - is a key link in the chain between pollutant sources and ultimate health effects, as shown in Figure 1.9 below. Exposure is much closer to what people are actually breathing.

According to Ott's (2007) risk conceptual model, pollutants first originate from sources and then undergo fate and transport processes as they move through the atmosphere. When either diesel or biodiesel exhaust exits a tailpipe, there are a number of physical and chemical atmospheric processes that may occur prior to entering the breathing zone of a worker or community member. Physical processes include wet or dry deposition, and chemical processes include oxidation or nitration. Diesel particulate matter less 1.0 micron in diameter may have a residence time of days before settling out via dry deposition (Winer and Busby 1995). Physical and chemical processes may modify the exposure — either increasing or decreasing the toxicity of the associated health effect. For example, PAH's released in the vapor phase of diesel exhaust may be chemically transformed in the atmosphere by the addition of nitrogen to become more potent mutagenic species like 1-nitropyrene (HEI 1995). Alternatively, physical and chemical processes may reduce exposure or reduce the toxic health effect. Rain events can remove particulate matter from the atmosphere, effectively scrubbing them out of the air, thereby reducing human exposures.

Moving from left to right in the shaded area of Figure 1.9, exposures next interact with the body's organs and defense mechanisms to result in some approximated dose to the target organ and associated health effect. Ultimately, the measured exposure (and estimated potential dose) determines the human health effect. Therefore, in any inhalation risk characterization of a chemical or pollutant, exposure data is necessary in addition to source data for fully understanding the impact of air contaminants on human health and the environment.

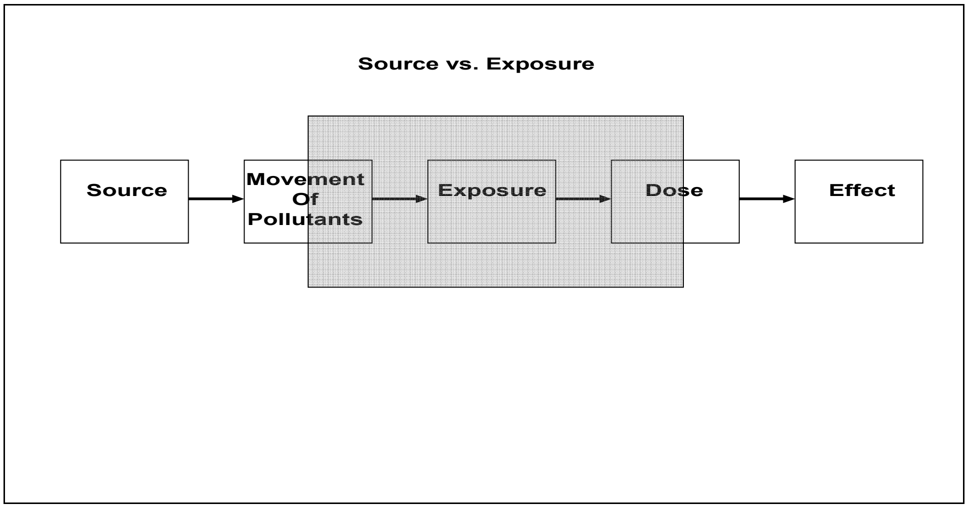


Figure 1.9: **<u>A Conceptualization of Source vs. Exposure (Source: Ott 2007)</u>**

An additional benefit of collecting exposure data is that exposure data is determined "in the field" or during real-world ongoing activities or processes. In contrast, most tailpipe emission profiles reported in the diesel and biodiesel literature are not "in the field" concentrations but are determined by testing tailpipe exhaust in a laboratory via the Federal Testing Protocol (FTP). The FTP involves sequential steps where the vehicle is in a controlled environment and the engine is operated at different speeds for set time periods. These steps are not expected to be the same as real-world engine operation, but provide a way to model emissions output at different speeds.

Tailpipe emission testing has advantages compared to exposure monitoring. In a lab setting, the researcher can control environmental variables like temperature and humidity. There is also no wind so there is neither dispersion of pollutants nor interference from another upwind pollution source. While the control of confounding variables clearly helps understand speciation of components generated during the combustion process, the data may not necessarily reflect emissions from actual stop and go urban driving conditions or on-highway moderate or heavy traffics.

It is because of the real-world variability in weather and driving/operating conditions that make it difficult to predict occupational or community exposures based on tailpipe emission datasets. Lab based tailpipe studies may not reflect typical engine types, engine use patterns or emissions profiles from "real use" scenarios. When Shah et al. (2004) used a mobile laboratory to measure petroleum diesel tailpipe emissions in real time from heavy duty trucks, the researchers found that PM, EC, and OC levels were highly variable and strongly dependent on the mode of vehicle operation. Higher emissions were determined from trucks in congested traffic conditions compared to highway cruise conditions (Shah et al. 2004). Other researchers found the organic carbon/elemental carbon ratio from a diesel engine tailpipe varies depending on operating conditions and vehicle load. Heavier load cycles increased elemental carbon levels and lighter load/idling conditions increased organic carbon levels (Shi et al. 2000).

A final gap in the biodiesel tailpipe emissions and exposure database is that nonroad engines are underrepresented in emissions characterizations. Yet, nonroad engines are more common in workplace scenarios such construction sites or industrial warehouses making them more relevant to understanding workplace or community exposures. These types of nonroad applications or scenarios are favorable for quantifying exposures, as activities may be consistent throughout a workshift, the population exposed is easily identifiable, and exposures tend to be higher and provide worst case scenarios for health impacts. The relationship between nonroad engines and typical workplace uses and the lack of current biodiesel exposure data is discussed in the next section.

1.5.4 Lack of Biodiesel Exposure Data

Nonroad engines are used in a number of work settings such as farming, construction, and industrial operations. With respect to existing diesel engine technology, and assuming the use of 100% petroleum diesel fuel, nonroad engines generate higher levels of NO_x and PM compared to onroad engines. As previously discussed, workplace exposures to diesel exhaust tend to be much higher than community exposures, raising important questions about the environmental injustice occurring inside compared to outside the facility fence. Nonroad engine applications that persist over long time periods in a community, such as a multi-year construction site, may impact both environmental and occupational health concurrently. For these reasons, nonroad diesel engine exposure data are particularly relevant and examination of biodiesel as an alternative to petroleum diesel especially compelling.

Biodiesel emissions data indicate pure biodiesel and biodiesel blends reduce particulate matter compared to petroleum diesel. Although this data has been collected mainly from onroad engines, the limited nonroad tailpipe tests also indicate PM is reduced by burning biodiesel. There is a large scientific database supporting the connection between fine particulate matter exposure and significant negative health effects such as lung injury, respiratory illness, asthma exacerbation, irregular heartbeat and heart attacks. Reducing fine particulate matter in both the workplace and local environment would have enormous health benefit. In fact, EPA quantitatively estimated public health benefits in the range of 9 to as much as 75 billion dollars by the year 2020 from reducing the fine particulate matter standard from 65 to 35 $\mu g/m^3$ (EPA 2006).

Biodiesel blends may offer an effective risk intervention that can reduce some of the key, harmful components like fine particulate matter associated with diesel exhaust in high exposure scenarios like the workplace. Because of the operational benefits to the diesel engine such as increased lubricity, biodiesel blends also appear to be an intervention that can be implemented immediately.

To fully understand the impact of biodiesel on human health and the environment, exposure data is needed. Yet, there is a critical lack of biodiesel exposure data in the scientific literature. At the time of this writing, a literature review found only one biodiesel exposure assessment - an internal Mine Safety and Health Association report that measured biodiesel work area exposures in different areas in a mine in Maysville, Kentucky. B20 use generally reduced PM & EC, and increased OC (Shultz 2003). There was no research identified that examined the effects switching to biodiesel may have on both occupational and environmental exposures concurrently.

This lack of integrated research is a symptom of the regulatory and institutional barriers described earlier that impede looking at ways to reduce both environmental and occupational chemical exposure risk. This study addresses that disconnect by evaluating biodiesel's impact on environmental and occupational exposures concurrently. Biodiesel may offer an important health risk reduction alternative to petroleum diesel exhaust. However, biodiesel's impact on NO_x is still unclear. The data gaps in the literature on biodiesel emissions and exposures, if not examined, may ultimately present new risk challenges, especially as biodiesel production capacity and distribution increases in the U.S. There has also been increasing concern among scientists and environmentalists that biodiesel use may result in unintended environmental and social harm. These points are discussed next.

1.5.5 Food vs. Fuel: A Challenge?

A big political push for biodiesel has been the need to identify renewable sources of energy that can replace liquid petroleum fuels. Decreasing domestic oil reserves, reliance on oil from the volatile Middle East, diminishing worldwide oil supply, global warming concern and other extrinsic drivers are driving the growth of the renewable energy industry (Klass 2003). Yet, in spite of the potential political benefits, biodiesel does have some detractors who point out what they perceive as significant problems with the alternative fuel.

Biodiesel is more expensive than petroleum diesel, and the cost varies depending on the feedstock used to make the biofuel portion. Pure biodiesel has an EEL (energy equivalent liter) cost of 82 cents per liter versus 53 cents per liter for diesel (Manuel 2007). An energy equivalent liter cost attempts to normalize the costs of the different types of fuel by accounting for both the energy that goes into making the fuel as well as the energy output of the fuel. B20 prices at the retail pump tend to be only slightly higher than pure petroleum diesel due to tax credits. In 2005, biodiesel could not compete economically with petroleum diesel without federal subsidy (Hill et al. 2006). This subsidy has been in the form of a tax credit for distributors at a penny per percent point of biodiesel blended into petroleum diesel, with the savings passed to consumers (Pahl 2005). Even with the subsidy, biodiesel is more expensive for consumers than diesel, but this difference has narrowed to a less than 5 cent difference per gallon for B20 in some regions of the country.

Coupled with biodiesel's higher cost have been feedstock availability issues. Current agricultural feedstocks such as soy cannot come close to meeting existing petroleum diesel demand. Even if all the soy grown in the U.S. today was converted to biodiesel fuel, the amount would only meet 6% of petroleum diesel needs (Hill et al. 2006). In addition, critics point out that soy may be an overall poor choice of feedstock with respect to an energy balance over the fuel's life cycle. With its low yield of soy oil per kg of soybeans (18%), Pimentel and Patzek (2005) contend soybean crops are poor producers of biomass energy. Per their calculations, production of 1000 kg of biodiesel with an energy output value of 9 million kcal requires an energy input of 11.9 million kcal, resulting in a net overall loss of energy of 32% (Pimentel and Patzek 2005). Other researchers also question the long term viability of a soy based fuel. Via their life cycle analysis that evaluates fertilizer impacts, Hill et al. (2006) found that cultivation of soy requires huge inputs of fertilizer (derived from fossil fuels) and releases nitrogen and pesticides from agricultural activities. In accounting for fertilizer impact, converting all soy to biodiesel would reduce biodiesel's net energy gain from displacing a maximum of 6% of petroleum diesel to displacing just 2.9% of diesel consumption (Hill et al. 2006). Conversely, Pimentel and Patzek (2005) found soy based biodiesel had little nitrogen impact and suggested biodiesel's limited nitrogen impacts were a benefit.

There is also concern among policy-makers that if biodiesel becomes more popular that the competition for soybean oil can set up a food vs. fuel war. Hill et al. (2006) believe that the potential for soy based biodiesel will be constrained by the important role that soy plays in human food supplies. While some biodiesel advocates believe this concern has been overemphasized (Pahl 2005), others argue that soy-based biodiesel is just a first generation biofuel. Biodiesel is considered by some to be a transition fuel with the critical next step developing biofuels from non-food based materials (Manuel 2007).

1.6 Research Question: How Can the Analytic-Deliberative Framework Help Move Beyond Regulatory Barriers to Investigate Biodiesel Exposures in a Real World Application?

The above analysis summarizes the multitude of factors that enter into a risk decision-making process such whether to use biodiesel as an alternative to diesel. The decision to replace diesel with biodiesel is multidimensional and requires a novel risk decision-making approach. I will summarize the main dimensions here, justify the need for a novel approach, and describe the goals of this research study. First, the problem of exposure to diesel exhaust is significant and complex. With its longevity, power and adaptability to multiple applications, the diesel engine is a useful, durable and reliable technology that will continue to be an integral part of the nation's transportation infrastructure into the foreseeable future.

Due to the diesel engine's longevity and slow fleet turnover, existing regulatory approaches to minimize diesel exhaust's public health impact will not fully manifest its expected benefits for 20 years or longer. Benefits within a workplace, where diesel exhaust exposures are orders of magnitudes higher and OSHA regulations are minimal to inadequate, may not occur at all.

As reviewed in section 1.2, the regulatory and institutional barriers to reduce diesel exhaust exposures pose a formidable challenge to implement nationwide exposure reductions in practice. I have also suggested an epistemological barrier exists when examining the role of science in risk decision-making. "Normal" science paradigms contribute to regulatory and institutional barriers. In short, EPA and OSHA regulatory approaches to manage the risk associated with diesel exhaust exposure are at an impasse.

Enter biodiesel. Tailpipe emissions data measuring biodiesel exhaust from various diesel engines have consistently showed reductions in fine particulate matter, an air pollutant with a substantial scientific database of negative health effects. However, the biodiesel fine particulate matter reductions reported in the literature have been mainly determined from lab based studies where biodiesel blends and petroleum diesel were burned in the same heavy duty engine. Exposure data is lacking. Exposures are more closely connected to ultimate human health effects than tailpipe emissions, and are of primary relevance in workplace studies since workplace exposures are significantly higher.

While the potential of biodiesel as a risk reduction intervention to reduce PM is worth investigating, it is but one dimension of the decision to use or promote use of biodiesel at both the national policy and local community level. Factors that appear at first blush to be deceptively simple (biodiesel is greener because it's renewable!) are upon further review much more complex (biodiesel may not be greener because it needs high levels of polluting fertilizers to grow those renewable crops!). Different concerns may take center stage depending on the scale of the decision and interests of stakeholders: national policy makers may be more concerned about long term viability of biodiesel feedstocks and associated market perturbations, and local policy makers may be more interested in operational impacts, availability and cost. How the decision is framed will also influence the decision-making process. Is biodiesel healthier than diesel exhaust? What about biodiesel's impact on NO_x? Is biodiesel better for the planet because of the associated net reduction in CO_2 emissions? Will increased demand for crops for fuel drive up food costs? The current state of scientific understanding provides much information but much is still unknown about biodiesel. In addition to scientific uncertainty there is operational uncertainty, economic uncertainty, and so on. Biodiesel production, distribution, and use trigger all these uncertainties due to its relative newness in the U.S. Biodiesel decisions at the local, regional and natural level highlight the tight linkage of science and policy. To better understand the impact of B20 on occupational and environmental exposures, an effective approach should be sensitive to these multiple decision-making dimensions.

The potential of biodiesel to reduce both occupational and environmental health risk associated with exposure to fine particulate matter, nitrogen dioxide and EC/OC was the driving force behind this study. The core justification of performing a B20/diesel exposure assessment is compelling: to move beyond regulatory and institutional barriers to manage diesel exhaust exposure, a cleaner burning fuel that could be used in diesel engines today would reduce harmful exposures today. Thus the main focus of the study was an analytic process; however, the decision to use biodiesel has multiple dimensions, suggesting deliberation is also needed. In moving forward to investigate the impact of B20 on occupational and environmental exposures from nonroad engines, instead of keeping science separate from policy as is typical in a regulatory approach or the NRC (1983) risk assessment/risk management approach, I applied the NRC (1996) analytic-deliberative (A-D) model of risk decision making to the research process.

1.6.1 Elaborate the Research Question

1.6.1.a What Are Its Components?

Therefore, the main research question for this study was: how can the A-D framework help move beyond regulatory and institutional barriers to investigate biodiesel exposures in a real world application? This question and subsequent research approach have multiple components needing elaboration. First, use of biodiesel as an alternative to diesel is the type of environmental problem or environmental policy decision envisioned as being appropriate to the analytic-deliberative model. Science by itself cannot provide sufficient information to make many environmental policy decisions because the phenomena are complex, reasonable people may disagree about what facts are most important, and scientists may disagree how best to interpret available information (Stern 2005). The use of biodiesel is a complex decision with multiple dimensions and multiple potential scientific research approaches. Dietz and Stern (1998) also point out that scientific analysis alone will be inadequate (and deliberative systems needed) in most environmental decisions due to these factors: multidimensional impacts, scientific uncertainty, value uncertainty or value conflict, decision urgency, and existing mistrust. Use of biodiesel as a “green fuel” substitute for diesel triggers many of these same factors, and thus calls for the use of deliberation to enhance the scientific analysis. Stern (2005) concludes that more science will not resolve factual or policy disputes in cases when these multiple factors exist; instead procedures need to combine good science with judgments to lead to well informed decisions. Of particular importance for this research was investigating biodiesel's impact on both occupational and environmental exposures, as a way to reconnect both environmental and workplace health risk management.

1.6.1.b Justify the A-D Model

The A-D Model was appropriate as the collaborative exposure assessment took place within a larger real world context: the City of Keene's use of B20 in its municipal fleet. In fact, the policy context and the exposure assessment were very much intertwined. Both Keene State College and the City of Keene Department of Public Works have used B20 (20% soy based biodiesel/80% petroleum diesel blend) fuel in both onroad and nonroad equipment since 2002. Not long after substituting B20 for petroleum diesel, employees in the City of Keene who work on or near diesel equipment perceived that burning biodiesel resulted in better local air quality and self-reported health (Russell 2006). Workers felt "better" after the fuel switch, noting fewer headaches, colds, and irritated eyes. This was noteworthy as the employees self-reporting improved health benefit were initially skeptical about biodiesel use. The Fleet Manager for the City of Keene, Mr. Steve Russell, began speaking at local venues and regional fleet conferences about the City of Keene's experience and "hidden" benefits of biodiesel use. In performing the collaborative exposure assessment, the relationship to local policy was always present because the decision to use B20 was always being discussed or revisited at annual city budget hearings or Russell's outreach presentations. In fact, the initial decision to use B20 was based more on the desire to reduce foreign oil dependency and to burn a more environmentally friendly fuel (Russell 2006). The perceived health benefit was not observed until after B20 was in the fleet. This real life context made the A-D framework attractive for application. Russell engaged researchers at Keene State College to try to help the City answer the initial question, “Is biodiesel healthier?” This question was refined to the testable hypothesis, “Does use of B20 result in differences in $PM_{2.5}$, EC/OC and NO_2 levels in the workplace and local environment?”

The study also used the A-D framework to conduct a concurrent evaluation of both occupational and environmental impacts of biodiesel use. This concurrent examination of occupational and environmental exposures moves beyond the regulatory and institutional separation of workplace and environment to reconnect environmental and occupational health in practice. Conducting the study at the Keene Recycling Center (KRC), where nonroad diesel equipment is used year round to move materials throughout the facility, offered the opportunity to simultaneously evaluate both environmental and occupational impacts. The KRC’s diesel emissions posed occupational risks to workers and the KRC is also a stable and long term source of diesel emissions in the local community. Since policy relevance was consciously incorporated into the design of the exposure assessment by examining those air contaminants ($PM_{2.5}$, EC/OC, NO_2) of public health concern, the results of the study were expected to inform local policy decisions and perhaps national policy debates about biodiesel use and impact. The A-D model is flexible enough to adapt to such interdisciplinary risk research.

1.6.1.c What is Novel About This Research?

In addition to helping to reconnect environmental and occupational health, I believed that connecting analysis and deliberation could meet substantive, instrumental and normative goals suggested by Fiorino (1990) for risk decision-making. Substantive goals could be met by increasing the state of knowledge about biodiesel via integration of local (Keene DPW) and technical (KSC research) knowledge. By opening up the analytic process as suggested by the A-D model, it was hoped that the collaborative exposure assessment (CEA) would better gather and synthesize all relevant knowledge. The collaborative exposure assessment data could also help meet instrumental goals by potentially legitimizing the local employee observations of cleaner air. If the CEA results indicated reduced exposures from B20 use, this evidence could help justify the decision to use biodiesel in the City fleet (at higher prices) and be used to advocate for B20 use at a regional level. It could also help justify using B20 in new applications. Normative goals would be met by expanding participation beyond the academic researchers to include interested and affected parties (those impacted by biodiesel exposures or use of biodiesel) in the research process.

The NRC (1996) argues that the analytic-deliberative framework should improve risk decision-making by enhancing communication between technical experts and decision-makers, increasing the substantive knowledge base of the decision, improving collaboration and trust among stakeholders, and decreasing scientific uncertainty. However, there are no prescriptive guidelines in the report on how to actually integrate analysis and deliberation. Implementation ideas are suggested by case studies and references to the public participation literature. Therefore, while mainly using the A-D framework and associated literature in the NRC (1996) report, I was also influenced by ideas from the literature on community based participatory research (O' Fallon and Drearry 2002; Judd et al. 2005; Sclove et al. 1998), in trying to increase participation in analytic activities. I was influenced as well by Fischer's (2000) critique of the NRC's (1996) focus on deliberation as leaving science squarely in the domain of experts, diminishing nonexpert participation in analysis. I attempted to help bring together experts and nonexperts in the performance of the CEA. The community based aspects were especially pertinent in involving KSC undergraduate students in the performance of much of the day-to-day field work, working alongside KRC employees at a location often frequented by community members.

Other benefits expected from application of the A-D model were increasing the policy relevance of the CEA results. Decisions do not occur in a vacuum – with science taking place on one side and policy on the other. However, technical experts tend to operate in disciplinary silos. For this project, instead of keeping technical experts and local decision-makers in separate silos, communicating occasionally, I hoped the emphasis on collaboration in both the CEA and Biodiesel Working Group (BWG) activities would more effectively translate the results into tangible policy outcomes. Although the exposure assessment could stand on its own as a novel scientific contribution due to the lack of other biodiesel exposure studies, I believed it was important that the contribution of local knowledge to the original research question be recognized. It was also important to the parties that the results at least be communicated via local outreach. I also thought that intentionally connecting both analysis and deliberation would better link any subsequent new knowledge from the CEA to both the local and wider policy discourse on the benefits and challenges of biodiesel. Additionally, the A-D model's recursive nature seemed especially well suited to the goal of understanding the exposure risks for a new technology like biodiesel that can have impact on both occupational and environmental health. Our team was entering into an ongoing conversation about biodiesel, and we hoped to make a contribution to the conversation about exposure and perhaps policy as well.

Finally, as mentioned at the beginning of this chapter, the words of a KRC employee really stuck with me throughout the dissertation, “It would be a shame if this research sat on a shelf.” I also did not want this work to sit on a shelf, or remain solely within a peer reviewed scientific journal context. There was also a sense among others within the collaboration to “do more” with the CEA results, to use the results in a practical way. The CEA results were especially important to the ongoing biodiesel outreach and public education that the City of Keene and City Fleet Manager Steve Russell were doing. There were also potential future policy decisions on the table: B20 was being used in some applications (fleet) but not others (heating) in the City.

1.6.2 Case Study Approach

As previously discussed, the City of Keene has an ongoing relationship with biodiesel. In fact, the City of Keene has been part of broader efforts to ensure City activities are sensitive to environmental impacts. In joining the Cities for Climate Protection (CCP) campaign in 2000, the City took a public step in committing to reduce greenhouse gas emissions. Use of B20 happened initially outside this CCP process, but eventually became integrated with it. Keene is also part of the Local Governments for Sustainability Association to prepare for and find ways to reduce climate change impacts (Keen 2008). Thus the City of Keene could be described as having a culture of environmentalism. With respect to B20 use, Russell became a local expert and would share his personal experience with how B20 reduced headaches and colds for him and his workers. Russell indicated he would always be asked, “Well, where are your facts, Steve?” and his frustration at the desire for “hard facts” inspired him to reach out to KSC in 2004. The background of Keene’s support for environmentally friendly initiatives made it appropriate for a case study approach focused on Keene’s relationship with B20 and more specifically the KSC/City of Keene B20 research collaboration. The actual methodological approach is a hybrid one and is reviewed in more detail in Methods, Chapter 2.

1.6.3 Applying A-D Concepts to Evaluate B20 Exposure Risk

1.6.3.a General Components of the Approach

KSC and the City of Keene had performed a pilot exposure assessment in 2004 indicating significant reductions in particulate matter, supporting local employee observations. During this time, informal discussions and building of relationships indicated the City had a desire to do more and learn more about B20. In applying the A-D model, this KSC/City collaboration was encouraged and formalized with meetings and discussions. How this was done is discussed in more detail in Chapter 2: Methods, but essentially through linking two main processes of analysis and deliberation. Interested and affected parties from both KSC (students and researchers) and the City of Keene (supervision and employees) participated in both the exposure assessment process (main analysis step) and a Biodiesel Working Group (main dialogue or deliberative step). In all activities, a collaborative partnership was emphasized.

1.6.3.b Monitoring and Exposure Assessment Steps

This involved using already established environmental and industrial hygiene air monitoring techniques, in addition to activity analysis methods developed by Treadwell (2003) to measure in-cabin, work area and local environment concentrations of $PM_{2.5}$, EC/OC, and NO_2. The work was performed by KSC researchers/students and informed by City of Keene employees. Specific roles and responsibilities for the exposure assessment are reviewed in Chapter 2. The exposure assessment step was a key way to fill in the gaps in the scientific literature and to get at the City's questions about biodiesel's impact on health.

1.6.3.c Dialogue Working Group

The main mechanism for deliberation and opening participation up to the City staff and employees was by creation of a Biodiesel Working Group. The Biodiesel Working Group (BWG) was used to provide a formal space for dialogue about the exposure assessment activities and to deliberate potential outcomes or future decisions about B20 that may result from the study. The BWG served as a way to organize the City of Keene's ongoing interest in B20 and to allow participation and feedback into analytic activities.

1.6.4 Expected Results

By connecting analysis and deliberation it was expected the research team would be able to enhance the overall analysis by involving local experts in the design of the exposure assessment and data collection. An improved exposure assessment was a main expected result. This was expected to increase overall understanding of B20 occupational and environmental exposures from use of nonroad engines, a critical data gap. Improving the understanding of B20's impact on exposures better informs the evaluation of B20 as an available risk reduction intervention to existing petroleum diesel fuel use. Reducing scientific uncertainty as well as being sensitive to the multiple dimensions of B20 use by applying the A-D model could help lead to a more decision-relevant synthesis of information regarding B20 for local, regional and potentially national decision makers. Application of the A-D model was expected to better fuse local and expert knowledge, increase collaboration, enhance the exposure assessment and increase the policy relevance of the results.

In a broader policy context, I hoped application of the A-D model would illustrate and reconnect the inherent workplace/environment relationship. I had further hoped it would help move beyond the regulatory, institutional and epistemological barriers that so often (as in the case of diesel exhaust) impede innovative risk reduction action. A cleaner burning fuel that is available today could reduce environmental and occupational exposures today, not 20 years from now as expected by current regulations. I hoped this local A-D research would help contribute to a more complete synthesis of knowledge and understanding regarding biodiesel use at a time when national policy mandates, concern about climate change and market forces are helping to shape the future of biodiesel in the U.S. It will hopefully add to the general literature about the theory and practice of risk decision making and more specifically document procedures to integrate analysis and deliberation in practice.

Methods

2.1 Analytic-Deliberative (A-D) Framework as Organizing Conceptual Approach to the Study: Overall Research Approach

The research design for this study is best described as multiple iterations of analysis and deliberation. Each A-D iteration revolved around a unique central research question. Each central research question was linked into the study's operative research question. In this section, I present the specific research questions and how I collected data in support of each question. I will review how I applied the NRC's (1996) analytic-deliberative framework to ongoing biodiesel research activities between Keene State College and the City of Keene. I will review the operative (or "linking") research question, the three central research questions, and the relationship between the operative question and central research questions. A condensed timeline of biodiesel research activities from 2004 to 2006, the start of application of the A-D model in June 2006, and subsequent A-D interactions and activities through June 2007 is shown in Figure 2.1.

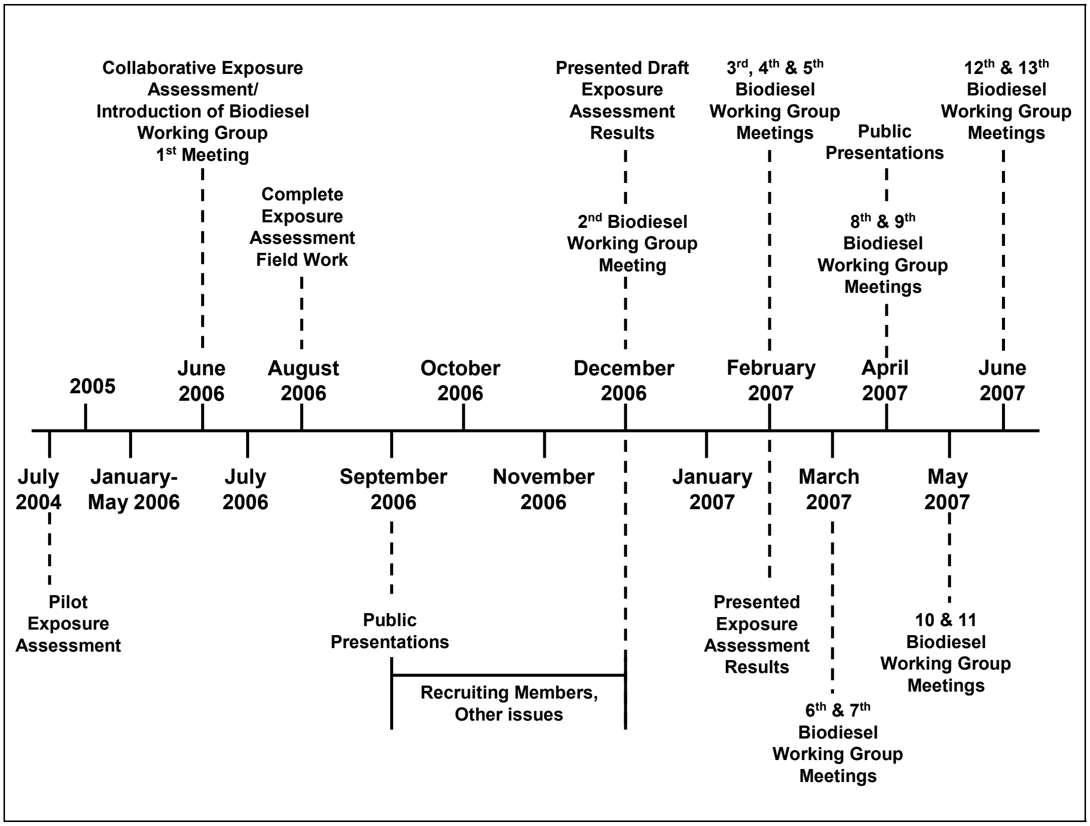


Figure 2.1: A Condensed Timeline of the Research Study (Note: The A-D Model was Formally Applied in June 2006).

2.1.1 Overall Design Framework and Operative Research Question: Does Applying an Analytic-Deliberative Approach to Understanding B20 Exposures Lead to Improved Decision-Making?

This section describes how the pieces of the study fit together. I applied the concepts of the analytic-deliberative model of risk decision making as defined by the NRC (1996) and summarized in Figure 1.8. The main application was the integration of a collaborative exposure assessment (CEA) (the “main analysis” in this study) with a Biodiesel Working Group (BWG) forum for deliberation. The collaborative exposure assessment (CEA) was performed at the City of Keene Recycling Center (KRC), a municipal resource recovery facility that utilizes non-road, construction-type equipment. The KRC is a relatively isolated, stable and long term source of diesel exhaust emissions in the local environment, which made it an excellent site to evaluate the relationship between occupational and environmental exposures.

The collaborative exposure assessment compared the impact of a 20% soy-based biodiesel/80% petroleum blend (known as B20) against 100% petroleum diesel on occupational and environmental exposures. The field work was performed by Keene State College (KSC) researchers, KSC students, and City of Keene employees. The CEA team measured in-cabin, work area, and local environmental concentrations of particulate matter, elemental carbon, organic carbon and nitrogen dioxide. The Biodiesel Working Group (BWG) was the deliberative forum for discussion of the collaborative exposure assessment strategies, activities, results, and potential future decisions related to the use of biodiesel by the City of Keene Department of Public Works (DPW). BWG members included participants in the collaborative exposure assessment, local decision-makers, and other interested and affected parties. The interconnected phases of analysis and deliberation informed each other throughout the dissertation research and after the dissertation data collection phase ended.

The CEA/BWG connection is the heart of this study. The linking, operative research question was: does applying an analytic-deliberative approach to understanding B20 exposures lead to improved decision-making? The initial goal of the CEA/BWG integration as illustrated in Figure 2.2 was to connect the technical analysis performed by the KSC/City team with deliberation to ensure the exposure assessment process captured all important knowledge, acknowledged uncertainties to the extent possible, evaluated both occupational and environmental exposures, and increased the local policy relevance of the expected results.

However, I must stress that the Biodiesel Working Group's initial envisioned purpose was to help improve the collaborative exposure assessment research process as described above and subsequently communicate the exposure assessment results locally in educational outreach initiatives. The primary aim in June 2006 at the first BWG meeting was that CEA/BWG participants would discuss exposure assessment strategies and uncertainties, any concerns relating to exposure assessment activities, and review where and how to communicate the results. No other structured goals were in place when the first BWG meeting was held; in this sense, this study was an application of the A-D model, not a test of it to predict specific outcomes. In fact, Central Research Questions #2 and #3 emerged from participatory aspects of the process. These questions were not predicted, but I studied them as they were a direct result of application of the A-D model. At the start of this study - the connection of the BWG to the collaborative exposure assessment - Central Research Question #1 was: Does use of B20 reduce exposures of $PM_{2.5}$, EC/OC and NO_2?

2.1.2 Central Research Question #1: Does use of B20 reduce exposures of $PM_{2.5}$, EC/OC and NO_2? (Figure 2.1)

Russell and the City engaged researchers at Keene State College in 2004 to try to help their organization answer the initial question: is biodiesel healthier? Researchers and undergraduate students from Keene State College had collaborated with City of Keene employees to examine the impact of biodiesel fuel on occupational and environmental exposures in a 2004 pilot study. The City wanted to more fully understand what they perceived to be real, undocumented benefits of biodiesel – the cleaner workplace air - in order to increase biodiesel awareness locally and regionally. Russell in particular was frustrated at being consistently asked during his local and regional presentations for “facts” to support his claim that biodiesel had made his workplace air cleaner (Russell 2006).

There are multiple ways to approach the question: “is biodiesel healthier?” For example, worker health surveys or animal toxicology studies are other potential research strategies. Based on the KSC and City of Keene team’s interests, collective expertise and available resources, we decided on a comparative exposure assessment strategy. We took the original question, “is biodiesel healthier?” and refined it to the testable hypothesis “does use of B20 compared to petroleum diesel result in differences in $PM_{2.5}$, EC/OC and NO_2 levels in the workplace (“occupational exposures”) and local environment (“environmental exposures”)?” These pollutants were selected because of their policy relevance, since there is a wide literature connecting $PM_{2.5}$ exposure to health effects, EC is widely accepted as a surrogate for diesel, and NO_2 is of key interest in regulatory circles for its connection to smog. When the 2004 pilot indicated significant reductions in particulate matter, both groups agreed to do an expanded exposure assessment study. Prior to the expanded exposure assessment field work, I organized and started the deliberative Biodiesel Working Group. Participants in both phases included KSC researchers, KSC students, City of Keene employees, and other interested and affected parties, as shown in Figure 2.2.

In Section 2.2, I will outline in more detail how the steps in the A-D model as shown in Figure 1.8 were applied to each Central Research Question. For the first question, this will include review of the strategy of the collaborative exposure assessment, the strategy of the Biodiesel Working Group, and the quantitative and qualitative data collection methods employed in each phase. I will also more fully describe the roles of the participants in the research.

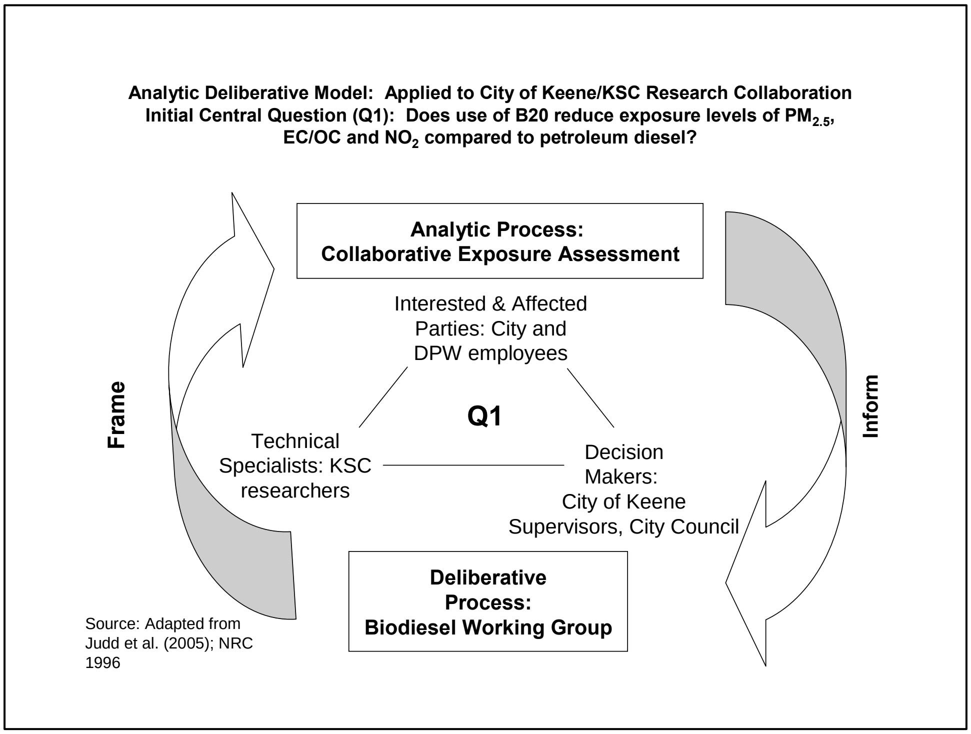


Figure 2.2: <u>**First Iteration of the Overall A-D Process: Central Research Question #1**</u>

The A-D interactions associated with Central Research Question #1 spanned the time frame in Figure 2.1 from June 2006 to December 2006. However, like a gear turning other gears in a watch, the initial integration of the exposure assessment with the BWG led to new, subsequent central research questions that continued the analytic-deliberative interactions among KSC researchers and interested and affected parties. As a real-world application of the A-D model, there was no guarantee that the BWG process would ever gain traction or much less lead to any tangible outcomes or decisions. However, participants desired to “do more” with the exposure assessment results, and this led to the development of subsequent Central Research Questions #2 and #3. The A-D framework was then applied to each of these questions.

2.1.3 Central Research Question #2: How Can Local Supply of B20 Be Increased? (Figure 2.3)

The results of the collaborative exposure assessment performed in July and August of 2006 led to a decision by the BWG to explore increasing use of B20 in Keene. Various ideas such as using biodiesel for heat were discussed, but almost immediately the lack of local biodiesel supply was identified as a critical structural barrier. Thus the second Central Research Question #2 in this process became: how can local supply of B20 be increased? This question and the participants in the BWG are shown in Figure 2.3. Of note, the BWG membership had expanded to include new interested parties, such as senior KSC administrative staff. While the main deliberative activities continued to be meetings of the BWG, new analytic activities included interviewing local fuel oil and diesel duel distributors. The time frame of Central Research Question #2 activities spanned from January 2007 to approximately March 2007. In Section 2.2, I will outline these activities in more detail and explain how the A-D steps of Figure 1.8 were applied to Central Research Question #2. Section 2.2 will include the multiple strategies and data collection methods employed, as well as my role and the roles of other key participants.

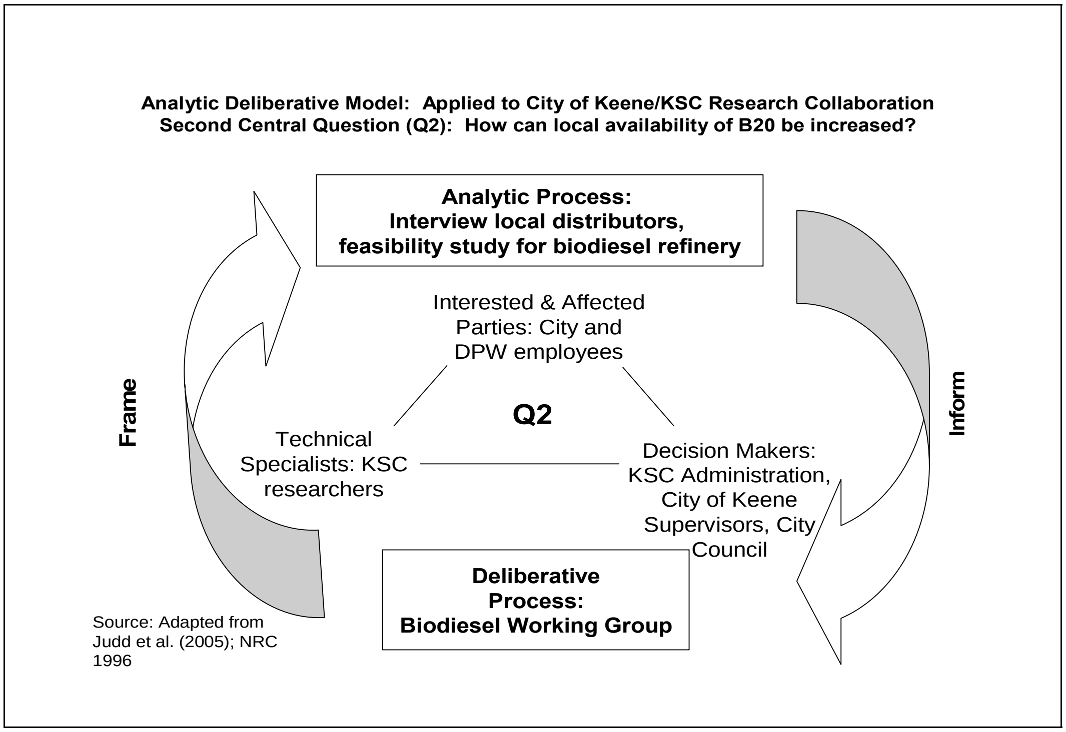
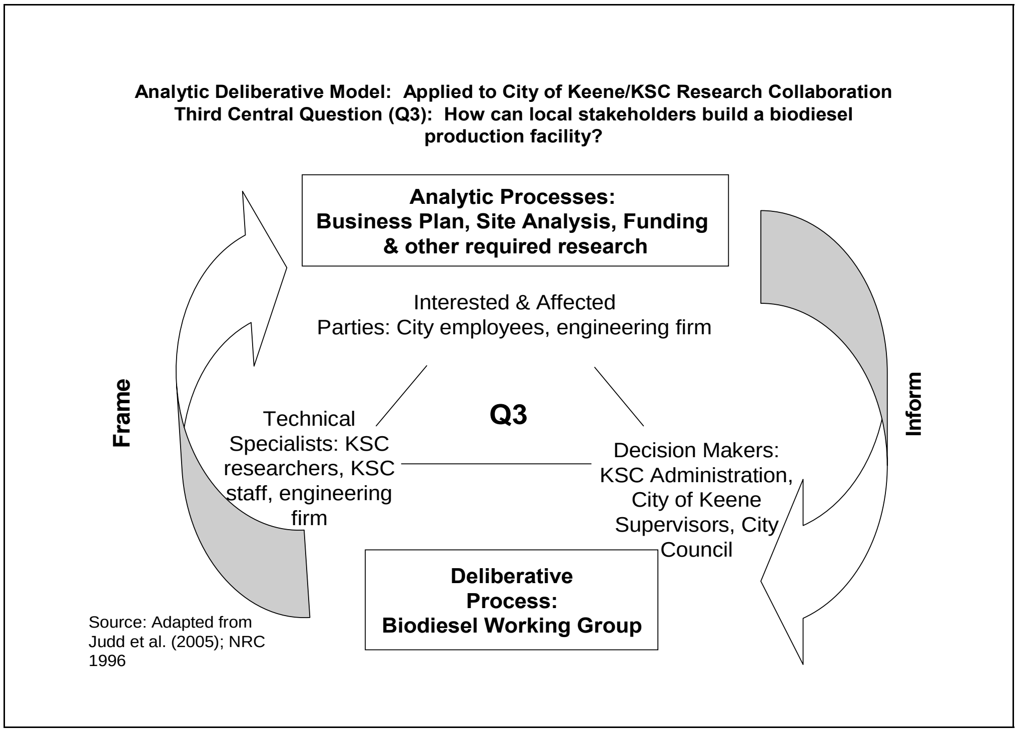


Figure 2.3: **<u>Second Iteration of the A-D Process: Central Research Question #2</u>**

2.1.4 Central Question #3: How Can an Innovative Public/Private/College Collaboration Manufacture Biodiesel in the Local Community? (Figure 2.4)

Further analysis and expanded deliberations (and an expanded-yet-again BWG) led to the final question, Central Research Question #3: How can local stakeholders collaborate to build a local biodiesel production facility? Information gathered during A-D activities for Central Research Question #2 indicated a number of external barriers impeding the expansion of biodiesel supply in rural areas like southwestern New Hampshire. The BWG membership had expanded yet again, to include a private engineering firm interested in collaborating with KSC in the production of biodiesel. This led to the final research question of this study, and numerous associated analytic and deliberative activities. Leadership of the BWG transferred from me to the KSC administration, and the BWG substantially expanded its membership. The decision-making process by this point had literally taken on a life of its own. These analytic and deliberative activities are still on-going as of the publication date of this dissertation, but I stopped collecting field data in June 2007. In Section 2.2, I will outline in more detail how the A-D steps of Figure 1.8 were applied to Central Research Question #3. This will include the multiple strategies employed, the methods used to collect data, and my role and the roles of other key participants.



Source: Adapted from Judd et al. (2005); NRC 1996

Figure 2.4: Third Iteration of the A-D Process: Central Research Question #3

2.1.5 Rationale for Linkage

The overall research design framework or organizing conceptual schema for this study is the integration of analysis and deliberation as recommended by the NRC (1996). This integration of analysis and deliberation was implemented as illustrated in Figures 2.2, 2.3, and 2.4. The 3 central research questions converge in support of the operative question: *does applying an analytic-deliberative approach to understanding B20 exposures lead to* *improved decision-making?* The NRC (1996) states application of the A-D model can lead to better risk decision-making by ensuring that decision-relevant knowledge level is as a complete as possible, uncertainties are addressed as comprehensively as possible, and concerns are acknowledged as fairly as possible. In this case, application of the A-D model was expected to better fuse local and expert knowledge on biodiesel and link any new knowledge that emerged from the CEA/BWG research process to the ongoing biodiesel policy discourse at the local, regional and potentially national policy level. I expected that accomplishing these aims would lead to an enhanced understanding of B20 exposures which could lead to overall improved decision-making as suggested by the NRC (1996). In short, I hoped purposely connecting analysis and deliberation would enhance the CEA process itself (design and data collection) as well as increase the policy relevance of the results.

From a broader, more theoretical perspective, I applied the A-D model to move beyond the existing risk assessment vs. risk management divide that artificially segregates science and policy, as well as segregating technical and other forms of expertise. Instead of keeping technical analysis and deliberations separate, as is common in scientific research performed in regulatory contexts (such as the assessment of diesel exhaust emissions and exposures), I hoped combining the two would increase collaboration among participants and help move beyond regulatory and institutional barriers to better inform understanding of B20 exposures.

Additionally, since Biodiesel Working Group membership consisted of diverse people involved in both analytic and deliberative activities, who represented various viewpoints and values systems, process concerns could be identified early and any decisions made had the potential to be considered more legitimate. And finally, the A-D model helped structure research and discussion of the concurrent impact of B20 on occupational and environmental exposures, to help move beyond regulatory and institutional barriers that tend to segregate the workplace from its environmental context.

In most cases from the environmental decision-making/public participation literature, citizens and stakeholders take information from technical experts as a "given" input to the decision-making process. Technical analysis activities are often kept separate from deliberation. The NRC (1996) report argues that this separation contributes to risk decisions that miss important relevant knowledge, do not address citizen/stakeholder concerns, are seen as illegitimate, waste regulatory agency resources over the long term and decrease citizen/stakeholder trust in regulatory processes. While citizen participation via town hall meetings, advisory panels and other mechanisms has become commonplace in environmental policy-making over the past 30 years, citizen involvement in the science that informs the policy is relatively recent (Lynn 2000).

While mainly using the A-D framework and associated literature referenced in the NRC (1996) report, I was also influenced by similar ideas from the literature on community based participatory research (O' Fallon and Drearry 2002; Judd et al. 2005; Sclove et al. 1998), in trying to increase participation in analytic activities. For example, three principles of community based participatory research relevant to this study were promoting active collaboration at every research stage, fostering of co-learning, and disseminating research results in useful terms (O' Fallon and Dearry 2002). While not explicitly identified as such by its advocates, community based participatory research (CBPR) may be considered philosophically similar to participatory action research, although the action in CBPR is guided more by the sponsoring research organization, not necessarily the participants

(Corburn 2005). In addition to CBPR principles, I was influenced by Fischer's (2000) critique of the NRC's (1996) focus on deliberation as leaving science squarely in the domain of experts, diminishing nonexpert participation in analysis. The community based aspects were especially pertinent in involving KSC undergraduate students in the performance of much of the day-to-day field work, working alongside KRC employees at a location often frequented by community members.

One final point about the overall study design: since both natural and social science phenomena were studied, this research employed both quantitative and qualitative methods to collect data. The research design (or application of the A-D model) was clearly unique and specific, and as such the overall methodological approach was hybridized. I found case study design principles provided a helpful methodological lens. Focusing on the KSC/City B20 research collaboration as a case unit of analysis helped coordinate the use of and clarify the purpose of different quantitative and qualitative research strategies and data collection techniques. According to Yin (1984), case study is an appropriate strategy for "how" or "why" questions for contemporary events over which the research has little or no control. My participation as both natural and social scientist meant this case could be considered revelatory per Yin (1984), as my role gave me insider status to phenomenon of risk-decision making not typically pursued or available to most natural scientists. Typically, scientists present and explain data to policy-makers under the traditional risk decision-making model that emphasizes a facts vs. values dichotomy. Finally, case studies use a variety of evidence in data collection to triangulate data analysis, an approach I followed for this study.

The need for quantitative strategies and data collection methods is relatively intuitive for studying natural phenomenon: to measure levels of air contaminants in the workplace and local environment, quantitative measurements were required. The Biodiesel Working Group and associated deliberations embodied the social phenomenon of this research. Social phenomena are better suited to qualitative inquiry. Creswell (1998, p. 15) defines qualitative research as follows:

> Qualitative research is an inquiry process of understanding based on distinct methodological traditions of inquiry that explores a social or human problem. The researcher builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting.

Creswell (1998) further clarifies that complex and holistic refer to a narrative examining the "multiple dimensions of a problem or issue". Since there are multiple dimensions to this study, qualitative methods provided a deeper understanding of the holistic and interactive relationship between the exposure assessment analysis and associated deliberations. Staying only within a quantitative realm would overlook the larger, more complex picture of how the collaborative aspects of the research emerged and evolved. Without a qualitative component, we would lose insight into the interactive nature of the process of scientific analysis and how connecting deliberation to analysis can better inform risk decision-making. Creswell (1998) emphasizes that qualitative inquiry is appropriate when such a detailed view of a topic is desired.

2.1.6 Relationship Between Operative Question and Central Research Questions

As described above, there were theoretical rationales for linking analysis and deliberation in this case. Case studies of decision-driven, integrated analytic-deliberative processes are limited. Cases where nonexperts participate in analytic or scientific activities that inform environmental policy are especially unique (Lynn 2000). The case of the KSC/City of Keene research collaboration makes a contribution to this limited database by providing an example of a participatory model of analytic-deliberative risk decision-making in practice.

The operative or linking question provided the theoretical frame or way to bound the study, as well as a lens through which to view the study: when all the data from the central research questions were collected and analyzed, did applying the A-D model to understanding B20 exposures lead to improved decision-making? Did application of the A-D model to evaluating B20 exposures, make a difference, and if so, what was it? Since there is no cookbook formula to applying the A-D model, only guidance from the public participation literature as well as limited case studies where both analysis and deliberation were intentionally integrated, empirical data are both novel and necessary to inform future risk decision-making theory and practice.

The central research questions flowed from the operative question and tracked the iterative yet forward moving progress that happened after the collaborative exposure assessment was connected with the deliberative forum provided by the Biodiesel Working Group. Central research questions #2 and #3 emerged from the interaction of analysis and deliberation that began with central research question #1. Each central research question was the result of a new problem formulation step, and evolved from the preceding central research question. All three central research questions fed data into the operative or linking question.

2.2 How the Concepts from the A-D Model Were Applied: Central Question #1

A summary of the how each of the A-D model steps (see Figure 1.8) were applied to each Central Research Question is shown in Appendix D. For the remainder of this section, I will explain in detail how these concepts were applied. First, I must note that while the central research questions and A-D model steps are listed sequentially, this does not imply the research activities actually occurred in a straightforward linear fashion, or that analysis or deliberation "neatly" interacted in a prescribed fashion. In fact, one of the main challenges in discussing the research methods (and later, presenting results) has been how to best capture the overlap and interactive relationships between analytic and deliberative activities, while clearly explaining what I did and the results that were observed in an accessible manner for the reader. While the A-D framework as illustrated in Figure 1.8 and applied in this case in Appendix D, is shown as an ideal progression of steps, the NRC (1996) emphasized that a "common misunderstanding" is that analysis and deliberation in decision-making will proceed in a prescribed sequence. The research activities in this study certainly did not proceed in a linear fashion or followed the steps in exact order as outlined in Appendix D. In fact, the research progressed more like the saying - three steps forward, two steps back. But even within the significant overlap or "messiness" of analytic-deliberative activities, there was an overall forward progression of decision-making. Therefore, I have attempted to organize these activities to be accessible, with as much clarity as possible. This study also does not fit in a neat methodological taxonomy, but rather borrows from a quantitative and qualitative methodological toolbox unique to the operative and central research questions. In this way, this dissertation was truly interdisciplinary. A simplified overview of the project is shown below in Figure 2.5.

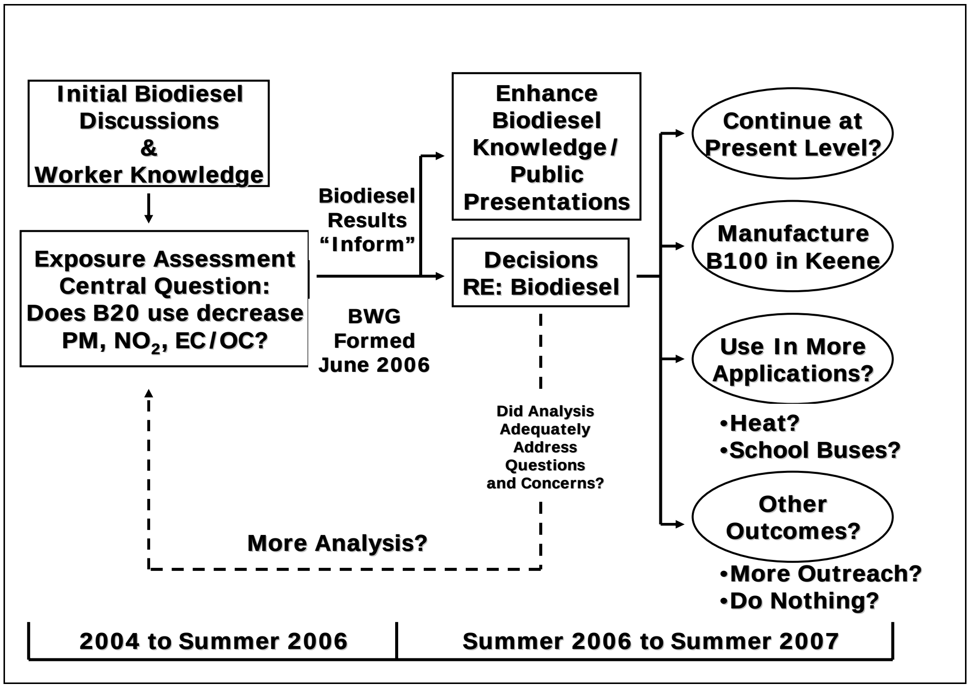


Figure 2.5: Project Overview of City of Keene/KSC Research Collaboration

2.2.1 Problem Formulation

Central Research Question #1 originated from the local observations made by City of Keene employees about B20 use in the Department of Public Works (DPW) fleet. As summarized by Russell, "You pull a truck into my shop now and you don't even know it's diesel" (Cohen 2003). Similar observations were shared with me during informal conversations with the City of Keene and Keene State College employees regarding their B20 and B100 use. Bud Winsor, Assistant Director of Physical Plant and Grounds at Keene State College noted, "Equipment operators report fewer headaches at the end of the day, the fumes don't smell bad; it was a great move" (Cohen 2003). These informal discussions framed the initial question, “is biodiesel (B20) healthier than petroleum diesel?” The dramatic impact of B20 in the workplace is best summarized by Russell (2006):

> I noticed it myself. My office in the old building was adjacent to the shop…every time they would drive a diesel engine into the shop… we had no air quality equipment in that shop. Those diesel fumes would stay there for a period of time and I found myself with a lot of headaches. I would go open the window, try and get rid of the headaches so fast forward to using biodiesel…the same equipment goes into the shop, same environment, same everything and I’m not getting any headaches. It was very strange and I’m trying to rack my brain, why aren’t I getting headaches now. Then I realized it was the B20. It was the biodiesel.

Russell and I approached Dr. Melinda Treadwell at Keene State College to collaborate on a research strategy to attempt to quantify this observation. Dr. Treadwell had specific expertise in lung toxicology, and she had pervious experience in performing diesel exposure assessments. She agreed the City of Keene observations supported exploring B20 as a risk reduction intervention to diesel exhaust exposure. Dr. Treadwell and I collaborated to refine the initial question of “is biodiesel healthier” to the testable hypothesis “does B20 compared to petroleum diesel use result in differences in occupational and environmental exposures of $PM_{2.5}$, EC/OC, and NO_2?” How to test this hypothesis became the initial problem formulation. Dr. Treadwell provided the funding, equipment, and student resources for the 2004 pilot exposure assessment and 2006 expanded exposure assessment. In summary, the genesis of Central Research Question #1 started the way many scientific studies begin, by developing a hypothesis for an observation made over time. In this case, the observation initially came from nonscientists. Further detail on roles and responsibilities in performing the research is discussed in the section 2.2.4.a.

2.2.2 Process Design

2.2.2.a Site Selection

The City of Keene Recycling Center (KRC) was chosen after internal deliberations as the best site for the exposure assessment due to a number of characteristics: remote location, consistent operations on a week to week basis, use of nonroad diesel equipment by workers, a stable source of diesel emissions in both the workplace and local environment, and generalizability of findings to other sites. The site is one of the largest municipal owned material recovery facilities in New Hampshire, but comparable to a number of privately owned facilities with respect to tons of material processed per year. Operations at the recycling center used non road or construction type equipment such as front end loaders to move cardboard, paper, plastic containers, glass and aluminum cans throughout the site. There was also a segregated trash transfer area on the far end of the KRC building where local refuse was dropped off, consolidated, and then picked up via a large track excavator and placed into open box trailers for off site transport to landfills. There were 3 main pieces of equipment used: a large front end loader (John Deere Model 624H - 160 HP), a small front end loader (JCB Model 409 – 67 HP), and a large track excavator. Due to a building fire during the petroleum diesel use time period, B20 data was not collected in the large track excavator area; therefore, this equipment and the work area will not be discussed further. The area of the fire was segregated from the other KRC recycling area and did not impact the data collection process for the other perimeters in this study.

The KRC consists of a single large building with one large bay door on the lower level/main floor area and 5 other side bay doors on the upper level of the building. Trucks from other towns and local trash hauling companies drive into the lower level area to dump cardboard and paper waste on the main floor. Town residents or other trucks drop off newspapers, aluminum cans or plastic containers at one of the side bays. Employees stand alongside a conveyor belt system to separate non-recyclables from the process stream. The conveyor belt and employee break room are located on a second level inside the facility. The small front loader works on the main floor area moving cardboard inside the building to another conveyor belt leading to a bailer machine located on a sub level in the building. The large front loader typically works on the metals pile in another outdoor location on the property, but also works on the main floor area inside the building to move paper into an open trailer for transport to another facility. Air monitoring was performed in areas designated Perimeter #1, #2, #3, and #4 during days when equipment operated on petroleum diesel and then on a B20 blend. Perimeter #5 was the large track excavator area; due to a fire in this area in early August 2006, B20 data was not collected for comparison purposes. These perimeter areas are illustrated in the schematic in Figure 2.6.

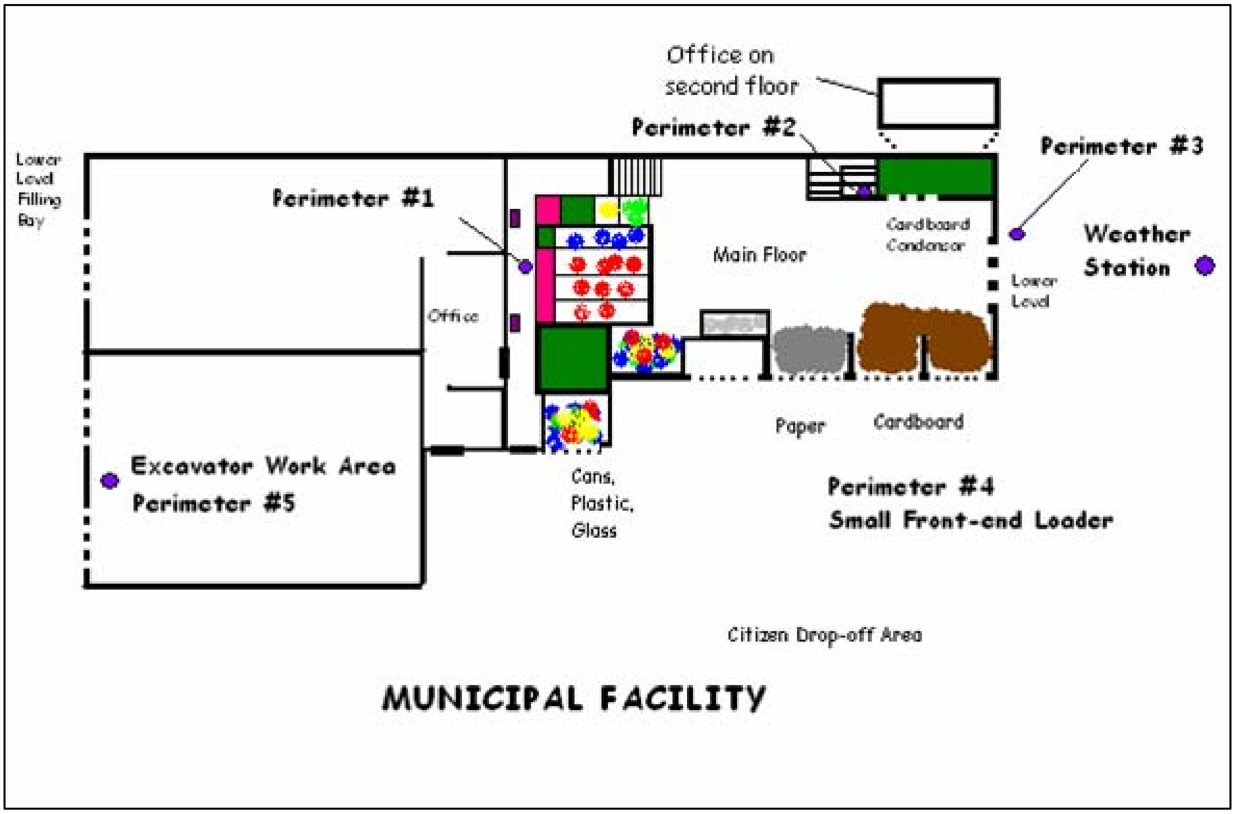


Figure 2.6: Schematic and Layout of the Keene Recycling Center

2.2.2.b Quasi Experimental Strategy for Exposure Assessment

The exposure assessment estimated diesel vs. biodiesel environmental and occupational exposures in "real world" scenarios at a rural recycling center. Exposure to a chemical is defined as the contact with that chemical with the outer boundary (i.e., skin, nose, mouth, eyes) of a human (EPA 1992). Mathematically, exposure is a function defined as the measured concentration over a specified time period, $E = \int C(t)\, dt$, usually simplified as a time weighted average, $E = \sum C_i t_i / T$ (Ramachandran 2005). Occupational exposure assessment is the process of defining and evaluating the acceptability of exposure profiles (Mulhausen and Damiano 1998). Because the workplace consists of many microenvironments through which and within which workers move, occupational exposure assessment focuses on measuring concentrations of air contaminants within the breathing zone of the worker (Ramachandran 2005). At a theoretical level, since the breathing zone area is emphasized, occupational exposure assessment closely estimates actual exposure, and is decision driven because it will typically compare the breathing zone concentration against a “safe” regulatory exposure limit.

Environmental exposure assessment measures concentrations of air pollutants in specific, stationary locations or areas. At a theoretical level, environmental exposure assessment is more focused on local/regional levels of pollutants, and determining the relationship between exposure and biologically effective dose. Exposure and the biologically effective dose (the delivered dose that impacts the target organ’s receptor sites and causes a response) are never the same due to complex pharmacokinetic [i.e., absorption, elimination] and pharmacodynamic [i.e., repair, compensation mechanism] processes (Ramachandran 2005). An EPA exposure assessment would take the measured air pollutant concentration and apply a standardized breathing rate to define an “intake rate”, then a potential dose (EPA 1992).

The quasi-experimental approach was appropriate for a number of reasons. A true experiment where a site is randomly selected from a population of similar sites was not possible since the KRC was the only site to which we had access, and no other recycling center in New Hampshire was using B20 in its equipment at the time of the study.

INDEPENDENT VARIABLE	**DESCRIPTION**	**NOTES**
Fuel	Petroleum diesel and B20 (20% soy based biodiesel/80% petroleum diesel)	Diesel fuel met ASTM B20 fuel met ASTM purchased from: Fleming Oil, Brattleboro, VT
Weather	Temperature Relative Humidity Wind Speed Wind Direction	Casella Weather Station
Activity	Documented activity level (High, Med, Low) of sources and source proximity to monitor at 20 minute intervals	Used standard activity log forms, one to two students responsible for documenting levels/types of activity at perimeters 1,2,3,4. Each student team given a digital clock
Vehicle Count	Counted Vehicles that passed through noting vehicle type (diesel vs. gas)	Students used standard vehicle count forms. Dedicated student team located at citizen drop off area

Table 2.1: Summary of the Independent Variables in Collaborative Exposure Assessment

A quasi-experimental design was used to test the central research question, “Does B20 use change levels of $PM_{2.5}$, EC/OC and NO_2?” Independent variables are summarized in Table 2.1. Independent variables were: fuel type, engine type, day, temperature, relative humidity, wind speed, wind direction, level of equipment activity, equipment proximity to monitor, and outside vehicle traffic. These independent variables were measured for statistical control. The dependant variables were the levels of air contaminants ($PM_{2.5}$, EC/OC and NO_2) at each Perimeter #1, #2, #3, and #4. We addressed threats to validity, as discussed in Section 2.2.4.h.

In the summer of 2006 we spent five weeks at the Keene Recycling Center conducting environmental air monitoring in operator work zones and in the local environment. $PM_{2.5}$ and EC/OC were measured at Perimeters #1, #2, #3, and #4. NO_2 data were measured at Perimeter #2 only. For ten days during the period June 27 to July 27, 2006, equipment was running on 100% petroleum diesel to 90% petroleum diesel/10% biodiesel. For eight days of the study, from the period August 7 through August 17th, equipment was running on a soy-based 20% biodiesel/80% diesel blend (B20). Nitrogen dioxide data only was collected on the days August 22 and August 23, 2006.

Each day was a replicate measurement to minimize bias. The same equipment was operating and was monitored during both fuel uses. The main equipment at the Keene Recycling Center that ran on B20 included the small front end loader (JCB Model 409 – 67 HP) and large front end loader (John Deere Model 624H - 160 HP). Integrated samples (over at least a 6 hour period) were collected. Integrated sampling is defined as the continuous collection of a sample over an extended specified time period, typically an 8 hour work shift (Bisesi 2004). A single, integrated value for the level of air contaminant for the time period was determined and is presented in the results chapter. The advantage of integrated sampling is that multiple shifts and associated integrated values can be measured and averaged into a long term average. The long term average is considered a relevant index of dose for chronic health risk (Mulhausen and Damiano 1998). Diesel exhaust is considered a chronic health risk, though acute health impacts may also be a concern for airway irritation; chronic exposure metrics were emphasized in this study.

While KRC operations varied from day to day, operations were relatively consistent on a week to week basis. Other scholars have supported a strategy of 6-10 measurements to estimate the mean of an exposure profile (or the mean of a series of daily time-weighted averages) of a similar exposure group (Mulhausen and Damiano 1998; Ramachandran 2005). Similarly, using statistical theory, six daily integrated $PM_{2.5}$ measurements are necessary to estimate the average daily exposure so that the sample mean is within +/- 5 $\mu g/m^3$ of the population mean at the 95% confidence level, assuming a standard deviation of 5 (cf. Kinney et al. 2000). This level of error is adequate for the goals of this study (pilot work indicated $PM_{2.5}$ results on the order of 100 to 5300 $\mu g/m^{3)}$, but may not be considered adequate for other exposure assessment goals, such as comparing the mean to an occupational exposure limit.

The rationale in selecting where to place air monitoring equipment within the KRC site itself considered the nonroad equipment as pollutant sources, and “in cabin” breathing zone measurements as “worst case” employee exposure. Each location was measured during each sampling day. Perimeters #1, #2 and #4 would be considered occupational exposures since they are located within a work area or in the equipment cabin. Perimeter #4 is also a mobile source moving in and out of the building so it makes a contribution to the outside environment. Perimeter #3 as the main outside location would be considered a near field or environmental exposure. Due to these multiple contributions and since the KRC is a stable, long term source of diesel emissions in the local environment, perimeter #1, #2, #3 and #4 measured concentrations for $PM_{2.5}$ and EC/OC were pooled together to triangulate the site to determine a “total KRC site average”. NO_2 was measured only in perimeter #2 which as an indoor work area, and at the height of the equipment exhaust discharge, was considered to be a “worst case” location. All employees who worked in Perimeter #4 were non-smokers in consideration of the potential confounding effects of cigarette smoking found by other researchers (Zaebst et al. 1991).

Consistency in the general air monitoring protocol was critical to minimize threats to validity from systematic errors. Students were trained by faculty and staff to perform basic air monitoring functions and traffic counts. For both petroleum diesel and biodiesel sampling days, researchers and students performed equipment calibrations before and after sampling activities, positioned the equipment in the same locations, and regularly performed operational checks on the equipment while in use. Preparation and calibration of the equipment was used as an instructional activity for the students. Therefore, the sampling interval was reduced for some days from a typical eight hour period to just over six hours. This still measured the exposures over the majority of the work shift. Field days were cancelled if rain occurred in the morning because precipitation will scrub particles from the air. Only 2 biodiesel days were cancelled due to rain, but this resulted in less biodiesel days compared to diesel days.

2.2.2.c Biodiesel Working Group

The Biodiesel Working Group was the mechanism used for formal deliberation between exposure assessment collaborators, and other interested and affected parties. Using standard definitions for participatory mechanisms in environmental decision-making, it was most like a citizen advisory committee (NRC 1996; Beierle and Cayford 2002). Advisory committees usually look at an issue in depth and provide recommendations to an organization. The Biodiesel Working Group (BWG) looked at the issue of biodiesel use in Keene and performance of the exposure assessment in depth. However, the BWG was not commissioned by any organization to give recommendations. It was also envisioned to be more actively involved in exposure assessment. The BWG provided a forum or mechanism for face to face deliberation of issues relating to the research collaborative to extend discussions beyond individual emails, phone calls, and spontaneous conversations. Achieving consensus was not emphasized as a goal of the group since participation was voluntary, and our recommendations were not requested by any organization. Since the City DPW approached KSC for expert assistance, my initial goal was to continue that conversation in a more formal way.

Webler and Tuler (1999) recommend that selection of members for a policy planning group, such as a Watershed Community Council, be based on representativeness, political clout, ability to motivate others, and ability to provide information and judgments. A snowball process is one way that members can be identified; this was the method I used to set up the BWG. I identified people with experience with biodiesel, internal decision-making authority, or were affected by biodiesel exposures. Then I consulted with Russell on these criteria and his ideas for the initial membership. Russell was aware of who in the City was involved in supporting the B20 decision, as well as who within the City organization may have a desire to become more involved in the exposure assessment research deliberations. Getting a BWG off the ground was the primary initial goal at this time because without it there was no application of the A-D model. In addition to the members Russell suggested, I reached out to the KRC supervisors for their participation and also to recruit KRC workers as both groups would be considered affected parties. Between June 2006 and December 2006, I also designed and distributed a Biodiesel Knowledge Survey (discussed in the next section) via email using the email "cover letter" to try and recruit new BWG members.

Motivating participation in decision-making processes in today's busy world has been recognized as a challenge (Webler and Tuler 1999). Many of the potential BWG members were already veteran "meeting-goers" and were averse to participating in another structured process. Since I had already been working with many of the BWG participants in other aspects of the pilot study collaboration, I did not document a detailed process design, such as clarifying roles, meeting procedures, decision-making procedures, or expectations of the group membership. These elements did not seem necessary in this case. Instead, I stressed openness, flexibility and transparency for the process: members could come and go as they pleased, all members were included on email exchanges, if members couldn't come to a meeting they could send feedback via email, previous meeting discussions were reviewed at the start of each meeting, and emphasis was on maintaining a safe, respectful and open place for dialogue. I told people their input was important because without them there would be no BWG. Webler and Tuler (1999) have suggested these strategies and others – such as giving participants ownership of the process - are helpful in motivating participation in environmental decision making processes.

I structured the first meeting in June 2006 toward getting feedback on the exposure assessment strategy before the start of actual air monitoring in the field, and to introduce and get feedback on the idea of starting a BWG. I sent out an email to 3 City of Keene employees suggested by Russell, and added 2 KRC supervisory staff. In the first email, I identified who I was, my dissertation research, and the idea of introducing a more formal collaborative approach to the exposure assessment. I suggested in my email three goals for the meeting: talk about the field work planned for the summer/present the proposed research sampling plan, ask for feedback (did we miss anything/should we add anything), and discuss ideas/request feedback for a BWG moving forward.

For the first BWG meeting on June 16, 2006, I asked attendees to suggest other BWG participants, to continue to build participation via a snowball selection process. I used the meeting to ensure that the KSC was getting the “right science” in the exposure assessment. In trying to apply the analytic deliberative model, I considered the NRC’s (1996) suggestion to spend time on problem formulation. But for the first meeting, there wasn’t really a classic “problem” confronting the BWG, and I didn’t want to suggest one. So I brought back into focus the original reason the City and KSC were collaborating on the exposure assessment: to answer the question, “Is biodiesel healthier than petroleum diesel?” via the specific question “Compared to use of petroleum diesel, does use of B20 reduce exposures of $PM_{2.5}$, EC/OC, and NO_2?” I asked the group to think about what they would like to do with the results of the exposure assessment. Without participants defining the BWG’s purpose, it seemed unlikely that meaningful participation would occur. I used open ended surveys at the first meeting as a way to encourage brainstorming on potential BWG goals and to structure future BWG discussions.

After collection of the open ended survey, I presented an overview of the project as conceptualized in Figure 2.7 to the participants at the first and second BWG meetings as a way of stimulating discussion about the BWG’s purpose and potential goals. I committed to making a number of local public presentations (communicating the exposure assessment results) as one goal of the BWG, requesting BWG support and participation. After the first meeting, I tried to facilitate discussions toward the idea of giving the BWG a decision to make. The BWG meetings were not intended to be brainstorming sessions or wide ranging discussions on everything related to biodiesel. Instead, the BWG was structured as being purposeful – the initial purpose being what to do with the exposure assessment results, if anything. I tried to be sensitive to the paradox that I wanted to encourage participation but I also needed to lead the process as there was initially limited interest. My role in these first meetings was to facilitate discussions to honor the desires of all members, but also get a conversation going about potential ideas for BWG goals. In emails confirming meeting dates and times, I requested feedback and agenda items from the potential participants.

I used Figure 2.7 in early meetings to try and get people to think about what the BWG could do, emphasizing the "could". Again this highlights the paradox of the initial BWG meetings: my influence was on the process was stronger, but without it there likely would be no process. In fact some BWG participants gave me feedback that I wasn't being strong enough of a group leader. I provide a high level of detail of the BWG meeting interactions in Chapter 3: Results to be as transparent as possible about my role and influence. It was very difficult to inspire participation between June 2006 and the second meeting in December 2006. I was surprised by how much time it took to schedule meetings and the difficulty in locking in time with an already very busy group. Meetings had to be suggested at least two to three weeks before having one. Even then, there was never one time that was best for everyone. As a strategy to encourage participation, I stressed openness and flexibility so there was no sanction for not attending.

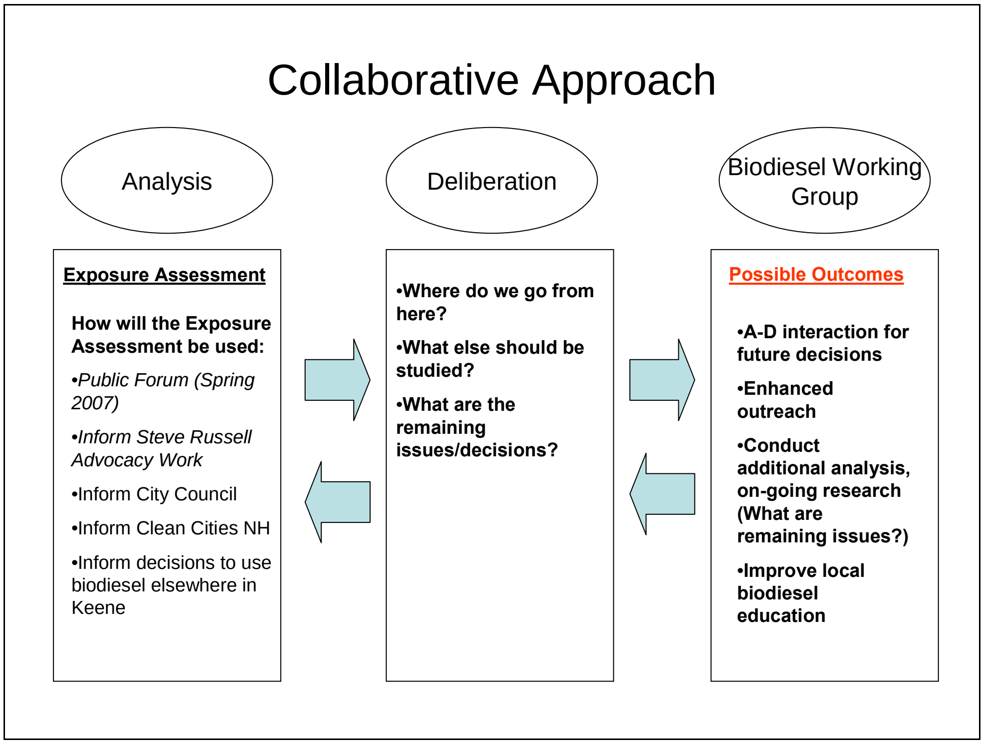


Figure 2.7: <u>**A Collaborative Approach: Initial Goal Setting for the BWG**</u>

Admittedly, much of my early strategy in the first two BWG meetings was simply "just do it". Juggling my roles in quantitative data collection, data analysis, making public presentations, recruiting BWG participation and then preparing for BWG meetings was extremely challenging. Task management issues led to part of this delay between meetings.

2.2.3 Select Options and Outcomes

This section overlaps with Process Design for the BWG. The initial suggested outcomes for the BWG are summarized in Figure 2.7. These figures inspired the initial deliberations within the BWG. However, another objective of this study (as an initial BWG goal) was to directly communicate the exposure assessment results locally through a series of workshops. This objective was important to support ongoing biodiesel educational outreach and to be sensitive to the community participation aspects of this project. A number of public presentations were held in late 2006 and early 2007. To assist in creating effective presentations, and to act as a tool for recruiting potential BWG members, a Biodiesel Knowledge Survey was designed and implemented among BWG participants and other interested and affected parties. Therefore there were a number of quantitative and qualitative data collection methods applied during this step of the A-D model. I will review the Biodiesel Working Group data collection methods first, the Biodiesel Knowledge Survey next, and the Outreach presentations last.

2.2.3.a Participant Observation

To gather data on the deliberations at BWG meetings regarding potential options and outcomes, I employed the following qualitative methods: participant/observation and documenting meeting minutes. Participant/observation was the primary qualitative data collection method used for BWG meetings. As my role as research project facilitator allowed me extraordinary access to biodiesel decision-makers in Keene and other participants such as workers, quite simply there was much data to be mined via the participant observation approach. Access was relatively straightforward for this research because I was approached by Russell in 2004 as an "outside expert" to help answer local questions about health and biodiesel. Over the next 2 years, I developed working relationships with many of the participants in this study revolving around issues of biodiesel use in Keene. This ongoing collaboration helped me gain access to other participants as I started the Biodiesel Working Group. For performance of the exposure assessment at the

KRC, I was able to coordinate access for the other KSC researchers and students to the site and to work with staff as needed.

During the BWG deliberations and field work phase of the collaborative exposure assessment, the study had many characteristics similar to ethnography (Hammersley and Atkinson 1995). First, I was in the field setting for a prolonged engagement. The initial biodiesel conversations through performance of a pilot exposure assessment and expanded exposure assessment through the BWG process spanned a 3 year timeframe. As an example of the type of working relationship developed, I would occasionally travel with Steve Russell during his educational and outreach presentations to various groups. I co-presented "Biodiesel: Lessons Learned" to the Sustainable Energy Resource Group in Hanover NH in September 2006. Similar to ethnography, the research activities in analysis and deliberation had an evolving nature as the story of the collaboration unfolded.

Other ethnographic elements: during the collaborative exposure assessment phase, as monitoring equipment was left in place for a 6 to 8 hour period, I had time to engage in informal conversations with workers about what they thought about the exposure assessment and biodiesel, questions they might have, or suggestions for how to communicate the exposure assessment results. I made detailed observations and took reflective notes. My data collection approach during this field work phase and throughout the BWG process was to document any relevant discussions relating to biodiesel or the City of Keene's relationship with biodiesel. In short, if the subject of biodiesel or other related environmental issues (such as sustainability, air pollution or public health) came up, I would try to flesh out the participant's meaning and write it down. But this study is not ethnography in key ways: I was not trying to describe the "workplace culture" at the KRC, or trying to understand social roles and relationships, or trying to describe the “day to day life” as common in ethnography. Instead, I kept detailed notes only of case relevant discussions or observations in a field journal. Therefore, while I kept the journal with me everyday, I did not necessarily take notes everyday but only when biodiesel or related discussions, observations, or interactions occurred. I would return to my journal notes as soon as possible after data collection but no later than 24 hours to make reflective comments and memo in the margins. I would also make analytic comments in the journal to process the data as I was collecting it, to ease the formal data analysis process completed later. I used different colored inks or specifically wrote “NOTE” to distinguish analytic comments from original journal notes.

2.2.3.b Meeting Minutes

Meeting minutes were taken by a KSC student during the first 4 BWG meetings. Students were asked to write down the names of meeting attendees, the activities of the meeting, any major comments or questions that arose, and who initiated the comments or questions. Student meeting minutes were usually more substantive on exactly what people said, and my field journal focused on my interpretation of the meeting energy, body language, tone, and important comments. Together, both the meeting minutes and participant/observation data collection provide a comprehensive record.

2.2.3.c Biodiesel Knowledge Survey

A main objective of the Biodiesel Knowledge Survey was to assess the baseline level of knowledge about biodiesel in the prospective Keene BWG member pool. For example, while many people within the City of Keene municipal organization and Keene State College staff might be aware that both organizations were using biodiesel, it was less clear what people actually knew about biodiesel. Data from the Biodiesel Knowledge Survey would then be used to identify knowledge gaps to help more effectively communicate the results of the collaborative exposure assessment. These outreach presentations were a major outcome of this step in the A-D model. A secondary objective of the survey was as a communication and recruiting tool to solicit and motivate more participation in the BWG process. I sent an internet survey via the e-survey site **Surveymonkey.com** to BWG members, names suggested as potential BWG members and any names from my participation/observation data (including meeting minutes) that were even peripherally associated with the decision to use B20 in Keene.

On December 1, 2006, I sent the Biodiesel Knowledge Survey (Table 2.2 for survey questions) to 19 people via email, including the mayor of Keene, other City department heads affected by biodiesel use, and a number of Keene State College employees who also used or supported the decision to use biodiesel in the college fleet. In March 2007, I sent the same survey to the KSC student research team. **Surveymonkey.com** was used to design the 12 question survey, with questions based on basic factual knowledge about diesel exhaust and biodiesel fuel characteristics derived from internet, government and media sources. A list of the survey questions is shown in Table 2.2 below.

I sent an email "cover letter" or "cover e-mail" and embedded the Biodiesel Knowledge Survey link in the email. **Surveymonkey.com** offers the option that responses are kept anonymous, which was used for this survey. I did not know who each individual respondent was, but could group them loosely according the internet protocol address, and when I sent the survey. To elicit a high response rate, I followed Dillman's (1978, 2000) suggestions for multiple contact strategy: sending a presurvey announcement, and multiple cover letters and emails over a two week period. Questions were constructed with attention to use of appropriate terminology relating to biodiesel. To assess knowledge levels, "True", 'False" and "I don't know" options were used. According to Fink (2003), including "I don't know" as an option decreases the likelihood that respondents will guess at an answer. Since the objective of the survey was to get at what the participants knew about biodiesel, identifying "I don't knows " was an important objective.

For those potential participants without email access, such as KRC site employees, paper surveys were taken to the specific work area locations for City employees to fill out. These surveys were dropped off during a workshift in January 2007 and then picked up 2-3 days later. The paper survey's were precoded with a date and location, but were not individually coded. Therefore only group categorizations and evaluation were performed. The Biodiesel Knowledge Surveys were categorized by group: "Keene DPW workers" "KRC workers", "Decision-makers", and "Students". I was unable to identify individual respondents but able to look at group averages to evaluate for inconsistencies against data I collected via other methods, such as interviews, document review and participant observation regarding knowledge levels.

BIODIESEL KNOWLEDGE SURVEY QUESTIONS		
1.	The term “biodiesel” is used to refer to the fuel that results from adding pure vegetable oil to diesel fuel	
2.	B100 or 100% biodiesel is the most common biodiesel level used in transportation	
3.	Using biodiesel fuel instead of petroleum diesel fuel may help to reduce the amount of carbon dioxide released into the air, which helps reduce the potential for global warming	
4.	Starting in 2007, EPA will require new on-road petroleum diesel engines to be much cleaner than current engines	
5.	Increasing the amount of biodiesel in a biodiesel blend is associated with increasing nitrogen oxide levels	
6.	High levels of nitrogen oxides in the outdoor air are harmful because these nitrogen oxides contribute to making smog.	
7.	The biodiesel blend B20 (20%) biodiesel can “gel” or “not flow” during typical New England winter temperatures	
8.	Since biodiesel is considered an alternative fuel, using it can void a new diesel engine’s warranty	
9.	An owner or operator must first make changes to their petroleum diesel engine before they can use biodiesel fuel	
10.	In urban areas and many rural areas, existing levels of outdoor exhaust from petroleum diesel engines are associated with lung and heart problems	
11.	Breathing petroleum diesel exhaust is associated with an increased risk of cancer in both animals and humans	
12.	If all waste grease and excess vegetable oil in the U.S. were converted to biodiesel, then biodiesel supply could fully meet existing petroleum diesel demand	
Biodiesel Knowledge Survey Multiple Choice Options		
True	False	I don’t know/not sure

Table 2.2: Biodiesel Knowledge Survey Questions

2.2.3.d Outreach Presentations

Public presentations relating to the KSC/City of Keene biodiesel collaboration were given in different venues. The presentations differed in tone and length, but typically gave some general background on biodiesel and reviewed the results of the exposure assessment research. Some of these presentations were free and open to the public, such as an Earth Day workshop that was held outdoors in downtown Keene (April 2007) or the September 2006 presentation in Hanover Library in Hanover, NH. Other presentations were invited: a scientific conference (EPA Washington, D.C., September 2006) and interested stakeholders from around New Hampshire (Granite State Clean Cities Coalition, April 2007).

The presentations, audience, dates, along with co-presenters where applicable are given in Table 3.18. In some cases, the KSC undergraduate team made the presentation as part of their involvement in the research project. I (or a student) tracked questions from the audience so we could understand the concerns and questions people had about both the exposure assessment and biodiesel in general. We used this information to refine future presentations to ensure technical data was understandable and concerns were being addressed. In addition to the presentations noted in Table 3.18, Steve Russell also made an additional 16 presentations during the first six months of 2007 to local and national fleet organizations. He incorporated the results of the exposure assessment into his presentations on the City's experience with biodiesel.

2.2.3.e Data Analysis

The data analysis description in this section applies not only to the BWG process during this step in the A-D framework relating to Central Research Question #1 activities, but to analysis of all qualitative data collected throughout this study. The data I collected via participant/observation and meeting minutes were organized into a binder, analyzed and coded. Journal notes from meetings, meeting minutes, and other key participant/observation field notes were typed before coding. I also included related documents such as local news articles in the coding process. First, I coded inductively by looking for similar ideas or codes to emerge organically from the data. For the first readings, I tried to read the data without any preconceived notions or ideas. "In vivo" codes (using the person's own words) were used whenever relevant. The aim for these initial reviews of the data was to be sensitive to emerging themes before applying a theoretical framework. These emerging themes may offer clues to alternative explanations for data results or may support the theoretical framework.

Then I went back to the binder and coded the data with an eye toward NRC (1996) terminology and theoretical concepts. I looked for examples of analysis or deliberation occurring, examples of an A-D interaction, evidence of trust (+ or -), example of participation (+ or -) and examples of collaboration. Sometimes the inductive and deductive codes overlapped, increasing the confidence in the result. For example, where I inductively coded "tension re: worker participation", this would be similar to the NRC (1996) concepts "trust [-]" or "participation [-]." Following Miles and Huberman's (1994) suggestions for data analysis, I followed the steps of data reduction, data display, and conclusion drawing. Data reduction refers to the use of coding and memoing to reduce the data volume to essential elements. I used creative data display tactics as a way to organize the data and support conclusion drawing.

For the Biodiesel Knowledge Survey, data were tabulated, organized, and analyzed using Microsoft Excel 2000. Descriptive statistics (% correct, % incorrect, % "I don't know") were calculated for each major group (City of Keene decision-makers, KRC workers, KSC students, City of Keene DPW mechanics) and are presented in the Results chapter.

2.2.3.f Validity

My role in the research process varied from active participant to data gathering observer depending on the Central Research Question and the step in the A-D process as summarized in Appendix D. I provide a detailed description of my role in the collaborative exposure assessment in the next section. In this section, I discuss the challenges to the study and relate the procedures I implemented to address issues of validity. Many of the tactics in this section were used throughout the steps of the A-D process; I provide the detail here, and I will refer back to this section as appropriate.

There is usually a concern about bias when a researcher is working closely over a long period of time with a group. Robson (2000) states that the greater the participation by a participant observer in a program, the more likely to influence the program itself, but also the easier to understand how the program is functioning via an insider point of view. A few points are worth mentioning again here. As both the City's and KSC's decision to use biodiesel in their fleets was made in 2002 before I even met any participants, I had no influence here. I was approached by Russell in 2004 as a technical expert in safety, not the other way around. From 2004 to summer 2006, my influence on the research collaboration is more direct as I assisted and helped conduct the pilot exposure assessment and expanded exposure assessment.

In setting up the BWG in the summer and fall of 2006, my influence was clearly critical; without my leadership, there would be no intervention, no application of the A-D model, no connection of deliberation to analysis. During 2006 to early 2007, my role in facilitating the BWG was strongly participant/leader; however, as the timeline progressed through spring 2007, the scope of the BWG and its leadership changed. My role as the BWG facilitator evolved through 2007 to more of a technical advisor and observer to decision-making activities.

While some aspects of this study did take place in my backyard, and built on pre-existing relationships developed since 2004, there are important distinctions. First, while I was a recognized safety and health professional, I did not work for the City of Keene or any state/local regulatory agency, so I had no real authority or power within the City organization. Other researchers in the environmental health sciences have used their unique access to transition from a professional role to a research role. A similar and pertinent example is Corburn's (2005) study of multiple Brooklyn neighborhoods' struggle for environmental justice against localized health hazards. Previously Corburn had been a New York City Department of Environmental Protection city planner involved in risk decision-making related to these specific cases. He later returned to these neighborhoods as a researcher studying the importance of local knowledge in reducing risk from environmental hazards.

Similar to my experience in explaining my research approach and methodology, Corburn highlights the challenge in situating his work in current methodological paradigms. Corburn specifies his research approach as hybrid or interpretive (2002), later calling it "street ethnography" (2005) - relying mainly on participant observation and acknowledging that his social status may influence his observations. Within this approach, he presents 4 distinct cases of community members performing what he terms "street science" or locally grounded, contextually informed analysis of data. While he is also a participant/observer in these cases, it is his unique understanding of the preexisting local policy making processes combined with access to local citizens that offers a fresh and insightful vantage point for research. As in Corburn's work, I believe my access and participation in the Keene case provides unique insight in how analysis and deliberation interacted but requires a hybrid methodological approach that acknowledges the researcher's influence.

Because of the level of my influence in the research, there was the potential for participants to exaggerate their level of biodiesel knowledge and/or their interest in participating in the collaborative exposure assessment and BWG. Conversely, participants may suppress their negative opinions about biodiesel or disguise their apathy towards the project because of my involvement, telling me what they think I want to hear. I implemented a number of counter-strategies for these possible "on stage effects" (Agnew and Pyke 1969). To assess the state of biodiesel knowledge, I conducted anonymous internet and paper surveys. I also followed Miles and Huberman's (1994) suggestions for countering on-stage effects. These included: staying engaged in the study for a prolonged period, explaining my role and intentions clearly, and finally, not inflating the problem or my importance. The extensive 3 year time frame of the project led to a comfort level where opinions were exchanged freely, and the longer period of engagement also allowed me to go back to initial journal notes to check if statements remained consistent over time. To guard against bias from the research site on me, I was friendly but maintained a professional distance, talked to as many people as possible when I was at the site (which was not everyday), and tried to think conceptually, not sentimentally.

Miles and Huberman (1994) suggest criteria for researchers to know if their emerging findings are good. These criteria are objectivity, reliability, and internal validity/authenticity. To meet the objectivity and reliability criteria, I have described my data collection methods in detail and discussed my role in the research extensively. I explained the A-D theoretical model in detail and how I applied it. I also considered a rival hypothesis throughout the study: that applying the A-D approach to understanding B20 exposures made no difference in any way. I looked for rival explanations for the outcomes seen in the study by inductively coding the journal notes, interviews, and other relevant documents first, and applying the A-D theoretical framework codes later. I interviewed people both inside and outside the BWG process to try to understand if the outcomes seen in this study would have happened anyway without the A-D intervention, perhaps as a result of preexisting political conditions or environmental programs already in place in Keene. For example, I asked key participants how the initial decision to use B20 in the City of Keene fleet in 2002 occurred - what was the process and who was involved. While this information was not necessary to inform study's overarching or central research questions, researching this contextual background was important when interpreting results later; perhaps local context such as community history influenced the results in this study more than the A-D model application. Other researchers have found that complex local dynamics overwhelmed and limited the attempt to integrate analysis and deliberation for a participatory risk assessment process in the Columbia River watershed (Kinney and Leschine 2002). Kinney and Leschine (2002) found that contextual factors, such as complex situational dynamics, a long and contentious background history, volumes of technical data, agency distrust, power imbalances, and strong perceptions of risk negatively impacted participatory risk decision making. Therefore, I built into my data collection and analysis processes a consideration and openness to alternative hypotheses.

To meet authenticity criteria, I followed suggestions of Miles and Huberman (1994) in providing detailed and context rich descriptions of events and interactions. Finally, I built in triangulation strategies throughout the data collection process to strengthen the quality of the conclusions. For example, I had students take BWG meeting minutes to compare against my journal notes of meeting activities. While I used the BWG as the primary mechanism of deliberation, I also interviewed BWG members one-on-one to see if statements were consistent in both settings, or if there were suggestions or concerns not being captured by the formal BWG process. Day to day informal conversations were documented in my field journal in detail to give insights into whether or not analysis and deliberation were interacting. I designed and implemented an anonymous Biodiesel Attitude Survey that asked questions similar to the interview guide and BWG meeting discussions as a way to allow anonymous feedback on group interest and support for a BWG and to assess if the BWG goals were clear. By triangulating these data sources, consistently observed results would support the strength of final conclusions. An example of how triangulation was applied to the question, "What do you think should be the goals of the BWG?" is shown in Table 2.3 below. The results from each of the data collection methods are categorized by columns.

KRC WORKER INTERVIEWS	**BWG MEMBER INTERVIEWS**	**BWG MEETING MINUTES P/O DATA**	**BWG MEMBER BIODIESEL ATTITUDE SURVEY**
BWG needs to be active	Participation that does something not just brainstorms good ideas	Needs to be action oriented	BWG should make policy recommendations to local government
Recommended education & channel 8 broadcast	Education is important goal	Increase biodiesel education	Conduct educational outreach
Don't let exposure assessment sit on a shelf	Channel 8 mentioned by one BWG member	Increase availability	Increase availability and use in new applications

Table 2.3: Triangulation Strategy as Applied to Data Collection Relating to BWG Goals

Finally, I practiced what is referred to as reflexivity (Hammersley and Atkinson 1995) or researcher self awareness, always being conscious of how my interaction may influence others. In my journal, I would document the verbal reactions, body language and non verbal communication during those interactions where I was in a leadership role, such as facilitating meetings or giving presentations. While reviewing my notes, I would reflect on whether the meeting outcomes were more from the group dynamic or more from my leadership. As a final check on my results and conclusions, I asked key participants to read and check the final dissertation narratives and to provide their feedback on my observations.

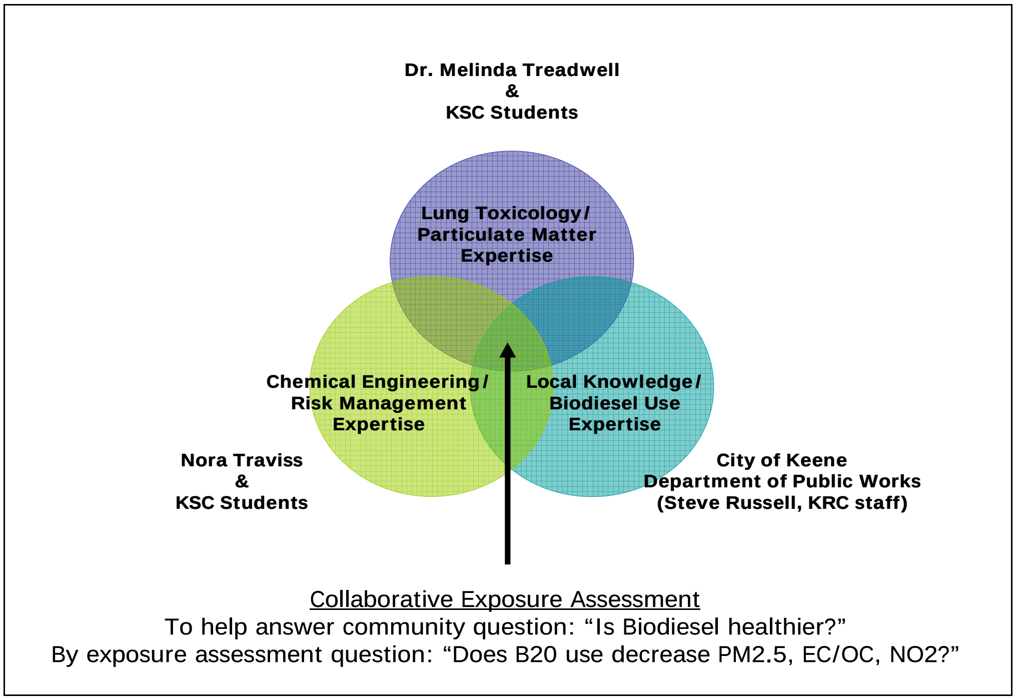
Regarding validity for the Biodiesel Knowledge Survey, I paid attention to construct validity by using correct technical terminology in crafting the survey questions. Many of the questions in the survey were based on audience questions from recent educational presentations. Because of the changing nature and flux in BWG membership, I did not perform a pre and post test in this study, to assess knowledge levels before and after the A-D intervention. Since the BWG membership was in a constant state of flux, I did a test-retest strategy as recommended by Litwin (1995) using the KSC student group.

2.2.4 Information Gathering and Interpretation

This section will detail the specific roles, locations, and sampling and analysis methods used during the summer 2006 collaborative exposure assessment performed at the Keene Recycling Center. The air contaminants that were measured were $PM_{2.5}$, EC/OC and NO_2, and while standard federal and other agency methods were followed, summaries of these methods are provided here, with the reader referred to external references where appropriate for more detail. The collaborative exposure assessment was a significant research study on its own, and as mentioned, the collaborative exposure assessment/Biodiesel Working Group connection forms the basis of the A-D connection and the heart of this study.

2.2.4.a Roles in the Collaborative Exposure Assessment

While there were many people who contributed to and supported the performance of the collaborative exposure assessment, there were three main individual contributors whose roles will be reviewed next: Dr. Melinda Treadwell, Mr. Steve Russell, and I. We, in turn, were supported by a number of Keene State College Safety Studies staff and undergraduate students, as well as the staff of the Keene Recycling Center. A novel aspect of the collaborative exposure assessment was the educational benefits and participation in data collection by multiple members of the community. After reviewing individual roles, I will also briefly discuss the research roles of each of these groups. The confluence and intersection of each of the individual contributors is shown in Figure 2.8.



<u>Collaborative Exposure Assessment</u>
To help answer community question: “Is Biodiesel healthier?”
By exposure assessment question: “Does B20 use decrease PM2.5, EC/OC, NO2?”

Figure 2.8: <u>Description of Roles in the Collaborative Exposure Assessment</u>

Dr. Melinda Treadwell – Dr. Treadwell has over 15 years of research and professional expertise in lung toxicology and particulate matter exposure, especially diesel particulate matter. She had performed previous diesel exhaust exposure assessments, including implementing novel combinations in the field of integrated and real time measurement methods to quantify diesel particulate matter concentrations. One study evaluated the impact of nonroad diesel engines and diesel exhaust at the Ground Zero site in downtown Manhattan post- 9/11. These previous exposure assessments included methods to document and assess equipment activity (Treadwell et al. 2003). We used similar measurement methods as well as the activity assessment methods for the collaborative exposure assessment. Dr. Treadwell provided her leadership, expertise, grant funding and resources at Keene State to conduct the collaborative exposure assessment. Her Research Assistant (Jaime Ingalls) and a team of KSC students were responsible for performing sampling and analysis for particulate matter, sampling for elemental carbon and organic carbon, and activity/weather measurements. Post field work, this KSC team consolidated and organized the data for $PM_{2.5}$, EC/OC, activity logs, and weather (wind, temperature, relative humidity).

My Research Role- My main interest was in examining the potential of B20 use as a risk reduction intervention for occupational and environmental exposures to diesel exhaust. My career up to this point had been as a practitioner working for various organizations to reduce risk in the workplace and local environment. I was familiar with Dr. Treadwell's expertise and the public health dilemma of diesel exhaust exposures: based on the positive observations of City of Keene and Keene State College biodiesel users, I connected Russell and Treadwell and helped develop the thesis to examine the impact of B20 on workplace and local area exposures. I actively collaborated with Dr. Treadwell to develop the exposure assessment strategy (i.e., where and what to sample) and hypotheses. During the field work phase, I was the main liaison between the KRC and KSC for logistics and communication, as well as being responsible for all sampling and analysis activities for nitrogen dioxide. Post-field work, I attended exposure assessment team meetings, helped organize the raw data for all the parameters, and performed data analysis, including all statistical analysis. Going forward, I was the main technical exposure assessment expert during the BWG process through February 2007. Many of these activities were supported by KSC undergraduate students in the applied research program.

Mr. Steve Russell – Mr. Russell approached me as a KSC representative in 2004 seeking assistance to answer the question, “Is B20 healthier than diesel?” Mr. Russell provided his expertise in the selection of the KRC site as the field site for the exposure assessment, organized access to the KRC site, and made introductions with site employees. Mr. Russell scheduled and supplied the B20 fuel deliveries to the KRC, and served as the main City of Keene research contact for the KSC research team. Mr. Russell participated in the exposure assessment deliberations both through the Biodiesel Working Group and also directly as the main City contact during this phase of the project.

KSC Safety Studies Staff and Students – KSC research faculty and staff trained KSC students in air monitoring and other data logging (such as vehicle count and vehicle activity) techniques prior to the field work. Students performed pre and post calibration, set up and operated air monitoring equipment, and performed assigned tasks. These tasks included:

performing vehicle counts, tracking equipment activity and proximity to monitors, operating the weather station, and making notes of all activity at the site. After the field work, students organized and typed field notes, and made visual representations of activity patterns. Students and KSC Safety Studies staff pre and post weighed filters in gravimetric analysis to measure $PM_{2.5}$ and archived filters for future metals analysis. Both students and staff performed quality assurance and chain of custody documentation.

KRC Employees – Before the field work, KRC employees were interviewed about job tasks, site activity patterns and fuel usage. KSC staff participated in the first BWG meeting before the field work to discuss the exposure assessment strategy and provide feedback. KRC provided information about exposure settings and variability that was used to improve the study's design. During the field work phase, KRC employees assisted as needed in setting up the monitors, especially inside equipment cabins.

2.2.4.b Where, What, and When We Sampled

Air monitoring was performed in areas designated Perimeters #1, #2, #3, and #4 during days when KRC equipment operated on petroleum diesel and then on a B20 blend. Perimeters #1, #2, #3 are shown in the KRC site schematic and were fixed locations throughout the KRC site. Perimeters #1 and #2 correspond to work areas inside the main KRC building, and would be correlated with occupational exposures. Perimeter #3 was located directly outside the main door to the KRC, and was considered representative of environmental exposure. Perimeter #4 is also shown in the schematic, but was actually the inside of the small front end loader cabin and therefore a mobile source for occupational exposure. $PM_{2.5}$ and EC/OC were measured at Perimeters #1, #2, #3, and #4. Nitrogen dioxide was only measured at Perimeter #2. Perimeter #5 data was not used in this study as there were no B20 data collected due to a fire in the excavator work area. A summary of what air contaminant was sampled at each location and the method used is shown in Table 2.4 below.

Air contaminant	location (s) sampled	collection method	Data Collected By:	analysis method	Data Analyzed By:
Particulate matter (<2.5 micron)	Perimeters 1,2,3; Inside cabins of small & large front end loaders	SIOUTAS cascade impactor; PTFE filter; 9 L/min average air flow rate*	Dr. Treadwell & Students	Gravimetric weighing of filters	Dr. Treadwell & Students
Elemental carbon	Perimeters 1,2,3	NIOSH 5040 (via SKC # 225-317 DPM cassette)	Dr. Treadwell & Students	NIOSH 5040 (thermal-optical analysis)	Clayton Laboratories, MI
Organic carbon	Perimeters 1,2,3	NIOSH 5040 (via SKC # 225-317 DPM cassette)	Dr. Treadwell & Students	NIOSH 5040 (thermal-optical analysis)	Clayton Laboratories, MI
Nitrogen dioxide	Perimeter 2	ASTM D 1607 (via Glass Midget impinger, Fritted Nozzle (SKC #225-36-5) and Gas Bubbler, Fritted Nozzle (Kimble Kontes #652265)	Nora Traviss & Students	ASTM D 1607 (uv spectrophotometry)	Nora Traviss & Students

Table 2.4: Summary of Sampling and Analysis Methods Used at Keene Recycling Center

The dates of field sampling and corresponding fuel ratios are summarized below in Table 2.5. This table also categorizes the fuel ratios based on fuel deliveries to the KRC site. This categorization scheme is discussed more fully in the next section. Unless otherwise indicated, an “X” means $PM_{2.5}$, EC/OC, and NO_2 were measured that day.

DATE OF FIELD WORK (AIR MONITORING)	100% PETROLEUM DIESEL	TRANSITION FUEL (BETWEEN B1 TO B9)	B20
6/27/06	X (except NO_2)		
7/10/06	X (except NO_2)		
7/11/06	X		
7/12/06	X		
7/13/06	X		
7/14/06	X		
7/18/06		NO_2 only	
7/24/06		X	
7/25/06		X	
7/26/06		X	
7/27/06		X	
8/7/06			X
8/8/06			X
8/9/06			X
8/10/06			X
8/14/06			X
8/15/06			X
8/16/06			X
8/17/06			X
8/22/06			NO_2 only
8/23/06			NO_2 only

Table 2.5: <u>Dates and Fuel Ratios for Diesel and B20 Sampling Days</u>

2.2.4.c Description of Fuel Use & Categorization of Sampling Days as Diesel or Biodiesel Days

The small and large front end loader were the two primary movers of materials throughout the KRC facility during this study. For the six data collection days that occurred during the time period June 27, 2006 through July 14, 2006, this equipment ran on 100% petrodiesel. The first shipment of 261 gallons of B20 occurred on July 18, 2006. The fuel tank for the KRC is a 500 gallon aboveground storage tank; therefore, the approximate percentage of biodiesel in the tank on July 18, 2006 was B10 after the delivery. The KRC does not keep records or receipts of individual equipment fueling. While there was no record of exactly when each piece of equipment was filled, multiple employee interviews at the site at that time indicated each of the equipment tanks were approximately ½ full on that date. The large and small front end loaders were refilled once per week according to the employees. The large track excavator (labeled Perimeter #5) was the largest user of fuel at the site and was refueled three times per week.

Therefore, as the small front loader and large front loader were refueled sometime between July 18th and July 25th, the percentage of biodiesel in each piece of equipment would also be at a ratio less than B10. For example, as the small front loader's 30 gallon fuel tank was depleted, filling it with 25-28 gallons of approximately B10 would result in an estimated final ratio of B8 **-**B9 by the next refill on the 25th or 26th. This however is an estimate. Thus during the time period from July 24 through the 27th the percentage biodiesel in each equipment tank could have ranged from B1 up to B10, until the next biodiesel (B20) shipment on July 31, 2006.

Based on the above information, the sampling days, July 24, 25, 26 and 27th were categorized as "transition fuel days". The exact percentage of biodiesel in each equipment tank or when each piece of equipment was filled was not known. However, these "transition fuel days" were still comparatively low in percent biodiesel, at approximately B10 or less. Theoretically particulate matter reductions may occur at these levels of biodiesel; therefore, for data analysis, I grouped the transition fuel days with the petroleum diesel days. This is a more conservative approach to data analysis as it would require even more substantial reductions in particulate matter during the biodiesel use days for the differences to be statistically significant. Data analysis was performed both with the "transition days" kept in the petroleum category and also completely removed from the analysis, so that 100% petroleum diesel is compared to B20.

On July 31, 2006 a second delivery of 469 gallons of B20 was made at the KRC. After this point, the site tank itself was approximately at a B19 to B20 level, with each equipment fuel tank operating thereafter at an estimated B18-B20 blend. By the start of biodiesel data collection on August 7, the small front loader and large front loader each went through approximately 3 equipment tanks of biodiesel fuel, so that the fuel blend in each equipment tank would be close to a B20 level. In the following sections I will provide detail on the sampling and analytical methods used to measure $PM_{2.5}$, EC/OC, and NO_2.

2.2.4.d $PM_{2.5}$: Sampling and Analysis

$PM_{2.5}$ was collected by use of Sioutas cascade impactors utilizing polytetrafluoroethylene filters (PTFE or Teflon) filters. The Sioutas impactor separates and collects particulate matter in five size ranges: greater than 2.5 micron, 1.0 to 2.5, 0.5 to 1.0, 0.25 to 0.50, and less than 0.25 micron (where the number is the mean aerodynamic diameter of the particle). An air stream containing particles of various size diameters is pulled via a vacuum pump through a series of impactor plates (assembled with filters) that have increasingly smaller slits or jet diameters between stages. Via this impactor plate sequence, larger particles are collected at the top, and the smaller ones at the bottom stage (Ramachandran 2005). The entire range of fine and ultrafine respirable particles in air is captured by this device. Each stage that is reached is assumed to have collected the particles in the air stream above the cutoff size for that particle stage (Ramachadran 2005). A high volume Leland Legacy pump drew air at 9 L/minute across the multiple filters. These pumps were pre and post –calibrated each day using Dry-Cal units as a primary standard. Each Sioutas impactor was prepared and disassembled according to detailed procedures developed by Ingalls (2006) that included photographs to show each step in the assembly and disassembly process. These procedures were used to train student participants.

Both preweight and postweight of filters were done in the same temperature and humidity controlled environment using a gravimetric balance (Denver Instruments P214). At the end of each day the Sioutas was diassembled in a humidity controlled environment and filters stored in an archival storage system (SKC Filter Keeper). The scale area was cleaned with an antistatic cleaner, and during the post weighing process the analyst wore gloves to carefully remove and weigh each filter. Results were recorded on standardized forms, and work in this study was performed by the same analyst. All the filter weights except the greater than > 2.5 micron filter were totaled together to give the total mass of $PM_{2.5}$ reported in the results.

For quality control, any time a negative filter weight (i.e., the post weight was less than the preweight) was recorded, that weight was not counted in the total. Negative filter weights can result from a number of issues: during disassembly and filter removal a small piece of filter may be inadvertently removed, a small humidity difference in the weighing room could impact the filters, or the lack of analytical sensitivity of the balance itself at extremely low weights might contribute to the negative result. All negative filter weights were not included out of the data analysis, so that the $PM_{2.5}$ values reported may be underestimates of true exposure. For more detail on the sampling and analysis methods followed for $PM_{2.5}$, see Treadwell et al. (2008).

$PM_{2.5}$ data from 8/9/06, although collected, was not used. On 8/9/06, negative weight filters were noted across the perimeter monitoring locations and in multiple size cuts of each SIOUTAS impactor; therefore this day was discarded from the sample pool in all biodiesel $PM_{2.5}$ analyses. This date was a low activity day so the lack of measurements could be tied to lack of activity, in addition to the issues identified above (limit of detection of scale, humidity change, or loss of filter during handling).

2.2.4.e Elemental and Organic Carbon: Sampling and Analysis

NIOSH (National Institute of Occupational Safety and Health) method 5040 was used to sample and analyze elemental and organic carbon levels. Elemental and organic carbon were collected on a factory preassembled SKC diesel particulate matter quartz filter cassette with precision jeweled impactor (to screen out particulate matter greater than 1.0 micron). Elemental carbon (or the carbon in the soot particle core) is made up of aciniform carbon and is widely considered a surrogate for diesel exhaust (Ramachandran and Watts 2003). The filter cassette used in this study is especially designed to be used with NIOSH method 5040 and differentiate diesel particles from other respirable dust by size cut. Air at 2 L/min was pulled through the filter using SKC Universal XR Series PCXR8 personal sampling pumps.

At the end of the day, the cassettes were wrapped in aluminum foil to prevent organic carbon interferences and sent offsite for thermal optical analysis via the NIOSH 5040 method to Clayton Laboratories in Michigan.

A summary of elemental and organic carbon analysis procedures is as follows (NIOSH 5040; Treadwell 2003): for analysis, a small punch from the filter (rectangular, 1.5 cm^2) is removed and placed in a small tube furnace. The sample is heated from 25°C to 850°C in a pure helium (He) atmosphere to evolve the organic carbon. This carbon is oxidized to CO_2 then reduced to methane (CH_4) for detection by a flame ionization detector. The temperature is then reduced to 550 °C and the atmosphere is changed to 2% O_2 in He. The heating continues to 850°C. The carbon evolved during this stage is elemental carbon.

A correction is made for charring of the organic carbon in the later stage of the first temperature ramp, using the measured reflectance of the filter sample. The light reflected by the surface of the filter from a laser is measured throughout the sample analysis. This reflectance decreases as the organic carbon is charred. Upon switching the purge gas to 2% O_2 in He, the reflectance of the filter returns to its initial value. The carbon evolved during this segment of the analysis is defined as organic carbon and the results are reported accordingly.

EC and OC values that were reported by the laboratory at less than the limit of detection (LOD) of the method (2 $\mu g/m^3$) were discarded and not used in the data analysis. Almost half the data collected in this study were under the LOD.

2.2.4.f Nitrogen Dioxide: Sampling and Analysis

The ASTM (American Society of Testing and Materials) D1607 test method for nitrogen dioxide in the atmosphere was used to measure nitrogen dioxide at Perimeter #2.

The ASTM D 1607 is considered a wet chemistry method and is less commonly used in the U.S. compared to the chemiluminesence method for NO_x, which measures and analyzes both NO and NO_2 via one analytical instrument. However, the ASTM D1607 is more commonly used outside the U.S. and in applications to measure nitrogen dioxide in remote locations, where use of a chemiluminesence analyzer is impractical.

The ASTM D1607 limits of detection for nitrogen dioxide (NO_2) in the atmosphere range from 4 to 10,000 $\mu g/m^3$ (0.002 to 5 ppm(v)) when sampling is conducted in fritted-tip bubblers. The NO_2 in air is absorbed in an azo-dye-forming reagent. Via the Griess Saltzmann Reaction**,** a red-violet color is produced within 15 minutes, the intensity of which is measured spectrophotometrically at 550 nm. The reagent color change increases with increasing concentrations of nitrogen dioxide.

The sampling train used in this study was slightly modified from that recommended in ASTM 1607D by the addition of an ozone scrubber and an SKC brand fritted nozzle impinger. The sampling train is shown in Figure 2.9 below. High ozone levels can interfere in analysis so we added an ozone scrubber to the sampling train. However, the ozone interference is expected after 3 hours, and we analyzed our samples within a 45 minute window. With the addition of the ozone scrubber and timely analysis, interferences from ozone were not a concern in this study.

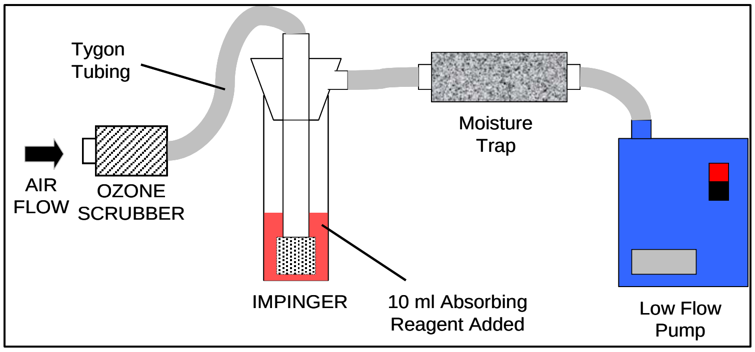


Figure 2.9: **<u>Schematic of Field Air Sampling Procedure Set-Up</u>**

As shown in Figure 2.9, air pulled at a flow rate of 0.4 L/min via a single Gilian Low Flow personal sampling pump (S/N 15260 or S/N 109697) was bubbled through a fritted nozzle glass impinger (25 ml volume, SKC # 225-36-2) filled with 10 ml of absorbing reagent. Per ASTM D 1607, the maximum sampling period is 60 min at a flow rate of 0.4 L/min. In this study, the maximum sampling period was 60 minutes, and the minimum was 30 minutes. One sample was taken in the late morning between 10 AM and 12 noon at the KRC Perimeter #2 location. A second sample was taken in the afternoon between 1 PM and 3 PM at the same location.

After the sample was collected, we immediately brought the solution to the Keene State College Science Center for analysis that by a spectrophotometer [Spectronic 20 Plus from Thermo Electron Corporation (SN# 3MUH301001)] located in the Chemistry Department. A calibration curve was plotted for this instrument using a stock solution of sodium nitrate as outlined in ASTM D1607. A new calibration curve was made for each new absorbing reagent batch. Per Figure 2.10, passing UV radiation through the sample at 550nm wave length will determine the sample's absorbance. The reduction in intensity of the UV radiation emerging from the sample indicates the concentration of the absorbing species. The output of the spectrophotometer is the parameter “absorbance”. The absorbance value was used to calculate the concentration of nitrogen dioxide in air in the 10 ml reagent sample. The calculated concentration was adjusted for ambient actual temperature and pressure conditions.

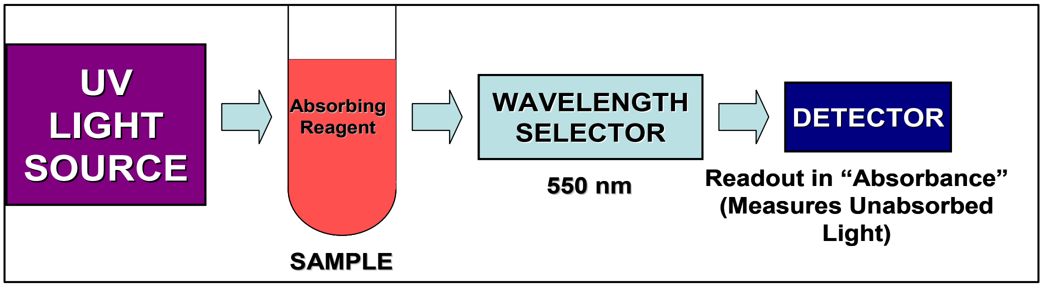


Figure 2.10: **An Overview of Spectrophotometric Analysis of Nitrogen Dioxide**

2.2.4.g Data Analysis

Data was collected and tabulated by KSC students and validated by KSC faculty and research staff. The decision to remove an outlier was made by KSC researchers, using Dixon’s rule of the huge error (Kebbekus 1998). Only one measurement in the study was discarded as an outlier, a measurement of elemental and organic carbon from a single filter on the last field work day (8/17/06). Measurements that were found to be below the limit of detection for the method were not used in data analysis.

Geometric mean (GM), geometric standard deviation (GSD), and minimum value unbiased estimate (MVUE) values were determined from using Industrial Hygiene Statistics Spreadsheet (IHSTAT) from the American Industrial Hygiene Association (Mulhausen and Damiano 1998). The rationale for selecting these parameters is described below. Distributions were checked for normality or lognormality using the W-test feature on the

IHSTAT package. All other descriptive statistics and inferential statistics were determined using Microsoft Excel 2000.

The frequency distribution of all data sets ($PM_{2.5}$, EC/CO, NO_2) was evaluated by W-test on the IHSTAT package and found to be either lognormal or both normal and lognormal. The lognormal distribution is best represented by the geometric mean (GM) and geometric standard deviation (GSD). For the lognormal distribution, the GM is always less than the arithmetic mean (AM). Since ambient environmental measurements can vary by orders of magnitude and tend to be lognormally distributed, reporting the GM is standard practice in environmental air monitoring data presentation and in many exposure assessments as well.

However, for exposures with chronic health effects, the arithmetic mean (AM) of the lognormal distribution is considered the most appropriate measure when evaluating the health risk posed by an exposure (Mulhausen and Damiano 1998). The arithmetic mean is considered a more conservative estimate of dose and is the recommended parameter for evaluation in occupational exposure assessment (Mulhausen and Damiano 1998, Ramachandran 2005). Therefore, data analysis in this study determined both GM and AM and both values are presented in the results chapter.

For small n ($n<20$), the sample mean represents the arithmetic mean of the lognormal distribution (Mulhasen and Damiano 1998). However, for larger n, the minimum variance unbiased estimate (MVUE) is preferred as the representation of the arithmetic mean of the lognormal distribution (Mulhausen and Damiano 1998, Ramachandran 2005). In summary, the GM and AM are reported for each perimeter location and air contaminant. The MVUE is presented for the total KRC site mean, or the arithmetic mean of the pooled data for all perimeter locations throughout the site. Standard error is reported for the arithmetic means at

Perimeter #1, 2, 3, and 4 and the MVUE. The GSD is reported for each GM at each perimeter and for the total KRC site. If not otherwise specified in the results chapter, the arithmetic mean is represented by the sample mean.

However, differences (% reductions or increases) are calculated using the GM value at each perimeter and the total KRC site GM. Statistical t-tests using the unequal variance option from Microsoft Excel 2000 were performed on logtransformed data to determine if there was a statistical difference between diesel and biodiesel fuels at each perimeter and also the total KRC site. The total KRC site GM reflects a conceptualization of the KRC as a stable and long term source of ambient air pollution in the near field environment. The total KRC site GM is an approximation of the contribution of this "source" to the near field.

2.2.4.h Threats to Validity

The threats to validity in this study can be best summarized by this question: how do we know that any changes in measured pollutant concentrations are due to the fuel switch and not from something else? The "something else" in this study can be a number of threats and include: the accuracy and precision of the measurement methods themselves, the level of maintenance of the equipment (poorly maintained equipment will tend towards higher emissions), day-to- day activity of equipment (moving with load = higher emission vs. idling), proximity of operating equipment to monitors, meteorological conditions/environmental variability (temperature, wind speed, wind direction), and the outside vehicle count. Interferences from pollution from other combustion sources would be another threat. Each of these threats was either measured as independent variables so their impact could be evaluated in the data analysis or eliminated in the research design strategy. Each threat will be discussed one by one in the next paragraphs.

Measured exposures are subject to three main sources of variability: environmental variability (random intra-day and day-to-day variations in concentrations), random sampling and analytical variability, and nonrandom systematic variability or bias (such as introducing ventilation controls). (Ramachandran 2005). Environmental variability includes weather conditions like temperature and humidity; systematic variability includes extreme differences in equipment activity, or if new equipment was introduced. Both sources of variability were measured as listed in Table 2.1.

2.2.4.i Validity: Methods

The air monitoring methods themselves had low coefficients of variability (less than 10%). Variability associated with the sampling and analytical methods is very low compared to overall environmental variability. Nicas (1991) estimates that for those sampling and analytical methods with a coefficient of variation less than 0.10 (most regulatory methods including those in this study fall within this category), the variability of the sampling and analytical process contributes less than 6% of the error in the result. Thus a small sample *n* can only estimate the long term average of the exposure profile – because of intra and interday variability a very large *n* must be collected to more precisely define an exposure profile's long term average. However, as mentioned previously, key industrial hygiene texts (Mulhausen and Damiano 1998; Ramachandran 2005) support an *n* of 6- 10 sample measurements to initially characterize the exposure profile. This sample size and resulting data are also useful to begin to estimate health impacts from these exposures by initial comparison to existing health standards.

2.2.4.j Validity: Activity

The same KRC equipment was used throughout the study. This KRC equipment was part of a consistent and historical preventative maintenance program run by the City of Keene fleet services division. The preventative maintenance checks included engine maintenance per the manufacturers' recommendations and engine oil analysis. As the equipment in this case was considered well maintained and the equipment remained the same, these factors were not considered threats to validity.

Activity levels can impact emissions and exposure; this was an important independent variable for consideration in this study. Equipment activity at the KRC site was tracked and documented by student teams positioned at Perimeters #2 and 3. Using digital clocks and standardized logs, students documented the activity of equipment and its distance from the monitoring instrumentation at 20 minute intervals for each perimeter. Although proximity to monitor was estimated, ultimately the proximity did not vary much due to the tight configuration of the main drop off area. For the duration of the study, there were few to no examples of more than one piece of equipment being near Perimeter #2 and 3 at the same time; proximity to monitor was not a concern as a confounding variable in this study. In between the 20 minute intervals, students made notations of any high activity events near the perimeter locations.

Activity levels were quantified by the number of activity events. Activity events were defined per Table 2.6 below as high (i.e., equipment moving with load) or low (i.e., equipment idling), and the events were later recorded on site maps for every 20 minute interval for each day of field work. Tracking the activity events in this manner allowed for quantitative comparison of activity levels during diesel and B20 operation at the KRC. While operational activities at the KRC were reasonably consistent on a week to week basis, and no unusual operating events occurred during our field work period, activity levels did vary on an hourly and daily basis depending on work loads. This presented an important analytic challenge: if the number of activity events during biodiesel monitoring days were consistently less than activity events during diesel days, then the reported reductions in $PM_{2.5}$ could possibly be attributed to lower activity levels.

To perform data analysis for activity, KSC researchers and students compiled all site maps of activity, reviewed them and developed a decision matrix. As mentioned, activity events were categorized by high activity or low activity. Then the numbers of high or low activity events per day were used to categorize that day as a high, medium, or low activity day. The decision matrix used is summarized in Table 2.6.

<table>
<tr><th colspan="4"><u>ACTIVITY EVENT CATEGORIZATION SCHEME</u></th></tr>
<tr><td></td><td colspan="3">Activity Event Definition</td></tr>
<tr><td>High Activity Event</td><td>Lifting/Digging</td><td>Moving without Load</td><td>Moving with Load</td></tr>
<tr><td>Low Activity Event</td><td>Vehicle at Standard Idle</td><td></td><td></td></tr>
<tr><td colspan="4"><u>Activity Day Categorization Scheme</u></td></tr>
<tr><td></td><td colspan="2"># of High Activity Events</td><td># of Low Activity Events</td></tr>
<tr><td>High Activity Day</td><td colspan="2">≥7</td><td>≥10</td></tr>
<tr><td>Medium Activity Day</td><td colspan="2">4-6</td><td>5-9</td></tr>
<tr><td>Low Activity Day</td><td colspan="2">≤3</td><td>≤4</td></tr>
<tr><td colspan="4">Examples:</td></tr>
<tr><td colspan="4">-A notation of “lifting/digging” would be categorized as a “High Activity Event”</td></tr>
<tr><td colspan="4">-Equipment documented at standard idle would be categorized as a “Low Activity Event”</td></tr>
<tr><td colspan="4">-The number of events per day is totaled and each day is categorized</td></tr>
</table>

Table 2.6: Activity Event and Activity Day Categorization Scheme

An example is helpful to illustrate the application of the above decision matrix to data analysis. If there were 7 or more high activity events (defined as moving with load, lifting/digging, moving without load) logged in any single day, that day as a whole will be labeled a “high activity day.” There were six diesel days meeting “high activity day” criteria and four biodiesel days meeting the same criteria. A statistical analysis was conducted to compare $PM_{2.5}$ levels, EC/OC, and NO_2 (pooled for all monitoring sites) for “diesel - high activity days” and “B20 - high activity days.” A two sample t test assuming unequal variances was used to compare the averages between the two fuel types during high activity days at the KRC.

2.2.4.k Validity: Weather Data

Weather data was recorded by a Casella on site weather station. Temperature, relative humidity, wind speed and wind direction were recorded. For 5 days during the study the Casella experienced operational difficulties so the temperature and relative humidity was taken from historical archives from Dillant Airport seven miles away in Swanzey, NH. Wind speed and wind direction data would only be relevant when considering Perimeter #3, as Perimeter #1 and Perimeter #2 were inside the main building. There also could be slight temperature and relative humidity variations between the indoor and outdoor sampling locations. The research design was done in the summer period, which is usually considered a worst case for background levels for these pollutants, and the variations in temperature and humidity would not be large enough to impact the sampling results seen in this study.

2.2.4.l Validity: Outside Sources - Traffic, Other Sources of Combustion

All vehicle traffic that passed by Perimeter # 3 or 4 was logged. Students tracked any vehicles that used the citizen drop off bays, as these vehicles could impact organic carbon or nitrogen dioxide levels at Perimeter # 2 or 1. Students were taught the difference between diesel and gas powered vehicles, and noted this on standardized vehicle logs. Total vehicle counts for each day (diesel vs. gas) are reported in the results chapter.

Interferences from other sources of emissions could be a threat to internal validity. This was considered in selection of the site. The KRC is approximately ½ mile off the state highway, so that nearby traffic should not contribute any outside sources of EC or $PM_{2.5}$. There are few nearby residences. The machinery used in the KRC runs on methane recovered from the landfill so that is not a competing source of combustion emissions, other than CO. There are no boilers on site to generate particulate matter. Sampling in the summer season also eliminates confounding by any boilers or nearby heating units (wood or fuel based). The contribution to $PM_{2.5}$ and EC from gas engines is small, and EC from gas engines should not interfere significantly with the NIOSH 5040 method (Birch 2003). However, OC and NO_2 concentration measurements can be impacted by gas engines, as well as external diesel, so these vehicles were counted.

2.2.4.m Challenges in Field Plan Implementation

With field work, there are typically unexpected challenges that arise. For the collaborative exposure assessment, we added a new area location (trash excavator) which had been identified during the first BWG meeting by KRC employees as a potential high exposure area. Although data for diesel days were collected for $PM_{2.5}$ and EC/OC, a fire occurred in the trash transfer building the first week of August 2006 which eliminated the opportunity to evaluate the area during biodiesel operations. The excavator and trash transfer area were moved to a remote outdoor area that was too different from the previous indoor sampling area for B20 comparative purposes. Therefore, Perimeter #5 data are not included in the data analysis or results chapter.

Secondly, the ASTM D1607 recommended impinger for the NO_2 sampling and analysis method was backordered for 6 weeks. Since this would have been in the middle of the field workplan, I used a standard order SKC impinger with fritted nozzle recommended for many gas to liquid absorption type sampling methods. By the time the preferred ASTM D1607 impinger was delivered, the site was already operating on B20. Therefore, although the

ASTM impinger was used side by side with the SKC impinger during B20 days, only SKC impinger diesel vs. biodiesel results are reported.

2.2.5 Synthesis of Information

Synthesis of information from the Collaborative Exposure Assessment occurred throughout the fall of 2006 during periodic meetings of the KSC faculty and student research team. These meetings typically occurred every two weeks throughout the fall semester. During these meetings, students were shown how to calculate time weighted averages, interpret data results, develop graphical representation of results, perform quality checks, and understand the meaning of the results. KSC faculty validated the final data used in the statistical data analysis. Students, faculty, and research staff worked together to develop ways to present the data that we believed would be easily accessible to the BWG and KRC site team.

A BWG meeting held on December 19, 2006 provided another opportunity for synthesis of information for the collaborative exposure assessment. The BWG reviewed the draft results, which initiated a whole series of deliberations. In fact, discussion of the exposure assessment activities and draft results immediately led to a new problem formulation for the BWG; this new problem formulation began to take shape at the December 2006 meeting. At the next BWG meeting on February 13, 2006, synthesis of information occurred again as the BWG met with the students to review and critique their formal oral presentation of the exposure assessment results. Discussions back and forth between the students and BWG members helped provide constructive feedback to make the results more accessible to the lay public. The BWG gave feedback to the students on venues for public dissemination. More detail is provided in the results chapter. Essentially, the analysis and deliberation started at the December 2006 meeting led to Central Question #2.

2.3 Central Question #2: How Can Local Supply of B20 Be Increased?

2.3.1 Problem Formulation

2.3.1.a Role of the BWG and Other Key Players

The process of recruiting members for the BWG during this phase of the research was challenging and will be discussed in the next section on Process Design. The BWG members participating in the December 19, 2006 meeting were personnel involved in the collaborative exposure assessment activities from both the City of Keene fleet and KRC staff, as well as myself and a student researcher. A Keene State employee working with environmental & sustainability programs also joined the group for a total of 5 participants at this meeting.

Initial draft results were shared with the BWG, specifically the result that $PM_{2.5}$ appeared to be significantly reduced by use of B20. A summary of the deliberations will be present in the results chapter, but essentially the BWG identified barriers to B20 and decided to address these barriers as a primary goal. As part of expanding participation in the BWG and getting feedback on this new problem formulation, I gathered qualitative data using the following methods: participant/observation, meeting minutes, and semi-structured interviews. Semi-structured interviews were also used to provide important contextual data, as previously discussed in Central Question #1. My approach to participant/observation and meeting minutes data collection was unchanged and has already been reviewed under Central Question #1. Therefore, I will only discuss the approach to semi-structured interviews in this section.

2.3.1.b Semi-Structured Interviews

Semi-structured interviews were a key strategy to involve KRC site workers and other interested and affected parties that were unable to attend BWG meetings in the BWG process. I also interviewed BWG meeting attendees. Many of the questions asked in the interview were the same as those asked in BWG meetings. I looked for inconsistencies in attitudes and comments between meetings and interviews. I used feedback from KRC workers and others to compare against BWG attendee deliberations. Finally, interviews were helpful in triangulation of the data, as I could compare transcripts against participant/observation notes when the same people were involved. The semi-structured interview guide is listed below in Table 2.7.

SEMI-STRUCTURED INTERVIEW GUIDE
What are your thoughts on biodiesel use in Keene?
Do you associate any risk with biodiesel? Can you expand on that?
When did you first learn about biodiesel?
Were you involved in the initial decision to use biodiesel in Keene? How so?
Do you have concerns or questions about biodiesel you would like studied further?
What do you think should be done with the results of the exposure assessment?
What would be your ideal vision for biodiesel use in Keene?
Do you think a biodiesel working group could assist in meeting that vision? Why or why not?
Who do you think should participate on the group?
What should be the goals of the biodiesel working group?

Table 2.7: Semi-Structured Interview Guide

I conducted an interview with Steve Russell because he initiated and championed the use of B20 and was a key informant in this work. I interviewed Russell's supervisor, Duncan Watson, as well as Keene's Mayor Mike Blastos, Department of Public Works (DPW) Garage Foreman Clevis Linwood, DPW employee Drew Armstrong, and a group of KRC employees. I interviewed Duncan Watson and Mayor Blastos as both were suggested by Russell and both had distinct local knowledge regarding the political climate in the City of Keene municipal organization and the general population. Watson also had overall responsibility for the KRC operation. I interviewed Linwood because he was suggested by Russell and he was a fleet mechanic for almost twenty years with experience pre- and post-B20 use. Linwood also supervised the other mechanics. I used a tape recorder for the Russell, Watson, Blastos, and Linwood interviews, and transcribed verbatim for Russell, Watson and Linwood. I did not transcribe the entire interview for Blastos as the interview was interrupted and got off track on issues unrelated to biodiesel. All respondents gave verbal consent to be interviewed and to use their names in this study.

For the other interviewees, I took detailed field notes and did not use a recorder. I interviewed Armstrong as a random interview of a DPW employee, not suggested by anyone. Armstrong was driving a Holder (equipment that plows sidewalks) and I recalled a presentation where Russell discussed how a Holder engine broke down after purchase. The equipment manufacturer challenged making the repair per the warranty when they heard about the use of B20. Eventually the cause was found to be grit in the engine from a faulty air filter and not the B20 fuel. I wanted to see if the Holder operator knew about this incident and his view of B20 use. Finally, I interviewed the KRC employees as a group during a break because they were directly affected by diesel exposures and were present during the exposure assessment. All employees gave their verbal consent to be interviewed and their names used in this study. However, in some cases, I elected not to name participants in the narrative because of potential sensitivity of the comment.

This study focused on biodiesel, which would seem to imply no sensitive comments would emerge. While verbal consent was given by all participants for all interactions and interviews, in any study charged comments may arise indirectly that necessitate sensitive handling by the researcher. Potentially controversial comments occurred in this study as well. For example, in discussions regarding worker involvement in the study, strong feelings emerged, and ultimately workers did not participate in the BWG meetings. Since relationships do not end for me or the participants after the dissertation, I chose to protect the anonymity of any person whose comments could be considered in any way controversial. In those specific examples, a person may be identified as a DPW employee, City of Keene decision-maker, or BWG participant to specify their role. Anonymity does not invalidate in any way the legitimacy of the data collected or subsequent analysis and conclusions. I used my personal judgment in deciding when to apply anonymous status to a participant. In most examples in study a participant is identified by name.

2.3.1.c Data Analysis and Validity

For guidance in how to conduct and transcribe interviews, I followed the recommendations in Weiss (1994). I used the questions in Table 2.7 as a guide but picked up markers and followed up on them with interviewees when appropriate. I read through transcripts prior to coding to get a sense of the data. I then coded interview transcripts or field notes inductively by looking for similar ideas or codes to emerge organically from the data, using the respondent's words as a code whenever possible. From the codes, I pulled together common threads or themes. Following Miles and Huberman's (1994) suggestions for data analysis, I followed the steps of data reduction, data display, and conclusion drawing.

2.3.2 Process Design

Recruiting members for the BWG process was challenging during the summer of 2006 through the early winter of 2007. I attempted to expand potential membership from the June 2006 meeting to include those people suggested by the meeting participants. Suggestions included reaching out to people from the Cities for Climate Protection committee, City Council members, and local school teachers as interested and affected parties. However, it was difficult to schedule another BWG meeting in the early fall of 2006 due to group scheduling conflicts and a general lack of interest in participating. For my part, I contributed to the scheduling problems due to workloads associated with the collaborative exposure assessment team meetings and making public presentations through September 2006. I was surprised by how much time it took to schedule meetings and the difficulty in locking in time with an already very busy group. Meeting dates had to be suggested at least two to three weeks before having one. It was quite simply difficult to organize as well as motivate participation in the BWG.

By November 2006, with the year coming to a close, I decided to take a different approach to recruit new members, generate interest in the process, and assess their initial state of knowledge regarding biodiesel. I sent an internet survey via Surveymonkey.com to the names suggested thus far as potential BWG members and any names from my participation/observation data (including meeting minutes) that were even peripherally associated with the decision to use B20. As discussed in Central Question #1, the knowledge survey was sent out to 19 potential participants. Subsequent participation in BWG meetings on December 19, 2006 and February 13, 2007 did increase.

Securing worker participation was a continuing challenge throughout the study. I had asked for KRC workers to participate in the June 14, 2006 meeting but was told they were unavailable. Noting organizational tension regarding worker participation, yet hoping to recruit their participation as a key affected party, I spent time in fall 2006 trying to deal with this challenge. I spoke with others within the DPW about the tension I noted at the 6/14/06 meeting and informal conversations, but the only comment I got was “no comment”. Since the KRC workers were the ones involved in the exposure assessment, I continued to try to recruit their involvement in the BWG.

I consulted professional colleagues not related to this study but who knew the personnel involved for advice. One suggestion made was to get a neutral facilitator who had skills in conflict management via another program within Antioch. In addition to helping with the worker/management conflict aspects, this seemed like a good idea to allow me to shift to a more observer role in my data collection. I attempted to find a facilitator but was unable to recruit any interested parties during September or October 2006. Another colleague suggested I appeal directly to another manager who had influence with the KRC. I sent an email November 1, 2006 to this manager asking for support of worker participation, explaining the importance of the A-D model concepts to involve interested and affected parties. I received a positive reply that KRC workers could participate in future BWG meetings. Unfortunately, this never materialized. Therefore, I used semi-structured interviews and the Biodiesel Knowledge Survey (as discussed under Central Research Question #1) as the main to involve workers in analysis and deliberation in this study.

2.3.3 Select Options and Outcomes

Options and outcomes began to emerge from discussions at both the December 19, 2006 and February 13, 2007 BWG meetings, as well as via the semi-structured interviews. The details of these meetings will be reviewed in the results chapter. The BWG decided that a desired outcome was to increase the use of B20 by the City of Keene organization, but the lack of available and cost-competitive B20 in southwestern New Hampshire was determined to be a key structural barrier to increased use. The BWG deliberations supported that the group's next step would be to gather information on why distribution was not expanding in New Hampshire, and if there was a way to collaborate with distributors to increase local demand and decrease fuel costs.

During the December 2006 to February 2007 time period, a concurrent path was being explored outside the formal BWG process (but involving myself) to consider making biodiesel from waste grease. A private engineering firm had heard about the collaborative exposure assessment research program and the City and College's long term use of B20. This firm approached Treadwell and I to organize a meeting with the KSC Administration, which occurred in January 2007. The BWG group was brought in to expand deliberations on the potential option of manufacturing biodiesel from waste grease on February 13, 2007. Therefore, at this point, analysis and deliberation turned to information gathering on two potential options: increasing availability of B20 in the region, or producing B20 from waste grease in Keene.

2.3.4 Information Gathering and Interpretation

A number of BWG meetings consisted of gathering information for Central Research Question #2. February 13, 2007, February 22, 2007 and March 5, 2007 were the key meetings during this phase. During the February 22 and March 5, 2007 meetings, the BWG held discussions with 2 local fuel distributors, asking questions about their current and future plans to sell B20 in the area. In addition, student researchers began a feasibility analysis of local biodiesel production. Finally, outreach presentations offered an opportunity to gauge public feedback on support for expanding biodiesel demand in the region. Questions from the audience were used to evaluate the level of support.

The information gathered during the BWG meetings themselves or reported back to BWG meetings during the March 2007 timeframe was synthesized in BWG meetings to lead to the Central Research Question #3. The timeframe of A-D interactions on Central Research Question #2 was relatively short, as meeting with distributors led directly to a new problem formulation.

2.3.5 Synthesis of Information

Interviews with fuel distributors uncovered important data as to why the lack of local supply persisted but also led the BWG to focus on a new problem: how can an innovative public/private/college collaboration manufacture biodiesel in the local community? By this point the BWG membership had expanded to include additional KSC and City of Keene staff, as well as a private engineering firm. Participation in these deliberations (except for KRC workers) was no longer a recruiting challenge. Leadership of the BWG had changed hands from me to the KSC Vice President of Finance and Planning, who worked under the direction of the President of Keene State College. I was no longer the leader or facilitator or organizer of BWG meetings after 2/22/07. By the end of March 2007, the group had taken ownership of the problem of lack of local B20 supply and settled on the manufacture of B20 from waste grease as a desired outcome. The BWG began discussions with the private engineering firm to explore opportunities for a unique public/private collaboration that would connect production, research, education and economic benefit. This collaboration led to the final research question, Central Research Question #3.

2.4 Central Question #3: How Can an Innovative Public/Private/College Collaboration Manufacture Biodiesel in the Local Community?

2.4.1 Problem Formulation

The integration of analysis and deliberation to develop a new problem formulation took place mainly in BWG meetings. The membership and the scope of the BWG goals expanded during this phase as the new Central Research Question became the main focus of the group. Meetings in March and April took place both at Keene State College and the City of Keene offices. Mainly the meetings during this phase could be categorized as brainstorming, initial feasibility analysis, and relationship building. There were also activities occurring outside of meetings: for example, in March 2007, the President of Keene State College formally asked the City Manager of Keene to begin negotiations of entering into a lease agreement. This led to two separate BWG's: one made up of only City employees and one consisting of mainly KSC employees. How to structure the idea of the collaboration as an actual organization quickly emerged as a challenge. Yet the above problem formulation remained unchanged through the summer of 2007, when I stopped formally collecting data, and was still the main focus of the BWG as of the publication date of this dissertation.

2.4.1.a Participant/Observation

Since the BWG meetings were the main place where both analysis and deliberation were occurring, participant/observation was the main data collection method during this phase. At this point, I was in a mainly observer role, except when contributing information/ideas about biodiesel research relating to exposure assessment or pollution prevention. How I did participant/observation did not change from the previous discussion under Central Question #1, and so will not be repeated here.

2.4.2 Process Design

The composition of the BWG membership and identification of new interested and affected parties evolved quickly as the idea of a collaboration to make biodiesel in Keene and connect ongoing and expanded exposure research took shape. There were certainly fluxes and flows in membership and participation, as shown in Figure 2.11 below. Many times the membership in the BWG was someone already a member of another organization or in another role that supported general environmental quality goals. The back and forth element of Figure 2.11 in how membership moved also is representative of how decision-making process could be described by this point: a complex back and forth interaction with some small forward progress.

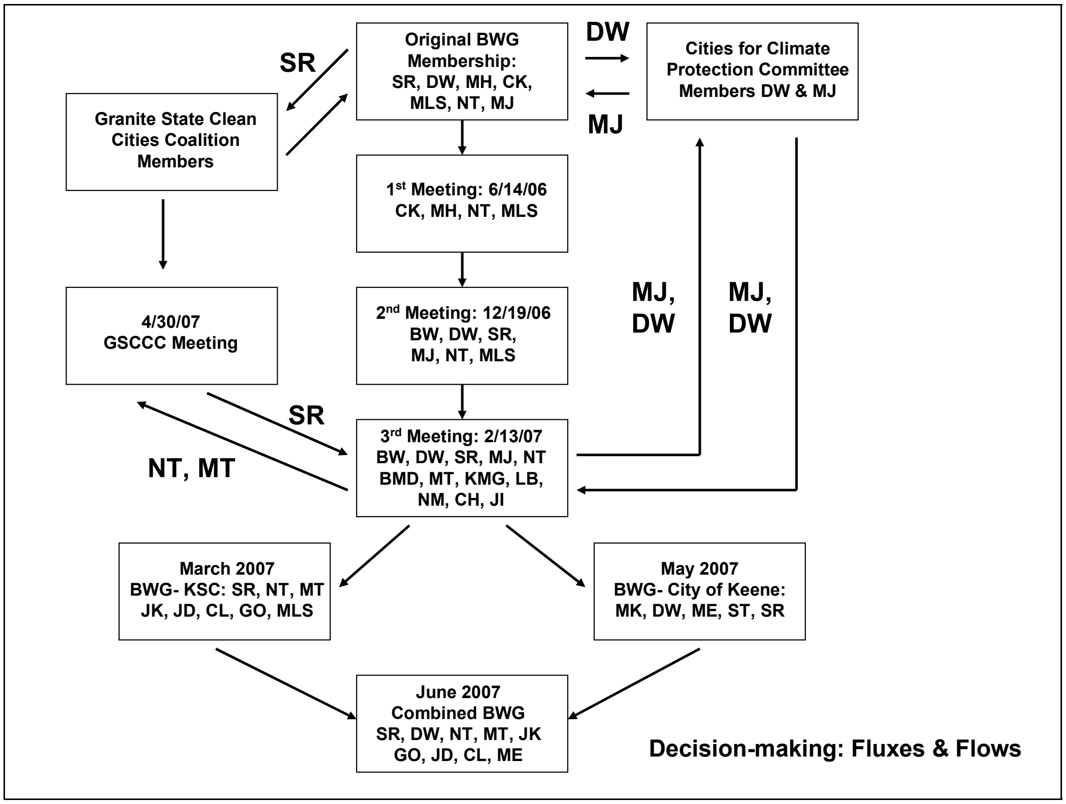


Figure 2.11: Decision-Making Fluxes & Flows

Eventually by June 2007, both BWG recombined into one group. I will review the above diagram again in the context of results, but include it here to show the flux in membership during this time.

2.4.2.a Data Collection: Participant/Observation, Semi-Structured Interviews, Biodiesel Attitude Survey, and Document Analysis

I used the above data collection methods during this phase of the study. Participant/observation and semi-structured interview protocols were unchanged from previous discussions in Central Research Question #1 and #2. Document analysis consisted mainly of reviewing local newspaper reports as well as magazine articles and City meeting minutes that were publicly available. These documents served to capture local comments and the level of community interest in the general biodiesel project. The Biodiesel Attitude

Survey was the last new data collection strategy employed in this study so I will discuss this next.

With the attitude surveys, BWG participants had an opportunity to respond in an anonymous manner to similar questions about biodiesel discussed in BWG meetings or in interviews. The Biodiesel Attitude Survey acted as a data triangulation tool to assess if the options or goals BWG members said they cared about in the meetings were the same goals they cared about in the survey. The same multiple contact delivery protocol for the Biodiesel Knowledge Survey (reviewed under Central Question #1) was followed for the Biodiesel Attitude Surveys. The survey consisted of 17 questions which are shown in Table 2.8 below, and was delivered via email to the Biodiesel Working Group in March 2007 via the internet survey service site **Surveymonkey.com**. There was also a space on the survey that requested written comments or feedback. I sent the survey to the initial ten BWG members that had participated up to 2/22/07. All ten completed the survey within 2 weeks. The survey's anonymous nature provided an opportunity for the voices of everyone in the BWG to be heard, not just the most vocal participants, as well as encouraged open feedback on the BWG process. Each question had 5 responses: 1 = strongly disagree, 2= mildly disagree, 3= neither agree nor disagree/neutral, 4= mildly agree, 5= strongly agree.

Biodiesel Attitude Survey	
Number	**Question**
1	I feel it is important to study exposure to petroleum diesel exhaust in my community
2	Biodiesel is a safe and environmentally friendly fuel
3	Using biodiesel is an important way to decrease U.S. dependence on oil from the Middle East
4	I support the City of Keene's decision to use biodiesel in city fleet vehicles
5	If you answered "mildly agree" to (#4) or "strongly agree" (#5) to the previous question, please answer this question. Otherwise skip to question #6. The Major reason I support biodiesel use by the City of Keene is:
6	There should be more community and worker education about biodiesel in Keene
7	I believe biodiesel is a healthier fuel for City of Keene workers and the community than petroleum diesel
8	Biodiesel is typically more expensive than petroleum diesel, varying from 3 to 20 cents more per gallon for a typical blend. I am concerned about the extra cost to purchase biodiesel compared to the cost to purchase petroleum diesel.
9	More research on biodiesel blends is needed in order to better understand biodiesel's risks and benefits
10	My ideal vision of biodiesel use in Keene means biodiesel would be (check your top three choices)
11	I would support the formation of a Keene Biodiesel Working Group to discuss what research is needed to better understand the risks and benefits of biodiesel
12	I would support the formation of a Biodiesel Working Group to make advisory recommendations regarding biodiesel policy and use in Keene.
13	A goal of the Biodiesel Working Group should be to improve education/conduct educational outreach regarding biodiesel use within Keene and New Hampshire
14	A goal of the Biodiesel Working Group should be to evaluate the need for additional analyses regarding concerns relating to biodiesel.
15	A goal of the Biodiesel Working Group should be to provide advisory policy recommendations to local government regarding biodiesel use in Keene.
16	A goal of the Biodiesel Working Group should be to improve collaboration of biodiesel projects with the Cities for Climate Protection initiative and other environment-related programs within Keene
17	I would like to participate on the Biodiesel Working Group.

Table 2.8: Biodiesel Attitude Survey Questions

As with the Biodiesel Knowledge Survey, the Biodiesel Attitude Survey was designed mostly to be a triangulation tool and to provide information back into the analytic-deliberative process. It took the pulse of the group’s analysis and deliberation activities and decision-making during a formative stage in the process. It provided a way to make the process fair by allowing individual, anonymous comment, and also provided a way to help legitimize decision making. It was not designed to be generalizable or extrapolated to any other population, and a follow-up survey was not given in this study; therefore, survey validity processes were not applicable to this study.

2.4.3 Select Options and Outcomes

The deliberation of options and outcomes happened primarily during BWG meetings. Deliberations often identified a need for additional analysis, which was presented at future meetings. There was an overall consensus among the BWG members on the desire to come together and build the biodiesel manufacturing/fuel testing/research facility. There was little conflict regarding this vision, at least among the BWG. The step of characterizing options and outcomes to support this goal was more challenging to the group. There was less clarity in understanding the roles and relationships of each of the partners. Working with a private firm in a business partnership was a new type of venture for the college, and working with the City as a partner was a new level of formal town/gown relationship. Options and outcomes emerged from frequent deliberations that occurred in BWG meetings. Meetings occurred every two weeks through June 2007, when I stopped collecting data.

Early deliberations at this stage began to identify numerous data needs, such as reviewing potential sites in Keene, funding options, and how different organizational structures of the business/research relationship could impact the final collaboration. Different members of the BWG would be assigned different analytic tasks and report back to the group. Data collection during this phase was still mainly participant/observation, as well as document analysis of emails, meeting minutes, and distributed documents.

2.4.4 Information Gathering and Interpretations

As imagined for a project of this scope and level of collaboration, there were a number of major information gaps identified during the time period May to June 2007. This included the need for a business plan that would identify funding sources, organizational structure, potential raw material sources, costs of production, and facility/maintenance/personnel costs. A draft business plan was one of the first main analytic activities that the BWG undertook. To perform this level of analysis, subgroups or subcommittees of BWG members formed to complete the tasks necessary to complete a business plan. Outside technical expertise (such as the Small Business Development Center) was consulted as necessary to help develop the business plan.

Other information gathering steps included researching federal funding options and site analysis. Dr. Treadwell and I continued to participate on the BWG, and submitted a number of federal grant applications to support future biodiesel exposure research, which would support the KSC research/educational interest aspects of the project. With my professional engineering background, I assisted other members in performing tasks related to identification of manufacturing space and facility needs. Our subgroup would report back to the main group as appropriate.

I illustrate these examples to show that much of the information gathering and interpretation during this step of the A-D process was performed by subgroups of BWG members, who reached out externally to technical experts as appropriate. The subgroups would report back to the main BWG group at a meeting every two weeks or so. As it did throughout the study, the BWG meeting forum continued to be the linchpin that connected analysis and deliberation. I would collect data on the A-D interactions primarily at these larger BWG meetings via participant/observation or later via document analysis. This step was still ongoing as of the point I stopped collecting data in June 2007, and ongoing as of the date of publication of this study.

2.4.5 Synthesis of Information

As of June 2007, this step was not completed. Similar to the information and interpretation step, there have been numerous iterations of analysis and deliberation. As of the publication of this dissertation, the collaboration was still focused on Central Research Question #3 and continues to gather and synthesize information as partners, funding, and site options have changed over the last 9 months. The BWG meeting forum continues to serve as the main process design element to connect analysis and deliberation.

Results

3.1 Central Research Question #1: Does Use of B20 Result in Reduced Exposures of $PM_{2.5}$, EC/OC, and NO_2?

3.1.1 Initial Application of the A-D Model – The First Biodiesel Working Group Meeting: June 14, 2006

The formal application of the A-D model began when the first Biodiesel Working Group (BWG) meeting was held on June 14, 2006, before the start of the collaborative exposure assessment field work. I structured the first meeting toward getting feedback on the exposure assessment strategy before the start of actual air monitoring in the field, and to introduce and get feedback on the idea of starting a BWG. I sent out an email to 3 City of Keene employees suggested by Russell, and added 2 KRC supervisory staff. In the first email, I identified who I was, my dissertation research, and the idea of introducing a collaborative approach to the study. I suggested in my email three goals for the June 14, 2006 meeting: to talk about the field work planned for the summer/present the proposed research sampling plan, ask for feedback (did we miss anything/should we add anything), and discuss ideas/request feedback for a Biodiesel Working Group.

Five potential members (plus a request for 2 KRC site workers) had been contacted and four replied that they would attend. However, besides my research assistant and me, only two participants attended the meeting: a KRC supervisor and a former City employee now working for an environmental non-profit organization. Workers from the KRC site did not attend this first meeting. Before the meeting began, one of the KRC workers was sitting in the conference room and I assumed he was staying for the meeting. Instead, he chatted for a while and then got up and left when I suggested we start the meeting. When I inquired if workers would be attending, I was informed by the KRC supervisor that the staff was “full out" and too busy to participate. When I remarked to the group having workers participate was important because we didn't want to miss their input, one of the meeting attendees stated, "It's not like any of them care."

Discussion on the exposure assessment was fruitful in identifying overlooked areas important to the overall strategy to integrate occupational and environmental health. One key contribution from this meeting was the suggestion to measure pollutant concentrations in new areas suspected of having the highest exposure potential. The trash excavator, which had been operated by a private company during the pilot study in 2004, was now under City control. The trash excavator picked up trash dumped by private haulers and moved it from the transfer area into waiting box trailers for transport. As the excavator operated in a semi-enclosed environment during the bulk of the work shift, this had high occupational exposure potential. The work area near the excavator was subsequently added to the exposure assessment field work plan as a new perimeter.

Another change to the field work plan was made as BWG discussions indicated that workers moved frequently inside and outside the main work area during the day. Therefore, personal monitoring of their breathing zone would be subject to high variability. It would also require a KSC student to monitor just that employee's movements when students were already assigned to vehicle and activity monitoring. The group decided to monitor the conveyor belt work area as a worst case work area instead. Employees spent the majority of their shift at the conveyor belt, and the local air circulation was minimal in that area. Finally, discussions about day to day operations revealed that Fridays were universally slow in activity. Some level of activity is needed to ensure results were above the limit of detection for the sampling and analysis methods so we decided to remove Friday sampling days from the field work plan. By improving research efficiency and contributing local knowledge, BWG interactions expanded, revised, and enhanced the exposure assessment strategy.

Next, I distributed an open ended survey to the 2 participants to explore their attitudes about the research and desired policy goals for biodiesel use in Keene. Questions on the open ended survey included: what would be your ideal vision for biodiesel use in Keene? Do you think a formal Biodiesel Working Group could help advance this vision? If so, how? Responses to the question for the ideal vision for B20 included identifying a local supplier, having a "minimum B20 in everything diesel" and being able to buy B20 in "all of the gas station [s] in Cheshire County". Regarding the BWG, both participants thought a BWG was needed to implement these goals. One felt it was important to work on bringing in a local supplier, and "dispel any myths" about biodiesel. The other respondent felt the BWG could help with conducting educational efforts on biodiesel. The rest of the meeting was spent on discussion of these ideas, as well as asking these participants who else should be participating on the BWG.

A key observation made during and after the meeting was that there were underlying tensions between workers and management at the KRC site. Since the City's role in the Cities for Climate Protection campaign indicated a culture of support for environmental projects in Keene, I simply did not think worker participation would be an issue. After the meeting, I asked if workers could fill out the open ended survey, a participant said "many of them can't write. I wouldn't bother. They will not fill them out." Notes from a conversation with another City employee affiliated with the KRC on 6/9/06 also indicated some underlying tensions. At that time my suggestion for worker participation elicited, "I don't know if that is such a good idea." The potential reasons for this tension were never really determined as part of this study. Although the subject of management/worker relations was broached in informal conversations, workers were not eager to share their opinions about KRC management staff or any other City of Keene managers. Keene DPW staff also would not elaborate. Since this observation was more related to the experiences of participants, I did not pursue this observation further. In my experience in the chemical process industries, it is common for tensions to exist between management and hourly personnel. However, the lack of worker participation has implications regarding limitations of the study.

3.1.2 Collaborative Exposure Assessment Results

3.1.2.a Particulate Matter (≤ 2.5 microns)

As indicated by Table 3.1, B20 use resulted in consistent reductions in the levels of $PM_{2.5}$ (particulate matter ≤ 2.5 microns) measured at monitoring locations throughout the KRC. $PM_{2.5}$ was reduced by 50.6% at P1 (inside conveyor belt location), 57.6% at P2 (inside main floor at stairwell), and 53.9% at P3 (outside main bay door) when KRC equipment was switched to B20. The in-cabin $PM_{2.5}$ was reduced by 77.6% when the small front loader burned B20. Those perimeter reductions that are statistically significant ($\alpha = 0.05$) are noted in Table 3.1. Comparisons for each perimeter and the KRC total site mean are shown in Figure 3.1.

The KRC total site mean combined data from Perimeters 1, 2, 3 and 4 (also known as Mobile Source 1 [MS1] or Small Front End Loader) to triangulate the site. The KRC total site B20 $PM_{2.5}$ mean exposure concentration (GM) of 92.4 $\mu g/m^3$ (GSD = 1.86) was significantly less (two-tailed t-test, p=0.00) than the diesel $PM_{2.5}$ mean concentration (GM) of 233.3 $\mu g/m^3$ (GSD = 2.51). B20 fuel use resulted in a 60.4% reduction in the mean KRC total site $PM_{2.5}$ concentration. In this analysis and subsequent analyses for EC, OC, and NO_2, the two-tailed t-test p-value is reported at the 95% confidence level ($\alpha = 0.05$).

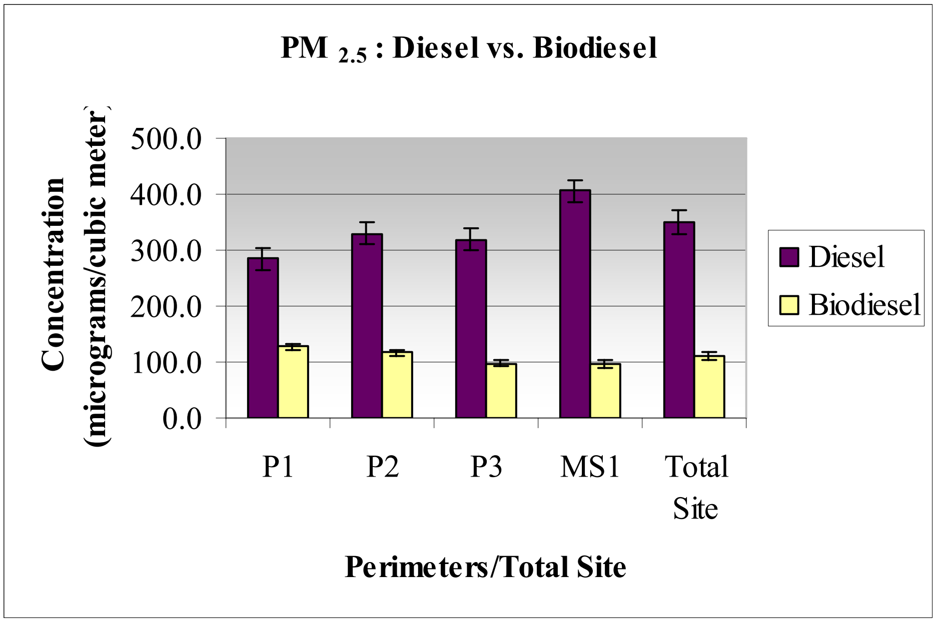


Figure 3.1: **Diesel vs. B20: Summary of $PM_{2.5}$ Concentrations at Each Perimeter Location and the Total KRC Site, reported in µg/m^3 (values shown are arithmetic mean ± standard error)**

PM $_{2.5}$	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Reduction
Diesel P1	10	285.1	70.16	213.90	2.25	50.58%
Biodiesel P1	7	128.0	37.19	105.70	1.87	
Diesel P2	10	329.2	95.41	236.50	2.38	57.55%**
Biodiesel P2	7	116.4	22.24	100.40	1.91	
Diesel P3	9	319.1	82.05	199.60	3.40	53.91%
Biodiesel P3	5	97.9	17.19	92.00	1.49	
Diesel P4 (MS1)	6	406.2	90.99	333.10	2.18	77.57%***
Biodiesel P4	7	96.7	29.26	74.70	2.16	
Total Site Diesel	35	350.2 (mvue)	40.97	233.30	2.51	60.39%***
Total Site Biodiesel	26	110.9 (mvue)	13.77	92.40	1.86	

Table 3.1: Diesel vs. B20: Summary of PM$_{2.5}$ Concentrations at Each Perimeter Location and the Total KRC Site, reported in µg/m^3 (Note: AM= simple arithmetic mean; SE= standard error; GM= geometric mean; GSD= geometric standard deviation; MVUE= arithmetic mean by minimum variance unbiased estimate method; ** $p < 0.05$; *** $p < 0.01$))

A boxplot of the KRC total site data (or combined P1, P2, P3 and P4/MS1 data) shown in Figure 3.2 illustrates the spread in PM$_{2.5}$ levels measured during diesel and B20 fuel use. PM$_{2.5}$ levels during diesel use ranged from a minimum of 28.5 µg/m^3 to a maximum of 1099.1 µg/m^3, with a median value of 285.3 µg/m^3. Half of the data or 50% of the data fell within the 115.5 µg/m^{3}and 493.3 µg/m^3 bracket of the first and third quartile. Diesel results showed wide variability which is likely caused by the transition impact of the first B20 delivery happening on 7/18/06 before the end of the final diesel sampling week. B20 results had less spread in the data, ranging from a low of 30.1 µg/m^3 to a high of 336.4 µg/m^3, with a median of 94.0 µg/m^3. For B20, 50% of the PM$_{2.5}$ data were between 62.5 µg/m^3 and 144.3 µg/m^3.

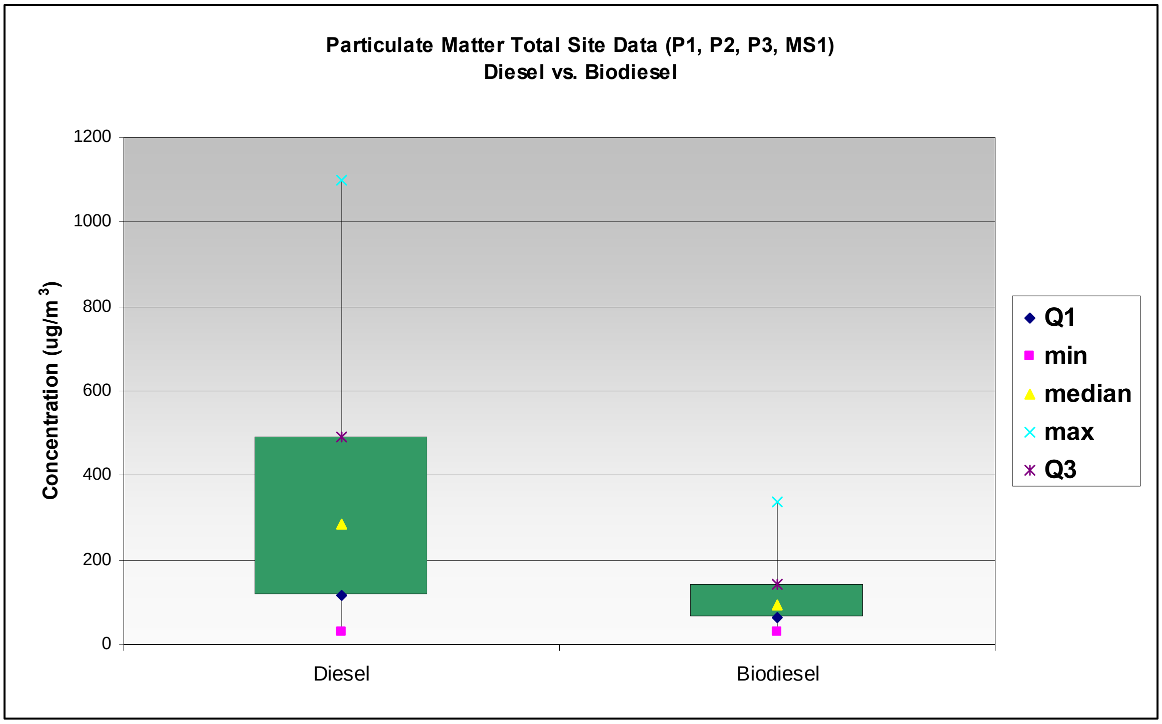


Figure 3.2: Diesel vs. B20: Boxplot Summary of Total Site Concentrations for PM$_{2.5}$, reported in µg/m^3

. When the "transition" days (the days immediately following the first B20 delivery to the KRC) are completely removed from the PM$_{2.5}$ sample set, the KRC total site mean for 100% diesel was 341 µg/m^3 (GSD= 2.2) compared to a B20 concentration of 92.4 µg/m^3 (GSD=1.86), a reduction in PM$_{2.5}$ of 72.9%. This KRC total site mean B20 PM$_{2.5}$ concentration was significantly lower than the mean diesel PM$_{2.5}$ concentration (p= 0.00).

PM $_{2.5}$ - No transition days	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Decrease
Diesel	23	439.57	47.41	340.97	2.2	72.89%****
Biodiesel	26	110.64	13.88	92.43	1.86	

Table 3.2: Diesel vs. B20: Summary of Total KRC Site PM$_{2.5}$ Concentrations Excluding All Transition Days, reported in µg/m^3 (****p<0.001)

3.1.2.b Impact of B20 Compared to EPA Particulate Matter NAAQS

B20 use at the KRC site brought the local air quality under the recently lowered National Ambient Air Quality Standard of 35 $\mu g/m^3$ (for a 24 hour $PM_{2.5}$ average). To better understand the impact of 20% biodiesel on $PM_{2.5}$ at each monitoring location, and the relationship to the NAAQS, please refer to the graph in Figure 3.3. The daily shift time weighted average value was used to calculate the 24 hour exposure level at each monitoring location (P1, P2, P3 and P4/MS1), with the remaining 16+ hours estimated from data collected from the nearest New Hampshire Department of Environmental Services $PM_{2.5}$ monitoring site. The background data was averaged into the work shift data to determine a 24 hour average, which could then be compared against EPA's National Ambient Air Quality Standard for $PM_{2.5}$, recently lowered to 35 $\mu g/m^3$. Figure 3.3 shows 24 hour average $PM_{2.5}$ levels exceeded the new NAAQS levels during diesel use, but 24 hour average $PM_{2.5}$ levels were less than or at the 35 $\mu g/m^3$ threshold during B20 operation. These results indicate B20 use can assist in helping local areas meeting local air quality standards for $PM_{2.5}$.

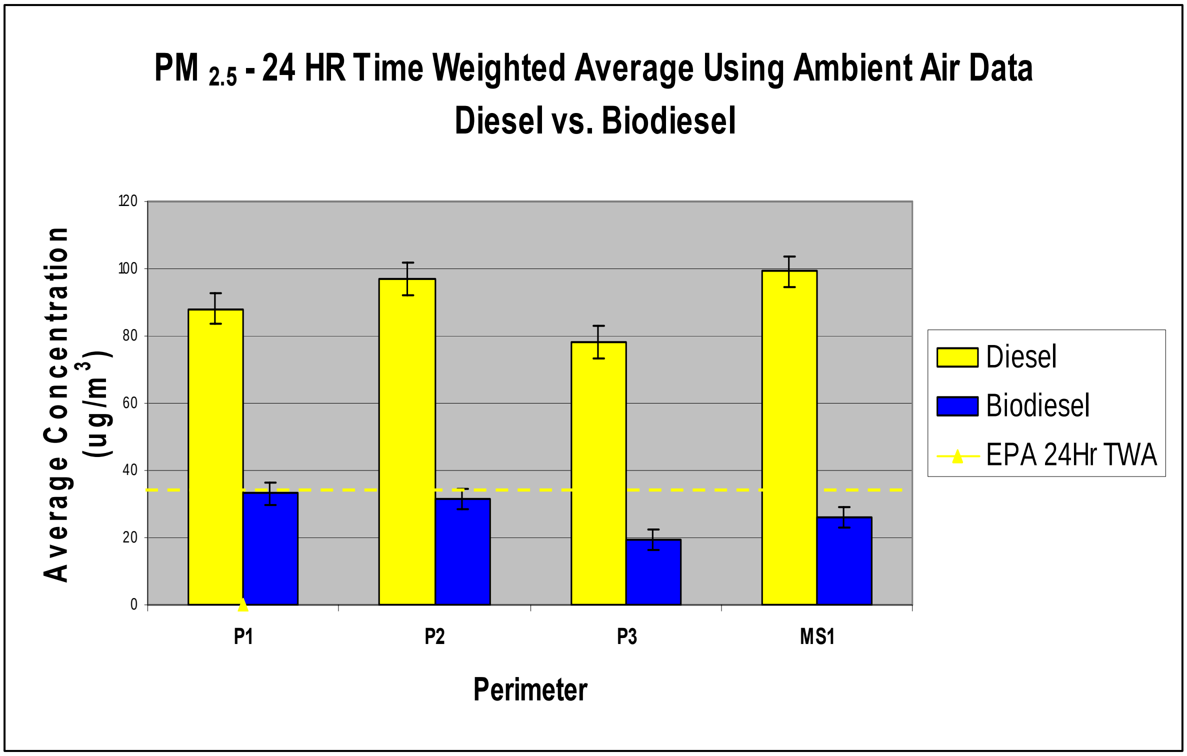


Figure 3.3: Diesel vs. B20: Comparison of $PM_{2.5}$ Perimeter Mean Concentrations to NAAQS, reported in µg/m^3 (arithmetic mean ± standard error)

3.1.2.c Review of the impact of activity levels and other variables at the Keene Recycling Center

As discussed in Chapter 2: Methods, one of the major confounding variables that must be addressed is the activity level of equipment during each sampling day. The data (categorized by fuel type) presented thus far is averaged across all sampling days, regardless of activity levels. While operational activities at the KRC were reasonably consistent on a week to week basis, and no unusual operating events occurred during our research period, activity levels did vary on an hourly and daily basis depending on work loads. This presented an important analytic challenge: if the number of activity events during biodiesel monitoring days were consistently less than activity events during diesel days, then perhaps the reported reductions in $PM_{2.5}$ could be attributed to lower activity levels. As described in

Chapter 2: Methods and detailed in Treadwell et al. (2008), KSC students kept detailed activity logs for perimeter locations P2, P3, and MS1 (in-cab for the small front loader). Using digital clocks to mark the time, students logged activity at each location at 20 minute intervals, documenting the identity of any equipment operating near the monitoring location, the intensity of that activity (i.e., idling, lifting, moving with load), and the approximate distance of the operating equipment from the monitors.

KSC researchers and students compiled all activity logs, reviewed them and developed a decision matrix using the number and intensity of **activity events** recorded in the student logs to categorize days by similar activity levels. The decision matrix used is summarized in Table 3.3:

<table>
<tr><th colspan="5">ACTIVITY EVENT CATEGORIZATION SCHEME</th></tr>
<tr><td></td><th colspan="4">Activity Event Definition</th></tr>
<tr><th>High Activity Event</th><td>Lifting/Digging</td><td colspan="2">Moving without Load</td><td>Moving with Load</td></tr>
<tr><th>Low Activity Event</th><td>Vehicle at Standard Idle</td><td colspan="2"></td><td></td></tr>
<tr><th colspan="5">Activity Day Categorization Scheme</th></tr>
<tr><td></td><th colspan="2"># of High Activity Events</th><th colspan="2"># of Low Activity Events</th></tr>
<tr><th>High Activity Day</th><td colspan="2">≥ 7</td><td colspan="2">≥ 10</td></tr>
<tr><th>Medium Activity Day</th><td colspan="2">4-6</td><td colspan="2">5-9</td></tr>
<tr><th>Low Activity Day</th><td colspan="2">≤ 3</td><td colspan="2">≤ 4</td></tr>
<tr><th colspan="5">Examples:</th></tr>
<tr><td colspan="5">-A notation of “lifting/digging” would be categorized as a “High Activity Event”</td></tr>
<tr><td colspan="5">-Equipment documented at standard idle would be categorized as a “Low Activity Event”</td></tr>
<tr><td colspan="5">-The number of events per day is totaled and each day is categorized</td></tr>
</table>

Table 3.3: Activity Event and Activity Day Categorization Scheme

While other potentially confounding variables besides activity (including temperature, humidity, outside vehicle traffic counts) were recorded by KSC students in this study, subsequent analysis of these variables (including time series analysis and *t* tests) indicated that only temperature was significantly different between diesel and biodiesel monitoring days. In other words, relative humidity and outside vehicle counts were not significantly different between diesel sampling and B20 sampling days, and therefore were removed as confounding variables in subsequent analyses. The evaluation of temperature, relative humidity and outside traffic is reported later in this chapter.

Based on the above decision table, $PM_{2.5}$ data for high activity days per fuel type were identified, tabulated and analyzed separately. The KRC total site mean $PM_{2.5}$ concentration was 239.6 µg/m^3 (GSD=2.61) for ***petroleum – high activity days*** compared to 118.5 µg/m^3 (GSD=1.53) for ***B20 – high activity days.*** This is equivalent to a 50.5% decrease in site $PM_{2.5}$ levels during B20 use (p=0.0095). Figure 3.4 graphically presents the arithmetic mean data comparison from Tables 3.2 (diesel vs. B20: no transition days) and 3.4 (diesel vs. B20: high activity days only). In both analyses, B20 use resulted in consistent reductions in $PM_{2.5.}$

PM- High Activity Days	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Decrease
Diesel	19	367.58	63.59	239.6	2.61	50.53%***
Biodiesel	12	128.54	15.97	118.5	1.53	

Table 3.4: Diesel vs. B20: Summary of Total KRC Site PM $_{2.5}$ Concentrations for Similar High Activity Days, reported in µg/m^3 (*p<0.01)**

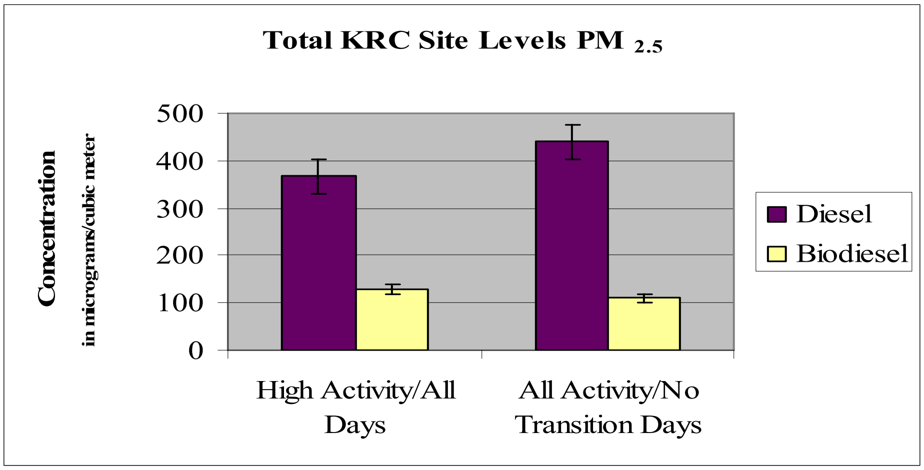


Figure 3.4: Diesel vs. B20: Comparison of Total KRC Site High Activity Day's PM$_{2.5}$ and Total KRC Site Excluding Transition Day's PM$_{2.5}$ Concentrations, reported in µg/m^3 (AM±SE)

Further excluding "transition" days from the "high activity" data analysis, the KRC total site mean B20 PM$_{2.5}$ concentration (GM= 118.5 µg/m^3) for "high activity" days was 74.6% less compared to 100% petroleum diesel (GM= 453 µg/m^3), a reduction found to be highly statistically significant (p=0.00)

A snapshot of two high activity diesel days compared to two high activity B20 days illustrates the dramatic decrease in PM$_{2.5}$ levels resulting from B20 use. It should be noted these reductions were seen almost immediately after introduction of the B20 fuel.

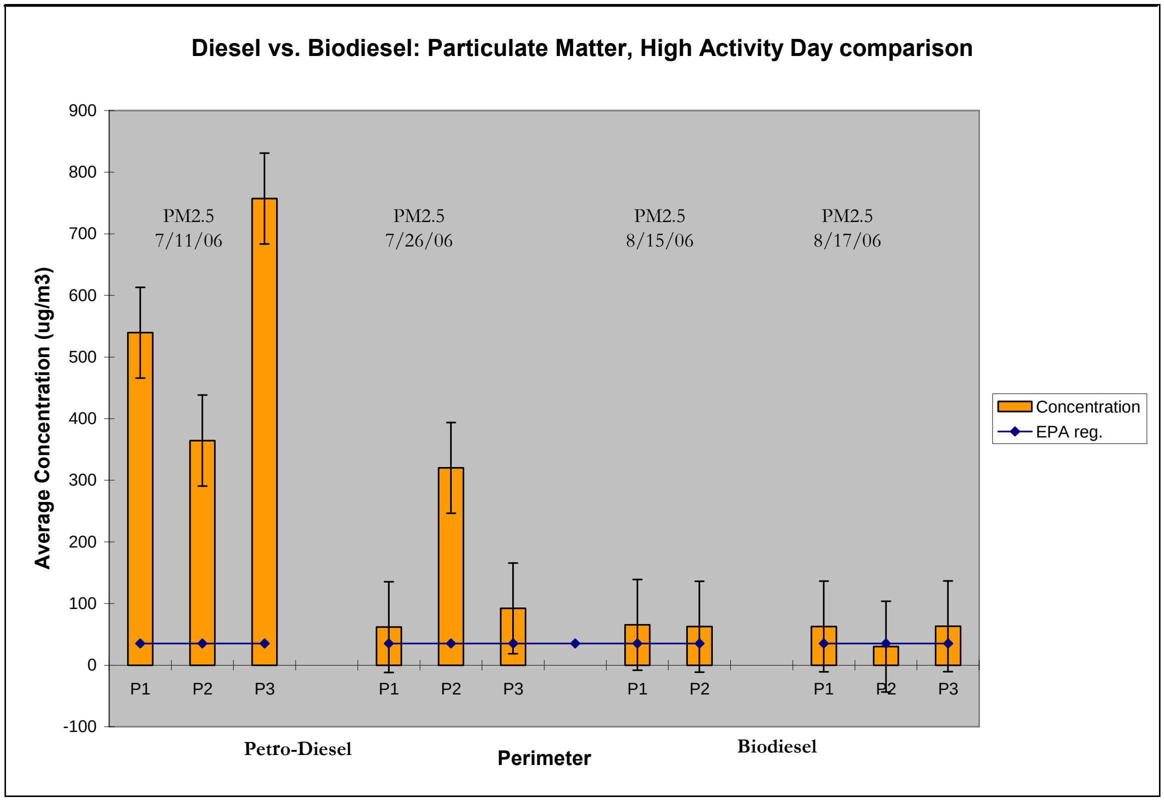


Figure 3.5: <u>Diesel vs. B20: Comparison of PM $_{2.5}$ Levels for Similar High Activity Days, reported in µg/m^3 (AM±SE)</u>

3.1.2.d Effect of "Transition Fuel Days" on PM$_{2.5}$

There was a transition fuel period the week of July 24, 2006, but the effect of biodiesel on PM$_{2.5}$ during this time was expected to be negligible. To our knowledge, neither the emissions nor exposures of low level biodiesel blends (as fuels are transitioned in a fleet) have been compared or studied. One of the challenges of applied research projects is that we must sample during real world conditions: in this case the fuel was delivered later than expected and we could not reschedule staff to sample at a later date in the summer. Therefore the dates of July 24 – 27 were a low blend of biodiesel (approximately B10 or less) in each equipment tank. These transition days were grouped with the diesel data set for KRC total site mean calculations instead of with the biodiesel days because 1) the fuel was predominately diesel, and 2) it is a more conservative assumption as it would require even more substantial reductions in particulate matter during the biodiesel days for the differences to be statistically significant.

An unexpected result of this study was the immediate impact even small percentages of biodiesel made on the $PM_{2.5}$ concentrations measured at the KRC. There was a significant reduction in $PM_{2.5}$ levels at the KRC during the "transition" time period almost as soon as the first shipment of B20 occurred and was started to be used by the fleet. To verify this, I analyzed the diesel days before the first B20 shipment and compared them against results from those "transition days" or the few days immediately following the first B20 shipment. A comparison of this subgroup of petroleum diesel days (90% or higher percentage diesel, called "transition days") against the 100% petroleum diesel sampling days resulted in a mean (GM) $PM_{2.5}$ concentration of 102.5 $\mu g/m^3$ (GSD=2.17) for "transition days" compared to a GM of 379.3 $\mu g/m^3$ (GSD =1.82) for 100% petroleum days. A two tailed t test assuming unequal variances was performed and found that this difference was highly statistically significant (p=0.00). In summary, even low levels of biodiesel (< 10%) appear to have an immediate and significant impact reducing $PM_{2.5}$ concentrations from nonroad engine sources.

3.1.2.e Elemental Carbon/Organic Carbon

Elemental carbon is the solid carbonaceous core component of particulate matter, and is the most widely used measure of diesel particulate matter in exposure assessments (HEI 2002). Since diesel combustion emits higher levels of EC compared to other sources, EC is considered a surrogate measure for diesel exposure. KRC elemental carbon concentrations were consistently decreased at P1, P2, P3, and MS1 during B20 use at the site.

The mean EC level (reported as GM) for the total KRC site during petroleum use was 6.2 μg/m^3 (GSD=1.42) while the mean total KRC site EC concentration during B20 fuel use was 4.8 μg/m^3 (GSD=1.42). To determine if this reduction in elemental carbon was statistically significant, a two sample t test assuming unequal variances was performed on logtransformed data. B20 use resulted in an average overall reduction of 22.4% in EC levels at the KRC site (p=0.014).

Elemental Carbon	N Value	AM (μg/m^3)	SE	GM (μg/m^3)	GSD	Percent Reduction
Diesel P1	10	6.8	0.96	6.14	1.60	5.86%
Biodiesel P1	6	6.2	1.20	5.78	1.47	
Diesel P2	9	6.7	0.47	6.60	1.22	29.24%
Biodiesel P2	6	4.9	0.67	4.67	1.41	
Diesel P3	2	4.3	0.30	4.29	1.14	7.69%
Biodiesel P3	4	4.1	0.49	3.96	1.28	
Diesel MS1	8	6.8	0.84	6.46	1.42	26.16%
Biodiesel MS1	6	5.1	0.93	4.77	1.46	
Total Site Diesel	29	6.6 (mvue)	0.43	6.22	1.42	22.35%**
Total Site Biodiesel	22	5.1 (mvue)	0.46	4.83	1.42	

Table 3.5: Diesel vs. B20: Summary of Elemental Carbon Concentrations at Each Perimeter Location and the Total KRC Site, reported in μg/m^3 (p<0.05)**

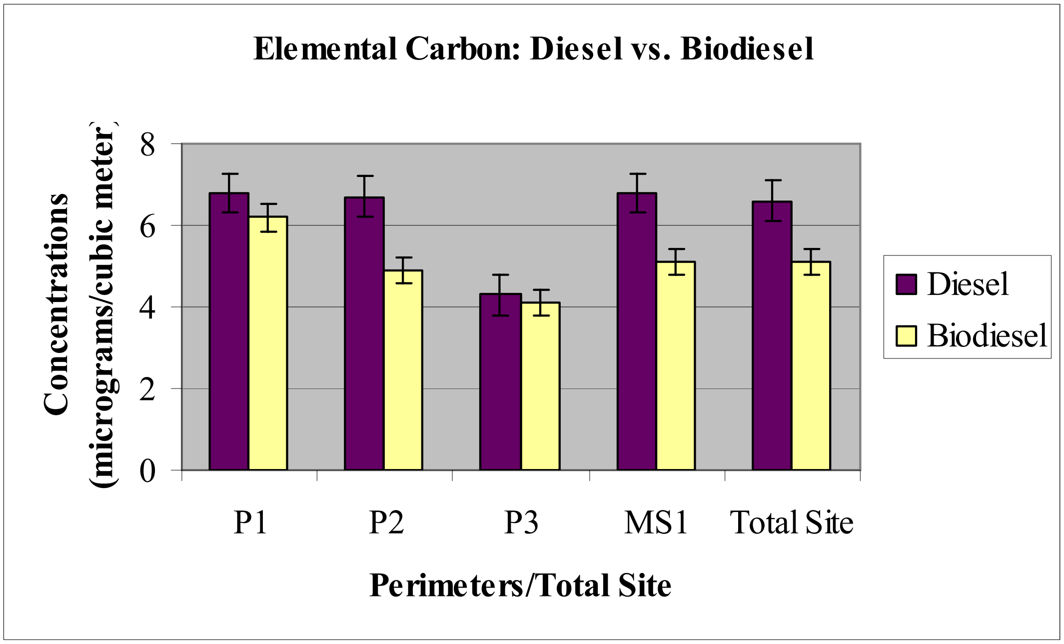


Figure 3.6: **Diesel vs. B20: Summary of EC Concentrations at Each Perimeter Location and the Total KRC Site, reported in μg/m^3 (AM±SE)**

A boxplot of the KRC total site EC data for diesel and B20 use is shown in Figure 3.7 below. EC levels during diesel use ranged from a minimum of 3.2 μg/m^3 to a maximum of 12.0 μg/m^3 with a median value of 6.2 μg/m^3. Half of the data was located between the first quartile (4.7 μg/m^3) and the third quartile (8.3 μg/m^3). B20 EC levels ranged from a minimum of 2.9 μg/m^3 to a maximum of 12.0 μg/m^3 with a median of 4.7 μg/m^3. Half the data was located between the first quartile (3.9 μg/m^3) and the third quartile (5.5 μg/m^3). Similar to the PM$_{2.5}$ results, the boxplot of EC during diesel use showed more variability likely due to the impact of the "transition days."

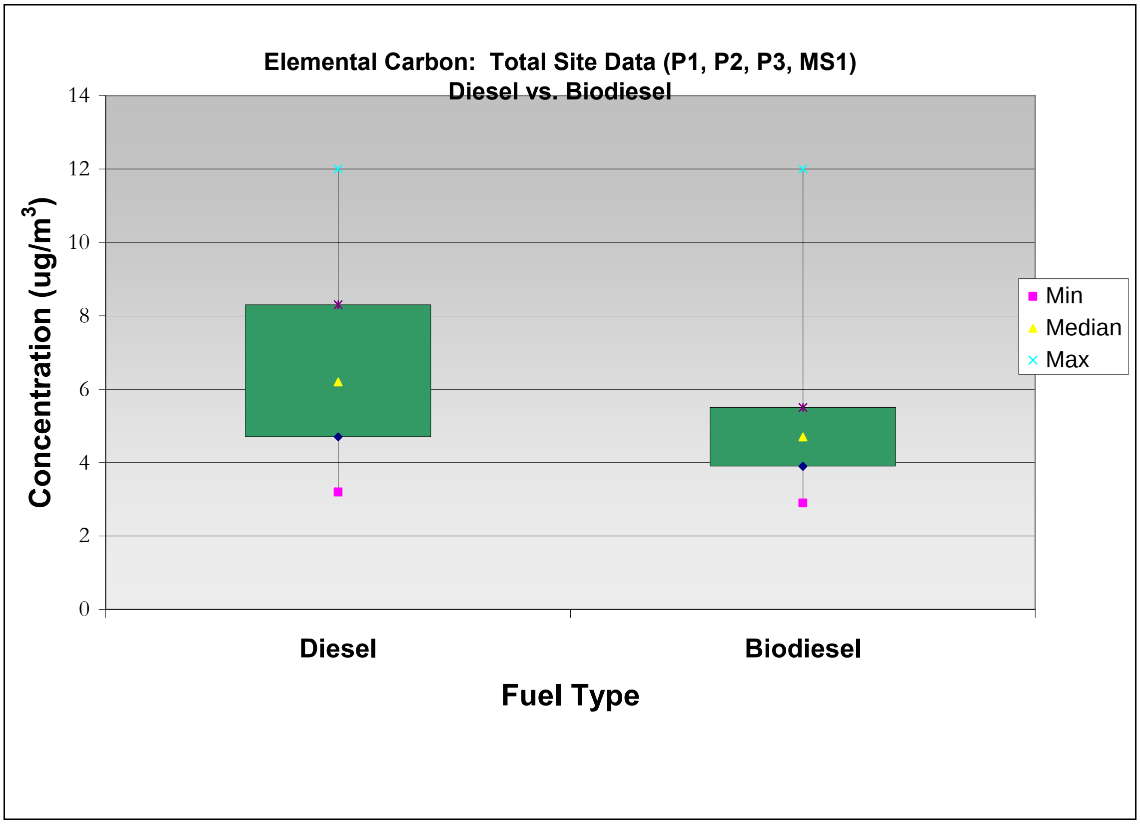


Figure 3.7: **Diesel vs. B20: Boxplot Summary of Total KRC Site Concentrations for EC, reported in μg/m^3**

The two sample t test with unequal variance was repeated for the KRC total site EC levels (the combined P1, P2, P3, P4/MS1 data) determined during ***high activity*** days. For ***high activity- diesel*** days, the mean KRC total site elemental carbon level was 7.4 μg/m^3 (GSD=1.31) and the mean EC concentration was 5.5 μg/m^3 (GSD= 1.49) for ***high activity-B20*** days. Therefore, comparing similar days of high activity, B20 use resulted in a 25.6% reduction in EC concentration at the KRC site. This EC reduction was considered statistically significant (p=0.039).

EC HIGH ACTIVITY	N VALUE	AM (μG/M^3)	SE	GM (μG/M^3)	GSD	PERCENT DECREASE
Diesel	16	7.64	0.53	7.4	1.31	25.6%**
Biodiesel	12	5.93	0.75	5.5	1.49	

Table 3.6: Diesel vs. B20: Summary of Total KRC Site EC Concentrations for Similar High Activity Days, reported in µg/m^3 (p<0.05)**

When "transition" days were removed from the diesel data sample, the mean KRC total site EC level was 5.8 µg/m^3 (GSD= 1.41) during diesel days and 4.8 µg/m^3 (GSD=1.42) during B20 use. EC levels were reduced during B20 use, yet the calculated 19.9% reduction in EC levels was not considered statistically significant (p=0.10). Figure 3.8 presents the arithmetic mean comparison for total KRC site EC levels (diesel vs. B20) measured during high activity and during "transition" fuel days.

EC-No Transition Days	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Decrease
Diesel	19	6.14	0.52	5.79	1.41	19.88%
Biodiesel	22	5.15	0.46	4.83	1.42	

Table 3.7: Diesel vs. B20: Summary of Total KRC Site EC Concentrations Excluding all Transition Days, reported in µg/m^3

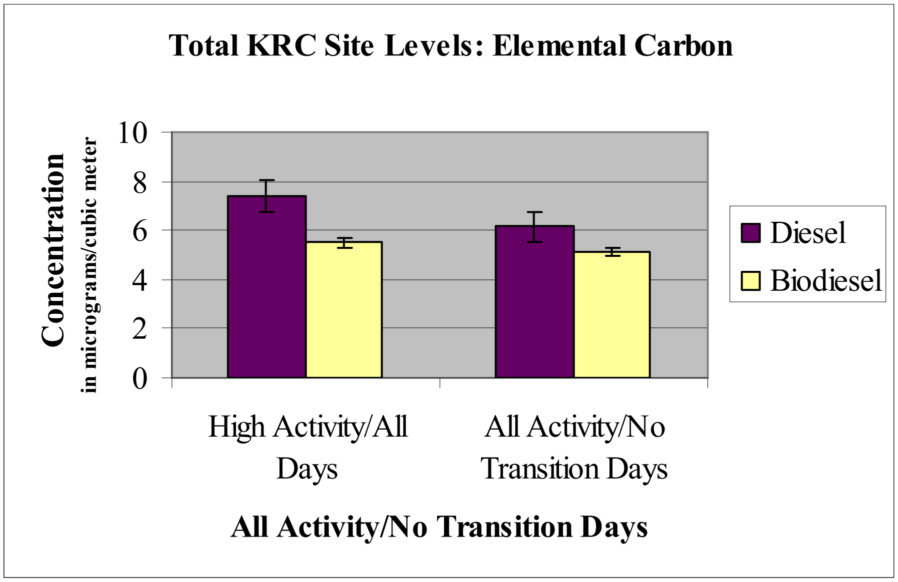


Figure 3.8: Diesel vs. B20: Comparison of Total KRC Site High Activity Day's and Total KRC Site Excluding Transition Days EC Concentrations, reported in µg/m^3 (AM±SE)

3.1.2.f Organic Carbon

Organic carbon results were consistently higher during B20 use days, as shown in Table 3.8 below. The mean KRC total site organic carbon level during petroleum diesel days was 5.7 µg/m^3 (GSD=2.43), compared to a mean organic carbon concentration of 27 µg/m^3 (GSD=2.11) during B20 fuel use. This equates to an increase in organic carbon concentration of 370.4% when B20 was burned. A two tailed t test indicated this increase was highly significant at the 95% confidence level (p= 0-00). The highest increase in measured organic carbon (472.4%) occurred in the indoor location of P2. The OC concentrations at each monitoring location and the KRC total site are shown in Figure 3.9.

Organic Carbon	N Value	AM ($\mu g/m^3$)	SE	GM ($\mu g/m^3$)	GSD	Percent Increase
Diesel P1	4	6.0	0.94	5.60	1.40	407.68%***
Biodiesel P1	6	28.8	2.24	28.43	1.20	
Diesel P2	4	5.0	0.79	5.15	1.34	472.43%***
Biodiesel P2	5	30.0	2.95	29.48	1.22	
Diesel P3	2	6.0	5.70	6.03	3.29	337.48%***
Biodiesel P3	6	26.5	1.15	26.38	1.10	
Diesel MS1	5	6.0	0.90	6.25	1.40	296.48%***
Biodiesel MS1	7	27.2	3.56	24.78	1.72	
Total Site Diesel	15	6.2 (mvue)	0.73	5.74	2.43	370.38%***
Total Site Biodiesel	24	28.3 (mvue)	1.30	27.00	2.11	

Table 3.8: <u>Diesel vs. B20: Summary of OC Concentrations at Each Perimeter Location and the Total KRC Site, reported in $\mu g/m^3$ ($p<0.01$)</u>

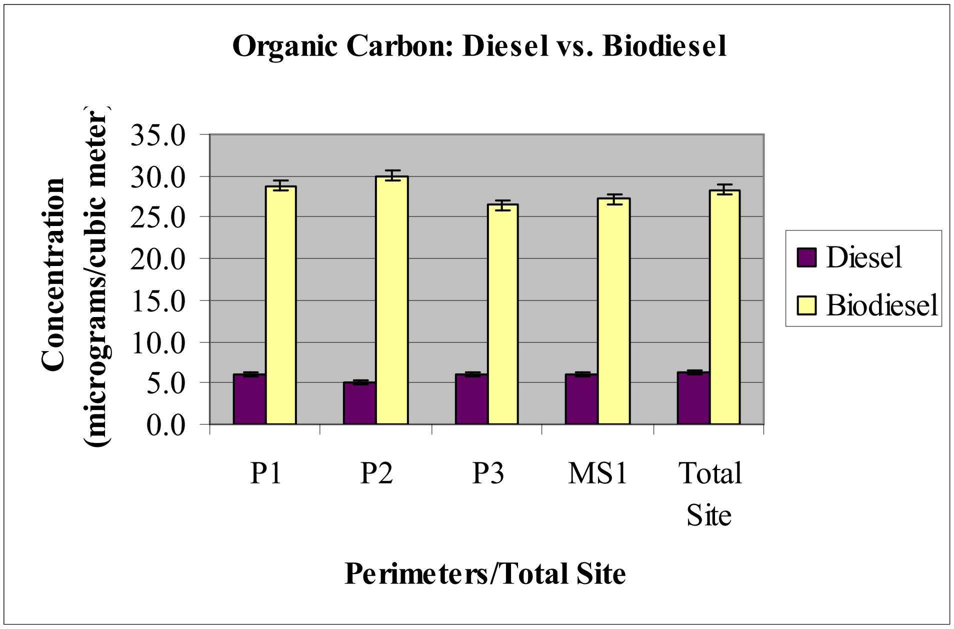


Figure 3.9: <u>Diesel vs. B20: Summary of OC Concentrations at Each Perimeter Location and the Total KRC Site, reported in $\mu g/m^3$ (AM±SE)</u>

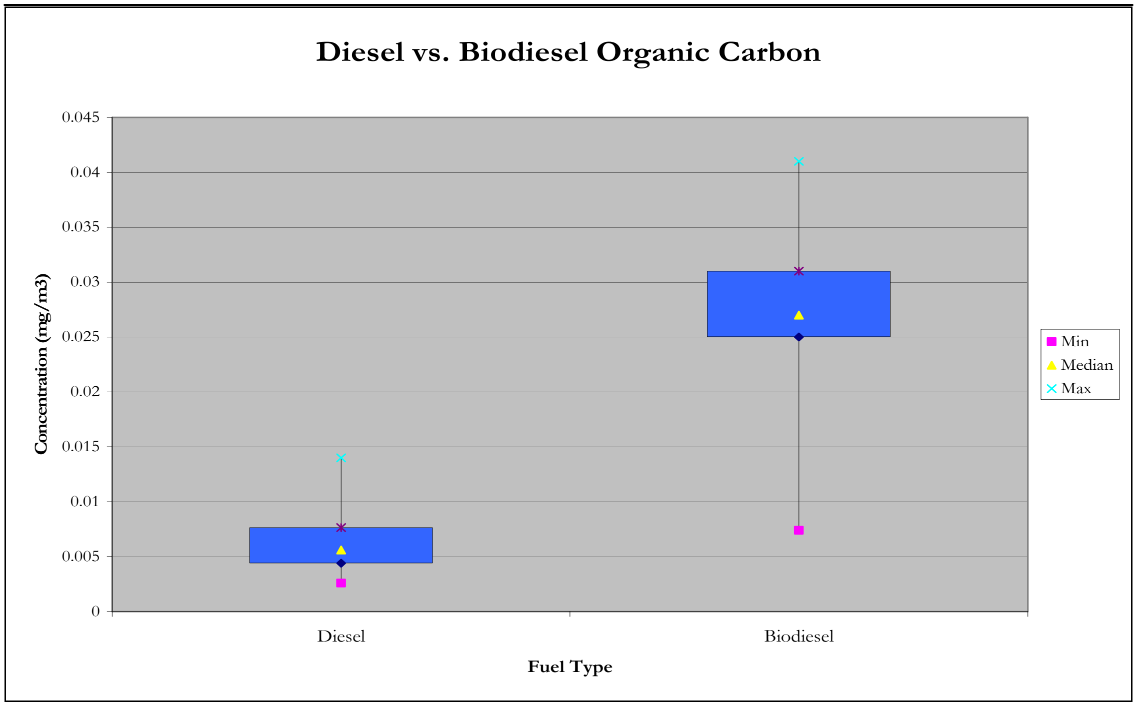


Figure 3.10: <u>Diesel vs. B20: Boxplot Summary of Total KRC Site Concentrations for OC, reported in µg/m^3</u>

A boxplot of the KRC total site data is shown in Figure 4.10. OC levels during diesel use ranged from a minimum of 2.6 µg/m^3 to a maximum of 14 µg/m^3 and a median of 5.6 µg/m^3. Half of the data was located between the first quartile (4.4 µg/m^3) and the third quartile (7.7 µg/m^3). OC levels during B20 use ranged from a minimum of 7.4 µg/m^3 to a maximum of 41 µg/m^3 and a median of 27 µg/m^3. Half of the data was located between the first quartile (25 µg/m^3) and the third quartile (31 µg/m^3).

Finally, organic carbon concentrations for days of similar high activity were compared. The mean KRC total site organic carbon level for **high activity diesel days** was 5.89 µg/m^3 (GSD=1.62), and the mean **high activity B20** level was 26.2 µg/m^3 (GSD=1.51). As expected, measured organic carbon was significantly higher at the KRC site during B20 use during similar days of high activity (p=0-00). For consistency in analysis, a two tailed t test was performed when the transition dates were removed from the data analysis. Mean organic carbon levels during B20 use (24.76 µg/m^3 GSD=1.60) was significantly higher (p=0-00), compared to the mean for diesel at 5.2 µg/m^3 (GSD=1.42).

OC-High Activity	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Increase
Diesel	11	6.5	1.00	5.89	1.62	344.82%***
Biodiesel	13	27.8	2.20	26.2	1.51	

Table 3.9: Diesel vs. B20: Summary of Total KRC Site OC Concentrations for Similar High Activity Days, reported in µg/m^3(***p<0.01)

OC- No Transition Days	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Increase
Diesel	10	5.48	0.55	5.2	1.42	376.15%***
Biodiesel	24	28.01	1.30	24.76	1.6	

Table 3.10: Diesel vs. B20: Summary of Total KRC Site OC Concentrations Excluding All Transition Days, reported in µg/m^3 (***p<0.01)

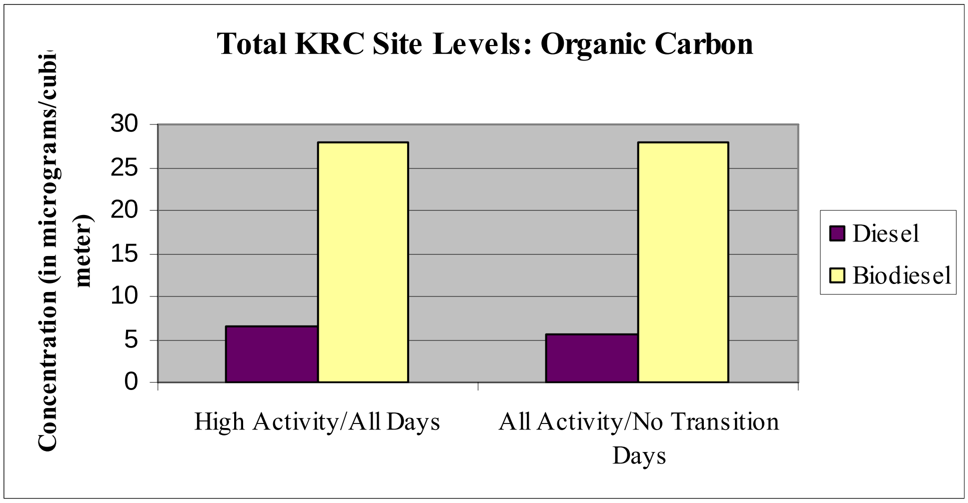


Figure 3.11: Diesel vs. B20: Comparison of Total KRC Site High Activity Day's OC Concentrations and Total KRC Site Excluding Transitions Day's OC Concentrations, reported in µg/m^3 (AM±SE)

3.1.2.g Nitrogen Dioxide Results

Nitrogen dioxide was measured as a surrogate for the broader category of NO_x, which is a concern in smog formation processes. Nitrogen dioxide was measured only at the P2 location. The data comparing petroleum and B20 results are summarized below. The average NO_2 concentration was 18.4 μg/m^3 (GSD=2.43)(n=12) during petroleum use and 21.8 μg/m^3 (GSD=2.11)(n=16) during B20 use. To summarize, use of B20 resulted in an increase of 18.5% in measured NO_2 levels as compared to petroleum diesel operation.

Nitrogen Dioxide	N Value	AM (μg/m^3)	SE	GM (μg/m^3)	GSD	Percent Increase
Diesel P2	12	25.2	5.58	18.37	2.43	18.51%
Biodiesel P2	16	27.8	4.80	21.77	2.11	

Table 3.11: Diesel vs. B20: Summary of NO_2 Concentrations at Perimeter 2, reported in μg/m^3

To determine if this increase is statistically significant, a two tailed t test was performed assuming unequal variances on the logtransformed data. The difference in average NO_2 levels measured at P2 comparing B20 and petroleum diesel use days was not found to be significant at the 95% confidence level (p=0.49).

A boxplot of the NO_2 data measured at P2 during B20 and petroleum diesel use is shown in Figure 4.12. The boxplot shows the variation in the data spread to be similar between both fuel types.

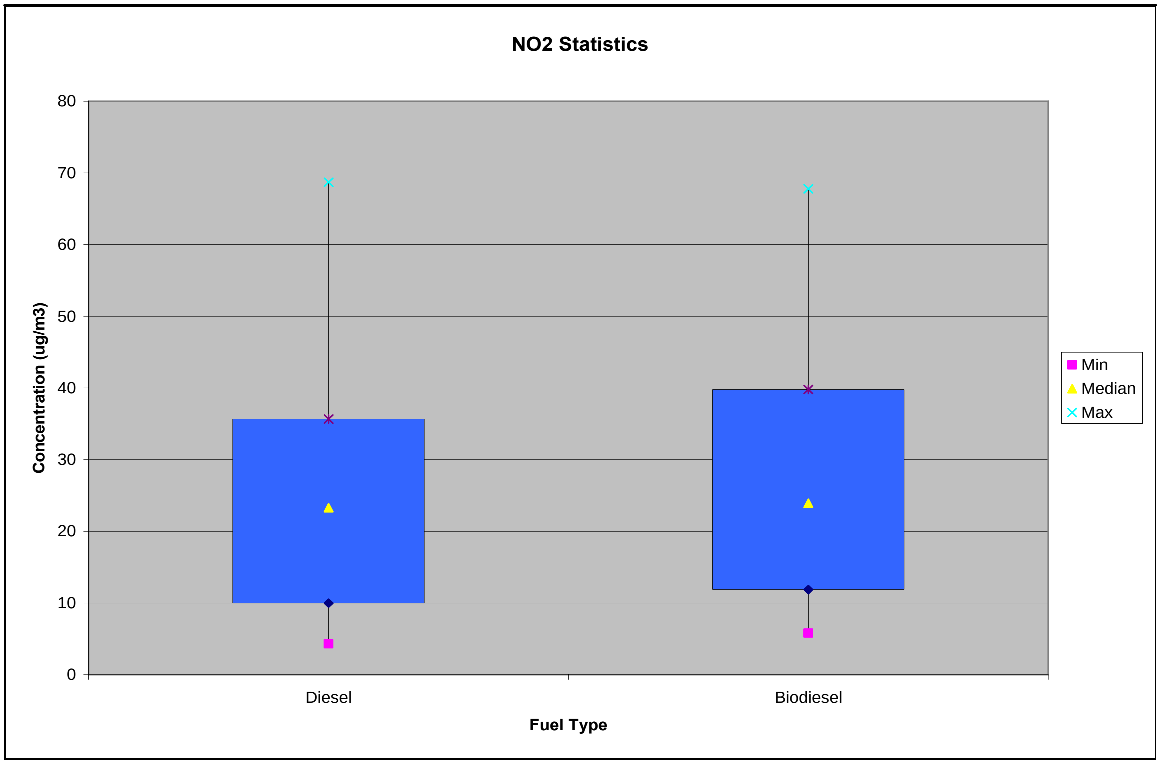


Figure 3.12: **Diesel vs. B20: Boxplot Summary of NO_2 Concentrations at Perimeter 2, reported in µg/m^3**

Nitrogen dioxide levels during diesel use ranged from a minimum of 4.3 µg/m^3 to a maximum of 68.7 µg/m^3 and a median of 23.3 µg/m^3. Half of the data was located between the first quartile (9.97 µg/m^3) and the third quartile (35.66 µg/m^3). Nitrogen dioxide levels during B20 use ranged from a minimum of 5.8 µg/m^3 to a maximum of 67.8 µg/m^3 and a median of 23.9 µg/m^3. Half of the data was located between the first quartile (11.9 µg/m^3) and the third quartile (39.8 µg/m^3).

However, activity, time and temperature can be confounding variables influencing NO_2 levels. (Outside vehicle traffic can also be a confounder; however, as discussed earlier, there was not significant difference in outside vehicle traffic between the different fuel days, so this factor was removed from further analysis). Activity, as mentioned above, will influence the level and composition of both petroleum and biodiesel exhaust emissions.

Time is a factor in NO_2 levels because of atmospheric chemistry. NO_2 will disassociate in sunlight as the day proceeds, but it will also be formed during free radical chemical reactions, such as the reaction of OH* radical with nitric oxide (NO). Temperature can facilitate smog formation reactions, with warmer temperatures resulting in conversion from NO to NO_2 as ozone is generated. Therefore, there can be a waxing or waning of NO_2 levels. These atmospheric chemical reactions are discussed further in the next chapter, discussion. Additionally, due to the indoor location of P2 and lack of ventilation controls, there also may be a buildup over time of NO_2 and/or NO. It should be noted that reaction chemistry and accumulation of NO and/or NO_2 would be random processes, with random variation, but such processes could be influenced by high activity, time of day, and temperature. As a consequence, further analysis of the concentration data specifically focusing on these variables is warranted and is performed next.

NO_2- High Activity	**N Value**	**AM (µg/m^3)**	**SE**	**GM (µg/m^3)**	**GSD**	**Percent Increase**
Diesel P2	5	22.76	6.58	17.96	2.33	65.59%
Biodiesel P2	7	34.86	7.48	29.74	1.89	

Table 3.12: <u>Diesel vs. B20: Summary of NO_2 Concentrations at Perimeter 2 for Similar High Activity Days, reported in µg/m^3 (Excluding Transition Days)</u>

The impact of activity on NO_2 levels was analyzed next. The mean NO_2 level during the 5 diesel high activity dates was 18.0 µg/m^3 (GSD=2.33), and the mean concentration during the 4 biodiesel high activity dates was 29.7 µg/m^3 (GSD=1.9). Use of B20 resulted in an increase in NO_2 of 65.6% during days of similar high activity. To evaluate whether this increase is statistically significant, a two tailed t test was performed on logtransformed data. In summary, use of B20 did <u>not</u> result in a statistically significant increase in NO_2 ($p=0.806$). Only high activity days were examined because these made up the bulk of the sample set.

Low activity days had only an n=3 (diesel) and n=4 (biodiesel) and medium activity days an n= 2(diesel) and n=1 (biodiesel) so statistical analysis was not performed on these activity days.

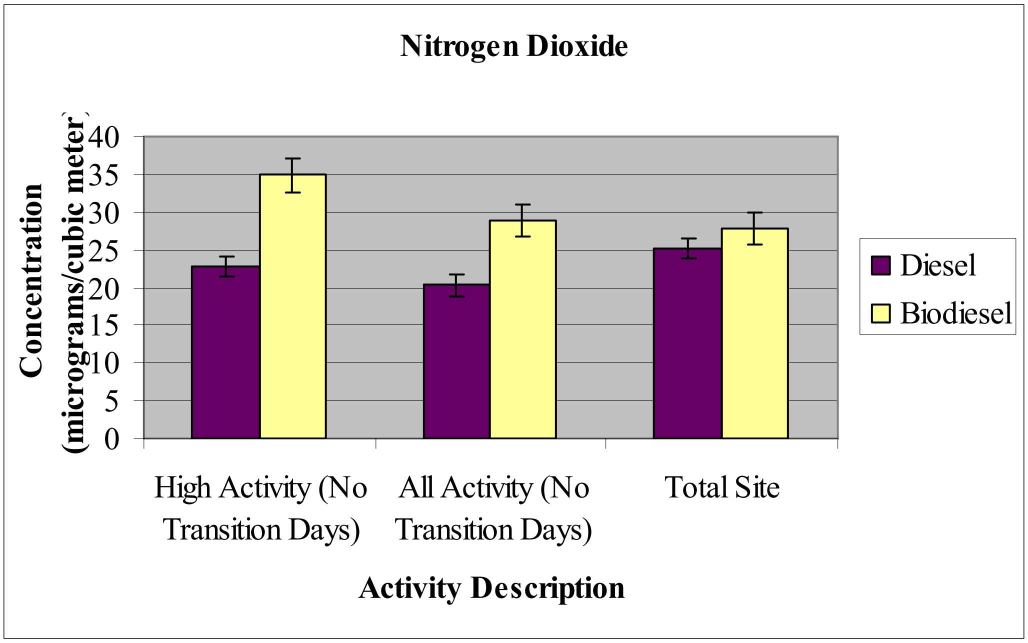


Figure 3.13: <u>Diesel vs. B20: Summary of NO_2 Concentrations at Perimeter 2 For Similar High Activity Days, and All Activity Days Excluding Transition Days, and KRC Total Site (Perimeter 2), reported in µg/m^3 (AM±SE)</u>

The influence of time was next examined by comparing AM (morning) vs. PM (afternoon) collected samples. First, the AM vs. PM samples were compared **<u>within</u>** each fuel type to evaluate whether a difference was noted between AM and PM concentrations for the same fuel. Although the boxplots appear to show a dramatic increase in concentration in the afternoon samples during both diesel and B20 use, this increase was not considered statistically significant. This is likely due to the wide spread in the data and the low number of samples overall from combining high and low activity days for either the diesel or B20 use days. The mean diesel NO_2 level in the morning was 13.11 µg/m^3 (GSD=1.98)(n=7) and 29.5 µg/m^3 (GSD=2.72) in the afternoon (n=5). This difference in morning and afternoon levels was not considered statistically significant (p = 0.16). The mean biodiesel NO_2 AM concentration was 16.9 µg/m^3 (GSD=1.64)(n=7) and the PM/afternoon concentration was 26.5 µg/m^3 (GSD=2.4)(n=9). Again, this increase in afternoon NO_2 concentrations was not considered statistically significant (p= 0.21). Figure 3.14 shows the results for diesel AM vs. PM comparison and Figure 3.15 reports the concentrations for biodiesel AM vs. PM.

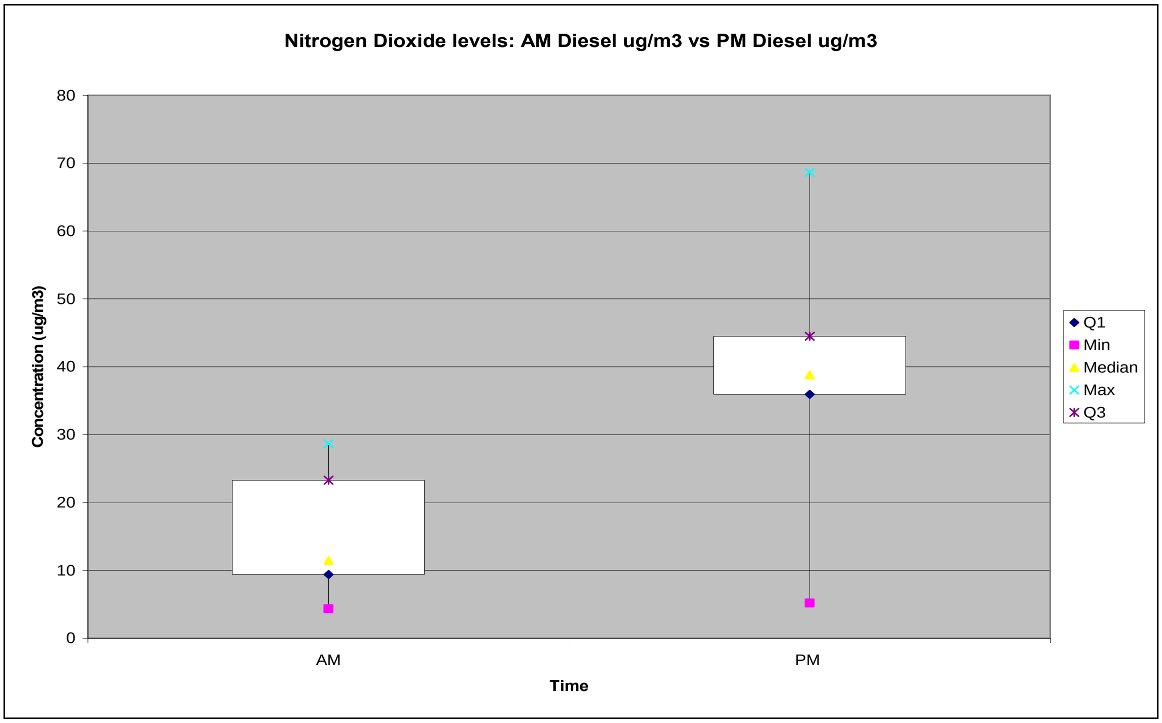


Figure 3.14: <u>Diesel am vs. Diesel pm: Boxplot Summary of NO_2 concentrations, reported in µg/m^3</u>

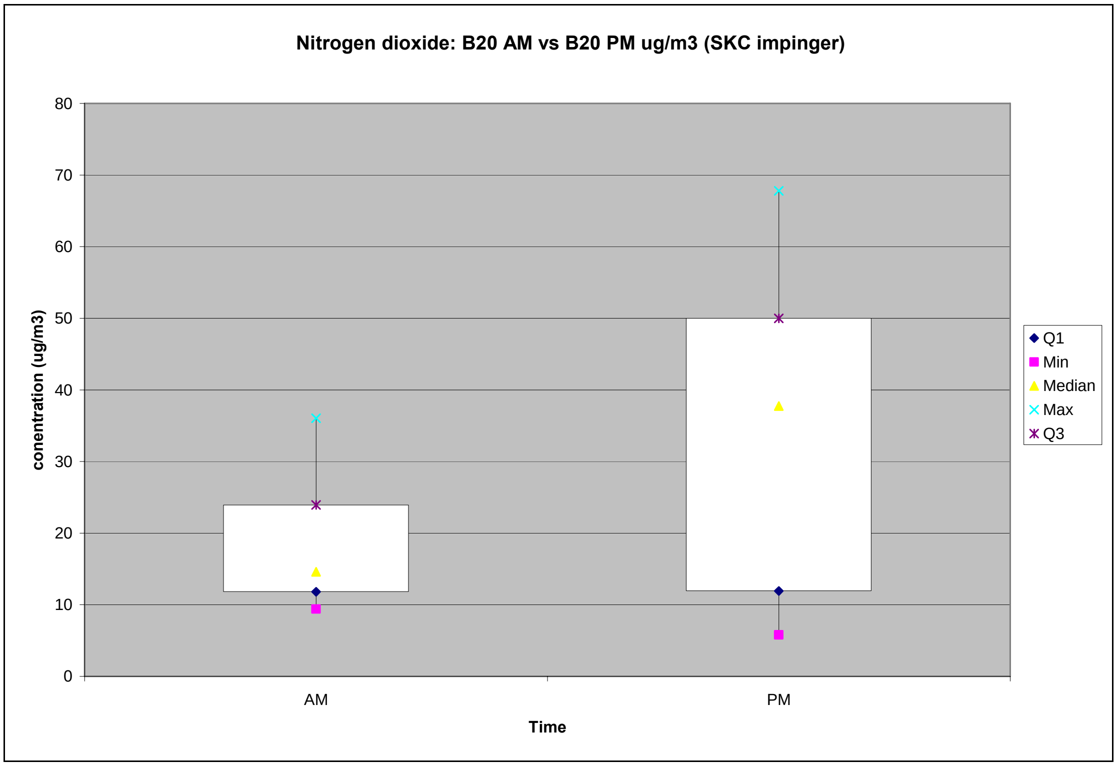


Figure 3.15: B20 am vs. B20 pm: Boxplot Summary of NO_2 Concentrations, reported in μg/m^3, (SKC)

The afternoon biodiesel boxplot does indicate a rather wide spread in the data compared to the AM boxplot. Further examination of the afternoon B20 values is necessary to ensure there was no systematic outside influence on the data to cause such variability. A few key possibilities emerge: the spread can be the result of pooling together the high and low activity days in order to have enough data to examine temporal effects, the spread can be due to the influence of atmospheric chemical processes, or the spread can be due to some combination of the two. However, it does appear there are a number of low NO_2 days in the afternoon B20 data set, indicating further activity analysis is warranted.

When the AM diesel data, mean 13.1 μg/m^3 (GSD=1.98)[(n=7)], is compared against AM biodiesel data, mean 16.97 μg/m^3 (GSD=1.64)[(n=7)], the difference between the fuels is not statistically significant (p=0.44). The mean PM diesel concentration of 29.5 µg/m^3 (GSD=2.72)(n=5) was also not statistically significant (p=0.85) from the afternoon B20 level of 26.5 µg/m^3 (GSD=2.4)(n=9).

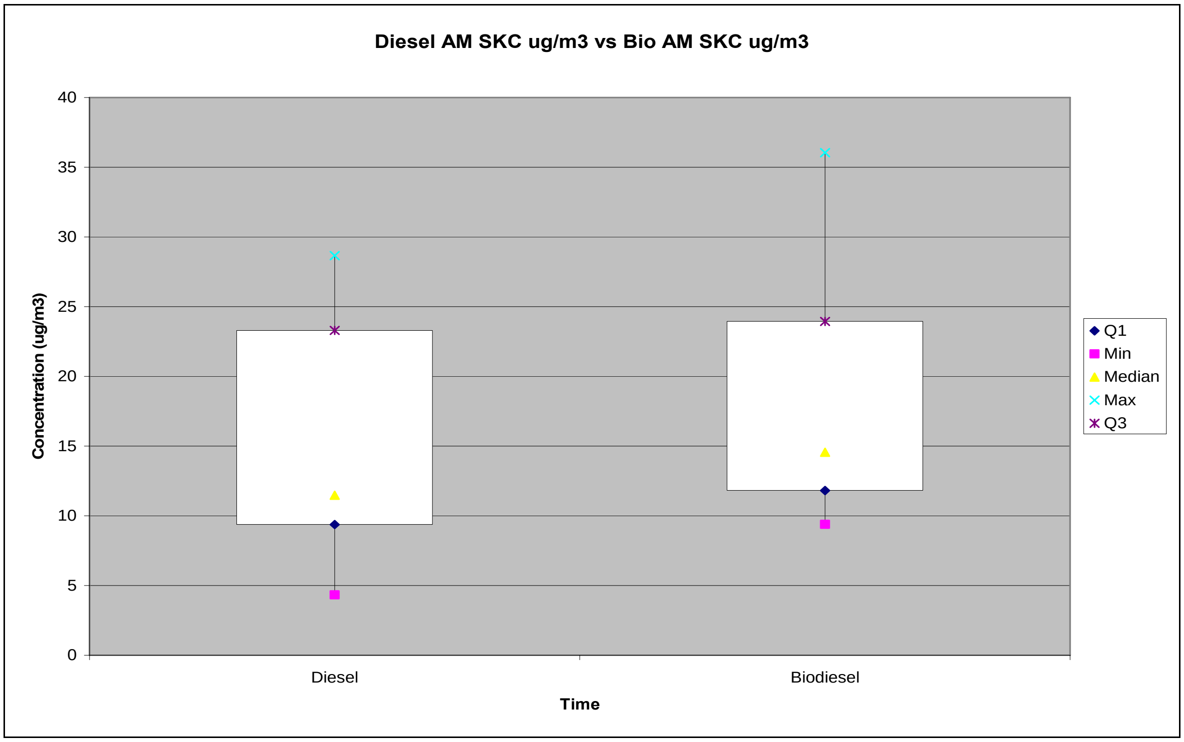


Figure 3.16: <u>Diesel am vs. B20 am: Boxplot Summary of NO_2 Concentrations, reported in µg/m^3 (SKC)</u>

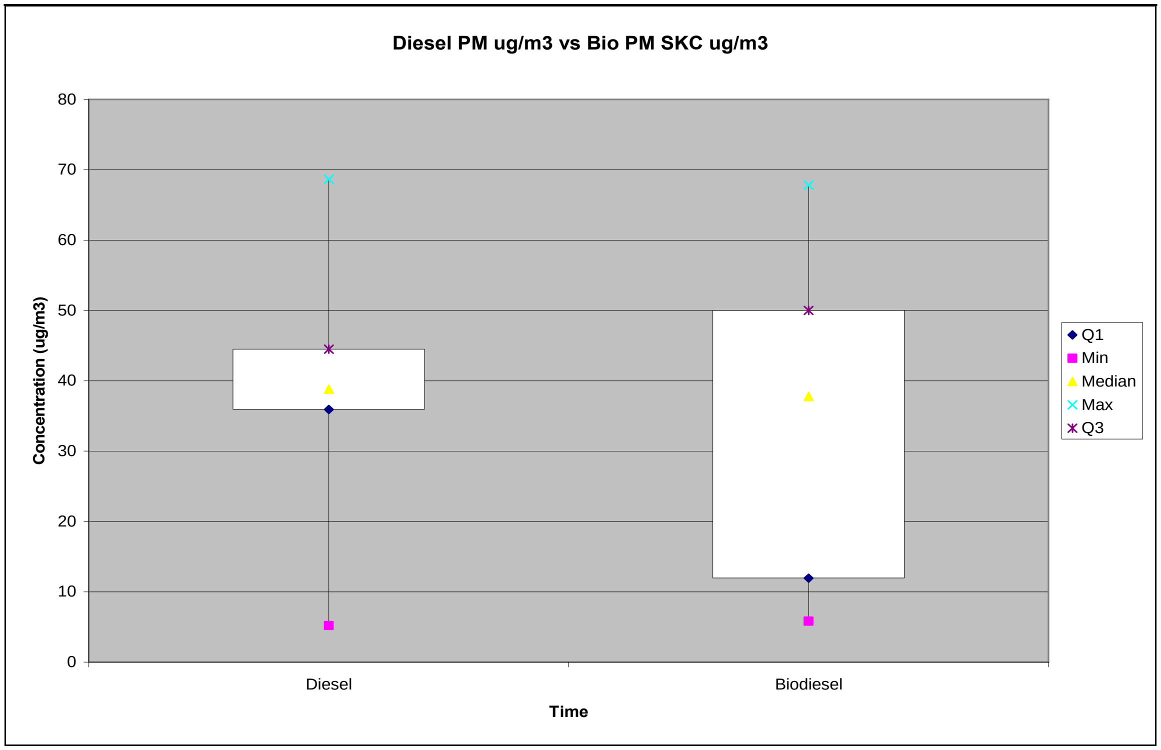


Figure 3.17: Diesel pm vs. B20: Boxplot Summary of NO2 Concentrations, reported in µg/m^3 (SKC)

To more fully understand however, if activity could be influence the spread seen in the above graph for afternoon biodiesel samples, a deeper level of activity analysis was undertaken. The samples in the NO_2 data set were one hour grab samples; in other words, the air was monitored for a one hour period in the morning and afternoon, resulting in two samples taken during two hours per day. Therefore, categorizing activity levels by day, while appropriate for daily 8 hour samples as taken for PM, EC and OC, may not be appropriate for NO_2. For example, if there were limited to no activity in the time period right before the afternoon NO_2 sample, even if the entire day met the criteria for a “high activity” day, this lack of afternoon activity would lead to a low afternoon NO_2 result. Going back to the activity logs, there were four B20 NO_2 samples (8/7/06 [5.8 µg/m^3], 8/15/06 [27.3 µg/m^3], 8/16/06 [10.4 µg/m^3], 8/17/06 [11.9 µg/m^3]) in the afternoon data set where there was little to no activity either immediately prior or during the one hour sampling period. This helps explain the spread in the data seen in the boxplot.

But to more fully understand these subtleties in activity, instead of categorizing each day into activity days, we went back and looked at activity events immediately preceding each NO_2 sample to ensure that only the grab samples that had consistent high activity events were compared in the analysis. For a grab sample to quality as a **high activity event** sample, there must have been at least one high activity event (defined as equipment digging or moving with load, or moving without load) or four low activity events (standard idle) either during the one hour grab sample period or in the twenty minute interval immediately preceding it. This further refinement of the data set leads to the following table:

Diesel SKC (n=7)	Time	Number of High Events	Number of Low Events	NO$_2$ (µg/m^3)	AM	SE	GM	GSD	Percent Increase
7/11/2006	2:13 to 2:43 PM	3	0	38.8	**27.2**	**8.52**	**19.5**	**2.54**	**52.90%**
7/12/2006	2:02 to 2:52 PM	1	3	5.2					
7/13/2006	9:48 to 10:48 PM	4	2	22.4					
7/13/2006	1:18 to 2:18 PM	3	2	35.9					
7/14/2006	10:15 to 11:15 AM	1	2	11.5					
7/25/2006	10:13 to 11:03 AM	0	5	8.2					
7/25/2006	1:33 to 2:52 PM	2	2	68.7					
Biodiesel SKC (n=7)	**Time**	**Number of High Events**	**Number of Low Events**	**NO$_2$ (µg/m^3)**	**AM**	**SE**	**GM**	**GSD**	
8/7/2006	10:16 to 11:13 AM	1	0	11.7	**34.9**	**7.48**	**29.7**	**1.89**	
8/8/2006	8:59 to 9:59 AM	2	4	26.1					
8/8/2006	1:07 to 2:07 PM	1	2	37.8					
8/9/2006	10:25 to 11:25 AM	0	5	36					
8/9/2006	1:50 to 2:35 PM	0	4	50					
8/10/2006	2:05 to 2:50 PM	2	0	67.8					
8/15/2006	9:24 to 10:24 AM	1	3	14.6					

Table 3.13: Diesel vs. B20: Summary of NO$_2$ Concentrations and Activity, reported in µg/m^3

In summary, comparing similar high activity event grab samples, the average NO$_2$ level measured during diesel days was 19.5 µg/m^3 (GSD=2.54) and 29.7 µg/m^3 (GSD=1.9) for B20 days. However, this 52.9% increase in NO$_2$ levels during B20 use was not considered statistically significant (p=0.51).

The influence of the "transition days" was examined next since biodiesel use does appear to cause a slight increase in NO_2. If the transition days resulted in an increase and was included in the petroleum diesel set, if diesel is generally lower in NO_2, the effect of the increase could be masked. This is the reverse of the concept of PM being included in the diesel data set. When the transition dates were removed, and mean diesel NO_2 and biodiesel NO_2 concentrations were compared, no significant difference was found (p=0.38). If the transition days were instead added to the biodiesel data set, again no significant difference was found (p= 0.34).

Nitrogen Dioxide	N Value	AM (µg/m^3)	SE	GM (µg/m^3)	GSD	Percent Increase
Diesel P2	7	20.34	5.27	15.29	2.44	45.39%
Biodiesel P2	16	28.83	5.04	22.23	2.15	

Table: 3.14: Diesel vs. B20: Summary of NO_2 Concentrations Excluding All Transition Days, reported in µg/m^3

The potential influence of temperature on NO_2 levels was examined next. The average temperature on diesel days was determined to be 77.8 ± 2.9 ^{o}F compared to an average temperature of 73.7 ± 2.5 ^{o}F. A two tailed t test assuming equal variances performed to compare average temperatures recorded during diesel and B20 use indicated a significant difference between fuel types (p = 0.05). However, when days with a temperature greater than 75 deg F were categorized as high temperature days and a two tailed t test was performed comparing diesel and biodiesel use, no significant difference in NO_2 concentrations was found between the fuel types during days of similar, high temperature (p=0.47).

In summary, B20 use, while resulting in an increase in NO_2 levels, does not result in a statistically significant increase in NO_2 levels when compared to diesel use. This overall result was robust even when the influence of activity, temperature, fuel transition, and time were evaluated.

3.1.3 Other Variables: Weather, Vehicle Counts, Environmental vs. Occupational Exposures

3.1.3.a Time Series Analysis

Confounding variables such as temperature, relative humidity, and outside vehicle count (gas and diesel vehicles) were recorded and examined via time series graphs to evaluate if any observable trends occurred that could influence the results reported here. Two tailed t tests (assuming equal variances) comparing diesel vs. B20 use days for the variables temperature, relative humidity, and outside vehicle count data were also performed.

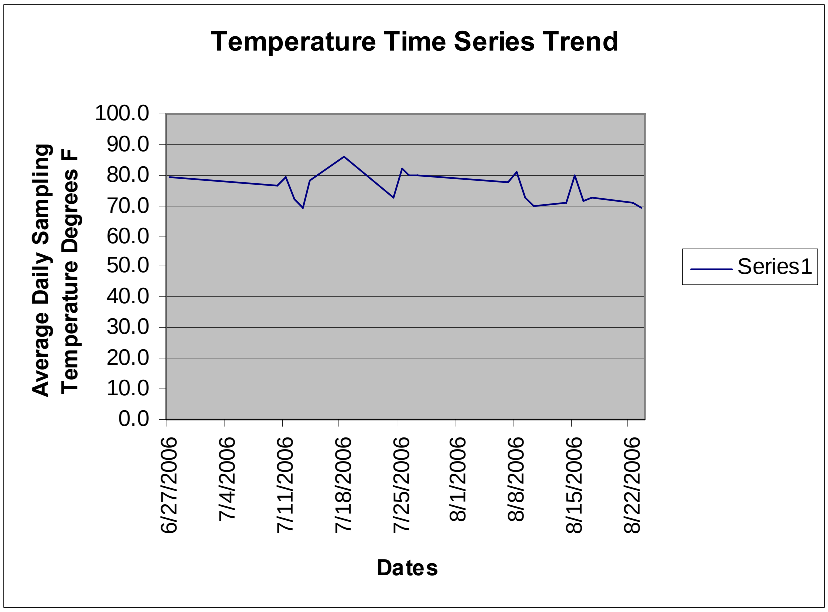


Figure 3.18: **Temperature Time Series Trend**

The temperature time series trend is shown in Figure 3.18 above, with the results reported in the previous section.

The average temperature on diesel days was determined to be 77.8 ± 2.9 deg F compared to an average temperature of 73.7 ± 2.5 deg F. A two tailed t test assuming equal variances performed to compare average temperatures recorded during diesel and B20 use indicated a significant difference ($p = 0.05$). Although the temperature difference was considered significantly different, the magnitude of the difference was less than 10 degrees, such that temperature's impact on $PM_{2.5}$, EC and OC levels measured here is likely to be negligible. Typically, impacts on $PM_{2.5}$ from temperature may be important when there are seasonal differences (summer versus winter) or temperature differences greater than 20 degrees. Temperature effects are expected across seasons but since monitoring at the KRC was conducted in the summer months, the impact on $PM_{2.5}$ should be minimal.

Relative humidity does not show any clear time series trends between diesel and B20 use days. The average relative humidity was 66.7% ± 6.0% on diesel days compared to 63.8 ± 6.6 % on biodiesel days. This difference was not considered statistically significant ($p=0.52$).

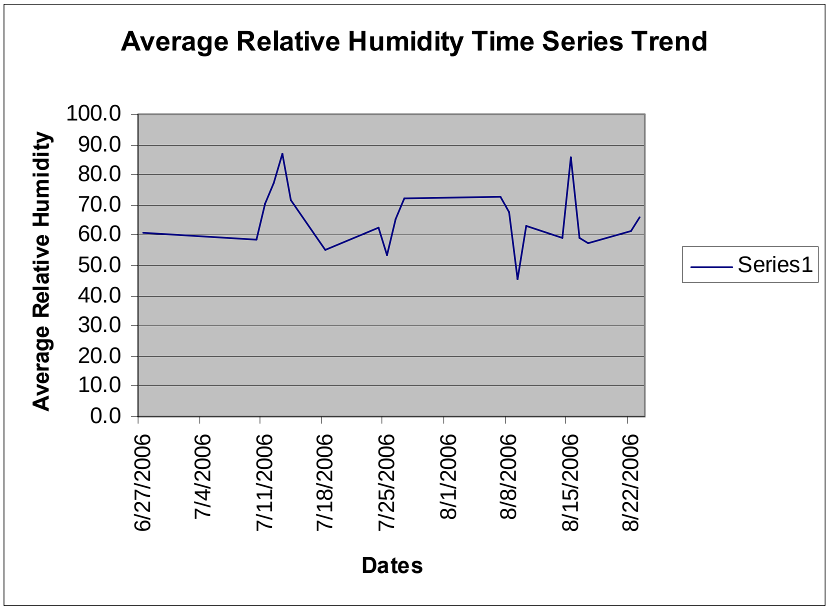


Figure 3.19: <u>Average Relative Humidity Time Series Trend</u>

Outside vehicle counts were made by students stationed throughout the site. Students were trained to distinguish between gas powered and diesel powered vehicles. The gasoline vehicle count appeared to show similar variability between diesel and biodiesel sampling days. Gas powered vehicles could be expected to contribute to $PM_{2.5}$, organic carbon and NO_2 levels. However, when the average number of vehicles were compared 80 ± 11 cars for diesel days and 68 ± 11 cars for biodiesel days, this comparison did not result in a statistically significant difference (p=0.17).

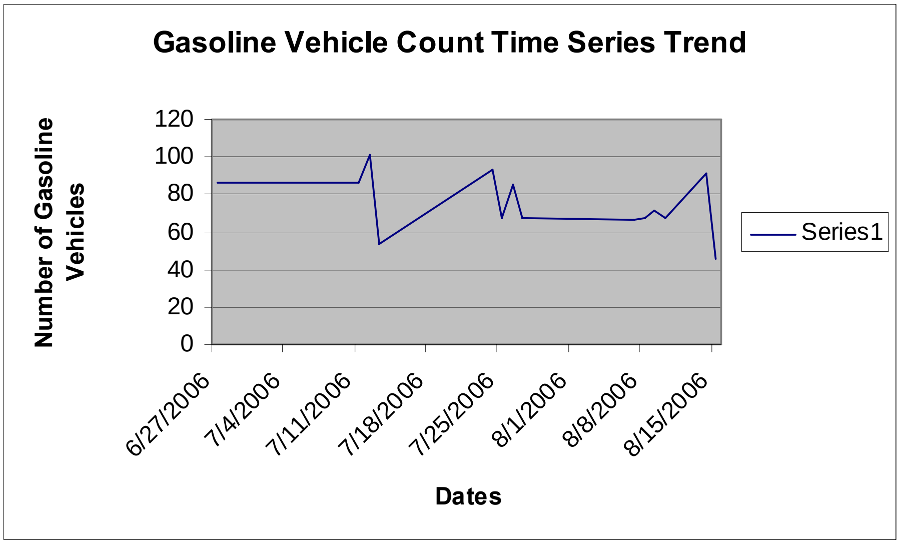


Figure 3.20: Gasoline Vehicle Count Time Series Trend

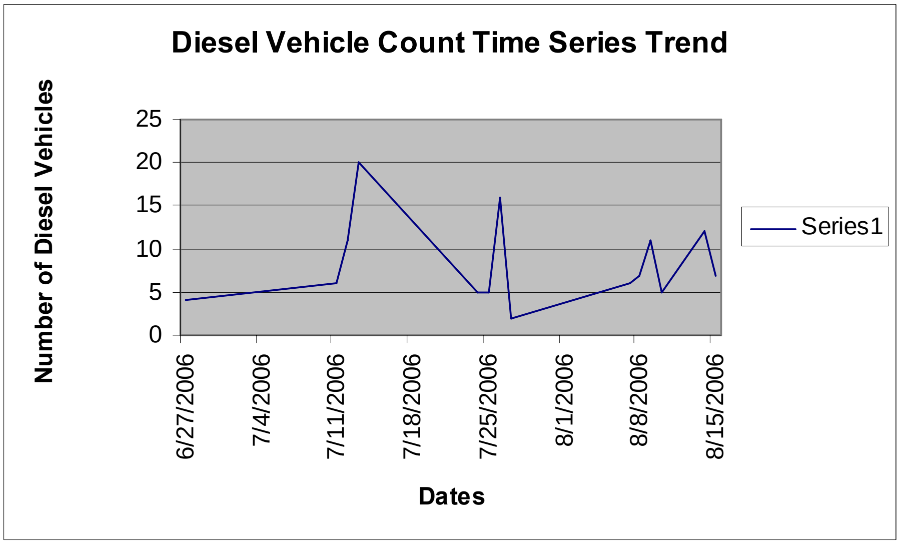


Figure 3.21: Diesel Vehicle Count Time Series Trend

The diesel vehicle counts show even more variability or lack of systematic trend between diesel and biodiesel days. The diesel vehicle average was 9 ± 4 vehicles and the biodiesel vehicle average was 8 ± 2 vehicles. A two tailed t test assuming equal variances was performed which determined this difference was not statistically significant (p=0.83).

Based on the above analyses, the variables temperature, relative humidity, and outside vehicle count were shown to exhibit similar trends across the entire field sampling time span. Relative humidity and outside vehicle count for gas and diesel vehicles were not statistically significantly different between diesel and B20 sampling days. Although temperature was significantly higher during diesel days, it did not appear to have an effect on measured NO_2 concentrations. A temperature difference of 10 degrees or less would not be expected to have an impact on measured $PM_{2.5}$, EC, or OC as measured in this study.

The last analysis performed evaluated whether there were statistically significant differences between environmental and occupational exposures of $PM_{2.5}$, EC and OC during similar fuel usage. Occupational exposures were expected to be higher than environmental exposures. P3 as the perimeter location directly outside the KRC building was selected as the environmental exposure and P4/MS1 (inside small front end loader cabin) was selected to represent occupational exposure, as it typically had the highest pollutant concentrations across the pollutants. Statistical analysis of P3 versus MS1 indicated no significant differences for $PM_{2.5}$ or organic carbon for either diesel or biodiesel fuel use. There was not enough data to evaluate elemental carbon. In other words, while environmental exposures were expected to be lower, there were no statistically significant differences found between environmental and occupational exposures. This was likely due to the near field location of the P3 perimeter area being in such close proximity to KRC site operations.

3.1.4 Biodiesel Knowledge Survey Results

On December 1, 2006, I sent the Biodiesel Knowledge to 19 people, including the mayor of Keene, other City department heads affected by biodiesel use, and a number of

Keene State College employees who also used or supported the decision to use biodiesel in the college fleet. A total of 14 people took the survey. As a BWG recruiting tactic, I included information in the email about participation. I also asked respondents to forward the survey to anyone else who might be interested in the BWG or who was involved in the decision to use biodiesel in Keene. In hindsight, this effectively eliminated the ability to do a pre and post test. Although 14 people took the survey, I do not know if those respondents were from the original group or from a forwarded email. For other groups, like the KRC workers, I used hand delivered paper surveys, so I could easily categorize those responses.

The results for the Keene decision-making group are summarized in Table 3.15.

	Keene Decision Makers							
Question	TRUE	FALSE	Don't Know	Ans. Key	% Correct	% Incorrect	% Answered Don't Know	% Incorrect or Answered Don't know
#1	5	9	0	FALSE	64.29%	35.71%	0.00%	35.71%
#2	1	13	0	FALSE	92.86%	7.14%	0.00%	7.14%
#3	12	1	1	TRUE	85.71%	7.14%	7.14%	14.29%
#4	9	2	3	TRUE	64.29%	14.29%	21.43%	35.71%
#5	7	3	4	TRUE	50.00%	21.43%	28.57%	50.00%
#6	12	1	1	TRUE	85.71%	7.14%	7.14%	14.29%
#7	3	11	0	FALSE	78.57%	21.43%	0.00%	21.43%
#8	3	8	3	FALSE	57.14%	21.43%	21.43%	42.86%
#9	1	12	1	FALSE	85.71%	7.14%	7.14%	14.29%
#10	12	1	1	TRUE	85.71%	7.14%	7.14%	14.29%
#11	13	1	0	TRUE	92.86%	7.14%	0.00%	7.14%
#12	1	9	4	FALSE	64.29%	7.14%	28.57%	35.71%
Averages					75.60%	13.69%	10.71%	24.40%

Table 3.15: <u>Biodiesel Knowledge Survey Results for Keene Decision Makers</u>

Questions 1, 5, 7, and 8 had the highest numbers of incorrect responses. These questions were as follows:

- Question 1: *The term "biodiesel" is used to refer to the fuel that results from adding pure vegetable oil to diesel fuel*
- Question 5: *Increasing the amount of biodiesel in a biodiesel blend is associated with increasing nitrogen oxide levels.*
- Question 7: *The biodiesel blend B20 (20%) biodiesel can "gel" or "not flow" during typical New England winter temperatures*
- Question 8: *Since biodiesel is considered an alternative fuel, using it can void a new diesel engine's warranty.*

In addition to questions 5 and 8, questions 4 and 12 had a higher number of "I don't know" responses. These questions are shown below.

- Question 4: *Starting in 2007, EPA will require new on-road petroleum diesel engines to be much cleaner than current engines.*
- Question 12: *If all waste grease and excess vegetable oil in the U.S. were converted to biodiesel, then biodiesel supply could fully meet existing petroleum diesel demand.*

The high number of incorrect or "I don't know" responses for Questions 4 and 5 was not unexpected for these highly technical, federal policy related questions. Of note is the need for education on Question 5. The scientific uncertainty associated with concerns about NO_x impacts from biodiesel have led to state regulators' cautious approach in allowing market penetration of biodiesel into ozone non-attainment states. The NO_x impact of biodiesel is frequently mentioned as a negative characteristic of biodiesel in newspaper reports. The high number of incorrects/"I don't know" responses for questions 1, 8 and 12 were surprising for this group. Since many of the individuals in this group were involved in supporting biodiesel use in some capacity, it was expected that this group would answer these questions correctly. In addition, Russell had done substantial local outreach on the background of biodiesel, and the warranty issue. KSC had done locally publicized work in diesel exhaust exposure research. These results indicated this group may not know what is going on in their own backyard and that continued local biodiesel education is needed. Future public presentations made sure the above questions were discussed in the information presented.

Other groups besides the Keene decision-makers were given the Biodiesel Knowledge Survey. While this dissertation cannot draw quantitative conclusions on whether the BWG process/public presentation forums increased biodiesel knowledge for survey participants, some tentative observations on the initial or baseline level of knowledge within the groups can be made. Surveys were distributed to these groups: KRC employees, attendees at a local conference (attendees were physical plant personnel from colleges throughout New England), KSC undergraduate research students, and DPW fleet mechanics. The KRC employees' and DPW employees' results are listed in Table 3.16 and table 3.17 below.

KRC Employees								
Question	**TRUE**	**FALSE**	**Don't Know**	**Ans. Key**	**% Correct**	**% Incorrect**	**% Answered Don't Know**	**% Incorrect or Answered Don't know**
#1	4	0	3	FALSE	0.00%	57.14%	42.86%	100.00%
#2	1	1	5	FALSE	14.29%	14.29%	71.43%	85.71%
#3	4	1	2	TRUE	57.14%	14.29%	28.57%	42.86%
#4	2	0	5	TRUE	28.57%	0.00%	71.43%	71.43%
#5	0	1	6	TRUE	0.00%	14.29%	85.71%	100.00%
#6	1	1	5	TRUE	14.29%	14.29%	71.43%	85.71%
#7	4	0	3	FALSE	0.00%	57.14%	42.86%	100.00%
#8	1	2	4	FALSE	28.57%	14.29%	57.14%	71.43%
#9	0	4	3	FALSE	57.14%	0.00%	42.86%	42.86%
#10	2	2	3	TRUE	28.57%	28.57%	42.86%	71.43%
#11	3	2	2	TRUE	42.86%	28.57%	28.57%	57.14%
#12	2	2	3	FALSE	28.57%	28.57%	42.86%	71.43%
Averages					**25.00%**	**22.62%**	**52.38%**	**75.00%**

Table 3.16: <u>Biodiesel Knowledge Survey Results for Keene Recycling Center Employees</u>

Keene DPW Fleet Mechanics								
Question	**TRUE**	**FALSE**	**Don't Know**	**Ans. Key**	**% Correct**	**% Incorrect**	**% Answered Don't Know**	**% Incorrect or Answered Don't know**
#1	2	3	0	FALSE	60.00%	40.00%	0.00%	40.00%
#2	0	5	0	FALSE	100.00%	0.00%	0.00%	0.00%
#3	5	0	0	TRUE	100.00%	0.00%	0.00%	0.00%
#4	5	0	0	TRUE	100.00%	0.00%	0.00%	0.00%
#5	1	3	1	TRUE	20.00%	60.00%	20.00%	80.00%
#6	2	2	1	TRUE	40.00%	40.00%	20.00%	60.00%
#7	3	1	1	FALSE	20.00%	60.00%	20.00%	80.00%
#8	1	2	2	FALSE	40.00%	20.00%	40.00%	60.00%
#9	0	5	0	FALSE	100.00%	0.00%	0.00%	0.00%
#10	2	1	2	TRUE	40.00%	20.00%	40.00%	60.00%
#11	4	0	1	TRUE	80.00%	0.00%	20.00%	20.00%
#12	0	4	1	FALSE	80.00%	0.00%	20.00%	20.00%
Averages					**65.00%**	**20.00%**	**15.00%**	**35.00%**

Table 3.17: Biodiesel Knowledge Survey Results for the City of Keene DPW Employees

Total knowledge levels from the survey were relatively low for KRC employees (25% correct, 52% “I don’t know”, with the balance 23% incorrect). Results were higher for DPW mechanics (65% correct, 20% incorrect, 15% “I don’t know”) but still low overall compared to the 76% correct response rate for Keene decision-makers. Attendees from the New England college physical plant staff conference held at KSC (representing an outside group of potential biodiesel users) scored 57% correct and 23% “I don’t know.”

The conference attendees had the lowest percentage correct except after the KRC employees. KSC students (research interns) scored 69% correct, 11% “I don’t know.” This subgroup was used to check reliability of the survey via a test/retest eight weeks after initial survey. Repeat scores by the KSC students for the retest were 67% correct, 13% “I don’t know.” Although their scores were higher than the outside group of conference attendees, the results of the City of Keene DPW employees were lower than expected due to their familiarity with biodiesel. In interviews, City of Keene DPW employees admitted relying on Steve Russell's assessment of biodiesel's benefits and may have simply trusted his judgment. On the other hand, KRC employees interviewed believed they were not well informed about biodiesel. This group was most likely to choose "I don't know" as a response.

Questions that were consistently answered incorrectly (such as Question 5 and 7) by all Biodiesel Knowledge Survey groups were noted so that this information could be incorporated into future public presentation materials. Therefore, this analysis was used in the public presentations forum.

3.1.5 Second Biodiesel Working Group Meeting – December 19, 2006

The next BWG meeting was held at Keene State College on December 19, 2006. As discussed in Chapter 2, Methods, through the Biodiesel Knowledge Survey and additional emails, I was able to recruit two new members. Developing this survey and conducting outreach presentations were two activities I undertook during this time period between meetings. Neither of the two new members were KRC site workers. The two participants from the June 2006 meeting were not able to attend the December date. So for this meeting, in total, there were 5 participants: the 2 new members, myself, a student researcher and Steve Russell in attendance.

Since this was the first time some of us had discussed biodiesel and the collaborative research in months, I developed a draft agenda suggesting we cover a brief review of the exposure assessment process, key results and two main goals for the meeting: to determine who else should be invited to participate on the BWG, and how/where do we want to present the exposure assessment results. I asked the group to think about what they would like to do with the results of the exposure assessment. For example, should the study results just be given to Russell, to provide the "scientific facts" he felt he needed for his presentations? Or were there other ideas from the BWG?

At the beginning of the meeting, I asked if anyone wanted to add anything to the agenda. No new topics were added. I delivered a short presentation reviewing the core exposure assessment results: significantly reduced particulate matter from use of B20, but significantly increased organic carbon. I suggested some possible goals for the BWG: such as improving local biodiesel education, conducting additional research, and thinking about where to go from here with respect to future use of B20 in Keene. I used Figure 2.6 as a guide to initiate and stimulate conversation regarding potential options. I also suggested that an option from today's meeting may be "do nothing" if the group felt that B20 use was at an acceptable level with both organizations and the community.

Upon hearing the main results that particulate matter decreased with B20 use, but organic carbon levels increased significantly (with unknown implications), some BWG participants adopted slightly defensive positions. One participant said, laughing, "we should hide that information." Another participant commented that no one expected biodiesel to be a "magic solution" but that when all the information is included in the decision to use B20 – such as decreased carbon dioxide and the reduction in foreign oil imports - biodiesel was still "positive overall." A rather intense dialogue began between me and one of the BWG members, who stated "the only purpose I can see [for the BWG] is using this for future education" and that the group needed to be more "action oriented." This member added that I should have set up clearer, more "actionable goals" for the group otherwise people were not going to participate. An additional comment was that no other BWG goals were possible (besides education) due to the problem of limited B20 supply. There was a clear sense of frustration from this member at both a BWG without clear goals as well as the problem of being constrained by the limited availability of B20 supply in New Hampshire. Others shared this participant's concern about lack of supply and agreed it was a real problem.

The tension in the room was likely due to heightened frustration at the paradox of having a BWG to discuss new policy or use of biodiesel in Keene when it was quite simply difficult to get biodiesel. Meeting attendees were communicating with their body language, "why are we here? Why bother?" Data from previous participant observation and the June 2006 meeting indicated a sense of frustration why more retailers and distributors were not selling biodiesel locally. BWG members asked why more people weren't using biodiesel. During public outreach and local conferences the issue of lack of supply usually came up either in questions from the audience or in side conversations afterwards. The lack of supply was a double problem: there was a lack of interest by most local distributors and there were issues with poor quality B20 from those distributors that did exist. At the time of the exposure assessment, the City had been using biodiesel in its fleet for 4 years but sourcing it was still difficult. A recent B100 delivery to KSC had resulted in temporarily shutting down some major pieces of equipment due to poor fuel quality due to high water content.

To defuse the tension in the room, I explained that as a participant/researcher, I was trying to walk a fine line between facilitating the meeting, and just simply setting up what I thought would be good goals for the group. My job as facilitator was to elicit what people wanted to do with the results of the research – if anything - and find out what their desired goals for the BWG were. The biodiesel exposure research was clearly important to both

KSC and the City groups since both had invested so much time and energy into it. The problem of lack of biodiesel supply in New Hampshire was not unexpected or new; neither was the fact that the BWG felt this was a significant barrier. In fact, about two months earlier an engineering firm had approached the KSC Safety Studies department (including myself) to discuss an idea of making biodiesel from waste grease and selling it within the local region/community. Via a collaborative partnership, KSC/City might expand existing biodiesel research. Our Safety Studies department had approached the President of KSC and gained initial support to research the concept of a biodiesel facility further. Knowing this, I suggested to the BWG group, "what if we made lack of supply the problem the BWG would address or a goal of the BWG? What if, as part of that problem, we expanded the list of possible solutions to include making biodiesel from waste grease?"

At that point the energy in the room turned positive. All the members agreed that the idea of making biodiesel from waste grease was worth exploring, and fit with the goals of the Cities for Climate Protection initiative by conserving energy and reducing carbon dioxide emissions. A comment was made by a BWG member that biodiesel could then be used in more applications in Keene, such as for heating oil or bioheat for buildings run by the Keene Housing Authority. I explained to the group the background of our initial discussions with KSC's President regarding the biodiesel facility concept. Some members thought the idea of a biodiesel refinery could at least bring local distributors to the table to discuss providing more options to purchase biodiesel. The rest of the meeting was centered on when/where to present the exposure assessment results, who to invite to the next meeting and setting up meetings with local distributors to gauge their interest in a biodiesel partnership, either to provide more B20 in the region or collaborate in a manufacturing venture. The group agreed that the exposure assessment results would be reviewed in detail at the next BWG meeting.

This meeting reflected a change in the problem formulation step of the A-D process. The initial problem formulation that brought KSC and the City together was: "Is biodiesel (B20) healthier?" The collaborative exposure assessment was designed to help answer that question. The results of this analysis started the conversation. The BWG members believed the results of the study were "positive overall" and supported a general goal that the City should use more biodiesel. However, members were frustrated by the barrier of lack of affordable local supply. Deliberation within the BWG framed the need for *new analysis* – for the City to use more B20, how can the local supply be increased to meet this goal? Lack of supply was a key point of frustration within the group, and I articulated that frustration by suggesting it as a problem for the BWG to address. A new series of analytic-deliberative interactions now began, this time centering on the challenge of increasing biodiesel supply in Keene.

Another key observation made in this meeting was the continued tension between management and workers in this case. Workers did not come to the December 19, 2006 meeting and when I remarked that I thought it was agreed that at least one worker would participate, a comment was made, "I don't see how they would gain anything. They are not interested, and [other people} can represent them." Worker participation in the BWG meetings was a challenge in this case. At this time, with the BWG process only just starting to gain traction, I was concerned that pushing the issue further would result in reduced participation by the few BWG members that were attending. I was quite aware I had little leverage. As an "outsider" to the City of Keene organization, I had limited ability to influence this decision any more than I had already done.

3.2 Central Question #2: How Can Local B20 Supply Be Increased?

3.2.1 Activities Between Meetings – December 2006 Through February 2007

During the time period before the next BWG meeting scheduled for February 13, 2007, an internal KSC team, including myself, KSC Administrators, and other Safety Studies staff, met for the first time with a private engineering firm to discuss a potential collaboration between the City, College, and the firm for a biodiesel manufacturing and research facility. This meeting focused mainly on introductions, brainstorming of ideas, and initial discussion of pertinent issues such as funding sources and intellectual property sharing. Deliberations centered on the risks and benefits to each partner via different types of organizational structures, such as nonprofit versus profit. The KSC internal group was energized by the potential partnership, and I shared that the BWG was interested in exploring ways to increase local B20 supply, and that this might include manufacturing biodiesel from waste grease. The internal KSC team agreed with the BWG idea to talk to local distributors to consider their input on the local biodiesel supply issue and KSC Administration staff made those initial contacts. It was decided to bring the BWG into the next meeting on the biodiesel manufacturing project since the membership on the BWG consisted of both KSC and City interested and affected parties. Also during this time, my colleagues and I submitted a grant to EPA to request funding for research at the proposed facility.

3.2.2 City of Keene DPW and Keene Recycling Center Employee Interviews

Since it didn't seem likely KRC or other City of Keene DPW workers would attend future BWG meetings, I decided to interview employees in their workplace location. I wanted to get worker input into the A-D processes as well as a background on their attitudes toward biodiesel and the research collaboration.

I interviewed a DPW employee who was operating a Holder on the street on January 17, 2007. A Holder looks like a very small bulldozer and usually operates on small streets or wide sidewalks to remove snow. After giving verbal consent for the interview and to use his name, I asked the operator an abbreviated version of the semi-structured interview guide: what he thought about biodiesel, if he had any concerns, and what he thought about the research between KSC and the City. While he thought the smell of biodiesel was "better", he consistently repeated his biggest concern was that the equipment ran well on the new fuel. The fact that it may be better for the environment, to this worker, was a "bonus", but he stressed his concern about operations, and that he noticed no difference between fuels.

I also conducted a group interview for the KRC site employees during their coffee break on January 24, 2007, using the semi-structured interview guide. All employees gave their verbal consent and permission to use their names in the study. Most KRC workers were happy to discuss their thoughts about biodiesel and the exposure assessment project. Interesting insights emerged from this interview, such as some workers noting they were not particularly concerned about diesel exhaust or biodiesel exhaust exposures but more concerned about the "stuff on the conveyor belt", like syringes in the plastic containers that came to the KRC. This was summarized by the comment: "the emissions are the least of our concerns." I asked them to expand on the specific concerns they had. Most of these were related to potential exposure to chemicals/pathogens in the incoming materials and dust. One comment was made regarding layers of dust that got on skin and on cars. I shared with them that it was typically the small, unseen particles from fuel combustion and not the large dust particles from moving materials that actually was most harmful to lung health. It was important to consider both particle sizes and this study looked at the smaller sized particles.

Most in the group felt the exposure results needed to be made public. The KRC staff had creative suggestions for disseminating the exposure assessment results, such as submitting it to Channel 8, Cheshire TV (a local cable access channel for Keene). The KSC student research team eventually put together a slide show presentation on the collaborative exposure assessment that was submitted to Channel 8 and ran during the July 4th week in 2007. Town/gown relationships were enhanced between students and KRC employees as a result of the actual research process as well. During the interview, one KRC employee stated, "[It was] good to see the college kids doing something productive, working and trying to learn." Another stated, "We liked it [the study]. People asked us what the kids were doing and we could tell them about the biodiesel testing." Finally, the group was interested in seeing that the research had some practical value. This idea was summarized by the comment, "It would be a shame if this research sat on a shelf." Interestingly, it was this same employee most concerned about the fruitfulness of setting up a BWG as "committees can drag out things…we need participation [that does something]." Like other BWG members, the KRC employee group had ambivalence about the usefulness of a BWG, and thought it needed an action focus.

3.2.3 Third and Fourth BWG Meetings – February 13, 2007

The next BWG meeting occurred on 2/13/07. The meeting actually consisted of two meetings: a morning meeting where KSC Safety Studies students formally presented the exposure assessment results to the BWG, and an afternoon meeting to discuss the biodiesel supply problem. Four senior KSC students presented an overview of the methods and results from the 2006 exposure assessment study. At this meeting, there were 4 BWG members (other than myself), the presenting students, and 4 other KSC faculty/staff and students present. After the presentation, a number of questions were asked by the BWG members. These included specific questions about the nature of organic carbon, and how new fuels like ultra low sulfur diesel could impact the results from the exposure assessment.

BWG members made suggestions to the students to clarify language and presentation style for future audience comprehension. BWG member comments included a suggestion to reduce technical language and remove the explanation detail about measurement methods. Besides these questions and comments, BWG members openly discussed the context of the results – especially the increased organic carbon of unknown speciation - in light of biodiesel's other perceived benefits. One BWG member stated, "no matter what the data comes out, we want to use biodiesel". This was explained in the context of biodiesel having benefits at micro and macro scales. A major macro scale benefit was described as the reduction in foreign oil use by switching to domestic biodiesel. This BWG member felt biodiesel had two levels of benefit, at the national policy level (by reducing reliance on foreign oil as a sustainable fuel) and at the local level (improved employee productivity from the cleaner workplace air).

In the afternoon meeting, the BWG group was expanded to include new members such as members of the KSC Administration, purchasing department, and additional faculty. This group met to discuss the idea of a biodiesel manufacturing, fuel quality testing, and research facility as a way to increase local supply and to build upon the City/KSC research collaboration already in place. This was the first meeting where non-KSC BWG members were brought together with KSC staff. Although the KSC VP of Finance and Planning was the chair of the afternoon 2/13/07 meeting, I was an active facilitator to bridge the deliberations between the internal KSC team and the BWG members, who were mostly City staff. The initial discussions focused on the viability of a production/research oriented facility that would be community and education centered. It was decided that contacting and interviewing local distributors regarding this approach would be a prudent first step. Also discussed were the goals of the City/KSC collaboration to make biodiesel, how to secure funding, and what would be the risks/benefits to each partner. The 2/13/07 meeting could best be described as continuing the "brainstorming"' or free discussion of ideas surrounding what it would take to build a biodiesel production/testing/research facility in Keene. At this point, it was still a possible outcome that the BWG process would instead encourage a local fuel supplier to make B20 more available and affordable.

3.2.4 Outreach Presentations

A number of public presentations were completed in the September 2006 to April 2007 timeframe. The details of these presentations are summarized in table 3.18.

Date	Location	Presentation/Audience	Sample Questions from Audience
9/14/06	Howe Library, Hanover, NH	Copresent with Steve Russell to Sustainable Energy Resource Group (SERG)/open to public	Why a PM decrease form only B20? What about weather? Wind speed effects? Is NO_x a concern?
9/24/06	Washington DC	Star Fellows Conference/EPA fellows & EPA Scientists	Why test only B20? Why is your study design necessary - just put instrument in exhaust for measuring emissions? Why not just put exhaust scrubbers on tailpipe? How is there such a big decrease in PM from only B20?
12/6/06	UNH Campus Manchester, NH	Copresent with Steve Russell to undergraduate class plus visitors from City of Manchester DPW including City Fleet Manager & Purchasing Director	N/A
3/16/07	Keene State College	NEAPPA/College Facilities/Grounds Managers & Employees	Does Europe have higher asthma rates that U.S. (since Europe uses more diesel cars?) How can PM decrease with only a B20 blend? What about fuel vs. food debate? Any concerns for heating?
3/30/07	NH DES Portsmouth, NH	Co-present with Treadwell Granite State Clean Cities Coalition, New Hampshire DES, Stakeholders in NH renewable energy (businesses, policy politicians, NH DES, public fleets and gov't)	How can $PM_{2.5}$ decrease 60% from a 20% biodiesel blend? How much time was allowed for a fuel transition between diesel and biodiesel? What about warranty issues? What is PM, EC, OC and the differences between them? How can PM decrease and OC increase? Why is there such a big difference between EPA and OSHA standards?
3/31/07	KSC Campus	KSC Academic Excellance Conference (Student Presentations), KSC academic community & open to public	Did KRC equipment have computer adjustment of air/fuel mixture to adapt/adjust air/fuel ratios? Doesn't B20 gel in winter? Why does $PM_{2.5}$ decrease and OC increase? What is impact of biodiesel on global warming? What is carbon impact?
4/18/07	KSC Campus	Earth Day Week, Brown Bag Lunch (Student Presentations), KSC community	Why did PM decrease so dramatically with B20? Why is there such a difference between EPA and OSHA? Why is OSHA so ineffective?
4/21/07	Downtown Keene, Main Street	Earth Day, Biodiesel Workshop, Open to public & outside	What was meant by carbon neutral and how does this relate to biodiesel? Why is the city only using B20? Is the city really going to build a refinery? Will using greater than B20 void engine warranties? Can you use biodiesel for heat? Do you have to make engine modifications before using biodiesel? Where can you buy biodiesel? Can you run B100 in winter?

Table 3.18: Summary of Outreach Presentations

While each presentation was made to a slightly different audience, the core of each presentation was about the exposure assessment results and the implications of using B20 in vehicles on environmental and occupational health. For open to the public presentations that took place after the Biodiesel Knowledge Survey, I included information on biodiesel from questions that were answered incorrectly or “I don’t know” in the survey. A few presentations were completed by the KSC students alone with faculty support. As noted above, there was a wide array of questions from the audience – some operational, some related to the exposure assessment, and some policy oriented. This highlights the diversity in public concern related to the idea of expanding biodiesel use.

Actually going out and doing these presentations, though time consuming, was an effective way to communicate the results and engage in a discourse about biodiesel with a wider audience. Answering audience questions directly made the research more policy relevant in those settings. Feedback from the BWG in the 2/13/07 meeting suggested the KSC research team edit public presentations by removing sections on methods or measurement techniques and focus more strongly on the exposure assessment results and their meaning, using non technical language whenever possible. This feedback was incorporated into the presentations and helped make the technical aspects of the research more accessible to lay audiences.

It is difficult to quantify or even qualify the impact of the presentations on future policy outcomes. The presentations to external stakeholder groups may have influenced decision-makers to try B20 in their fleets, or may have had no effect at all. For some of the audience members, it was the first time hearing about biodiesel; others had very specific questions about the exposure assessment study itself. Since these initial presentations, my colleagues and I have continued to receive presentation requests. While it is difficult to assess the actual impact of presentations on local policy or individual decisions, they are effective at helping researchers and others participate in larger conversations with the local and regional community about the use of biodiesel fuel and its impact on environmental and occupational health. It was also effective to help researchers better understand the specific concerns of the community, which as indicated by the questions above, may be unrelated to environmental or occupational health.

3.3 Central Research Question #3: How Can an Innovative Public/Private/College Collaboration Manufacture Biodiesel in the Local Community?

3.3.1 Fifth Biodiesel Working Group Meeting – February 22, 2007

This meeting was organized by the Vice President of Finance and Planning of Keene State College. As the idea of a unique collaboration to produce/test/research biodiesel was gaining momentum, a project team was formed by the President, and directed by the VP. At this stage in the A-D application, I no longer organized group meetings or set agendas, although for this meeting, I did actively facilitate discussions. Since many of the members of the BWG were also on this project team, essentially this group going forward became the new BWG.

The purpose of the meeting was to get feedback from the President of one of the largest local oil distribution companies on the emerging business plan. The BWG wanted to understand what worked in the business plan and what didn't. As part of the discussions, the BWG team asked the oil company President for information regarding the biodiesel market, including his interest in buying and selling more biodiesel blends in the local region. There were still members of the BWG who wanted to examine the idea of increasing local supply via discussions with local distributors.

The meeting was a revelation in many aspects. First, the oil company President was quite clear he was not interested in adding biodiesel to his fuel portfolio. He did not know much about biodiesel, and admitted as much. He stated it would be too expensive for him to add a new, dedicated biodiesel fuel storage tank, or the trucks to move biodiesel product. He also said, if he would consider selling biodiesel, he would not want to buy B100 but rather buy a pre-blended and pre-certified B20 fuel. He summarized his lack of enthusiasm for entering the biodiesel market as follows: “Part of it is I’m old. I don’t like change. The other part is that my market is only interested in lowest cost. I have people who only care about the price I post. That’s why they pick me over the other guy.”

The oil company President went on to add that he was having enough problems finding ultra low sulfur diesel (ULSD) which had begun to be implemented nationwide in 2006/2007 due to EPA mandates. The President was also frustrated that he had to now dedicate trucks to ULSD, and he could no longer use a single truck to distribute both fuel oil #2 and diesel fuel deliveries as he could in the recent past. Now that the ULSD was set at 15 ppm sulfur, a fuel oil #2 truck that contained distillate at 500 ppm sulfur could no longer used. It did not matter that the BWG told the distributor that the City of Keene and Keene State College wanted to purchase more B20 in bulk. At the end of the meeting, the President recommended that the BWG contact another distributor more interested in biodiesel.

This meeting helped identify a number of structural barriers limiting the market penetration of B20 in the southwestern New Hampshire region. One was that many people – even those in the fuel business - are simply unfamiliar with biodiesel and may not like change. Another was that the fuel distribution business operates on very tight profit margins, and these companies are very sensitive to anything that increases costs, such as biodiesel.

Some companies like the one interviewed at the 2/22/07 meeting base their reputation and market share on being a low cost oil supplier in the region. Finally, due to the concurrent EPA implementation of ULSD requirements for on road diesel fuel, distributors were focused on that issue and the associated capital upgrades and quite simply did not have the resources to consider additional new equipment dedicated to biodiesel.

3.3.2 Changes in BWG Roles and Membership: A Summary of Post February 2007 Activities

The movement of BWG members between partner organizations as well as stakeholder organizations or committees like the Granite State Clean Cities Coalition and the Keene Cities for Climate Change Committee helped increase dissemination of the exposure assessment results as well as increase its policy relevance. This movement is shown in Figure 3.22.

The BWG member movements increased policy relevance by a diffusion-like process. For example, Treadwell and I presented the exposure assessment results to the Granite State Clean Cities Coalition (GSCCC) on 4/30/07. There were 2 BWG members already on the GSCCC. BWG members would move back and forth between these other affiliated groups, communicating information about the exposure assessment, as well as the idea to make biodiesel in Keene. Feedback from these groups was brought back to the BWG. During this time period, the decision-making process of the BWG was a series of fluxes and flows of member movements, which helped ensure the process as well as potential outcomes were seen as legitimate to a wider group of interested and affected parties. Most BWG members did double duty on another stakeholder group, as shown in Figure 3.22. A legend identifying the organizational affiliation of the BWG participant's initials in Figure 3.22 is presented in Table 3.19. Figure 3.22 highlights how BWG participants were involved not only in BWG deliberations but worked with other external stakeholder groups with a pro-environmental focus. The figure also shows how at one point the KSC and City of Keene organizations had separate BWG's for a short time in May 2007, to be reviewed in the next section.

DECISION-MAKING: FLUXES & FLOWS LEGEND	
Abbreviation	**Title**
NT	KSC Researchers
MT	KSC Researchers
JI	KSC Researchers
CL	KSC Researchers
MJ	KSC Employee "Sustainability"
SR	City of Keene Supervisor
MH	City of Keene Supervisor
CK	Former City of Keene Employee
JK	KSC Administration
JD	KSC Administration
GO	KSC Small Business Liaison
MK	City of Keene Official
ME	City of Keene Official
DW	City of Keene Official
BW	KSC Fleet
MLS	KSC Student
BMD	KSC Student
KMG	KSC Student
LB	KSC Student
NM	KSC Student
CH	KSC Student

Table 3.19: <u>Organizational Affiliation of BWG Participants</u>

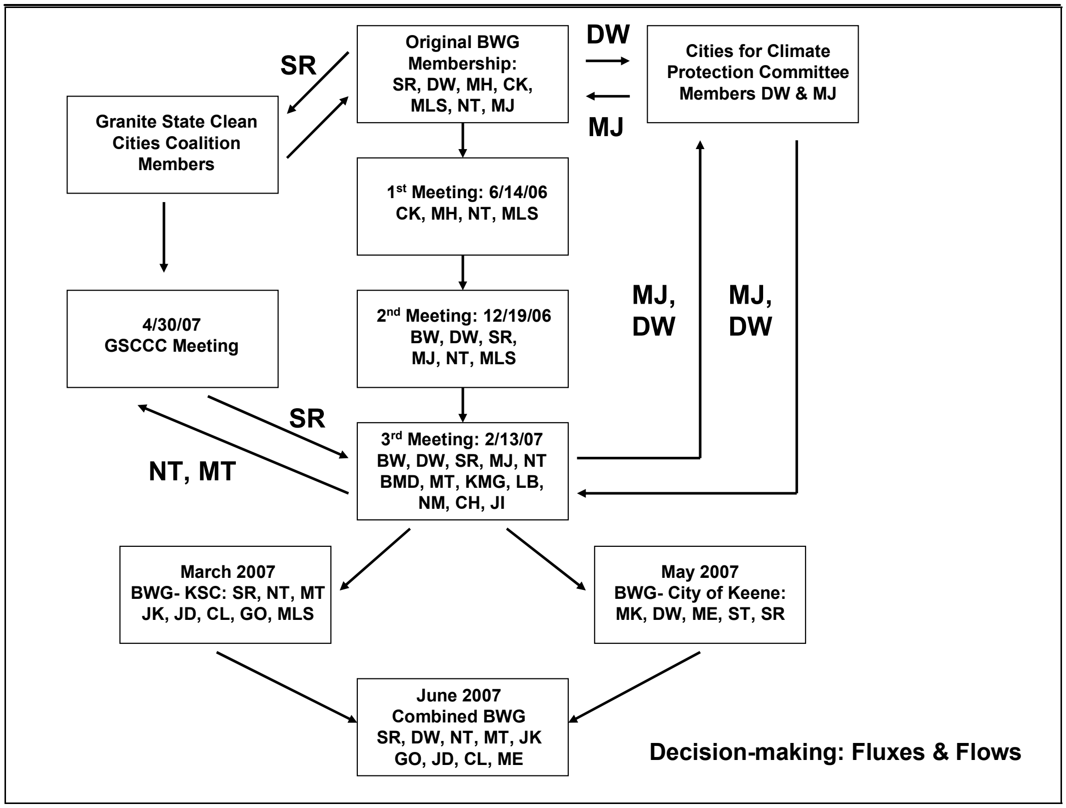


Figure 3.22: **<u>How BWG Members Moved Between Internal/External Stakeholder Groups</u>**

After 2/13/07, meetings were held approximately every two weeks as shown in Table 3.20. In some of these meetings, external interested and affected parties were brought in to seek out their opinion and solicit advice on the venture. On March 5, 2007, a regional oil distributor expressed interest in the collaborative biodiesel production/testing/research facility, specifically to purchase biodiesel locally produced. The vision of the Monadnock Biodiesel Collaborative was stated in an April 2007 version of the draft business plan:

> **Statement of Purpose:**
>
> Keene State College and the City of Keene have been using 20% biodiesel (B20) in their respective fleets since 2002, and have collaborated since 2004 in a scientific research study to examine the impact of biodiesel fuel on occupational and environmental exposures. The purpose of the non-profit organization is to manufacture high quality biodiesel fuel from waste grease from Keene State College and local restaurants in Keene, NH, and then distribute this biodiesel for use by KSC, the City of Keene, and other potential public sector consumers, such as local school districts. The local manufacture of biodiesel will remove price and availability barriers in southwestern New Hampshire, leading to new applications of biodiesel, use of higher percentage blends in existing applications, produce health benefits to the community and extend KSC's current biodiesel research into new exposures. This organization will embody a "first in the nation" private/public/college sector collaboration that connects resource conservation, waste minimization, and health risk reduction with a sustainable economic/ecological model.

Biodiesel Working Group Meetings Schedule	
6/14/06	Initial Goals: Education in Community/Increase local supply
12/19/06	
2/13/07 AM	
2/13/07 PM	After this date one of the main outcomes of BWG was to work on the collaborative "biodiesel refinery" project. After 2/22/07, I did not lead the BWG meetings.
2/22/07	
3/5/07	
3/26/07	
4/10/07	
4/30/07	
5/17/07	
5/25/07	
6/12/07	
6/19/07	

Table 3.20: **<u>BWG Meetings Held During 2007</u>**

The BWG would continue to undergo membership transformations over the next few months, as new experts were brought in for advice where appropriate. Leadership of the

BWG – setting meeting dates, agendas and assigning tasks – was taken over by the KSC VP of Finance and Planning after the 2/22/07 meeting. Membership during late spring/early summer 2007 consisted generally of KSC staff, City of Keene staff, and the biodiesel private production engineering firm staff. Tasks were divvied up with some members scouting locations in Keene to site a facility, other members researching grant funding for facility start up and operation, and others gathering data on the availability of waste grease in Keene. A draft business plan was developed by a KSC student, with input from the KSC management faculty and other internal experts. Over the upcoming months, this business plan would be revised at least half a dozen times.

The KSC VP of Finance and Planning KSC administration made an informational presentation to the Keene City Council on April 11, 2007, which resulted in a positive vote to explore the biodiesel production idea further. “It sounds like a wonderful idea,” said Councilor Frederick B. Parsells. “I’m greatly encouraged by what I heard, and the city should continue exploring the viability of such a program” (Berry 2007). Councilor Ruth Venezia was quoted, “This sounds like a win-win for everyone” and Mayor Blastos added, “This can be such a savings to our community, as well as a benefit to us. We would be helping ecology all the way around. I can’t speak highly enough of this program” (Berry 2007).

As a result of the City Council vote, during the early summer months, the City of Keene developed its own internal BWG, but after two meetings, the “City BWG” was merged with the existing BWG and the two groups became one BWG with expanded membership. In addition to the renewed focus on the policy goal of the local refinery, the expanded BWG increased opportunities for the KSC/City staff to work together on a Keene

City Council supported project. As evidenced by the above comments, this type of collaboration can lead to improved town/gown relationships. This was a key, although unexpected, result of this ongoing project.

3.3.3 Biodiesel Attitude Survey

In March 2007, I sent the Biodiesel Attitude Survey to 9 BWG members and received a 100% response rate. The Biodiesel Attitude Survey acted as a data triangulation tool to assess if the options or goals BWG members said they cared about in the meetings were the same goals they cared about in the survey. The survey's anonymous nature allowed an opportunity for the voices of everyone in the BWG to be heard, not just the most vocal participants, as well as encouraged open feedback on the BWG process. Each question had 5 responses: 1 = strongly disagree, 2= mildly disagree, 3= neither agree nor disagree/neutral, 4= mildly agree, 5= strongly agree.

Some of the key survey results are presented here; all results are presented in Appendix E. None of the results conflicted with data collected via participant/observation or semi-structured interviews. Six of ten respondents selected "strongly agreed" with the following statements:

- *Biodiesel is a safe and environmentally friendly fuel.*
- *Using biodiesel is an important way to decrease U.S. dependence on foreign oil from the Middle East.*
- *More research is needed on biodiesel blends in order to better understand biodiesel's risks and benefits.*

The first two responses support the results from interviews and participant/observation that contextual and external political factors influenced the decision to use biodiesel in Keene. Since the City of Keene was actively participating in the Cities for Climate Protection program and had already implemented biodiesel in the fleet, that a majority would see biodiesel as environmentally friendly is not surprising. The political factor of reducing foreign imports was observed multiple times in BWG discussions and City employee presentations and interviews.

Although 60% strongly agreed biodiesel was environmentally friendly, 90% strongly agreed with the statement: *I believe biodiesel is a healthier fuel for City of Keene workers and the community than petroleum diesel.* While 90% of the BWG may think biodiesel is healthier, 60% still think more research is needed. This seemingly contradictory result may be explained by the interactions seen in the BWG meetings. While participants acknowledged the need to better understand the high organic carbon result from the exposure assessment research, they felt that overall, biodiesel was "positive". In meetings, BWG members believed that biodiesel was a healthier alternative to petroleum diesel when looking at a broader context of risk such as evaluating the global warming impact of the fuels. In interviews, the non-Keene Recycling Center employees or the DPW employees interviewed in this study – when asked if they had concerns about biodiesel - were most concerned about the potential impacts on the operation of the equipment. This is best summarized by the quote from a Holder operator, "If it's [biodiesel] better overall, then it's good, but the most important thing is that the equipment runs well."

Although securing participation was difficult in the early stages of the BWG, the survey results were generally very favorable toward the BWG process. Most people strongly agreed (70%) that forming a BWG group was necessary and that the goals of the group should focus on education and policy recommendations. An anonymous comment suggested "one good way to educate the public would be a Bio-diesel Expo". However, there was less enthusiasm for evaluating the need for future analyses regarding concerns relating to biodiesel. Only 40% selected strongly agreed for this statement: *A goal of the Biodiesel Working Group should be to evaluate the need for additional analyses regarding concerns relating to biodiesel.* Desire to participate on the BWG was also less (only 40% selected strongly agreed) and issues with participation were reflected in the anonymous comments. One anonymous response stated "would be happy to advise but think I could not fit in any more unpaid consult/volunteer projects at this time." Yet, although participation was shaky in the beginning meetings, once the collaborative biodiesel refinery project gained traction in early 2007, attendance and meeting participation grew stronger. Finally, the survey provided further evidence that BWG members showed support of the idea of manufacturing biodiesel in Keene (a survey option) and supported the goal of increasing the volumes and types of use of B20 within the City organization.

3.3.4 Key Results From Selected Interviews

In this section I include key results from interviews that provided insights into BWG participants' level of involvement, interest, or into other factors that influence decision-making regarding B20 use and the City/KSC research collaborative.

One key result from the semi-structured interview process was that the initial decision to use biodiesel in the City of Keene fleet originated primarily with Russell and separately from other City-supported environmental initiatives like the Cities from Climate Change program. When asked, the other respondents interviewed all point to Russell as being the critical component of the decision to use B20 in Keene. As Duncan Watson, Assistant Director of Public Works, and currently Russell's supervisor, puts it, "Steve Russell really took the initiative to get biodiesel into the fleet. Steve was the primary driver on this" (Watson 2007). Russell's leadership was a key contextual factor that resulted in the use of B20 in Keene in 2002.

Russell demonstrated a strong personal interest in environmental issues that influenced his decision to push for B20 use in his fleet. Evidence of Russell's pro-environmental attitude is apparent as soon as one walks into Russell's office in the DPW fleet services building: taped on the wall is the front page of the February 3, 2007 San Diego Tribune with the headline "Report on global warming: 'We have to do something.'" Also on the office walls are photos of alternative fuel vehicles, like a subcompact electric car, and a photo of Russell receiving the 2004 Governor's Award for Pollution Prevention. Russell's interest in biodiesel was strongly influenced by personal connections relating to environmental health. When Russell first started considering biodiesel, he remembered two women who had worked as secretaries for decades in the former City fleet services maintenance building. Both of them retired, and then died shortly thereafter from cancer. He also recalled the death of his sister's father-in-law from what he termed "the farmer's cancer" or colon cancer.

According to Russell (2006), the father-in-law sold his dairy farm, and then:

> A year and a half later he was dead of colon cancer. And my sister overheard the doctors from Dartmouth [hospital] say, 'Yeah that's the farmer's cancer, colon cancer.' I'm thinking to myself, now where's the correlation here? Why did this guy die of cancer? Now there may have been a million other things in

> his environment that may have caused that… but what's the odds he sits on a diesel tractor with a stack sitting in front 8 hours a day, mowing the fields, just on the tractor, all the time. I'm thinking, "Holy Mackerel," maybe this thing with diesel, there's some merit to this. Yeah, I got ladies [in Keene's former fleet maintenance office] dying of cancer and I don't know what kind of cancer it was, but there's some correlation."

For Russell, use of biodiesel was one way to make the air cleaner by reducing the pollution from diesel exhaust. As he explained to a local newspaper reporter in 2003, "I think a lot of people don't even know we are burning it and it's cleaning the air. You pull a truck into my shop now and you don't even know its diesel" (Cohen 2003). Therefore, use of biodiesel combines Russell's pro-environmental attitude and leadership qualities with a sense of personal responsibility to make a positive change in the workplace.

Another key result from the interview process was that general support for environmental projects should be translated into tangible actions for any project to be successful. The BWG needed to produce tangible outcomes, not just talk about them. Duncan Watson, an original BWG member and Assistant Director of Public Works and Solid Waste Manager, felt it was important to make biodiesel more available in the region and to do so by bringing biodiesel users and distributors together to increase local supply, increase local demand and thereby lower local biodiesel costs. While Watson (2007) noted that, "Environmental initiatives are very well received in Keene" he stressed the importance of action: "we could sit around and brainstorm all day long on about all the great things we can do with biodiesel but if the distributors themselves don't commit to distributing biodiesel in ways that make it so that regular folks can use it, all they're going to be are good ideas." Watson (2007) emphasized the need for the Biodiesel Working Group to avoid "paralysis by analysis" by adding: "You need someone to take… and this is something for the biodiesel working group… you need somebody who can take some of these ideas… synthesize them to some degree… and see if some of them can be initiated to making them real."

Tangible actions also must consider available budgets. Interview data revealed that environmental initiatives in Keene, including and beyond the use of B20, must be cost-justified to succeed. Mayor Blastos (2007) recalled when the City Council initially voted against use of B20, due to its higher cost: "It wasn't until we were having a budget hearing [in 2002 for 2003/2004 budget] and Steve came to us and said, 'Biodiesel fuel costs $6000 more' for the limited program we had at the time. The Council couldn't see the justification of spending $6000 extra, so they took it out. Hence Steve came back again and tried to tell us the advantages, and the Council bought right into it." The increased funding for B20 was eventually supported and has been supported since 2002. Pro-environmental initiatives will not be supported if the economics are seen as too controversial or if economic benefits are not clearly understood. As summarized by Watson (2007): "If we can do these types of things, reduce emissions, reduce our cost of disposal and recycle things, those are things people can get their hands around and ultimately they will support them...as long as we can make the business cases for them."

Implementation of increased biodiesel use can be further hampered by other external constraints, such as regulatory barriers (such as ULSD mandates) or simple lack of availability. These barriers can be difficult to overcome, even if the desire to promote biodiesel is strong. As noted by Watson (2007):

> My father and I, we own a gas station that has diesel fuel and our supplier doesn't have the ability to drop small drops that we would need. We have a 500 gallon tank. We would probably convert and sell biodiesel if it were available to us. It's simply with our distributor, it's not available right now.

The semi-structured interviews also revealed that local experience with biodiesel combined with the exposure assessment results led to near universal support for increased use of the fuel by the City of Keene. Additionally, although the increased organic carbon results were broadly disseminated and the KSC research team related the concern and need for additional research to investigate what was in this fraction, there was little to no concern among other participants about long term health risk related to biodiesel. This sentiment is captured by Watson (2007):

> Some of the findings we saw through the research was interesting… it answered some questions and pointed arrows in other directions. I think overall the general direction was positive towards biodiesel and it encourages further use of it. I mean my main concern comes from a practical standpoint, you know. How can we get the availability of biodiesel consistent, cost effective and be able to integrate it into our operation on a long-term basis? Those are the sort of the nuts and bolts. I mean I think I don't need to be sold (emphasis) any further on biodiesel…

Clevis Linwood (2007), DPW fleet services garage foreman, was likewise convinced by his personal experience that biodiesel is healthier than diesel:

> When the trucks run in the building, some of our older trucks used to smoke a lot. You'd get a heavy odor of diesel fuel, diesel smell. With the biodiesel, you don't get that at all. The smell is completely gone. It helps all the mechanics… plus up here we're in an enclosed environment, pretty much… In the afternoon [I] used to get groggy, pretty tired. You get that a lot from the kind of work we do, but a lot of that's gone down, now, or some of it's even gone away… I attribute a lot of that to the biodiesel.

The data from the semi-structured interviews supported increasing biodiesel use in Keene. The support came from personal experience or the exposure assessment results or both. Additionally, most participants generally supported the BWG goals of increasing B20 use by either working with distributors or making it in Keene. Almost all participants in the study felt biodiesel was better for health and the environment, or at least did not think it was as harmful as diesel fuel. These last points were also captured by KRC workers. One KRC worker stated about biodiesel, “[I’m] not really concerned about health vs. gas or kerosene. It is probably the same.”

3.4 Operative Research Question: Does Applying an Analytic-Deliberative Approach to Understanding B20 Exposures Lead to Improved Decision Making?

The results from each of the Central Research questions #1, #2, and #3 were used to link back into the operative research (or linking) question. Applying an analytical-deliberative approach to understanding B20 exposures led to improved decision making in a number of ways as indicated in the bullets below.

- Applying an analytic-deliberative approach fused local and technical knowledge to enhance the performance and quality of the exposure assessment analysis, thus increasing understanding of B20 environmental and occupational exposures.
    a. The initial self-reported improvement in City and KSC workplace air quality and health was unique local knowledge that inspired the technical exposure assessment hypotheses.
    b. The City and KRC staff contributed important improvements to the exposure assessment strategy for researchers, such as selecting the KRC as a remote and ideal monitoring site, adding previously unknown high diesel exhaust exposure areas to the field sampling plan, and eliminating Friday as an inefficient sampling day, saving resources. The BWG members also identified that personal monitoring (or employees wearing vests with

instrumentation) would be ineffective due to high employee variability in tasks, so the researchers instead measured pollutant levels in work areas.

c. The exposure assessment results indicated a robust, significant reduction in $PM_{2.5}$ from B20 use, across all monitoring locations and equipment activity levels. Elemental carbon levels were also decreased for the overall site, though not significantly reduced at each perimeter. The most dramatic pollutant reductions consistently occurred for the occupational exposure represented by Perimeter #4, the small front end loader. The $PM_{2.5}$ and EC results in particular legitimized the local knowledge of observed cleaner air, as summarized by Linwood (2007): “In the afternoon [I] used to get groggy, pretty tired. You get that a lot from the kind of work we do, but a lot of that’s gone down, now, or some of it’s even gone away… I attribute a lot of that to the biodiesel.”

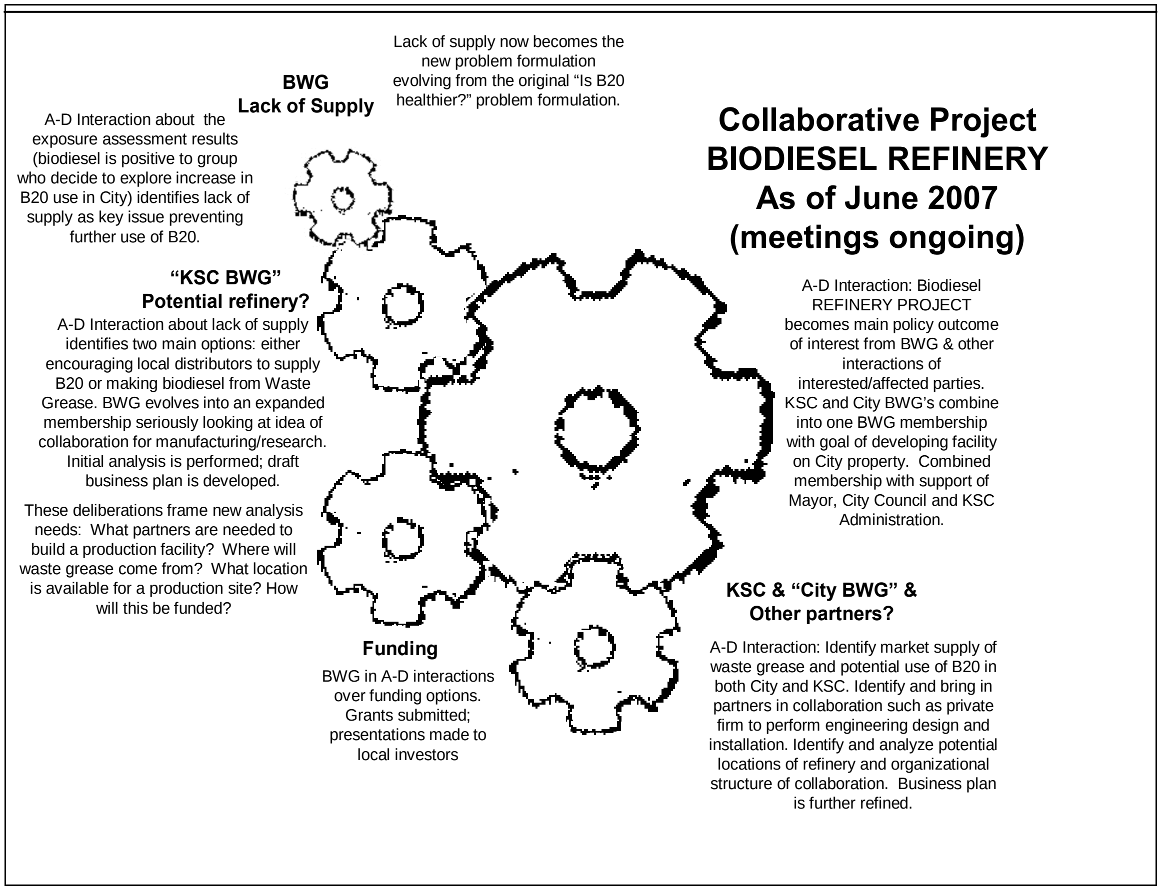
d. The exposure assessment results reduced scientific uncertainty about the impact of B20 blends on environmental and occupational exposures. The data from this phase made a novel scientific contribution to identified gaps in biodiesel exposure research.

e. Expanding participation in the BWG and the exposure assessment increased non-expert collaboration in the process of scientific inquiry. BWG members provided specific feedback to make the dissemination of the exposure assessment results more accessible to the general public. KRC workers enjoyed participating in the exposure assessment phase. One worker noted “I think it’s important. We liked it. People asked us what are the kids doing and we could tell them about the biodiesel testing." Another KRC site employee added, "[The] public saw we cared about health and environment here at the Recycling Center and learned about biodiesel a little."

- Applying the A-D model increased the policy relevance of the results and led directly to novel policy outcomes.
    a. The biodiesel production/testing/research project was a major policy outcome of the formation of the BWG and connection to exposure assessment process. Although the BWG did not identify community biodiesel manufacturing as a goal back in 2006, initial BWG meetings acted as a "spark" for the subsequent actions and deliberations within the KSC and City organizations. The BWG provided a forum for open discussion of the exposure assessment results and group reflection on potential policy outcomes. These deliberations directly led to Central research questions #2 and #3. Without the BWG forum, dialogue would have likely stayed contained to emails and informal conversations about the research results. The very act of setting up BWG meetings often led to interesting conversations and action plans. Discussions between BWG members inside and outside BWG meetings expanded membership, increased transparency of decision-making, and maintained the institutional momentum of the Monadnock Biodiesel Collaborative project as a main policy outcome. This dynamic interaction of analysis and deliberation can be envisioned in Figure 3.23 as a series of gears turning together to move the Monadnock Biodiesel Collaborative idea of a Keene-based biodiesel production/testing/research facility forward.

b. Since there was overlap in the BWG/exposure assessment process by intentional integration of analysis and deliberation, problem formulation and other A-D steps moved more quickly as BWG members were aware of and understood technical information associated with the decision to expand biodiesel use.

c. Public outreach presentations also made the results relevant in those settings, and allowed the study participants to engage in a wider discourse about biodiesel, identifying audience questions and concerns.



Collaborative Project BIODIESEL REFINERY As of June 2007 (meetings ongoing)

BWG Lack of Supply

Lack of supply now becomes the new problem formulation evolving from the original "Is B20 healthier?" problem formulation.

A-D Interaction about the exposure assessment results (biodiesel is positive to group who decide to explore increase in B20 use in City) identifies lack of supply as key issue preventing further use of B20.

"KSC BWG" Potential refinery?

A-D Interaction about lack of supply identifies two main options: either encouraging local distributors to supply B20 or making biodiesel from Waste Grease. BWG evolves into an expanded membership seriously looking at idea of collaboration for manufacturing/research. Initial analysis is performed; draft business plan is developed.

These deliberations frame new analysis needs: What partners are needed to build a production facility? Where will waste grease come from? What location is available for a production site? How will this be funded?

A-D Interaction: Biodiesel REFINERY PROJECT becomes main policy outcome of interest from BWG & other interactions of interested/affected parties. KSC and City BWG's combine into one BWG membership with goal of developing facility on City property. Combined membership with support of Mayor, City Council and KSC Administration.

Funding

BWG in A-D interactions over funding options. Grants submitted; presentations made to local investors

KSC & "City BWG" & Other partners?

A-D Interaction: Identify market supply of waste grease and potential use of B20 in both City and KSC. Identify and bring in partners in collaboration such as private firm to perform engineering design and installation. Identify and analyze potential locations of refinery and organizational structure of collaboration. Business plan is further refined.

Figure 3.23: Interaction of Analysis and Deliberation for Novel Policy Outcome in Keene/City of Keene Research Collaboration

- Participation in A-D processes increased trust among collaborators. Town/gown relationships were enhanced.
    a. While there was a brief time period when both the College and the City had separate "BWG" project teams to evaluate the biodiesel production/testing/research project, the teams soon merged back into one team. Meetings were held every two weeks throughout the summer of 2007.
    b. Public comments about the collaboration were positive from decision-makers in the community. As Mayor Blastos stated after the KSC presentation to City Council, "This can be such a savings to our community, as well as a benefit to us. We would be helping ecology all the way around. I can't speak highly enough of this program" (Berry 2007).
    c. Community interactions with KSC students during the exposure assessment were positive. As one KRC employee stated, "[It was] good to see the college kids doing something productive, working and trying to learn."
    d. Organizational capacity increased. KSC and the City jointly submitted a grant to the Department of Energy in 2006. KSC researchers submitted grants to the Environmental Protection Agency, National Institute of Health, the Department of Energy, and private foundations. Awards were received from some of these sources, which increased project momentum.
- A-D processes fostered co-learning and active collaboration.
    a. BWG members learned about diesel/biodiesel exposures and KSC researchers learned about biodiesel's operational characteristics. This increased overall understanding of B20 impacts and implications for both groups.

b. BWG members gave feedback to KSC on technical information in presentations to help disseminate results in useful terms for the general public.
c. City of Keene staff and KSC staff co-presented at numerous stakeholder presentations/shared presentation materials.
d. KRC employees contributed additional ideas for creative dissemination of the exposure assessment results; the KSC student team took on the project based on the idea of creating a slide show presentation for Channel 8, a local cable channel. This was aired the week of July 4, 2007.

3.4.1 Key Triangulation Results

Results from the Biodiesel Attitude Survey, document analysis and semi-structured interviews indicated that these participants supported opinions and decisions made in the BWG forum at a meta-level. For example, BWG members supported the idea of increasing the use of B20 in Keene. No opinion was identified via triangulation methods that did not support this meta-goal, although semi-structured interviews indicated that people within the City and KSC organization may have had different strategies to reach the goal. For example, many BWG members initially supported the idea of increasing B20 availability via active collaboration with distributors to motivate them to make biodiesel available. This strategy had more traction and support than manufacturing biodiesel in early meetings. However, as discussed previously, interviews with distributors identified a number of barriers to this approach, and BWG members soon came to support the Monadnock Biodiesel Collaborative. Triangulation methods did not identify any conflicting opinions such as BWG members against the idea of a biodiesel production facility.

Triangulation of data was consistent and served to increase the confidence in the results seen in this study. Other examples where triangulation of data revealed consistent results: almost all BWG members and other participants like KRC employees cited increased biodiesel education as an important goal. This came through via interviews, meeting minutes, and the Attitude Survey. The results of the Biodiesel Knowledge Survey supported that increased knowledge and education was a needed goal. Another example is that regardless of research concern about the increased organic carbon results, almost all other participants were not concerned or did not associate any health risk with biodiesel exhaust exposure.

Although triangulation methods identified areas of conflict in the study, such meeting minutes/journal notes identifying the tension between KRC workers and management, triangulation of data did not find contradictory results to the main conclusions noted above. Triangulation of data was also useful in assessing rival hypotheses and identifying limitations in the overall study approach. These uses of triangulation of data and their contributions to evaluation of the study will be reviewed in the discussion chapter.

Discussion

4.1 Discussion of Collaborative Exposure Assessment Results: Biodiesel as a Technical Solution to the Problem of Health Risk from Diesel Exhaust Exposure

4.1.1 B20's Impact on Local and Workplace Air Quality

Compared to use of petroleum diesel, the use of B20 at the Keene Recycling Center resulted in significantly lower $PM_{2.5}$ exposures, some significantly lower elemental carbon (EC) exposures, significantly higher organic carbon exposures (OC), and higher nitrogen dioxide exposures. At first glance, these mixed results may seem to indicate that there is limited promise to the use of B20 as a technical solution to the problem of diesel exhaust exposure. But a deeper analysis shows otherwise; in this section I discuss the meaning and implications of the exposure assessment results.

Fine particulate matter exposure is well associated with numerous acute negative health effects, ranging from asthma, to arrhythmia, to increased emergency room visits, to premature death (EPA 2003b; Lippmann et al. 2003). Chronic low level exposure for healthy adults to high levels of fine particulate matter (similar to those seen in urban areas) is associated with a predicted reduction in total life expectancy (Pope 2000). Fine particulate matter exposures are even more harmful to children, elderly, and those with preexisting heart or lung disease. Diesel exhaust is an important source of fine particulate matter in many parts of the country, especially urban airsheds (EPA 2002a). Due to the body of evidence connecting fine particulate matter exposure and acute/chronic health effects, any intervention that could reduce fine particulate matter exposures from diesel engines would be highly relevant to environmental, public and occupational health policy. Any reduction in fine particulate matter exposures would be expected to have tangible and immediate improved health benefits for an exposed population.

Comparing diesel vs. biodiesel exposures, use of B20 at the KRC site resulted in consistent reductions in fine particulate matter levels in both the workplace and near field locations. The total KRC site mean during B20 use was significantly less (60.4%) then during petroleum/low biodiesel blend use. When the "transition fuel" days were removed from the analysis, the total KRC site mean for $PM_{2.5}$ was significantly less (72.9%) during B20 operation than during 100% petroleum diesel operation. The decrease in $PM_{2.5}$ after switching to B20 at the site was observed across all perimeter locations and during both high and low equipment activity levels.

While a reduction in $PM_{2.5}$ was expected from B20 based on tailpipe emissions literature, the magnitude of the reduction observed in this study was unanticipated. The literature consistently supports significant reductions in particulate matter in tailpipe emissions when biodiesel blends are compared to petroleum diesel (EPA 2002b; Wang et al. 2000; Graboski and McCormick1998; Bagley et al. 1998; Sharp et al. 2000a; Chen and Wu 2002; McCormick et al. 2006). However, our study exceeded the higher end of reported particulate matter reductions in the literature (between a 30-40% reduction) that resulted from burning a B20 blend. It is possible some of the difference in magnitude is related to the different measurement methods used in tailpipe emissions studies, which typically measure a larger diameter particulate matter ($< PM_{10}$).

Yet the reduction in fine particulate matter remains an intriguing question: why was a 60% to almost 78% reduction (at P4) in $PM_{2.5}$ seen from use of only a B20 blend? This was actually a common question my colleagues and I were asked during both BWG deliberations and public forum presentations. There are multiple explanations. First, the chemistry of biodiesel fuel is fundamentally different than petroleum diesel. Unlike petroleum diesel, biodiesel does not contain aromatic hydrocarbons or sulfur, but is made up of methyl esters, which have oxygen embedded within the hydrocarbon chain. Biodiesel has a higher cetane value than diesel – due to its higher oxygen content in the fuel. The increased oxygen content enhances combustion, thereby reducing soot formation, which when combined with the lack of sulfur and aromatics results in lower overall particulate matter mass. Other researchers have hypothesized that the increased oxygen content in biodiesel could result in more efficient combustion, reducing particulate matter (Wang et al. 2000). The enhanced combustion hypothesis to reduce particulate matter is also supported by this study's significant 22.4% reduction in KRC total site elemental carbon (carbon soot) levels from B20 use. Carbon soot is the core of diesel particulate matter. Use of B20 immediately translates to a 20% reduction in sulfur, which is also part of $PM_{2.5}$. Reduced aromatics in the B20 fuel as well as lack of metals within the biodiesel portion of the fuel also would be expected to reduce the total mass of $PM_{2.5}$ as seen in this study.

This study measured exposures from nonroad engines, typically dirtier than onroad engines. The nonroad engines in this study were often operating under load which also produces more particulates. The higher exposures can lead to the potential for more dramatic particulate reductions for an oxygen rich fuel like biodiesel. Connecting back to the local observations of Keene workers, the 60 to 78% overall reduction in $PM_{2.5}$ mass seen in this study could be enough to reduce acute impacts like eye irritation and headaches, leading to the anecdotal observations made by workers in both the City and KSC organizations.

However, while the exposure assessment showed a decrease in $PM_{2.5}$ and EC, there was a highly significant 370.4% increase in organic carbon levels. Using other sampling and analytical methods, the soluble organic fraction of the PM has generally been reported as higher for biodiesel (Bagley et al. 1998; Graboski and McCormick 1998). As biodiesel fuel has a higher boiling point than diesel, less biodiesel will be vaporized and it is likely more unburned fuel will condense on any particles exiting the tailpipe. While higher organic carbon levels were expected, the highly significant increases highlight the need for additional research. Are the increases in organic carbon simply unburned biodiesel fuel, which is relatively nontoxic, or other species of hydrocarbons from incomplete combustion products?

For diesel particulate matter, adsorbed organic species are of particular health concern because many of these species have been found to be mutagenic (HEI 2002). The long term implication of chronic exposure to adsorbed, potentially toxic species on particulate matter may not be immediately noticeable. This may be especially problematic in local use contexts, like the City of Keene, where participants did not associate any health risk with biodiesel exposure, even after being informed of the organic carbon results. Further research in the speciation of the organic carbon is a recommendation from this study. Other researchers have stressed that higher soluble organics in biodiesel indicate a pressing research need to conduct more long term health effects research for biodiesel (Swanson et al. 2007; Kado and Kuzmicky 2003).

The PM and EC/OC results have been interpreted to propose a conceptual model of the difference in diesel and biodiesel particulate matter composition. This model is shown in Figure 4.1 below. Emissions from the tailpipe include unburned fuel and lubricating oil, and combusted fuel and lubricating oil. This separates out into broad two phases: vapor and particle. Vapor phase would include inorganic gases such carbon dioxide and nitrogen dioxide (among others), and organic gases like formaldehyde and benzene (among others). As reviewed in Chapter 1, particles from diesel emissions are chemically complex but consist of two major parts: soluble (adsorbed hydrocarbons) and insoluble (soot plus other solids). The insoluble includes the elemental carbon core and the soluble includes the organic adsorbed fraction.

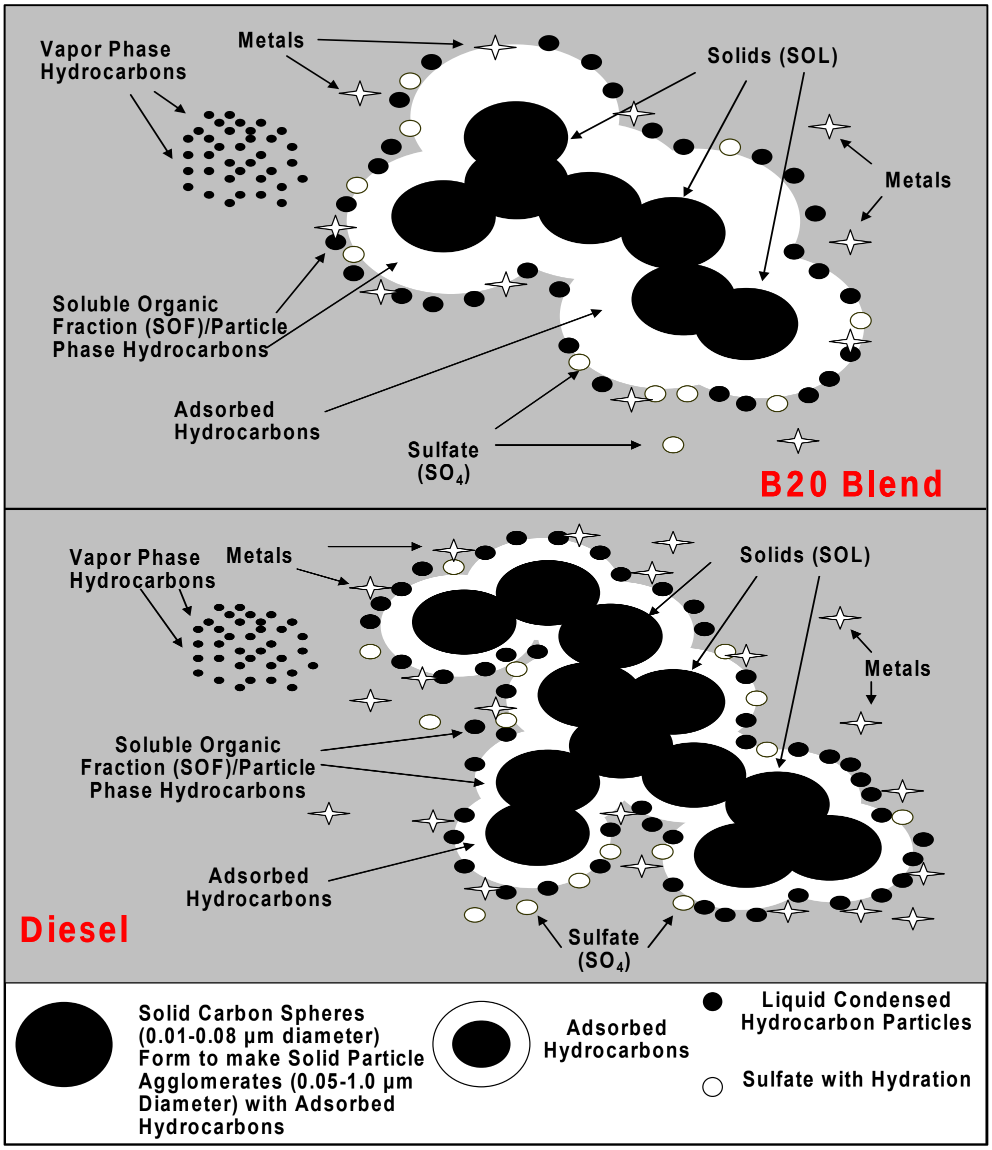


Figure 4.1: <u>Traviss/Treadwell Conceptual Model Comparing Diesel Particulate Matter and Biodiesel (B20) Particulate Matter (Adapted from HEI 2002)</u>

The conceptual model represents the results seen in the collaborative exposure assessment (as well as suggested in the tailpipe emissions literature) by illustrating how there can be a decrease in $PM_{2.5}$ mass but an increase in organic carbon fraction. As there is less solid carbon due to decreased elemental carbon, as well as less expected metals, aromatics, and sulfates, the overall mass is decreased in biodiesel particulate matter (top diagram) compared to petroleum diesel particulate matter (bottom diagram). The adsorbed organic fraction – or white area in the diagram - is increased for biodiesel particulate matter. This suggests either that the insoluble fraction makes up most of the particle mass in DPM or that the biodiesel organic fraction is substantially lighter in mass compared to diesel organic fraction. A lighter organic fraction suggests the composition of the biodiesel soluble organic fraction may be quite different than petroleum diesel. This is an area of future research. Emerging studies indicate biodiesel emissions contain less PAH's than diesel (Correa et al. 2006).

The above schematic also assumes that the actual particle size (mean aerodynamic diameter) remains the same. This may or may not be the case. Chen and Wu (2002) found a soy based B100 blend (compared to diesel) produced emissions with a 24-42% decrease in total particle number, a 40-49% decrease in total particle mass, but no impact on mean particle diameter. However, Tsolakis (2006) compared diesel to rapeseed based B100 emissions and found a total mass reduction but an increase in the number of ultrafine particles. Jung et al. (2006) also found the size of the particle decreased when B100 was burned. Ultrafines have greater surface area available for adsorption of organics. Diesel particulate matter aggregates with high surface area are very efficient at adsorbing semi-volatile organic compounds, polycyclic aromatic hydrocarbons, and nitro-polycyclic aromatic hydrocarbons (HEI 2002). Understanding biodiesel particle morphology and the toxicity of adsorbed species is an area for future research.

Finally, due to the local scale of the exposure assessment, physical and chemical transformation processes were not expected to have a substantial impact on the measured particulate matter or elemental or organic carbon. However, there are exceptions. Smaller particles emitted from the exhaust tailpipe may combine upon exiting the tailpipe into larger particles. In this way, particle size may increase with increasing distance away from the tailpipe. There was some evidence to support this hypothesis. Elemental carbon analysis was performed at four perimeter locations but the highest diesel levels and the associated highest percent reductions occurred at P2 (inside main floor) at 29.2% and P4/MS1 (in cabin small front loader) at 26.2%. P2 and P4 are physically closer to the equipment tailpipe sources so it was expected these would be higher. The more remote sampling locations of P3 (outside main door) and P1 (conveyor belt) had lower EC levels for diesel and lower associated B20 reductions at 7.7% and 5.9%, respectively.

In comparison, the $PM_{2.5}$ diesel levels and B20 reductions were relatively consistent across P1, P2 and P3 (50.6%, 57.6%, and 53.9% respectively), although the reduction at P4 was more dramatic at 77.6%. What could explain this? Elemental carbon sampling methods prescreened any particles greater than 1.0 micron, and $PM_{2.5}$ at 2.5 micron. Thus as the particles exit the tailpipe, one possibility is that the smaller particles are either combining to form larger ones by the time they reach the monitors, or they are not reaching the more distant monitors due to physical deposition.

4.1.2 Review of other Literature on Diesel Exhaust Exposure Assessment – How the Results of this Study Compare

In this section, I compare the diesel exposures from the collaborative exposure assessment to results from other comparable diesel exposure assessment studies in the literature. While there were no other studies that directly measured exposures at recycling centers, there were workplaces with similar high diesel exposures for workers such as warehouses, loading docks, electrical utilities and mines. These results are summarized in Table 4.1 below.

AUTHOR	**STUDY**	**DESCRIPTION**	**EC** $\mu G/M^3$	**OC** $\mu G/M^3$	**PM** $_{2.5}$ $\mu G/M^3$
Traviss & Treadwell et al. (pending)	Total Site Average at Recycling Center (nonroad equipment)	Biodiesel (B20)	4.8	27.0	92.4
		Diesel	6.2	5.7	233.3
Cantrell, Bruce K. et al 1997	Personal Concentrations of Dockworkers	Diesel Dock#1	23.2 GM	49.4 GM	n/a
		Diesel Dock#2	54.6 GM	138 GM	n/a
	Survey of Truckers	Dockworker	22.7 GM	n/a	n/a
		Mechanic	12.1 GM	n/a	n/a
		Road Drivers	3.8 GM	n/a	n/a
Shultz, Mark J. 2003	MSHA Dust Division- Carmeuse North America, Inc., Maysville Mine	B50 Area #1	175.4	52.6	n/a
		B50 Area #2	167.7	50.3	n/a
		Diesel Area #1	341.5	102.5	n/a
		Diesel Area #2	303.8	91.2	n/a
		B50 in Cab	163.1	48.9	n/a
		B50 out Cab	240.8	72.2	n/a
		Diesel in Cab	169.2	50.8	n/a
		Diesel out Cab	230.8	69.2	n/a
Kinney, Patrick et al. 2000	Harlem Sidewalks Pilot Study	Diesel Site #1	6.2	n/a	45.7
		Diesel Site #2	3.7	n/a	47.1
		Diesel Site #3	2.3	n/a	36.6
		Diesel Site #4	1.5	n/a	38.7
		Site Average	3.4	n/a	42
Levy, Jonathan I. et al. 2003	Roxbury, MA, (Diesel) Neighborhood Levels	Mobile	n/a	n/a	49
		Mobile Estimate	n/a	n/a	15
Zaebst et al. 1991	Diesel Comparison of OC/EC by Job	Dockworkers	23.5	45.2	n/a
		Highway	3.4	7.4	n/a
		Road Drivers	5.1	28.3	n/a
		Mechanic	26.6	55.9	n/a
		Total Average	14.3	33.8	n/a
Whittaker et al. 1999	Diesel Comparison of EC/OC by sample type	Bay	6	109	n/a
		Personal	4	60	n/a
		Lineman	3	58	n/a
		Winch Truck	4	65	n/a
Groves and Cain 2000	Personal & Background Bus Garage/Repair	Personal	39	109	267 PM4
		Background	43	90	211 PM4
Garshick et al. 2002	Long distance/short distance truckers, other workers (personal and work area)	Long distance	3.6	27.3	55.1
		Short distance	6.0	48.0	119.5
		Dockworker	7.4	87.1	278.8
		Winch Truck	3.6	56.4	152.4
Treadwell, Melinda et al. 2003	5 Northeast Locations (Diesel Exhaust Impact)	Diesel All Site Ranges	0.8-27	n/a	1-100

Table 4.1: Summary of Relevant Diesel Exposure Assessment Studies

The $PM_{2.5}$ and EC/OC levels determined in this collaborative exposure assessment were most similar to the studies performed by Whittaker et al. (1999), Garshick et al. (2002), and Treadwell (2003). In the Whittaker et al. (1999) study, researchers measured work area and personal breathing zone concentrations of EC and OC for various employee positions within an electrical utility company. Exposures were from diesel exhaust only. Linemen were workers who worked at elevation in a bucket but near diesel trucks; WTO's were winch truck operators. Exposures to EC ranged from 3 to 4 $\mu g/m^3$ and to OC from 58 to 65 $\mu g/m^3$. These tight ranges indicate a relatively high predictability to their work routines for these two job classifications. The KRC total site average biodiesel concentration measured for OC at 27.0 $\mu g/m^3$ (perimeter averages ranging from 24.8 to 29.5 $\mu g/m^3$) was much less than the 58 to 65 $\mu g/m^3$ reported by Whittaker et al. (1999) for diesel exposure. These researchers did not measure fine particulate matter in their study.

Garshick et al. (2002) did an extensive research sampling plan for workers in distribution terminals. This followed up on a warehouse terminal study similar to the Zaesbt et al. (1991) study in Table 4.1. All results were for diesel exhaust exposures only. Dockworkers (7.4 $\mu g/m^3$) and short distance truck drivers (6.0 $\mu g/m^3$) had the highest reported EC levels, and dockworkers (87.1 $\mu g/m^3$) and winch truck operators (56.4 $\mu g/m^3$) had the highest reported OC levels. Again, the collaborative exposure assessment was typically under these values, for both diesel and B20 exposures. However, diesel $PM_{2.5}$ exposures from the collaborative exposure assessment were higher than most of the $PM_{2.5}$ employee exposures in the Garshick et al. (2002) study. The KRC employees experienced exposures most similar to short distance truck drivers and winch truck operators, although the

KRC small front end loader operator experienced higher exposures to $PM_{2.5}$ than all the employees in the Garshick et al. (2002) study.

Treadwell et al. (2003) performed diesel exposure assessments using real time and integrated $PM_{2.5}$ sampling at 5 different industrial locations utilizing nonroad equipment. These work sites included building construction projects, a highway construction project, a lumber yard and farm operations. EC results ranged from 0.8 to 27 $\mu g/m^3$ and $PM_{2.5}$ levels ranged from 1 to 100 $\mu g/m^3$. Similar to the results in the KRC study (discussed in the next section), worker 24 hour exposures to $PM_{2.5}$ exceeded the National Ambient Air Quality Standard (NAAQS) by 2 to 3.5 times. Treadwell et al. (2003) estimated that as many as 200,000 workers across the Northeast may be exposed to harmful levels of $PM_{2.5}$. Besides also measuring occupational exposures to nonroad equipment, the KRC collaborative exposure assessment used similar methods and activity tracking techniques as those followed in Treadwell et al. (2003).

Another important observation from the research in Table 4.1 is the very high levels of EC, OC, and fine particulate matter in the workplace compared to the community studies. Kinney et al. (2000) conducted their study in Harlem, where asthma rates are among the nation's highest. These researchers determined EC levels ranging from 1.5 to 6.2 $\mu g/m^3$, and $PM_{2.5}$ levels of 36.6 to 47.1 $\mu g/m^3$. The researchers argued that Harlem community residents were at elevated health risk at these levels of exposure, which were much lower than levels experienced by the KRC site workers. Levy et al. (2003) measured $PM_{2.5}$ levels in a Roxbury community near Boston MA ranging from 15 to 49 $\mu g/m^3$. While these community exposure levels are higher than the EPA National Ambient Air Quality Standard of 35 $\mu g/m^3$, the exposures are much lower than those typically experienced by KRC and other workers, as evidenced by Table 4.1.

The discrepancy between acceptable exposure limits in the community and workplace are even more dramatic when examining the data from the 2003 Mine Safety and Health Administration report on diesel vs. biodiesel exposures. As of this writing, the MSHA study was the only other example of a biodiesel exposure assessment that was found during a literature search. The concentrations measured in the mine study were orders of magnitude higher than the levels at the KRC. EC work area samples in the mine ranged from 303.8 to 341.5 μg/m^3 during diesel use and 167.7 to 175.4 μg/m^3 in the same two work areas when the equipment burned a B50 blend (Schultz 2003). Use of B50 blends resulted in a decrease in the two work area levels of EC of 44.8 % and 48.6 %, respectively. It is important to note these were EC levels that were measured, not $PM_{2.5}$. Therefore measurements of $PM_{2.5}$, although not determined in the MSHA study, would be expected to be much higher. Interestingly, the MSHA study did not find substantial differences in OC between B50 and diesel use.

In 2007, MSHA promulgated a safe exposure limit of 400 μg/m^3 for TC (which is EC + OC). EC is regulated currently at 350 μg/m^3, and the TC limit is set to be reduced to 160 μg/m^3 by May 2008. While B50 helped dramatically reduce the work area EC levels in the mine compared to petroleum diesel fuel, the B50 exposures still appear to be far above agency targets. This MSHA target is far above EPA's reference concentration for diesel particulate matter of 5 μg/m^3 to prevent lung irritation, inflammation, and other harmful pulmonary health impacts. EPA's reference concentration (R_fC) is not specific as to measurement method, as is MSHA's limit which specifies use of EC (which indicates

NIOSH method 5040). Approaches to evaluate air quality against the EPA R_fC have been to evaluate EC only against the R_fC (underestimating DPM), combine OC and EC to determine DPM similar to the TC level recommended by MSHA, and to adjust EC by a numerical factor as done in Whittaker et al (1999) and Schultz (2003).

4.1.2.a B20 as a Viable Risk Reduction Option

Mining is a unique workplace scenario with unique ventilation challenges that contribute to much higher exposures than experienced by other occupations. In the KRC study, use of B20 did significantly reduce total site fine particulate matter and elemental carbon levels. The results of the study for $PM_{2.5}$ can be compared to the EPA National Ambient Air Quality Standard (NAAQS). In justifying the urgent need to reduce the NAAQS from 65 to 35 $\mu g/m^3$, EPA quantitatively estimated public health benefits in the range of 9 to as much as 75 billion dollars by the year 2020 from this action (EPA 2006). The health benefits were expected by the prevention of as much as 13,000 premature deaths in people with heart or lung disease, as well as prevention of 5000 nonfatal heart attacks, 7300 cases of acute bronchitis, 1200 emergency room visits for asthma, among other benefits (EPA 2006).

$PM_{2.5}$ levels at the KRC during diesel use ranged from a minimum of 28.5 $\mu g/m^3$ to a maximum of 1099.1 $\mu g/m^3$, with a median value of 285.3 $\mu g/m^3$. Due to the order of magnitude difference between environmental and occupational exposure limits, most of these 8 hour time weighted average values were far above safe environmental exposure levels (35 $\mu g/m^3$) but still well below acceptable occupational exposure levels (5000 $\mu g/m^3$). In adjusting the 8 hour average to a 24 hour average to compare to the NAAQS, <u>KRC workers potentially experienced 24 hour average fine particulate matter exposures during diesel fuel</u>

use ranging from 80 to 100 μg/m^3. In calculating this range, we took a very conservative approach and assumed only ambient background exposure levels for the remaining 16 hours. These 24 hour averages indicate workers at the KRC experienced $PM_{2.5}$ exposures during diesel operations that were almost 3 times higher than EPA's National Ambient Air Quality Standard (NAAQS) of 35 μg/m^3.

As shown in Figure 3.3, B20 blends were able to reduce 24 hour average fine particulate matter levels at the KRC to levels below the NAAQS. The B20 24 hour average $PM_{2.5}$ levels were less than the NAAQS. These results indicate B20 use can assist in helping communities meeting local air quality standards for $PM_{2.5}$. For environmental health and safety professionals, businesses, and communities looking to reduce fine particulate matter health risk associated with diesel exhaust exposure, B20 is a risk intervention option to reduce particulate matter exposures at a workplace, local and possibly regional scale. B20 offers particular promise for workplace risk reduction, as this study and others have shown that workers typically experience higher and more intense $PM_{2.5}$ diesel exposures that are orders of magnitude higher compared to the general public, even populations in polluted urban areas. For state regulators in non-attainment areas for fine particulate matter, the collaborative exposure assessment demonstrated B20 blends could be a useful compliance tool.

It is more complicated to compare the KRC study's EC/OC levels against the EPA R_fC of 5 μg/m^3 for whole diesel exhaust. The R_fC is a 24 hour average that is considered a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Since the ambient community background levels of EC and OC were not available for this study, it is not possible to conclusively determine if the 24 hour level of 5 $\mu g/m^3$ was exceeded. However, the consistent reduction in EC by a B20 blend is also noteworthy and indicates the promise of B20 blends in reducing health risk associated with EC. Another important note: even the highly significant B20 OC levels determined in the KRC study were still lower than almost all of the other OC levels reported in Table 4.1. This suggests that when viewed in context of the diesel exposure assessment literature, B20-related OC levels may not be worse than diesel associated OC levels in the general workplace. Of course, this must be evaluated further, and would not necessarily be true if there were more potent species within the B20 OC fraction.

4.1.3 Nitrogen Dioxide

The other side to the promise of B20 reducing fine particulate matter exposures is the associated increase in NO_x. The PM/NOx tradeoff predicts that lower PM will likely result in higher NOx. The EPA (2002b) meta-analysis of tailpipe emissions data indicated burning B20 would be expected to increase NOx by 2% and burning B100 by 12%. These increases were statistically significant. Sharp et al. (2000a) also showed NO_x levels increased significantly with biodiesel compared to petroleum diesel. Other tailpipe emissions studies have shown no significant difference or a slight (but not significant) increase in NO_x generation from B35 and B20 use (Wang et al. 2000 and Durbin et al. 2000). Although these studies have all measured NOx in the tailpipe, they have recruited different engine types, compared different fuels (B20, clean diesel, B35) and followed different emissions testing protocols, making interpretation of the impact of biodiesel fuel on regional NOx levels challenging.

The scientific and policy concern about NO_x is due to its role in smog formation. NOx, which is typically measured as nitric oxide and nitrogen dioxide, is a precursor to ground level ozone. There are a number of complex chemical reactions (see Figure 4.2) that participate in smog formation and scientific debate continues on the role of NOx . Lawson (2003) contends that the "weekend effect" or the lack of ozone reduction in urban airsheds like Los Angeles over the weekend when traffic is reduced indicates the role of NOx is more complex than initially thought. Lower NOx levels over the weekend may actually shift reaction chemistry to paradoxically favor increased ozone formation. Even drastic NOx reductions may not ultimately impact ozone levels (Lawson 2003). Scientific uncertainty has created confusion for policy-makers in how to reconcile these contradictory findings.

Overall, policy-makers have been cautious in embracing biodiesel in light of the EPA (2002b) report. Any fuel that could increase NOx levels poses a practical dilemma for policy-makers in those regions like the Northeast, Southern California and Texas which are in non-attainment with ozone NAAQS. Texas, which has a number of counties in non-attainment for ozone pollution, has considered (though not implemented) a ban on biodiesel in part due to the predicted NO_x increases (Schmidt 2007). However, Texas' political economy and the state's relationship with the oil industry may also be factors in this cautious approach to biodiesel.

The above discussion illustrates how NOx is still an important issue in the debate over the benefits and challenges of widespread biodiesel use. A few points need further emphasis. This study did not measure tailpipe NOx but rather measured only indoor ambient concentrations of nitrogen dioxide in the workplace at Perimeter 2. The measured NO_2 concentrations were orders of magnitude less than recommended occupational exposure limits. The KRC results indicated B20 use resulted in an 18.5% increase in nitrogen dioxide compared to diesel fuel use. Consideration of the impact of activity and the transition fuel days still resulted in higher measured levels of nitrogen dioxide during B20 use compared to petroleum diesel operations. For example, comparing only days of high activity, the average NO_2 concentration increased 65.6% during B20 fuel use. However, none of the data analyses resulted in statistically significant increases. This is likely due to the wide variability in the data set as indicated by the high geometric standard deviation. The NO_2 geometric standard deviation for diesel ranged from 1.89 to 2.54 and for B20 ranged from 1.89 to 2.11. In addition, some of the analyses such as the high activity day subset involved a small sample set or small n.

Therefore, interpreting the nitrogen dioxide results from this study must be done with caution. Other researchers have recently challenged the EPA (2002b) report, stating the data was biased toward a specific engine type, and more recent tests indicated that there appears to be no net effect of B20 on NO_x levels, or at most a +/- 0.5% effect (McCormick et al. 2006). Additional tailpipe emissions testing using soy based B20 in bus, coach, and truck engines resulted in an average NO_x change of 0.6 +/- 1.8% (McCormick et al. 2006). This change was not considered to be statistically significant. Morris et al. (2003) have suggested that even using the EPA's (2002b) predicted 2% NO_x increase, the air quality impact of a 100% market penetration of B20 in several urban areas would result in ozone increases of less than 1 ppb. This raises the larger question of whether aggressive NOx control is the best approach to reduce ozone, a point also raised by Lawson (2003).

Since the collaborative exposure assessment did not measure NOx (NO + NO_2) but only NO_2 , and measured exposures not emissions, additional caution in comparing these results to the existing literature is necessary. It is possible the ratio of NO/NO_2 is changed by burning B20, but overall NO_x levels may remain relatively unchanged. I measured NO_2 because it is a human health hazard at lower concentrations than NO and it is the start of a key chain reaction in ozone formation, as shown in Figure 4.2 below. The NO_2 dataset also experienced the highest environmental variability of any parameter measured in this study. This can be observed by visual examination of the NO_2 boxplots in chapter 3, indicating widely spread distributions for both diesel and B20 datasets, making interpretation challenging. This wide spread was not seen in fine particulate matter or EC/OC boxplots. One avenue of inquiry: what could be contributing to this variation or spread in the NO_2 boxplots?

. Chemical transformation processes are suspected to have impacted the NO_2 results. The boxplots all show a wide spread in the NO_2 data, regardless of activity or time of day. The boxplots in Figures 3.15 and 3.17 are particularly intriguing because they show a very wide spread in the afternoon data set for B20 days. While low activity has been shown in Chapter 3 to be a contributing factor in the wide spread of the box plots, NO_2 is also subject to a number of interconversion reactions as shown in Figure 4.2. Typically more NO is emitted from diesel exhaust than NO_2 in a ratio of 35% NO_2/65% NO (NIOSH 1976). In the presence of the other hydrocarbons emitted in the exhaust, radical species that are formed in ambient air will react quickly with NO to form NO_2. After NO is depleted by these reactions there is usually a temporary increase in NO_2, which subsequently declines when NO_2 reacts with radical species such as the hydroxyl radical to form HNO_3 (Manahan 2000). NO will also react with ozone (O_3) to form NO_2. Therefore, days with high temperatures and small increases in background ozone levels can lead to increased NO_2 formation. However, the major transformation for NO_x is the conversion to gaseous HNO_3 via reaction of NO_2 with hydroxyl radical (Winer and Busby 1995).

The atmospheric halftime of NO_2 and NO ranges from 2 minutes to 2.5 days depending on concentrations of radical species present (Winer and Busby 1995). In the KRC study, radical species were expected to be plentiful, based on the indoor location and lack of forced ventilation. NO_2 will also photodissociate or split up in sunlight. All this information supports a conclusion of waxing and waning NO_2 levels at the KRC from chemical transformation processes, with NO_2 levels increasing by late afternoon then decreasing over the evening period. For future studies, to better understand and compare diesel to biodiesel exposures of NO_2, samples should be collected in the early morning period only, before these atmospheric chemical reactions become prominent.

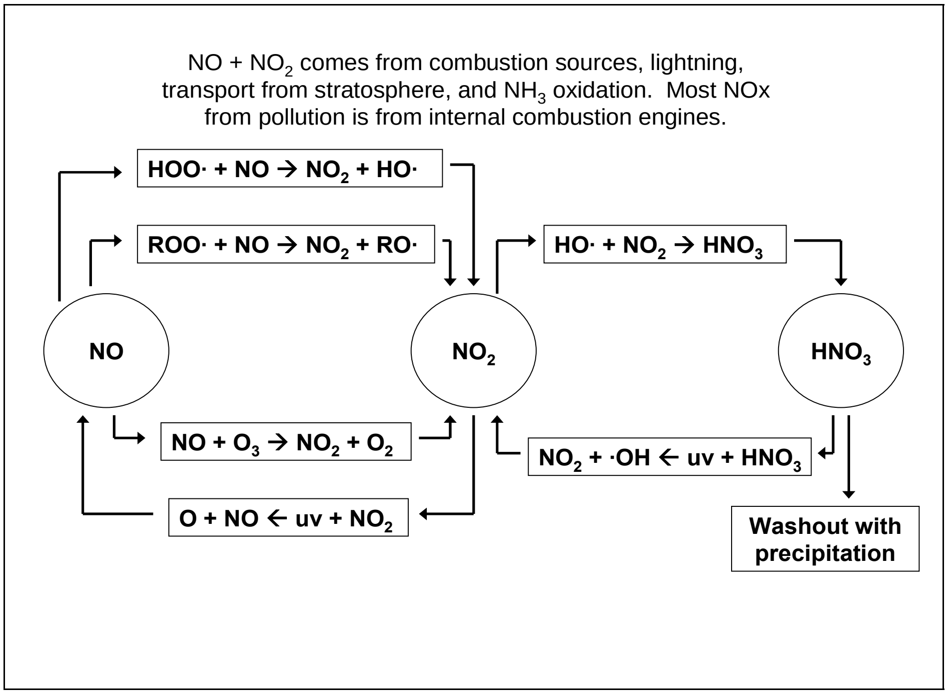


Figure 4.2: **Key Atmospheric Chemical Reactions of NO + NO_2 Showing Interconversion between Species (Source: Manahan 2000, p. 341)**

4.1.4 Benefits and Challenges of the Exposure Assessment

A main benefit of exposure assessment studies versus tailpipe studies is that exposures are more closely related to human dose and associated health impacts. Exposure profiles can be characterized as acceptable or not acceptable by comparing them to existing regulatory limits to protect public health. For example, the KRC exposure assessment was able to demonstrate reductions in $PM_{2.5}$ from use of B20 that lowered 24 hour exposures below the recommended NAAQS for fine particulate matter. Regulatory limits are a useful decision-making approach to determine whether exposures are at a harmful level.

While computer models attempt to predict what lab-measured tailpipe pollutants will translate to in human exposure levels, the only way to ultimately validate the computer model and understand the dose/response relationship is to actually measure what people are breathing. Exposure assessments measure pollutant concentrations under "real world" conditions. These conditions include existing background pollution, outside traffic, weather impacts, atmospheric chemical processes, varying engine types, engine models, and engine activity levels. Data from laboratory tests cannot mimic real world conditions due to the multiple variables that can influence an exposure.

Ironically, the strengths of exposure assessment present the biggest challenges. Exposure assessment is often considered the weak link in quantitative risk assessment due to uncertainty in extrapolating results across other populations due to the environmental variability in the measurements (Kolluru et al. 1996). Tailpipe testing of diesel and biodiesel has numerous advantages compared to exposure monitoring because there is little to no environmental variability. In a lab setting, the researcher can control or eliminate confounding environmental variables like temperature and humidity. There is also no wind so there is no dispersion of pollutants or interference from another upwind pollution source. Lab based studies are also highly replicable; exposure assessment studies may not be. Under current scientific paradigms, internal and external validity are highly prized.

However, the collaborative exposure assessment demonstrated that with careful study design, these internal validity concerns can be incorporated and addressed. Pollutant data were collected in the same season; weather data were measured, analyzed, and found not to impact the results. Activity patterns and outside traffic were carefully documented and considered in the data analysis. Perimeter locations for monitoring were also considered to help triangulate the site as well as capture each important environmental and occupational exposure. While certainly field work brought unexpected challenges – a late biodiesel fuel delivery and a fire in one of the original perimeter locations – our team was able to adjust for them in the data analysis.

The results of the collaborative exposure contributed to an important initial understanding of B20 exposures. As one of two biodiesel exposure assessments to date, it is a critical first step. Clearly, more data are needed. Ideally, future exposure assessment research would benefit from not having a transition fuel period so the distinction between fuels dataset (B20 vs. 100% petroleum) would be larger. However, scheduling and timing fuel deliveries will continue to be a challenge in real world field work. To address external validity concerns, more research at the KRC and in other workplaces is recommended to evaluate the results seen in this study. Additionally, data should be collected in other seasons, like winter, where activity levels in closed indoor environments can result in higher exposures.

4.1.5 Future Research Directions: Healthiest Blend (Tradeoffs between PM, OC, and NO_x)

One of the key results from the KRC study was the decrease in PM, but with an associated increase in NO_x. As reviewed in Chapter 1, Section 1.1.3.d, a decrease in PM will result in an associated increase in NO_x. Typically, the increased combustion temperature and air needed to reduce PM when burning diesel will result in higher NO_x levels in a PM/NO_x tradeoff. However, biodiesel has different fuel chemistry with more oxygen in the fuel, leading to a higher cetane value and quicker ignition – which should reduce NO_x. While there are a number of theories regarding the increased NO_x from biodiesel, the cause is unknown (McCormick et al. 2001).

McCormick and colleagues (2001) performed a detailed examination of the impact of varying biodiesel feedstocks on PM and NO_x emissions. Above a cetane value of 45, fuel density was a key predictor of PM reduction potential. Those fuels with a density less than 0.89 g/cm^3 produced similar PM levels regardless of the biodiesel feedstock. However, feedstock chemistry of the biodiesel raw material may play a more critical role in NO_x emissions. Those feedstocks with higher iodine numbers (a measure of the double bonds in the fuel) produced higher levels of NO_x; for example, soy based biodiesel produced higher NO_x levels in the exhaust compared to tallow based biodiesel (McCormick et al. 2001).

McCormick et al. (2001) concluded that fuel chemistry is at the root of biodiesel's emissions properties, including NO_x. This conclusion and the results of the collaborative exposure assessment highlight important research directions. The B20 used in the collaborative exposure assessment was a soy based blend, as is typical of most commercially available biodiesel in the U.S. today. In addition, market availability of biodiesel is limited to a 20% blend, mainly due to cost constraints and support for warranties from engine manufacturers. But this does not mean a 20% soy based blend is the best biodiesel blend from an emissions – and ultimately exposure – viewpoint. Diesel engines can run efficiently on B100, as evidenced by numerous fleet experiences including Keene State College. Since NO_x continues to be an environmental policy concern from use of biodiesel, waste grease could have less NO_x forming potential compared to soy based biodiesel and should be investigated.

The collaborative exposure assessment also indicated significant increases in OC. Speciation of this OC remains a pressing research need. Empirical data are necessary to inform whether feedstock and/or fuel chemistry can be modified to identify a "healthiest" blend of biodiesel that attempts to reconcile the PM, NO_x, and OC tradeoff. It is possible that a 30% - 100% biodiesel blend may be ideal or that 20% best balances the inherent PM/NO_x/OC tradeoff in emissions and exposures. Waste grease or other raw material sources (such as rapeseed/canola oil) may be better feedstock candidates for healthier biodiesel emissions profiles. The area of modifying future blend ratios and feedstocks could offer valuable insight into biodiesel characteristics and benefits. Identifying less expensive, non-food critical, and lower emissions feedstock may help decrease current costs of biodiesel while maintaining the PM reduction benefits. These are all areas needing future research to best inform biodiesel decision-making, at a time when soy based biodiesel production is growing exponentially.

4.2 Discussion of the Biodiesel Working Group: How Analysis and Deliberation Interacted

4.2.1 Benefits and Challenges

There were a number of benefits to using a Working Group strategy as the main forum for deliberation in this case. Since the participants were somewhat familiar with each other from the pilot exposure assessment, it took a relatively short time to set up the BWG (although it took slightly longer to motivate participation). Introductions and connections were either not necessary or could take place quickly. Calling it the Biodiesel Working Group instantly communicated a local group working on biodiesel related decisions.

As mentioned in Chapter 3, much of my initial strategy in setting up the BWG was "Just do it." I did not focus formally in the set up of the BWG on procedural issues of fairness or meeting protocols, like Robert's Rules of Order. My hope was that since many of the participants knew each other from the pilot exposure assessment, the process design could be adjusted once decision-making momentum started. The key was to get that momentum going. B20 had been used for over 5 years in Keene, but had stayed mainly limited to the central DPW fleet. In short, no new decisions about use of biodiesel (either to increase use, or use in new applications) had been made in Keene in 5 years, so I was concerned the BWG was not going to go anywhere either. I paid attention to issues of fairness during my facilitation of meetings by issuing agendas early, frequently asking for feedback on agendas and during meetings, and periodically asking if there concerns that needed to be addressed.

Another benefit to using a working group mechanism was that many of the participants were already familiar with either college or city committee processes or both. Since most of the BWG either worked or lived in Keene, people could meet face to face relatively frequently, as long as they felt their time was being used effectively. Thus it was important to emphasize the purpose of each meeting, especially the early ones, when the BWG goals were more open. Maintaining purpose and focus was assisted by sending an agenda prior to meeting, but keeping that agenda flexible to revision by participants.

Having people meet face to face on a periodic basis was valuable in the steps of problem formulation, information gathering, and synthesis. Face to face meetings helped revisit goals, problem formulations and achieve a common sense of purpose. Concerns, questions and opinions could be expanded and fleshed out during these meetings, as well. A few of the spring/early summer 2007 meetings had the tone of a group therapy session. The engineering firm felt the process was moving too slowly, KSC believed the process was moving too fast, and the City was somewhere in between. While BWG members were excited about the vision of the Monadnock Biodiesel Collaborative, actually translating that energy to forward decision-making action was an amorphous process. The problem formulation step for Central research question #3– specifically the HOW to implement a biodiesel production/fuel quality testing/research collaboration – took a long time. There were months of multiple meetings revisiting the risks/benefits of different business structures for each contributing partner. Participants needed to hear how the pieces would fit together a number of times. I stopped collecting data in June 2007 when it became clear this stage was going to take months. However, as a new innovative venture for all the partners involved, the time period is probably appropriate.

Another benefit of the BWG process: BWG member involvement in or familiarity with the collaborative exposure assessment phase meant the technical results were more easily "translated" or communicated to non-technical members; communication between the

KRC researchers and other groups were enhanced by the participatory aspects of the research. Co-learning took place among the members - while KSC researchers were exposure assessment experts, we had the opportunity to learn from City of Keene warranty experts and engine experts. Frequent meetings allowed relationships to grow and the collaboration to build, increasing the levels of trust among participants and associated organizations.

Synthesis of information took place at the BWG meetings as well. While this synthesis was documented in various ways like business plan revisions, site analyses, process flow diagrams and other reports, clarifications and additions to these documents were reviewed and discussed at the BWG meetings. With so much information involved, meetings provided the opportunity to address areas of confusion and revisit prior questions. Participants would be assigned “homework” (usually analytic activities) and would report those results back to the group. Then deliberation helped clarify the analysis, and identified new analytic needs.

The BWG mechanism was critical in facilitating A-D interactions by being an effective touchstone for deliberation of novel options and outcomes. Since BWG members also participated in external stakeholder groups, like the Cities for Climate Protection committee, members could communicate important broader policy impacts and other information back to the BWG to influence decision-making. Participants would come back to the BWG and connect these broader ideas to the idea of increasing biodiesel use in Keene. By member involvement in external groups, the BWG was able to gauge regional interest and support, as well as use this support to legitimize decisions, especially regarding the Monadnock Biodiesel Collaborative. Decision-making occurred rather quickly within the first 8 meetings – turning through 3 problem formulations - ultimately supporting a decision to build a biodiesel production/fuel quality testing/research facility. The BWG helped build a wider and more efficient communicative infrastructure similar to how using fiber optic cable allows faster data transmission over the internet.

However, there were challenges in using the BWG as the main deliberative strategy. Faster decision-making is not necessarily better decision-making. The BWG process design had some deficiencies, while not problematic as of this writing, could be problematic in this case in the future. First, the process design did not include all interested and affected parties on the BWG. Although City council officials expressed support on behalf of the community, other than the private engineering firm, there were no non-City or non-KSC affiliated members on the BWG. There was no voice for the average citizen or KRC worker; more importantly there was no voice of a citizen who may be living in the neighborhood of the future biodiesel facility. This can be a source of conflict later on during the construction phase.

Additionally, once leadership of the BWG switched in early 2007, formal attention to concepts of the A-D model began to decrease. With changes in leadership come changes in leadership style. For example, agendas were no longer circulated prior to meetings and feedback was no longer directly solicited, as I had paid attention to these process design aspects as part of my research and application of the A-D model. On one hand this allowed the BWG to proceed without my direct influence, as the group clearly took ownership of the process. On the other hand important opportunities for expanding participation to non-represented interested and affected parties may have been missed, especially once the BWG locked into the final goal of the Monadnock Biodiesel Collaborative. For once the City and

KSC publicly committed to the biodiesel production/testing/research facility, the decision-making process became very focused on how to execute that project. Having a senior KSC administrator lead the project lent both credibility and critical momentum but it also may limit dissenting voices because of power dynamics.

But it is likely that these process design and power dynamics issues would be universal challenges in any application of the A-D model, not just in this case. Webler and Tuler (1999) note participants in watershed planning may have unequal access to the process, to necessary resources, or to technical expertise. I used strategies to try to address the BWG challenges in this case. For example, I directly reached out to citizen groups and City management for expanded BWG participation during the study. I interviewed the KRC workers as a way to get their input and participation. I implemented the Biodiesel Attitude Survey as a way to gauge process interest, support, and/or concerns anonymously. My colleagues and I made numerous local presentations in the community, and the KSC students used creative communication mediums. Finally, as suggested by Webler and Tuler (1999), we made this information widely available and understandable by having the BWG critique the presentations before they were given.

Overall, the BWG was an effective strategy to put the ideas of the analytic-deliberative model of risk decision-making into practice. The early BWG meetings acted as a catalyst for additional problem formulation and institutional momentum for an innovative private/public/college collaboration to make high quality biodiesel from waste grease and expand research and educational opportunities.

4.3 Discussion of Case Study Results: Integrating Analysis and Deliberation to Understand B20 Exposures and Lead to Better Decision-Making

4.3.1 Benefits and Challenges of Overall Study Approach: Review of Results

Intentionally integrating analysis and deliberation resulted in a number of positive outcomes. The exposure assessment process was enhanced by the experiential knowledge of the City of Keene employees in multiple ways. First, the self–reports of cleaner air in the workplace indicated that this knowledge may be novel to the scientific community and highly policy relevant. Second, involving KRC staff and others in the BWG process helped improve the exposure assessment strategy. We were able to maximize our efficiency in when and where to sample based on collaborating with KRC staff. Our team focused on those pollutants with high policy relevance to environmental and occupational health: fine particulate matter due to the body of science connecting exposure to lung and heart damage, nitrogen dioxide due the controversy surrounding biodiesel increasing NO_x levels, and elemental carbon due to its recognition as the best diesel surrogate for exposure. Coordination with the KRC team for delivery of fuels and assistance in setting up equipment ensured we were able to complete all field work within a tight 2 ½ month summer window, ensuring we could execute the logistically complex study with adequate student researcher support.

Connecting the BWG to the exposure assessment led to deliberation of the results and motivated discussion of what to do next with the KRC study information. Besides encouraging dissemination of the results in local education efforts, scientific conferences, and stakeholder presentations, the BWG believed the results legitimized the City's observations that biodiesel was healthier. BWG members were subsequently motivated to discuss options that would increase B20 use in Keene. It is unlikely a study conducted somewhere else would have had this motivating effect; I believe BWG members wanted to do more with the exposure assessment results because of their association with the analytic process. As summarized by a KRC employee, “It would be a shame if this research sat on a shelf.” The BWG contextualized the data determined by the exposure assessment; for example, the reductions in fine particulate matter were no longer about numbers. Integrating analysis and deliberation made the data tangible and real: these numbers were about people, and people the BWG knew. The numbers were about improving the air quality in their workplace and community.

Ultimately, these deliberations catalyzed decision-making for KSC, the City of Keene, and a private engineering firm to collaborate to start a biodiesel production/fuel testing/research facility. The scale and scope of this project would be impressive and highly innovative for a large university in a populated area much less a small liberal arts college in a rural city in New Hampshire. The vision of the Monadnock Biodiesel Collaborative is to connect resource conservation, waste minimization and health risk reduction research with a sustainable economic/ecological model. While biodiesel use is increasing, there are very few places in the U.S. that are both manufacturing *and* using biodiesel fuel within the local community on a sustainable scale. There are no known public/private/college partnerships that manufacture biodiesel from waste grease for energy use within the local community *and* connect this to existing research on “real world” biodiesel exhaust emissions in the workplace and local environment. A summary of the roles of the partners within the collaborative is shown in Figure 4.3 below.

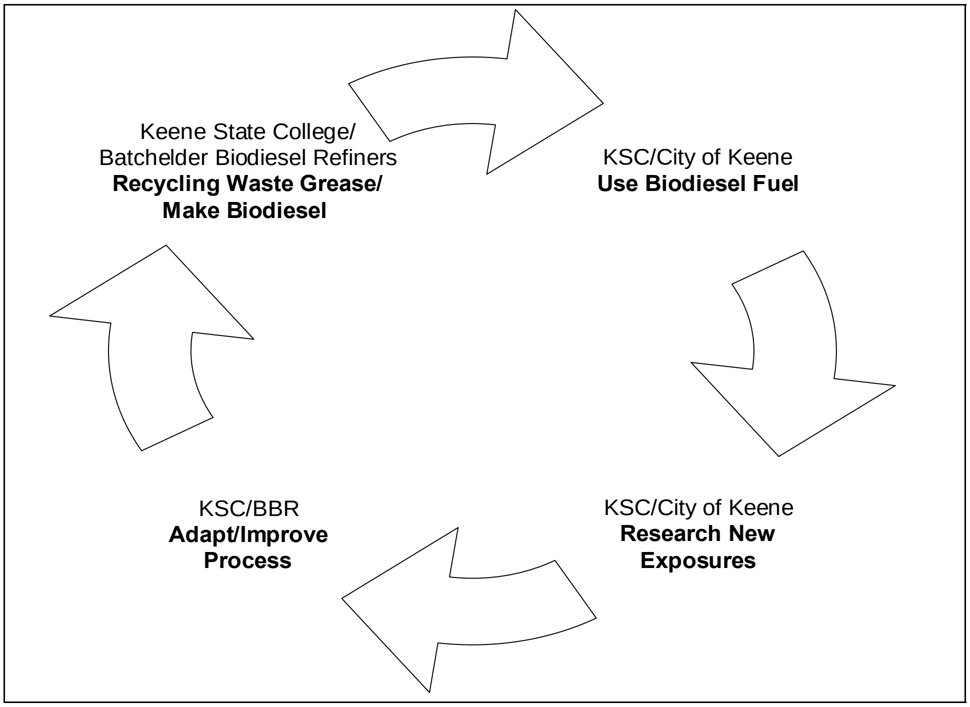


Figure 4.3: **Summary of Collaboration for Monadnock Biodiesel Collaborative**

While these and other results such as improved town/gown relations were benefits of the integration of analysis and deliberation, there were challenges to the overall study approach. The main challenge was in my role as researcher: managing the scale and scope of the project and applying skills in both natural and social science methods simultaneously. Simply from a time, resources, and organization standpoint, it was a challenge to attempt to apply the A-D concepts to the B20 decision-making process. I had to take a year unpaid leave of absence just to manage the BWG process, exposure assessment data analysis, and public presentations. This highlights the second challenge to integrating analysis and deliberation: it takes significant extra time and personnel hours. This was my dissertation study, so I was unusually motivated to apply the A-D concepts. Many organizations would be hard pressed to find an existing staff member to dedicate the necessary time or allocate resources to hire someone specific to this task. Although organizations could hire consultants as an option, I believe my role in both the collaborative exposure assessment and the BWG helped increase the success of the BWG process, especially in the first 5 to 8 meetings.

4.3.2 Overlap of Activities and Research Challenges

My rationale for asserting a consultant skilled in participatory processes may not have been able to duplicate the results seen in this study was that, while I have presented the results in apparently linear fashion, decision-making was not sequential. Applying the A-D model has to happen at a meta-level of decision-making, not in a cookbook fashion. Webler and Tuler (1999) note this as well: the five steps of the A-D model do not necessarily take place in a sequential step by step fashion; process design and problem formulation can happen at the same time with iteration between them. In one BWG meeting, the members might have revisited a problem formulation, synthesize, do information gathering and then revisit the desired outcomes. Alternately, it took over 10 meetings to get to an agreed upon point in problem formulation, such as when two separate BWG's formed (KSC and the City) and then merged back again.

Many times BWG members interacted via email between meetings to do information gathering and discuss options. While decreasing transparency of the process, email communication did increase efficiency and movement toward decision closure. Since I had a more prominent role in both the exposure assessment and BWG processes, I was able to act like a thread throughout the decision-making process – for KSC meetings, City meetings, and emails. It is unlikely an outside consultant would have the necessary knowledge of or access to institutional culture to act as this type of thread. While certainly another interested party could have also acted in my role, it most likely would have had to be someone familiar and known to all participants. A long term consultant somewhat dedicated to the process may also be another option for this or future similar cases to integrate analysis and deliberation.

While dedicating a staff person or hiring an outside consultant would involve a more direct expense upfront, the potential value of the benefits to organizations is substantial. This has also been recognized in the NRC (1996) report, which noted benefits such as reduced conflict, reduced uncertainty and increased trust. In this case, even without the Monadnock Biodiesel Collaborative outcome, the integration of analysis and deliberation saved time and resources in the exposure assessment, provided educational opportunities for undergraduate students, improved town/gown relationships, and resulted in novel outreach and co-learning opportunities. KSC was also asked to participate in a prestigious National Institute of Health grant as a result of the exposure assessment results and the Monadnock Biodiesel Collaborative concept. Adding the Monadnock Biodiesel Collaborative further underscores the benefits of the time and resources invested.

4.3.3 Rival Explanations for Results Seen in this Study

As part of my triangulation process in data collection and analysis, I considered throughout my involvement in the study this alternative hypothesis: what if the integration of analysis and deliberation did not produce the results seen in this study? What if applying the A-D approach to understanding B20 exposures made no difference in any way? In other words, these results would have happened anyway. For example, one rival explanation was that the time was ripe for the City of Keene and Keene State College to come together in the

Monadnock Biodiesel Collaborative. The City already had a number of pro-environmental projects in place under the banner of the Cities for Climate Protection, and making biodiesel in Keene was a natural extension. The private engineering firm had approached the college separately from the BWG process, so perhaps the biodiesel facility may have happened regardless.

Therefore, to assess this rival hypothesis, I collected background, contextual data on the decision to use B20 in Keene and associated environmental programs from documents (newspapers and websites) and from the semi-structured interviews. I then coded the data inductively to determine 4 influential factors on the initial decision to use B20 in Keene. These data are presented in Appendix A. The four contextual factors found were: Russell's pro-environmental attitude; Russell's leadership/savviness; a culture of environmentalism in Keene; internal/external political factors. For example, an external political factor to Russell trying B20 in 2002 was the receipt of a small $2500 grant from the New Hampshire's Governor's Office to cover the initial differential cost between diesel and biodiesel.

While clearly these four factors helped facilitate the results seen in this study, I suggest that the results would not have occurred without the direct integration of analysis and deliberation. As mentioned previously, both the City and KSC had been using B20 since 2002. While successfully championing these programs, the use of B20 was still overall a fraction of what it could be in both organizations. A major irony in this case that has not been mentioned until now but warrants deeper discussion– in spite of the exposure assessment results indicating the health benefit of reducing fine particulate matter by using B20, after the research was completed the KRC site had to return to use of 100% petroleum diesel. The City of Keene staff could not justify a permanent switch to B20 due to its higher cost and lack of availability in small drops (less than 1000 gallons per delivery). In addition to B20's higher cost per gallon (5 to 30 cents more depending on market conditions), there was a delivery surcharge of an additional $500 or more to make small drops. Adding this surcharge made the economics difficult to justify, even in an environmentally proactive community like Keene. B20 was not being used in the City of Keene organization beyond pick-ups that could be made at centrally located underground tanks. Before the BWG process, use of B20 in remote locations like the KRC and the airport, as well as in new applications like diesel generators, simply could not even be considered.

When the BWG process began, it made sense members keyed in on the issue of lack of supply. But initially the lack of B20 at a fair price in the region was suspected by BWG members to be simply low consumer demand in the area. This was summarized by the concern at the first BWG meeting, "Why aren't more people using biodiesel?" But deeper discussions and inviting two local distributors for their feedback helped BWG members better understand the local cost vs. benefit breakdown and the disadvantages to distributors to add biodiesel capacity. Learning that some local distributors did not have the capital to expand their fleets for both biodiesel and the EPA mandated ultra low sulfur diesel (ULSD) is "street knowledge" - similar to Corburn's (2005) "street science" - that directly bears on the problem. The federal policy of ULSD has resulted in a structural barrier to motivate implementation of other innovative emissions control options like biodiesel and retrofits such as tailpipe particle scrubbers.

The timelines in Figures 2.1 (an overview) and Appendix F (a detailed timeline) show additional evidence of the impact of analysis and deliberation on the results. I have included

Figure 2.1 (renamed Figure 4.4) here for the reader's convenience. Note the lack of decision-making activity in the entire year of 2005.

Biodiesel use had reached a plateau in Keene soon after 2002 and increasing its use was not likely due to the structural barriers identified. Since B20 was simply not available locally at a reasonable price, no new decisions about B20 use were being made in the City organization. When application of the concepts of analysis and deliberation took place in 2006, active decision-making increased as shown in Figure 4.4. Meetings with local distributors confirmed structural barriers to increased local supply. Coming to this conclusion separately without the private engineering firm's involvement led to BWG support of the Monadnock Biodiesel Collaborative and to partner with Batchelder Biodiesel Refineries.

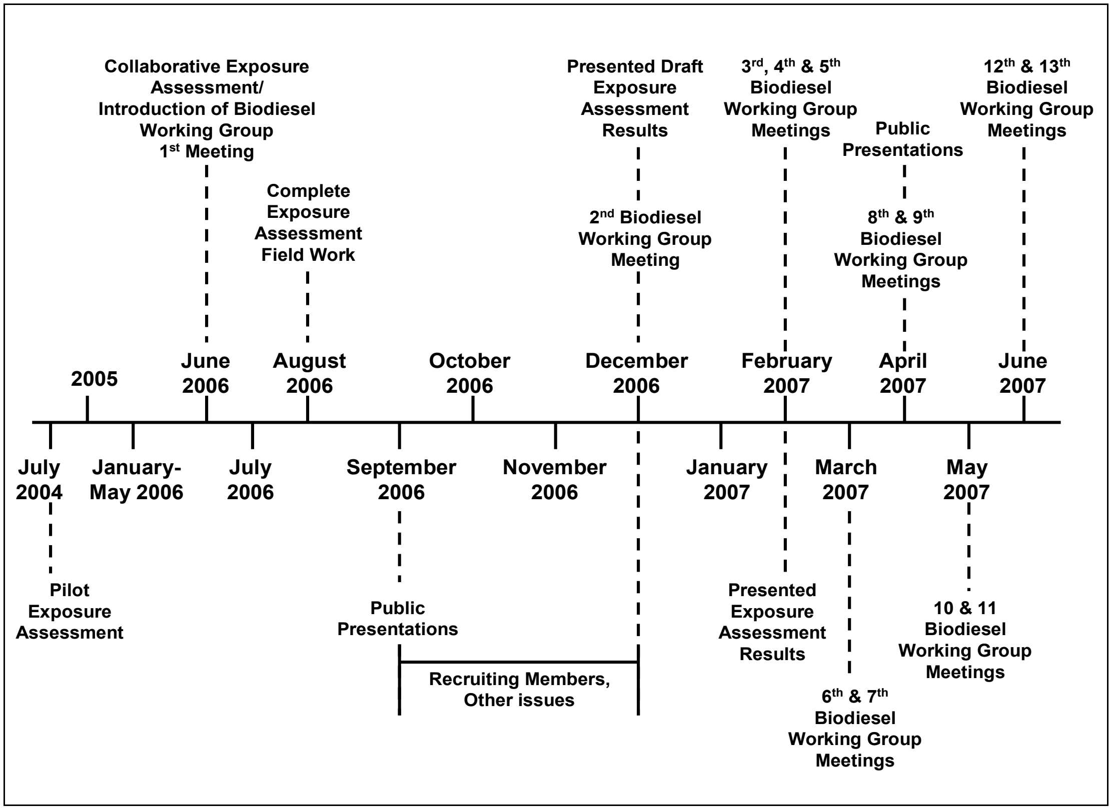


Figure 4.4: **A Condensed Timeline of the Research Study (Note: The A-D Model was Formally Applied in June 2006).**

4.3.4 Barriers to Increased Biodiesel Use

While the application of analysis and deliberation did lead to novel policy outcomes in this case, it is critical to acknowledge both the positive and negative effects of outside factors that influenced the decision-making process. These types of factors can enhance or limit this or future A-D processes in other contexts.

The economic barrier to B20 use is substantial. Without the initial grant from the NH Governor's Office, Russell may not have tried B20 in his fleet. Since B20 has become more widely available across the nation in the past 5 years, these types of incentive grants are no longer common, if they exist at all. Yet there remains a critical need for them. In today's economy, it is difficult to justify an additional 20 to 30 cents more per gallon of fuel, even if the health impacts are positive and may result in long term lower costs. As the local oil distribution company President identified, "…my market is only interested in lowest cost." Cost is a critical consideration in the use of biodiesel fuel and is currently a significant barrier to its availability.

Lack of biodiesel education is a barrier. There remains a critical need for education and networking. Education is needed as evidenced by the Biodiesel Knowledge Survey results and also by the wide variability in audience questions. Many people simply do not know much about biodiesel or think it may be a futuristic type technology. As the Biodiesel Knowledge Survey results showed, many people think biodiesel is the same as adding straight vegetable oil, and that using it may void engine warranties.

Networking organizations and environmental advocacy groups are critical to education processes as well as to connecting organizations interested in trying biodiesel with available resources. While Russell knew a little about biodiesel, it was his association with the Granite State Clean Cities association that connected him to more information and the grant to try B20. The existence of such networking groups is an important external factor to help expand biodiesel use.

Industry support is also critical. Although most engine manufacturers now have biodiesel statements on their website supporting quality assured B20 use in their engines, this was not the case in the early part of the decade. According to Russell (2006), at that time some engine manufacturers were taking a negative stance towards biodiesel use. Russell actually did substantial legwork in warranty research. Now that industry is clearer about supporting biodiesel, this barrier is less of an issue. Yet there are still concerns among potential users about it.

Finally, regulatory barriers exist. Ironically, the use of a cleaner, low sulfur fuel mandated by the EPA and expected to have enormous health benefits can also act as a regulatory barrier. Since businesses must ensure their operations are in compliance to avoid sanction, this limits the support for other more innovative approaches. Other scholars have noted that the EPA's focus on compliance initiatives carries high transaction costs, especially for smaller businesses, that offer little incentive to do more than comply (Fiorino 2006). Fiorino (2006) further adds that EPA's compliance focus means opportunities to reduce pollution are missed. An interesting future study would be to compare the exposure reductions of ULSD/new engine technologies with biodiesel and include a lifecycle cost analysis. Would using biodiesel blends alone have resulted in similar benefits? At what cost? An additional irony is that use of ULSD reduces lubricity in the engine, which can cause engine failure; biodiesel use does not damage engines and increases lubricity.

4.4 Implications for Risk Decision-Making Theory and Practice: How Can the A-D Framework Help Move Beyond Regulatory Barriers to Investigate Biodiesel Exposures in a Real World Application?

This case showed how local initiatives can come up with innovative ways to move beyond regulatory and other barriers by taking ownership of an environmental and occupational health policy problem. The Monadnock Biodiesel Collaborative was the innovative outcome of three problem formulations that started with evaluating B20's exposure impact, looking at the problem of lack of local supply critically, and deciding to make biodiesel locally as a way around the barriers. The support for B20 was enhanced by the locally performed exposure assessment, which contextualized the data and made it real and relevant. Participation also enhanced the quality of the exposure assessment. The practice of analysis and deliberation in this case resulted in numerous benefits to the researchers, BWG members, KSC students, Keene State College and the City of Keene.

The implications to risk decision-making practice are clear: in the terminology of the NRC (1996) report, applying the A-D model in this case resulted in reduced scientific uncertainty, enhanced communication between technical experts and decision-makers, increased substantive knowledge base of the decision, and improved collaboration and trust among stakeholders. Also, following the NRC (1996) recommendation of "getting the right participation" helped in "getting the science right" by enhancing the quality of the exposure assessment.

However what are the implications of this case for risk decision-making theory? In the following sections, I revisit the traditional risk decision making process and reflect on how to relate the meaning of the results in this study to future theory.

4.4.1 Diesel Exhaust as an Illustration of the Disconnect between Occupational and Environmental Health: Theoretical Reflections

The regulatory process for management of diesel exhaust exposures was reviewed in detail in Chapter 1 and is summarized here again. From the broad policy context of managing exposures to harmful chemicals, EPA is responsible for programs outside the workplace. OSHA has issued permissible exposure limits for certain chemical exposures inside the workplace.

EPA's main regulatory approach to manage diesel exhaust exposures has been two fold: requiring enhanced engine technology in new engines to reduce emissions (starting in 2007 for onroad, 2014 for nonroad), and reducing sulfur content of highway diesel fuel from 500 ppm to 15 ppm. EPA also supports a number of voluntary programs such as technical and financial assistance through its National Clean Diesel Campaign. Additionally, EPA has established a reference concentration (R_fC) of 5 $\mu g/m^3$ for diesel exhaust. This R_fC is a non-binding (or guidance) level for daily exposure over a lifetime that is sufficiently protective from lung inflammation and other non-cancer health effects for the general population.

EPA's determined the R_fC through its 2002 Health Assessment Document. The HAD also addressed the carcinogenic potential of diesel exhaust. The HAD followed the traditional NRC (1983) quantitative risk assessment paradigm of hazard identification, exposure assessment, toxicity assessment and risk characterization. Ultimately the document supported implementation of policy decisions for EPA's required compliance mandates (such as ULSD fuel) and voluntary programs. However, there was a major departure in the HAD from EPA's usual (i.e., traditional) risk assessment/risk management process. Typically, the end product of a risk assessment is the risk characterization that includes a quantitative estimate of excess unit cancer risk (or slope factor). Due to scientific uncertainty, EPA (2002a) did not develop a slope factor for diesel exhaust. Instead EPA qualitatively described diesel exhaust as likely to be carcinogenic to humans by inhalation. Without a quantitative estimate of cancer risk indicating risk below an EPA policy threshold of 1 excess cancer per 1,000,000 people exposed, maximum achievable control technology for sources is not required under current legislative mandates.

The Occupational Health and Safety Administration does not regulate whole diesel exhaust exposure in the workplace. NIOSH (1988) identified diesel exhaust 20 years ago as a potential occupational carcinogen, estimating at the time that over 1,000,000 workers were exposed to diesel exhaust. However, there is no legally binding occupational standard for whole diesel other than in mines where MSHA limits average workday DPM exposure to 160 $\mu g/m^3$. Outside of mines, any reductions to diesel exposures in the workplace such as ventilation controls or "no idling" policies result from voluntary actions by employers.

The problem of diesel exhaust is a case study in how environmental and occupational health risk management remains disconnected. Traditional risk assessment/risk management paradigms have led to a decision-making quagmire. Scientific uncertainty in the diesel cancer and exposure models means new, more stringent regulation of diesel by EPA to protect public health is highly unlikely in the future. This is the likely outcome even though the durability of diesel engines means exposures at current levels will continue for at least another 10 years or longer. Workers as a subpopulation experience much higher exposures and are even more at risk, and less likely to find regulatory relief. OSHA has not updated most of its PEL's since 1971. OSHA is unlikely to issue a new whole diesel exhaust PEL due to the same scientific uncertainty EPA is facing as well as OSHA's constraints from the *Benzene* case.

The problem of diesel exhaust - with its emphasis on reaching a scientific solution - is a classic case of the politics of expertise versus counterexpertise (Fischer 2000). Science is kept separate from policy in this "facts versus values" paradigm. Scientists keep trying to improve the risk characterization of diesel exhaust by reducing analytic uncertainty. As shown by the challenges faced by both EPA and OSHA, this may not be the wisest use of resources since diesel engines are entrenched in all aspects of U.S. society. Ultimately science by itself cannot solve these types of policy dilemmas simply because reasonable people (including scientists) disagree how to interpret information as well as decide which information is most important in making decisions (Stern 2005). In the meantime, diesel occupational and environmental exposures will continue into the foreseeable future, unless other novel risk interventions are examined and implemented.

4.4.1.a Theoretical Reflections

Traditional risk decision-making in the diesel exhaust case is at a crossroads. Not only is future regulatory action by EPA, the scenario of an integrated EPA/OSHA approach to manage diesel exposure risk for workers is even more remote. The A-D framework offers one alternative approach to traditional risk decision making. Recognizing risk characterization as a complex nexus of science and judgment, the National Research Council (1996) recommended that risk characterization be reconceptualized as decision-driven activity oriented towards solving problems and performed via an iterative process of analysis and deliberation.

Unlike traditional regulatory approaches to risk, the A-D approach emphasizes collaboration among interested and affected parties, an orientation towards solving problems with decision-relevant analysis, and an open acknowledgment of uncertainty. Uncertainty is accepted more as a given, and instead of a focus on reducing it at the expense of other options, the focus is on iterations of analysis and deliberation to get to a point of a useful, and decision-relevant synthesis of knowledge. This emphasis on collaboration is important to try to get at what information is necessary for the decision, and incorporates the concerns of interested and affected parties in the process. Policy and science are no longer necessarily separate, nor do they need to be, as decision-making in practice is typically a combination of both.

The results in this study demonstrated that application of analysis and deliberation can make useful contributions to both practice and theory. Mainly the study demonstrated the A-D theoretical concepts can work effectively in practice. But the study makes important contributions to theory, too. Collaborating in analysis and deliberation by engaging citizens in analytic activities has been suggested as a way to capitalize on the local knowledge of lay people (Webler 1998). The expanded participation in the exposure assessment – between experts, Keene employees, and KSC students – helped combine local knowledge with expert knowledge by involving a wider range of participants not typically engaged in analytic activities into the exposure assessment process.

The participation in the collaborative exposure assessment helped contextualize the data; people cared about doing something with the results, they didn’t want it to “sit on a shelf.” The finer points of environmental regulatory policy making – whether diesel exhaust is a “known carcinogen” or “highly likely to be carcinogenic” – was not a critical epistemological barrier to the BWG. Instead the data motivated the group to action – at a minimum to do more education. The personal impact of B20 in the workplace and the connection to the important of action to improve air quality and health was summarized by Russell (2006):

> So now that I am responsible for staff and a facility… you know, it comes home. It all comes back to, what are we exposing our employees to? Is it fair? And mechanics are wonderful… they love (emphasis) their job…they love what they do…they would sit there for hours and let the engines run and they don't care because they are used to it. But I care, because it's not fair for them.

Connecting analysis and deliberation also met substantive, instrumental and normative goals suggested by Fiorino (1990) for risk decision-making. Substantive goals were met by improving overall understanding of B20 exposures by fusing Keene DPW and KSC researcher knowledge in performance of the collaborative exposure assessment. Collaboration between KSC and KRC/City staff led to a higher quality research project that synthesized all relevant knowledge and collected important exposure science data. The results from the collaborative exposure assessment data helped meet instrumental goals of risk decision-making by legitimizing the Keene employee observations of cleaner air. The combined collaborative exposure assessment/Biodiesel Working Group process helped legitimize the decision to expand biodiesel use by supporting the creation of the Monadnock Biodiesel Collaborative. Normative goals were met by expanding participation beyond academic researchers to include interested and affected parties in both analytic and deliberative processes. While not ideally involving all affected parties equally in the process, the expanded participation and open communication helped build trust and strengthen collaborative relationships. Fischer (2000) recommends expanded participation in environmental decision-making as a way to enhance democracy in practice.

With respect to overcoming regulatory barriers, Fiorino (2006) outlines in detail the design principles (for environmental regulation) that are needed to move from the old, compliance form of regulation to a new, more innovative regulation framework. Relevant to this study is the critical need to move from the more adversarial relationships that currently exist between industry and EPA to more collaborative relationships. Fiorino (2006) argues that a fundamental shift must happen toward the idea that (except for a few actors that need the adversarial hammer of enforcement) collaborative relationships will offer the best overall outcome for society. To get there, opportunities for learning, dialogue, repeated interaction, and ways to build trust are needed.

Fiorino (2006) does not make specific recommendations on how best to get there, instead offering examples of cases where collaboration occurred. However, the A-D framework offers an appropriate theoretical conceptual model to help achieve the goals of a new regulation. The results from this study offer one way to apply the A-D model in practice, but the flexibility of the model lends itself to other types of problems and applications. For example, Renn (1999) suggests a cooperative discourse model he developed with Tom Webler that integrates analysis and deliberation in a way that stresses the fairness and competence of decisions.

The KSC/City research collaboration was able to move beyond the regulatory barriers relating to diesel exhaust exposure by researching B20 exposures in real world applications. When the data supported a reduction in fine particulate matter health risk, the BWG took ownership of the problem of lack of biodiesel supply and supported the novel policy outcome of a biodiesel production/testing/research facility. These are the types of innovative environmental solutions Fiorino (2006) is trying to facilitate via his suggested regulatory framework.

4.4.1.b Different 'Safe' Exposure Levels and Connection to Environmental Justice

A gap in Fiorino's (2006) otherwise compelling outline for a new environmental regulation is overlooking the inherent connection between environmental and occupational health. The KRC site was a good example of a workplace that connects both occupational and environmental health exposure risk in a tangible way. Not only are workers exposed to equipment exhaust, but as the community recycling center the KRC is a stable, long term source of diesel emissions in the local environment. In fact, the collaborative exposure assessment demonstrated there was no statistical difference in the fine particulate matter concentrations measured at the environmental exposure location (P3-outdoors) and the occupational exposure locations (P1, P2, P4).

The lack of an integrated approach to manage occupational and environmental regulatory disconnect remains a pressing policy problem. Although EPA's regulation of diesel exhaust exposure may be considered lacking, OSHA does not regulate whole diesel exhaust exposure at all. While both agencies regulate certain components of diesel exhaust such as particulate matter, the orders of magnitude difference there is striking. OSHA's permissible exposure limit is 5000 $\mu g/m^3$ compared to EPA's level of 35 $\mu g/m^3$. The OSHA PEL is an 8 hour time weighted average, as opposed to EPA's 24 hour time weighted average exposure limit. OSHA's PEL for nitrogen dioxide is a 9000 $\mu g/m^3$ ceiling limit that cannot be exceeded during a workshift compared to EPA's 100 $\mu g/m^3$ averaged over a year. This study, similar to others, has demonstrated that even accounting for the relative differences in measuring times, workers typically experience exposures far above allowable environmental protective levels yet below allowable occupational protective levels. Since the science of exposure and health effects is the same in both environmental and occupational health (as both deal with the human exposure/health effect relationship), there is no justification - based on science - for these discrepancies.

Treadwell (2005) has identified the ethical challenges facing environmental health and safety professionals responsible for worker health protection when other public/environmental health standards (like EPA's) are far lower than occupational health standards. With respect to this study, while the KRC had concentrations of fine particulate matter during diesel use far above the NAAQS (35 $\mu g/m^3$), the concentrations never came close to OSHA's permissible exposure limit of 5000 $\mu g/m^3$. The KRC exposures remained in compliance with both EPA and OSHA requirements. But the higher exposures are acceptable only because workers do not have the same regulatory protection as the public – a situation that has broader environmental justice implications.

4.4.1.c Environmental Justice

Typically environmental justice is associated with environmental pollution occurring disproportionately in areas of low socioeconomic wealth, such as siting a hazardous waste incinerator in a poor, minority neighborhood. According to Shrader-Frechette (2002), if environmental justice is concerned with equalizing the burden of pollution across all segments of society, then environmental injustice occurs when one group bears a disproportionate risk, has less opportunity to participate in decision-making or has less access to environmental goods. Workers exposed to diesel exhaust appear to experience a disproportionate risk compared to the public and also appear to have less opportunity to participate in decision making, as seen in this study.

Both Shrader-Frechette (2002) and Kasperson and Kasperson (1991) suggest that the OSHA and EPA discrepancies in chemical exposure standards exist due to embedded societal beliefs including the following: job selection is considered a voluntary, individual choice, workers are both well compensated and well informed of the risks, and workers' compensation programs exist to pay for work-related injuries and illnesses. The idea behind the compensating wage differential (CWD) or hazard pay premium is that workers are compensated for hazardous occupations and voluntarily trade safety for increased pay. The CWD theory assumes that workers have a number of job opportunities to select from, and are well informed of the risks.

Shrader-Frechette's (2002) detailed analysis debunks many of these societal beliefs, showing for example, that workers in high hazard industries often do not earn better pay, nor are they well informed of the risks. Nonunionized workers typically receive less pay as risk increases. Her arguments are compelling and outline important societal and ethical questions as to the fairness of different 'safe' exposure limits between agencies. For example, even if workers could be shown to be well informed of the risks they were facing, there are moral issues associated with allowing unsafe conditions to continue and workers to trade their health for compensation (Shrader-Frechette 2002). In summary, from an environmental justice viewpoint, workers should have the same relative level of protection as members of the public with respect to similar exposures.

4.4.2 Other Approaches to Risk Decision-Making: the Precautionary Principle

Other policy approaches such as the Precautionary Principle (Kriebel et al. 2001; Tickner et al. 1999) and pollution prevention (Armenti et al. 2003) have been suggested to help decision makers make better decisions related to chemical exposure risk. There are various interpretations of the Precautionary Principle but almost all versions agree that scientific uncertainty should not delay regulatory protective actions against threats to the environment and public health. Another tenet of the Precautionary Principle recommends that new alternatives to existing chemicals or technologies be thoroughly studied before implementation so that unintended consequences are avoided (Tickner et al. 1999). Pollution prevention is considered the reduction or elimination of pollutants by techniques such as source reduction, waste minimization and process modifications. With the primary emphasis on source reduction, or the reduction in the quantity or toxicity of hazardous emissions at the source, the implementation of pollution prevention techniques has promise to simultaneously reduce worker chemical exposures and environmental emissions.

However, both the Precautionary Principle and pollution prevention frameworks have struggled to gain a foothold in national regulatory policy making or local risk decision-making practice. The Principle's inherent vagueness makes it difficult to determine when precautionary action is most appropriate and does little to direct which specific alternative or precautionary action to reduce risk is more "precautionary." The reality of risk decision making – even decision-making guided by precautionary ideals - is that it is context dependent. With respect to chemical exposures, decision-makers are typically faced with a large degree of technical uncertainty. This has been exemplified by the case of diesel exhaust. The model of pollution prevention runs into the same issue: what is actually meant by the "best pollution prevention" approach?

Although the Precautionary Principle and pollution prevention may be helpful as a guide, inevitably scientists and policy-makers must analyze and deliberate the evidence and implications of a specific risk problem within its unique context. Unique, expanded risk problem formulations are especially relevant to occupational and environmental health challenges.

A-D processes are well suited to address these types of regulatory complexities because the focus is on two way communication and iterative problem solving. A unique aspect of this study was how analysis and deliberation was performed iteratively by many of the same people. In other words, there was cross-over in the people performing the collaborative exposure assessment, and people participating on the biodiesel working group. Policy emerges from shared understandings or knowledge. According to Fischer (2000), effective policy making incorporates a constructivist understanding of knowledge into a deliberative framework that reflects both the true nature of scientific inquiry and incorporates local knowledge into an "evolving conversation." Instead of looking at policy via traditional views where policy is primarily technical with the need for some public input, decisions should be viewed as "fundamentally public with the need for some technical input" (Beierle & Cayford 2002).

4.4.3 Can an A-D Framework Help Reconnect Environmental and Occupational Health Risk Management for Chemical Exposures?

This study demonstrated how it could be done at the local level by being sensitive to both environmental and occupational health impacts in the research study design. The exposure assessment research strategy measured both occupational and environmental exposures, and used both occupational and environmental monitoring methods, as appropriate. Data analysis evaluated fine particulate matter occupational exposures against the more health-conservative environmental exposure standards (NAAQS) to determine if the air quality was improved by use of B20. BWG deliberations considered ways to increase local supply of B20 in both the community and specifically in the workplaces of the Keene DPW. Public presentations also highlighted the discrepancies in occupational and environmental health standards, and how B20 can benefit both workers and the community. The KSC students made this a core focus of their work especially in their conference presentation and TV program.

4.4.3.a How Can Occupational and Environmental Health Risk Management of Chemical Exposures be Integrated at the Regulatory Policy Level?

Gottlieb (2002) has stressed the inherent relationship between the workplace, community and environment, and calls for a new integrated language of work and environment. But the only way integrated risk reduction can occur is if these relationships are openly discussed during the risk problem formulation stages. The analytic-deliberative framework suggests an approach to situate the conversation of protection of both worker health and environmental health into risk decision-making.

Unfortunately, most risk reduction efforts at the regulatory policy level are based on a narrow problem definition that looks at “how to protect workers” or “how to protect the environment." Regulatory and institutional barriers contribute to the fragmented approach to risk decision making. EPA regulates outside the facility fence, and OSHA regulates inside. Current regulatory decision making is also vulnerable to strategic use of scientific uncertainty, and glacial with respect to the pace of setting health protective standards. Additionally, regulators must define risk per statutory mandates, which in light of judicial interpretations, constrains pragmatic risk reduction. The ripple effect flows outward to practitioners who typically rely on risk guidance provided by agency policies.

Although the analytic-deliberative framework seems well suited to the task of reconnecting occupational and environmental health at the local level, can the A-D model be applied to regulatory policy levels of risk decision-making? If so, then how? In the following paragraphs, I suggest some ideas toward moving toward broader implementation of analytic-deliberative processes in both environmental and occupational health policy making.

Traditional environmental health policy making can be described by the steps in Figure 4.5. As summarized by Johnson (2007): pressure is put on the political system, typically on elected officials or senior policy makers by lobbyists from environmental organizations, businesses interests, or professional societies. Other technical and academic experts may also apply pressure for policy change. Testimonies at public hearings usually take place, along with reports in the media and/or meetings with policy makers. At some point, when pressure is sufficient, action will occur, in the form of some recommended policy change, either as a proposed statute, regulation, ordinance or voluntary program. The change is implemented; in the case of an environmental law, the EPA translates the statutory language into applicable regulations. Finally, data is collected on the policy change (such as through air monitoring) and the policy change is evaluated (i.e. does the new Clean Air Act NAAQS result in cleaner air?).

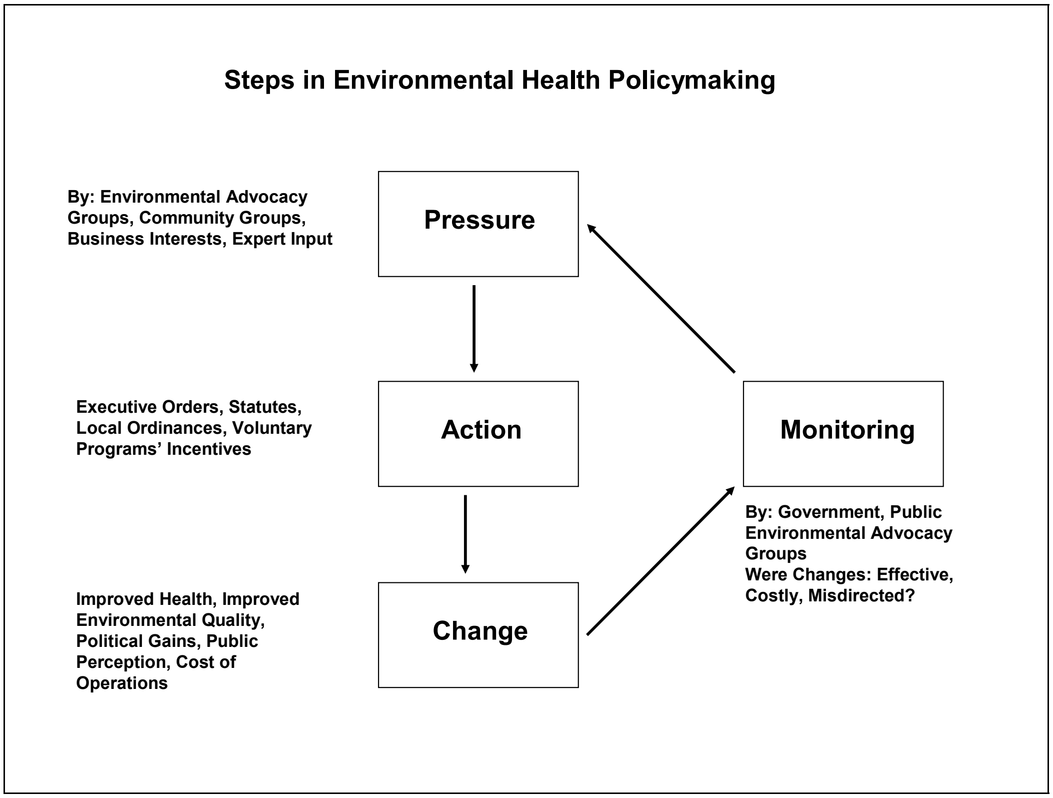


Figure 4.5: **Steps in Environmental Health Policymaking in the U.S. Source: Johnson (2007)**

There are numerous flaws with this type of policy making system. The ones related to this research are:

1. The process is top down,
2. The process is slow and inflexible as a mainly legalistic approach,
3. The process relies heavily on science as "facts" vs. policy as "values".

The segregation of facts vs. values leads to stakeholders with competing agendas trying to establish the best "facts" with their science (Fischer 2000). Science becomes the exclusive domain of experts, and other important and relevant types of knowledge may be overlooked. But since policy arguments are made up of technical, social and political components, connecting these different types of knowledge is critical to understanding decision-making effectiveness and improving policy analysis (Fischer 2000). Fischer (2000) suggests that instead of relying solely on scientific data in risk decision-making, the main task is to connect empirical data, normative assumptions, judgments made in the interpretation of the data, and the local context to evaluate a risk decision.

Fischer (2000) sketches out a way to do this by suggesting the need for policy epistemics or focusing on how people and groups communicate across differences and disciplines, and how some of these differences end up as controversies. Risk controversies are the sources for learning because that is where the traditional system has failed. Policy analysis then would center on identifying and evaluating arguments in the formal and informal policy communities as the main arenas where debates take place. In other words, besides understanding the facts, the policy epistemics practitioner would understand the way knowledge is interpreted across communities and how it flows across different levels of policy making structures. The policy epistemics practitioner would try to thread the arguments together.

The analytic-deliberative model can be used to help lay the groundwork to a more discursive approach to environmental and occupational health policy making that builds on Fischer’s (2000) concepts of policy epistemics.

The A-D model can facilitate policy making processes that are:

1. either top down or bottom up,
2. more flexible,
3. faster,
4. connecting analysis & deliberation rather than separating facts vs. values.

I suggest some initial conceptual ideas for how this could work in Figure 4.6.

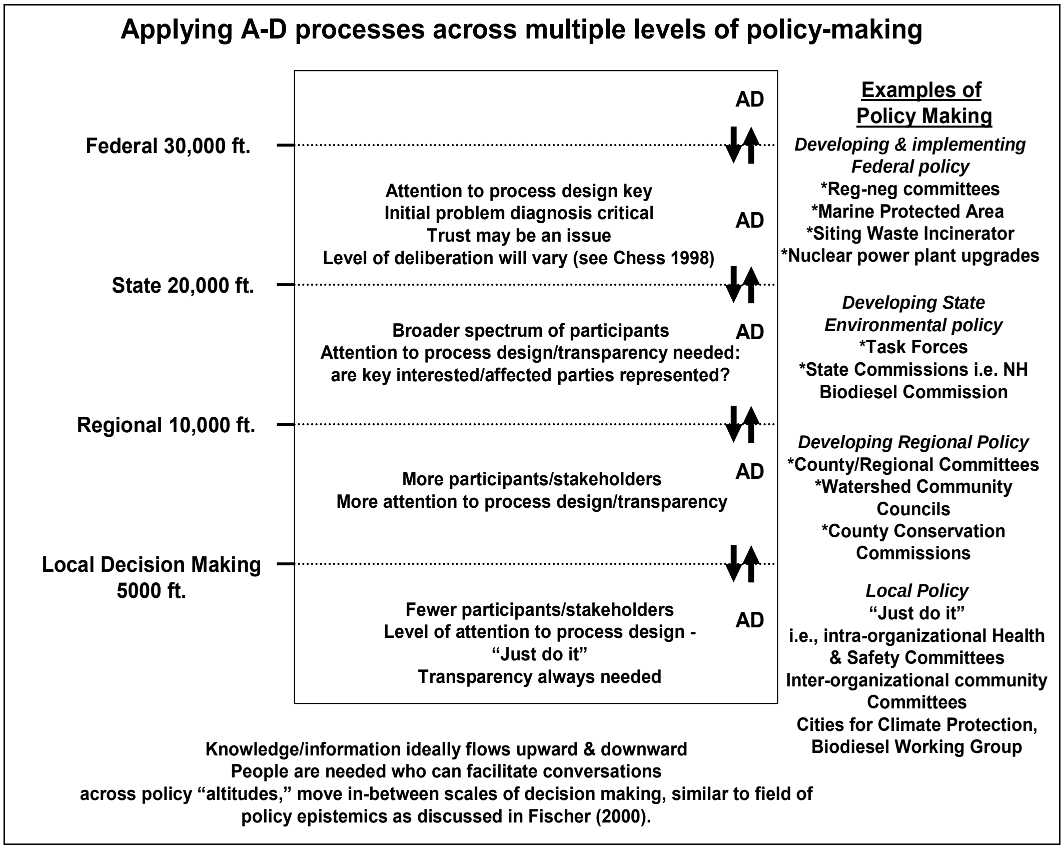


Figure 4.6: Applying the A-D Processes Across Multiple Levels of Policy-Making

Essentially this figure can be interpreted as follows: the higher the level of the policy making process, the higher the potential for complexity and conflict in decision-making. For example, with respect to environmental regulation, federal policy making processes typically are related to developing new regulations/standards, dealing with controversial problems (like siting a new incinerator), and enforcement of large scale violations. I call this the 30,000 foot level of policy making because federal regulations often have to consider nationwide applicability, and take a panoramic view. Analytic-deliberative processes can be helpful in developing regulations, either through a working group structure, or regulatory negotiation mechanism. Challenging policy problems could benefit from more sophisticated A-D applications like the cooperative discourse model (Renn 1999). In this model, three steps are emphasized: identification of stakeholder concerns and evaluative criteria, identification and measurement of impacts of different policy outcomes, and conducting a discourse with randomly selected citizens as jurors and interest groups/stakeholders as witnesses.

As the higher level altitude processes can be more prone to stakeholder value conflict, attention to process design is more critical than perhaps at the local or regional level. Important process design elements include how interested and affected parties (including public citizens) will be represented and included, how transparency of decision-making will take place, and how decisions will be made (i.e., consensus or 2/3 majority). Regarding process design and participation, there is a full literature on public participation in environmental decision-making (Renn et al. 1995; Beirele and Cayford 2002; Chess 1998, 2000; Webler and Tuler 2000). There are levels of process design needed depending on the complexity of the decision. Chess (1998) outlines how a matrix of decision complexity can inform the level of participation (and subsequently process design) needed. This literature can be valuable as well to the State and Regional levels of decision-making.

The lower altitude or on the ground policy-making processes can also benefit from the application of analytic-deliberative framework, as shown in this study. But although certainly every case in decision-making will have its own unique context, the level of attention to process design and to how options and outcomes are determined will usually not be are intense as at the federal level. This study demonstrated a "just do it" approach can work that pays attention to key concepts in the A-D to facilitate decision-making.

Ideally, analysis and deliberation can also take place across all the different levels of decision-making, ensuring that knowledge and information is communicated both upward and downward. This study was locally situated but provides important data for regional, state, and federal policy-makers to consider regarding the impact of B20 on occupational and environmental exposures and the application of an A-D model to risk decision-making in practice. A key way to facilitate these analytic-deliberative flows would be to have the types of policy epistemic practitioners recommended by Fischer (2000) in these roles. To be effective, it would have to be personnel supported by various organizations (such as regulatory agencies or non governmental organizations), but dedicated to building the collaborative relationships, communicative infrastructure, and knowledge needed to apply these concepts to various scenarios. Similar to how I acted as a thread tying together different aspects of the A-D process as applied in this study, a thread to connect the knowledge generated at each level is needed to ensure analysis and deliberation can happen and policy making can move beyond traditional paradigms.

4.4.3.b Future Research Directions: For this Case and Others

From a theoretical standpoint, additional cases of integration of analysis and deliberation remain a critical research need. While there is more literature on public participation in environmental decision making, there is little relating to specifically integrating analysis and deliberation. Other scholars have taken somewhat similar approaches to improving environmental health decision making. Judd et al. (2005) applied selected A-D concepts to community based research projects managing contaminated seafood risk in local communities. Corburn's (2005) study of environmental health policy making using street science to link local knowledge to professional knowledge also resulted in improved science and improved decision-making in most of the cases. For example, EPA exposure assessments that had previously overlooked the intake of chemicals from consistent subsistence fishing in polluted waters incorporated this local knowledge into their final analysis. Corburn (2005) emphasized how street science can enhance the procedural democracy of environmental health decisions, as it is geared towards helping community members organize and meet goals of environmental justice. While the theoretical and practical approaches of these researchers were somewhat different than this study, core ideas of expanding participation in analytic activities and connecting local and technical expertise were very similar.

In this specific case, future research should consider evaluation of the process against the NRC's (1996) evaluative criteria: did the process get the science right and the participation right? Did the process get the right science and the right participation? What are the implications of these criteria? The NRC (1996) report offers guidance in how to answer these questions. An evaluation of the process would be especially worthwhile as time passes from the initial collaborative activities. Did the attitudes of BWG members changed? What are the attitudes of initial BWG members who are no longer participating? Has trust among participants increased, decreased, or stayed the same? There are other evaluative approaches of participation in decision-making such as fairness and competence criteria (Renn et al.1995). Analyzing the case against the community based participatory research framework would also provide useful insight as another lens through which to view this research (O' Fallon and Drearry 2002).

4.4.4 Lessons Learned and General Reflections

4.4.4.a Effectiveness of the A-D Approach

Earlier in this chapter, I detailed how the A-D approach was effective in this case. Even without the Monadnock Biodiesel Collaborative outcome, the integration of analysis and deliberation saved time and resources in the exposure assessment, provided educational opportunities for undergraduate students, improved town/gown relationships, and resulted in novel outreach and co-learning opportunities. The flexibility and adaptability of the A-D model make it a better risk decision-making approach that traditional paradigms, and even newer policy ideas like the Precautionary Principle. The A-D model can be adapted to local contexts, and does not have to be fixed in place in a regulatory structure. The A-D model can be informed by ideas like the Precautionary Principle but does not have to be restricted by it. The A-D model is applicable only to the decision - and as the decision changes (or the problem formulation changes) the model can adapt accordingly.

Of course, this assumes local contextual issues will not impede the application of the model or constrain decision-making. Unfortunately, this is not always the case, as other researchers have shown (cf. Kinney and Leschine 2002). External barriers to decision-making may exist that preclude even trying to apply analysis and deliberation. For example, biodiesel market expansion is constrained by high cost. Many communities simply can't get over the hurdle of biodiesel's higher per gallon cost. Even in Keene, the DPW can't justify to taxpayers the increased cost of delivering B20 to the remote KRC, regardless of the benefits determined in this study. Sometimes decisions make themselves. This can happen at the federal or state level of policy-making when legislative mandates require specific actions. As OSHA must perform a quantitative risk assessment for each new or revised permissible exposure limit per the Supreme Court's ruling in the Benzene case, to create or revise a permissible exposure limit the decision-making steps for OSHA are clear. A-D processes may be able to creatively open up new problem formulations, but it is not a panacea. If there is extreme conflict among stakeholders, application of the A-D framework may not be effective at all.

4.4.4.b Limitations and Shortfalls

Collaborative processes are time consuming. The NRC (1996) report said to expect this. But local decision-making regarding B20 use in Keene did not happen (though there was lots of discussion of ideas) until key people were intentionally brought together in a collaborative forum to discuss the exposure assessment results. Getting the BWG to gain traction took over 5 months. It was difficult to get decision-making momentum going, though once BWG members moved into Central research questions #2 and #3, momentum soon became significant. Building relationships among the different groups to get that point took facilitation skills and dedicated time. Other organizations may not have the capacity to contribute a similar high level of resources.

Combining analysis and deliberation is messy. Part of this messiness includes conflict, such as the management/worker tensions, which has been noted to be a theme in community based research programs (Sclove 1998). Another part of the messiness includes the rapid flux in membership and the need that creates to revisit steps in the A-D process, like problem formulation. The process of the BWG stakeholders aligning on a similar problem formulation was amorphous, lengthy, and sometimes difficult to sit through. In some meetings, people needed to hear multiple times how the pieces would fit together such as how waste grease would be delivered to the site, processed, converted to biodiesel, analyzed, stored and distributed. There were also a few meetings in the March 2007 to August 2007 timeframe where just the concerns, or everything that could go wrong, were aired. These meetings were like group therapy. The BWG process was not the sequential steps of problem formulation through synthesis of information suggested by the NRC (1996) model but much more back and forth, three steps forward and two steps back. Although managerial efficiency didn't happen, the attention to negotiation and discussion helped make the Monadnock Biodiesel Collaborative goal more legitimate as each partner saw their role and benefit more clearly.

As mentioned previously, it was challenging to balance research activities in both the exposure assessment and Biodiesel Working Group. The scope of the project was ambitious (probably too ambitious) and the overlapping roles of exposure assessment researcher/BWG facilitator/BWG participant/BWG observer sometimes blended. I found the journal notes helped me keep on track, but it is easy to see why experts tend to migrate to familiar disciplinary silos.

Finally, a major limitation for the study was the lack of involvement in BWG activities of key interested affected parties, especially KRC workers. It also would have been beneficial (as well as recommended by the NRC (1996) report) to have citizen representation on the BWG. While I was creative in ways to involve the workers, one interview cannot make up for the potential contributions and building of trust that could result from fuller participation.

Although the NRC (1996) does not provide a cookbook for analysis and deliberation, this dissertation suggests a recipe for success based on the data in this study.

Recipe for the future: Applications of A-D Model

- ☆**One Part- Intraorganizational Champion**
- ☆**One Part- "Open Process" involving interested & affected parties**
- ☆**One Part- Common Problem Formulation (by group)**
- ☆**One Part- Skilled Facilitation & Process Design**
- ☆**One Part- Technical Expertise**
- ☆**One Part- Local Support & "Community- focused" issue**
- ☆**One Part- Access to resources (Funding, Programs, Organizations)**

Figure 4.7: <u>A Recipe for Future Application of the A-D Model</u>

The importance of organizational leadership cannot be overstated. By his initial decision to use biodiesel, to advocate its use in numerous public presentations, and his desire to seek KSC expertise to research B20 exposures, Steve Russell could be considered an environmental champion. Hewes (2005) study of environmental champions who led in the implementation of eco-industrial parks found that the champions' strategies emphasized social connections over technological connections. In addition, Hewes (2005) found champions are visionaries, and invested leaders. Others have described champions as having skills at identifying, packaging & selling environmental issues as well as unique abilities at framing and presenting environmental issues in appropriate organizational (sometimes financial) terms (Andersson & Bateman 2000). The data collected in this dissertation suggest Russell possessed a number of these identified key attributes and skill sets of an environmental champion. Without a strong champion in a key intraorganizational position biodiesel use probably just wouldn't have happened in Keene. It is important to ensure that a key internal champion is present to assist with on the ground implementation of decision-making processes. Viewing this case through the lens of environmental leadership may lead valuable insights for future groups looking to implement environmental initiatives.

As mentioned previously, there is a full literature on public participation in environmental decision-making. As a locally grounded process, the Keene BWG could adapt much more quickly to issues. I did not spend a lot of time up front on issues of procedural fairness, like Robert's rules of order, maintaining meeting minutes (other than for my research), and developing rules for voting on issues (i.e., simple majority or consensus). Our initial goals were pretty loose and open: to educate the community on biodiesel and to discuss options to increase biodiesel use. This had advantages: people didn't feel pressure;

there was the opportunity for motivating people to make novel contributions. But there were disadvantages too: as the process moved forward there was much confusion on individual and organizational roles, repeated discussion of ideas, and limited accountability for tasks.

Resources are necessary for A-D processes. I was able to dedicate a 12 month period to the BWG and initial biodiesel refinery processes because I was on a non-paid leave of absence working on this dissertation. KSC had grants that were able to support the exposure assessment work. The City allowed staff to participate in the study and allowed City staff time for BWG meetings. Although it seems obvious, it bears repeating: support for A-D processes is needed for success. If the problem is based within a community, then community support is critically needed as well. Biodiesel was seen as a part of the Cities for Climate Protection initiative which helped gain community support for the differential higher cost.

Technical expertise is needed in this process. It is doubtful that citizen participation in science will make scientists obsolete. First, science is permeated throughout the political world in making complex decisions, and this science has become increasingly more sophisticated. There will always be a need for knowledge that comes from the scientific method. Second, there is almost a cultural reliance on science as evidenced by Russell's persistence in wanting "scientific facts" to support his personal observations. People put stock in science. While Russell and others participated in the collaborative exposure assessment, participation was mainly in the form of helping with the research strategies and coordinating logistics. KRC employees and others were curious as to the instruments and techniques we were using to measure air quality but there was never any interest to actually learn how to do conduct air monitoring. Experts are experts for a reason; it takes education and training to develop expertise.

Finally, expertise is needed to provide evidence to inform decision-making. Just because knowledge is local does not mean it is good. Russell's connection of diesel exhaust exposure to cancer was strongly motivated by his personal belief that his co-workers may have developed cancer from diesel exposure. This could suggest much of his decision to initially use B20 could be related to the availability heuristic, or assigning a higher probability to events to which one has been frequently exposed. People (including experts) make faulty judgments all the time, so multiple lines of evidence, including technical expertise, are needed to inform decisions.

4.4.4.c Biodiesel and Climate Change

In closing, recent attention has focused on the potential of biodiesel to reduce greenhouse gas emissions and in this way reduce or mitigate the impacts of global warming and associated climate change. A joint USDA/DOE study found that use of soybean-based 100% biodiesel in an urban bus reduced net carbon dioxide emissions by 78% and B20 reduced CO_2 by almost 16% (Sheehan, et al. 1998). Hill et al. (2006) performed a more recent life cycle accounting and determined that soy based biodiesel provides 93% more energy than the fossil fuel energy invested in its production, and reduces greenhouse gases by 41% compared to diesel (Hill et al. 2006).

However, the science is becoming increasingly politicized. Part of this is the media confusion between ethanol and biodiesel as they are often both referred to as biofuels. But they are very different in many respects: ethanol reduces greenhouse gases by only 12%

compared to gasoline, and the nitrogen, phosphorus, and pesticide released from farming corn for ethanol is much higher than that released from farming soy for biodiesel (Hill et al. 2006). Hill et al. (2006) concluded that neither biofuel can replace current petroleum demand without impacting food supplies. This is more likely for ethanol than biodiesel. In fact, biodiesel took off as a market response from soy farmers dealing with the glut of excess soy oil in the 1990's (Pahl 2005). Ethanol requires the whole corn to make the fuel, but biodiesel requires just the oil.

A more recent study only increases the controversy. Fargione et al. (2008) conclude that biofuels (including biodiesel) will result in 93 times higher emissions of greenhouse gases because of land use shifts. This means that as land is dedicated to biofuels around the world, new land must be cleared to make room for crops. When rainforest or vegetation able to effectively sequester carbon are cleared, excess carbon dioxide is released, creating a carbon debt.

A fundamental issue with these studies it is that it overlooks how biodiesel can be made from other feedstocks, not just soy. Also, the studies look at the problem of whether biodiesel can displace petroleum diesel. This might not be the best problem formulation. Most biodiesel supporters acknowledge that no feedstock or feedstock combination at this time can replace petroleum due to its volume of use. Research continues into non-food feedstock sources, such as oil producing algae, but in the meantime, biodiesel at best will be only one tool in any future renewable energy portfolio. Finally, the bracket for the analysis may be too fuzzy: Hill et al. (2006) included the energy that went into manufacturing the equipment that farmed corn and soy. While a comprehensive life cycle analysis, is it decision-relevant? Do life cycle analyses of petroleum diesel include the energy that went into manufacturing oil platforms and ocean going cargo vessels? The wider the lens, the fuzzier the photo.

These framing examples overlook biodiesel's potential to reduce greenhouse gases. When biodiesel is made from a waste grease feedstock, the benefits are clearer: the waste oil came from a vegetable source at some point in the life cycle, so that reduction of greenhouse gases is a straightforward calculation. This would also apply to biodiesel made from algae. Although biodiesel use is still relatively new in the U.S., a facts vs. values, expertise vs. counterexpertise frame is emerging with respect to biodiesel and climate change. Policy makers at the federal and state level face uncertainty in the science and competing stakeholder values. There is decision urgency when public health, foreign oil political concerns, and climate change are considered. It appears that the potential of biodiesel to reduce greenhouse gases is a case study ripe for the application of the analytic-deliberative process.

Appendix A: Complete Raw Data Summary of Collaborative Exposure Assessment

Diesel	Dates	PM$_{2.5}$	PM$_{4.0}$	EC	OC	NO$_2$ am	NO$_2$ pm	Average Daily Temp	Temp Class	Average Relative Humidity	Humidity Class	Activity Class	Gasoline Vehicle Count	Vehicle Count Class Gasoline	Diesel Vehicle Count	Vehicle Count Class Diesel
P1	6/27/2006	0.2209	0.13038	0.0047	<0.0026	NDC	NDC	79.3	High	60.6	Low	High	86	High	4	Low
	7/10/2006	0.1155	0.5322	0.0032	<0.0027	NDC	NDC	76.6	High	58.4	Low	Medium	NDC	NDC	NDC	NDC
	7/11/2006	0.5397	0.5992	0.012	0.0057	NDC	NDC	79.4	High	70.6	High	High	86	High	6	Low
	7/12/2006	0.6463	0.6484	0.0074	<0.0026	NDC	NDC	71.8	Low	77.2	High	Medium	101	High	11	Medium
	7/13/2006	0.5904	0.28076	0.0092	<0.0028	NDC	NDC	69.5	Low	86.9	High	High	54	Low	20	High
	7/14/2006	0.2795	0.7048	0.0041	0.0056	NDC	NDC	78.3	High	71.6	High	Low	NDC	NDC	NDC	NDC
	7/18/2006	NDC	NDC	NDC	NDC	NDC	NDC	86	High	55.0	Low	NDC	NDC	NDC	NDC	NDC
	7/24/2006	0.1178	0.1349	0.0034	<0.0027	NDC	NDC	72.6	Low	62.4	Low	Low	93	High	5	Low
	7/25/2006	0.1146	0.1295	0.0095	0.0037	NDC	NDC	82.3	High	53.6	Low	High	67	Medium	5	Low
	7/26/2006	0.0618	neg	0.0054	0.0083	NDC	NDC	80.1	High	65.6	High	High	85	High	16	High
	7/27/2006	0.164	neg	0.0087	<0.024	NDC	NDC	80	High	72.2	High	High	67	Medium	2	Low
P2	6/27/2006	1.0991	0.3749	0.0067	0.0037	NDC	NDC	79.3	High	60.6	Low	High	86	High	4	Low
	7/10/2006	0.0873	0.1333	0.0053	0.0074	NDC	NDC	76.6	High	58.4	Low	Medium	NDC	NDC	NDC	NDC
	7/11/2006	0.3644	0.2581	0.0059	0.0056	NDC	37.7	79.4	High	70.6	High	High	86	High	6	Low
	7/12/2006	0.3967	0.124	0.0096	0.0046	4.3	5.2	71.8	Low	77.2	High	Medium	101	High	11	Medium
	7/13/2006	0.4228	0.13747	0.0068	<0.0027	22.0	35.4	69.5	Low	86.9	High	High	54	Low	20	High
	7/14/2006	0.2786	0.5506	0.0052	<0.0027	11.1	NDC	78.3	High	71.6	High	Low	NDC	NDC	NDC	NDC
	7/18/2006	NDC	NDC	NDC	NDC	23.4	NDC	86	High	55.0	Low	NDC	NDC	NDC	NDC	NDC
	7/24/2006	0.1147	0.1318	<0.0027	<0.0027	10.7	45.1	72.6	Low	62.4	Low	Low	93	High	5	Low
	7/25/2006	0.1456	neg	0.0083	<0.0027	8.1	68.4	82.3	High	53.6	Low	High	67	Medium	5	Low
	7/26/2006	0.3202	neg	0.0062	<0.0026	NDC	NDC	80.1	High	65.6	High	High	85	High	16	High
	7/27/2006	0.0626	0	0.0065	<0.0032	28.6	NDC	80	High	72.2	High	High	67	Medium	2	Low
P3	6/27/2006	0.356	0.12156	<0.013	0.0026	NDC	NDC	79.3	High	60.6	Low	High	86	High	4	Low
	7/10/2006	0.2853	neg	0.004	<0.0029	NDC	NDC	76.6	High	58.4	Low	Medium	NDC	NDC	NDC	NDC
	7/11/2006	0.7573	0.3098	<0.0034	<0.0034	NDC	NDC	79.4	High	70.6	High	High	86	High	6	Low
	7/12/2006	0.3073	0.7605	0.0046	<0.0026	NDC	NDC	71.8	Low	77.2	High	Medium	101	High	11	Medium
	7/13/2006	0.5259	neg	<0.0028	<0.0028	NDC	NDC	69.5	Low	86.9	High	High	54	Low	20	High
	7/14/2006	0.4883	0	<0.0028	<0.0028	NDC	NDC	78.3	High	71.6	High	Low	NDC	NDC	NDC	NDC
	7/18/2006	NDC	NDC	NDC	NDC	NDC	NDC	86	High	55.0	Low	NDC	NDC	NDC	NDC	NDC
	7/24/2006	0.0285	0	<0.0027	<0.0027	NDC	NDC	72.6	Low	62.4	Low	Low	93	High	5	Low

	7/25/2006	0	neg	<0.003	0.014	NDC	NDC	82.3	High	53.6	Low	High	67	Medium	5	Low
	7/26/2006	0.0921	0	<0.0029	<0.0029	NDC	NDC	80.1	High	65.6	High	High	85	High	16	High
	7/27/2006	0.0316	neg	<0.0034	<0.034	NDC	NDC	80	High	72.2	High	High	67	Medium	2	Low
MS1	6/27/2006	0.4906	0	0.0061	0.0076	NDC	NDC	79.3	High	60.6	Low	High	86	High	4	Low
	7/10/2006	0.6047	neg	0.0039	0.0042	NDC	NDC	76.6	High	58.4	Low	Medium	NDC	NDC	NDC	NDC
	7/11/2006	0.1967	0.1672	<0.0042	<0.0042	NDC	NDC	79.4	High	70.6	High	High	86	High	6	Low
	7/12/2006	0.6442	0.2585	0.0077	<0.0023	NDC	NDC	71.8	Low	77.2	High	Medium	101	High	11	Medium
	7/13/2006	faulted	0.55348	0.0057	0.0078	NDC	NDC	69.5	Low	86.9	High	High	54	Low	20	High
	7/14/2006	0.4129	0	0.0045	<0.0028	NDC	NDC	78.3	High	71.6	High	Low	NDC	NDC	NDC	NDC
	7/18/2006	NDC	NDC	NDC	NDC	NDC	NDC	86	High	55.0	Low	NDC	NDC	NDC	NDC	NDC
	7/24/2006	0.088	0.1296	<0.0026	<0.0026	NDC	NDC	72.6	Low	62.4	Low	Low	93	High	5	Low
	7/25/2006	P5	neg	0.0092	0.0085	NDC	NDC	82.3	High	53.6	Low	High	67	Medium	5	Low
	7/26/2006	P5	neg	0.0065	0.0045	NDC	NDC	80.1	High	65.6	High	High	85	High	16	High
	7/27/2006	P5	0.5629	0.011	<0.0033	NDC	NDC	80	High	72.2	High	High	67	Medium	2	Low

B20	**Dates**	**$PM_{2.5}$**	**$PM_{4.0}$**	**EC**	**OC**	**NO_2 am**	**NO_2 pm**	**Average Daily Temp**	**Temp Class**	**Average Relative Humidity**	**Humidity Class**	**Activity Class**	**Gasoline Vehicle Count**	**Vehicle Count Class Gasoline**	**Diesel Vehicle Count**	**Vehicle Count Class Diesel**
P1	8/7/2006	0.3364	neg	<0.0039	<0.0039	NDC	NDC	77.6	High	72.9	High	Low	66	Medium	6	Low
	8/8/2006	0.1244	neg	0.012	<0.0036	NDC	NDC	80.9	High	67.7	High	High	67	Medium	7	Low
	8/9/2006	NDC	0.2621	<0.0024	0.024	NDC	NDC	72.9	Low	45.4	Low	High	71	Medium	11	Medium
	8/10/2006	0.1528	neg	0.0064	0.033	NDC	NDC	70	Low	62.9	Low	High	67	Meduim	5	Low
	8/14/2006	0.0592	NPW	0.0051	0.025	NDC	NDC	70.7	Low	59.2	Low	Meduim	91	High	12	Medium
	8/15/2006	0.0653	NPW	0.0044	0.026	NDC	NDC	80	High	87.9	High	Low	46	Low	7	Low
	8/16/2006	0.0952	neg	0.0046	0.027	NDC	NDC	71.6	Low	59.2	Low	High	NDC	NDC	NDC	NDC
	8/17/2006	0.0626	0.2671	0.0047	0.038	NDC	NDC	72.7	Low	57.3	Low	Meduim	NDC	NDC	NDC	NDC
	8/22/2006	NDC	NDC	NDC	NDC	NDC	NDC	70.9	Low	61.2	Low	NDC	NDC	NDC	NDC	NDC
	8/23/2006	NDC	NDC	NDC	NDC	NDC	NDC	69.3	Low	66.0	High	NDC	NDC	NDC	NDC	NDC
	8/7/2006	0.1122	neg	<0.0045	<0.0045	11.8	5.8	77.6	High	72.9	High	Low	66	Medium	6	Low
	8/8/2006	0.2119	neg	0.0074	<0.0034	29.2	42.2	80.9	High	67.7	High	High	67	Medium	7	Low
	8/9/2006	NDC	0.0944	0.004	0.041	36.7	50.9	72.9	Low	45.4	Low	High	71	Medium	11	Medium
	8/10/2006	0.1485	neg	0.0058	0.029	81.7	69.6	70	Low	62.9	Low	High	67	Meduim	5	Low

P2	8/14/2006	0.1178	NPW	0.0055	0.026	38.0	33.7	70.7	Low	59.2	Low	Meduim	91	High	12	Medium
	8/15/2006	0.0624	NPW	0.0029	0.024	15.9	29.8	80	High	86.0	High	Low	46	Low	7	Low
	8/16/2006	0.1316	0	0.0038	0.03	22.4	10.7	71.6	Low	59.2	Low	High	NDC	NDC	NDC	NDC
	8/17/2006	0.0301	0.963	0.045	0.25	NDC	12.4	72.7	Low	57.3	Low	Meduim	NDC	NDC	NDC	NDC
	8/22/2006	NDC	NDC	NDC	NDC	9.7	58.6	70.9	Low	61.2	Low	NDC	NDC	NDC	NDC	NDC
	8/23/2006	NDC	NDC	NDC	NDC	12.3	47.1	69.3	Low	66.0	High	NDC	NDC	NDC	NDC	NDC
P3	8/7/2006	0.1491	0	<0.0028	<0.0028	NDC	NDC	77.6	High	72.9	High	Low	66	Medium	6	Low
	8/8/2006	0.0923	neg	<0.0037	<0.0037	NDC	NDC	80.9	High	67.7	High	High	67	Medium	7	Low
	8/9/2006	NDC	neg	0.005	0.027	NDC	NDC	72.9	Low	45.4	Low	High	71	Medium	11	Medium
	8/10/2006	0.0611	neg	<0.0026	0.023	NDC	NDC	70	Low	62.9	Low	High	67	Meduim	5	Low
	8/14/2006	0	NPW	0.0033	0.028	NDC	NDC	70.7	Low	59.2	Low	Meduim	91	High	12	Medium
	8/15/2006	0	NPW	<0.0027	0.025	NDC	NDC	80	High	86.0	High	Low	46	Low	7	Low
	8/16/2006	0.1241	0	0.0031	0.025	NDC	NDC	71.6	Low	59.2	Low	High	NDC	NDC	NDC	NDC
	8/17/2006	0.063	0	0.0048	0.031	NDC	NDC	72.7	Low	57.3	Low	Meduim	NDC	NDC	NDC	NDC
	8/22/2006	NDC	NDC	NDC	NDC	NDC	NDC	70.9	Low	61.2	Low	NDC	NDC	NDC	NDC	NDC
	8/23/2006	NDC	NDC	NDC	NDC	NDC	NDC	69.3	Low	66.0	High	NDC	NDC	NDC	NDC	NDC
MS1	8/7/2006		neg	<0.0041	<0.0041	NDC	NDC	77.6	High	72.9	High	Low	66	Medium	6	Low
	8/8/2006		neg	0.0095	0.0074	NDC	NDC	80.9	High	67.7	High	High	67	Medium	7	Low
	8/9/2006		0	0.004	0.028	NDC	NDC	72.9	Low	45.4	Low	High	71	Medium	11	Medium
	8/10/2006		neg	0.0055	0.031	NDC	NDC	70	Low	62.9	Low	High	67	Meduim	5	Low
	8/14/2006		NPW	0.0046	0.027	NDC	NDC	70.7	Low	59.2	Low	Meduim	91	High	12	Medium
	8/15/2006		NPW	0.0035	0.034	NDC	NDC	80	High	86.0	High	Low	46	Low	7	Low
	8/16/2006		0.1399	<0.0027	0.036	NDC	NDC	71.6	Low	59.2	Low	High	NDC	NDC	NDC	NDC
	8/17/2006		0.4304	0.0035	0.027	NDC	NDC	72.7	Low	57.3	Low	Meduim	NDC	NDC	NDC	NDC
	8/22/2006	NDC	NDC	NDC	NDC	NDC	NDC	70.9	Low	61.2	Low	NDC	NDC	NDC	NDC	NDC
	8/23/2006	NDC	NDC	NDC	NDC	NDC	NDC	69.3	Low	66.0	High	NDC	NDC	NDC	NDC	NDC

LEGEND		P5	= Data Collected at Perimeter 5
NDC	= No Data Collected	NPW	= No pre-weights
< # # # #	= Below minimum detection limit	neg	= negative accumulation after post weight

Appendix B: Detailed background and review of the City of Keene/Keene State College research collaboration – contextual factors results

The City of Keene - Background

Keene is a small city of approximately 22,000 people located in southwestern New Hampshire. Keene is governed by the mayor and a 15 member City Council, who are elected by the citizens of Keene to represent their interests in local decision-making (City of Keene 2007). The mayor attends the council meetings but has no vote except to break a tie. The mayor nominates each council member to one of three standing committees: Municipal Services, Facilities and Infrastructure Committee; the Planning, Licenses, and Development Committee; and the Finance, Organization and Personnel Committee. The City Council votes on the mayoral committee nominations and also appoints a City Manager, who serves as the CEO of the City (City of Keene 2007). There are a number of city departments that make up the municipal organizational structure: fire, police, parks, public works, health, code enforcement, planning, and others. The department of public works (DPW) is responsible for managing a number of activities that have environmental impact such as drinking water quality, wastewater treatment, fleet maintenance and solid waste management. The Keene Recycling Center (KRC), the research site for the exposure assessment, is managed by the City DPW.

With respect to environmental awareness, Keene could be considered a community more concerned about protection of the environment than most. In 2000, Keene signed the Cities for Climate Protection Campaign, administered by the International Council for Local Environmental Initiatives (City of Keene 2007). The Cities for Climate Protection (CCP) Campaign focuses on local solutions to global warming, primarily by reducing emissions of greenhouse gases at the municipal level. Keene has signed on to reduce emissions of carbon dioxide and methane by 10% of 1995 levels by 2015, but the City municipal departments have committed to a 20% goal. To meet this goal, a number of environmental projects have been initiated, such as installing a methane recovery system at the local landfill, and implementing energy conservation measures in municipal buildings. Although biodiesel use is listed on the 2004 Local Action Plan (City of Keene 2007), this case study indicates the decision to use biodiesel happened concurrently and outside the formal CCP process, at least initially.

A Brief History of the Initial Decision to Use B20 in Keene

A main result of this case study is that the decision to use biodiesel in the City of Keene fleet originated with one man, DPW Fleet Manager Steve Russell. When asked, the other respondents interviewed as part of this case study all point to Russell as being the critical component of the decision to use B20 in Keene. As Duncan Watson, Assistant Director of Public Works, and currently Russell's supervisor, puts it, "Steve Russell really took the initiative to get biodiesel into the fleet. Steve was the primary driver on this." Russell himself has acknowledged becoming a kind of biodiesel expert, "I guess I'm the biodiesel king" (Cleary 2005).

In 2001, Russell attended a Granite State Clean Cities meeting at Antioch New England Graduate School (now Antioch University) where the question of use of biodiesel came up. Through his previous experience with the National Association of Fleet Administrators (NAFA), Russell knew a little bit about biodiesel, and knew it was a fuel that could be used without retrofitting existing equipment. At the Clean Cities meeting, he stood up and offered to try the alternative fuel in his municipal fleet, but stated his budget could not allow for the extra 35 cents per gallon cost for B20.

The next day he received a call from the Governor's Office of Energy offering a small $2500 grant to offset the cost differential to purchase B20. At that point, Russell recalls, "I started doing my homework." He developed a list of biodiesel's positives and negatives, and looked up cold weather properties, and warranty issues. At the time, some engine manufacturers were taking a negative stance towards biodiesel, stating that use of the fuel could void the warranty. This meant that any problems with an engine subsequent to trying the fuel could be challenged. However, Russell researched the language in the warranties of some of the engines in his fleet and determined that engine warranties cover workmanship of parts. If he used an ASTM certified biodiesel the engine manufacturers had to stand by their commitment. He contacted other fleet managers for advice about biodiesel use. At a meeting in New Jersey, he met and spoke with Tom Lupus, the Fleet Manager for the Port Authority of NY/NJ, and learned they were testing B20 in LaGuardia Airport. By this time, he felt confident enough to try the fuel, "The light went off in my head. It's good enough for airports so little old Keene can do it."

However, instead of immediately placing the order for a B20 delivery, Russell spent the next six months meeting with department heads across the City's organization in a long process of education and advocacy to address concerns and build support to try the fuel. Eventually he got that support, although some wanted Russell to start running B20 on a trial basis, starting with a separate tank and only one piece of equipment. Instead, he insisted on a full tank delivery into the central 10,000 gallon underground storage tank system. When the

$2500 from the initial grant ran out, Russell kept using B20 in the fleet, wondering if this would result in problems for him later:

> I kept it going for a while, and then I thought when my budget goes over, and they start asking questions, I am going to be in trouble. I said, I'll take the chance. I noticed it was doing good things for the fleet. I noticed the air was cleaner, the mechanics noticed it. There were a lot of positives.

B20 has been used in the fleet since that time. As of 2007, the City of Keene DPW has used over 200,000 gallons of B20 in their centralized fleet. But B20 has not been consistently used in the remote locations such as the recycling center and local airport due to the associated increased delivery costs and difficulty finding a local supplier willing to make smaller deliveries.

Linking to KSC and the Pilot Exposure Assessment

In April 2004, Russell approached me at a Granite State Clean Cities meeting and asked if Keene State College's Safety Studies program would be interested in doing a B20 emissions study. Russell was interested in getting scientific data to give him the "ammunition" he felt he needed for his biodiesel outreach presentations. Since 2002, Russell had become a local expert on biodiesel use and gave numerous powerpoint presentations on the Keene DPW experience. When Russell would try to encourage organizations to try biodiesel, he would share his personal experience how B20 use reduced headaches for him and his workers. Russell said he would invariably be asked by someone in the audience, "Well, where are your facts Steve?" This lack of appreciation for his practical, local knowledge – “I don’t have any facts. I just feel better you know” - and the continued requests for “facts” from audiences frustrated him enough to reach out to KSC.

A preliminary literature review I performed in 2004 revealed the knowledge base on biodiesel exposures was very limited. Yet in listening to Russell and his employees’ talk about their improved health since using biodiesel, I wondered if Russell and his workers had local knowledge that scientists and the policy community didn’t have on biodiesel exposures. As Russell (2006) explained in describing the fleet services building after the switch to B20:

> I noticed it myself. My office in the old building was adjacent to the shop…every time they would drive a diesel engine into the shop… we had no air quality equipment in that shop. Those diesel fumes would stay there for a period of time and I found myself with a lot of headaches. I would go open the window, try and get rid of the headaches so fast forward to using biodiesel…the same equipment goes into the shop, same environment, same everything and I’m not getting any headaches. It was very strange and I’m trying to rack my brain, why aren’t I getting headaches now. Then I realized it was the B20. It was the biodiesel.

Biodiesel was beginning to figure more prominently in the national discourse as a renewable, ‘green’ fuel that was good for the environment and provided a domestic source of energy. I also was intrigued by the relative lack of research performed on biodiesel – especially in real world applications and settings - which could lead to future controversies about risk. KSC faculty and students conducted a pilot study in 2004 to compare one day’s operation of diesel vs. biodiesel at the Keene Recycling Center, measuring particulate matter, elemental carbon/organic carbon, and toxic pollutant exposures in the workplace and local environment.

The pilot study data indicated a dramatic 85% reduction in particulate matter. The results of this study are published elsewhere (Traviss et al., pending publication). This result was remarkable in comparison with EPA’s (2002b) predicted 10% PM reduction from tailpipe emissions, indicating that Russell and his employees' local knowledge was indeed noteworthy about a unknown potential benefit of biodiesel. Russell began using the 85% $PM_{2.5}$ reduction result in his presentations, which elicited more discussion and questions about biodiesel. But the pilot study measured $PM_{2.5}$ for just one day of diesel vs. one day of biodiesel, and the KSC research faculty and Russell knew that more days would be needed to support a conclusion in both the scientific and policy communities. Therefore, we planned to conduct an expanded exposure assessment in the summer of 2006.

Contextual Factors

Interviews and document analysis provided data for developing pertinent background on the City of Keene's initial decision to use B20. Four main contextual factors were identified (pro-environmental attitude, leadership/savviness, Keene culture of environmental support, and internal/external political factors) that influenced the initial decision to use B20. These factors also helped set the stage for the policy outcomes seen in this study.

Factor #1: Pro-Environmental Attitude

Russell demonstrated a strong personal interest in environmental issues that influenced his decision to push for B20 use in Keene. Evidence of this pro-environmental attitude is apparent as soon as one walks into Russell's office in the fleet services building: taped on the wall is the front page of the February 3, 2007 San Diego Tribune with the headline "Report on global warming: 'We have to do something.'" Also on the office walls are photos of alternative fuel vehicles, like a subcompact electric car, and a photo of Russell receiving the 2004 Governor's Award for Pollution Prevention. It most ways, the fleet maintenance building is unremarkable: it is a 2 story, non-descript cinder block building with high ceilings in the work bays and the faint, familiar smell of fuel, rubber and oil permeating the air. Anyone who has picked up their car at a service station knows this smell. Except in this building, one immediately notices the ***lack*** of garage smell, which is another clue something is different about this operation.

Russell's interest in biodiesel was also influenced by personal connections relating to environmental health. When Russell first started considering biodiesel, he remembered two women who had worked as secretaries for decades in the former city fleet services maintenance building. Both of them retired, and then died shortly thereafter from cancer. He also recalled the death of his sister's father-in-law from what he termed "the farmer's cancer" or colon cancer.

According to Russell, the father-in-law sold his dairy farm, and then:

> A year and a half later he was dead of colon cancer. And my sister overheard the doctors from Dartmouth [hospital] say, 'Yeah that's the farmer's cancer, colon cancer.' I'm thinking to myself, now where's the correlation here? Why did this guy die of cancer? Now there may have been a million other things in his environment that may have caused that… but what's the odds he sits on a diesel tractor with a stack sitting in front 8 hours a day, mowing the fields, just on the tractor, all the time. I'm thinking, "Holy Mackerel," maybe this thing with diesel, there's some merit to this. Yeah, I got ladies [in Keene's former fleet maintenance office] dying of cancer and I don't know what kind of cancer it was, but there's some correlation."

For Russell, use of biodiesel was one way to make the air cleaner by reducing the pollution from diesel exhaust. As he explained to a local newspaper reporter in 2003, "I think a lot of people don't even know we are burning it and it's cleaning the air. You pull a truck into my shop now and you don't even know it's diesel" (Cohen 2003). Therefore, use of biodiesel combines Russell's pro-environmental attitude with a sense of personal responsibility to make a positive change for the workplace. But biodiesel is not the only environmentally friendly project Russell has spearheaded, though it is the one he is most known for locally. He added a new gasoline-electric hybrid pick-up truck to the fleet in 2005, and set up a bike program to encourage city employees to bike between offices. This sense of responsibility to protect the environment and the drive to act on it tied into the next factor identified in this study, leadership and savviness.

Factor #2: Leadership & "Savviness"

Russell has been recognized by others in this study as a leader in the biodiesel project. City of Keene Mayor Blastos remarked how he was impressed by Russell's "eloquence" in describing biodiesel's benefits at the 2003/2004 budget hearing and believed that was a key reason why the City Council Finance Committee decided to keep biodiesel in the budget. For this case study, I defined leadership as evidence of an action or statement that had one of the following characteristics: taking a personal risk in any way to help facilitate biodiesel use by the city (i.e. evidence of leading the "biodiesel project"), showing evidence of self-initiative or simply that his involvement was somehow crucial to the implementation of biodiesel.

There were a number of examples of Russell's leadership that emerged from the case study, such as insisting the fuel be tried across the fleet instead of via a piecemeal approach. Russell's leadership has been balanced with a quality I have termed 'savviness'. Savviness refers to an ability to negotiate among different internal/external stakeholders, and a sensitivity to others' concerns and viewpoints, such as being sensitive to cost concerns. The decision to use biodiesel after the funding ran out is particularly reflective of the leadership/savviness combination: continuing to use the fuel was a risky choice, but he had already publicly identified the cost barrier, knew the City was committed to the CCP initiative, and gained city department heads' approval after a six month negotiating process.

Factor #3: Keene's "Culture of Environmentalism"

A number of patterns emerged during this study that highlighted the City of Keene municipal organization has a culture of environmentalism. I use the word "culture" here to refer to the social and political landscape within the city organization specifically, but also by extension, the citizen population more generally. The fact that Keene has been participating in the CCP program (and is one of only about 300 cities worldwide doing so) since 2000 is a clear example of the value city leaders place on local environmental protection. Blastos summarized Keene's environmental awareness with, "Before global warming was even murmured or at the forefront like it is now…we were concerned about air pollution here in Keene." Environmental protection as a core value of the community translates into support for projects that help meet that core value. For any major capital project or initiative like the CCP program to take place, a majority of votes of the City Council is required. Therefore, the community as a whole, proxied through the City Council, is providing a culture of support of environmentally focused projects. As Watson states, "Environmental initiatives are very well received in Keene." This preexisting cultural background of support is a crucial factor that helped in the implementation of B20 in the fleet. Russell has been quick to cite the support of the Council in his outreach efforts, whether he is presenting to local public or professional audiences.

Factor #4: Internal/External Political Factors

This category reflects the other, somewhat more intangible, but clearly important, factors that also influenced the decision to use B20 in Keene. For example, while Russell demonstrated personal leadership in offering to try B20 at the 2001 Clean Cities meeting, without the external grant funding from the Governor's office, use of biodiesel may not have happened. This is a clear example of how an external political factor influences decision-making, in this case, by removing the structural barrier of higher cost to try the alternative fuel. Another example of an external political factor is the existence of a Clean Cities organization that provides networking with peers, information and resources for individuals like Russell interested in learning more about environmentally friendly options for their fleet. Finally, internal political factors like discussions with peers or other fleet managers using B20 played a key role in influencing Russell's eventual decision to try biodiesel. Another important factor was support from the engine manufacturers to ensure B20 use would not void warranties. This could be considered an industry political factor. Finally, there was an external political factor not mentioned during the open-ended interview but consistently mentioned during Russell's outreach presentations: the belief that use of B20 equates to a reduction in use of foreign oil. Therefore, use of B20 makes a political statement that energy options should be domestically sourced, reducing the probability of extended conflicts like the present one in Iraq.

In summary, the results from the case study indicated that in addition to the organizational leadership Russell demonstrated and others recognized in implementing biodiesel, there were 4 key factors that facilitated the decision to use B20 in Keene.

Russell's pro-environmental attitude contributed to his being sensitive to ways to make his workplace cleaner and less polluting. Fleet managers without a similar personal attitude may be less likely to prioritize environmental protection within their job responsibilities. Russell advocates use of B20 via his presentations to other organizations and school districts to try to get more people to use what he considers a green fuel. The culture of environmentalism in Keene allows this type of environmental leadership to take root and grow. That his employer allows him to make some of these outreach presentations during the work day stresses the value the city organization places on regional environmental protection. By June 2007, Russell had made more than 16 presentations to other interested fleets and related conferences about his experience using B20. Finally, the existence of other political factors also contributed to the decision, such as the grant money from the Governor's office removing the initial structural barriers of higher cost to try the fuel.

One can visualize the interaction of all these factors working together just the way a heavy duty tractor trailer operates: Russell may have been the one to turn the key to start the ignition (leadership), and filled up the tank with a green fuel (pro-environmental attitude), but equally important is that the truck systems be well maintained (culture of environmentalism) and that there is good quality oil in the engine to help the truck run properly (external/internal political factors).

Appendix C : Monadnock Biodiesel Collaborative Draft Business Plan

Statement of Purpose:

Keene State College and the City of Keene have been using 20% biodiesel (B20) in their respective fleets since 2002, and have collaborated since 2004 in a scientific research study to examine the impact of biodiesel fuel on occupational and environmental exposures. As a further commitment to biodiesel fuel alternatives, the College is proposing creation of a collaborative organization to manufacture high quality biodiesel fuel from waste grease from Keene State College and local restaurants in Keene, NH, and then distribute this biodiesel for use by KSC, the City of Keene, and other potential local consumers, such as local school districts or regional distributors. The local manufacture of biodiesel will remove price and availability barriers in southwestern New Hampshire, leading to new applications of biodiesel, use of higher percentage blends in existing applications, produce health benefits to the community and extend KSC’s current biodiesel research into new exposures. This organization will embody a “first in the nation” private/public/college sector collaboration that connects resource conservation, waste minimization, and health risk reduction with a sustainable economic/ecological model.

Description of Business:

The basic operations of this collaboration are to collect and recycle waste grease, convert waste grease into biodiesel, distribute biodiesel within the community, and build capacity for future research. This business plan also proposes the establishment of an on-site ASTM testing lab to demonstrate product quality, thereby ensuring consumer confidence, as well as potentially growing into a source of revenue by providing testing services to other biodiesel producers in the Northeast. Finally, research, curricular growth, and community education will be pursued as additional goals of the organization. Research capacity in exposure assessment, biodiesel fuel development, pollution prevention, and community based research in occupational/environmental health will be expanded over time. Project benefits such as resource conservation and air pollution reductions will be communicated to the community. Finally, this organization will result in numerous, enhanced educational opportunities for KSC students in multiple majors, including but not limited to Safety Studies, Environmental Studies, Management, and Natural Sciences.

Since research activities are on-going, and community collaboration already exists, the main missing link is the design and start-up of a biodiesel manufacturing facility. Keene State College will organize a collaborative partnership to start-up and operate the recycling waste grease/manufacturing biodiesel process with a full time, dedicated staff. KSC will partner with a local engineering firm, Batchelder Biodiesel Refiners (BBR), to design, install, and start-up the biodiesel processing facility. BBR has already designed a process that produces ASTM 6751 quality biodiesel, and will ensure this level of quality during their involvement. KSC will design, install, and start-up an ASTM certification laboratory to verify on site product quality and potentially serve as a lab for other biodiesel manufacturers in the Northeast. BBR is committed to operating the process for the first 12-18 months of manufacturing, maintaining inventory records of production and sales during this time. After this initial period, the collaborative venture will be evaluated for potential transition of responsibility of manufacturing operations. Engineering process design will include the ability to manufacture biodiesel from both waste grease and virgin oil feedstock to maximize production capability and research opportunities.

Keene State College will seek a partner to collect waste grease from its own dining commons and local restaurants (all in close proximity) as the primary raw material for biodiesel manufacturing. Ideally, this partner would be also able to source waste grease from outside the region to meet production demand. At full capacity, approximately 150,000 to 175,000 gallons of waste grease would be processed on an annual basis. Improper disposal of waste grease into sewers (an important local concern due to Keene's aging sewer infrastructure) will be reduced as local pickups will be offered as part of this project.

Quality assured biodiesel will be used by both by Keene State College on site and delivered to the City of Keene's central public fleet storage tanks. Keene State will seek a partner for distribution of the manufactured biodiesel fuel to the City of Keene, Keene State College, and potentially expand/distribute biodiesel to new markets within the community. Examples of new markets include bioheat, nonroad equipment, or onroad retail distribution. The distribution partner would be responsible for transparent account management and billing. ***Keene State/BBR also reserves the option to sell wholesale directly to other distributors.*** See Figure 1 below for a summary of the relationship between collaborators. The next page outlines roles and responsibilities of each partner in the collaborative.

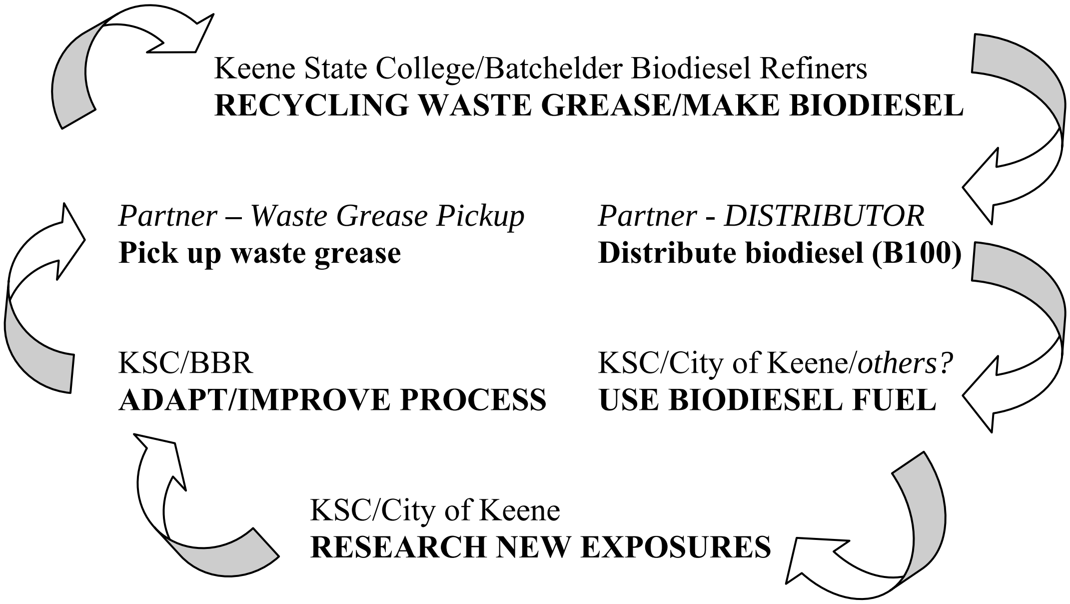


Figure 1: Summary of collaboration for business plan

Monadnock Biodiesel Collaborative
Roles & Responsibilities

Board of Governors (made up of one member from each partner)

Director (This person would be a KSC Employee)

Assistant to Director (This person could be a KSC, City or BBR employee)

KSC	**BBR**	**City of Keene**	**Pick up of waste grease****	**Distribution of biodiesel****	**[Waste Grease]**
· ASTM lab grease	· Design	· Space	· Brings waste to refinery	· Distributes biodiesel	· Provides large source/supply
· Research	· Engineering	· Partner	-Administration	-Administration	
· Grants	· Operation/QA/ Inventory (12-18 months)	· Consumer			
· Education					
· Consumer					

All potentially supported by 3rd Party Investment (grants, gifts, investments, etc.)

**Out Sourcing of Tasks [] Potential corporate partners

Director = "Plant/Project Manager" – responsible to make monthly reports to Board, day to day administration & troubleshooting. Overall organization will be a KSC entity, think of this as a new department ("Biodiesel department") plugged into existing infrastructure - similar to SBDC or CEMS grant (KSC employees who are funded via grants).

Market

Since both Keene State College and the City of Keene use biodiesel, the "demand" side of the market is already in place. Fleet use of B20 by both entities is approximately 60,000 – 70,000 gallons per year (12,000 to 14,000 gallons of B100). Biodiesel is not entirely used city wide across the fleet; the recycling center and airport both use petroleum diesel year round due to delivery restrictions by companies for loads less than 1000 gallons per drop. Both KSC and the City are not presently using biodiesel in any amount in heating applications due to the barriers of cost and availability. Through discussions with contacts within the Keene region, other potential users – especially rural, small users - of biodiesel find its limited availability and higher price a significant barrier to try the fuel. Local school bus districts have not made the switch to biodiesel although requested by local students and parents. In addition, in-house and other potential biodiesel users have concerns about product quality so that biodiesel does not void equipment warranties. This project will make ASTM 6571 grade biodiesel to encourage hesitant potential users in the local area to try biodiesel and to demonstrate this model is transferable to other geographic areas.

For use in vehicles, equipment or electrical generators, the estimated sale price of B100 is $3.70 per gallon. The average national price of B20 is $2.79 per gallon; KSC paid $2.65 in 2005 for B20. Based on KSC's experience, B100 can be used from April through November without modifications to a diesel engine. In heating applications, Fuel Oil #2 prices have averaged $2.37 per gallon in October 2006 in NH; Bioheat (from 5% up to 20% blends) has been offered by NH fuel suppliers at or near Fuel Oil #2 prices or less than 0.05 above the Fuel Oil #2 price. This low pricing is explicitly stated by suppliers to introduce market demand for "a renewable, domestic energy resource"; thus such low prices for bioheat are not expected to continue in the future. KSC averaged use of approximately 30,000 gallons per year of Fuel Oil #2, and 770,000 gallons per year of Fuel Oil #6 from the time period 2001 to 2005. Fuel oil #6 was projected to cost KSC $1.60 per gallon for 2006 per internal energy budget documents. There have been few studies on substituting Fuel Oil #6 with biodiesel blends, although pilot studies have indicated no major operational difficulties. The low cost of Fuel Oil #6 is the likely reason this biodiesel market has not gelled.

Since the highest market price for biodiesel would be obtained by selling B100, the most revenue would be generated by trying to fill the local market for on road and nonroad transportation use. It is believed that both KSC and City of Keene could easily increase to close to 25,000 gallons a year B100 use in vehicles, generators and equipment, with addition of the local school bus districts significantly increasing that volume. However, as a fallback strategy, KSC could easily absorb any excess production capacity in heating applications. Up to 100% biodiesel can be used when stored in indoor tanks. It should be noted fuel oil applications would reduce revenue generation for the non profit business.

Description of Location

Since biodiesel manufacturing is relatively low hazard (other than methanol storage), an industrial or light industrial space should be sufficient. Modifications to an industrial/light industrial space would have to be made for methanol storage. A loading dock is necessary for transfer of waste grease and fuel. The finished product storage tank will hold approximately 10,000 gallons of B100 and should be located indoors. The biodiesel production process and associated ASTM quality lab would need about 15,000 square feet for production and storage, but an additional 10,000 square feet should be initially scouted for the research expansion, leading to the need for a 25,000 square foot building, if all three platforms (production, quality lab, research) are to be located in one building. This additional 10,000 square feet would include research labs, faculty/administrative offices, conference rooms, and classroom space.

Competition

In Cheshire County, Fleming Oil is currently selling B20 retail as well as biodiesel in heating fuel. Rymes Oil is also selling B20 retail as well as local wholesale delivery but in large quantities only (greater than 1000 gallons per drop) and at least one client indicates they have had significant issues with product quality and service. Evans Oil is selling in other parts of NH, near Lebanon. Sprague Energy is selling biofuels near Portsmouth, and also is a potential source of waste grease. The price of biodiesel is tied closely to diesel – B20 tends to cost 1-2 cents more per gallon than petroleum diesel; B100 up to $1.50 more. All fuel prices have been rather volatile.

Description of Management

BBR – Lee Batchelder from L.A. Batchelder & Sons, a NH-based engineering firm with over 50 years engineering experience with developing and transferring new technology. Founder of Batchelder Biodiesel Refiners, (BBR), focusing solely on biodiesel processing; has developed a small scale production process that manufactures high quality ASTM grade biodiesel.

Keene State College – Nora M. Traviss is a Safety Studies faculty member at KSC with an undergraduate degree in Chemical Engineering and graduate degree in Environmental Science. She has over 13 years experience in the chemical process industries as both an engineer and Environmental Health and Safety Manager. Her dissertation examines biodiesel fuel impacts on occupational and environmental exposures and she has received an EPA STAR Fellowship to support this work.

Keene State College - Dr. Melinda Treadwell is a Safety Studies associate professor at KSC with a PhD in Toxicology and research experience in petroleum diesel exhaust exposures. Her expertise is in particulate matter exposure and she is the Principal Investigator on a NIH grant examining particulate matter and risk in New Hampshire partnered with Dartmouth Medical School.

Description of Personnel

See above plus

City of Keene – Fleet Manager Steve Russell has used biodiesel in his fleet since 2002 and speaks locally and at national conferences about the benefits of using biodiesel. Mr. Russell has years of experience with B20 operation in vehicles are varied as fire engines to dump trucks. The City of Keene is also one of 150 cities worldwide to participate in the Cities for Climate Protection initiative.

Appendix D: Summary of Application of the Analytic-Deliberative model (method)

A-D MODEL STEPS	CENTRAL QUESTION #1		CENTRAL QUESTION #2	CENTRAL QUESTION #3	
	Analysis	Deliberation	Analysis & Deliberation	Analysis	Deliberation
Problem Formulation	Local observations lead to initial main question: Is biodiesel healthier?	Informal Deliberations	Collaborative Exposure Assessment results are discussed at BWG meetings, leading to new question: How can local supply of B20 be increased?	Expanded BWG leads to new question: How can an innovative public/private college collaboration manufacture biodiesel in local community?	
Process Design	Collaborative Exposure Assessment: Roles, Site Selection, and Strategy	Biodiesel Working Group: Roles and Strategy	Biodiesel Working Group: Participation challenges Qualitative data collection by participant/observation, semi- structured interviews	BWG	
Select Options and Outcomes	Biodiesel Knowledge Survey	Biodiesel Working Group and Outreach Presentations: Data collected by participation/ observation, and meeting minutes	Options emerge from BWG & Interviews	Draft business plan, research funding options, identified partners, performed preliminary site analysis	Review in BWG meetings
Information Gathering and Interpretations	Collaborative Exposure Assessment: Collection of data by EPA, NIOSH, and ASTM methods	Biodiesel Working Group Meetings	Hold BWG meetings to interview outside fuel distributors, perform initial biodiesel production feasibility analysis, conduct outreach presentations	Biodiesel Attitude Survey, document analysis	Ongoing BWG meetings (data collected by participant/ observation)
Synthesis of Information	Research Team Meetings: Analyze data	Biodiesel Working Group Meetings	BWG meetings discuss information, expand the BWG membership, leads to new problem formulation	This step is ongoing through 2007 as information from business plan revisions and funding options is fed into BWG meetings	

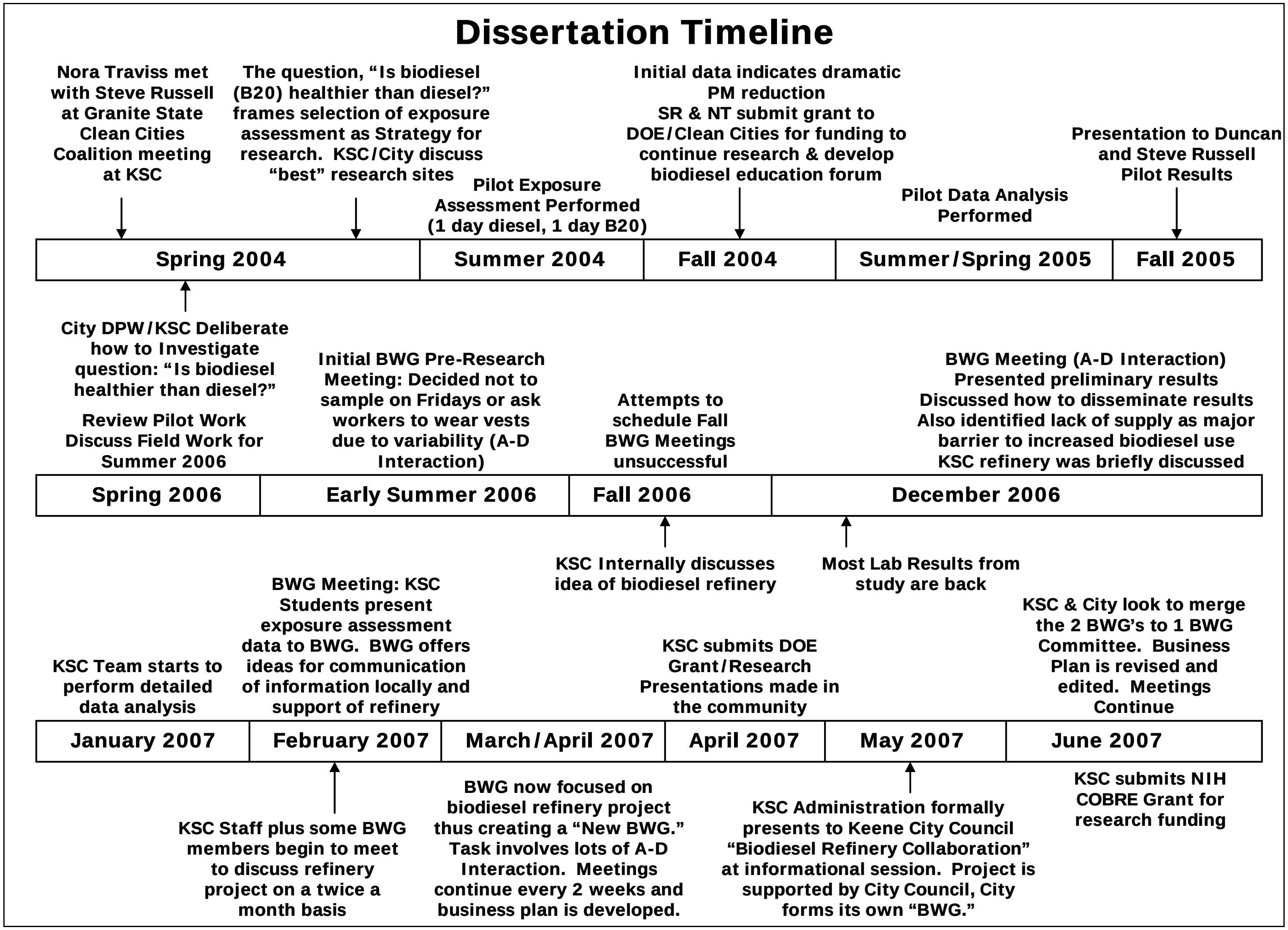
Appendix E: Biodiesel Attitude Survey Results

Number	Strongly Disagree	Mildly Disagree	Neither Agree nor Disagree/ Neutral	Mildly Agree	Strongly Agree
1	0.0%	0.0%	10.0%	10.0%	80.0%
2	0.0%	0.0%	0.0%	40.0%	60.0%
3	0.0%	0.0%	10.0%	30.0%	60.0%
4	0.0%	0.0%	0.0%	10.0%	90.0%
6	0.0%	0.0%	0.0%	20.0%	80.0%
7	0.0%	0.0%	0.0%	10.0%	90.0%
8	40.0%	10.0%	40.0%	0.0%	10.0%
9	0.0%	0.0%	10.0%	30.0%	60.0%
11	0.0%	0.0%	11.1%	11.1%	77.8%
12	0.0%	0.0%	10.0%	20.0%	70.0%
13	0.0%	0.0%	0.0%	30.0%	70.0%
14	0.0%	0.0%	10.0%	50.0%	40.0%
15	0.0%	0.0%	0.0%	30.0%	70.0%
16	0.0%	0.0%	20.0%	30.0%	50.0%
17	10.0%	0.0%	30.0%	40.0%	20.0%

Number	I think biodiesel is good for the environment	I think biodiesel is good for the economy by helping create jobs	I think biodiesel is good for the USA to reduce our dependence on foreign oil	I think biodiesel is good for human health
5	55.6%	0.0%	33.3%	11.1%

Number	Used in all City of Keene diesel engines i.e.. Recycling center, airport, buses, etc.	Used by vendors working with the City of Keene	Available for local use at every retail diesel pump	Used in new applications, not just trucks & equipment (i.e., heating, emergency generators)	Manufactured in Keene and used by City and other interested parties	I feel Keene doesn't need to use more biodiesel, i.e. we are at a good level now
10	70.0%	20.0%	60.0%	60.0%	50.0%	0.0%

Appendix F: Detailed Dissertation Timeline



Dissertation Timeline

Nora Traviss met with Steve Russell at Granite State Clean Cities Coalition meeting at KSC

The question, “Is biodiesel (B20) healthier than diesel?” frames selection of exposure assessment as Strategy for research. KSC/City discuss “best” research sites

Pilot Exposure Assessment Performed (1 day diesel, 1 day B20)

Initial data indicates dramatic PM reduction
SR & NT submit grant to DOE/Clean Cities for funding to continue research & develop biodiesel education forum

Pilot Data Analysis Performed

Presentation to Duncan and Steve Russell Pilot Results

Spring 2004 | **Summer 2004** | **Fall 2004** | **Summer/Spring 2005** | **Fall 2005**

City DPW/KSC Deliberate how to Investigate question: “Is biodiesel healthier than diesel?”

Review Pilot Work
Discuss Field Work for Summer 2006

Initial BWG Pre-Research Meeting: Decided not to sample on Fridays or ask workers to wear vests due to variability (A-D Interaction)

Attempts to schedule Fall BWG Meetings unsuccessful

BWG Meeting (A-D Interaction)
Presented preliminary results
Discussed how to disseminate results
Also identified lack of supply as major barrier to increased biodiesel use
KSC refinery was briefly discussed

Spring 2006 | **Early Summer 2006** | **Fall 2006** | **December 2006**

KSC Internally discusses idea of biodiesel refinery

Most Lab Results from study are back

KSC Team starts to perform detailed data analysis

BWG Meeting: KSC Students present exposure assessment data to BWG. BWG offers ideas for communication of information locally and support of refinery

KSC submits DOE Grant/Research Presentations made in the community

KSC & City look to merge the 2 BWG’s to 1 BWG Committee. Business Plan is revised and edited. Meetings Continue

January 2007 | **February 2007** | **March/April 2007** | **April 2007** | **May 2007** | **June 2007**

KSC Staff plus some BWG members begin to meet to discuss refinery project on a twice a month basis

BWG now focused on biodiesel refinery project thus creating a “New BWG.” Task involves lots of A-D Interaction. Meetings continue every 2 weeks and business plan is developed.

KSC Administration formally presents to Keene City Council “Biodiesel Refinery Collaboration” at informational session. Project is supported by City Council, City forms its own “BWG.”

KSC submits NIH COBRE Grant for research funding

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