

Regional Scale Monitoring of Methane Production by Dairy Farm Ungulates; A proposal to the National Science Foundation (NSF) and the National Ecological Observatory Network (NEON, Inc.)

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By

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**Regional Scale Monitoring of Methane Production by Dairy Farm Ungulates; A proposal to the National Science Foundation (NSF) and the National Ecological Observatory Network (NEON, Inc.)**

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**1. Project Summary**

The National Ecological Observatory Network, Inc. (NEON, Inc.) is a National Science Foundation (NSF) project that collects data about global climate change as well as other biological factors through experiments and observations. The purpose of this proposal is to suggest that with NEON's help, we will examine the rich agricultural setting of the San Joaquin Valley and how methane production from ungulates relates to the South Central Valley Smog phenomenon. This information will be collected in order to share it with the public. This will allow the public to make more informed decisions in order to reduce the impact that human-caused climate change is having on the planet. NEON's current plan is to conduct observations like these on a wide range of domain sites throughout the continental United States, Alaska, Hawaii and Puerto Rico. These observational studies are projected to last several decades. Collectively, it is our hope to bring awareness to the public, decision-makers, and industry of the harmful effects of climate change and pollution that promotes South Central Valley Smog.

Dairy farms in the San Joaquin Valley have been transformed from small family-run operations to an industry that has become the leading source of methane emissions in the region. Smog forms from a chemical reaction between volatile organic compounds (VOC) and nitrogen oxides (NO<sub>x</sub>). When combined with VOC's and nitrogen oxides, methane emissions from ungulates can cause global warming, add to air pollution, and have a negative impact on human health. South Central Valley Smog has caused the air quality in this region to rival that of Los Angeles as the "smog capital" of California, which has left residents of the San Joaquin Valley and environmentalists upset at the local farming industries.<sup>11</sup> There is concern about the negative effects of agricultural practices amongst residents of the San Joaquin Valley. However, there have been several dairy farms in the region that are trying to become more environmentally friendly by taking the methane gas that the cows produce and "digesting" it to make renewable energy that can be recycled to fuel the dairy farm and surrounding infrastructure.

NEON's plan is to do monitoring projects all over the country. Their goal is to measure causes of global warming. This project proposal is relevant to NEON, Inc's goal because monitoring methane and other harmful particle emissions that come from dairy farms in the San Joaquin Valley will benefit not only the people that are experiencing health issues from the smog that is formed, but we will also be able to collect data about an industry that has proven to be a major producer of greenhouse gases. It is our hope that this

data will encourage the dairy farmers and the San Joaquin Valley Unified Air Pollution Control District to set up strict regulations on their particle emissions. With the help of NEON Inc, we could set up domain sites near or on dairy farms in the San Joaquin Valley to track greenhouse gas emissions using their already established Airborne Observation Platform (AOP) at each site. In order to measure the population of cows at each dairy farm, in-field surveys can be established and methane conversions can be completed to estimate the amount of methane produced per cow. We will choose a number of large industry dairy farms and smaller family-based dairy farms to compare their methane production. We hypothesize that the larger industry dairy farms will emit a greater amount of methane and VOCs into the atmosphere. This project would add to NEON, Inc's observational studies and bring awareness to the public about the production of greenhouse gases by ungulates like dairy cows. Investing in methane "digesters" to take the emissions that would be released into the atmosphere and use them to fuel the entire dairy farm is another strategy that dairy farms can utilize to reduce their contribution to South Central Valley Smog.

## **2. Project Description**

### **2.1 Objectives and Expected Significance**

NEON, Inc is a revolutionary observatory project that is designed to detect ecological changes on a continental-scale over multiple decades. The data that NEON, Inc collects at each of its domain sites across the country will be compiled into a database that will be available to the public. It is NEON, Inc's hope that decision-makers will use the data to make informed decisions about climate change and that the public will raise their awareness of what is occurring due to human actions to our planet.

NEON Inc's goal is an admirable one and it coincides with this proposal to document the damaging affects of South Central Valley Smog in the San Joaquin Valley. Creating similar domain sites adjacent to large-scale and small-scale dairy farms in the San Joaquin Valley will allow us to determine the rate of greenhouse gas emissions being produced by ungulates in the area. This is an important addition to NEON, Inc's observational program because it is an issue of public health and air quality. The San Joaquin Valley is an agricultural powerhouse for the state of California. However, NEON, Inc's observations and measurements of the amount of methane and other pollutants that are emitted into the atmosphere will give environmentalists and residents of the San Joaquin Valley an indication that dairy farms are a major cause of South

Central Valley Smog. This could result in San Joaquin Valley dairy farms being put under more severe emission restrictions under the Environmental Protection Agency's Clean Air Act (CAA). Ever since the agricultural exemption of the Clean Air Act was repealed, the Environmental Protection Agency (EPA), San Joaquin Valley Unified Air Pollution Control District and farmers (especially those deemed to be "major emitters") have had to deal with a permitting process under Title V of the CAA. This ordeal has influenced a select number of dairy farmers in the San Joaquin Valley to experiment with methane digesters to recycle their methane emissions for alternative uses, one of which could be to fuel the actual dairy farm. This proposal will highlight methane digesters in the Research Description section.

This proposal is taking an already well-established premise that NEON, Inc has come up with and is applying it to gain more information about the South Central Valley Smog that is harming Southern Californian's health and an agricultural industry that has been a major cause of it since 1976.

## **2.2 Background and Technical Need**

Construction of NEON, Inc's domain sites is expected to begin in late 2010 and the entire construction process should be completed by January 1<sup>st</sup> 2016. During construction, NEON, Inc's sites will be built and data will begin to be collected. This time frame will allow us to adequately plan and develop additional domain sites at dairy farms in the San Joaquin Valley to document the emission of greenhouse gases that would supplement NEON, Inc's domain sites in California. In order to collect enough data to depict ecological changes over time, these projects will have to last several decades. NEON, Inc is funded by the National Science Foundation, which is committed to supporting NEON, Inc well into its projected multiple decades of research. As long as NEON, Inc's domain sites are maintained and run by dedicated scientists and staff, NEON, Inc will continue to collect and provide ecological data based on observations across the continent.

Barriers to progress with this project could include uncooperative dairy farms that are not willing to allow us and NEON, Inc to conduct observations near their farms due to the damning evidence that could arise. Another barrier to progress could be that there is not enough interest to attract volunteers or staff to conduct observations and surveys. Many agricultural industries may not

wish to associate themselves with this project because it could lead to extensive limitations on the amount of particle emissions that they are allowed to release into the atmosphere by the EPA.

This project is necessary because South Central Valley Smog is having a negative impact on health in the form of respiratory problems. According to the article, *Comment: Title V of the Clean Air Act: The Effects of California's Agricultural Exemption on the San Joaquin Valley*, the rate of children with asthma in Fresno (a major city located in the San Joaquin Valley) is 16.4%, which is more than triple the national rate.<sup>11</sup> This same article states that “a major source of air pollution will result from the production of between 25 and 50 tons of Volatile Organic Compounds and NO<sub>x</sub> per day. It is predicted that in 2005 livestock waste will emit 72 tons of VOC's per day in the San Joaquin Valley Air Basin, thus constituting a ‘major source’ of air pollution”.<sup>11</sup> It is a well-known fact that ungulates, especially cows, are major producers of greenhouse gases like methane. The amount of methane that a cow produces can be found by estimating the cow's basal metabolism based on its body weight.<sup>3</sup> The type of feed and the quantity given to the ungulates also has a great deal to do with methane emissions from an individual cow. Until recently, there was an agricultural exemption in California that did not hold agricultural industries accountable for the amount of greenhouse gases and particulate matter they released into the atmosphere. South Central Valley Smog in the San Joaquin Valley is a major indication that the pollution has been occurring for far too long and that farming industries in this agricultural-rich region are mostly to blame.

The results of this study conducted by NEON, Inc will portray to the public just how damaging dairy farms, as well as other large factory-farm operations, in the San Joaquin Valley can be to the environment. Ultimately, the goal of this project is to link the presence of South Central Valley Smog to dairy farms in the San Joaquin Valley which contain ungulates that produce Volatile Organic Compounds (VOCs) and harmful greenhouse gases like methane.

### **2.3 Research Description**

We propose to monitor the particulate emissions released from select dairy farms in the San Joaquin Valley in order to establish the dairy farm as a significant contributor to South Central Valley Smog. These select dairy farms will also serve as domain sites for NEON, Inc for the state of California. Working with NEON, Inc on this particular project will allow us to use their

monitoring protocol, and will allow them to make observations about a human-caused phenomenon that is harming the environment. NEON, Inc will be able to take the data from this project and make it accessible to the public through their database.

The Central Valley is one of the most agriculturally productive regions in the entire world. It is comprised of the Sacramento Valley to the North and the San Joaquin Valley to the South. The San Joaquin Valley is surrounded by mountains on the east, west and south sides. The Valley begins at the Sacramento-San Joaquin Delta in the North and stretches down to the Tehachapi Mountains in the South. Food production has been the primary focus of the San Joaquin Valley since it became an agricultural powerhouse for California during the Gold Rush, but recent years have shown dairy farms, cattle ranching and sheep ranching's rise in importance and productivity. However, the increase in ungulates has caused an increase in air pollution and introduced the South Central Valley Smog phenomenon to the region. The location of the San Joaquin Valley and the surrounding mountains creates stagnant air patterns that trap pollution, particularly to the south.<sup>2</sup> The San Joaquin Valley also features hot, dry summers and cool, foggy winters. The sunshine and hot weather in the summertime lead to the formation of ozone (photochemical smog).<sup>2</sup> If pollution is most commonly found in the southern regions of the San Joaquin Valley, it must feature the South Central Valley smog that is harming the Valley's residents. According to the San Joaquin Valley Unified Air Pollution Control District, the San Joaquin Valley is currently classified as a serious non-attainment area for the health-based, Federal eight-hour ozone standard and is being reconsidered as an extreme non-attainment area for the Federal eight-hour ozone standard.<sup>2</sup> Due to the San Joaquin Valley's geographic and meteorological conditions, the Valley is extremely sensitive to increases in emissions and experiences some of the worst air quality in the nation.<sup>2</sup>

The San Joaquin Valley Unified Air Pollution Control District is a public health agency whose mission is to improve the health and quality of life for all Valley residents through efficient, effective and entrepreneurial air quality management strategies.<sup>2</sup> The production of South Central Valley smog in the San Joaquin Valley has proved to be a daunting adversary to the district's mission. In order to attain their goals and protect the health of the Valley's residents, the district uses air quality standards that are required under State and Federal law. The district takes on measures that are aimed at reducing emissions from a broad range of sources using permits, and

working with the State and Federal law requirements. Dairies are significant sources of smog-forming fine particulate matter and Volatile Organic Compounds (VOCs) like methane in the San Joaquin Valley. VOCs are emitted directly from the Valley's approximately 2.5 million dairy cows, from the fermentation and decomposition of cattle feed, and from the decomposition of waste excreted each day from dairy cows in the San Joaquin Valley.<sup>2</sup> The San Joaquin Valley Unified Air Pollution Control District notes that dairies are among the largest sources of VOCs in the Valley, and these smog-forming VOC emissions have a significant adverse impact on efforts to achieve attainment with health-based air quality standards.<sup>2</sup> The San Joaquin Valley Unified Air Pollution Control District was mandated by federal law to create an ozone attainment plan in order to demonstrate how the Valley would reach attainment with the Federal eight-hour ozone standard.<sup>2</sup> This ozone plan featured every feasible measure of reducing NOx and VOCs which produce ozone. However, even though the district will be requiring every practical VOC and NOx control, and will be relying on the state and federal governments to significantly reduce emissions from mobile sources of pollution, the San Joaquin Valley will still need the development and adoption of future, not-yet-developed, clean air technologies to reach attainment by the 2023 deadline.<sup>2</sup> Achieving this goal with air quality standards will require continued contributions from all industries, businesses, and individuals in the San Joaquin Valley.<sup>2</sup> The San Joaquin Valley Unified Air Pollution Control District's plan is something that we can stand by, and they are working hard to achieve their goals.

In January 2010, the San Joaquin Valley Unified Air Pollution Control District issued an Air Pollution Control Officer's Revision of the Dairy VOC Emission's Factor. In this report, the emission factors of VOCs like methane were reanalyzed based on the best available scientific research and experimental tests and recorded. The emissions factor explained in the report will be used for permitting dairies in the San Joaquin Valley.<sup>2</sup> This report shows us that the San Joaquin Valley Unified Air Pollution Control District is attempting to regulate the San Joaquin Valley's dairy farm contributions to South Central Valley smog. With the cooperation of NEON, Inc and the San Joaquin Valley Unified Air Pollution Control District, we will be well equipped to understanding South Central Valley smog and how dairy farms play a role in its production.

The Clean Air Act (CAA) was created by Congress in 1970 in order to provide healthy air for all Americans. The CAA's goal was to have completed this by 1975, yet the San Joaquin Valley is

still suffering from air pollution and South Central Valley Smog. According to the CAA, under Title V, the Environmental Protection Agency (EPA) administrator's authorization to approve state permit programs is regulated to the extent that "the Administrator may not exempt any major source from such requirements"<sup>11</sup>. Title V requires that sources of air pollution, which are categorized as "major sources", must apply for and receive operating permits<sup>11</sup>. A major source of pollution depends on the area's non-attainment status<sup>11</sup>. This all sounds like an optimal plan, but Title V excludes agriculture from its permitting requirement. In 1976, the California state Legislature granted agriculture an exemption from Title V of the CAA, and as a result farmers could operate their businesses without having to comply with federal air permit requirements<sup>11</sup>. Because California is one of the highest grossing agricultural regions in the entire world, it makes sense that the state would want to make its farmers happy by not putting strict regulations on their operations, but instead the state is risking the health of its citizens for the sake of the economy. In enacting the CAA, the EPA wanted "to protect public health" with "an adequate margin of safety"<sup>11</sup>, but it has taken a very long time for the EPA to repeal its 1976 decision and to hold agricultural industries in the San Joaquin Valley accountable for their methane and VOC emissions.

Under California state law, agricultural sources of air pollution, including dairies, were previously exempt from air district permitting requirements and new source review emissions limitations<sup>2</sup>. This exemption was removed effective January 1<sup>st</sup> 2004<sup>2</sup>. This is thanks to Senate Bill 700 which amended the California Health and Safety Code to eliminate the Title V exemption of agriculture, as well as many lawsuits filed by angry residents of the San Joaquin Valley and environmental groups that sued the EPA. However, the farmers of the San Joaquin Valley were not thrilled with the decision that was made by the EPA, and also filed lawsuits against the EPA. In the end it was decided that under the terms of the settlement agreement, farmers will be required to apply for Title V permits<sup>11</sup>. Ultimately, this decision could set a precedent for the regulation of various agricultural related acts, such as the concentrated animal feeding operations, due to its high methane emissions<sup>11</sup>. Farmers still maintain that their operations do not cause air pollution and that there is no scientific data to back this up. However, data suggests that farming related operations emit a significant amount of the pollutants that make up "smog" (VOCs and methane) in the San Joaquin Valley Air Basin<sup>11</sup>. The "mega dairies" that are commonly found in the San Joaquin Valley are no exception. In 2001, California dairies



were home to approximately 721 cows per dairy, while Fresno County dairies averaged 789 cows, Kern County dairies averaged 1,884, and Tulare County averaged 1,215 cows per dairy<sup>11</sup>. All of those listed counties are found within the San Joaquin Valley. The amount of VOCs, methane and particulate matter emitted from these dairies have and are causing major respiratory health problems for the residents of the San Joaquin Valley.

According to the San Joaquin Valley Unified Air Pollution Control District, a health advisory was issued five times during the summer of 2002, as opposed to one health advisory the previous year<sup>11</sup>. Asthma is a huge problem for the residents of the San Joaquin Valley, especially children who are more vulnerable to the respiratory illness. The leading cause of absences in the Fresno Unified School District is also due to asthma<sup>11</sup>. Because of the presence South Central Valley Smog due to agricultural emissions like dairy farms, asthma has the potential to become an epidemic among Valley children if the air quality does not improve<sup>11</sup>.

The EPA and the San Joaquin Valley Unified Air Pollution Control District need to come together under the CAA's Title V and regulate the amount of particulate matter, VOCs and methane being emitted into the atmosphere by agricultural industries like dairies. It was predicted that in 2005, livestock waste would emit 72 tons of VOC's per day in the San Joaquin Valley Air Basin, thus constituting a "major source" of air pollution<sup>11</sup>. The implementation of the air permit requirements prescribed under Title V of the CAA will adequately monitor the Valley's air<sup>11</sup>. The San Joaquin Valley Unified Air Pollution Control District needs to also do its part in implementing strict permitting requirements for dairies and other agricultural industries that cause South Central Valley smog. Based on its Dairy Emissions Factor Report published in January 2010, The San Joaquin Valley Unified Air Pollution Control District is on the right track in discovering the rate of emissions of dairy farms through research studies and enforcing regulations on major polluters. The repeal on the exemption of agriculture from Title V was the right decision for the EPA and California state Legislature to make because they have decided to value the health of the citizens over the state of the economy. Requiring that agricultural industries within the state of California, and especially dairies in the San Joaquin Valley, that are major producers follow the CAA's permit guidelines will ensure that the rates of methane, VOCs, and particulate matter entering the atmosphere decline. With this study, we hope to further emphasize the San Joaquin Valley Unified Air Pollution Control District's and the EPA's

CAA work in targeting ungulate emissions from dairies in the San Joaquin Valley as a leading factor of South Central Valley Smog.

In order to perform this research study, we will coordinate with NEON, Inc by means of the technical equipment they will use to detect the levels of greenhouse gases being emitted into the atmosphere from their own domain sites. We will also come up with our own strategies of determining the affects that individual dairy cows have toward contributing to South Central Valley Smog.

NEON, Inc has an abundance of technologically advanced machinery that will be used to gather data and lead to thorough observations about each domain site. An airborne observation platform (AOP) captures images of the domain site landscape including vegetation. These platforms could be a good tool for us to use in determining the lay of the land and could even indicate how many ungulates are prevalent in each domain site. The AOP platforms will consist of instrumentation deployed on three aircraft that fly scientist-defined and routine patterns over NEON, Inc's domain sites.<sup>5</sup> The instrumentation found on the platform consists of an imaging spectrometer that operates in the range of visible to shortwave infrared spectral region and creates an image of the ground<sup>5</sup>. A ranging (wLiDAR) instrument and a high-resolution digital camera are the final instruments found on the platform. wLiDAR sends out a laser pulse and measures the time difference between the outgoing and returning light to determine the structure of vegetation and buildings below.<sup>5</sup> NEON, Inc also boasts about their leading edge cyberinfrastructure that will calibrate, store and publish all of the information that they gather.<sup>7</sup> This technological achievement is central toward NEON, Inc's goal of sharing their observations with the public.

A non-mechanical yet crucial part of the data collection process will include trained field crews that will observe and collect data throughout the domain sites. For our study, these NEON, Inc trained field crews will be taught to partake in in-field surveys in order to count the number of cows per domain site. This aspect of the study will be discussed in more detail later on, but it is important for us to get an estimate of just how many dairy farm cows are in the San Joaquin Valley in order to determine that South Central Valley smog can be attributed to their presence. Another useful technique that NEON, Inc is utilizing is their Land Use Analysis Package (LUAP). By studying maps and historical data of their planned domain sites, NEON, Inc will

gain an insight into the past histories of the land they are observing. These maps and historical data could range from federal agency data pertaining to past and current land use practices, economic and social data, satellite remote-sensing data on ecosystem performance, and topographic data from national databases.<sup>6</sup> In order for us to understand the South Central Valley Smog phenomenon that is presently occurring in the San Joaquin Valley in regards to dairy farms, we need to look into the past land uses and histories of our target dairy farm domain sites. Utilizing this NEON, Inc procedure will allow us to get a better idea of what will occur to South Central Valley Smog, the health of the residents of the San Joaquin Valley, and the local dairy farms in the foreseeable future.

Coordination with NEON, Inc in this study will allow us to employ their high-tech equipment in order to determine South Central Valley Smog's connection with dairy farms in the San Joaquin Valley. One crucial aspect that is required in order to complete this study is to conduct in-field surveys to quantify how many dairy cows exist on each domain site and get an idea of how many are found in the San Joaquin Valley as a whole. In order to do this, we will need to get approval from dairy farmers from around the San Joaquin Valley to set up our NEON, Inc-style domain sites and conduct our observations. Once approval has been obtained, we propose to go out and take a "rapid survey" for the number of dairy cows which is sure to be expensive because it will take many well-trained volunteers. Using trained volunteers is one way we can obtain a census of how many dairy cows are around our domain sites. Another way could be to utilize NEON, Inc's Airborne Observation Platforms to get an aerial view of the acreage surrounding our chosen domain sites. Using the aerial images, we could count the number of cows we see or we could use a quadrat technique of randomly selecting plots of land within the images of a certain size and counting the number of dairy cows within that selected area. The quadrat technique could also be done on foot by our trained volunteers who could randomly select dairy farms that gave us approval, and count the number of cows within their randomly selected quadrat to get an idea of how many cows each dairy farm contains. A very simple strategy could be to just ask the dairy farm owner how many dairy cows they have on their farm. The dairy farmer could also already have these VOC and methane estimates from his own research, and if cooperative could provide this information. The purpose of determining how many dairy cows are within the San Joaquin Valley is to predict the methane production of each farm surrounding our domain sites. Whether it is directly from the cow or from the waste it produces. This could be done by determining the

quantity of cows, the overall land use of the farm, and what kind of feed the dairy cows are ingesting, which is highlighted later on in the proposal.

Volatile Organic Compounds (VOCs) are a significant contributor to South Central Valley smog in the San Joaquin Valley. VOC and fine particulate matter emissions have taken over the San Joaquin Valley and have negatively impacted the health of its residents. VOCs and Nitrous oxide (NO<sub>x</sub>) combine to form ozone which is a major component of photochemical smog, what makes up South Central Valley Smog. Dairy farms are a significant source of VOC, especially methane produced directly from the dairy cow and the cow's manure. The San Joaquin Valley Unified Air Pollution Control District's revision of their Dairy Emission Factor report for January 2010 was brought about due to additional significant scientific research methods for dairy particulate emissions. Recent dairy emission research studies performed under the direction of California air quality agencies and stakeholders have significantly increased knowledge of dairy emissions and also shed some light on potential strategies to reduce these emissions.<sup>2</sup> However, dairies are fairly complex emissions sources that emit several types of VOCs from the different dairy processes. Because of this, it is difficult to design and carry out a single research effort that would measure all of the VOCs emitted.<sup>2</sup> The main VOC we want to focus on is methane, which is highlighted later on in this report. The results of the studies done will be used to augment or replace values in the current dairy emissions factor for categories of dairy processes or compounds emitted for which better emissions research is now available.<sup>2</sup>

The studies highlighted in the San Joaquin Valley Unified Air Pollution Control District's Dairy Emissions report included enteric emissions (or emissions from the intestines of the ungulate), milking parlor waste emissions, freestall barns waste emissions, corrals waste emissions, lagoons (storage ponds and settling basins) emissions, liquid manure land application, solid manure land application, separated solids, solid manure storage, silage piles, total mixed ration (bunker feed) emissions, and composting. The majority of these studies completed by various California-based scientists were conducted in flux chambers. Dairy cows were placed in the controlled environmental chambers (flux chambers) and various methodologies were used to quantify VOC emissions from cows and the manure deposited in those chambers.<sup>2</sup> The measured flux values and the surface areas of specific processes at the dairies were used to determine the emissions rate. The emissions rates were then divided by the number of cows at the dairies to arrive at the

emissions factors for the dairies.<sup>2</sup> The categories in which the studies of the dairy emission factor report were organized measure the Total VOC (including VFAs and amines) as methane directly from the ungulate's gastrointestinal system or from the manure it produces. The best available scientific studies highlighted in this report have allowed the San Joaquin Valley Unified Air Pollution Control District to create a new Emission Factor for various categories that it will enforce on polluting industries like Dairy farms in the permitting process.

The San Joaquin Valley Unified Air Pollution Control District's revised dairy research studies have found important findings. Manure storage ponds and lagoons, which were previously thought to be a major source of VOC emissions at dairies, now appear to emit a comparatively small fraction of the overall dairy VOC emissions.<sup>2</sup> Feed at dairies is a significant source of VOC emissions.<sup>2</sup> Emissions of alcohols (primarily ethanol) from feed, fresh manure, and directly from cows appear to comprise a significant fraction of dairy VOC emissions.<sup>2</sup> Seasonal variation in emissions may be an important factor to consider when developing annual emission estimates.<sup>2</sup> These are just a few of the important findings that the revised emission report has concluded from its experiments. Future research is crucial in order to continue to improve the quality of dairy emissions factors. The San Joaquin Valley Unified Air Pollution Control District recommends future research on the following items: Additional data are needed on different process emissions and effects of management practices on emissions.<sup>2</sup> Additional data are needed in comparing the effects of different sample collection techniques (e.g. flux chambers and wind tunnels) on calculated emissions rates.<sup>2</sup> Specific research should be undertaken to determine which gases should be included from amines, oxygenated VOCs, Volatile Fatty Acids, phenols, methane, and other potentially important compounds, as well as to develop improved sampling, analytical and quantification methods.<sup>2</sup> The San Joaquin Valley Unified Air Pollution Control District's Dairy VOC Emissions Factor report is an important source of information regarding how VOCs arise from dairy cows and produce South Central Valley Smog. The best-science-available studies outlined in this report could be duplicated in our study, or we could collaborate with the San Joaquin Valley Unified Air Pollution Control District to determine how VOCs like methane that come from dairy ungulates contribute to South Central Valley smog and, ultimately, climate change.

When one hears about climate change in the news, carbon dioxide (CO<sub>2</sub>) is the greenhouse gas that is commonly discussed and what comes to mind. CO<sub>2</sub> is emitted from the burning of fossil fuels like coal, oil and gas through activities such as driving a car, which millions of people from developed countries partake in. The combined use of fossil fuels around the world is driving CO<sub>2</sub> emissions up and increasing the rate of climate change. While carbon dioxide receives the most attention as a factor in global warming, there are other gases to consider, including methane, nitrous oxide (N<sub>2</sub>O) and chlorofluorocarbons (CFCs).<sup>3</sup> However, methane is 25 times more potent as a greenhouse gas than carbon dioxide, but there's far less of it in the atmosphere—about 1,800 parts per billion.<sup>4</sup> Methane plays a large role in the photochemistry of the background atmosphere. It is produced and released by various biological processes and is mainly decomposed in the troposphere by reaction with hydroxyl radicals (OH)<sup>1</sup>. The hydroxyl radical, which is present in the atmosphere at an average volume mixing ratio of only  $2 \times 10^{-4}$ , is primarily responsible for the breakdown of natural and anthropogenic (man-made) trace gases in the atmosphere.<sup>1</sup> As the rate of methane being emitted into the atmosphere increases, the global level of OH have been decreasing because the OH are unable to break down the excess natural and anthropogenic gases being released. NEON Inc. is determined to observe the harmful effects of climate change from all aspects through their domain sites. With this proposed study, we would like to determine methane's harmful contributions toward South Central Valley Smog in the San Joaquin Valley through agriculture with the help of NEON, Inc.

The rising concentration of methane is correlated with increasing populations and currently about 70% of methane production arises from anthropogenic sources and the remainder from natural sources.<sup>3</sup> Agriculture is considered to be responsible for about two-thirds of the anthropogenic sources.<sup>3</sup> Biological generation in anaerobic environments (natural and man-made wetlands, enteric fermentation, and anaerobic waste processing) is the major source of methane.<sup>3</sup> Agriculture contributes about 60% of the total anthropogenic emissions of methane into the atmosphere.<sup>3</sup> In terms of agriculture, for this study we want to focus on dairy cows and the amount of methane that they produce which contributes to South Central Valley Smog and climate change. A cow is an example of a ruminant, because it is a mammal that digests vegetation with its complex digestive system. One of these digestion structures is the rumen, which further breaks down plant matter that has already been semi-digested. Methane is a by-product of microbial breakdown of carbohydrates (mainly cellulose) in the digestive tracts of

herbivores. Highest methane losses are reported for ruminants, which host large populations of bacteria and protozoan in their rumens.<sup>1</sup> Both quality and quantity of the feed, together with the individual performance of the animals, have been found to determine the amount of energy that is lost by methane production.<sup>1</sup> The energy content in food is transformed in the process of digestion and partly lost as chemical compounds in feces, urine and fermentation gases. The rest is used to produce heat, to perform body work or to build new body tissue.<sup>1</sup> It was discovered that the methane release rates by ruminants were lower when fed with protein-rich diets and higher when fed with crude fiber.<sup>3</sup> The quality of the feed and the amount of feed that is given to the ruminant are both important factors. The feeding of ruminants to optimize rumen and animal efficiency is a developing area and the efficient deployment of this information to all livestock producers would benefit the environment in terms of both methane and nitrogen emissions.<sup>1</sup>

In the year 2000, it was found that enteric fermentation from ruminants such as cows produced 80 million tons of methane per year that was emitted into the atmosphere. Methane emitted into the atmosphere from animal wastes was 25 million tons per year.<sup>3</sup> The dairy industry in California is a \$4.5 billion industry.<sup>11</sup> California's San Joaquin Valley is prevalent in dairy farms because farmers are able to pay a reasonable price for a large acreage of land. Based on the information introduced in this section, we know that dairy cows are a large producer of methane and that this greenhouse gas is a major factor in the phenomenon of climate change. When VOCs such as methane are emitted into the atmosphere from dairy cows in the San Joaquin Valley, it contributes to South Central Valley smog, polluting the region and harming human health. While some may argue that other factors contribute to the smog and climate change, production by animals represents one of the most important individual sources within the tropospheric methane cycle. It is about two times larger than the production from coal mining and natural gas leaks.<sup>1</sup>

Biogas (or biofuel) is a multi-purpose energy source that is obtained from local resources.<sup>8</sup> It is a carbon neutral fuel made from biomass or manure that is produced by anaerobic digestion, which is when bacteria degrade biological material in the absence of oxygen. Many countries in Central and Northern Europe have implemented this system in rural regions and wish to encourage application of it in developing countries as well. Biogas, like methane, is used as a renewable energy source where it mitigates the emission of greenhouse gases and it is used as a local resource where it diminishes the dependence on imports of energy sources.<sup>8</sup> Agricultural systems

have a large potential to become a producer and supplier of energy through biogas systems. While many biogas systems use cultivated energy crops from agriculture like alfalfa, maize and barley, ungulate manure produced on a dairy farm is also a prime source of fuel.<sup>8</sup> The average methane content from agricultural crop batch digestion experiments after approximately 28 days under mesophilic conditions (moderate temperature) ranged from 50-60%.<sup>8</sup> This compares to the same experiment but with cow and pig manure as the fuel source which received an average methane content of 60-65%.<sup>8</sup> While both agricultural crop systems and ungulate manure systems are highly effective, the manure tends to gain higher methane yields, which is why many systems often combine the two fuel sources.

About 30 years ago the development and construction of the first biogas plants was to remove the odor of animal waste, but also to provide electric energy and heat to farms.<sup>8</sup> Very few changes have been made from this original purpose of using biogas as a fuel source. Although, other organic wastes like food crops or food residues have been added to the mix. The development of using large biogas plants for the sale of electricity has also become a popular scenario. Many large farms in Europe have two or three digesters of several thousand cubic meters volume and combined heat and power facilities (CHPs) with an electrical capacity level of 500 to 1,000 kW.<sup>8</sup> These digesters are typically made out of concrete with a steel skeleton or just completely out of steel.<sup>8</sup> Most have a cylindrical form that stands upright and their sizes can vary depending on the size of the farm it is supplying energy for. The digesters are flow through systems, which are fed several times a day. In the case of agricultural biogas plants, the slurry comes directly from the animal stables or is collected in small storages before entering the digester.<sup>8</sup> The structure of the digester contains a pre-mixing pit where the manure or agricultural crops can be added to the slurry with water before it is pumped through an inlet and into the large digester storage tank.<sup>8</sup> The average retention time in the main digester is approximately 28 days but could take longer if there are more agricultural crop residues in the slurry mix than manure.<sup>8</sup> An agitation jet is found in the storage tank which stirred to further mix the slurry. An internal gas tank makes up the top portion of the cylindrical digestion structure and collects the methane bubbles as the manure slurry ferments. This gas can be collected and piped to be used as fuel or it can be pumped back into the storage tank through a pipe to run the agitation jet. After the typical 28 days, the digested fuel is transported to the post-digester through an outlet where it stays in a pit in the form of sludge, a more solid state.



In Austria, Denmark, and Germany, the biogas is combusted in a combined heat and power facility (CHP) where the electricity is then fed to the national grid and the heat is mainly used for the own purposes of the farmer.<sup>8</sup> CHPs usually work with a gas engine, and pure gas engines need less maintenance work. The operation costs are low for them but the investment is high.<sup>8</sup> Just recently, the availability and functionality of micro-turbines have increased. Micro-turbines are advantageous when compared to gas engines because: the exhaust of nitrous oxide (NO<sub>x</sub>) and carbon monoxide is very low, maintenance is very comfortable, and exhaust temperature of micro-turbines is above 500 degrees Celsius, which opens a broad range of heat utilization.<sup>8</sup> This is good news for dairy farmers interested in biogas technology because the trade off of using an efficient combustion engine is the emission of Nitrous oxide into the atmosphere, which as we've discussed, is a known contributor to South Central Valley Smog. Biogas digesters that use methane are advantageous because they provide on-site electricity and energy to the farm, they reduce odors from overloaded manure storage facilities, provide high quality fertilizer since organic nitrogen is converted to ammonium during the digestion project and finally, lead to a reduced threat of surface and groundwater contamination because the manure is being utilized for energy production.<sup>9</sup>

One dairy farmer in the San Joaquin Valley has put this biogas technology to the test on his farm in Modesto, California. John Fiscalini of Fiscalini Farms has taken advantage of the amount of methane his dairy cows produced and utilized that energy into a more productive outlet. With the help of the non-profit group, Sustainable Conservation, Fiscalini has constructed a state-of-the-art methane producer that converts his 1,500 cows' manure into electricity. The biogas technology's system includes two 860,000-gallon tanks that trap 5,400 cubic feet of methane and produces more than 700 kilowatts of electricity each hour.<sup>10</sup> Fiscalini will be producing so much power, that he will be able to run his entire operation on this electricity, as well as power an 88,000 square-foot cheese factory that he has planned out and feed the rest of the electricity he has left over to the electrical grid to power 200 of his neighbor's homes.<sup>10</sup> Sustainable Conservation not only helped Fiscalini in securing funding for this massive project, but has influenced utilities like Pacific Gas & Electric Company (PG&E) purchase power from renewable sources like Fiscalini's at fair prices.<sup>10</sup> This gives dairy farmers a greater incentive to create systems like the methane digester to cut down on the amount of animal excrement in cesspools, the amount of

pollution and greenhouse gases emitted into the atmosphere that creates the South Central Valley smog and energy costs for the farmers and their neighbors. One large smog-producing factor that the methane digester does not account for is the VOC and methane being produced from enteric emissions.

Enteric emissions come directly from the cow itself, whether it is through manure or through the air as gas. When these gases in the form of VOC and methane are released into the atmosphere, it can be difficult to measure. The San Joaquin Valley Unified Air Pollution Control District's Dairy Emissions Factor Report includes research studies performed by California scientists from air quality agencies, stakeholders and universities to measure these enteric emissions. A study at UC Davis, led by Dr. Frank Mitloehner entitled "*Volatile Fatty Acids (VFA), Amine, Phenol, and Alcohol Emissions from Dairy Cows and Fresh Waste*" measured the emissions of alcohols, VFAs, and amines directly from lactating and dry cows and also from their fresh manure using environmental chambers.<sup>2</sup> This study provides valuable information on enteric emissions from cattle as well as emissions from freshly excreted manure.<sup>2</sup> Dr. Mitloehner completed this study in May 2006, but recently recreated the same study which was completed in October of 2009 for more accurate results. The second time around he used ammonia filters so that readings of ammonia emissions weren't incorrectly recorded as alcohol emissions. Dr. Mitloehner used INNOVA photoacoustic analyzers to quantify ethanol and methanol emissions from dairy cattle and fresh manure and emissions of VFAs and phenolic compounds were sampled using a modified sorbent tube method and quantified using thermal deposition and gas chromatography (EPA TO-17).<sup>2</sup> The San Joaquin Valley Unified Air Pollution Control District has used these results to calculate an acceptable VOC and methane emission factor for dairy farms in the San Joaquin Valley. After taking several factors into account, like storage and transport loss with the sorbent tube and the use of ammonia filters, the enteric VOC emissions from milk cows are determined to be 4.1 lb/hd-yr.<sup>2</sup> After much research, we believe that there does not seem to be much emphasis on collecting the methane and VOC emitted directly from the ungulate as gas and reusing it like Mr. Fiscalini with his methane digester in the form of ungulate manure. Research studies like Dr. Mitloehner's do seem promising in that methane and VOCs can be quantified and recorded using environmental flux chambers. We believe that if there was a way to use those same chambers to keep the methane gas separated from the atmosphere and applying the same

strategies and also technologies that a methane digester does for the separated gases to create electricity and heat, a great deal of climate change and smog-related issues would be solved.

It is important to highlight the ingenious technology and ideas that are being implemented throughout the world in order to combat climate change. NEON, Inc. would approve of and encourage these technologies because they are taking a harmful greenhouse gas that would have been emitted into the atmosphere, and putting it to good use as an efficient source of energy for homes, dairy farms, and other enterprises. The fact that select dairy farms in the heavily polluted San Joaquin Valley are using their waste products in a more efficient manner and therefore decreasing the amount of methane, VOCs and greenhouse gases they emit that ultimately contributes to South Central Valley Smog, should make us all hopeful for the future.

#### **2.4 Education and Human Resources**

In this report, we hope to contribute to developing the education for science at all levels within the university system. With the growing threat of global climate change, college-educated individuals should especially be aware of this phenomenon's many contributors and be introduced to ways that it can be combated. Learning more about agriculture, its importance in California's San Joaquin Valley, and its role in producing South Central Valley Smog are also important for us to learn about because the smog is negatively impacting human health. The Principal Investigator of this report, with the help of NEON, Inc., wishes to capture the attention of the agricultural and scientific communities with its data of the amount of greenhouse gases that are emitted from agricultural systems like dairy farms that have a harmful effect on air quality, human health, and the overall environment. It is the Principal Investigator's hope that the data that is collected in this study intrigues fellow scientists to further investigate the South Central Valley Smog issue and to contribute to finding a solution that will suffice for both farmers and residents of the San Joaquin Valley.

#### **2.5 Plan of Work**

The goal of this project is to collaborate with NEON, The San Joaquin Valley Air Pollution Control District and other relevant agencies to determine dairy farms' contribution to South Central Valley Smog within the San Joaquin Valley. We have included much discussion within this proposal about the causative factors of South Central Valley Smog, the responsibility that

agricultural industries need to take, the health issues that arise from the smog, and the technologies that are being implemented in order to mitigate the impact of VOCs and methane emissions. With these things in mind, we know that in order to obtain enough information to make an educated and accurate inference into tying South Central Valley Smog to dairy farms in the San Joaquin Valley, our study will need to take several decades like NEON, Inc's projected studies. However, since this is a first time study, we propose that the National Science Foundation fund us for at least 3 years so that we can give our study a try.

In order to complete this project on time, we will coordinate with NEON, Inc. who's observational and experimental techniques will be applied in this study to determine methane emissions from dairy ungulates. These techniques include creating domain sites at selected dairies, both large-scale and small-scale, within the San Joaquin Valley in which we will collect our data from. We will measure the particulates being emitted into the atmosphere with NEON's Airborne Observational Platforms (AOP) at each site, take in-field surveys to determine how many dairy cows reside at each farm, and also replicate research studies like the ones highlighted by the San Joaquin Valley Air Pollution Control District in which the enteric emissions from the ungulate itself are measured. We will work together with the dairy farmers of the San Joaquin Valley to figure out the type of feed and how much feed the cows are being given. We will also work with the San Joaquin Valley Air Pollution Control District, who has the power to give out permits to the dairy farms and control the emission factors that the dairies must follow. Like NEON Inc., we strive to keep the residents of the San Joaquin Valley, and any interested members of the public in general informed of our progress and results. A database much like NEON's will be created and updated regularly, streaming data from our chosen domain sites as the methane emissions are calculated weekly. Once our study has been completed or as funding permits, we will create a formal report that ties together our entire study with graphs, analysis, methods and a discussion of the results.

We know that as time goes on, there may be certain tactics or areas of the study that need to be reconsidered or reworked and we are prepared to make any necessary adjustments to the study. However, we are confident that the results from this study will speak for themselves when it comes to the staggering amount of VOCs in the form of methane that is produced from dairy

cows within the San Joaquin Valley which contributes to the damaging South Central Valley Smog.

### 3. Results from Prior NSF Support

The Principal Investigator of this report has not received any previous support from the National Science Foundation.

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## **5. Biographical Sketches**

The Principal Investigator of this report is completing a Bachelor's of Science degree in Environmental Management and Protection with a minor in Biology in June of 2011. The Principal Investigator has completed two internships during the summer months of 2008 and 2009 at Ducks Unlimited in Rancho Cordova, California. The Principal Investigator is considering pursuing a Graduate degree in either Environmental Science or Biology in the near future. Career goals for the Principal Investigator include working for The Nature Conservancy or a range of other non-profit environmental conservation organizations.

## **6. Budget**

We believe that our research study of dairy ungulate's emissions of methane and VOCs in the San Joaquin Valley which is related to South Central Valley Smog will take decades to complete in order to obtain enough information to track methane and VOC emissions over time. Because this is a new study, we propose that the National Science Foundation give us funding for 3 years for an initial study and if it is successful we will apply for more funding for the future. We will need a lot of help and cooperation with other agencies to conduct this study, especially NEON Inc. We are asking for a budget of \$1,000,000 a year in order to complete this study. If the National Science Foundation accepts our proposal, the money will be broken down into the following categories:

Task	\$ Amount allocated per year
<b>The construction and upkeep of NEON-imitation domain sites</b> on 5 dairy farms within the San Joaquin Valley	<b>\$250,000</b>
Training and payment of <b>in-field survey crews</b> whom will count the dairy cows and carry out <b>Quadrat sampling</b> techniques	<b>\$150,000</b>
<b>NEON equipment-</b> Airborne Observation Platform, Land Use Analysis Package, Database to share information with the public	<b>\$250,000</b>
<b>Methane and VOC emission detecting equipment</b> — environmental flux chambers, ammonia filters and INNOVA photoacoustic analyzers and analysis of the data	<b>\$250,000</b>
<b>Further research into methane digestion systems</b>	<b>\$100,000</b>