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Emergent Geographies in Green Energy

A Dissertation

Presented to

the Faculty of Natural Sciences and Mathematics

University of Denver

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Sean Tierney

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ABSTRACT

A consensus on climate change is spurring an energy transition, but the geography of this transition is uneven and this paper evaluates the energy landscape globally, in the United States and in Colorado. Developed countries have taken the lead in installations and of next generation energy technology ownership. Green electricity has still not achieved parity with fossil fuels, which puts their adoption in the hands of policy makers who are trying to spur innovation with minimal financial disruption. Yet the future of green electricity is in question due to weak and fragmented policy regimes, but also because of inadequate R&D levels. Wind is maturing with large global players and a settling of technology, but solar is marked by scattered manufacturing and fluctuating technology platforms. Within the United States, venture capital (VC) is playing an active role for the cleantech sector; cleantech encompasses broad themes of sustainability to include electricity as well as materials, buildings, water, energy software, and recycling. Cleantech is among the leading economic sectors securing the most VC money and the future geographic landscape is likely to feature California and Massachusetts, who lead as the top destinations of cleantech VC money, but other pockets of innovation are clear. Finally, while large urban utilities are prepared to transition away from fossil fuels, smaller cities and rural areas, for various financial and scale issues are disadvantaged with incorporating more green energy into their electricity mix. This was evident by the results of Colorado's Amendment 37, which created a statewide RPS and passed with strong

support in the Denver metro area, but limited support in the rest of the state. Nevertheless, all utilities must now diversify and this study surveyed the managers at the state's rural utilities to gauge their attitudes concerning: carbon legislation, conservation and efficiency programs, and their plans for making the electricity transition. Nearly all of the utilities are making progress, but there is broad apprehension and distrust about mandates and the impacts on their communities.

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List of Acronyms

AM	Advanced Meters
APPA	American Public Power Association
ARPA	Arkansas River Power Authority
ARRA	American Recovery and Re-Investment Act (2009)
AWEA	American Wind Energy Association
BIPV	Building-Integrated Photovoltaic
CDM	Clean Development Mechanisms
CSP	Concentrating Solar Power
DOA	Department of Agriculture
DOE	Department of Energy
DORA	Colorado Department of Regulatory Agencies
EEF	Electricity Emissions Factor
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPACT	Energy Policy Act (1992)
EWEA	European Wind Energy Association
ETS	Emissions Trading Scheme
FERC	Federal Energy Regulatory Commission
FIT	Feed-in Tariff
G&T	Generation and Transmission
GAO	Government Accountability Office
GPP	Green Power Program
IEA	International Energy Association
IE	Industrial & Energy (economic subsector of Venture Capital investments)
IOU	Investor-owned Utility
IPO	Initial Public Offering
IPP	Independent Power Producers
ITC	Investment Tax Credit
JI	Joint Implementation
kW(h)	Kilowatt (Hour)
LCA	Life-Cycle Analysis
MW(h)	Megawatt (Hour)
MU	Municipal Utility
NSF	National Science Foundation
NUG	Non-Utility Generators
NVCA	National Venture Capital Association
OECD	Organization of Economic Cooperation and Development
PACE	Property Accessed Clean Energy
PEHV	Plug-in Electric Hybrid Vehicle
PTC	Production Tax Credit
PUC	Public Utility Commission
PURPA	Public Utilities Regulatory Policies Act (1978)

PV	Photovoltaic
REC	Rural Electric Cooperative
RPS	Renewable Portfolio Standard
SEC	Securities and Exchange Commission
SME	Small & Medium Sized Enterprises (businesses)
TF	Thin-Film (solar)
UNFCCC	United Nations Framework Convention on Climate Change
VC	Venture Capital
VCF	Venture Capital Firm
WTO	World Trade Organization

Chapter One: Introduction

The way we produce electricity is slowly changing. Limited technological breakthroughs, timid political leadership, and high financial costs have all played a role in keeping green technologies from the mainstream. Yet a closer look reveals the evolution of a green electricity industry that is building momentum, and under the right conditions, might finally allow us to transition away from fossil fuels. This paper examines components of energy related issues at three scales; globally, within the United States, and within the state of Colorado, to understand the different technologies, identify the necessary political and economic conditions that will bring them forward and various stumbling blocks that may be encountered along the way to a new energy economy.

Chapter two provides the foundation for this research. It sets the backdrop by summarizing the existing literature in economic geography more broadly, but also allows readers to nest this research in more specific scholarly works related to the fields of policy, energy research and development, venture capital, and the nexus of economics and the environment. Chapter two also frames the problems set to be analyzed, asks the research questions and finally, outlines the methods and data that were anticipated in answering those questions.

Chapter three takes a global view of the green electricity industry. It should be no coincidence that the geography of green electricity installations is concentrated in the

same handful of countries where the most aggressive policies have been enacted to support the transition. Meanwhile, public sector spending on energy R&D has seen a shift towards green supplies (at the expense of fossil fuel and nuclear), but this emphasis has come amidst rapidly and unrelenting cuts to overall energy R&D. The broader wind industry and wind technologies are maturing as turbine manufacturers appear to be coalescing around fairly standard turbine designs, leading to lower costs and aggressive market penetration. Solar remains a highly dynamic and fragmented industry, due in part to costs, but also because the market is still waiting for the industry to settle on a winning technology. Geothermal technology is still geographically concentrated, but technology improvements are setting the stage for expansion into areas where geothermal was previously unsuitable.

Chapter four examines the role of venture capital in the cleantech industry within the United States. Cleantech is the umbrella term that captures more than just green power generation; it includes materials, buildings, efficiency technologies, services, water, transportation, energy software, and recycling. The level of investment activity by venture capitalists in cleantech has risen slowly over the last decade, but quite rapidly over the last three years, to the point that cleantech is now the industry receiving the second highest level of financial activity in the country. Is this an asset bubble waiting to burst or the early stages of a techno-economic paradigm shift? There is a symbiotic relationship between the location of venture capital firms that make the investment, and the cleantech firms that are innovating new products and technologies. And yet, cleantech firms are found in nearly every state and reaches most metropolitan areas of

the country, meaning that as the transition to more sustainable technologies is made, at least as far as the early footprint of these industries is concerned, the economic impact is set up to deliver benefits around the country.

Chapter five offers a glance at the utility industry in Colorado. Either as generators or wholesale buyers, utilities are the most important players in the electricity sector, and are very sensitive to price fluctuations. As if gyrating energy prices were not enough, the state of Colorado recently passed legislation requiring that all utilities put additional green electricity supplies into their energy mix, which in the near-term means at higher costs. Utilities serving small rural communities are finding it financially difficult to absorb these mandates, thus leading to a politically charged climate between the unregulated rural utilities and state lawmakers in Denver. Yet the mandates are law, and so while these rural utilities wait for cheaper generation technology, most are pursuing strategies designed to curb demand by customers within their service territory.

Countries around the world are embracing new electricity technology far too slowly and the principal reason behind the sluggish adoption rates is cost. Our ability to make an electricity transition is wrapped up in the fourth law of ecology, which states that there is no free lunch; unincorporated externalities have lulled us into thinking we are entitled to cheap energy. Our current fossil fuel based system is not cheap, it is dishonestly priced. This accounting failure has led us down a dangerous path, a path that burgeoning investments in cleantech within the United States and around the world are designed to help us reverse. Ultimately, the price of generating electricity will fall so far that people in rural communities, developing countries and everywhere in between will

benefit from the break-up with fossil fuels. Without disputing that the economic costs of an energy transition are sure to create some sticker shock, it is equally indisputable that once those systems are in place, they will be financially lucrative and ecologically rehabilitating.

Chapter Two: The Proposal

Introduction

For nearly two centuries, fossil fuels have powered the global economy. By most measures, improvements in life since the dawn of the industrial revolution can be characterized by improvements in industrial agriculture, increased efficiencies, vast transportation and communication networks, longer life expectancies, and unprecedented technological innovation. These gains however were not free. As humans transitioned from animate to inanimate power, environmental compromise was rarely considered. It was not until 1992, with the first earth summit in Rio de Janeiro that global leaders gathered to speak publicly about anthropogenic externalities. Unfortunately, the summit failed to spur action, and carbon emissions have continued to grow. In 1992, global carbon emissions were 21.3 billion metric tons and in 2005 (the most recent year of data), global carbon emissions had grown by nearly 30% to 28.2 billion metric tons (EIA 2008).

Since the earth summit in Rio, political fragmentation among the states in the developed world has prevented the international community from finding common ground. Meanwhile, the developing world, eager to achieve better living standards, remains uneager to divert resources from their economic expansion for the sake of a

global problem they did not create. States have been left to act independently and the result has been a sluggish piecemeal approach.

That is not to suggest solutions have not been put forth. In fact, in the 15 years since Rio, interest, acceptance, and market penetration of green energy has steadily climbed; unfortunately, it has failed to keep up with overall energy demand, leading the world to increasingly lean on traditional fossil fuel sources. While green energy's transition from fringe to mainstream is happening, until a collective catalyst enables the world to exponentially scale up green energy production, the world is still beholden to fossil fuels. Fortunately, green energy's time may be at hand.

Green energy is defined by the industries that generate electricity from non-polluting sources, like wind, solar, geothermal, lunar, biomass and small scale hydro (Menz and Vachon 2006). Countries all over the world are at different stages of transitioning to power produced by green energy, but no country has been able to achieve the sorts of scale economies necessary to abandon their reliance on traditional energy sources. As a result, fossil fuels remain the dominant form of energy production everywhere. Given the vast infrastructure, abundant and accessible raw materials, cost advantages, and deep political ties, coal, oil, and natural gas will remain part of the international energy portfolio for decades. However, the speed and effectiveness with which green energy has chipped away at fossil fuel's many competitive advantages, makes the prospects of a global economy powered by green energy seem more viable than ever.

In the United States, more than 70% of our electricity generation comes from fossil fuels (mostly coal), while nuclear and hydroelectric (which are not considered green energy) make up the rest. This ignores the role that petroleum, another fossil fuel, plays in powering our transportation sector. Green energy provides just over two percent of our electricity generation, a percentage that has remained essentially flat for the last two decades (Energy Information Administration, 2008). Reasons for a lack of investment in green energy are directly tied to cost of traditional energy sources. Cheap fossil fuels have discouraged a national imperative to usher in a new energy economy. In addition to the economic barriers, the stagnant green energy industry has had to overcome many other obstacles. At first, climate change science was not sound. Then the technology seemed inadequate. The economic costs of this new energy were always too high and the political climate was never quite right.

But now, there is ample evidence to suggest that the time for the green energy revolution has arrived. There has been an explosion in venture capital investment dollars chasing cleantech broadly and green energy specific start-ups; meanwhile green energy IPOs are receiving favorable reactions from Wall Street. Cleantech has emerged as the term to describe a broad array of sustainable technologies, including but not limited to green energy. Despite an otherwise bleak national employment picture, job growth in the sector continues, reinforcing the public's appetite for green energy options. The confluence of several macroeconomic and geopolitical factors has also given green energy a boost: record fossil fuel prices, the rise of the developing world as global energy competitors, globalization's assault on manufacturing jobs, and most importantly, a

consensus of the human influence on climate change. The green energy industry provides something for everyone, offering it the unique distinction of making bedfellows out of foreign policy hawks, tree huggers, and entrepreneurs. Green energy appears to have eclipsed the tipping point, serving as the grand slam answer to the four pressing policy issues of the day: national security, energy security, economic security, and environmental security. But many questions remain.

The dynamic nature of green energy, concatenated by its youthfulness, diverging technologies, converging interest, and a lack of international consensus, has generated interest from a variety of business, consulting, government, and non-governmental organizations. The academic community has also chimed in with extensive contributions from both the hard and soft sciences, but few within geography have studied this evolving industry. Many of the themes in this study, from looking at the spatially fragmented rates of adoption, to the varying policy proposals, the clustering of innovation and R&D, the role and outreach of electric utilities, the role of entrepreneurs, as well as the importance of the capital markets, are well suited to an economic geography analysis. As a result, the focus of this research will be to describe spatially, and analyze economically, the green energy industry at three different scales; globally, nationally within the United States, and locally within the state of Colorado.

Literature Review

New Economic Geography / New Growth Theory

The middle of the twentieth century was marked by insular economic policies. Correspondingly, economic geography had settled on national boundaries as the unit of analysis for understanding the spatial differentiation of economic activity. Of course, this ignored the first round of globalization that took place pre-WWI. “The inhabitant of London could order by telephone, sipping his morning tea in bed, the various products of the whole earth ... he could at the same moment and by the same means adventure his wealth in the natural resources and new enterprises of any quarter of the world.” (Keynes 1920, p 11). Writing at a point in time when the world become more autarkic with decades of war, political instability and depression, John Maynard Keynes could very well have been describing the world as it is currently viewed through the eyes of economic geographers. It took a while to get to this point.

For about 50 years, the research path pursued by economic geographers was based in the realities of the time. The Fordist economic model ruled the day as countries attempted to remain more-or-less self-sufficient. Scott (2000) catalogs the societal themes and thus, the themes written about by economic geographers, which was done largely in descriptive terms. Starting in the 1950s, theoretical ideas like industrial location and interaction began to permeate the field, followed slowly by a shift towards regional science, all remaining under a Fordist rubric (Clark et al. 2000). Import-substitution was essential national economic policy. This line of thinking was radically disrupted by Harvey (1973), who opened the door for others to shine the light on

deindustrialization, and the ills of capitalism's destructive forces such as poverty and regional decline. The fixation on economic activity with a national context would quickly dissipate. While some of the literature in the late 1960s and 1970s assumed a Marxist tone, a growing group began writing on regions that were emerging as powerful economic nodes in a not-yet-fully-understood, post-Fordist era (Scott 2000). Economic institutions began organizing themselves globally, and so geographers, as well as researchers in other disciplines, most notably economics, began trying to explain this new spatial arrangement.

In its most simplistic form, economic geographers studied this new arrangement in a regional form. Globalization created a world where regions or cities, not countries, became the unit of analysis; and where international trade (due to low transport costs) connected more people and places, but factor endowments like raw materials, labor, and knowledge made the impacts of these connections starkly uneven. While the old economic geography was rooted in traditional ideas like perfect knowledge and constant returns-to-scale, the new economic geography tossed out those paradigms in favor of a world based on monopolies, which brought imperfect competition and increasing returns to scale (Krugman 1990 and 1991; Romer 1986). Unlike constant returns-to-scale, which exhibit a linear relationship between inputs (labor or capital, for example) and output, increasing returns-to-scale provides for proportionally higher output, given some lesser amount of inputs (ie: increased productivity).

The premise of increasing returns relies on the idea that profits and productivity are generated endogenously. Said differently, growth comes from within the firm or the

metropolitan area. Dixit and Stiglitz (1977) were the first to account for monopoly power, but others soon followed with more robust models that could better account for increasing returns (Grossman and Helpman 1990; Segerstrom et al. 1990). Much of this research was being developed in the field of economics, and it all pointed to a new growth theory and a new trade theory; nevertheless, economists were having problems. As Romer (1993) pointed out, traditional development analysis favored modeling ‘objects’ (roads, factories), but that the realities of this ‘new growth theory’ would require better modeling of the more abstract ‘ideas’ (knowledge, interaction).

Measuring future development based on ideas would become increasingly important, and difficult, in a world with more joint ventures, collaborative research, and public/private partnerships. As a result, the new economic geography and new growth theory converged, as both were interested in the factors that generate regional economic growth within a world of highly connected nodes. These nodes seem to retain, and subsequently build upon, their advantages by becoming larger, more influential, and smarter. Much of the research began to hone in on those ‘ideas’ that generated such advantages by looking more closely at factors like agglomeration economies, innovation, and spillovers.

Agglomeration Economies

The geography of agglomeration economies owes its roots to Alfred Marshall whose pioneering research on industrial districts first set in motion the ties between economics and geography (Marshall 1919 & 1920). Three factors were put forth to

explain the clustering tendencies of industry: a) specialized labor b) backward and forward linkages and c) knowledge spillover. Spillovers will be discussed in the next section, but the first two offer distinct and tangible financial benefits. Industrial districts create economies of scale for small and medium sized enterprises (SME) that locate close to one another. These economies are external to the individual firms (ie: available to all) but internal to the region within which the SMEs reside. Asheim (2000) summarizes the legacy of Marshallian economic theory and provides an updated understanding of how the nexus of economics and socio-cultural infrastructure lend themselves to regional dominance in a global economy.

Initially, city formation was rooted in physical geographic factors like a good port or river access, but cities also emerged by chance. It is here where Krugman (2000) discussed the importance of place, particularly in the new economic geography, which tends to place importance on historical significance. Entrepreneurial firms tend to locate in space for a variety of reasons and thus become a stable source of prolonged economic development. Per Krugman, start-up firms tend to locate at the behest of its founder, who usually prefers his or her home region (Mueller and Morgan 1962; Reynolds and White 1997). Stam (2007) argues that young firms are 'unilocational' and often decide on their home region because entrepreneurial opportunities are more often local, rather than universal. This superior local knowledge, as well as access to their known suppliers and customers, enhances the firm's chances of success which can eventually be parlayed into broader geographical growth.

The fields of evolutionary economics and industrial economics suggest that as companies grow and their markets expand, they trade in the early growth phase geographic allegiances for the more practical or perhaps necessary locational choices. Van Dijk and Pellenbarg (2000) discuss a set of papers that use biological metaphors to describe the firm as a living organism, making choices about, among other things, location.

Agglomeration tendencies have been spurred by an evolving set of motivations. At first, it was to reduce transportation cost, then it was proximity to a specialized labor pool, but in the 21st century, the predominant factors in agglomeration economies are the creation and transmission of ideas (Glaeser 2000). Agglomeration effects of business or industrial location are an important component of the economies in many countries, states, or even regions, and they are everywhere. “Clusters are not unique, however; they are highly typical -- and therein lies a paradox: the enduring competitive advantages in a global economy lie increasingly in local things-- knowledge, relationships, motivation - - that distant rivals cannot match” (Porter 1998). Porter makes another important point about agglomeration, in that clustering creates intense competition among the players, but more importantly, a cluster yields incredible cooperation among the firms within the region.

Understanding the locational tendencies of the green energy industry now, in its ‘entrepreneurial stage’, should enhance the predictive nature of the industry’s geographic footprint when it matures. By this argument, cities and states should be leapfrogging one-another to nurture a local or regional green energy friendly environment in order to

attract firms. Should an environment emerge where initial host cities lose their start-up firms to other areas, a plausible scenario in the new globalized economy, there are still opportunities for all regions to grow. Nijkamp (2003) suggests that all urban areas, or even non-urban areas, can capture the windfall benefits provided they offer venture capital, training programs, education facilities, and public support. These attributes will serve as magnets should the green energy industries begin to adopt more footloose characteristics

R&D and Innovation

The impact of R&D on innovation and economic growth has always been implied, but articulating a direct causal relationship is something that is difficult to isolate. Dosi (1988) provides a nice discussion on the contribution of innovation to technological change at the local level, but concludes with many unanswered questions. In the 20 years since, many of those unanswered questions remain.

Although measuring R&D investments is easy, so many other problems arise when attempting to quantify its impact. For example, what is the proper accounting methodology for the lag between research outlays and productivity improvements? Grossman and Helpman (1991, p. 14) cite a series of case studies which suggest the near impossibility in properly quantifying R&D investments, due to possible social returns, non-rival nature, and inter-industry benefits that often accrue. Another problem stems from trying to detangle currently derived revenues from previous investments. Isolating R&D benefits is problematic given econometric problems of multi-collinearity and

simultaneity; in other words, in a complex economic system, there are many facets moving together, making a model or empirical test too complex (Griliches 1979). Finally, there is the notion that it is innovation, not R&D which more heavily influences productivity and employment growth (Raspe and Van Oort 2006). Nevertheless, as difficult as it may be to measure the link between R&D and economic growth scientifically, the link is unquestionable (Teece 1986).

Romer (1990) argues that technological change drives economic growth. His premise relies on market incentives to generate value creation and his model determines that those societies with larger human capital stocks enjoy faster economic growth. In fact, when measuring economic growth using the production function, 'new' economic theory includes knowledge among its inputs (joining land, labor, capital, and raw materials), and a significant source of that new knowledge (ie: innovation) is derived from R&D (Audretsch 1998).

Geographic proximity plays a crucial role in innovation, particularly in areas with groups of people sharing (among other things) high levels of creativity, education, training, skills, and expertise (Knudsen et al 2008). Feldman (1999) confirms this idea by summarizing several empirical studies to support the notion that a concentration of human capital, at a high level, invigorates economic growth; a relationship that is strengthening with every decade (Glaeser 1994). Furthermore, Lucas (1988) identified a willingness to pay higher land rents in exchange for access and interaction to high human capital.

As it relates specifically to energy, R&D has been in decline ever since the oil shock ended in the early 1980s. Dooley and Runci (2000) suggest that the world has come to expect cheap energy as a result of technological advances in discoveries and extraction, productivity enhancements, and the energy future's market to insulate us from wild price swings. The perception that abundant energy supplies would persist has discouraged energy R&D, since any viable market for non fossil-fuel based energy has been absent for a generation, which would explain the lack of any meaningful innovation. According to Nemet and Kammen (2007), the United States' R&D investments in green energy have shrunk by about \$1billion over the last decade.

Spillovers

Among the most important causal relationships between agglomeration and innovation is the concept of spillovers. Knowledge spillovers remain a central tenet of agglomeration economies, and more importantly rationalizes the clustering tendencies of like-firms. Sometimes the spillovers are between industries and other times it is within industries (Glaeser et al 1992; Jacobs 1969). Nevertheless, close geographic proximity has been proven to stimulate innovation. Knudsen et al (2008) suggest that "if the ability to receive knowledge spillovers depends on distance from the knowledge source, then clustering of knowledge-producing inputs should ensue".

Although analyzing spillovers can make for a slippery science, they exist and they are important (Griliches 1992). One attempt to measure spillovers, or cross-fertilization as it is also known, as it relates to innovation was done by Jaffe et al. (1993) which found

a strong geographic correlation between patents and patent citation. Looking at five-year increments following the issuance of a patent, a strong localization effect was found among those citing that patent, suggesting that innovation within a specific technological gamut tends to be concentrated. Audretsch (1998) reaffirms this point and shows that despite globalization and the fluidity of information flows created by the telecommunications revolution, knowledge is a key source of comparative advantage resulting in spillovers remaining a local phenomenon.

Sizable R&D budgets at universities and private corporations act as magnets for those seeking to capitalize on knowledge spillovers, proving to be of great benefit for third parties that locate within close proximity (Audretsch and Feldman 1996; Jaffe 1986; Jaffe 1989). Acs et al. (1994) expand upon Jaffe's research and find that private corporate R&D benefits large corporations (more than 500 employees), while the university R&D spillovers disproportionately benefit small firms. This is the central tenet behind a widely cited article by Teece (1986), explaining how innovators often fail to benefit financially from their work and that in the absence of iron-clad patent or copyright protections, second or even third to market firms have a history of greater profits than the innovators.

Policy and regulation

The literature is rich with examples of ways that government involvement can either distort market efficiencies or promote growth (for a review, see: Grossman and Helpman 1991). And while many agree that most innovation takes place in the private

sector, starting in the 1960s, a similar consensus emerged that government played a direct role in influencing the pace and direction of innovation (Roessner 1988). With respect to the government's stewardship of the environment, history provides us with three policy prescriptions – regulation, incentive instruments, and voluntary agreements – that are most traditionally applied (Turner 2000).

As the transition from a manufacturing to a knowledge based economy continues, several have argued that promoting industrial districts, or what are now referred to as technology districts, provide an essential competitive advantage in the global economy (Del Ottati 1994; You and Wilkinson 1994). The aforementioned agglomeration economies simultaneously foster cooperation and competition between firms, driving innovation; thus, promoting technology districts becomes a national imperative. Expanding participation to build quasi public-private partnerships that harness the knowledge creating capacity of universities, government agencies, and research institutions leads to 'learning regions' or 'development coalitions' (Asheim 2000).

Storper (1995) outlines how a national policy aimed at developing regional technology districts serves the dual function of enhancing a country's competitiveness and spurring innovation. He specifically identifies regional technology foundations, made up of organizations with a wide encompassing and forward looking view, which are intimately familiar with the region and can act as custodians for those long-term development projects; entities like public utilities, universities, and foundations that already have relationships with the government (state and/or federal) and are well

positioned to balance the regional economic priorities with policies aimed at its stimulation.

Government policy decisions to invest in education, training, knowledge centers, and R&D will create successful entrepreneurial activity which is essential in this interwoven global network economy (Nijkamp 2003). The idea that government institutions should promote policies that encourage the development of the green energy industry is supported by the evidence that countries that export a larger share of their output tend to enjoy the highest levels of growth, particularly among the more developed countries (Michaely 1977; Feder 1983).

Policy is also needed to level the playing field. Promoting innovation must not only seek to stimulate R&D, but it must remove those barriers that prevent first-to-market-firms from losing their ability to recapture their investment to looming imitators with better complementary assets and underlying infrastructure (Teece 1986). An example is appropriate here – if a policy to bring hydrogen fuel cells to market is promoted, the government must remove the subsidies to oil companies who could undercut the first-to-market hydrogen firms that lack the distribution networks and service stations, where the oil companies already enjoy a huge advantage. By this measure, government should play an important role in the development of national green energy industries, as policy designed to stimulate competition as well as cultivate collaboration will yield long-term economic benefits.

Very little has been done to study the impacts of specific state policies and economic growth, but one study by Holmes (1998) found that states with a right-to-work

law, or pro-business as he defined it, attract more manufacturing when compared with a neighboring state that does not have a right-to-work law (anti-business). With respect to the ability to form unions, state policies matter. It would appear that there is also evidence on this union variable at play with the distressed American automobile industry in the pro-union Midwest, compared with the thriving auto industry set up by foreign manufacturers in the non-union southeastern US. Nevertheless, unionization rates are not the sole driving factor in quality as Mitsubishi and Honda have plants in union territory (Illinois and Ohio, respectively) while GM has a plant in non-union Tennessee

The idea that state policies can impact the locational decisions of private enterprises raises an important issue. Some could argue that taxation levels, regulatory/permitting hurdles, and worker organization laws are levers that state officials can tinker with in order to attract business. Others would counter that the obligations/restrictions imposed by federal regulations tend to cover the most important issues and are inescapable at the state level. Additionally, educational attainment, urban and localization economies, and the creative class components offered by a city are equally important factors luring business, and lie largely outside the reach of policy makers (Florida 2002). Hopefully this research will offer evidence as to the impacts state policies can have on attracting green energy businesses.

Venture Capital and Financing

The recent surge in (financial) interest in green energy should not be all that surprising; given the finite nature of fossil fuels and the world's seemingly insatiable

demand for energy, it was logical that the money would soon actively drive innovation. The entrepreneurial successes enjoyed by the United States remain the envy of the world, but venture capital's track-record as a dominant driver of innovation can be traced back only a few decades. The Employee Retirement Income Security Act (ERISA) of 1979 is responsible for an important shift in the way venture funds went about raising capital. ERISA paved the way for pension funds to invest a significantly larger portion of their assets in venture capital, thereby expanding the number of entrepreneurial opportunities that could obtain seed money. In 1978 pension funds account for 15% of the \$424 million in new venture capital funds, but by 1986 pension funds supplied more than half of the \$4 billion raised by venture capital firms (Kortman and Lerner 2000).

That money drives innovation is nothing new. While examining nearly 1,000 inventions in four different industries, Schmookler (1966) found "...the stimulus was the recognition of a costly problem to be solved or a potentially profitable opportunity to be seized; in short, a technical problem or opportunity evaluated in economic terms". Kortum and Lerner (2000) found that innovation is driven by venture capital, which is three times more powerful than corporate R&D. The notion that market opportunities generate technological progress is corroborated by Dosi (1988) but he finds that scientific discoveries outside the profit arena also make important technological contributions.

Energy technology continues to claim a more significant percentage of the venture capital funds. Less than one percent of all venture capital was invested in energy technology in 2000, but had grown to 9.1% by 2007 (Makower et al. 2008). More than \$1.5 billion was invested in cleantech (no specific breakout of green energy) in 2006,

launching 1,500 start-up companies worldwide. In the past two years alone, 50 of these companies have gone public (Veverka 2007).

Economic and environment interaction

Historically speaking, the field of research within economic geography that pertains to environmental issues is still in its infancy. Much of the geographic research on the relationship between economics and the environment was centered on trends and impacts in production and consumption decisions. The research focused on the descriptive, like explaining resource extraction, energy use, or decarbonization of production. Specifically, ideas of how to make industry more 'green' was topically dominant. Whether that means greening the supply chain, greening the manufacturing, recycling or general waste reduction (Florida 1996; Fischer and Schot 1993, Roome 1996), the focus remained on empirical industry analysis.

More recently the research has adopted a more theoretical tone looking for ways to improve environmental performance. Two broad versions of the economic/environment interface have characterized much of the writings in economic geography. Some believe that regulation will play a critical, if not overwhelming role in improving environmental performance (Gibbs and Healey 1997, Lipietz 1992), while others says that a combination of incentives, proper pricing signals, and selective oversight will allow the market to bring about ecological modernization (Mol 1996, Simonies 1989, Christoff 1996, Gibbs 2003).

Permeating this regulation vs. free-market approach, Angel (2000) describes three distinct sub-themes. First, he cites the double-edge sword of globalization in that it both accelerates energy and materials accumulation, but can also provide the opportunity to mobilize the collective economic, social, and political imperative to be better environmental stewards. Second, some question the calls for broad international policy prescriptions to environmental security for there is precedent to defer to policy that is locally tailored. In other words, top-down regulation may be inferior to bottom-up localized initiatives that attract more robust adherence and enforcement due to social and geographical constructs. Finally, a third idea is that scale matters and more research needs to be conducted that links the decisions made at different levels of analysis. Policy, both nationally and internationally, are important components of any environmental debate, but the economic choices made by individual firms are equally critical in forming a comprehensive understanding of the issue. In several ways, this research will touch each of these sub-themes.

Problem Statement

Globally, the world uses about 15 Terawatts (TW) of energy per year. A Terawatt is 1,000 gigawatts (GW), and a gigawatt is 1,000 megawatts (MW), or the average size of a coal-fired power plant. Financially speaking, it is a business that translates into about \$6 trillion annually. Based on a global GDP figure of around \$60 trillion, energy represents ten percent of the global economy (Economist 2008). In a business as usual scenario, with spiking oil prices and rising living standards, this percentage is sure to rise.

While there are upfront/construction costs for both green energy and fossil fuel energy that must be recovered, in addition to ongoing costs associated with maintenance and operations, fossil fuel energy is burdened with recovering the additional costs associated with exploration, mining, extraction, transportation, and potentially carbon emissions. It is clear to see how, in time, green energy will substantially lower our energy bill, freeing up massive amounts of capital which can then be invested in other areas. A world burning no fossil fuels is an easy one to envision, but achieving a carbon-free world will have to overcome numerous political, economic, technological, and ecological hurdles.

Forecasting green energy's penetration rates has been a challenge. Despite the acknowledged damage that fossil fuels are doing to our climate, the void of international leadership on a global green energy strategy has created a vacuum for individual countries to try and fill. With that in mind, the first broad theme of this research will be to dissect the economic incentives and policy proposals that have succeeded and failed among the different countries of the world attempting to usher in the new energy economy.

Internationally, Europe has most closely followed the Kyoto guidelines for the transition away from carbon polluting sources, and yet, within the European Union (EU) there are significant differences in adoption and installation rates. Japan has embarked on a very ambitious solar initiative, but with the sunset of its federal subsidy, solar installations are on the decline. China has emerged as one of the leading solar producers, yet because the costs are still out of reach for a majority of its people, ranks very low on installed solar capacity. Meanwhile, the United States, which withdrew from Kyoto and

continues to fumble away policy opportunities, is the global leader in installed MW of green energy electricity.

Most countries of the world believe that the United States remains the real obstacle in fusing a coherent global policy towards green energy. As the sole developed country not to ratify the Kyoto Protocol, the United States, which has been and remains the world's fossil fuel glutton, rejects the scientific research, refuses to compromise its sovereignty with an international treaty, and is reluctant to enact climate friendly legislation. Despite this lurid federal policy position, the fledgling US green energy sector has been nurtured by entrepreneurs, industry, and the capital markets, all of whom are eager to lead. This backdrop serves as the platform for the second broad research theme, which is to understand the spatial variation of the green energy industry in the United States. To what extent have the sub-federal policy initiatives spurred investment? Are research dollars and innovation concentrating in particular areas? Does proximity to national research labs or research universities generate agglomeration effects that can provide a blueprint for regions seeking to carve out a place in the new energy economy?

In the absence of a federal policy initiative, green energy advocates have taken their cause to the states. Colorado is among the leaders in supporting the green energy industry, with Xcel Energy, the state's largest utility, supplying green energy to more customers than any utility in the country in 2006 (DOE 2007). Other state utilities are following suit.

The third broad theme of this study will focus on the utility companies, which play a pivotal role as the liaison between commercial and residential interests, green

energy power producers, and legislators. For some utilities, their actions are a result of customers demanding more green energy. Others are bringing on more green energy in anticipation of a national carbon cap-and-trade system or a carbon tax, while others still are trying to bring some calm to gyrating energy prices. Whether these utility companies build green power production or buy it from third party providers, their role as custodians of the new energy economy is paramount to its success, and so their position on where the future lies will serve as an important barometer towards understanding this energy transition.

Study Area

This research will attempt to dissect the green energy industry at three scales: globally, nationally, and locally. In general terms, the international component will compare all the countries of the world, but because the combination of the green energy industry infancy and the prohibitive costs of implementing this technology, the international study will quickly hone in on those select countries with meaningful green energy programs; most of which are found in the three global cores of North America, Western Europe, and Eastern Asia. With this smaller subset of countries, a more detailed description and comparison of those countries that have made ‘significant’ green energy implementation inroads will be made.

Within the United States, the picture is more complex. Most states are aggressively pursuing green energy strategies in response to public opinion, impending environmental regulation, and economic opportunities. As a result, the geographic

picture of green energy will enable a broader analysis. Although the southwestern United States offers the most abundant solar energy potential, states in Northeast and Midwest are home to many solar manufacturing facilities. The wind turbine supply chain runs all across the country, and yet two states, Texas and California account for nearly half of all the domestically installed MW capacity. This research expects to uncover a series of geographic patterns with respect to green energy production, employment, financing, and policies.

Finally, the state of Colorado will offer a unique platform for a more disaggregate understanding of the green energy industry. Colorado combines two critical characteristics that should enhance the state's position as a hub of green energy activity. First, the physical geographic characteristics are attractive to all forms of energy; 300 days of sunshine, a powerful wind corridor, geothermal activity, a large established agricultural sector, and abundant fossil fuel reserves. Second, Colorado has the human capital necessary to drive the green energy economy forward; a highly educated workforce, a large and growing metropolitan area, an openly progressive environmental policy agenda, and an economy that is heavily reliant on tourists that are attracted to the state's natural beauty, which the green energy industry is designed to protect. It should be no surprise to realize that a fledgling green energy industry has emerged. And while talking with the specific companies and policy makers responsible for cultivating this new economy would provide interesting insights, it would seem more practical to get the perspective of the state utilities for a better understanding of the tradeoffs required to make Colorado effectively a powerful player in a green energy world.

Data

A variety of data sources and types will be used in this analysis. A lot of the information will be temporally varied in order to look at the geographic and economic change over time. Aggregate data will be used at the smaller international scale, while more disaggregate data are more widely available for the US and Colorado units of analysis. GIS will also play a crucial role in this study. A variety of thematic maps will illustrate the difference in green energy adoption at both the international and national scales. GIS can help analyze trade flows, industrial location, and proximity values which are all important economic geography concepts. A more detailed breakdown of these data follows.

This study will use both quantitative and qualitative analysis using data acquired through a variety of sources. The government has done a reasonable job of aggregating both international and domestic data. However, because green energy accounts for only two percent of our total electricity supply, government statistics fail to break down more thoroughly some of the information to make it useful for this analysis. Therefore, government data will be supplemented with data obtained through other sources: consulting firms, banks, green energy websites, and weekly publications. It is important to note that some of the data used in this analysis may possess inaccuracies. As is the case with government economic statistics, revisions are often made to previously released information; the same is also true for green energy data. Because of the industry's youth, a certifiable and central data collection system has not been formed, leaving industry

observers to use the best available estimates. As a result, this study will reflect those inaccuracies, making the inexact science of this study unavoidable.

As stated in the introduction, green energy is defined by the industries that generate electricity from non-polluting sources, like wind, solar, geothermal, lunar (tide), biomass (excluding municipal solid waste) and small scale hydro (<10MW). When green energy is bundled with municipal solid waste and large scale hydro, it is collectively referred to as renewable energy (Menz and Vachon 2006). Others, particularly in the business and consulting arenas, have adopted an umbrella term, cleantech, to incorporate the previously mentioned green energy solutions, in addition to those industries that represent products or services designed to promote energy efficiency, pollution-abatement, water technologies, recycling industries, nuclear, renewable transportation fuels, and energy storage. For this research however, the focus will remain on electricity generation (excluding nuclear and large-scale hydro), and therefore, will remain focused on green energy.

These distinctions are important, because most of the investment data used for this study breaks out cleantech industry investments, without further disclosing the exact type of technology. As a result, some broad generalizations are used to describe the economic geography of green energy, which is sure to include non-green energy (electricity producing) technology.

This research will use different data at each of scale of analysis. The global component of the study will rely largely on descriptive statistics. Given the concentration of green energy innovation and adoption in the three global cores, this regional approach

offers the opportunity to describe the nature of the industry in different parts of the world, something that has yet to be done within the field of economic geography. In addition to this regional analysis, this study will also describe the historical build-up of the global green energy industry, the impact of trade, the evolving pattern of demand, the role of government, corporate strategies, and technological change. The Department of Energy (DOE) will supply much of the time series data, as well as the data concerning country-by-country specifics, such as the types and amount of energy used, population, GDP, carbon emissions. The year 1992 will serve as the base year of analysis for two reasons: first, it was the year of the earth summit in Rio, placing climate change and environmental issues for the first time on the global stage and second, it is the inaugural year for countries like Germany, Czech Republic, Russia, etc, enabling clean time-series analysis to be done. Since the DOE does not disaggregate specific types of green energy in use by specific countries, alternative data sources will comprise the remainder of the information used in this section. Examples of other data sources are International Energy Agency (IEA), the Organization of Economic Cooperation and Development (OECD), and the UN Sustainable Energy Finance Initiative.

For the study of the United States, data will be obtained from both government and industry sources. In addition to the DOE, useful government data will come from the United States Patent and Trademark Office for example, which should provide a spatial understanding of where the green energy innovation is taking place. Hopefully these data will enable a further breakdown of those patents being generated by established players in the field as well as the cutting edge research being conducted by incubators around the

country. NCAIS information (obtained from the economic census) serves as another example of useful government data, and will help paint a picture of where specific green energy sub-sectors have employment concentrations.

When looking at industry specific segments of the study, trade or industry groups will serve as valuable sources of information. The American Wind Energy Association (AWEA) and the Solar Energy Industry Association (SEIA) are good aggregators of industry news and data. Several clean energy organizations, including, 'Greentech Media', 'New Energy Finance', 'Cleanedge', have formed websites that act as clearinghouses of information, private sector press releases, financing announcements, policy proposals, and industry data. Thompson-Reuters owns a leadership position in aggregating daily venture capital activity in all sectors of the economy, including cleantech. Other data sources including the independent government organizations like the National Science Foundation (NSF) and national energy labs, banks and consulting firms' industry reports from firms like PriceWaterhouseCoopers, SEC filings of publicly traded companies, and non-profit groups will help fill in the gaps of government data and should hopefully allow for information that is broad, deep, and most importantly duplicative.

For the local analysis, the emphasis will shift from descriptive and quantitative analysis to one utilizing a qualitative approach, using data obtained from a survey/questionnaire. Questions from this survey are included in the appendix (Appendix B). Colorado has 57 utilities. More than half of the state's population (1.3 million people) is served by Xcel Energy, the state's largest utility, and one of only two publicly

traded, investor-owned utilities in the state (see Table 1). The rest of the utilities are either municipal (operated by a city or town) or consumer owned (operated by several, usually neighboring, towns), with the largest of these utilities having about 203,000 customers.

Table 1: Utilities in Colorado by type

	Number of Utilities	Customers	% of total population
Investor-owned	2	1,415,784	59.0%
Municipal	29	433,210	18.1%
Consumer	26	548,814	22.9%

Source: DORA 2008

All of the utilities in the state are subject to control by the Public Utility Commission (PUC) but only some were subjected to the Renewable Portfolio Standard (RPS) mandates set forth when the voters passed Amendment 37 in 2004, requiring 10% of Colorado electricity to be generated from renewable resources by 2020. In fact, Colorado was the first state to pass an RPS at the ballot box (Levesque 2007). In 2007 however, the legislature, along with newly elected Democratic governor Bill Ritter doubled the RPS to 20% by 2020 for the state’s largest utilities and mandated that the smaller municipal and consumer (also known as co-ops or rural electric providers) achieve 10% by 2020. While Xcel serves the large metropolitan areas around Denver, the other utilities serve small towns and rural areas of Colorado.

Now that all the utilities are included in the mandate, the state of Colorado should see accelerated green energy activity. Some of the power will be provided by the utilities themselves but most of it will be provided by independent power producers (IPP). IPP,

also known as non-utility generators (NUG), build electricity generation facilities or plants, and sell the power to the utility companies. In these scenarios, the utilities act as the middle-man in the process.

As such, the utility offers the unique perspective as the liaison between the government that is mandating the renewable energy, the IPP that are investing in and building green energy production facilities, and the consumers who use the electricity. In its current state therefore, understanding where and how the green energy economy is and should function is probably best seen through the eyes of the utilities. And that is what the third part of this study aims to do by asking a series of policy, adoption, technology, and environmental questions in order to provide more clarity to an industry sector that is being pulled in a variety of different directions.

Chapter Three: A Global Energy Shift

Introduction

Since the end of WWII, the move to market based economies has been a consistent trend for countries hoping to prosper in the global economy. But for all the virtues of capitalism and open trade, no real free market mechanism has been developed to counter environmental degradation. Furthermore, this void has not been filled by any international agreements designed to promote environmental stewardship. As Pigou (1932) wrote in *The Economics of Welfare*, ‘Markets are superb at setting prices, but incapable of recognizing costs’. More than a decade ago, the Commission on Global Governance (1995, page 135) sounded the alarm, ‘while the world has become much more highly integrated economically, the mechanisms for managing the system in a stable, sustainable way have lagged behind’. In particular, the institutions to deal with the climate change and the externalities associated with fossil fuel emissions have been fragmented, non-binding, non-enforceable, and highly contentious.

In 1972, the UN Conference on the Human Environment was held in Stockholm, Sweden. Coming on the heels of the first earth day in the United States, it marked the first time that global leaders gathered to consider environmental preservation and enhancement. Focusing on general pollution and aquatic exploitation, the words

'greenhouse gas' nor 'carbon' appear nowhere in the notes (UNEP 1972). It was not until 20 years later, with the convening of the Earth Summit in Rio de Janeiro that global leaders gathered to speak publicly about carbon emissions for the first time. Because the summit failed to produce binding carbon targets, carbon emissions have been rising steadily ever since; in 1992, global carbon emissions were 21.5 billion metric tons and in 2006, global carbon emissions had grown by more than 35% to 29.2 billion metric tons (EIA 2008a).

Since 1992, the world has pursued various initiatives to usher in a new energy economy. In the 17 years since Rio, interest, acceptance, and market penetration of green energy has steadily climbed; unfortunately, it has failed to keep up with overall energy demand and with electricity consumption projected to double by 2030, the world is increasingly leaning on traditional carbon-based fuels. While green energy's transition from fringe to mainstream is happening, the imbalance of knowledge, skills, and wealth to deal with climate change possesses significant challenges, leading to a geographic imbalance in green energy installations and adoption. Despite a world that is still beholden to fossil fuels, a collective mix of market forces, international treaties, and national policies, a scaling up of green energy technologies is under way in many parts of the world.

The Dominant Role of Fossil Fuel in Energy

There are many sources of greenhouse gases, which when released into the atmosphere contribute to climate change, but it remains carbon emissions from the

burning of fossil fuels (coal, natural gas, and petroleum) that dominate the climate change debate. Coal is primarily used in the production of electricity; petroleum is primarily used as a transportation fuel; with natural gas serving both in electricity generation and for transportation, as well as in several other capacities.

Using fossil fuels as our primary energy source has resulted in rising living standards, but also rising levels of carbon in the atmosphere. The spatial unevenness in energy use, and thus carbon emissions, reveals an enormous concentration of energy consumption by a handful of countries. Historically, advanced economies have consumed more carbon-based fuels and are thus responsible for the vast amount of carbon that has accumulated in the atmosphere. With the recent brisk economic expansion in India and China, the leading carbon emitters in the 21st century is a mix of developed and developing countries (Table 2). Concentration levels for carbon emissions in 2006, reveal how the top five countries account for 73% of carbon emissions from coal, 44% from petroleum, and 46% from natural gas emissions.

Table 2: Carbon Emissions for top five global emitters by energy source in 2006

	Total		Coal		Petroleum		Nat Gas
China	6,017.7	China	4,947.0	US	2,581.2	US	1,163.1
US	5,902.7	US	2,134.1	China	960.2	Russia	888.6
Russia	1,704.4	India	883.5	Japan	626.2	Iran	215.1
India	1,293.2	Japan	430.0	Russia	389.2	Japan	190.6
Japan	1,246.8	Russia	426.6	Germany	352.2	Germany	184.7
Top 5 Total	16,164.7		8,821.1		4,909.0		2,642.1
World Total	29,195.4		12,064.6		11,218.9		5,715.8

Totals in million metric tons

Totals do not match due to rounding.

The near-term solution boils down to curbing carbon emissions by the world's heaviest emitters, while the longer-term solution must focus on ways to persuade less-

developed states that their energy needs can be met using non carbon-based technologies. As a result, making substantial cuts in emissions should be feasible because the top 20 global emitters accounted for 80% of the world's emissions in 2006; and if the developed world can meet their energy demands with environmentally-benign energy sources, they will be able to scale up production in a manner that should drive down costs and allow the rest of the world to develop on non-fossil energy. History suggests however, that measurable emissions reductions are not easily achieved.

Since the Rio World Summit, members of the international community have made several attempts to forge a treaty that would promote broad-based carbon reduction efforts. The most recent international climate change meeting took place in Kyoto, Japan in 1997. Broadly speaking, Kyoto established an average 5.2% carbon emission reductions target from 1990 levels by 2012, taking aim at the industrialized economies of the world,. While exempting major emitters in the developing world, the Kyoto Protocol has been a critical roadmap for the early phases of global de-carbonization¹.

With Australia ratifying the treaty in 2008, the United States remains the only uncommitted Annex 1 country². And yet, ratification itself does not ensure that commitments will be upheld; despite widespread agreement to the emissions reduction goals, only a handful of Annex 1 countries have been able to meet their targets. After excluding former Soviet Republics and eastern European countries, which pose serious data challenges given that their 1990 emissions levels were wrapped up in the former

¹ Carbon Dioxide is one of six greenhouse gases listed in the protocol. The other five include: Methane, Nitrous Oxide, Hydro-fluorocarbons, Per-fluorocarbons, Sulphur-hexafluoride (UNFCC 2008)

² Annex 1 refers to the 41 parties (40 industrialized countries and the EU) with binding carbon reduction commitments.

Soviet Union, Table 3 focused on those countries where a clean comparison between 1990 emissions levels can be made against more recent emissions data. By 2004 only a handful of countries had reduced their emissions, and only three (Iceland, Germany and the UK) are set to meet their obligations (UNFCCC 2007).

Table 3: Emissions levels from major Kyoto Protocol annex 1 parties

Party	Total CO2 emissions (millions tons)		Change (%) 1990-2004	Kyoto Target (%)
	1990	2004		
Australia	423.1	529.2	25.1	+8
Austria	78.9	91.3	15.7	-8
Belgium	145.8	147.9	1.4	-8
Canada	598.9	758.1	26.6	-6
Denmark	70.4	69.6	-1.1	-8
Finland	71.1	81.4	14.5	-8
France	567.1	562.6	-0.8	-8
Germany	1226.3	1015.3	-17.2	-8
Greece	108.7	137.6	26.6	-8
Iceland	3.28	3.11	-5.0	+10
Ireland	55.6	68.5	23.1	-8
Italy	519.6	582.5	12.1	-8
Japan	1272.1	1355.2	6.5	-6
Liechtenstein	0.229	0.271	18.5	-8
Luxembourg	12.7	12.7	0.3	-8
Monaco	0.108	0.104	-3.1	-8
Netherlands	213	218.1	2.4	-8
New Zealand	61.9	75.1	21.3	0
Norway	49.8	54.9	10.3	+1
Portugal	60	84.5	41	-8
Spain	287.2	427.9	49	-8
Sweden	72.4	69.9	-3.5	-8
Switzerland	52.8	53	0.4	-8
Turkey	170.2	293.8	72.6	no target yet
United Kingdom	776.1	665.3	-14.3	-8
United States	6,103.3	7,067.6	15.8	-7

Source: UNFCCC 2007

Perhaps most surprising is that of the 25 countries, more than half (14) experienced double-digit increases in their emissions. Ignoring for a moment that many

of these countries may have experienced emissions per/capita decreases or GDP intensity improvements, the fact that so many countries were either unable or unwilling to address their emissions reveals the inherent weakness of international agreements. Without real carrots and sticks, too many of the countries face domestic economic and political pressures preventing them from diverting funds for emissions reductions schemes. Additionally, international competitiveness issues abound, as honoring Kyoto targets are sure to curtail short-term economic performance, as transitioning away from legacy energy sources will incur financial costs. In fact, the primary objection leveled by the United States for refusing to ratify the Kyoto protocol was its desire to avoid a self-imposed economic handicap, while no emissions limits were to be placed on some of the fastest growing, yet least-developed economies in the world.

And while China is the world's leading emitter and set to remain that way far into the future, on a per capita basis China's carbon footprint is a fraction of what is found in the industrialized countries (Table 4). Other countries, including heavily populated ones like India, Mexico, and Brazil have even lower per capita emissions rates than China; yet all are increasing electricity consumption and their reliance on carbon based fuels for a majority of that energy (see next section of electricity emissions factors).

Table 4: Per capita emissions for select countries in 2006

Country	Population*	Emissions^	per/capita
Australia	20	417	20.6
United States	298	5,903	19.8
Canada	33	614	18.8
Saudi Arabia	27	424	15.7
Russia	142	1,704	12.0
Korea, South	49	515	10.5
Germany	82	858	10.4
South Africa	44	444	10.0
Japan	128	1,247	9.8
United Kingdom	61	586	9.7
Spain	40	373	9.2
Italy	58	468	8.0
Poland	39	303	7.9
Iran	65	472	7.3
Ukraine	47	329	7.1
France	63	418	6.6
China	1,314	6,018	4.6
Mexico	107	436	4.1
Brazil	188	377	2.0
India	1,112	1,293	1.2

Source: EIA 2008

*Population in millions

^ Measured in million metric tons of CO₂

Emerging from this picture is the central argument framing emissions-cuts under Kyoto and any future agreement; countries with high emissions per capita levels are industrialized and considered advanced by almost every measure. They have used fossil fuels to achieve high standards of living and contributed the lion's share of global carbon emissions in the process. Rapidly industrializing economies like China, India, and Mexico still emit relatively low levels of carbon per capita and are unwilling to delay

economic development, which has only just begun, in order to wait for green electricity technology to power their progress. Finding equitable solutions to the climate problem will require some way to bridge the historically uneven contributions of carbon in the least economically disruptive fashion.

The targets set forth in Kyoto can be satisfied by reducing carbon emissions in any number of ways, but the conversion to green electricity generation is a critical component to any long-term solution. So although petroleum use accounts for 38% of global carbon emissions in 2006 (EIA 2007), most of the viable green energy options currently available are concentrated in the electricity generation sector. Since petroleum is principally a transportation fuel³, and the green electricity alternatives are intended to initially displace coal and some component of natural gas, it is important to tease out only those carbon emissions generated from electricity production while ignoring those from petroleum.

The EIA (Energy Information Administration) calculates an electricity emissions factor for every country in the world. An electricity emissions factor (EEF) reflects the ratio of carbon emissions to total electricity produced, which is typically measured in kilowatt hours (kWh). Two steps are required in order to calculate the EEF. First, a carbon output rate must be derived and second the output rate must then be applied to the portfolio of electricity generating sources for each country. Marnay et al. (2002) discuss

³ Electric vehicles and plug-in hybrid electric vehicles are important to the energy transition. As more of them are added to our fleets, they will need electricity to recharge their power supplies which will drive up electricity demand (and reduce petroleum demand). But there are complexities in dealing with mobile sources of carbon emissions which is why this study excludes the transportation sector and focuses on stationary emissions sources.

in greater detail the challenges with calculating an EEF, but it boils down to accurately identifying the fuels used to generate electricity

The output rate takes the total kWh of electricity generated from all sources (some combination of coal, natural gas, petroleum, nuclear, hydro, and green) and divides by the carbon intensity ratio, which is a reflection of the total amount of carbon emitted during the electricity generating process. Measuring the carbon intensity ratio for the fossil fuel portion of electricity generation is difficult for two reasons. First, coal remains the dominant fuel for electricity generation, but there are four types of coal, which emit varying levels of carbon when burned. Anthracite coal emits 5,865 lbs of carbon for each ton of coal burned, Bituminous emits 4,931 lbs of carbon, sub-bituminous emits 3,716 lbs of carbon, and lignite coal is the least polluting with only 2,782 lbs of carbon emissions for every ton burned (EIA 2009a). Second, while a standard measure of 120 lbs of carbon emissions for every 1,000 cubic feet of natural gas is widely accepted, it is difficult to tease out exactly how much natural gas is used to generate electricity. According to the EIA (2009a), the United States consumed 23,058 billion cubic feet of natural gas in 2007, but only 7,089 billion cubic feet (30.4%) was used to generate electricity⁴. The United States maintains a careful accounting of fossil fuel use, but determining the carbon emissions from electricity generation is difficult for those countries in the world where the specific sector uses of natural gas are not broken out. Broadly speaking however, countries like France that rely heavily on nuclear generation

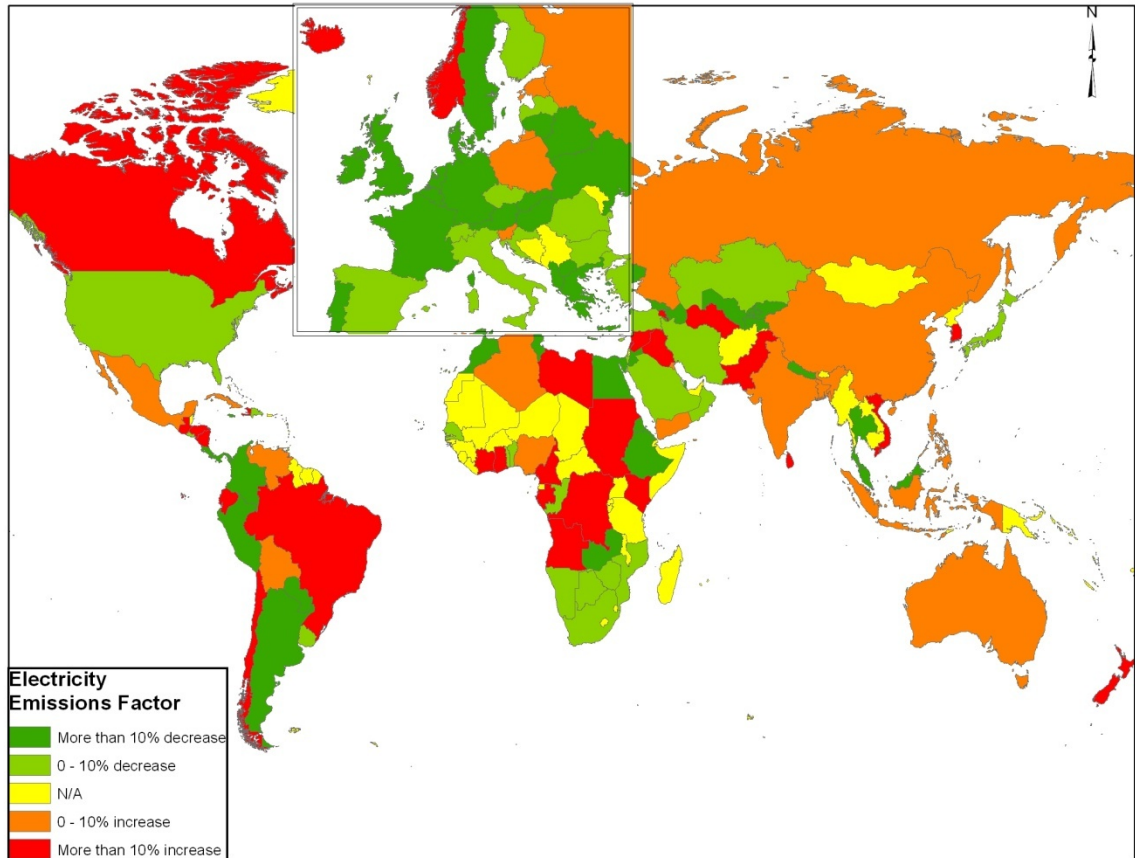
⁴ Other uses for natural gas are found in the residential and commercial sectors (cooking, home heating, water heating), the industrial sector (manufacturing of plastics and chemicals, as well as fertilizer), and transportation (powering some of the automotive and public transit fleets).

and use very little fossil fuel to generate electricity have extremely low EEF, while countries like Australia have a much higher EEF due to their reliance on coal.

Two issues are most likely to move the EEF. First, as the portfolio mix of electricity generation transitions to more renewable energy, the result will be a reduction in the emissions factor. Second, the emissions factor will also fall with improved carbon reduction technologies applied to the plants that produce electricity from fossil fuels.

Figure 1 displays the change in electricity emissions factors for the years between 1991-1994 and 1999-2001, as measured by the EIA (2007). These data were collected through voluntary reports by individual countries, so for many countries, no data exist.

Figure 1: Change in Electricity Emissions Factor, 1993-2000



Source: EIA 2007

Other than the former Soviet Republics, all the countries experienced an increase in overall electricity consumption, albeit at radically different rates; Sweden saw its consumption barely rise, (by only 0.01%) compared with countries like Syria, Benin, Vietnam, and Ivory Coast, where consumption of electricity jumped by over 100% between the two periods. The manner with which that electricity was produced however, suggests that some countries are attempting to minimize their carbon output ratio, by investing in green energy or emissions reduction technology as they add additional electricity generation. Nearly all Europe experienced decreased EEF with Denmark and the UK moving very aggressively to add green energy to their electricity supplies. Japan (-3%), the United States (-1.6%), Singapore, and several countries in Latin America and surprisingly several in the Middle East were also able to reduce their EEF.

On this flip side are those countries emitting more carbon per unit of electricity. These countries like China, India, and Russia, are adding cheap and dirty capacity to their supply, thus resulting in additional carbon output per kWh of electricity. Despite their rising EEF, emissions do not appear to be growing at an accelerating rate; a factor explained by their electricity generation portfolio which has remained essentially unchanged during the study period, which is to say that fossil fuels continue to serve virtually all of their electricity needs.

When looking at the map, some obvious idiosyncrasies appear. Countries like Norway, Brazil and Iceland, all registered increases in EEF, and while their use of fossil fuels did increase, its representation is skewed because for all three countries, hydro power accounts for more than 75% of their electricity (for Norway it is over 98%); as a

result, they are starting from such a low base, that despite rising levels of fossil fuel use, their carbon impact is negligible. Two other surprise countries register substantial EEF increases during the study period, New Zealand and Canada. New Zealand appears to have maximized its hydro potential, producing a relatively unchanged 23 billion kWh per year for the last two decades. In the absence of nuclear energy and without making any meaningful efficiency gains, New Zealand has looked to fossil fuels to meet its growing electricity demands. And in the case of Canada, it appears something happened to its nuclear generation for the second data period used in this analysis. Canada was generating far more electricity in the early 1990s from nuclear, ramping down by 2000, only to see a nuclear resurgence again in 2006. Perhaps some significant maintenance downtime for its nuclear facilities caused Canada to lean on fossil fuels as backup/replacement. Nevertheless, should the study period include EEF from 2005, rather than 1999-2001, it is likely that its EEF would show a reduction, similar to the other industrialized countries.

Research and Development

Global Trends

Transitioning to green energy alternatives has been a slow process. Our ability to bring additional green energy online improves each year, unfortunately it has been outpaced by an accelerating global demand for electricity. While there are many ways to explain green energy's poor penetration track record, one of the most compelling answers

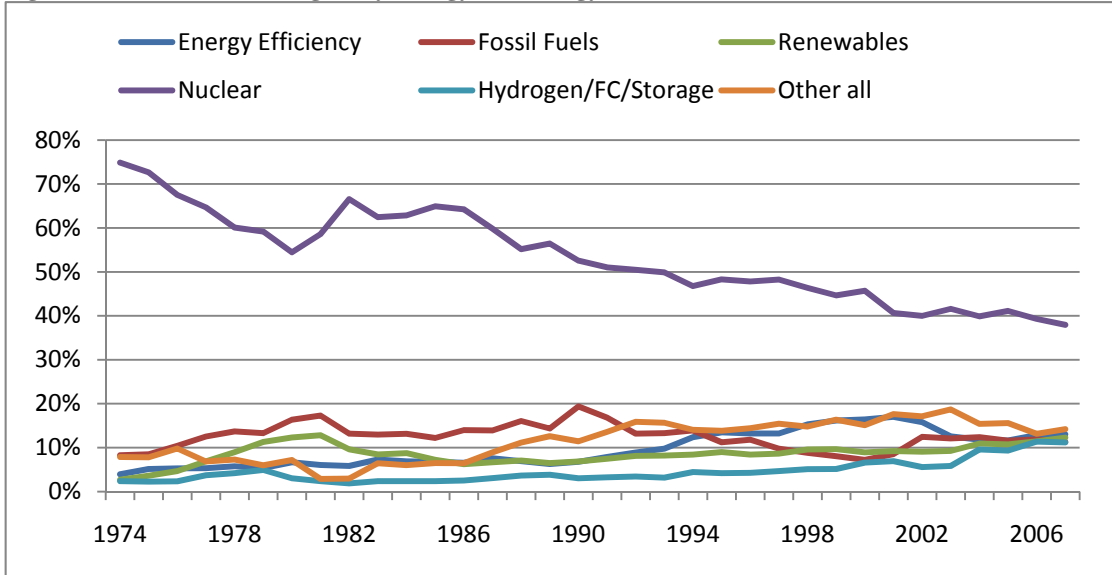
lies in the lack of funding dedicated to renewable energy by both the public and the private sectors.

There is a strong consensus within the literature that the vast majority of investment funding, and therefore R&D decision making, is concentrated in the three cores of North America, Western Europe, and East Asia (Patel and Pavitt 1991; Patel and Pavitt 1997; Rugman 2000). It is no surprise then that nearly all of the green energy activity is also concentrated within the countries of these regions. Given the costs associated with transitioning to a green energy economy, a substantial financial commitment for research, development, and deployment needs to be made. And once these commitments bear fruit, developed states must be more active in donating knowledge, financial resources, and technology to developing states that enable them to leapfrog the dirty energy choices that were made by the industrialized countries.

The sad truth remains a declining commitment to overall energy research initiatives. In 1974, immediately following the OPEC oil embargo, total world commitments to energy R&D were \$11.4 billion and although global investments peaked in 1980 at \$20.1 billion, total R&D commitments have retreated over the last decade and a half, and by 2007 stood at \$12.0 billion, a small fraction higher than where it was in 1974 (Figure 2). The bulk of R&D budgets in the developed world remain dominated by a nuclear agenda; a continued commitment that has left a green energy sector woefully underfunded. According to data gathered by the International Energy Agency, global R&D for nuclear energy related research accounted for 38% of all dollars in 2007. And while nuclear R&D is only half of what it was in the mid-1970s, when it accounted for

75% of all R&D dollars, nuclear still commands more of the R&D resources than the total amount of money committed to green energy (renewables, efficiencies, hydrogen & fuel cells, and power & storage), which collectively in 2007 accounted for 37% of all R&D (IEA 2008).

Figure 2: Global R&D budgets by energy technology 1974-2007



Source: IEA 2008
In 2007 \$

In a world with potential carbon constraints, momentum is building for a nuclear renaissance, and many cite the track record of France, where nuclear power safely supplies 70-80% of the country's electricity. However, what is typically absent from the discussion is that Germany, a larger economy that consumes more electricity, has passed a nuclear phase-out whereby there will be a cessation of nuclear power from the country's nineteen nuclear power plants by 2020 (Nelles 2007). Spain, Sweden, Italy, and Belgium are other countries where phase-outs have passed legislatively, although they are still subject to review, in particular as it relates to their respective green party's

capacity to remain incorporated in the ruling coalition (Greenpeace 2006). But given the size of Germany's economy, it is a more important test-case. In 2006, nuclear power accounted for 27% of Germany's electricity and there is now talk of new coal plants to fill this gap, which would run in stark contrast to the decarbonization efforts underway throughout Germany. Natural gas from Russia remains an option, but the political relationship between Europe and Russia remains tenuous. As a result, the nuclear phase out is adding urgency to conservation and efficiency programs, as well as new green electricity supplies.

According to the International Energy Agency (IEA 2009) in 2006, the last year for which disaggregate data are available for all countries, the energy R&D budgets of the top five countries in the world accounted for more than 80% of the total, with a 60% concentration in just two countries: Japan and the United States. Table 5 shows the drop off to third-place France which accounts for only 10% of the global total, followed by Canada and Germany. Nuclear research is even more concentrated, where Japan accounts for half of the world's total; amounting to 62% of its own budget despite nuclear generation contributing only 28% of its electricity in 2006. France, which generates nearly 80% of all electricity from nuclear, is a distant second followed by the United States. Nuclear R&D is a highly concentrated endeavor, with the top five countries accounting for 88.3% of all commitments. In terms of green energy⁵, the global R&D picture is slightly more encouraging, where the top five countries account for only 70% of the global total, led by the United States and Japan.

⁵ Green R&D combines: Energy efficiency, renewables, hydrogen & fuel cells, and power & storage

Table 5: Countries with the top five commitments to energy research

Total Energy	% World Total	Nuclear	% World Total	Efficiency/Renewable/Hydrogen/FC/Storage	% World Total
Japan	31.7	Japan	50.1	United States	25.5
United States	28.0	France	15.6	Japan	24.6
France	10.3	United States	12.3	Italy	7.8
Canada	5.2	S. Korea	5.5	France	6.4
Germany	4.9	Canada	4.8	S. Korea	5.7
Top 5 Total	80.1%		88.3%		70.0%

Source: IEA 2008

With green energy R&D more dispersed, it is worth noting exactly where these investments are taking place as a percentage of the individual budgets with each country (Table 6). In 2006, with the exception of Norway, every other major country with a meaningful focus on energy research and development is dedicating increasingly larger shares of budgets for projects aimed at efficiency, renewables, and hydrogen/fuel cell/storage technologies. What is more remarkable is that in some of these countries, their total R&D budgets are shrinking, which exaggerates the migration away from funding research into nuclear and fossil fuel projects. In the case of Norway, the only country listed where total R&D increased, but green R&D decreased, they generate more than 98% of their electricity from hydro power; so Norway is less concerned with green technology. Furthermore, given that it remains one of the largest oil exporting countries on a continent with very few oil reserves, it is rational to expect greater R&D commitments in fossil fuels technology, which explains the 150% increase in fossil fuel research over the same 13 year period.

Table 6: Change in total R&D and Green R&D, 1993-2006

	Total R&D			Green R&D		
	1993	2006	Change	1993	2006	Change
France*	761.5	1153.1	51%	26.1	258.1	889%
New Zealand	4.5	15.2	234%	2.0	9.6	385%
Japan	3036.7	3432.6	13%	187.3	908.2	385%
Canada	394.1	604.8	53%	75.3	255.1	239%
Turkey	6.2	8.9	43%	2.7	7.8	188%
Denmark	73.5	136.6	86%	50.7	116.4	130%
Finland*	68.2	140.2	106%	48.0	98.2	105%
Italy	471.9	485.6	3%	147.0	297.3	102%
United States	2939.4	3584.5	22%	635.1	1216.6	92%
Austria*	35.0	59.3	70%	26.0	47.4	82%
Sweden	103.5	119.9	16%	58.5	96.1	64%
Spain	131.6	96.7	-27%	43.6	61.0	40%
United Kingdom	281.4	232.5	-17%	100.9	117.5	16%
Germany	572.2	588.3	3%	200.5	210.3	5%
Netherlands*	291.6	185.6	-36%	185.3	139.2	-25%
Norway	108.5	138.3	27%	48.8	36.4	-25%
Switzerland	204.7	147.5	-28%	112.4	83.7	-25%
Portugal	7.1	2.7	-62%	4.1	1.2	-71%
Est. IEA Total ^	9840	12048	22%	2080	4402	112%

\$ in constant 2006

^Totals due not match due to the IEA estimates for countries not reporting

*2005 figures, as 2006 figures unavailable

In looking at the United States and Japan, far and away the two leading energy R&D countries in the world, several important trends emerge (Figure 3 & 4). First, both countries have substantially increased funding over the 13 year period, with the United States up 92% and Japan up close to 400%. Second, the technology choices each has shown the most interest in since the Rio Earth Summit are quite similar. With the exception of solar R&D, which is moving in opposite directions⁶, the investment choices and percentage increases are on similar tracks. Hydrogen and fuel cells have become very high priorities, but storage is getting very little attention, while biofuels and

⁶ There is ample evidence to suggest that the private sector, as marked by venture capital investments, has picked up the slack for the drop off in solar R&D in the United States (Tierney 2010).

transmission & distribution are also areas of major funding in Japan and the United States. Surprisingly, geothermal energy, has seen its share of funding drop in both countries, while wind power is not a priority in Japan, but remains an important component of the US electricity mix, and thus R&D portfolio.

Figure 3: United States Green R&D

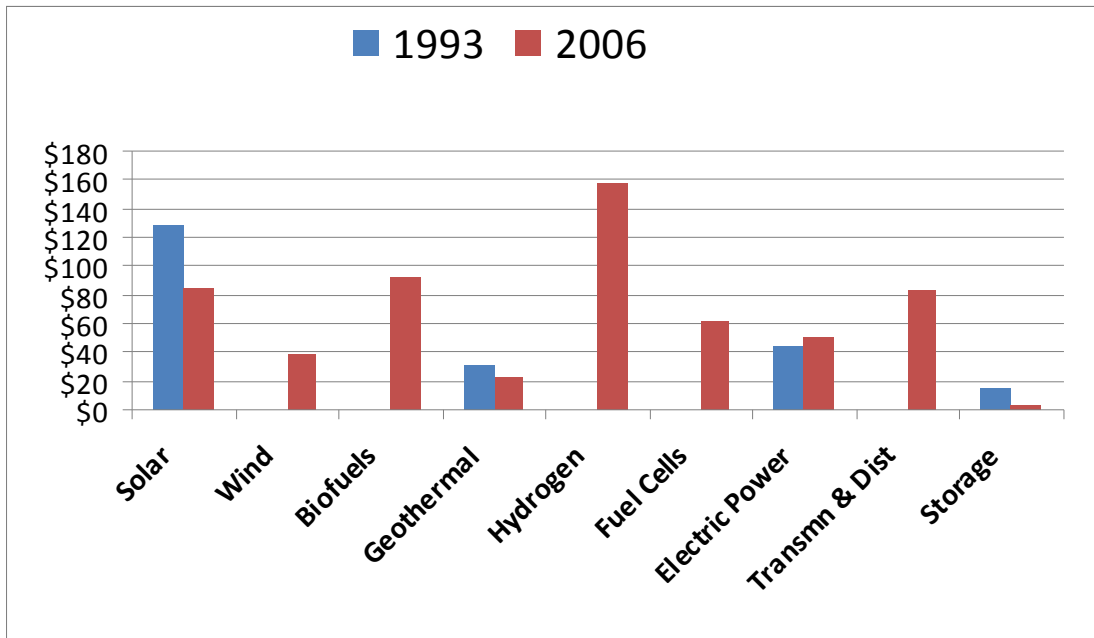
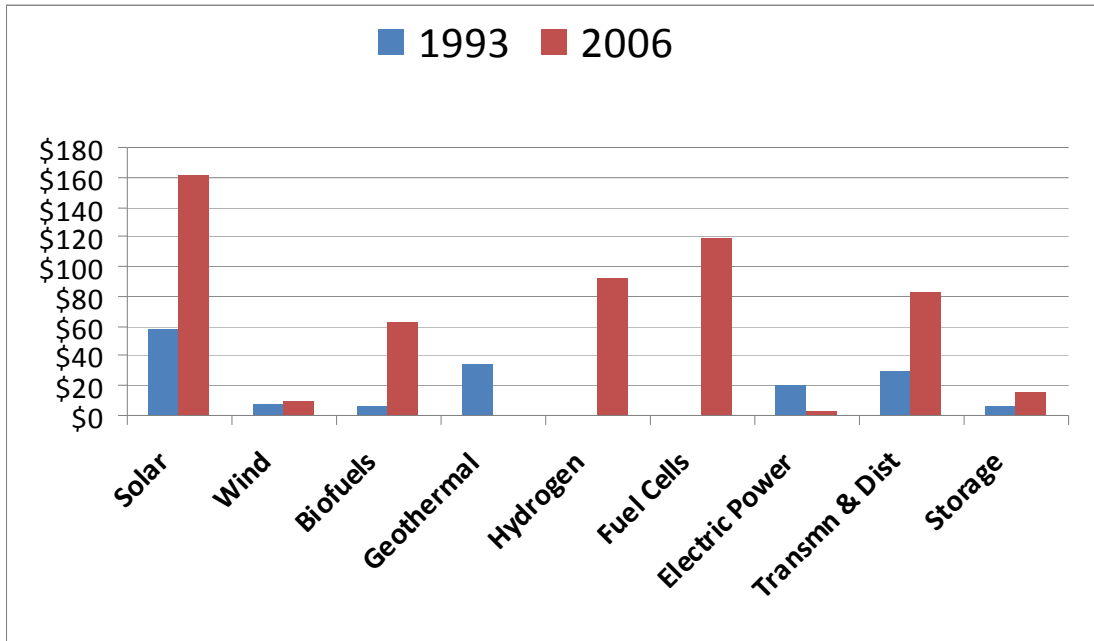


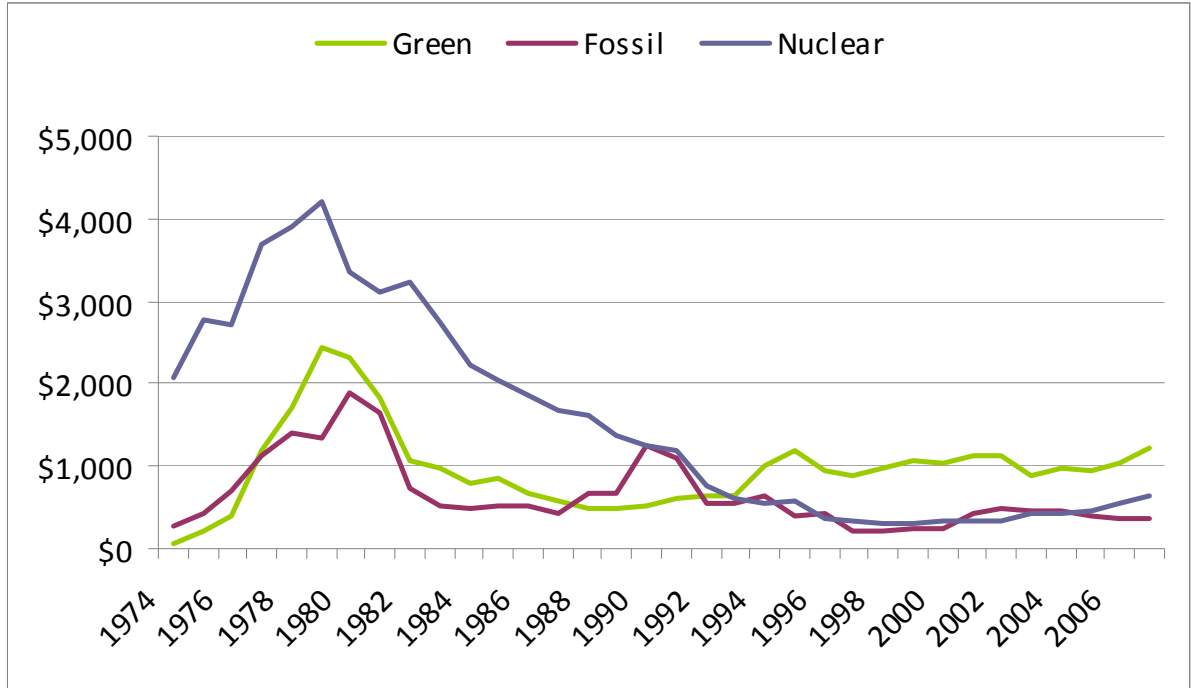
Figure 4: Japan Green R&D



The United States

Looking specifically to the United States, while the R&D picture in energy technology is encouraging, it remains weighed down in a political system that has systematically devalued investments in energy for years. Following the Yom Kippur war in 1973, and the ensuing OPEC oil embargo, energy R&D was elevated on national security grounds. Increased funding was allocated to all three major energy categories; nuclear, fossil, and green. But as Figure 5 displays, funding has steadily retreated since the mid 1980s and although there has been a slight uptick in the last few years, funding by the federal government for energy R&D is at the same level in 2007 as it was in 1986. The ‘green’ category has been capturing a plurality of funds for over a decade, but green refers to hodgepodge of technology that is far more mixed than fossil fuels.

Figure 5: DOE Budget Authority for green, fossil, and nuclear R&D, 1974-2008



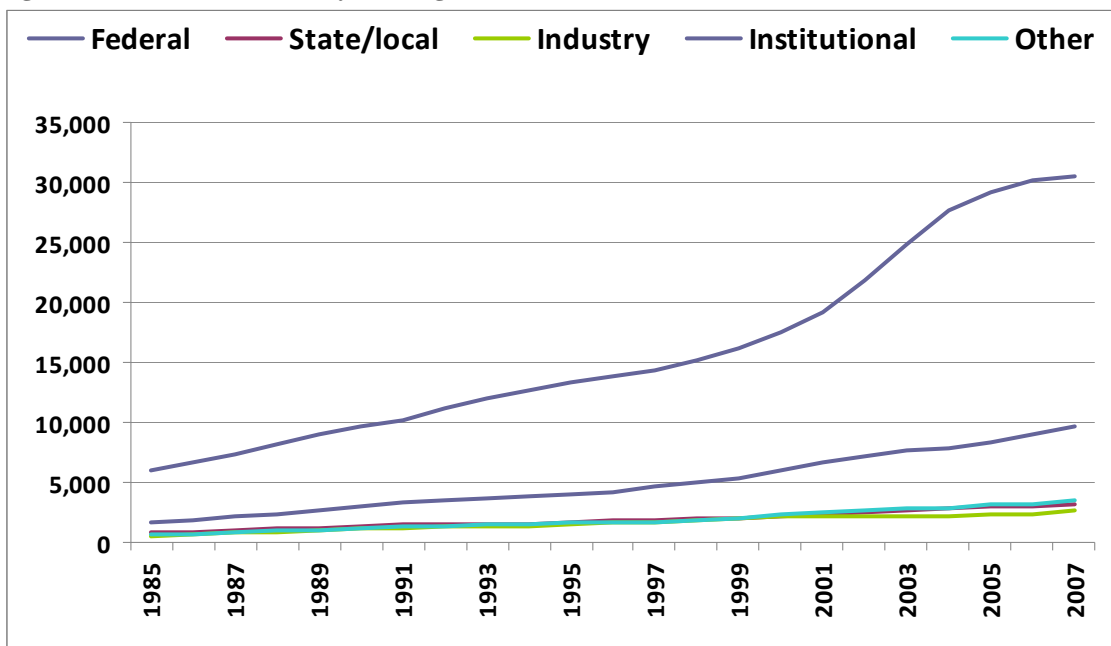
2007 \$millions
Source: IEA 2008

Unlike many other countries, the United States has divorced itself from nuclear R&D. But it isn't just the government, the private sector has also shunned nuclear power mostly because the cost for building nuclear power plants had risen so dramatically thanks in part to the global financial crisis, but also due to the aging nuclear labor pool and materials input scarcity. When compared with green energy alternatives it is clear where the risk/reward profile is steering private capital; in 2007, renewables attracted \$71 billion in private capital whereas the global private markets invested nothing in nuclear energy (Grunwald 2009). And given what the Rocky Mountain Institute describes about the capital market's view on nuclear, it would seem that if there is a future for new nuclear power, it is years away.

...the private capital market isn't investing in new nuclear plants, and without financing, capitalist utilities aren't buying. The few purchases, nearly all in Asia, are all made by central planners with a draw on the public purse. In the United States, even with new 2005 government subsidies approaching or exceeding new nuclear plants' total cost failed to entice Wall Street to put a penny of its own capital at risk during what were, until autumn 2008, the most buoyant markets and the most nuclear-favorable political and energy-price conditions in history—conditions that have largely reversed since then. (Lovins et al. 2009).

One of the areas where the Federal Government has remained a powerful and growing force is on University campuses. According to national pattern of R&D resources reported by the National Science Foundation (2009), the federal government continues to supply the lion's share of the R&D money to colleges and universities, hovering around 60% of total funding every year since 1985 when the statistics were first broken out (Figure 6).

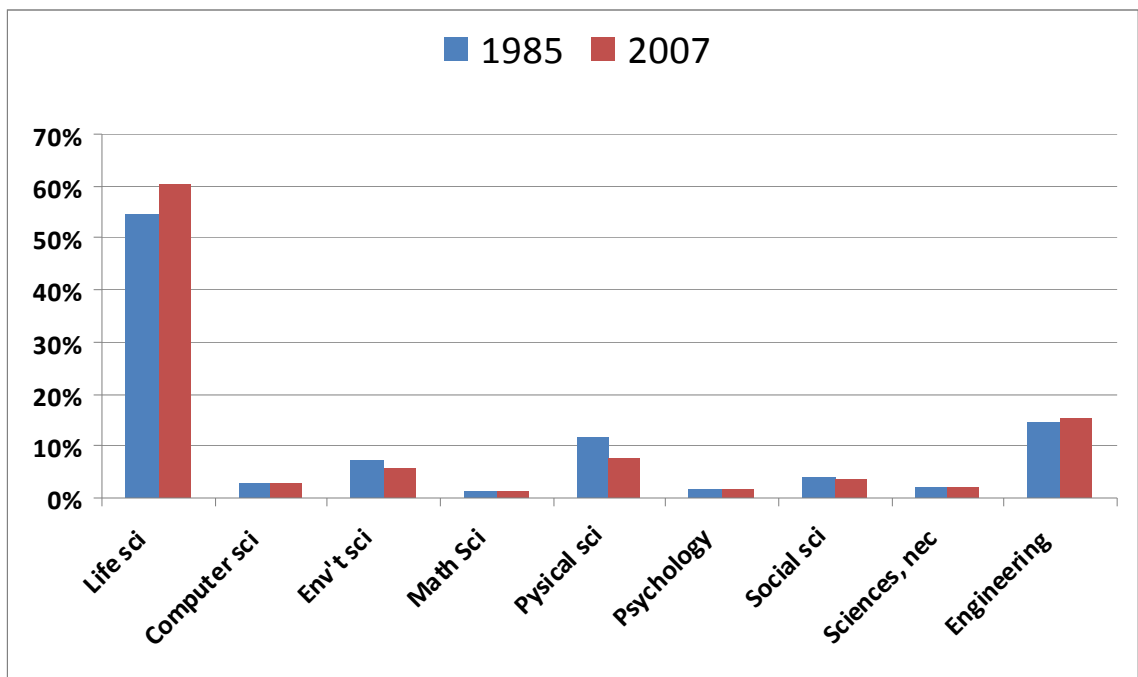
Figure 6: Sources of University funding, 1985-2007



\$ in thousands
Source: NSF 2009

Unfortunately for those in the energy sector, the R&D money going into the sciences overwhelmingly supports funding in the life sciences, while the other disciplines linger (Figure 7). Between 1985 and 2007, life sciences have consistently obtained between 55-60% of all federal R&D money. Meanwhile, funding for R&D in engineering, arguably the field where the skills are honed to most effectively produce the next generation of energy technology has barely ticked up in the last two decades.

Figure 7: Federal Government R&D expenditures at Universities 1985 vs. 2007



Source: NSF 2009

The Department of Health and Human Services is the federal agency that receives the largest share of federal dollars, it should be no surprise the life sciences remain the area within universities that are the most financially lubricated (Figure 8). Consequently, it is important that the DOE funds those parts of the academy that are likely to support its

mission: energy. The DOE continues funneling a majority of its financial R&D resources into engineering; meanwhile, the NSF, which has less of a specific industry or curriculum mandate, appears to be supplementing support for those areas that are likely to yield energy technology breakthroughs, steering a sizable portion of its financial resources toward engineering, physical sciences, and environmental sciences (Figure 9). In the end, it would seem that for the federal government to play a more meaningful role in R&D at the University level though, money is going to have to be redirected from life sciences to energy science – a policy choice that might seem untenable unless public opinion on climate change shifts meaningfully.

Figure 8: Federal Funding for R&D by Agency in 2006

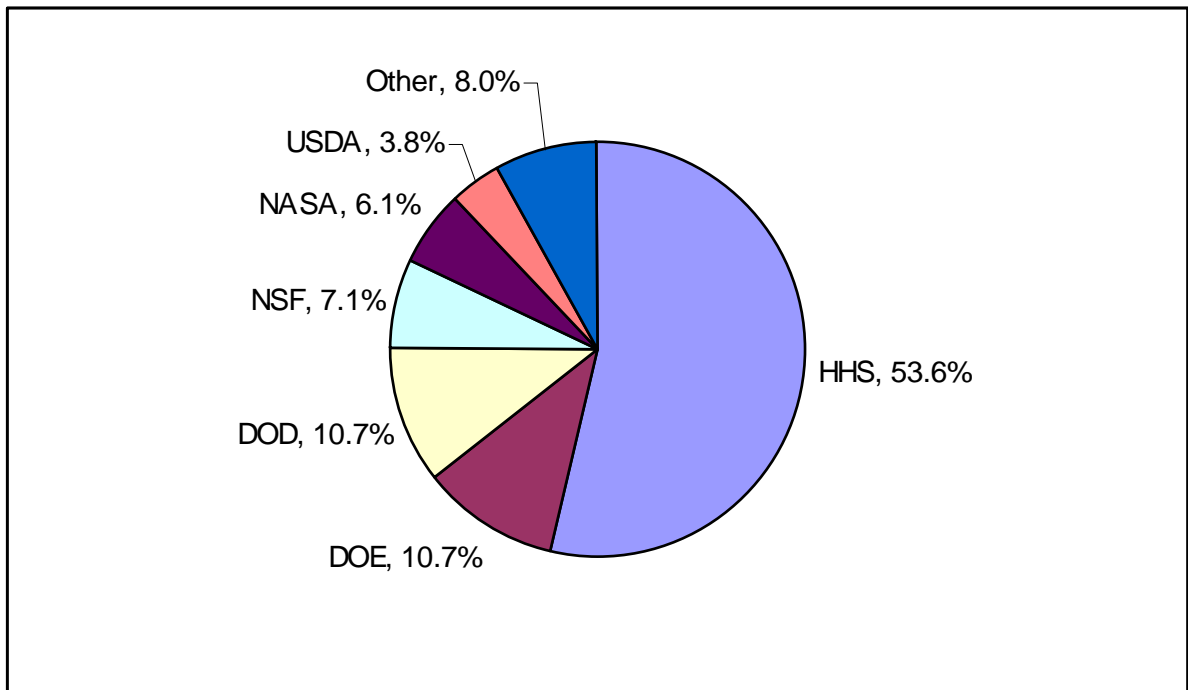
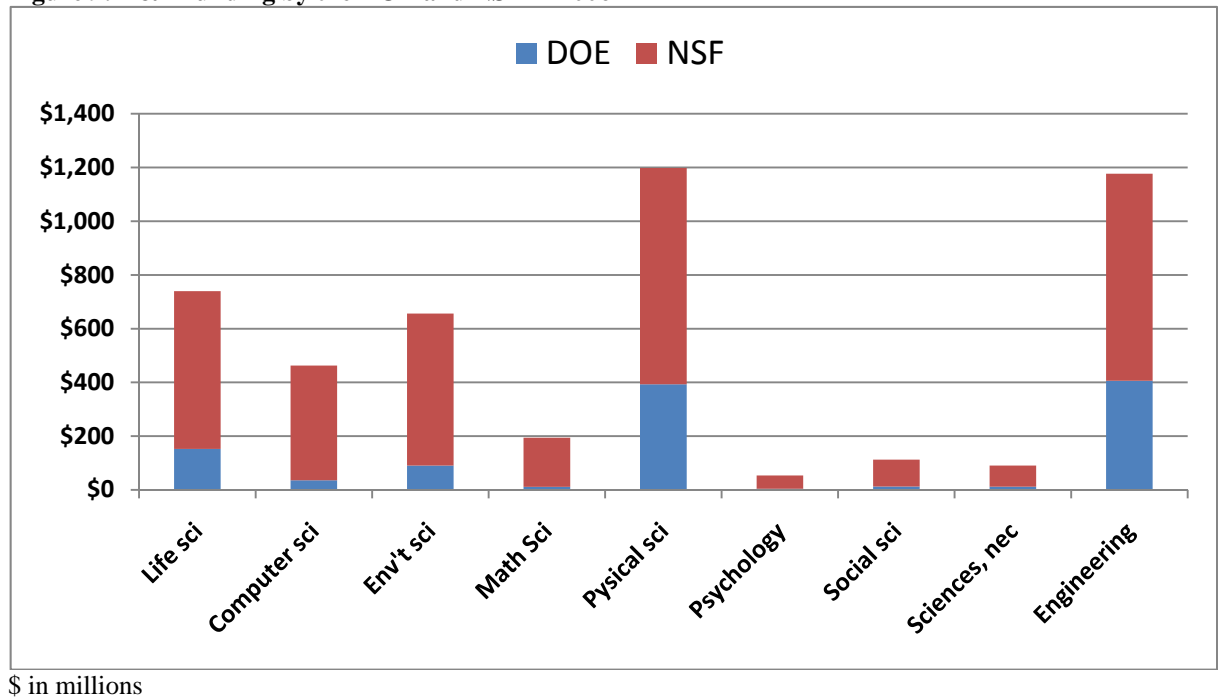


Figure 9: R&D funding by the DOE and NSF in 2006



At the core of the government's role in innovation remains a commitment to basic research, and the benefits to society have been immeasurable. Embracing this responsibility enhances the likelihood that future technological breakthroughs will yield similar social gains that match past breakthroughs where the government has been the dominant player, including Apollo, the Manhattan Project, and the Strategic Defense initiative (aka, Reagan Defense Initiative) to name a few (Kammen and Nemet 2005).

And while R&D is critical, the government's role extends beyond funding basic research:

Over the past five decades it (R&D) has led to the development of the Internet, lasers, global positioning satellites, magnetic resonance imaging, DNA sequencing, and hundreds of other technologies. Even when government was not the inventor, it was often the facilitator. One example: semiconductors. As a study by the Breakthrough Institute notes, after the microchip was invented in 1958 by an engineer at Texas Instruments, "the federal government bought virtually every microchip firms could produce." This was particularly true of the Air Force, which needed chips to guide the new Minuteman II missiles, and NASA, which required advanced chips for the on-board guidance computers on its Saturn

rockets. "NASA bought so many [microchips] that manufacturers were able to achieve huge improvements in the production process—so much so, in fact, that the price of the Apollo microchip fell from \$1,000 per unit to between \$20 and \$30 per unit in the span of a couple years." (Zakaria 2009)

Globally speaking, the world has recently become interested in funding green energy technologies once again, but the precedent is poor as historical surges in spending have faded over time. For the world to make the transition away from fossil fuels, a sustained government R&D commitment is paramount, because the scale of the endeavor is too broad for the private sector. Private corporations are active in R&D, but are constrained by liquidity and shareholder pressure. Few private companies have the liquidity to sustain meaningful long-term R&D commitments, especially expensive techno-paradigm shifting technologies with exorbitant capital costs, and because private firms are measured on a quarterly basis (by shareholders), only those firms with the deepest pockets would be able to withstand the short- and medium-term financial losses hoping for a long-term payoff. With the private sector void, Dooley and Runci (2000) envision a role for OECD countries to adopt a long-term strategy to develop the next generation of green power, which was critical in the moon landing as well as the emergence of nuclear energy.

Time will tell if the threat of climate change is pervasive and deep-rooted enough to withstand a collapse in energy prices similar to the one that ultimately served to undermine Project Independence in the early 1980s when the OPEC oil embargo was lifted. One thing appears for certain, if global innovation for new energy technology is

going to come from the governments, it is going to come from a handful of countries in the developed world.

Patents

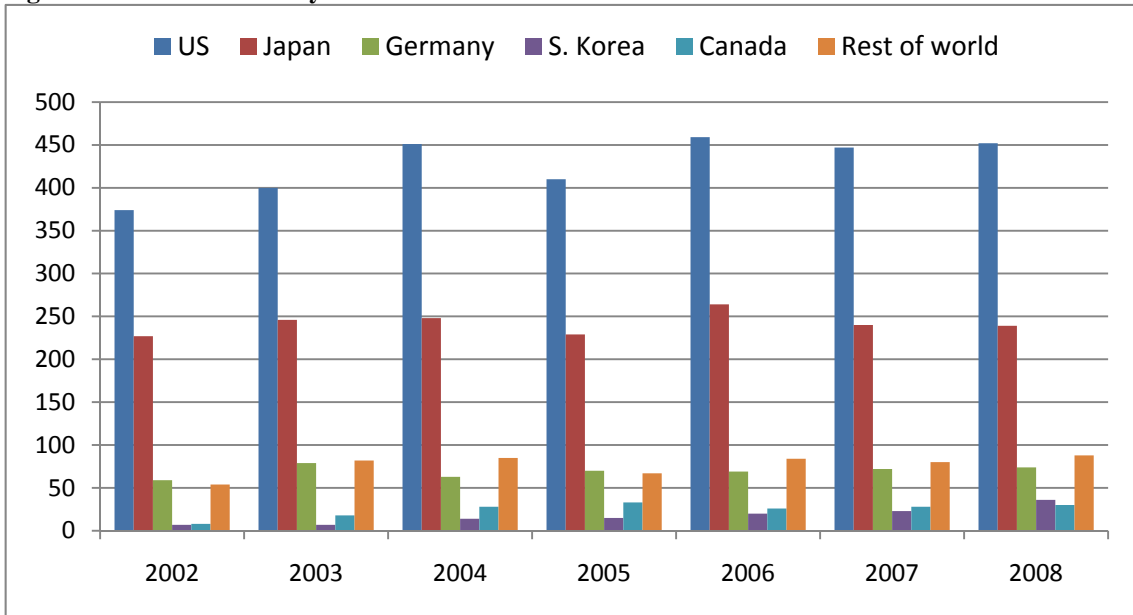
Patent data have been used as one component to help understand the dynamics of economic growth (Griliches 1990). Existing patent information can tell us what research fields are attracting the most attention, but more importantly patent approval is a leading indicator because most patents, particularly those in nascent fields are designed to protect ideas that are still early in the development process. Understanding the geography of patent activity can help us locate concentrations of activity for particular technologies and thereby hone in on the potential future economic landscape for those industries.

Patents offer useful information as to where entrepreneurial efforts are focused within a specific field. The literature is rich with patent related research explaining the dynamics of economic growth over time; Sokoloff (1988) looking at the Northeast a century ago, Ullman (1958) investigating the mid-1900s in California and the Midwest, while many have looked at national data over the last 40 years (O’Uallachain and Leslie 2005; Johnson and Brown 2004; Co 2002). Broadly speaking, regional or state patent strength is attributable to vibrant university systems, R&D commitments by private industry, quality infrastructure, and recreational access (leisure) for a creative population. A consensus emerges from most of the prior research that patent activity is an important component of regional economic growth while those regions lacking such innovation will lag economically.

A broad examination of the global patent market reveals that home companies dominate the patent landscapes within their home countries, such as German and Japanese companies dominating patent activity in Germany and Japan (OECD 2009). But it is the United States that is the most dynamic patent market; in 2007, more than 80,000 patents were registered with the US Trademark and Patent Office, which is more than the rest of the world combined (Porter 2008). Honing in on the trajectory of patents filed in the US with respect to green energy, some interesting and unexpected trends emerge.

Green energy patent registrations with the US patent office reveal a global consolidation of innovation among a few developed countries (Figure 10). Japan, the EU, and the United States are the dominant players in the overall patent market, securing 90% of total patents in 2005 (OECD 2009). It is no surprise that the United States leads the way with patents issued by the US patent office, securing roughly 50% of all the patents issued in each of the last six years. Japan has seen its share of the patent market decline over the years from 31% in 2002 to 26% in 2008, but Japan is still the second most prolific country as measured by patents. Outside of Japan, Western Europe and North America, only three other countries, Korea, Taiwan, and Israel, have secured patents in the United States

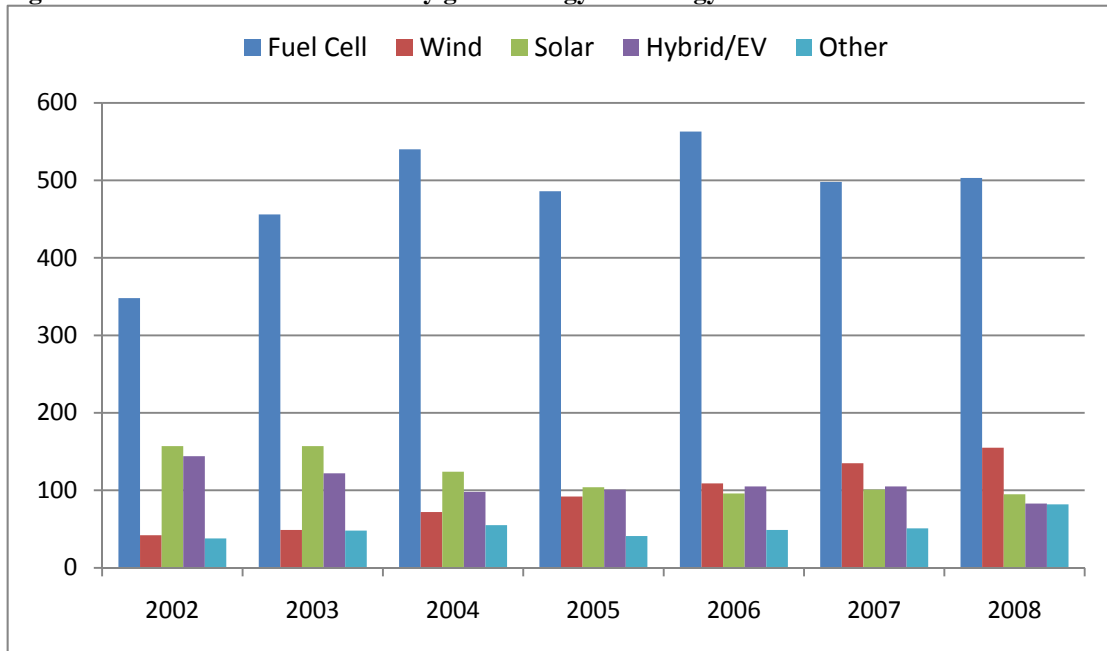
Figure 10: Patents issued by the US Trademark and Patent Office



Source: Heslin Rothenberg Farley & Mesiti P.C. 2009

When looking at the specific technologies, it becomes clear why the US and Japan, and to a lesser degree, Germany and South Korea, exceed the patent activity of all other countries. Fuel cell technology is commanding the most interest among the major green energy technologies and these four countries, led by the US and Japan remain the dominate players in the auto industry (Figure 11). Although fuel cell research focuses on other aspects of renewable energy, like batteries and chemical processes, the links to automobiles remain the central connection. Since 2002, the number of patents issued for fuel cell technology has climbed from 348 to 503. Although hybrid and electric vehicles have seen a decrease in total patent activity, the combined automotive categories dominate patent activity and explain why Honda, General Motors, Toyota, Nissan, and Ford are among the top ten in total patents during the period.

Figure 11: Patents issued in the US by green energy technology



Source: Heslin Rothenberg Farley & Mesiti P.C. 2009

The number of patents for wind technologies has jumped nearly four-fold in the 6 years led by General Electric (United States) and Enercon (Germany). Meanwhile, the number of solar patents issued is moving in the opposite direction, falling by nearly 40% over the same period of time. The divergent trend for wind and solar is counter intuitive. Although both are considered rapidly evolving second generation technologies, according to the IEA (2006), wind is a more mature technology where many of the breakthroughs have already been captured and incorporated by wind companies. On the other hand, the dominant technology for solar is still very much in question; with patent activity supposedly reflecting potential breakthroughs, patents for solar technology should be rising. Instead solar patents in the United States are falling, despite the overwhelming emphasis by incubator investments as measured by venture capital flows (Tierney 2010).

A better explanation stipulates that the more established markets of Europe and Asia have a first-mover advantage in solar, thus securing all the technological breakthroughs and therefore, more robust solar patent markets are found outside the US.

Fuel cell technology is currently geared toward solving our transportation problems, so while it does provide optimism for Michigan's struggling economy, it has little influence on the short-term nature of electricity consumption. An uncommitted patent market with low level federal support of basic research, has yielded few truly transformational green energy breakthroughs. And yet, an unmistakable truth remains; combining the growing electricity appetite of the world with the finite supply of fossil fuel, a transition to new sources of energy will have to take place. The important question now will be the duration of the fossil fuel sunset, and the answer will pivot on the rise of alternative energy options.

The energy transition and the case for green electricity

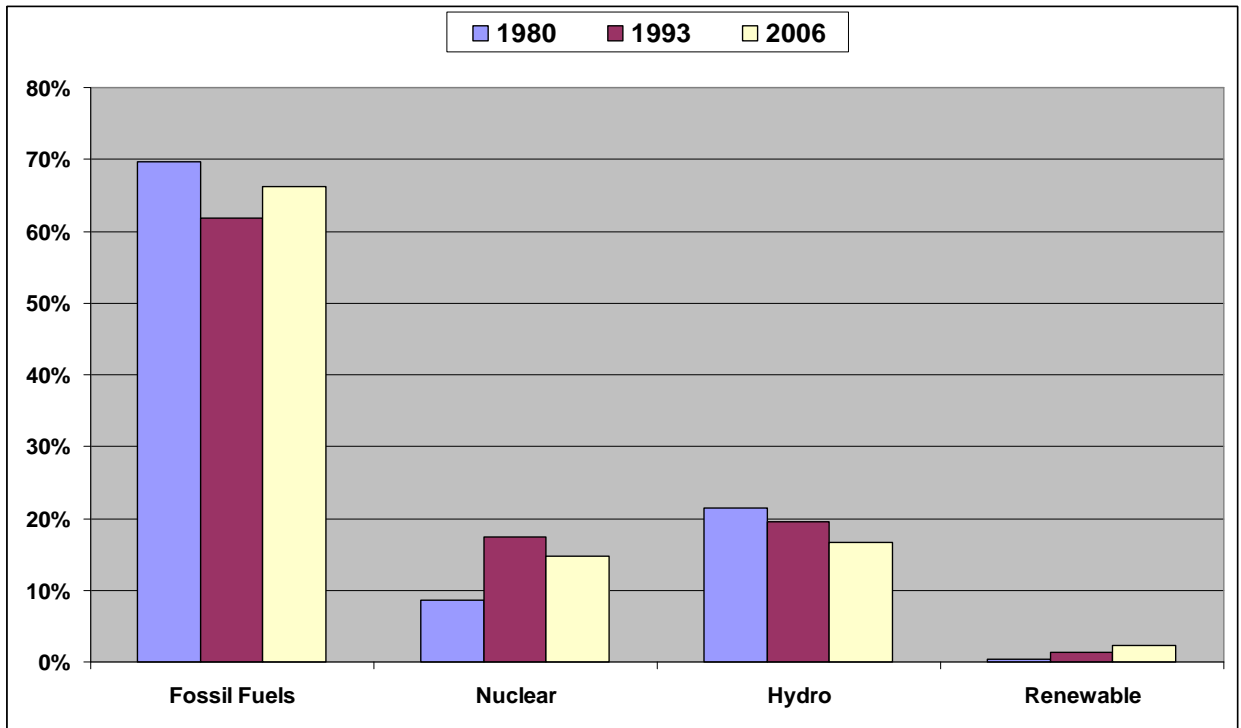
Freeman and Perez (1988) broadly identify four types of technological change, each having a progressively greater impact on society than the last: incremental innovations (modifications to existing products), radical innovations (disruptive event for particular technology), changes of technology systems (emergence of new economic sector), and changes in techno-economic paradigms (alters modes of production for the entire economy). Within economic geography, it is this fourth stage, the techno-economic paradigm, which is also known as the fourth Kondratiev wave. Much has been written about Kondratiev waves (Freeman et al 1982; Hall and Preston 1988), which

identifies 50-year economic cycles of prosperity, recession, and recovery; but generally speaking it explains how an old paradigm is deposed by a new era of economic organization.

Most waves end with a highly disruptive economic event; time will tell if the global recession of 2008/2009 has brought an end to the fifth Kondratiev wave marked by information and communication technology. If it were to be the end, its duration would be more than a decade shorter than prior kondratiev waves. While the previous waves brought about new industries and ways of doing business, most were accompanied by some breakthrough source of energy serving to grease the economic wheels of general business innovation. The first wave was powered by the steam engine, the second wave was enabled with major advancements in coal, the third wave with distributed electricity, and the fourth wave with petroleum based technologies. While the fifth wave (information and communication technologies) emerged in the absence of a revolutionary energy source, it would seem the foundation for the sixth wave will be energy technology.

The global electricity portfolio remains heavily reliant on fossil fuels. Since 1980, global electricity generated from fossil fuels has remained consistent between 60-70%, nuclear and hydro have settled in on about 15% each, with renewables providing 2.3% of the total in 2006, up from less than half of one percent in 1980 (Figure 12).

Figure 12: Portfolio of global electricity supplies; 1980, 1993 & 2006

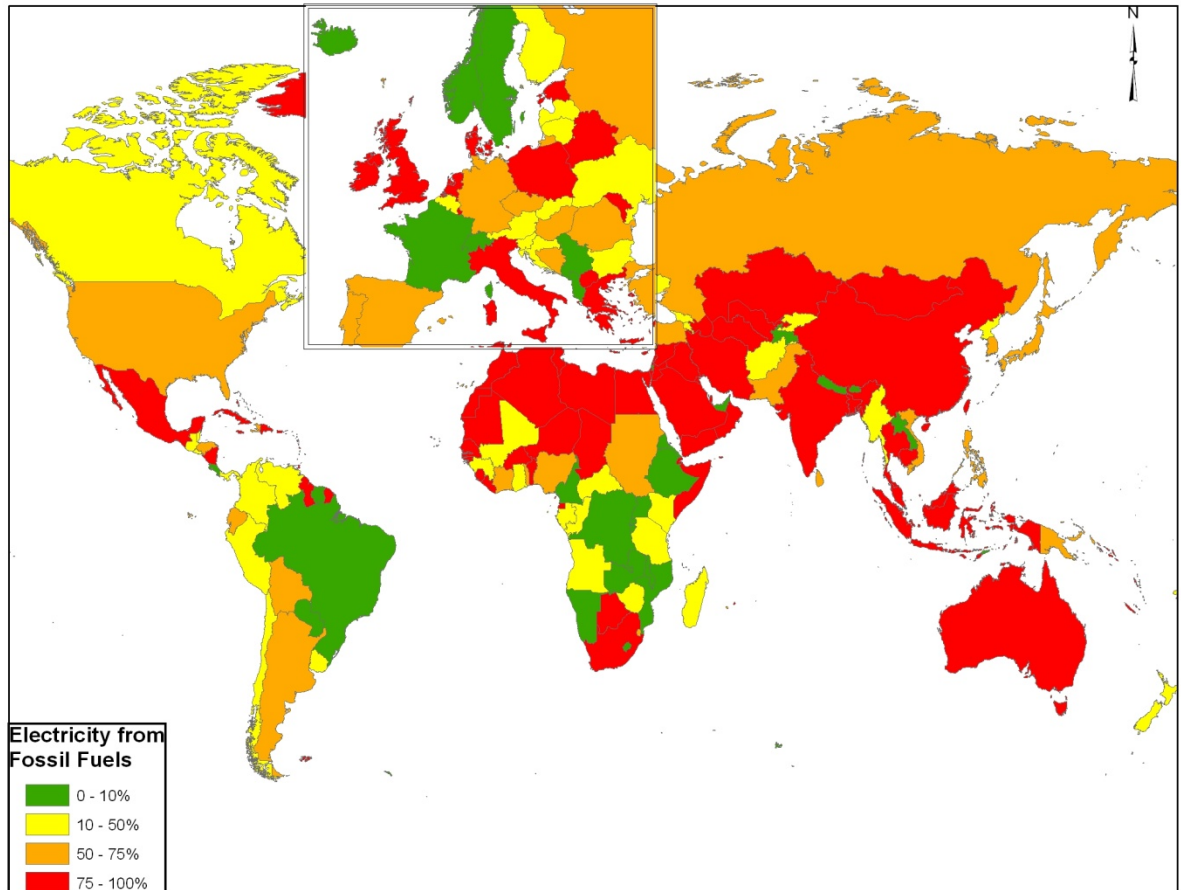


Source: EIA 2008

While nuclear and hydro both contain certain unsustainable elements, fossil fuels pose the most immediate carbon and climate risk and therefore the fuel source that most urgently needs to be replaced. Moving away from fossil fuel electricity generation however will impose a variety of short-term financial costs, which will ultimately serve to impede adoption rates. Despite the finite nature of fossil fuels as well as the climate change threats, bringing additional renewables into the electricity generation portfolio remains challenging for the following reasons; fossil fuels are established and reliable, failure to incorporate externalities into the cost makes fossil fuels inexpensive, albeit mispriced; existing infrastructure to generate and transmit electricity from traditional

fossil fuel sources, and fossil fuel's baseload power⁷ security. Figure 13 identifies the geography of fossil fuel electricity generation as a percentage of overall generation as reported by the EIA (2008).

Figure 13: Fossil fuels as a percentage of overall electricity generation



Source: EIA 2008

The average U.S. household now has 26 plug-in devices (Grunwald 2009). With the rest of the world eager to enjoy a similar living standard, global electricity

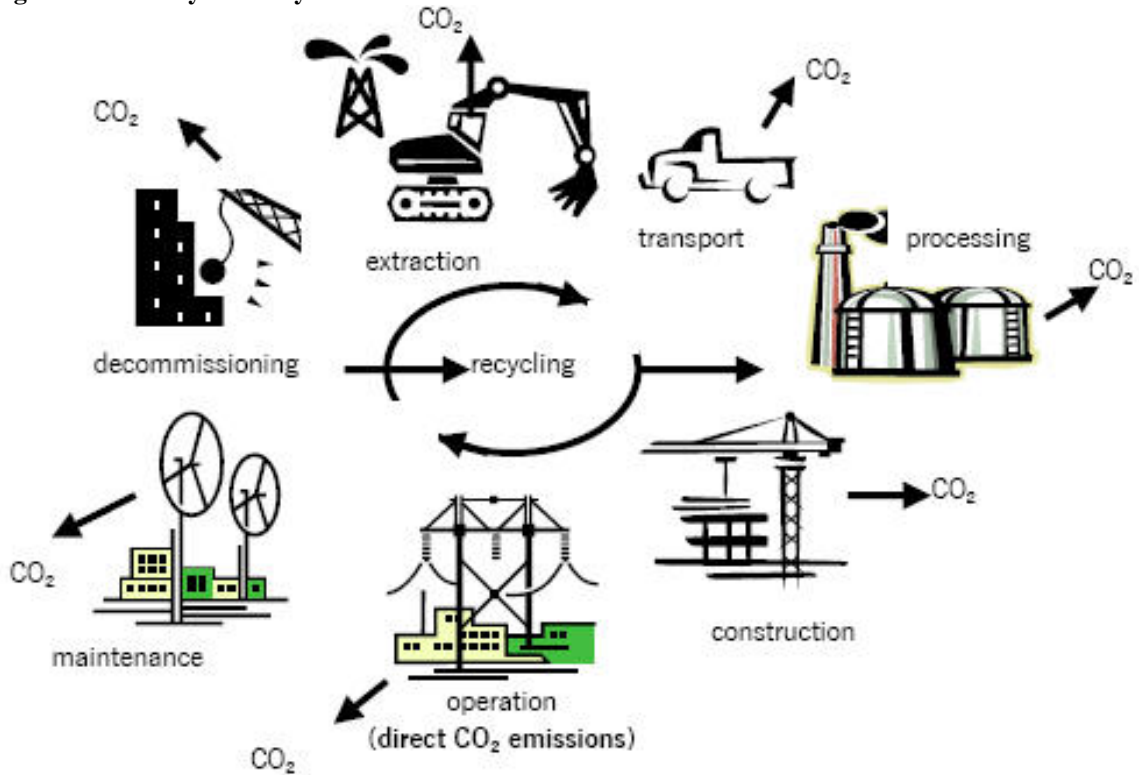
⁷ Baseload power refers to the minimum level of electricity that a Utility must ensure is available based on typical customer demands. Coal and nuclear are baseload energy technologies because the primary reason they are unavailable is for maintenance reasons, whereas energy sources like wind and solar are considered intermittent and turn off in an unpredictable fashion.

consumption rates climb higher. But as we build the additional generation capacity, we need to understand the overall carbon impacts of our technology choices and so a more careful analysis of the complete emissions picture surrounding all electricity generating technologies must be conducted. Gagnon (2008) says “It is unlikely that major reductions in greenhouse gas emissions will be achieved by energy options that, themselves, require large energy consumption”. Two factors that can help us make the most environmentally benign electricity choices are to calculate the effective carbon output for generating units using a life-cycle analysis and an energy payback ratio for each particular technology over its useful life.

To obtain a comprehensive carbon emissions figure, a life-cycle analysis (LCA) method is used, which offers a complete cradle-to-grave analysis of the carbon emissions associated with an electricity generating station (Figure 14). Fossil fuel generating technologies emit carbon during their operation, others (fossil fuels, nuclear and solar) emit carbon during the extraction of the raw materials, while all power generating technology emit CO₂ during the construction, maintenance, and decommissioning phases. Life-cycle analysis is reported as a number, which represents the total carbon output per unit of electricity generated. It is calculated by dividing the sum-total of carbon emitted during these various phases, in relation to the total electricity produced over the lifetime of the facility (eq. 1). A higher number represents a more carbon intensive electricity choice, and several things can influence the LCA. The expected life of the plant is important, particularly for those plants (like nuclear) where the most intense carbon impacts come during construction and decommission – thereby allowing

the unit to produce more electricity over their life, thus lowering their LCA. Without question though, the most important factor driving the LCA is the fuel –fossil fuel plants are adding to their carbon output through the extraction and combustion/processing of the fuel in perpetuity, while non-fossil fuel plants emit no carbon when they produce electricity.

Figure 14: Life-Cycle Analysis



Source: POSTNOTE 2006

$$LCA = \frac{FC + C\&D + O\&M}{kWh} \quad (\text{eq. 1})$$

Where: LCA = Life Cycle Analysis

FC = Emissions from fuel cycle

C&D = Emissions from power plant construction and decommission

O&M = Emissions from power plant operations and maintenance

A second method for evaluating the usefulness of an electricity generating facility is to measure the energy payback ratio. A simple equation is used to calculate the payback ratio; take the total electricity produced by the system over its lifetime, and divide by the total amount of energy required to build, fuel, operate, and decommission the plant (eq. 2). Any plant with a ratio of one is net energy-neutral, meaning the plant will produce the same amount of energy over its lifetime that was required to bring the plant online – making it useless to build. An energy-payback of ten indicates that the unit will produce 10X the amount of energy that is required to build, maintain, and fuel the plant. With energy payback, several factors will drive the numerator including the life expectancy of the plant and its reliability in producing electricity (or intermittency), while the denominator is influenced by the energy required to obtain the fuel as well as the size of the plant (requiring more inputs). When calculating payback, the environmental performance is greater when the ratio is larger⁸. Both LCA and energy payback are open to interpretation, as carbon emissions for things like construction and maintenance having various methods of calculations, resulting in different scores, but both are useful in analyzing the carbon impacts of our electricity options.

⁸ The average life for a coal, natural gas (combine-cycle), solar, and nuclear plant is 40 years, while wind turbines have a life-expectancy of 25 years.(which are accounted for in the calculations)

$$EPR = \frac{E_{n,L}}{E_{mat,L} + E_{con,L} + E_{op,L} + E_{dec,L}} \quad (\text{eq. 2})$$

Where: EPR = Energy Payback Ratio

$E_{n,L}$ = net electrical energy produced over plant lifetime, L

$E_{mat,L}$ = total energy invested in materials for the plant over its lifetime L.

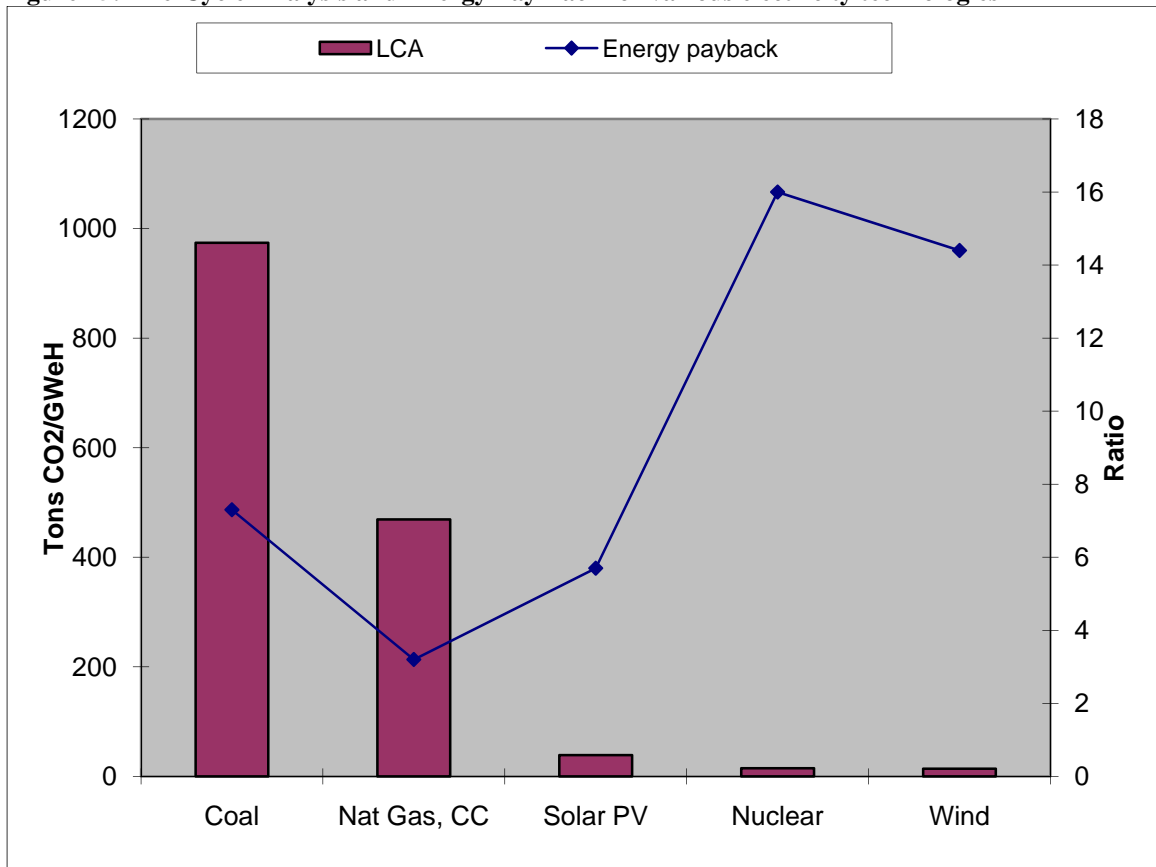
$E_{con,L}$ = total energy invested in constructing the plant over its lifetime L.

$E_{op,L}$ = total energy invested in operating the plant over its lifetime L.

E_{dec} = total energy invested in decommissioning the plant.

Figure 15 provides an illustration of two separate studies on both the LCA and energy-payback ratio for five electricity producing technologies (Meier 2002; White and Kulcinski 2000). In terms of total CO₂ emissions, both nuclear and wind are more benign than fossil fuel sources. Solar falls somewhere in between, due mostly to the heat requirements for silicon processing. For fossil fuels, coal emits more than twice as much carbon as natural gas per unit of electricity over the lifetime of the plant, but both score very poorly using LCA due mainly to the fuels. Using the energy payback ratio, nuclear and wind offer the greatest electricity generating potential as measured by the net energy yield over the plant's lifetime. Coal performs better than solar PV; a comparison that should flip in solar's favor once thin-film solar plays a more dominant role in the energy mix (more on thin-film later). Solar and both fossil fuel options are less favorable electricity options using energy payback ratios, primarily due to the energy intensity in securing the raw material inputs.

Figure 15: Life-Cycle Analysis and Energy Pay Back for various electricity technologies



Notes: LCA units are tons of CO₂-equivalent emitted per GWh of electricity generated
 Source: World Energy Council (2004); Meier (2002); White & Kulcinski (2000)
 See Fripp (2009) for a list of studies on LCA and Gagnon (2008) for a list of studies on energy payback.

Fossil fuels score poorly on a LCA calculation and have inferior payback ratios, so fossil fuels are the poorest performing energy choice. And their prospects are diminishing. Why? Future fossil fuel discoveries are going to be more difficult to reach, raising the discovery, recovery, and most likely transportation inputs for both LCA and energy payback equations. In the case of natural gas, more of it will require ocean tanker transportation, which means converting it to liquid form for trans-oceanic transportation,

followed by a re-gasification process that will generate larger energy intensity scores. It is worth noting that both coal and natural gas have high variability in their LCA and payback ratio because of the potential energy required in transporting the fuel; should the plants be built and operated closer to the energy source, both the LCA and energy payback ratios improve. In the end however, coal and natural gas use a fuel source that is not local, so the discovery, mining, and transport are driving CO₂ impacts that are inescapable.

Critics of these two methods point out how newer plants have longer life expectancies (more than 50 years). Others cite renewable energy's land requirements. And while it is true that solar arrays and wind farms are dilute, accounting for these impacts is more complicated. Solar fields typically require vast areas of land, land that could accommodate other economic activities, disrupt ecosystems, or obstruct scenic views; but many solar arrays are on rooftops, which have no alternative use. But if the land requirements are going to be factored, the landscape disruption from traditional energy sources must then not be ignored. Mountaintop removal coal mining requires vast areas of land. A large-scale hydro reservoir will flood hundreds of square miles of upstream land when dams are built (although there is a flip side to hydro, which is the benefits of boating and fishing recreation that was attained as a result of the project). All of these arguments fail to discuss the water requirements needed for virtually all electricity production except wind (and thus a major concern in many parts of the world).

Neither LCA nor energy payback set out to account for any of these issues. These two methods are designed to describe and evaluate the carbon and energy impacts when

accounting for all the stages in electricity production. These methods can and should be used in conjunction with other methods including electricity performance metrics, system integrity, water intensity requirements, and a cost/benefit analysis in order to establish an energy policy. And the energy policy within many countries of the world is beginning to carve out greater space for green electricity.

As of 2009, several roots of green energy technology are taking hold. Of the top 90 countries in terms of electricity consumption (representing 98.6% of all electricity consumed in 2006) ten countries were all able to generate more than eight percent of their electricity from green sources in 2006 (Table 7). Several other countries, including the United States, Japan, and Brazil, are among the world's leaders in the generation of green electricity (as measured by total kWh), yet because they consume so much electricity, green sources constitute a fraction of their overall supplies (Table 8). Meanwhile, a review of global green electricity⁹ reveals that many countries, most notably within Europe, are making progress towards incorporating green sources into their respective electricity mixes (Figure 16).

⁹ Hydro is often referred to as a renewable, but for the purposes of this study, hydro is excluded for two reasons: first hydro is often broken out as its own source of electricity generation and second, despite some renewable aspect to hydro, its electricity producing profile is not benign, given many of the problems associated with large dams. Therefore, green electricity refers to solar, wind, geothermal, municipal solid waste, landfill gas, biomass, small hydro (less than 10 MW) and wood/wood waste.

Table 7: Countries where green electricity makes up the largest % of total generation

Country	1993	2006
Iceland	5.2%	25.7%
Denmark	5.2%	22.1%
Philippines	22.9%	18.4%
Finland	9.7%	13.5%
New Zealand	8.2%	10.6%
Portugal	2.9%	10.3%
Netherlands	2.0%	9.8%
Spain	0.5%	9.4%
Germany	1.3%	8.7%
Austria	2.7%	8.3%

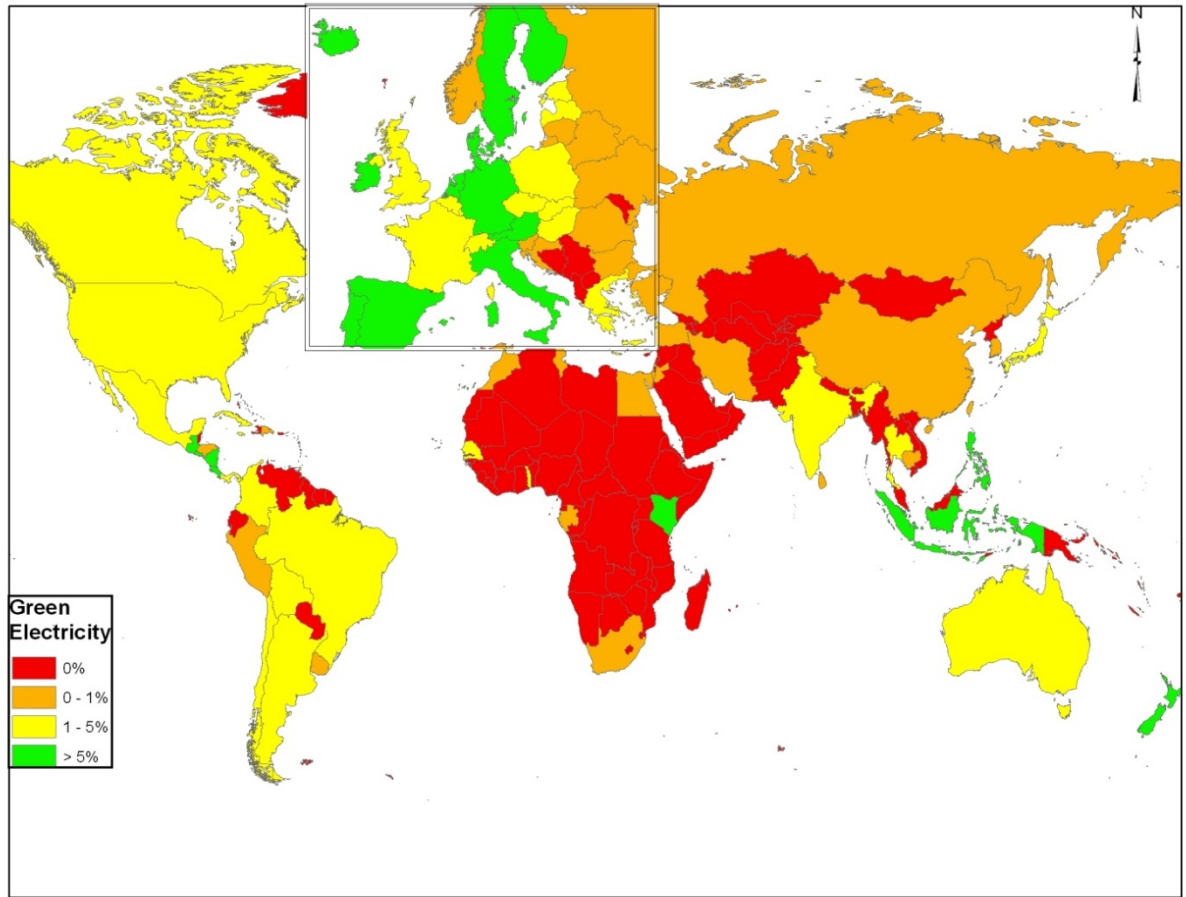
Source: EIA 2008

Table 8: Countries with the most green electricity generation in total kWh

Total kWh of green electricity generation	1993	2006
United States	79.7	110.4
Germany	6.53	51.55
Spain	0.8	26.75
Japan	13.14	25.86
Brazil	5.62	17.09
Italy	4.03	15.49
United Kingdom	1.5	15.34
Canada	4.53	11.03
Finland	5.66	10.51
Philippines	5.38	9.94

Source: EIA 2008

Figure 16: Green electricity as a percentage of overall electricity generation



Source: EIA 2008

Both the tables and the map are revealing in that they highlight those areas of the world where green electricity sources are being developed and implemented. Of course, it also exposes Africa and much of Central Asia as places where the transition to green electricity has not yet begun. Europe is at the core of the green electricity revolution, but a few other countries stand out. Indonesia, Kenya, New Zealand, and a few countries in Central America are making use of energy technology, with most of the green electricity contributions in those countries stemming from waste-to-energy facilities rather than the more traditionally thought of solutions like geothermal, wind, and solar.

Globally, investments in green electricity have been accelerating. Total global investments in 2007 from venture capital/private equity, government R&D, corporate R&D, public and asset finance, and small project financing, hit a record \$155 billion, compared with the \$59 billion invested in 2005 (New Energy Finance 2009a). Despite the financial meltdown in the second half of the year, 2008 was the first time where investments in renewable energy projects (including hydro) eclipsed projects for fossil fuel generation - \$140 billion compared with \$110 billion. After removing money invested into small projects as well as corporation and government R&D budgets, nearly \$119 billion was invested in renewable energy with wind and solar commanding the lion's share of those resources (Table 9). In sum, 40GW of renewable energy generating facilities and 25GW of hydro generation were brought online in 2008 accounting for 41% of the global total nameplate capacity (New Energy Finance 2009b).

Table 9: New investment by technology, 2006-2008

Technology	2006 (\$)	2007 (\$)	2008 (\$)	'07 - '08 change	% of total 2008
Wind	25	51.3	51.8	1.0%	43.7%
Solar	10.3	22.5	33.5	48.9%	28.3%
Biofuels	18	18.6	16.9	-9.1%	14.3%
Biomass	7	10.6	7.6	-28.3%	6.4%
Marine/small hydro	1.5	3.4	3.2	-5.9%	2.7%
Geothermal	1	0.9	2.2	144.4%	1.9%
Efficiency	1.6	2.8	1.8	-35.7%	1.5%
Other	1.9	2.4	1.5	-37.5%	1.3%
Total	66.3	112.5	118.5		

\$, billions

Source: New Energy Finance 2009b

Many of the potential sources of green energy are still in their infancy. Private and public sector investments will be needed to push green energy from the fringe to the mainstream, but there needs to be strong political will in place to help prevent the industry from retreating in the face of potentially derailing forces. Kyoto attempted to set forth an international framework that could serve as a source of support, but given how slow most countries are moving to meet their obligations, international treaties have so far lacked the necessary teeth. The next chance will be in late 2009 when the world meets in Copenhagen, Denmark to try once again to set some binding regulations. While there are mixed signals that an international consensus will emerge from the Copenhagen meetings, domestic policy proposals throughout the world are filling the void and providing a working foundation for how, potentially, an international agreement could be reached. But until a consensus is found, the disaggregate policy formation is going to continue to unevenly shape the international landscape of the new energy economy.

Policies

The rationale for coordination

While globalization will continue to alter the interaction between states and firms, knowledge systems will remain central to economic prospects for those areas (cities/regions/states) that are best able to harness and nurture technological innovation (Dosi 1999). New techno-economic paradigms in the view of Schumpeter (1942), take the shape of creative destruction; long-term economic growth requires radical innovation

(usually by entrepreneurs), that often times transitions market power away from those who have enjoyed a large measure of monopoly control. To mark this displacement as purely technological is itself too simplistic. Beyond the technology, there are demographic, social, industrial, financial, and demand conditions that must also be appropriately lined-up for paradigm shifts to occur (Dicken 2003, page 87). Along these lines then, many issues are required to usher in the next k-wave, but policy is necessary to ensure the competitive landscape does not thwart the ability for new knowledge and ideas to replace outdated, yet powerful ones.

Knowledge creation is highly localized, which is why knowledge accumulation, utilization, and enhancement remains something of vital interest, because it is usually done most intensively in the places where knowledge is first created (Archibugi and Michio 1997; Metcalfe and Dilisio 1996). Some countries understand this idea better than others. In fact, in directly refuting Charles Kindleberger's (1969) claim that "the state is just about through as an economic unit", in the world of green energy, the role of the state offers a unit of analysis that reveals sharp attitudinal, technological, and policy differentiation. Broadly speaking, the state has served to catalyze green energy innovation and adoption, and in a globalized world, states are one of the more important components driving economic activity (Porter 1990). Furthermore, there is a relationship between environmental policies and innovation, and the state plays an important role in establishing those policies (Jaffe et al. 2002; Johnstone et al. 2008).

The state plays an important role in shaping policies that foment the necessary political and economic institutions, but the state is also influential in setting forth the

framework for sub-state actors to most effectively harness their local strengths. In particular, cities or regions taking advantage of intimate local knowledge and a more fluid information exchange, should work to establish high-intensity clusters or technology districts of knowledge creation and innovation (Crevoisier 1999; Scott et al . 2001). Recognizing that tacit knowledge is sticky, those places that can hone the intellectual horsepower to develop a first-to-market advantage are likely to reap the benefit far into the future. Dicken (2001, page 116) explains this sticky aspect of tacit knowledge, where a steep distance decay curve reinforces geographic proximity, with interaction and direct experience playing a central role in economic growth and development. With this backdrop, it is easy to see how a country's competitive advantage is enhanced with the formation of national innovation systems (Freeman 1997; Lundvall and Maskell 2000), technology districts (Storper 1993; Matthews 1997) or technopoles (Castells and Hall 1994). Whether the state should be competing at all is the subject of much debate, but the fact is the state plays a forceful role in international trade as agents striving to create a competitive advantage that will materially benefit the welfare of its people.

In the case of energy technology, the state is also a custodian for the wellbeing of future generations – which for many of the industrialized countries has demanded the establishment of a framework for dealing with global warming. With the threat posed by climate change and the economic opportunity for crafting solutions, the state must play an active role in the market to serve as both a regulator of GhG emissions and as economic stimulator, encouraging private sector investments in energy technology.

Nijkamp (2003) recounts how policy is by no means the only, or even the most important factor in stimulating entrepreneurial activity, particularly in a modern network economy, but for complex techno-economic paradigm shifts, entrenched interests flex the kind of muscle that require governments to serve in a counter-balancing capacity. Without question, the growth of green electricity is policy driven, encouraged by the various support mechanism designed to spur manufacturing and installation activity that will generate the necessary scale economies to ultimately drive down costs.

Still, in a world with vastly divergent views on climate legislation, it is important to recognize that states are not the only places policy is made, so scale becomes integral in explaining the various perspectives. Scale rigidity must be partially suspended when attempting to dissect policy related energy technology initiatives. While policies related to the various innovation and adoption rates of energy technology can be explained well at a national scale, there are critical supra-national and sub-national policies influencing decisions; and the feedback loops are fluid. With so many divergent policy trends, it will be necessary to maneuver between scales to better explain the relationship between technology, innovation, and policy. Or as Thrift and Olds (1996) suggest, a network approach, with a dynamic interplay between scales. Within the literature, the term ‘nesting’ defines this cross-scalar approach; because assigning causal priority is increasingly difficult as signals are sent in both directions – bottom-up and top-down (Swyngedouw 1997; Howells 1999). While such a multi-scalar analysis is complex and perhaps not neatly boxed into a theoretical framework, increasing evidence suggests that because events do not occur in isolation but rather simultaneously across scales, its

explanation is best done within a construct that is not constrained by scale (Bunnell and Coe 2001).

Supranational

In 1992, 154 countries convened in Rio for the world's first earth summit. Although the UN Framework Convention on Climate Change (UNFCCC) established in Rio in 1992 was the first agreement dealing with climate change, it was not until the Kyoto meeting in 1997, when real commitments on greenhouse gas reductions (GhG) were established. Under the provision of "common but differentiated responsibilities", the 132 states classified as 'developing' have no binding rules or emission targets, due to obvious economic and technical deficiencies. The real focus of the protocol was on the developed states of the world, 40 countries referred to as Annex I countries, found primarily in North America, Europe, and East Asia (including Australia and New Zealand).

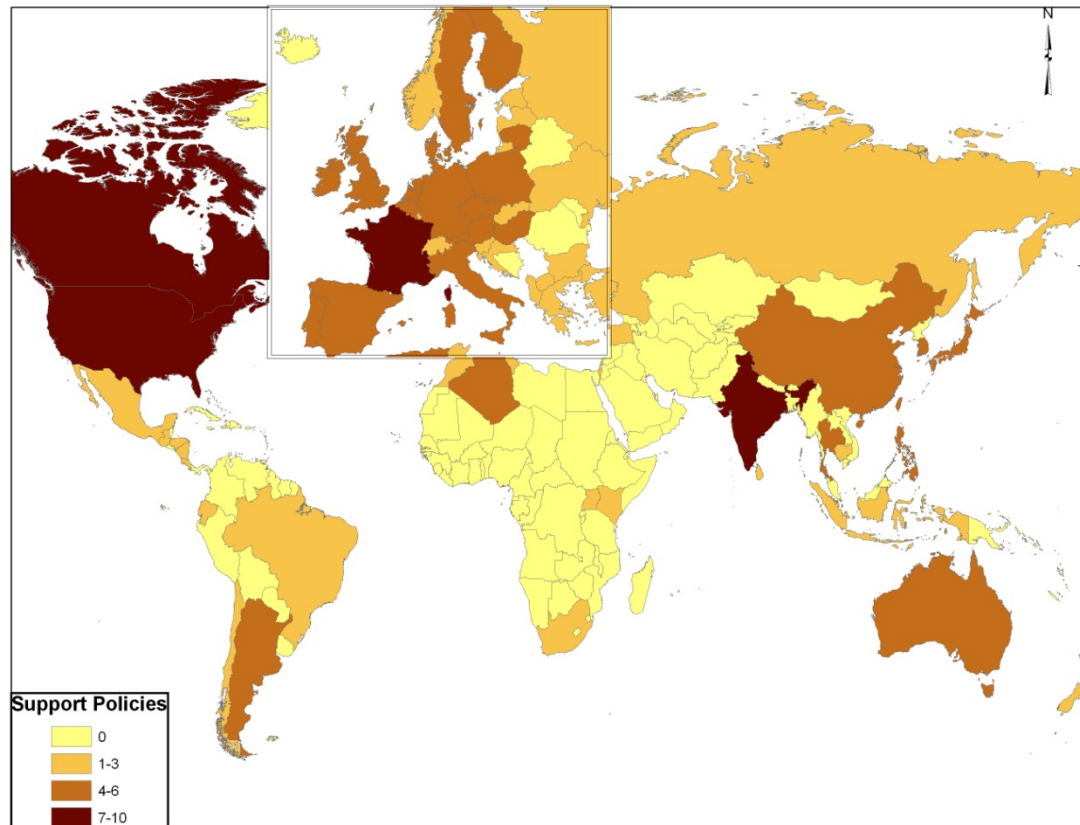
In an effort to meet their Kyoto obligations, broadly speaking 10 different types of promotion policies are used by governments around the world to support green electricity (Renewables 2009). Feed-in tariffs, capital subsidies, investment tax credits, and tax reduction strategies are used by most of the countries in the developing world, as these tend to provide green electricity developers with immediate cost relief in an effort to decarbonize the energy mix. The second half of the list provides some of the other creative ways to lure additional players (both large and small) into providing more green electricity (Table 10).

Table 10: Promotion policies used by governments

Feed-in tariffs / fixed premiums	Tradable renewable energy certificates
Renewable portfolio standards	Energy production payments
Capital subsidies, grants, or rebates	Net metering
Investment or other tax credits	Public investment, loans, or financing
Sales, energy, or excise tax reductions	Competitive bidding

Nearly all the countries in the developed world utilize some form of a feed-in tariff, although in Canada, the US, Japan, and India, the programs are administered at a sub-national level. The feed-in tariff has been the most effective method to accelerate the green electricity industry. Feed-in tariffs encourage the development of green supplies, by guaranteeing that the price paid for clean electricity sources will be higher than conventional sources and most important from an investor perspective, the premium is guaranteed for many years. Generally speaking, all of the policies provide some sort of subsidy to bring additional green electricity supplies online either through legislative methods or market-based approaches. Premiums can be paid for either by the government through transfer payments or through the individual utilities as they pass the costs to their customers. Either way, there is a socialized aspect to restructuring electricity supplies. All in all, 65 countries have implemented at least one of the following policies to support renewable energy, with about 1/3 of them classified as developing economies (Figure 17).

Figure 17: Renewable energy promotional policies



Source: Renewables 2009

In addition to meeting their own reduction targets (5.2% below 1990 rates between 2008-2012), Annex I countries are permitted to provide assistance and technology to the other countries, since the Kyoto objective is a global reduction in emissions. As alternatives to investing in emissions reduction schemes domestically, Kyoto has established two flexible mechanisms to encourage the cross-border investments; clean development mechanisms and joint implementation (World Bank 2008). Clean development mechanisms (CDM) encourage investments in developing states by including a provision that allows Annex 1 countries to benefit from any green project. For a variety of reasons, developed countries might find it cheaper to undertake

a project in the developing world, and using the CDM, Annex 1 countries can obtain credit towards their Kyoto targets for these projects. Joint implementation (JI) allows investments in non-developing states, most likely the transition states of the former Soviet Union (but other Annex 1 countries are also suitable) and also allows the Annex 1 country to count the projects' emissions reductions towards its own targets.

Equally important to direct investment, trade is critical not only in empowering the developing world with the tools to reduce emissions, but the technology transfer enables them to potentially further enhance those goods and services (Hakura and Jaumotte 1999). According to a recent report by the World Bank (2008), highlighting 43 specific climate friendly technologies, the combination of tariff and non-tariff barriers have erected numerous obstacles that impede the exchange of environmental technologies. According to the report, the average tariff imposed by the low- and medium-income WTO member for the 43 goods in the World Bank study was 8.6% with the most defensive countries imposing tariffs of 20-30% on environmental goods and services. Among the high-income WTO members the average imposed tariff was 3.3%, but again, at least one country had imposed double-digit tariffs on each of the 43 environmental technologies. And when China was granted low-tariff access to foreign markets through the WTO, it promised to sign a separate agreement that would limit state involvement in companies competing internationally; China has never signed the deal and therefore is able to make low cost loans to domestic companies. Furthermore, China has been building out its green electricity infrastructure using procurement rules that

favor domestic companies, causing western competitors to complain of protectionism (Bradsher 2009).

Expedited liberalization of trade policies needs to be pursued in a fashion that enhances the spreading and development of clean energy technologies to promote their increased use around the world. And while the developed world, where most of the companies involved in mitigating the impacts of climate change are located, is sure to reap the most significant short-term benefits, provisions could be put in place to help generate a comparative advantage in some of the more labor intensive technologies in the developing world. Part of that transition should be assisted with the international renewable energy agency (IRENA). Created in early 2009, it is the first international body established to facilitate the development of renewable energy around the world. Working in coordination with other influential agencies like the International Energy Agency and the UN Industrial Development Organization, IRENA's main objective is to increase the penetration rates for renewables and will do so by spurring technology transfers, helping to navigate the capital markets, improve access to financing, and enhance knowledge availability in areas where it is needed. With 78 initial member countries, IRENA has more than 135 members including the United States which officially joined in 2009 (IRENA 2009).

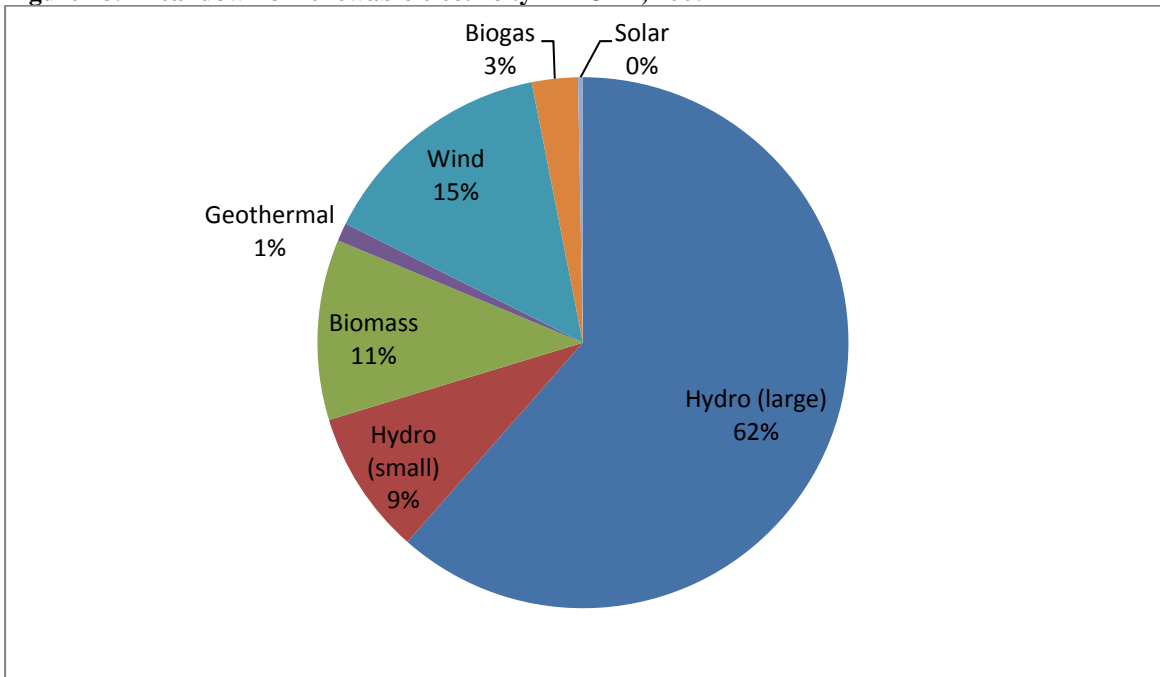
The next international climate meetings are set to be held in Copenhagen in late 2009. While there is much anticipation with respect to what these meetings might produce, the two core issues remain unresolved: given that the developed world is responsible for virtually all the carbon build-up in the atmosphere - how much additional

responsibility should they bear in financing a decarbonized world? And what obligations should the developing world accept in pursuing non fossil fuel options as their economies develop? As the world waits for this multilateral impasse to find some resolution, a fragmented patchwork of energy technology policies is emerging in countries and regions around the world.

Europe, the EU, and member states

Europe continues to serve as the nucleus of global green energy. Not only has the European Union declared its intention to achieve a 20% cut in emissions below 1990 levels by 2020, they have also set a target whereby 20% of its electricity will be generated from renewables. As a frame of reference, the EU-27 generated 15% of its electricity from renewables in 2005 (Commission of the European Communities 2008). Despite renewables achieving such a high percentage of overall generation, hydro power still accounts for more than 70% of the total, making the EU highly dependent on adequate rainfall (Figure 18). While the targets are ambitious and there are reasons to be skeptical, Europe's strength lies in the collaboration by states to share the burden as evidenced by the comprehensive agreement to the individual emission targets set forth and accepted by each country in order to meet their collective 2020 targets (Renewables 2009). Nevertheless, Europe will need to increase the penetration rates of new electricity technology if it hopes to meet its goals.

Figure 18: Breakdown of renewable electricity in EU-27, 2005



Source: Commission of the European Communities 2008

The most important community-wide mechanism in place is a market based emissions trading scheme that was first established in 2005. The emissions trading scheme (ETS) is designed to create a financial incentive for companies to invest in carbon mitigating technologies or transition away from carbon sources of energy all together. Recognizing the expense of transitioning the economy to renewable sources of energy, the ETS allows companies to conduct their own internal cost/benefit analysis, rather than comply with a government mandate.

Under the first phase of the ETS, the EU gave away emissions permits to companies operating in the energy and industrial sectors, allowing companies to emit an amount of carbon each year equivalent to the value of the permit. Each permit, also known as an allowance, gives the polluter the right to emit one ton of carbon. Each

subsequent year, the number of permits are reduced, but in a linear fashion providing a visible forecast and allowing companies to plan accordingly. Some companies will choose to invest in carbon-mitigating technologies, which will serve to reduce the amount of GHG emissions. Those companies will have excess permits to sell, which will help them offset the cost of their pollution-reducing investment. Other companies will determine that the cost to invest in carbon mitigation is too high, and will opt to purchase credits on the open market for the right to exceed their emissions quota.

The EU is now in their second phase of the ETS. Phase one of the EU ETS extended for a three year period, ending in 2007 and the EU is now in the middle of phase two, which is a five year period, running from 2008-2012; a timeframe that coincides with the Kyoto targets for EU and its member states to meet their obligations (6.5% reduction in emissions below 2005 levels). Despite billed as a 'learning by doing', there have been many areas where phase one of the ETS has failed to meet its objective (Blanco and Rodriguez 2008).

First, there was an over-allocation of carbon credits, emasculating any incentive to curtail emissions. The over-allocation of permits, caused largely by politicians inflating their own domestic economic growth targets and therefore emissions projections for their domestic markets, causes the carbon trading market to sputter. Despite the surplus permits, a market, albeit an underpriced one marked by supply and demand imbalances, emerged. In 2005, 362 million tons of CO₂ were traded on the carbon exchange (about 18% of total EU emissions), valued at more than 7 billion Euros (Point Carbon 2006); rising in 2006 to more than one billion tons of carbon valued at more than

18 billion Euros (Point Carbon 2007). The over-allocation of permits had the unintended consequence of stunting clean technology investments, because in the absence of real carbon constraints, green energy alternatives did not make financial or business sense.

Second, the allowances were given away. For future phases, the EU expects to transition away from free allocation to a format where auctions will determine the number and price of allowances. An auction approach will enhance the system as it should more accurately reflect the real needs of the emitters. Finally, several important sectors were excluded from the ETS. Over 10,000 installations in the energy and industrial sector were covered, collectively accounting for about half of the EU's carbon emissions. However, the transport sector (21% of total CO₂ emissions), households and small businesses (17%) and agriculture (10%), were excluded (EU 2006). While individual countries are expected to have national plans to encourage GhG reductions in these sectors, according to Eurostat (2007), transport is the economic sector experiencing the highest GHG growth which is forcing the EU to consider incorporating both air transport and autos when phase three begins in 2012.

As previously mentioned, the EU has already set the emissions levels for phase three (Table 11). This linear contraction is necessary to provide visibility to the companies participating in the ETS, as well as broadcast the permit scarcity that should create a vibrant carbon market. As a point of reference, among the ETS participating installations the EU emitted 2,050 million tons of CO₂ in 2007, which was a slight increase from the prior year (EU 2007).

Table 11: EU permit reduction schedule for ETS

Year	Tons of CO2 (in millions)
2013	1,974
2014	1,937
2015	1,901
2016	1,865
2017	1,829
2018	1,792
2019	1,756
2020	1,720

Source: EU 2008

Through 2007, the EU-ETS dominated the global carbon trading market, accounting for nearly 80% of all traded permits (New Energy Finance 2009a). Despite limited participation, the Kyoto Protocol's framework for a carbon market has attracted the investments of those countries seeking to take advantage of the CDM and JI credits. Developing a global carbon market is critical to establishing a real price on carbon, but until binding commitments are made by all the players in the international community, individual countries are following the EU lead; Japan is in the trial phases of a trading scheme and Australia is set to launch its carbon reduction scheme in 2010. Meanwhile, in the United States, the House of Representatives passed the Waxman-Markey bill in the summer of 2009 creating a cap on carbon emissions.

While the ETS is perhaps the most ambitious program in place to stimulate a green energy economy (creating a market where one did not exist), it is not the only method used to promote a viable green energy industry in Europe. Currently, the 27 member-states of the EU operate 27 different and independent schemes. In addition to the physical and administrative obstacles associated with trading electricity across

international boundaries, the variations in national plans are also explained as each country seeks economic growth.

The various support mechanisms can be broadly categorized into direct and indirect policy measures, whereby direct measures stimulate the installation of green electricity generation, and indirect measures attempt to change the long-term energy framework to be more conducive for green electricity. Some traditional fiscal methods are used such as subsidies, quotas, tradable certificates, and tax credits, all receiving some attention to one degree or another, but it is the feed-in tariff (FIT) which has had the most wide-spread success. Table 12 shows the different strategies to place within Europe to spur green electricity and several sources have described the methodology behind each measure (Held et al. 2006; EWEA 2005).

Table 12: Classification of EU promotional strategies

		Direct		Indirect
		Price Driven	Quantity Driven (Quotas)	
Regulatory	Investment focused	- Investment Subsidy - Tax Credit	- Tendering System	- Environmental Taxes
	Generation based	- Feed-in Tariff - Fixed price system	- Tradable Green Certificates (TGC)	- Connection Charges
Voluntary	Investment Focused	- Shareholder Program - Contribution Program		- Voluntary Agreements
	Generation Based	- Green Tariffs		

Source: Held et al. 2006

Much like with the ETS, it is fundamentally important that the underlying costs of producing green electricity continue to fall and this is precisely how the FIT is designed. FITs are considered the most effective means to rapidly usher in, but more importantly sustain the development and deployment of, renewable energy technology (Couture and

Gagnon 2010). The tenets of the FIT are simple; green electricity is put onto the grid, and producers are entitled to a fixed minimum price for their electricity. FITs provide investment security with a guaranteed stated duration and a pre-defined price per kWh of energy which amounts to a premium above the conventional rate paid for electricity from legacy facilities. Once a project comes online, the producer locks in their FIT for 20 years, and while the project is guaranteed the same premium for the 20-year life of the facility, each year, the FIT for new projects is reduced by some amount (usually about five percent). As the FIT sunsets, the cost of newly installed green electricity should be driven down to a point where hopefully parity with fossil fuels sources is achieved and the subsidy is no longer required.

As an example, a new solar project obtains a 20-year guaranteed duration FIT that allows a producer to calculate the investment return for installing this more expensive (solar) electricity option. This project creates demand within the solar market, which enables manufacturers to move along the cost and technology curve, benefitting the next project in corresponding fashion. This is critical, because the FIT will be less generous the next year, so in order for the economics to work year after year, inefficient producers need to be weeded out and only the most promising technologies supported. When compared against most other energy sources, green electricity projects have larger upfront capital costs, making the FIT essential at the outset because of the cash-flow visibility it provides. FIT have a track record of accelerating the deployment of green energy technology, compared with other policy mechanisms like net metering or rebates (Fouquet 2007, Held et al. 2007, Ragwitz et al. 2007). Furthermore, once all the transfer

payments are tallied against other support schemes, FIT achieve greater green electricity penetration at a lower overall cost to ratepayer (de Jager and Rathmann 2008).

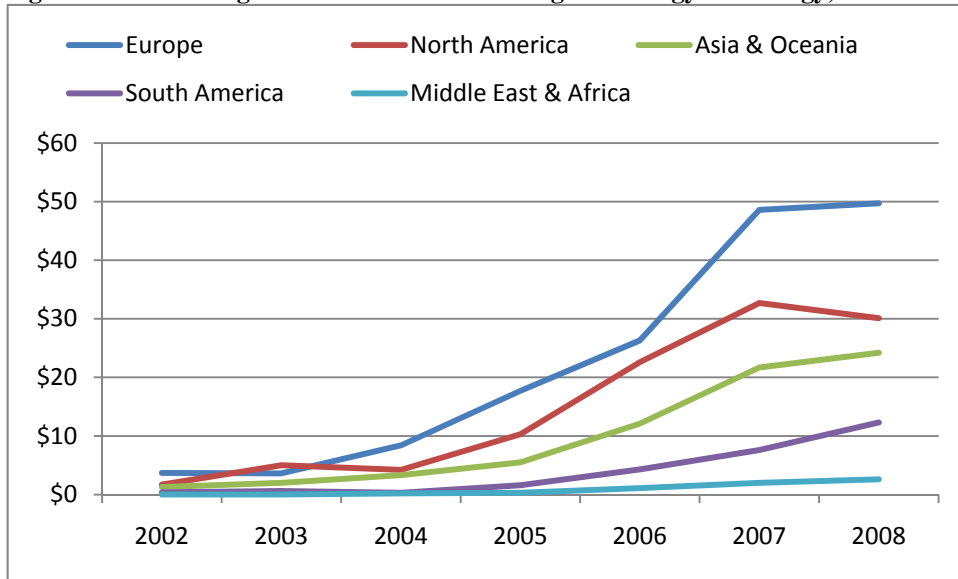
FIT are not a panacea as they do have some obvious shortfalls. Most notably, they drive near-term electricity prices higher, as utilities have to compensate for the mandate to accept and buy green electricity. There is also the technical problem of connecting this distributed electricity to the grid, which must be guaranteed if the program is to be successful. Finally, a FIT does not address the high upfront costs of green electricity, but rather a continued revenue stream over the life of the project. Most banks and lending institutions have become comfortable with the FIT arrangement which allows for cost-recovery, but over the long-term, wide-scale deployment is going to require more substantial cuts in the costs of green electricity systems, in addition to the added administrative requirements of monitoring and verifying the program (Couture and Cory 2009). Nevertheless, 20 of the EU-27 use some price-based FIT to stimulate the green electricity market (Commission of the European Communities 2008).

The seven other countries use quotas, making it the other preferred method to support new energy technologies. Generally speaking the quota framework is two-fold, the electricity and a 'tradable green certificate' that accompanies the generation of that electricity. These tradable green certificates (TGC) are issued to accredited green electricity producers for each unit of energy produced (usually one MW) which are sold separately. A quota system mandates that suppliers put a certain amount of green electricity on the grid; in addition, they have to buy the TGC which compensates the green producers with additional revenue to offset the operating loss they incur from selling their electricity. Of course, the utility can choose to generate the green electricity

themselves, and based on the value of the TGC, this becomes a business calculation. At the end of the year, should the utility have inadequate TGC, they pay a penalty to the government.

These various systems are needed because for more than a decade, efforts were made to impose a tax on electricity to force generators to account for their environmental externalities, Despite an EU agreement in 2004 on such a system it has yet to find its way into law. As a result, 10 member states (Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Portugal, Spain, and the Netherlands) have introduced their own tax incentives for renewable energy, include things like tax holidays, generous deduction schedules, depreciation benefits, and tax free dividends, among others. None of the countries have identical systems, but all the member-states continue to fine-tune their methods in an effort to adopt the best practices and improve overall system performance. For all the fits and starts associated with European policies to support green energy, the results are unmistakable; Europe has led the world as the region receiving the highest level of new green energy investments (Figure 19).

Figure 19: Global regional investment flows for green energy technology, 2002



\$billions

Source: New Energy Finance 2009b

The United States

A review of domestic environmental policy is rich (Harris 2009; Byrne et. al. 2007). Rosenbaum (2007) condenses the last 50 years into two environmental eras: the environmental decade starting in the 1960s and extending through the end of the 1970s during which laws concerning the welfare of water, air, endangered species, and wilderness, as well as other laws controlling pesticides, chemicals, and energy were put into place. The second era beginning in the late 1980s witnessed the internationalization of environmental initiatives, starting with the Montreal Protocol, implementation of UNCLOS, and extending to earth summits in Rio and Kyoto. And while the United States has an impressive history in promoting some elements of environmental protection, it has failed terribly to pursue agreements that seek to regulate carbon.

In June 2008, the US House of Representatives passed a bill that would authorize a ‘cap-and-trade’ program to curb GhG emissions. In the years following 1997, the international community proceeded in the spirit of the Kyoto Accords, hoping the US would soon join, but all doubt about the US intentions were removed when the US withdrew from treaty. As she recounted for a Frontline interview in 2008, the then head of the Environmental Protection Agency, Christie Todd Whitman said “with one stroke of the pen, the president has determined that there are more important things in the world than the rest of the world” (Frontline 2008). Meanwhile, Time Magazine labeled the US a ‘rogue nation’ (Karon 2001). Internationally, where it was assumed that the US was not interested in making the tough choices on climate change, global rallies were held condemning the US’s decision. In addition to withdrawing from Kyoto, two other decisions, namely its prioritization of next generation fossil fuel and nuclear energy technologies over renewables; and its efforts to highlight the lack of scientific consensus on climate change, continue to fuel international opinion that the United States was out of step on global energy policy (Byrne et al. 2007).

Ever since withdrawing from the Kyoto Protocol in 2001, the world has waited for the United States, which emits more GhG per capita than any other country in the world, to confront climate change with effective and compulsory legislation. If a cap-and-trade bill is signed into law, it is sure to see some significant alterations in the Senate, but the bill signals a change in both acceptance and attitude from Washington DC about climate change that has represented the most significant obstacle to any binding international climate treaty. And while many blame the Bush administration for

withdrawing from Kyoto, guilt lies at the feet of both parties in the United States; for the Kyoto Protocol was disingenuously signed by President Bill Clinton, who for political calculations, never submitted the bill to the Senate for ratification.

There is some hope that should the house bill reach the Senate, it might have a chance at passing; in 2008, Senators Lieberman (I-CT) and Warner (R-VA) introduced the Climate Security Act, which is a comprehensive and aggressive attempt at climate legislations, but due to presidential election year politics and a looming recession, the bill was never seriously considered. That is not to say the federal government has ignored energy, climate, or sustainability issues. In fact, since the OPEC oil embargo of 1973, the federal government has periodically enacted laws pertaining to renewable energy. Table 13, though not comprehensive, highlights the most important pieces of legislation.

Table 13: Major legislation in the United States affecting renewable energy

Year	Federal legislation	Effectuated Energy
1974	Geothermal Energy Research, Development, and Demonstration Act	Geothermal
	Solar Heating and Cooling Demonstration Act	Solar
	Solar Energy Research Act	Solar
1978	Solar Photovoltaic Energy Research, Development and Demonstration Act	Solar
	Public Utilities Regulatory Policies Act (PURPA)	All Renewables
	Energy Tax Act	All Renewables
1980	Wind Energy Systems Act	Wind
	Biomass Energy and Alcohol Fuels Act	Biofuels
	Crude Oil Windfall Profits Tax Act	All Renewables
1981	Economic Recovery Tax Act	Wind, Solar, Geothermal
1986	Tax Reform Act	All Renewables
1992	Energy Policy Act (EPACT)	All Renewables
1999	Tax Relief Extension Act	Wind, Biofuels, Waste
2000	Biomass Research and Development Act	Biofuels
2002	Economic Security and Recovery Act	Wind, Biofuels, Waste
	Farm Security and Rural Investment Act	All Renewables
2005	Energy Policy Act	All Renewables
2008	Food, Conservation, and Energy Act	All Renewables
2008	Energy Improvement and Extension Act	All Renewables
2009	American Recovery and Re-investment Act	All Renewables

Source: Gielecki et al. 2001; Authors notes

Menz (2005) highlights PURPA in 1978 and EPACT in 1992 as playing the most significant role in accelerating investment in green electricity. PURPA created competition in electricity markets by mandating that utilities purchase power from small-scale renewable sources. EPACT further opened the electricity markets by mandating access to transmission lines by all electricity producers. EPACT also created two financial incentives. The first was the Production Tax Credit (PTC) which is an inflation adjusted tax credit that benefits investors producing electricity from wind. The PTC has since been updated to provide tax credits for electricity produced by other technologies including geothermal, solar, some biomass, and smaller scale hydro (Menz and Vachon 2006). The second is the Renewable Energy Production Incentive (REPI) which is similar to the PTC, in that it provides a per/kWh tax credit, but it is an incentive for projects that are not subject to federal tax liabilities like not-for-profits, local and county governments, rural electric co-operatives, and tax-exempt public utilities (Bird et al., 2005).

Notably absent from this chronology of policy are any federal mandates that would meaningfully transition our energy off of fossil fuels. Despite the federal void, there is ample evidence to demonstrate how the state and local governments are enacting climate legislation. There are a variety of factors leading to these uncoordinated approaches, but the accessibility of policy makers, particularly at the local levels, is an inherently attractive mechanism of the US political landscape. With competing interests diluting legislation at the federal level, Bryne et al. (2007) suggest that a bottom up energy policy initiative will best ensure political durability, and will also serve to prime

the pump for national legislation. As an example, the US Conference of Mayor’s Climate Protection Agreement was signed in 2007 by the mayors of 850 cities representing more than 80 million people. By the middle of 2009, more than 1,000 mayors have signed on to an agreement that is working to reduce GhG emissions in line with the Kyoto Protocol (US Conference of Mayors 2009).

Although the mayor’s agreement is important, most of the meaningful and enforceable climate legislation is found at the state level. According to the Pew Center for Climate research, there are 21 different initiatives put forth by the states in an effort to deal with electricity, energy, conservation, and efficiencies. Pew categorizes these initiatives into four categories: climate action, energy, transportation, and buildings (Table 14).

Table 14: Types of state level policies used to promote a new energy economy

Climate Action	Energy Sector	Transportation	Buildings
Regional Initiatives	RPS	Vehicle GhG Standard	Green building std for state buildings
Climate Action Plan	Public benefit fund	Mandates/incentives for biofuels	Commercial building energy codes
Climate Change Commission	Carbon cap/offset for power plants		Residential building energy codes
GhG Targets	Net Metering		Appliance efficiency std
GhG Inventory	Green Pricing		
GhG Registry	REC Tracking		
State Adaptation Plan	Energy efficiency resource standards		
	State buys green power		
	DeCoupling		

Source: Pew 2008

Focusing on the energy sector, many of the measures warrant further explanation. Decoupling laws are an attempt to divorce the energy sales from revenues. Under the current rate structure, utilities are encouraging more electricity consumption because it

translates into more revenues; as a result, utilities are not interested in promoting conservation or efficiency programs. And yet, as regulated monopolies, utilities have their rates set by the public utility commission which guarantees them a fair profit. Decoupling allows utilities to promote less electricity consumption without jeopardizing their revenues, and currently nine states have passed electric utility decoupling laws. Net-metering laws allow customers to own their own power generation and sell excess electricity back to the grid using advanced (two-way) meters; 17 states support universal net-metering laws while 25 other states have laws supporting net-metering for their largest utilities.

Green pricing programs offer a good gauge on where customers are feeling altruistically. David Moskovitz (1993) first describes green pricing programs as an option offered by utilities so that customers can choose to pay a premium for electricity to ensure that the additional renewables are offered beyond what the utility deems to be a cost effective level. In other words, customers are willing to pay more to help bring additional green electricity supplies online. According to Bird and Kaiser (2007) the source of electricity and its accessibility for the utility will determine the price premium for a residential utility bill, but generally speaking the costs are less than \$5 per month and in 2006, the combined total of all the green power programs nationally generated \$40 million in additional revenue. By the end of 2007, two states had more than 100,000 participants in their green pricing program (Texas and Oregon) while Oregon and Wyoming have managed to get more than 2% of its total population to enroll (Table 15).

In total, more than 835,000 customers are enrolled in green pricing programs at the end of 2007, served by a total of 591 utilities (public, municipal, and consumer).

Table 15: Top ten states by enrollment in green pricing program, 2007

Rank	State	Total Customers	% of population
1	Oregon	100,595	2.7%
2	Wyoming	13,225	2.5%
3	Colorado	57,501	1.2%
4	New Mexico	21,273	1.1%
5	Delaware	8,914	1.0%
6	Maryland	55,954	1.0%
7	Utah	23,406	0.9%
8	Minnesota	44,034	0.8%
9	District of Columbia	4,854	0.8%
10	North Dakota	5,086	0.8%

Source: DOE 2008a

States and local governments are experimenting with a host of other options as well. For example, homeowners that install solar panels on their roofs are shielded from higher property valuations as a result of the solar installations in 29 states. One of the more popular policies pursued by state and local governments is a financing mechanism known as Property Assessed Clean Energy (PACE). Pioneered in Berkeley, California, the program enables local governments to offer financing to property owners for the purposes of solar system installation. The loan is then repaid through a special assessment on the property tax bill, which amounts to about \$2,000 per year (Barringer 2008). Should the house be sold, the system stays with the house and the buyer assumes the payments (and the benefits of cheaper electricity). PACE is popular because it is a government program that creates jobs with no local government budgetary implications (IREC 2009). Despite their success in Europe, FITs have made little headway in the

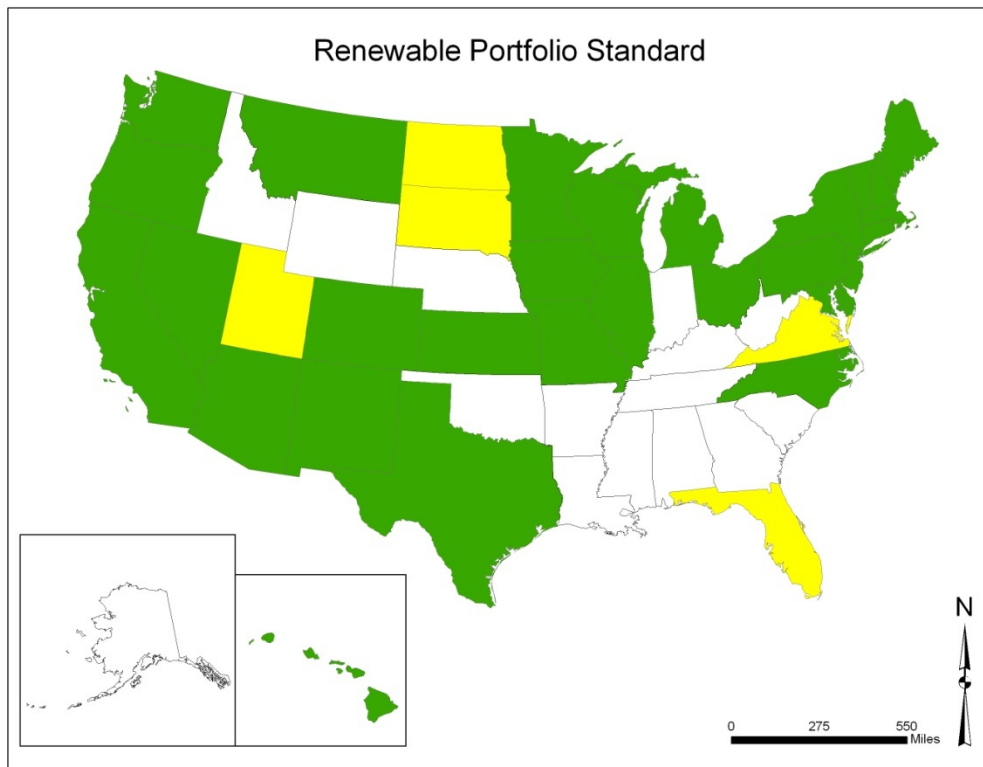
United States, as only six states (California, Vermont, Oregon, Washington, Wisconsin, and Florida) have passed either a statewide or a more limited utility specific FIT (Couture and Cory 2009).

Finally, the PEW list fails to mention rebate programs, which offer lump-sum payments to a project's owner to help cover a portion of the upfront capital requirements to initially install the system. Most states' rebate programs are tied to system-size and are paid on a fixed dollar/watt basis. To ensure the rebate program remains solvent for all those who want to participate, the programs typically rebate a percentage of the system costs or set a cap as the maximum value. This latter point of solvency, stresses the importance of the public benefit fund. Public benefit funds are a surcharge assessed to all utility bills which the government then uses to invest in research and development, promote efficiency, or used to support renewable energy. The public benefit fund needs to be sufficiently financed through flat-fee or progressive utility bill charges, and most importantly must be protected from the state's general fund, to ensure the long-term uninterrupted support for green energy programs.

States have become very aggressive in pushing legislation to promote green electricity and the most effective tool has been the renewable portfolio standard. Twenty-nine states as well as Washington DC have passed renewable portfolio standards (RPS) which typically mandate that the larger utilities in the state have to obtain a certain percentage of their electricity from renewable sources (Figure XXXX). California had the most aggressive RPS in the country, requiring 20% of all electricity by 2010, and it was recently extended by executive order, lifting the requirement to 33% by 2020. Other

states require more than 20%, but they all have deadlines extending out to 2020 or 2025. Typically an RPS will allow the utilities in the state to meet their RPS requirements with the most affordable energy technology options, generally speaking, wind. But since 2007, many states have placed a specific emphasis on solar's contributions to the RPS targets with many states incorporating solar set-asides within their RPS (DSIRE 2009). Given the expense and relative immaturity of solar as a source of electricity, some of the states are offering 'multiplier benefits' for each kWh of electricity, which means allowing the solar electricity to count for double or triple its actual electricity production. The objective is to provide large orders for the solar industry and help bring some financing relief to the industry, which currently suffers from considerable up-front costs.

Figure 20: States with renewable portfolio standards and targets

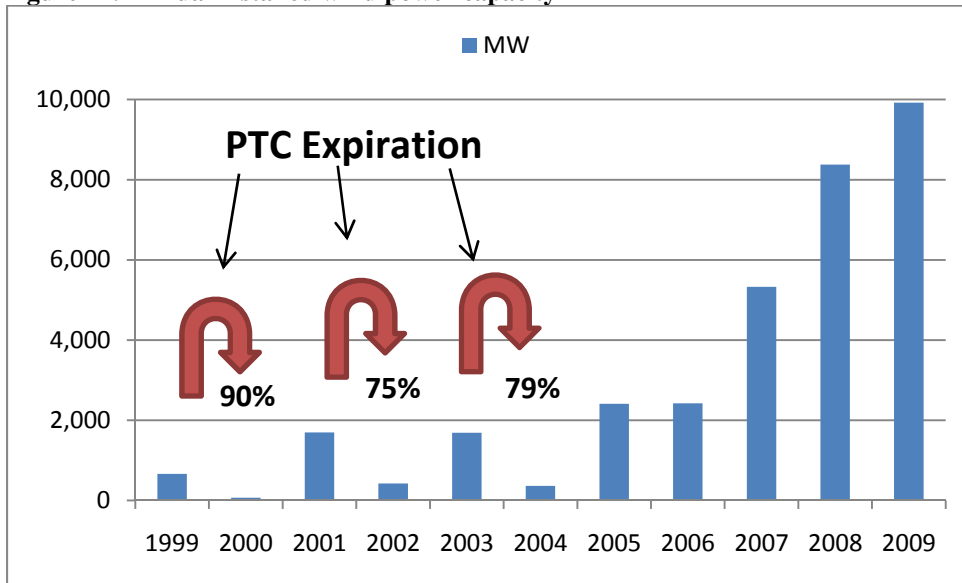


Source: DSIRE 2009

As previously stated, wind is the technology most capable of meeting RPS targets, and to help encourage wind production, the Production Tax Credit (PTC) provides 2.1 cents per kWh of electricity produced which can be used to offset other taxable income¹⁰. Developers can use the PTC for ten years from the date they bring their wind project online. When the PTC was initially introduced as part of the Energy Policy Act of 1992 it was intended to sunset at the end of the decade. Although the PTC did not sunset in 1999, it has been inconsistently renewed, making the wind policy landscape opaque for developers that rely on the tax credit to ensure profitability for their projects. Since 1999, the PTC has lapsed on three separate occasions; and as the expiration date approaches, developers halt construction on their wind-farms as the financial value of the PTC is paramount to the profitability of the projects (Figure 21). The United States has a track-record of inconsistency that has created a yo-yo trend in wind, compared with places like Germany and Spain where smooth growth trends are a reflection of consistent government policy.

¹⁰ The PTC was initially 1.5 cents per kw, but was designed to increase annually for inflation.

Figure 21: Annual installed wind power capacity



Source: AWEA 2009

Wind energy planning and permitting can take more than two years. As a result, interest in wind development is curtailed when there is uncertainty surrounding the PTC reauthorization. Annual extensions have proven adequate, but the American Recovery and Reinvestment Act (ARRA) in 2009 extended the PTC through 2012, providing visibility that the wind industry had not seen in nearly a decade. Critics of the PTC argue that their wind projects are financial losers without the PTC and therefore are a bad deal for tax-payers. No doubt the PTC is public subsidy with opportunity costs. According to the GAO (2004), while contemplating the PTC extension in 2003 (through 2013), the cost to the government was calculated to be close to \$3 billion (\$300 million annually). And yet, as compared with some of the precedents for federal government spending on large-scale national security programs like the Manhattan Project, Apollo Program, or the

War on Terror, these are minor financial commitments to what many argue is an equally worthy goal (Kammen and Nemet 2005).

The same federal incentives have been a boon for the solar industry, where the primary mechanism used by the federal government is the investment tax credit. The investment tax credit (ITC) provides a tax benefit to the owner of a solar system to take a tax credit equal to 30% of the value of the system, up to \$2,000. Solar installations boomed following the three-year extension of the ITC in 2005, with total installations in 2008 more than triple the installed capacity of 2005 (Sherwood 2009). With the ITC set to expire in 2008, Congress extended the ITC for another eight years (through 2016) and equally important, it removed the \$2,000 tax credit cap, allowing property owners to recoup a larger percentage of the installation costs (Wang 2009b). Finally, the bill also allows electric utilities to use the tax credit, which had been prohibited under earlier versions of the ITC. It is too early to tell, but lifting the cap and allowing utilities to invest in solar projects will allow solar technology to move rapidly down the cost curve and serving as an important basis of support for solar over the next few years.

The ARRA made some other important changes to encourage renewable energy development and production, like extending the PTC for small-hydro, municipal-solid waste (MSW), bio-energy, geothermal, wave, and tidal energy through 2013. The ITC was expanded to include fuel-cells, small wind, geothermal heat pumps, and microturbine systems. The ARRA also directed millions of dollars toward the green energy sector, with the industry poised to receive more than 10% of the \$787 billion stimulus money, spread across various energy sectors (Table 16). The money is critical because traditional

loans have dried up in the face of the credit crunch that seized the financial markets at the end of 2008. Given the speculative nature of these companies and their technologies, their capacity to tap private funding sources is limited, yet without capital, many of these companies and these projects would fold. As a result, the government stimulus money fills an important void; allowing these companies, many of which are forging ahead with promising technologies that will enable our energy transition, to access capital as part of the stimulus bill.

Table 16: Stimulus funds for the new energy economy

Project / technology	Amount
Tax incentives / Credits (renewable energy, plug-in hybrids, & efficiency)	\$20 B
Grid Modernization / Smart Grid	\$11 B
Loans for renewable energy projects	\$12.3 B
Buildings	\$9.5 B
Batteries and Electric Vehicles	\$2 B
Mass Transit and High-Speed Rail	\$17.7 B
Water	\$6 B
Efficiency and Renewable Research	\$2.5 B
Total	\$81 B

Source: Makower et al. 2009

Because the capacity to transport wind and solar power, which is generated in remote areas, to the population centers (largely along the coasts) is inadequate, grid modernization is at the heart of a new energy economy in the United States.. The transmission infrastructure is outdated, is prone to failure, and is often congested, all of which contribute to more expensive electricity. Despite these shortcomings, and the fact that the federal government has money set aside for grid modernization, regional differences may jeopardize the grid modernization program. In particular, policy makers in the east are unwilling to endorse a transcontinental transmission grid, because their

constituents would fail to benefit from the millions of green collar jobs created in the construction of green energy projects but would suffer with higher utility costs. Most of the best wind and solar sources are far from the east coast, but the long run plan to help pay for the grid would impose a surcharge on every rate-payer. The east coast coalition is unwilling to sign on to the deal because too much emphasis is placed on moving mid-western energy eastward, rather than building the projects closer to where the demand resides (Wald 2009). Disagreements over what, where, and how to build are going to face intense political scrutiny as regional coalitions jockey for federal money.

Japan

As a small country with limited natural resources, Japan faced an extraordinary energy squeeze with the OPEC oil embargo, relying on imports to meet 99% of its fossil energy requirements (Nakata et al. 2005). Starting in 1974, Japan set out to diversify its energy supplies, invest heavily in R&D and support conservation efforts. Much like the United States, Japan's support for both applied and basic energy research was a coordinated effort by government, industry and universities. By 1994, the focus shifted from R&D to market support mechanisms whereby Japan launched its first efforts to define a renewable energy framework, centered around solar. The Japanese government mandated a set of net-metering laws, established a 70,000 roofs initiative to stimulate residential demand, and created generous subsidies to help offset the costs of solar installation. Public support has been consistent and growth of the PV market in Japan has remained steady. Subsidies initially started at close to 50% of the installation costs, but

by 2005, when the program ended, amounted to only four percent. Nevertheless, the program serves to grow the solar market so that by the program's completion, 200,000 homes had more than 800 MW of installed solar (Renewables 2009).

Because Japan has been committed to improved efficiencies for decades, much of the low-hanging fruit has already been realized. Nevertheless, a voluntary reduction plan, an RPS, and a third approach, known as the top runner approach have been put in place to further enhance efficiencies and decrease energy use. The voluntary action plan is a program dedicated for specific industries to work in coordination to lower CO₂ emissions. Companies that commit to the plan can apply for subsidies from the government. The top runner program mandates efficiency improvements for 21 items, like freight trains, autos, TVs, and air conditioners. The targets were initially considered ambitious, but consumer preference for new goods and a public awareness campaign to communicate the need for higher-efficiency goods has allowed manufacturers to meet their goals (Lee et al. 2009). Both these programs, in coordination with a 2003 RPS that set a goal of 16 million MWh of electricity by 2014 (RPS 2009), have successfully cut carbon emissions

Developing world

From a policy perspective, only a handful of countries in the developing world are pursuing carbon mitigation. Given the costs associated with making an energy transition and the 'blame' they place on the west for creating the problem, it is unlikely that they will play a leadership role in the new energy economy. And yet, their role is vital, given

the direct correlation between affluence and energy consumption. It is essential that the energy and electricity choices made in the developing world are sensible for the long term, because once a financial commitment is made to a particular technology, these countries are locked-in with limited resources available to help them change course.

Without any policy support in Africa, Central Asia, and Latin America, penetration of green electricity has been non-existent. Even in places like Indonesia, Brazil, India, and China, where some policy supports are in place, their political focus remains on economic development, not climate change, a concept that is not lost within the Kyoto framework. Using the CDM, Kyoto is tackling climate change at the global level, acknowledging that any carbon mitigation scheme is worthwhile. Annex One countries are willing to make investments in other countries largely because the costs may be more favorable than investing in a similar carbon reduction project at home. Kyoto has also written the rules so as to potentially accelerate the technology transfer that the developing world desperately needs. Knowing how tacit knowledge is usually locally retained, countries seeking to establish a foothold in the green energy industry, particularly those that are economically lagging, should hone research, educational, and policy resources into these emerging technological fields. As the developing countries ramp up their energy demand, and thus electricity consumption, CDM may serve as an important tool to help them leap-frog the same fossil fuel choices that remains a hallmark of development.

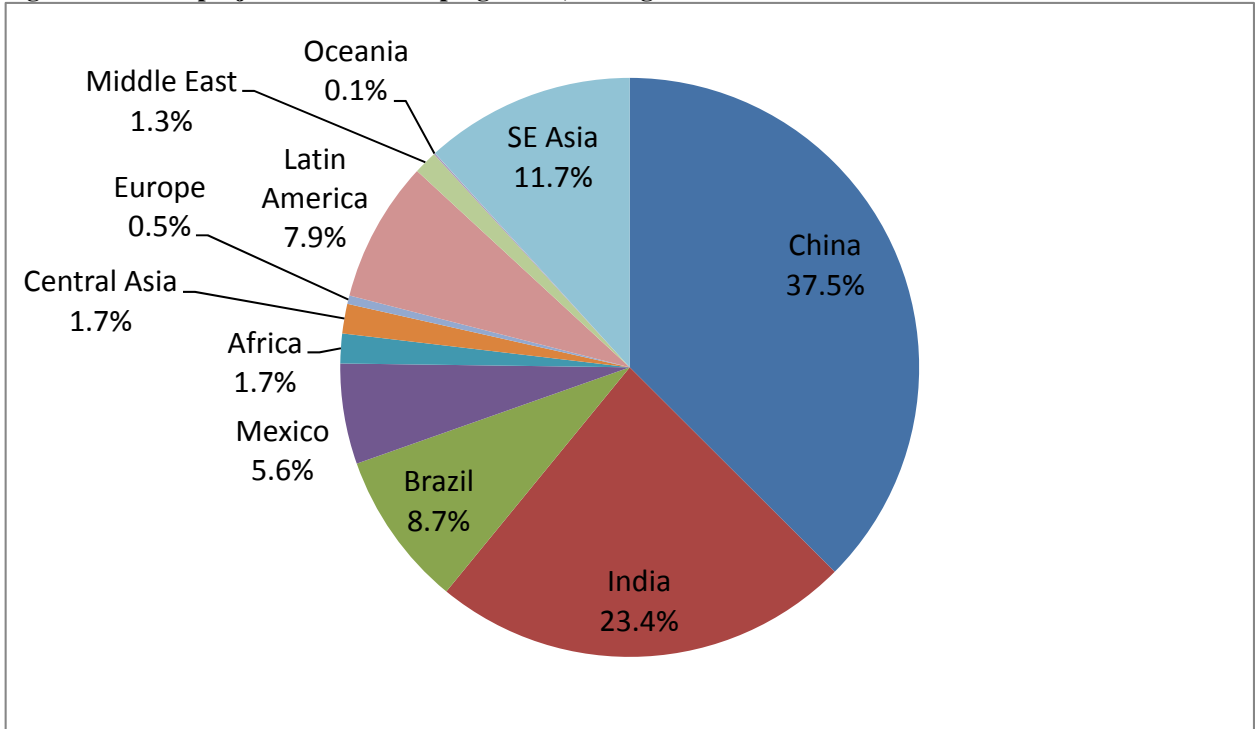
The leapfrog hypothesis states that developmentally lagging regions climb the economic hierarchy by embracing innovative technologies rather than outdate

technologies or modes of production (Brezis, Krugman, and Tsiddon 1993). In particular, cheap rents and low wages offer competitive advantages that limit the maneuverability of regions still operating profitably under the old paradigm. These older regions, home to firms with strong footholds in established industries, are likely to delay making the technological transition because initially, the new technology is inferior and therefore less profitable. In other words, during periods when economic growth and change are incremental, increasing returns to scale promote concentrations of economic activity as geographic nodes of specialization establish commanding leadership positions for certain industries or methods of production. However, during periods of economic dislocation, as outdated industries cling to old technologies, regional transition opportunities are created.

According to the IGES (2009), which maintains both the JI and CDM project database, nearly 2,000 CDM projects and close to 300 JI projects have been submitted. Referring specifically to the CDM, more than 60% of the projects are taking place in India and China and most are supported by European countries. Brazil and Mexico are hosting the third and fourth most CDM projects, with the other countries benefitting significantly less (Figure 22). Regionally, Latin America and SE Asia are attracting investments, while the Middle East, Africa, and Central Asia lag. These investments are critical; both the technology transfer capacity that might help reshape their economies, but the leapfrog nature of sustainable energy choices will help them make path dependent decisions that will free up capital to invest in other areas of society. At the end of 2008,

nearly \$35 billion worth of CDM transactions have been accounted for, mostly from the EU and Japan (GWEC 2009b).

Figure 22: CDM projects in the developing world, through October 2009



Source: IGES 2009

And while the developing world is willing to partner with Annex one countries to foster domestic development, limited policy provisions are found in only a handful of these countries. In 2005, China passed its 11th five-year plan, which included renewable energy law. With respect to renewable energy, China passed an RPS in 2007 mandating one- and three-percent by 2010 and 2020 respectively. However, for power companies operating more than 5GW of installed capacity shall have non-hydro renewables of three percent by 2010 and 8 percent by 2020. No national FIT is in place, but limited support for wind is in place and there is speculation that a FIT requiring that all renewable energy

be purchased by grid companies and utilities will pass in 2010. India, which already had a renewable target for electricity, upped their goal to 14GW of new capacity by 2012. India also enacted a national FIT in 2009 and equally important solar PV subsidies and loan guarantees.

Global Trends in Wind

Mounting arguments for wind

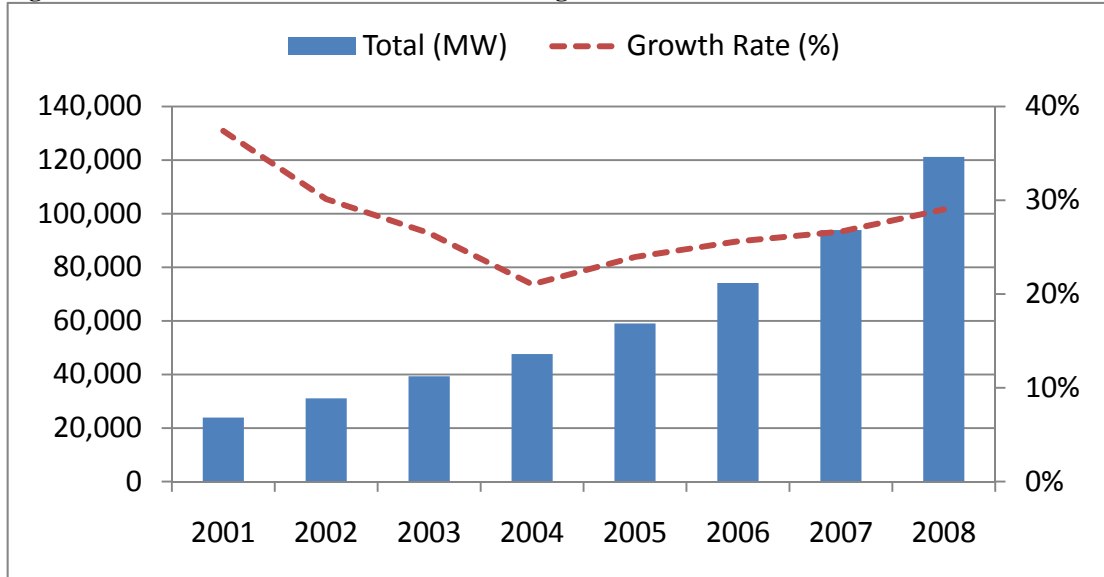
Much has been made about the prospect for wind and solar to solve our electricity problems. But as of 2009, wind has firmly established itself as the most important near-term green electricity option, whereas solar remains an evolving technology. The long term prospects for solar are very promising (and will be outlined in the next section), but for several reasons, wind is poised to capture the lion's share of the green electricity market in the coming years. First, wind is cost competitive with traditional fossil fuel sources – meaning it can generate electricity at a much lower price per unit than other green technologies. Many of the economies of scale within wind have been realized, the market is maturing, and the turbine size have brought the price per watt of electricity down to a point where parity with fossil fuels is close; in a carbon-regulated world, the benefits tilt heavily in favor of wind. Second, wind is scalable now, which is critical as countries seek a more aggressive transition to green electricity generation. Solar is not cost competitive, nor do solar manufacturers have the production capacity to meet the demands of countries seeking to satisfy their renewable targets.

Third, wind is a more diversely accepted technology with larger and a more geographically diffuse base of demand. The two largest markets for solar electricity (Spain and Germany) account for nearly 75% of global demand, making solar much more concentrated, and therefore susceptible to potential policy shifts in a small group of countries. On the other hand, the top two markets for wind (US and Germany) represent only 40% of the market, with China and India carving into that market share rapidly. The largest solar project in the world is a 60 MW plant in Spain, whereas there are nearly a dozen wind farms with a nameplate capacity 10X that amount (600 MW). For the renewable electricity production required to make a dent in fossil fuel's contribution to our overall electricity mix, solar suffers from a severe price disadvantage and in its current form lacks that ability to scale-up in a meaningful manner to meet the scope of our energy challenge. Finally, solar is still in its infancy; currently 90% of the market is PV technology, but because of disruptive technologies like thin-film and utility scale solar thermal, the landscape is likely to change significantly in the near-term as the market shakes out. As a result, solar penetration is weak as consumers wait for signals that the market has settled on a winning technology.

For all these reasons, wind remains the technology choice for countries seeking to diversify away from carbon-based fuels today. Despite selling for a premium compared with legacy electricity like coal and nuclear, wind energy installations have accelerated over the last five years. Since 2001 total wind installations have increased annually by 27.5% and by 2008, the world had more than 120,000 MW of install capacity (Figure 23). It remains to be seen how the global financial crisis of 2009 will impact the wind

landscape around the world, but for the United States, it appears as though installation rates will show a slight retreat from the record pace set in 2008.

Figure 23: Global wind installations and annual growth rates

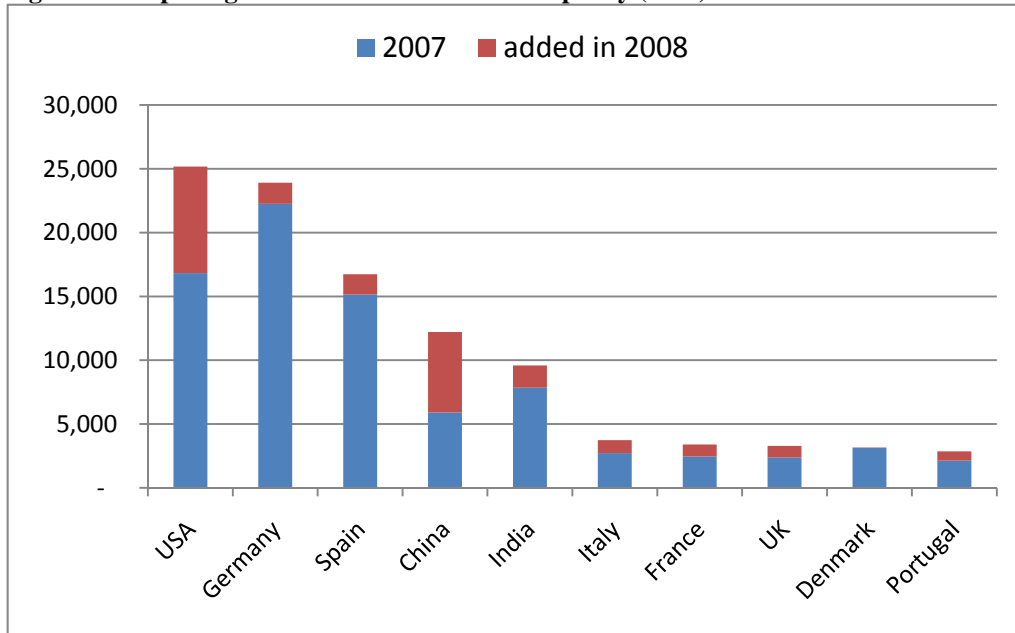


Source: GWEC 2009a

Europe leads the world in wind installations. Only five countries in the world were able to generate at least 5% of their electricity supplies from wind, and they were all in Europe: Denmark, Spain, Portugal, Ireland, and Germany (IEA 2008). Other countries are beginning to catch up, and in 2008, the United States overtook Germany as the country with the most installed MW in the world (Figure 24). China and India rank fourth and fifth in the world respectively, but China's entry in the wind market is especially noteworthy. In 2004, China had only 764 MW installed, but has since more than doubled the prior year's capacity in four straight years, an impressive growth rate and one that China seems set to maintain (Zhao et al. 2009).

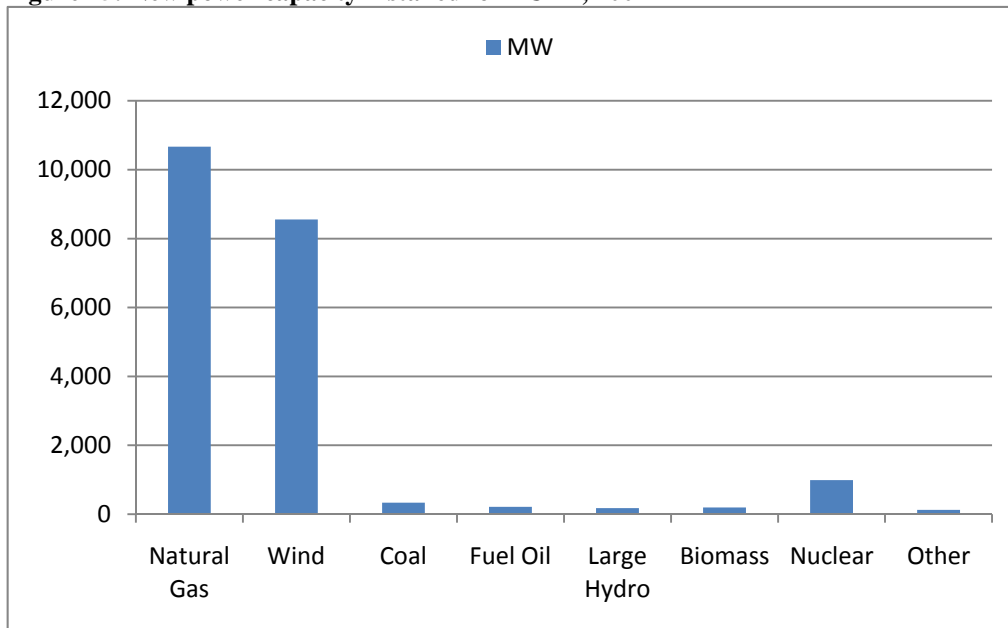
In an attempt to meet its Kyoto obligations as well as satisfy its ETS constraints, Europe is seeking the most environmentally benign electricity solutions. Natural gas accounted for half of the new power capacity installed in Europe in 2007 with more than 10,000 MW, but wind was a close second accounting for 40% of the total (Figure XXXX). A similar story is unfolding in the United States, where as recently as 2004, wind accounted for less than 2% of new electric generation capacity, but by 2008, 42% of new capacity was wind (AWEA 2009).

Figure 24: Top ten global installations of wind capacity (MW)



Source: GWEC 2009a

Figure 25: New power capacity installed for EU-27, 2007



Source: EWEA 2008

The business side of wind

Over the last 25 years, the cost of wind power has fallen by more than 90%, driven primarily by an increase in turbine size. Larger turbines are able to generate more electricity for two reasons. First, they are taller, meaning they are further from the ground where wind speeds are both faster and more consistent. The capacity to generate electricity from wind is incredibly sensitive to wind speeds. Based on the cube rule, every time the wind speed doubles, electricity output grows eight times (Table 17). Therefore a 10% wind speed improvement at a site (for ex. from 10mph to 11mph) actually generates 33% more electricity (the cube of 11 is 1,331, compared to the cube of 10, which is 1,000). As a result, a small difference in wind speed can generate a meaningful amount of additional electricity.

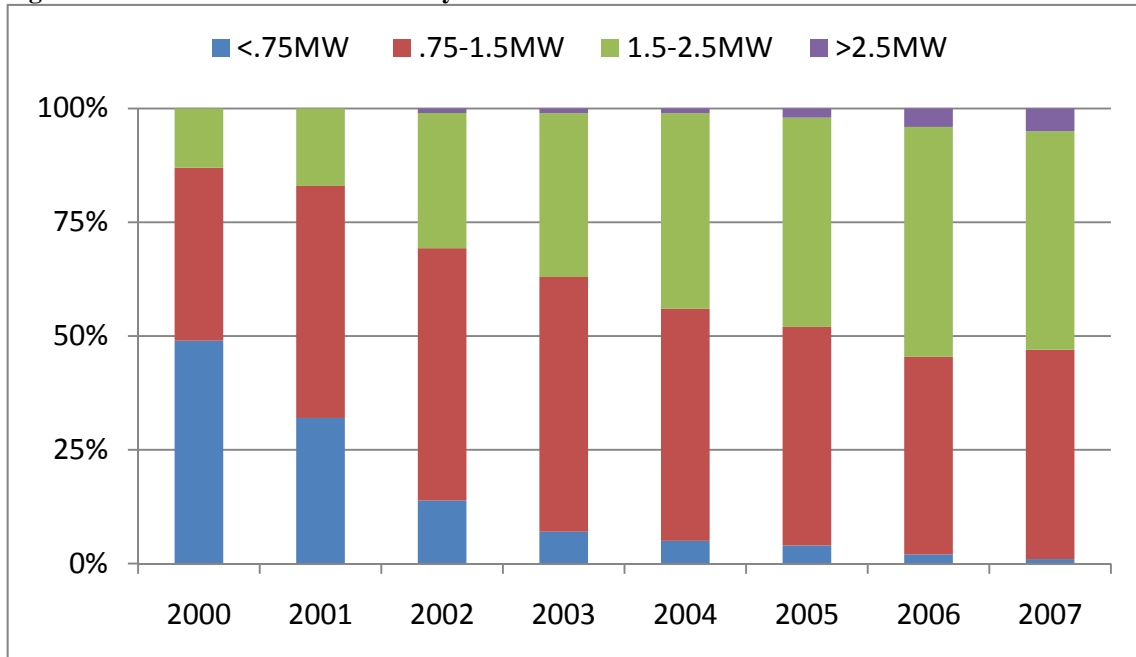
Table 17: Turbine size and annual electricity of an average turbine, 1980 - 2010

	1980	1990	2000	2010 e
Nameplate capacity	30 kW	250 kW	1.5 MW	5 MW
Rotor Diameter	15 m	30 m	70 m	115 m
Annual electricity	35,000 kWh	400,000 kWh	3,500,000 kWh	17,000,000 kWh

Source: Yates et al. 2008

Second, larger turbines can support longer blades. And while larger turbines have more expensive inputs, higher transport costs, and more technical and complicated installations, they are able to generate electricity far more reliably, which is why wind energy today, depending on the size of the wind farm, can produce electricity under 5 cents / kWh (including the PTC), which is comparable to conventional fossil fuel plants. Wind costs in the 1980s ran about 30 cents / kWh, when turbines averaged less than 100kw in size. Today, of the more than 5,000 turbines installed in the US in 2008, about half are 1.5MW, and 40% were larger than 1.5MW in size, with 3MW turbines becoming more common (Figure 26). And in Europe, where turbines in excess of 2MW represented only a fraction of total installations in 2001, in 2007, two-thirds of new installations used these larger designs (EWEA 2009).

Figure 26: Global Wind installations by turbine size



Source: Yates et al. 2008

Offshore wind is still only a minor contributor to overall wind power generation. In 2008, offshore wind accounted for one percent of the total wind capacity, with a geographic concentration in northern Europe where eight countries have a combined total of 1,471MW installed: Denmark, Sweden, the UK, Ireland, the Netherlands, Finland, Belgium, and Germany. Meanwhile, China and Japan are in the construction phase of several off-shore projects. The obvious limiting factor for offshore wind remains its higher installations costs; specifically those associated with the more formidable task of anchoring a turbine's foundations as well as connecting to an on-shore substation for electricity delivery. Despite a similar overall cost for the turbine, as a percentage of total costs, the turbine represents only 48.5% of the offshore installations, compared to 75.6%

for onshore (Table XXXX). Only two manufacturers (Vestas and Siemens) have turbine options for offshore installation (Yates et al. 2008)

Table 18: On-shore vs. Off-shore wind cost comparison

	On-shore		Off-shore	
	1000 €/MW	% of total	1000 €/MW	% of total
Turbine	928	75.6%	815	48.5%
Foundation	80	6.5%	350	20.8%
Electric installation & grid connection	131	10.7%	355	21.1%
Design and project management	15	1.2%	100	6.0%
Land	48	3.9%	0	0.0%
Misc	26	2.1%	60	3.6%
Total	1,228	100%	1,680	100%

Note: Currency in Euros because currently, the only offshore installations are in Europe
Source: EWEA 2009

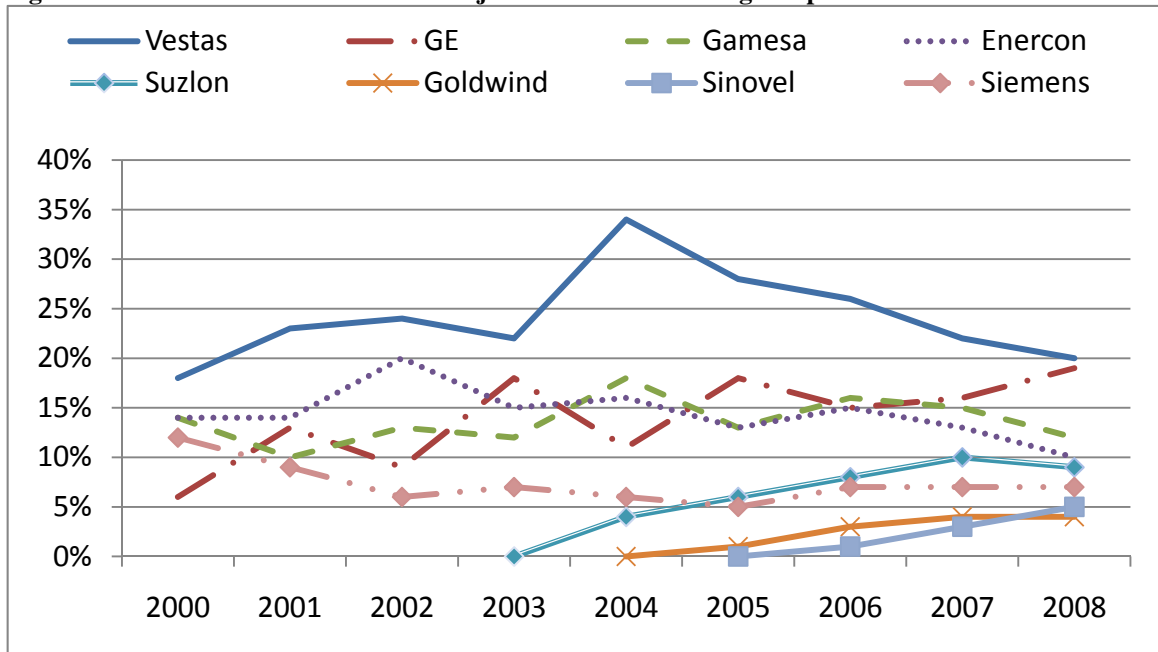
Wind Turbine Manufacturing

Wind turbine manufacturing is a rapidly maturing, yet still evolving industry.

While the same dominant companies have remained unchanged for a decade, new upstarts from emerging markets are beginning to challenge the hierarchy. Back in 1995, nearly all of the major players were found in Europe with limited manufacturing activity in the United States. Vestas Wind Systems of Denmark has consistently been the top player in the industry. In 2004, Vestas Wind Systems acquired its largest competitor NEG Micron, and their market share surged to capture one-third of the market (Figure 27). In fact, by combining the turbine sales for NEG and Vestas for each of the three years prior to the merger, the combined company controlled between 40-45% of the market. It has since fallen back as new entrants in China (Goldwind and Sinoval) and India (Suzlon) entered the market starting in 2004. In fact, Suzlon's growth strategy has been two-pronged, by capitalizing on turbine demand in India as well as expansion

through acquisition, when in 2007 it bought REPower of Germany to establish a foothold in the European market. Meanwhile, prior to its bankruptcy in 1996, Kennetech was a major player in the US as was Enron Wind. As part of its liquidation, Enron's assets were bought by GE in 2001, and GE has seen its fortunes rise in the global wind arena ever since. GE's fortunes mirror the authorization lapse of the PTC in the United States, but since 2004, it has internationalized its revenue stream and is now perched atop the industry alongside Vestas.

Figure 27: Global market share of the major wind manufacturing companies



Source: Author's calculations

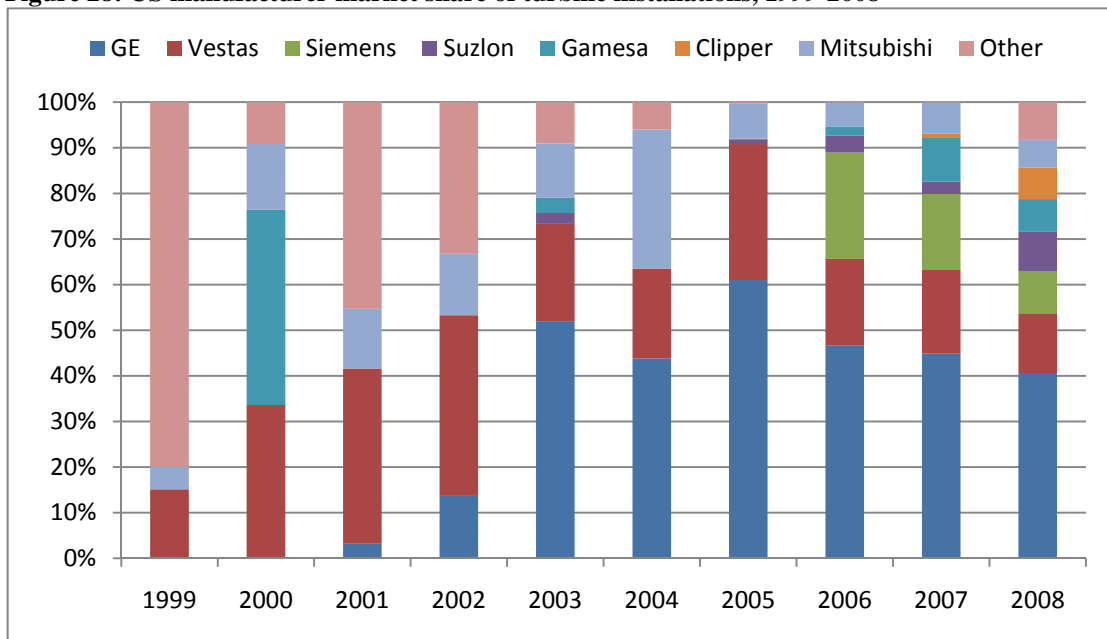
An improvement in wind technology and market acceptance of its capacity has generated global business appeal, but the manufacturing landscape is mixed. On the one hand, companies like Vestas, Gamesa, Enercon, and Suzlon are dedicated wind companies. On the other hand, large multinational conglomerates like GE, Mitsubishi,

Ecotencia (recently purchased by Alstom), and Siemens have been lured in by the obvious growth and profit potential of this still nascent industry. Given their expertise to finance and build big projects, the entry of these diversified industrial behemoths was a natural fit. While the industry is still in its infancy, the capital intensity of wind turbine construction suggests that economies of scale should enable these companies to solidify their positions making it difficult for potential upstart companies. Consolidation at the top has been the norm since 2000, as the top five companies have controlled no less than 70% of the global market every year.

That is not to say there is no room for additional players. As the market for wind continues to grow, it is certain to attract additional capital which should spawn new manufacturers and increased competition. Despite high barriers to entry, the explosive revenue potential in wind turbine construction and installation will be too tempting and new entrants should be expected. Barriers are not insurmountable and new manufacturers can establish footholds in certain market niches. For example, as the top companies invest in higher-margin larger units, an opening should emerge in the smaller turbine market, that will allow new companies to establish industry traction it can leverage in future years. Alternatively, the market is sure to become more segmented as larger turbines or offshore installations grow, creating opportunities for new specialized players. Recent history supports new entrants based on the industry's attractive profile, with the turbine makers emerging from India and China, as well as Clipper Windpower in the United States.

All of the dominant wind industry companies are global players, but all have carved out commanding footholds in their domestic markets. Local demand serves as a revenue anchor for a new company, and as a result, the local policy framework which is critical in the early years as a company ramps up sales. In the United States, which is the world's largest wind market, GE was not a player in 2000. In 2001, it earned less than five percent of all orders, but by 2003 GE was the market leader and has captured no less than 40% of all orders, but by 2003 GE was the market leader and has captured no less than 40% of the US market in each subsequent year (Figure 28). GE has used the commitment to wind in the United States to secure a dominant global position.

Figure 28: US manufacturer market share of turbine installations, 1999-2008

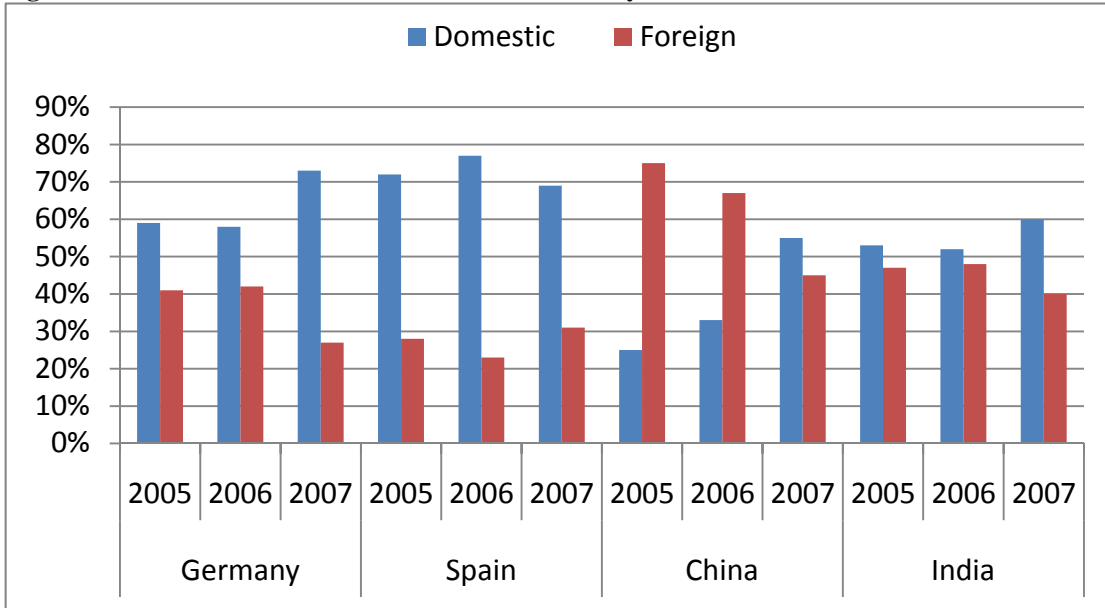


Source: Authors calculations

The same story holds in Spain and Germany, the two next largest wind markets, where domestic manufacturers have installed anywhere from 58% - 77% of new turbines in their home market over the last three years. And a similar story is evolving in China and India, where their domestic manufacturers are still relative newcomers, but have

quickly become the dominant players in their home markets (Figure 29). In fact, China has done more than simply support wind from an installation perspective, its policy mandates that at least 70% of the turbines be locally produced. (Li and Gao 2007).

Figure 29: Share of domestic wind market controlled by domestic manufacturers



Source: Authors calculations

With the exception of Vestas, each of the other major manufacturers is dominant in their domestic market. But the Vestas story is no different in that Denmark was a very early mover in the wind industry, installing most of their turbines more than a decade ago, but has seen its pace of wind installations slow significantly. As recently as 2002, Denmark trailed only Germany, Spain, and the US in total installations, with 2,500 MW, but has since fallen to ninth place globally adding roughly 25% in the last five years, while other countries have doubled or even quadrupled their installed capacity. Needless to say, Denmark's commitment to wind was a boon for Vestas early on, and Vestas has

since leveraged that expertise to expand its international business and capture market share in other countries. While the installations in each country that is home to a major turbine manufacturer is dominated by that domestic company, Vestas has established market leadership positions in those countries that lack a major manufacturer (Table 19). For France, Canada, the UK, Portugal, and Italy, Vestas holds either the top spot or the second spot in terms of total installations. In fact, Vestas is the only company among the top three manufacturers for each of the top ten wind installations countries in 2006.

Table 19: Leading manufacturers in major global wind markets, 2006

Country	2006 installed (MW)	Top 3 Manufacturers		
USA	2,454	GE Wind	Vestas	Siemens
Germany	2,233	Enercon	Vestas	REPower
India	1,840	Suzlon	Enercon	Vestas
China	1,334	Goldwind	Vestas	Gamesa
Spain	1,587	Gamesa	Acciona	Vestas
France	810	Nordex	Vestas	REPower
Canada	776	GE Wind	Vestas	Enercon
UK	631	Vestas	Siemens	REPower
Portugal	629	Vestas	Gamesa	Enercon
Italy	417	Gamesa	Vestas	Enercon

Source: Efiog and Crispin 2007

When looking at the list of major players in the export market, there is a clear geographic discrepancy. The companies headquartered in Europe and the US are exporting to the world, while the Asian companies are not. There are several possible explanations for this. It could be that Asian markets are growing so rapidly that domestic demand is soaking up any excess supply. It could also be that Asian manufacturers are building smaller turbines (less than 1.5MW) and so their product offerings do not match demand in the developed world. It could also be that their turbines are still unproven.

Although cheap labor allows Asian manufacturers to build for less, with so many moving

parts inside a turbine, cheaper prices offer little consolation if it is sitting idle and unable to produce electricity because the turbine is in constant need of repair. It may take a few years for the Asian manufacturers to establish a track-record that will assuage western concerns. This gap in technology and western confidence might explain part of the rationale for Suzlon of India to buy REPower of Germany, thus accelerating its penetration into more established markets.

Despite the industry's relative youth, it is showing signs of maturation, in particular with respect to the supplier networks. A wind turbine is comprised of more than 8,000 parts (Schoof 2009), but something of a consensus has been reached across the industry on the optimal design. This will be good news years from now, as substitution potential on parts will be available as component makers standardize their inputs; unfortunately in the near-term, there is virtually no slack in the supply chain and fewer and fewer third party vendors to fill the growing demand. As a result, keeping pace with overall demand has been the source of greatest frustration. Equally challenging has been the rapid transition to larger parts. Most specifically, bigger turbines require larger generators to capture and convert the additional wind resources into electricity. Furthermore, some of the critical components in the turbine supply chain are dominated by a small number of players particularly bearings and gearboxes (Aubrey 2007).

With the rapid growth in the wind industry over the last five years, spare capacity in the turbine market is limited. Order volumes and sizes are increasing and turbine makers are hoarding component parts to ensure it meets its delivery obligations. The strongest companies enter into long-term agreements with component suppliers, while

turbine manufacturers that lack visibility on component supplies are at a disadvantage in the market place. And yet, because the component supply business has so few players, all turbine manufacturers face market risk, for the system is constrained in that turbine companies can't procure parts from a secondary manufacturer should its primary supplier experience disruption. Additionally, this limited competition has kept component prices high. Thus as the market continues to mature at the component level, more competition, a more flexible supply chain, and better pricing power should follow.

And yet, few new companies are stepping in to meet the demand. There are several explanations for why these tight market conditions persist. For one, plant and manufacturing equipment is very capital intensive; given the global credit crunch, these conditions are tough to overcome. Second, the opaque nature of policy implications driving much of the wind demand in the United States, the world's largest wind market, has forced many companies considering expanding into products that would serve the wind supply chain to think twice. Many have been unwilling to fully embrace the wind industry and its fickle policy foundations, opting instead for businesses with greater financial visibility. Third, turbine makers are pushing a lot of the warranty issues onto their suppliers. As a result, the costs to component manufacturers, particularly those with lots of moving parts, are still in flux.

It is no surprise then that with increased frequency, turbine manufacturers have brought component suppliers in-house in an effort to guarantee security over its supply chain (Table 20). This move towards vertical integration allows turbine makers to more confidently and more firmly commit to delivery deadlines. Blades and control systems

have been brought in-house for most of the big manufacturers, whereas for the most part, gearboxes and generators are still outsourced. And while it is no surprise that for those outsourced components, turbine makers are tightly integrated in procurement, the lack of component manufacturers, particularly for gearboxes has created an interesting market twist. Two of the largest gearbox suppliers, Winergy and Hansen, were recently purchased and brought in-house by Siemens and Suzlon respectively. Yet, one or both companies supply gearboxes to nearly all of the major turbine manufacturers. For the moment, these acquisitions reflect a competitive advantage for Siemens and Suzlon, until new suppliers enter the market and provide alternatives.

Table 20: Wind industry supply chain

Manufacturer	Rotor Blades	Gearboxes	Generators	Towers	Controllers
Vestas (Denmark)	Vestas, LM	Bosch, Rexroth, Hansen, Winergy, Moventas, Fellar	Weier, Elin, ABB, Leroy Somer	Vestas, NEG, DMI	Vestas, NEG
GE Wind (USA)	LM, Tecsis	Bosch, Rexroth, GE Rail, Eickhoff, Fellar, Winergy Moventas	Loher, GE	DMI, Omnical, SIAG	GE
Gamesa (Spain)	Gamesa, LM	Gamesa, Winergy, Hansen	Gamesa, Cantarey	Gamesa	Gamesa
Enercon (Germany)	Enercon	N/A	Enercon	KGW, SAM	Enercon
Siemens (Denmark)	Siemens, LM	Winergy, Hansen	ABB	Roug, KGW	KK Electronic, Siemens
Suzlon (India)	Suzlon	Hansen, Winergy	Suzlon	Suzlon	Suzlon, Mita Teknik
Nordex (Germany)	Nordex	Winergy, Eickhoff, Maag	Loher	Nordex, Omnical	Mita Teknik, Mordex

Source: Aubrey 2007; Efiang and Crispin (2007)

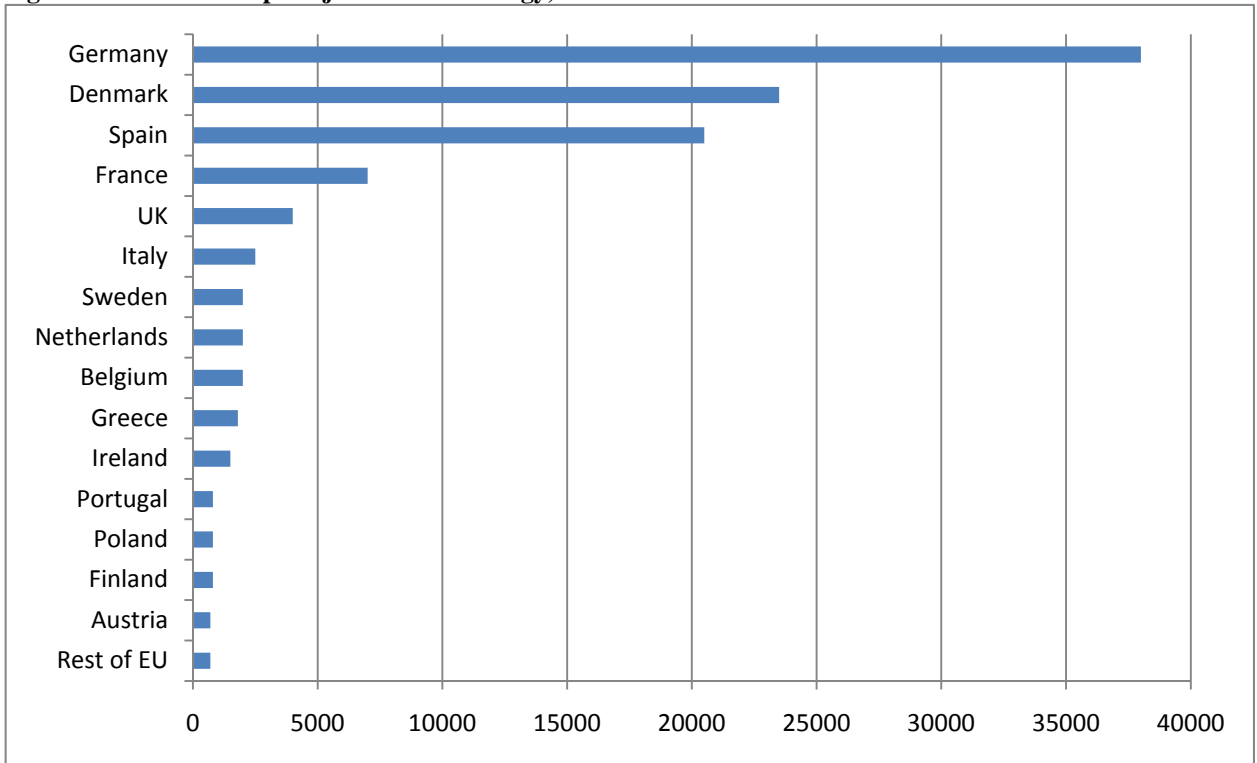
Gearboxes tend to be the most troublesome component of a turbine and the part that has represented the most crucial industry bottleneck. In 2007, 80% of the profit warnings from publically traded wind companies were a result of gearbox issues (Efiong and Crispin 2007). The market suffers because there are only a handful of gearbox manufacturers, and because of their historically low margins, few new entrants have come online. Margins are low, because gearboxes are more susceptible to breaking, thus the warranties erode profit margins for manufacturers. Vertical integration trends are appearing, in part because ramping up gearbox production to serve the newer multi-megawatt models can take several years (Aubrey 2007), and so companies that make their own gearboxes might be better positioned to capture market share in the event of a sharp spike in demand or rapid technological changes. From Table 20, only two of the companies rely exclusively on outside suppliers for their gearboxes (Vestas and Nordex), making them perhaps a bit more vulnerable, since gearboxes have to be slightly altered depending on the turbine's size.

Of note is the lack of a gearbox supplier for Enercon whose technology marks an important departure from orthodox turbine design. Because gearboxes tend to serve as the bottleneck in the supply chain as well as the component most likely to need repairs, Enercon has abandoned the gearbox altogether. Instead, Enercon, as well as a few other small manufacturers like AWE Wind, have pursued direct drive technology. Gearboxes connect the rotor with the generator, and they serve to accelerate the somewhat slow rotations of the turbines into faster rotations needed to generate electricity. Direct drive technology converts the blade rotations directly into electricity using magnets and while

the design is mechanically much simpler, it is much heavier and larger, which has its own set of design implications (Enercon 2009). Nevertheless, as design breakthroughs are concerned, direct-drive technology has the potential to sharply reduce turbine downtimes and costly repairs, thus improving the financial and energy performance for wind technology.

Jobs are highly concentrated in a few countries within Europe which is similar to the concentration of top turbine manufacturers globally. Based on a study conducted by the Global Wind Energy Council (GWEC 2009a), 15 jobs are created for every MW of wind installed – which includes manufacturing (both turbines and components), development of wind farms, installation, and indirect jobs. Additionally, there are the ongoing maintenance and operations aspects to wind-farms, which the study concluded produced 1 job for every 3 MW of installed capacity. In 2007, wind energy related jobs employed more than 108,000 people in the EU-27 countries (Figure 30). More than half of the countries support wind jobs, with Germany, Denmark, and Spain leading the way. In addition, the report cited 42,700 indirect jobs, resulting in a total of 151,000 jobs in the EU in 2007. While 75% of the jobs are found in three countries (accounting for about 70% of EU installed capacity), the labor impacts are actually diffusing as 89% of all EU wind-related jobs in 2003 were found in these three countries (EWEA 2008). Although the study did not look at the United States, because it has installed 25,000 MW, similar to Germany, it stands to reason that the employment benefits would resemble Germany.

Figure 30: Direct European jobs in wind energy, 2007



Source: Wind energy: the facts 2009

Most importantly, these job gains in wind energy are cushioning the blow from the liberalization of the energy sector a decade ago which resulted in decimating job losses in traditional fossil fuel areas (UNEP, ILO, ITUC 2007). More importantly, employment assumptions rise when the wind is installed offshore, where projections are for significant growth in the coming decades. But at the moment, nearly all of the wind energy is generated on land.

Wind remains the most cost competitive source of alternative electricity generation, and its benefits could serve to revitalize small towns and rural communities. As the US is faced with increased pressure to reduce farm subsidies, the supplemental income from situating wind turbines on farm land will help them make the transition off

the public dole. The Farm Bill that passed in 2002, began the process of introducing farmers and ranchers to the financial benefits of wind power (and other renewables), by authorizing the 'Renewable Energy & Efficiency Improvements Program' which provides \$115 million to the Department of Agriculture for energy projects (DOA 2002). When the next Farm bill passed in 2008, the program was renamed to 'Rural Energy for America Program', with the program increasing its commitments to more than \$250 million (DOA 2009). According to a study released by the GAO (2004), a farmer can expect to receive royalty payments from \$2,000 to \$5,000 per turbine, in addition to the tax benefits that accrue to the local government, money these communities need as more rural areas continue to suffer from a declining tax-base as a result of out-migration. Furthermore, in the absence of direct government payments through agricultural subsidies, these rents offer an alternative 'stable' payment that will last for the duration of the lease (20-25 years).

Capacity Factor and Capacity Credit

There is an important near-term obstacle for wind. According to the British Wind Energy Association (BWEA 2005), wind turbines generate optimal power when wind speeds are about 30mph; a typical turbine can begin to generate electricity when the wind is blowing at 8 mph, but the turbines must be shut down when wind speeds exceed 50 mph in order to prevent damage to the gear boxes. The most obvious benefit that wind has over conventional sources of electricity is that the fuel is free. The obvious drawback for wind is that the fuel is intermittent. There are two important drawbacks to wind:

capacity factor and capacity credit. Capacity factor measures the amount of electricity that a turbine will produce in a year and capacity credit reflects the amount of legacy units that can be retired as wind assumes a more reliable portion of the electricity supplies.

Calculating a capacity factor is a simple calculation. A windfarm with a single 1.5 MW turbine operating at full capacity¹¹ for a year would have an installed capacity of 1.5 MW (sometimes referred to as 'nameplate capacity') and it would produce 13,140 MWh of electricity. But because wind is an intermittent resource, installed capacity is a theoretical number that is never reached. As a result, its capacity factor measures the total amount of power that a wind turbine actually produces, when averaged over a year, compared with what it would produce if it were running at maximum capacity all the time.

According to the Global Wind Energy Council (GWEC 2009a), there were 11,603 MW of installed capacity in the United States at the end of 2006, and according to the IEA (2009), wind generated 26.6 billion kWh of electricity. 11,603 MW, generating electricity at full capacity would produce 101.6 billion kWh, which means that the capacity factor for the United States was 26.2%. The numbers are less impressive on a global basis, where in 2006, there was 74,223 installed MW, generating 130 billion kWh of electricity (IEA 2009), resulting in a capacity factor of 20%. In fact, for 2006, the last year for which data are available, of the ten countries with the most installed MW of

¹¹ Full capacity refers to 8,760 hours per year (24 hours a day, 365 days per year) A unit of energy is call a watt (w); a kilowatt (kW) is 1,000 w, and a megawatt (MW) is 1,000 kW. When electricity consumption is measured for a household, it is done in kWh. If a 50w light bulb is left on for 20 hours, it uses 1 kWh of electricity. The average home consumes about 10,000kWh per year. If a 1 MW wind turbine operates 24 hours a day, 365 days a year (8,760 total hours for the year), it will produce 8,760,000 kWh of power.

wind energy, none of them have achieved a capacity factor greater than the United States (Table 21).

Table 21: Capacity Factor for Wind among top ten countries of installed capacity

	Installed MW (2006) ^a	Electricity generation ^b	Capacity Factor
Germany	20,622	3,506	17.0%
Spain	11,615	2,630	22.6%
US	11,603	3,045	26.2%
India	6,270	913	14.6%
Denmark	3,136	697	22.2%
China	2,604	442	17.0%
Italy	2,123	339	16.0%
UK	1,963	482	24.6%
Portugal	1,716	334	19.5%
France	1,567	245	15.6%
World Total	74,223	14,840	20.0%

^(a) GWEC 2009a

^(b) IEA 2009

Capacity credit is a more complicated calculation. Whereas capacity factor is a simple relationship between nameplate capacity and the amount of electricity that is actually produced, capacity credit is a reflection of the older generation units (typically fossil fuel) that can be removed from the grid while still maintaining grid integrity (Dale et al. 2004; Milligan 1997). Because it is not reliable, the capacity credit for wind is going to be less than the capacity factor, but it is not going to be zero¹². In other words, because wind power is intermittent, it cannot be relied on to deliver its average electricity at all times, and in particular when there are spikes in demand. And while wind is not the

¹² While wind speeds can fall to zero, that rarely happens, because wind farms do not operate in isolation, Because wind power is dispersed across a broad geographic landscape, wind does provide some level of reliability and energy planners use statistics to handle the loss of load probability, which uses historical data to calculate the odds of insufficient supply. It turns out that the capacity credit for wind is a reliable mathematical calculation (for a list of studies, see Giebel 2005)

only intermittent resource, its ability to generate electricity is temporally inconsistent compared with solar or tidal power which have predictable daily variations.

The output gap (the difference between the average and the minimum) is what forces utilities to continue operating their spinning reserve. Spinning reserve refers to other generating units that must continue operating in the event wind resources suddenly disappear. Units that serve this reserve capacity are still burning fuel but are not creating electricity; they serve an emergency function, but they cost money for which the operators will not be compensated. Other electricity sources must therefore remain operating as back-up, usually gas or coal, and as a result, it is the capacity credit that helps utility managers calculate the role for wind in its day-to-day operations.

In July 2008, the US Department of Energy published a report calling for the steps necessary to generate 20% of the domestic electricity supply from wind by 2030 (DOE 2008b). According to the report, US electricity consumption is expected to grow to 5.8 billion MWh in 2030 and suggests that wind will supply 20% of the demand. The report says that 305,000 MW of wind will need to be installed by 2030¹³, which would have a nameplate capacity of 2.67 billion MWh. Should wind provide 20% of the total projected electricity demand in 2030, it would need to produce 1.16 billion MWh, which works out to be a 43.4% capacity factor. With the US capacity factor of 26.2% in 2006, achieving this more ambitious goal would suggest that the best wind resources have not yet been exploited, which seems odd given the for-profit liberalized economic policies driving wind development in the United States. Expecting such an improvement in the

¹³ When the report was released in July 2008, the United States had an existing 20,000 MW of installed wind capacity, so meeting the 305,000 MW would require 285,000 MW of new wind.

capacity factor for wind is unlikely unless major improvements in turbine technology (larger towers and longer blades) or offshore wind is more fully embraced and exploited.

Solar

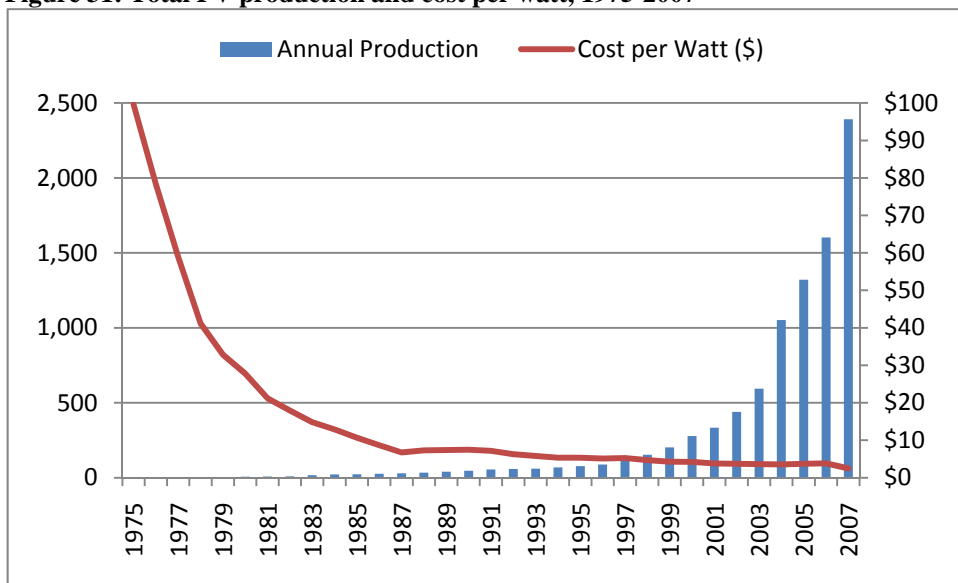
The Basics of Photovoltaics

Generally speaking, there are two ways the sun is used to produce electricity: photovoltaic (PV) modules produce electricity when their cells are exposed to the sun, while concentrating solar power systems (CSP) focus sunlight in a large-scale system that spins a turbine. A third type of solar power, low-temperature solar thermal, concentrates the sun's energy to heat water for residential use; penetration rates for solar hot-water systems have been mixed around the world, with developing countries using the technology in off-grid rural areas. Thanks to the federal tax credit, installations of solar hot-water (and swimming pool) systems in the United States have been robust since 2005, with Hawaii home to about half of the solar hot-water systems. Meanwhile, China leads the world in solar thermal installations (Sherwood 2009). Despite the surge in solar-hot-water systems, and their important role in curbing energy consumption, this report will focus on the two electricity generating technologies.

There are many benefits to electricity generated from the sun including: free fuel, no moving parts (for PV), no noise or pollution, quick installations, and limited maintenance. For all of these reasons, there is widespread optimism that solar represents the long term solution to our electricity problems. While many obstacles remain, the most important near-term challenge is the cost. Solar manufacturers are in a desperate

attempt to reach parity; the point at which energy from solar is equal to the cost of electricity generated from the conventional units. Ignoring government support, which is notoriously fickle and geographically varied, the drive towards parity is drawing a lot of interest, resulting in falling costs. The cost for solar technology has been falling annually by about five percent (Figure 31), where in 1980 they were \$27/watt, but by 2007, were below \$3/watt.

Figure 31: Total PV production and cost per watt, 1975-2007



Source: Earth Policy Institute 2008

Several types of photovoltaic cells (PV) are on the market today, but crystalline silicon based solar has achieved the highest penetration rates. With 90% of global solar installations in 2007 and 19 of the top 20 largest power plants in operation, crystalline based PV has been the technology choice through 2008; that it shares the same basic underlying technology used in the electronics industry has served to benefit industrial understanding and comfort with the silicon based solar (EPIA 2009). Crystalline PV

remains the optimal choice because it has the highest efficiency ratio of any solar technology. Efficiency ratios are calculated based on the amount of electricity produced given the amount of surface area exposed to solar irradiance, and the higher the efficiency ratio, the better the module does at converting sunlight into electricity. At the moment, crystalline PV cells have efficiency ratios between 15-19%. But crystalline modules¹⁴ are bulky and heavy, requires large amounts of silicon (which is the most expensive input), and has a lengthy production procedure. Of the two types of crystalline based-PV in Table XXXX, mono crystalline is more efficient, but it is also more expensive.

Thin-Film Solar

An emerging technology known as thin-film solar, has shown some real promise in the laboratory, and possesses some advantages over crystalline PV technology. Thin-Film (TF) requires substantially less silicon, is low-weight, possesses a smooth appearance, has a simplified manufacturing process, and can generate electricity in low or dimly lit conditions. The critical drawback for TF remains its lower efficiency ratio, so anyone looking to invest in TF will need more space and will have to buy more cells in order to match the electricity produced from a smaller amount of crystalline PV. These cost advantages are luring a lot of research and development attention into TF, and researchers are experimenting with different types of material. The winning technology

¹⁴ Modules are a group of solar cells. Solar cells are the device that converts sunlight into electricity, and a group of cells assembled together is called a solar module (also referred to as solar panel). A group of panels is called a solar array.

is still unknown but if the efficiency ratios can match (or exceed) crystalline, the potential for TF on a cost-per watt basis would enhance its competitiveness in the market place.

Table XXXX lays out the major differences between the leading solar technologies.

Table 22: Efficiency and land requirements for leading types of solar technology

Technology	Thin-film based			Crystalline Wafer based	
	Amorphous Silicon (a-si)	Cadmium telluride (CdTe)	CIGS	Mono-crystalline	Multi-crystalline
Cell efficiency	5-7%	8-11%	7-11%	16-19%	14-15%
Area per kWh	15 m ²	11 m ²	10 m ²	7 m ²	8 m ²

Source: Solar Generation V 2008

Following the bursting of the dot.com bubble at the start of the century, many of the silicon companies dedicated to supplying the semi-conductor market went out of business, and companies having so recently been burned, were reluctant to get back into the silicon business. What limited silicon supplies existed was enough to satisfy the PV market in its infancy in the early part of the decade. But as the technology matured and demand began to rise, a silicon shortage constrained the PV market. By 2006, silicon sales to the solar market eclipsed sales to the semiconductor market (Jennings et al. 2008), yet silicon suppliers were still not stepping in to meet this increased demand. Ironically, silicon for solar cells can be of lower quality than the silicon required for semiconductors. As a result of the shortages, PV manufacturers sought ways to use silicon more effectively and efficiently, thus leading to the rise of TF. Amorphous silicon, cadmium telluride, and CIGS (copper indium gallium selenide) make up the three thin-film technologies. In addition to the advantages listed above, thin-film offers one additional advantage of crystalline-based ‘thick-film’ competition; as the name implies,

thin-film solar is highly versatile and can be embedded on very thin or flexible substrates, thus allowing it to be integrated into buildings.

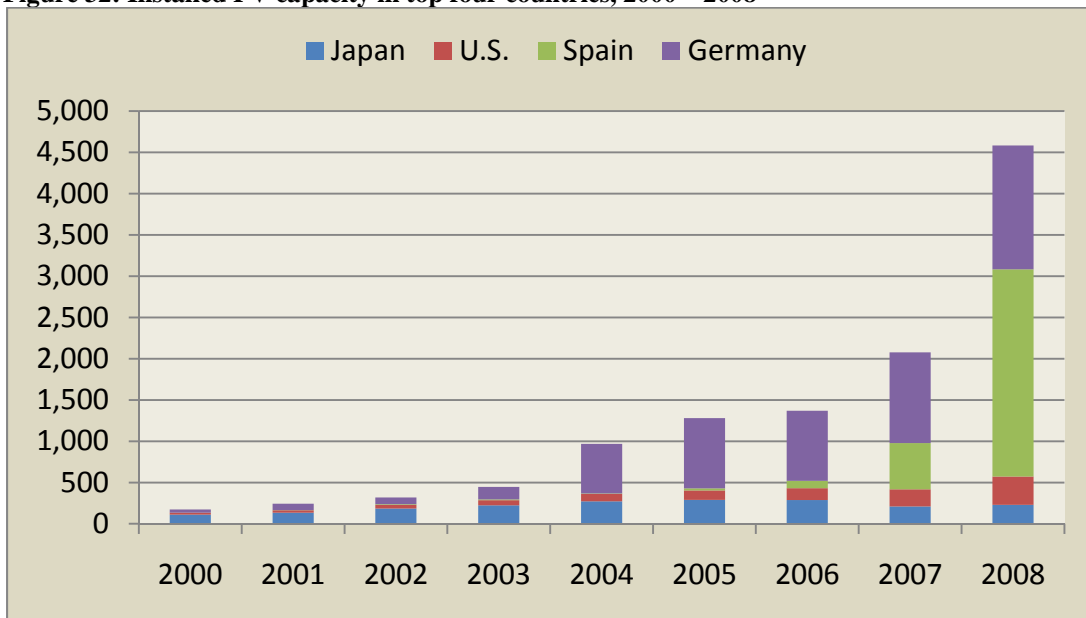
The near term picture seems to favor crystalline, particularly as the silicon glut is removed, thus reducing the cost. Over the medium- to longer-term however, improvements in efficiency ratios combined with better pricing power should favor TF. Over the last three years, these trends have begun to play out; in 2005, TF represented only 24% of all US domestic PV shipments, but because TF production has been doubling every year, TF now accounts for about 40% of the solar market in the United States (EIA 2009b). Globally, the penetration rates for TF hover around 20%, but it is trending up, and the IEA (2009) estimates that by 2009 TF production will represent a third of global productive capacity. The stock market seems to think that TF will be the longer-term winner as well. Of all the pure play public solar companies traded on a United States stock exchange, First Solar (USA), which makes cadmium telluride TF, has a \$12 billion market capitalization, four-to-six times greater than the next largest solar companies like Suntech Power (China), Sun Power (USA), LDK Solar (China), Solarworld (Germany), Canadian Solar (Canada), Evergreen (USA), or Trina (China), who are all involved in crystalline silicon production.

A snapshot of global installations

Only four countries in the world have more than 1,000MW of cumulatively installed solar capacity (Figure XXXX); three others (S. Korea, Italy, and China) have less than 1,000 MW but more than 100 MW of cumulatively installed solar capacity.

There are several explanations for solar's slow adoption. First, the costs are too high. In order for solar to become more competitive, either economies of scale are going to need to push the manufacturing costs down or the technology is going to have to improve the efficiency ratio so that more electricity can be generated. Alternatively, a regulatory framework can be put in place that makes solar's cost structure more palatable. This can be done by raising the cost of fossil fuel electricity through the introduction of carbon legislation, or by subsidizing electricity generated from solar, which is what both Spain and Germany have done. Support for solar in Germany and Spain are directly related to policies by the Renewable Energy Sources Act and Royal Decree respectively. Despite the comparatively high install rates, the outcomes in each country are very different.

Figure 32: Installed PV capacity in top four countries, 2000 – 2008



Figures are in MW
 Source: Earth Policy Institute 2009

Since 2004, no country has installed more PV than Germany. Thanks to a tweak in the feed-in tariff, solar installations have exploded, accounting for more than half of all global installations from 2004-2007. But the installation story is one of diffusion, with a diverse mix of solar ownership. Just over half of all PV in Germany were 10-100kw systems installed on multi-family houses, farms, warehouses or commercial buildings. An additional 7% were very large systems (>100kw) on oversize commercial buildings. Residential systems accounted for 30% of the PV, and extremely large ground-mounted (utility scale) PV accounted for the remaining 10% (EPIA 2009). PV installation rates are attributed to the FIT, which more than anything reduces the risk of green electricity projects, by establishing a visible payment structure that facilitates rapid deployment.

Spain offers a view of what can happen when the legislative support is not thought through. In 2007, Spain authorized a very generous FIT that caused a rush of installations by developers seeking to capitalize on the subsidy. The Spanish government, overwhelmed by the financial strains of the boom, was forced to alter the tariff system; at first they raised the number of permitted projects from 400MW to 1,200 MW, but soon the government realized that the market would zoom through the new ceiling and lurched again, this time with a 30% cut in the subsidy. Although Spain was the top market for solar development in 2008, its reputation was stained as many developers, who rushed in to take advantage of the FIT, were burned when the subsidy was suddenly cut. As a result, developers and manufacturers are moving their money and projects to where policy support is more consistent. Going forward, Spain has introduced caps on the number of projects that will be eligible under its FITs in an effort to smooth

out the installation trends (Wang 2009a). Spain has declared that only 500MW of solar projects will be eligible for subsidies in 2009, which is why installations in Spain, which totaled 2,800 MW in 2008, is expected to fall to 500MW or less in 2009 (Voosen 2009).

Solar support legislation needs staying power. Maturation and market awareness take time, which makes sufficient funding and administration important. When subsidies dry up, or are changed, as was the case in Spain, the market will likely materialize more slowly because solar projects need public support. A global financial crisis is sure to drag global solar installations in 2009, but Spain's faulty and poorly conceived regulatory approach will also hurt future installations, as many within the industry have had their supplies disrupted. Most countries, including Italy, France, and the Czech Republic, are embracing the German model, which was framed around sustained financial support through legislation, and led to a healthy ramp up in demand followed by a surge in production. Support has been consistent in Germany for years and the FIT is part of a feed-back mechanism that has built up a strong solar political constituency in Germany (Jacobsson and Lauber 2006). Because of Germany's sustained public support for PV, it has developed a vibrant solar manufacturing sector.

It was not until 2004 that Germany claimed the top spot, usurping Japan as the global leader in solar installations. Japan has enjoyed consistent support beginning in 1994, when the government mandated that 200MW of PV be installed by 2000. Although it missed the target by one year, the Japanese solar market has been growing by 30% per year for the early part of the decade while the rest of the world had only begun to commit significant resources to solar development (Waldau 2006). The commercial

market is still only a minor component of the overall solar landscape in Japan, with residential roof-top solar accounting for about 90% of the nearly 2,000 installed MW at the end of 2008. A new RPS will be announced in 2010 and it is expected to include a provision that will allow for double-counting for all PV installation, which should jump-start demand now that the residential solar program has expired.

Installation rates in the United States have been limited to a handful of states and remain dominated by the state of California. According to the SIEA (2008), of the 292 MW of newly installed PV in 2008, 179MW was in California, bringing the cumulative total for the state to 530 MW, or 67% of the total for the United States. California has benefitted from the country's most aggressive RPS, which requires 33% by 2020 from renewables. Furthermore, the California Solar Initiative is a progressive program offered through the state's utility commission that makes funds available for homeowners to offset the cost of solar installations; the initiative has a goal of 1,940 MW of installed solar by 2017. Other than California, New Jersey, Colorado, Nevada, Hawaii, and New York are the only states with more than 10MW of installed solar (SEIA 2008). The investment tax credit, which was extended for 8-years at the end of 2008, remains a critical support mechanism to help pay for residential solar systems.

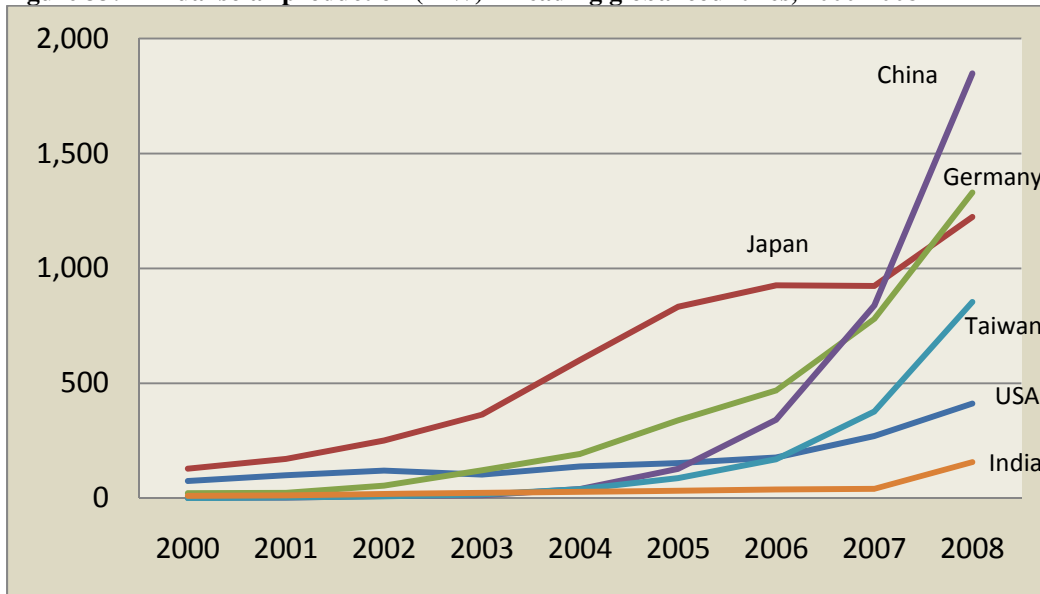
Solar installations elsewhere are in their infancy. Korea recently launched a 100,000 rooftop program where the government will pay for 60% of the costs for single family homes and 100% for apartments. In China, a FIT was implemented with its 2006 energy law, but there are problems because more than 90% of China's PV systems are off-grid electricity projects (EPIA 2008).

The geography of solar manufacturing

PV production is still dominated by a handful of countries but a clear geographic trend has set in. Led by China, three of the top four producers are in Asia (Figure 33). The low-level of production in the United States and Europe, coupled with high levels of production in Asia might be explained through comparative advantage, where the technological comfort with crystalline silicon PV has allowed manufacturers to move production to low cost states. This narrative is further confirmed in that neither China nor Taiwan rank high in domestic installations, making their production principally export driven¹⁵. Meanwhile, the US continues investing in TF technologies, where venture capitalists have invested heavily in recent years (Tierney 2010). The geography of crystalline production differs sharply from TF production, where the United States produces more than the rest of the world combined (Earth Policy Institute 2009).

¹⁵ It is important to note that there is significant uncertainty with solar data as some companies report production while others report shipments. Furthermore, companies have the capacity to produce a certain unit of solar cells each year, but never achieve those totals.

Figure 33: Annual solar production (MW) in leading global countries, 2000-2008

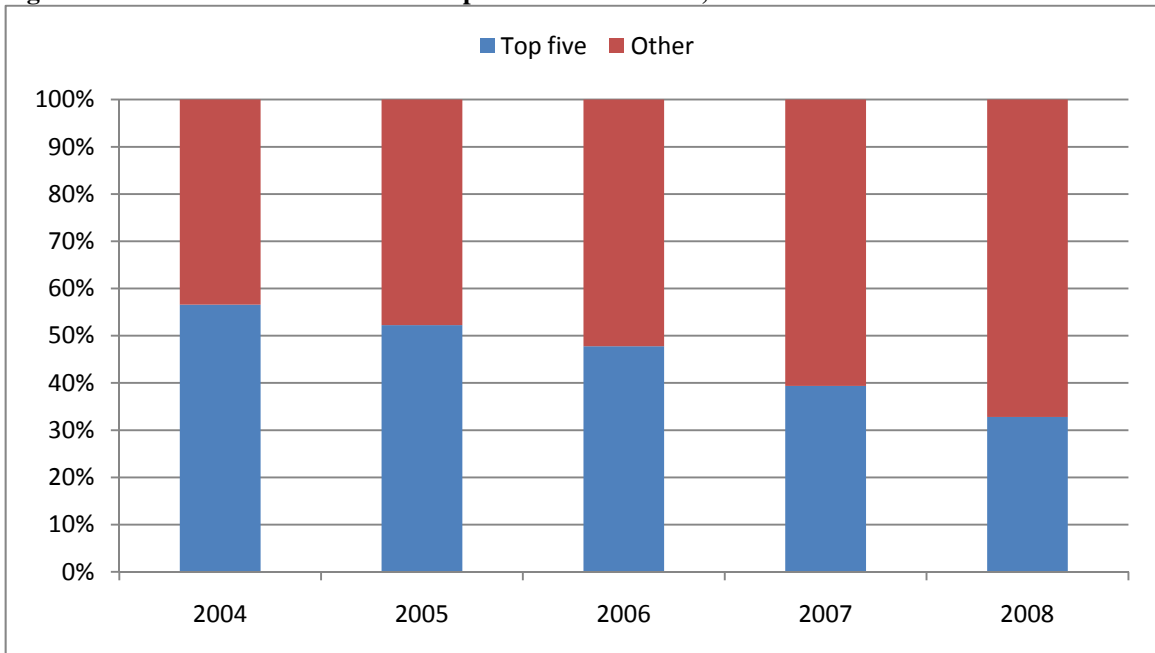


Source Earth Policy Institute 2009

Despite the obvious concentration of solar production in a handful of countries, the stage is set for a globally diffuse industry. The geography of production, according to Solarbuzz (2009), now extends to several other countries. In the case of Greece, Ukraine, the UAE, Thailand, Russia, Croatia, or Norway, these countries are home to solar companies, many of them still small, but some, as in the case of REC in Norway, have a rapidly growing international footprint. Other countries are getting into the solar market as a result of outsourcing operations by solar companies in the developed world, which are building manufacturing facilities in Malaysia, Mexico, the Czech Republic, and Singapore. And so despite the concentration of solar ownership in a handful of countries, it should be no surprise that a very competitive and increasingly fragmented marketplace has emerged among the companies operating in the solar space. In 2004, the top five global companies manufactured 57% of all the PV on the market led by Sharp of Japan, which itself had 27% of the market (Figure 34). By 2008, the top five companies

supplied 32.8% of all the PV to the world market, led by Q-Cells of Germany, which has only 8% global market share, and was fourth in 2003.

Figure 34: Global PV market share of top five manufacturers, 2004-2008



Source: IEA 2009 and author's calculations

Consolidation in the solar sector has been less robust than in the wind sector.

Two of the larger deals have been initiated by German firms, with SolarWorld acquiring the assets of Shell Solar in 2006 and then two years later, Ersol Solar was acquired by Bosch. Much of the integration has been vertical, particularly of polysilicon suppliers, where the silicon supply shortages have made procurement problems more acute. This is particularly true among Chinese firms which are seeking to protect and expand its market position as the world's leading solar supplier, producing more than 25% of the world's solar cells. In order to maintain the momentum for solar production and to prevent getting squeezed in another global supply rut, China is committing to a vertical supply

chain by investing heavily in its own silicon supplies (Joint Research Center 2008). Two of the industry's fastest growing Chinese solar companies, Yingli and Trina, have brought most of the silicon and wafer operations in-house (Braun 2009).

Vertical integration is nothing new; China is following the model initiated by some of the industry's early movers like Schott Solar towards controlling upstream supplies (Marinova and Balaguer 2009). But some believe the cost containment benefits of vertical integration are off in the future, while the near term race is to bring costs down in a more meaningful way. As a result, market leader Q-Cells has shied away from vertical integration and specialized on solar cell technology improvements (Kho 2007). On the thin-film side, there is very little need for vertical integration; most of the costs for TF production are upfront costs associated with manufacturing equipment.

In the mean time, the leadership position within the solar cell manufacturing sector changes from year-to-year (Table 23). While vertical integration may enable further cost containment, economies of scale are paramount to realize any material production benefits that will drive down costs. Equally important will be new technological breakthroughs in efficiency ratios, particularly among TF producers, where most of the research remains in the United States. As the hierarchy has shifted in each of the last five years, new manufacturers and new methods of production should produce more leadership disruptions in the future.

Table 23: Top Ten global solar cell manufacturers

	2004	2005	2006	2007	2008
Q-Cells (Germany)	75	165	250	390	580
Suntech (China)	20	80	160	320	553
First Solar (USA)	5	15	60	205	505
Sharp (Japan)	315	425	430	360	475
Kyocera (Japan)	105	145	185	205	290
Yingil Solar (China)	0	10	25	140	285
JA Solar (China)	0	0	20	134	280
MoTech (Taiwan)	25	50	105	198	275
SunPower (USA)	0	20	60	155	230
Sanyo (Japan)	70	120	160	165	210
Solarworld (Germany)	100	60	85	120	210

Data is in MW

Source: Author's calculations

Specific data on export markets for these producers is not available, but it stands to reason that the national concentration of the PV manufacturing industry combined with the small number of countries that have made real commitments to supporting solar installations, that the geography of trade will remain tightly woven around these countries. The best available data come from the US Energy Information Association (2009b) which tracks the import/export market for the US PV market. It should be no surprise that the top export markets for US manufacturers in 2007 were Germany, Spain, and Italy. Domestically, US companies supplied 54% of the total capacity in 2007, while the remaining 46% were satisfied by imports coming from Japan, China, Germany, and Mexico.

Developing a diffuse global manufacturing sector is not the only change that can be expected in the coming years. The global installation picture is changing as well. As a result of a massive stimulus package, China is allocated about five percent of its \$400 billion stimulus for green energy programs, including a direct subsidy for solar installations passed in early 2009. The subsidy, one of the most aggressive in the world, will offer nearly \$3 per watt for systems greater than 50kW, accounting for about 60% of the installation costs (St. John 2009). Given the large and growing solar manufacturing industry in China, the policy is a clear effort to support its growing manufacturing sector. Time will tell if China can avoid the fraud and policy alterations that doomed Spain's recent experience. China is already the global leader in solar hot-water heaters, but it appears set to ramp up its installations of green electricity, as China has set a goal of 20,000MW installed solar by 2020. Not to be outdone, India established the exact same set of goals (20,000MW of solar installed by 2020). Taiwan is also looking to install more solar, as it recently set a renewable electricity standard that will produce 6,500MW of electricity over the next 20 years, with 20% coming from solar (EPIA 2009).

Concentrating Solar Power

To achieve these goals, PV efficiency ratios are going to have to improve dramatically, but significant advances will have to be made in the second major technological solar arena, concentrating solar power. Concentrating solar power (CSP) reflects sunlight onto mirrors or lenses which in turn powers a generator. CSP differs from PV in several important ways. First, CSP is utility scale solar, which means large

projects owned and operated by corporations (either utilities or independent power producers). CSP is not designed to diffuse at the residential level. As a result, CSP systems are built to rival nuclear or coal plants in terms of their output capacity. Second, electricity generated from PV systems must be used instantly, unless it is connected to some battery back-up, which is rare. By using molten-salt to retain heat, CSP has the ability to deliver electricity 24-hours a day, as compared to PV systems which are only able to generate electricity during daytime hours. Finally, economies of scale may end up benefiting CSP more quickly than PV. PV systems need to be tailored individually in residential settings, resulting in labor and installations costs comprising an enormous percentage of the overall system cost. CSP systems are huge projects typically built in secluded desert environments, thus reducing installation costs due to repetition and a simplified landscape.

Unlike wind, where the major players have agreed on most of the basic design features for turbine design, solar is still in the process of identifying the winning technology. That is particularly true for CSP, where four types of designs are in the development stages and they all vary in the way they track the sun and harness its light. The four designs are: parabolic trough, fresnel reflectors, dish-engine, and central receivers. Parabolic troughs use long curved mirrors, and direct sunlight onto a pipe that contains a liquid, which is heated and used to boil water that can be used in a steam generator. Similarly, fresnel reflectors focus the sun's ray onto a pipe, but the pipe is shared by many mirrors and typically the mirrors are flat. The reduced land requirements to build a fresnel reflector system create an opportunity to build these systems in closer

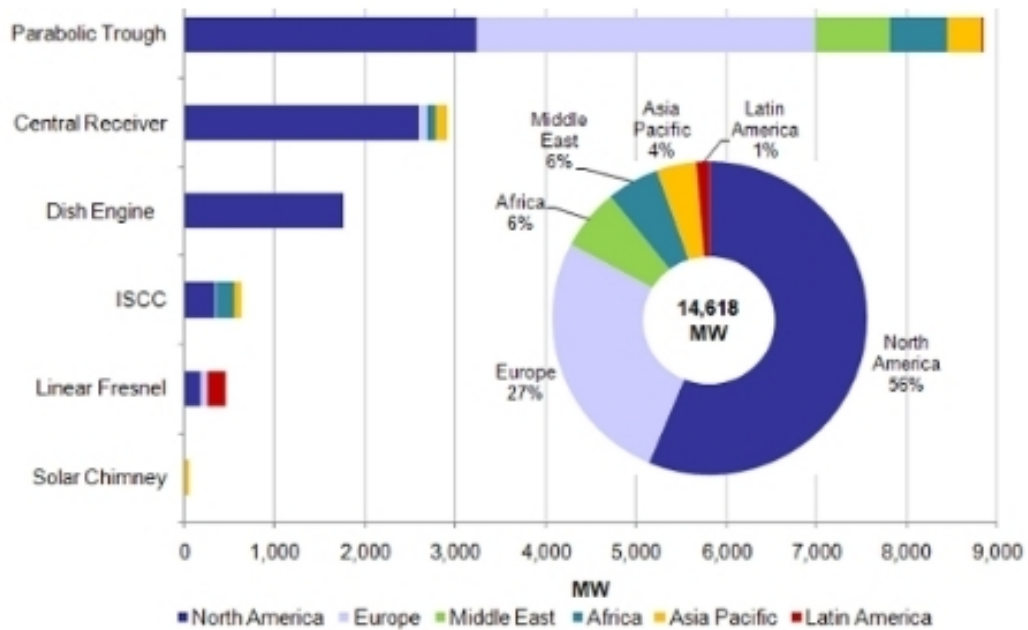
proximity cities where land might be more expensive. A dish-engine system is a group of mirrors, shaped like satellite dishes, individually reflecting the sun's rays onto a receiver above the dish, which is used to heat a fluid which can power a generator. Central receivers, also known as power-towers, utilize a central tower to collect the sun's rays that are reflected off of hundreds of surrounding mirrors, which is used to make electricity. All these systems are built on mounting structures with tracking systems so they can capture as much solar irradiation as possible. Both power-towers and dish-engines can achieve higher temperatures but both suffer from higher maintenance costs because they have more moving parts and have larger space requirements.

New innovations in these various designs are helping to make CSP more cost effective and while its commercial viability is very promising, much remains unknown. There are several CSP demonstration plants functioning around the world, but only two CSP (parabolic trough) plants in excess of 100MW are operational. The first is in California's Mojave Desert with a nameplate capacity of 354MW, while the second is a 100MW system in Granada, Spain (along Spain's southern coast). Spain has more than 2,000 MW of parabolic trough systems under construction, and another 1,000MW of plants in the planning stages, while the United States has more than 4,000 planned plants using various technologies, although construction has not begun for any of them (PV Resources 2009).

The economics of CSP suggest that it will capture a majority of the interest from utilities and independent power producers, but the race is on to determine the winning technology. According to Emerging Energy Research (2009), of the 14,000 MW of

global CSP projects in the pipeline, nearly two-thirds are parabolic trough and 20% are central receivers (Figure XXXX). Spain has bet heavily on the parabolic trough designs, with virtually its entire pipeline dedicated to that particular technology, while the United States has a more diversified technology emphasis; parabolic trough represents about 40% of the pipeline, central receivers accounting for just over 30% and dish-engines another 20%.

Figure 35: Global concentrating solar plant pipeline by technology



Source: Emerging Energy Research 2009

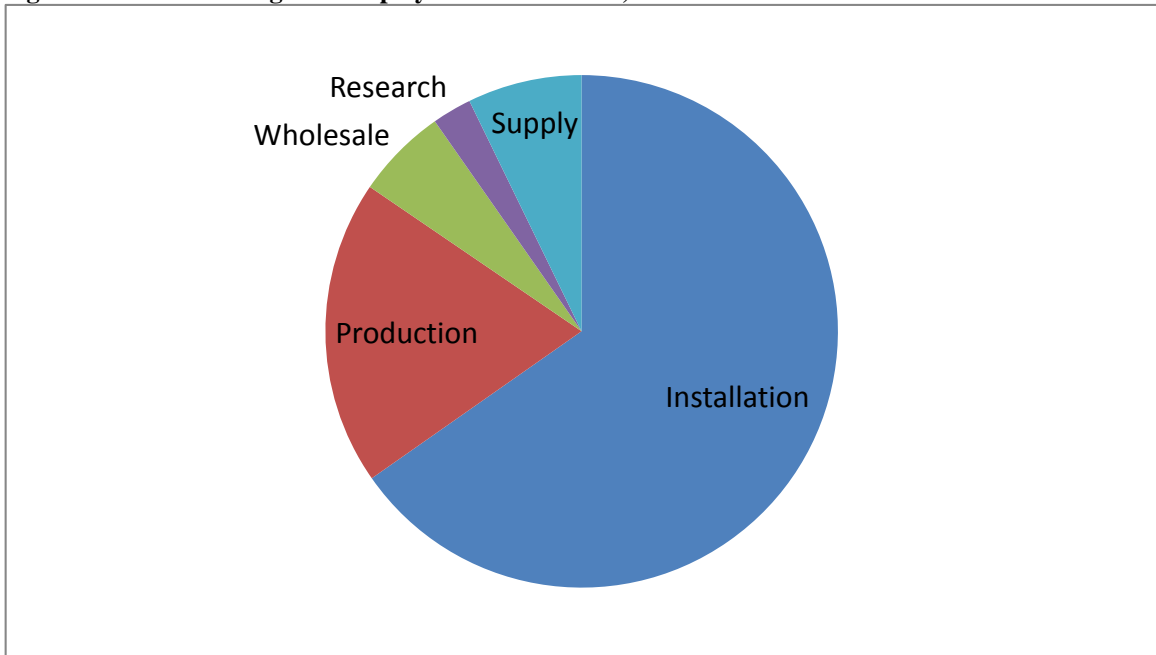
Employment

While the world waits for the commercial roll out of CSP technology, large scale solar projects are opting for fields of PV modules. Virtually all of the utility scale grid-connected solar systems installed in the last three years have been concentrated PV systems and as is the case with smaller scale PV, they are clustering in Europe. Of the 19

global PV fields with nameplate capacity exceeding 20MW at the end of 2008, 16 are in Spain, with one each in Portugal, Korea, and Germany. Interestingly, the 40MW German PV field (located in Brandis, outside Leipzig) is the only thin-film field, made from cadmium-telluride (PV Resources 2009).

One of the important aspects of solar is the employment benefits. As the industry continues to seek grid parity, the research side of solar is critical to its long term success, but in terms of jobs, PV's real social benefit will be on the installation side. For each MW of solar, 33 jobs are created in installation, 2 jobs are created in research, with the production side supporting an additional 10 jobs (EPIA 2009). Over time, it can be expected that the employment benefits on the production side will slow as technology replaces labor (Figure 36). This will occur rapidly as thin-film PV increases its market share, as most companies are experimenting with a roll-to-roll manufacturing process that will require very little labor. Nevertheless, installations will always require labor, whether it is large PV fields, roof-top systems, or building integrated solar (BIPV).

Figure 36: Solar sector global employment breakdown, 2007

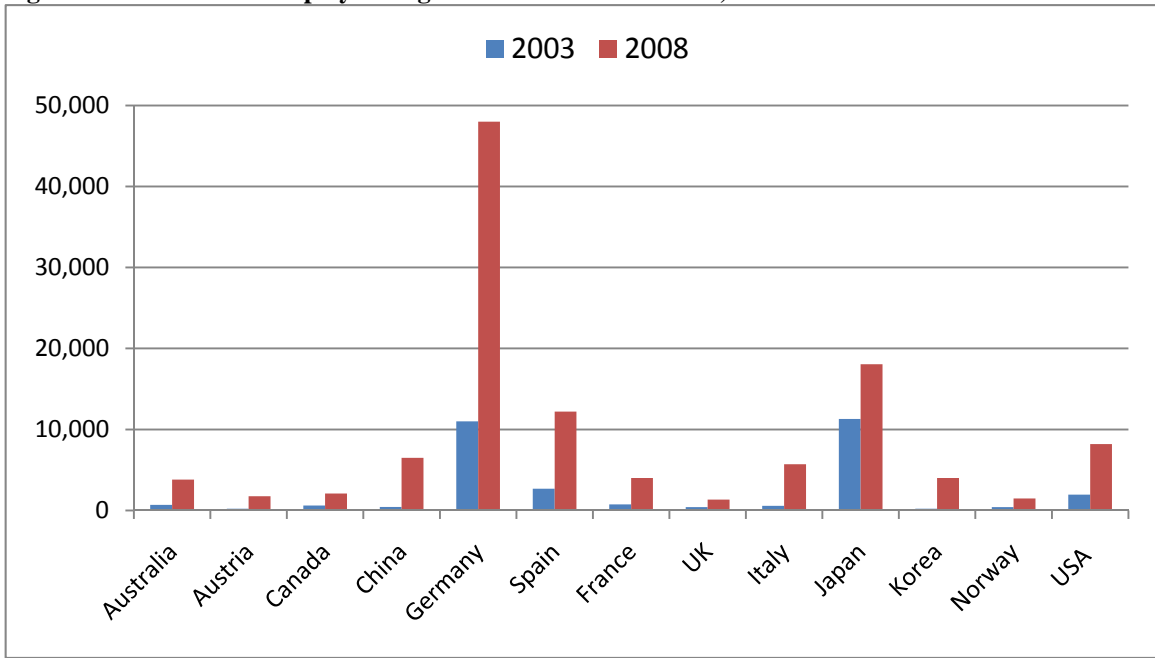


Source: EPIA 2009

It is no surprise then that the countries with the highest number of people employed in the solar sector are found in the countries with the highest installation rates of solar technology (Figure 37). Back in 2003, Japan and Germany were the two countries with targeted solar regulatory support and both had more than 10,000 people employed in the solar sector. While Japan has had sustained yet modest support for solar, by 2008, Germany's aggressive and rising commitment has unleashed a solar employment boom. With more than 48,000 solar jobs, Germany leads the world in solar employment. Job growth in Spain would have been stronger if not for the FIT debacle, which forced the Spanish solar industry to lay off huge numbers of its employees as

manufacturers were forced to halt production in the face of subsidy cuts (Voosen 2009). The United States has 8,190 solar jobs, up from 1,950 just five years ago (EIA 2009b)

Figure 37: Solar sector employment growth for select countries, 2003 & 2008



Source: IEA 2009

Geothermal

The Basics

Wind and solar tend to attract a large percentage of the attention within the field of green electricity, and rightfully so, given that of the \$71 billion invested globally in new renewable capacity, 42% went to wind and 32% went to solar (Renewables 2009).

Geothermal is a much less emphasized technology, yet will play a vital role in electrifying those regions suitable for the technology, many of which are found in the developing world. The opportunities for geothermal in meeting baseload electricity

demand is what separates it from other green technologies. Geothermal is a proven technology that satisfies baseload potential, but its deployment is geographically constrained to active geological zones. Geothermal has the highest capacity factor of the various renewable energy technologies (Table 24); whereas wind and solar are variable, geothermal energy is reliable because its fuel source is both continual and inexhaustible. But different geothermal technologies yield different capacity factors and some operational units already currently achieving 90% capacity factors (IGA News 2008).

Table 24: Global renewable capacity, total electricity, and capacity factor

	2007 Capacity (MW)	Electricity (GWh)	Capacity Factor
Geothermal	10,026	56,782	64.7%
Solid Biomass	22,500	115,900	58.8%
Hydro	344,600	1,286,300	42.6%
Tide, Wave, Ocean	300	550	20.9%
Wind	63,700	116,200	20.8%
Solar PV	4,100	2,626	7.3%

Source: IEA-GIA 2008

By cycling water trapped below the earth's surface, geothermal energy uses hot water created naturally to power a generator, before pumping the water back down into the ground in a closed loop system. Flash steam is the preferred method of geothermal electricity generation, with more than half of the installations since 2000 opting for single or double flash systems (IGA News 2008). Although there are limitations for flash steam, namely requiring hot water (>360°F) found in the shallow subsurface, there are plenty of untapped opportunities around the world. Two other geothermal methods exist; dry steam which is even more geographically limited, this time to areas where steam rises naturally to the earth's surface. The second technology is binary cycle geothermal, which

can generate electricity with cooler underground reservoirs(DOE 2009). Binary cycle geothermal is already capturing a large share of the market and is poised to become the dominant choice because it can tap moderate temperature water, a break-through that bypasses the current hot-water restrictions and should facilitate rapid diffusion of geothermal electricity.

As of 2007, geothermal energy was part of the electricity portfolio in only 24 countries (Table 25). While the United States is the global leader in both installed capacity and total electricity generation from geothermal power, Iceland, El Salvador, Costa Rica, Kenya, and the Philippines all rely on geothermal energy for more than 10% of its electricity portfolio. In addition to the United States, which has great untapped geothermal potential in Alaska, Hawaii, and the western states, geothermal energy is a mature technology in countries like the Philippines, Indonesia, Mexico, and Italy where it has been exploited for years. An additional 22 countries have expressed a significant level of interest in bringing geothermal into their energy mix – including several in Africa (along the Rift Valley) and in the Caribbean (Gawell and Greenberg 2007).

Table 25: Global geothermal electricity snapshot by country

Country	Installed Capacity 2007 (MW)	Electricity Produced 2007 (GWh/yr)	% of National Electricity
Australia	0.12	1.8	Negligible
Austria	1.1	3.2	Negligible
China (Tibet)	28	95.7	Negligible
Costa Rica	163	1,145	15
El Salvador	204	967	24
Ethiopia	7	na	n/a
Guadeloupe (Fr)	15	95	9
Germany	3.23	0.4	Negligible
Guatemala	53	212	3
Iceland	485	3,600	29.9
Indonesia	992	6,085	6.7
Italy	810	5,233	1.8
Japan	535.26	3,102	0.3
Kenya	129	1,088	19.2
Mexico	958	7,393	3.3
New Zealand	452	3,272	7.7
Nicaragua	87	270.7	9.8
Papua New Guinea	56	17	n/a
Philippines	1,970	9,419	19.1
Portugal	23	90	n/a
Russia	79	85	Negligible
Thailand	0.3	1.8	Negligible
Turkey	38	105	Negligible
USA	2,936.50	14,500	0.3
Total	10,026	56,782	

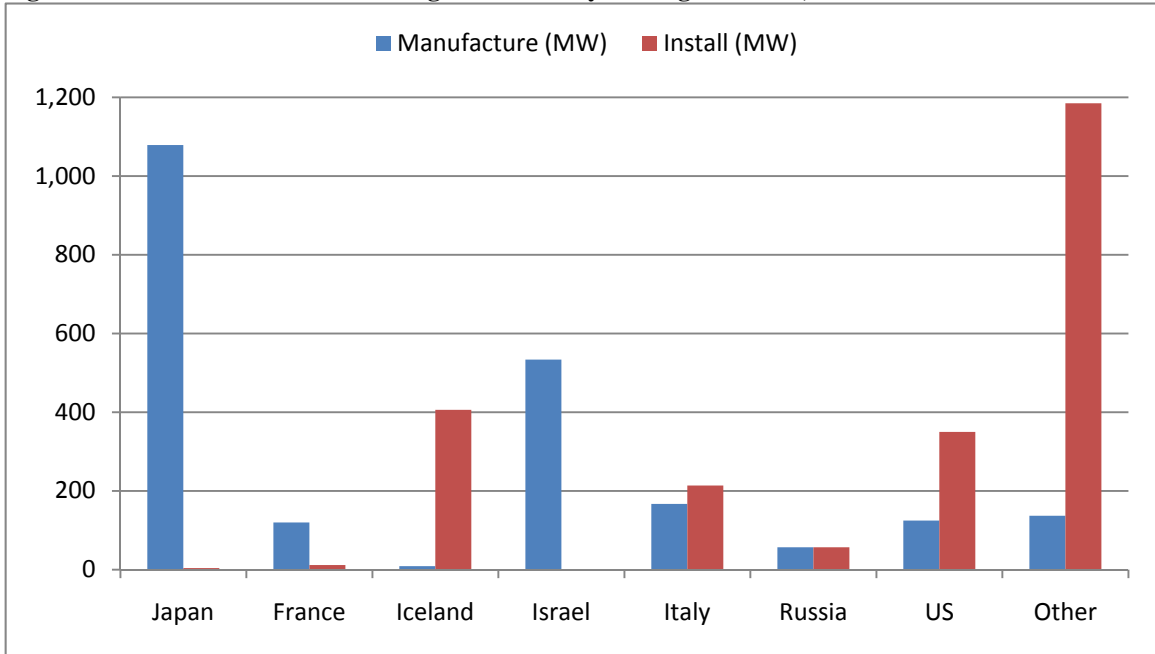
Source: Bertani 2005; IEA-GIA 2008

The firms

More than 2,000 MW of geothermal capacity has come online since 2000 and equipment manufacturing is concentrated in five countries: Japan, Israel, Italy, France, and the United States. Although Japan has the sixth most installed MW, geothermal power has not been a priority for the last decade as the country has actually decommissioned more capacity than it has installed (IGA News 2008). That leaves only

the United States and Italy (and to a lesser degree, Russia) as major manufacturing countries that also have domestic geothermal demand; the rest of the producers are exporting their technology (Figure 38).

Figure 38: Geothermal manufacturing and install by leading countries, 2000-2008

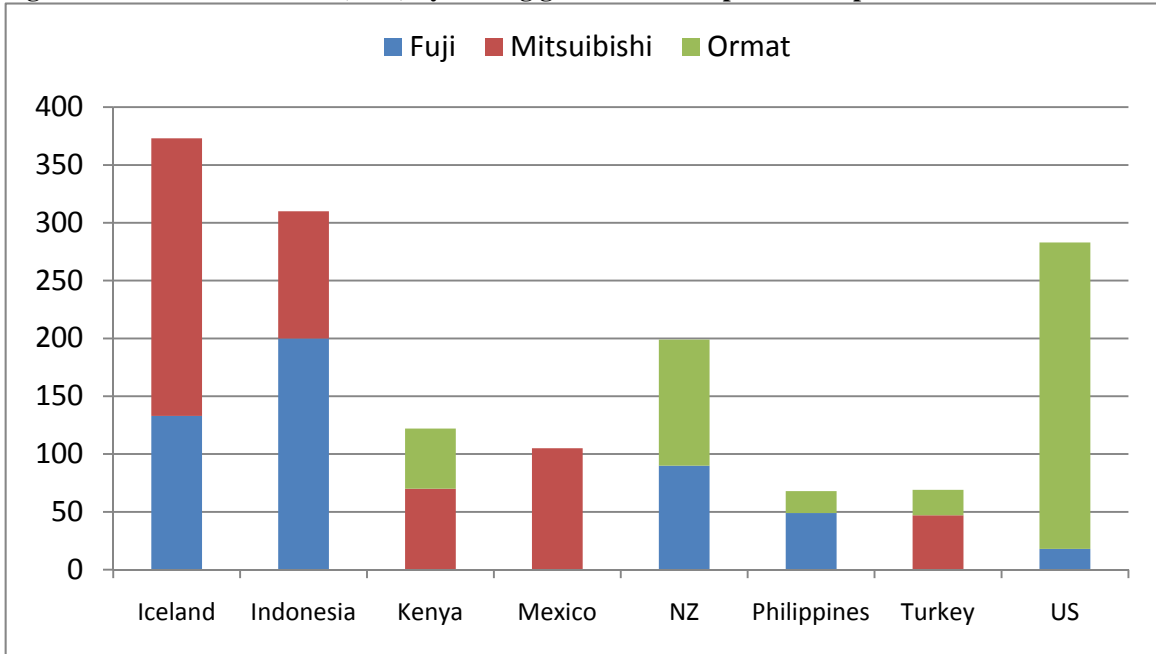


Source: IGA News 2008

Even greater concentration is found at the producer level, where a handful of firms dominate manufacturing. Since 2000, 92% of the global geothermal installations were controlled by eight firms, and the top three Fuji and Mitsubishi (Japan) and Ormat Technologies (Israel) controlling 71%. Although Mitsubishi has the lead, each firm has installed roughly 500MW since 2000. Of the top ten installation markets since 2000, Fuji and Mitsubishi shared the top two, Iceland and Indonesia (Figure 39). But of the three major manufacturers, only Ormat Technologies had a major presence in the United States, which is the third largest market. Among the top ten global markets, Italy and

Russia do not appear in Figure XXXX, as the geothermal needs for both countries were met by domestic manufacturers, and as it turns out, these firms exported none of their technology to foreign markets.

Figure 39: Total installations (MW) by leading geothermal companies in top markets



Source: IGA News 2008

It can be expected that Ormat Technologies will continue to gain market share for two reasons. First, they are the leading firm in the United States, with more installations than either of the top two domestic companies. The US is the largest geothermal market in the world with about 3,000 MW in operation, and dominated by Nevada and California, the United States has another 5,000 MW in development (Jennejohn 2009). Second Ormat Technologies has very little competition in the binary cycle category – recall that binary cycle can perform with cooler underground reservoirs. Nearly all of the units it has installed since 2000 have been binary, giving Ormat a clear market leadership

position and early mover advantages in any new market where geothermal had previously been unsuitable.

Geothermal heat pumps

Geothermal energy of a different variety has surged in recent years thanks to its applications in direct use applications. Direct use application takes advantage of ground temperatures using geothermal heat pumps, also known as ground source heat pumps or geo-exchange. Whereas geothermal energy is typically utility scale, ground source heat pumps are much smaller and used primarily to reduce residential and commercial heating and cooling costs, but can serve other uses as well (Table 26).

Table 26: Growth of ground source heat pumps

Category	Capacity (MW)				Utilization (GWh)			
	1995	2000	2005	2007	1995	2000	2005	2007
Geothermal heat pumps	1,854	5,275	15,384	19,010	4,060	6,465	24,306	29,167
Space heating	2,579	3,263	4,366	-	10,619	11,924	15,349	-
Greenhouse heating	1,085	1,246	1,404	-	4,373	4,962	5,739	-
Aquaculture pond heat	1,097	605	616	-	3,748	3,259	3,049	-
Agricultural drying	67	74	157	-	312	288	559	-
Industrial uses	544	474	484	-	2,811	2,839	3,019	-
Bathing and swimming	1,085	3,957	5,401	-	4,373	22,096	23,061	-
Cooling/snow melting	115	114	371	-	312	295	564	-
Others	238	137	86	-	625	843	290	-
Total	8,664	15,145	28,269	35,570	31,234	52,972	75,937	91,464

Source: Lund et al. 2005 & Antics and Sanner 2007

Like geothermal power, ground source heat pumps are closed loop systems, but they are not geographically limited, in that ground source heat pumps can take advantage of the consistent temperatures in the ground, almost anywhere in the world. Ground source heat pumps are designed to tap into the shallow ground, where seasonal variations

in temperature disappear. Temperatures a few meters below ground are warmer than the surrounding air in the winter and cooler in the summer, so by installing a series of ground loops, the system exchanges the warm summer air with the cool air found below ground, and vice-versa in the winter time and their use has exploded in recent years. When measured against the electricity produced from central geothermal power plants, direct use geothermal produced nearly twice the total electricity in 2007. The United States makes up nearly all of the global geothermal heat pump market, with installations concentrated in the upper Midwest (EIA 2010).

Conclusion

Since the end of the cold war, the world has been transitioning from one based on military security and alliances to one based on economic security through global partnerships. At its most fundamental point, today's economic security is rooted in energy availability. Unfortunately, if we continue in a business as usual fashion with respect to energy supplies, a growing global middle class will be competing for a shrinking supply of fossil fuel reserves creating a perverse scenario where globalization threatens the very economic security it has sought to create.

Energy demand is growing at a staggering rate and the capacity for conventional sources of energy to satisfy this demand is unlikely. Transitioning to an economy running on green, rather than fossil energy supplies, should eventually dismiss the 'availability' issues associated with economic security. But green energy may hold the solutions to many of the world's other vexing problems. Green energy will enhance

local, regional, or national economic opportunities as the transition will be knowledge, labor, and policy intensive. A green energy economy will mitigate and eventually reverse the climate problems that have been perpetuated by our carbon based energy systems. With this backdrop, the world should be making a coordinated and quick transition, yet the global energy portfolio remains remarkably similar to decades past. This should not be surprising as this techno-economic paradigm shift comes with substantial financial costs, costs that the developing world cannot absorb and costs that many in the developed world are still resisting. As such, the formation of an international framework for ushering in a new energy economy shows little promise, and with so many countries unable or unwilling to meet even modest carbon reductions in accordance with the Kyoto agreement, pessimism grows.

In many ways, the absence of top-down leadership has led to landscape in green energy and electricity that is a multi-scale and disjointed patchwork of a policies, producers and technologies. And while these forces are not harmonious, the evidence suggests that the movement to decarbonize the electricity supplies is gaining strength. Today's global map of technological specialization remains centered in the global economic core. But it will not be concentrated for long. Countries in the developing world are aware of the benefits to leapfrogging the legacy energy options and are crafting policies to ensure that the opportunities of the green energy economy do not pass them by. Supply chain networks will solidify cross-border relationships as the synergies of international trade will benefit the global south with outsourcing opportunities. Unlike other forms of international trade, that have caused great pain and economic dislocation

in the developed world, protectionism will play a reduced role in the growth of the green energy economy. Why? Because the benefits will be widespread. Although manufacturing and production will boost low-cost producing states, the techno-economic paradigm shift will create a host of local installation, maintenance, and operating jobs in the developed world; jobs that will demand additional policy support that will reinforce and accelerate the energy transition.

Any number of things will push green energy technologies from the margin to the mainstream, including prolonged spike in fossil fuels prices, an increase and sustained financial R&D commitment, transparent policy support, or technological breakthroughs that enable green electricity to achieve parity with conventional sources. If investment flows are an early indicator, the focus has honed in on wind, solar, and to a lesser extent geothermal, but breakthroughs in technologies like biomass, waste-to-energy, small nuclear, tidal (ocean) and liquid biofuels will be crucial in the energy transition. It is an energy transition that will not come cheap and will upset many entrenched interests, yet for all the financial and political capital that will be required to push the energy transition past the tipping point, momentum is clearly building to reshape the global energy map.

Chapter Four: Venture Capital and Cleantech Symbiosis

Introduction

In his 2006 state of the union address, President Bush proclaimed that we are addicted to oil. He could have gone a step further and claimed that we are addicted to energy; living lifestyles that require copious amounts of fossil fuels and raw materials are environmentally compromising and unsustainable. A new sector of economic activity has emerged in recent years to develop the tools, manufacturing processes, and energy sources that will offer up a transitional path towards a lifestyle that is more in harmony with the planet. Cleantech is the umbrella term that has come to define the companies operating in this space. While the cleantech industry has been nascent for more than a decade, it has remained a largely underground enterprise, failing to capture the attention of policy makers or attract the innovative capacity of leading entrepreneurs. Starting in 2006, that all changed.

Cleantech has become a highly visible source of potential prosperity and prestige. In fact politicians love to tout the prospects that green collar jobs will serve as the next wave of economic growth. Employees for companies working in the cleantech space would be classified as green collar, but cleantech means more than wind and solar power; it also encapsulates materials, buildings, water, recycling, electricity transmission, and

energy software. While many large global corporations are formidable players in the cleantech space, a vibrant and growing collection of small private companies are starting-up with the intention of capitalizing on the challenge to improve environmental performance. Financing is critical for this fledging sector and the venture capital industry has stepped in to nurture, bring to market, and monetize the varying technologies.

This paper provides a snapshot of this infant industry and will illustrate the spatial and financial landscape associated with venture capital funded start-ups. In terms of the overall venture capital industry, cleantech is now the sector of economic activity drawing the second largest amount of financing from venture capital firms, after software. Dollar commitments as well as total deal volume has been rising each year, and while the bulk of small businesses are concentrating in some of the likely entrepreneurial hotspots like California and Massachusetts, other clusters of cleantech activity are noticeable. Finally, while solar remains the most attractive technology choice by venture capital firms, several technologies in the biofuels and storage arenas are making significant inroads and garnering sizable later stage funding commitments.

What is cleantech

PricewaterhouseCoopers (2008b) describes Cleantech as: “not one tidy group, but rather an array of distinct sub-sectors: solar, wind, and geothermal energy generation, biofuels, energy storage (power supplies such as batteries and uninterruptible power supplies), nuclear, new pollution-abatement, recycling, clean coal, and water technologies. The common thread is that all of these sub-sectors represent technologies,

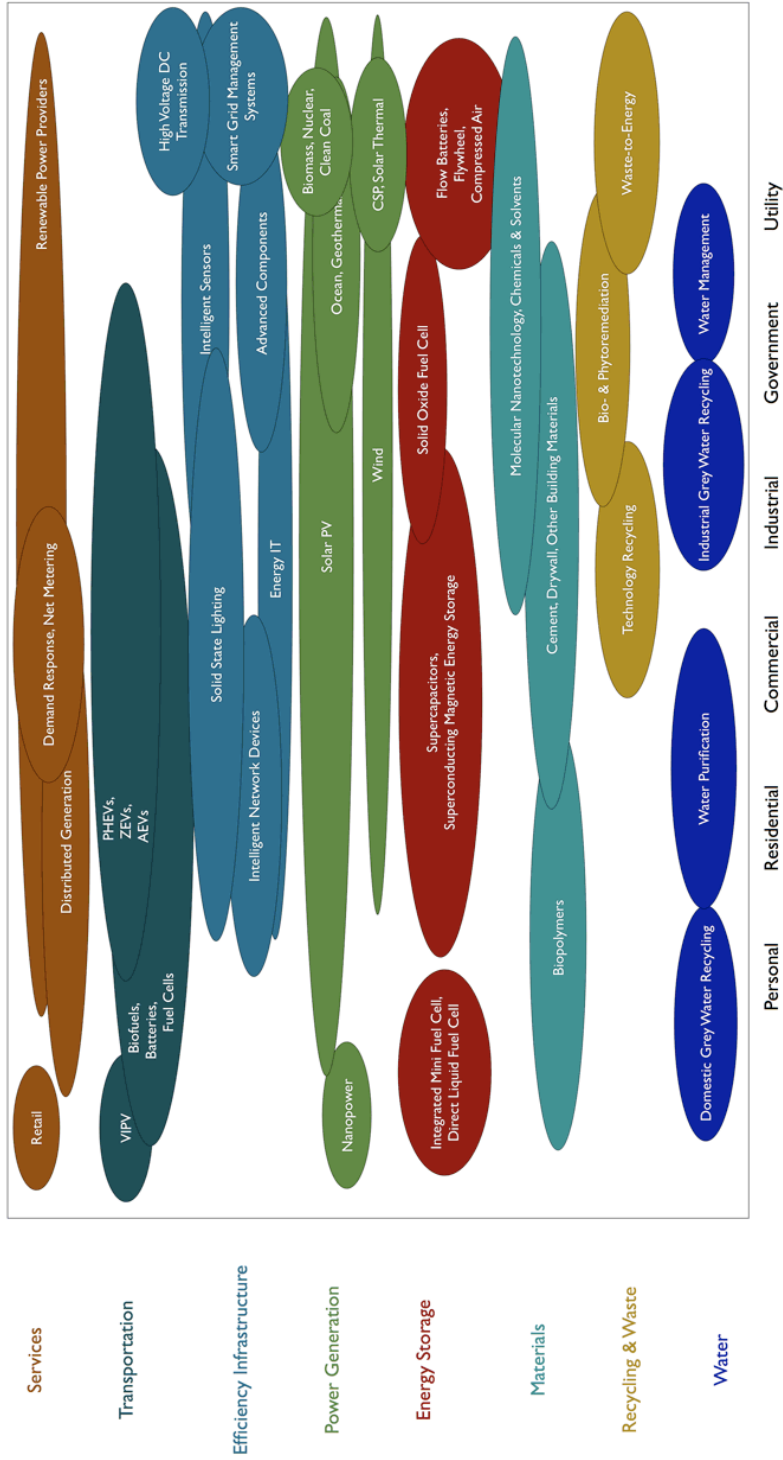
services, or products aimed at reducing greenhouse gas emissions and other pollutants and promoting energy efficiency and the conservation of natural resources.”

Cleantech can be broken down into supply side and demand side technologies. The supply side gets more of the attention with sexy components like wind turbines, electric cars, and solar panels. These represent the technologies that change the way we make and use energy, but because of their capital costs and technological immaturity they represent investments that will pay off over the medium- to long-term. Of a less sexy variety, but with greater near-term benefits, are the demand side technologies. Demand technologies include things like commercial lighting, programmable thermostats, efficient televisions and refrigerators, and smart grid applications, all where the technology exists and the scale economies are within reach that the potential to yield enormous savings in cost and carbon in the near term represent the obvious and attractive low hanging fruit. While the long-term answers lie in our ability to produce electricity from green sources, the near-term picture is clear – fossil fuels are going to play an important, if not dominant role in our energy mix for the foreseeable future. As such, investments in demand technologies must be aggressively pursued, because most of these gains would be virtually imperceptible to consumers while delivering better service with lower utility bills.

Firms in the cleantech industry are dedicated to finding technological solutions to our energy, materials, and industrial processes while growing the economy and improving environmental productivity. Solving for the three Ps (people, planet, and profit) is luring a lot of intellectual horsepower to the industry, which is why it has

become a favorite VC investment category. Figure 40 illustrates the taxonomy of the industry's technologies (down the left hand side) as well as the specific users within the economy that will benefit (across the bottom).

Figure 40: Cleantech Taxonomy



Source: Greentech Media 2009

Venture Capital in a Market Economy

One of the most important foundations of capitalism is the ability for business to access capital. Generally speaking, accessing capital through traditional channels like banks or credit unions is a relatively simple transaction; a borrower provides either a down payment or some collateral and in exchange a lender loans the money, with the expectation that principle and interest will be paid back over a defined period of time. Quantitatively, bank finance is the most important source of small business capital (de Bettignies and Brander 2007), capital that is used to pay for the essentials associated with getting a business off the ground: securing office space, buying computers/hardware, paying employees, establishing supplier relationships, contracting for product samples, etc. When a small business loans money from a bank, they retain full control of the business, and consequently, exclusive ownership to any of its profits.

Some start-up companies are unable to access these sources of capital, for there ideas are too risky for traditional financial institutions. This void in the capital markets has been filled by venture capital. Venture Capital (VC) is aggregated sums of money from wealthy individuals or institutional investors, which are then used to make investments in small privately held firms (Figure 41). Venture Capital Firms (VCF) then takes that money and invests it in small start-up companies. Most of the investments made by VCFs are concentrated in high growth segments of the economy like software, biotechnology, or cleantech. Although many high risk/high reward companies seek venture financing, only a select few companies are ultimately funded – those with viable

business plans (see Figure 42). It is critical to remember that most firms do not seek venture funding, in fact 90% of start-ups do not tap the venture markets for their capital needs and 95% of the financing for small businesses is done through non-venture channels (Davis 2003). VCFs usually have technological expertise within their specific sub-sectors (VCFs tend to focus all of their investments into specific sectors; for example, biotechnology, software, or telecommunications), so the due diligence that is conducted prior to the VCF making an investment decision is rooted in considerable specialized knowledge.

Figure 41: Venture Capital Fund Structure

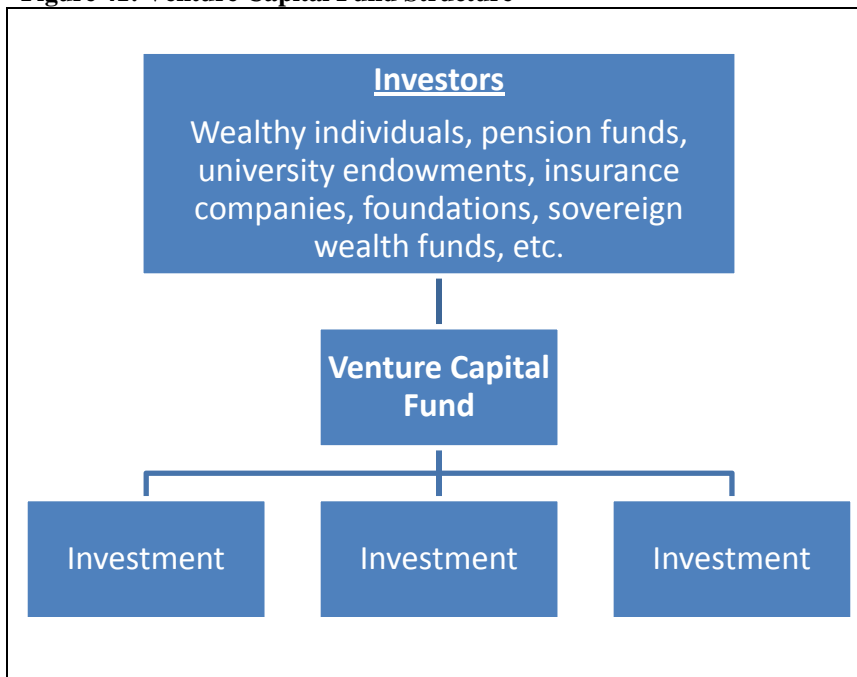
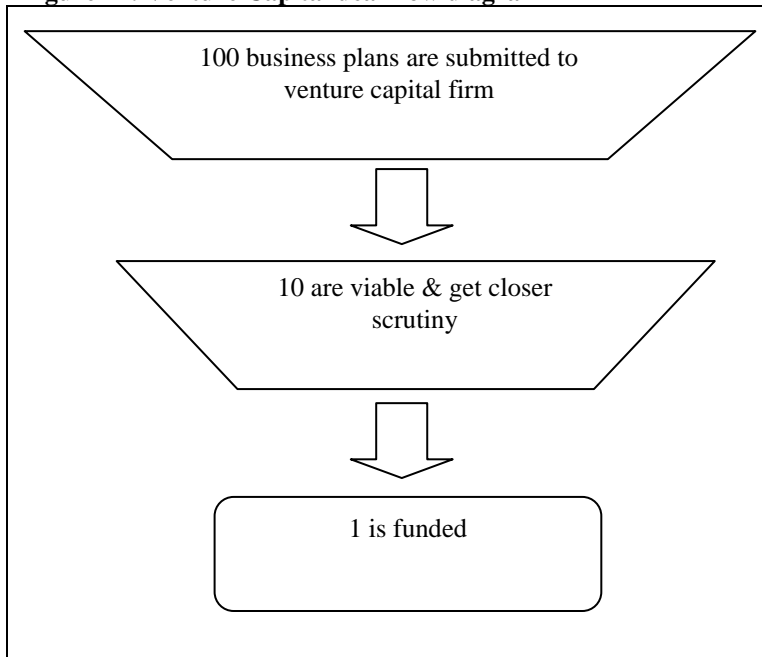


Figure 42: Venture Capital deal flow diagram



According to Global Insight (2009), the role of VC in the economy is both wide and deep; with companies that have received venture backing between 1970-2005, responsible for more than 10 million jobs and \$2.1 trillion (17% of the economy) in economic activity in 2005. A small sampling of the many companies that are products of the venture process reveal some of the largest corporations, many of which are household names: Google, Microsoft, Intel, FedEx, Home Depot, eBay, Starbucks, and Apple.

As with the small business that secured financing from the bank, money is the most important part of the equation, however the terms of the relationship enjoyed by a small business and a VCF are very different from the relationship a small business would have with a bank. First, the money invested by the VCF is not a loan that the entrepreneur is expected to repay, but rather the VC expects the company to mature so that the VCF will recoup its investment when the company is either bought by a

competitor or goes public through an Initial Public Offering (IPO), presumably at a substantial valuation premium. Given the length of time needed for some of these companies need to scale-up their operations, VCFs have an investment time horizon anywhere from three-ten years, thus making the pools of money solicited by the VCF from its investors illiquid in the short- to medium-term.

Second, when a small business secures money from a VCF, the entrepreneur's ownership is diluted. Third, a VCF contributes technological, operational, and managerial experience to each of its investments, helping to nurture its start-up companies who are burdened with the tasks of running the day-to-day operations, which are often viewed as distractions from the entrepreneur's core expertise, but are vital to the long-term health of the company (Casamatta 2003). There is also the 'rolodex' benefit, which stems from the VCFs previously mentioned economic sub-sector expertise; they know lots of people within the industry, contacts that might provide additional value to their investments as the company grows. Succinctly, venture capital is 'private money, professionally managed, always growth oriented, and always providing managerial assistance' (Cornelius 2005).

Once a start-up demonstrates its market viability, it secures the investment from the VCF. VCFs tend to make incremental investments, establishing clear milestones for each company in its portfolio, targets that must be achieved in order to receive the next round of funding (Gorman and Sahlman 1989). This works well for both the entrepreneur, who wants to retain as much control/ownership as possible, and the VCF, who is trying to gauge the viability of the company; because the VCF is making

investments in lots of firms, these smaller upfront capital commitments enable them to make more ‘bets’ and limit their downside exposure should they choose to walk away. By casting this wide net, the VCF has exposure to many different technologies, anticipating that one or perhaps a handful of the companies will lead the next technological wave. The first round of financing is usually referred to as a Series A round, and should the company continue making progress, the VCF might make a second round, or a Series B round, and so on and so forth.

Few VC funded start-ups actually mature, making the VC arena fraught with risk (Kaplan and Stromberg 2004), which explains their extraordinary due diligence before making investments. While calculating the ‘success and failure’ of a VCF’s portfolio is highly subjective, it is widely accepted within VC circles that only a small fraction of the investments ever go public, let alone become the next Microsoft. According to the NVCA (2009), 40% of companies fail, 40% are able to generate a small return for the VC, and 20% or less produce high returns. In a review of the investments made by VCF from 1991-2000, the endgame is more clear (Global Insight 2007). Of the 11,686 companies that received venture funding, less than half were able to go public or attract a suitable acquisition partner during the decade of the 1990s (Table 27)

Table 27: Outcome of VC investments between 1991-2000

Went/going public	14%
Acquired	33%
Known to have failed	18%
Still Private or unknown*	35%

*assumed to have quietly failed

Source: Global Insight 2007

Failure or inadequate performance among start-up firms can result from poor management, insufficient funds, or product non-viability. In fact, there are four primary reasons a venture funded company fails: technology risk; people risk, market risk; and financial risk. Technology risk is a feasibility issue; can the technology be built, and if so how long will it take before competition emerges to cut into the profit margins required to pay back the initial investment. People risk is associated with the management of the company. Can they execute and bring their product to market. In some cases, upon receiving some of the VC money, the entrepreneur loses their motivation, leading to the VC to dismiss existing management and seek alternative leadership (Gorman and Sahlman 1989). Market risk refers to the viability of the product. Financial risk is always tricky, because it measures the amount of funding required by the VC to get the product to market. Are the financial resources adequate and will the VCF be compensated in a manner that makes up for the opportunity cost of not pursuing other investments?

Financial risk is really the most perilous because it leads to one of the golden rules in VC – being early is indistinguishable from being wrong (Gertner 2008). If the market is not prepared to accept a certain technology, is the VC willing to sustain the business until the market matures? Sometimes, a VCF proceeds with an investment as it may be the only way to determine the viability of a product – sometimes it works, but often times it does not. Venture in cleantech is especially daunting for it takes longer for products to get to market than it does in the industries VCF are used to operating in. Software could usually be written in a few years and the VC would make their money

back. Medical technology takes longer, but the market is pretty clear and if the product is viable, it will sell. Cleantech takes years, perhaps a decade or more, and capital commitments are needed for the duration. As a result, VCF end putting a lot of chips on the table with any one particular technology because of what is known as an escalation of commitment. An escalation of commitment is defined as throwing good money after bad, or rather, once a sizable financial investment is made to a particular technology, these cumulative legacy investments somehow justify further investments even as other indicators are suggesting that the entire endeavor was wrong.

Fortunately for the VC, because of the combination of their (usually) sizable ownership stakes coupled with the types of high growth segments they invest in, only a handful of the companies need to fulfill their expectations for the VCF and its investors to earn a handsome profit.

VC plays an important role in getting small companies up to scale, because as active investors with managerial and technical experience, they are able to help companies navigate the competitive landscape more efficiently than companies with passive investors (Inderst and Mueller 2009). Along these lines, it is especially helpful when the VC brings valuable prior business experience (Bottazzi et al 2008), which tends to signal a more actively involved VCF, thus reinforcing the notion that entrepreneurs with active VCFs are quicker to scale, thus achieving market viability more rapidly.

Of course, with nascent industries, there may be a lack of industry expertise, hastening some VCF to stray from the core areas of economic acumen to pursue investments in the “hot” new area. Should this scenario unfold, problems arise as capital

ends up chasing investments, with little expertise to offer the entrepreneur after the investment is made. With so much capital flooding the 'new' industry, there is an increased likelihood of an asset bubble emerging, because money is chasing deals, without the proper due diligence (Gompers and Lerner 2000).

Over the longer term, Cornelius (2005) suggests that the role of venture capital might be in danger, becoming a victim of its own success. Too many people, she argues, have been lured by the potential for huge financial returns, but their credentials are void of the requisite business expertise needed to guide small businesses through the competitive landscape of their specific industry. The fear is that in the near-term, an asset bubble will encourage the funding of too many bad ideas, and that this bubble will soon generate a lot of pain and capital destruction. Over-time then, as the industry recovers, more VC money will become risk averse and gravitate toward the funding of later stage/established companies or technologies, rather than the Series A rounds that incubate tomorrow's technology. Additionally, any early stage investments that are made will tend to follow in the footsteps of those few VCF that possess more technological savvy. As a result, institutional theory dictates that a homogeneous set of small businesses tend to obtain a majority of the VC funding, perhaps at the expense of other nascent technologies (DiMaggio and Powell 1983).

Data

Data for this research were collected from several sources. First, broad venture capital industry data were collected from the National Venture Capital Associations

(NVCA 2009). The National Venture Capital Association (NVCA) aggregates VC activity into a variety of sub categories, including economic sector of activity, investment round (series A, series B, etc), VC exits (referring to a venture backed company that had an IPO, was acquired by a competitor, or was merged), performance, and fundraising. This research only used the aggregated data on economic sub-sectors and investment round.

The first step in the analysis portion of this study required building a database of cleantech firms, VCF, and the relationship between them; as such, four separate data tables were built. The first table started with the list of all VCF in the country as registered with the NVCA, and was subsequently parsed to find only those with a current or former investment in a cleantech company. Information for this table included the name, address, and zip of the firms primary headquarters. The second table was a list of all the domestic privately-held cleantech firms that have taken money from a VCF. Information in the cleantech firms table included the name, city, state, and zip code of the firm, and its specific cleantech technology focus. Thirty different technologies were identified, with an additional category – cleantech noc (not otherwise classified) – accounting for other types of ambiguous companies (appendix A). The third table was a relational table that indicated which VCF has invested in which cleantech company. The fourth and final table was the sequence and dollar amount each cleantech firm has received.

Gathering data in this manner is both time consuming and prone to errors. As a result, verifying the data was done using three sources of information. First, nearly every

cleantech firm issues a press release to tout the investment from a VCF. They do this for two reasons: it provides a short-term visibility boost, and to a large extent, it validates their technology because it was deemed credible enough by outside experts to put some money behind the technology. Second, most of the VCF also issue press releases when they participate in an investment round. VCF are always preparing to raise their next round of funds from outside investors, and more often than not, it enhances their credibility to be active investors with the capacity to find promising technology. Finally, there are several websites that serve as clearing houses for venture capital activity and so the third verification method used to ensure data accuracy is to check the data from the press releases against the information maintained by Venturebeat (2009).

One aspect of these data is the degree to which some VCF or cleantech companies were not counted. While it is likely that some companies were missed, the accuracy of the database assembled for this study is rooted in two facts. Most VCF make investments in syndication; meaning they solicit some portion of the necessary investment from other VCFs to both spread the risk and harness as much industry expertise as possible. As such, missing an investment would mean missing it while combing through multiple VCF websites, and while it is likely that some companies were missed, it is unlikely that they were larger companies receiving significant investment dollars, and therefore if omitted, these companies would not materially impact this study. Second, when compared with the aggregated cleantech data compiled by the NVCA the integrity of the data becomes more sound, particularly in the last three years when VC activity in the cleantech space really heated-up (Table XXXX).

Table 28: Data Comparison of VC dollars from NVCA with this study

Year	NVCA - Cleantech	This Project	Difference	% difference
2000	\$596	\$10	- \$586	(98.3%)
2001	\$400	\$26	- \$374	(93.5%)
2002	\$391	\$29	- \$362	(92.6%)
2003	\$271	\$69	-\$202	(74.5%)
2004	\$444	\$209	- \$235	(52.9%)
2005	\$550	\$263	- \$287	(52.2%)
2006	\$1440	\$1367	- \$73	(5.1%)
2007	\$2666	\$2802	+ \$136	5.1%
2008	\$4115	\$4490	+ 375	9.1%

\$ in millions

The years when this study undershoots the NVCA can be explained because they have been tracking these data in real time every day since 1995. The discrepancy in the first five years of the data would be best explained by the fact that most of those companies are no longer in business and therefore, their websites, and any corresponding information on the VCFs website would no longer exist – yet investments were made and captured by industry analysts at the time. The overshoot from this study in 2007 and 2008 can be explained by a discrepancy in categorization. This study may classify a company engaged in producing smart-grid software for example, as cleantech, whereas the NVCA may classify that company as part of the software sector.

This study adhered to some strict data collection rules, resulting in some obvious omissions. First, the company had to be privately held at the end of 2008; therefore, if a company had received VC at some point in its history, but had since been acquired or conducted an IPO, they were excluded. Second, only domestic companies were used, so if a cleantech company listed an international address for its headquarters, it was not used. Since the objective of this study was not to document the activity of international VCF, domestic companies that had received VC funding from an international VCF were

included, but their relationship with the VCF was with a generic “international VCF” category. Third, private companies working in the cleantech space that are funded through non-VC channels are excluded. And finally, any subsidiary activity/investments that are currently funded in-house at major corporations are excluded. In other words, GE is a leader in wind technology, and it is possible that they are investing in high-altitude wind technology, but it would be impossible to tease out exactly what kind of investments they are making, because GE does not break down R&D for its subsidiaries.

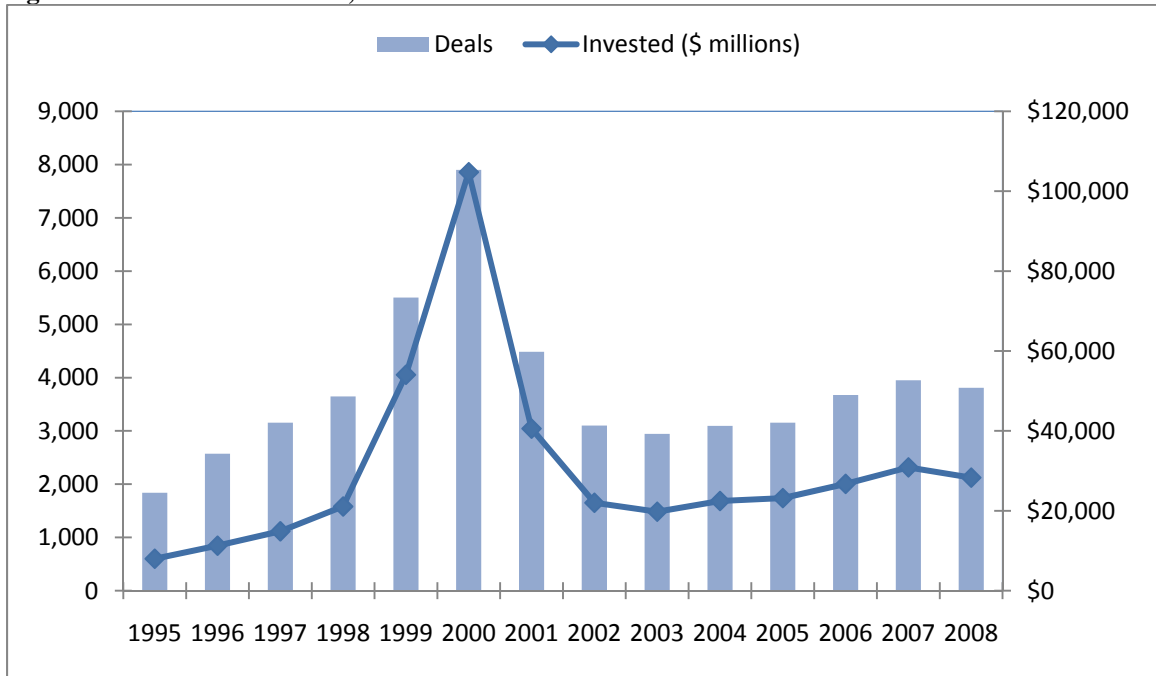
As it relates to the timing of this study, the financial crisis that struck in the fall of 2008 created a unique opportunity to do this research. Prior to the credit crunch, it would have been tough for the data analysis to reflect the market conditions, because VCF funding was pretty fluid with several VC investments per week. While the credit crunch froze the traditional lending apparatus, investments on behalf of the VC industry have shown a similar contraction; since the start of 2009 only a handful of very small VC investments have been made. Therefore, these data reflect VC investments made through the end of 2008, corresponding to a period when VC investment activity in the cleantech space has been suspended; an interruption that is unlikely to last for long.

Results

According to the NVCA, there are 714 VC firms in the United States managing \$257 billion in 2007 (NVCA 2009). Since 1995, VC firms have invested \$428 billion in 52,000 different funding rounds for small and medium sized enterprises (SME); the industry peaked in 2000 at the height of the dot.com bubble when 7,900 deals were done

totaling \$104 billion (Figure 43). As the figure XXXX shows, the ramp up of VC investments at the end of the 1990s is very clear, with the total dollars and deals suffering steep declines in the years since 2000. In fact, both have failed to recover half of where the industry peaked, with 2008 registering 3,808 deals totaling just over \$28 billion.

Figure 43: All VC investments, 1995-2008



Source: NVCA 2009

The NVCA breaks down VC investments into 17 broad economic sectors. Within these sectors, a large percentage of cleantech investments should fall within the ‘industrial/energy’ sector. In 1995, VCFs invested a total of nearly \$8 billion, with the industrial/energy (IE) sector securing \$544 million, or 6.8% of total investments. By 2008, IE investments more than doubled its share of the total to 16.4% of the \$28.3 billion, trailing only ‘software’ as the most attractive sector destination for VC money (Table 29).

Table 29: Total VC investments by sector, 1995 & 2008

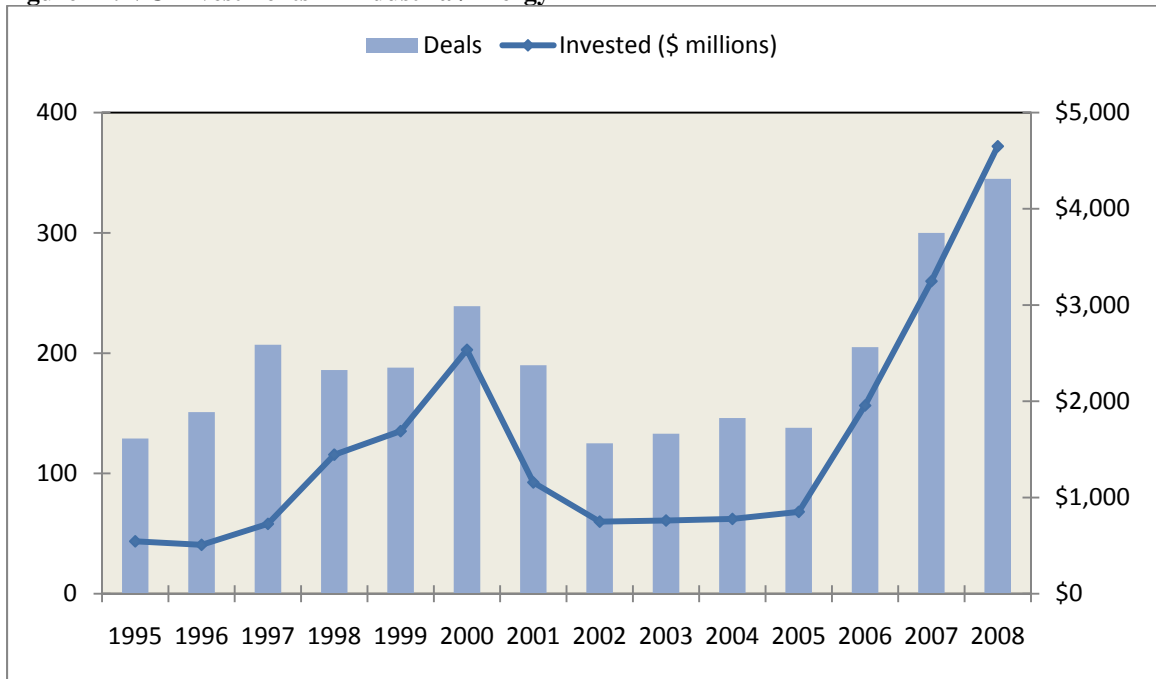
Industry	1995	Industry	2008
Software	1,164	Software	4,919
Telecommunications	957	Industrial/Energy	4,651
Media & Entertainment	916	Biotechnology	4,500
Biotechnology	829	Medical Devices / Eq.	3,460
Medical Devices / Eq.	662	Media & Entertainment	2,039
Consumer Products & Srvs	556	IT Services	1,832
Industrial/Energy	544	Telecommunications	1,688
Healthcare Services	456	Semiconductors	1,651
Networking and Equipment	354	Networking and Equipment	645
Computers & Peripherals	326	Electronics/Instrumentation	573
Retailing/Distribution	318	Financial Services	534
Semiconductors	207	Business Products & Srvs	482
Financial Services	194	Consumer Products & Srvs	436
IT Services	185	Computers & Peripherals	409
Business Products & Srvs	178	Retailing/Distribution	268
Electronics/Instrumentation	137	Healthcare Services	195
Other	12	Other	15
Grand Total	7,996	Grand Total	28,298

(\$ - in millions)

Source: NVCA 2009

That the VC industry invested only \$28.3 billion in 2008 is evidence of the damage done to the VC industry following the popping of the dot/com bubble in 2000. However, when looking specifically at the IE sector, a very different picture emerges (Figure 44). There was a run-up in investments in the IE sector at the end of the decade, securing \$2.5 billion in 239 deals, and while the sector suffered similarly in the years following the dot.com bubble burst, IE has more than eclipsed its 2000 peaks, with IE closing 345 investment rounds totaling \$4.65 billion in 2008.

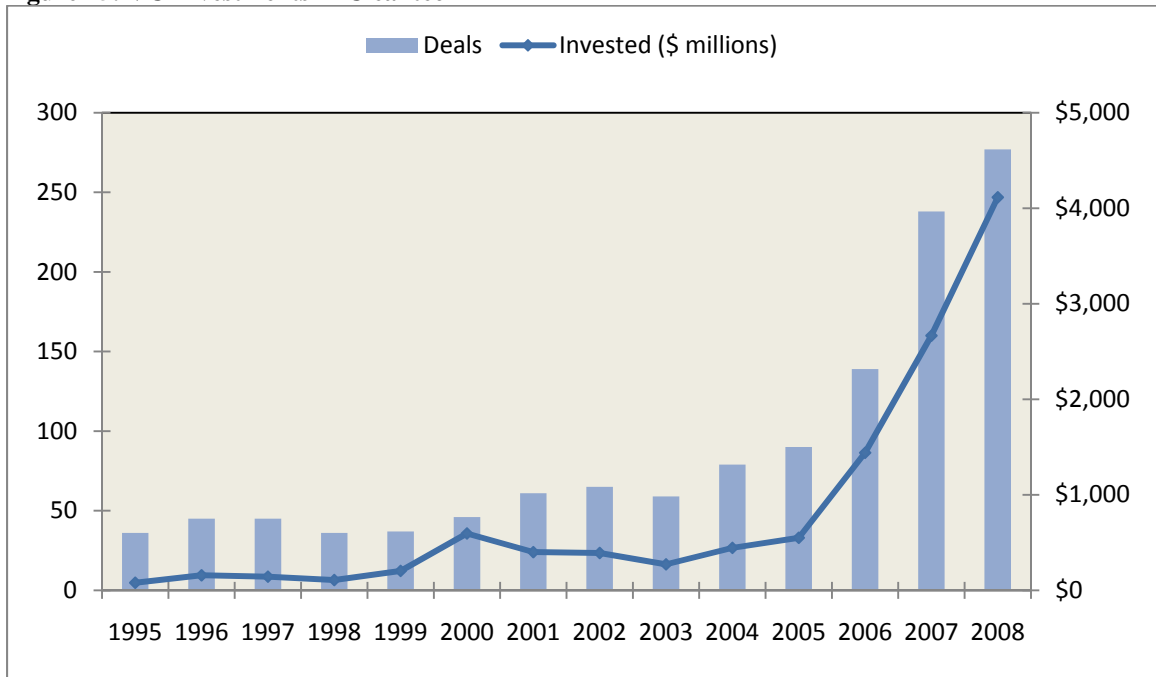
Figure 44: VC Investments in Industrial/Energy



Source: NVCA 2009

While the composition of the IE sector has never been worth breaking down historically, a burgeoning cleantech sub-sector became so vibrant in 2006, that the NVCA released a separate accounting of the VC investments going into this new category (Figure 45). It is the only sub-sector the NVCA breaks out from its broader sector classification. Most of the technologies attracting money from VCF would be classified naturally in the IE sector, as compared with any of the other sectors found in Table 29 (with the exception of the smart-grid software company outline previously). U.S. venture capital investments in IE sector are targeted at ‘Producers and suppliers of energy, chemicals, and materials, industrial automation companies and oil and gas exploration companies. Also included are environmental, agricultural, transportation, manufacturing, construction and utility-related products and services’ (PricewaterhouseCoopers, 2008a).

Figure 45: VC Investments in Cleantech



Source: NVCA 2009

What becomes clear is how the trends in cleantech investments comprise an increasing share of the IE; where in 1995, when cleantech captured only \$79 million, or 14% of the \$544 million taken in by IE sector companies, compared with 2008, when cleantech investments totaled \$4.1 billion, or 88% of the \$4.6 billion taken in by the broader IE sector companies. This reveals how the IE segment of VC investments in 1995 focused on companies engaged in enhanced fossil fuel recovery technologies, chemicals, and the electric utilities, but now those traditional IE segments are getting virtually no financing, as nearly all of the money in the last three years is going into cleantech.

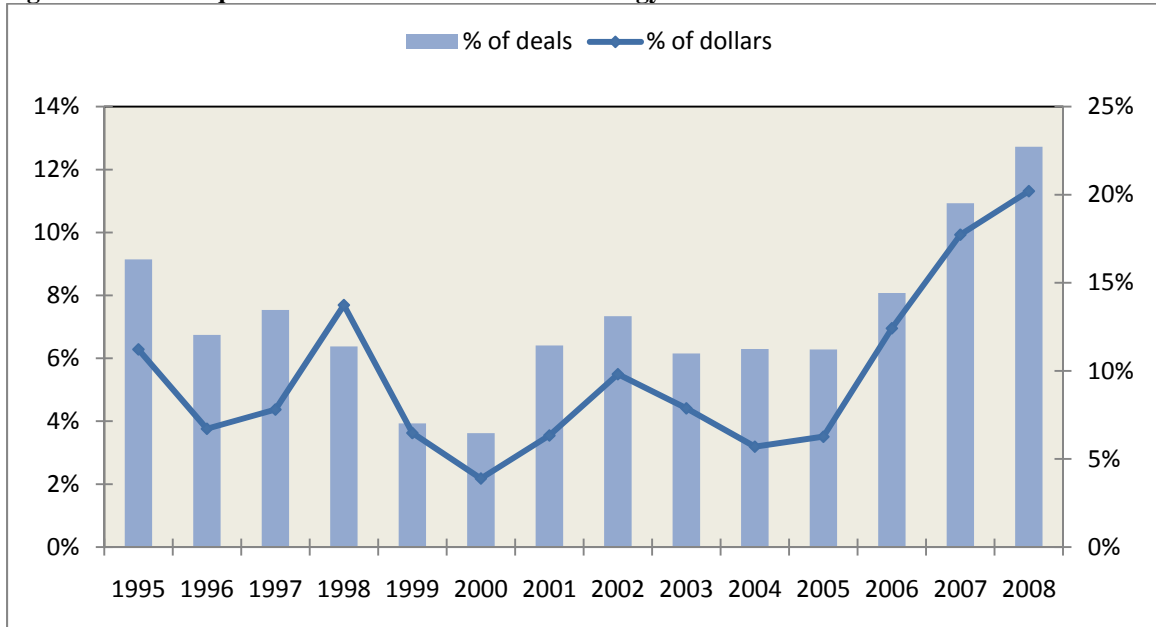
And while the total dollars and deals associated with the cleantech is promising for the future of this industry, it is perhaps more telling to notice the level of VC activity

within the first sequence round of investment – the Series A round. First sequence investments are critical lead indicators for an industry. Two things have been triggered as a result of cleantech’s sexy status. First, VCF find it easier to raise money when they tell their client/investors that they are going to be investing in clean technology. Many of those wealthy investors listed in Figure 41 above (foundations, universities, etc) that were quick to divest themselves from any investment associated with tobacco companies or companies operating in Sudan (due to the Darfur genocide), are equally eager to tout their own socially responsible investment portfolios that are helping to bring clean technology, carbon mitigating, and sustainable companies to market. The prospect of high investment returns has been equally compelling. The second trigger associated with the rise in cleantech VC activity has been on the side of the entrepreneur. Since VCF are flush with cash, anyone thinking of developing a technology will show less hesitation, given the financing opportunities within this favorable funding environment.

NVCA does not breakout first sequence investing in cleantech, but they do breakout first sequence investing for its 17 broad sectors. Figure 46 displays how first sequence investing in the IE sector has grown substantially over the last four years. In fact, in 2007, when the IE sector secured more than 17.7% of all first sequence investment dollars, it had finally eclipsed the software sector, which has lured the most Series A investment dollars every year since 1995. IE expanded its lead in 2008, when it secured 20.2% of all the first sequence investments dollars, compared with 14.7% for software. In terms of deals however, Software retains a substantial lead securing 240 in 2008, compared with 149 for IE; the reasoning is simple, as VCF can fund many more

software companies since they take far fewer total dollars to get off the ground, especially compared with the more manufacturing intensive IE start-ups.

Figure 46: First sequence investment in Industrial/Energy



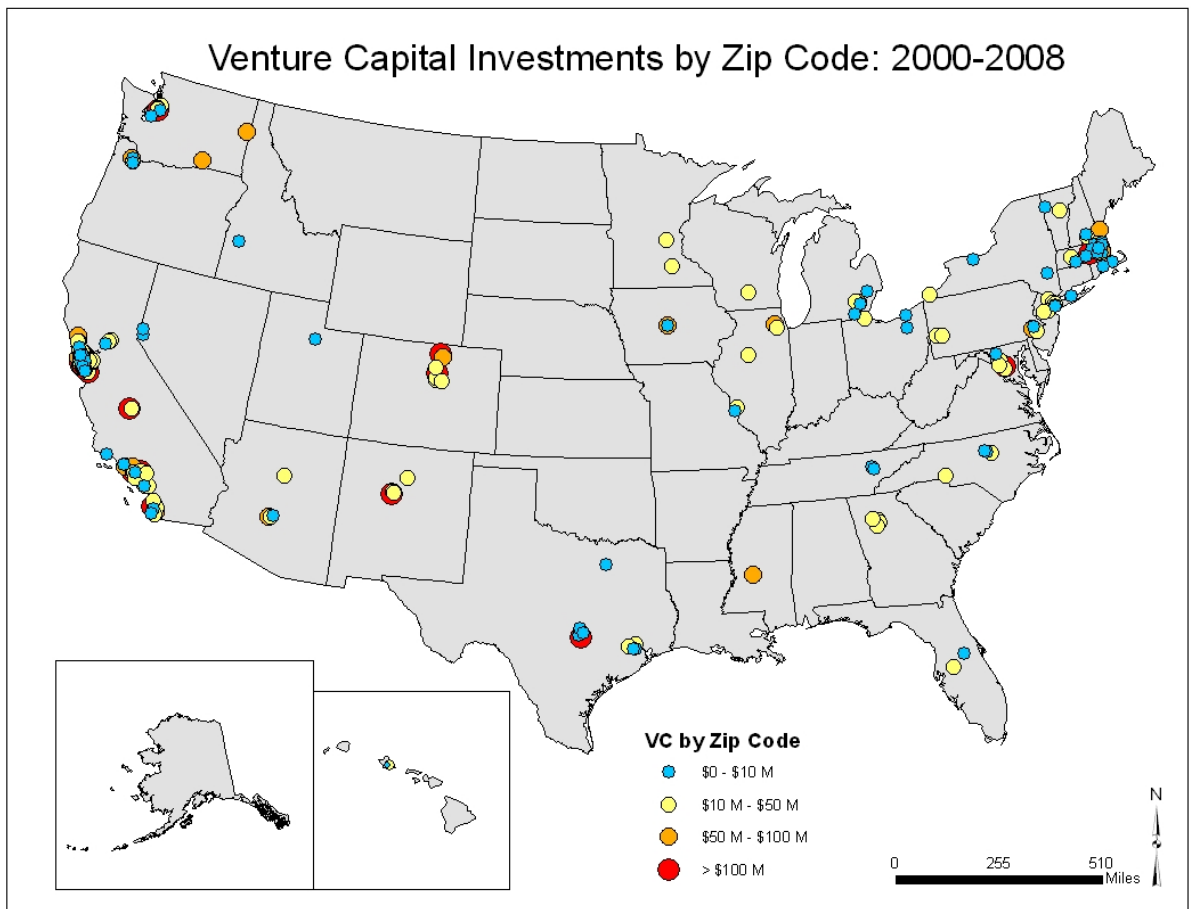
Source: NVCA 2009

Moving on to the disaggregated data used for this study, the data revealed that 270 of the 714 VC firms participated in at least one investment round for a cleantech company from 2000-2008. A total of 299 cleantech companies received funding during this time, many obtaining only a Series A round, but many others receiving several ensuing funding rounds as their technologies progressed. This study calculated \$9.3 billion of total investments from 2000-2008, but 94% (\$8.7 billion) was invested in just the last three years, 2006-2008.

Geographically speaking, a major imbalance exists with respect to both the location and the concentration of the VC investment dollars (Figure 47). California has secured more than half of all VC investments during the study period, while

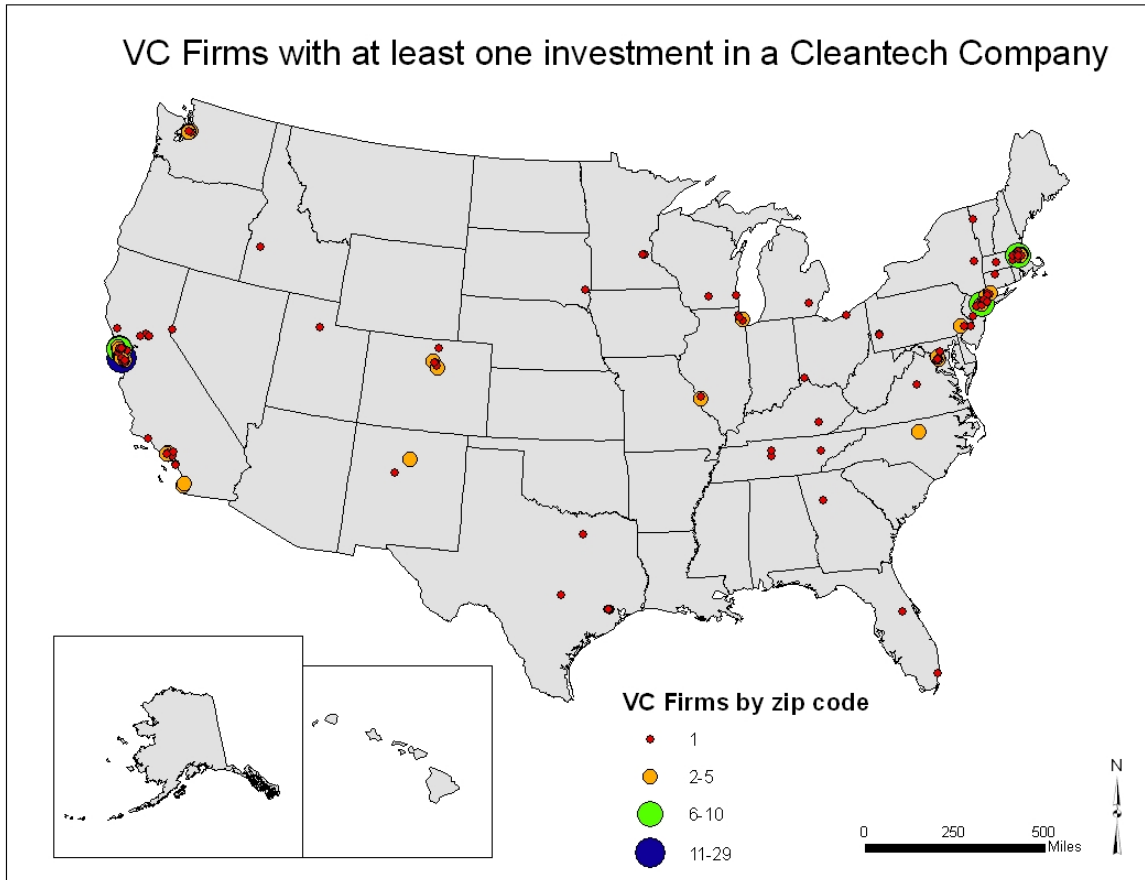
Massachusetts is the only other state to amass more than \$1 billion. In sum, 31 of the 50 states had at least one cleantech firm obtaining some VC financing. As far as clusters of cleantech activity, several obvious yet important regions are evident. With more than \$5 billion in California, firms are concentrating in the logical spots of the SF, LA, and SD metro areas. The Route 128 corridor of Massachusetts, which like Silicon Valley became a VC destination hotspot during the internet bubble, is home to many of cleantech companies. Elsewhere, clusters of cleantech activity are identifiable in Colorado's Front Range, in the New York/New Jersey/Philadelphia region, and in the Washington DC metro area.

Figure 47: Combined VC investments by zip code, 2000-2008



In terms of agglomeration effects, the clustering of cleantech firms in California should be even less surprising since 115 of the 270 VCF that made at least one investment in a cleantech firm are located in California. Furthermore, the high concentration of cleantech firms in Silicon Valley might also be partially explained by the proximity to the VCFs that have made Sand Hill Road such a famous concentration of VC activity; the data show that of the 115 VCF, 48 are in either Menlo Park or Palo Alto. New York (31) and Massachusetts (30) rank second and third respectively as states which are home to the VCF that have made the most cleantech investments (Figure XXXX). While much has been made of capital's footloose characteristics, 22 states have sourced no VC, with most of the funds originating in three logical locations of New York, Boston, and the Bay Area.

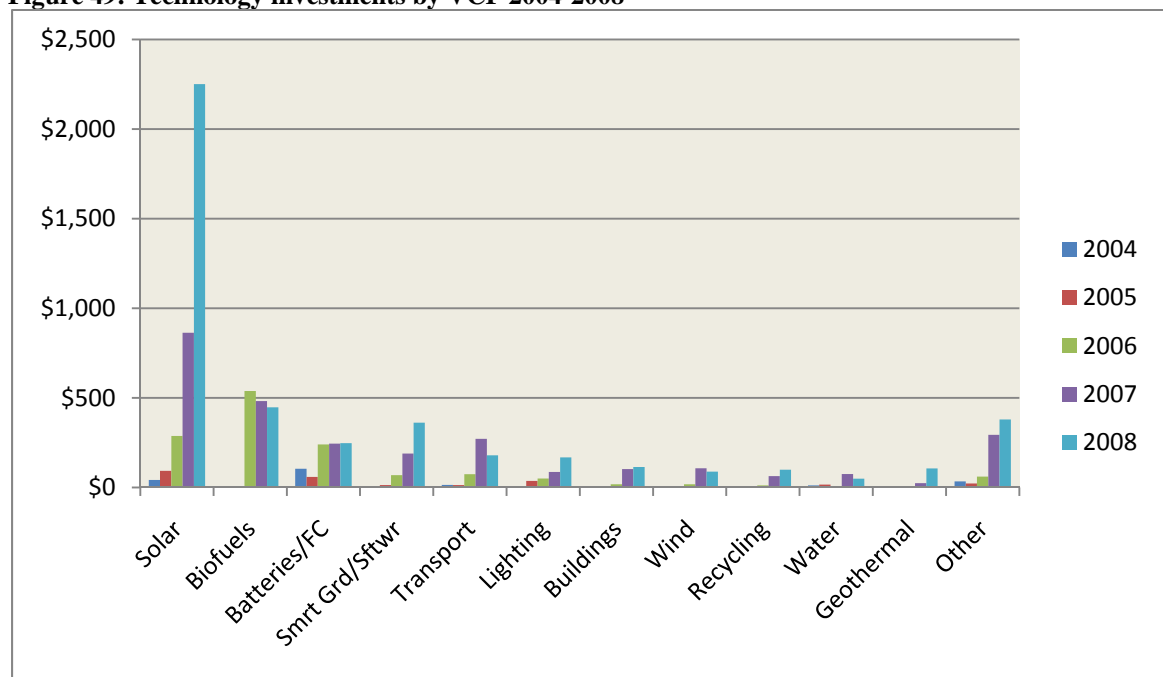
Figure 48: Location of VC Firms with at least one cleantech investment



In an effort to determine the technology with the greatest promise in the eyes of the VC investment community, which has both the expertise and the resources to help bring these concepts to market, this study created several different technological categories. In order to obtain a better gauge of the more viable technology choices by VCF, the 31 different technology types listed in Appendix A have been consolidated into 12 different categories. For example, investments in wind, materials-wind, high-altitude wind, and micro-wind have all been consolidated into one category – wind.

Over the period 2000-2008, the breakdown of these various technologies reveals the attractiveness of solar, at least when measured by what the private growth money has chosen to fund (Figure 49). Biofuels and batteries/fuel cells are also promising, while in 2008, the smart-grid and energy software category jumped significantly, most likely in anticipation of Obama’s proposed upgrade of the national grid that would coincide with other smart-grid and demand-side technologies.

Figure 49: Technology investments by VCF 2004-2008



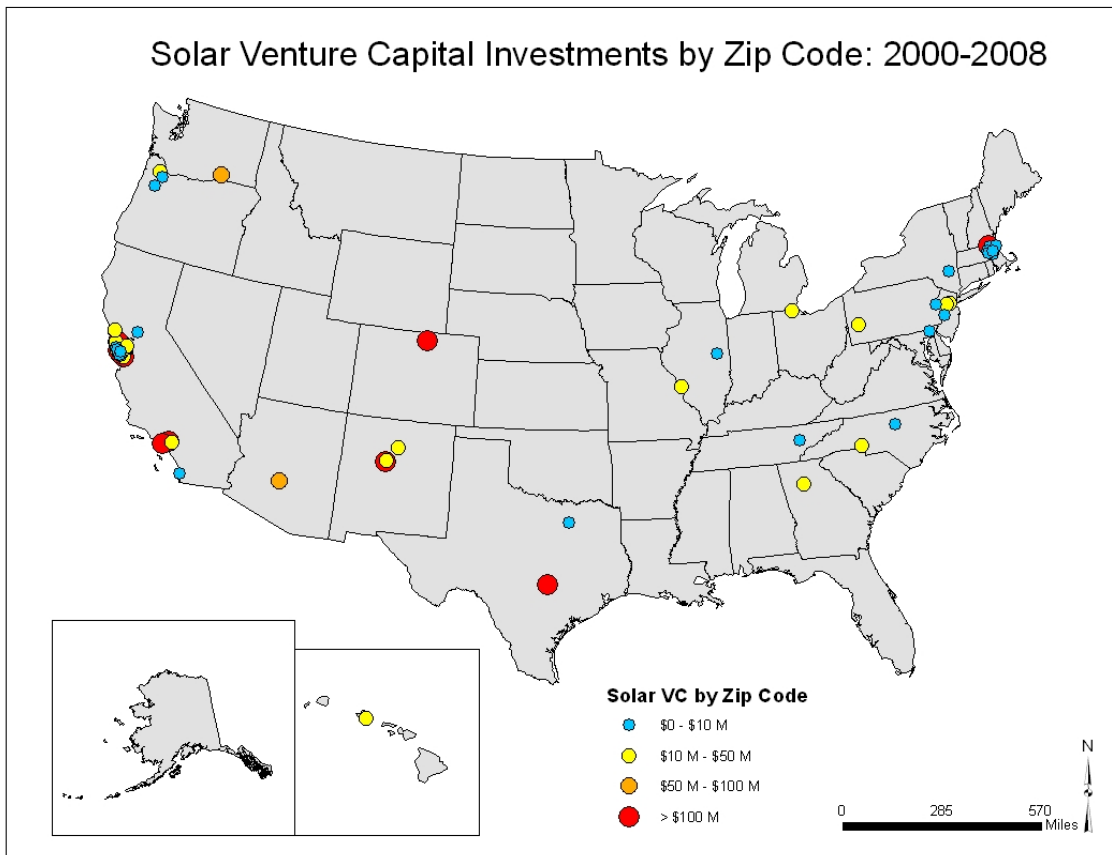
\$ in millions

These data also reaffirm the void of any large-scale publicly traded company with respect to dominating the solar space – unlike the dominant players that have emerged in more established wind industry (Vestas, GE, and Gamesa) or ethanol (Pacific Ethanol, Andersons Inc., Green Plains Renewable). In fact, while there are a variety of publicly traded solar manufacturers, a market leadership role is still very much up for grabs. And yet, the potential for other solar companies to emerge is enormous, given the variety of

competing residential solar technologies, as well as the utility-scale solar thermal technologies, where only a few pilot projects are in demonstration mode.

The location of firms engaged in solar mirrorsthe overall comprehensive VC funded cleantech map (Figure 50). As expected, many of the companies are located in California, but four very promising companies, with VC investments exceeding \$100 million have emerged elsewhere; Austin, TX (Heliovolta); Ft. Collins, CO (AVA Solar), Albuquerque, NM (Advent Solar); and Lowell, MA (Konarka).

Figure 50: VC investments in Solar technology by zip code



Summary and Conclusion

It may be a coincidence that the rise in cleantech VC coincided with the rising price of oil, which topped out at \$147 per barrel in July of 2008. Fears of persistently high fossil fuel prices led investors to seek alternatives, but we have been here before, most recently with the OPEC oil embargo. When the embargo was lifted, cheap fossil fuels undercut any momentum that had taken hold in the renewables sector. Today, cleantech investments face discouraging headwinds. For one, fossil fuel prices have collapsed, particularly for natural gas, but oil is also off about 50% from its 2008 highs. Secondly, during a recession, public support erodes for what remains a more expensive technology option. The recession has also spooked the VC community. Preliminary indications are that VC activity for 2009 will contract, and through the third quarter, investments in the IE subsector were on track to shrink by more than 50% from the 2008 record levels.

Prior to the crisis, the surge in VC cleantech investments displayed similar parallels to the inflated valuation that kindled the dot-com bubble. VC, particularly in cleantech, has become a victim of its own success, transitioning from retired professionals that had run successful corporations with expertise to share, into a field of mostly young generically trained MBAs with limited industry experience (Cornelius 2005, Dizzard 1982). These newcomers are more risk tolerant, but lack the capacity to play leadership roles on the boards of small firms, and so their investment decisions are often driven by profit potential rather than technological promise. These are the classic conditions that lead to the formation of investment bubbles. Is it for this reason that the

cleantech sector is showing some of the preliminary (warning) signs similar to the dot.com bubble of the late 1990s – namely inflated valuations and too much capital chasing too few investment ideas? Certainly the timing of the credit crunch has temporarily suspended the risk of a bubble forming, but for how long?

Despite the great recession, the largest VC investment in 2009, was a \$285 million placement for Fremont, CA based Solyndra, a solar manufacturer. The third largest placement was a \$105 million investment in Silver Springs Networks which designs smart-grid software (NVCA 2010). Evidently, there is still a lot of money betting on a fundamental shift in our energy economy. Is this a resumption of the cleantech bubble or is a more profound techno-economic paradigm shift underway (Freeman and Perez 1988)? And are the two mutually exclusive? Afterall, the dot.com bubble legacy is one of revenue-less internet companies and lost fortunes, but it was also a period that put in place cheap communication infrastructure and saw the widespread adoption of desk-top computing.

Nevertheless, the dynamics of the cleantech industry are in constant flux. Should the political and economic circumstances remain unchanged, financing for high-risk high-reward cleantech companies will remain dominated by more aggressive VC investors. However, with the passage of a federal cap-and-trade law, a tidal wave of new companies would be spawned; and with a legal framework supporting the penetration opportunities for new technologies, traditionally conservative banking institutions and a host of new money would find the investment profile for these companies a lot more palatable. Meanwhile, the profitability of the supply side cleantech companies is still

heavily reliant on existing policy supports, which are notoriously fickle. And still, the great recession is far from over. A shock to the financial markets would emasculate the industry; promising technologies might perish as the necessary funding dries up. Should this happen, this industry will face a critical set-back, because early stage companies are responsible for the preliminary breakthroughs that pave the way for rapid and large scale technological adoption down the road.

One thing remains clear, VC will continue to play a role in cleantech. Even if the asset bubble bursts, as it did for the computing industry back in 2000, there seems to be so much momentum behind cleantech that its disappearance is unlikely. Rather, similar to the internet industry, it might consolidate in the hands of a few key players before diffusing again on more solid financial footing, at which point VC money returns. If on the other hand, the cleantech industry is not overvalued, but rather these investments mark the early stages of creative destruction in the energy industry, many of these early industry leaders will capture new markets and the VCFs that supported them in the early years will profit handsomely. For cleantech to fully achieve market acceptance, it must move down the cost curve, so the virtues of capitalism and VC will remain crucial to ushering in the technologies needed for a carbon conscious world.

Chapter Five: The electricity transition in Colorado: the perspective of municipal utilities and rural electric cooperatives.

Introduction

Transitioning to a renewable portfolio of electricity supplies must be a central component of any serious effort by the United States to tackle climate change, which means reducing the dominant role played by coal, and to a lesser (but growing) degree, by natural gas. According to the Environmental Protection Agency (2009), the electric power sector contributes 42% of all carbon emissions, more than any other economic sector, including transportation, which contributes 33% of all carbon emissions. At the center of our electricity transition is the utility. Yet utilities are quite different from one another in size, scope, customers served and geographic market, and most importantly, different utilities are subject to different rules.

Most of the emphasis on curbing greenhouse gas emissions takes aim at investor-owned utilities serving large urban populations; and rightly so as more than 75% of the US population obtains their electric service from investor-owned utilities. Programs and policies designed to mitigate environmental impacts, combat climate change, or improve efficiencies, would stand the best chance of achieving their objectives by targeting the largest utilities serving the densest population clusters. The remaining 25% of the

population live in small towns and rural communities, where electricity is typically provided by municipal utilities or rural electric cooperatives.

In the absence of any real federal energy policy, states have enacted a host of laws designed to reduce our dependence on carbon based fuels and force utilities to bring additional renewable generation into their electricity portfolios. Most of the emphasis to decarbonize our electricity supplies has focused on those utilities that can best afford to absorb the initial costs of what remains a more expensive electricity option, which at the moment, means investor owned utilities. For reasons mostly having to do with scale, large urban utilities are better positioned to facilitate this transition. Although this makes sense, it does neglect a meaningful portion of the population and a vast majority of the geography: Municipal utilities are found in every state except Hawaii and 75% of the service territory within the country is served by rural electric cooperatives (Wilson et al. 2008)

As regulated entities, and often publically traded companies, investor-owned utilities are subject to oversight and many of their activities must be available in the public domain, meaning there is plenty of data to examine. As a result, a majority of the research concerning the success or failure of various programs designed to accelerate the adoption of renewables has honed in on large urban utilities. These same data do not exist for unregulated rural utilities. As a result, understanding their efforts in making this energy transition is poorly understood and poorly documented.

This paper is a preliminary attempt to shed some light on the electric power sector as it relates to the rural utilities in Colorado, all of whom are preparing to meet newly

enacted electricity standards passed in 2007. Despite resistance from rural communities, the law mandates that all utilities in Colorado, not just the two regulated utilities, incorporate green electricity supplies into their portfolios. This paper surveyed managers at the rural utilities to identify what conservation, efficiency, and green energy policies are in place as they prepare to meet their obligations. Furthermore, the survey attempts to gauge the attitudes of these utilities toward law-makers and toward carbon legislation in general. This paper provides a valuable contribution to an important yet neglected component of our electricity sector, and will help frame future discussions on comprehensive carbon legislation, because the ideas and cooperation from rural communities will be an important component of any medium- and long-term attempt to alter our electricity sector.

Utility Facts and history

Electric utilities date back more than 100 years as cities, first aiming to illuminate their streets at night, were eager to grant permits for entrepreneurs in order to electrify home and industrial life. By building generating stations and delivering electricity to the surrounding homes and businesses, investor owned utilities were the first companies to make electricity accessible to urban dwellers. Over time, the fragmented urban utility landscape was consolidated, and the resulting natural monopolies eventually led to financial misconduct and poor service. Municipal utilities were born during the early days of electricity as a way to combat the monopolistic tendencies of investor owned utilities. Cities thought they could provide better service at a lower cost if the electric

utilities were run by their own citizens with a non-profit structure. Combined, the two types of utilities served the electricity needs of the country through the progressive era.

Unfortunately, farms and rural communities lacked power because the major players in the electricity market found no economic justification to extend service to the sparsely populated countryside. Following the depression, that all changed. In 1933, Congress created the Tennessee Valley Authority to provide cheap power to impoverished southern communities. As part of the New Deal, President Roosevelt passed the Rural Electrification Act providing financial resources to electrify small towns. Rural electric cooperatives spread quickly through the sparsely populated interior; in the mid 1930s, nine in ten rural homes were without electricity; by 1953, nine in ten rural homes had electricity (NRECA 2008).

Broadly speaking, retail customers are served by three major types of utilities today: investor-owned utilities, municipal utilities, and rural electric cooperatives. Investor Owned Utilities (IOU) are very large for-profit corporations, found in densely populated urban areas, but because they are monopolies, IOUs are subject to regulation. Municipal Utilities (MU), also known as publically-owned utilities, operate within defined cities or towns and are not-for profit government entities. They are owned and operated by the residents within their respective cities and range in size from very large (for example: Los Angeles, Sacramento, Seattle, and Orlando), to very small (towns of fewer than 1,000 people). Rural electric cooperatives (REC) serve rural areas and like MU, they are non-profit enterprises run by their members. RECs can, and do operate

across states line, when the proximity of two neighboring communities would warrant a REC as the most efficient way to ensure the cheapest possible electricity.

IOU are run as profit-making enterprises deriving capital funds by issuing shares of stock that are purchased for the potential appreciation. Like any publically traded firm, stockholders in IOU have voting rights, are usually paid a dividend, and expect the firm to maximize its return because profits from the business are shared with stock holders seeking investment income. REC and MU on the other hand are owned by their members and the public respectively; they charge similar fees for their product and services but do so in a manner free from shareholder scrutiny, rather relying on its board members to ensure the most efficient organizations. Furthermore, any profits from operations are returned to their members/public. Although there are relatively few IOUs, they are large organizations with sizable customer bases representing 76% of all the electricity sold in the United States in 2006 (EIA 2009a). Conversely, REC and MU are small organizations selling 10% and 14% of the country’s electricity respectively. Because RECs and MUs tend to be smaller organization serving less populated areas, there are many more of these organizations (TABLE 30).

Table 30: Metrics for each of the three major types of utilities, 2006

Utility Type	# of organization	Customers (millions)	Average # of customers	% of national electricity sales
IOU	220	102	400,000	76%
MU	2,000	20	2,000	14%
REC	930	17	12,500	10%

Source: NRECA 2009

There are two types of RECs: generation & transmission cooperatives (G&T) and distribution cooperatives. G&T coops produce and distribute electricity, meaning they operate and maintain the plants and the transmission lines. Distributive coops deliver the electricity to its members and are generally responsible for the last-mile; most RECs are distributive. Because most RECs serve small communities, the cost to any one REC of building, operating or maintaining generation facilities is prohibitive. As a result, many RECs band together to form a regional G&T charged with the wholesale generation and transmission of electricity to the distribution coops members. While this arrangement is typical, it is by no means universal, as some RECs buy their electricity from IOUs or other suppliers.

Due to their size, IOUs tend to be vertically integrated, whereby they generate, transmit, and distribute their own electricity. Similar to an IOU, large MUs generate and distribute their own power, but this vertical integration describes only a small fraction of the MUs. About 2/3 of the MUs serve communities with populations less than 10,000, forcing them to behave like RECs and form regional organizations, enabling them to spread the costs associated with building generation and transmission capacity (APPA 2009b). MUs also buy power from federal agencies like the Bonneville Power Authority or the Western Area Power Administration.

The role of electricity generators in addressing climate change

According to a poll conducted by the Opinion Research Corporation (2006), two of the top responses to a survey explaining why residential consumers buy renewable

energy included the desire to improve the environment and to support the development of new technology. The non-residential sector, which represents a significantly larger amount of green energy consumption, was more direct, indicating that GhG reductions play a major role in their decision to purchase green power (Hanson 2005). And yet, the federal government has continued to avoid passing legislation to deal with greenhouse gas emissions.

In the absence of federal leadership, the urgency to mitigate greenhouse gases is falling to local governments, state governments, and private institutions. Nine hundred seventy-one mayors representing 85 million people from all 50 states have signed the US Conference of Mayors Climate Protection Agreement (US Conference of Mayors 2009). American College and University President's Climate Commitment, with a mission to neutralize greenhouse gas emissions and focus the efforts of higher education to climate stabilization restoration, has been signed by the Presidents or Chancellor of 606 colleges and universities in all 50 states (Presidents Climate Commitment 2009). Climate Leaders is a partnership between the government and private industry, whereby corporations receive recognition as environmental leaders from the EPA for complying annually with self-imposed greenhouse gas emissions targets. Two hundred eighty-six of the largest corporations have signed up for the program including global brands like American Airlines, Applied Materials, 3M, Bank of America, Best Buy, Caterpillar, Cisco, Coca-Cola, ConAgra, Dell, GE, GM, Marriott, Merck, Sprint, Target, and Xerox (EPA 2009). Smaller companies also participate, but it is the larger companies, which can flex their

muscle to influence their suppliers and partners which will most likely yield the greatest near-term environmental benefits.

Unfortunately, of the 286 companies signed on to the Climate Leaders initiative, only 10 are utilities and only one is a MU or REC (Bluebonnet Electric Cooperative in Texas). Some utilities have made their voices heard on climate change in other ways, led by Pacific Gas and Electric (northern California), Exelon (Chicago), and PNM Resources (New Mexico) who have all ended their affiliation with the National Chamber of Commerce in protest of that organization's opposition to carbon legislation (Krauss and Galbraith 2009). Still, most utilities are skeptical of climate initiatives that they fear will dramatically alter their businesses, which for many of them, are aligned with fossil fuels.

This lack of federal climate legislation has left an important leadership void in energy policy, a void that has convinced states to enact their own energy laws. Renewable Portfolio Standards (RPS) have been passed in 28 states (as well as the District of Columbia) requiring an increasing share of electricity to come from green sources. The mandates vary across the country, with California leading the way requiring that 20% of its electricity come from green sources by 2010. Other states have higher requirements, but these states provide for greater lead time with target dates that are more than a decade away. In addition to varying by state, adhering to the requirements varies among the different utilities in the states. Because of both their size and economies of density, IOUs are the primary target for RPS legislation. IOUs by their nature are better prepared to bring additional green energy into their portfolios. The reasoning is simple; green energy is more expensive to generate, and because they are regulated, IOUs can

request a rate hike from the public utility commission (PUC) that enables them to pass along the cost. Some states require MU and REC to meet the same targets but generally, the targets are relaxed, principally because it would be disproportionately expensive for smaller utilities to pass the cost of green energy onto their members/owners when measured on a per capita basis.

RPS put the generators at the center of the most pressing issue associated with climate change – addressing the way we produce electricity. On the surface it would appear that utilities are able to offer a mix of energy options when they produce electricity, as reflected by their nameplate capacity (Table 31). Nameplate capacity indicates the total amount of electricity that a facility can produce at a given time by a given energy source. But it is a misleading figure. Utilities lean heavily on their baseload power plants to generate most of their electricity. Baseload power represents the electricity needed to meet a community's continuous needs, and because of its low marginal cost they are the least expensive to operate. Baseload power is usually fueled by coal or nuclear, and utilities prefer to run them continuously because they are terribly inefficient during their slow and lengthy power-up (or power-off) times. Baseload power is not expected or capable of handling spikes in electricity demand; rather peaking power units are brought online during load imbalances. Peaking plants are cheaper to build and are designed for quick activation, but because they use a more expensive fuel (natural gas or oil) they are more expensive to operate. As a result, a utility's nameplate capacity is rarely going to reflect the mix of energy used to generate electricity. As an obvious example, nuclear accounted for about 20% of the total electricity generation in the United

States in 2007, and yet represented no more than 10.1% of the total nameplate capacity for any of the generators.

Table 31: Portfolio of electricity generation by generator in 2007

	IOU	MU	REC	Federal	IPP	Total
Coal	188,806	29,519	24,002	18,233	75,480	336,040
Natural Gas	125,553	38,241	20,085	5,776	262,397	452,052
Nuclear	41,177	8,814	3,034	7,205	45,535	105,765
Oil	23,241	8,595	1,242	27	29,289	62,394
Hydro	24,363	20,628	913	41,710	10,385	97,999
Other	2,668	809	103	2	29,962	33,544
Total	405,808	106,606	49,379	72,953	453,048	1,087,794

Totals reflect nameplate capacity (MW)

Source: EIA 2009b

All three of the traditional utilities are heavily invested in fossil fuels for the largest percentage of their energy supplies. And while the nameplate capacity suggests that all of the utilities obtain less than 50% of their electricity supplies from coal, it remains the fuel source responsible for half of our total electricity. The federal government, through its control of large-sale conventional dams, is the principal supplier of hydro power. Meanwhile oil appears to play a role in electricity for IOU and MU, but oil is typically one of the last fuel options and gets dispatched only when there is a severe spike in demand. The role of ‘other’, referring primarily to green electricity, is less than one percent of the total for all the entities except independent power producers, where it constitutes an impressive 6.5%.

Historically, electric generation implied utilities, but in more recent years, Independent power producers (IPP) have taken on a huge role in electricity production. IPP are mostly private, non-regulated entities that sell wholesale electricity to utilities or

cooperatives. IPPs emerged from PURPA¹⁶ in 1978, which guaranteed that energy produced by qualified producers (as determined by a set of criteria established by FERC¹⁷) would be purchased by utility companies so long as it was produced in-line with the economics of avoided cost. Avoided-cost meant that the price to purchase the power from a third party had to be less than the total costs for a utility to generate its own electricity. For a variety of antitrust issues coupled with the energy crisis, PURPA was thought to serve as a catalyst for small enterprises that might unlock our energy independence by promoting greater use of alternative, renewable, and distributive sources. With the 1992 Energy Policy Act, access to transmission for wholesale providers became a right, paving the way for an avalanche of IPPs seeking access to the energy business (Union of Concerned Scientists 2009). In 2007, independent power producers assumed the risks for nearly all of the green electricity supplied nationally, controlling more than 85% of the nameplate capacity in all of the major green energy technologies (Table 32).

Table 32: Total renewable capacity by owner type, 2007

	IOU	MU	REC	Federal	IPP	Total	IPP % of total
Geothermal	38	220	0	0	2,975	3,233	92.0%
Solar	9	2	0	0	491	503	97.7%
Wind	2,081	284	10	2	14,219	16,596	85.7%
Biomass	489	302	93	0	11,460	12,344	92.8%
Hydro	24,363	20,628	913	41,710	10,385	97,999	10.6%
Total	26,981	21,436	1,015	41,712	39,530	130,674	

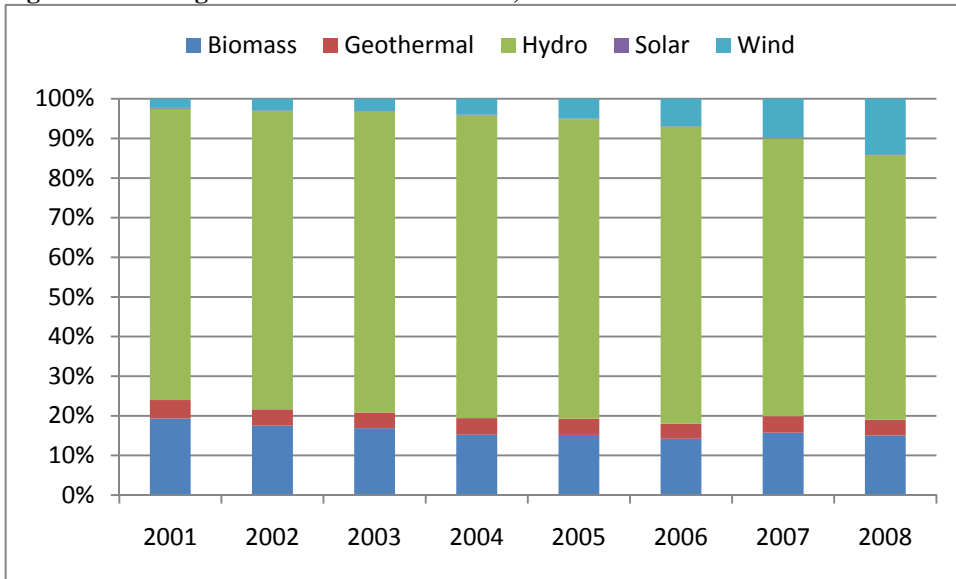
Totals reflect nameplate capacity (MW)
Source: APPA 2009a

¹⁶ PURPA (Public Utilities Regulatory Policies Act) of 1978, created competition in electricity markets by mandating that utilities purchase power from small-scale renewable sources. It is first piece of federal legislation crafted to stimulate investments in renewable electricity.

¹⁷ FERC (Federal Energy Regulatory Commission) is responsible for (among other things) electricity transmission oversight.

According to the Energy Information Administration (EIA2009), the United States generated more than 371 million MWh of electricity from renewable sources in 2008, which was nine percent of the total electricity supplies. By removing large-scale hydro, other renewables accounted for 2.9% of total generation in 2008, up from 1.8% in 2001. But the source of that generation and the types of organization/utilities engaged in its development is highly fragmented (Figure 51). Nearly 70% of that electricity was generated from large scale hydro projects while biomass accounts for 15%. Geothermal has retained roughly four percent of the total supplies throughout the decade, while solar is simply too unproven and too expensive to make even a minor contribution to the mix. Meanwhile, wind accounts for 14% of the total and since 2001, wind has experienced a six-fold increase in its share of renewable generation, coming mostly at the expense of hydro and biomass, and as previously described, independent power producers (IPP) are responsible for adding virtually all of the additional wind capacity (AWEA 2009). Therefore, as we decarbonize the national electricity generating portfolio, any overhaul of the industry will require coordination not only with electric utilities, but with independent power producers as well; thus the role of IPP, also known as non-utility generators, as wholesale electricity generators is worth a closer examination.

Figure 51: Total generation from renewables, 2007



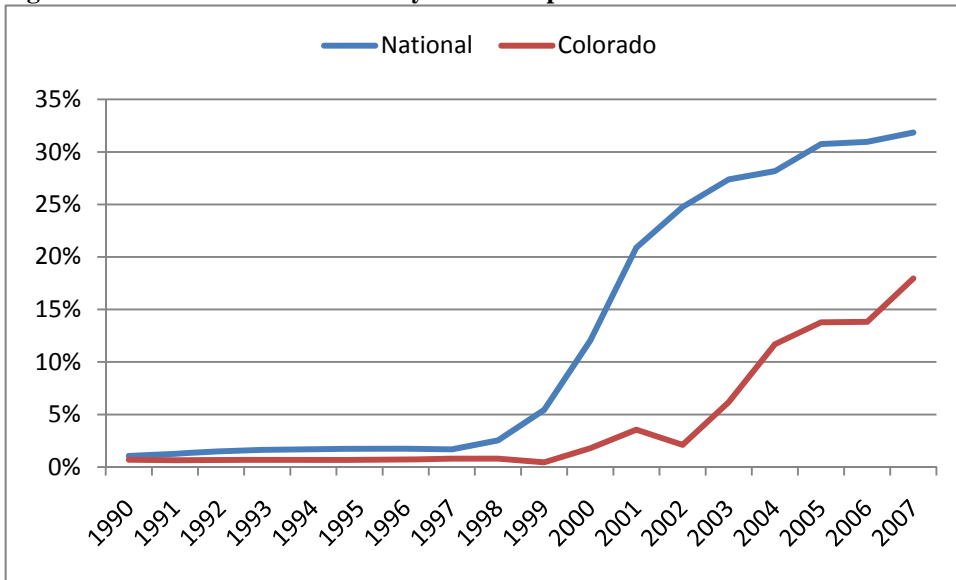
Source: EIA 2009b

For several reasons, independent power producers (IPP) have seen their influence in the electricity markets grow over the last 20 years. For one, they offer a choice to utilities. The emergence of wholesale competition means that future electricity load demands can be evaluated in a “buy versus build” scenario. Historically when utilities needed to add additional capacity, they built new units; but with IPPs selling generation, utilities can weigh the costs of buying electricity from a wholesaler against building, operating, maintaining, and financing their own generation. Larger utilities face a slew of regulatory hurdles when trying to build new capacity¹⁸, whereas IPP fall under no state or national regulatory jurisdiction (Colorado Energy Forum 2006); and while they still face enormous development, financing, construction, and operating risks, they are more nimble and can get a project built quicker. Nationally, IPPs contributed 31.8% of all the

¹⁸ Because the costs are going to be passed on in the form of higher utility bills to its customers, the Public Utility Commission, which acts to protect consumers, must approve the construction of any new generation or transmission capacity. As a result, IOU have to go-through a lengthy and rigorous approval process.

electricity in the United States in 2007, up from one percent in 1990 and 12% in 2000 (Figure 52). The jump in Colorado has been less dramatic, with non-utility generators contributing 18% of the total electricity production, up from 0.7% in 1990 (IEA 2009b).

Figure 52: Contribution of electricity from Independent Power Producers



Source: EIA 2009b

Second, the aggressive move into green electricity can be explained by the induced demand created by the state RPS. IPPs are eager to supply this demand because of the tax incentives that have been enacted and reauthorized by Congress over the years to support green electricity production. The incentive most widely used is the production tax credit (PTC), which offers a tax credit for every kWh of electricity generated from renewable resources. Because the tax credit requires the operator to have other income sources (against which they can apply the tax credit), many IPPs are actually subsidiaries of other large institutions that view electricity generation as a way to reduce their tax liability (Ishii 2006, Harper et. al 2007). Use of the tax credit is restricted for it is only

available to those companies that have offsetting taxable income; it is not available to tax-exempt entities (ie: MU and REC, among others). And while the federal government has experimented with ways to encourage renewable energy developed by the entities excluded from the PTC, they have had a checkered, and thus ineffective history (Wiser et al. 2007).

The dominance of IPP in the green electricity sector is one of the most important changes to the electricity sector over the last 20 years. It is also a natural marriage for rural utilities to be partnering with IPPs, especially in the development of renewables, where the best resources are found in the rural areas. Rural utilities, because of their non-profit nature, are seeking the lowest cost electricity option. Green electricity is not yet low cost, yet IPP offer an avenue for rural utilities to begin buying allotments of green energy, without having to assume both the risk and the expense of constructing their own green generation. Without IPPs, the road to a rural utility future based on non-carbon fuels would be more challenging

Several factors contribute to contextualizing the difficulties in decarbonizing the electricity mix of rural utilities. First, the limited and often non-existent RPS mandates have insulated these utilities from making any transition. Second, their inability under the tax code from attempting to profit from constructing new generation restricts their operational decision making capacity. It is the only option for a REC or MU that wants to bring green energy online, to buy that electricity from IPPs; and while this might make smart business sense, the lack of choice is a limiting factor. Third, it is possible that institutional resistance factors have made rural areas suspicious of urban elites, which

might contribute to resisting top-down strategies. Finally, these utilities are owned and operated by neighbors within their communities and are more visible than the employees of an organizational behemoth like an IOU or a PUC bureaucrat, making it personally prohibitive, particularly in the more impoverished communities to voluntarily accept more expensive electricity. As a result, REC and MUs are likely to remain disengaged on any national carbon mitigation plan, which makes decarbonizing the electricity mix for rural utilities a great challenge.

Nevertheless, it is critical to understand the behavior of rural and small town utilities because RECs are more carbon intensive in their electricity production. Nationally, coal is used for 50% of the total electricity production, yet RECs are 80% reliant on coal (NRECA 2009). And while MU mirror the generation percentage of the United States as a whole, there is greater reliance on coal in the sparsely populated MU service areas, and demand for electricity in rural areas is growing twice as fast as the national average (Mufson 2007).

In fact driven by urban sprawl many of the coops are now assuming the responsibility for electrifying exurban and even suburban communities that are encroaching on these one-time remote locales. Furthermore, according to the Department of Agriculture, the migration patterns of baby boomers will have a material impact on non-urban and more isolated areas that offer lower housing costs and high natural amenities (Cromartie and Nelson 2009). By 2020, the rural population of people between the ages of 55-75 will increase by 30%. The changing role of electric providers in rural

areas will pose a series of questions for the energy industry and policy makers as the country attempts to transition away from fossil fuels.

Colorado energy and utility landscape

Within the state of Colorado, 57 different entities deliver electricity to customers; there are two IOUs, 26 RECs and 29 MUs. Collectively the IOU in Colorado serve 60% of the customers, but of the two IOU, Xcel Energy represents more than 90% of that segments’ totals for the state, with 1.3 million customers, consuming 28 million MWh of electricity, while generating more than \$2 billion in revenue (EIA 2009b). Black Hills Energy is a minor player with only about 10% of the IOUs total market share. Separately, the 26 RECs in Colorado serve more customers, have more revenues, and sell more electricity, than the 29 MUs, but their influences are mixed. The second largest utility in Colorado with 208,000 customers is the MU serving Colorado Springs, while the smallest utility in the state is the city of Fleming with just over 200 customers. Intermountain REA is the state’s largest REC with 135,000 customers (3rd largest in the state), while White River Electric is the smallest REC with about 3,000 customers. An aggregate breakdown of Colorado utility data are presented in Table 33.

Table 33: Colorado utility breakdown

	Utilities	Revenues (000)	Sales (000 MW)	Customers
IOU	2	2,266,934	29,935,092	1,421,319
REC*	22	1,046,651	11,558,022	586,346
MU	29	614,170	8,878,210	417,591
Total	53	3,927,755	50,371,324	2,425,256

*Excludes four RECs that generate a fraction of their revenue in Colorado.
Source: EIA 2009b

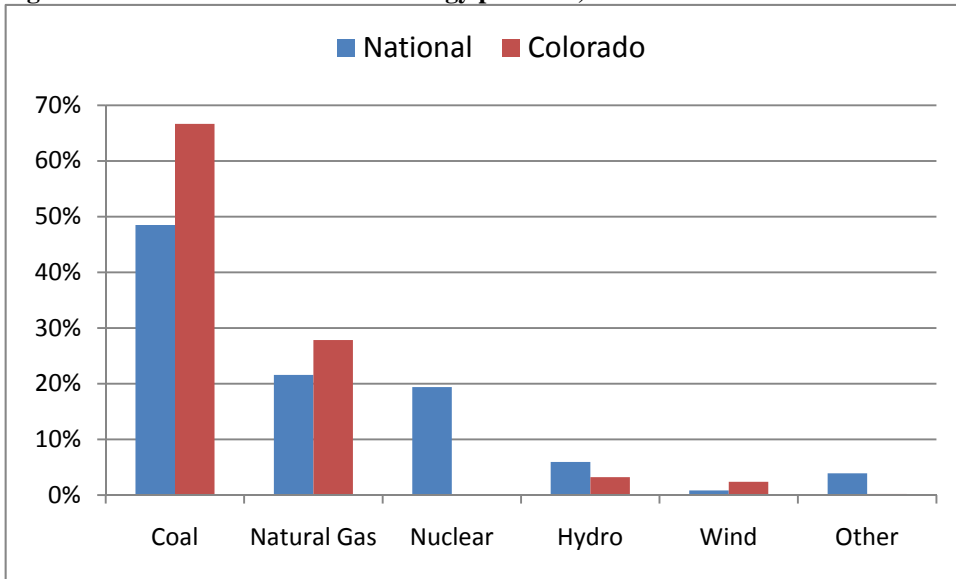
Of the 22 RECs, 18 buy their energy from Tri-State G&T Association, which produces and delivers electricity to 44 distribution coops in four states (Wyoming, Nebraska, Colorado, and New Mexico). Colorado represents the largest chunk of Tri-State G&T's business; despite accounting for less than half of the 44 distribution RECs, the 18 Colorado RECs account for roughly 60% of their system-wide meters and sales. None of the RECs generate their own electricity¹⁹. The four RECs that do not buy from Tri-State (Grand Valley, Holy Cross, Intermountain, Yampa Valley) buy their energy from Xcel (Governors Energy Office 2008). Additionally, several have hydro-power purchase agreements with the Western Area Power Association, a Department of Energy organization that distributes power to 15 states (WAPA 2009). Because it engages in interstate commerce, Tri-State G&T cannot be regulated by any one state.

Electricity for the 29 MUs in Colorado is more complicated. Colorado Spring is the state's largest MU and it owns, generates, and distributes nearly all of its own electricity. Colorado has established two municipal joint action agencies, Platt River Power Authority (PRPA) and the Arkansas River Power Authority (ARPA), which serve as dedicated wholesale providers to its member MUs (Governors Energy Office 2008). Like Tri-State G&T, which provides electricity to its member coops, ARPA and PRPA are generation and transmission associations that are governed by a board of representatives from the member utilities. The other MUs in Colorado buy from varying wholesalers, including Western Area Power Administration (WAPA), the Municipal Energy Agency of Nebraska (MEAN), as well as the two IOUs (Xcel and Black Hills).

¹⁹ In 2007, Sangre De Cristo Electric Association produced 57 MWh from small demonstration facilities. Sangre De Cristo sold more than 100,000 MWh in 2007, making the 57 MWh insignificant.

Given their abundant supplies in the surrounding Rocky Mountain Region, coal and natural gas dominate the energy mix in Colorado. In 2007, coal supplied 48.5% of the national electricity mix, but in Colorado, utilities obtained 2/3 of its electricity from coal (Figure 53). Because Xcel serves customers in eight states, it is impossible to determine the portfolio mix of fuel sources within Colorado. However, according to Xcel (2009) its generation is largely coal based, producing 50% of its electricity, with natural gas accounting for 30%, nuclear making up 11% and renewables accounting for 9% (dominated by hydro) at the end of 2007 (Xcel Energy 2009). Coal is also the dominant fuel source at Tri-State, accounting for 72% of its electricity (Tri-State G&T 2009), PRPA, where it generates 73% (PRPA 2009) and ARPA where it generates 72% from coal (ARPA 2009). Colorado also exceeds the national average with respect to electricity generated from natural gas, with 28% compared with slightly less than 22% nationally. Colorado is running ahead of the national average in wind generation and since the Fort St. Vrain nuclear generating unit was converted to a gas fired facility, Colorado has been without nuclear power since 1989 (Colorado Energy Forum 2006).

Figure 53: National and Colorado energy portfolio, 2007



Source: EIA 2009b

With such a fossil fuel dependent electricity portfolio, it is no surprise that Colorado has some of the cheapest retail electricity rates in the country. Despite consuming an average of 710 kWh per month (11th in the US) at an average price per kWh of 9.25 cents (23rd in the US), Colorado rate payers enjoyed the third cheapest average utility bill in the country. In 2007, only New Mexico and Utah retail customers paid lower average monthly electricity bills than the \$65.72 paid by the people of Colorado (EIA 2009c). Part of this is explained by the low electricity usage due to the mild climate and lower penetration rates for air conditioning units (Colorado Energy Forum 2006), but lower transportation costs associated with the extraction of coal and natural gas are also beneficial. Despite these cheap average utility rates, individual ratepayers at the various utilities are subject to a wide range of electric pricing. In 2007, Xcel charged on average 9 cents/kWh, with Yampa Valley the cheapest REC (8.55 cents/kWh) and the city of Gunnison the cheapest MU (6.06 cents/kWh); while at the

other end of the range, the most expensive REC and MU respectively were San Isabel (13.8 cents/kWh) and the Town of Granada (13.34 cents/kWh) (EIA 2009c).

A new energy landscape in Colorado

Following the November 2004 elections, Colorado voters passed Amendment 37, and became the first state to pass a renewable portfolio standard through the ballot process. While more than half of the states in the US have renewable portfolio standards (RPS), they were all passed through the traditional legislative process. On the ballot was a proposal to transition away from fossil fuel sources so that by 2015, the state's regulated utilities, as well as MUs serving more than 40,000 customers were required to obtain 10% of its total generation from renewable sources²⁰. Twenty-seven of the 29 MU have fewer than 40,000 meters, meaning that Fort Collins and Colorado Springs were the only two MUs required to participate (the city of Longmont is likely to reach 40,000 by 2010, increasing the number of participating MUs to three). The rest of the MUs and none of the RECs were subject to any of the renewable generation provisions voted on in Amendment 37. That changed in 2007, when the Colorado legislature passed House Bill 1281, doubling the requirements on IOUs to 20% by 2020, and extended requirements to RECs and the smaller MUs, mandating that renewables contribute 10% to their electricity mix by 2020 (DSIRE 2009).

In addition to the increased RPS targets passed by the Colorado legislature in 2007, Governor Bill Ritter passed the Colorado Climate Action Plan (CAP) in that same

²⁰ Renewables include: Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, "Recycled Energy", Anaerobic Digestion, Fuel Cells using Renewable Fuels

year, which called for a 20% reduction in carbon dioxide emissions by 2020, with nearly half the goal to be achieved through improvements in energy efficiency. The efficiency programs will take the form of DSM, lighting (use of high-efficiency lighting and lighting applications), updated building energy codes, greening government buildings, and industrial efficiency measures. Also in 2007, Colorado passed Senate Bill 100, legislation designed to break the ‘chicken and the egg’ deadlock that has stalled so many wind projects; whereby wind turbines are not constructed because there is no transmission and utilities don’t invest in transmission because there are no turbines. SB 100 forced regulated utilities to identify high potential wind corridors and then construct transmission lines, with the regulatory agency approving rate hikes to help offset construction costs. One of the main tenets of the bill was to consider how building out the transmission infrastructure would encourage more local ownership of renewable facilities (Cox 2008). In other words, enabling the smaller utilities or perhaps other IPP to build, own, and operate renewable generation due to the excess capacity. Another objective of the bill was to fix the transmission bottlenecks that were preventing the state from maximizing the benefits of its vast wind corridors and hampering the state’s efforts to meet its RPS. These policy actions are fomenting an entrepreneurial climate that is helping to position Colorado as a leader in the new energy economy.

It became necessary to go through the ballot process to pass Amendment 27, because the traditional legislative mechanisms were routinely blocked by powerful utility coalitions (Purdy 2004). In fact, the Colorado Association of Municipal Utilities (CAMU), which represents the state’s MUs, opposed the legislation citing the “incursions

into local control of municipal utilities” (CAMU 2009). Although still tepid, RECs were supportive of the legislation, but significant disagreements remain. In fact, two of the state’s RECs, Intermountain REA and Holy Cross Energy recently signaled a move away from renewables, by making sizable investments in Comanche 3, a new 750 MW coal plant schedule to open in 2009 (Williams 2009).

Within the individual organizational structure of the RECs, disagreements are becoming louder about the future role of renewables. Within individual RECs, promoting and protecting member’s interests in a fiduciary role is played by an elected board of directors. Each member of the board represents a geographic region within the coops district, and depending on the size of the coop and the number of members of the board, members are up for re-election every 3-5 years. Since the passage of Amendment 37, and in particular with House Bill 1281 (HB1281) in 2007, these once quaint and quiet elections have adopted a fierce political and environmental tone. Over the last year, traditionally safe board seats at several of the states coops, including Yampa Valley (2009), Holy Cross Energy (2009), and KC Electric (2009), have seen pro-fossil fuel incumbents defend their seats against challengers with a more aggressive green energy agenda. Nowhere however, has the election for board seats been more contested than at the state’s largest REC, Intermountain REA (Williams 2009). In addition to its \$366 million investment in the Comanche 3 coal plant, Intermountain also funds science that denies climate change (New York Times 2006). Three of the seven board seats were contested in 2009, and like the elections at the other REC, the pro-fossil fuel incumbents

retained their seats. The debate within and between the various RECs remains contentious.

One area where all states can pursue electricity reduction methods is through the use of demand-side management solutions, and Colorado has moved aggressively in this area. Demand-side management (DSM) refers to programs implemented by a utility to reduce demand by influencing the amount and timing of consumers' electricity use. According to the EIA (2009b), DSM spending by utilities has risen steadily since the 1990s. The literature is very thin with respect to DSM studies, particularly as it relates to the type of program offerings by RECs and MUs. Nevertheless, seen as a low-cost mechanism to reduce energy consumption, DSM program offerings have been on the rise (Wilson et al. 2008). DSM has been a part of the Colorado energy equation since the 1990s when the Colorado legislature instructed the PUC "to give the fullest possible consideration to the cost effective implementation of new clean-energy and energy-efficient technologies in its consideration of generation acquisitions for electric utilities while bearing in mind the beneficial contributions such technologies make to Colorado's energy security, economic prosperity, environmental protection, and insulation from fuel price increases" (Colorado Energy Forum 2006).

The nexus of efficiency, electricity load management, and incorporating green electricity supplies is found in smart grid technology. Smart grid technology changes the dynamic of the electricity grid from the old electricity model, where homes and business have little knowledge or control of their electricity consumption, to a dynamic relationship where the end-user is a more active decision maker. Ultimately, smart grid

technology is a DSM tool designed to help reduce energy consumption because individuals will have more information and make more economical decisions that will help save energy. There are many aspects to making smart grid technology functional, including software applications, appropriate green energy options, and an educated population willing to alter energy preferences as a result of new energy information; but at the heart of a successful smart grid are advanced meters.

Unlike traditional meters, which only provide one-way information (and need to be read in-person by utility employees), advanced meters offer two-way electronic technology that delivers more accurate time of use electricity consumption patterns. Advanced meters are a necessary first step in the broader goal of smart-grids which seek to coordinate the advanced meters with smart appliances, home area networks²¹, renewable energy resources, and demand management options. Advanced meters (AM) increase the transparency of electricity consumption by taking advantage of digital interfaces that enable consumers to coordinate their demand in the most cost-effective way possible and enable suppliers to deliver electricity more predictably by avoiding expensive and sometimes disruptive spikes in consumption. By reading the meters more frequently, say every 15 minutes or every hour, utilities can understand the specific demand patterns and formulate responses to address peak load stress. AM deployment has accelerated over the last two years (Table 34), with nearly six million newly installed devices around the country. Penetration rates have reached 4.7 percent up from less than

²¹ Home-area networks (HAN) are self-contained network within a residence that enable the utilities to see electricity demand by specific electronic devices and manage them as the system load may require. HAN require that manufacturers installed software and network access on their appliances, thermostats, and other electronic devices to enable those devices to communicate with the advanced meter and ultimately the grid.

one percent just two years ago. According to a survey conducted by FERC (2008) there is momentum building in the deployment of AM with 12 utilities already committed to the installation of more than 25 million AM over the next few years.

Table 34: Advanced Meter penetration rates by state, 2006 and 2008

Rk	State	2006			2008		
		AM	All meters	%	AM	All meters	%
1	Pennsylvania	18,200	6,053,110	0.3	1,443,285	6,036,064	23.9
2	Idaho	29,062	739,199	3.9	105,933	769,963	13.8
3	Arkansas	75,118	1,494,383	5.0	168,466	1,488,124	11.3
4	N. Dakota	29	367,776	0.0	33,336	375,473	8.9
5	S. Dakota	7	484,728	0.0	41,191	475,477	8.7
28	Colorado	39,274	2,263,873	1.7	39,873	2,246,184	1.8
	US Total	947,224	141,994,039	0.1	6,733,151	144,385,392	4.7

Source: FERC 2008

The survey reveals that penetration rates for AM in several states have surged over the last two years led by Pennsylvania, where PPL, a utility serving most of the state's eastern and central regions – excluding Philadelphia –upgraded nearly all of its network. While the transition to advanced meters in the top two states of Pennsylvania and Idaho was largely a result of efforts by IOU, for the next three states on the list (Arkansas, N. Dakota, and S. Dakota), the jump was a function of more aggressive deployments by the REC. In fact, despite serving far fewer people than IOUs, RECs were able to transition nearly the same number of customers over the last two years, resulting in far higher national penetration rates of advanced meters (Table 35)

Table 35: Penetration rates for advanced meters by type of utility

Penetration	2006	2008
IOU	0.2%	2.7%
MU	0.3%	4.9%
REC	3.8%	16.4%

Source: FERC 2008

With more AM, smart grid technology will enable greater reliance on green electricity supplies, specifically wind. Because wind is an intermittent resource, it comes with a low capacity factor and an even lower capacity credit. Capacity factor reflects the ratio of energy a generating unit actually provides with its nameplate capacity. Because the wind is not always blowing, its capacity factor is about 20%; whereas for coal being a reliable fuel, its capacity factor is much closer to its nameplate capacity. Capacity credit is even more punitive for wind in a world without smart grid technology. Capacity credit reflects the minimum power capacity that wind can reliably supply at any given time (Dale et al. 2004; Milligan 1997). Coal's capacity credit is close to its capacity factor because coal is a proven and stable electricity technology. Conversely, wind is intermittent and its reliability is harder for utility managers to count on, particularly during those periods when there are spikes in electricity demand. So although additional wind supplies should prevent the use of traditional fossil fuel units, utility managers cannot count on the average electricity generated by wind power when forecasting load requirements and therefore fossil fuel systems need to remain operational so as not to compromise load security.

The capacity for wind to help meet demand is especially hampered in the current environment where consumers have very little control over their electricity decisions. But smart grids should alter the electricity consumption habits as more information is relayed to consumers. And as SB 100 promotes bringing additional wind resources onto the grid, the ability for utility managers to allocate a higher capacity credit for wind also

improves. For example, smart grids can encourage people to postpone energy consuming decisions until wind supplies are plentiful. By delaying their consumption, not only is their decision enabling them to enjoy lower utility rates, but they are also effectively supporting wind, by telling their utilities that they are willing to wait until the wind blows. AM are the communication link in this transition which will help smooth out the daily electricity trends, in an effort to more fully exploit intermittent resources. Thus, wind power's capacity credit will rise, as utility managers can more firmly rely on its availability and utilization.

Colorado ranked 28th nationally in terms of newly installed AM, but the role Colorado is going to play in AM installations, and the ensuing smart grid deployment, is set to change. When FERC releases the results of its survey in 2010, Xcel will have fully deployed its "Smart Grid City" pilot project in the city of Boulder. Despite its location in Denver's metropolitan shadow, Boulder was selected in part because of its own ambitious greenhouse gas reduction targets, but also due to its relative isolation for which this project will yield the sort of disaggregate data to help pave the way for future smart grid roll-outs (Fairley 2008). Xcel Energy in conjunction with various other technology companies will invest more than \$100 million into Boulder's smart grid, in an effort to give residents more active control over their energy decisions. When it is completed, 50,000 AM will be deployed providing financial, operational, and environmental benefits for Xcel and its customers²² (Smart Grid City 2009).

²² Some of the benefits of include operational savings, demand-management, grid reliability, managing peak load demands, conservation options, more effective use of renewable energy, intelligent appliances, and vehicles with electricity requirements.

Due to Xcel's "Smart Grid City", Colorado is likely to experience a more robust roll-out of the applications associated with smart grid technology, particularly in the Xcel's service area, which includes about half of the state's population living in the Denver metropolitan area. Furthermore, according to the FERC survey, although integration with home-area networks (HAN) was not a principle driver for AM deployment in 2008, it appears set to drive many of the installations going forward as utilities are demanding their inclusion in future models. Provided that consumers are willing to trade some control over their electricity choices for cheaper electricity bills, utilities can control electricity demand on devices inside the home that are connected to the HAN further enhancing their ability to ease the strain on the power grid.

Smart grids will also help states meet RPS requirements. Achieving compliance with the RPS will be the result of bottom up benefits, by using technology to shift, and ultimately reduce consumption, and from the top down, with more renewable supplies. Colorado's prospects are especially strong. Not only should Smart Grid City lead to an avalanche of energy strategies, but according to the American Wind Association (AWEA 2009), Colorado generated 2.4% of its electricity from wind (trailing only Minnesota and Iowa in terms the highest proportion), while Xcel Energy is the country's leading utility in supplying wind energy to its customers.

Methods and data

This study attempts to explain the perspective of the utilities serving the less urbanized people of Colorado as it relates to conservation and efficiency programs,

energy legislation, and renewable energy. Colorado was chosen specifically because it was the first state in the country to pass an RPS through the ballot box, and then subsequently raised the targets through traditional legislative channels. The raised limits brought the rural communities into the RPS fold, and in many cases, it was against their wishes. Understanding the dynamics of these rural communities is at the heart of this research, for rural utilities in Colorado deliver electricity to a broad cross-section of towns with varying levels of urbanization, size of customer base, and socioeconomic factors. Furthermore, Colorado is an ideal place for this research because it is aggressively pushing a green energy agenda, as evidenced by its Climate Action Plan, Senate Bill 100, and Smart-Grid City project in Boulder.

As stated previously, there are 57 utilities in Colorado; two IOUs, 22 RECs and 29 MUs. Four additional RECs sell electricity in Colorado, but they operate primarily in neighboring states with only a small fraction of their business in Colorado; these four coops – Moon Lake Electric Association, High West Energy, Wheatland Electric Cooperative, and Tri-County Electric Cooperative – were not included in this study. Because the two IOUs, Public Services Company of Colorado (a subsidiary of Xcel Energy) and Black Hills Energy (formerly Aquila), are large complex and regulated organizations with inter-state operations, they were also excluded from this study. However, the IOU influence, particularly Xcel is felt on many levels, because of their large customer base, active policy formation, and their commercial relationships with several of the RECs and MUs as an electricity supplier. Figure 54 and Figure 55 illustrate the service areas for the RECs and MUs in Colorado. With the exception of

Colorado Springs and Fort Collins, the service areas for each of the other MUs is geographically limited, where as each of the RECs has an expansive service territory. In many cases, the MU is a small piece of territory carved out within the broader service area of the REC.

Figure 54: Service area for RECs

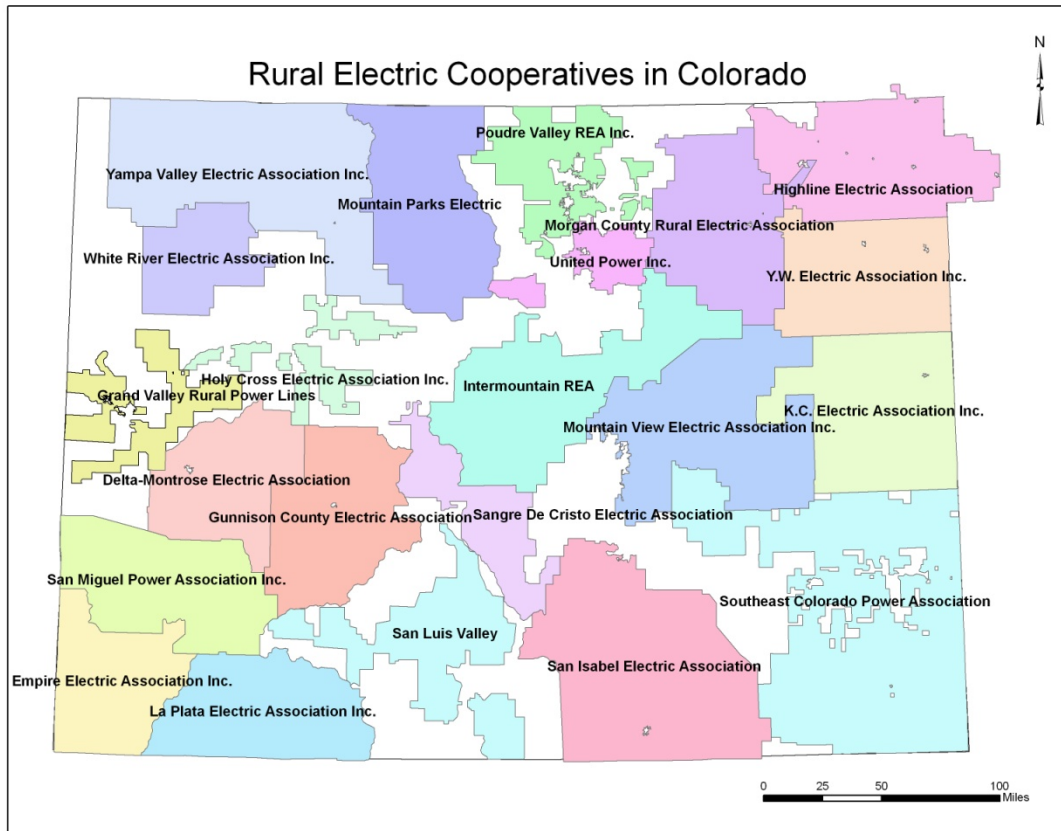
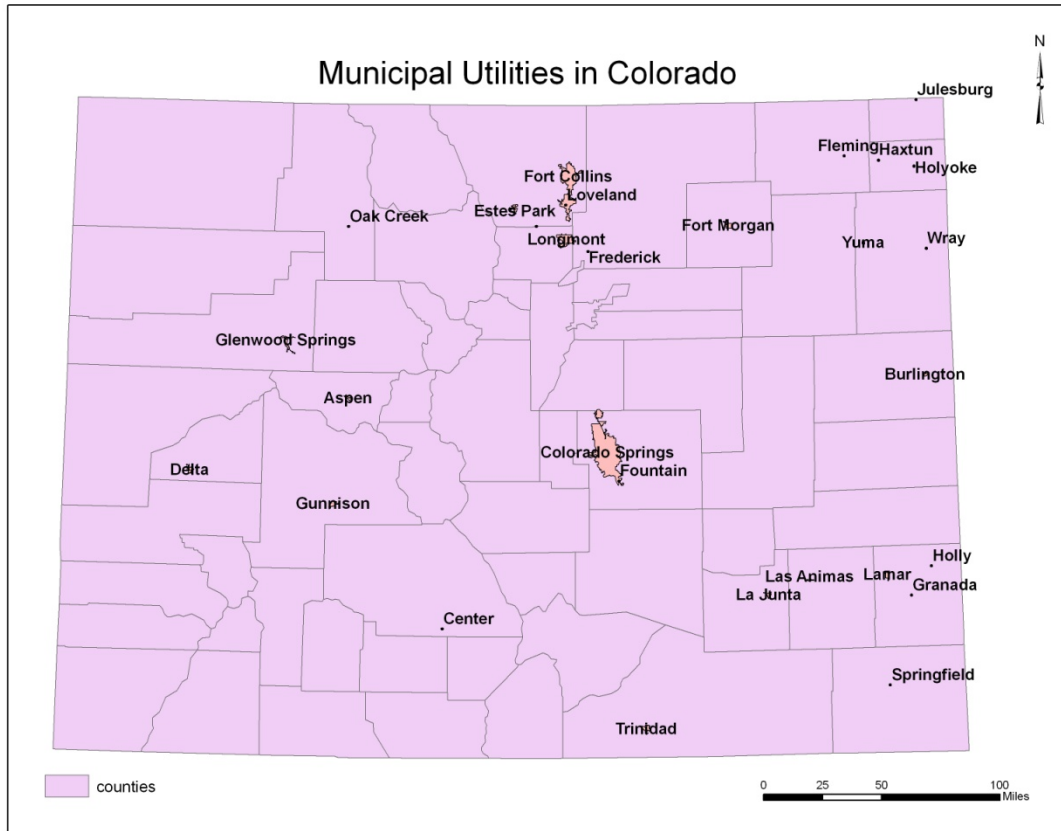


Figure 55: Service territory for the MUs



These two maps illustrate why the different utilities will have different perspectives on energy legislation; namely the obvious disparity in the number of customers per mile. Nationally, RECs have only seven customers per mile of line (electrical line) compared with 35 for IOUs and 47 for MUs (CREA 2008). IOUs benefit from both economies of scale and density, whereas most MUs lack scale economies, but benefit from a reasonable dense customer base (Table 36). RECs on the other hand have neither scale nor density, and yet, they are responsible for 43% of the total line miles in the country (NRECA 2009). As a result, investor-owned utilities get almost six times the revenue-per-mile-of-line compared with RECs, and the revenue figure is even higher for

MUs. Although data for Colorado IOUs and MUs are not available, the Colorado Rural Electric Association (2008) indicates that its members have 7.8 customers per mile, mirroring the national average.

Table 36: National utility line and customer statistics

Utility Type	Distribution line miles (%)	Customer / miles of line	Revenue per line mile
IOU	50%	35	\$62,665
MU	7%	47	\$86,302
REC	43%	7	\$10,565

Source: NRECA 2008

This was a survey based study where each of the RECs and MUs in the state were given a set of questions related to their conservation, efficiency, policy, and green energy programs (appendix B). For two reasons, preliminary contact with each of the utilities was made over the phone. First, by introducing the study and its intent, a phone introduction improved the chances that it would be completed, rather than emailing out the survey blind. It also gave the participants a chance to ask questions and allowed for some direct feedback with respect to their organization’s challenges on energy policy. Second, it was essential that the survey was put into the hands of the most senior person at each of the utilities. Since Amendment 37 was passed in 2004, and HB 1281 updated the RPS legislation in 2007, it was essential that the survey capture more than a snapshot opinion, but rather incorporating historical considerations with a thoughtful future perspective. For the REC, this was almost always the general manager or the CEO. At the MUs, the most appropriate person varied. At the larger MUs, a dedicated renewables coordinator was employed and so the survey was given to them; while at the smaller MUs, where two or three people represented the entire municipal staff the survey was

given to the utility director or town manager. Smaller MU presented a credibility dilemma for this study, because for a few of these towns, city hall was a small operation responsible for handling all of the town's business, (police, recreation, public works, etc) there was a chance that even the most senior person might have little energy knowledge or background. Nevertheless, senior town representatives are familiar with the town's electricity buying decisions and should have general ideas about the attitudes their customers have toward energy issues.

The survey included 35 questions grouped into several categories. Questions were designed to gauge the perspective of these utilities on national carbon legislation, state electricity mandates, as well as the attitudes of their members/customers. In addition, the survey attempted to quantify the number and types of efficiency and conservation programs that were in place at the various utilities, including green power programs, appliance rebates, and subsidized energy audits. Finally the survey was an attempt to understand the efforts these smaller utilities are taking to bring more control over their electricity decisions; either by building their own generation, investing in generation or encouraging IPP to build in their service area.

Descriptive statistics comprise a major component of this analysis. There are going to be some areas where rural utilities are moving in different directions, in particular because of the broad socio-economic differences found between places like the farming and ranching communities in the eastern plains compared with the resort havens of Colorado's mountains towns. However, there are sure to be areas where utilities agree. All but one of the RECs (Intermountain REA) belong to the Colorado Rural

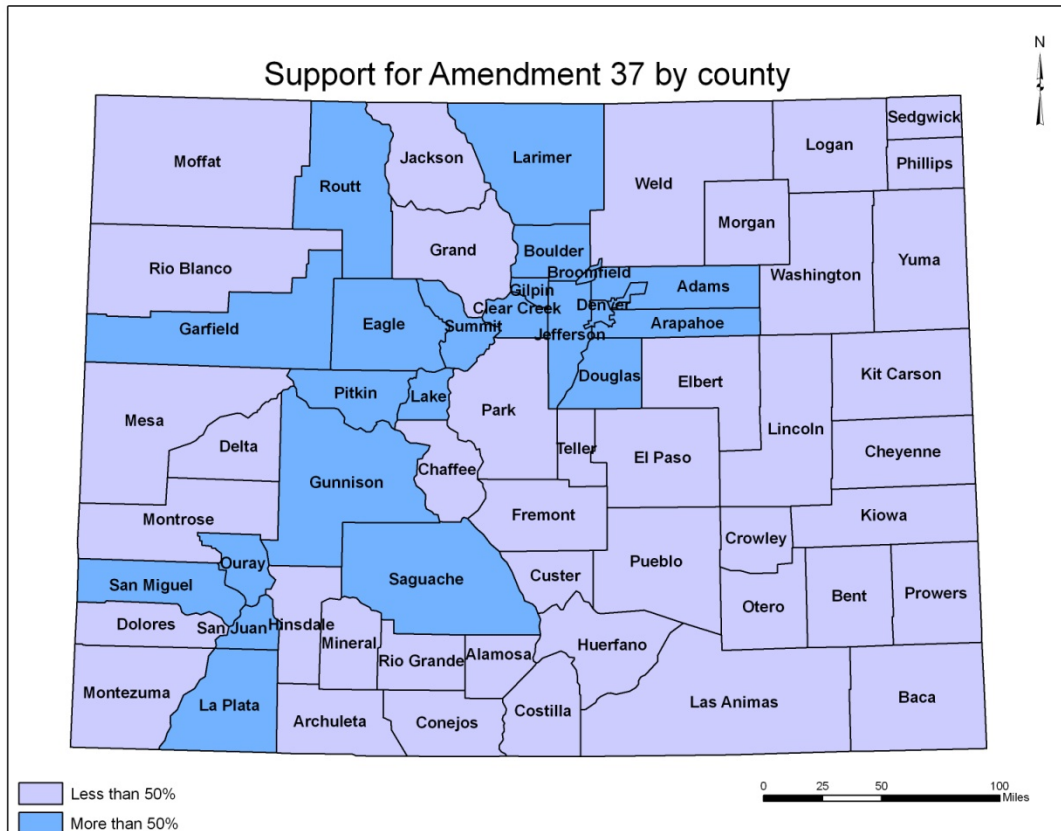
Electric Association as well as Touchstone Energy, a powerful energy brand composed of nearly 700 RECs throughout the country. All of the MUs are members of CAMU.

Nearly all of the RECs buy their power from Tri-State G&T, and so the generation and transmission decisions impose a shared burden on all of the participating distributive coops. The same is true for the MUs who combine their power and influence in making electricity purchases.

Results

The basis of this study is an attempt to explain how the various utilities are positioning themselves in a carbon constrained world. Considering the possibility that an RPS will lead to higher energy costs, in particular for those utilities with less ability to spread those costs, it should be no surprise that there was a geographic imbalance in voter support for Amendment 37. All of the rural counties in eastern Colorado and most of the rural counties in Western Colorado rejected the bill, garnering less than 50% of the vote (Figure 56). Overall 42 counties rejected the bill compared with 22 counties that supported the bill. Despite the near 2:1 count for counties opposing the bill, the counties supporting the bill are more heavily populated, with more than twice as many people in the state, including all of the counties surrounding Denver. In fact, of the eight counties with more than 100,000 voters, only El Paso (made up mostly of Colorado Spring) did not support the bill. All of the counties comprising the immediate Denver metro area supported the bill's passage despite being served by Xcel Energy which faces the most stringent requirements under the RPS.

Figure 56: Support for Amendment 37 by county



Given the problems outlined earlier for rural utilities to incorporate more expensive energy options into their electricity mix, it should be no surprise that Amendment 37 failed in most of the sparsely populated areas served by RECs and MUs. And yet, several of these rural communities voted in favor of a statewide RPS. In fact, as a percentage of the total vote, the six most supportive counties, all passing the bill with 2/3 or more voting in favor, were Pitkin, San Miguel, Summit, Boulder, Eagle, and Gunnison: with the exception of Boulder, the other five counties are home to major ski

resort destinations (Table 37). The only county with a major ski destination that did not pass Amendment 37 was Grand County, where it failed by a very narrow margin.

Table 37: Amendment 37 results by county with a major ski resort

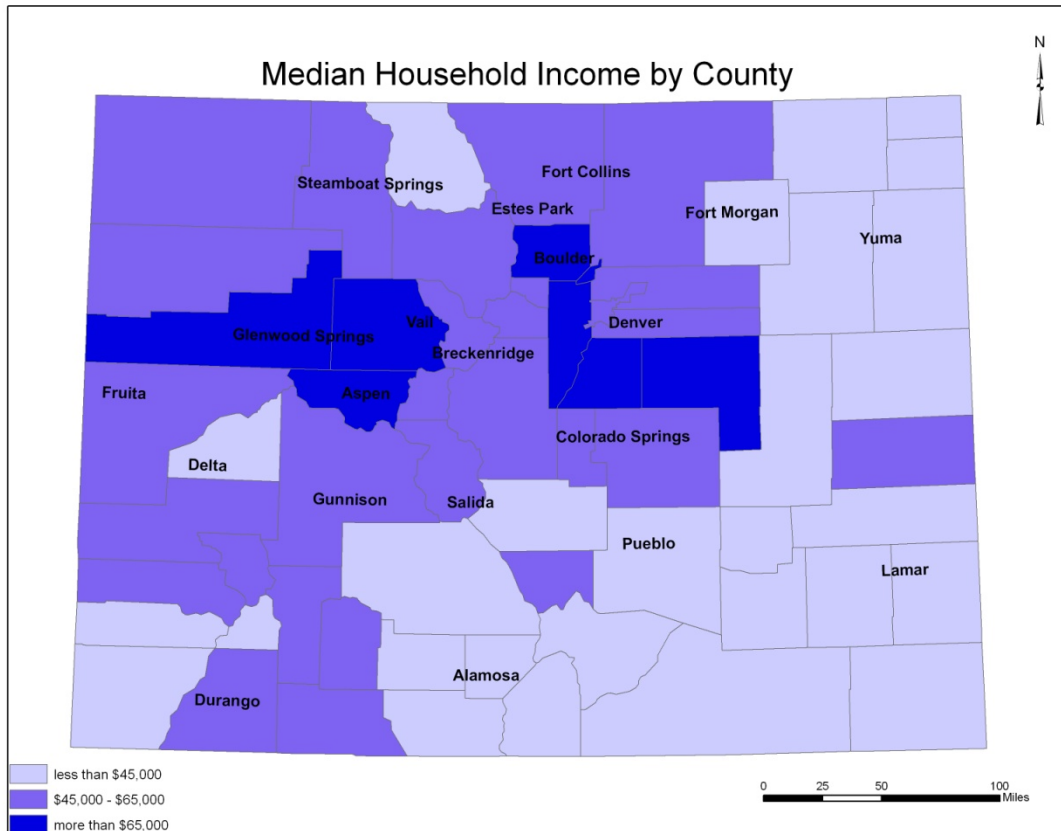
County	Total Vote	% Yes	% No	Major Ski Resorts
Pitkin	8,385	81.6%	18.4%	Aspen, Snowmass
San Miguel	3,671	79.0%	21.0%	Telluride
Summit	12,950	71.8%	28.2%	Breckenridge, Keystone, Copper
Eagle	17,415	69.7%	30.3%	Vail, Beaver Creek
Gunnison	7,922	66.5%	33.5%	Crested Butte
La Plata	23,257	62.1%	37.9%	Durango
Routt	11,024	55.8%	44.2%	Steamboat
Grand	7,208	48.6%	51.4%	Winter Park

Because of the disproportionate economic impacts of green energy on rural communities, it is easy for these counties to reject the amendment on financial grounds. The argument could be made that ski counties have higher incomes and therefore can better withstand higher electricity prices. Another explanation might hone in on the tourism dependencies of these counties, which would be jeopardized in the event of warmer winters and shorter ski seasons. Given the obvious connections between their business and climate change, one of the largest ski companies, Vail Resorts bought renewable energy certificates to offset their own carbon emissions starting in 2006 (Johnson 2006).

When compared against the county map showing the results of voting for Amendment 37, the county map of the state’s median household income shows the wealthier counties are found around the Denver metro area as well as a few of the mountain counties, while the counties with lower household income are found in eastern

and southern Colorado (Figure 57). An obvious association can be drawn from these two maps showing how the wealthier counties were more supportive of Amendment 37.

Figure 57: Median household income by county

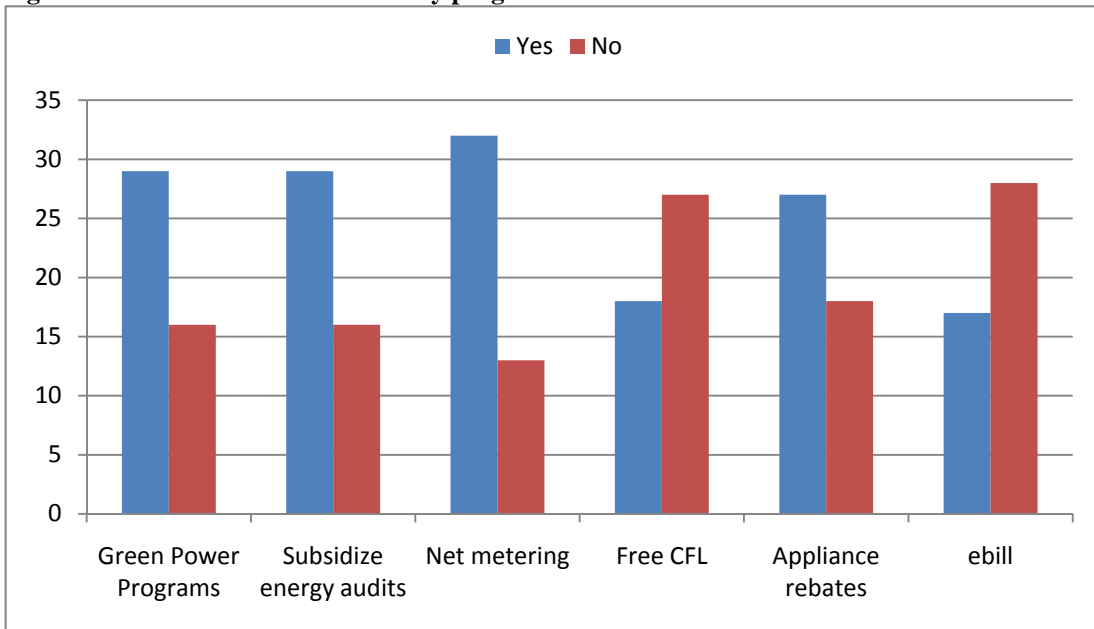


Of the 51 utilities contacted for this study, 45 filled out their survey, including 21 of the 22 RECs and 24 of the 29 MUs. It was initially hypothesized that many of the smaller utilities would resist the efforts of the state’s RPS mandates, and this study asked the utilities how they felt about the RPS requirements. Recall, the updated RPS raised the requirements for the IOUs and largest MUs, while for the first time, incorporating the

smaller MUs and RECs into the mix, mandating that they obtain 10% of their electricity by 2020. Of the 45 respondents, only three indicated that the RPS targets were not aggressive enough, compared with 60% that thought the mandates were too aggressive; the remaining utilities all felt the targets were just right. Meanwhile, six utilities said they expected to exceed the RPS requirements. And although 20 said they simply planned to satisfy the state requirement, 19 said they were not sure.

Despite these mixed attitudes about the RPS, many of the rural utilities were already moving aggressively in DSM prior to the 2007 legislation. Net-metering, subsidized energy audits, free compact florescent light bulbs (CFL), and rebates for buying energy efficient appliances represent some of the other programs designed to reduce energy consumption (Figure 58). With the exception of offering free CFL, a majority of utilities are promoting these other programs with varying degrees of success. By a count of nearly 2:1, rural utilities offered green power programs (GPP) and yet, only 5 of the 29 utilities offering a GPP did so in response to the state RPS; half offer a GPP because of pressure or demands from their customers. Although participation is light, with enrollment of less than five percent for all but two of the utilities, this resembles the national average where enrollments are typically around two percent (EIA 2009a). Interestingly, less than half of the utilities offer electronic billing, which is not a DSM program, and it may speak to internet penetration rates more than anything else. But ebills can be viewed as a sustainability metric, and fleshing out any potential relationship between people's environmental instincts and their use of paperless billing is worth some future thought.

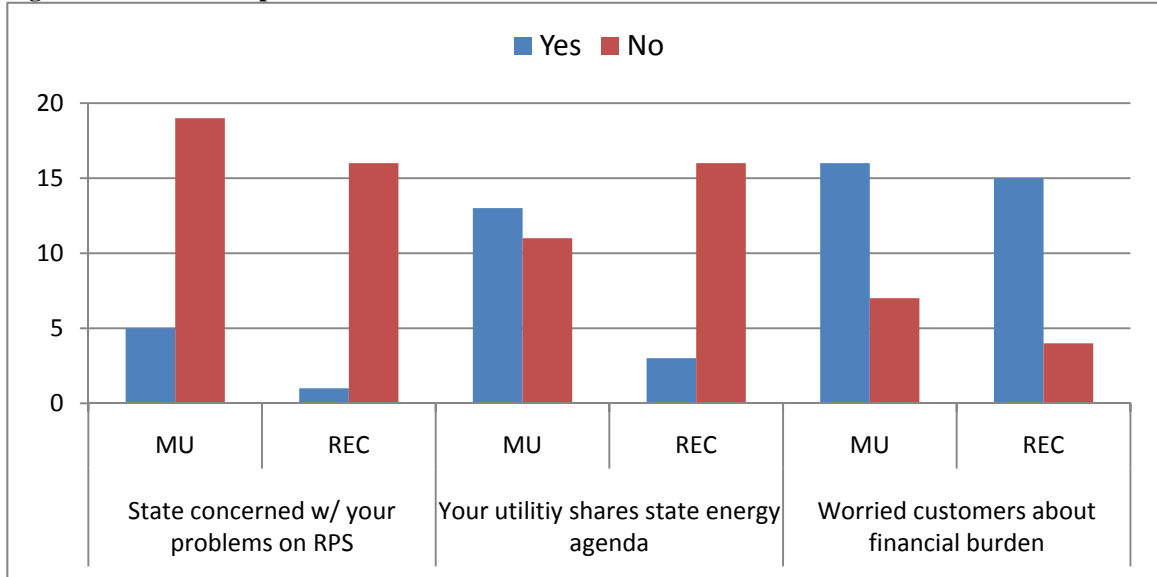
Figure 58: Conservation and efficiency programs



With the passage of HB 1281, rural utilities were brought into the RPS regardless of their desires and irrespective of their service area's vote on Amendment 37. It is no surprise then that as related to the RPS, only 6 of the 45 respondents felt as though the state legislature is concerned with their utility's problems in meeting the goals/targets (Figure 59). In conversations with many of the general managers prior to administering the survey, several claimed that they believe the state is interested in regulating all of the state's utilities (not just the two IOUs), so that state bureaucrats could impose even stricter green energy standards. In the opinion of these managers, the 10% requirement under the RPS for RECs and MUs was viewed by the legislature as a failure in that they were unable to impose stricter requirements on the rural utilities; several managers

expressed fears that the state views HB 1281 as an opening bid and will move quickly to pry open this door further with tougher standards in the near future.

Figure 59: Utilities responses to state mandates



One component of meeting the RPS would be customer acceptance or ability to pay higher electricity bills; 74% of the respondents, spread evenly among the MUs and RECs, indicated that a majority of their customers were fearful of a material financial burden in meeting the statewide RPS. Despite this consensus view on the two previous questions, that the RPS was a top-down mandate without taking into considerations the problems of rural utilities and the fear of escalating electricity rates among its customers, 16 utilities felt as though their interests and the interests of their customers were in line with the statewide energy agenda. In other words, 36% of the utilities feel that elements of the state energy policy would provide some benefit within their service territory. This question cast a wider net on state energy policy, beyond a narrow focus on renewables.

This more expansive question is an important differentiator because Colorado is quickly emerging as a powerful player in the natural gas industry. Part of the more favorable response rate for this question, particularly among the MUs, might be explained by the aggressive statewide natural gas leasing activity which has brought economic benefits to many of the smaller communities. Through the end of 2007, active natural gas wells totaled 33,625, up from 23,000 at the beginning of 2002, while the number of new drilling permits has tripled to 6,100 over that same period (Frank 2007).

In the midst of the splintering views on climate legislation, rural communities are adhering to many of the principles espoused by the legislation to decarbonize their electricity mix. Electricity generation in Colorado is owned principally by the IOUs, IPPs, Tri-State G&T, and Federal Agencies, with Colorado Springs the only utility in this study that owns a generating plant larger than 25 MW (EIA 2009b). Generating capacity is owned by 14 other MUs and 2 RECs, but nearly all of these are small-scale distillate fuel oil operations with minimal impact on overall electricity usage. That may be set to change.

When asked if they expect to build generation of their own in the coming three years, half (23) had no plans, but 12 intended to build some generation and the other 10 utilities said that plans were being considered. The type of generation that gets built is going to be a critical question. Although some coal plant construction plans are moving forward, as is the case with Comanche 3, Xcel's first new coal-fired power plant in 30-years, new fossil fuel generation is a risky financial proposition for two reasons. First, regulated utilities have historically appealed to their PUC in order to justify rate-hikes

commensurate with the costs of construction, but history suggests that in times of spiraling construction costs, as the industry faces today, the PUC may protect rate-payers and not approve the full recovery of costs as it did during similar cost overruns with nuclear power plant construction in the 1960s and 1970s. More importantly, saddling the rapidly escalating construction, operating and maintenance costs of traditional fossil fuel generation, linger the possible cap-and-trade costs which may make such generation prohibitively expensive. Financial institutions must be very cautious when lending money to utilities that face unknown legislative roadblocks, which threaten its capacity to generate the necessary revenues for loan repayment.

These problems are more acute for MUs and RECs which cannot appeal to a PUC in order to generate the additional revenues for debt service. Instead, these utilities must pass on their costs in the form of higher rates. It is no surprise then that half of the surveyed utilities, evenly split between RECs and MUs, say they have spoken with a company in the business of building green generation about locating a project within their service territory. There are two primary drivers for this dialog. First, part of their desire to seek green electricity supplies for their members/customers is a business decision to begin diversifying away from fossil fuel generation, even if it is on a small scale. A second explanation is the potential economic and employment benefits; of the utilities that spoke with a green electricity developer, most of them felt as though there would be a material green collar job benefit in their service area.

Due to the challenges of owning electricity generation, particularly for smaller organizations, investing directly in green generation facilities has become a desirable

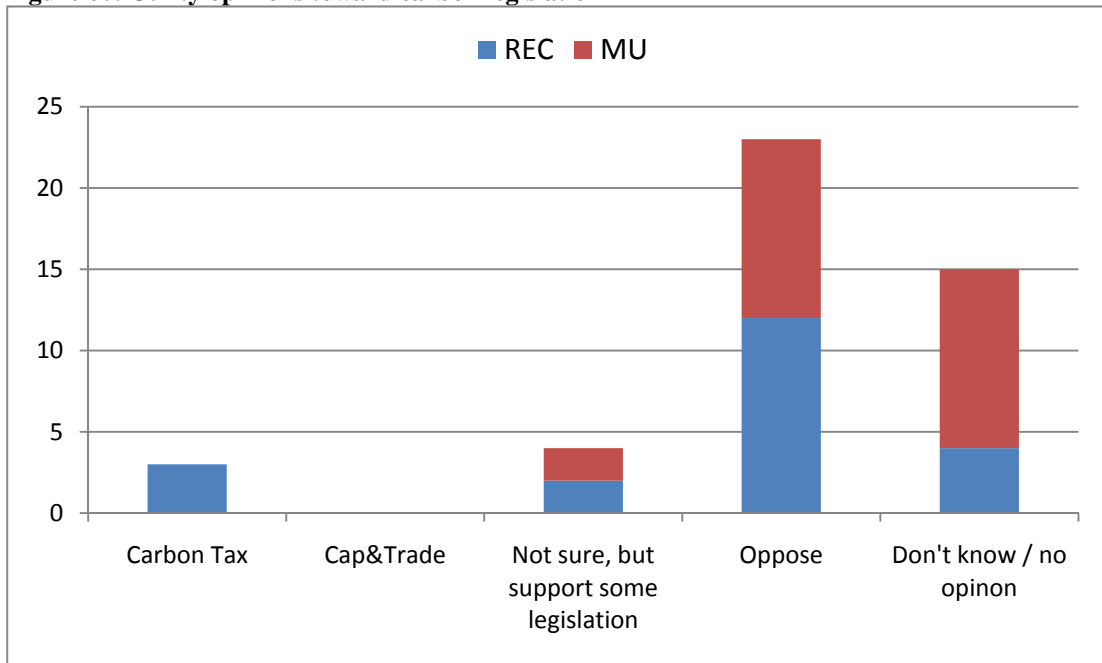
option. Although 14 of the 45 utilities said they had not explored potential investments in green generation, 31 of them had explored green investments. More specifically, 16 of the 21 RECs have explored a green electricity investment, which is significant, because the RECs are distributive and buy their electricity from wholesale generators, primarily Tri-State G&T. So while the distributive RECs are party to any green investments made by Tri-State G&T, their participation is a function of the generation decisions Tri-State makes which is based on the collective opinions of their distributive partners. These survey results reflect a position that the RECs seek more active control in green electricity's contribution to their overall energy portfolio. According to the survey, the two dominant investment technologies discussed by the utilities were wind (mentioned nine times) and solar (mentioned seven times). Although wind was the dominate green electricity technology discussed, and the siting of wind turbines on farm land was an integral part of the campaign for the passage of Amendment 37 in the rural communities, only 14 utilities have had conversations with ranchers or farmers about locating wind generation on their land.

Whether it is to show leadership or help defray some of the costs associated with bringing additional green electricity supplies online, many local governments are required to buy green energy for their buildings. With an executive order in 2005, Colorado mandated several environmental goals for state government buildings, but buying green electricity was not one of them. Only two cities, Aspen and Boulder (served by Xcel) have local laws that specify how local governments will buy wind power for municipal buildings (DSIRE 2009). Yet according to the survey, seven

utilities have deals to supply local governments with green electricity, including five MUS and two RECs. Furthermore, nine MUs and 7 RECs are working with local governments on measurable ways to reduce greenhouse gas emissions. Still, 16 of the 45 utilities integrating GhG reduction strategies with local governments suggest that most of the rural areas are focusing their efforts elsewhere.

As for the debate over pending carbon legislation, the rural communities of Colorado appear to have carved out their position. More than half are opposed to regulating carbon, while only seven utilities support any legislation, with none favoring cap-and-trade. Interestingly, 15 of the utilities did not have any opinion (Figure XXXX). Meanwhile, their position on nuclear generation appears to be equally strong, with only two (both MUs) of the utilities saying they oppose building new nuclear generation. All but four of the RECs and 11 of the remaining 22 support nuclear power as a matter of corporate policy, while the remaining 15 utilities did not have an opinion.

Figure 60: Utility opinions toward carbon legislation



Expecting the rural utilities to strongly oppose any carbon legislation, a follow-up question was posed that asked about what would be the best first step to reduce carbon emissions. The utilities were split between a national building weatherization program and a robust smart-grid deployment. Only two thought a tax on carbon made sense and none of the utilities thought that a decoupling law would be effective. Decoupling laws disconnect electricity volume sales from utility profits. By discouraging more electricity use, decoupling laws substitutes a financial incentive to offer efficiency and conservation programs designed to sell less electricity. PUC can offer a host of provisions that ensure regulated utilities are able to service their debt and make a profit, but unregulated utilities do not have access to these mechanisms, which explains why none of the rural utilities in Colorado choose this option on the survey.

Another subject where rural utilities show agreement is that the government's role should be limited in building out a new national transmission grid. With the emphasis of a new high-voltage national transmission system aimed at bringing electricity from the wind-rich and solar-intense remote locations of the country to the energy hungry urban areas, the economic benefits of a new national grid for the rural communities would be two fold. First, rural areas will operate and maintain many of the green generation, and second, most the electricity highway will pass through or between rural areas, translating into construction jobs. And while all but one of the utilities view a new national grid as necessary, only four utilities felt that the federal government should build the grid. Even fewer felt it should be privately built and six felt as though the utilities should build out the grid. The remaining responses all thought that the grid should be a public/private partnership. When asked about the specific role of the federal government in a national grid modernization effort, most felt that the government should provide access to financing and use its power of eminent domain to secure the corridors; a few felt that the federal government should manage and design the construction, with a equally small set of utilities saying that the federal government should not be involved in any capacity.

Summary and Conclusion

In the summer of 2009, the US House of Representatives passed a bill that puts a federal cap-and-trade bill one step closer to law. It will surely face alterations in the Senate, but the framework for establishing a price on carbon appears imminent. Nowhere will the impacts of a cap-and-trade bill be felt more directly than in the electricity sector,

where fossil fuels still dominate. Many of the states have pursued RPS legislation that has improved the penetration rates for renewables, but the transition to green electricity is still in the early stages. This is especially true in the rural areas of the country, where green electricity is simply too costly to incorporate into the electricity mix leading to stronger resistance levels by the residents of these communities.

It has been more than two years since Colorado Governor Ritter signed into law House Bill 1281 which amplified the effects of Amendment 37 by doubling the RPS and extending the responsibility of adding renewables to all of the state's utilities. The bill lays out milestones for utilities to achieve penetration rates for renewables and according to the legislation, rural utilities must satisfy multi-year performance metrics. Stage one, which requires that one percent of their retail electricity sales must come from green supplies, does not end until 2010, so it is still too early to evaluate their progress.

This much is clear; wind is most cost effective when large projects take advantage of scale economies, which is something that rural utilities are in no position to finance. As long as wind remains the technology of choice to meet RPS targets, rural utilities are going to have to rely on their wholesale providers. All but four of the Colorado RECs buy their electricity from Tri-State, making their ability to meet their RPS targets largely dependent on Tri-State G&T renewable investment decisions, and in the summer of 2009, Tri-State contracted for a new wind project in Colorado (Jaffe 2009). For the MU, their capacity to meet the RPS is more difficult to determine, but neither PRPA nor ARPA have added any new green generation since the legislation passed, and MEAN which generates only a fraction of their revenue in Colorado recently added a very modest

18MW of wind to its entire system in the last year, which covers seven states (NMPP 2009).

While wind provides more immediate assistance in meeting RPS targets, the prospects for solar in Colorado remain promising. For one, the federal tax subsidy supporting solar projects is designed to provide immediate tax relief (year one of the project) in an effort to help offset the huge upfront capital requirements. Second, HB 1281 stipulates the IOU must generate four percent of their targets from solar. Rather than a mandate, the bill provides solar incentives for rural utilities, whereby they would receive a 3-1 benefit towards their RPS requirements for every kWh of solar generation, as compared with the IOUs which only get a 1.25% boost for in-state solar generation (Haight et al. 2008). As a result, the last two years have seen solar grow from zero to more than 18,000 MWh of generation, making Colorado the state with the third most installed capacity in the country, trailing only California and New Jersey (SEIA 2008). It might also explain why in addition to the new wind project, Tri-State also announced a new solar project to enhance its members' capacity to meet their RPS (Tri-state 2008). As the price of solar continues to fall, the cost-benefit calculation should create a scenario where rural cash-strapped utilities are even more compelled to invest in solar.

Although it is time consuming and expensive, some of the rural utilities are making progress on their RPS mandates by adding green electricity to the grid. As a more cost effective and immediate approach, bottom-up remedies are being pursued by a majority of the utilities serving rural communities. Because of DSM programs such as subsidized energy audits, free CFL, and appliance rebates, utilities are proactively

encouraging conservation and efficiency. Net metering and GPP are other ways to support renewables, and are endorsed and offered by nearly all of the utilities. Rural communities seem to be more capable of taking these incremental steps, due primarily to the lower costs, as opposed to a more comprehensive large-scale transition. Most of them believe that they will shoulder a very heavy financial burden in meeting the current state-wide RPS which calls for 10% of electricity from renewables by 2020. A more aggressive mandate would probably push electricity rates higher still, at least in the short run. Should a more aggressive mandate pass, or a national cap-and-trade bill force a dramatic change in their electricity profile, it would reinforce the views of these rural communities that their voices are not being considered in the legislative process.

And yet, these bottom-up approaches suggest that rural utilities are proactively pursuing programs outside the mandate framework. Thus the challenge becomes finding a way to soften the financial burden of an energy transition but equally important will be to diffuse the distrust that characterizes the rural / urban relationship. As Colorado moves more aggressively to stake out its position as a leader in the new energy economy, soliciting the participation and ideas of rural communities will be paramount, and this research suggests that certain obstacles must still be overcome.

Chapter Six - Conclusion

For two centuries, fossil fuels have played a dominant role in the energy profile of developed countries. But those fossil fuels are finite and our reliance on them has exposed some important vulnerabilities. As a result, those same countries that have become developed on the strength of fossil fuels benefits, have been talking about ways to wean themselves off those same fuels and rebuild the global economy on a new energy paradigm, one supported with inexhaustible and clean supplies. That transition has been slow to materialize as the institutional support has been dubious and geographically uneven, and thus any sparks that may catalyze new technologies have remained faint.

An inflection point may be on the horizon. Recent fossil fuel price volatility has once again honed our attention; growing demands for limited supplies will create an environment of soaring energy costs, something that is both politically untenable and in the wake of the global financial crisis, economically devastating. And yet, mandating new and expensive technologies in an effort to speed the energy transition would also be a flawed approach. Many people will not pay more, and most people can't. The middle ground seems to be a combination of ideas that are currently (or have historically been) utilized, but they need to be expanded to a much larger scale.

Funding basic research through increased public sector energy R&D should yield the type of benefits and breakthroughs that were seen as the world responded to the

OPEC oil embargo. And the private sector, which through direct VC investments has already shown it is willing to fund promising technology, will play an ever larger role knowing the government has made it a priority. From a policy perspective, a price on carbon (phased in over a period of time) needs to be established and a global marketplace created, similar to the EU ETS. We can no longer afford to keep piling on to our already sizable ecological debt. And with a carbon market established, any and all new energy technologies will have a much broader outlet for their environmentally benign products; the market will determine which are the most efficient and cost effective and it will do so with great precision. Finally, the low hanging fruit needs to be more aggressively picked. Conservation and efficiency efforts, as already practiced by rural utilities in the United States are scalable. They offer sizable environmental returns and the cost benefit analysis overwhelmingly supports action over inaction.

What is most important remains the simple notion that our lack of movement is not due to a lack of solutions. As noted in this paper, we have deployed or are close to developing a whole host of solutions. Our lack of action goes back to that fourth law of ecology – there is no free lunch; we remain committed to the idea that energy is both plentiful and cheap. It is neither. Replacing fossil fuels with renewable and green sources will cost money, but the wealth creation potential is often overlooked. This transition will require political skill as well as the finesse and speed of the private sector. Knowing and embracing upfront, the true public private partnership aspect of this endeavor can help overcome a lot of the political and institutional dysfunction that has weighed down and stalled the energy transition.

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Appendix A – VC Technology Categories

Batteries
Biofuels
Buildings
Cleantech - NOC
Fossil Fuels
Fuel Cells
Geothermal
Geothermal - Drilling
Geothermal - heatpump
Lighting
Materials - Buildings
Materials - Solar
Materials - Wind
Nuclear - Small Scale
Recycling
Smart Grid
Software
Solar - CPV
Solar - CST
Solar - General
Solar - PV
Solar - Thin-Film
Solar-to-Hydrogen
Tidal
Transport
Waste-to-Energy
Water
Wind
Wind - High Altitude
Wind - Micro
WoodPellets / biomass

Appendix B – Survey Questions for Utilities

- 1) Please indicate what type of utility you represent
 - a. Investor-owned
 - b. Municipal
 - c. Consumer (co-op)
- 2) If you proactively inform customers about ways to reduce their energy consumption or promote efficiency- indicate the methods you use to increase program awareness?
 - a. Pamphlets in their bill
 - b. Local TV commercials
 - c. Website updates
 - d. Invited lecturers/speakers at annual meetings
 - e. Newsletters
 - f. Emails
- 3) Do you offer a green power program for your customers?
 - a. Yes
 - b. No
- 4) About what percentage of your customers are enrolled in the green power program?
 - a. None
 - b. Less than 5%
 - c. 5-10%
 - d. 10-25%
 - e. More than 25%
- 5) What factors have led your utility to implement its green power program?
 - a. Colorado's passing of its Renewable Portfolio Standard (RPS)
 - b. Lock in relationships with Independent Power Producers / whoelsalers
 - c. Consumers demand it
 - d. Pressure from shareholders / residents / members
 - e. Protection from gyrating energy prices
 - f. We don't offer a green power program
 - g. Other _____
- 6) With respect to Colorado's Renewable Portfolio Standard (RPS), do you think obtaining 20% of all electricity from renewables by 2020 is:
 - a. too aggressive
 - b. just right
 - c. not aggressive enough
- 7) As it relates to the RPS, do you feel that policy makers are concerned with your needs or problems in meeting the goals/targets?
 - a. Yes
 - b. No
- 8) Do you feel as though the interests of you and your customers/members are in line with the state-wide energy agenda?

- a. Yes
 - b. No
- 9) Based on your interaction with customers/members, are a majority fearful of a 'material' financial burden in meeting the RPS targets?
- a. Yes
 - b. No
- 10) Does your utility plan to go beyond the state requirements for its commitment to the `?
- a. Yes
 - b. No
- 11) Do you subsidize energy audits for your customers?
- a. Yes
 - b. No
- 12) Is net metering available in your area?
- a. Yes
 - b. No
- 13) Do you offer free Compact Fluorescent light bulbs?
- a. Yes
 - b. No
- 14) Have you ever offered rebates for purchasing certain appliances?
- a. Yes
 - b. No
- 15) Do make renewable energy credits (RECs) available for purchase for your members/customers?
- a. Yes
 - b. No
- 16) Do your customers/members have the option of receiving an ebill (online bill payment) rather than a paper bill?
- a. Yes
 - b. No
 - c. If Yes, indicate what % receive an ebill _____
- 17) Do you own any of your own generation (please ignore small design/education generation facilities)?
- a. Yes
 - b. No
- 18) Do you plan to build and operate your own generation in the coming three years?
- a. Yes
 - b. No
- 19) Have you spoken with large-scale green energy projects (solar-thermal, PV fields, wind farms, etc) and encouraged them to build within your service area?
- a. Yes
 - b. No
 - c. If Yes, which technology _____

- 20) Has your utility explored potential opportunities to invest ‘directly’ in renewable energy projects (solar-thermal, wind, hydro, etc)
- Yes
 - No
 - If Yes, please explain _____
- 21) Has your utility spoken with a rancher/farmer about siting wind turbines on their land?
- Yes
 - No
 - Do not know
- 22) Do local governments in your service area have to buy green energy for their buildings/facilities?
- Yes
 - No
- 23) Are you working with local/county governments on ways to achieve measurable reductions in greenhouse gas emissions?
- Yes
 - No
 - If Yes, please explain _____
- 24) With respect to ‘small’ green technology (solar pv, small wind turbine, ground source heating and cooling, etc), do you have mechanisms in place to enable, encourage, and/or assist your customers with installations?
- Yes
 - No
 - If yes, please explain. _____
- 25) To the best of your knowledge, will there be a material green collar job benefits in your service area?
- Yes
 - No
- 26) Based on your experience/knowledge/interactions with customers, what has been the primary driver for the green energy industry?
- Spike in energy costs
 - Improved technology
 - National dialog on global warming
 - Links to economic recovery (green collar jobs)
 - Other _____
- 27) Who should pay for a new/modernized transmission grid?
- By the Federal Government
 - By the States
 - By the Utilities (with commensurate rate hikes authorized by regulators)
 - Privately
 - Combination
 - No opinion / Don’t know

- 28) What role should the Federal Government play in the national grid (check all that apply)
- Funding
 - Manage, design, and coordination
 - Use of eminent domain to obtain the corridors
 - None of the above
 - No opinion / Don't know
- 29) Which of the following will be the best 'first step' to reduce electricity consumption?
- Decoupling laws
 - Smart-grid / smart-meters / smart-homes
 - Energy tax
 - Other
 - No opinion / Don't know
- 30) Which type of national carbon legislation does your utility endorse?
- Cap-and-trade
 - Carbon tax
 - Not sure, but we support some sort of legislation
 - We oppose carbon legislation
 - No opinion / Don't know
- 31) As a matter of corporate policy, do you support expanding nuclear power?
- Yes
 - No
 - No opinion / Don't know
- 32) Some have suggested the United States generate 100% of its electricity from non-fossil fuel sources by 2050 – do you agree?
- Yes
 - No
 - Maybe
- 33) Of the total number of bill-paying customers, approximately what percentage are businesses?
- Insert # _____
- 34) Of the total number of bill-paying customers, approximately what percentage are seasonal/part time residents?
- Insert # _____
- 35) Please indicate if you would like me to provide a summary of the data to you after all the surveys have been completed.
- Enter email address _____