The Academic-Industry Research Network

# The Makings of a Champion or, Wind Innovation for Sale: The Wind Industry in the United States 1980-2011

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# INTRODUCTION

Long before General Electric or Clipper were spreading electric wind turbines around the country a handful of companies, government agencies, and academians were inventing the wind industry from which GE is today generating billions in revenue. The roots of the industry cannot be credited to a single country, and there is not a central person, group, or collection of companies providing a clear origin. Many countries have actively pursued wind power in different historical periods to different outcomes.

The use of windpower by society is an ancient practice most clearly symbolized by the Sail and the Windmill or Windpump. The idea of using wind to generate electricity dates back to at least the 19th century, and some of the earliest experiments occurred around that time. Hence there is little which is truly "new" about the idea of using wind as an energy source, though we can credit the last several decades as proof that a new industry has arrived. Wind energy and other renewable energy forms provide a glimpse into an energy revolution which will transform the design and execution of energy infrastructure around the world. Energy revolutions have provided the basis for mass economic transformations in the past, as when steam technologies gradually replaced water wheels, horses, and sails, enabling more places in the world access to the energy needed to sustain industrial growth.

This paper argues that despite its uneven performance the United States succeeded in establishing a wind energy industry in the decades which follow the 1980s. Core technologies for wind turbines were advanced during the industry's formative years, reducing energy costs, and wind companies headquartered in the United States competed in a global market for wind power. The early U.S. wind industry accomplished this within an evolving energy policy context that took shape in the late seventies and morphed continually throughout the 1980s and 1990s, climaxing with the decision to deregulate energy markets in the 1990s and revived support for renewable technologies in the 2000s.

These critical changes began a search for profits between energy generators, both established and emerging, restructuring the energy infrastructure and altering the competitive framework. Early mistakes of the wind industry and a loss of policy support cost the United States a decade of wind energy development. It then began a rapid ascent marked by the rise of General Electric as a major wind turbine manufacturer. This followed a string of bankruptcies or acquisitions in the mid 1990s that destroyed the leading U.S. wind companies.

The best early wind energy pioneers of the United States accepted the challenges of developing a new technology and hoped to make profits while also countering the legacy of pollution caused by past energy development decisions. They faced a complex and changing policy environment and incumbent technologies that had much lower average costs. The advent of wind energy meant not only that development of national wind resources had to occur, but also that a cost effective and technically advanced manufacturer had to emerge. Developer and Manufacturer would have to serve domestic markets and compete effectively with foreign companies in an embedded international supply chain. The irony behind these tasks was that all incumbent energy technologies in the United States were still in fact actively subsidized by the government, which historically includes R&D. Foreign governments developed their own policy schemes as well, further complicating the competitive landscape but also providing additional opportunities.

Thus amidst the apparent wreckage of the wind industry taking place in the 1990s, in the early 2000s General Electric became quite suddenly the world's 4th largest wind turbine manufacturer in the world, a position which it improved upon but which has yet to answer to competitive challenges from abroad, which are today steadily eroding their position of global leadership. This pathway is far removed from the path suggested by the late 1970s, when massive aerospace companies were selected to lead the nation's charge into the wind industry. In following the path, one can illustrate a development story in which the cumulative activities of the business and public sector drive innovation. The wind industry is an example of how collaboration, commitment of resources, parallel work, and strategic investment provide the foundation of industrial development.

# PART I. GROWTH OF GLOBAL AND NATIONAL WIND POWER

At the end of 2010 the Global Wind Energy Council (GWEC) estimated that 194.39 GWs of installed wind capacity existed in the world. Not more than 0.01 GWs existed in 1980. Just five of the 73 countries developing wind resources have developed in excess of 10 GWs in the last several decades. This list includes the United States, China, India, Germany, and Spain. Together these countries represented approximately 74 percent of all the wind capacity in the world in 2010. This suggests by extension that these are also the largest markets for wind power in the world. According to Pernick et al. (2012), wind power was a $4 billion dollar global market in 2000, peaking at $63.5 billion in 2009 before succumbing to souring global economic conditions (p.4). A $60.5 billion market in 2010, wind has since rebounded to $71.5 billion in 2011, largely reflecting Chinese investments (Pernick, et al., p.4).

Until the early 1990s, world wind capacity development was overwhelmingly a result of U.S. market activities. A loss of U.S. policy support from the mid 1980s through the early 1990s pushed wind power development overseas to Europe (especially Germany). Asia emerged as an aggressive competitor and currently leads the world (especially China). The United States represented close to 100 percent of all wind energy generation in the world during the period of 1980-1987 before eroding to a low point of perhaps 14 percent in 2004.

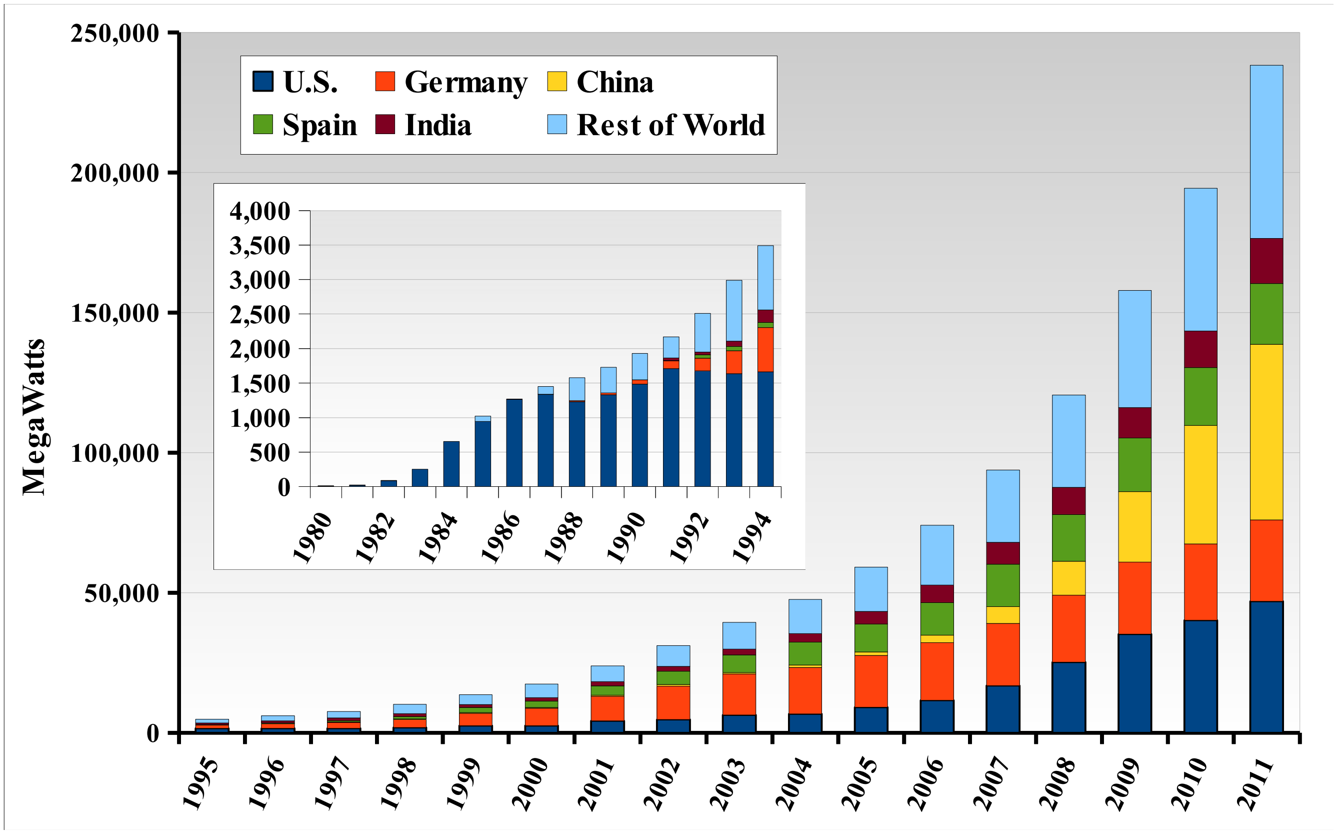
Correspondingly Europe, with the leadership of Germany in particular but also Spain, Italy, France, Denmark, the UK, Portugal, the Netherlands, Sweden, Ireland and others arose as aggressive adopters of the technology. As a result in many European countries wind now represents a significant percentage of the total amount of energy generated. Denmark generated 21% of its electricity with wind power in 2009, while in the United States wind represented only about 2 percent of electricity generation (Flowers, 2010).[1] Regionally, Europe leads the world in wind power development with about 97 GW or 41 percent of the world's existing wind capacity in 2011 (GWEC, 2011, p.2).

As figure 1.1 illustrates below, world wind power development has tended to be a result of the activities occurring in the United States, Germany, Spain, and now China and India. About 74 percent of world capacity could be found in those countries at the end of 2011. Figure 1.2 illustrates the change in wind development leadership as understood by the total amount of wind capacity installed.[2] During the last several decades, global leadership has changed several times, from the United States, to Germany, and now China. Figure 1.3 shows that the United States was outpaced by Germany for the six years prior to 2005, when it became the world leader in terms of net annual capacity additions. Chinese capacity additions surpassed U.S. efforts in 2009. Following the 2008 financial crisis, the United States has not yet managed to add capacity at its 2009 rate.

1 Estimations per Flower's report: Denmark 20.5%, Portugal 14%, Spain 13.9%, Ireland 11.5%, Germany 8.1%, Greece 4.1%, Netherlands 4%, UK 3.2%, Italy 3%, India 2.9%, Austria 2.7%. In terms of energy consumption, Denmark reached 26% in 2011, and the United States was almost 1% in 2010.

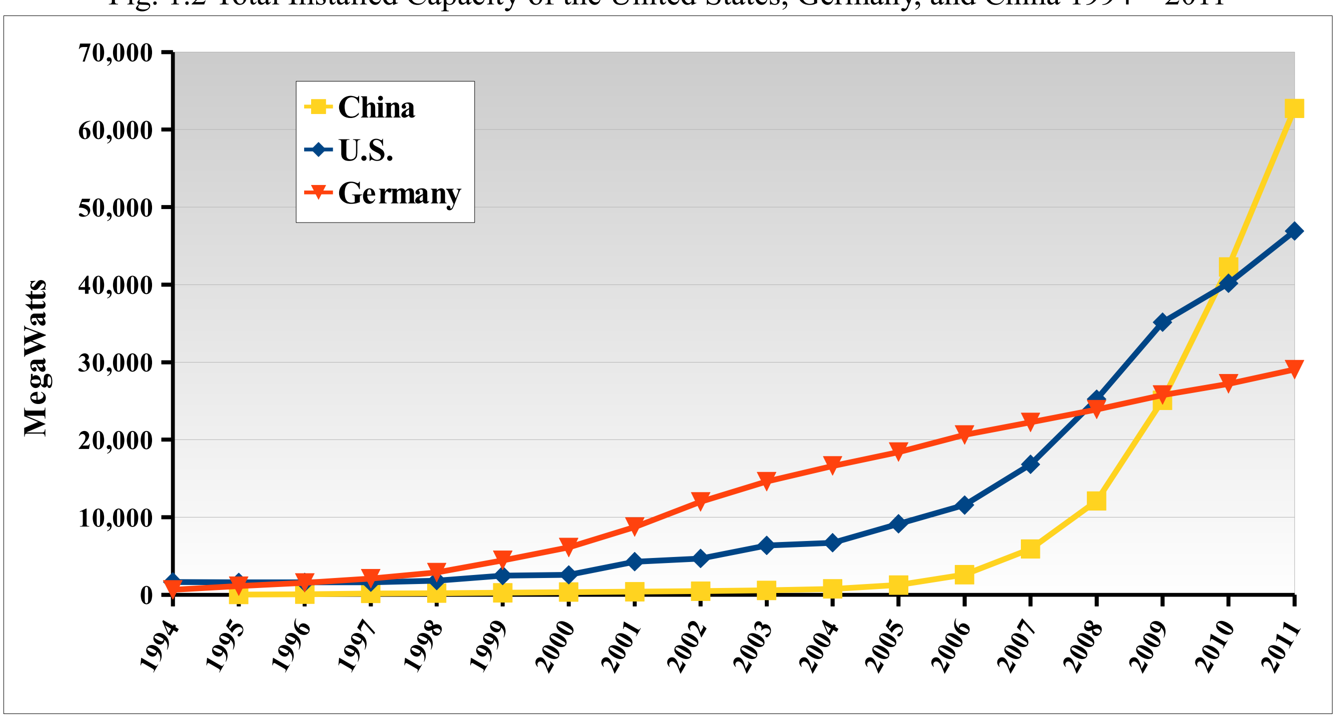
2 Installed wind capacity is not necessarily the final say in wind power leadership. For our purposes it provides a rough proxy for understanding growth in wind manufacturing and investment. My research has indicated that countries leading in wind capacity installations have tended also to have their dominant share of wind turbines supplied by a domestic wind manufacturer. This is true of GE in the U.S., and Enercon in Germany, for example. Public support is vital to the formation of a strong domestic market, and a strong domestic market has tended to aid in the emergence of a strong domestic manufacturer.

Fig. 1.1 Global Installed Wind Capacity 1980 – 2011, Megawatts



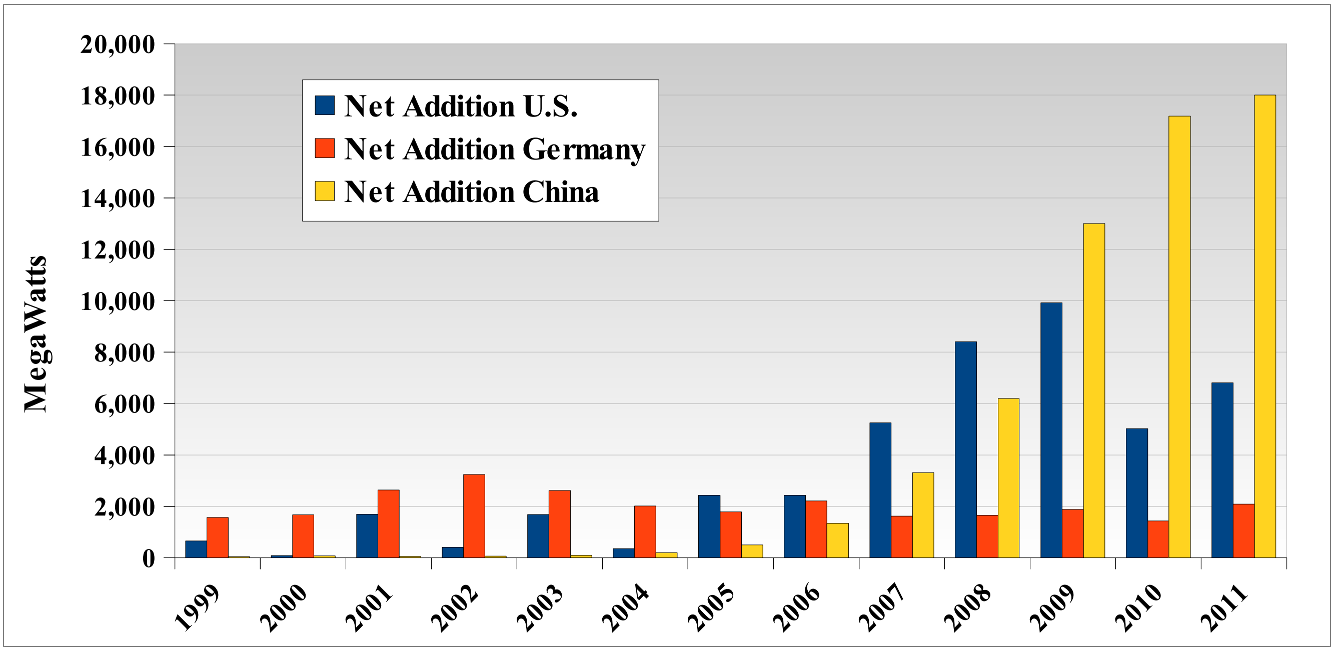

Source: Earth Policy Institute, Global Wind Energy Council.

Fig. 1.2 Total Installed Capacity of the United States, Germany, and China 1994 – 2011




Source: Earth Policy Institute, Global Wind Energy Council.

Fig. 1.3 Net Annual Wind Capacity Additions (MWs) 1999 – 2011




Source: Earth Policy Institute, Global Wind Energy Council.

China's dramatic rise to the top of the charts suggests a big shift in wind industry momentum. In just four years, China has managed to approximately double its installed wind capacity every year, reaching 63 GWs in 2011 from just 1 GW in 2005. It is a stunning ascent. China's addition of 18 GWs in 2011 is nearly twice the best attempt by the United States so far, which added 10 GWs of capacity in 2009 alone. Only a handful of countries have so far managed to add much over 1 GW of wind capacity on an annual basis, though the United States and Germany achieved such rates beginning around 1999.

## *The National Market for Wind in the United States*

Wind energy is an increasingly important form of renewable energy in the United States. Between 2007 and 2009 wind energy represented about 40 percent of all planned new generation capacity (AWEA, 2009, p.5). This is about 7 GWs despite a weak economy and serious political uncertainty. Wind currently represents about 3.5 percent of all installed capacity in the United States and generates about 2.3 percent of its electricity (NREL, 2011, p.10). As late as 2004, non-hydro renewable energy sources barely produced more than 2 percent of the nation's electricity. In 2010 they are producing 4 percent.[3] Proportionally small, it should be noted that the United States is still the world's second largest consumer of energy following China. Thus increased renewable penetration here would be good for global environmental integrity overall.

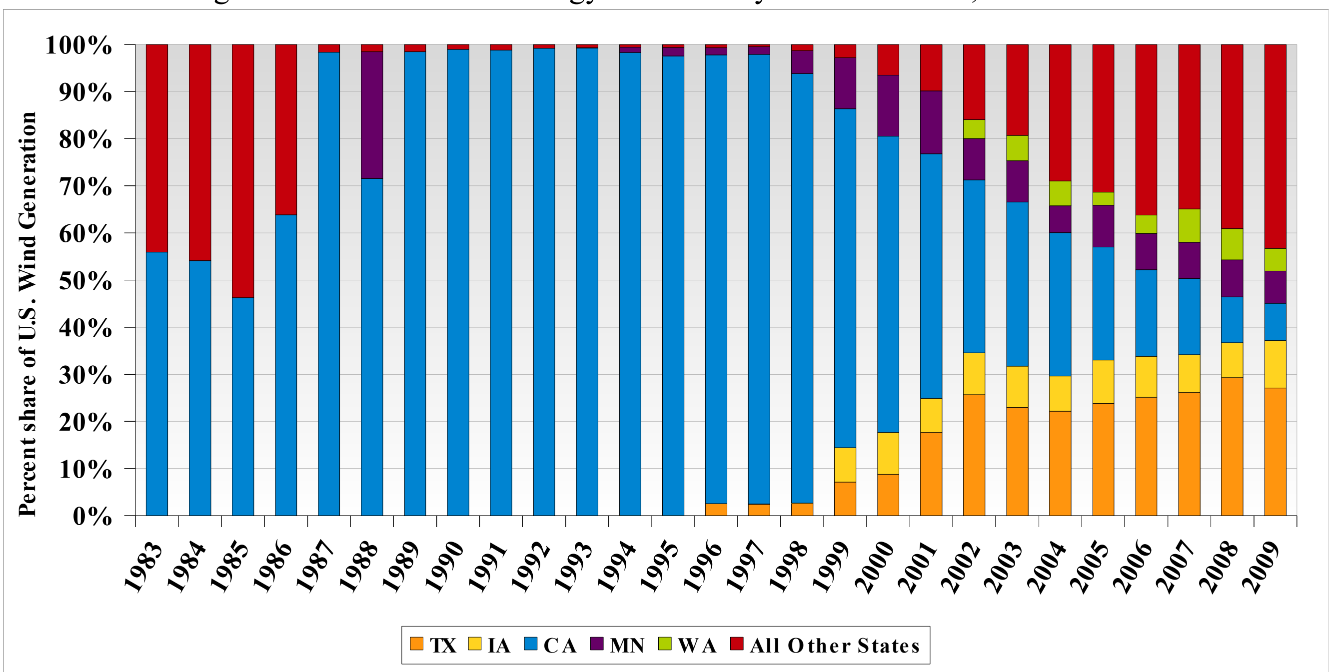
Focusing on capacity expansion can be misleading if it is being used also to connote economic momentum. One precaution is that focusing on increases in capacity does not communicate to the reader which manufacturers are supplying the wind turbines meeting that capacity. It also does not tell

3 i.e. Solar P/V, Solar Thermal, Geothermal, Biomass, and Wind. The installed capacity is still so proportionally low in the United States that these technologies are typically grouped together into a single statistic. If we based our figure on consumption instead of electric generation, the contribution of non-hydro renewables would be about 5.7% in 2010, mostly due to biomass.

us which companies are performing the construction and development. A large share of the U.S. market, for example, is supplied by imported turbines or foreign-owned companies. The American Wind Energy Association claims that domestic content of U.S. wind turbines grew from about 25 to 50 percent between 2005 and 2010, for example (AWEA.org, 2012). This does not conclude, however, that the sum of industry activity in the United States is or isn't benefiting the nation generally.

The modern wind energy industry has important origins in the United States. The world wind industry began in earnest in the early 1980s with the rise of California as a central market for the technology as it entered its first phases of rapid commercial deployment. In many ways California unified and provided opportunity for early European, Japanese, and American companies to develop their manufacturing capabilities. This first wind rush, as it became known, was fertilized by statewide resource evaluation, policy changes at the federal and state level, and by the provision of strong market incentives. Shown in figure 1.4 below, this had the effect of solidifying California's position as a major location for wind energy generation well into the mid 1990s.

Fig. 1.4 Percent of Wind Energy Produced by Selected States, 1983 – 2008




Source: United States. Department of Energy. "State Energy Data System." *Energy Information Administration*. Accessed April 2011.
*Prior to 1990 "all other states" is effectively the state of Wyoming.

Taken in consideration with the world data just reviewed, California in a sense *was* the world market for wind energy for a long time, as it was the location of almost all wind capacity in the United States. By 2002, the year of General Electric's (GE) entry into the wind energy business, Texas and California alone represented over half of U.S. wind energy generation in what was already a billion dollar industry.

The triple digit percentage growth in wind energy capacity was halted quickly in the mid 1980s by several factors which ultimately undermined and in some cases bankrupted leading turbine manufacturers and wind developers. It also allowed for a shift in industry momentum to Europe.

Growing from about 1,000 MWs to around 1,600 MWs through the 1990s, installed wind capacity lapsed at times into negative values and many developers focused on repowering existing wind sites rather than seeking new sites for development.[4]

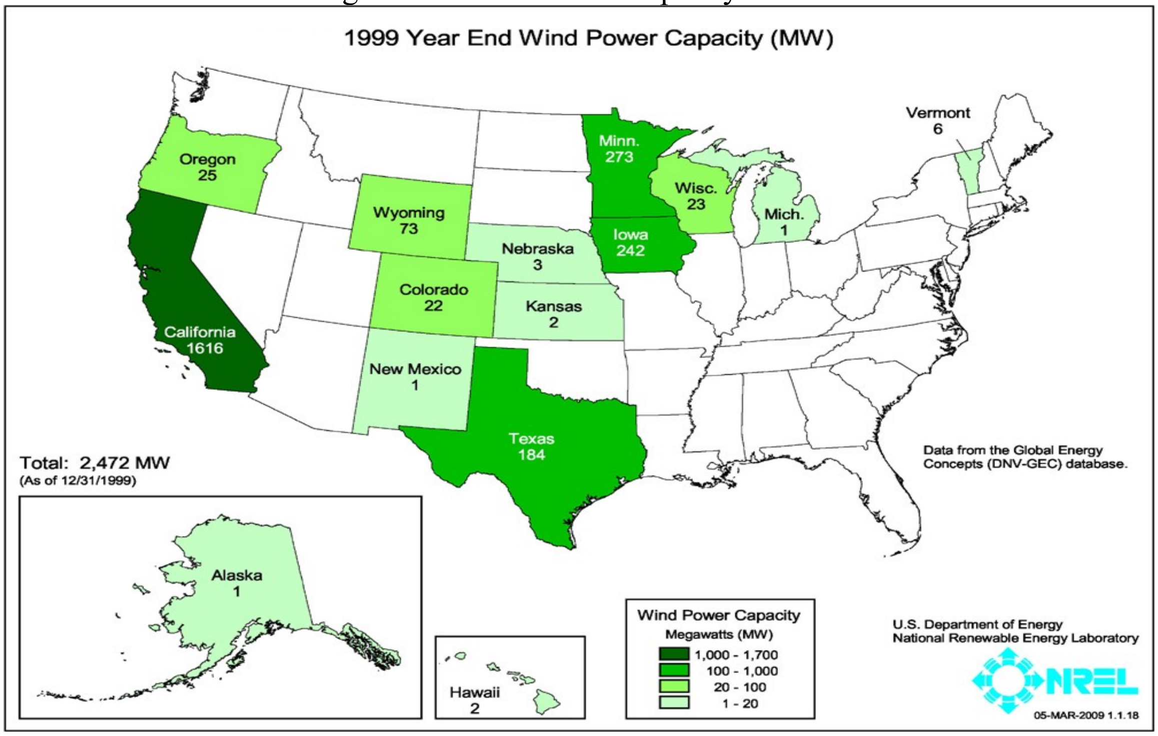
Innovations providing for new efficiencies or the up-scaling of wind turbine technology slowed or were imported. An unfavorable policy environment, lack of utility buy-in, and difficulty acquiring capital after the expiration of tax credits were all part of the wind industry's lackluster years which we explore in more detail below. The industry failed to maintain a good reputation as well, suffering from the mistakes it made during its formative years. In short, the story of the U.S. wind power industry has been the erosion of California's centrality as a prime development site and the emergence of the American Midwest, Texas, Oregon, Washington and Oklahoma as new states and regions where total wind development is exceeding that of many European countries. Figure 1.5 and figure 1.6 below illustrate the shift in the distribution of wind capacity in the United States between 1999 and 2010.

This trend is supported by numerous factors, but in a basic sense the American west along the Great Plains typically has a combination of very high land availability and high average wind speeds, along with state level policy support in the form of mandatory or sometimes voluntary renewable energy development requirements.[5] Even so, it is important to note that currently, Texas possesses approximately a quarter of the 40.18 GWs of wind capacity installed in the U.S. as of 2010.

4 Repowering means that new turbines replaced old. Typically, new designs were more productive, so a net loss in capacity didn't mean that performance or revenues were not enhanced. Many developers would have had long term purchase power contract with utilities guaranteeing that the energy would be sold into the grid.

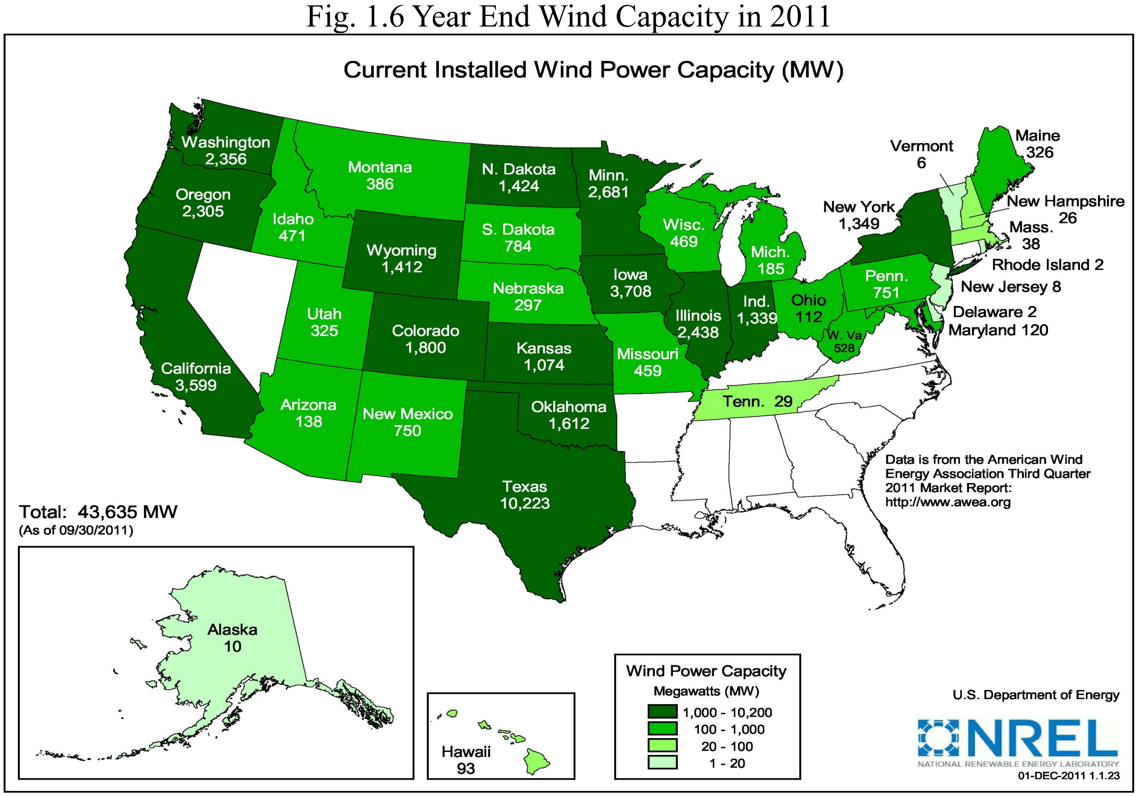
5 The Renewable Portfolio Standard (or RPS) is described in greater detail later. States also tax ratepayers in order to fund public benefit funds which support renewable energy development or energy conservation efforts. Though many states specify multiple qualifying energy sources, it is somewhat certain that wind will continue to be a major benefactor of these sorts of policies for now as the technology is more developed.

Fig. 1.5 Year End Wind Capacity in 1999




Source: Adapted from Department of Energy Windpoweringamerica.gov. 7 Apr 2011. Web. Jul 14 2011.
http://www.windpoweringamerica.gov/wind_installed_capacity.asp#current

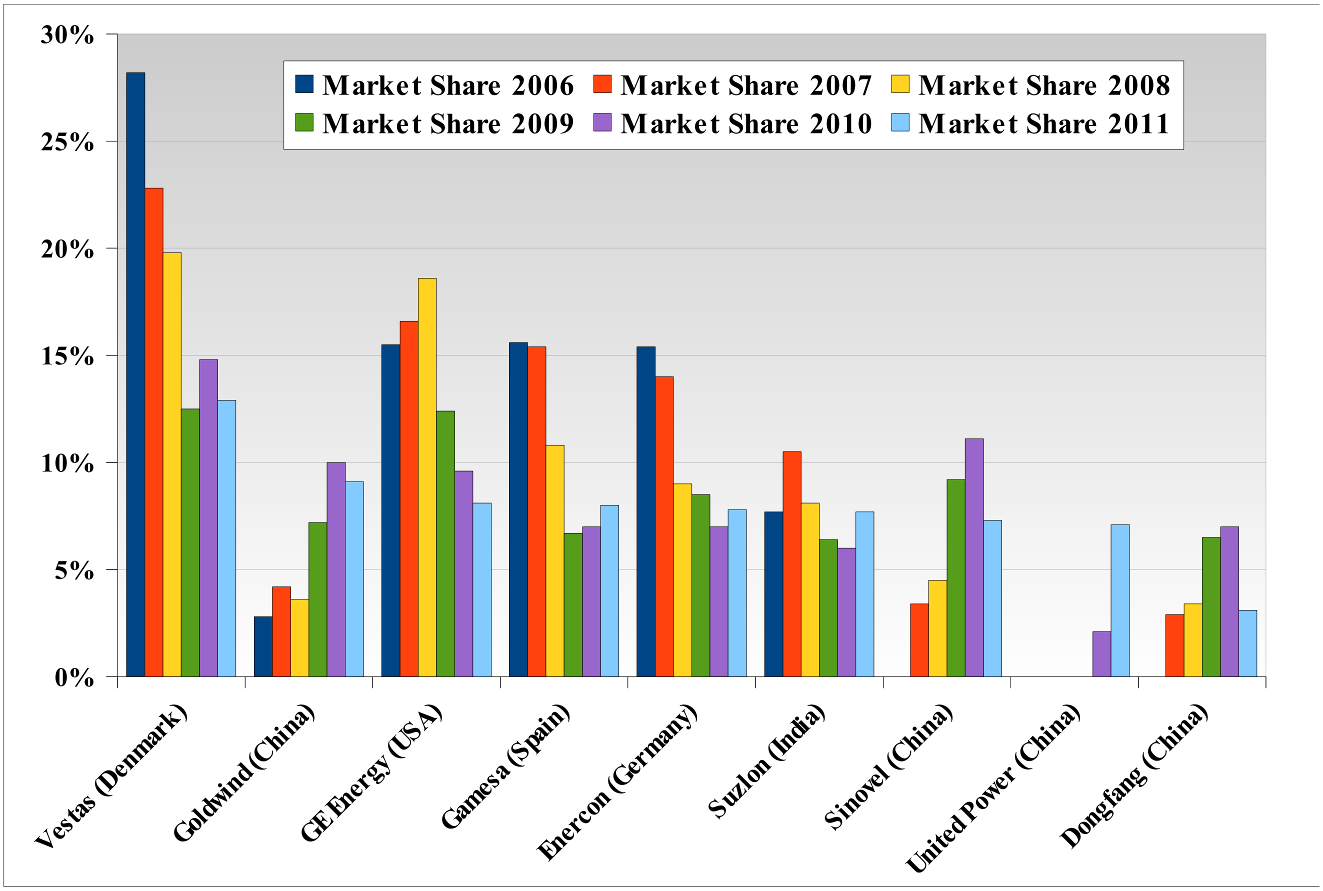
Fig. 1.6 Year End Wind Capacity in 2011




Source: Adapted from Department of Energy. *Windpoweringamerica.gov*. 30 Sept 2011. Web. 29 Mar 2012.
http://www.windpoweringamerica.gov/wind_installed_capacity.asp#current

# PART II. THE MAJOR PLAYERS / U.S. WIND POWER COMPANIES

Fig. 2.1 Global Turbine Market Share, Selected Companies, 2006 – 2011




Sources: (1) Adapted from United States. International Trade Commission. "Wind turbines: Industry and Trade Summary." June 2009. Web. 7 Apr 2011. http://www.usitc.gov/publications/332/ITS-2.pdf
(2) "Wind Turbine Market Shares 2008-2011, Installed Capacity." *ekopolitan.com*. 28 Mar 2012. Web. 30 Mar 2012. http://www.ekopolitan.com/tech/global-wind-turbine-market-shares
(3) BTM Consult. MAKE Consult. Various Years.
*Estimates by MAKE and BTM do not have parity across years and by company so the data shown should be considered approximate. No data for Dongfang, 2011, who fell out of the top 10. I estimated 3.1% on news that they lost 3.9% of global market share in 2011.

There are already thousands of companies contributing to the wind power supply chain at this time. The top six companies delivered over half of the global supply of wind turbines in 2011. Wind turbines alone represent about 50 to 70 percent of the total cost of wind project installations, with construction, and operation and maintenance costs making up the final costs of a wind project investment.[6] As indicated by figure 2.1, above, Chinese manufacturers are rapidly gaining market share while many companies which once supplied well over 10 percent of the market are experiencing rapid year over declines.

That said, in 2010, wind investment represented a $71.8 billion dollar market while also

6 The cost of installing offshore wind projects is higher than onshore projects because of its unique construction challenges. The cost of the turbine itself is not as large a driver of total project costs, and hence the total investment needed to complete a project.

employing approximately 500 million people globally (Global Wind Energy Council, 2009, p.8 and Global Wind Energy Council, 2010, p.10). Danish BTM Consult reported that the industry had grown to $75 billion in 2010 and forecasted a $124 billion industry in 2014, a growth of 65 percent in just four years (BTM Consult, 2010).[7] Investment in wind power is expected to accelerate globally and is unlikely to subside in the near future, even if uncertainty and instability in the U.S. economy reduces its role as a primary driver of the technology.

## The Global Leader: Vestas

Table 2.1 Selected Vestas Figures, 2006-2010 (billions of USD)

| Year | 2010 | 2009 | 2008 | 2007 | 2006 | Percent Change 2006-2010 |
|---|---|---|---|---|---|---|
| **Revenue** | $9.13 | $7.06 | $8.67 | $5.24 | $5.22 | 75.00% |
| **Operating Profit** | $.409 | $.349 | $.903 | $.277 | $.255 | 60.00% |
| **Profit for the Year** | $.206 | $.174 | $.691 | $.142 | $.141 | 46.10% (390% between 06-09) |
| **Turbines Produced** | 4,057 | 6,131 | 6,160 | 4,974 | 4,313 | -6% (up 43% in 2009) |
| **R&D Expenditures** | $.688 | $.485 | $.470 | $.244 | $.163 | 322% |
| **Employment** | | | | | | |
| **R&D Workers** | 2,277 | 1,490 | 1,345 | 650 | 519 | 339% |
| **Workers Outside DM** | 8,127 | 6,569 | 5,320 | 3,232 | 2,025 | 301% |
| **Total Employment** | 23,252 | 20,730 | 20,829 | 15,305 | 12,309 | 89% |
| ***Avg Annual Exchange rate*** | 1.32 | 1.39 | 1.47 | 1.37 | 1.25 | |

Source: Vestas Annual Reports, various years.

*Accounting changes in FY 2010 resulted in revised figures – most significantly, reduced year end profit of $174 million in 2009 versus $805 million reported in FY2009

*Vestas claims to have manufactured about 43,000 wind turbines since 1979 – 59.6% of these would have occurred in the last 4 years

Vestas was founded in 1898 by a blacksmith named H.S. Hansen in Lem, Denmark. Early on the company built steel window frames. By the 1940s they manufactured home appliances. Farm equipment like milk coolers became a key product for the company in the 1950s. By 1986, the company's core business was the manufacture of hydraulic cranes for trucks. Their first wind turbine was not installed until 1979.

Through most of the 1980s Vestas supplied wind turbines to the California wind rush in large part through Zond, one of the first U.S. wind energy developers.[8] Their orders for 705 wind turbines contributed to Vestas' employment growing from 200 to 870 employees. An additional 1,200 turbines were ordered by Zond in 1986, of which not all were taken in delivery.[9] In combination with revised Danish tax laws the company entered dire straights. Following near collapse in 1986, the company

7 *Cleanedge* offers a more conservative estimate in their 2012 report: $116.3 billion by 2021. The possible rapid rise of competing energy technologies no doubt makes accurate forecasting difficult.

8 Zond is described in detail below. Originally an importer, Zond turned to the design and manufacture of turbines later in its history.

9 Vestas company history: http://www.vestas.com/en/about-vestas/history.aspx After a bankrupt shipping company caused a delivery delay, Zond refused to pay for the second part of the turbines shipped. Vestas claim is that Zond could not pay for the rest of the turbines they had ordered. This may in fact be true, as 1986 also marked the year in which Federal and California tax credits were set to expire.

reorganized and reemerged as Vestas Wind Systems A/S, now fully specializing in wind turbine technology. In 2004 the company merged with NEG Micon to become the largest wind company in Denmark.[10]

Vestas is now the world's leading wind turbine manufacturer, generating $9.1 billion in revenue in FY2010 while employing 22,216 people. Close to a third of their employees worked outside of Europe and 2,277 were involved in R&D. Compared to 2006, revenue was up 64 percent and gross profits had more than doubled to $1.6 billion. Employment overall had grown by 89 percent and the number of R&D workers was up 339 percent.

Vestas estimates that it has supplied about 44 thousand MWs of wind power from 43 thousand turbines installed in at least 32 countries worldwide (Vestas, 2010). 60 percent of the total number of turbines they have produced were therefore shipped between 2006 and 2010. Countries receiving the largest number of turbines in 2010 included the United States (1,093 MW delivered), China (857 MW delivered), and the UK (533 MW delivered). In 2009, Spain received 762 MW. As Vestas grows, their employment base is increasingly based on production and R&D activities, no doubt a sign of their success and commitment to remaining a global leader.

## The U.S. Challenger: General Electric

Table 2.2 Selected GE figures, 2006-2010 (billions of USD)

| Year | 2010 | 2009 | 2008 | 2007 | 2006 | Percent Change 2006-2010 |
|---|---|---|---|---|---|---|
| **Total Revenue (Billions)** | $150.2 | $155.2 | $181.6 | $171.6 | $150.8 | 0.40% (-17.29% from 2008) |
| **Total Profit (Billions)** | $11.6 | $11.0 | $17.4 | $22.2 | $20.7 | -43.96% |
| **Energy Infrastructure Revenue (Billions)** | $37.5 | $40.6 | $43.0 | $34.9 | $28.8 | 30.21% |
| Energy Revenue[1] | $30.9 | $33.7 | $36.3 | $24.8 | $20.8 | 48.56% |
| Energy Infrastructure Profit | $7.3 | $7.1 | $6.5 | $5.2 | $3.8 | 92.11% |
| Energy Profit[2] | $6.2 | $6.0 | $5.5 | $4.1 | $2.9 | 113.79% |
| **R&D Expenditures[3]** | $4.9 | $4.4 | $4.4 | $4.1 | $3.5 | 40.00% |
| **Employment (thousands)** | | | | | | |
| **Total** | 287 | 304 | 323 | 327 | 319 | -10.03% |
| **U.S.** | 133 | 134 | 152 | 155 | 155 | -14.19% |
| **Non-U.S.** | 154 | 170 | 171 | 172 | 164 | -6.10% |
| **U.S Manufacturing** | 6.3 | | | | | |

Source: General Electric Annual Reports, various years

Energy Infrastructure includes sales and service which include gas, steam, controls, wind turbines, solar, and water treatment technologies

[1]Aggregated Energy and Energy Financial Services Data. Excludes Oil and Gas activities.

[2]Energy profit excludes Oil and Gas activities but is not representative specifically of wind turbine sales

[3]Figures for 2010, 2009, 2008, 2007, and 2006 include $1, $1.1, $1.3, $1.1 and $0.7 billion in additional funding provided by the government

10 NEG Micon had itself already merged with the Danish wind company Nordtank in 1995, WEG in 1998, and NedWind in 1998. Thus Vestas was at the head of a consolidating Danish industry.

General Electric (GE) was formed in 1892 from the merger of Edison General Electric and the Thomson-Houston Electric Company. A point of contrast is that Vestas is today entirely focused on wind energy while GE, which entered the wind business in 2002, is a conglomerate that produces a diversity of products including jet engines, medical equipment, and financial services. In 2010 GE Capital Services funded 20 startup companies that focus on competitive clean technology solutions.

The company as a whole generated $150.2 billion in revenue in 2010, down from a previous peak of $181.6 billion in 2008. Of its 287 thousand employees, 154 thousand (or 54 percent) work outside the United States. Total employment was down 12.2 percent from a peak of 327 thousand in FY2007. U.S. employment dropped 14.2 percent from 2006, and Non-U.S. Employment is down 10.5 percent from its previous peak in 2007. Approximately 6,300 manufacturing jobs are in the United States in 2010. The company spent close to $4 billion on R&D in 2010, up 40 percent from $2.8 billion in 2006 (not counting government R&D funding).

Navigating GE's annual reports is anything but straightforward. The company has five major business segments which wrap around still more sub-segments. Revenues from their wind turbine operations are aggregated into their energy infrastructure business. Not including oil and gas revenues the energy segment generated $30.9 billion (or 21 percent) of the company's 2010 revenue and $6.2 billion (53 percent) of its profits. The company claimed that a decline in energy revenues from $33.7 billion in 2009 reflected decreases in thermal and wind equipment sales. Interestingly, profits of $6.2 billion in 2010 were higher on this lower revenue.[11]

GE claims to have produced over 15,500 wind turbines, and a 2008 *sustainablebusiness.com* article reported that GE had earned $4 billion (about 16.1 percent of total Energy Infrastructure revenue) from its turbine business in 2007, up from approximately $500 million in 2002. From 2004, the company's turbine production had grown by 500 percent. About 2,000 employees supported its wind activities worldwide. Lacking more concrete and current data for the performance of GE's wind segment, I nevertheless estimate that wind energy contributes to at least 15 to 25 percent of its energy revenues and that this proportion will grow if GE continues to aggressively pursue the world market for turbines and public commitments are sustained.[12]

Globally, General Electric competes with Vestas for world dominance of wind turbine markets, with a market share of 16.7 percent compared to Vestas' 17.8 percent. Along with Gamesa (10.8 percent), and Enercon (9 percent), just four companies had supplied approximately 50 percent of the world's existing wind turbines in 2009. Illustrated by figure 2.1 at the beginning of this section, at the end of 2010 the world supply of wind turbines began to shift toward China, which emerged with three top turbine suppliers for the year. Each now compete with Vestas for world dominance (having bumped GE from its number two spot). In general, Vestas, GE, Enercon, Suzlon, and Gamesa are companies which have remained in the top 10 of world suppliers for many years. They have also seen their

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11 We might add, by extension, that the energy sector is one of GE's more profitable, having almost doubled its profits over the last four years.

12 I am assuming that $4 billion in wind revenue in 2007, representing 16.1 percent of segment revenues grew to at least $6 billion in 2010 or greater, which would have made it 19.4 percent of segment revenue (on $30.9 billion non oil and gas activities reported). A 2008 *Rueters* article pointed out that GE expected wind turbine business to reach $6 billion in 2008, so this may be a conservative estimate. Likewise, the downturn in development recently has likely had a negative impact on that business segment.

positions erode as India and especially China have developed their own domestic suppliers and begun relying on them to feed their appetites for wind energy.

The somewhat frenetic shifting of market share and manufacturing activity since 2006 on the international stage is as much a product of unstable U.S. wind policy as it is a story of Chinese ascension. Even so, Vestas has continued to lead the world from as far back as 2004. Along with GE, Gamesa, and Enercon, just four companies have continued to supply close to half the world's demand for wind turbines so far, and each are unlikely to want to relinquish that role. Despite this, the continuity of this trend is coming into question.[13]

Even as international competition heats up and a greater number of suppliers appear on the market, the tendency has appeared to be that countries with major wind markets tend to meet the supply of their own domestic markets with a *national champion*. This suggests that the most competitive context for wind turbine manufacturers is indeed typically occurring on a global, rather than national scale. This has certainly been true in the United States, Denmark, and Germany.

## *The Battle for the U.S. Market*

GE dominates the U.S. market for utility-scale wind turbines, providing half of all the wind turbines supplied in 2010. This was more than its next four competitors combined. Vestas and Siemans are the only other companies have supplied 10 percent or more of all turbines in recent years (see table 2.5, below). GE entered the wind business with its 2002 acquisition of Enron Wind.[14] Along with Clipper, also founded in the early 2000s, and Northern Power Systems, founded in 1974, GE is one of the few major suppliers of wind turbines that have headquarters in the United States.

Table 2.3 is a snapshot of the U.S. domestic market between 2007 to 2010 and it is heavily lopsided. At least 15 total suppliers now compete for what market share can be generated given the unsteady U.S. wind business and policy environment. Illustrated in table 2.4, below, Vestas and Siemans combined make up approximately 29 percent of the wind capacity in the United States, still quite far behind GE.

Examining markets for wind power through capacity expansion, power generation, or even by looking at the number of turbines on the ground fails to tell the complete story of the industry. The complexity and reach of international competitors and an operating global supply chain can confuse any sense of direct competition occurring between countries. Many foreign companies present in the United States set up domestic manufacturing, for example. Regulations can force manufacturers to give local suppliers priority also, helping to increase the employment impact that foreign investment brings.

Not all businesses focus on final assembly of turbines. American Super Conductor of Massachusetts, for example, designs turbines and licenses its advanced technology to China and other

13 For the data that I have been able to examine, these four companies supplied approximately 80% of the world market in 2005 (estimate), 75% in 2006, 70% in 2007, 60% in 2008, 40% in 2009, and 36% in 2010. Chinese companies supplied over 30% of the world market in 2010 (by estimate). The number of suppliers is tending to increase, and there are many countries with vast resources that have yet to begin developing them. There is ample opportunity for market leadership to continue changing hands and for new companies to form.

14 As will be explained later, Enron Wind was formed from the acquisition of Zond, an early U.S. company, and Tacke, a German company. The former was intended to serve the U.S. market and the latter the European.

Table 2.3 Domestic Market Shares, 2007 – 2010

| | No of Turbines Sold | | | | MW Capacity | | | |
|---|---|---|---|---|---|---|---|---|
| **Company (Country of Origin)** | **2007** | **2008** | **2009** | **2010** | **2007** | **2008** | **2009** | **2010** |
| GE Energy (USA) | 1,560 | 2,438 | 2,663 | 1,679 | 2,340 | 3,657 | 3,995 | 2,543 |
| Vestas (Denmark) | 537 | 569 | 830 | 75 | 953 | 1,120 | 1,488 | 221 |
| Siemens (Germany) | 375 | 344 | 505 | 360 | 863 | 791 | 1,162 | 828 |
| Mitsubishi (Japan) | 356 | 515 | 428 | 146 | 356 | 516 | 751 | 350 |
| Suzlon (India) | 97 | 363 | 344 | 153 | 197 | 736 | 702 | 312 |
| Clipper (USA) | 19 | 238 | 242 | 28 | 48 | 595 | 605 | 70 |
| Gamesa (Spain) | 287 | 308 | 300 | 281 | 574 | 616 | 600 | 562 |
| All Other Companies | 1 | 381 | 390 | 158 | 3 | 475 | 694 | 213 |
| GE Share | 48.27% | 47.28% | 46.70% | 58.30% | 31.87% | 34.78% | 33.28% | 35.77% |
| **Total (Utility-Scale)** | 3,232 | 5,156 | 5,702 | 2,880 | 7,342 | 10,515 | 12,006 | 7,109 |
| **TOP 5 Companies** | 3,115 | 4,174 | 4,770 | 2,619 | 4,709 | 6,821 | 8,098 | 4,254 |

Sources: (1) "A manufacturing Blueprint from the Wind Industry." *American Wind Energy Association*. June 2010.
(2) American Wind Energy Association Annual Report. Various Years.

Table 2.4 Wind Turbine Manufacturers' Share of Total Installed 2010 U.S. Wind Capacity

| Company | Country of Origin | Share % | Total Capacity[1] |
|---|---|---|---|
| GE Energy[2] | United States | 41.3% | 16,594 |
| Vestas[3] | Denmark | 17.3% | 6,951 |
| Siemans[4] | Germany | 11.6% | 4,661 |
| Mitsubishi | Japan | 7.6% | 3,054 |
| Gamesa | Spain | 6.0% | 2,411 |
| Suzlon | India | 5.2% | 2,089 |
| Clipper | United States | 3.3% | 1,326 |
| Acciona | Spain | 1.5% | 603 |
| Repower | Germany | 1.2% | 482 |
| Kenetech | United States | 0.6% | 241 |
| Others | N/A | 0.6% | 241 |
| Unknown | N/A | 3.8% | 1,527 |
| Total U.S. Capacity | | | 40,180 |

Source: "2010 U.S. Wind Industry Annual Market Report: Rankings." *AWEA.org*. May 2011.
[1]Estimated.
[2]GE figures include Enron, Zond, and Tacke
[3]Vestas figures include NEG Micon, Micon, Nordtank, Windane, Wind World, and NedWind.
[4]Siemans figures include Bonus

countries interested in acting as a market supplier. All major and leading wind turbine companies have shown a willingness to license or cross-license technologies in exchange for access to markets or perhaps as a means of generating revenue. Most critically, the wind industry necessitates a development component which is primarily construction, but which also supports or can include the growth of energy service companies which help to plan, site, and permit projects.[15]

15 For example, Nextera energy is the largest wind energy developer in the United States. With 4,700 employees, the company finances and develops a variety energy sources in the country, including nuclear and fossil fuels.

National concentration and fierce competition for markets have consequences. Enercon was prevented from supplying U.S. markets for years because of disputes over variable-speed technology patents, which began with U.S. Windpower and were inherited by GE. Mitsubishi also filed suit against GE in May of 2010, claiming that GE was warding off foreign competition and damaging their business by claiming patent infringements (Kirkland, 2010). Truthful or not, companies are not shy about bringing intellectual property into the competitive arena in an effort to protect – or acquire – market share. In fact, the International Trade Commission (ITC), is currently handling claims by wind (and solar) companies which are reacting to the ascension of strong Chinese competitors.

Technology which has been shared and used to develop domestic capability elsewhere means that new wind turbine suppliers are emerging and finding their ways back into the U.S. or European markets for wind energy. There are some 8 thousand parts in a modern wind turbine, and while the market moves toward advanced direct-drive systems[16] and 5-10 MW designs with 400 foot or greater rotor diameters, dozens of companies within the supply chain will find opportunities to innovate wind turbine sub-systems. Wind turbines are fantastically sophisticated despite their simple appearances.

Table 2.5 Wind Manufacturer Share of Turbine Capacity Installed (MWs), 2005-2010

| Manufacturer | Country of Origin | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| GE | United States | 60% | 47% | 45% | 43% | 40% | 50% |
| Siemans | Germany | 0% | 23% | 16% | 9% | 12% | 16% |
| Gamesa | Spain | 2% | 2% | 9% | 7% | 6% | 11% |
| Mitsubishi | Mitsubishi | 8% | 5% | 7% | 6% | 8% | 7% |
| Suzlon | India | 1% | 4% | 4% | 9% | 7% | 6% |
| Vestas | Denmark | 29% | 19% | 18% | 13% | 15% | 4% |
| Acciona | Spain | 0% | 0% | 0% | 5% | 2% | 2% |
| Clipper | United States | 0% | 0% | 1% | 6% | 6% | 1% |
| REPower | Germany | 0% | 0% | 0% | 1% | 3% | 1% |
| Nordex | Denmark | 0% | 0% | 0% | 0% | 1% | 0% |
| DeWind | Germany | 0% | 0% | 0% | 0% | 0% | 0% |
| Other | N/A | 0% | 0% | 0% | 0% | 0% | 0% |
| Total Installed | | 2,402 | 2,454 | 5,249 | 8,350 | 9,993 | 5,113 |

Source: Adapted from United States. Department of Energy. "2010 Wind Technologies Market Report." *Office of Energy Efficiency and Renewable Energy*. June 2011. p.19. Author's calculations.

The American Wind Energy Association (AWEA) claimed that at least 240 companies supplied for the domestic wind power market in 2009, "up from a few dozen in 2004," and that these companies are in fact found all over the country (2010, p.12). For the year 2010, this figure has grown to 400 companies. Approximately 80,000 persons are directly or indirectly employed in the U.S. wind energy industry, with perhaps 20,000 in manufacturing (DOE, 2010, p.24). As shown in figure 2.2 below, some regional concentration in the Midwest, Colorado and Texas is apparent.

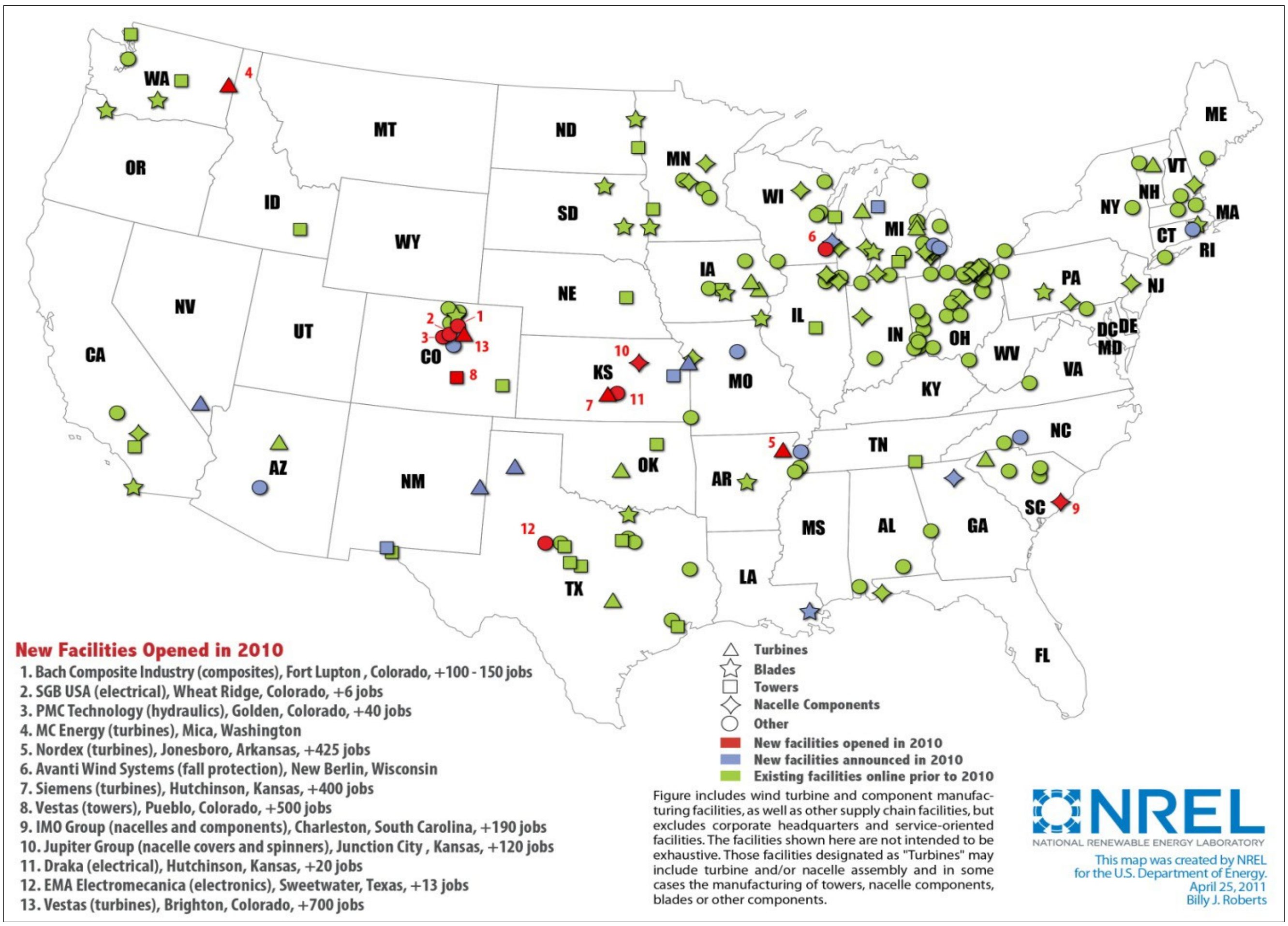
One of GE's major turbine manufacturing factories resides in Tehachapi California, the same facility built by U.S. Windpower. While this current supply chain distribution corresponds roughly with the pattern of regional wind energy resource development mentioned earlier, it is notable that several southern states have facilities which are part of the national supply chain. It is not necessarily true, in

16 Direct-drive systems do away with gearboxes. This is now a feature one might find in about 10-20% of wind turbines. A disadvantage of the machines using these is that they can spin faster than a gearbox would have allowed, creating different sound pressure or aesthetic impacts.

other words, that a strong potential market for wind development ensures or limits opportunities to manufacture for the sector.

Despite this good news, *Good Jobs First* argued in March 2010 that about half of the turbines in the U.S. are made in other countries, creating a $2.6 billion dollar trade deficit in 2008 (p.7). They caution that America risks an import-driven expansion of wind power (and other clean technologies) and point out that the advanced manufacturing tax credit, meant to support many clean technology companies in the United States, in fact accrues benefits to domestic companies about 59 percent of the time.[17] In addition, U.S. companies receiving credits have typically received them for smaller projects, averaging $11 million versus $20 million awarded to other companies (Good Jobs First, 2010, p.9).

Fig. 2.2 Location of Wind Companies in the United States, 2010




Source: Adapted from United States. Department of Energy. "2010 Wind Technologies Market Report." *Office of Energy Efficiency and Renewable Energy*. June 2011. p.20.

In contrast, Platzer (2011) points out that increased development activity in recent years encouraged foreign companies to locate manufacturing facilities within the United States. This has increased the domestic parts content of wind turbines to around 50 percent, while imports dropped from 64 percent in 2006 to 32 percent in 2009 (p.23). While this is partly attributable to declines in capacity

17 This is a $2.3 billion program by the American Recovery and Reinvestment Act providing tax credits to clean tech companies which manufacture in the United States.

additions overall as a result of the financial crisis (discussed later), it illustrates some of the value of promoting a strong domestic market for wind turbines.

The process of globalization makes it a challenge to comprehend how the generation and movement of wealth around the world through manufacturing supports or fails to support a nation. It is also a challenge to differentiate between wealth that is created here by foreign-born companies versus wealth that was created here by a native company. Each might compete nationally and internationally. More importantly, there is always a question of whether or not native or foreign-sourced wealth is truly different in a market for goods and services which one senses GE has appropriately categorized as "infrastructure development".

All countries want employment opportunities for their population. They might also want tax revenues from business activities which can be directed into investments in new industries, or used to fund public services, education, or other quality of life enhancements for citizens. The size and scale of wind technology and the rapidity with which it can be deployed has in the past rewarded manufacturers that remained close to actual project sites, for example. The sheer size of modern turbines can discourage their export, making locating abroad a logistically advantageous decision.[18]

Foreign companies can benefit from locating in the United States. Likewise domestic companies can benefit from the public support and incentives found abroad. They can also find skilled and educated labor they need, possibly at lower costs. Investments made in the United States by foreign companies or through import of their products and services are not clearly a reflection of something good (or bad) happening to the country. But they certainly speak to the success or failure of the United States to develop a strong domestic manufacturing base capable of competing successfully at home and abroad by being the obvious choice for highest quality and low price.

## *Market Foundations*

Like other energy technologies, wind power development requires a technological component, the wind turbine, and a construction component. Development requires significant capital, typically on the order of millions for land based projects and now billions for off shore projects.[19] Asset-based financing for the wind capacity installed between 2007 and 2010 has amounted to between $9-$12.3 billion, for example (DOE, 2011, p.115). The performance of the technology has relied as much on optimal siting choices as it has on constant improvements to wind turbines themselves. Along with this economies of scale have been achieved through increasing the swept-area of turbine rotors or increasing the total number used in a single project. Wind turbines today can weigh several hundred tons and stand taller than the Statue of Liberty. The primary material used in their construction continues to be steel.

The longevity of the current technology has tended to be pegged at 20 to 30 years.[20] However it

18 A key reason why offshore turbines can be gargantuan, for example, is because they are not limited in transport by tractor trailers and roads.

19 Distributed wind is the term used to describe local, or community projects. It sometimes also connotes turbines that generate less than approximately about 100 kWs (though I've also heard of machines as large as 600 kW included in discussions of community wind) of electricity, and this should be thought of as a separate market which is not described in this paper. Local wind energy in the future may come to relate more to ownership schemes than turbine size.

20 This is not intended to mean that the turbines "break" after this period. Rather, it would be time for new gearboxes,

was considered good practice by leading U.S. companies in the 1980s and 1990s to "re-power" projects when new technology promised performance enhancements.[21] In some cases this practice meant that total installed U.S. wind capacity fell, even if productivity rose for the developer overall.

Successful wind developers were made during the 1980s California wind rush. Developers could acquire long-term contract agreements with utilities which paid high energy prices which could sustain a business while they lacked technical cost advantages. This provided a period of time during which a search for new efficiencies could occur. This typically came to mean the upgrade of wind sites either through the optimization of wind turbine placement, or through deployment of newer turbine models which promised additional revenue through increased energy output.[22]

By the time GE joined the industry through the acquisition of Enron Wind (which itself had acquired Tacke Windtechnik GmbH of Germany and Zond Systems of California) in 2002, the United States was already very different place for the wind industry. For one, average capacity growth every year between 2000 and 2010 was about 30 to 40 percent. Additionally, revenues from Enron's wind division had expanded from about $50 million in 1997 to $750 million by 2002, demonstrating that wind energy was rapidly becoming a billion dollar business for well-positioned companies. As we have seen, the turbine business is today generating billions for GE, which had not itself made any of the key prior investments in the industry.[23]

It is true that many opportunists also entered the wind business to exploit the tax credits fueling it, meaning that industry building was not on their minds so much as just making money. Early companies that survived the damage of Wind Rush 1 developed business strategies that could make money from large wind turbine installs that included several or dozens of turbines. They discovered many of their own best practices, engaged with community objections to wind development, studied or became aware of their own environmental impacts, and spent millions upgrading technology with the direct and indirect support of state and federal governments. They also worked with incredulous utilities whose own paradigm was typically at odds with their needs, and who lacked much incentive to adopt a mostly unproven technology which produced more expensive electricity.

Despite the successes, "nearly all U.S. wind turbine manufacturers [were] out of business by the early 1990s" and the stock of domestic wind capacity steadily eroded while foreign companies increased their shares (CEC, 2001, p.24). This is because wind development is not dependent solely on who has the best turbine technology. Utility scale wind power is a form of infrastructure development and engenders changes to our national energy grid.[24] Wind developers face competing energy technologies, high capital costs, vulnerability to foreign competition, and an evolving regulatory scheme, all of which can facilitate or undermine their efforts. Projects that hit the ground compete with other land and now increasingly water uses, and must deliver energy reliably and profitably over a

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power electronics, etc. Cost savings can be realized by giving turbines a second life by replacing worn parts.

21 Specifically this meant taking older models out of service and replacing them with newer, probably larger machines that promised better average capacity performance and/or increased total annual generation.

22 Or in other words, an improved capacity factor.

23 With a caveat to come later. GE participated in the DOE "MOD" program for a time, an early attempt to rapidly develop multi-megawatt wind turbines with commercial potential.

24 A report by the Department of Energy "20% by 2030" documents a scenario wherein wind energy provides 20% of U.S. electricity, the maximum considered possible given current grid constraints. Impacts relate to transmission needs, land use, short-term inability of domestic manufactures to keep up with the pace of development, and so on. The report can be viewed here: http://www.20percentwind.org/20p.aspx?page=Report

multi-decade time horizon.

The wind industry is increasingly distancing itself from two realities occurring during a time period which we might date as 1980-2002. One reality is that California was the first and in many ways most important market for wind power in its first decades as an infant industry. This was true not only for the United States, but also for other countries developing turbine technologies, particularly for Denmark manifested in Vestas, and Japan manifested in Mitsubishi. Secondly, General Electric was not America's champion of wind technology in its critical formative years, despite the fact that their 1.5 MW turbine has become one of the most common models diffusing throughout the United States and world at this time. Instead we can draw lines which link the activities of the NASA, the DOE, and the University of Massachusetts to U.S. Windpower (aka Kenetech) and Zond before GE entered the business.

Third, even though the early attempt to commercialize wind turbines involved such major players as Boeing, Westinghouse, Lockheed, McDonnell Douglas, Grumman, Kaman, and GE, none of these companies would produce a viable design in the early bid for wind energy dominance. In fact, the early attempt to commercialize large wind turbines has been described as a complete failure for "big science" in the United States, which ultimately refocused its efforts later on cost-sharing collaborations between federal labs and enthusiastic turbine pioneers. This was also, however, a failure of some of the most storied companies in the United States, who were thought to have the right capabilities to scale and produce the key technologies. That they failed while a Danish farm equipment manufacturer succeeded is one of the great ironies of the developing industry.

As of 2010, GE remains positioned to be a top producer of wind turbines in the world, even as its overall market share begins to erode from the acceleration of wind power development in other countries and the emergence of new manufacturers in the world supply chain. That GE could enter this $100 billion dollar world market for approximately $300 million with the Purchase of Zond (aka Enron Wind) seems astounding.[25] Zond had itself, somewhat ironically, purchased U.S. Windpower's key assets and technology in the mid 1990s for about $425 million. The move had not only signified the loss of a then current world leader in wind turbine technology and development in the United States, but would contribute to the formation and success of a new world leader in a short while to come.

## *Technological Development:*
### *The Early Wind Pioneers*

Detailed history of the earliest wind energy programs and wind power in general can be read in greater detail in Heymann (1998, 1995), Neilsen (1999, 2010), Manwell (2009) and Gipe (1995). Some reproduction of their arguments is worthwhile as the wind energy industry, growing in importance globally, is still not well understood by many; the origins of many of its most important companies even less so. Harnessing the wind is an ancient human solution to many problems, from mechanical needs such as milling, grinding, or pumping, to transportation needs such as from sails. Wind has also supported sophisticated manufacturing activities before. Wind technologies have left their mark on almost every continent.

Wind energy fell out of fashion during the industrial revolution that swept through Europe and

25 Zond had tried to sell itself for $600 million during its bankruptcy proceedings.

the United States in the 18th and 19th centuries, and it is argued that it could not keep pace with the growing appetite for energy in these developing economies (Reynolds, 2005). This didn't keep the motivated from developing machines however, and small electricity generating turbines continued to be used in the United States in an uninterrupted if diminished role throughout the 20th century. The 1936 rural electrification act built power lines into neglected rural areas of the United States, further removing incentive for relying on the machines. One of their key features had been that they could generate electricity just about anywhere.

Windmills, the machines that collect kinetic wind energy and convert it for pumping, milling, grinding, or some other duty were considered for their electrical potential as early as 1881, when William Thomson considered their use before the British Association for the Advancement of Science. Alfred Wolff of the United States was an early advocate in 1885, and Joseph Freely and George McQuestion of Massachusetts actually built machines in the late 1880s (Hills, 1994). Charles Brush of Cleveland, Ohio built a machine in the 1890s and was able to charge 408 batteries that powered many of the lights in his house. He drove other electric motors with it as well.

Across the ocean Poul La Cour of Denmark began pursuing wind turbine development with disciplined rigor in the 1890s, and founded “the Danish Wind Electricity Corporation with the purpose of bringing electricity to the rural population” (Nielsen, 1999, p.191). He was out to teach farmers, essentially, how to use wind power and integrate it with existing DC generating utilities. He taught for five years before his death in 1908. Working under the Danish government, La Cour was a visionary who believed that wind energy could become a major part of a *hybrid* power system, where it would exist in parallel with steam and hydro systems while also reducing unemployment and helping to stabilize the energy supply.

It was later during World War II and the post-war years leading up to the 1960s when wind sourced electricity made many of its most important strides. Johannes Juul (born 1887), one of Poul La Cour's farmer-students who attended the Folk High School in Askov, completing his studies in 1904 around the age of 17. At the late age of 60, in 1947, he began developing a wind machine. He built his own wind tunnel for testing, and tested blade and rotor designs which eventually produced AC power and could connect to the grid. He went on to develop the 200 kW Gedser Turbine by 1957, discovering that support rods were needed in order to reinforce the blades (Heymann, 1998, Nielsen, 1999).

The design ran reliably for 10 years, providing evidence for the stability and reliability of a 3-bladed wind turbine design, along with the superiority of an upwind, active yaw system (Heymann, 1998). Future Danish designs would be heavy like the Gedser design, and the attempt to scale up power generation occurred much more incrementally in part for Juul's preference for trial and error (Nielsen, 2010). The additional mass of Danish designs in the future would prove to be one of the most important design features of successful early wind turbines they built for the United States. They were more reliable than U.S. models that preferenced lightweight designs ill suited to the wind regimes they operated within.

Ulrich Hütter of Germany is credited with bringing modern aerodynamic science into the design of wind turbines, ultimately deciding that a 2-bladed design would provide maximum aerodynamic efficiency with the added expectation of reduced costs. He built 2-bladed designs with active yaw and teetering hubs that proved to be some of the most aerodynamically efficient turbines ever built, but these were less reliable and cost effective overall than 3-bladed designs. Hütter's many designs led to an AC unit by 1952, and he also made a 100 kW turbine called the W34, a lightweight 2-bladed turbine with a 34 meter downwind rotor featuring active yaw and pitch. It also used a teetering hub and glass composite blades. The W34 achieved the best aerodynamic efficiency ever recorded. It broke a shaft in 1957, and was dismantled in 1968.

Hütter and Juul helped establish the fundamental compromise for wind power, which boiled down to either designing for a high blade tip speed which is costlier, or a medium tip speed 3-bladed design proving to be ultimately more reliable while allowing for greater simplicity in other turbine components (Heymann, 1998). Hütter is also criticized for having conflated technical optimization with economic optimization, a problem that would be exported, perhaps, to the Department of Energy and National Renewable Energy Lab programs which Gipe (1995) criticized, with others, for showing signs of becoming the modus operandi of the government's approach to wind turbine development. Targeting Robert Thresher's defense of government R&D, Gipe stressed the importance of entrepreneurial activities driven primarily by incentives in promoting economic performance.

As we will discover later, neither technical nor economic focus resulted in perfect turbines or a perfect industry, as these machines and the applications for which they were used required fundamental research as well as practical engineering solutions. Development required advancements in the understanding of the wind resource and development of the tools used to evaluate and test it. This is without mentioning how business models formed in response to policy and financing choices.

Around the same time Juul and Hütter were developing their machines Palmer Putnam, then an MIT graduate engineer, was convincing the dean of engineering, Vannevar Bush, of the feasibility of wind technology. Dean Bush connected Putnam to Thomas Knight in 1937, then VP of General Electric of New England, who would help supply the parts necessary for turbine construction (Nielsen, 2010). In 1939 Putnam found financial backing for a large turbine in Beauchamp Smith of the S. Morgan Smith Company, which had intentions of manufacturing a successful wind turbine design.

By 1941, with the backing of MIT, the U.S. weather service, Harvard, General Electric, the California Institute of Technology, Wellman Engineering, and others, Putnam developed what was then world's largest wind turbine capable of generating up to 1.25 MW. Installed at Grandpa's Knob in Vermont, the outbreak of World War II sped up final design details and the blades had not been fully stress tested (Nielsen, 2010). The wind turbine subsequently lost a bearing in 1943, and wartime supply shortages kept it offline until 1945. Finally repaired, it threw an eight ton blade before its next month of operation was complete, and further development ended (Nielsen, 2010). It was notable for being large, but it was also the first wind turbine to produce AC power and feed it directly into the power grid.

What these early wind pioneers had in common aside from a major fuel-starved World War and government support for renewable sources of energy was a general conclusion by their respective utility companies that, despite live demonstrations and successful field testing, wind power was not wanted. Energy officials of utility companies would argue that the costs of wind energy were too great compared to available coal, petrol, or steam alternatives. Utilities were also unwilling to accept the risks and uncertainties of a young technology or spend to develop them. This is despite the irony that it was in part the volatility of price and scarcity of fossil fuels that had prompted research into wind power in the first place.

With utility companies positioned to choose the technologies they use for energy production on the basis of cost and the advent and promise of the nuclear age of the 1950s, any interest in wind power seems to have been pushed aside. Nuclear power would never to live up to Lewis Strauss's infamous promise of being “too cheap to meter” however, giving many in the energy industry reason to consider re-thinking how the costs of energy are determined in the first place.

Heymann argued also that Nuclear and other traditional energy sources were strongly favored for their more straightforward integration into the grid. Nuclear power promised emissions free power production, dispatchability, and of course the comfort and flexibility of an extractable, manageable, and transportable fuel source—albeit a radioactive or a polluting one. In short, utilities were not interested in agitating business as usual or being asked to invest in potentially disruptive technologies.

The United States attempted the widespread development and commercialization of wind turbine technologies in the late 1970s, building on the series of U.S., Danish, and German prototypes described above. Long before the U.S. experience of a general failure to create and commercialize huge turbines in 1970s, therefore, many of the issues related to modern wind technology had been laid out. The early pioneers understood that wind resources were diffuse and variable, but reliable. They understood the practical problem of optimizing blade tip speed and generator ratios to balance the trade-offs between energy efficiency and rotor loading.

The pioneers also experienced difficultly finding ideal blade materials, and recognized other trade-offs engendered by various design features. Wind, argued Heymann, failed to make much of an impact before the 1970s because of “its structural incompatibility with the emerging electric power system” (referenced in Nielsen, 1999, p.161). According to Heymann, “the nature of wind power essentially entailed deregulation efforts instead of monopolization, and decentralization of power production instead of centralization” (Nielsen, 1999, p.161). Johannes Juul's vision of a hybrid power system had to wait, as the rapid development and centralization of modern power systems had little use for renewable energy technologies.

## *Wind in the U.S. Power System*

The regulated power system of the United States was born in part by a generation of abuses which wounded the credibility of market organized power delivery. The regulated system was chipped into the stone of the Public Utility Holding Company Act (PUHCA) of 1935 which was passed in part to regulate utility holding companies which had proven too powerful and important to be trusted to the market and market alone. Energy and transmission prices were regulated by the Federal Power Act of 1936. The Rural Electrification Act of 1936 followed to promote expansion of the energy grid into underserved rural areas of the country. This act was also meant to stimulate employment in what was then a United States floundering in economic depression.

The North American Electric Reliability Council (NERC) was voluntarily created in 1965 after a major blackout demonstrated a need for greater reliability in the energy grid. Heiman and Solomon (2004) argue that the “watershed event in modern energy policy” was the creation of the Department of Energy (DOE) and Federal Energy Regulatory Commission (FERC) under President Carter in 1977 (p.95). Their creation followed the Oil Embargo of the 1970s which helped expose the vulnerability of the United States economy to fluctuations in fossil fuel prices. The policy changes also consolidated federal R&D work pertaining to energy technology under the DOE and granted the FERC authority to control energy and transmission prices.

The 1978 Public Utility Regulatory Policies Act (PURPA) then deregulated energy generation markets for the first time in decades. This opened the door for new developers and renewable technologies like wind turbines to compete in energy markets across the country.[26] As described elsewhere in the paper, utilities were forced to pay an "avoided cost" for energy that new Independent Power Producers sold them, taking away some of their ability to pick and choose energy technologies. Around 1996 however, in California, the FERC reinterpreted the meaning of the avoided cost to reduce the rates that utilities had to pay Independent Power Producers, which hamstrung wind energy developers who had previously won contracts lasting a decade and paying a higher price for energy.[27]

This is a brief and incomplete summary of key policies defining the U.S. energy system. Price support, regulation, R&D, security, and grid reliability are all part of the policy structure preceding the wind industry. So are the beginnings of a deregulated system wherein new energy generators are allowed to supply the grid and compete for customers. Heiman and Solomon (2004) claim that "support for renewable energy, when mentioned in the political struggle over restructuring, came largely as an afterthought designed principally to build political support for market reform and to entice residential customers to switch power suppliers and participate in the restructured market" (p.98). We see some examples of this with Enron's promotion of Green Power Pricing, described elsewhere, which encouraged consumers to pay more for energy that included renewable energy. Of course, it also put "choice" into energy purchase decisions, differentiating power sources in the consumer's mind.

Renewables like wind widen the geographic dispersion of power generation, which also widens the potential for diffuse ownership schemes. It is clear that renewables will not live up to this possibility anytime in the near future, as investor-owned utilities increasingly become wind project owners and ownership over major wind projects concentrates into fewer hands. In the United States, as more projects are completed they are rapidly integrated into an increasingly difficult to grasp separation of generators from generator owners. Gipe (1995) expressed the irony that incentivized electric cooperatives in Denmark created a more stable wind industry than did the United State's early marriage of Aerospace R&D to massive capital subsidies.[28]

Johannes Juul understood that the social value of wind technology was up against a grid system that had developed, for the most part, to support utilitarian applications of steam and fossil fuel technologies. These technologies embedded themselves in the earliest years of the rapid economic transformation and electrification of developing countries. The decentralized nature of renewable power collection, the intermittancy of its energy sources, and its lack of dispatchability ran counter to the expectations of centralized, large-scale utilities. Utilities expected reliability, low cost, and the ability to plan and forecast energy supply and demand. Any social value of wind power was discounted

26 Energy transmission is still considered a natural monopoly, and remains regulated.

27 U.S. Windpower/Kenetech, for example, had negotiated some of its first power contracts during a time when energy prices were high (around 10 cents/kWh). This was about three times the price that could be fetched later as energy prices relaxed and Natural Gas began producing power at low rates – helping to keep the "avoided cost" of energy low.

28 Vestas had a background in producing farm machinery. Gipe also argues that aerospace companies were used to building machines that would be completely rebuilt after short operating periods. In contrast, farm equipment needed to be rugged and long lasting. Thus farm machinery businesses brought the appropriate engineering approach to wind turbines initially. Also, greater local ownership and control over community wind development promoted widespread public acceptance of the technology, as both the costs and benefits of wind turbines could accrue to the communities which bought them.

because there was no threat of climate change understood at that time, nor obvious threats or limits to future energy supplies.

Acid rain and other major environmental disasters perpetuated by existing energy technologies were yet to be linked together in the collective conscious. Wind technology also resisted attempts to be scaled up rapidly, as the technology itself was not so simple as it might have seemed. It also sold at higher prices compared to incumbent technologies which had already sunk the benefits of decades of development, support, and subsidy. The fact that early machines were far from optimized or fully developed was beside the point at the time.

These issues were not always relevant. The national energy crises that prompted countries to explore the potential of wind energy was based on the vulnerability exposed by basing energy systems on a limited number of technologies that were completely useless without the unrestricted availability of, and access to, limited and unequally distributed stores of fossil fuels and uranium on the planet. Renewables like running water, sunlight and heat, geothermal, biomass, and of course wind could not be restricted in a time of war or subject to fuel scarcities. The sun is expected to radiate for billions of years and cannot be given to, nor taken from people because of geopolitical hostility or disagreements. Renewable energy sources are what and where they are and belong to the countries as a regional and local resource.

Energy, as one of the central pillars of modern society should inspire people to embrace a diversification of its sources and not abhor them. Cost would be of little concern the day that factories stopped running, refrigerators failed, and a scorching heat or freezing cold occured. Negro, Simona, and Hekkert (2010) pointed out that major infrastructure wide technological changes can require 30-65 years before one observes widespread diffusion of a new technology. Given that significant time horizon, what can we say about the first decades of U.S. wind energy development?

## *Market Development in the U.S.*

Birthe Soppe (2009) criticized the short term nature of early U.S. wind industry development incentives, arguing that they ultimately caused stagnation in the industry through the 1990s. Soppe also argued that U.S. incentive policies remain based primarily on tax credits rather than R&D, co-evolution of policy, and incentive or guaranteed pricing—features of Danish and German development strategies most clearly manifested by the feed-in-tariff.[29] Such policies are credited with producing more predictable development and also the formation of strong leading manufacturers.

Klaassen (2003), and Gipe (2004) also argue that the sustained development and diffusion of wind turbines were supported by policies like the feed-in tariff, and also that the United States has generally failed to uncork its full innovative potential in its wind markets by failing to provide higher prices for a higher quality source of energy. Instead, the United States has provided a flat rate

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29 Generally speaking, a “feed in tariff” or “advanced renewable tariff” as it is sometimes called means that wind energy producers or other renewable energy producers received a guaranteed and fixed (above market) price for energy over an extended time period. This provides many advantages to developing technologies. It stabilizes revenues which assure developers and investors that project costs will be paid. Germany paid different technologies different prices for their energy according to existing and expected performance. Over time, the value of the FIT declines to reflect cost reductions achieved through innovation.

production tax incentive of 1.5 cents/kWh to wind energy producers since 1992.[30]

Mattias Heymann (1998) described the U.S. approach to wind power development as a general failure, arguing that despite the superior financial commitment made in the 1970s, the U.S. failed to develop a utility-scale, commercially viable, and reliable turbine design. The top-down approach and roots of this strategy "[revealed] the limits of science-oriented technological development . . . and [hinted] at technological hubris" (Heymann, 1998, p.643). As we noted, the calling for the development of renewable technologies in general is closely associated with the energy crises of World War II and the the early 1970s, periods in which advanced economies became more acutely aware of the relationship between energy, economy, and social welfare.

Development is also closely associated, however, with the attempt to use the NASA as an energy innovator and the subsequent abandonment of this idea in the late 1970s after which an integrated and newly formed Department of Energy became both the steward of U.S. nuclear arms and her key agency for promoting energy innovation. Also, it doesn't seem as though "technological hubris" should have been such a surprise. Famous undertakings like the Manhattan and Apollo Projects did produce rapid results, and probably formed an expectation that big research could transcend existing social and commercial constraints. As we will discuss later, formation of the DOE and reliance on more inclusive and collaborative research has not meant that the United States proceeded with clear, coherent energy policies that take advantage of new technologies that respond to economic, environmental, and social issues.

## *The First Wind Rush*

A combination of factors ripened conditions for the first wind rush in the United States, which can be dated as occurring between 1981 and 1986. This was a five-year span in which the state of California would temporarily become the largest and arguably most important market for wind power in the world. About 66 percent of the total wind energy capacity installed in the state between 1981 and 1995 occurred in those short five years.

The state of California under Governor Jerry Brown (1979-1981) initiated a Wind Program in the late 1970s and expanded its scope in 1978 to help expedite the commercialization of utility-scale wind turbines. Brown was a known backer of alternative energy programs, and worked to develop policies that could support the burgeoning wind industry. Brown was a predecessor to Ronald Reagan (governor of California between 1967 and 1975), who would have a heavy hand in interrupting wind industry development when he assumed the presidency in 1988.

Dennis Hayes was a Stanford and Harvard Kennedy School Graduate and co-founder of the first Earth Day under Senator Gaylord Nelson.[31] Also a Director of the Solar Energy Research Institute (SERI) from 1979 to 1981, Hayes commented that the favorable funding activities which occurred under President Carter and Energy Secretary Schleiss were followed, under Reagan, by a layoff of half the staff and a "[reduction of] our $135 million budget by $100 million. [The Reagan Administration] terminated all our contracts with universities — including two Nobel Prize winners — in one

30 Because this incentive is indexed for inflation, its actual value today is 2.2 cents/kWh. Also, periods of lapse have occurred, that are discussed later in this paper.

31 The first Earth Day occurred on April 22, 1970.

afternoon" (quoted in Scanlon, 2010). The move was the start of a remarkable reversal of fortune for the young wind industry, which had been set in motion but was hardly ready to stand on its own.

Another key factor in the formation of the early wind industry was the evaluation of California's wind resources in 1977. The land where these resources were found was made cheap and available to developers. Favorable power purchase rates became possible after Pacific Gas and Electric (PG&E) and California Edison were fined $15 million and $8 million, respectively, for failing to quickly adopt renewable energy into their long term energy planning (Gipe, 1995). A genuine energy capacity shortage was also created by a rejection of nuclear power and hesitancy to adopt natural gas. As a consequence more coal power was selected for incorporation into the grid. Gipe (1995) and Asmus (2001) also include that California maintained a culture of acceptance for new technologies in general.[32]

By no means exclusive to wind power but applicable was the availability of a federal energy tax credit of 10 percent, and a business energy tax credit of 15 percent. Combined with a matching California state tax credit of 25 percent, federal and state incentives created a 50 percent tax credit for early wind power developers. Asmus (2001) states that the California tax credits generated $528 million in private investment for wind power whereas the federal program generated $880 million.[33] Bird, et al. (2003) claimed that from 1983 onward early wind companies could expect capacity payments for 20-30 years coupled to 10 year fixed rate contracts paying 5 to 12 cents/kWh, earning variable rates thereafter (p.7).[34] Wind Rush 1 was born.

At the federal level there was unprecedented R&D support from the United States government to support wind technology research. The PURPA made it possible for just about anyone to become an energy generator and attempt to earn revenues from the energy business.[35] This combination of factors drew about 50,000 investors, turbine manufacturers and developers from all over the U.S. and Europe along with about $2 billion dollars in financial capital (Gipe, 1995, p.31). It also created a somewhat confusing state of affairs.

On one hand, the prospect of receiving a 50 percent tax benefit just for locating turbines in California meant that some, like Windtricity president Dennis Scullion entered the business pitching his company's ability to “cut your taxes 100%” in 1984, returning your investment 20 times over in cash flow and enabling one to recover back taxes for up to 3 years with “the best non-abusive tax shelter” for the right six-figure investors. On the other hand, the rush to complete projects inside the incentive

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32 It should also be noted that California remains the largest market for energy in the United States. Subsequently, forcing the largest utilities to purchase more renewable energy likely set an important precedent.

33 Asmus (2001) reveals that Tyrone Cashman of the Brown administration was a key progenitor of the California tax credits. Believing that tax credits are what created superior English longbows in the medieval age, he hoped to use them as the spur incentive for wind turbines. He admitted in hindsight that the tax credits may have been too generous. Additionally, he was an early president of the AWEA, providing western U.S. leadership in what had been a typically east coast dominated group.

34 Variable rates or the “avoided cost of energy” typically related to the cost of fuel. This was significantly less than 10 cents/kWh (perhaps 3 or 4 cents/kWh). Combined then, early wind company contracts could last up to 30 years albeit becoming more risky after the 10 year period expired.

35 Formally, the PURPA created “Independent Power Producers” from which utilities were forced to allow interconnection into the main grid. This did not mean however, that IPPS did not have to compete with other energy sources. Additional policies developed later, such as the RPS described elsewhere in this paper helped to ensure that renewable energy generators would find markets for their energy in the U.S.

window sometimes meant that businesses would install turbines anywhere they could, without much of a care as the impact it would have on the reputation of the industry in the future.

This is because early incentives were not tied to the productivity of wind sites but rather to the size of the capital investment made. The Production Tax Credit (PTC) would later attempt to correct this, by lashing the value of the credit to the productivity of the wind turbines. In the early days, productivity was ensured only by the will of the developer and the need to maximize revenue with energy sales. Despite the millions being poured into the NASA MOD program, for example, it was not unheard of to see wind turbines using helicopter blades fixed to their rotors or to see fields populated by various two or three bladed models turning at different rates and cluttering the landscape.

By 1983 Representative Fortney Pete Stark, a Democrat, was blasting the great tax rip-off that the first wind rush was promoting in California, to the tune of $700 million dollars. As noted in Asmus (2001) however, the incentives attracted about $1.3 billion in investment to the state despite causing total annual losses of $200 million for the five years that the program ran. This indicates that the tax expenditure had successfully stimulated investments exceeding the program cost by a factor of about six. Additionally, renewable energy investments tended to be small relative to other energy forms such those based on fossil fuel or nuclear technology. Thomas Gray, Executive Director of the AWEA (from 1981-1989) would spend $250,000 dollars in 1983 lobbying for tax credit extensions, one of the first of many attempts to sustain or enhance policy support for the industry. No such stability was forthcoming however, and the consequences of these policy choices would follow the industry well into the 1990s.

Despite what Senator Stark claimed, not all the action in the early 1980s was about collecting on a sudden lucrative splash of tax credits. Some, like James Dehlsen, founder of Zond, were already calling for an industry that did not need subsidies to be competitive. Indeed, by 1985, some 50 manufacturers supplying the wind industry would watch industry revenues climb from $20 million in 1981 to $650 million in 1984, a 3,150 percent increase. Wind power capacity tripled between 1981and1984, and reached its first important milestone of reaching over 1,000 MWs installed by 1985.[36] Alongside instances of tax fraud, in other words, a real industry was budding.

As Gipe (1995) pointed out, “prior to the 1980s, wind energy development focused on the individual wind turbine,” while after this period the industry became aware that they were “in the business of building power plants and generating electricity with wind energy, not simply building wind turbines” (p.13). In other words, dense arrays of turbines were distributed across the land until they met a certain level of energy production and a desirable rate of return. In 1988 Southern California Edison and Pacific Gas & Electric were purchasing 95 percent of all the wind energy produced in California, and it would be some time before wind energy producers broke significantly into other state energy markets.

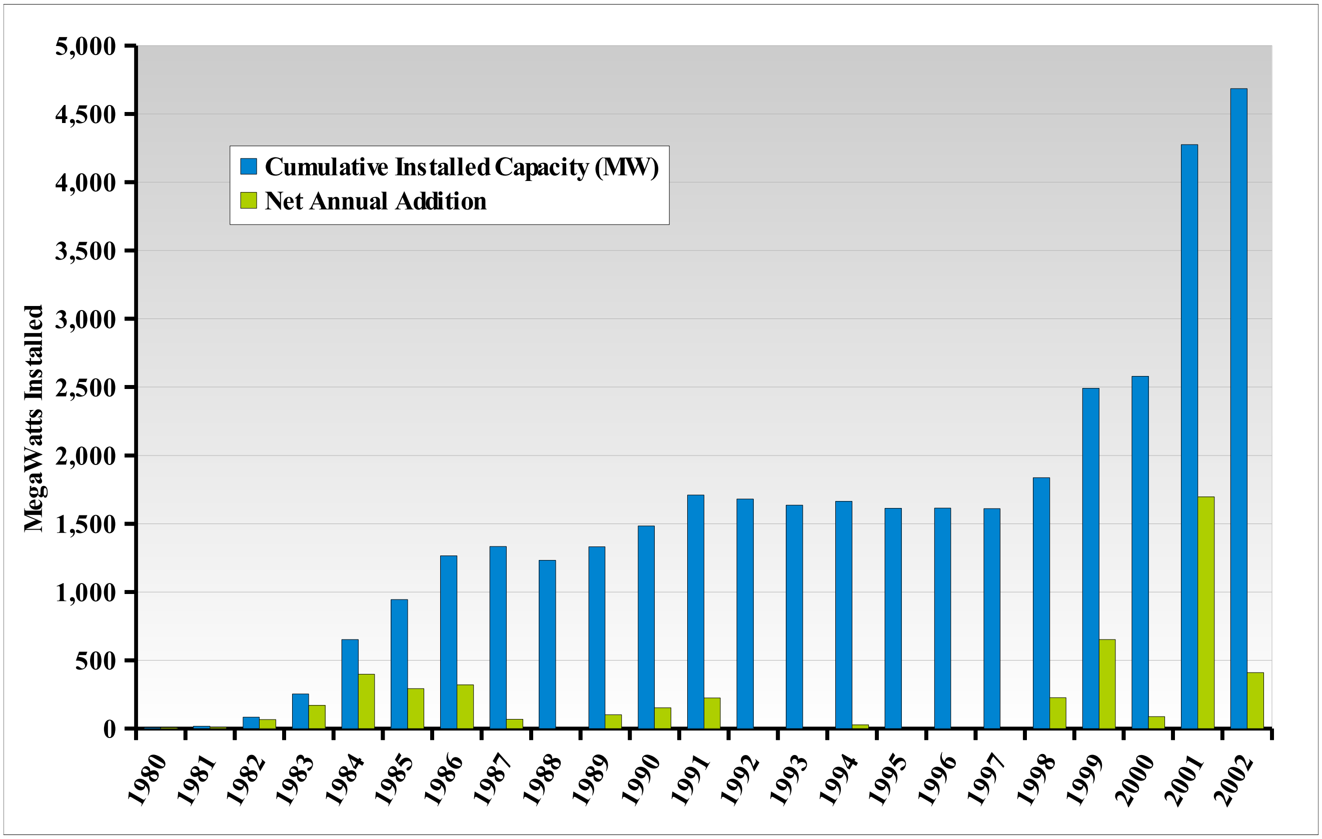
Highway 580, which in 1989 connected three of the major wind sites in California – found at the Altamont Pass, Tehachapi, and San Gorgonio – represented 44, 29, and 25 percent of all the turbines in the state, respectively. Thousands of the machines generated over 1,000 MW. Despite the chaos and the challenge of the early years, 1984 and 1986 were record years for wind capacity additions (at 399 and 320 MWs, respectively). These records were not broken until the turn of the 21st century. By then, it was too late for the small energy pioneers to claim responsibility for that

36 This is the approximate amount of capacity of a nuclear power plant, for example.

turnaround, even if their work had done so much to help make that turnaround possible.

Figure 2.3 below illustrates the failure of wind energy to find much investment following its first boom period in the 1980s. It would be much later, at the turn of the century, before the wind industry began its turnaround.

Fig. 2.3 Total installed Wind Capacity 1980-2002

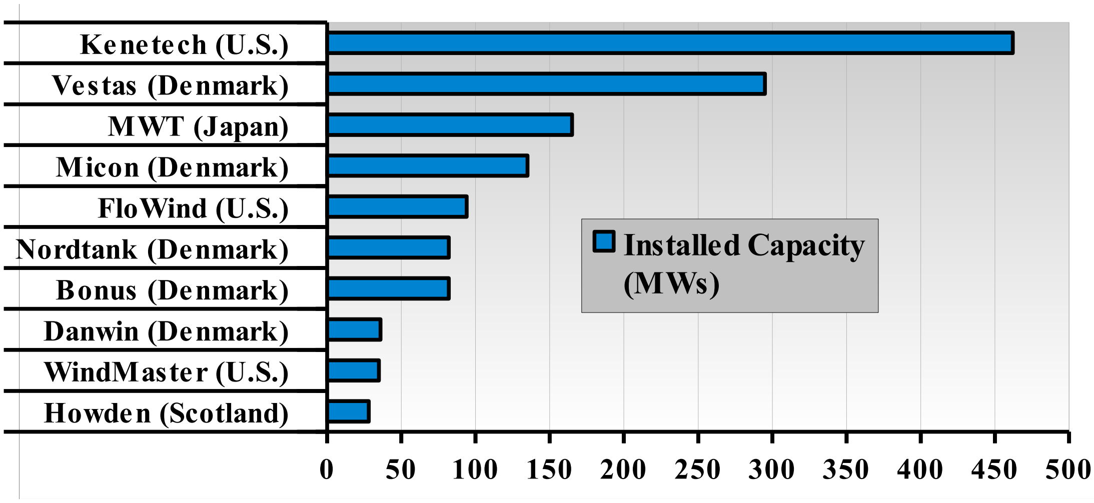



Source: Earth Policy Institute, Global Wind Energy Council. Various years.

A 1995 California Energy Commission (CEC) report showed that between 1985 and 1995 U.S. wind manufacturers were gradually losing, not gaining, market share in the United States overall. About 1,523 MW of wind (or about 50 percent more) capacity had been added in the 10 years following 1985. Shown in figure 2.4, below, Kenetech, Zond, and Seawest represented about 70 percent of this capacity in 1995. Kenetech was the largest manufacturer with 462 MWs installed. The next three major manufacturers were Vestas (295 MW) of Denmark, Mitsubishi (MWT, 165 MW) of Japan, and Micon (135 MW) of Denmark.

By the late 1990s, Kenetech and Zond had installed approximately 6,500 of the approximately 12,000 turbines in the state of California. As with GE today, this is a figure from which no other combination of foreign manufacturers could compare. This is even despite the fact that the data produced by the CEC suggested continued infiltration of foreign wind turbines into U.S markets. Even so, Zond's designs, benefiting from the defunct Kenetech company's variable-speed technology, were beginning to approach capacity values of close to 30 percent, which would be fairly competitive even by today's standards.[37]

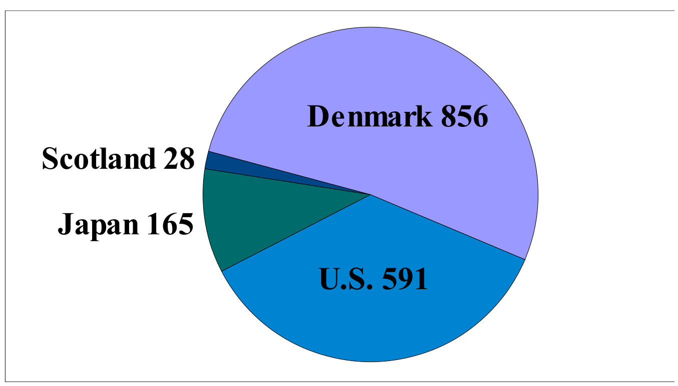
Fig. 2.4 Installed Wind Capacity by Manufacturer, 1995




Adapted From: "Wind Project Performance." *California Energy Commission*. Jun 1995. Web. 3 Jan 2011. http://www.energy.ca.gov/wind/documents/1995_wprs_report/95WINDREPORT.PDF

While Kenetech in particular manufactured most of the wind turbines in 1995, the Danish were suppliers most wind turbines in the aggregate (see figure 2.5). Additionally, the CEC (1995) report reveals that Danish wind turbines had higher average capacity factors and greater energy generation per square meter of rotor area (pp.27-28). As the report notes this may have been attributable to siting as opposed to technical superiority.

Fig. 2.5 Installed Capacity by Manufacturer Country of Origin, 1995




Source: "Wind Project Performance." *California Energy Commission*. Jun 1995. Web. 3 Jan 2011. http://www.energy.ca.gov/wind/documents/1995_wprs_report/95WINDREPORT.PDF

## *Kenetech - Bad Management, Bad Timing, or Bad Support?*

The company also known as U.S. Wind Power (USW) was founded in 1974 in Burlington, Massachusetts by engineers Stanley Charren and Russell Wolfe. Charren had previously founded

37 Zond was in fact a major importer of Vestas turbines prior to developing their own designs. See the section on Zond.

Compo Industries, Inc., and Wolfe had founded MKS instruments.[38] Both of these prior companies had also been based in Massachusetts. In 1987, U.S. Windpower merged with CNF, a power project general contractor.

In 1988 U.S. Windpower changed its name to Kenetech. The name change reflected an attempt to brand itself globally after the expiration of broad support for renewable energy soured markets in the United States and prompted a search for growing markets elsewhere. A Boston Route 128 company initially, the company shifted its major activities to California in the 1980s.[39] A manufacturing facility was set up near the Altamont Pass, in Tehachapi California, where the lion's share of their turbines would eventually be located. The stretch of I-580 connecting California's major wind sites is still populated with a large number of wind turbines.[40]

Peter Asmus (2001) claims that the decision for Russel Wolfe to enter the wind energy business occurred at the urging of his daughter, who had learned about the technology from the daughter of the late Professor William Heronemus (1920-2002). Each were attending Wheaton College in Illinois at the time. His interest stoked, Wolfe elected to meet with Professor Heronemus personally at the University of Massachusetts Amherst. He apparently became a quick convert after being filled in on the state of the technology and its potential.

Heronemus was conducting fundamental research about wind power and had founded the University of Massachusetts Renewable Energy program in the early 1970s, forming its Wind Power Group in 1972. A former Navy Captain, he had helped design the first nuclear submarine for the United States, and would later abandon interest in nuclear power for renewables. He is considered a father of modern wind power, the first to propose offshore wind projects and certainly was one of the technology's early champions in the United States.

Professor Heronemus's plans and testimony eventually caught the attention of President Carter, whose own support for renewables led to funding for the UMass efforts. A National Science Foundation (NSF) grant supported the creation of the original Wind Furnace 1 (WF-1) wind turbine in 1976.[41] This turbine was developed in part by an ex-Vietnam helicopter pilot named Woody Stoddard, one of Heronemus's graduate students who, along with Van Duzen (another graduate student) were recruited to USW in order to provide the company with its first functional wind turbines (Stoddard, 2011).[42]

Asmus (2001) points out that as a principal of a Small Business Incubation Corporation, Stanley "Charren helped Wolfe set up a company to market his [vacuum] pressure-measuring device, and it was a financial success" (p.58). Wolfe knew Charren "had the money to invest in new technologies" and

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38 Compo Industries produced specialty chemicals. MKS Instruments produces semiconductors, flat panel displays, magnetic and optical storage, solar panels, glass, cutting tools, and more.

39 "Route 128 Company" is meant to connote a connection to Massachusetts' high-tech company cluster.

40 See Paul Gipe's *Wind Works* website for interesting photos. http://www.wind-works.org/photos/index.html

41 A more detailed history comes from Stoddard at the UMass Amherst Website. See references at the end of this paper.

42 Stoddard and Duzen were also both fired shortly after developing the company's first working wind turbine models. Asmus (2001) relays that this is partly the result of Stoddard's frustration at not being given adequate time and resources to ensure the development of reliable turbines that performed. The intimation is that the rush to attract investors hurried the design process to the extent that Stoddard believed that the company would quickly lose any technological advantage it might have. In his mind the company was mostly focused on financial, not technological, performance.

Charren had a track record of launching successful businesses (Asmus, 2001, p.57).[43] He had also tried to recruit professor Heronemus, who turned down the offer.

USW then began assembling much of its top personnel from some of the best schools in the country. Charren was himself a Brown graduate with a Masters of Engineering from Harvard. Gerald Alderson served in different top positions such as president, CEO, and Director, beginning in 1981. He had a B.A. from Occidental College and a Harvard M.B.A. Table 2.6, below, documents the composition and background of many of the company's directors and executives, some of which served during the company's formative years.

Table 2.6 Background, Tenure, and Education of Kenetech Directors and Executives

**Kenetech Directors**

| Name | Age | Position(s) with the Company | Year Started | Education |
|---|---|---|---|---|
| Gerald R. Alderson | 49 | Director | 1981 | B.A. from Occidental College, M.B.A. From the Harvard University Graduate School of Business Administration |
| Charles Christenson | 65 | Director | 1980 | B.S. From Cornell University and M.B.A. and D.B.A. from Harvard University. Was also Royal Little Professor of Business Administration, Emeritus, at the Harvard University Graduate School of Business Administration |
| Angus M. Duthie | 56 | Chairman of the Board of Directors | 1980 | B.A. from Miami University (Ohio). General partner of Prince Ventures – Associated with F.H. Prince & Co. |
| Mark D. Lerdal | 37 | President, Chief Executive Officer | 1990 | A.B. Stanford University and his J.D. from Northwestern University School of Law |
| Howard W. Pifer III | 54 | Director | 1986 | B.S. in chemical engineering, M.S. in industrial administration and Ph.D., economics, from Carnegie Mellon University |

**Kenetech Executives**

| Name | Age | Position(s) with the Company | Year Started | Education |
|---|---|---|---|---|
| Michael U. Alvarez | 40 | Vice President | 1991 | B.A. And J.D. from the University of Virginia |
| Joel M. Canino | 56 | Chief Executive Officer of CNF Industries | 1989-1995 | Also a President and CEO of CNF Industries from 1984 |
| James J. Eisen | 40 | Vice President and General Counsel | 1986 | two Bachelor of Science degrees from MIT and his J.D. Degree from New York University School of Law |
| Michael A. Haas | 32 | Vice President | 1993 | A former manager of engineering on 56-100 turbine, became an executive in 1993. |
| Steven A. Kern | 46 | President of Kenetech Windpower | 1993 | B.S. From Alfred University College of Ceramics |
| Mark D. Lerdal | 37 | President, Chief Executive Officer and | 1990 | A.B. Stanford University, J.D. from Northwestern University School of Law |
| Nicholas H. Politan | 34 | Vice President and Chief Financial Off | 1992 | B.A. from Duke University and his J.D. from Stanford Law School |

Source: 14A Proxy Statement. *SEC.gov.* 2 Jul 1996. Web. Accessed 10/10/2011. http://www.sec.gov/Archives/edgar/data/807708/0000807708-96-000007.txt

The FY1996 proxy statement[44] shows that in FY1995, one of the last years of Kenetech, Ralph Muse was the highest paid executive, at $945 thousand. Muse had been paid severance, resigning in

43 Charren's previous ventures included simulated leather, and a recyclable floor tile company known as Interface. Charren had some graduate level training in aerodynamics (Asmus, 2001, 58).

44 At the time of this writing, also the only proxy statement available prior to the company's bankruptcy and subsequent reorganization and new ownership.

November of 1995. Alderson had seen his total compensation drop from $617 thousand in 1993 to $592 thousand in 1995, a 4 percent decrease, while he possessed about $10.4 million in stock.[45] Joel Canino earned $526 thousand (down 25% from $658 thousand in 1993) in 1995 and held about $12.1 million in stock. William Griffin was paid $237 thousand (down 35% from $367 thousand) and held $5 million in stock. Alvarez was compensated $391 thousand (approximately the same as years prior) and held approximately $2.7 million in stock. Together, this group of four (not counting Muse) commanded 76 percent of all stock held by executive officers. While bonuses and stock options suffered in the latter years of the company, all of the top executives of Kenetech continued to enjoy salary raises from 1993 onward and, I assume, had received them in earlier years as well.

Initial funding for USW/Kenetech was raised from friends and family, as venture capitalists declined to back the company in its formative years. In its latter years, however, the Hillman Company held 35 percent of Kenetech Shares. Added to holdings of the State of Wisconsin Investment board and F.H. Prince & Co. Kenetech was roughly 52 percent venture and public interest. USW/Kenetech also attempted to diversify into biomass and natural gas alongside their wind projects, however these activities do not seem to have ever been a key source of revenue.[46]

Kenetech was the first wind company in the United States to complete an Initial Public Offer (IPO). In September of 1993 six million shares sold for approximately $16.50/share, raising $99 million. At the time, Kenetech would have had a market capitalization of approximately $565 million. At its peak share price of approximately $29.50, the company's market capitalization likely reached $1.1 billion or more.[47] Between FY1993 and FY1996 the company would post $335 million in losses.

The early work of USW reflected the vision and the product developed by Professor Heronemus, whose Wind Furnace (or WF-1) project developed a 25 kW turbine with pitch control. It also had other advanced features like a computer control system and variable speed operation. At the time it was the largest turbine in the world (with a 32 ft rotor), and at night when it could not interconnect with the grid, it was used to heat a nearby building (See Stoddard, and Manwell, also McGowan, and Stoddard). It is referred to as one of the first modern turbines in the world and a forerunner of the turbines later built by USW. Charren and Wolfe each "credit [William Heronemus] with the vision and plan which created the entire wind power community" (Stoddard). The UMass link is important to the wind power industry since:

> *"Many of the students who worked on WF-1 went on to work for major wind turbine manufacturers in the US when the industry was just beginning. At least 3 students who worked on the WF-1 worked for US Wind power very early on: Louis Manfredi, Forrest (Woody) Stoddard, and Dan Handman. Others joined Kenetech wind power, Zond, Fayette, Enron Wind, and Second Wind. Two of the original students (Sandy Butterfield and Jim Sexton) were principals of ESI, a one time major manufacturer of wind turbines. Many*

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45 In calculating the value of stock, I am relying on a known peak value of Kenetech stock assessed at about $29.50 in March 1994 (Salpukas, 1995). By the end of FY 2005 share value had dropped to about $2. Obviously, the value of options are subject to market forces and company performance. Lacking better information it is clear that many of the executives were positioned to be multi-millionaires if the company ever managed a successful IPO. Even if the average value of a share of stock were $20, or less than half of the estimate, all of the holdings, not adjusted for inflation, would still be worth millions.

46 See March 1996 10-Q. In the first three quarters of 1996 (the year for which data was available), Kenetech reported to the SEC that $36 million (49%) of its $73.7 million in revenue derived from construction activities. Maintenance fees amounted to $16 million (22%), energy sales were $12.1 million (16%), and windplant sales were $7.1 million (10%). Total revenue for the year was about $92 million.

47 As based on approximately 36 million shares outstanding between 1993 and 1996.

*veterans of the WF-1 project still work in the wind industry, such as at GE Wind, the DOE's National Renewable Energy Laboratory, Northern Power Systems (in VT) and at Second Wind (in Somerville, MA).”* (Manfield, McGowan, and Stoddard)

USW had 60 employees by 1981 which included about 30 technicians, 12 administrators, and about 18 engineers and draftsman. Included among them were Alvin Duskin, and Herbert Weiss of MIT's Lincoln Laboratories. Asmus (2001) claims that Alvin Duskin stole an early draft of a California wind resource report being developed by Bob Thomas of the California Energy Commission. He then used its findings to convince USW to go to California, which appeared to have abundant wind resources.

From its beginnings USW positioned itself as a vertically integrated company with aspirations of developing medium scale wind turbines which would fit somewhere between distributed wind products and the DOE MOD program's multi-megawatt giants.[48] This gave the company a key advantage in that it didn't need to pay the cost of profit to turbine suppliers. On the downside, a lack of interaction with other wind energy companies might have contributed to its reputation for arrogance and a perception that the company worked outside what was an interwoven group of major players.

USW's turbine systems brought together fiberglass blades, microprocessor controls, and Apple computers to battle design weaknesses caused primarily by a focus on light weight rather than robust designs. The integration of sophisticated power electronics is one of the strategies deployed early in USW’s history that became a hallmark of successful wind companies to come.

Table 2.7 below shows that USW was generating over $160 million in revenue by FY1989, and $338 million in FY1994 while commanding approximately a half a billion dollars in assets (SEC 10-K filing). The 60 employees in 1981 grew to approximately 480 in 1987 and 300 in 1988, and then to a peak of over 1,000 in 1994 before rapidly contracting to about 120 employees in 1996. A large proportion of its workforce were involved in manufacturing prior to its downturn (about 400 at the end of 1995), which had achieved ISO 9001 certification in the spring of 1994.

Table 2.7 Sketching the Growth and Decline of Kenetech 1981-1996

| ($Millions) | 1996 | 1995 | 1994 | 1993 | 1992 | 1989 | 1987 | 1986 | 1985 | 1984 | 1983 | 1982 | 1981 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Revenue | $91.9 | $327.6 | $338.2 | $236.4 | $209.0 | $160.0 | | | $70.0 | $46.0 | | | |
| Net Income | -$84.2 | -$250.1 | $4.3 | -$7.6 | $2.8 | | | | | | | | |
| Employment | 120 | 728 | 1,063 | 859 | 742 | | 480 | | | | 200 | | 60 |

USW was one of the most successful early wind power companies, developing and scaling up its own turbine designs, and was the first U.S. company to produce a variable speed wind turbine for the United States. The patent for this technology links to 73 different patent families that are “either directly or indirectly” drawn upon by modern wind companies (DOE, 2009, p.46). It remains one of only five companies that have generated more than five patent families (DOE, 2009). This bests the patent performance of Boeing, Westinghouse, Lockheed, and almost the Department of Energy itself. This is quite impressive performance for a company bankrupt in 1996 after an active industry span of a little over 15 years. All of the patents earned by the company have since transferred (e.g., to Zond and then General Electric) or expired.

48 Distributed wind typically refers to small turbines (rated at 100 kWs or less) used in home or small commercial applications.

USW's first wind project was in New England, and by 1981 they had built and placed 20 wind turbines on Crotched mountain in New Hampshire at a cost of $1.2 million, or about $150,000 per installed turbine. Each turbine had 30 ft diameter rotors, 60 foot towers, and generated up to 30 kWs. Objections to the project were handled with respect by the company, which would earn a reputation over time for operating with a consciousness which extended beyond the bottom line. Karl Bach, who made the initial investment for the project with his two sons gained $250,000 from it. After only one year, the project was destroyed with dynamite.

Presumably, the goal of the project was mainly to provide investors with a proof of concept: that the company's wind turbines arranged in arrays could produce power for the energy grid. Asmus (2001) claims that early termination of the project also masked problems with the early wind turbines they had developed, which in fact required more servicing than the company wanted investors to realize. Asmus (2001) points out that early models literally fell apart when turned on in front of an investors meeting in 1979, and despite struggling to solve numerous issues with the design after several weeks, the company used the model for the Crotched Mountain project anyway (pp.60-61).

Having proven their basic concepts, USW authored a red book based on their 'success' and used it to attract more investors to the company. The early effort brought $5 million to the company "primarily from wealthy New Englanders who were friends or acquaintances of Charren or Wolfe or [Norman] Moore" (Asmus, 2001, p.59).

In 1979 USW planned to build 20 second generation 50 kW turbines (tested in Burlington, Mass.) in the Altamont pass in California, an area now known for average wind speeds of 18 to 30 mph with gusts up to 60 mph. The company was planning to eventually install 200 of the turbines worth about $10 million across the United States. Aside from being larger, these turbines also used microprocessors to help control turbine behavior in different wind conditions which could boost their reliability and productivity. In the process of developing these models, the company lost Woody Stoddard, who felt that company management was rushing development of the turbines to the detriment of the technology.

Altamont was a prime site for maximum wind power production, though companies like USW were still years away from developing variable-speed wind turbines which could make power from a wider range of wind speeds. At $75 million, USW's Altamont project was the biggest project in the world at the time and was probably completed around 1981. The somewhat drastic decision to move operations across the country was partly based on a California Energy Commission report described earlier which described wind potential in key California areas in detail. As a result they built a 33,000 sq. foot manufacturing facility in Livermore, California which was located within approximately 10 miles from the Altamont pass and 40 miles from San Francisco.

In 1983 USW had about 200 employees and 407 wind turbines operating. By 1984 the company had several banks of Apple computers running 600 turbines (at 50 turbines to 1 computer, this is at least 12 Apple computers) worth about $64.5 million in Altamont Pass. The company planned to spend $72 million dollars for 550 more turbines by 1985, completed just in time for tax credits to expire. Having placed 30 MW of wind power in California in just a couple years, the addition of another 27.5 MW by the end of 1985 would almost double USW's installed capacity in the area.

USW was one of about 30 other manufacturers active during the first wind rush. Each hummed along on combined state and federal incentives and generally high contract prices for wind power worth between 5 cents and 12 cents/kWh – a high “avoided cost” of energy resulting from higher than normal fuel prices in the U.S. (Parsons, et al., 2003, p.7). As suggested by Asmus (2001), a sympathetic PG&E still stacked with many of Governor Brown's administration alumni may have aided in the technologies acceptance. As one of the first companies to establish a relationship with a major utility company, USW and PG&E developed the standard contracts which would become the industry norm, in this case taking on the SO1 to SO4 nomenclature.

What primarily distinguished the early contracts was the length of a fixed price for wind electricity over a time period giving way to a variable rate later which was pegged to utility fuel cost. These initial price levels were easily more than 2-3 times the price most utilities would pay by the time deregulation, falling fuel prices, and the rise of natural gas caught up to the industry in the 1990s. These prices, usually contracted for a period of at least 10 years under a standard SO1 agreement (after which 20 years of variable prices began) made it possible for USW to pay off installed machines in just five years, freeing capital for new expansion. Parsons, et al. (2003) claims that such agreements were common as early as 1983 (p.7).

Of the estimated $650 million dollar turbine manufacturing business in the United States in 1984, 7.1 percent went to USW which sold about $46 million dollars worth of turbines and expected to sell $70 million more in 1985, a 52 percent growth in sales. The 1984 sales had generated a $3 million dollar profit, the companies first ever. In 1985 USW had installed 1,300 wind turbines at Altamont pass, 15.3 percent of the 8,500 turbines installed in the state. USW had been fortunate to lock in a 30-year contract for 100 of its turbines in 1981, worth between $750 thousand and $1.5 million for 15 million kWhs produced annually (at price estimates of 5-10 cents kWh).

It was typical to site the turbines in large arrays, sometimes referred to as wind farms or wind plants, that could approach the power output of a modern power plant. Using another idea credited to Professor Heronemus, the large arrays also provided the advantage of aggregating the intermittent wind resource over a larger number of turbines, helping to minimize the effect of single turbines producing lower average energy output or breaking down.

Between 1981 and 1985 the company's own power output grew from about 10 MWhs to 750 MWhs, and at the turn of 1986 the company was operating 40 percent of the turbines found in the Altamont Pass. Nearly all of the power produced was being sold by contract to Southern California Edison or PG&E. Their second-generation turbine, called the 33-100 was a 100 kW design with 108 ft (33m) rotor that cost about $155,000 dollars installed, and was capable at the time of earning $20,000 dollars annually at a utility payment rate of 9 cents/kWh (while assuming 220,000 kWhs of annual output). Even so, a big shake out of the industry was anticipated for 1986-87, as the expiration of federal tax credits meant a slowdown in investment in new wind capacity and industry wide layoffs, plant closings, and the fleeing of under-capitalized wind developers, who sometimes moved into other industries entirely.

Thirteen wind farm operators in the area in 1985 had dropped to just five by 1989. Perhaps a response to the downturn in support for wind energy, USW merged with Connecticut based CNF, a power projects general contractor and formed Kenetech, a more diversified energy company and global brand. This positioned them to hedge against shifts in the domestic wind power market with biomass plants in Stratton, Maine and other locations, and investments in natural gas. Despite their attempts to capitalize on their expertise as a manufacturer, developer, or even consultant, it would appear that wind energy continued to be the largest single source of revenue for the company.

Early in February 1987 the wind industry had reached an average cost of electricity that could rival or even perform more cheaply than nuclear power, important since the average cost of fuel had begun to drop thus eroding the attractiveness of wind power to utilities and probably halved the revenue potential of new turbines that entered the energy market. In effect, the cost of wind power generation, while declining to around 10 cents/kWh during this time period, was still too high to protect against plummeting fuel prices.[49]

Utilities were also working hard to escape the long term contracts they had accepted in the early 1980s in response to the shift in energy markets. In 1988 USW would agree to restructure 200 MWs of its projects, paying PG&E $15 million and deferring 60 MW of new capacity which had been planned in exchange for pricing changes and buy-back agreements on 80 MWs. Utilities were seeking to get out from under many of the contracts they had signed in the 1980s, which had locked them in to higher electric rates for wind energy producers over a long term, and which were appearing increasingly expensive compared to declining fuel rates. In short, the belief that fossil energy prices would continue a rapid climb did not materialize. Utilities also argued that new energy capacity was not needed in the state for ten years.

The relationship between utilities and wind companies was not necessarily sour. A study conducted by PG&E, USW, and Virginia Power for the Electric Power Research Institute (EPRI, founded 1973) showed that the third generation USW turbine, the 33-300 could capture 10 to 11 percent more wind power with its variable speed design. It was also expected to be a turbine that utilities might want to use, as its new power controls provided important power conditioning abilities. This suggests that USW worked with utilities to develop and adapt turbine technology to their needs.

By 1989, the experiences of USW and other wind companies had taught some of the early lessons of the wind industry. For one, the wind resources in California did not blow as hard and steadily as was first reported, and many sites within the state were benefiting from being more closely monitored. Gipe (1995) commented that in the 1980s developers were checking wind resources with "one anemometer per 150 to 350 proposed turbines of 50 kW each or 10 to 20 MW of proposed capacity . . . [and] by the late 1990s, California developers had seen the light and were monitoring the winds with one anemometer for every 0.5 MW of new capacity" or one for every two or three average sized turbines (p.151). In other words, wind resources could vary over short distances.

Many of the early turbines that hit the ground tended to lose their blades, as the steel spars which connected them to their rotors often failed. Despite problems with earlier designs, Kenetech was nevertheless arguing that the optimum size for wind turbines was around 200-500 kWs, far from the multi-MW designs being tested by NASA and far also from the 50-100 kW machines they utilized during Wind Rush 1. Kenetech also argued that all turbine manufacturers were seeking higher quality parts suppliers for turbines, which would boost reliability and performance. Kenetech was sourcing blades from Tillotson-Pearson Inc. which had proven itself capable of mass-producing quality balanced

49 Wind turbines first hitting the market for energy in the 1980s are known to have had costs of energy as high as 30 cents/kWh.

blades, a vital component.

With the rapid expansion of wind capacity fueled by the first wind rush over, companies like Kenetech had to become more focused on squeezing more revenue out of the capacity that they had, in part through the active replacement of older generation turbines with new generation technology.[50] These optimizations resulted in larger revenues for the companies, which at this point were beginning to weather years of minimal or zero wind capacity demand. Asmus (2001) argues in addition that Kenetech skirted past turbine failures resulting from lightweight and under-engineering many turbine components with their investment in aggressive computer controls which boosted performance in favorable wind regimes and shut the turbines down when conditions became too turbulent.

Kenetech also became a funder of independent power projects by sponsoring the Energy Investors Fund in Boston.[51] This fund created $160 million in total for 10 to 15 independent power generation projects. It was an important move for an industry not tapped in to significant venture capital and which was still recovering from its reputation for tax fraud. Gipe (1995) described Kenetech as one of the most well bankrolled companies that had started out in California, which Asmus (2001) clarified as including about $300 million from Merrill Lynch, coupled to a $60 million dollar revolving line of credit from the Bank of New England (p.94). Additionally "USW also raised nearly $20 million in equity capital to support its growth and its research and development . . . from eight venture capital companies" (Asmus, 2001, p.95). As mentioned earlier, the company's other equity sales and IPO would raise approximately $200 million in the early and mid 1990s.

At the turn of the 1990s Kenetech won an award to distinguish it among medium-sized wind manufacturers, having built more grid connected turbines than any other company in the world. They commissioned a 1,500 person survey with the Sierra Club, Luz International (which was responsible for 90% of the countries solar power at the time), and the California Energy Company (each member making up the Coalition for Energy Efficiency and Renewable Energy, or CEERE). The survey found that there was a demand for green energy and that ratepayers would accept up to $5 dollars more on their monthly electric bills for access to clean energy. New states were also starting to get involved with wind. Vermont's Mountain Energy Inc., a subsidiary of Green Mountain Power put in $2.5 million to test two Kenetech 100 kW turbines in the colder, harsher winds of Vermont.

The company was also was expanding into new markets, and along with Barakat & Chamerlin Kenetech received $37 thousand from the CEC Tech Export Program to conduct wind power assessments in Jordan, which were considered by the Solar Energy Research Institute (SERI) to be the country with the densest wind resources of all the developing countries. Knowledge of wind resources was developing over these years in general, with support from the government.

Dale Osborn was president of Kenetech from 1988 to late 1992, and also a president of the American Wind Energy Association (AWEA) in the early 1990s. He had worked for Texas Instruments for 13 years before joining the wind industry. Osborn argued that the problems being faced by the wind industry were not so much technical in nature as a matter of policy and the continued need to establish and protect market credibility. Gipe (1995) traces the formation of the AWEA to a "motley group of

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50 Upgrading or replacing wind turbines is sometimes referred to as "repowering".

51 This group included John Hancock Mutual Life Insurance Co., Energy National Inc., Salt Lake City, the independent power affiliate PacificCorp, CNF Industries, Hydra Co Enterprises, the independent power affiliate of Niagara Mohawk Power, and Kenetech. Each contributed $5 million to fund with the exception of John Hancock contributing $30 million.

hippies . . . in the basement of a Detroit church" who now "walk the tightrope between cajoling DOE into what AWEA wanted and responding to DOE's need for political support" (90).

Founded in 1974, the AWEA was the trade association and lobbying arm of the wind industry, typically staffed and led by industry insiders. The practical consequences of the relationship described by Gipe between the DOE and the AWEA was time spent working to justify increases in the DOE's operating budgets from which the AWEA would derive proportional funding in the form of contract work that it would complete for the DOE. Gipe (1995) claims in fact that 50 percent of the budget of the AWEA was based on such DOE contracts in 1993. Ken Karas of Zond, president of the AWEA in 1993, actually wanted to divorce the AWEA's funding as much as possible from the DOE for fear of too great a dependency.[52] Karas, like James Dehlsen, the founder of Zond, perhaps considered an industry mature when it could be profitable absent any sort of government support, though the realities of energy markets in the United States make it difficult to imagine such a scenario.

Indeed, the arrival of the first President George Bush, and energy secretary James Watkins re-focused federal energy plans on expanded nuclear power, increased oil production, speculative drilling in the Arctic Refuge, and expanded nuclear capacity with the help of Bechtel, the San Francisco company behind about 40 percent or 18 of the nation's nuclear power plants at the time. All the major oil companies were involved in such policy shifts, and Crowley Marine, for example, positioned itself to sell oil spill cleanup gear to the companies rushing into offshore drilling. As noted elsewhere in the paper, each new energy secretary and president to take the reigns of the DOE tended to reflect new energy priorities, and this meant that there was little stabilization or long-term support for renewable energy that could be counted on, even after wind companies began to make wind energy a substantial player in U.S. markets and abroad.

1991 was a big year for Kenetech as well, as it teamed up with Pacific Gas, Niagara Mohawk Power Corp, and EPRI (founded in 1972 Palo Alto, California) to embark on a five-year long $20 million dollar project to develop a new variable speed wind turbine. By 1996 the 33M-VS, as it was known, represented a cumulative investment of about $70 to $80 million dollars for Kenetech with possible funding from the DOE.[53] The lessons of the 1980s, according to then CEO Gerald Alderson, were chalked up to the series of broken rotor blades, efficiency lost due to blades caked with bug corpses, and installation sloppiness – turbines spaced too close together, or set at the wrong height.

Gipe (1995) quoted Woody Stoddard as claiming that Kenetech's turbines succeeded on the "volume of failure statistics," of early machines rather than as a result of government R&D (p.71). As Asmus (2001) adds that each major site in California presented different challenges. Insects were primarily a problem at the Altamont pass, while the other major wind sites in California, the Tehachapi and San Gorgonio pass battered turbines with freezing weather or sand storms.[54] It was to Kenetech's advantage that its manufacturing facility in Livermore was located very close to its actual wind turbine

52 Increasingly, the AWEA is now generating revenues through membership fees and the sale of its industry analysis and data. Conferences charge exorbitant amounts to participating companies and individuals. Many countries today have wind energy associations and to date, only the American one appears to charge for information.

53 To date, I have one reference claiming that "Kenetech . . . made variable speed drives work" with DOE funding, but I have not concluded that government support was an unacknowledged benefit to Kenetech's development of the 33M-VS (see Pelsoci, 2010, p.2-17).

54 Blades gummed up with dead insects could lose aero efficiency or perhaps even fall out of balance. Freezing weather could compromise the strength of metals not selected for cold weather performance, and sand could get inside machines and damage components.

arrays, providing for rapid response when repairs were needed, and a shorter feedback loop between technicians and designers.

There was a relatively short period between design and testing, with many turbine designs undergoing short testing periods before hitting the proving grounds. The government funding slump that had hit in the late 1980s and 1990s had shifted somewhat, and the SERI was actively researching new efficiencies for wind turbine designs. One output of the activities was a more efficient blade that was expected to be broadly available to manufacturers in 1993—just in time for Kenetech's new 33M-VS to hit the wind power market. The variable speed design of their new turbine widened the performance envelope of its turbines, granting the capability to make power between 8 and 60 mph, compared to its older fixed-speed turbines that produced power in 12 to 45 mph winds.

In September 1991 the SERI became the National Renewable Energy Laboratory (NREL), part of the restructured DOE's Office of Energy Efficiency and Renewable Energy. With the winding down of the cold war, the perceived need for increased nuclear weapon production eased, helping shift the focus of the DOE to its non-defense related programs. The CEC had reported that the 17,000 turbines in California were averaging 13 to 20 percent capacity figures, with U.S. designs generally inferior to leading Danish companies in this regard.

The newly formed NREL then launched a $40 million cost sharing program with eight wind power companies. It was a 50-50 arrangement, meaning in that NREL provided $20 million for technology development, and participating companies would provide a matching $20 million in total to develop their technologies and products. Bergy, Zond, SeaWest, and FloWind (which had entered Chapter 11 bankruptcy in September of 1990, restructured and was still determined to develop Darrieus turbines) were among the companies that seized on this opportunity.[55] While their competitors sought to develop their own technologies, Kenetech had managed 1,000 MW of wind energy development in the United States, Spain, Great Britain, and Japan.

In February 1992 Kenetech's turbines were competing with the Danish for Canada, which developed a 9.9 MW wind farm in order to evaluate the climate performance of different turbine designs. Though Kenetech, like other companies at the time, sought international markets for wind as a hedge against floundering support in the United States, the Danish industry in fact was the most successful exporter of turbines, producing 11,497 turbines between 1980 and 1991 and exporting 8,267 of them (72%). 7,447 (711 MW) of those turbines were in California, while other markets were India (286 turbines/40.7 MW) Germany (206 turbines/39 MW), Greece (69 turbines/11 MW), Sweden (59 turbines/105 MW), Spain (38 turbines/6 MW), UK (22 turbines/5.5 MW), Holland (24 turbines/4.6 MW), and China (28 turbines/3.2 MW). 732 turbines were shipped to other countries, about 10 percent of the U.S. total.

The 17,000 turbines in California were not as environmentally benign as first thought, and the CEC revealed a study in 1992 citing higher than expected avian kills as a result of the turbines spinning in the Altamont pass. The three-bladed, latticed, guy tower designs used by Kenetech were cited as having particular impact. Kenetech responded to the problem by allocating $1 million to a follow-up study of the bird deaths in partnership with the Idaho Peregrine Fund, Cornell University, and others in

55 Darrieus turbines were vertical-axis designs which had the advantage of being able to turn from wind entering from any direction. Unfortunately, this same feature tended to produce more stress on blades which lessened performance as compared to conventional horizontal-axis designs.

effort to identify problems and generate mitigation strategies. Endangered and protected species like the Golden Eagle were included in the kills, amplifying the importance of a response.

Paul Gipe (1995) would commend this response, adding that bird deaths are not simply caused by wind turbines, but are site specific. In contrast, Dale Osborn criticized the decision by Kenetech to explore its own environmental problems with government agencies while he was president: "At my naive direction, we sought help from federal and state agencies to help resolve the problem but were ultimately widely condemned as mass slaughterers of birds" (Windpoweringamerica.gov, 2003). At Altamont, it would later be discovered that a lot of favorite Eagle foods, like ground squirrels, were in the area, no doubt increasing the risk of death to birds attracted to the site as a hunting area. In addition, the pass was also an important migratory route.

While bird deaths often still receive press and generate policy conflicts, concerns about the aesthetic and noise impacts of the turbine arrays also tended to follow developers as they moved from site to site. These kinds of environmental impacts had consequences as they became better publicized, such as when Kenetech approached the Montana Power Co. for a 150 MW project spread over 40,000 acres of ranch land. Their plans were stalled by concerns over aesthetic impacts and now bird deaths. The controversies that built up also increased the perceived risk and costs of projects, which could deter investors and create delays on top of the already somewhat slow planning, permitting, and construction process (typically requiring a year or two). As turbines diffused through more states, so did their reputations. The irony was that the most active opposition typically seemed to come from national environmental groups like the Audubon Society or the Sierra Club.

Despite the technological and development challenges, the knowledge and market potential of wind power resources continued to expand and change. The first wind resource assessments occurring between 1979 and 1987 were based on weather station data combined with actual tower data. Between 1990 and 1993, Dennis Elliot (another UMass Amherst Alum) of the NREL led a team gathering wind resource data from across the nation, forming a detailed data set describing the total wind resource amount and its distribution across the country. These maps estimated wind resources at the 50 meter height which was fairly typical for wind turbines at the time.

This figure was later revised in 2001-2008 with higher resolution 50 meter maps. Between 2009 and 2010 80 and 100 meter high resolution maps appeared (Elliot, et al., 2010). As a consequence total wind resource potential, closely associated with actual turbine characteristics of the period reached 10.5 million MWs, dwarfing the estimated 3 million MWs described in the 1990s. The capabilities of the technology were expanding and the cost per kWh had dropped from a peak of 30-50 cents in 1981 to about 7 cents in 1991.

New turbine designs were being tested using sophisticated computer models that analyzed wind turbulence effects in 3D, and in greater detail than was typically used for airplanes and helicopters. The engineers had learned that "fatigue cycles [for wind turbines] are at least an order of magnitude higher than those of bridges or auto engines" (Glanz, 1992, p.36). Kenetech continued to champion the economic performance of wind turbines, arguing that basic economics was the real driver behind the business, not environmental or other social concerns.

Continual public and private collaboration over the development of the technology also became more commonplace, as manufacturers proved their designs with government tests and standards prior to introducing them into live sites. Robert Thresher of the NREL at this time described Kenetech, with their new variable speed turbine design as world leaders in turbine technology, and the company was planning to take the new technology to Iowa with a contract with the Iowa-Illinois Gas & Electric Co.

Though the first President Bush had described the NREL in Golden, Colorado as the official national laboratory for renewable energy technologies, research also took place at Sandia National Laboratory, Albuquerque, New Mexico, Pacific Northwest National Laboratory in Washington, and a number of Universities such as UMass Amherst. Business funded R&D occurred at Kenetech, Airfoils inc., Zond Systems, Phoenix Industries, and a dozen other companies.

James Tangler of the NREL and Dan Somers of Airfoils Inc. researched solutions for airfoils that included shaping the blades to give the inner and outer portions different tasks to perform: high torque at lower wind speeds, and lower torque at higher speeds. They created a turbulent boundary layer to prevent insects from hitting the blade, and used a non-laminar surface so that insects could not stick to the blade. The solutions were not intuitive according to the researchers, but when complete the blade designs were available to the industry. These activities help prove that the California experience was not being wasted. The research philosophy of the government had changed again, and the handful of key government labs supporting renewable energy based their research efforts on active collaboration with wind entrepreneurs on a cost shared basis.

In October 1992 Kenetech proposed a public offering of $100 million of senior secured notes (1st payback debt), underwritten by their preferred banker Merrill Lynch. The funds were meant to help fund marketing and development of the 33M-VS further – a significant amount of money as the company at this time had $69 million in outstanding notes. The company would ultimately earn more than 130 patents from the design however, which introduced many hardware developments and would feature a dedicated operating system. The company's IPO, in contrast, also raised about $100 million but authorized an immediate sale of about 3 million shares, worth about $49.5 million. No doubt this was meant to provide value to their investors (Reeves, 1993).

Kenetech also entered into negotiations with Ukraine, which, after the Chernobyl incident, was planning to replace nuclear capacity with wind capacity. The company signed a contract for 25 MW with the Dutch Groningen and Denthe Power Company. In addition, Kenetech licensed technology to allow for the manufacture of 500 MW of capacity in Ukraine, based on the discontinuing second-generation 56-100 turbine, which provided Kenetech with the benefit of having additional parts sourcing to go along with a new source of revenue.

In 1993 Kenetech was still being touted as the world's leading developer of turbines in the United States. They reported $209 million in revenue and about $2.8 million in profit over FY1992. With contracts worth $400 million in turbine sales over the next 4 yrs (420 MW), the outlook was good, even though revenues had last peaked in 1990 at $258 million and declined steadily thereafter for two years. While a somewhat diversified company, 40 percent of Kenetech's revenue was derived from its wind activities. In July 1993, however, wind power production was down 39 percent, and price reductions for the power being sold cut revenues by 12 percent. By July of 1993 the company was expecting a $7.1 million net loss on about $120.9 million in revenue (they in fact reported a $7.6 million loss on $236 million in revenue – see figure 2.7). Even so, the company remained worth about $487 million and would crest $500 million in two years.

Gerald Alderson had estimated that Kenetech would be a billion dollar company by 1998. In 1993 he discussed changes in the industry, describing the future of energy as mainly about the deregulation of generation but the continued natural monopoly of transmission facilities. He perceived that none of Kenetech's business activities really touched a retail customer. To Alderson, the wind power business engaged primarily in transactions between utilities and independent financial institutions.

Alderson also claimed that the 33M-VS had "[allowed Kenetech] to deliver energy at the cost of fossil fuels . . . [allowing the company] to enter into a series of development agreements . . . which are several times the size of the company" (WSJ, 1993). Such a statement indicated that the company had the capability or was willing to sell energy at 5 cents/kWh.[56] Alderson was describing the plan to complete $2.5 billion in projects, while the company had generated only $250 million in revenue annually during its best years. Their capital requirements, in other words, outstripped their financing abilities.

Kenetech was also spending on R&D. The total cost of developing the 33M-VS was between $70 and $80 million over a six year period. The wind turbine was first released in 3rd quarter 1993, selling 100 units, with 500 more planned. Expecting five times the production for 1993, and 10 times the production by 1995, their role as a final assembler of turbines was pushing production capacity of the new design to the limit. Kenetech's basic strategy was to build up a very large backlog of new projects, each delayed by 2-3 years of necessary site development, permit acquisition, and so on. With projects in queue, this backlog would convince investors that their rapid growth was assured. This was ultimately a gamble for Kenetech. Technological problems, competition, or public backlash always threatened to foil their plans.

Therefore it must have come as a huge disappointment when the largest wind power company in the United States began to unravel. As early as 1994 the 33M-VS, the product that Alderson thought would bring the company into the billion dollar club and prove wind energy could compete with cheap fossil fuels, began showing start-up problems. These problems were dismissed by the company and its underwriter Merrill Lynch as normal bugs in a new products final development phase. 206 of the turbines were already operating at three different sites in California however, and perhaps as many as a third were not operating at all. Components were breaking and blades were cracking. Still more turbines delivered to other countries ran into similar problems.

By the end of 1995, the company had lost no less than $250 million trying to keep up with the repairs. Legal problems began to stack up. Shareholders that had purchased preferred stock in the company revolted and filed a class action suit in September 1995, alleging that Kenetech executives had mislead them about their wind turbines and business prospects. In 1996, Enercon tried to reverse Kenetech's patent infringement charges, which Kenetech had successfully used to block Enercon and New World Order wind turbines from being imported into the United States. Kenetech had other ongoing legal troubles with Westinghouse and General Motors, for example (1 Apr 1996 10-K).

Perhaps smelling weakness in the company, Hank Hermann, a securities analyst for Lazard, Laidlaw & Mead downgraded Kenetech's stock to a "sell" on news of Kenetech's failing wind turbines.

56 Which, coupled to the PTC, would made the subsidized cost of wind energy about 3.5 cents/kWh. This was an utterly fantastic claim at the time, and likely would not stand the test of reality in many cases.

Hermann was also a consultant to Kenetech's competitor, the New World Power Corp (Salpukas, 1995). New World Power was one of the companies that had been prevented from competing in U.S. wind markets by Kenetech's patent disputes. Merrill Lynch jumped to the defense of Kenetech, arguing that problems with the turbines were not symptomatic of a long-term issue with the company.

Kenetech began a long process of removing turbine blades, which had shipped and been installed out of balance. They repaired cracks with epoxy and rebalanced the blades, and also replaced defective fuses and circuits and a shipment of bad yaw systems. Their blade supplier eventually corrected the process, but it did not ultimately matter. Warranty losses destroyed the company's bottom line and credit. With its IPO only recently on the books, investors were ready to flee the company, unwilling to wait for supply chain adjustments to reverse future revenue losses.

Salpukas (1995) wrote for the *New York Times* that Kenetech's slide came also after the FERC had in the spring of 1995 “scrapped a requirement for California utility companies to buy renewable energy sources, including wind power, at prices that had become uncompetitive to fossil fuels.” Making matters worse, wind turbines shipped abroad to boost sales for the company were also defective. In Spain blades were flying off their machines, prompting a cancellation of the wind project entirely.

Executives began leaving the company. Gerald Alderson had hired a new Chief Operating Officer in 1995 to handle Kenetech’s anticipated expansion, and founder Stanley Charren, now 70, retired. He was replaced by Lawrence Wagner, 55, the company’s majority shareholder from the Hillman Company. Charren was fortunate to retire just before watching the company he had overseen since the early 70s apply for bankruptcy in 1996. Too many of the turbines had hit the ground in what became a live test of the design, and many of the different parts suppliers were failing to get everything just right.[57] The costs of retrofitting the defective turbines were too great for the company, which was already long past the days of 10 cent/kWh for the energy that had kept it afloat in its early days.

The negative PR from technical troubles notwithstanding, the company was also unable to protect the wind rights that it had purchased as part of anticipated expansion occurring along with the new turbine model. The company failed to successfully challenge Zond's contract with the Minnesota Public Utilities Commission. Claiming that it wasn't possible for Zond to deliver on energy prices of 3 cents/kWh, Zond's cutthroat move nevertheless succeeded.[58] The United States Fish and Wildlife Service had also reviewed avian deaths from turbines and decided that in the future, deaths of protected species would be considered a criminal offense even if conducted by wind developers—adding to investor uncertainties about wind projects.

Late in 1995 Gerald Alderson stepped down from Kenetech, moving on to work for Wattage Monitor. He was replaced by a “turnaround” specialist named Richard Saunders. The stock price had plummeted from a high of $29.50 to about $2 dollars a share between November and December of 1995. Blades were falling off of turbines that had been delivered to Spain, and in the spring of 1996 they had lost $250 million in part from the significant warranty retrofit program launched as a result of the 33M-VS. They had also lost credit with the banks and their own champion Merrill Lynch.

57 It is unclear whether or not the company's design may have been fundamentally flawed.
58 Zond may have been willing to play hardball with Kenetech in part because of its reputation as an industry “outsider” or “bully” (as characterized in Asmus, 2001). I believe that they simply took Kenetech's 5 cent/kWh price point one step further, bidding for the project with the PTC “discount” included.

It is unclear which group of investors was most adversely affected by the horrible twist of fate unfolding in the mid-1990s, though it was known that of the 36.8 million shares outstanding in 1996, 58.8 percent of the shares belonged to just four groups – The Hillman Company of Wilmington, Delaware (34.9%), The State of Wisconsin Investment Board (9.7%), The Prudential Insurance Co of Newark, N.J. (6.5%), and the FH Prince & Co Family of Chicago (7.7%) (2 Jul 1996 Def 14A). Asmus (2001) summarizes the damage:

> "By March 1996 the value of Kenetech's stock had declined from a high of over $29 per share for common and $20 for preferred to just one dollar for both. All told, investors had purchased some 36 million shares of common stock and over 5 million preferred. The total drop in value was cataclysmic, amounting to more than $1.1 billion. Both the company and the underwriters were named as defendants, on grounds that they had artificially inflated the value of the Kenetech securities in a coordinated campaign of misinformation amounting to fraud." (p.177)

Taxpapers in Wisconsin (funded in part with retirement funds) lost approximately $105 million on their stock investment. Taxpayers of the nation also ultimately lost as well – having provided the knowledge base, production tax credit, and other public benefits (recall cheap California land and so on) which promoted the company's growth.

On the 30th of May 1996, the company filed for Chapter 11 bankruptcy. The official rationale included blaming deregulated markets and their associated short-term expectations, along with declines in the price of electricity that utilities paid as the "avoided cost" of electricity, and unexpected warranty repairs for their new turbine. Unable to restructure existing contract agreements they also defaulted on the $100 million in senior notes they had raised, and which were due in 2002. The bankruptcy sent a shock through the wind power industry, which denied that the loss of the U.S.'s (and indeed one of the world's) largest turbine manufacturer was a setback for the industry as a whole. When Kenetech went up for sale, they listed $150 million in assets and $300 million in liabilities.

The company's working KVS-45 (or 45M-VS) technology, including two prototypes, were sold for $1.25 million and the technology transfer and license for the 33M-VS turbine were sold for a paltry $500 thousand. This meant a savings of about $75 million to Zond Systems, who was in line for the sale and eager to take their own business to the next level through advanced turbine manufacture. Altogether about $5.05 million in projects and technology were sold, some of these assets as sold are listed below in table 2.8.

Many of the people who worked for Kenetech remained in the wind industry or active in other Clean Tech industries after the bankruptcy. Dale Osborn would spend some time working for the AWEA, and then become president of Distributed Generation Systems of Evergreen, Colorado, a wind power company. Thomas Kent left to work for the Zytec Corp, an OEM computer parts supplier, in 1996. Michael Alvarez is currently President & CFO of First Wind, a wind developer with projects all over the country. Louisville Gas & Electric (LG&E) took over three of Kenetech's wind power projects and retrained 21 workers to support the 120 MWs of installed wind capacity. Asmus (2001) adds that the manufacturing employees lost their jobs and much of their future incomes when the company folded, having all been investors in company stock.

There are many different perspectives on the demise of the company. Gipe (1995) claimed that the company was mismanaged. Indeed, it seems as though the aggressive rollout of their last turbine model was a bad choice. Additionally, their desire to attract investors and their willingness to play down or mask issues may have added hype to their strategic decisions. That they inflated company performance by basing projections on an unusually productive wind site seems stupid, greedy, and corrupt.

Table 2.8 Summary of Kenetech Sale

| **Projects** | **Detail** | **Price** |
|---|---|---|
| SMUD Phase II | 45 MW | $750,000.00 |
| U.K. NFFO round III Bid | | $600,000.00 |
| Arbutus, Mojave Desert, CA | 22 MW | $400,000.00 |
| Midlum, Wales, U.K. | 85 MW | $330,000.00 |
| Vansycle, Umatilla County, Ore | 25 MW | $250,000.00 |
| Gaspe Peninsula, Quebec | 105 MW | $200,000.00 |
| Galicia, Spain | | $150,000.00 |
| Foote Creek Rim, Carbon County, Wyoming | 68 MW | $100,000.00 |
| Columbia Hills, Goldendale, Wash | 31.2 MW | $100,000.00 |
| Boundary Mountains, Maine | 20 MW (requires $8 million transmission line) | $25,000.00 |
| Ireland | Unknown | $10,000.00 |
| | Total | **$2,765,000.00** |
| **Land Rights / Bids** | | |
| Texas | | $60,000.00 |
| Sidewinder | | $50,000.00 |
| U.K. NFFO/SRO winning bids | | $25,000.00 |
| | Total | **$135,000.00** |
| **Manufacturing / Technology** | | |
| Ukraine | Contract and agreement to train workers to produce the KCS 56-100 | $50,000.00 |
| KVS-45 Technology | | $1,250,000.00 |
| KVS-33 Technology | | $500,000.00 |
| | Total | **$1,800,000.00** |
| | **Grand Total** | **$5,005,000.00** |

Source: “Kenetech Releases 'Realistic' Sale Values for Projects, Technologies.” *Independent Power Report*. 23 Aug 1996. p.3.
*$200,000 dollars appears to be undisclosed or missing, therefore the table itself only shows $4.85 million of the total sale.

Their attempt to bid for contracts with a lower cost per kilowatt both frustrated competition and was ultimately unrealistic even for the company itself – energy sales alone would not provide sufficient revenue to cover costs and their balance sheet proved that. What is worse is that such behavior may have been required in order to attract the financial capital needed to launch such expensive projects.

Recall that Gerald Alderson, CEO, had said that the company's projects often required capital in amounts several times the value of the company itself. Dale Osborn has since claimed, in his interview found on the *Wind Powering America* website that:

> "Being a relatively large company with owners who were very sophisticated financially, the firm focused on maximizing the economic gain to shareholders. Being the industry leader, as usual, the company displayed a measure of arrogance in the marketplace that added to its difficulties in the mid-1990s.
>
> It is my view that investors were looking for an exit strategy, which required a market-leading technology and a sizable backlog of orders. We demonstrated the market-leading technology in the KVS 300-kW wind turbine in the early 1990s, but it was a complicated product deploying a state-of-the-art variable-speed drive, the grandfather of the product that GE Wind Energy offers today. It was also one of the largest and heaviest turbines at that time, though it resulted in the lowest cost of energy. The large backlog for the turbines was created by regulatory requirements in California.
>
> The company was taken public in the mid-1990s. The technology had a few correctable problems, speculative inventory was purchased, and a cash limitation emerged. The biggest issue, though, was that as regulatory requirements changed, a significant part of the backlog disappeared.
>
> I no longer served in the highest ranks at that time, but my conclusions are that (1) the owners never understood the complexity of the technology, (2) they made a fatal mistake in purchasing speculative inventory, (3) the board knew only what the CEO told them, and (4) their focus on economic gain versus quality engineering was the death knell. These conditions seem strangely similar to the horrendous failures of some major businesses in the last few years." (*WindpoweringAmerica*, 2003).

Osborn's comments describe $150 million in turbine inventory built up to serve project sites that were unpermitted and clearly at risk of going to competitors instead. The company's focus on maximizing shareholder value also took its attention away from its role as an innovator of wind turbines. As they would learn, the United States stock market is very much a fair weather friend. While their key investors had provided them with a basis to launch their company publicly, their rush to lock in capital gains was easily turned to fear of absorbing even heavier losses.

Osborn adds however, that the company was concerned very early on with minimizing and managing environmental impacts, broadly understood as aesthetics, noise, and bird fatalities. But when USW/Kenetech sought help from the government to resolve bird death issues, it had the unintended consequence of highlighting the company and young industry to be "mass slaughterers of birds" (WindpoweringAmerica, 2003).[59] Thus environmental issues also hampered the freedom of the company to develop prospective wind sites, and battles began to follow them wherever they went. The data generated in the Altamont pass demonstrated that siting choice and not turbines in particular are key contributors to environmental issues. Worse, the company was all too willing to overstate performance, understate costs, and bid for projects with "paper turbines", a reality which eventually caught up to them.

In any event, the demise of Kenetech is a swift horror, and a positive turn of events might have been possible. Bad management or arrogance certainly can be blamed, but so too could the unceasing policy environment which placed price competition well ahead of technological development. Certainly young wind companies worked hard to attract investors by advertising their long term contracts and revenue streams without necessarily fully understanding the state of their own technology or the quality of the wind resources they were assigning themselves to. It would appear also that their key investors failed to provide the patient capital necessary to ensure their long term success.

59 Again this was a $2 million dollar study which Kenetech committed $1 million. It concluded, among other things, that over half of bird deaths caused by Kenetech's turbines related to turbine placement and topography. See Asmus (2001).

With utilities serving as primary customers, wind companies like Kenetech were also bowing to the demands of centralized, large scale generation with little tolerance for the higher price or the technological realities of windpower. Finally, focusing on creating shareholder value not only distracted the company from its core activities, but teased management and investors with millions in the sudden wealth which they knew was possible from locking in capital gains. The company ultimately paid $35 million in dividends as it was dissolved ($5 million between FY1993 and FY1994) , and was prepared to let investors sell approximately $50 million in stock following its IPO by authorizing the sale of 3 million shares. Without the prospect of enormous gains to be made from their investments, key investors in the company and the public showed that their commitments to the company's success were severely limited.

The loss of a single company is not necessarily a thing to lament over. Key shareholders might have been a reason for many of the company's poor decisions, which hoped to use its status as innovator to find success in the stock market rather than to ensure its long term growth as an industry leader. This is what is meant when investors, having dedicated millions to the small company, find themselves in a hurry to exit a market and realize a capital gain. Kenetech's strong links back to the public University of Masschusetts system however, where a vision, and key personnel were be drawn, and the backing of other significant public resources reveal however that multiple stakeholders were ultimately let down by Kenetech's failure.

## *Zond Systems – Surprising Staying Power*

James Dehlsen founded Zond in 1980 as a developer of California's solar and wind resources, not as a manufacturer of wind turbines. Asmus (2001) stated that Mr. Dehlsen, the son of a Danish businessman, had grown up in a railroad car in Mexico and served in the United States Airforce before receiving an engineering degree from the University of San Diego. He also has six patents to his name (Clipperwind.com, 2011). Asmus (2001) described Zond as a new money company, contrasting this with USW/Kenetech old money funding. This is because Dehlsen started a successful $200 million stock investment corporation prior to founding Zond.

Dehlson had also founded the Triflon company in 1976 which sold Teflon-based lubricants, advised the congressional office on wind energy, and would much later serve as a director of the AWEA. The sale of Triflon helped to finance the start up of Zond. Dehlsen purchased 750 acres in California and partnered with his neighbor Daniel Reynolds and friend Robert Gates. The former had built racing boats, and the latter had experience in marine equipment sales. Dehlsen even built an eco-friendly house out of recycled materials to serve as a base for public PR and sales pitches. Kenneth Karas joined the company as president from 1986 to January of 1991, when he became CEO. In 1993, he served as a president of the AWEA and by 1997 he was a chairman on the board of Zond. He had been "a USC graduate with a theology degree from Ambassador College . . . [who eventually raised] $500 million in institutional project financing" for Zond (Asmus, 2001 pp.186-87).

With limited resources however, the company quickly abandoned solar technology for wind, experimenting with 10 turbines in 1981 as the first developer to break ground in California's Tehachapi pass. Dehlsen is quoted as saying that these early models "were so dismal we started designing a Zond machine" (Windpowering America, 2003). The first Zond turbine, the Z-40, would not arrive until the early 1990s however, and in the interim Dehlsen turned to Ed Carr of Stormaster for turbines. The 2-bladed models are storied by Asmus (2001) as tending to fall apart shortly after being put in service, and faulted for relying on leaky gearboxes from India.

Eventually Vestas was identified as a better option for wind turbines, but not before the patents for Ed Carr's Stormasters became the property of Zond.[60] As a result, Zond became a major importer of the Danish turbines, starting in 1981 with an order for 155 turbines. In 1982, the company ordered 550 more. According to Vestas' website, this had the effect of boosting employment from 200 to 870 employees, a sign that Vestas' growth was at that time closely intertwined with a key customer. In 1985 the company interconnected 200 Vestas 90 kW V-17s with PG&E. According to Vestas' own company history, Zond would order 1,200 more wind turbines in 1986, only taking delivery of a first shipment, and refuse to pay for a second when a delivery delay was imminent. In all likelihood, Zond didn't want the turbines because it knew the tax credits were soon expiring.

Despite the often better performance of the Danish technology, Zond's early projections for wind energy were off, meaning that they did not understand the true character of the wind resources they had purchased. As a result wind energy production was only a little over half what was expected after anemometer readings had measured the winds of the Tehachapi Pass. Luckily, California Union had insured the company against the revenue losses resultant from unexpected wind performance. In addition even the Vestas turbines were struggling with the turbulent California winds. Zond had to retrofit at least 143 of their mighty Vestas turbines with new blades after finding that many had formed stress cracks dealing with the prevailing winds.

The growth of Zond systems, like that of USW/Kenetech, was rapid in the early 1980s. 294 Danish turbines were spinning in Tehachapi Pass in 1984. In December of 1984 1,000 additional machines were ordered from Vestas, and by February of 1985, Zond was operating 1,900 wind turbines in California, 22 percent of the 8,500 turbines then existing in the state. Like USW/Kenetech, the early contracts procured by Zond helped to ensure a reasonable flow of revenue after tax incentives expired. Turbines, however, that were being added to the California grid had peaked at 5,000 a year during the early 1980s, and slowed to just 1,700 a year by 1988. Zond was relying on Vestas V-15 and V-17 models, 65 kW and 90 kW models at probably $88,300 dollars per V-15 (or approximately $140,000 dollars installed), suggesting a small possible cost advantage compared to the earlier described USW/Kenetech designs. A bigger advantage would perhaps have been their general reliability, and 90 percent availability.[61]

Dehlsen described this rapid expansion as “intended to show Wall Street that wind power was on a course of great progress and deserved attention from the capital markets” (Windpowering America, 2003). It was also the reflection of state and federal incentives assisting in the rapid capitalization of the company, which after losing favorable incentives in the 1980s would also stand to lose its favorable contract pricing just a few years later, in 1995. In similar fashion to Kenetech, Zond planned and attempted a successful IPO as a means of accumulating additional financial capital for continued project development and turbine development. Ultimately Zond would find growth through acquisition.

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60 Zond is reported to have contacted the company in 1980 to view their turbines, but found a supplier in the Netherlands instead. Vestas pursued Zond, and the company eventually agreed to purchase two turbines. See: http://www.vestas.com/en/about-vestas/history.aspx

61 “Availability” means, the proportion of time a generator standing by and ready to make power.

Like Kenetech, Zond sought to weather the lean years of the early wind industry by looking for productivity gains, whether through site optimizations or turbine performance improvements. Dehlsen claims that Zond increased their site electricity outputs by 22 percent between 1986 and 1989 in this way. The company also wanted to “remove the manufacturers profit margin” from the cost of the energy it generated, which meant that it was eager to produce its own turbine model. This strategy was not pursued right away because the company still had not found the backing of major institutional financiers.

Not all of the challenges faced by the company were related to driving down the cost of energy. An August 1989 attempt to place a wind project on 68 acres in Los Angeles County was met with resistance by landowners, the Audubon Society, and the Sierra Club. A “grassroots” environmental group calling themselves the Save the Mountain Committee also formed in resistance. Supported by the Tejon Ranch Group (a corporate sponsor) whose principal shareholders were the Chandler Family of the Los Angeles Times Publishing group, the Save the Mountain Committee protested the loss of property value should the turbines be allowed into the area and impact the vista.

Their backers, the Tejon Ranch Group developed real estate in the area, incinerated toxic waste, extracted oil, operated sand and gravel quarries, and in 1981 had a development plan that included the construction of thousands of homes near where the wind farm would have been located (Chase, 1989). Chase (1989) claims that they also had their own plans for a wind projects. Thus it was perhaps the competing interests manifest by the Tejon Ranch Group that promoted a notion that property values are negatively impacted by the presence of wind turbines. This mattered little to the environmental groups like the Audubon Society which championed the protection of birds and their habitats over all other considerations.

Delhsen countered objections to the wind farm by arguing that the project would kill fewer birds than buildings, cars, or radio towers do each year, and would also conserve as much oil as the Exxon Valdez spilled into Alaska. They lost the project to a town vote of 5-0, with the active commission citing environmental concerns. Zond appealed, and threatened a lawsuit if the project was blocked, as the company had spent $800,000 dollars in lease and other costs (Wolcott, 1989). It was a well publicized conflict that pitted the environmental impacts of wind power against its own environmental benefits.

In addition were complaints that the CEC had released a report in 1987 claiming that no new electric capacity would be needed in the state for 10 years, estimates which Dehlsen claimed did not take into account a projected increase in energy consumption, or the planned shutdown of a nuclear power plant in the state. Even so, the project was revised from 458 turbines down to 145 but it did not matter. The project was rejected.

Despite difficulties that Zond faced, Dehlsen would claim that their sky river project helped to solidify the company's financial footing:

> “The 77 MW, $157 million, Sky River facility in 1990 . . . was realized despite what "experts" indicated were insurmountable obstacles, including Southern California Edison's (SCE's) extraordinary requirement that we provide 75 miles of 220 KV transmission lines, adding $30 million to the project cost. This, however, was the largest project in the industry to date, and its accomplishment became widely recognized

> for its performance and as a new model for wind projects of substantial scale and remote from the existing grid. Completing Sky River meant Zond's survival was now assured and that we could finally make good to the banks and our other generously supportive creditors who had grown to share our vision." (*WindpoweringAmerica*, 2003)

By 1990 Zond was operating 2,400 turbines in California, through 17 contracts with California Edison. Despite their relative success in continuing to grow in absence of much policy support, they were sued by a group of 70 investors claiming that they were misled when they opted to invest in the company. They were expecting fabulous returns. These were investments made in 1984 and 1985, and SEC filings revealed in fact that some of these sites may have experienced problems. For one, the wind resource, while measured with anemometers was not perfectly understood, and wind turbines needed to be repositioned for better productivity. With project productivity lower than expected, investor returns would not materialize as expected.

Total energy output could vary by large amounts from year to year as well, in some cases as much as 25 percent, reducing energy revenues accordingly. In addition, many of the Vestas turbines were cracking or losing their blades, which became impossible to replace when the company declared bankruptcy shortly after the expiration of tax credits in 1985. California and Zond had been such important customers that the Danish company was not prepared for the sharp downturn brought on by the loss of an order of a major U.S. customer. This was far from the end of Vestas however, which recovered under Danish bankruptcy law and continues to do business today as an international leader.[62]

By 1992 the National Wind Technology Center under the NREL completed the first complete examination of wind resources in the continental United States. This was a key component of determining the market potential for wind energy in different regions of the country. It was also a general knowledge contribution. With the data out, the Midwest became the new region of the country most obviously endowed with a large amount of high average wind speeds, and thousands of potentially viable new wind project sites became possible.

In 1993 Zond was able to take advantage of collaboration with the DOE's NREL. Using the Vestas V39 turbine as a baseline, they set out to develop the 550 kW Z-40 which had a 40m (131 ft) rotor. A complete turbine would stand 130 ft high and weigh 55,000 pounds. It would cost about $500,000 installed, but Zond claimed that it could make power for about 5 to 6 cents/kWh at 15-16 mph average wind speeds (6-7m/s). This high performance in somewhat slow wind speeds would have represented a real threat to Kenetech.[63] The Z-46 was a future 750 kW design with a 46 meter rotor (150 ft) that was developed with at least one $8.3 million contract from the DOE to support value engineering (cost reductions of the design). The turbine would also spawn the basis for Z-48 and Z-50 models that were 3-bladed, upwind, variable speed designs (Migliore and Calvert, NREL, 1999).

The Z-40 would be the largest wind turbine in the United States when it was released in 1995, having benefited from a $2.8 million contract from the DOE to seek cost savings either by improved

62 Vestas company website claims that Zond stopped making payments on October 3rd 1986. Vestas had stockpiled turbine inventory in part from Zond's refusal to pay for the second half of a late shipment of turbines. Vestas also experienced a reduction in Danish tax rebates for turbines, and found itself in dire straights. Reduced to just 60 employees by the time it had reorganized solely as a wind turbine provider in 1987 (from a peak of close to 1,000) Vestas rapidly restructured and began to seek international markets, getting its first break in a deal with India.

63 Since much of the U.S. (and many other countries for that matter) have a much greater abundance of lower average wind regimes than high ones, it was obviously a great advantage to have turbines that performed well in low wind speed areas.

design or optimization of the manufacturing process (Inside Energy, 1994, p.11).[64] It was part of the Advanced Wind Turbine (AWT) Program launched by the DOE in 1990 as an effort to increase the competitiveness of U.S. wind turbines through cost-shared R&D. Carried out in multiple stages, the stated goals included reaching a cost of 5 cents/kWh in 13 mph winds and some years later reach 2.5 cents/kWh at 15 mph sites (Migliore and Calvert, 1999, p.4).

In 1993, the company imported Finn Hansen, "the former managing director of Vestas . . . Hansen took control of Zond's design program in 1993 to the chagrin of his Danish compatriots" (Gipe, 1995, p.82). Finn had been responsible for developing the aesthetic character of the highly successful Vestas V15 turbine, which Gipe (1995) argued became the standard for aesthetically pleasing wind turbine designs. Aesthetics were critical to the public acceptance of the technology. Reliability was aided by weight and tractor like toughness, which was part of the approach taken by Zond, no doubt having been influenced their use of Vestas technology. Indeed, Zond is notable for its understanding that the technological approach and talent that they might need to successfully compete would have to come from overseas.

In 1994, in anticipation of finance restrictions resulting from the maturation of wind contracts, the company proposed an IPO but failed to raise interest in the company as investors were aware that the company's wind power would earn only about 3.2 cents per kWh, – the avoided cost of energy for utilities purchasing their power at that time. This meant that the company had timed its IPO to coincide with a degradation of the balance sheet because of lower energy revenues. The company would receive lower and more uncertain variable rates. Despite the challenge, Zond was aggressively pursuing new wind power sites, and signing 30-year contracts for power delivered at 3 or 4 cents/kWh.

With the 1992 Energy Policy Act Production Tax Credit (PTC)[65] in effect, the implication is that Zond had technology that could produce electricity at between 4.5 and 5.5 cents/kWh, unheard of and objected to by Kenetech and other industry commentators. The pricing likely seemed cannibalistic. Kenetech's anger toward the company was based at least partially on the reality that Zond could successfully win bids for new wind sites on this low pricing that most other companies may have (rightfully) avoided, knowing they were too low to sustain a healthy business. As stated by Migliore and Calvert (1999) "Kenetech turbines were not developed in partnership with DOE, but negotiations were under way at the time of their bankruptcy to jointly develop a new turbine" (p.3). Surely Kenetech had found it frustrating that the government helped enable Zond to emerge as a stronger player with a steadily improving product.[66]

The governments role in wind energy promotion was not limited to R&D or financing support however. In 1995 Department of Energy Secretary Hazel O'Leary went abroad to help secure contracts for U.S. based wind energy companies. Zond was able to win a contract for a $110 million project in China from this effort, along with a $5 million interest free loan provided by the United States

64 Additionally the company was comparing performance differences between pitch-controlled or aileron controls for braking the turbine in high winds, and so developed 2 prototypes.

65 The value of the production tax credit when it was introduced was 1.5 cents/kWh, indexed for inflation. It will be described in detail later in the paper.

66 This is also possible exactly what Asmus (2001) was intimating when he recorded Kenetech's protests of U.S. government support for wind turbine manufacturers—even when it provided improvements that could be broadly shared. Its basic argument was that ample foreign competition existed, which I have considered to mean that America already had its wind turbine champion.

government, $15 million from China, and $90 million to be raised from regular bank loans.

In 1996 the FERC challenged the classic interpretation of the PURPA in California—claiming that it forced utilities to pay higher prices for renewable energy, and interestingly enough, Zond's 5 cent/kWh turbines began advertising project performance right at the FERC's new avoided cost of power, which was approximately 3 cents/kWh. Shortly after this ruling, in June of 1996, Kenetech filed for bankruptcy, and Zond was able to purchase the company's state of the art 33M-VS technology and licenses for approximately $500 thousand.

Kenetech's bankruptcy left the United States with about one major utility-scale wind turbine producer. Tom Gray of the AWEA was announcing an expected $330 million in U.S. wind turbine sales at the end of 1996, by companies which had been a part of the DOE's turbine development program. The forecast was dominated by Zond's Z-40 design which was expected to capture $182 million, or 55.2 percent of all sales. 12.7 percent or $42 million of the sales were expected to go to New World Grid Power Co., which left about $30 million in sales to accrue to four other companies that had been involved with the program. The development costs had used about $11.9 million in public funds and $8.7 million in business sector dollars (*Energy Conservation News*, 1996).

The Z-40 was field tested with an $11 million grant from the DOE and $7.9 million from Green Mountain Power in Vermont in 1996 (Norman Terreri of Green Mountain Power went on to became the first utility executive to serve as president of the AWEA in 1996). This marked a high-visibility return of wind power to the New England region and would be an important test of the performance of 11 of Zond's Z40 turbines in much colder and more turbulent mountain environments. The Z-40s were delivered with black blades coated with a Teflon-like substance meant to prevent ice build-up during the cold months.

Heaters were also installed, and Dehlsen drew on his days working with Triflon to utilize Teflon-based lubricants that could operate at temps as low as -40 Fahrenheit. It was not meant to be an easy environment for the turbines. The turbines endured 125 mph winds during a storm in July of 1995. By spring of 1997 the project ran into its first problems. When nine steel bolts holding blades to the rotors started to break, it took two months for the company to replace the bolts with a softer steel that was better suited to the colder weather. Anticipating possible problems to come, the company took the drastic step of replacing all 2,640 bolts associated with each turbine nacelle (*Associated Press*, April 1997). With the turbines motionless during the two month repair process, the gearboxes also rusted and then froze.

Shortly after, in 1997, the company was partially sold to Enron, whom Zond encouraged to also acquire the recently bankrupt Tacke Windtechnik GmbH from Germany. At the time, Tacke was the 5th largest manufacturer of turbines in the world, and had been the first to supply a 1 MW class turbine to the European market in 1995. Combined with Zond, the pair would represent just 4.2 percent of the international market share for wind turbines, far behind the dominance of Danish NEG Micon (19.7%) and Vestas (18.5%) (*Børsen*, 1998). Zond's acquisition represented a second means of survival following Kenetech's implosion. According to Ken Karas, Enron provided marketing muscle and cheaper capital for Zond.

The move also marked a return of Woody Stoddard to our story, who is noted in Asmus (2001) as recognizing Enron's willingness to give engineers the resources they needed.[67] With about 200 employees, Zond still operated 2,400 turbines, comparable to the number that they had owned in 1989, though they had managed to boost the output of their arrays from about 256 million kWhs to 600 million kWhs in the same time period – a 234% increase in electricity production and evidence in part of their improving mastery over the wind resources they owned. It was also proof of the value of continually upgrading turbines or using new models as they became available, an effective productivity booster when acquiring or developing new sites was not possible.

With Kenetech gone, however, the company was also picking up more contracts, such as a 30-year agreement from Portland General Electric which was previously promised to Kenetech. In addition, the company bought a 20 MW wind site in Maine for $150,000, and wind development rights for $825,000. Originally this was going to be a $200 million project along 26 miles of Maine's Boundary mountains. A sign of how rapidly the industry was changing in the 1990s, Zond planned to develop the site with about 200 turbines, versus the 639 originally planned by Kenetech.[68]

The bankruptcy of Kenetech and absorption of Zond into Enron were both critical moments for the wind industry, though Randall Swisher, then of the AWEA hailed the acquisition as a solution to one of the industries main problems—lack of capital (*Energy Conservation News*, 1997).[69] Zond had a quarter of the employees of Kenetech but did have their key technology going in.

Popular knowledge of Enron can perhaps be chalked up to its infamy as one of the world's true great corporate swindlers, and in fact it was. But in the late 1990s it was a rising star among energy companies, buying Portland General Electric Corp. for $3.2 billion in stock in 1997. Having formed in 1985, the company dominated the electronic trading of energy and was eager to enter the California market for power, which it knew was deregulating its energy markets and which represented a $20 billion market for energy.

Primarily a huge natural gas power “marketing” company, Enron was based in Houston Texas.[70] Paving the way for the company’s penetration into the California power trade was the acquisition of significant green power companies. Amoco (previously Solarex of Frederick, Maryland) was the largest solar power company in the United States and was acquired in 1994. Zond was acquired in 1997. Upon purchase of Zond the AWEA cheered the “foresight of Enron, the leading power marketer in the United States” (*Energy Conservation News*, 1997). In fact Enron was a $20 billion company at the time absorbing green “niche” company's like Zond (about $1 billion) with aspirations of charging a premium for green sources of energy while projecting a responsible and progressive corporate image.

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67 Additionally, Stoddard commented that while wind turbines attracted top engineering talent in Germany, in the United States, many of the best engineers tended to work for the NASA. While the USW 56-100 needed about 60 maintenance days a year, German designs were known to need maintenance only twice per year.

68 Meaning that, fewer turbines were needed to reach high levels of electricity production. This is mainly because the much larger rotors now in use had the same swept area of the hundreds of smaller models that otherwise would prevail.

69 For example, Enron is credited by former Enron employee Robert Bradley as having lobbied for Texas' RPS law, but also done a great deal to enhance visibility of the wind industry. See the *MasterResource Blog*: http://www.masterresource.org/2010/01/the-day-enron-saved-the-u-s-wind-industry-january-7-1997/)

70 Indeed, beginning by the end of the Clinton administration (25 GWs in 2000) but highlighted by the second Bush Administration (2001 to 2008), the U.S. was adding 220 GWs of Natural Gas Capacity at a peak rate of 54 GWs in 2002, utterly dwarfing the best efforts to build out wind capacity and exceeding any annual investment previously or later achieved by the Coal or Nuclear industries.

Accompanying the multi-billion dollar merger with PGE were promises to provide goods and services for 5,000 low income families, and financial and organizational support for river, fish, and other environmental groups along with a $50,000 grant for volunteer activities. They also agreed to distribute $2.75 million per year equitably to 13 different groups for 5 years ($13.75 million total) and spend $9 million for environmental restoration projects through 2006. Of course these numbers were little compared to the $1 billion that PGE was claiming as stranded costs, or the $700 million in shareholder value being engineered by the merger. Stranded costs refer typically to the plants, equipment, infrastructure, or other investments which, in a deregulated environment, become "redundant" and lose their value. Utility companies were typically able to pass these costs onto customers in the form of higher electric rate costs.

Overlapping the period of mega mergers taking place in the changing energy markets, was the emergence of Green Power Pricing. This was essentially Enron's decision that the environmental value of wind power was something for which consumers should pay a premium. Enron along with other utilities started programs to build product differentiation between power sources to end users. Such schemes supported the broad assumption that deregulation of energy markets was going to allow for energy-arbitrage. This gave an implicit advantage to generators and power distributors that had the lowest energy costs. The arrangement was also sure to fix attention on the short-term cost of energy irrespective of the social promise that technology like wind or solar energy provided.

Richard Rudden, President of R.J. Rudden Associates Inc., a New York company that consulted utility and natural gas companies asserted that power industry changes were guaranteed to place non-diversified energy companies not focused primarily on reducing costs at risk of acquisition. Companies like Enron sought economies of scale or access to the most innovative companies through merger and acquisition. Their efforts were meant to promote rapid growth and protect market position. Rudden described the PURPA as a "byzantine structure of regulated prices" and was relieved to see large power companies moving into unrelated industries, such as with Tyco's purchase of ADT (*Bank Loan Report*, 1997). The aggregate profits of wholesale and retail power markets were worth $23-$37 billion, and small firms seeking to "maximize shareholder value through being acquired" needed to become "strong niche [players]" (*Bank Loan Report*, 1997). Zond was perhaps such a lucky "niche" company when it became a subsidiary of Enron. The company was re-named Enron Wind in July 1997.

Iowa had attempted to create impetus for renewable energy investment in 1983 with a mandatory renewable energy power purchasing law, the first of its kind in the United States, but did not enforce the rule until 1996 when IES Utilities of Cedar Rapids planned to purchase 112.5 MW from Enron Wind, which was supplying 150 Z-46 (Also referred to as the Z-50, or Z-750) 2-bladed variable-speed turbines rated at 750 kWs. Along with a 100 MW project planned for Minnesota, Zond was building the largest wind power projects in the country.

In becoming Enron Wind, the company was consistently landing the largest wind deals in the nation, and its employment doubled to about 400 in the summer of 1997. Under Enron, revenues grew from about $50 million in 1997 to $300 million in 1998, while employment reached 600. Zond had produced about 100 turbines in 1997 and 500 in 1998, and was targeting $1 billion in revenue by 2001. The wind manufacturing industry had made its first $1 billion *worldwide* in 1994. In fact, about the time Enron filed for bankruptcy in December 2001, its wind division was making $750 million for the company. Acquisition, it turns out, was less a shield from failure than it first may have seemed.

Through the late 1990s things had changed so much that on April Fools Day of 1999, Paul Gipe was writing about the second great wind rush – the wind rush of 1999. The 480 MW being added that year bested 1985 for largest annual capacity addition ever. Increasingly, he observed, American wind production was being dominated by Enron and Florida Power and Light (also a Zond customer). Fewer suppliers were in the country, as Enercon, for one, was still prevented from competing in the United States because of patent enforcement by Kenetech and then Zond for variable speed technology.

Gipe seems to conclude that the low prices paid for wind energy prevented independent power producers from gaining a real foothold in the consolidating energy industry (Gipe, 1999). Independent power producers, struggling with the low price paid to energy producers, started carving out a smaller niche to compensate. Mostly they targeted farmers for localized installs of turbines. More often they sought financing outside of the United States through European banks which were more familiar and comfortable with the risks and rewards that wind energy projects entailed. In a 2001 *Los Angeles Daily* article, Gipe commented on the lack of transmission lines for all the power being developed in the United States, and the shifting of tax benefits toward investors with large tax liabilities which consumed tax credits attached to energy production (as noted in Bostwick, 2001).

By the end of 1999 the wind industry had grown into a $2.5-$3 billion industry globally, and the Wind Turbine Verification Program had been initiated by the EPRI and the DOE. 732 MW of new wind capacity was added to the grid and 173 MW was re-powered with new turbines. Zond and The Wind Company were moving forward with 1 MW turbine designs in partnership with the DOE. These were turbines that were finally approaching the power output envisioned and attempted by the NASA MOD program, with whom several aerospace companies had sought to develop the first commercial grade multi-MW wind turbines and failed.

In 2001 Enron Wind was generating $800 million in revenue and employing about 1,500 people. In November of that same year, the "Windpowering America" initiative began, the DOE's quite undisguised attempt to promote the energy source and provide information about it online. Capacity additions were beginning to break, over and over, the previous record of 1985's 400 MWs. Randall Swisher, of the AWEA, credited the momentum as a reflection of "progressive state policies and growing consumer demand for green power" (Giovando, 1999). Indeed, by the late 1990s, many states were already beginning to establish RPS policies meant to mandate, or otherwise encourage, the infusion of renewable energy into energy grids. Like California, they were also actively considering, or actually deregulating energy generation markets, setting up green power pricing schemes, and taxing ratepayers to build up funding for state renewable energy or energy efficiency programs.

Having managed to install about 2,500 MW of wind capacity, the United States of 1999 represented a quarter of all the wind capacity in the world, compared to Germany's 3,400 MW and Denmark's 1,500 MW. Zond had a relative lock on utility scale wind markets and supplied over 540 new Z-46 750 kW variable speed turbines to states like Iowa and Minnesota (which had 250 MW and 270 MW of wind capacity, installed at the time, respectively).

Yet all was not necessarily harmony in the new Zond. In 2000 Ken Karas, the longtime chairman and chief executive of Enron Wind resigned from the company, to be replaced by Dave Ramm. It could be that Enron stock had hit a 52 week high of about $73.01, and Karas had timed his exit accordingly. It was also possibly the height of his frustrations with the company. Robert Bradley, an Enron economist who wrote a book bashing renewable energy, also wrote at least one piece for the

Cato Institute that did damage to the image of wind power.

Excerpts of the CATO piece were later quoted in news articles mentioning bird deaths, high energy costs, subsidies from the government, and more, aggravating Karas. As another example, Bradley was invited to speak to the DOE about the cost of renewable energy. Enron CEO Kenneth Lay appears to have asked Bradley to recommend Ken Karas to do this on January 8, 1998. In a January 30 1998 memo, Karas claimed that they “violently [took] issue with some of what [Robert Bradley] wrote for the CATO institute” (1998 memo between Karas and Bradley) and requested that Zond/Enron Wind be treated as the experts and key contact on the cost of renewable energy and related questions. Bradley maintains this old correspondence at his “politicalcapitalism.org” website, where he defends his “principled” stance against climate alarmism and corporate welfare. He also expresses his views through his related nonprofit, the Institute for Energy Research, to promulgate his selective criticisms of renewable energy and energy markets.

This digression is important, if only to illustrate the manner in which one of the largest energy companies on the planet was at the time unwilling to control the mouthpiece of an energetic critic of wind power. Enron was at the same time involved directly in the development of the technology, its projects, and marketing of its energy. This is a speck of sand compared with the rest of the activities in which the company was engaged—which ultimately led Enron president Lay and Jeffrey Skilling, and several others to be convicted of, among other things, securities fraud. As the company started to sink, these executives dumped their Enron stock even as they told their own employees to roll their pensions into it, which guaranteed the complete loss of retirement savings for thousands of workers following the collapse. Then again, this occurred at Kenetech as well.

On December 2, 2001 Enron declared chapter 11 bankruptcy. By February 21, 2002, GE agreed to purchase Enron Wind's manufacturing assets for $325 million while also assuming $100 million in debt and obligations – a steal considering the cumulative investments that had been made by Kenetech and Zond since 1980, and the intellectual property that came with it. GE's purchase thwarted Caterpillar's bid for the company, but not its interest in diversifying into the industry. Perhaps because of Enron, wind power had finally caught the interest of the biggest companies in the United States.

Following their successful bid, GE acquired plants in the United States (specifically the Livermore, California plant built by Kenetech), Germany, and Spain. GE also acquired state-of-the-art U.S. and German turbine technology that had been developed up to 1.5 MW – an output value better fitting with the failed NASA program of which it had itself been involved. The technology was also a distant product from the 25 kW wind furnace 1 created at the University of Massachusetts and Kenetech 33M-VS which was described earlier as its great grandfather.

The founder of Zond, James Dehlsen, went on, with most of his employees, to found Clipper Windpower. Clipper is currently a small but major technological competitor to GE and others in the wind energy business. Robert Gates of Zond became the new VP of GE's Wind Division. Upon purchase GE’s Wind Division became in effect the 4$^{th}$ largest manufacturer of wind turbines in the world. Wind would now complement GE's $19.1 billion energy business in 2003, which included 20 active subsidiaries and locations around the world.[71] The sheer differences in scale between the size of

71 FY2004 GE Annual Report. In their 2003 annual report, GE stated that they had already begun adding GE technologies to wind turbine designs. Drive trains, power controls, and blade materials, for example.

GE Wind and the whole of the world that had been making and selling turbines is telling; recall again that wind power had not earned its first billion dollars of annual revenue worldwide until 1994. GE was expecting to fulfill $16 billion in energy orders for 2003, and $18.7 billion in 2004. For a time one might add that Enron was trying to sell off its wind assets for $600 million.

Kenetech and Zond are just two of the important companies that helped to shape the U.S. wind energy industry in its formative years. The assumption that capital limitations hampered the sustainability of many of the companies fighting for position in the early industry is perhaps proven by the success that GE has had following their purchase of the defunct Enron Wind. On the other hand, Kenetech provides some evidence that investor commitment, or patient capital, was also important.

The early days of the industry were partly about the formation of business strategies centered on vertical integration or on project development, but no companies were successful without reliable wind turbines that could tame the immense and turbulent California winds in which they operated. Kenetech and Zond were each instrumental in developing and promoting standard industry contracts which had to provide sustainable revenue streams to the companies. Some of the advantage of locking in favorable energy rates disappeared when federal laws revised the PURPA to the benefit of utilities. Kenetech had the foresight to locate manufacturing and development activities closely together, which enhanced the product feedback loop between wind technicians and engineers, and proved the value of marrying computer controls to wind turbines that, though under-designed, would last longer and produce more power than competing designs without such controls.

Each company had to learn about, and then defend against their own environmental impacts, a process which Kenetech helped finance. Zond's experiences trying to accommodate communities unfortunately taught it to avoid compromise and seek victory instead. Their negative experience also gives us a glimpse of how wind power developers discovered the many competing interests which are out there. Wind companies learned they could lose development opportunities if they did not focus on moving wind projects rapidly through to construction phases. Each company survived downturns in government support in part through their long-term contracts, but also through the optimization of existing wind sites and turbine technologies. “Repowering” projects allowed them to take immediate advantage of technology improvements prior to contract expiration.

The end of top-down government design and promotion of close government-industry partnerships produced real results for wind technology, and provided a source of coordination for the industry. It helped to set performance targets, create benchmarks, and clarify where best wind sites might be in the United States. The government had taken a clear interest in the success of the industry. The benefits of these practices spread to many of the best wind turbine manufacturers in the country. Partnership also ensured that future testing would occur in isolated testing environments, rather than as live tests in actual wind project sites which were much more visible and risked damaging the reputation of the technology. Such testing was a smarter way to prove designs before investors put millions on the line and companies like Kenetech risked massive warranty losses on new technology. Thus if the 1980s were about the speed of development, the decades that followed revealed a better appreciation for for prudence and more respect for co-evolution of technology and market organization.

# PART III GOVERNMENT SUPPORT

*Funding Energy Like it Mattered*

Making a solid estimate of government expenditures in support of energy technologies requires both the presence of data and careful assumptions. For example, it makes sense to count subsidies meant to promote a market for renewable energy as much as subsidies meant to promote technological innovations that will supply those markets with higher quality, lower cost goods. Many tax subsidies granted by the United States are not necessarily specific to an wind energy, however. The Production tax credit (PTC) for example, is extended to virtually all of the known renewable energy technologies, and so we cannot necessarily conclude favoritism of one technology over another. Historically, PTC expenditures so far appear to have favored wind energy, while the government has spent more on solar R&D. Which technology has been given the key advantage?

Should we count the entire annual budgets of the Department of Energy? Not if in doing so we are counting funds which are meant to supply or sustain the nuclear arsenal. Even assuming that an accurate picture of public support for all energy technologies could be easily derived, what of business sector investments? It is at least possible that business sector funding has supported changes in energy technologies, which we might only be able to grasp through examining cost sharing contracts and R&D expenditures of public companies. Perhaps these business sector investments would change our view of which technologies have received the most financial support for development and deployment. Then again, if the cost of financing and price subsidies are high enough, it would be reasonable to argue that companies would not necessarily have an incentive to seek innovations in their energy technologies if it weren't for clear signals provided by government policy as an alternative to the presence of market profits.

Molly Sherlock's 2010 Congressional Research Service report focused mainly on tax expenditures meant to “reduce oil independence and enhance national security”, the broad objectives of U.S. energy policy since 1970 (p.2). She provides us with numerous examples of the folly of assuming that having the tax dollar value in front of us communicates clearly the amount of support an industry did or did not get. Historically, she shows that the majority of government tax expenditures for energy promoted oil and gas from 1916 to 1970, and promoted a “Free-Market” approach to energy in the 1980s. The “interventionist” 1990s were next and a period more focused on renewables grew out of the 2000s. The “unconventional fuels credit” was “designed to induce the substitution of coal for oil” in the 1990s but also encouraged some qualifying “firms . . . [to] simply” start “spraying newly mined coal with diesel fuel, pine-tar resin, limestone, or some other substance to induce [a qualifying] chemical change” (Sherlock, 2010, p.17). Abuse of the credit was bad enough that it was revised in the 2000s.

By 2006, Sherlock adds, 23 percent of tax expenditures going to renewables was paying for the PTC. Outlays were even higher for renewable *fuels*, which she argues was “primarily attributable to 'black liquor'”, a fuel created as a byproduct of pulp mill processes (Sherlock, 2010, p.18). Originally this incentive was expected to “cost less than $100 million annually. In the first half of 2009, $2.5 billion in tax credits was claimed” (p.18). The cost of fossil fuel and oil tax credits drove expenditures in the 1970s, while alcohol fuels are driving expenditures in the 2000s.[72] $2 billion was spent on renewable electricity support in 2006, for example, while about $5 billion went to alcohol fuels that same year, growing to $18 billion in 2010 while renewable electricity expenditures fell to less than $2

72 A common example would be the 10-15% ethanol fuel blend now at many gasoline pumps around the country.

billion (Sherlock, 2010, p.31). Many of the policies that have been problematic in the past, or promoted unintended behaviors have changed. Oil and Gas tax breaks were not eliminated in the "free market" 1980s however, and low prices of fossil fuels in the 1990s stunted interest in comprehensive energy legislation.

Such are some examples of the challenges of understanding not just the amount of money spent on different kinds of energy, but also doing so without necessarily knowing what are the key drivers of those costs. Aggregate expenditures, in other words, cannot clearly predict the quality of outcomes. The following articles reviewed attempt to describe public outlays for energy technologies broadly, and should be taken with caution. Each make different assumptions, and each draw their conclusions based upon different time periods.

Pfuynd and Healey (2011) point out that "nature made coal abundant," and "public policy made it cheap," for it "did not arrive on the scene as a mature, low-cost and competitive fuel source. Rather, government support over many years helped to turn it from a local curiosity in Schuylkill County, Pennsylvania into the dominant fuel source of its time" (p.14-16). Attempting to account for all energy subsidies provided to the energy sector over 100 years is a daunting task, as it requires, as they point out, accounting for tax policy, regulation, research and development, market activity, government services, and disbursements. Accounting for all of it objectively is not simple.

As Pfund and Healey (2011) point out, for example, NASA is estimated to have spent $1 billion developing Solar technology between 1950 and 2006 – back when solar technology was mainly an aid to space exploration, not the energy grid (p.18). Those activities spilled over into emerging energy technology companies which have since adapted it and developed it in new directions. Likewise, the defense department built pipelines to transport oil during WWII which today are being used by the Natural Gas industry.

This does not mean that such expenditures made it into the calculus describing their expenditures (they didn't). All energy technologies that they describe had uses that are older than their data allows us to grasp. Coal and Hydro subsidies began in the 19th century for example. Ethanol, an increasingly important biofuel, tends to be produced from corn, but subsidies to farmers intended to promote the growth of corn were not counted because that is not the sole objective of the fund. For renewable energy, the authors ignore state subsidies, and focus on the PTC and ITC as key federal subsidies encouraging renewable development. Therefore the figures, summarized in table 3.1 below, while telling, are not ideally complete.

Table 3.1: Cumulative Subsidies for Energy

| **Technology** | **Period** | **Billions USD** | **Average Annual Energy Subsidy** |
|---|---|---|---|
| Oil and Gas | 1918-2009 | $446.96 | $4.86 billion |
| Nuclear | 1947-1999 | $185.38 | $3.50 billion |
| Biofuels | 1980-2009 | $32.34 | $1.08 billion |
| Renewables | 1994-2009 | $5.93 | $0.37 billion |

Source: Pfuynd and Healey. "What Would Jefferson Do?" *Dbl Investors*. Sept 2011. Web. Sept 30 2011.
http://www.dblinvestors.com/documents/DBL_energy_subsidies_paper.pdf

Projecting their figures into the future would show only that the lack of parity in funding efforts would continue, even as costs of the subsidies rose overall across technologies. This is because technologies other than renewables have continued to received proportionally more government support. As Sherlock revealed above, this can relate to the failure of government to end subsidies or change laws which served a good purpose in the past but remain on the books today, for whatever reason.

It would be a mistake to think that the goal of energy policy should be providing equal funding to all technologies since each technology presents is own unique costs and challenges. Even if the government no longer supported Fossil Fuel technologies, for example, people may have to pay a much higher cost of energy, or suffer from a loss of industry jobs as other technologies out-competed it. The savings created by ending subsidies could also be eroded by new efforts to repair damage done to the environment or the necessity of doing so.

In addition, as in the case of renewables, wind energy is the current 'real driver' behind the rising cost of the PTC. This is as much a reflection of the state of the technology as it is a reflection that wind developers have developed strong capabilities in the monetization of the credit for purposes of attracting investors (as we will read about below). It is conceivable that other energy technologies will one day draw more heavily on the credit, if it still exists, and by then, having simply seen the credit rise into the tens of billions will not be proof that subsidies must end, or that all renewable technologies are now fully developed and competitive.

The Environmental Law Institute (2008) examined federal subsidies to the fossil fuel sector and renewable energies over the 2002 to 2008 time period.[73] ELI estimated that fossil fuels received 71.5 percent of the $101 billion in subsidies they recorded. Direct subsidies to fossil fuels totaled $72 billion and renewables totaled $29 billion. Also notable were their findings that most of the subsidies available to fossil fuels are permanent features of the tax code while support to renewables is subject to expiration if not renewed.

As shown in table 3.2 below, About 40 percent of fossil fuel subsidies they derive come either from what is essentially an income tax credit and also a support for coal based fuels. More telling is the approximately 57 percent of renewable subsidies that are spent in the support of corn ethanol fuel, “a fuel whose production and use raises serious questions about effects on climate” (pp.27-28). Not typically mentioned is that the Energy Policy Act of 2005 created a renewable fuels mandate, which declares that 36 billion gallons of renewable fuels must be included in the transportation sector by 2022.[74]

Molly Sherlock (2010) estimates that cumulative losses from tax incentives provided to the Oil and Gas industry were approximately $193.4 billion between 1968 and 2009 (appendix B). The losses are primarily created by just two policies, the expensing of intangible drilling costs, and percentage depletion allowances. Renewable subsidies are less expensive in the aggregate, but driven proportionally by incentives for renewable fuels, the production tax credit, and investment tax credit (which together are 77.3 percent of the total cost). In total, Sherlock finds $19.4 billion in subsidies for

73 The Authors included petroleum, coal, and natural gas. Renewables included wind, solar, biofuels and biomass, hydropower, and geothermal energy production. The study ignores nuclear energy.

74 No such requirement has yet been outlined, at the federal level, for a renewable electricity requirement. Instead, states have taken the lead in this area, as discussed below.

the various renewable and energy efficiency incentives between 1977 and 2010 and $36.8 billion for renewable fuels between 1980 and 2010.[75]

Table 3.2 Summary of Fossil and Renewable Energy Subsidies 2002-2008 (Millions of Dollars)

| | | | |
|---|---|---|---|
| **Fossil Fuels** | **Grand Total** | **$72,473** | **Percent of Total Expenditures** |
| | Foreign Tax Credit[1] | $15,300 | 21.1% |
| | Credit for Production of Noncoventional Fuels[2] | $14,097 | 19.5% |
| | Oil and Gas Exploration & Development Expensing | $7,100 | 9.8% |
| | Oil and Gas Excess Percentage over Cost Depletion | $5,411 | 7.5% |
| | Credit for Enhanced Oil Recovery Costs | $1,575 | 2.2% |
| | All Other Subsidies | $28,917 | 39.9% |
| **Renewables** | **Grand Total** | **$28,943** | |
| | Alcohol Credit for Fuel Excise Tax[3] | $11,577 | 40.0% |
| | Renewable Electricity Production Credit | $5,224 | 18.0% |
| | Corn-Based Ethanol[4] | $5,007 | 17.3% |
| | Renewable Energy Investment Credit | $259 | 1.0% |
| | Five-Year Modified Accelerated Cost Recovery System (MACRS) Period for Solar, Wind, Biomass, and Ocean Thermal | $200 | 0.01% |
| | All other Subsidies | $6,857 | 23.70% |

Source: "Estimating U.S. Government Subsidies to Energy Sources: 2002-2008." *Environmental Law Institute*. Sept 2009. Web. Sept 24 2011. http://www.elistore.org/Data/products/d19_07.pdf

[1] allows Taxes paid to foreign governments to be deducted from domestic income taxes. This is a general tax benefit, meaning that it is not exclusively available to oil, gas, and related companies. The authors argue that the credit is "construed to disproportionately benefit the oil industry" (p.30).

[2] Generally a credit for the coal industry (p.7). Sherlock (2010) argues that "substantial abuse" of this credit lead to its elimination in 2009, which is outside the period of these author's examination.

[3] This credit supports fuel ethanol production.

[4] The Authors conclude that USDA support for corn farming leads to a large proportion of farmers growing corn for the purpose to transformation into ethanol fuel, and so include this subsidy as a direct payment.

## *The Social Cost of Energy*

The social costs of any economic activity can relate to health or environmental impacts that they may have, the costs of which are born onto individuals or groups as opposed to a producer. It is often a form of market failure in the sense that it distorts the true costs of an economic activity. It is not the

75 These figures were not adjusted for inflation. Renewable energy incentives also included provisions for accelerated depreciation (MACRS), Clean Renewable Energy Bonds, Credits for investment in advanced energy property, and residential energy efficiency credits. Renewable fuel producers can earn 45 cents/gallon for ethanol, for example, and have reached and output of over 13 billion gallons in 2010.

objective of this paper to provide an answer which can provide a complete answer to the whole of the energy economy of the United States. In order to develop a sense of the value at stake however, we shall briefly discuss the social costs of energy.

The Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption of the National Research Council (NRC) attempted to calculate the cost of environmental impacts or "externalities" of energy production in their book titled *Energy's Hidden Cost* (2010). The cost estimates were based mainly on air pollution created by energy production and its effects on human health, crops, buildings, recreational areas and vistas (p.4). That said, they found that costs in their studies were driven in greatest proportion by premature mortality associated with air pollution. Thus far from exhaustive, we can assume that the author's figures represent a highly conservative estimate of the total social costs of our energy production and use.

The NRC does not for example, factor in the billions in damages that nuclear accidents could cause if an accident occurred from plant meltdown or during the transportation and storage of spent fuel rods. In Japan, the Fukishima nuclear crisis of 2011 created problems for major businesses like Honda and Toyota. It is also ruining life, land, and economy for a whole population. Yet, this energy crisis occurred at the hands of earthquake and tsunami. How does one account for the separate costs? For another example, the NRC might have included the impact of worker injuries sustained while installing or maintaining solar panels and wind turbines, or perhaps the environmental cost of their manufacture and eventual disposal in the environment.[76]

If their estimates are accurate reflections of reality, than it would seem that externalities dwarf the cost of public subsidies which helped to develop energy technologies and support markets for them (especially in the case of fossil fuels). For the year 2005 *alone*, they estimated approximately $120 billion in total costs were born on society. The basic breakdown can be viewed in table 3.2, below.

The NRC's lifecycle approach to calculating the social cost of energy focused mainly on air pollution created by coal and natural gas based electricity production, which was about 70 percent of all electricity production in the United States (p.5). They contended that the majority of external costs associated with coal, which totaled $62 billion in *2005 alone*, were the result of about 10 percent, or just 40 of the power plants used in their sample (NRC, 2010, p.6). The NRC offered no estimate of the costs associated with Nuclear plants but recognizes the challenge of long term storage and transportation of spent fuel rods.

Externalities of wind energy are limited in their study mainly to bird deaths, of which the current rate is deemed too low to lead to long term impacts on bird populations. In effect, their study does not provide a complete image of what the full social costs of energy production are, but their attempt is still ambitious and revealing. For one, a tremendous proportion of the costs that they recorded are a result of energy production and transportation, and from this we can assert that a relatively small number of likely older coal plants either updated or replaced with competing energy technologies could have a large impact on overall GHG emissions and corresponding health issues examined in their study.

76 On that note, it is said that wind turbines are carbon neutral within the first year of operation generally speaking. Obviously, the assumptions make a difference. Should a technician driving a truck out to a wind turbine to service it count as emissions related to wind energy? And so on.

Table 3.3 Summary the 'Hidden Cost of Energy' Estimates for the Year 2005

| Activity | | Assumed Annual Cost |
|---|---|---|
| Electricity Generation (Coal) | | $62 billion |
| Transportation | | |
| | Light Duty | $36 billion |
| | Heavy Duty | $20 billion |
| Heating (Natural Gas) | | $1.4 billion |
| Electricity Generation (Natural Gas) | | $740 million |
| Nuclear Energy | | *Not Calculated* |
| Renewables | | *Not Calculated* |
| | Total Cost | $120.14 billion |

Source: Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption; National Research Council. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington DC: The National Academies Press. 2010. Web. Sept 24 2011. http://www.nap.edu/catalog.php?record_id=12794

In the transportation sector, the committee found that about two-thirds of social costs were associated with the manufacturer of autos, extraction of fuel components (or electricity), their transportation, and fuel refining. Perhaps as expected then, much of the social cost of transportation could be reduced greatly through the development and use of new kinds of motors combined with less damaging sources of energy.

Only Pfund and Healey included the cost of R&D into their estimates, which we will see historically favored fossil fuel and nuclear energy technologies to much the same conclusion as the subsidies discussed here have. Even without an authoritative text to draw from which offers absolutely conclusive and exhaustive analysis of government support for energy technologies, it would seem clear that energy subsidies from the federal government have tended to support fossil fuel and nuclear energy development over that of renewable technologies. Additionally, the social cost of legacy technologies are substantial and a result of continued widespread use of identifiable energy technologies. While renewables carry their own penalties for humans and the environment, at this time, they would appear to be far healthier.

## *Research and Development Expenditures*

According to Dooley (2008), $4 trillion was allocated and spent by the United States for R&D purposes between the years 1961 and 2008. About half of that money was allocated to the Department of Defense, one-third was spent on the space race, and health accounted for 20 to 25 percent of spending outlays beginning in the 1990s. Outlays for energy peaked at about 10 percent of the budget between 1977 and 1981 and have averaged closer to 1 percent since the 1990s. By extension we can add that it is relatively common knowledge that the United States has a highly innovative military-industrial complex with some of the most advanced hardware in the world and the invention of the Internet to its credit.

Other milestones include expansive technology and capability in space, and a booming healthcare industry. It has been said that Americans do not think of energy as a highly sophisticated or innovative industry, perhaps because the industry has been heavily regulated in the past and not particularly visible aside from one's monthly utility bills or a trip to the gas pump. On the other hand the Manhattan Project produced infamous bombs, and laid the groundwork for the formation of a nuclear power industry in the 1950s. Such activities were an answer to a gnawing question: how can we get nearly unlimited power at virtually no cost? As an enabler of economic growth, energy has few peers.

Energy is taken for granted by a world who's basic survival depends upon it. It is easy to forget that scarcely 100 years ago this nation had barely begun to build a massive modern energy infrastructure. We didn't have lightbulbs or the electricity to power modern electronics. Once such infrastructure is completed, developed nations such as ours cannot start over, they must transform.[77] China provides a recent example of the importance energy as it has made unprecedented investments in energy infrastructure as its economy grows. While it invests heavily in coal, like other developing countries had, however, it is making unprecedented investments in clean energy and rapidly developing them.

So one might find it ironic that perhaps the single most important ingredient in all of society's modern economy and technology, energy, has tended to receive such a small portion of financial support from the government. In the history of United States R&D approximately $172 billion (in 2005 dollars) or 4.3 percent of $4 trillion of all public dollars have been channeled into the development of no less than a dozen major energy technologies. Nuclear energy commanded 70 percent of that funding between 1961 and 1973. Following the Arab Oil Crisis of 1973, between 1974 and 1980 outlays for fossil energy grew from $143 million to $1.41 billion, primarily to support synfuel technology. The search for a nuclear breeder reactor meant funding growth from $643 million to $1.69 billion. The first solar, geothermal, and energy conservation programs took root in 1974, eventually leading to $2 billion spent on solar demonstration programs.[78]

A report by Sissine (2008) reaches further back into the history of energy R&D funding, to 1948. As shown in table 3.4, below, the lion's share of funding support for renewable energy occurs in the years following 1978. Sissine also finds that about $184 billion has been spend on energy related R&D since 1948, of which about half was absorbed by nuclear programs, and a quarter by Fossil energy. During the last ten years, and even between 1978 and 2010, fossil and nuclear energy have continued to draw proportionally higher amounts of R&D support, even as renewable technologies appears to have commanded a greater share of the budget in the 2000s.

The apparent doubling of the share of R&D for power systems is a partial result of the approximately $2 billion set aside by the 2009 ARRA for advanced battery R&D and $4.5 billion for investments leading to a Smart Grid—critical activities which could lead to big changes in the

77 When Thomas Edison began developing DC power plants in New York to power his light bulb, for example, he often laid wire along existing gas routes. Technology is transformative then, but often might conform to existing development decisions.

78 As an interesting note, between 1978 and 1998 the DOE's budget authority for energy R&D dropped from about $6 billion to $505 million. With $57.5 billion spent over the 30 years between 1978 and 2008, the nation's energy mix reflects only a minimal change in energy composition. Major energy sources remain fossil fuel based. Renewable energy produces perhaps 1% of the energy share, and nuclear power made the greatest advancement growing from about 1% to 8% of the country's energy mix between 1973 and 2006. See the testimony of Mark E. Gaffigan in U.S. GAO "Advanced Energy Technologies: Budget Trends and Challenges for DOE's Energy R&D Program." Mar 2008.

Table 3.4 Federal R&D Expenditures 1948 – 2010, Billions of 2010 dollars

| Technology | FY2001-FY2010 | FY1978-FY2010 | FY1948-FY2010 |
|---|---|---|---|
| Renewable Energy | $6.42 | $19.50 | $21.06 |
| Energy Efficiency | $6.50 | $16.87 | $17.02 |
| Fossil Energy | $10.55 | $30.87 | $46.61 |
| Nuclear Energy | $8.85 | $43.63 | $91.12 |
| Electric Systems* | $5.78 | $7.92 | $8.09 |
| **Total** | **$38.10** | **$118.79** | **$183.91** |
| **Technology** | **FY2001-FY2010** | **FY1978-FY2010** | **FY1948-FY2010** |
| Renewable Energy | 16.8% | 16.4% | 11.5% |
| Energy Efficiency | 17.1% | 14.2% | 9.3% |
| Fossil Energy | 27.7% | 26.0% | 25.3% |
| Nuclear Energy | 23.2% | 36.7% | 49.5% |
| Electric Systems* | 15.2% | 6.7% | 4.4% |

Source: Adapted from Sissine, Fred. "Renewable Energy R&D Funding History: A Comparison with Funding for Nuclear Energy, Fossil Energy, and Energy Efficiency R&D." *Congressional Research Service*. Jan 26 2011. Web. Sept 24 2011. http://www.fas.org/sgp/crs/misc/RS22858.pdf
*Electric Systems includes R&D for transmission and storage technologies.

transportation sector while also developing advanced capabilities for the energy grid. Smart Grid coordination might leverage the energy generation and distribution of all homes and businesses in the country more efficiently, while creating new market incentives. In the most recent decade, however, the amounts spent on renewables or energy efficiency R&D continue to trail expenditures for other energy technologies.

The DOE (indicated by Ruegg and Thomas, 2009) showed that about $609 million, or 38 percent of the $1.62 billion (in 2008 dollars) allocated for wind energy research and development between 1978 and 2008 occurred in the brief period of 1974-1982, years in which the national effort to generate utility scale wind turbines was in full effect and where the greatest amount of funding was allocated. Funding was cut severely in the late 1980s, before averaging about $40 million annually between 1994 and 2008, commonly resulting in DOE/NREL collaborations with industry for research, product development, and other activities. Easily two to four times that amount ($80-$160 million) has been spent annually on solar or hydrogen programs since 2003, suggesting that wind energy has been, remarkably, one of the fastest growing energy technologies without necessarily commanding a high proportion of the DOE R&D budget.[79] It also reflects the effectiveness of public/private partnerships in the identification and solution of technical issues hindering the competitiveness of the wind energy industry.

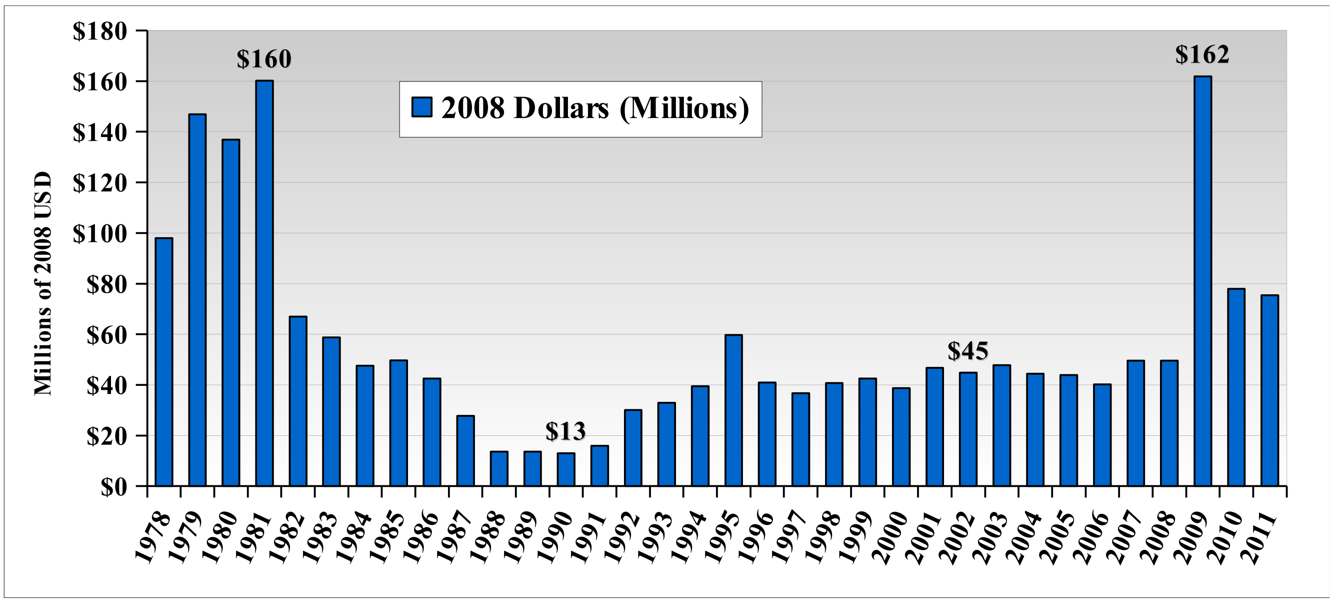
Figure 3.1 below shows funding levels for wind energy R&D specifically between 1978 to 2008, with estimates for 2009 and 2010. In 2008 dollars, approximately $1.6 billion or just under 1 percent of Dooley's $4 trillion R&D expenditure between 1960-2008 funding estimates have gone into wind power R&D. This amount is gargantuan, however, compared to outlays spent in Denmark, which Gipe claims began its world leading industry out of a mere $203 million in combined R&D and

79 Wind energy has never commanded more than approximately 2 percent of all energy R&D funding. Among renewables Biomass and Solar technologies have tended to command the greatest funding. Yet, the cost of wind energy fell quickly decades ago while solar continues to require greater cost cutting.

subsidy (of which $53 million was R&D related). This is as compared to compared to $195 million spent in Germany ($178 million in R&D), and $1.386 billion spent in the United States which included $486 million in R&D (Gipe, 1995, p.73).

Pelsoci (2010) finds that of the $1.7 billion (2008 dollars) spent by the DOE between 1976 and 2008, $371 million in DOE program funds were invested without industry partners (p.4-9). An additional $868 million was spent that generated an estimated $304 million in matching funds from industry partners (ibid, 4-9).[80] These R&D expenditures overcame deficits in fundamental understanding of wind turbine aerodynamics, for example, and also supported development of general and proprietary technologies. One significant impact of the programs was the rapid decline in the cost of wind energy from 90 cents/kWh at the start of the 1980s to less that 10 cents/kWh by 1990.

Fig. 3.1 R&D expenditures on Wind, 1978 – 2011 (Millions of 2008 Dollars)




Source: (1) Ruegg, Rosalie, and Patrick Thomas for the Department of Energy. "Linkages from DOE's Wind Energy Program R&D to Commercial Renewable Power Generation." *Office of Energy Efficiency and Renewable Energy*. Sept 2009. Web. 26 Mar 2012.
http://www1.eere.energy.gov/ba/pba/pdfs/wind_energy_r_and_d_linkages.pdf
(2) Gallagher, K.S. and L.D. Anadon, "DOE Budget Authority for Energy Research, Development, and Demonstration Database." Energy Technology Innovation Policy. John F. Kennedy School of Government. Harvard University. 29 Feb 2012.
http://belfercenter.ksg.harvard.edu/publication/21788/doe_budget_authority_for_energy_research_development_demonstration_database.html
*2009 includes additional funds from the ARRA.

Debate over the market value wrested from those figures notwithstanding, the fact remains that Danish investments and policy proved more conducive to the formation of a competitive wind industry than those of either the United States or Germany at the time.[81] Vestas remains the world's leading wind

80 Industry matching funds were based on an estimated 35% average. The range of funding match was between 20% and 50%.

81 Some explanation to the vast difference in starting costs was related to the technological approach taken. The Danish are noted as having taken a much more incremental approach to turbine development. Communities owned wind projects and turbines "co-evolved", restricting total sales volume while designs were proven for mass deployment (Bolinger, et

turbine manufacturer, and as of 2009 Denmark derived about 20 percent of its energy from the wind (*Danish Energy Agency,* 2010). We should add that Vestas has spent over $2 billion on R&D itself between 2006 and 2010 (see table 2.2).

One explanation for the great variance in energy R&D funding is political. When former California governor Ronald Reagan (1967-1975) appeared in the White House in 1980, support for energy programs were cut approximately in half, the better to establish the idea that the proper role of government moving forward would be the conduct of fundamental, as opposed to applied research. Tearing the solar panels off the roof of the White House in symbolic protest, the president was convinced that the basic functioning of the energy supply and the development of its infrastructure was properly organized by market forces.

Reagan had in fact under the 3rd and 4th energy secretaries James Edwards and Donald Hodel attempted in the early 1980s to dismantle the Department of Energy altogether, which had operated since October 1977 as an amalgamation of disparate energy related agencies and offices pulled together by Jimmy Carter and combined with the U.S. nuclear weapons program. Reagan was ultimately unsuccessful, and Fehner and Hall (1994) document the department's continuing awkward navigation of its role as both a manufacturer and steward of nuclear weapons, a role which contrasts with the agency's other identity as the United States' guardian against future energy crises as an active promoter of the development and diffusion energy technologies.

Heiman and Solomon (2004) point out that research funding and incentives have been lopsided and unequal in the United States; as an example in 1999 natural gas received about $1 billion in incentive support compared to just $19 million for renewable energy. For the first 15 years of power generation nuclear energy received 30 times the federal support per kW generated as compared to wind (reflecting expenditures between 1947-1962 for nuclear and 1975-1990 for wind). With both incentives promoting energy deployment and R&D so lopsided, we should not be surprised that, after over five decades of expenditures, the current energy grid illustrates a country heavily reliant on fossil fuels and to a lesser extent, nuclear and then renewable energy.

It is not just the development of high performance, low cost technology that matters in the eventual success and penetration of clean energy. The economic environment created by policy and realized through institutional interactions are equally important. So are the financial commitments made in the form of subsidy or R&D, from either the public or business sector. To a great degree, success depends on the country choosing a course of action and seeing it through to its end. If neither the government nor the business sector can sustain a long term vision and make the sacrifices it may demand, then all the investment in the world is waste – no matter the source.

## *The NASA MOD program: a Huge, Embarrassing Failure, or the Proper Role?*

The origin of the NASA's involvement with wind technology and part of the basis for Reagan's reversal actually traces back to 1970, when the NASA was approached by the Secretary of the Interior of Puerto Rico in 1970 to develop of a wind turbine that could power Culebra island (Lyons and

al., 2004, p.7). Similar to the experience of USW/Kenetech, the first Vestas turbines produced less than 100 kW and would not produce more than 1 MW for a number of years. The United States approach, oft criticized, might also be described as quite ambitious.

Levine, 2009, p.4). The National Science Foundation (NSF) and a federal wind energy program under the Energy Research and Development Administration (ERDA) were interested and willing to fund what would become the MOD-0 wind turbine for $1.5 million. Things escalated from there.

After the 1973 Oil Embargo, the NSF funded wind energy programs under a "national needs" category, and the ERDA maintained a wind energy research program under its existing solar program (DOE, 2009, p.8). In 1974 the NASA Authorization Act gave the NASA an official role in energy research. The MOD-0 was the first of five different wind turbine designs and 13 total machines. The purpose of the program was to demonstrate 100 kW (medium) to up to 7 MW (large) wind turbine designs. Eventually, the wind turbines would be commercialized by program participants. In all likelihood, they would have been commercialized by the Aerospace companies contracted to build the prototypes.

The engineers in the NASA program had actually spoken to Ulrich Hütter and Palmer Putnam, and reviewed Juul's Gedser turbine while the wind development program was under design. It is perhaps not surprising then that they were attracted to the aerodynamic-science disciplined German designs, which promised efficiency and good looks that the Danish Gedser design appeared to lack. The organizational backing and ability of Putnam's 1.25 MW 2-bladed design to run successfully for several years also likely promoted confidence in these approaches. The major U.S. aero-companies also favored Hütter and Putnam's work, and came to the basic conclusions that a 2-bladed, variable pitch, constant speed downwind rotor was the best overall design approach. The first turbine, the MOD-0, was based on on Hütter's W34, while eliminating its teetering hub and using steel for its blades (Heymann, 1998). This ran in opposition to the 3-bladed, upwind designs favored by the Danish.

Hope for a 7 MW design was manifested in what became the MOD-5B which was built by Boeing and actually scaled back to 3.2 MW when 7 MW was found to be too impractical. Other collaborators with NASA included Boeing, General Electric, Grumman, Kaman, Lockheed, McDonnell Douglas, and Westinghouse. The entire project ran from roughly through the end of 1973 until 1992. By that time, Boeing's MOD-5B in Oahu, Hawaii had managed 67% availability before being shut down for "poor economic performance and chronic malfunctions" causing both the NASA and its major subcontractors to "[retreat] from wind technology development" (Heymann, 1998, p.657).[82]

The Boeing 3.2 MW MOD-5B was the world's largest turbine in the world for the 2.3 years it ran. Indeed, none of the other turbines developed under NASA's program managed more than 2.3 years of operation. Puerto Rico's Westinghouse 100 kW MOD-0 logged about 19 hours before failure, and General Electric's 2 MW MOD-1 never logged any hours at all (and cost around $7.5 million to build). Remarkable given, as Heymann (1998) noted, that the United States spent about $427.4 million between 1975 and 1988 on their wind program compared to Denmark's at $19.1 million and Germany's $103.3 million. The lion's share of funding was driven into the development of multi-MW designs, while smaller turbines received support but developed as a separate U.S. market. The ambition of the NASA program prompted many early wind power companies to develop commercial designs that fell ultimately in the 100 kW to 750 kW range.

As Ruegg and Thomas noted, the key to wind energy research was believed to be in developing

82 Availability refers to the proportion of time a turbine is in a state ready to make energy. Modern turbines now often have approximately 90% or higher availability, meaning that they will run all the time providing the winds are strong enough.

large-scale designs that would be “acceptable to utility companies . . . [turning] wind into a major contributor to U.S. energy supply” (DOE, 2009, p. 9). In effect however, while the prototypes produced by the MOD program failed to lead directly to commercialization of technologies, lessons were learned and developing turbines “meant much more than mounting airplane propellers on towers for utility-scale power generation and tweaking small windmills from the past for distributed use. Both large and small systems showed lower performance, lower energy-conversion efficiencies, shorter durability, and higher cost than had been expected” (ibid, p 8). In other words, some of the brightest minds in the country, and its most capable companies grossly underestimated the task at hand.

Larry Viterna and Bob Corrigan of the NASA Glenn Center were approached by Danish engineers struggling to develop more effective analytical models that could predict wind energy generation at different wind speeds. Viterna and Corrigan had developed an analytical model to predict wind power generated at different wind speeds which contradicted existing theories. Viterna was “known around the world as a bit of a quack” (Wittry, 2006) for the model that he helped develop at the time but in fact would discover much later that his had become *the* leading model for wind power prediction.

The Viterna model went on to become a key lesson of the NASA program and an important tool for screening future turbine designs. Another example of a contribution of the NASA program is a 1980 Government Accounting Office (GAO) report that described all of the major subcontractors as failing to produce adequate blades for the MOD projects, despite experimenting with concrete, pressed wood, aluminum, fiberglass, and steel. All the materials had issues related to their performance, durability, or cost. This is partly what may have lead designs of the future to try fiberglass composites, for example. Today, advanced composites like carbon fiber are sometimes used. As we have seen with the NREL research described earlier, however, the shape of the blade can be equally important in determining performance, and engineers recognize that best designs may be counter-intuitive. Additionally, blades benefit from strong materials, but also may need to manage ice and insects effectively.

In addition, actual wind resource knowledge was incomplete in the United States, with the exception of California which had measured its own resources in the late 1970s. Understanding U.S. resources better was key to ensuring that turbine technologies of the future would be properly sited in areas where high average wind speeds insured good productivity. On the other hand, engineers recognized the importance of developing capabilities for periods of lower average wind speeds. This would expand the reach of the technology and its ability to be used in a wider range of wind regimes.

The NASA's CERES project would target these issues, as would future efforts by the National Renewable Energy Laboratory (NREL) in the 1990s. Despite the criticisms of top-down innovation models (or technological push as they are also called) suggested by some authors, business capabilities also came into play. Gipe (1995) argued the common sense notion that aerospace industries were used to building “aircraft” that “[fly] only a few hours relative to many hours of skilled maintenance” while wind turbines “must work reliably over long periods with little maintenance” (p. 56).

Like farm equipment, wind turbines needed to be rugged, durable, and capable of running with a minimum of maintenance. This is perhaps one explanation for why Vestas was ideally positioned to develop its wind turbines. It had developed experience and capability in delivering cranes and other farm equipment. Wind turbines have to efficiently convert the wind to energy, but they also needed to operate reliably in harsh environments far more dynamic than realized. The longer a turbine lasted, the more its costs could be spread over the life of its energy production, lowering its energy unit cost.

Other than perhaps the symbolism of a large government agency and large private companies taking a stake in the early wind industry in the United States, it is clear that the contributions and problems encountered by the program had applicability that went well beyond the basic goal of commercialization. Computer-tools and computer aided analysis were not prepared or optimized for the intense dynamic loads actually faced by turbines, for one. Also, wind resources and the nature of those resources were not yet well understood. Even in California, where resources were measured in the late 1970s, average wind speeds were in some areas overestimated, which would have made some early turbines appear to be poor performers when in fact they were poorly sited.[83]

From an investment standpoint, these problems guaranteed that project costs and risks would be misunderstood. No one, for example, could have guessed that bird deaths, insects, ice, and sandstorms would one day in the future be guiding turbine design. The California landscape provided some but not all challenges the technology would face. Engineers could not necessarily have anticipated that aesthetics or sound pressure would become key hurdles in the public acceptance of the technology.

In addition, early turbine designs were radical departures from generally successful, albeit smaller turbine designs that had sometimes run for a decade or more. Those designs, while successful, were also essentially prototypes. Cost and failure rates of the NASA program must have exceeded expectations, but such risks and costs are necessary. As a pilot program, the NASA was forced to put together a great number of custom parts, fabricated just for the project. This would not occur as part of a normal manufacturing process.

The pattern of including industry in the development process, as well as utilities which ultimately would have to accept and integrate the technology, was not lost but established under the NASA program. The clearest mistake that seemed to have been made by all of the major actors involved was that the design approach and philosophy came from Germany and the United States, not Denmark. The assumption that scaling the technology would be a straightforward process proved naive.

Theory and big science confronted the realities of wind turbines, and theory lost. Or, as Heymann (1998) suggested, the United States committed the sin of "technological hubris." The MOD program was not just a huge, embarrassing failure for the NASA. It was a huge, embarrassing failure of some of the most storied businesses in the United States. In that sense, Reagan's fixation on the proper role of government was miscalculated: neither government nor business can be expected to have the right tools, wisdom, and resources required for something so important as innovation in energy.

## *Other U.S. Government Support for Renewables*

We have already covered the significant government subsidy, R&D, and NASA MOD program as examples of government support for renewables. Here we examine some of the changes prompted by regulation like the PURPA, and the formation of dedicated Agencies like the Department of Energy.

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83 Or, as Asmus (2001) pointed out, very high performing wind sites would be used as a benchmark for all wind sites, providing a basis for inflated performance numbers to attract investment to a company. This is precisely what USW/Kenetech did with one of its wind sites.

Originally suggested by President Nixon in the early 1970s, the genesis of the Department of Energy (DOE) was meant to provide the government with expanded capacity and tools necessary to significantly influence energy infrastructure and market outcomes. In particular, the DOE was also addressing the reality that the United States was highly vulnerable to disruptions in its fuel supply, and of course that its position as a leading economy was intimately threatened by shortages in the domestic or international supply of energy, and also the stability of energy markets.

As the largest consumer of energy in the world and as a consequence one of its largest polluters, the United States also faced growing visibility as both the creator of climate change and the need for a solution to it. President Ford would continue to promote the idea of an active energy policy in the United States. The NASA wind turbine program had overlapped with other federal agencies and offices until President Carter managed to successfully draw together at least a dozen of the United States' nuclear defense programs, energy programs, and energy research and development programs into the newly formed DOE on October 1, 1977 (Fehner and Hall, 1994). Fehner and Hall (1994) argued that "none of the key elements of Carter's Nation Energy Plan were original" but "the difference was that Carter combined these elements into a unified policy framework and placed much greater emphasis on conservation" (p.21).

By 1978 Carter had also put his signature on the Public Utilities Regulatory Policies Act (PURPA), which Gipe (2004) argued "for the United States . . . was downright revolutionary" (p.206). It created the basis for market competition between renewable energy and traditional energy markets almost overnight, by defining Independent Power Producers (IPPs) and allowing them to enter the market for energy and compete with each other and existing generators.

Regulated utilities were forced to accept interconnection and to buy their power at an "avoided cost" of energy which initially meant the cost of fuel plus capacity, but which overtime became based on the average cost of fuel alone (Gipe, 2004). A key problem was that the United States was operating under an assumption that the days of cheap fossil fuels were numbered, and that prices would rise indefinitely. We now realize high prices for fossil fuels alone cannot be depended upon as a long term catalyst for industrial change.

As expected, however, IPPs began to show up in numbers as the ripening wind power industry developed business models and raced to claim tax incentives (See figure 3.2, below). In 2010, 34 percent of all power producers were IPPs, growing from 21 percent in 2000. From 2000 to 2010, Utilities fell from 56 to 48 percent and Combined Heat and Power Producers declined from 23 to 18 percent of all power producers.

In 2010 IPPs represented 86 percent of all wind energy capacity, 90 percent of solar capacity, 18 percent of biomass capacity, and 93 percent of all geothermal capacity (see EIA Table 1.1.B. Existing Net Summer Capacity of Other Renewables by Producer Type, 2000 through 2010). The share of generation attributable to IPPs is continuing to grow in the United States as well. Between 1999 and 2010 the share of generation by IPPS across all energy technologies grew from about 5 percent to 32 percent, while Utility generation declined from close to 90 percent, to about 60 percent (see figure 3.3 below).[84] Certainly, the PURPA has had an effect on the make up of energy markets and its participants.

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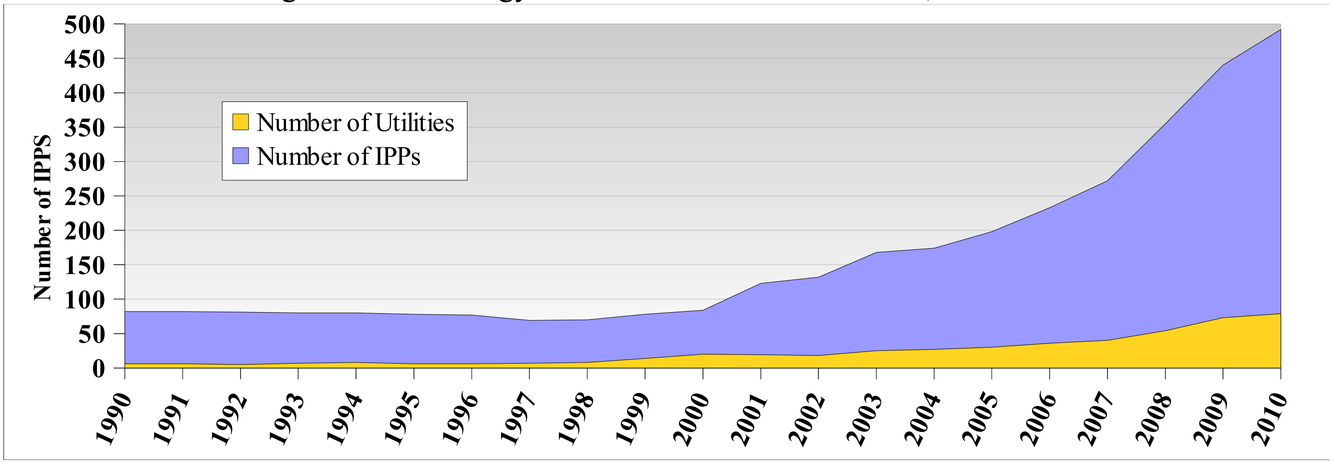
84 It should be noted that the largest share of energy is being generated by Coal, Natural Gas, and Nuclear IPPs. Non-

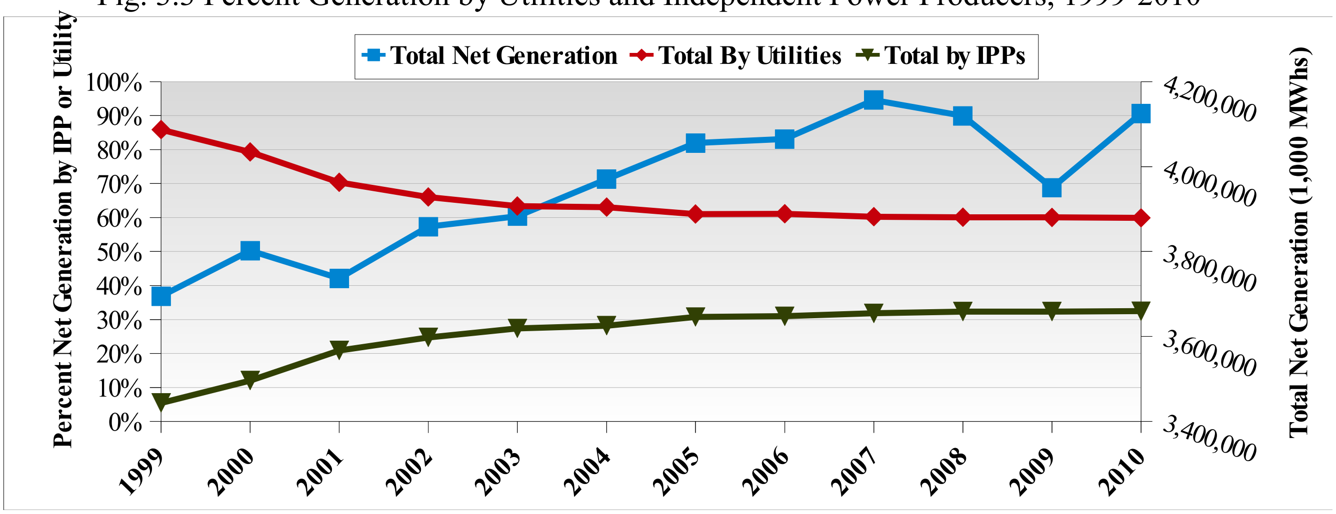
Fig. 3.2 Wind Energy Producers in the United States, 1990-2010




Source: United States. Department of Energy. "Existing Nameplate and Net Summer Capacity by Energy Source, Producer Type and State (EIA-860)" Electric Power Annual with data for 2010. *Energy Information Administration*. 4 Jan 2012. Web. Accessed 26 Mar 2012. http://www.eia.gov/electricity/data/state/

A large share of renewable generation is produced and brought to the grid through IPPs. Figure 3.4 shows that approximately 50 percent of IPP renewable energy generation is from wind. In contrast, the whole of generation by Utilities across the same renewable energy technologies was about 10 percent in 2010.[85] Utilities today clearly do not feel compelled to choose renewable energy generation when investing in new capacity, though it could be that they prefer to pay for the energy produced and avoid the capital costs of installations, operations, and maintenance. On the other hand, utilities like Florida Power and Light own independent renewable energy companies, like NextEra energy which is currently one of the largest renewable energy developers and owners in the United States. Thus the rise of IPPs does not tell the whole story about who and how energy is being produced in the United States.

Fig. 3.3 Percent Generation by Utilities and Independent Power Producers, 1999-2010




Source: United States. Department of Energy. "Table 2.1.A Net Generation by Energy Source by Type of Producer, 1999 through 2010." *Energy Information Administration*. Dec 2011. Web. 28 Jan 2012.

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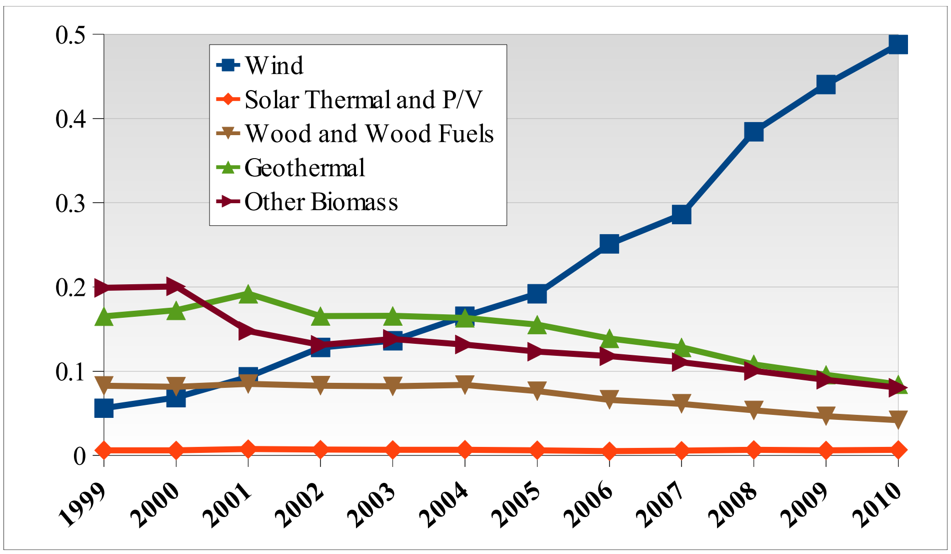
Hydro renewables would represent about 3% in 2010.

85 Alternatively, Wind producers make up 23% of IPPs, as compared to Hydro (22%), Natural Gas (18%), and Biomass (13%). In the same order, however, Wind IPPs make up 8% of capacity, Hydro (1%), Natural Gas (50%), and Biomass (1%).

*Combined Heat and Power not Included in the percent totals.

The ability to enter into energy markets spawned numerous business models, some of which have been discussed already. Included was a focus on selling tax credits to investors or wealthy individuals as a lure for project capital, which may or may not have been driven into shoddy products and shoddier installations. A more successful model included doing essentially the same while relying on importing proven Danish, Japanese, or German turbines until sufficient capital accumulation had occurred which could support the design, manufacture, and installation of turbines developed in-house later. Working toward becoming a vertically integrated company was an ambitious undertaking, but also a key means of controlling of the higher total costs of wind power projects (where the turbines themselves were the highest single cost component).

Fig. 3.4 Independent Power Producer Share of Renewable Generation, by Source, 1999-2010




Source: United States. Department of Energy. "Table 2.1.B. Net Generation by Selected Renewables by Type of Producer, 1999 through 2010." *Energy Information Administration*. Dec 2011. Web. 28 Jan 2012.

## *Government Support Intersects with Business*

The intersection of policy and business can be described from many different perspectives. What we cannot do in describing the emergence of the wind energy industry is separate the two. If incentives like the PTC help drive expansion of the industry, for example, policies protecting endangered birds restrain it. If public universities and government labs develop the human talents which contribute to innovation and long-term competitiveness, slashing R&D budgets, canceling resource evaluation plans, or avoiding the revision of permitting standards undermine industry potential. As we shall see, state policies add a layer of complexity to government support, but also create new opportunities for wind power.

Regulation created IPPs like U.S. Windpower/Kenetech. Better capitalized by large private investments, Kenetech could form a vertically integrated business model that included the manufacture, installation, service, and research and development of turbine technology. They also attempted to diversify business activities by selling other energy technologies in order to hedge against unfavorable shifts in the wind market. Patent laws came to the aid of the company when it wished to prevent foreign competitors from entering the U.S. market. Kenetech benifited from gaining early access to

Callifornia's wind map, and DOE funding for UMass Amherst, which gave the company a prototype, a vision, and key engineers.

Zond focused on wind energy from the beginning. They identified superior Danish technology and learned from it. Zond eventually developed their own high tech designs with government support and modeled their approach on Danish designs and talent. Along with Kenetech technology, they exemplify the cumulative nature of innovation. With the superior financial strength of Enron, they were able to build up an industry that had been floundering. Kenetech and Zond benefited from state and federal subsidy. Each, we might argue, inherited other public investments which we covered in more detail above.

As we learn in the next section, the structure of project financing also makes it easy for wind projects to swap ownership (even encourages it). It helps developers obtain the capital needed to complete projects, but constrains the way in which that will occur, and influences the organizations that will be involved. A side effect to the possibility of ending subsidies (as they are often only guaranteed for a period of a few years) is instability and uncertainty in wind markets. It prompts wind developers to rapidly pursue projects, contributing to an image (at times) that they are not invested in the communities they operate or in becoming long term producers of energy. Finally, federal support is not optimized for all stakeholders which might be interested in financing a wind project

The policy landscape and incentives provided to the emerging wind industry went through several shifts including the provision and then loss of tax credits from 1981 to 1986, the refocusing of DOE activities away from applied R&D toward fundamental R&D, along with significant cuts in overall funding between 1981 and 1990. By 1990 funding was just 8% of the $160 million (in 2008 dollars) allocated for wind energy R&D in 1981. Subsequent support for the industry took the form of the PTC (introduced in 1992 and effective beginning in 1994) which subsidized the cost of wind energy, and marked the approximate return of applied R&D support to the wind industry. Wind energy has not received the same amount of subsidy as other energy technologies, yet the cost of the energy it produces fell precipitously between the 1980s and today.

Throughout the 1990s and by the beginning of the 2000s a growing share of states became active participants in the future of wind power, instituting renewable portfolio standards (RPS), green power pricing, net metering standards, public benefit funds, and a myriad of other policies and incentives meant to compensate for occasional lack of market action or federal promotion of renewable energy technologies. These are covered in greater detail below. Despite growing state support, however, disruption of available incentives for wind energy led to general stagnation of the industry at different points in its history, which helped shift market gravity elsewhere. Even so, states are providing market signals and coordination lacking at the federal level.

Innovation in wind energy occurred from the efforts of small companies which eventually proved technologies and made generational improvements, typically within shared-cost R&D partnerships between NREL and company engineers. It was also possible to innovate on their own. Some authors like Gipe (1995) claim that the leading company, U.S. Windpower/Kenetech, developed its turbine models in the absence of direct government support.

It should now be clear, however, that many of the people and academic collaborations with the company owe their success in part to deliberate DOE funding. Pelsoci (2010) adds that the DOE funded “approximately 50” university wind power programs which have contributed to innovation in the industry and delivered a competent workforce (p.7-12). This funding supported, for example, a wind-power program at the University of Massachusetts from which the company drew some of its key early technology and personnel.

Perhaps even more important, Kenetech could draw its vision, approach, and knowledge of the potential of wind from the school. Additionally, the company intended to make greater use of government programs just prior to its bankruptcy. The history and long span of wind technology make it impossible to view its development as anything other than a cumulative process. Linkages can be indirect, they can also be direct.

The demands of setting energy policy and an R&D agenda to provide the basis for a competitive domestic energy industry was mostly lost through the uneven decades of the 1980s to 1990s. Under Reagan, the DOE was selected for termination, and funding for the collaborative research efforts that proved a key ingredient for early wind-power development were halted. The challenge of managing the nuclear weapons program in the absence of a DOE prevented its outright termination, however, though Reagan was successful in redefining the role of government R&D as performing only the riskiest research which the business sector would not conduct on its own (Fehner and Hall, 1994).

The DOE's role is under attack again today, having used loan guarantees to help capitalize some clean tech companies which are failing after the fact. While its role is in question, the department of defense and department of the interior continue in their development of clean technologies or preparation for an offshore wind industry. The failure of the NASA program was a step backward for the DOE, as the bankruptcies of some Clean Tech companies are becoming today. This conversation will likely continue in the future, many stand to gain (or suffer) from disruptive innovations in energy.

Heiman and Solomon (2004) argued that despite the apparent development of research, policy, and regulatory framework centered on the goal of exploiting renewable energy technologies using a market-based structure, the United States approach to energy innovation has no real teeth. Few administrations of the past were willing to take a hands-on approach to energy despite the nation wide impacts of energy crises. In effect, the DOE of today researches but does not regulate, and the NRC and FERC regulate but “are neither proactive nor comprehensive policy units” and “energy decisions are made through a complex mix of markets and piecemeal federal and state regulation” (Heiman and Solomon, 2004, p.96).

While Heiman and Solomon recognize weakness in energy policy, they don't recognize apparent strengths. A renewable fuels mandate was signed into law in 2007, requiring that 36 billion gallons of cellulosic or corn-based biofuels enter our energy system over a couple decades.[86] Yet a renewable electricity mandate at the federal level has not yet been possible. Renewable capacity enters the U.S. energy grid in relative trickles, starved for capital, yet Natural Gas capacity expanded over the last decade at a rate eclipsing any other technology in history (about 54 GWs alone in 2002). The United States seems quite capable of making drastic changes in short order if it wishes to.

Despite making inroads in the 1980s, renewable energy (of which wind in particular dominated as it still does today) faced hostile utility and energy industries: “Chief among [challenges to

86 As of 2010, production of biofuels had already reached 13.2 billion gallons, an eight-fold increase from 2000.

Renewable Energy] is continuing market volatility, distortion of the 'deregulated' market through recapture of stranded costs and other forms of assistance for conventional generation, and the phaseout of lucrative PURPA-derived contracts for renewable energy that were first signed in the 1980s" (Heiman and Solomon, 2004, p.103).

Despite the complex and meaningful strides taken toward deregulation of energy markets by the United States, energy policy and hence energy markets lack effective coordination and momentum toward obvious goals. A consequence of this lack of clear strategy is of course a failure to seize on potential for the development of competitive advantage in one of the most important industries and opportunities in the global economy. Without patient capital originating from the public or business sectors, as we have seen, we cannot hope to establish and maintain a strong industry.

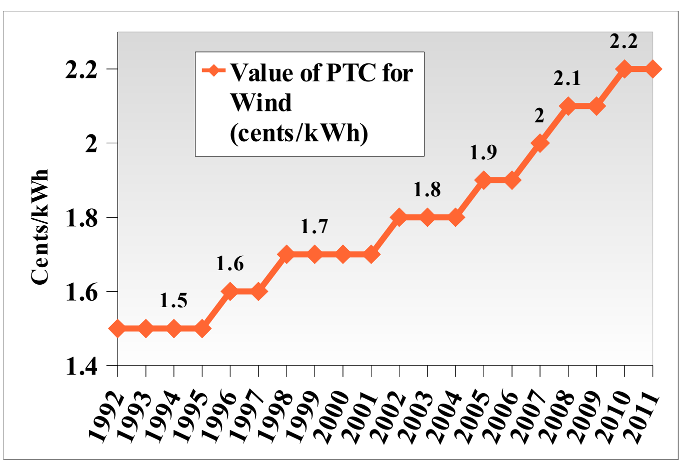
# PART IV. THE FINANCE OF WIND ENERGY

Discussed earlier, the tax credits of Wind Rush 1 cost about $1 billion while generating about $1.4 billion in private investments in the brief span between 1980 and 1985 (Asmus, 2001). Meanwhile, approximately $1.6 billion (in 2008 dollars) was spent in support of wind energy by the U.S. government through the DOE between 1978 and 2010. In 1990 the DOE allocation for wind energy R&D reached an all time low of $13 million, and from the period 1990-2010 just $528 million (in 2008 dollars) was allocated to wind energy R&D(See Figure 3.1 above (wind R&D exp 1978-2010).

The 2009 American Recovery and Reinvestment Act (ARRA) added approximately $118 million over and above continuing DOE budgets for wind R&D. Subsidies to Renewable Energy, not including subsidies to renewable fuels, were approximately $14.6 billion ($2010 dollars) between 2000 and 2010, and $4.3 billion ($2010 dollars) between 1979 and 1999 (Author's calculations from Sherlock, 2011 p.35). This funding supports manufacturing as well as resource development activities.[87]

Beginning in the 1990s this funding has supported a myriad of wind-related activities not just related to wind energy development. Some examples are joint product development for wind turbine manufacturers, as well as wind resource evaluation in the United States and in other countries which might receive future U.S. exports. Information sharing and outreach in the form of dedicated DOE websites provide the public with information about wind energy but also disseminate documents relevant to business owners, engineers, and others invested in the technology. Product testing and standards compliance are also available with support from the government. Here however, we turn to other sources of government support which have influenced the evolution of the finance and attraction of investment to wind energy projects.

Fig. 4.1 Value of PTC, 1992-2011




Source: IRS. “Internal Revenue Bulletin.” various years.

With an effective beginning date of 1994 but officially in place for the initial period of 1992 to 1997, the production tax credit (PTC) began to subsidize wind energy at 1.5 cents/kWh. The credit is adjusted for inflation each year, and reached a value of 2.2 cnts/kWh in 2010. Following 1992 the PTC has been allowed to expire or has been renewed roughly every one to two years.

Over 20 years 17 total months of lapses in the availability of the PTC have been allowed to occur, and each lapse has contributed to vastly lower or delayed annual investments in new wind capacity. The duration of the PTC has shortened with each renewal, forcing the wind industry to face shortening time horizons from which to identify new wind sites, acquire permits, court and negotiate with investors, and then complete

87 These subsidies are not exclusive to wind energy.

construction in time to receive maximum government support.

Table 4.1 below illustrates the legislative history of the PTC in greater detail. Following the ARRA in 2009 the industry received the longest guarantee of a PTC since its original inception, along with the creation of an Investment Tax Credit (ITC). The ITC provides a 30% tax credit for new wind projects as a substitute for a PTC.[88] The value is of the ITC is evidenced by the $4.21 billion in tax expenditures in caused 2010 alone (Sherlock, 2011, p.25).[89] The ITC has provided the wind industry with buoyancy during the financial crisis of the United States which began in 2008. This crisis constricted the tax appetites of potential equity investors and eliminated some key investors altogether. This problem is discussed in more detail below.

Table 4.1 Legislative History of the PTC

| Legislation | Date Enacted | PTC Eligibility Window (for wind) | PTC Lapse Duration | Effective Duration of PTC Window (considering lapses) |
|---|---|---|---|---|
| Section 1914, Energy Policy Act of 1992 (P.L. 102-486) | 10/24/1992 | 1994-June 1999 | n/a | 80 months |
| Section 507, Ticket to Work and Work Incentives Improvement Act of 1999 (P.L. 106-170) | 12/19/1999 | July 1999-2001 | 6 months | 24 months |
| Section 603, Job Creation and Worker Assistance Act (P.L. 107-147) | 03/09/2002 | 2002-2003 | 2 months | 22 months |
| Section 313, The Working Families Tax Relief Act, (P.L. 108-311) | 10/04/2004 | 2004-2005 | 9 months | 15 months |
| Section 1301, Energy Policy Act of 2005 (P.L. 109-58) | 08/08/2005 | 2006-2007 | None | 24 months |
| Section 201, Tax Relief and Health Care Act of 2006 (P.L. 109-432) | 12/20/2006 | 2008 | None | 12 months |
| Section 101 & 102 Emergency Economic Stabilization Act of 2008 H.R. 1424 | 10/03/08 | Jan 2009-Jan 2010 | None | 12 months |
| Section 1101 & 1102* American Recovery and Reinvestment Act of 2009 H.R. 1 | 02/17/09 | Jan 2011-Dec 2014 | None | 36 months |

Sources: (1) Adapted from Wiser, Bolinger, and Barbose. "Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States." *Lawrence Berkeley National Laboratory*. Nov 2007. Web. 11 may 2011. http://eetd.lbl.gov/ea/emp/reports/63583.pdf
(2) "Renewable Electricity Production Tax Credit." *Dsireusa.org*. DSIRE. Web. 14 Jun 2011 http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F
*Section 1102 introduced the ITC as an alternative to the PTC

The key distinction between the ITC and the PTC is that the PTC is based on energy production while the ITC is based on the size of the capital investment being made, which is similar to the incentive approach of the 1980s. The ITC, however, can be taken as a grant, sidestepping the need to seek tax equity investors entirely. The PTC and ITC are generally used to attract investors to wind projects, who might otherwise be risk-adverse or wary of the benefits that the investment would provide.

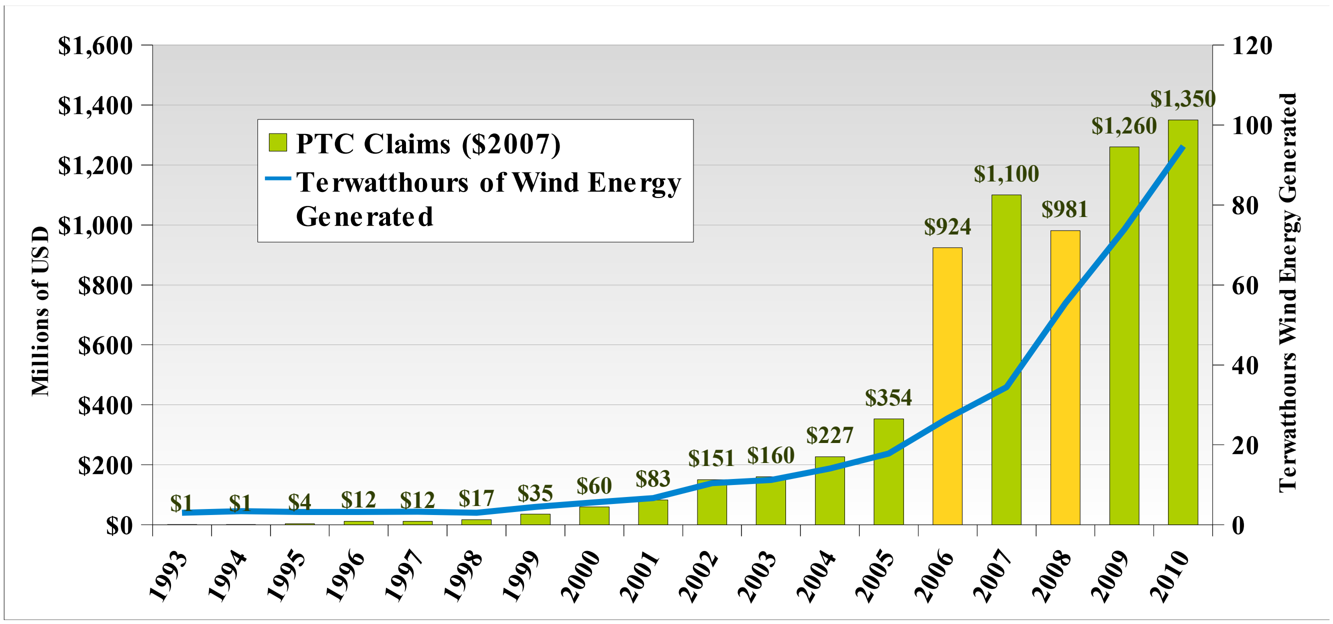
The value of the PTC is ultimately based on the output of a given wind project however, and as projects can easily range in size from a handful of turbines into the hundreds, and cost millions or even

88 Or alternatively, the total value of the ITC can be provided as a grant.
89 Sherlock records $1.1 billion in ITC expenditures between 2000 and 2009 ($2010 dollars).

billions of dollars to complete, it is difficult to know what the exact value of the PTC has been. Wiser, et al. (2007, p. 13) estimated that the cost of the PTC between 1994 and 2007 was $2.7 billion, with up to $2.2 billion in 2008 and 2009. While the PTC supports a variety of technologies, Wiser et al. (2007) point out that wind energy claims represent about 90 percent of the cost of the PTC through 2004 (p.13).[90]

By way of comparison, they point out that federal subsidies for energy cost about $75 billion in 2006, "with over 85% of those subsidies going to fossil fuels ($49 billion), nuclear energy ($9 billion), and ethanol ($6 billion)" (ibid, 2007, p.13). Figure 4.2, below, clarifies these estimates to reveal that use of the tax credit reached $1 billion annually sometime between 2006 and 2007. Expenditures are plotted against wind energy generation, and do not appear to track in a linear way.

Fig. 4.2 PTC Claims in Millions of 2007 Dollars*



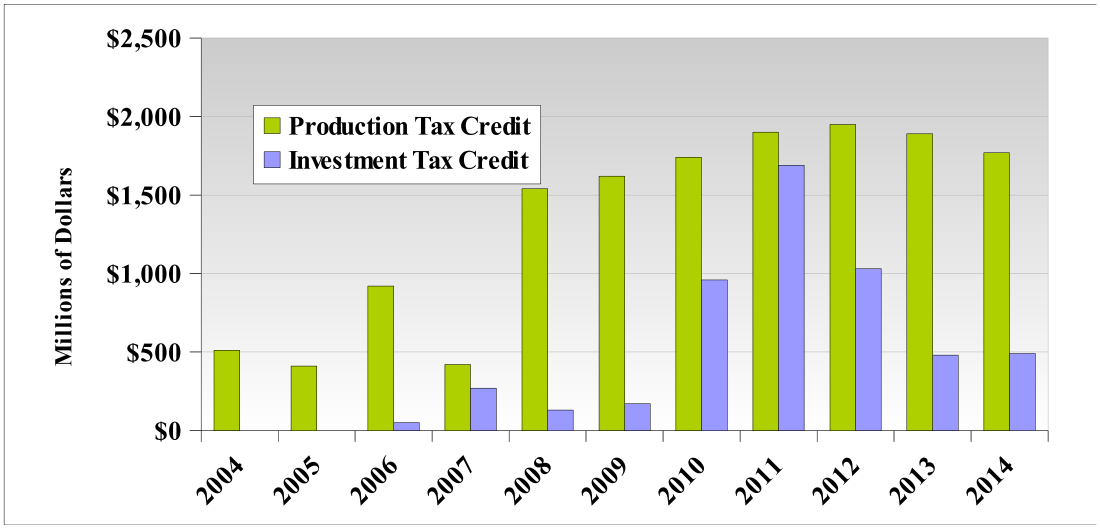

Sources:(1) Sissine, Fred. "Renewable Energy: Background and Issues for the 110th Congress." *Congressional Research Service*. 10 Dec 2008. Web. 27 Mar 2012. http://www.policyarchive.org/handle/10207/bitstreams/19190.pdf
(2) Sherlock, Molly. "Energy Tax Policy: Historical Perspectives on and Current Status of Energy Tax Expenditures." *Congressional Research Service*. 2 May 2011. Web. 23 Mar 2012. http://www.leahy.senate.gov/imo/media/doc/R41227EnergyLegReport.pdf
(3) United States. Department of Energy. "Table 8.2a Electricity Net Generation: Total (All Sectors), 1949-2010 (Sum of Tables 8.2b and 8.2d; Billion Kilowatthours)." *Energy Information Administration*. 9 Nov 2011. Web. 27 Mar 2012. http://www.eia.gov/electricity/annual/
*For 1993 and 1994 (not shown), PTC claims were less than $1 Million.
*2006 and 2008 PTC claims are estimates and the bars are yellow.

As shown in figure 4.3 below, PTC claims after 2005 are expected to cost taxpayers up to in excess of $5 billion (in 2007 dollars), which is a small amount considering that numerous technologies benefit from them, even as wind energy currently dominates the distribution of the benefit. Based on

90 The PTC is not exclusive to wind energy. Since 1992 qualifying technologies have also included Landfill Gas, Biomass, Hydroelectric, Geothermal Electric, Municipal Solid Waste, Hydrokinetic Power, Anaerobic Digestion, Small Hydroelectric, Tidal Energy, Wave Energy, and Ocean Thermal. The rate of payment varies and, it should be noted, fossil fuels also receive similar benefits, albeit paid for out of a separate government fund.

Sherlock's (2011) figures, the total cost of the ITC and PTC has been approximately $12.2 billion ($2010 dollars) between 1979 and 2010. The ITC taken in grant, rather than tax credit form, adds $5.3 billion ($2010 dollars) to this figure (Sherlock, 2011, p.35). Unless

Fig. 4.3 Projected PTC Expenditures, 2004-2014




Source: United States. Analytical Perspectives, Budget of the U.S. Government Reports, Various years. Office of Management and Budget.

About $18 billion was invested in wind energy projects in the United States between the 1980s and 2006 (Harper, et al, 2007, p.1). About 72 percent of this investment, or $13 billion, occurred in the ten years between 1996 and 2006, and $4 billion occurred in 2006 alone (Wiser, et al., 2007, p.3). In 2006, about 2,600 MWs of new wind capacity was added to the grid. New wind capacity doubled for 2007, reached 8,300 MWs in 2008 and almost 10,000 MWs in 2009 before the financial crisis caught up to the industry, reducing 2010 to about 5,000 MWs. 2011 has since shown some recovery to 7,000 MWs. In dollar terms 2007 represented about $9 billion invested, growing to $17 billion in 2008 (Schwabe, Cory, Newcomb, 2009, p.1). About $20 billion was spent in 2009 and $8 to $10 billion in 2010. The amount of money being invested in new wind projects has vastly outpaced public expenditures so far mentioned.

Considering the negative or small annual additions to wind capacity in the United States in the period of 1988 to 1997, it is clear that the PTC has been a critical part of the attraction of capital to the wind industry. The industry otherwise may have been trapped re-powering existing projects or awaiting technical advances before economic viability was sufficiently improved to convince investors to take the risk. PTC expenditures have already crested the $1 billion mark annually and will likely continue in this direction.[91]

Wind energy must also compete with other economic sectors which have tax credits to distribute. Bloomberg New Energy Finance (BNEF) estimated that $2.4 billion in tax equity financing would be needed for wind projects in 2012. Including the needs of a broader range of renewable projects places this requirement at $7 billion, "[exceeding] the investment appetite of the established tax equity providers" (BNEF, 2011, p.1). However, BNEF also adds that about $137 billion in tax

91 A 2.2 cent/kWh PTC works out to $22 dollars/MWh $220 dollars/GWh and $2,200 dollars/TWh.

liability exists in the United States, suggesting that the real challenge may lie in courting new tax equity investors into renewable energy projects (ibid, p.8). With the economic attractiveness of the PTC closely associated with project performance however, it is unclear how the rate of return for a wind project compares to rates of return for investments in affordable housing, which BNEF points out is also a popular source of tax credits to investors.

The uncertain frequency of tax credit extensions combined with finance challenges contributes to a boom and bust cycle of development, wherein wind capacity additions can smash records one year and flop the next. In addition, reliance on tax credits lash wind companies to the tax appetites of potential funders. In economic downturns such as the one currently playing out in the United States, demand for tax credits evaporate as profits decline and political and market instability take hold.

As a result, wind projects can face higher costs or longer delays. Independent power producers may find themselves squeezed out of the competition for new projects as well, as better capitalized developers manage to complete their projects while they must wait for a more bullish investment environment to develop. Many wind developers are also too small and generate too little profit to utilize the tax credits they create for themselves.

Less discussed but available from 1986 onward is The Modified Accelerated Cost Recovery System (MACRS) which allows wind projects to claim 100 percent depreciation over just 5 years. This allows for a faster recapture of some of the development costs of wind projects and is a boost to a project's bottom line. The MACRS, like the PTC, is not exclusive to wind power. Many technologies benefit from some form of accelerated depreciation, such as solar thermal, solar P/V, geothermal, and fuel cell technologies.[92]

Wind projects are currently allowed to claim 100 percent depreciation in just 5 years. In 2008, wind projects became eligible for 50 percent bonus depreciation for the first year of installation. In 2011, 100% bonus depreciation became possible. For 2012, the bonus rate is reduced to 50 percent bonus depreciation. From the year 2000 through 2010, however, this represented a $800 million expenditure (Sherlock, 2011).

## *State Policy Overload*

The United States federal government lacks obvious national energy policy goals as well as the political will for more direct action into the formation and support of new energy technologies and evolution of the energy grid. As a result, policy leadership has tended to passively defer to state level actions for the promotion of renewable energy.[93] This has its intelligence. Energy resources vary regionally, and state policy strategies can respond to the needs, challenges, and opportunities in a more direct way. Deregulated power markets, while not sidestepping the material reality of electron travel, provide a means for states to source their energy from virtually anywhere.

As both the character and the needs of the industry have shifted following its still somewhat

92 Typically periods of 3 to 50 years are considered when determining what rate a given technology (asset) is allowed to depreciate. In the case of wind, 5 year depreciation is aggressive considering that project life spans are 20 to 30 years.

93 DSIREUSA.org is a fantastic repository of regulation and incentive information regarding renewable energy in general. There are currently literally over a thousand different rules, regulations, and policies related to renewables, though many relate in different ways, the overall number makes it difficult to analyze.

short history, states have increased the number and range of policy tools for renewable energy development. One of the most important policies have been Renewable Portfolio Standards (RPS) which create demand for renewable energy generation within state borders. RPS policies vary widely in definition and execution, making direct comparison difficult.[94] The first RPS policy in the country was put into place in 1983 in Iowa, which mandated 105 MW of new capacity for the state, and indeed this capacity was eventually given to wind developers. Minnesota was the second state to institute an RPS in 1994, then Arizona in 1996.

From there, the rate of RPS adoption began to cascade, which table 4.2 below, shows in detail. Institution of RPS policies has coincided with creation of Renewable Energy Credits (RECS) which represent proof of contribution toward RPS goals. Wind developers can raise project financing through the sale or trade of RECs.[95] As discussed below however, the value of RECs can be volatile and not all states allow for their trade across state borders.

It would take a massive paper to examine the relationship between regional and state level incentive programs and to analyze how they might interact with existing federal programs to generate investments in renewable energy which might not otherwise occur. Many RPS policies have also been revised several times throughout the years which makes proving a relationship between the strength of the policy and outcomes in the state difficult—though it seems clear that states which adopted policies do in fact develop more renewable energy than states which do not.

Understanding the impact of the RPS is a challenge as it requires comparing individual state RPS targets to actual state outcomes based often on estimates. During the Great Recession, for example, the slowdown in economic activity reduced overall demand for energy. If the reduction in energy demand resulted in taking some fossil power off the grid temporarily, it could make it appear as though a given state were closer to its RPS target. In a sense, a state RPS policy only makes sense under the assumption that the demand for energy will always rise. Obviously, many other factors can influence a state's changing energy mix, most notably efforts to promote greater energy conservation.

Grasping the impact of RPS policy also requires a discussion of RECs, which many states also define on their own. In the most basic sense, when RECs are issued and sold they represent proof of compliance with RPS targets. RECs can be sold bundled or unbundled to the sale of electricity in order to raise capital for developers completing projects, however the value of both RECs and the value of this practice varies. In effect, some states allow generators to trade RECs within state and regional markets while other states allow RECs to be sold both regionally and nationally.

According to the DOE, “buyers of nationally sourced voluntary RECs are often large corporations that have facilities in multiple locations across the country” (DOE, Green Power Networks, 2011). The Environmental Protection Agency (EPA) maintains a list of major corporate green power purchasers in the United States. Currently the largest buyer of green energy in the country is Intel, but this list also includes Kohl's, Whole Foods, the City of Houson, Texas, Starbucks, Staples,

94 The aggressiveness of goals vary and the wording can change to reflect different assumptions about what constitutes renewable or clean energy. Pennsylvania, for example, provides for waste coal or liquid coal to contribute to its “alternative energy portfolio standard”. For 2011, 8 States will have enacted voluntary standards wherein stated goals are not binding. I use RPS as a descriptor for all state laws, compulsory or voluntary, which influence development of renewables.

95 REC markets are still very new, and will be discussed in greater detail below.

Lockheed Martin, the University of Pennsylvania, Dell, Nokia, Cisco, Sony, and others.[96]

Table 4.2 RPS Policy additions by year Enacted, 1983-2012

| Year | States With a RPS | States Adding a Mandatory RPS Goal | Name of State(s) | States Adding a Voluntary Goal | Name of State(s) | Total U.S. Capacity (MWs) |
|---|---|---|---|---|---|---|
| 1983 | 1 | 1 | Iowa | | | 18 |
| | | | | | | |
| 1994 | 2 | 1 | Minnesota | | | 1,663 |
| 1995 | | | | | | 1,612 |
| 1996 | 3 | 1 | Arizona | | | 1,614 |
| 1997 | 6 | 3 | Massachusetts; Maine; Nevada | | | 1,611 |
| 1998 | 8 | 2 | Pennsylvania; Connecticut | | | 1,837 |
| 1999 | 11 | 3 | Wisconsin; Texas; New Jersey | | | 2,490 |
| 2000 | 12 | 1 | New Mexico | | | 2,578 |
| | | | | | | |
| 2002 | 13 | 1 | California | | | 4,685 |
| | | | | | | |
| 2004 | 18 | 5 | Colorado; Hawaii; Maryland; New York; Rhode Island | | | 6,725 |
| 2005 | 21 | 3 | Wash D.C.; Delaware; Montana | 1 | Vermont | 9,149 |
| 2006 | 22 | 1 | Washington | | | 11,575 |
| 2007 | 26 | 4 | Illinois; North Carolina; Oregon; New Hampshire | 2 | Virginia; North Dakota; | 16,824 |
| 2008 | 29 | 3 | Missouri; Michigan; Ohio | 2 | South Dakota; Utah | 25,237 |
| 2009 | 30 | 1 | Kansas | 1 | West Virginia | 35,159 |
| 2010 | | | | 1 | Oklahoma | 40,180 |
| 2011 | | | | 1 | Indiana | |
| 2012 | | | | | | |
| **Total** | | **30** | | **8** | | |

Sources:(1) Author's table from DSIREUSA.org database review. Last update Mar 2012.
(2) Earth Policy Institute, Global Wind Energy Council

In many cases companies, schools, or municipalities are genuinely interested in being connected to the positive image which environmental sensitivity provides. In other cases, it could be a form of "green posturing" - a relatively inexpensive way for a firm to project an environmentally friendly image, despite their shipping of toxic e-waste abroad. Even the U.S Airforce makes the list, hinting at the military's growing interest in rapid adoption and deployment of clean technologies. When Google invests in wind projects, one assumes that their ability to absorb tax credits doesn't hurt.

Still other companies like Pepsi that were once chart toppers as long ago as 2007 have either abandoned the program or as of late fallen off the top 50 roster.[97] Closely associated with REC markets are Greenhouse Gas (GHG) or carbon ($CO_2$) reduction schemes in which energy marketers or other businesses sell carbon offsets to companies based on a portfolio of renewable or green energy resources they maintain. In either case, the expectation is that commodification of environmental benefits and

96 Intel leads in the aggregate, purchasing 88 percent of its 2,502 GWh (2,201 GWh) from green sources. There are many companies that obtain 100 percent of their energy from renewable sources, and use much less energy for that matter. Kohls leads with 1,420 GWhs and is followed by Whole Foods with 752 GWhs. All figures are derived from the EPA's July 2011 listing. Major sources of energy included in the purchase programs are Wind, Solar, Biogas, and Biomass.

97 In the Spring of 2010, Pepsi announced that they were dropping out of the REC market because of changing "investment priorities." In effect, the company is now putting $30 million (between 2010 and 2013) into renewable energy projects in the United States which likely provide a better return. Rob Schasel's April 9, 2010 statement can be read at Greenbiz: http://www.greenbiz.com/blog/2010/04/09/why-pepsico-changing-renewable-strategy

pollution can be used as a market solution for biasing current and future business development decisions toward environmental sustainability.

This practice will hopefully produce a net benefit to the environment, rather than simply giving those that can afford it an option to "opt out" of solution seeking. Likewise, it should lead to real investment and not provide for the the exploitation of speculative gain. Such trading schemes may give businesses and consumers incentives to invest in green technologies like wind energy. For now, it is still a challenge to grasp the size of the REC market which is still relatively new. Holt and Bird (2005), estimated that the value of compliance and voluntary REC markets existing in 2004 was about $155 to $185 million, growing to $700 to 900 million by 2010 (p.65).[98] Their figures are based on estimated power sales of 11 to 16 million MWhs in 2004 and 65 million MWhs in 2010.

Bird et al. (2009) estimates that 8.5 million MWhs of clean energy were sold in 2005 and 24.3 million MWhs were sold in 2008. They estimated the above-market value of clean energy sales in 2008 to be "between $110 and $190 million" (p.3).[99] This was driven mainly by nonresidential customers and REC purchases (ibid, p.4). The sale of wind energy-sourced RECs represented 70 percent of green power sales in 2008 (ibid, p.3).

In her updated report Bird and Sumner (2010) estimated 30 million MWh of renewable energy sold and noted that above market green power costs in 2009 were "between $136 million and $236 million" (p.3). Wind energy represented 74 percent of this renewable energy. Thus as more state RPS policies are factored in and more renewable energy projects come online, the value of REC trading (and other green power projects) is increasing. There are a wide range of estimates however, and as we will discuss, States will have a very important role in influencing the value of RECs through their RPS policies.

## *Examples of State RPS Outcomes*

California led the U.S. in wind energy production for a number of years in absence of a defined RPS, which it adopted in 2002. As we discussed earlier, a combination of factors contributed to the state's leadership. This included active R&D support at the federal level stoked by a national energy crisis, early knowledge of high quality wind resources, generous tax incentives, a favorable political climate, and at least one company with access to technology developed by the University of Massachusetts, and another with access to Danish technology. All these factors partly explain California's rapid renewable energy development in the early 1980s and the emergence of U.S. manufacturers of wind turbines.

According to Holt and Bird (2005) California also originated the idea of using RECs to separate

98 For 2004 the variation in these figures is due to a compliance market range of 8 to 13 million MWh, accepted as $140 million and a 3 million MWh voluntary market adding $15-$45 million in value. For 2010, estimated compliance markets represent 45 million MWhs and $600 million in value added to an estimated voluntary market of 20 million MWhs ranging in value from $100 to $300 million.

99 Bird's figures include sales from REC markets, Competitive markets, and Utility Green Pricing and thus do not have parity with the aforementioned figures. That said, REC based purchases have typically represented 45% to 62% of the energy sold between 2005 and 2009, per her own estimates and data. That share of the total value represents steady growth each year in the share of value generated by RECs. Bird adds that because not all market participants supply data, her estimates are conservative.

markets for renewable electricity with markets for environmental benefits in the mid 1990s (p.7). California maintained much of its early wind energy development but lost national leadership in 2006 to Texas, then fell behind Iowa in 2008. In 2008 California revised its RPS goal to demand 33 percent renewable energy by 2020 as opposed to an original target of 20 percent by 2017.[100] In 2001, the state received about 24 percent of its energy from renewable sources. As of 2009, the state's combined renewable electrical resources represented about 26 percent of its electrical generation.[101] The most clear contributor to the gain in the share of renewable electricity is wind energy, which was 7 percent of all renewable energy in 2001 and 11 percent of all renewable energy in 2009.

In 2009, The California Public Utilities Commission (CPUC) estimated that a total expenditure of about $16 billion in new transmission lines would be necessary to support what would the tripling of renewable energy generation set by its 2020 RPS target. In addition, the state forecasted energy prices to increase by 16.7 percent regardless of whether or not generation was sourced from renewables (CPUC, 2009, p.1). The cost of energy is partly influenced by the mix of technologies used to meet the RPS target. On this note Solar P/V technologies are forecast to provide a growing share of the state's RPS mix in the future, while wind is expected to peak at approximately 30 percent of the renewable energy mix according to CPUC projections ("RPS Program Update", *cpuc.ca.gov*, 2010).

Since 2003, 1,701 MWs (or about 40 percent) of new renewable capacity in California has come from out of state, while 2,587 MWs of new capacity has been developed in state, suggesting that the state's RPS goal has promoted some reliance on new capacity developed elsewhere in meeting its targets. California began allowing for tradeable RECs in March of 2010.[102] Until the end of 2013, RECs created in California are capped at $50 per credit. At this time then, it would seem that many of the advances in the state's renewable energy mix would not be a result of the marketability of RECs.

Texas, on the other hand, has maintained a low REC trade value for a number of years despite continuing to lead the nation in terms of capacity expansion. This is because the state's RPS requirement for 5,880 MWs of new renewable energy capacity by 2015 was surpassed in 2005, and its current capacity of about 10,000 MWs has already surpassed the target set for 2025 (*Center for Energy Economics*, 2009, p.1). Texas RECs are unbundled, meaning that while most new capacity was built in the west of the state, the RECs generated by projects could be sold anywhere, allowing Texas to meet its RPS requirement without having to purchase all of the wind electricity it actually generated.

The success of Texas' wind energy build out has run up against transmission constraints, making additional capacity expansion difficult and potentially unreliable.[103] The Center for Energy Economics add, in their survey discussion, that many commenting on the success of the Texas RPS policy emphasize the importance of the PTC over the RPS itself for providing the incentive to invest in new renewable capacity. They also highlight that little diversity in renewable investment occurred as a result

100 California's goal, like many other states, is based on retail sales of electricity. States like Maine have required that 10% of new capacity be renewable by 2017. The difference is subtle, but important. California does not necessarily need to develop local renewable resources in order to meet its target, while Maine does.

101 These figures include Hydroelectric, Wind, Solar, and Biomass technologies. Non-Hydro renewables represented 11% of electric renewable generation in 2001 and 12.5% in 2009. Only certain qualifying hydro sources may contribute to the state target.

102 Tradable RECs are allowed to change ownership several times before actually contributing to state RPS compliance.

103 Wind developers "routinely submit negative bids in order to get dispatched and collect PTC and REC revenues" (Center for Energy Economics, 2009, p.1). This means developers are accepting negative energy revenues in order to continue capturing PTC and REC benefits (ibid, p.19).

of the RPS and that energy transmission restraints are limiting the performance of future investments.

It is unclear, in other words, to what extent the speed in which Texas has met its requirements was a result of their mandate versus, for example, the quality of their wind resources and the value of tax credits they could create. Given that transmission build out is still regulated in the United States, it is also unclear how transmission constraints can be lifted fast enough for the state's enthusiasm for wind energy to continue. Asking ratepayers to absorb the cost of new lines that primarily benefit wind developers might not suit everyone.

Like California achievement of Massachusetts' RPS target is based on sales. Massachusetts goes a step further however, specifying that 15 percent of energy sales be derived from *new* renewable energy sources by 2020 with an annual increase of 1 percent thereafter. Currently, there is no ceiling to this annual increase. In 1998, the year following the decision to adopt an RPS, Massachusetts derived 6.8 percent of its electricity from renewable energy. In 2002, the first year of compliance, this figure was 5.1 percent. In 2009 Massachusetts derived approximately 6.2 percent of its electricity from renewables and must more than double this value in less than a decade in order to reach its initial target.[104]

Partly because of this reality, renewable energy generators can command high prices for RECs, which peaked at just over $50/MWh in late 2007 and dropped below $20/MWh in 2010 (Holt and Bird, 2011). Massachusetts experienced a shortage of RECs between 2003 and 2006, but REC supply exceeded demand between 2006 and 2009. Massachusetts allows Alternative Compliance Payments (ACPs) to be paid to the Massachusetts Center for Clean Energy as a substitute for acquiring Class I RECs.[105] This added up to about $52 million in payments between 2003 and 2008.(Mass Dept of Energy Resources, 2010, p.10)[106]

Class II RECs in Massachusetts are directed at renewable capacity already existing prior to 1998, and generated $13.9 million in compliance payments (Mass Dept of Energy Resources, 2010, p.16). Massachusetts requires that a portion of energy come from such pre-existing renewables. Alternative Portfolio Standard compliance resulted in $890 thousand in the class II market (ibid, p.19). ACPs are generally more expensive than RECs, helping discourage “opting out” of renewable energy development or purchase by electricity suppliers.

An explanation for the change in REC prices, despite little change in the state's overall energy composition, is that the RPS requirement in Massachusetts can be met by the purchase of RECs from other states which generate renewable energy. For 2009, about 64 percent of combined RPS compliance was purchased in REC markets from Maine, New Hampshire, and New York. Massachusetts generators supplied just 9.3 percent of RPS Class I compliance (ibid, 2010, p.12).

Increasingly, Massachusetts is obtaining RECs from outside its own ISO-NE grid to make up

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104Information about Massachusetts's energy mix is from the EIA's State Profiles: http://www.eia.gov/cneaf/solar.renewables/page/state_profiles/massachusetts.html

105In 2009, no ACPs were purchased to help meet compliance. In 2005 however, $19.6 million were purchased. About $52 million in ACPs were purchased between 2003 and 2008 ( Department of Energy Resources Executive Office of Energy and Environmental Affairs, Massachusetts, 2010, p.10). Currently, one ACP costs about $60/MWh.

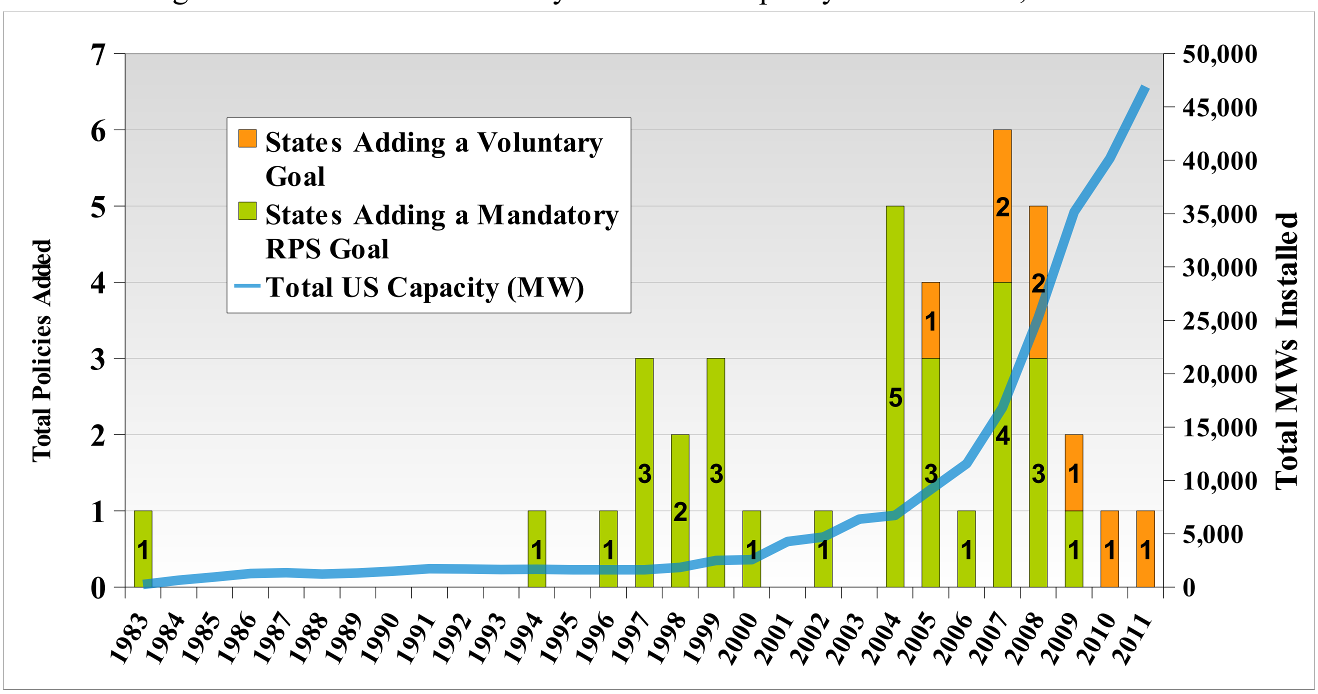
106Different rates are charged for Class I renewables ($61/MWh), Class II renewables ($20/MWh) and Class II Waste Energy ($10/MWh). The alternative portfolio standard (APS) allows for certain coal and steam technologies.

for a lack of more local investment in renewables. RECs primarily came from power purchased in New York and Canada in 2009 (ibid, 2010, p.14). State compliance has thus been met with a mixture of ACPs, and from using both new and banked RECs obtained from previous years.[107] The technologies contributing the most to the state's current compliance are wind energy (37 percent), landfill gas (32 percent), and biomass (27 percent). While Massachusetts makes the cost of compliance with RPS requirements less expensive than paying ACPs, it is currently dependent on renewables development taking place in other regions in meeting its RPS.

## *Gaging the Success of the RPS for Wind Energy Development*

Twenty-nine states plus Washington D.C. currently use some form of a mandatory RPS policy. Eight states have a voluntary standard or one which allows for non-renewable energy sources to contribute to state energy goals. Thus 37 states have adopted a policy in one form or another. Among the 11 states adopting an RPS requirement before the year 2000, only Texas (1999), Iowa (1983), and Minnesota (1994) are part of the country's current top 10 wind states based on capacity alone. Four states in the current top 10 adopted RPS policies after 2000. The list includes California (2002), Oregon (2007), and Illinois (2007). North Dakota (2007) and Oklahoma (2010), also in the top 10, created voluntary standards after having already experienced significant wind development. Figure 4.5 below shows that RPS adoption seems to have peaked in the years 2004 to 2008, which roughly corresponds with rapid expansion of wind capacity in the country.

Fig. 4.4 State RPS and Voluntary Goals with Capacity Trend Plotted, 1983-2011




Sources: (1) DSIREUSA.org. "Rules Regulations & Policies for Renewable Energy." Accessed Jul 2011.
(2)United States. Department of Energy. "State Historical Tables for 2010." *Energy Information Administration*. 9 Nov 2011. Web. 28 Jan 2010.http://www.eia.gov/cneaf/electricity/epa/epa_sprdshts.html
*Washington D.C. Is included in 2005 data

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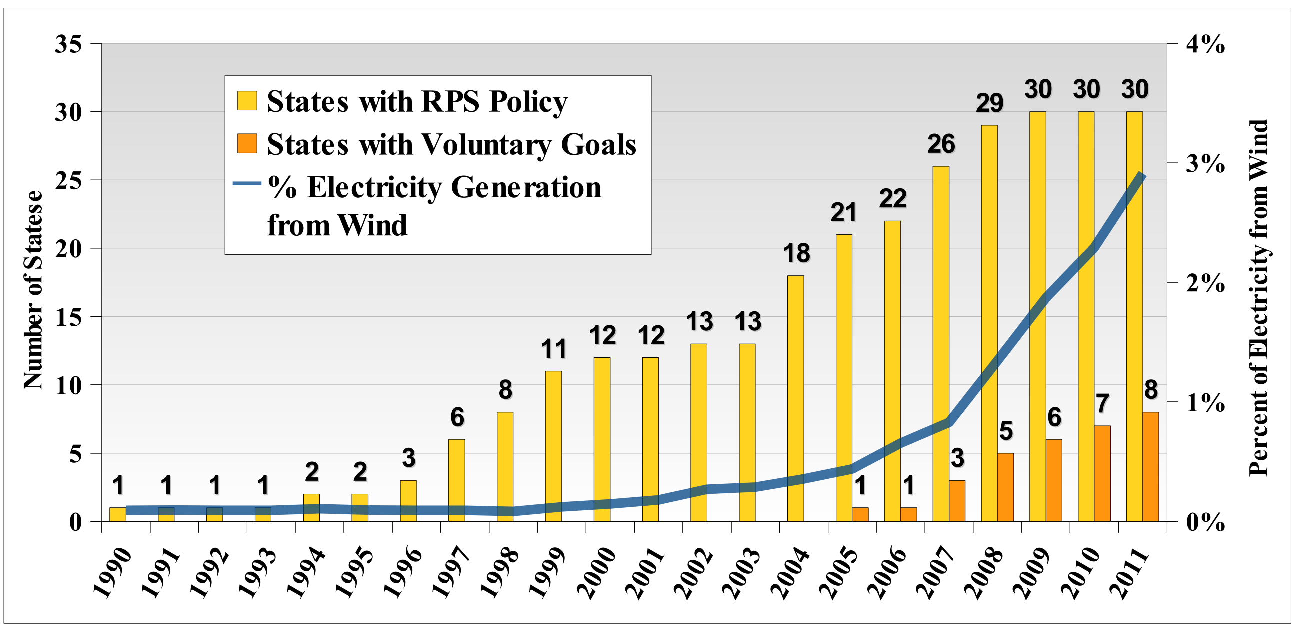
107190 GWhs of "banked" RECs were added to 2,130 GWhs to meet compliance, suggesting that surplus RECs would tend to be a small portion of the RECs used to actually meet compliance.

23 percent of Iowa's electric capacity was based on wind power in 2009, surpassing its Alternative energy law requirement back in 1999.[108] North Dakota adopted a voluntary standard in 2007, and has seen its wind capacity penetration almost doubling every one to two years, reaching 20 percent back in 2009. Wyoming, the third place holder, has neither a mandated nor a voluntary RPS policy in place and has achieved 14.6 percent wind capacity penetration. Four other state leaders all adopted policies after 2006 and have wind energy penetrations in the range of 6 to 12 percent. As noted earlier, Texas met its RPS goal of 10,000 MWs 15 years ahead of schedule and has thus managed a 9.5 percent wind capacity penetration.

Figure 4.5 below plots the total number of states with RPS policies against the overall percentage of electricity derived from wind power in the United States. In the 1990s, the amount of energy generated from wind power was negligible. In 2011, the latest year which data is currently available, national penetration of wind energy reached roughly 3 percent.

Fig. 4.5 RPS and Voluntary Goal adoption plotted with Percent of Energy Generation from Wind Energy, 1990-2011*




Sources: (1) DSIREUSA.org. “Rules Regulations & Policies for Renewable Energy.” Accessed Jul 2011.
(2) Author's calculations from United States. Department of Energy. “Table 2.1.A. Net Generation by Energy Source by Type of Producer, 1999 through 2010.” and “Table 2.1.B. Net Generation by Selected Renewables by Type of Producer, 1999 through 2010.” *Energy Information Administration*. 9 Nov 2011. Web. 27 Mar 2012. http://205.254.135.7/electricity/annual
*”States with Mandatory RPS Policy” includes Washington D.C.

With more states interested in supporting renewable energy development, it would appear that some change in the United States is beginning to occur.

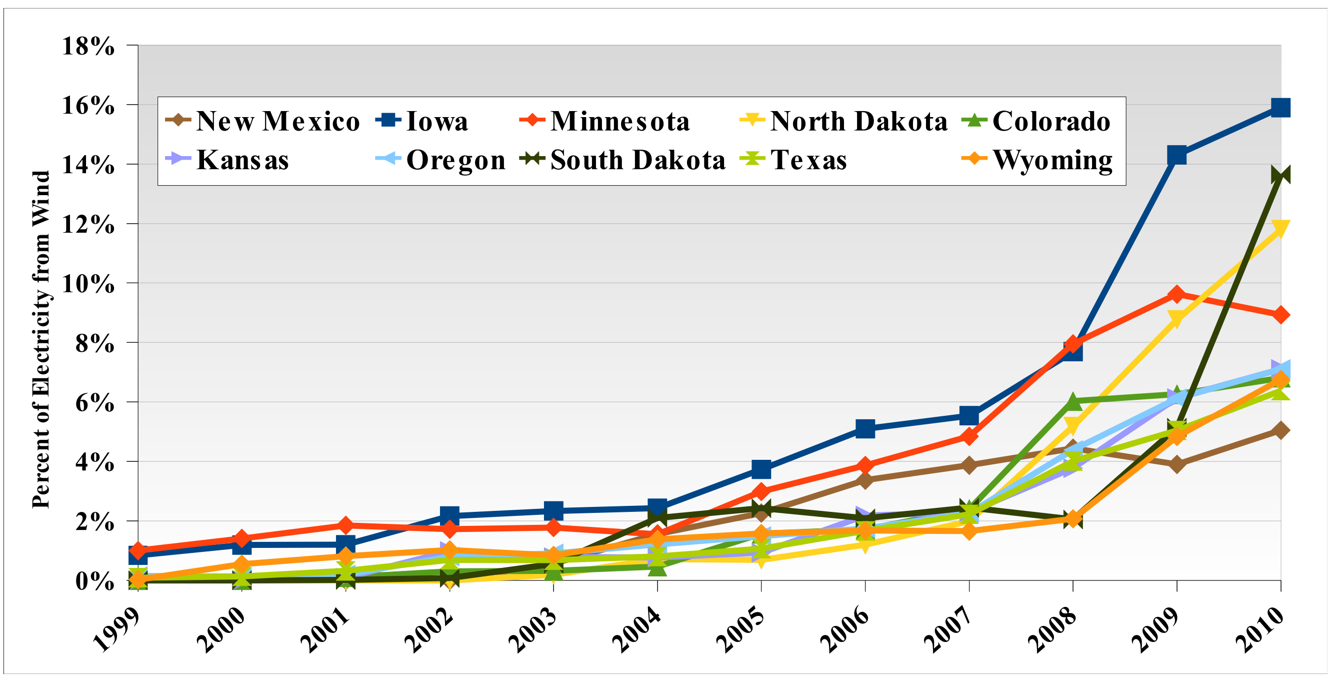
Figure 4.6 compares the top 10 states based on the percent of state energy that is derived from wind. We can see that Texas, for example, rapidly doubled its wind generation between 2007 and 2008,

108Generally speaking, the total penetration of wind capacity will exceed actual electric generation. 14.3% of Iowa's electricity was based on wind in 2009.

reaching about 6 percent and appearing to level off between 2008 and 2009. Minnesota has seen relatively steady growth while Iowa took off after 2008. South Dakota adopted a voluntary goal in 2008 and achieved a meteoric jump from 5 to 14 percent between 2009 and 2010. Changes to the state energy mix of our leading states seems relatively flat for a number of years but has since 2005 and especially 2007 shown a lot of momentum. These ten states are now generating somewhere between 5 and 16 percent of their electricity from wind in 2009.

It is unclear to what extent RPS policies used by states are managing to drive new investment in renewable energy technologies, and wind energy in particular. Some of the examples covered have shown, however, that wind energy has been a key contributer to state compliance. Other technologies, like solar energy, will play a larger role in the future. For now, it would seem that RPS policies have helped wind developers find new markets and the use of wind power is more widespread as a result. It is still early to attempt to judge the effectiveness of policies like the RPS, in part because associated REC markets are still relatively new and because targets are still a decade or more away.

Fig. 4.6 Wind Electricity as a Percentage of Total State Electric Generation, Selected States 1999-2009

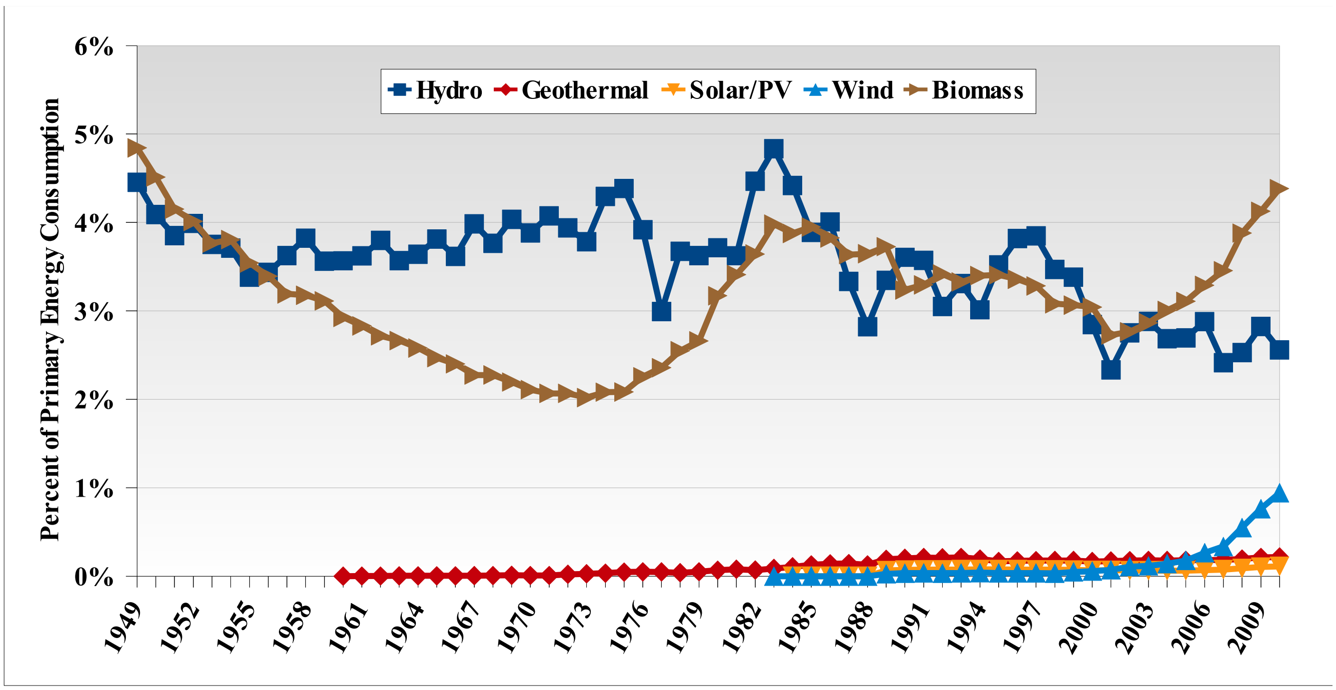



Source: Author's calculations, United States. Department of Energy. “Net Generation by State by Type of Producer by Energy Source.” *Energy Information Administration*. 9 Nov 2011. Web. 27 Mar 2012. http://www.eia.gov/electricity/data/state/

RPS policies represent an attempt deliver a market-based solution to much needed structural changes in the energy grid. The goal of the various state RPS programs, taken in consideration with federal incentives we have examined, are to stimulate investment and influence development of a broad range of energy technologies which are not limited to wind turbines. They impact the energy planning process and ensure that renewables will play a part. The number and variety of state RPS policies creates a complex regulatory environment and it appears that has so far they have not stimulated a great deal of increased energy diversity. Like key subsidies to renewables, they are also at political risk, capable of being re-defined or abandoned after each election cycle.

All renewable energy made up approximately 8 percent of the nations primary energy consumption in 2010. As shown in figure 4.7 below, Biomass and Hydro technologies have tended to be dominant energy technologies in the primary consumption of renewable energy.[109] On closer examination, solar and wind energy have begun to gain slightly in their shares of renewable energy consumption. In the case of wind energy, it would seem a noticeable increase in share has occurred. Electric net generation has increased in the United States at a rate of about 0.7 percent annually between 2000 and 2011, while wind energy electric net generation has averaged closer to 186 percent annual growth over the same period.

Fig. 4.7 Renewable Energy as a Percent of Total Primary Energy Consumption, 1949-2009




Sources: Authors Calculations. United States. Department of Energy. “Table 1.1 Primary Energy Overview, 1949–2010” and “Table 10.1 Renewable Energy Production and Consumption by Primary Energy Source, 1949–2010.” *Energy Information Administration*. 19 Oct 2011. Web. 10 Aug 2011. http://www.eia.gov/totalenergy/data/annual/index.cfm#summary

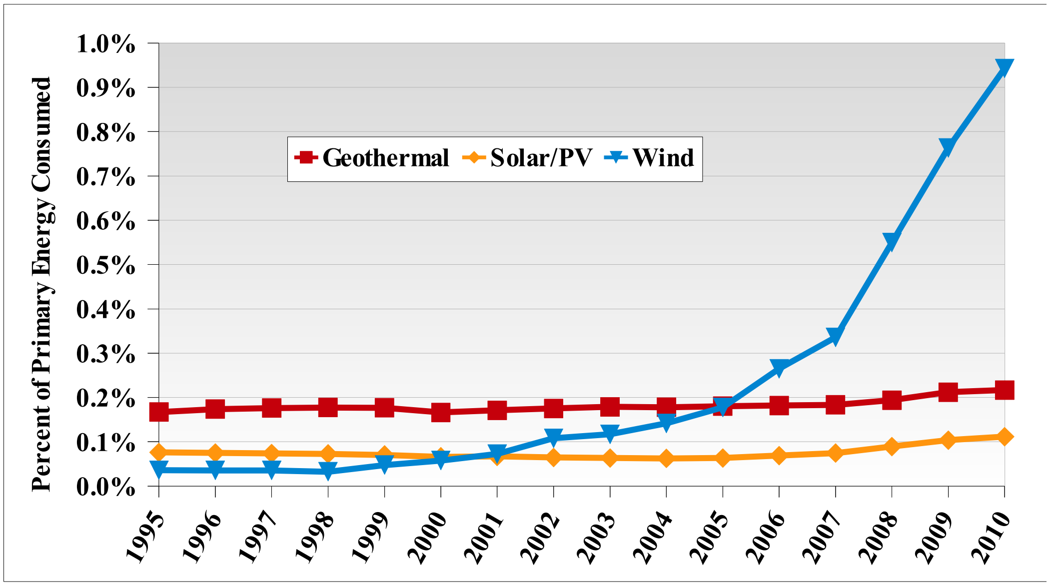
Even assuming that the United States froze at its 2009 level of about 4 billion MWhs of electric generation per year, it would take seven times the current amount of wind energy electric generation to approach a 20 percent penetration.[110] If wind energy is to provide 20 percent of all *primary energy consumed*, it would need to increase 20 fold from its 2010 levels. Should this become the goal, it is clear that there is ample room for growth of the wind industry.

109According to the EIA: Primary Energy is “energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy. For example, coal can be converted to synthetic gas, which can be converted to electricity; in this example, coal is primary energy, synthetic gas is secondary energy, and electricity is tertiary energy.” See the glossary here: http://www.eia.gov/tools/glossary/index.cfm?id=P

110The figures from which these values are derived are based on the EIA's “Table 1.1. Net Generation by Energy Source: Total (All Sectors), 1998 through January 2012” and “Table 1.1.A. Net Generation by Other Renewables: Total (All Sectors), 1998 through January 2012.” *Energy Information Administration*. 27 Mar 2012. Web. 28 Mar 2012. http://www.eia.gov/totalenergy/data/annual/index.cfm#electricity

It would also seem reasonable to believe that RPS policies have increased the number of tools that states have to encourage wind development. These policies, when aggressive, can also send a strong signal to investors that viable markets for wind energy will last into the future. In looking at the basic statistics however, it is clear how powerful a national target could be.[111]

Fig. 4.8 Percent of Primary Energy Consumption Attributable to Solar, Geothermal, Wind 1995-2009




Sources: Authors Calculations. United States. Department of Energy. "Table 1.1 Primary Energy Overview, 1949–2010" and "Table 10.1 Renewable Energy Production and Consumption by Primary Energy Source, 1949–2010." *Energy Information Administration*. 19 Oct 2011. Web. 10 Aug 2011. http://www.eia.gov/totalenergy/data/annual/index.cfm#summary

While it is unclear how widespread and effective RECs are at generating project capital, it is clear that the value of REC sales can play a significant role in project finance in states where its value is high. It also allows some states greater flexibility in achieving their RPS targets given the challenge of large scale local developments which may or may not have much political or business support, and which may seem at this early juncture to benefit wind energy more than other technologies. Perhaps most important, not all states are blessed with a large amount of wind or solar resources.

States like Pennsylvania and Iowa host strong coal and ethanol industries and likely want to balance the potential for political and economic struggle against the choice of supporting renewables more aggressively. Sometimes it is also prudent for states to be conservative, watching the development process unfold in other states rather than assuming the role of trailblazer. Growth in wind capacity and electricity generation has also coincided, as we have noted, with longer term and uninterrupted subsidy by the PTC and ITC. These incentives required innovations in the finance of wind projects large and small, which we cover in the next section. In effect, none of these policies are effective until a process of organizational learning is complete at all levels of activity.

The PTC and ITC have been relatively uninterrupted since 2006 and greater diffusion of

111I have not attempted to calculate the aggregate value of all state RPS policies and their impact on energy levels. California is the largest consumer of energy in the nation, and therefore their RPS target will make a greater difference than the efforts of Maine, for example. This does conclude however, that targets will be met through indigenous development of resources versus the trade of RECs and other Green Power Purchasing schemes across borders.

effective wind project financing schemes (such as flip models) began around 1999. There is no doubt that RPS policies contribute to enhanced visibility of renewable energy sources and signify a demand for renewable energy development. The emergence of carbon policy in the United States may be the final piece of this policy regime, as it will likely force a greater number of groups to seek structural solutions for pollution mitigation. The number and range of investments in clean technologies would have to expand, either indirectly through tax equity investment, REC, and Carbon Offset purchases (interaction with existing markets), or directly through innovation (the decision to invent and produce clean technologies).

## *Emergence and Erosion of Financial Capital Markets*

Harper et al. (2007) divide the history of wind project finance into two periods. Between 1998 and 2002 "Strategic Investors dominated the market" during a resurgence of wind capacity expansion; and the period 2004 to 2006 "the entry of Institutional Investors and the expansion of debt offerings" occurring in the U.S. market (p.5). In fact, Harper et al. point out that Zond/Enron Wind had overseen half of the 800 MW expansion that occurred late in the 1990s in several 100 MW transactions that were "the largest in the world at the time" (2007, p.6). Strategic Investors like Florida Power and Light company, Edison Mission Energy, and Cinergy "dominated early markets" and GE Capital "was the only major Institutional Investor during [the period 1998-2002]", soaking up tax benefits made available by the PTC (p.6).[112]

Shell emerged as a major Strategic Investor in 2001, and electric utilities began to purchase wind power projects that had completed by IPPs that could not make use of tax credits. Florida Light and Power (Aka NextEra Energy) the largest renewable energy owning Utility in the United States, owning approximately 8.6 GWs (or about 20 percent) of all wind capacity installed. It has since drawn at least $1.6 billion from the PTC and $158 million from the ITC program between FY2005 and FY2011 (SEC 10-K filings).[113] According to Bloomberg New Energy Finance (BNEF, 2011), early wind project investors like JP Morgan and GE Capital had experience monetizing tax credits for low-income housing projects and hence were experienced in managing the risks and benefits of tax equity (p.3). The capability to make use of credits as a financing and investment vehicle was likely more important than interest in renewable energy.

In the latter period of 2003 through 2006, Harper et al. (2007, p.7) argued that planned projects grew in size and thus capital appetites grew as well. More independent project developers emerged during this period seeking financing structures that made efficient use of tax credits. The researchers attribute this paradigm shift in the finance of projects (toward more institutional investors and debt based finance) to numerous factors including: bonus capital depreciation made available after the September 11, 2001 attacks on the World Trade Center, clarification of transaction details from the IRS related to the PTC, the maturation of debt financing structures, and the arrival of financial intermediaries like Babcock and Brown to the wind sector which provided greater expertise in tax equity financing.

The successful financing of newer, larger wind projects contributed to wind-turbine scarcities

112According to Sissine (2008), the total value of PTC claims during this same period was approximately $350 million (in 2007 dollars).

113Nextera reported net income of approximately $2 billion in 2011 on $15 billion in revenue.

which raised capital costs but also provided new incentive for the expansion of manufacturing activities. Following changes in investment strategies were consolidations of the industry. Investors with large amounts of financial capital began to absorb smaller project developers in order to acquire an aggregate amount of wind projects which better matched tax appetites of investors and responded to the desire for greater economies of scale.

## *The Rationale for Tax Equity Investing*

The economics of tax equity finance in wind energy boils down to a search for optimal returns negotiated between developers and investors. Unless the financing method is corporate, meaning financed internally by a firm, completing a wind project will require more than one party. Neither party will settle for returns which they do not perceive adequately reward the risks involved. The tax appetite of a given investor relates to the amount of taxable income which it generates each year.

No investor would likely put in more funding for a wind project than they would otherwise have to pay in taxes. The advantage to investing in a wind project, aside from getting a 10 year source of tax savings for the future, is that the investor can earn an income from the project as an "owner" (even if the ownership scheme is relatively short) and hence generate a rate of return which is presumably better than other investments they could have made. Implicit in any decision also is that the rate of return is better than that provided by just paying taxes. If a given wind project generated 10 million kWhs a year, on average, for example, the value of the tax credit each year would be:

10,000,000 kWhs x 2.2 cents kWh (current PTC value) = $2,200,000

Because the value of the tax credit is payable for ten years, the total amount of the credit accruing to the investor would be $22,000,000 (we are assuming that the value of the credit will not change, i.e. no inflation). An investor might then be willing to invest a maximum of $22 million in the wind project based on the value of the PTC alone, and would assume some or a majority of ownership over that project while its tax benefits were distributed.[114] Depending on the ownership scheme in play, the investor (or group of investors) would be able to receive a portion of cash created by the project, generating a rate of return at the end of the period.

It sounds like a great deal for an investor. Do they get something for nothing? Not entirely, as they must themselves be sure that they will have a large enough tax appetite each year, for up to 10 years. Their investment could sour if their taxable income drops low enough (say, because of a massive global recession). The project developer which they have partnered with could do a shoddy job installing the project, which is later rejected by the public at large. Their rush to complete a project could lead to expensive repairs in the future (and thus unusual down time). Poor siting practices could cause lower than expected productivity and hence fail to generate the PTCs which induced the investor. There is plenty that can go wrong.

That said, Harper et al. (2007) provided a hypothetical 6 to 33 percent rate of return over a ten

114We are not assuming that MACRS depreciation or other tax deductions are in play. In a "Flip" model, for example, the equity or tax investor would represent 99% ownership, and the developer, 1%. In like fashion, over their period of ownership they would receive about 99% of cash generated and 99% of tax benefits available. It is just as likely in an "institutional flip" model that the tax equity investor might only represent half, or more than half, of all the equity in the project, but would still capture 100% of tax benefits and some portion of cash.

to twenty year period in their project financing models. BNEF (2011), places returns for developers at 6 to 19 percent and investors at 10 to 49 percent (p.1). With a cash and tax benefit ensured, the rest of the investment task is about managing the risk of the project. A number of risk factors are relevant, which is why the benefits of the project (or the Investor Rate of Return / Net Present Value) must be sufficient to overcoming its costs (or risks).

Table 4.3, below, is an example of different rates of return in play for the same initial investment. Year 0 is negative because it represents the investors initial equity stake. At the end of the period however, the investor gets their cash distribution plus the amount they originally invested (they are "bought out"). This is why the negative value becomes a large positive value under "total return".

Table 4.3 Looking at Hypothetical Investor Returns

| | **Length of Investment** | **Year 0** | **Average Cash Flow Year 1,2,3,4,5, …etc.** | **Total at End of Period ("Profit shared")** | **Total Return** |
|---|---|---|---|---|---|
| Rate of Return @ 6% | 10 Years | -$22,000,000 | $1,320,000 | $13,200,000 | $35,200,000 |
| Rate of Return @ 10% | 10 Years | -$22,000,000 | $2,200,000 | $22,200,000 | $44,000,000 |
| Rate of Return @ 30% | 20 Years | -$22,000,000 | $6,600,000 | $132,000,000 | $154,000,000 |

Assuming an investor agreed to invest their tax equity into a wind project for 10 years at an IRR of 6%, they might expect to be returned $35,200,000 by the end of the ten year period. The same investment at 10% IRR would yield a total of $44,000,000 over the ten year period. At a 30% IRR and after 20 years total, the investor would yield a total value of $154,000,000.

Without knowing any other details, this is a basic explanation of why an investor might want to invest in a wind project which offers them tax equity as a primary benefit. Their equity stake in the project does not mean that they have a direct role in the management or maintenance of the project, only that their ownership stake grants them a claim on cash and tax credits generated. Not only is income sheltered from taxation, but it actually earns a profit. Just paying $22 million in taxes benefits the investors, who may benefit from the myriad of government programs which subsidize their technology, employees, and provide them with access to world class infrastructure. As we have seen however, that money can also promote a clean technology while promising them greater income in the future.

Why should a developer "give up" portions of their profit over such a long period? Mainly because they have no other access to the financial capital required they need to complete the project. The cost of alternate means of finance could be prohibitive. Wind developers face large up front costs getting a wind project up and running, but also will officially "own" the project for 10 to 20 years if they wish. During that time they can capture all project revenues, hopefully without any unforeseen difficulty or added cost.

Even much smaller projects, such as the community owned Fox Islands Wind in Vinalhaven, Maine can generate significant tax credits from the wind. Its 12.1 million kWhs generated from three GE 1.5 MW turbines in 2009-2010 created about $266 thousand in PTCs for its Portland-based tax equity investor, which adds up to about $2.7 million over ten years. The project itself cost over $10 million to complete. Electricity costs at 20 cents/kWh generate $2.4 million in revenues annually. This means that over the next ten years or so over $24 million can be distributed to recover project costs, pay investors, and so on. Eventually the project will pass savings onto the island ratepayers in the form of lower overall energy rates.[115]

Despite the relatively rapid evolution of the finance of wind projects over the last decade, "the pace of sector development has outstripped the ability of most developers to fund project capital costs and to make efficient use of the Federal Tax Benefits. In response, the sector has been successful in creating novel project financing structures to attract both Institutional Investors and Strategic Investors wanting to enter the sector" (Harper et al., 2007, p. 48).

Availability of financial capital is not writ in stone, even with a strong incentive like the PTC. Schwabe et al. (2009) recorded the damage that the U.S. financial crisis did to the wind energy sector, which lost at least fifteen major tax equity investors of wind energy projects, reducing the number of major investors from twenty to just five. Four of the investors, Lehman Brothers, Wachovia, AIG, and Merrill Lynch, the original champion of USW/Kenetech, disappeared in merger or in bankruptcy. Schwabe et al. claim that only half a dozen large investors to remain active in wind energy markets, even as the size of the tax equity market balloons from about $5.4 billion in 2007 to an estimated $17.6 billion in 2010.

BNEF (2011) estimates that $137 in tax liabilities are generated across economic sectors of the top 500 U.S. Public companies each year (pp.8-9). Even so, renewable energy tax credits are far from the only tax incentives available, and may not be as attractive to tax equity investors as other options. The number of investors and the attractiveness of wind projects impact the success of the PTC as an investment stimulus. On this, it should be noted that the ITC, which allows project costs to be returned in grant form, provides a significant option to wind energy developers impacted by the financial crisis but looking to complete projects.

In addition to the squeeze felt by the financial sector and resultant flight of available tax equity and debt investors from the sector, the amount of installed wind capacity shrank almost in half from 2009 to 2010 from about 9,900 MWs installed to about 5,400 MWs. Supported, but not assured by the availability of the ITC, capacity additions for that year would have likely been far lower had the ITC not been available as a substitute to the PTC for wind project developers.

While the United States continues to struggle to address the fallout of its historic financial sector meltdown, wind developers will continue to be constrained by the availability and mood of financial capital. It is perhaps instructive to again mention China which has managed to meet and exceed the United States' ability to capitalize new wind energy projects, by completing over 18,000 MWs in 2011. This approaches nearly twice the amount of wind energy the United States developed in its record year of 2009 (financial downturn did not create immediate impacts on the industry).

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115Vinalhaven and North Haven experience abnormally high electric rates. This is related to their need to import a majority of their energy and pay for an underwater power connection to the mainland. The island also faces large shifts in population between summer and winter months. New England more typically has a cost of energy in the 14-15 cent/kWh range. The island had to establish a LLC in order to make use of tax credits, despite the fact that power generation is otherwise based on a cooperative. It also raised financing with a USDA Rural Development Loan, which is unusual.

China has also established itself as the most aggressive investor in clean technologies in the world, spending close to double the amount of the United States at $54.4 billion in 2010, which was about 23 percent of global expenditures that year (Pew Trust, 2010, p.7). While Europe and North America struggle to sustain financing opportunities for burgeoning clean tech industries, other regions of the world are charging ahead.

## *Diverse Approaches to Finance*

Harper et al. (2007) describes seven common financing models for wind projects utilized from 1999 to the present. The role of finance in the advancement of the wind industry is complicated, primarily because the allocation of financial capital and distribution of project benefits vary according to unique project requirements and the resources of a given developer. Each model must "attract various investors to projects, manage project risk, and allocate Tax Benefits to entities that can use them most efficiently" (Harper et al., 2007, p.2). All of the models are a balancing act between raising a source of financial capital and using tax credits and accelerated capital depreciation as a means of distributing benefits to project owners. Based on their modeling they find that, for example, PTC and cash leveraged projects provide a high investor return and relatively low cost of energy (LCOE).

Corporate financed projects produce, by their estimates, a cost of energy that is 24 percent higher. Wind projects are financed in many ways, they argue, in part as response to changing market conditions. Developers respond to the tax appetites of investors as well as the availability or anticipated expiration of the PTC. As a result, projects might be financed in ways that might be suboptimal for providing the lowest possible cost of energy, but optimal in the sense that financing and closing can occur over a shorter period.

Prior to 1999, they argue, "the financing community generally perceived the wind market as exotic, i.e., complex, small, and risky" (ibid, p.5). This concludes that it was not until Enron entered the marketplace for wind through the acquisition of Zond in the late 1990s that perception of the technology and its value shifted in favor of wind turbines. Further maturation of technology and the arrival of larger developers and manufacturers to the industry attracted more institutional investors.

The strategic flip model is considered a financial innovation emerging out of the challenge of utilizing the PTC. It "was one of the first structures to be developed to attract third-party equity able to utilize the Tax Benefits, while allowing the developer to retain an interest in the project" (Harper, et al., 2007, p.21).[116] Invented by Dan Juhl 1999, this is also sometimes referred to as "the Minnesota flip" (Bjorhus, 2010, St. Anthony, 2009). Under this model an investor temporarily owns a wind project for the purpose of capturing tax benefits. Upon expiration of these benefits they are bought out (ownership "flips") to the original developer or minority owner(s).

Flip models mitigate the inability of many developers to finance the total cost of a wind project as well as make use of the available tax benefits. Flip models have been used to finance non-profit and cooperatively owned wind projects as well, having the ability to typically provide half of the financing needed. Once the benefits of the wind projects have been distributed, in other words, owners of wind projects have mainly energy revenues from which to cover costs and seek profits or to provide a low

116Dan Juhl, currently of Juhlwind in Minnesota, is credited with inventing the flip model of finance for wind developers. He has had a long career in the wind business, completing his first community wind project in 1999.

cost of energy to a community.

Of all the financing structures described by Harper et al., however, the most common is the corporate structure, which they argue is mainly due to the projects completed by Florida Power and Light (AKA NextEra) in recent years. Under this structure, a strong investor has all the financial resources necessary to finance a project and capture incentives. The corporate parent may choose to set up a subsidiary or other separate entity for the project, but does not necessarily need to. Harper, et al., argue that a primary benefit of this structure is simplicity. I would add that it also insures that all incentives and revenues generated by the project flow back its owner, also, maximizing benefits in a way not possible with ownership schemes which require 3rd party capital.

The analysis provided by Harper et al. is useful for grasping changes between many of the private entities involved in for-profit wind energy project development. There is no question however that the business oriented incentive schemes of the United States fly in the face of the community and local-ownership approaches taken by Denmark and Germany, for example. Non-profit organizations, communities, and co-ops in the United States are increasingly making inroads into renewable energy. Locally-owned wind energy projects are often blocked from the use of available financial incentives by virtue of their tax status.

On this note, renewable energy bonds (or CREBS), U.S. Department of Agriculture rural development loans, and the ITC have been combined in different ways to join low-interest government financing with tax incentives in ways that have allowed more public utilities and cooperatives to develop local wind energy resources. In a February 2011 *Wind Powering America* webinar the attractiveness of the ITC was noted for its ability to lessen “the need for large tax appetites,” simplify financing, and reduce performance risk (meaning additional flexibility in turbine choice). It also enables leasing, and the combination of tax incentives with government loans (Hinnen, 2011, p.16). Bolinger (2011) claims that small or community scale wind projects “[provide] a proving grounds for new turbines” and also “[serve] as a laboratory for experimentation with innovative new financing structures” (p.1).

The state of Minnesota is credited as the “birthplace” of community wind in the United States by Bolinger et al. (2004, p.28). It is also the site of the entry of many new manufacturers: “Suzlon (in 2003), DeWind (2008), Americas Wind Energy (2008) and later Emergya Wind Technologies (2010), Goldwind (2009), AAER/Pioneer (2009), NordicWindpower (2010), Unison (2010), and Alstom (2011)” (Bolinger, 2011, p.1). While it has not been our focus, community wind should not be ignored for the value and sense of control it gives communities. It also provides the complimentary benefit of providing new markets for potentially innovative companies. Utility scale development is useful for rapid wide scale deployment, while greater local scale deployment would likely enhance long term acceptance and integration of the technology.

States are beginning to revise or introduce new policies such as group net metering or feed in tariffs which will make it possible for many people to exact the benefits of a turbine(s) purchased together. The participants “combine” their electric meters into one which is subsidized by the energy their wind project produces. A similar arrangement could be done virtually, by policies that enable interested persons living in different geographies to connect their energy use to a common source of renewable energy they have invested in. Feed in tariffs provide a per-kW price for clean energy which helps improve the economics of ownership and are being given consideration in some states.

Farmers in the United States that own their wind turbines can exact greater overall economic benefit from them. Alternatively, they can simply lease their land to a developer without losing much crop space. In short, the policy regime in the United States is not just attracting billions in capital investment. It is also promoting a great deal of financial and political ingenuity which makes it possible for community and non-profit wind developers to get involved in renewable energy. More should be done. These communities could provide the market for emerging foreign and domestic wind turbine producers.

## *Financing Practices*

It might be useful to consider some of the important financing practices that developed out of the original 1980s wind rush. For one thing early wind companies found banks in Europe to be more familiar with wind energy projects and therefore more comfortable financing them. No doubt this was because of emerging German and Danish wind industries which provided effective incentives for early industry development. Kenetech's managers connections to Merrill Lynch helped them lead to one of their most important financial backers.

Kenetech acquired a vision and key personnel from the University of Massachusetts which led to its first turbine prototypes, which was used to prove the technology to investors in their red book. California's state effort and national efforts to estimate the amount of wind energy extractable helped to prove that wind energy was a viable source of energy not limited by nature. There is enough wind energy in the territorial United States to power it several times over. Government activities and Universities overarching the early industry's development helped to rapidly reduce costs while overcoming deficits in our understanding of the dynamics of wind turbine technology and operating environments.

USW/Kenetech's red book eventually attracted big capital to the firm, in the form of three back to back $100 million dollar credit lines from Merrill Lynch, a bank that had been recommended to the company by its incumbent management as willing to finance wind energy projects. It still took the wealth of Karl Bach, and friends and family in order to provide seed funding for the company's activities however. This problem has not appeared to hinder other clean technologies, such as solar energy, which has caught the attention of, and attracted large shares of business and venture capital investment.

On the development side, companies purchased wind rights to land but also promised a share of gross profits to land owners. In the early days this might have amounted to two to five percent of gross profits but today might typically be fixed at about two percent. Tax incentives in the 1980s were based primarily on the size of the capital investment made, and not the productivity of a given wind site, meaning that many participants in the early wind rush sometimes marketed wind energy not as a means of producing energy so much as an easy way for investors to receive significant tax benefits. Zond, on the other hand, appears to have relied in part on the wealth of its founder James Dehlsen, who nevertheless also had access to the 50 percent tax incentives that started the California wind rush.

Perhaps more conscientious than others, Dehlsen was vocal about the importance of getting wind energy to a state of development where it was not reliant on subsidy and could be internally financed. After the collapse of tax credits and support for wind energy in the mid to late 1980s, USW/Kenetech and Zond each attempted to build up project backlogs and proprietary state-of-the-art turbine technology to position themselves as vertically integrated companies with long-term development portfolios. Confident in their positions, each attempted to overcome internal capital constraints with IPOs which were a mixed success.

The IPO of USW/Kenetech did bring significant financial support to the company. Its enjoyment of public finance was too short-lived to have proven itself a reliable means for emerging wind energy companies however. As it stands today, Kenetech is the first and only wind company to have gone public in the United States.[117] Zond attempted an IPO, but ultimately found financial constraints lifted through acquisition. As we discussed, this may have compromised their autonomy to a point, and certainly placed them in an awkward position as the association with Enron did little for the image of the industry. On the other hand, by the turn of the century, some of the largest businesses in the United States were ready to take wind power seriously, and the fall of Enron was thus a unique opportunity.

It would appear that the potential of wind energy in the United States would ultimately be unlocked by much larger companies, such as Enron and later GE, which had deep pockets and much stronger market positions. Enron differentiated wind and other renewable technologies with its Green Power Purchasing schemes, to try to charge higher energy prices to those willing to pay more. This was ultimately a practice which was better matched to the actual performance of wind turbines at the time. It also helped to legitimize the technology in a way which could draw new investors to the technology. The downside, even today, however, is that Green Power Purchasing often bundles a variety of energy sources together, meaning that consumers are also paying their premium for green energy, and nuclear, and some natural gas, etc.

Given the positive changes in the finance of wind energy, the scale and cost of projects continues to vary a great deal and successful projects appear to remain based upon the distribution of project benefits to financial and other investors rather than to its community hosts. Smaller wind projects in Maine in the 2000s have cost upwards of $10 to $15 million for three installed 1.5 MW turbines while new offshore wind energy project proposals can easily exceed $1 billion and are indeed estimated to cost upwards of $6 billion dollars, while representing 500 to 1,000 MWs of wind capacity installed.[118] The appetite for financial capital will continue to grow, and developers large and small will continue to find challenges satiating this appetite.

The development of technology and the use of tax credits to stimulate activity in the early years were not enough to stabilize the wind industry, which still depended on acceptance from utilities for customers and banks for capital. Asmus (2001) described the creation of standard offer contracts (the SO1 and SO4 varieties) as a solution to the need for some sort of risk management in transactions coupling profits to risks. On this note, wind companies like Kenetech were pioneers, willing to claim that a given wind project would have a useful lifespan of 20 to 30 years. The company might earn, from a SO4 contract for example, 10 cents/kWh for 10 years and then earn the real (or avoided cost)

117 Juhl Wind listed itself without an IPO. Noble Environmental Power attempted an IPO in 2008 but shelved it when markets did not seem responsive.

118 A proposal for a pilot floating offshore project in Maine is estimated to cost $5 billion or so by its completion in 2030 and would include about 100 hundred wind turbines with 400 foot rotors. At such a high cost, the focus is on scale, scale, scale. At such a scale, however the capacity investment is approximately the size of a nuclear power plant.

rate of electricity from a utility, which tended to be in the 3 cent/kWh range in later years. Parsons et al. (2003), clarify that SO4 contracts were common beginning in 1983, and typically included capacity payments for 20-30 years and a fixed price for energy of between 5 cents/kWh to 12 cents/kWh (p.7).

Following the development of the 33M-VS, Kenetech began to claim that the cost of wind energy had reached the 5 cents/kWh range, and the company went so far as to suggest that the need for government support was at an end. Their perceived advantage was short-lived however, when Zond proved itself willing to enter bids for wind projects at a cost of 3 cents/kWh, which, coupled with the PTC represented a real cost of 4.5 cents/kWh. This development shows some of the willingness of wind companies to bid project cost levels down to levels which were perhaps foolishly unrealistic, but the necessity of doing so was driven in part by the failure of oil price forecasts to come true. Without $100 dollar barrels of oil, fossil energy became more, as opposed to less competitive. Additionally, the United States had clearly made the choice to rapidly develop a strong Natural Gas sector in the 2000s.

Zond's underbid was made based on the assumption that it could acquire wind rights which Kenetech had purchased, an aggressive move which ultimately paid off for the company. Zond showed that a company with wind rights did not necessarily have a guaranteed project in its future. Even having paid for extensive permitting, attracting creditors, and securing power purchase agreements, developers can be blocked by environmentalists or angry community hosts. Only a turbine turning in the wind provides a clear indication that most of the big uncertainties are over. With energy prices dropping and the demand for new capacity among California utilities on the wane, the industry had to continue looking internally for cost reductions or risk losing new bids for capacity to cheaper alternatives like natural gas. With the cost of energy such a critical part of wind energy projects in the early years, it seems hardly surprising that some companies would take to building large backlogs of projects, engage in cutthroat competition, or oversell turbine capabilities in the struggle to find financial support and economic sustainability.

The subsequent bankruptcy of world leading USW/Kenetech and acquisition of Zond into Enron Wind highlighted the intensity of competition between wind companies. It also showed the mistake of submitting to market pressure to perform on short-term cost interests rather than seek technological innovation, or optimal of business models premised first and foremost on competitive capabilities. There seemed to never be enough cash flow, and the investor lawsuits against Kenetech highlighted how the U.S.'s leading wind energy company had often been willing to fudge numbers and mask unresolved technical problems in order to lure new capital into the company. Merrill Lynch, Kenetech’s key institutional ally, continued to support the company through its difficulties. We would have expected it to, however, as Merrill would make millions underwriting transactions, suggesting that accountability in some cases was also weak.

In any case, the institution of the PTC seems to have been a logical policy direction following the 1980s, though it has taken time for the industry to find ways to use it to support larger projects, which today can cost into the billions of dollars. It can be used by wind companies to lower the cost of wind energy on paper. It also communicated the improving performance of new turbine models and provided a way for investors to benefit for assuming some of the financial risks of investing in wind energy development. Given today's political climate however, and potential for rapidly escalating costs, the future of a policy like the PTC is uncertain. We shall see if it is renewed before 2013, until then, Vestas recently cut 2,235 jobs in the United States response to Chinese competition in recent years, and claimed another1,600 jobs will be cut if the PTC expires in the United States (Morales and Blakewell, 2012).

## *Wind Energy Challenges/Conclusions*

There is no shortcut to understanding great, albeit slow changes in energy markets brought on by significant technological investments. Attempting to summarize technological innovations alone is not adequate, and neither is focusing exclusively on market revenues and business leaders. Kenetech and Zond were once small companies which never produced $1 billion in revenues annually or employed tens or even hundreds of thousands of employees like GE or world leader Vestas. I have come to believe that these companies were near the center of the history of the early wind industry in the United States and provide important pieces of the story.

Until the arrival of the financial crisis in 2008, well over a third of GE's revenue was derived from its financial services segment, along with nearly half its profit. Diversification reveals its value in GE, which has had other business segments to isolate it during economic hard times in the United States. There would have been little to no reason to believe that General Electric would be America's champion of wind turbines prior to its entry to the business in 2002. Yet currently its continued participation in the wind energy industry is vital if a global presence of the United States is to be maintained.

Without a national champion positioned to fill in for GE, the United States could very quickly find itself without significant representation in world markets. Whatever U.S. company should come to lead U.S. wind manufacturing in the future will lead because of the significant cumulative investments that were made before it. Like GE, they would be positioned to acquire and build upon decades of work and investment. Innovation is complicated, but in many ways it is an apotheosis of history. Wind energy is today just a part of GE's core activities and not a driving force (as with Vestas). For that reason it would seem that this industry stands on soft ground even today.

Industry formation and innovation have been presented as part of a significant and cumulative historical process which includes many different stakeholders at all levels of society. That the Kenetech/Zond family line leads to a “hand off” to Enron and then GE illustrated that technology and key personnel could circulate through industries in their formative years. The United States government and its business community are both responsible for the failure to ensure that leading companies in newly forming industries make it to maturity.

The pain of unrealized economic potential is especially acute when the importance of the industry goes far beyond its product, profits, jobs, or the markets it must serve. Wind energy is an infrastructural choice which can change how energy is delivered to modern economic systems, and it will help to undo and prevent some of the catastrophic and costly environmental and health damage caused by past development decisions. A more sustainable energy system would seem to me to be desirable no matter the cost, yet the data makes it seem as though we are just beginning to make much needed changes.

Much is made of the concept of “maximizing shareholder value” in today's business news as if the shareholder were the only member of the economy that matters. A similar logic of placing economic efficiency above all other considerations can be heard in the corridors of policy discussion and in my personal case, from friends, neighbors, and family as well. To be clear, the public resources committed to all energy technologies are on the order of hundreds of billions, and other public resources such as land, or education, are often put into the service of industrial needs. Problems like pollution are costs born on everyone. This is as much evident when a company like Kenetech directly benefits from research conducted at UMass as it is when community colleges across America race to train the workforce which can install and also service wind turbines, solar panels, and more. These investments do not appear on company balance sheets, but they are not less vital to the success of the firm. Likewise, taxpayers, employees, students, community members, consumers, etc. are all stakeholders in the process of economic development. To acknowledge this simple fact can only make our efforts to develop our economy more effective.

The technology, policy, and markets which grew out of early efforts to promote development of a wind energy industry in the United States have converged to form a recognizable, dynamic, and unique market for wind power in this country. Manufacturing co-evolved with wind development activities however, and there are many sectors which interact and compliment one another. There is manufacturing, development at the local or utility scale, and the leverage of national and international supply chains.

The success of the industry required significant government and business support in allocating financial capital, conducting R&D, developing business models, and creating markets for renewable energy. It also required interaction between public and business sector interests, which has itself influenced strategic approaches to wind energy development. If interactions were at times combative (as between the Sierra Club or U.S. Fish and Wildlife Service, for example), I have little doubt that they were a inevitable part of finding the balancing point between public and business interests. Moving forward, early mistakes served to define best practices which can be utilized by companies with a long term business perspective, or policy makers seeking to protect constituents from the social costs of wind power development.

Generally condemned as a failed top-down approach, I have argued that the NASA provided a starting point for the long process of learning which influenced future government efforts to support renewable energy technology. The DOE and others responded to inadequate fundamental knowledge, and developed general technologies before committing close to $1 billion developing proprietary technologies in partnership with industry. Only GE seems to have retained a desire to continue pursuing wind energy following the end of the NASA program. To be fair, the early failures of the U.S. wind programs were a failure of many highly capable businesses as well.

Following the 1990s renewed interest in financing public and business partnerships contributed to wind turbine development and testing which has slowly achieved what the early NASA program did not: large and increasingly multi-MW turbines that produce reliable and inexpensive energy. Even discounting NASA's involvement, it is still obvious that UMass Amherst and other colleges around the country, along with government labs, played a role in developing and diffusing key wind turbine technologies. Innovation has occurred for decades, as sharp reductions in the cost of energy and increases in performance have attested to.

Universities also educated many of the students which entered the industry in its early years and continue to occupy important roles. It would appear that the vision and potential of the industry was laid out quite early on, and the memory of Professor Heronemus will be honored by the first offshore wind turbine installations to occur in the United States. On the other hand, Zond appears to have benefited from its links to Danish Vestas, and Kenetech, rightfully or not, muscled through its first variable speed design in a controversial manner but also at real expense to the company.

Had Kenetech been more willing to take advantage of government support, they may have found a less expensive way to prove their designs. Indeed there is evidence that this was going to be the case just before the company declared bankruptcy. Quite objectionable is the fact that some executives of the company made $2 to $3 million in compensation during its decline and liquidation, while, as noted, its employees lost their jobs and their retirement savings, having been encouraged to invest in company stock. Lacking the patient capital required to ensure stable growth however, the market did not tolerate Kenetech's mistakes and there was no government rescue.

Investment has been drawn to the industry in a number of different ways, but our discussion revealed how financial innovations were important and necessary in order for wind developers to monetize incentives and reduce the perceived risk of wind projects to acceptable levels. Where friends and family were available to finance some start ups, venture capital has not been as big part of the wind energy story as it has for Solar Power, or Internet startups, for example. Following the recent bankruptcy of Solyndra, for example, it would appear that business investors prefer shorter time horizons when assuming risk than many modern power technologies allow. Additionally, the speed of financial capital vastly outstrips that of productive capital, allowing financiers and shareholders to respond to shifts in the market much more quickly than can manufacturers. Committed finance is vital to providing companies with investment capital, but also must be made to weather downturns in the market as well.

Without extensive and committed finance, the rapid expansion of the wind industry in recent years has demonstrated the importance in particular of the committed finance of the government. In response to a loss of major tax-equity investors, the ITC has provided a vital alternative incentive which prevented the wind industry from a more serious downturn in recent years. These incentives are still a bargain in comparison to legacy energy technologies. In reaching a moment when these credits are beginning to cost into the billions however, one would think that these incentives become politically vulnerable. This is especially the case in the United States and some parts of Europe, where fiscal austerity seems to have taken hold, and the growth and development of younger, riskier industries is just another luxury “we” can't “afford”.

A continued and growing demand for energy in the United States is not assured by market forces alone, and neither is the profitability and willingness of potential tax equity investors. With a relatively small number of large backers around to sustain the wind industry in its current form, the reduced performance of the wind industry during Chinese ascension should be a clear sign that it is time to consider new policy tools or a strengthening of old ones. Providing low cost financial options to support smaller-scale or non-profit local development schemes, for example, could get more groups actively involved in markets for wind turbines. In like fashion, we could explore options for wind project financing which are still based on site productivity, but not so much on the availability of tax equity investors. Additionally, it would seem like a good idea to encourage the emergence of more turbine manufacturers in general, which help ensure a competitive domestic market and a stronger international presence.

It is worth questioning why, after so many decades of trying, the United States has failed to see more clean sources of energy penetrate its grid. One important reason for this is that the United States has spent and offered much more to competing energy technologies. Another is that, by forcing wind developers to find markets for tax credits and debt, rather than providing them with prices for energy that provide sufficient revenue to cover the costs of business and innovation, we have in fact tied the fate of the wind industry to the health and commitments of other non-related industries.

Additionally, events such as recession or a reduction in energy demand will make themselves felt by the wind industry, even if our best intentions are to transform our energy infrastructure. A final argument I would make is that all renewable energy sources will benefit from complimentary investments made in other technologies which provide better energy management and storage solutions. Until those innovations develop and diffuse the maximum potential for renewable energy will likely not be realized.

The strongest evidence for the emergence of a market for wind energy appears to have occurred out of the energy crisis of the 1970s. WW II also provided some momentum for renewable energy, and in more recent years, much of the argument has centered around Climate Change or recurrent spikes in the price of fossil fuels, such as the recent spike occurring in 2008. Markets for renewable energy and wind in particular have been sustained by active state and federal efforts to collect data about wind resources, modification of policy frameworks to accommodate the technology, and growth in the number and type of incentives available. These incentive groups support the competitiveness of wind energy and the manufacture of wind turbines, and have helped to create domestic businesses as well as attract foreign ones.

State level mandates (or goals) to purchase more renewable energy help create long term demand for renewable energy sources like wind. But these policies are still generally too new to fully evaluate. The early indication is that such policies provide a step toward ensuring that renewable energy will have a place in meeting future energy needs. The problem would appear to be that many targets are being met rapidly, suggesting that they are not necessarily aggressive enough, and many of these policies will be at the mercy of changing political regimes. Additionally, it would seem that not a lot of energy diversity is necessarily promoted by policies currently, and states may be able to shirk developing their own resources in favor of importing energy from elsewhere (such as seems to be the case in Massachusetts so far). If renewable energy systems are to emerge, transmission lines need to keep up with projects, and more must be done to support non-wind renewable technologies which are currently either expensive or not yet ready for commercial deployment.

The cost of energy alone is still a primary force driving markets, and it would seem that the growth of renewable energy markets in the future will depend partly on how the nation chooses to monetize pollution and support continued innovation in key renewable technologies. It is clear that wind energy companies, even in the early days, were willing to operate in whatever countries wanted development and provided incentives for it. Businesses also helped expand the market for wind power by, for example, conceptualizing the "wind plant" which provided higher power output and provided reliability for utilities, who by and large are their primary customers.

Wind businesses also target farmers, for example, for more tailored projects which generate revenue for them like a continual wind harvest. Some also pursue "hybrid systems" which combine wind and hydro power in ways with allow for more favorable energy deployment. Company's like Enron helped to differentiate Green Power in the 1990s and make renewables more visible to consumers, and helped to convince ratepayers to choose Green Power. Today, many ratepayers are beginning to see the effect of this sort of practice on their energy bill—one can choose to pay a little more to know their energy source comes from cleaner technologies.

Regulatory environments have changed to address issues raised in the growth of the industry. This is perhaps most clearly manifested by the inclusion of environmental impact studies necessary for project permitting centered around aesthetics, avian populations, sound pressure levels, and so on. More states, concerned with the impacts the technology imparts against communities, are careful to balance the need to protect the public interest with the need to provide opportunities for economic development.

In response, more wind developers are paying attention to communities and if not looking for ways to spread benefits unto them, being asked or compelled to do so. It is also not unheard of for businesses to pay for acceptance through lease agreements or lump sums to homeowners living in close proximity to sites. This is not unique to wind power, however. As federal policy toward renewables remains generally unclear, and the goals of states so veritable, additional study on such matters is warranted. The advent of offshore wind, for example, means that agencies such as the Department of the Interior will play a larger role in the future. New issues, manufacturers, and stakeholders will take the forefront of the wind development story. Military investment, not explored in this paper, is another interesting topic which may very well provide important innovations for many clean technologies, wind included.

The cost and difficulty of maintaining vertically integrated business structures may be a reason why today's wind industry includes very few actual utility scale turbine manufacturers and a larger number of developers. This can also be a reflection of policies toward wind energy, which in the United States have been described as supporting development to a greater extent than manufacturing. Obviously, however, much of how we can judge the success or failure of policies relates to the goals from which we set forth. If the point is to promote environmental health, renewable energy, or jobs creation, we do not necessarily care the extent to which an industry is foreign or domestic. If the point relates to generating long term national wealth, than the distinction might matter more.

On that note it should be taken seriously that the United States has essentially one major manufacturer of wind turbines in GE. Significant competition is realized abroad, though it seems unlikely that the United States will ever lead wind turbine manufacturing without a sustained effort to maintain a strong domestic market and enough R&D activity to provide technological leadership abroad. None of the research indicates that renewables have ever received the amount of R&D or subsidy that has been enjoyed by other energy technologies and indeed, other government programs. Resource and commitment have to come from government and business if a globally competitive industry will be sustained. As GE's global market share begins falling while Chinese companies gain, it is time to start asking what more could be done to support the competitiveness of a national wind energy industry, lest they revolutionize their energy grid, and we clamor to import it.

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