Soaking Up the Sun and Blowing in the Wind: Clean Tech Needs Patient Capital

by

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A World Crushing Problem: The Carbon Crisis

According to the International Energy Agency (IEA 2012, 45), global emissions of carbon dioxide (CO2) nearly doubled between 1973 and 2009, 65 percent of these emissions originating in the 30 Organization for Economic Cooperation and Development (OECD) countries and China, altogether representing about 37 percent of the world's population (Maddison 2010). It is common knowledge that failure to control and reduce our greenhouse gas (GHG) emissions will result in climate change and catastrophic global instability.

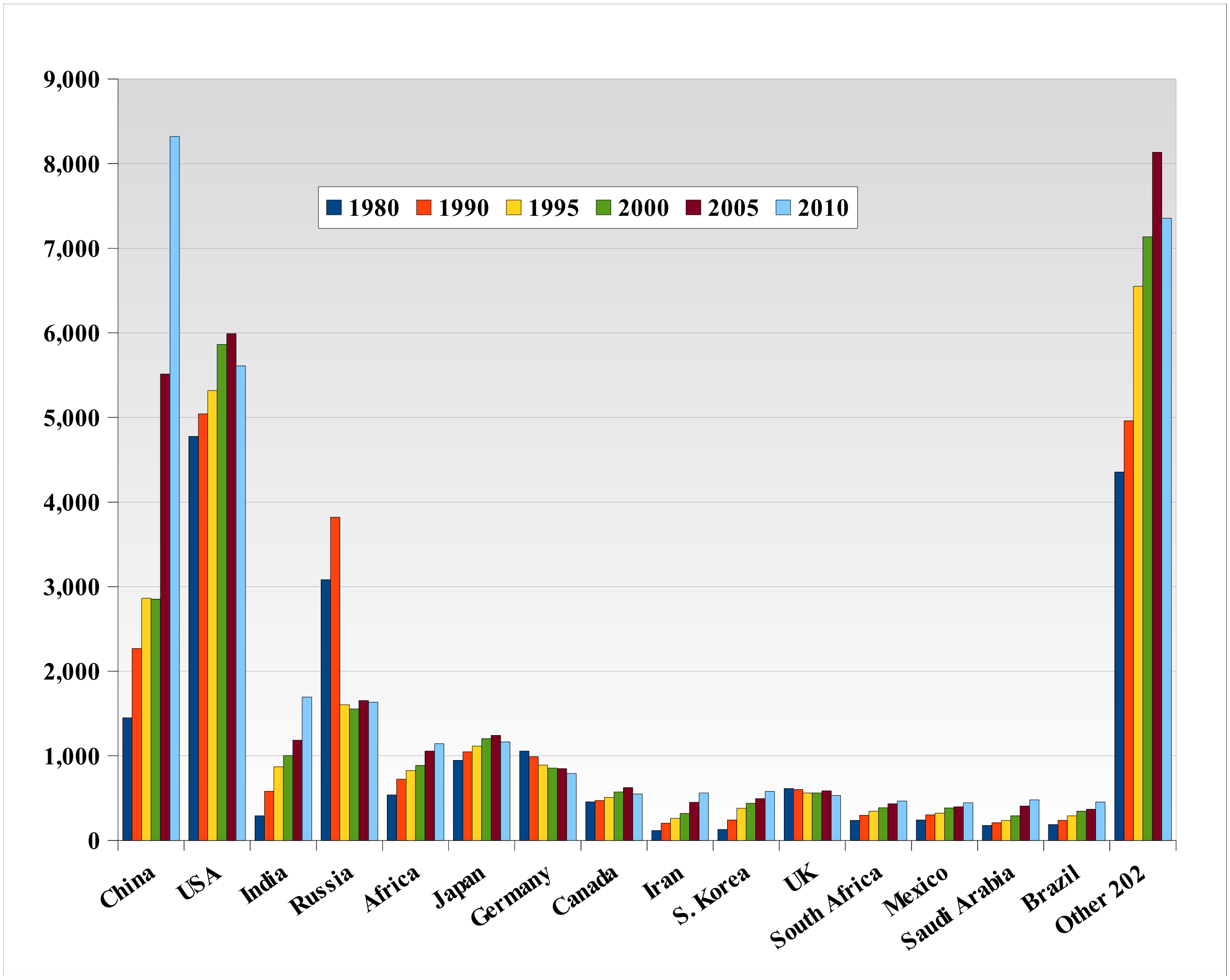
Increased concentrations of CO2 and other GHGs in the atmosphere cause the earth to warm, and these warmer temperatures greatly affect weather and other natural patterns. According to the *epa.gov*, pre-industrial CO2 levels were 280 ppm (parts per million). *350.org* documents that we are currently at 392 ppm and rising – and that reducing our CO2 concentration to 350 ppm or less is the way to avoid the worst expected impacts of climate change. Countries around the world have sought to deploy economic, political, and technological solutions in response to the threat of global climate change, and this response has generally placed emphasis on energy production and transportation sectors.

GHG emissions are directly related to world energy patterns. For more than a century, most developed or developing countries have relied on fossil fuels for electricity generation or transportation fuels. Additionally, the growth of economies is dependent on abundant and relatively inexpensive energy. The emergence of China as a major economy has provided a contemporary reminder that energy consumption and economic growth are inextricably linked. As China's real GDP increased by almost nine times from 1973 to 2009, its share of the world's total CO2 emissions expanded from 6 percent to 24 percent (IEA 2012, 45; Maddison 2010).

Figure 1 below shows the amount of CO2 emitted from various countries based on their consumption of energy. CO2 emissions are unevenly created around the world, with the combined contributions of the United States and China exceeding the CO2 production of most of the rest of the world. China stood as the world's top GHG emitter in 2009, having rapidly surpassed the United States during the 2000s.

The emissions of some countries such as Germany and the United Kingdom are falling over time as a result of renewable energy development and long standing commitments to reducing GHG production. In the cases of Russia after 1990 and the United States in 2009, reduced emissions likely have more to do with reduced economic activity than with significant changes in the energy infrastructure (Broder 2012).

Figure 1: Total Carbon Dioxide Emissions from the Consumption of Energy (Million Metric Tons), Selected Countries, 1980-2009



Source: "Total Carbon Dioxide Emissions from the Consumption of Energy (Million Metric Tons)" *eia.gov*. Energy Information Administration. International Energy Statistics Data. Accessed 13 Apr 2011.

Figure 2 shows that the composition of the world's primary energy supply is overwhelmingly based upon fossil fuels. There was a marked decline in the use of oil between 1973 and 2009, while over the same period the use of coal, natural gas, and nuclear power supplied a growing global demand for energy that almost doubled from 6,111 Mtoe to 12,150 Mtoe.[1] The "other" category in Figure 2 is where we find combined sources of renewable energy (not including hydropower). Despite massive global investments underway over the last decade, these clean energy sources failed to exceed 1 percent of the global energy supply as of 2009. OECD countries are only slightly better, deriving about 1.2 percent of total primary energy from clean energy.

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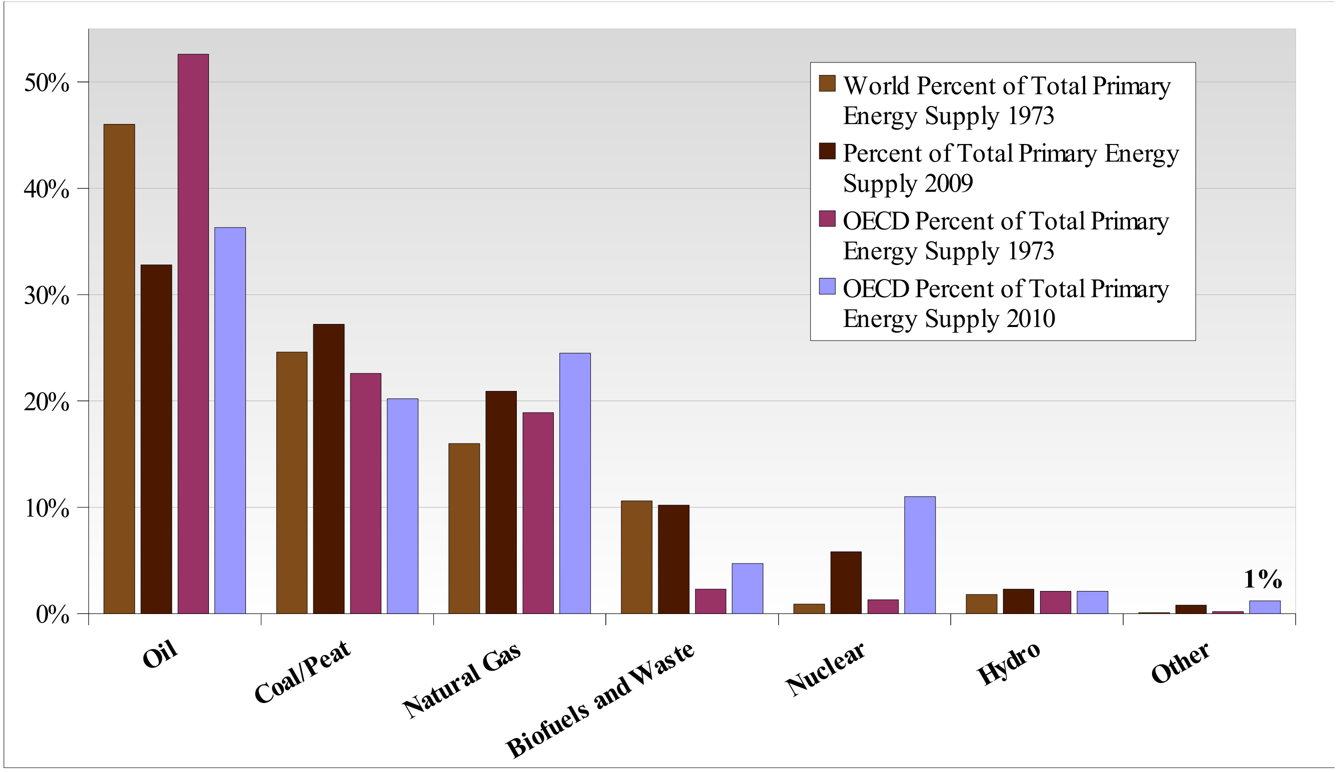
[1] Mtoe is "Millions of Tons of Oil Equivalent." 12,150 Mtoe equates to approximately 141,304,500,000 MWhs of electricity. All the electricity generated by the world in 2009 would equal about 1,724 Mtoe, or 14 percent of the total.

Figure 2: Total Primary Energy Supply, World and OECD



Source: "Key World Energy Statistics 2011." *International Energy Agency*. Oct 2011. Web. 20 Jan 2012. PP 6-7. http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1199

According to the IEA "Other" includes geothermal, solar, wind, tide/wave/ocean energy, electricity, and heat.

There were 34 members of the OECD in 2010, and 24 in 1973. 34 Members exist currently.

According to the IEA "Total Primary Energy Supply" (TPES) *is made up of production + imports – exports – international marine bunkers – international aviation bunkers ± stock changes. For the world total, international marine bunkers and international aviation bunkers are not subtracted from TPES.*

According to the IEA (2012, 24-28) the OECD and China generate approximately 71 percent of the world's electricity, only 3.3 percent of which comes from renewable sources such as wind and solar (and 19.5 percent including hydropower). China generates 36 percent of the world's coal fired electricity and the United States 23 percent.

In the United States GHG emissions originate primarily in energy production and transportation sectors. The Environmental Protection Agency (EPA 2012, table 2-1) finds that 84 percent of GHG emissions in the United States are CO2, and 94 percent of those emissions originate from fossil fuel combustion.[2] With other GHG's included, across sectors the electric power industry was responsible for 34 percent of the U.S.'s GHG emissions in 2010, while transportation contributed 27 percent, industry 20 percent, agriculture 7 percent, commercial 6 percent, and residential 5 percent (EPA 2012, table 2-12).[3]

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[2] The EPA (2012, table 2-1) notes that CO2 from fossil fuel combustion has generated about 78 percent of U.S. GHG emissions since 1990. Other GHGs include Methane, Nitrous Oxide, and Flourinated Gases.

[3] According to the EPA, less than 1 percent originate in U.S. territories.

Anadón (2012) argues that countries currently investing in clean technology RD&D are "mission oriented" in their approaches to clean technology, with their energy policies of the last decades reflecting several priorities. The first is to develop clean technologies which reduce aggregate GHG emissions. In many countries the lion's share of GHGs are generated by energy production and transportation sectors. In the absence of dramatic changes in those sectors, we cannot expect successful mitigation of Climate Change. The challenge for policy makers and businesses is therefore to strike a balance between developing innovative technologies that produce desired environmental benefits while doing so in a sustainable and profitable manner.

The second burden placed on clean technologies is that they should promote energy independence. Fossil fuel supplies are finite and developing economies like China place additional pressure on limited supplies and refining capabilities. Imports of petroleum products in the United States were about $332 billion in 2011, making petroleum the largest single contributor to the trade deficit, and a number which will increase as fossil supplies are exhausted there and abroad (Amadeo, 2012). Clean technologies that utilize virtually infinite supplies of energy such as the sun and wind not only enable the United States to meet energy needs with domestic resources, but they prevent dollars from going overseas for the sole purpose of perpetuating fossil energy consumption.

A central consideration in investing in clean technology is the increasing costs of extracting fossil fuels that lie ever more deeply in the bowels of the earth. Assessments of the costs of alternative energy sources should highlight the poor thermodynamic relationships between modern sources of power and typical uses.[4] We should also highlight the health and environmental costs which many sources of energy impose, often to an extent which may render them inefficient were those costs included in the cost of the energy they produce.

While most renewable energy technologies have been in use for centuries, their development and deployment as utility, community, or individual energy solutions is still fairly recent in history. Most wind and solar technology in use today, for example, was known in the 19th century. Development and deployment of these technologies as energy alternatives began, however, only in the early to mid 20th century. Widespread global deployment of these technologies characterizes the 1980s and 1990s. It was mainly in the last decade that renewable energy gained significant momentum as a viable alternative energy source on the world stage.

In the wake of the economic crisis beginning in 2008, however, a third burden was placed upon clean technology investment. This burden was that clean technologies should produce jobs. About $200 billion in economic stimulus was directed at clean technology innovation, in an unofficial "global consensus" between eastern and western countries that such investments could reverse devastating unemployment and lay a foundation for long-term economic growth (NSB 2012, 6-62).

There are many benefits to renewable energy. Wind and solar power access a virtually inexhaustible source of energy and create no GHG emissions from their operation.[5] Because the energy

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[4] For example, if 3,412 BTUs are needed to produce 1 kW of electricity, and 1 pound of coal contains 12,000 BTUs, than burning that coal will produce 1 kW of electricity and 8,588 BTUs of heat. That energy is "wasted" unless the heat can be recycled into the electricity generating process.

[5] Alternatively, lifecycle emissions of solar or wind power do create GHG emissions (such as during production of a wind turbine or solar panel), however the amounts are very small, and would vary dependent on what factors are included in making the lifecycle assumptions.

captured is a feature of local climate rather than an extractable, transportable resource, renewable energy can neither be given to nor taken away from people as a result of war or geopolitical conflict. It is also highly scalable and predictable. Technology already exists to generate electricity that meets residential or utility scale needs, suggesting that we have only begun considering the various applications into which renewable energy fits.

What is Clean Technology?

Clean Technology companies produce goods and services across a broad range of economic sectors, including energy, energy efficiency, transportation, electronics, or agriculture, to name a few. While a variety of groups track clean technology companies, there is not as yet a standard definition of clean technology.

The competing definitions of clean technology will influence statistical data gathering activities in the future, enabling more complete analysis. For example, the United States Bureau of Labor (BLS) found 333 relevant NAICS codes and reported that 3.1 million green jobs existed in the United States in 2010 (BLS, 2012).[6] Their results were based on a survey estimating the total output of green goods and services, including jobs that contribute to environmentally beneficial production processes.[7] Such estimates therefore include jobs from which experts will disagree on their relative “greenness”, since core activities of a given firm may create negative environmental impacts. Most estimates however, indicate that “green” or “clean technology” jobs represent substantial and growing parts of the economies where they can be found.

The focus on reducing GHG emissions risks making definitions of clean technology a misnomer. Nuclear energy is often considered “clean” because it emits no GHGs. Yet Japan's Fukushima disaster of 2011 revealed its great risks. Furthermore, safe disposal of radioactive waste is a major problem without an adequate long-term solution. Biomass fuels are also considered a clean technology because sources of biomass are renewable. Yet in the United States ethanol is created primarily from genetically modified corn crops that make liberal use of chemical pesticides. Corn is also ironically a large part of a food system that is second only to the transportation sector in its consumption of fossil fuels (Pollan 2008). Wind turbines still require a substantial amount of steel, which creates CO2 during production. Even solar energy has its faults. Cadmium, a common ingredient in some thin-film solar technologies (such as those manufactured by First Solar), is a toxic heavy metal. Crystalline solar technologies utilize silane, trichlorosilane, and other chemicals, and create kerf dust, all of which can pose health hazards.

Moving away from non-renewable sources of energy can do a great deal of good for the earth, but all human-made technologies for creating energy have environmental impacts. They also face their own possible material constraints. Limits to rare-earths, the food system, geographic inequality of resources, and so on could limit the ability to manufacture and use certain clean technologies indefinitely. Instead, a continual process of innovation will be required to ensure that highest productivity technologies are in use, and that maximum long-term sustainability is achieved.

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[6] The North American Industry Classification System (NAICS) is used to collect statistical data on businesses in the United States.

[7] These types of jobs could include workers who operate fuel-efficient, electric, or hybrid transportation vehicles in completing job tasks. Another example are persons using the substitutes for plastic packaging materials which may be recycled, or biodegradable.

Most importantly, the cleanest and cheapest energy on the planet is the energy that we do not use. Continual and committed efforts to conserve energy and promote energy efficiency also provide economic stimulus, jobs, and can improve environmental quality. Not all "green" products designed to improve efficiency or provide non-toxic building materials are healthy or sustainable however. Thus care must be taken to ensure that health impacts continue to weigh in alongside environmental impacts.

In short, Climate Change is an issue that requires both a global strategy as well as sustained global support for the emergence of clean technology industry. Advances in clean technology will not end the need for a commitment to protecting the environmental quality of the earth and the health of its inhabitants. What they can do, however, is combine the active pursuit of economic and environmental value, and make sustainability the new competitive advantage.

The Transition to Renewable Energy

Renewable energy is often associated with clean technology, and its expanded development is one of the key activities in Climate Change mitigation strategies.[8] With a virtually infinite fuel source (the sun), scalability, and even transportability, renewable energy solutions hold a great deal of promise for the world. However, the technical realities of renewable energy impose a need for broad and complementary structural changes in the overall energy supply and energy economy. The issues of energy storage, grid coordination, and grid balance are just a few of the problems that need to be solved in step with renewable energy investment. Yet the organizational and technological challenges to develop clean alternatives are the reasons why they represent such great value-creating potential for advanced economies in the decades to come.

The problem of transitioning to renewable energy is in part the existence of a "legacy" energy infrastructure that, for some countries, developed over a century ago. Installation of these legacy infrastructures was integral to the development of these economies, and these were scaled and adapted to meet changing needs. While the cost of many wind and solar technologies have been vastly improved over the past few decades, and have fallen at an accelerated rate more recently, it will still take massive capital outlays to replace even a quarter of the world's fossil infrastructure with renewable sources.

The massive investments to transform the energy infrastructure to clean technology require *patient capital.* The bankruptcies of Spectrawatt, Evergreen Solar, and Solyndra in August 2011 highlighted solar energy as a U.S. clean technology industry that is struggling to compete internationally. In like fashion, bankruptcies have occurred as well among clean technology companies in biofuels, advanced energy storage, and wind manufacturing. Patient capital is required both to develop the clean technologies and to sustain the process of accessing markets until a sufficient volume of products can be sold to generate financial returns.

These solar energy bankruptcies, and especially the case of Solyndra, have raised questions about the value of U.S. public support for clean technology companies. One easy answer is that these U.S. companies were doomed to failure because of Chinese competition, with its less expensive labor is and "unfair" subsidies. Objections also include the sensitivity of profits to fluctuations in raw materials

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[8] Other important activities include energy conservation, electrification of transportation networks, sustainable agriculture, better waste management, and so on.

prices. When Solyndra declared bankruptcy, some even suggested that political corruption was a culprit.

As we discuss in detail later in this paper, all of these explanations fail to explain the problems facing the solar energy sector. What is missing from the standard economic and political analyses is a theory of innovative enterprise (Lazonick 2012). Substantial technological development and scaling of production require massive amounts of investment in the face of inherent uncertainty. Many innovative U.S. clean technology companies have been in operation for a decade or more, and are still unprofitable, as they seek to do what every innovative enterprise must do: develop higher quality products through collective and cumulative learning processes and utilize these investments in innovation by gaining the large market shares that drive down unit costs. Developing those technologies and accessing those markets require substantial, and coordinated, *financial commitment* from government agencies and business enterprises from the time at which these investments are made until such time that they can generate the high quality, low cost products that bring financial returns.

This financial commitment must be made, moreover, in the face of uncertainty over whether positive financial returns will ever be generated. There is uncertainty concerning the development of superior technologies. There is uncertainty concerning the extent of the markets that will be available to ensure a high level of utilization of these expensive technologies, even when they are superior. And there is uncertainty concerning the emergence of new competitors who are better at developing and utilizing the new technologies. But if a national economy like the United States wants to be a player in global clean technology, government and business will have to collaborate in confronting this uncertainty by providing the patient capital that is essential to the innovation process.

Replacement of conventional sources of energy with emerging renewable technologies is a difficult and long-term process. Conventional energy technologies benefit from economies of scale combined with the economic advantage of sunk investment costs that always serve as a disincentive to invest in new technologies (Negro and Hekkert 2010; Negro et al. 2012). In addition, institutional structures are in place that seek to protect vested interests in conventional technologies, and that can impede the development of renewable technologies that might replace them. Investment in a renewable technology such as solar energy or wind energy requires a powerful coalition of government, business, and household interests that can put in place the new set of policies that incentivize these investments.

Disruptive technologies such as solar and wind power, therefore, face an array of technical, economic, social, and political challenges as they compete with the established infrastructure. The productive capabilities of these technologies cannot be developed without long-term planning and major financial commitment. These new technologies must be developed to integrate with, and in some cases replace, the existing energy system. Neither government nor business can accomplish this transition alone. They have to do it together, with lots of patient capital.

Growth in World Solar and Wind Technologies

Globally, wind and solar power, along with biofuels, are the fastest growing energy technologies on the planet. Thus even as renewable energy in general remains a blip in the context of the overall energy picture, these technologies are already part of multi-billion dollar growth markets.

The Energy Information Administration (EIA) finds that non-hydro renewables, which includes solar, wind, geothermal, and biomass electric power production rose from virtually 0 percent in 1980 to 4 percent of world electricity production in 2010.[9] In 2010, wind energy represented 45 percent of non-hydro electric power generation while solar, tide, and wave energy was 4 percent, having rapidly increased its share in the last decade.[10] This change is roughly consistent with data from the IEA described above, which showed renewable energy to be in its global infancy as indicated by the proportion of global primary energy consumption which was renewable.

Table 1 draws on the EIA database for electric power generation in 217 countries. These data permit a comparison of renewables like hydropower, solar, and wind power.[11] Based on EIA data, only six countries in the world make the top 10 list for *both* solar and wind electric generation: The United States, China, Spain, Germany, Italy, and France. The United States generated close to twice the amount of wind electricity as its next nearest competitor China, while Germany and Spain generated over 62 percent of the world's solar electricity.

Table 1: Top 10 Wind and Solar Electric Power Producers, 2010*

	Top 10 Wind		Top 10 Solar	
Rank	Nation	% of World Total	Nation	% of World Total
1	United States	27.7	Germany	37.4
2	China	13.1	Spain	22.8
3	Spain	12.9	Japan	12.2
4	Germany	11.1	Italy	6.1
5	India	5.8	United States	3.9
6	United Kingdom	3.0	France	3.5
7	France	2.9	South Korea	2.5
8	Portugal	2.7	China	3.0
9	Italy	2.7	Czech Republic	2.0
10	Denmark	2.3	Belgium	1.8
	Rest of World	16	Rest of World	5

Source: Authors' calculations, Energy Information Administration, International Energy Statistics. Accessed 8 Nov 2012.

Yellow highlighted countries have top 10 representation in both solar and wind power.

*Solar is based on the EIA's solar, tide, and wave data (in billions of kWhs generated). Nation output is output as a percent of total output in that category. There is virtually no tidal or wave energy power being produced on the planet at this time, so the figures are meaningful for showing leadership in solar power.

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[9] The actual figure is approximately 0.003.

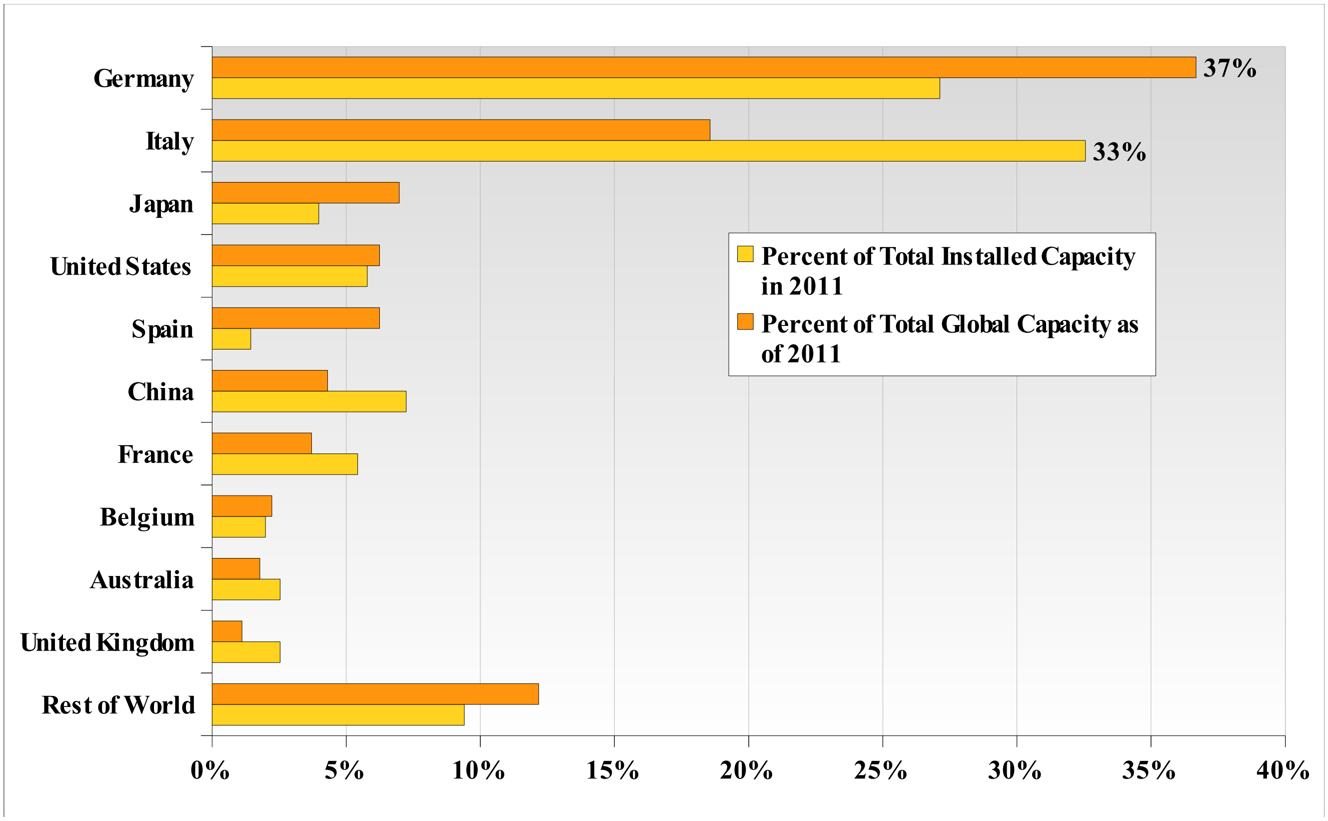
[10] The EIA's international energy data does not yet disaggregate solar from tide and wave. Nor, for that matter, is solar thermal energy isolated in statistics. Concentrated solar power (CSP) is another important solar technology which is also distinguishable from solar PV but not readily observable.

[11] Relying on generation statistics means that overall values are likely to be slightly overstated since total energy production tends to exceed energy consumption.

Solar Photovoltaic (PV)

Figure 3 shows that over half of installed solar PV capacity of the world can currently be found in Germany and Italy. Total world solar PV capacity is approximately 67.3 GWs (EPIA, 2012).[12] According to Marc (2012) 28 GWs (or 42 percent) of this total installed capacity was developed in 2011. The majority of installed capacity occurred in Italy and Germany, which combined made up approximately 70 percent of the global market for solar PV in as of 2011. Only the Czech Republic, Italy, and Germany have managed to add solar PV capacity at a rate of 1 GW or more annually.[13]

Figure 3: Percent of Total World Solar PV Capacity, Cumulative and Installed, by Nation, 2011*



Source: Authors' calculations. "Market Report 2011." *EPIA*. Jan 2012.
*Shown are the top 10 ordered by total amount of total capacity installed as of 2011. Total capacity represents the maximum aggregate generator value of all solar PV generating equipment installed globally. The percent of total installed capacity, represents that nation's share of the 28 GWs of solar PV capacity installed in 2011.

The United States was once a world leading solar PV manufacturer, losing leadership to Japan and Europe between 2001 and 2008 (Ardani and Margolis 2011, 22). As late as 1998 the United States and Japan supplied the majority of all solar PV technology in the world. China and Taiwan captured a growing share of solar PV manufacturing. At the end of 2010 solar PV manufacturing remained

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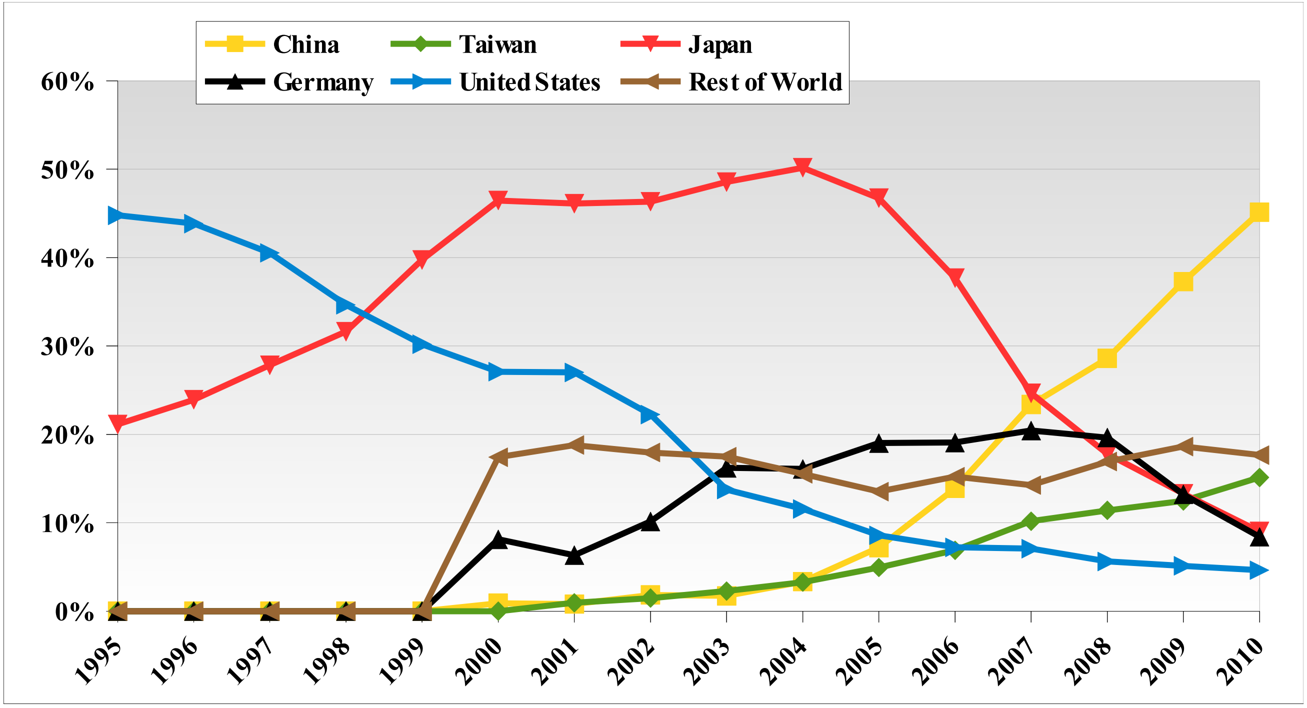
[12] Capacity, as opposed to electricity generation, is often used by market analysts to describe changes in the solar or wind markets. Capacity reflects the maximum output of a given generator, such as a 2 MW wind turbine, or 300 watt solar PV panel. Because actual performance is both technology and site limited, these values have little to do with actual energy generation. But these values do convey a sense of industry sales and growth.

[13] 1 GW = 1,000 MWs, or the approximate capacity of a nuclear power plant.

fragmented across many countries with ample room for a dominant leader or leaders to emerge (Ardani and Margolis 2011, 23).[14]

Despite the fact that solar PV development is heavily regionally concentrated in Europe, production of solar PV technology occurs globally. China has become the world's major solar PV manufacturer. Figure 4 below shows that the United States, Japan, and Germany have all lost positions as dominant manufacturers of solar PV over the decades to China and Taiwan. The top five countries shown consistently produced over 80 percent of all solar PV in the world between 2001 and 2010. Over the same period, aggregate production soared from 371 to 24,000 MWs annually, averaging 60 percent increases in production each year.

Figure 4: Producers of Solar PV by Percent of Annual Total, Selected Nations, 1995-2010



Source: "Annual Solar Photovoltaics Production by Country, 1995-2010." *Earth Policy Institute*. 27 Oct 2011. Accessed 14 May 2012. http://www.earth-policy.org/data_center/C23

As a result, and shown in Figure 5, below, current market share leaders in solar PV are largely Chinese firms. Like other firms globally, almost all current solar PV technology is based largely on modern versions crystalline silicon (C-Si) PV technology (the same basic technology developed at Bell Labs in the 1950s). Other advanced technologies exist such as thin-film amorphous (a-Si), cadmium telluride (CdTe), copper indium gallium selenide (CIGS), building-integrated solutions, or high-concentrating (HCPV) solar PV. Most alternatives to C-Si PV technologies in existence either suffer from low efficiency relative to C-Si, high cost, or both, making competition with more established C-Si technologies difficult.

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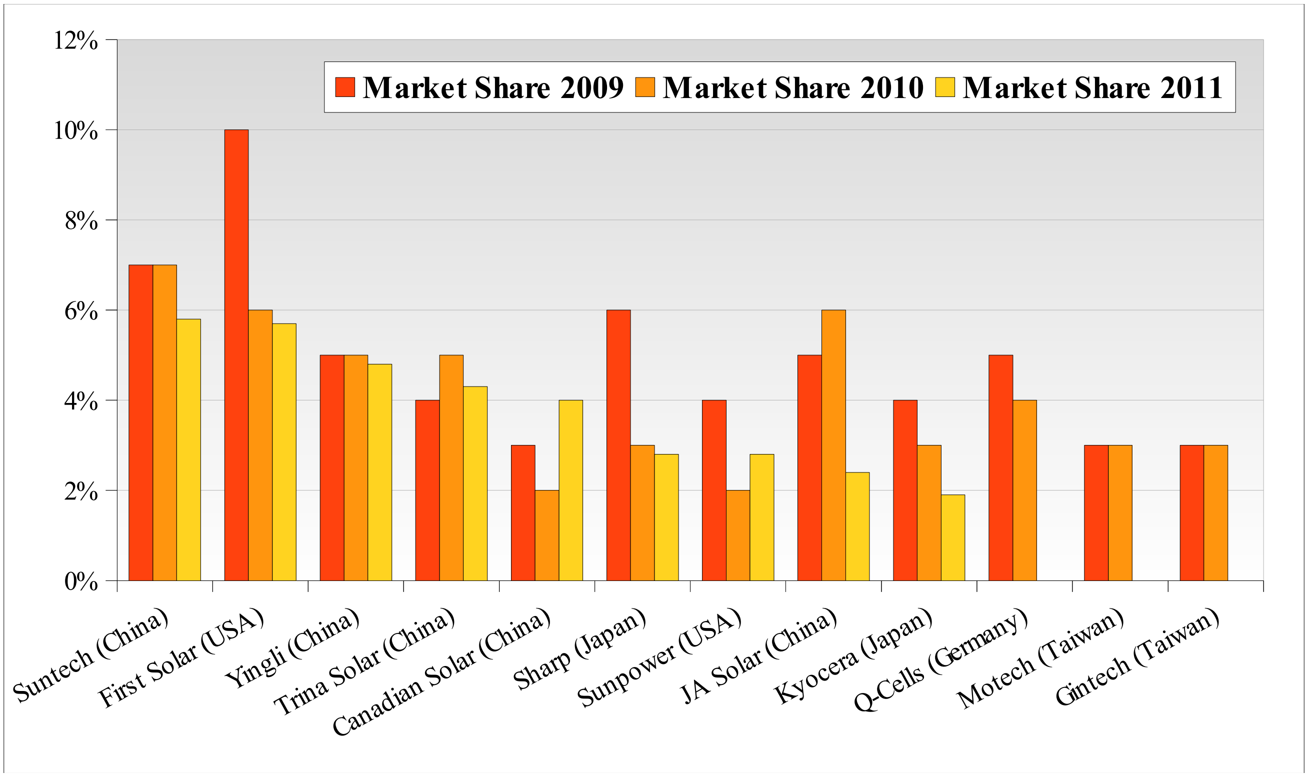
[14] Discussing market share in solar PV is complicated by the global supply chain. This includes production of silicon, silicon ingots, silicon wafers, cells, and solar modules (panels). A leading solar cell manufacturer, in other words, is not necessarily producing the final product in the chain. Nevertheless, some of the top cell/module companies at the end of 2010 were Suntech (China), JA Solar (China), First Solar (USA), Yingli Green Energy (China), and Q-Cells (Germany). As many companies become more vertically integrated, their market positions become more substantial.

Figure 5: Market share of Leading Solar PV Producers, 2009-2011



Source: REN21 Global Status Reports, various years.

Wind Power

The United States was the most important market for wind power in the 1980s. Then, through the 1990s and most of the 2000s Europe and especially Germany had the most rapidly developing wind markets. In the last few years, the picture has changed dramatically. In just four years, China has become the largest market for wind power in the world. In 2011 alone, China added two to three times the wind capacity added in the United States, and up to nine times the capacity added in Germany.[15] As shown in Figure 6, China alone installed close to half of all wind power in 2011. As shown in Table 1 above, the top 10 countries developing wind power generate 86 percent of the world's electric wind energy. China is poised to increase its share of wind electricity generation dramatically as more of its wind capacity is brought online.

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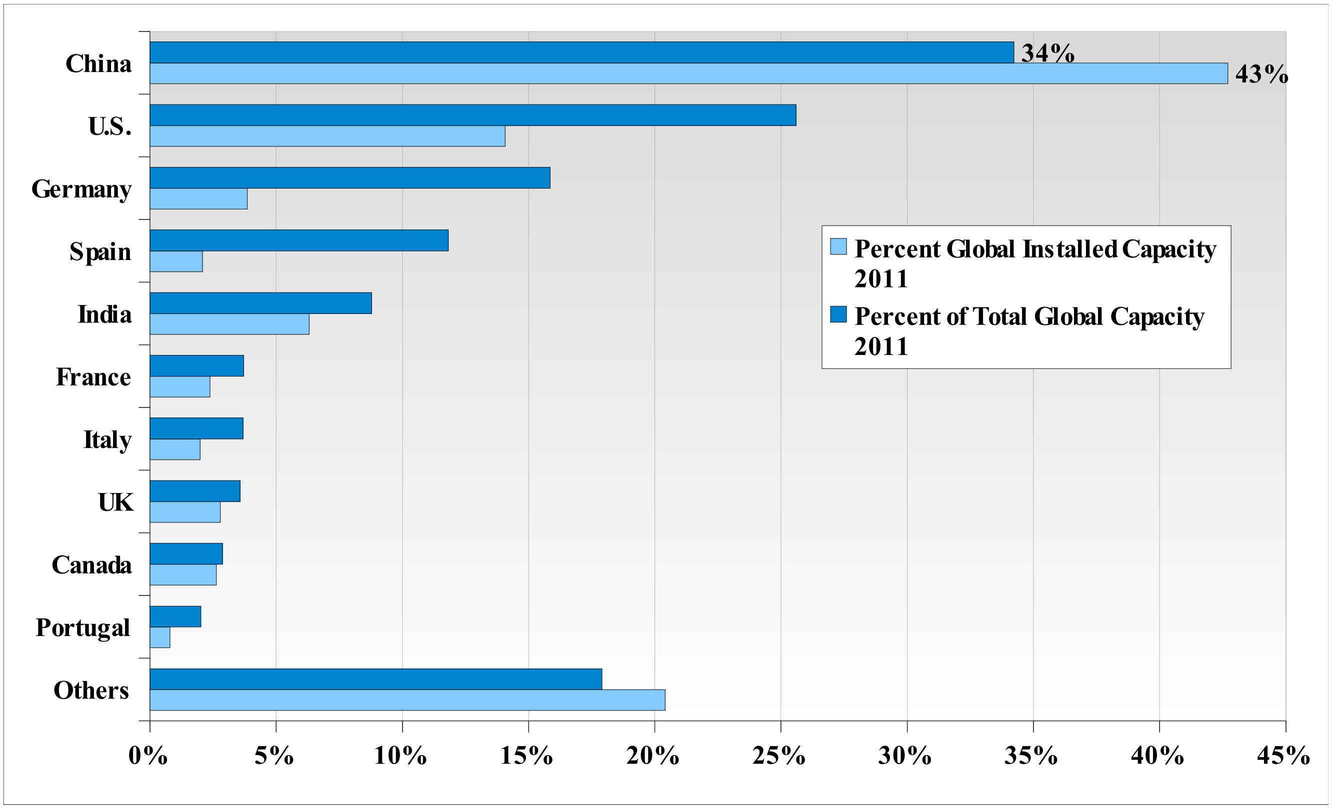
[15] As with solar PV, the wind power industry is often described in terms of installed electric capacity, as opposed to the total number of wind turbines installed/produced, or total amount of electricity generated (or consumed). Table 1, shown earlier, broke down national leadership by billions of kWhs generated, which is a different metric. Capacity conveys a sense of the physical amount of wind power in existence, as wind turbines are rated according to their on-board generator (1.5MW, 2 MW, 5 MW and so on) rather than their swept area, which would be a more accurate performance metric. Swept area is calculated from the diameter of the rotor. Each 1-foot increase in rotor diameter yields 23% more swept area, which can capture 23% more power. The power generated triples with each unit increase in wind speed.

Figure 6: Percent of Total Installed World Wind Capacity, 2011*



Source: Authors' calculations, Earth Policy Institute, Global Wind Energy Council.

*Shown are the top 10 ordered by total amount of total capacity installed as of 2011. Total capacity represents the aggregate generator value of all wind turbines installed globally. One wind turbine might equal 1.5 MW. The percent of total installed capacity represents that nation's share of the wind power capacity installed in 2011.

The Global Wind Energy Council (2010, 59-60) pointed out that approximately 3 GWs (or 12 percent) of the 25 GWs of wind power installed in China in 2009 was not yet connected to the grid. Otherwise, Chinese turbine projects often experience 3 to 4 months of operational testing prior to grid connection. Table 1 above shows that in 2010 the United States generated more wind energy than China despite the fact that the United States had approximately 40 GWs of wind power installed to China's 42 GWs.[16]

As with solar power, in recent years wind power production has been shifting to China, whose major companies have rapidly acquired significant global market share. For many years Denmark, led by Vestas, has led the world in wind turbine manufacturing, despite the relatively small size of its domestic market for wind energy. While global competition among wind manufacturers is fierce, domestic markets tend to be dominated by one or two national champion companies; for example, General Electric in the United States, Vestas in Denmark, and Enercon in Germany. Illustrated in Figure 7, below, the tendency in recent years has been for U.S. and European-based firms to lose market share to China's companies.

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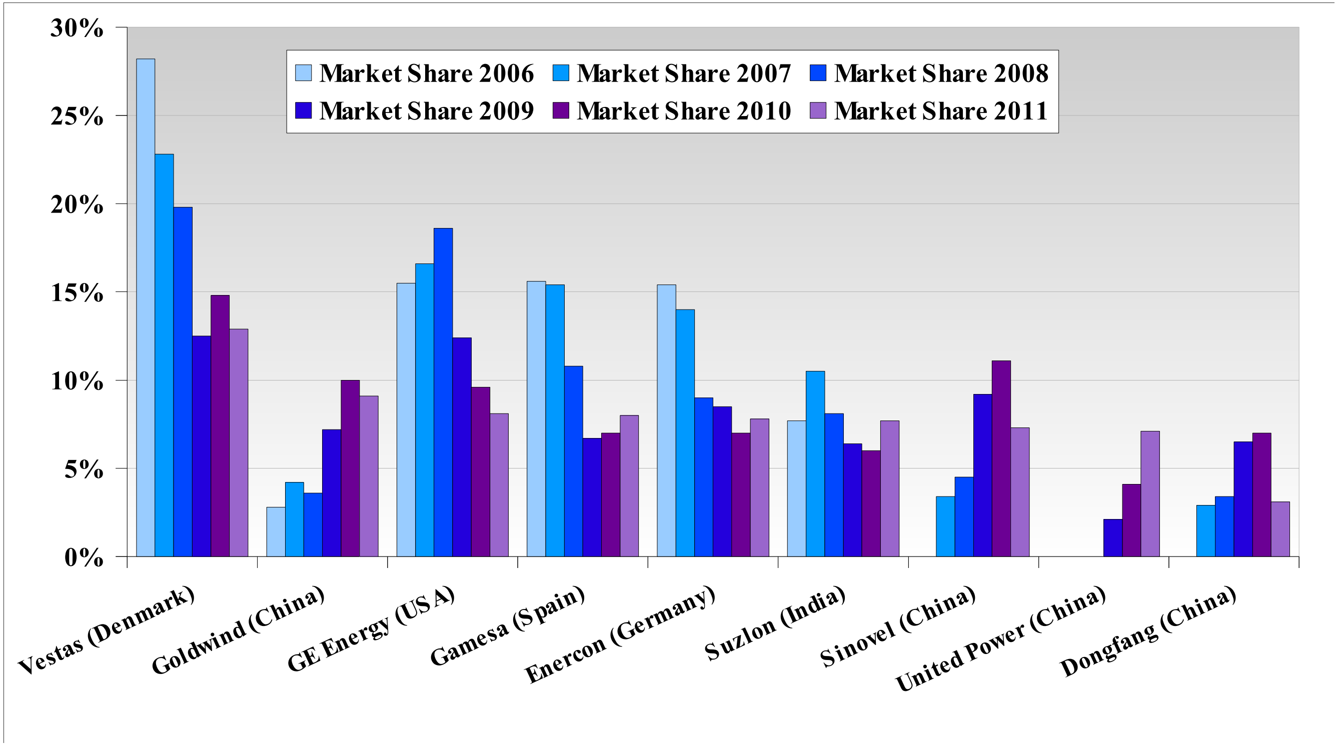
[16] Other than interconnection challenges in China, however, there is little reason to assume that 1 GW in the U.S. and 1 GW in China would be equally productive since productivity is heavily affected by siting and turbine model deployed.

Figure 7: Wind Manufacturer 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. We estimated 3.1 percent market share on news that they lost 3.9 percent of global market share compared to 2010.

The Cost of Renewable Energy

As more renewable energy technologies substitute for fossil energy technologies, we can expect a reduction in overall CO2 and other GHG emissions. Several decades of new renewable energy development have failed, however, to make a large impact on world energy statistics. There is simply too little renewable energy being developed in the world relative to other technologies, and relative to increased energy consumption overall.[17]

The world's energy infrastructure is massive, and there are significant parts of the still serviceable legacy infrastructure that were put in place many decades ago. As with the diffusion of any new technology, the high fixed costs of putting it into operation must overcome the cost advantages of the existing technology, the costs of which have already been sunk and, in many cases, even written off. Wind turbines and solar PV panels have been used as grid connected sources of energy for approximately four decades making them somewhat new additions to the energy infrastructure. As other technologies are developed (such as the aforementioned tidal or wave technologies), the amount

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[17] Total renewable energy electric generation increased 137% between 1980-2010, for example, while total non-renewable electric generation increased approximately 157% over the same period. Meanwhile renewable capacity has grown 160% between 1980 and 2010 while non-renewable capacity grew 154%, giving renewables only a slight lead.

and types of renewable energy available will increase, intensifying competition.

We have seen that solar and wind power development are highly concentrated geographically, with a handful of countries and companies dominating the world market for these renewable energy technologies. In order for these energy technologies to compete in world markets, they require *both* further technological development to increase their efficiency relative to existing technologies as well as the attainment of large market shares to drive down unit costs. Eventually these costs must reach levels comparable to existing energy technologies that have the benefit of sunk costs. This competition demands high-productivity technology as well as careful site selection because not all places on the earth have equal access to good average wind speed or sunshine.

Capturing greater economies of scale in wind or solar energy is about achieving technological innovation, which produces higher quality, lower cost solar modules or wind turbines. R&D supporting innovation increases costs for businesses, which cannot benefit from the innovation unless it increases market share, allowing it to spread the cost of R&D and drive down unit costs. Where renewable energy development occurs mostly as a form of infrastructure development, manufacturers depend on sales to renewable energy developers for this increased market share.

Innovations in renewable energy technologies diffuse mainly through their consumption by renewable energy developers, who have the incentive to use as many solar modules or wind turbines as possible. Utilizing a maximum number of machines spreads project costs, and generates higher revenues through electricity sales (and in the case of the United States, also tax and other subsidy as we shall see) which are then returned to project owners and investors. This multiplication of machines also reduces project risks and increases reliability, given that renewable energy projects will continue to produce most of its expected output even if there is a problem with an individual module or turbine.

Renewable energy innovations, in other words, occur as a result of a sustained pattern of support for continued R&D, manufacturing, and development activities. Each level requires tremendous commitment in the face of uncertainty faced by business and government, which may not capture the economic or social benefit of innovation should R&D succeed but manufacturing fail, or should manufacturing succeed but demand for new projects disappear. The long-term results of this commitment to renewable innovation are higher performance, lower cost technology, GHG emission reduction, job creation, and effective exploitation of domestic energy resources (energy “independence”).

Kristen and Margolis (DOE, 2011, 60) report that to date the overall cost of solar PV modules dropped from about $23/watt (2010 dollars) in 1980 to about $2/watt in 2010.[18] *Solarbuzz.com* reports that in early 2012, the lowest prices for solar modules had fallen into the $1/watt to $.84 cents/watt range. Kristen and Margolis (DOE 2011, 61) add that the cost of completed solar PV projects dropped from approximately $12/watt in 1998 (2010 dollars) to approximately $7/watt in 2010.[19] Pernick, et al. (2012, 5) report that the cost of energy produced by solar PV stood at approximately 28-47 cents/kWh in 2007 and 14-23 cents/kWh in 2011. They project that solar PV will cost as little as 6 cents/kWh by 2020, a figure more directly comparable to today's conventional energy technologies.

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[18] Their data is based on projects in the USA. Manufacturers are rapidly driving costs of below $1/watt.

[19] Project costs will always be higher, as the cost of a solar module must be factored in with the cost of construction and installation.

In contrast wind energy project costs declined from about $4.5/watt ($2010) in 1982 to approximately $1.5/watt ($2010) in 2000 (Wiser and Bolinger 2011, 47). Since that time, project costs have risen to about $2-2.5/watt ($2010).[20] As such energy prices as low as 3.2 cents/kWh ($2010) were achieved in 2002 but have since risen to about 7.3 cents/kWh in 2010 (Wiser and Bolinger 2011, 39). Historically, the first wind projects in the United States in the 1980s carried costs of about 30 cents/kWh, dropping to less than 10 cents/kWh in the 1990s (Pelsoci, 2010, 4-14).

Typically, the wind turbine itself is about half of a project's cost. In like fashion, solar modules are just part of an energy system's total cost. Renewable energy projects also face competing land (or water) uses, regulatory and siting constraints, and the technology must be productive enough to pay for construction, permitting, financing, and operation and maintenance costs. It is critical to support increasing scale and market shares of manufacturers, because manufacturers still produce the most expensive part of every renewable energy project. Also, developers are consumers, not innovators of renewable energy technologies, and while their feedback might influence the direction of innovation, it is up to manufacturers to implement innovative changes. Developers have an interest in purchasing the highest performing, lowest cost solar modules and wind turbines available, not only because it lowers their fixed costs but also because it can impact the long-term costs of operation and maintenance.

While improvements to technology in the lab and large-scale manufacturing represent a core part of the innovation “loop” for renewables, the impact of innovative technologies is ultimately bound to project performance. Projects will maximize exploitation of cumulative investments in energy technology innovation insofar as siting characteristics permit. These factors include average wind speed, exposure to sunlight, access to transmission lines, and less predictable characteristics such as frequency of bad weather or bird and bug debris. Economies of scale play a role, as a greater number of solar modules or larger wind turbines can lower unit costs. While technological performance can increase, in other words, other cost factors are outside the influence of the technology itself and may be likely to increase in cost over time.

The unit cost of wind energy has been reduced as the size of wind turbines has increased, as increases in rotor diameter and hub height increase their relative productivity. The American Wind Energy Association (2011) reports that a typical turbine that is five times larger than one produced in 1990 produces 15 times more energy. Turbines that might have had a 56 foot rotor and driven a 100 kW generator in the 1980s might today have a 370 foot rotor driving a 3 MW generator. But the cost advantages of these larger machines are only realized if installers achieve sufficiently large capacity utilization to bring down their unit cost of energy.

The cost of solar modules scale in step with increases in their size, so manufacturers seek to maximize economies of scale and focus on achieving higher conversion rates.[21] First Solar, a major U.S. CdTe thin-Film solar PV producer, announced that they had created “world record breaking” 14.4 percent efficient thin-film solar cells last January (Brown 2012). First Solar also once established record efficiency for their C-Si cells at 17.3 percent.

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[20] Wiser and Bolinger (2011) attribute these rising costs to rising demand for wind turbines coupled to opportunistic manufacturers, fluctuations in the price of oil and steel, up-scaling of turbines, and other factors. Generally speaking, increases in wind capacity have accompanied reductions in the cost of energy.

[21] Cutting larger solar cells and making larger modules may impart efficiencies, such as reduction in silicon “wasted” by the cell cutting process. That said, an increase in the size of a module requires equivalent increases in connecting hardware and backplates and so on.

In other words, state of the art thin-film solar technology can convert about 14 percent of the sunlight reaching it to electricity. Older crystalline solar technologies currently fare better. SunPower of California announced crystalline solar cells with 22.4 percent efficiency back in 2011 (Shahan 2011). Suntech of China is pursuing crystalline technology promising to exceed 20 percent efficiency. As the relative efficiency of solar technology increases, its ability to compete with conventional sources of energy improves.

Although C-Si PV technology is more efficient than thin-films currently in production, thin-films use much less raw material in production, making it cost competitive with more efficient products. Thin-films can also exploit other efficiencies in practice, such as Solyndra's cylindrical design promising to capture more direct and reflected light as the sun arced over the sky. Certain thin-film technologies are more productive operating in hotter climates or exposed to a lot of indirect sunlight. Finally, thin-films utilize different materials in their manufacture, which in Solyndra's case provided a possible advantage given skyrocketing costs of raw silicon during a critical period of their growth – a transition to mass production. It is currently questionable however, whether improvements to thin-film efficiency and economies of scale can occur rapidly enough to maximize and exploit cost advantages before major thin-film producers lose market share to major Chinese C-Si producers, who are rapidly scaling and producing world-class solar modules.

Government support for clean technology in the United States, Germany, and China

When government supports innovation in clean technology, it is able to support technological developments which can address the need for GHG reduction, job creation, and energy independence. Because the innovation process entails high fixed costs (that derive from its collective and cumulative character) and is highly uncertain, the business sector cannot be expected to consistently champion all risks nor absorb all costs. Likewise, the government can potentially mobilize a larger and broader range of technical expertise to generate knowledge of the technologies needed today, and those which may be needed tomorrow.[22] There is therefore a critical role for government to play in funding research and subsidizing utilization of clean technology by business enterprises that seek to produce higher quality, lower cost goods and services.

For several decades the government of the United States, Germany, and China have all deployed policies to support renewable technology development and deployment, but with very different outcomes. We have already observed that CO2 emissions are high in the United States and China, and have fallen over time in Germany (see Figure 1). Electric renewable energy consumption as a percent of all electric energy consumption was 11 percent in the United States, 20 percent in Germany, and 21 percent in China in 2010 (author's calculations, Energy Information Administration, International Energy Statistics).[23] Between 2007 and 2011, total electric renewable energy consumption increased 47 percent in the United States, 38 percent in Germany, and 63 percent in China.[24]

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[22] An example of how the government can exploit the knowledge base to greater impact is funding of national energy laboratories (such as the National Renewable Energy Lab), or providing competitive grants to businesses and universities in exchange for directed and often specific research activities.

[23] Renewable energy electricity consumption includes hydro, solar, wind, geothermal, and biomass based electricity generation. Here we ignore biofuels consumption, which is also considered renewable, but which is specific to transportation. China is the world's largest market and user of solar water heaters, though this would not be reflected in this statistic.

[24] China (2010) and the U.S. (2011) each generated less than 1% of their electricity from solar power, but generated 3%

The United States remains a leader in wind power adoption, and it's wind sector was more productive than China's in 2010 despite less installed capacity (see Figure 5 above, also Wang, et al., 2010; GWEC 2010). But the overall growth of renewable energy consumption continues at a slower pace in the United States than in other leading countries. Through a comparison of the U.S., German, and Chinese approaches to the development and diffusion of renewable energy, we can build our understanding of the ways in which the interaction of government and business in the process might yield to beneficial results.

The U.S. Approach

Almost 200 countries have signed the Kyoto protocol since it became possible to do so in 1998. The United States, however, remains the only country which has signed the treaty and not ratified it (United Nations 2012). In 2010, the United States also shelved the 2009 Waxman-Markey bill, which would have created a market for CO2, provided billions in energy R&D funding, and established national carbon reduction and renewable energy targets. To date, the United States has not adopted GHG standards. This gap in energy policy is partially addressed by the 2009 Regional Greenhouse Gas (RGGI) and 2007 Western Climate Initiatives (WCI), which are state-led efforts to reduce GHG emissions.

Heiman and Solomon (2004, 96) claim that "the federal institutional structure for energy decision making in the United States is weak," and, "strong geopolitical interests in energy issues prevent these institutional failings from being readily fixed". Additionally, U.S. energy policy has tended to be reactive rather than proactive, able to respond to crisis but unable to produce long-term goals or address global issues requiring national coordination, such as climate change.

As an example, in 1978 President Carter established the Department of Energy (DOE) to administer national energy R&D programs while the Federal Energy Regulatory Commission (FERC) was created to regulate wholesale energy prices. Carter's energy plan was unoriginal, yet it arguably required an energy crisis for the possibility of implementation (see Fehner and Hall, 1994). The DOE faced dismantling by the Reagan administration that followed. That attempt failed, but not before altering the trajectory of federal R&D research. Renewable energy development has since followed a fractured and uneven course of federal and state policies.

Sovacool (2008) adds that the U.S.'s "portfolio approach" to energy has contributed to its failure to adopt a long-term energy plan or develop renewable energy effectively. Indeed, even today, the United States supports and continues to subsidize many legacy technologies to a greater extent than renewables. Despite the hundreds of billions committed through different programs and research, the U.S.'s energy mix has failed to change a great deal since the 1980s.

Much of the policy complexity in the U.S. stems from changing policies supporting renewable energy deployment. The Public Utility Regulatory Policies Act (PURPA) of 1978 forced power distributors to purchase renewable energy and instructed them to give renewable developers a price of energy that reflected their "avoided cost". In the early 1980s, this policy had the effect of granting wind

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and 1% from wind energy, respectively. In 2011, Germany generated 3% of its electricity from solar power and 8% from wind power.

developers 10-year contracts at 5-12 cents/kWh (Bird, et al. 2003).[25] This price, however, was below the capability of existing wind technologies, which produced electricity for 20-30 cents/kWh. The price of wind power would not drop to under 10 cents/kWh until the 1990s. Instead, the viability of early wind projects was supported by combined state and federal capital subsidies of approximately 50 percent, which supported about $1.4 billion in investment during the 1980s wind rush (Asmus 2001).

At the federal level, the Production Tax Credit (PTC) has provided price support for renewables since 1992. Indexed for inflation, the tax credit's value for wind power was 1.5 cents/kWh in 1992, and is approximately 2.2 cents/kWh today. The value of the credit is tied to power production, making it increase in value in step with the productivity of a renewable energy project. As part of the *American Jobs Creation Act of 2004*, the credit was revised to include solar energy at 2.2 cents/kWh, then rescinded as part of the *Energy Policy Act of 2005*. While the benefit is often considered vital for the wind industry, it has been allowed to expire before (see Table 2, below), causing new wind energy development to grind to a near halt in 2000, 2002, and 2004 (Wiser et al. 2007, 3). In the late 2000s the PTC reached an annual cost of about $1 billion, driven mainly from wind development activities.

Solar PV development has been driven mainly by the Investment Tax Credit (ITC), which has been revised several times since its 1978 institution under the Energy Tax Act of 1978. Yet the lack of much solar development occurring until more recently suggests that removal of the residential benefit cap of $2,000 under the *Emergency Economic Stabilization Act of 2008*, and institution of a 30 percent capital deduction or grant by the *American Recovery and Reinvestment Act of 2009* (ARRA) are more effective solar PV development drivers. As the United States begins to complete more utility scale solar power plants, the value of this credit and its affect on the solar industry will be better known.

The *2005 Energy Policy Act* funded clean coal research, created loan guarantees, mandated biofuel production, and forced all utilities to accept net metering programs, but generally allocated more financial support for fossil fuels than clean technologies.[26] In response to the financial crisis of 2008, the 2009 ARRA reintroduced the ITC as a substitute for the PTC, providing a 30 percent credit on total project expenses for solar and wind developers.[27] Additionally, wind project developers had the option of taking the ITC in grant form through the end of 2011. Solar PV developers could take grant funding through 2016.

A key difference between these incentives is that the value of the PTC increases with the output of a given wind project, while the ITC grows with the total dollar value of the project. The ITC taken in grant form provides an upfront and low-cost benefit to a wind developer wishing to finance a project. The PTC and ITC, as tax credits, are generally used to attract 3rd party investors to raise project finance, which introduces new costs into the energy-development process as investors will seek an agreeable rate of return in exchange for project finance.

R&D support has for energy had generally been the most stable form of patient capital provided by government. Since 1992, approximately $3.4 billion in 2011 dollars has been spent on solar R&D

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[25] Prices would later be determined by the cost of fuel, which could be as low as 3-5 cents/kWh.

[26] Net Metering allows ratepayers to use renewable systems to earn income from utilities if their energy system produces more energy than they use. Generally speaking, the rate they would receive for producing power for the grid is a few cents a kWh.

[27] The previously mentioned capital subsidy of the 1980s was also essentially an ITC.

and $1.2 billion on wind R&D.[28] R&D has sought to develop new technologies, improve on the state-of-the-art, and also bridge technologies into commercialization in collaborative efforts with business. Otherwise the PTC has provided, albeit intermittently, the longest-term incentive for renewable energy investment. The government extends other incentives periodically. The 2009 ARRA, for example, provided $37.5 billion in loan guarantees, meant partly to finance solar and wind projects, while offering limited funding for advanced manufacturing in an effort to develop a more competitive clean technology industry.

Many individual states have tried to fill the void left by a subsidized but unfocused and unstable federal energy agenda. Renewable Portfolio Standards (RPS) are given greatest credit for promoting renewable energy development.[29] Twenty-nine states and Washington D.C. adopted RPS policies between 1983 and 2012, while eight states created voluntary standards between 2005 and 2012. Typically, RPS policies establish a timetable and goal for future renewable energy development. Goal achievement is tracked by the issue and sale of renewable energy credits (RECs), which are sold bundled or unbundled to energy produced by qualifying renewable energy projects. Additionally states often have green power purchasing schemes, and set aside funding for renewable energy or energy efficiency programs funded by ratepayer surcharges. The aforementioned RGGI and WCI programs divert revenues into state energy programs meant to reduce GHG emissions. At their discretion, states may also provide subsidies or incentives to influence manufacture location decisions. *Dsireusa.org* indicates that about 39 policies meant to encourage clean technology manufacturing are in place in 25 states, many of which based on tax credits.

Numerous states have outperformed their RPS targets. Wind power has so far tended to overshadow other technologies in the achievement of RPS goals. As a result many states add to RPS laws a specified amount of solar power development. Despite the popularity of the RPS, there is no actual “standard” observed by states, which create their own definitions of qualifying facilities and allow a variety of technologies to contribute to compliance. Pennsylvania, for example, allows for several coal technologies to contribute to its “alternative energy portfolio standard.” Maine recently proposed modifying its RPS law to allow large hydropower facilities to contribute to its target, though doing so would allow a much older technology to perhaps undermine deployment of new on and off shore wind energy. RPS laws are, in other words, subject to revision or elimination as a result of changing political administrations.

Achievement of an RPS goal can be based upon a given amount of electricity generation, a proportion of energy sales, or new capacity, making it difficult to directly compare the relative aggressiveness of each approach. Given the political vulnerability of the laws, and their need to be updated or revised to reflect the changing technological and competitive landscape, it is unclear the extent to which this approach will support a strong and long-term domestic market for renewables. Many U.S. states with leading supplies of renewable energy offer their own financial incentives in combination with established goals, such as California's $3.2 billion solar rebate program. Thus, complex policy interactions further complicate analysis of how the RPS in particular can be granted credit for driving outcomes in renewable energy development and by extension, technological progress

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[28] Funding for renewable energy R&D tended to aggregate all technologies together prior to 1992, making it difficult to know total expenditures since the 1970s. The late-1970s to the mid-1980s was a period of large funding outlays, however, similar to those being made recently.

[29] Other important policies include Net Metering, Public Benefits funds, Green Power Purchasing, and state-specific incentives, rebates, or other resources like inexpensive land.

given that none place emphasis on innovation by U.S.-based firms.

The German Approach

Like the United States, modern German energy policy can be traced back to German government investment in renewable energy R&D in response to energy crisis. The 1986 Chernobyl nuclear accident worked in favor of renewable energy R&D as nuclear power was perceived as potentially disastrous.[30] In the last half of the 1980s, raised awareness of climate change influenced policy and made it a central environmental issue. According to Lauber (2006, 105), annual expenditures on renewable energy R&D rose from 10 million Euros in 1974 to 150 million Euros in 1982, declining to about 80 million Euros by 1986. In the 1990s, reunification of East and West Germany prompted policy makers to support renewables as an important economic frontier that could create job opportunities (Ball, 2012).

Lauber (2006, 105-106) states that in 1987, Germany's first climate commission established a goal of reducing carbon production by 80 percent by 2050, while laying the basis for feed-in-tariffs (FIT) to provide above-market prices for qualifying renewable energy technologies like wind and solar power. At the same time, Germany set in motion targets for 100 MWs of new wind capacity (revised to 250 MW in 1991), and established a 1,000 solar roofs program. A 70 percent combined capital subsidy went into effect between 1991 and 1995, which ultimately overlapped with the feed-in law of 1991. The result, according to Lauber (2006, 3), was that “newly installed wind capacity very nearly exploded”. Wind turbines receiving government subsidy were then monitored for 10 years in a “combined market stimulation and scientific program” which promoted their improvement (Soppe 2009, 13).

The FIT program initially set the above market price of renewable energy at 90 percent of the sales price, amounting to approximately 16-17 pfennig/kW (31-33 Eurocents/kW) between 1990 and 2000. The subsidy was high enough to spur significant growth in wind energy, but too low to encourage significant solar development. In 1999 Germany passed the *Renewable Energy Sources Act of 2000* (RESA), creating a new fixed cost FIT. Subsidies were changed to reflect differences in technological performance, by granting regressive wind power subsidies of between 8-9 eurocents/kWh for five years, with 5-6 eurocents/kWh for 15 years thereafter. Subsidy rates declined 1 percent each year on a fixed schedule. Solar power was eligible for 54.6 eurocents/kWh for 20 years, with the regressive subsidy declining by 5 percent each year thereafter. The FIT ultimately provided investors with long-term certainty coupled to expectation that technology costs would fall over time.

Recognizing the success of its earlier renewable drive, Germany launched the 100,000 solar roofs program in 1999, just ahead of the RESA. Park and Eissel (2010, 329) document the success of German programs, showing that Germany raised the proportion of electricity generated by renewables from 4.8 percent to 15.1 percent between 1998 and 2008. Wind energy generation grew from just 40 GWhs in 1990 to 40,400 GWhs in 2008, while solar grew from 1 to 4,000 GWhs over the same period (Park and Eissel 2010, 331). Overall, in 2006 Germany surpassed its renewables target of 4.2 percent of primary energy by 2010, many years ahead of schedule (Park and Eissel 2010, 325). In 2010 consumption of renewable electricity in Germany reached 20 percent, well on the way toward achieving targets set for 35 percent by 2020, growing to 80 percent by 2050.

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[30] The U.S. equivalent event was probably the 1979 Three Mile Island accident in Pennsylvania. As we documented however, nuclear R&D funding continues to outpace support for renewables.

During the 1990s the German government allocated at least 1 billion Euros for renewable R&D, to which its state governments added about 850 million Euros (approximately $2.2 billion total). The diversity of activity promoted by R&D programs eventually created many new wind firms (Soppe 2009). Park and Eissel (2010, 333) add that the Market Incentives Program provided grants for solar PV manufacturing and deployment, could be combined with other government funds, and promoted growth of 40 firms which produced for each step of the solar industry supply chain.

The FIT policy also had the effect of promoting much higher local ownership rates than can be found in the United States. Over 50 percent of renewable power systems in Germany in 2010 were owned locally (Gipe 2012). The high prices that generators could earn encouraged investors and homeowners to purchase the technology and sell energy at a profit to utilities, knowing that their rates were fixed for 20 years and enough to pay for the equipment over time.

As noted earlier, Germany's energy policy has promoted both the expansion of renewable energy as well as strong businesses in the solar and wind sector. National goals to address GHG emissions and increase renewable energy consumption were backed by significant government R&D and deployment funding, using a subsidy structure that better reflected the performance of existing wind and solar technologies. This approach helped to promote continued development and diffusion of technology.

The Chinese Approach

While countries like the United States and Germany attempt to reform and reshape their energy grids, China's challenge is to expand its infrastructure fast enough to keep up with growing energy needs. Between 2000 and 2010, total installed electric capacity across all energy sources in China tripled from 320 to 988 GWs (retrieved from EIA International Statistics Database). By 2010, China's electric energy grid was over six times the size of Germany, and 95 percent of the total capacity of the United States.

China began developing renewable energy in the 1980s, focusing on wind and solar power in the 1990s. Ma et al. (2010, 440) claim that China's interest in renewable energy was a technical solution for bringing power to under-served rural areas, not a response to an energy crisis.[31] Huo and Zhang (2012) add that China did not begin on-grid application of solar PV power until 2008. According to REN21 (2009, 2), for example, China's Township Electrification Program spent $293 million between 2003 and 2004 on small hydro and solar PV technologies to provide electricity to 1.3 million people.

Energy conservation became more important as China's industrialization continued. REN21 (2009, 9) argues that the 1997 Energy Conservation Law that guided Chinese energy policy from the 1980s reduced energy intensity by approximately half between 1990 and 2005.[32] Revised in 2008, China's 11th Five Year Plan targeted a reduction of energy intensity of 20 percent by 2010, and the 12th

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[31] Development of wind power in the United States would conform to this statement, as the market for early electric wind turbines was in fact rural parts of the country without access to the electric grid in the late 19th and early 20th century.

[32] Energy intensity is a measure of energy consumption relative to GDP. As energy intensity declines, it is a sign that greater economic value is created relative to each unit of energy use. Because energy use imposes economic and environmental costs, reducing energy intensity has positive implications for the economy as well as the environment.

Five Year Plan specifies an additional 16 percent by 2015.

China's long-term energy plans have been integral to its strategy for industrial development. In the 1980s and 1990s China reduced or exempted customs on wind turbine and solar PV imports, defining them as high technologies. China also spent 1 billion RMB in 1999 (approximately $121 million) for “small- and medium-sized technical enterprises” with grants and low cost loans, financing 1,000 projects (Wang et al. 2010, 1874).

REN21 (2009, 10) highlights five rounds of concession programs meant to promote large-scale wind development and achieve lower energy prices. The concession programs granted wind developers 25-year contracts, which provided a fixed price for energy based on competitive auction for 15 years followed by 10 years at prevailing market rates. Winning bids for wind developers typically guaranteed a rate of return, low-cost financing, interconnection, and transmission subsidized by local governments (Wang 2010). Martinot (2010, 6) notes that the 2003 concession program encouraged Chinese manufacturing with a 70 percent domestic content requirement, which was also supported by favorable import and value-added tax on innovative wind technology. This regulation was eliminated in 2010 after Chinese firms had begun to dominate global markets.

It is widely agreed that the 2005 renewable energy law was pivotal in modern Chinese energy policy (Wang et al. 2010; Kang et al. 2012; Martinot 2010; Ma et al. 2010). Shortly after the passage of this law, renewable energy manufacturing and deployment began to accelerate rapidly in China, with wind at the forefront. China forced power distributors to accept and pay for renewable energy generated, and above-market energy pricing was created to facilitate more rapid deployment.

The law also established a public fund for renewable energy R&D and projects. Funds are awarded as grants or used to subsidize loan interest. Modified in 2009 to pool ratepayer surcharges together, Finamore (2010) describes a fund of $689 million in 2009, and would grow to $1 billion or more in 2010, making it a substantial source of public funds. The renewable energy law also specified preferential loans for renewable energy projects, and continued with value-added tax benefits for certain renewable technologies. These benefits, established in 2001, collected taxes from operating renewable projects and returned them to manufacturers, the tax rate varying from 8.5 percent (wind) to about 17 percent.

The 2005 renewable energy law also specified that renewable energy should represent 20 percent of total energy consumption by 2020 (compared to 2.5 percent in 2004). In 2007, the *Medium and Long-Term Development Plan for Renewable Energy* changed China's renewable energy goal to 15 percent of *final energy* consumption by 2020.[33] Development targets have been revised several times, beginning with 1.8 GWs of solar PV and 30 GWs of wind power by 2020. As the latter target was quickly surpassed, Casey and Koleski (2011, 11) add that the 12th Five Year Plan includes 70 GWs of new wind power, and 5 GWs of new solar power capacity. Martinot and Junfeng (2010) highlight that drafted plans may specify as much as 150 GWs of new wind power, and 20 GWs of solar PV by 2020.[34]

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[33] Martinot (2010, 7) claims that final energy engenders a “larger absolute quantity of renewables” and commits China to the same target format as the European Union.

[34] China announced in the summer of 2012 that 21 GWs of solar power would be constructed by 2015: 20 GWs of solar PV and 1 GW of solar thermal.

Martinot (2010, 5) claims that in China a FIT for wind power was established in 2009 and set at between 0.54 and 0.61 yuan/kWh (approximately 7.9 and 8.9 cents/kWh), with higher prices paid to developers constructing in lower quality regional wind areas. Additionally, off-grid solar PV became eligible for 70 percent capital subsidies and grid-connected solar PV 50 percent, as well as price subsidies of 15 or 20 yuan/kWh (2.2 or 2.9 cents/kWh) depending on application. Gifford (2011) notes that a FIT policy was officially adopted for solar power in China in August 2011, providing 16-18 cents/kWh.

After its FIT was introduced in 2009, China built 37.6 GWs of wind power between 2010 and 2011. *Solarbuzz* (2011) reports that China has approximately 14 GWs of solar PV queued for development since introduction of the FIT, despite the fact that its price subsidy is substantially lower than that of Germany. China's domestic markets for solar and wind power will continue to be strong, and there is little doubt that China's renewable energy policy approach will promote growth in manufacturing to meet that domestic demand as well, contributing in the long-term to reduction in GHG emissions.

Similar Policy Ideas to Very Different Outcomes

Policy support for renewable energy is a critical but complex undertaking. None of the regimes detailed above are comprehensive reviews of each country. But the most important lesson is that technological development, manufacturing, and diffusion of technology through markets has not occurred absent public support. In fact, it has occurred best where the strongest policies are in place. All three countries reviewed seek to impact GHG emissions, create employment opportunities, and promote energy independence. China and Germany have more holistic approaches to combining economic and environmental value in their renewable energy policies (i.e., development should result in reduced emissions and industry formation). Each country reviewed generally forced its energy distributors to interconnect with, and pay for, renewable energy.

Each country also promotes or promoted R&D, manufacturing, and diffusion of renewable energy technologies, by setting goals for renewable energy deployment and emissions targets (with the exception of the United States), and subsidizing innovation, industrial development, and technological diffusion. It should be noted that each country also created standards for renewable project permitting and zoning along with interconnection standards, though this can occur through different levels of government.[35]

An important cross-national distinction is that U.S. incentives for renewable energy development generally provide a 10-year investment horizon, while Germany provides a 20-year horizon and China mandated 15-years of fixed prices followed by prevailing rates. Investors in each country therefore have different time horizons over which they attempt to generate profitable returns. The threat of incentive expiration creates market uncertainty in the U.S. while Germany and China have signaled long-term commitments for renewable projects which are not mainly driven by tax credits. While direct price support comparisons are tricky, as project cost factors vary from region to region, it is quite clear that developers have an advantage in Germany, and can likely expect to cover

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[35] For example, wind projects are beholden to laws by the U.S. Fish and Wildlife Service which protects endangered birds, and also FAA regulations which force them to report structures in excess of 200 feet for the purposes of air safety and radar integrity. At the state level, Maine enacted an expedited permitting law to benefit wind developers which complete various impact studies and meet certain criteria meant to minimize negative public impact.

project costs more easily than in the United States. What is more, these higher price supports have not stifled innovation, as demonstrated by Germany's performance in producing leading wind and solar firms while the cost of each technology has fallen over time.

Each country has also pursued renewable energy development for decades, demonstrating that it is a long-term process. Unlike Germany and China, the policy approach of the United States does not recognize the differing developmental realities of renewable energy technologies, including barriers to the adoption of renewable energy posed by the legacy of conventional power sources. The United States has also failed to adopt GHG regulations that could broaden potential sources of funding for renewables, such as through institution of a carbon tax or ratepayer surcharges which could create national funds for renewable energy innovation, manufacturing, and diffusion. The U.S.'s failure to address its major share of global emissions remains an unexploited opportunity in its policy regime.

The United States also has yet to establish a national renewable energy goal to be met by existing and future renewable technologies. Allowing policy gaps to be filled by states limits the total resource commitment available to renewable technologies and also political power backing them. For lack of a comprehensive energy development strategy, U.S. policy has come up short in mitigating investor uncertainty because incentives and subsidies are at risk of expiration with relative frequency. Despite periodic large expenditures on renewable energy, the United States has been less successful in deploying renewable energy than smaller and less wealthy countries. This deficiency is a result of government support that is less patient than it needs to be, in the sense that both policy direction and funding do not provide a long-term horizon on the basis of which clean technology businesses can confidently make strategy and invest.

Policy criticism is not limited to the United States. Wenman (2011) criticizes Chinese government subsidies for potentially stifling innovation. The charge is that these subsidies help Chinese companies reduce costs and grab market share with older technologies, without encouraging a search for greater efficiency gains or development of innovative technologies. Wenman (2011) argues, for example, that China's policy to subsidize wind power equipment in 2008 helped launch strong wind companies but has not promoted wind site productivity. China's decision to base price support on regional wind characteristics, providing a higher price for lower quality resources, may undermine the incentive to improve performance of wind turbines in low average wind speed areas. The opposite is true in the U.S., which has developed higher performing wind turbines in response to a shrinking availability of wind sites which combine prime wind resources *and* transmission.

According to Sovacool (2008, 254), as energy technologies diffuse, their capacity factors tend to increase. Capacity factor typically describes the percentage of time for which a generator runs at its full potential, an indication of its efficiency. Sovacool points out that coal and steam boilers used in the 1930s had capacity factors of about 20 percent, rising to an average of over 60 percent by 1997 when the technology had diffused much more. Capacity factors for solar PV technologies today are approximately 20 percent, while wind technology can deliver rates of 30 percent to 50 percent depending on various factors such as turbine model and site quality.

Diffusion of solar technology is currently much more limited than wind, and, as we have seen, heavily concentrated in Europe. The Chinese and U.S. solar industries either must continue to focus on export-led growth, or fail to develop robustly. While Germany has strong domestic demand, intense competitive pressure, especially from China, could undermine its domestic solar PV industry.[36]

Expansion of wind energy in China is occurring so rapidly that a lag in overall grid development is bottlenecking the process, causing Chinese wind power development to generate much less wind energy than its total installed capacity suggests. This problem occurs in the United States as well, as Texas has developed the largest share of wind power in the country but may be unable to maximize new wind energy generation for lack of adequate transmission. Rapid deployment of renewable energy requires that complementary sectors keep up, and transmission needs add significant investment to the process, with a lack of clarity of who among utilities, developers, or ratepayers will bear this expense.

Government Support for Clean Energy

According to Badcock and Lenzen (2010, 5046), their study is “the most complete and comprehensive collation of energy subsidies so far at a global level”. The authors attempt to consolidate R&D and subsidy support for energy technologies while accounting for externalities (i.e., social or health impacts) unique to different energy forms at the global level in order to derive per-kilowatt (kW) public costs of energy. Most conventional sources of energy are included in their study with the exception of petroleum and natural gas.[37]

Because of the variety of definitions of subsidy, inconsistency across reporting agencies and in some cases a lack of historical continuity, their conclusions cannot be considered definitive nor fully complete. Nevertheless Badcock and Lenzen (2010) provide significant insight into some trends in global public support for most energy forms, including renewables. For the year 2007, Badcock and Lenzen (2010, 5046) identify that subsidies to energy technologies tend to be highest during their development periods (as high as $10/kWh), and can decline to as little as $.01/kWh.[38]

Badcock and Lenzen (2010, 5046) find that wind energy represents a “spectacular success story in reducing the need for subsidization”, while they also highlight the continued high cost of solar PV subsidy (driven primarily by $15.5 billion in R&D expenditures in 2007). They point out the relatively low per-kW costs of geothermal, nuclear, and hydro power, which are long past their infant stages. Interestingly, global R&D expenditures for nuclear power especially, but also coal, are shown to have cost several orders of magnitude more than other energy technologies throughout the 1970s and 1980s.

These expenditures are roughly $9 billion for nuclear, and $2.5 billion for coal in peak years annually as compared with peaks of $500 million annually for most renewables (Badcock and Lenzen 2010, 5044, Figure 3a). The high overall cost of coal subsidy is a result of its significant estimated cost of externalities which, as with nuclear R&D, are orders of magnitude larger than alternative forms of energy generation (reaching as much as $9 trillion). Thus Badcock and Brown find coal to be the most

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[36] This competition is already occurring. As we will argue later, several major manufacturers, such as Q-Cells, have faced bankruptcy or acquisition. Additionally, continuity of renewable energy policies has not occurred without backlash.

[37] This omission is unfortunate, as Natural Gas became a major source of American energy in the 2000s – in part through exempting the technology from existing clean air and water regulations but also as a result of supportive government R&D.

[38] These figures would include the per-kW impact of R&D, subsidy, and externalities. The authors divide the billions spent globally on the technology by its global energy generation. For the year 2007, this yields figures of 3.1-24.6 cents/kWh for Coal, 0.7-1.6 Nuclear, 6.6-6.8 Wind, 64 solar PV, 29 CSP, 1.4 Geothermal, 6.7-10.7 Biomass, 0.1 Hydropower. See Badcock and Lenzen 2010, table 4.

heavily subsidized form of energy in the world.

Global R&D

The National Science Board (NSB 2012, 6-64-65) finds that, globally, \$16.7 billion in public research, development, and demonstration (RD&D), was spent on clean technologies in 2009, up from \$8.2 billion in 2000. The United States led funding efforts with approximately \$7 billion.[39] In fact the United States has tended to come in third in RD&D funding, behind Japan and Europe. Japan has provided about \$4 billion in R&D funding annually for clean technologies from 2000 through 2009, while the European Union allocated about \$2 billion between 2000 and 2004, growing to \$4 billion in 2009. The United States allocated as little as \$1.5 billion through 2004, growing to \$3 billion in 2008, but reaching \$7 billion in 2009. U.S. spending in 2010 declined to about \$4.4 billion.

Global funding for renewable energy grew from \$900 million to \$3.9 billion (or 23 percent of the global total above) between 2000 and 2009 (NSB 2012, 6-64). Combined with spending on energy efficiency, total commitment to these clean technology areas was approximately \$8 billion in 2009, compared to \$4 billion in 2003.

Government R&D and Subsidy in the United States

According to Sissine (2012), in 2011 dollars, the United States provided \$194 billion in energy related R&D between 1948 and 2010, with 11.6 percent (\$23 billion) allocated to renewable energy.[40] Half of U.S. energy R&D funding went to nuclear power over the same period, and approximately a quarter supported fossil energy. According to Gallagher and Anadón (2012), between 1992 and 2012 (years in which they are observable as line-items), in 2011 dollars, the government spent \$3.4 billion on solar energy R&D and \$1.2 billion on wind energy R&D.

The PTC, often mentioned by Clean Technology companies in their 10-K filings, was instituted in 1992, and is estimated by Sherlock (2011, 35) to have cost approximately \$7.9 billion in 2010 dollars from its inception in 1992 through 2010.[41] The ITC cost \$11 billion in 2010 dollars between 2009 and March of 2012, and is expected to reach \$15 billion before it expires.[42]

These expenditures, even in aggregate, are small relative to the business investment that they encourage. In 2011 these subsidies contributed to the United States' global leadership in clean technology with overall investments made of \$48.1 billion across clean technology sectors. We explore global investment patterns in greater detail below.

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[39] The reported figures include an estimated \$5.3 billion for nuclear R&D for 2009, which is claimed to be the approximate amount of R&D spent *each year* globally. Also, U.S. expenditures reflect the one-time impact of stimulus funding.

[40] 9.7 percent over this period was allocated to energy efficiency (\$19 billion).

[41] Wiser et al. (2007, 13) states that 90% of PTC claims through 2004 have generally gone to wind energy, suggesting there is a great deal of growth possible in this expenditure as more renewable energy technologies are installed. Sherlock (2011 3), states that \$1.1 of \$1.4 billion (80%), of the PTC expense went to wind projects in 2011.

[42] Following the 2009 American Recovery and Reinvestment Act (ARRA), the ITC was available in grant form. At the end of 2011, this grant was unavailable to wind projects, but continued as a maximum 30% tax credit for solar projects.

Business as a Source of Patient Capital

The business sector provides its own forms of patient capital that can complement government investments in renewable energy. Private equity (including venture capital), retained earnings, and public bond issues are the major sources of investment finance that enable the growth of the firm. In some nations such as Germany, Japan, and China, institutional arrangements enable banks to play developmental roles, making bank credit a form of patient capital.

This patient capital can be used to fund not only the firm's R&D but also the training and retention of employees who can engage in the organizational learning that is the essence of innovative enterprise. Especially for companies that have invested in this "absorptive capacity" (Cohen and Levinthal 1990), knowledge can also be transferred to the firm through joint ventures with other businesses and collaborations with government or university research institutes. The strategic choice to share technology with other enterprises can provide the firm with access to new markets. Mergers and acquisitions can protect or enhance market positions, and may allow a firm to obtain key technology or personnel.

Global Investment in Clean Technology

According to Sustainable Asset Management Ag (SAM 2011, 20), on a global scale business invested approximately $964 billion in clean technologies between 2001 and 2010, with 70 to 80 percent of this investment directed at clean energy.[43] In 2011, an additional $225 billion was invested, bringing the global commitment thus far to approximately $1.2 trillion, approximately half of which occurs in the form of asset financing for renewable energy projects.[44] [45] Considering the limited impact this financing has had on the overall world energy picture in the last decade, many trillions more must be invested in the future if renewable energy and other technologies are to fulfill their collective role in reducing GHG emissions, creating jobs, and promote energy independence on a significant scale. The expansion of renewable energy adoption must outpace *both* growing energy appetites and the continued diffusion of legacy technologies that, as stated previously, maintain their advantages of "sunk costs".

According to Pernick et al. (2012, 4) global investment in solar, wind, and biomass technologies was approximately $246.1 billion in 2011 (from $144.5 billion in 2009), with a projected increase to $385.8 billion by 2021. These investments mainly reflect consumption of energy technologies like solar PV panels and wind turbines. Notable changes have included a shift of investment into solar and biofuel markets, which each surpassed wind power in 2010. As a result of heightened and growing demand for these technologies worldwide, venture capital (VC) and private equity (PE) investors have flocked to them. Figure 8 shows that between 2004 and 2008, global VC and PE investment reached $11 billion. VC and PE funding levels have yet to reach their pre-financial crisis peaks, but it is clear that much of this financing activity occurs in the United States.

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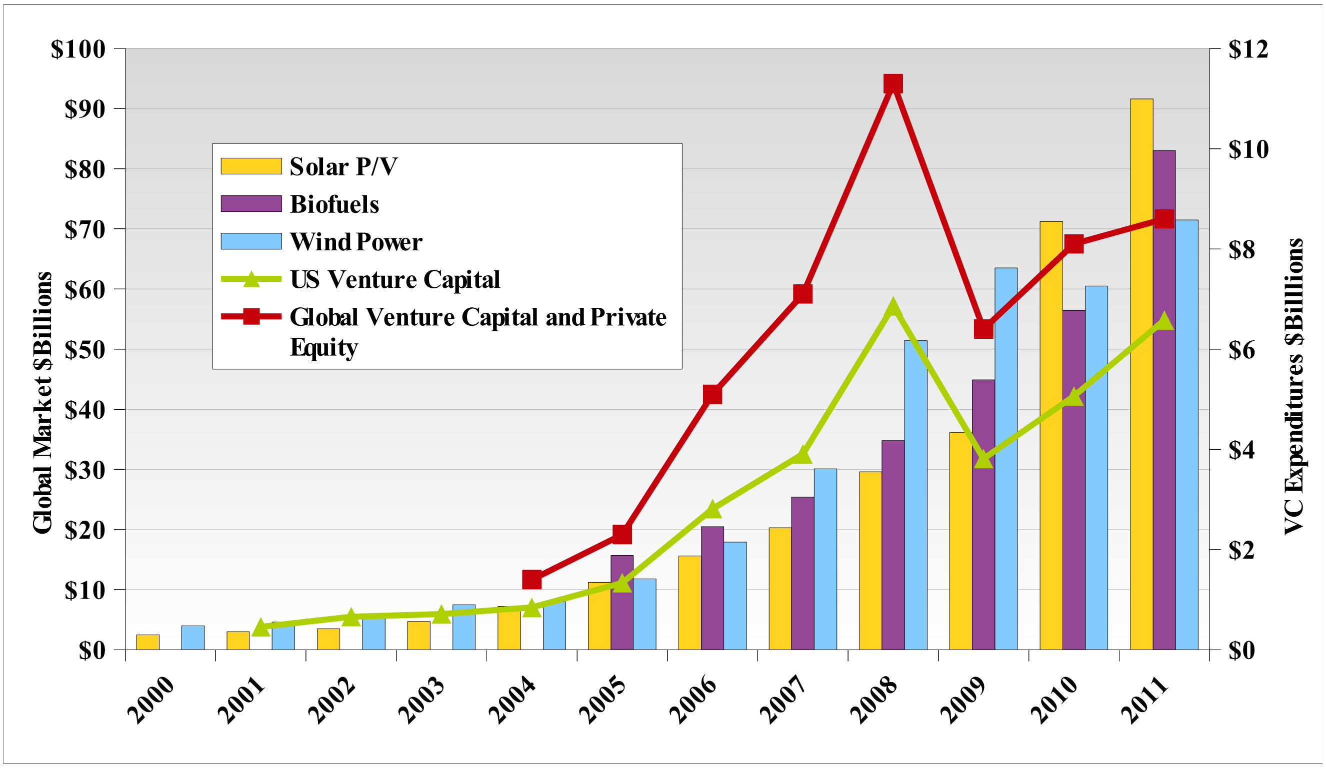
[43] SAM's figures include $70 billion in government R&D, which was subtracted from their total of $1.34 trillion.

[44] The figure of $225 billion in global investment was recorded by the PEW (2011, 3) as "nongovernmental" nonresearch based investments. Both PEW and SAM reference Bloomberg New Energy Finance, although their reported aggregate totals are not an exact match. The PEW does not include R&D figures. SAM found $250 billion in expenditures in 2010, for example, while the PEW found $215.5.

[45] According to the Pew Charitable Trust (PCT 2012, 22), from which asset financing figures are often drawn in this paper, asset financing "includes all money invested in renewable energy generation projects, whether from internal company balance sheets, debt finance, or equity finance. The category excludes refinancing and short-term construction loans. Asset financing typically is associated with installation of clean energy equipment and generating capacity."

Figure 8: Global Clean-Energy Market Size and VC Spending, 2000-2011



Sources: (1) Pernick, Ron, et al. "Clean Energy Trends 2012." *Cleanedge*. Mar 2012. Web. 15 Mar 2012. Available at: http://www.cleanedge.com/reports
(2) "Who's Winning the Clean Energy Race?" *Pew Charitable Trust*. Various Years.

A growing proportion of U.S.-based VC is directed at U.S.-based clean technology companies. From just a 1.2 percent share of total U.S. VC investments of $458 million in 2001, clean technology companies received 23.1 percent of total VC investments of $6.6 billion in 2011. The NSB (2012, 6-58, 6-65) adds that between 2004 and 2010 the majority of VC investment has been allocated to "energy smart" (aka smart grid) technologies and solar power.

According to the Pew Charitable Trusts (PCT 2012, 6), global business expenditures on clean energy technology have grown from approximately $34 billion in 2004 to $237 billion in 2011, of which $128 billion went to solar power. In 2011 the United States led the world in clean technology financing for the first time since 2008. Four countries accounted for 64 percent of total global business expenditures in 2011: United States led with $48.1 billion ($34 billion in 2010), China $45.5 billion ($54.4 billion), Germany $30.6 billion ($41.2 billion), and Italy $28 billion ($13.9 billion) (PCT 2012, 15).

The United States was the only country PCT (2012, 24) found to utilize a significant amount of VC and PE in the financing of clean technology, amounting to approximately $6 billion in 2010 and in 2011. Otherwise, VC and PE expenditures in 2011 were $635 million in Germany and $458 million in China, while public market finance (including public stock market equity financing) was greatest in China ($4.9 billion) followed the United States ($2 billion), and Germany ($1.2 billion).

Combined, in 2011, PE and VC financing in the United States represented $8 billion, or just 3.4 percent, of total global clean technology investment and 17 percent of U.S. investments of $48 billion. In 2010, PE and VC represented 27 percent of total financing in the United States, an increase from 21 percent in 2009. This important role for startup financing distinguishes the United States from the finance approaches of other countries investing heavily in clean technology. It highlights the heightened role that this form of finance plays in the United States, which is relied upon to identify, launch, and support companies hoping to commercialize innovative technology, and then generate returns for their shareholders.

According to the PCT (2012, 26), the majority of renewable energy financing in Germany, Italy, and Japan was done at the residential scale (under 1 MW). These are small-scale projects which would include rooftop solar PV installations, for example. China and the United States rely on, and lead the world in, asset financing – an effect of their booming wind power markets and also a reflection of a preference for multi-GW projects that can require hundreds of millions in project finance and which are implemented at the utility-scale.

What is the impact of business finance of renewable energy when considered in conjunction with government financing? According to PCT (2012, 3, 18), the United States also led in public and business R&D financing, representing $7.8 billion (30 percent) of the $26 billion world total. With less installed wind capacity than China, and less installed solar capacity than Italy or Germany (despite investing $30 billion in new projects in 2011) the PCT (2011, 5) concludes that "the [United States] fails to deploy into the marketplace the clean energy innovations it creates in the laboratory", while noting that China manages to "encourage manufacturing and deployment".

China's world leading renewable power capacity, which now stands at 255 GWs, is made up mostly of wind and hydro power.[46] At the same time, China is able to produce leading manufacturers in the renewable sectors in which it competes. To the PCT's analysis we would hypothesize that a key cause of this failure is impatient business capital in the United States.

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[46] Some comparable data for this section comes from the NSB (2012) and REN21 (2011). Heightened clean technology investment in recent years was in part a strategic choice to invest in clean technologies in an effort to mitigate the effects of the worldwide economic downturn. The NSB (2012) points out that this collective response generated $194 billion in additional funding for clean technologies in 2008 and 2009. The United States led in stimulus spending with $67 billion, followed by China with $47 billion, and the European Union and South Korea which each added $27-$28 billion (NSB, 2012, 6-62).

Collectively, these four countries supplied world markets with 85 percent of global stimulus funding. REN21 (2011, 36) claims that this stimulus led to governments worldwide outspending the business sector in 2010 on R&D at $5 billion compared to $4 billion. The longer term trend however, has been decline in European and U.S. spending while Chinese spending accelerates (NSB, 2012, 6-62, 6-55).

Equity investors (those who invest in firms in exchange for stock and expected future stock returns) allocate substantial funds to Clean Technology companies, which can easily reach into the hundreds of millions. The NSB (2012, 6-61) claims that global commercial investments grew from $20 billion in 2004 to $154 billion in 2010, with U.S. investment peaking at $34 billion in 2008. Commercial investment momentum is 69 percent higher in China, where in 2010 some $54 billion in commercial investment was driven into its clean technology companies (NSB, 2012, 6-61).

The Interaction of Business and Government Finance: Firm Formation

Business enterprises can build on government investments in physical and human capital as well as government subsidies to make innovative investment. The executives who run these business enterprises have to make decisions to allocate resources to strategically chosen products and processes. The essence of the innovation process is investment in the development of technology through organizational learning. These executives then have to mobilize committed finance to sustain the innovation process until the realization of financial returns occurs.

As an example, many start-up clean technology companies in the United States derive revenue from government R&D contracts, upon which they may in fact be dependent until a commercial product is successfully developed and ready for manufacture. Government funds can influence technologies on which the business will focus and by extension the capabilities it develops (for example, the contract or grant may be for thin-film solar PV). Transitioning to manufacturing requires more capital as well as possible innovations in the production of the technology. In order to justify and sustain manufacturing growth, large markets for the technology are needed. In the case of wind and solar energy, large markets require additional government funding to support renewable projects that are also extremely capital intensive.

The $34.7 billion loan guarantee program funded as part of the ARRA has provided low cost loans to aid companies seeking to manufacture or develop renewable energy. This funding may induce venture capital to back young companies that have yet to commercialize a product or make a commercialized product profitable, by signaling to investors that the government is willing to bear some of the risk of commercializing an innovation. If the company can do an IPO on the stock market – NASDAQ is favored because of its lax listing requirements in terms of capitalization and profits – the venture capitalist may be able to "exit" his investment, and reap a financial return, even when the company in which he had invested has not yet become profitable.

An IPO and subsequent secondary issues on the stock exchange can provide companies with promising technology with funds to begin manufacturing. These investments by public shareholders are always highly speculative; the shareholders will typically sell the shares long before the firm's product has become a commercial success. Nevertheless, rock-solid finance from government, strategic finance from business (as in the case of venture capital), and speculative finance from households (often through institutional investors) can combine to fund the capital investments and ongoing operations of a high-tech startup (see Lazonick and Tulum 2011; Janeway 2012).

The flow of funding supporting "exit" by investors from their clean tech startups is significant. According to SAM (2011, 26) the average clean-tech IPO raises $150 million. $59 billion has was raised by 356 IPOs completed between 2005 and 2011 (SAM 2012, 35).[47] About half of 2010 and 2011 deals occurred in Asia, raising $22 billion and $30 billion. 72 IPO deals amounting to $8 billion were allocated to North America in 2010, followed by 92 deals raising $10 billion in 2011. Merger or acquisition (M&A) represent two other strategies for exiting clean tech company investments. SAM (2012, 37) reports that 1,719 disclosed mergers or acquisitions valued at $132 billion occurred between 2006 and 2011, with 1,550 more occurring but unreported. 892 M&A deals were allocated to North America, generating $51 billion.

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[47] The upper bound can be much higher. GT Advanced Technologies and First Solar, for example, completed IPOs which raised $400-$500 million.

The Interaction of Business and Government Finance: Technological Diffusion

In the United States, the PTC has contributed to complex financing schemes meant to promote technological diffusion of renewable energy. Renewable energy developers "sell" the credits to 3rd party tax equity investors, who offer investment capital in exchange for access to the tax equity and other benefits that the renewable project provides (such as project revenues from electricity sales). As a result, investors are able to shelter a portion of their own income against taxation, while obtaining a rate of return from their stake in the project. In effect, income that would otherwise have been taxed becomes investment income that generates higher returns for the investment firm (for an example see Hopkins 2011, 92). These transactions can occur without developers surrendering control over projects. Rather, the financing structure provides a ten-year period during which tax credits are generated and given to investors. After this period ends, full ownership and capture of economic benefits returns to the developer.

As noted earlier, the provision of subsidies followed by the threat of expiration have tended to promote boom and bust periods in renewable energy development in the past. Aware of an upcoming subsidy expiration, developers rush to complete projects, and may opt out of future project development completely until new subsidies are available. The price of energy alone (in the United States) provides inadequate returns to finance and complete renewable energy projects. New development of wind energy has slowed to a crawl whenever the PTC has been allowed to expire (see Table 2 below). Yet developers are not necessarily "dependent" on the subsidy – rather, the credit lowers the risk of investing in projects to investors.

Table 2: Legislative History of the Production and Investment Tax Credit

Year	Event
1978	ITC introduced
1985	ITC discontinued, except for Solar PV
1992-1999	PTC introduced
Jan-1999 July 1999	PTC lapses for 6 months
Jan 2002-Mar 2001	PTC lapses for 2 months
Jan 2004-Oct 2004	PTC Lapses for 9 months
2009	PTC Set to expire Dec 2012
	30% ITC reintroduced for 24 months for Wind
	30% Grant Option offered to wind through 2012
	30% Grant Option offered to solar through 2016

Sources: (1) 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
(3) "Business Energy Investment Credit." *Dsireusa.org*. DSIRE. Web. 12 Nov 2012. http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=0

When the financial crisis caused by Wall Street took effect, the number of tax equity investors available to wind projects fell from 20 to about five. Four major investors, including the Lehman Brothers, Wachovia, AIG, and Merrill Lynch, went bankrupt or disappeared through merger. Other investors such as Bank of America, New York Life, Wells Fargo, Wal-Mart, GE, and Google have continued to make investments, and the Obama Administration more recently has sought the attention of at least 79 corporations such as Exxon and Walt Disney in an effort to expand interest in the incentive (see Schwabe, et al., 2009; Tracy, 2012). The ITC was then enacted to supply renewable energy developers with more finance options as well as an outright tax incentive.[48]

Now several years later, project developers have shown some preference for the ITC *grant* program, which has paid out over $13 billion to over 45 thousand projects between its creation in the 2009 ARRA and March of 2012, the majority of funding accruing to wind power while the majority of projects financed utilized solar PV.[49] This subsidy is larger than the PTC, which Sherlock (2011) claims has cost approximately $7.9 billion between its inception in 1992 and 2010, but in recent years has generated less finance for renewable energy projects.[50]

The Solar Energy Industries Association (2012) has estimated that the ITC program has leveraged $26 billion in business investment for energy technologies like wind and solar power, with approximately $5 billion (or 19 percent of that investment) supporting solar power. In effect then, government subsidies for renewable energy development generate more economic activity than they cost.

Why is the United States Falling Behind in the Clean Technology Race?

We have argued that policy support for innovative solar and wind power technologies are part of a strategic and global response to a long-term need to reduce GHGs, promote energy independence, and support economic growth. This strategy requires that a degree of coordination between government and business which must provide capital and direction for clean technology R&D, manufacturing, and diffusion activities. Policies promoting clean technology innovation overlap and compliment each other. Yet what distinguishes countries with stable development are stable policies.

Innovation in technologies such as wind and solar power are required in order to reduce costs and increase efficiency, which makes these technologies more competitive with legacy power systems. Because innovation is a cumulative process that unfolds over often long periods of time with uncertain returns, the capital provided to clean technology must be a form of patient capital. Committing large funds to clean technology innovation is a dead end without support for commercialization as well as diffusion of the technologies. As mentioned before, the United States has committed approximately $3.6 billion in 2010 dollars to solar R&D and $1.1 billion to wind R&D. Yet this investment means little if, as mentioned earlier, technologies cannot “leave the lab.”

The regional identities of wind turbine and solar PV manufacturing show that technological development and firm formation benefit from direct and indirect government support and the presence of businesses which can recognize opportunities. These businesses must then finance a combination of

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[48] There are several reasons why tax credits can be unattractive to banks and corporations. The most important, arguably, is that these businesses cannot, with certainty, expect to make use of the tax credits each year for ten years, limiting their impact on the bottom line. This could be a result of the impact of recession. Additionally, they have access to other tax credits, such as those for affordable housing, which they may understand and trust more.

[49] The large numbers of projects are due to federal tax credits to households who install solar panels on their homes. The U.S. Department of the Treasury (2012) recorded $9.2 billion directed to wind projects, and $2.8 billion for solar PV as of July 20, 2012. Conversely, this funding supported over 44 thousand solar projects and over 748 wind projects.

[50] Wind projects represent approximately two thirds of the program cost (and represented 80% of the cost in 2011). The SEIA (2012) shows that tax equity financing for renewable projects peaked in 2007 at $6.1 billion and declined to $1.2 billion in 2009.

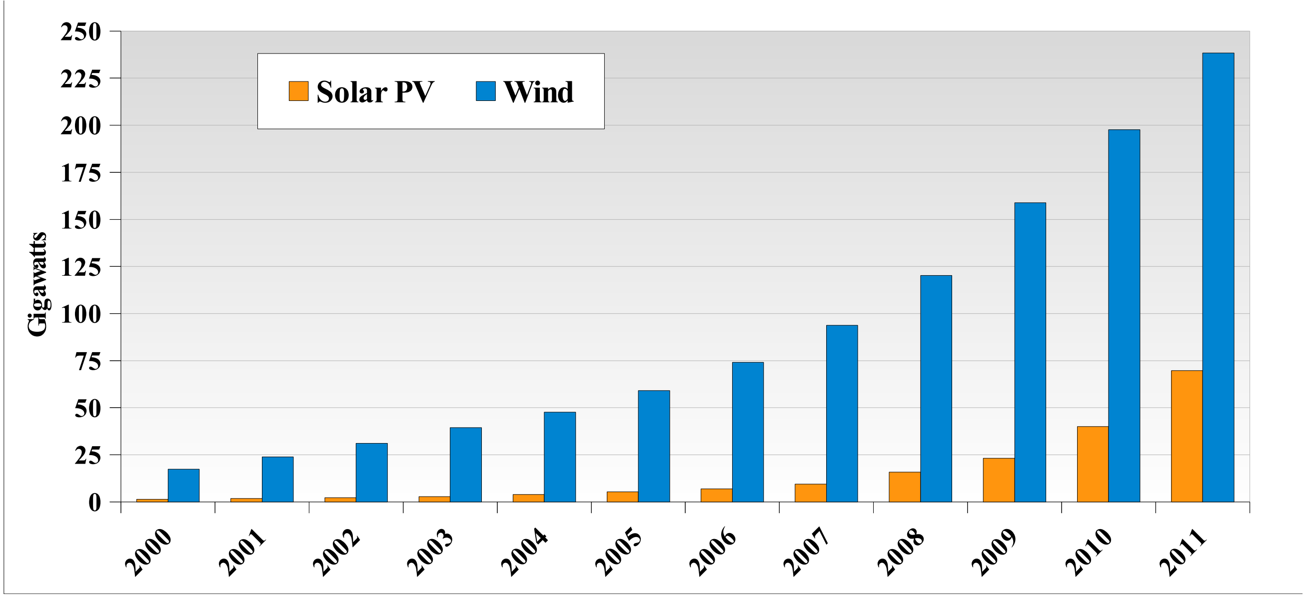
R&D and commercialization activities until they achieve economies of scale. As a result of a failure to invest sufficiently and persistently in the development and utilization of productive resources, the United States and Europe have lost leading positions in the manufacture of these important clean technologies to China.

While several wind turbine manufactures still vie for world market leadership, China has promoted the largest market for wind power in the world, providing their manufacturers with ample opportunity to achieve economies of scale. A side effect of this process is that it has eroded the market share of foreign competitors which mostly do not produce for China, but may rely on the second largest wind market, the United States, which maintains a state of uncertainty with many of its renewable energy development incentives.

The future for solar PV manufacturing is less certain, as the United States and Europe are experiencing well publicized bankruptcies of firms, both young and old, which have been directly involved in solar PV manufacture or have done it as a compliment to other activities. In this case, Chinese firms continue to capture market share in foreign markets. With access to national and regional public financing and subsidy support, Chinese start-up firms have avoided the valley of death that characterizes some current U.S. firm failure. While Chinese firms are rapidly achieving dominant levels of economies of scales, U.S. firms struggle with a failure of venture capital and equity financing to act as patient capital during periods of transition from R&D to commercialization to, finally, large-scale manufacturing.

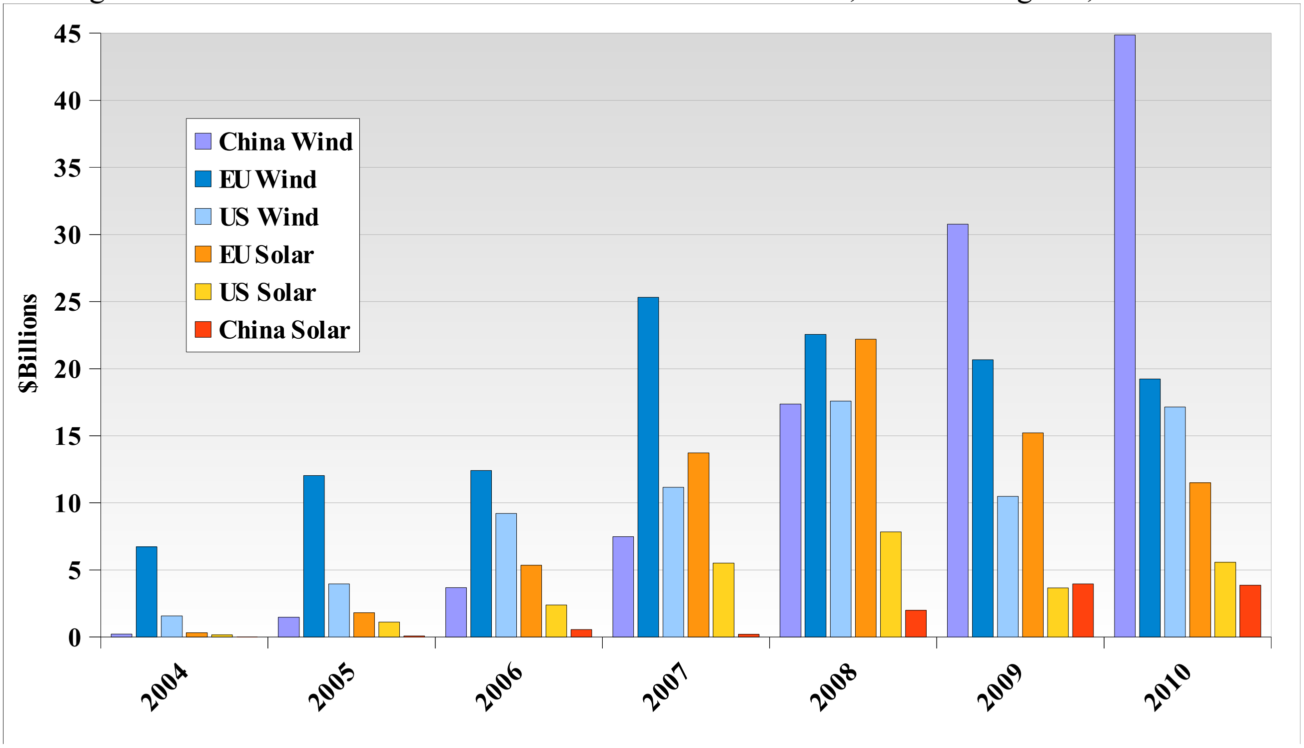
As shown in Figure 9, the development and diffusion of wind and solar PV is accelerating. Where it has accelerated the most is a reflection of progressive policies as well as large financial commitments provided from public and also business sources. In Figure 10 below, the geo-economic centers of the development and diffusion of these technologies tends to reflect broader financing patterns. We should not be surprised that most wind development is occurring in China, and most solar PV development in Europe.

Figure 9: Total Global Installed Capacity of Solar PV and Wind Power, 2000-2011



Sources: European Photovoltaic Industry Association, Global Wind Energy Council.

Figure 10: Financial New Investment in Solar or Wind Power, Selected Regions, 2004-2010



Source: NSB (2012) "Table 6-12 Financial new investment, by selected region/country and energy/technology: 2004–10" p.6-64.
According to the NSB "Financial new investment includes venture capital financing raised from private equity, and public capital markets. Mergers and acquisitions are excluded."

Long-term incentives that support market growth for new solar PV and wind power capacity manifest a nation's long-term commitment to the technologies. This type of incentives provides certainty and stability for manufacturers seeking to make investments in production capacity. When coupled with finance schemes that minimize commercial investment risk, or even circumvent it (such as through provision of public financing), long-term manufacturing growth supports development of domestic supply chains which can strengthen regional competitiveness and justify the expenditures on R&D aimed at improving the technologies of the present while preparing for the technologies of the future.

Even where policy and business are successful in generating innovative technologies and launching leading companies, long-term competitiveness is not assured. In the case of wind and solar power, past successes have not guaranteed future leadership in each sector. The United States invented C-Si PV but has not diffused it through the world with U.S. firms. The United States created leading manufacturers in the wind industry, but its young firms went bankrupt. GE and Clipper are two of the few wind companies which compete for turbine markets at the global scale.

The destruction of today's solar PV companies helps to illustrate the multidimensional challenges surrounding the production of energy innovation. This includes heavy reliance on tax-credit based diffusion policies which limit overall market participation and design, as well as equity-financed growth of small innovative firms which must rely on investors who are unwilling to maintain relationships with companies that do not produce expected stock market rewards (or which produce rewards despite firm failure).

The response to heightened competition in solar PV in recent years has been to initiate trade wars. There is a widespread belief that the U.S. industry suffers from "unfair subsidies" to solar in China. The real long-term crisis, however, is the limited access to, or size of renewable power markets, as well as an inadequate supply of patient capital flowing to innovative U.S. firms. Policy revisions are possible given the experiences of other countries, and the role of business enterprises in financing energy innovation deserves closer examination and criticism.

European Revenue Dependency in Solar PV

The clearest manifestation of a failure of U.S. policy to support rapid and sustained diffusion of solar PV is its global reliance on Europe for provision of major market opportunities. Figure 3, above, showed that much of the momentum in the global diffusion of solar PV was centered around Europe, which, with Germany as an example, has adopted progressive policies favorable to solar power development. The DOE (*SunShot Vision Study*, 2012, 27) highlights that China and Taiwan produced 53 percent of global solar PV modules while Europe represented 80 percent of the destinations of all solar PV produced in 2010.

Grau et al. (2012, 8), estimated that the present value of Germany's FIT program, described above, cost approximately $5.7 billion on average between 2003 and 2009. This compares favorably with the $14 billion in grants and loans issued to solar PV developers as part of the one-time ARRA stimulus. According to Grau et al (2012, fig 13), $17 billion was spent in 2009 in Germany alone promoting solar PV development.

As Tables 3a and 3b show, many leading solar PV manufacturers derive significant proportions of their revenues from Europe (and in some cases Germany in particular). In 2011, many of the same leading solar companies experienced significant losses as a result of falling PV prices created in part by the success of Chinese manufacturers in supplying those markets with low-cost solar PV panels.

As a result even leading German solar companies are in trouble. Q-Cells, a major manufacturer of crystalline silicon and thin-film solar technologies was purchased by the South Korean Hanwha Group in late 2012, and German Solon and Solar Millennium have also declared bankruptcy (Schultz, 2012). Neither China nor the United States, which have each produced billion-dollar solar companies, is able to absorb the growing world capacity for solar PV, for lack of either comprehensive clean technology policy or for lack of full policy implementation (China's solar scheme is still relatively new, for example, and still clearly export-led). Yet Chinese producers have shown an ability to rapidly meet growing solar PV demands where they exist, with rapidly falling costs.

Table 3a: European Dependency (millions of USD), 2010

Company	Country	FY2010 Revenue ($ Millions)	FY2010 Net Income ($ Millions)	FY2010 Employment	% Revenue from Germany	% Revenue from Europe
Sanyo	Japan	4,815.3	255.3			
SunTech Power	China	2,901.9	237.9	20,231		66
First Solar	USA	2,563.5	664.2	6,100	46	60
LDK Solar Co.	China	2,509.3	296.5	22,400	36	36
REC Solar	Norway	2,359.9	223.9	4,210	21	45
MEMC/Sun Edison	USA	2,239.2	34.4	6,500		29
Sharp	Japan	2,234.8				
SunPower Corp	USA	2,219.2	178.7	5,150	21	46
Yingli Green Energy	China	1,893.9	210.1	11,435		69
Trina Corporation	China	1,857.7	311.5	12,863		77
Q-Cells	Germany	1,809.5	25.3	2,379		82
JA Solar Holdings	China	1,781.9	266.0	10,725	18	19
Solar World AG	Germany	1,743.3	116.7	1,000	40	57
Kyocera Solar	Japan	1,681.3	212.6	6,783		
Canadian Solar	China	1,495.5	50.6	8,733	80	80
Renesola	China	1,205.6	169.0	7,869	15	35
Hanwha SolarOne	S Korea	1,140.5	114.8	10,241	63	74
Motech Solar	Taiwan	1,018.3	156.2	2,861		36
Gintech	Taiwan	967.7	155.3	1,632		40
JinkoSolar	China	705.3	133.6	6,735	25	52
Evergreen Solar	USA	338.8	-465.4	1,034	61	

Table 3b: European Dependency (millions of USD), 2011

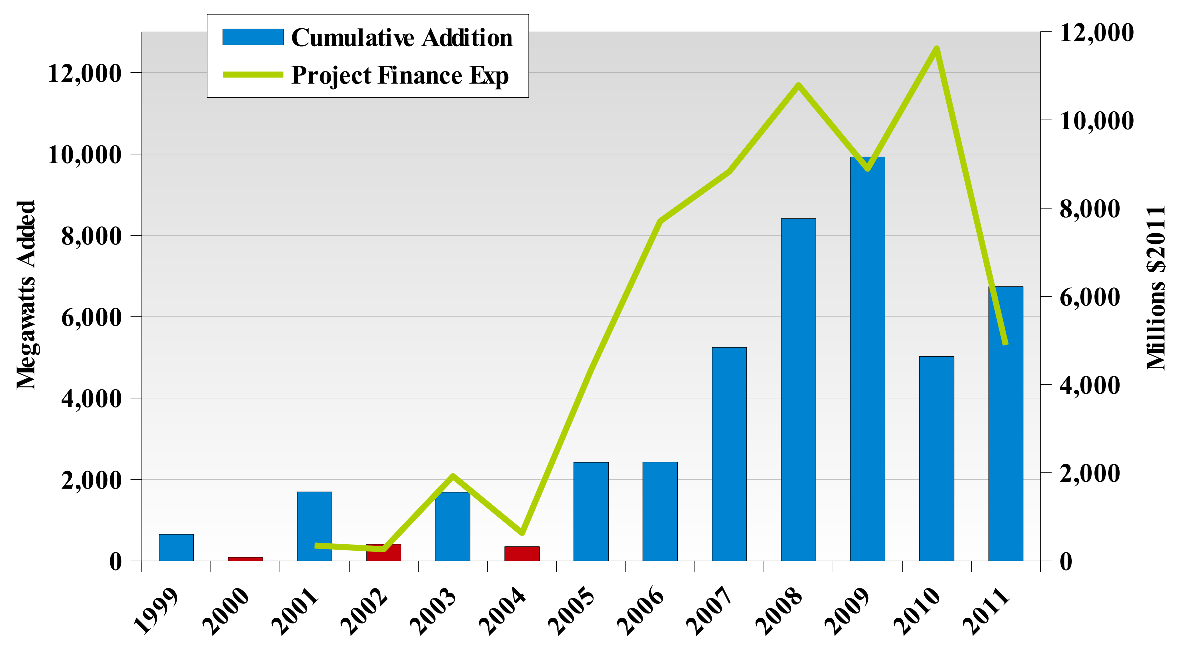
Company	Country	FY2011 Revenue ($ Millions)	FY2011 Net Income ($ Millions)	FY2011 Employment	% Revenue from Germany	% Revenue from Europe
Sanyo	Japan	5,151.5	476.0		0	0
SunTech Power	China	3,146.6	-1,018.6	17,693	20	45
First Solar	USA	2,766.2	-39.5	7,000	23	38
LDK Solar Co.	China	2,157.8	-609.0	24,449	0	29
MEMC/Sun Edison	USA	2,715.5	-1,536.0	6,350	0	10
Sharp*	Japan	3,208.0			0	0
REC Solar	Norway	2,230.4	-1,661.2	3,587	26	86
SunPower Corp	USA	2,312.5	-603.9	5,220	8	31
Yingli Green Energy	China	2,332.1	-509.8	16,054	45	45
Trina Corporation	China	2,047.9	-37.8	14,386	37	68
Q-Cells	Germany	1,323.8	-1,094.4	2,416	59	80
JA Solar Holdings	China	1,705.3	-89.7	11,639	20	20
Solar World AG	Germany	1,354.6	-387.2	2,701	42	60
Kyocera Solar	Japan	2,388.1	351.0	7,606	0	0
Canadian Solar	China	1,898.9	-90.8	9,087	42	65
Renesola	China	985.3	0.3	7,595	11	29
Hanwha SolarOne	S Korea	1,019.5	-58.0	9,624	41	49
Motech Solar	Taiwan	686.9	-81.1	3,142	0	38
Gintech	Taiwan	628.0	-67.3	1,650	0	32
JinkoSolar	China	1,173.4	188.7	7,941	33	71

Sources: Authors' Calculations, 10-K filings, Published Company Annuals. Sorted by Revenue

Tax Equity Shenanigans in the U.S. Wind Industry

Weakness in U.S. deployment of innovative wind turbines relates to the uncertainty created by instability of a key government incentive: the PTC. As discussed earlier, the U.S. government provides the PTC at a cost of approximately $1 billion per year. It promotes tax equity financing of wind projects in the United States by major banks and corporations. The temporary grant provided about $8.4 billion to wind developers in an effort to reduce the damage created by the financial crisis on many of the tax equity financiers on which they rely for project capital. As shown in Figure 11, the additional financing has not reversed the downturn in wind capacity construction which began in 2010.

Figure 11: Cumulative Additions of Wind Capacity, Project Financing, 2000-2011*



Sources: Earth Policy Institute. Department of Energy, Renewable Energy Data Book, 2011.
*Red bars represent years impacted by PTC interruption

Also highlighted is the fact that, for years in which the PTC expired (see Table 2, above), the apparent willingness to invest in new wind projects was almost completely undermined. The sum of $2 billion in 2011 dollars raised in 2003 collapsed to just $700 million in 2004. Scheduled to expire at the end of 2012, it seems obvious that wind capacity additions will be negatively impacted. The absence of a large domestic market for solar PV combined with a wind power market notable for its vulnerability to recession and uncertain government commitment limits the effectiveness of other policies meant to promote commercialization of wind and solar technologies.

The Sun Could Set on U.S. Solar Manufacturing

As part of the loan guarantee program, the U.S. DOE provided $1 billion to support solar manufacturing. According to Pernick (2012, 5) $31 billion (or 62 percent) of global venture capital and private equity were driven into U.S.-based clean technology companies between 2004 and 2011, making the U.S. by far the center of VC and PE finance in clean technology companies globally. According to the DOE (2012, 110), between 2001 and 2011, $10.5 billion in 2011 dollars in U.S.-based

VC and PE finance has flowed into solar PV start-ups, representing 29 percent of all VC and PE reaching the clean technology sector. Solar is thus one of the largest clean technology sectors receiving VC and PE financing. Yet in many cases of promising startups with innovative technology, this finance has failed to ensure that the firms could grow to the point at which they can begin capturing market share and generate profits.

VC and PE investors depend on capital gains created as a result of a successful initial public offering (IPO), merger, or acquisition to reward their decision to invest in a startup. As Lazonick and Hopkins (2011) have argued, business investors prematurely exited their investments in Solyndra because they realized that they would be forced to endure a longer incubation period to generate financial returns than they were willing to endure.

Solyndra was founded in California in 2005, and over the six years of its existence raised $1.1 billion in venture capital. In December 2009, with the economy in recovery and with $535 million in government-guaranteed loans that it had secured earlier in the year, Solyndra registered to do an IPO. At the time, however, the company had accumulated $558 million in losses since its founding, and in a filing to the Securities and Exchange Commission in April 2010, Solyndra's auditor, PriceWaterhouseCoopers, wrote that its financial condition raised “substantial doubt about its ability to continue as a going concern” (Snyder and Martin 2011). That nixed the possibility that, as the equity investors had hoped, Solyndra could do an IPO.[51]

Without the prospect of an IPO that could generate quick returns on their Solyndra investments, investors abandoned their $1.1 billion investment, 1,000 jobs were lost, and taxpayers were left footing the bill for Solyndra’s $535 million government-guaranteed loan. Solyndra was a manufacturer of innovative Copper Indium Gallium Diselenide (CIGS) thin-film solar technology. The tubular design of their solar panels were advertised as capable of capturing more solar energy as the sun arced over the horizon, by utilizing direct and reflected light – without the added complexity of mechanical tracking. Perhaps most importantly, the design of the solar panels required no raw silicon, which had risen drastically in price through 2008 but then crashed down.[52] Cost savings therefore did not materialize, undermining the company's bet that CIGS technology would prove a cost-effective alternative to crystalline silicon solar panels. Solyndra had never achieved profitability, losing $778 million between 2006 and 2010.

Spectrawatt started as a $50 million spin-off of Intel in 2008, which benefited from a $1.1 million grant from the state of New York and $31 million in federal funding meant to facilitate the growth of solar industry in the New York region (Anderson 2011). This funding had attracted the company away from Oregon, and it was to manufacture up to 200 MWs of mono and multi-crystalline solar cells in New York starting in 2010. A batch of defective components (Chu 2011), and the rise of Chinese competition, combined with the refusal of investors to allocate an additional $40 million to fund continued operations closed the door on Spectrawatt. During its bankruptcy auction proceedings, Spectrawatt hoped to hasten the sale of its solar PV equipment, which it projected would lose value as

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[51] Solyndra filed for its IPO in December 2009 hoping to raise about $300 million, and withdrew its application in June of 2010. Chris Gronet of CEO of Solyndra, is quoted as having pointed to “ongoing uncertainties in public capital markets” as justification for pulling their registration (see Wesoff, 2010). Solyndra then sought additional financing from existing investors.

[52] The price of silicon rose rapidly between 2005 and 2008 from about $60/kg to a peak of $450/kg. By 2009, the price had dropped to below $100/kg.

"the market [was] flooded with used equipment as other solar companies [went] out of business" (LaMonica, 2011).

Evergreen solar was founded in 1994 after Mobil PV sold its PV business, but not before a novel approach to raw silicon production, called "string ribbon" had been discovered by employees working there but ultimately unfunded. Evergreen attracted $58 million in Massachusetts' state subsidies, a record for the state and set up manufacturing in Devens, Massachusetts (Haley and Schuler 2011, 36). In 2010 the company opened a 75 MW manufacturing facility in China, and in 2011 reported plans to shut down their Massachusetts plant (Evergreen 10-K 3/9/2011, 4). In moving abroad, Evergreen claimed that its multi-crystalline silicon wafers with string ribbon technology could be produced at 0.35 cents/watt in the Devens, Massachusetts plant, compared with 0.25-0.30 cents/watt in Chinese facilities (10-K 3/9/2011, 3). Evergreen had projected that they would reach 0.23 cents/watt in their Chinese facility in late 2011, surpassing other large-scale Chinese manufacturers and industry leaders (Evergreen 10-K 3/9/2011, 3).

The cost savings of Evergreen's string ribbon technology came from using about half the typical amount of silicon needed for wafer manufacture, and positioned the company to become a cost leader in solar wafer technology. Unlike Spectrawatt and Solyndra, Evergreen completed an IPO in 2000 for $42 million. The company never became profitable, however, losing $1.1 billion overall between 1996 and 2011. Following their bankruptcy, the state of Massachusetts launched a lawsuit in attempt to recoup its subsidies. Haley and Schuler (2011, 35) argue that Evergreen's decision to shift production to China was a response to the availability of low cost public finance on favorable terms, which covered two-thirds of the cost of opening the foreign facility, in contrast to its Massachusetts grant which covered only 5 percent of the cost of the Devens facility. With a desire to expand operations and the Chinese offering larger subsidies than U.S. sources, why wouldn't Evergreen take advantage of the deep pockets of Chinese public banks?

Value Extraction at Solar PV Firms: Picking Winners and Losers

Since the 1980s 22 IPOs have generated $1.4 billion for U.S.-based solar company startups.[53] Two of the largest IPOs to come to the sector were GT Technologies in July 2008, generating $500 million, and First Solar in November 2006, an IPO that drew in $400 million. A problem is that, whether they succeed or fail, solar PV startups generate tremendous value for those who control the allocation of resources in these firms. As was amply demonstrated in the dot.com boom of the late 1990s (see Gimein et al. 2002; Carpenter et al. 2003) and as has been shown in recent studies of the U.S. biopharmaceutical industry (Lazonick and Sakinç 2010; Lazonick and Tulum 2011), stock-market speculation and manipulation often enables financial interests, including VCs and top executives to win even when everyone else loses (more generally, see Lazonick and Mazzucato 2012). An important question thus becomes whether or not VC and PE finance, which depend on financial rewards generated by innovative technology and speculative stock markets is capable of delivering long-term innovation and sustained support for the growth of the firm.

We begin with the case of First Solar, a once successful U.S. solar company whose shareholders

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[53] This figure draws on data from Thomson-Reuters VentureXpert data (accessed 29 Nov 2011) and independent data collection by Hopkins. It should not be considered definitive or wholly complete as data for older companies is less readily available. It does not include merger and acquisition data which also produces value for equity investors and VCs.

have made billions even as the fortunes of the company itself have waned. At Glasstech Solar founded in 1984 in Ohio by Harold MacMaster (1916-2003), early solar ambitions abandoned pursuit of thin-film amorphous solar PV for cadmium tellurium (CdTe) thin-film solar PV designs. Later renamed Solar Cells Inc. in 1990, Solar Cells became First Solar in 1999, following the arrival of their new key financial backers.

Working with the University of Toledo and the National Renewable Energy Lab, First Solar would both boost the efficiency of CdTe technology and overcome commercialization challenges, and by 2000 build the world's largest solar PV manufacturing plant. The plant was built in part with $45 million from True North Partners LLC, a partnership between Michael Ahearn and John Walton (1946-2005). Over time, First Solar has also benefited from at least $91 million in subsidies from Germany, the state of Ohio, and the U.S. Department of Energy.

First Solar is one of the only major producers of CdTe thin-film panels on the planet, and has set record efficiency in its class of 17.3 percent. It is the first company to produce solar panels for less than $1/watt (and currently produces for about 75cents/watt), establishing the company as a cost leader helping it to produce 5 GWs of its solar panels worldwide, despite global domination of C-Si technologies (Runyon 2012, Osborne 2012).[54] First Solar's successes saw its stock value rise to over $300/share in 2008. The company maintained a stock price over $100/share until 2011, when changing global markets and increasingly competitive C-Si solar PV technology began to close the price/performance gap with First Solar.

In 2007, Ahearn opined about the company's stock option plan:

"*The more the stock price goes up, the more people internally start thinking about the stock price and how you perpetuate that, and how we meet expectations . . . I think that can really take you out of your game . . . We need to spend a little more time internally making sure we keep our focus.*" (as quoted in Gelsi, 2007).

Ahearn is describing the need to resist temptation to focus on stock-price performance, rather than focusing on the innovation process which, with government support, helped establish First Solar's competitive lead in the first place. Missing from Ahearn's account however is about $2.8 billion in stock sales by First Solar's major equity investors (the estate of John Walton and JCL Holdings) as well as $740 million of his own stock sales. With his fortune in hand, Ahearn has since rejected any future equity-based compensation from the company.

First Solar needs to focus on innovation. It may soon have to compete with GE for thin-film CdTe markets in the United States and abroad. With falling share prices and negative net income for the first time in years, GE announced its intention to build a CdTe thin-film solar manufacturing plant in Colorado in 2011, only to retract its decision in the summer of 2012, citing a need to focus on further cost reduction given plummeting global prices. Not only might GE's ample resources provide a stabilizing force for thin-film solar PV technology, but it creates a serious possible competitor for First Solar in the future.

Evergreen Solar's large net losses did not prevent the company from allowing $17.1 million to

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[54] According to Osborne (2012), the average commercial panel is about 13 percent efficient. For crystalline technologies, this figure would be approximately 13 to 16 percent.

be paid to top executives in the forms of salaries and stock-option gains between 1999 and 2010. CEO Richard Feldt reaped approximately $6 million between 2005 and 2007 when the company's stock soared, while Brown Williams received approximately $2 million in salary and stock option gains in 2005 and 2006. In each of these years, Evergreen generated negative net income between $17 and $27 million even though revenues more than doubled from $44 million to $103 million before falling to $70 million in 2007.

As another example, Astropower went bankrupt in February 2004 and was later purchased by GE. The company stopped its financial reporting after FY 2002, showed overall net income of $9.5 million between 1992 and 2001. CEO Allen Barnett took home $1.5 million in 2000, and another executive, Thomas Stiner, bankrolled $901,000 in 2001. Astropower had received at least $30 million in various public subsidies prior to its bankruptcy.

Many clean technology companies in the solar industry do not produce profits while they await commercialization, growth, and economies of scale. Yet they are still able to produce millionaires – both inside their companies but also outside as their primary investors reap capital gains following successful IPOs conducted on speculative stock markets. While some well-positioned investors and executives are cashing in, the interests of taxpayers who have supported these companies are typically ignored.

Indeed, there are many stakeholders aside from shareholders which matter in producing the success or failure of these companies. These stakeholders include those who have prepared the knowledge base (such as government labs or universities), ordinary taxpayers, and of course the hundreds or thousands of employees who lose their livelihoods when businesses fail (see Lazonick and Mazzucato 2012). That top executives of these companies manage to reward themselves with multi-million dollar salaries while their companies have yet to achieve a profit undermines the process of innovation while extracting financial resources for private gain that could be used to support the growth of the firm. As Lazonick 2012 argues, these firms become "financialized", as those who exercise control over the allocation of resources of the business enterprise see their own financial returns as the primary goal of the firm. The objectives of reducing greenhouse gases, promoting energy independence, or establishing leading manufacturers – that is, the pursuit of value creation – become secondary considerations when those in charge are bent on value extraction.

As in biopharmaceuticals (see Lazonick and Tulum 2011), it is not clear that the VC-dominated business model is appropriate for the development of solar PV manufacturing. When the going gets rough, even the VC community takes note of the problem. Following the bad news from the solar sector, Marc Andreesen of Andreesen Horowitz. a venture capital firm, announced that his company was uninterested in clean tech investment as "it requires a different skill set than investing in IT companies" (Oran 2012). Clean tech also requires a larger, longer-term financial commitment on the order of 10-15 years.

American Innovation Council: Giant Corporations to the Rescue?

In 2002 General Electric (GE) became America's champion of wind power through the purchase of bankrupt Enron's Wind's assets and debt for $425 million (Hopkins 2011). Today, GE has emerged as a leading world wind turbine supplier, and dominates the U.S. market. From an international perspective however, it is losing market share to emerging Chinese companies alongside its European competitors. Recently Vestas, which has invested $1 billion in Colorado factories to supply U.S. wind markets, openly threatened to slash 1,600 U.S. jobs in response to a threatened expiration of the PTC (Sulugiuc and Morales, 2012). The ITC grant, which as we have mentioned contributed $9.2 billion to over 748 wind projects beginning in 2009, expired for wind projects in 2011. For large wind projects however, the incentive already expired at the end of 2011. Given that GE is the major benefactor of U.S. wind diffusion, it will continue to lose market share should the patient capital of the PTC disappear and undermine project development.

But in wind energy, as in other high-tech industries, innovation depends on business investment that builds on government investment and subsidy. While the United States lack a consistent and persistent set of policies for the development and diffusion of clean technology, the bigger problem, in our view, is the lack of financial commitment for clean tech from leading companies. GE is a case in point. From 2001 through 2011 GE spent $48.5 billion on stock repurchases, making it the tenth largest stock repurchaser in the United States over that decade. As Lazonick (2012a) has argued, the practice of stock buybacks serves only to manipulate share prices, allowing shareholders to extract value in the form of capital gains received from the sale of artificially pumped up shares of stock. In practice, this supports extraordinarily large incomes for top executives of the company while depriving GE of resources it could, for example, use to support new innovations in wind energy which may reestablish international market share leadership in wind turbine manufacture. One might assume that, if there is difficulty supporting the growth of clean technology startups with the smaller resources of VC and public investment, that America's richest corporations would jump at the chance to enter promising new clean technology markets. As it turns out, these companies are eager to do so but only at the taxpayers expense.

Here is an example. In June 2010 Jeffrey Immelt (CEO of GE), as a member of the self-styled American Energy Innovation Council (AEIC), joined Bill Gates (Microsoft), John Doerr (formerly of Intel, and since 1980 of VC company Kleiner Perkins Caufield and Byers), Ursala Burns (Xerox), Norman Augustine (formerly of Lockheed), Chad Holliday (Bank of America), and Tim Solso (Cummins) in calling on the United States government to more than triple government expenditures on energy R&D to $16 billion annually (see Lazonick 2011 and 2012b, 38). GE alone spent $4.9 billion in R&D in 2010, $1 billion of which was attributable to the government. For 2011, $5.4 billion in R&D was allocated with $0.8 billion derived from the government.

In a *New York Times* article on the AEIC initiative (Broder 2010), Doerr was quoted as saying: “When our company shifted our attention to clean energy, we found the innovation cupboard was close to bare. My partners and I found [that] the best fuel cells, the best energy storage and the best wind technology were all born outside of the United States.” Why have US companies not been more active in supporting the development of these alternative energy technologies? Over the decade 2001-2010, the seven corporations whose current or former leaders were represented on AEIC wasted a total of $237 billion – an average of $23.7 billion per year – buying back their companies’ stock, including $110.0 billion by Microsoft, $52.1 billion by Bank of America, and $48.5 billion by General Electric. This money, even a small portion of it, could have been spent on research to “restock the cupboard” with US-based innovations. Instead it went to boosting stock prices and, in the process, lining the pockets of these highly paid executives who lobby Congress to have taxpayers make investments in America’s energy future (Lazonick 2012a).

In AEIC’s “Business Plan”, Immelt states: “No business will invest when there is no certainty about what a market will look like two, five or 10 years into the future. If we're serious about transforming our energy markets, we must send the right signals and create demand for the technologies that solve these problems," adding that, "for a challenge as mammoth as energy, innovation must adapt – and policy must encourage it" (AEIC 2010, 11). In calling for the U.S. government policy to take the lead in the form of intensified government energy R&D, Immelt ignores the role of the firm in allocating its own resources to support innovation.

Worse, Immelt appears oblivious to his own firm's decision to allocate more funds to repurchasing the company's stock than to internal R&D. In calling for heightened investment in government R&D, by extension, he acknowledges the role of government in making key investments which lead to future profits to large business enterprises positioned to benefit from them. In that case, Immelt and his CEO colleagues at AEIC should also be calling for the companies that they control to pay part of the profits from the gains of innovative enterprise back to the government to reward taxpayers and fund the next round of government investment. On this issue, most US corporate executives such as those who constitute AEIC are at best silent and at worst advocates for lower taxes for business (and themselves personally) even as they demand that the government spend more to support high-tech industry.

Conclusion: Whither Renewable Energy in the United States?

There is a widespread global recognition of the need to produce innovations in clean technology to address the trifold goals of GHG emission reduction, energy independence, and economic growth. Besides supporting economic growth, renewable sources of power such as wind and solar energy emit no GHGs during operation and can access a fuel supply that will never run out and will always be part of local environmental assets. What then are the prospects for renewable energy to become a major source of meeting our energy needs?

The key questions are: 1) What will it cost to develop renewable energy to the point where it can not only supplement traditional non-renewable energy sources but actually displace them to a significant extent and, 2) How will the high fixed-cost investments in renewable energy be shared between government agencies and business enterprises? Put succinctly, who will supply the "patient capital" that is required to develop wind and solar energy to the point of becoming primary sources of energy?

An advanced economy such as that of the United States possesses a large existing legacy energy infrastructure which benefits from sunk costs, a long history of technological development, and ongoing subsidy meant to encourage its continued development and utilization. It has also spawned some of the largest and richest corporations on earth. These businesses represent powerful vested interests who recognize that investment in clean technology is a threat to their continued profitability, dominant market position, and control over the energy infrastructure. Any investment in new innovative sources of energy such as renewables must confront the considerable economic advantages that derive from sunk costs. Vested business interests thrive off of those sunk costs and seek to perpetuate their economic advantages through the political arena.

The development and utilization of renewable energy requires massive and persistent government financial support for R&D, manufacturing, and deployment. This support must confront and eventually overcome the uncertainty present in all innovative investment. There is technological uncertainty: Can the new energy source, e.g., solar, be developed to a level of efficiency at which it can compete with, or even become superior to, existing technologies? There is market uncertainty: Can the new energy source capture sufficient market share to drive down unit costs to affordable levels? There is competitive uncertainty: Will companies from other nations, e.g., China or Germany, produce the new energy source faster, better, and cheaper?

In the case of energy innovation, the government's role must go even further than it has for other high-tech industries, given the need to overcome both the productivity and sunk cost advantages of legacy energy infrastructure. Against these incumbent economic cost advantages, renewable energy requires investment that values its potential environmental, social, and health benefits, and not merely its potential to become cheaper than legacy technologies. By its very nature, investment that seeks to reap this type of social return will have to come from government, and, like the quest to land a person on the moon, will have to be "mission-driven": committed to the goals of combating Climate Change, achieving energy independence, and producing economic growth. What all of these goals have in common is that they all require a long-term commitment.

Given the high fixed costs and the uncertainty of success inherent in investment in clean technology innovation, the pursuit of clean technologies like wind turbines and solar PV panels require a massive supply of patient capital to succeed. Government investment can and must provide a foundation of patient capital in the manner of, for example, the National Institutes of Health with their $31 billion annual budget to support life sciences research. We have shown that the U.S. government does allocate substantial funding to support clean technology development and deployment, evidenced by expenditures on wind and solar power. We depend, however, on business enterprise to develop technology to the point of commercialization, and then to access large enough markets for the commercial product to drive down unit costs. If the government supplies sufficient patient capital, will business also do the same? Or will a financialized business sector begin to look upon government sector spending as a convenient form of "rent"? – Such as by allowing average households to assume the cost and risk of clean technology innovation while arguing that only lower taxes on business and wealthy individuals can incentivize business enterprises to invest in "innovation".

Here we arrive at the problem of the financialized political economy of the United States. In our view, financialization is rooted in the industrial enterprises on which we rely to invest in innovation, which is in turn the foundation for economic growth as well as national objectives like political security (e.g., energy independence), and social well-being (e.g., environmental sustainability). Rather than making value creating investments in innovation, many of the nation's largest and most successful firms instead spend billions annually on stock buybacks to manipulate their companies' stock prices. The same corporate executives who make these allocation decisions benefit personally from their stock-based compensation of which the gains from exercising stock options are typically the largest single component (Lazonick 2012a). Under the mantra of "maximizing shareholder value", this value extraction concentrates income into the hands of the few, while the few justify their own wealth by purporting to be the purveyors of value creation for society at large.

Meanwhile, the financiers of startup firms demonstrate a similar commitment to value extraction. Venture capitalists are happy to take advantage of government funding for technological development, as it provides a foundation for the startups that they fund. These venture capitalists then look for a quick "exit" from their investment through completion of a speculative IPO on NASDAQ, which accesses a larger investing public and then allows them to lock in huge capital gains. What is more, this value extraction can be accomplished before the startup has become profitable, and in many cases even before it has generated a product (Lazonick and Tulum 2011; Mazzucato 2011; Lazonick and Mazzucato 2012).

As we have begun to show in this paper, even in the case of renewable energy, a critical clean technology, it is hard to get away from the fact that the U.S. business sector has become driven by the search for high returns on financial assets. These returns are particularly (but of course not exclusively) related to stock market performance rather than a quest to develop higher quality products at lower unit costs – the essence of innovation. If this "financialization hypothesis" is correct, then the sun does not shine bright for solar energy technology in the United States. As applied to the renewable energy industry, the verification of the financialization hypothesis and its broader implications for a transition requires much more research. But as we observe the highly financialized political economy that the United States has become, we have the not-too-optimistic feeling that, if one poses the question of whether the United States has a renewable-energy future, "the answer," to quote Bob Dylan from another context, "is blowing in the wind".

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