Going Completely Renewable: Is It Possible (Let Alone Desirable)?

With the right mix of leadership and policy, a completely renewable electricity sector for New Zealand and the United States is feasible, achievable, and desirable.

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The authors express their appreciation for the extensive editorial comments from Paul Gipe. Despite his help, any opinions, findings, and conclusions expressed in this material are those entirely of the authors.

I. Introduction

The great satirist G.K. Chesterton once told a story about an English pub that served poisoned beer. After a few hundred people dropped dead suspicious citizens caught on, tested the beer, and petitioned the local magistrate to repeal the pub's license. The magistrate responded that before he could take such a drastic course of action, the people had to weigh a problem of great difficulty. He said, ''Have you considered precisely what building you would put in its place?''[1] The ridiculousness of the magistrate's point is that when something is found bad enough one doesn't always need to put anything in its place. Just remove it and be glad to be done with it.

Thankfully, when it comes to something else ''bad enough''—pollution-belching conventional forms of electricity supply that degrade the land, foul the world's climate, and impoverish the environment—readily available alternatives do exist. This article argues that a completely renewable electric utility sector where wind farms, solar systems, bioelectric power stations, hydroelectric facilities, and geothermal power plants generate 100 percent of electricity is possible using today's technology. This would include not just large and centralized power plants but also to a significant degree small-scale decentralized technology. The article demonstrates that the benefit of shifting to such an industry far outweighs potential cost. It finally argues that at least two countries, New Zealand and the United States, could achieve a renewable power sector by 2020 and outlines the policy mechanisms needed to do it.

The importance of such an exploration, perhaps obviously, is that the world desperately needs alternatives to fossil-fueled and nuclear power generation. The costs from these conventional sources, even when the risks of climate change are excluded, remain immense. Looking at just the United States, in 2007 oil-, coal-, gas-fired, and nuclear power plants produced $420 billion in negative externalities but only $277 billion in revenues.[2] In the short term, finding ways to transition away from them in *all* countries will yield notable social and environmental benefits.

In the long term, a transition to renewable forms of energy and electricity supply will have to occur. M. King Hubbert, the famous geophysicist who correctly predicted that American oil production would peak about 1970, often remarked that it would be difficult for people living now, accustomed to exponential growth in energy consumption, to assess the transitory nature of fossil fuels. Hubbert argued that proper reflection could happen only if one looked at a time scale of 3,000 years. On such a scale, Hubbert thought that the complete cycle of the world's exploitation of fossil fuels would encompass perhaps 1,100 years, with the principal segment of this cycle covering about 300 years.[3] Indeed, some are already projecting that, at current rates of consumption, the world has less than 200 years of fossil fuel supply and 65 years of natural gas, 70 years of uranium, and 164 years of coal left.[4] As German Parliamentarian Hermann Scheer put it, ''Our dependence on fossil fuels amounts to global pyromania, and the only fire extinguisher we have at our disposal is renewable energy.''[5]

The benefits of shifting to small-scale, decentralized technology far outweighs potential cost.

II. The Feasibility of Renewable Power Supply

In order to be technically, economically, and thermodynamically feasible, a renewable power sector would have to perform as reliably as its conventional counterpart, do so at a reasonable cost to society, and minimize wasted energy. This section demonstrates that commercially available renewable power plants meet all three requirements.

A. Technical feasibility

As virtually anybody working for the electricity industry already knows, demand for electricity varies greatly throughout the day, week, and season. Daily load variances occur as routine practices reinforce the effects of changing from day to night, such as turning lights on, raising indoor temperature when waking up, taking showers before breakfast, cooking in the dinner hour and washing dishes, or charging electric vehicles at night. Over the course of a week, energy use changes as the weekend approaches and, throughout the year, as seasonal differences in temperature and climate occur. To match these loads, electric utilities and power providers employ a series of practices that include bringing generators with different cycles and corresponding cost structures online at different times. Baseload plants have the longest cycling times and lowest average costs and operate continually. Peaking plants have the shortest cycling times but the highest average costs and operate sporadically. Intermediate plants fall somewhere in the middle.

The conventional wisdom is that renewable power plants cannot provide reliable power in any of these forms because the electricity generated from the

 1040-6190/$–see front matter doi:/10.1016/j.tej.2009.03.011

fuels they rely upon, such as wind, water, and sunlight, is variable. Therefore, many utilities and power operators consider renewable power plants non-dispatchable and, hence, inferior.

The conventional thinking is wrong. Some renewable power sources already provide baseload power, the variability of sources such as wind and solar can be smoothed out through shrewd planning and storage technologies, solar power is excellent at displacing peak demand, and some renewable systems already operate *more* reliably than conventional units. Let's explore each point in order.

First, hydroelectric, geothermal, and bioelectric power plants provide predictable, 24-hour baseload power in many parts of the world, including the United States (where they satisfy more than 7 percent of national electricity demand). Many of these systems are woefully underinvested in, so much that both hydropower and geothermal plants could provide almost the entire world's electricity *by themselves* if their technical potential was fully tapped.[6]

Second, the intermittency of renewable power plants can be mitigated and even eliminated by geographically interconnecting dispersed resources, integrating renewable systems together, utilizing smart meters and batteries in electric-powered vehicles, and/or coupling them to large-scale storage technologies. Without backup, interconnected wind farms can provide power more than 50 percent of the time; with backup, well above 90 percent (and often at an extra cost of less than 1¢/kWh).[7] Modern wind and solar systems can also be matched to hydrogen production facilities,[8] pumped hydro storage facilities,[9] compressed air energy storage,[10] electric vehicles and batteries,[11] and molten salt storage facilities,[12] or linked to biomass generators to minimize and eliminate intermittency. Each of these options is commercially available, has immense amounts of untapped potential, and is relatively inexpensive (adding an extra 0.7 to 5¢/kWh).[13]

Conventional baseload plants are not as reliable as they appear. They suffer from a host of reliability problems.

Third, the raw amount of electricity potential in a region provides only a crude idea of its value. Not all electricity is created equal. A better metric is ''effective load-carrying capability,'' or ELCC. The ELCC refers to the difference between the amount of energy a generating unit produces and the amount of energy that can actually be used by consumers at any given time. Because solar generators tend to produce the greatest amount of energy during the same times consumer demand is highest, solar has an amazingly high ELCC relative to other technologies, frequently above 60 percent and sometimes above 90 percent. The ELCC of solar systems has convinced dozens of utilities around the world to use it to displace fossil-fuel-fired peaking units.[14]

Fourth, and lastly, conventional baseload plants are not as reliable as they appear. These units suffer from a host of reliability problems, just of a different type from renewables and for which utility engineers have long experience. The average coal plant is out of service 10 to 15 percent of the time, and nuclear power plants have unscheduled outages during heat waves and lengthy downtimes for refueling. The technical availability for wind and solar systems, by contrast, is above 97 percent. Renewable power plants have a number of advantages over their conventional alternatives: they are more modular and can be distributed through a utility's service area, helping to minimize grid congestion and displacing the need to construct expensive transmission and distribution infrastructure. They have quicker lead times, reducing the risk of cost overruns and inflation and improving debt to equity ratios. They use widely available and non-depletable forms of fuel, which are not subject to the speculation and price volatility exhibited by coal, oil, natural gas, and uranium. Such systems often

  doi:/10.1016/j.tej.2009.03.011

contribute to system stability rather than the other way around.

B. Economic feasibility

Not only are available renewable power systems technically feasible, they also tend to score favorably in terms of their cost. Consider two prices: marginal capital cost and marginal levelized cost.

The marginal overnight capital cost for building conventional and renewable generators is presented in **Table 1**. Looking at today's prices and drawing on data from the United States, renewable technologies such as wind and biomass are already the fourth and fifth cheapest systems to build, and virtually every renewable system is cheaper to build than fuel cells and nuclear power plants with the exception of rooftop solar photovoltaic systems.

Of course, capital costs tell only part of the story. Far more useful is the marginal levelized cost, or the expense of building, fueling, operating, and maintaining a power plant. Here, as shown in **Table 2**, marginal levelized costs still favor renewable power sources, five of which offer the cheapest power available on the market today. And these prices are still heavily biased against renewable resources, for they do not include currently quantifiable positive and negative externalities (discussed in the next section), which would make all renewable resources but solar PV cost-competitive. Nor do they account for the benefits from renewable energy to future generations.

When looking at the numbers presented in Tables 1 and 2, readers should be aware that continued technological advances will likely make renewable power plants cheaper. If current trends continue, the cost of solar electricity generation is expected to drop to 6 to 10¢/kWh by 2020

Table 1: Capital Cost New Conventional and Renewable Power Plants ($2007/installed kW) in the United States[15]

Technology	Range	Mean
Conventional combustion turbine	$350 to $800	$500
Combined-cycle turbine	$807 to $1,054	$878
Scrubbed coal	$1,300 to $2,100	$1,534
Wind	$1,240 to $2,600	$1,710
Biomass (MSW gas)	$1,450 to $2,010	$1,897
Hydroelectric	$800 to $3,000	$1,900
Biomass (combustion)	$1,940 to $2,628	$2,300
Geothermal	$1,493 to $3,300	$2,400
IGCC with carbon sequestration	$1,900 to $3,900	$2,537
Solar thermal	$2,200 to $4,800	$3,744
Fuel cell	$3,800 to $7,050	$5,374
Nuclear power	$3,600 and $8,000	$5,800
Solar PV	$4,700 to $7,000	$5,850

Table 2: Marginal Levelized Cost of Electricity for Different Generators ($2007 ¢/kWh) in the United States[16]

Technology	Marginal Levelized Cost
Offshore wind	2.6
Hydroelectric	2.8
Biomass (MSW gas)	4.1
Onshore wind	5.6
Geothermal	6.4
Integrated gasification combined cycle	6.7
Biomass (combustion)	6.9
Scrubbed coal	7.2
Advanced gas and oil combined cycle	8.2
Gas oil combined cycle	8.5
IGCC with carbon capture	8.8
Parabolic troughs (solar thermal)	10.5
Advanced gas and oil combined cycle with carbon capture	12.8
Solar ponds (solar thermal)	18.8
Nuclear	24.0
Advanced combustion turbine	32.5
Combustion turbine	35.6
Solar photovoltaic (panel)	39.0

  doi:/10.1016/j.tej.2009.03.011

due to improvements in module production through thinner layers, the introduction of a broader range of materials (including crystalline silicon, gallium arsenide, cadmium telluride, copper indium selenide, and recycled silicon), the integration of glass and PV production facilities, the construction of adhesives on-site, innovative designs, and better economies of scale.[17] The same ''learning effect'' will likely reduce costs by 20 to 60 percent for other wind and bioelectric power stations.[18]

It is sometimes stated that since renewable resources are so diffuse and remote from users, constructing transmission and distribution lines to them will be prohibitively expensive. This belief ignores the fact that many small-scale renewable systems will be decentralized, integrated into buildings, and close to end-users. For those more remote, a recent survey of transmission studies in the United States refutes this view. After looking at 40 different estimates from 2001 to 2008 of building transmission and distribution lines to remote wind farms across a broad geographic area of the country, researchers at Lawrence Berkeley National Laboratory estimated that the median cost of new transmission would be about 1.5¢/kWh.[19] While this extra cost is notable, when combined with the levelized costs presented in Table 2 total costs for renewable systems are still competitive with other sources of electricity supply.

C. Thermodynamic efficiency

Finally and often overlooked, power technologies must be thermodynamically efficient and require or waste as little of their fuel as possible. One useful technique for assessing the thermodynamic efficiency of a power plant is ''energy payback ratio,'' or EPR. The EPR refers to the ratio of total energy produced by an energy system compared to the energy needed to build and operate that system. The higher the EPR, the better the technology, for it implies a given system produces vastly more energy than it takes. Luc Gagnon surveyed EPRs for a variety of energy systems in 2007 and found that the EPRs for coal, oil, and natural gas were strikingly low at between 1.6 and 5.1 (or a mean of 3.35).[20] That is, for every one unit of energy put into these fossil-fueled energy systems, one got only 3.35 units out of them. That may sound good, but the EPR can be as high as 280 for hydroelectric power stations, 34 for onshore wind farms, 27 for biomass power, and 15 for nuclear power plants. This makes the most efficient hydro, wind, and biomass technologies between 84 and 8 times better from an energy payback perspective. More worryingly, Gagnon found that the EPR for fossil fuels is set to decline further in the years ahead as these fuels become depleted and more energy-intensive to extract and transport.

More worryingly, the energy payback ratio for fossil fuels is set to decline further in the years ahead.

III. Benefits of Renewable Power Supply

Perhaps because of its technical, economic, and thermodynamic advantages, a renewable power sector would have six benefits over one reliant on conventional power plants, including (1) lower negative externalities per kWh, (2) more stable and predictable fuel prices, (3) fewer greenhouse gas emissions, (4) less water use, (5) improved efficiency, and (6) greater local employment and revenue.

A. Lower negative externalities

The most significant benefit of renewable power supply is its ability to generate electricity with fewer negative externalities than every other power source (the exception being energy efficiency and demand-side management). While renewable power systems do have their own associated set of environmental and social

 1040-6190/$–see front matter doi:/10.1016/j.tej.2009.03.011

impacts, these are magnitudes of order less than those for fossil-fueled and nuclear units. Renewable power stations, for example, do not melt down, rely on hazardous and combustible fuels, or depend on a fuel cycle of mining or milling that must beat, drill, or leech fuels out of the earth. When roughly quantified and put into monetary terms, the negative externalities for coal power plants are 74 times greater than those for wind farms, and the ones from nuclear power plants are 12 times greater than solar PV systems.[21] Every single kWh of renewable power, therefore, saves lives, enhances human health, improves social stability, and minimizes environmental degradation.

B. Stable fuel supply

Disruptions and interruptions in supply due to accidents, severe weather, and bottlenecks can all prevent fuels such as natural gas, coal, and uranium from being adequately and cost-effectively distributed to conventional power plants. Such depletable fuels are also prone to rapid escalations in price as well as significant price volatility, and exposed to sudden fluctuations in currency rates. Between 1995 and 2005 natural gas prices rose by an average of 15 percent per year; between 2001 and 2006 coal prices rose by 7 percent per year; and between 2001 and 2006 uranium prices rose by more than 600 percent (although they have recently dropped). Renewable fuels, by contrast, are free for the taking, widely available, and non-depletable. They are less prone to speculation, do not need to be transported (with some exceptions), and insulate the power sector from dependence on foreign suppliers. Given that electric utilities in the United States spent more than $100 billion on uranium, coal, and natural gas in 2006 (and that the global trade in energy fuels surpasses $1 trillion every year), the potential for renewable power systems to displace imports and offset fuel prices is immense.[22]

C. Fewer greenhouse gas emissions

Renewable power plants are the least carbon dioxide-intensive forms of electricity supply currently available. When emissions from the entire lifecycle are taken into consideration, along with opportunity costs (such as long planning times and construction delays) and the risk of accidents and leakage, wind farms, hydroelectric power stations, solar PV and solar thermal power plants, bioelectric facilities, and geothermal units all emit the equivalent of between a mean of 5.1 and 59.6 grams of carbon dioxide per kWh (**Table 3**). The next closest source, nuclear power, emits a mean of 124 grams of carbon dioxide per kWh, and clean coal and carbon capture and storage systems emit a mean of 439 grams of carbon dioxide per kWh. Conventional fossil-fueled units are even worse and emit between 443 and 1,005 grams per kWh. This makes renewable energy technologies 2 to 24 times more effective on a per kWh basis at mitigating the risks of climate change than other sources of electricity.

D. Less water use

One of the most important, and least discussed, environmental issues facing the electricity

Table 3: Lifecycle Equivalent Carbon Dioxide Emissions (grams of CO_2/kWh) for Selected Generators[23]

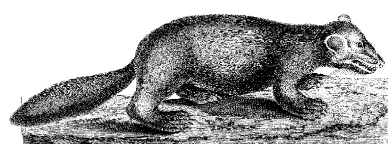
Technology	Lifecycle	Opportunity Costs	Risk of Leakage, Accident, and Disruption	Total	Mean
Wind	2.8 to 7.4	0	0	2.8 to 7.4	5.1
Concentrated solar power	8.5 to 11.3	0	0	8.5 to 11.3	9.9
Geothermal	15.1 to 55	1 to 6	0	16.1 to 61	38.6
Solar PV	19 to 59	0	0	19 to 59	39.0
Hydroelectric	17 to 22	31 to 49	0	48 to 71	59.5
Nuclear	9 to 70	59 to 106	0 to 4.1	68 to 180	124.0
Clean coal with CCS	255 to 442	51 to 87	1.8 to 42	308 to 571	439.0

  doi:/10.1016/j.tej.2009.03.011

industry is its water-intensive nature. Thermoelectric oil, coal, natural gas, and nuclear facilities withdraw trillions of liters and consume billions of liters of water every day. Wind and solar PV systems, on the other hand, use virtually no water: they need only 1/600th as much water per unit of electricity produced as does nuclear plants, 1/500th as coal units, and 1/250th as natural gas facilities. Drought is a normal, recurring part of the hydrological cycle, and large thermoelectric power stations have already been forced to shut down during heat waves and water shortages in Canada, China, France, Germany, India, the United Kingdom, and the United States in the past five years. Renewable power supply will therefore insulate the electricity industry from water scarcity with benefits for both electricity and water customers.

E. Improved efficiency

Distributed renewable power generators can improve grid reliability, lessen the need to build expensive transmission infrastructure, reduce congestion, offer important ancillary services, and improve energy security through geographic diversification. Deploying distributed solar, biomass, and small-scale wind units offers an effective alternative to constructing new transmission and distribution lines, transformers, local taps, feeders, and switchgears, especially in congested areas or regions where the permitting of new transmission networks is difficult.[24] Distributed renewable systems can provide utilities with a variety of important ancillary services as well, including system control, reactive power supply, and spinning reserves. Because of their smaller size, renewable generators have lower outage rates, decreasing the need for reserve margins. Indeed,



researchers at the University of Albany and the National Renewable Energy Laboratory determined that dispersed solar PV resources are so valuable they could have prevented the $6 billion blackout affecting 40 million people spread across the Canada and the United States in 2003.[25]

F. Local employment and revenue

The more capital intensive a power plant is, the less embodied labor it has. Nuclear and fossil derived electricity are the most capital-intensive, and create net reductions in regional employment as ratepayers must reduce expenditures on other goods and services to finance construction. Renewable energy technologies such as wind and solar, however, generate three to 10 times as many jobs per MW of installed capacity as fossil-fuel- or nuclear-based generation.[26] Renewable power sources also contribute to local economic growth and provide *better* jobs. The manufacturing of renewable power technologies involves a highly skilled workforce and a modernizing of the local industry base. The use of renewable energy makes local businesses less dependent on imports from other regions, frees up capital for investments outside the energy sector, and serves as an important financial hedge against future energy price spikes. In some regions of the United States, such as the Southeast, electric utilities expend $8.4 billion per year importing the coal and uranium needed to fuel conventional power plants. Investments in those power plants send money *out* of the economy whereas investments in renewable power keep money *in* the economy. About 50 cents per every dollar expended on conventional electricity leaves the local economy (and in some areas 80 to 95 percent of the cost of energy leaves local economies), whereas every dollar invested in renewable electricity can produce $1.40 of gross economic gain.[27]

IV. Who Could Do It?

At least two countries, New Zealand and the United States,

 1040-6190/$–see front matter , doi:/10.1016/j.tej.2009.03.011

have the resource base necessary to transition to a renewable electricity sector. New Zealand was selected because the country is composed of islands, has low aggregate population and population density, and has a comparatively small industrial base. The United States was selected because it contrasts New Zealand in almost every way, being mostly composed of 48 contiguous states, has a large aggregate population with pockets of high urban population density, and has a large industrial base. For good measure, a third section on the global potential for renewable power technologies is also provided.

A. New Zealand

The New Zealand electricity market began the process of deregulation and restructuring in 1993, when industry players established a joint venture to design a wholesale electricity market to enhance ''competition.''[28] The existing electricity market consists of five dominant generators who offer their generation at grid injection points and retailers bid for electricity offtake at 28 grid exit points. New Zealand has a centralized generation regime, which requires electricity to be shunted back and forth between the two main islands dependent on hydroelectric lake level storage. Ownership varies from fully government owned commercial enterprises to publicly listed companies and local community-owned trusts.[29] In 2007, total installed capacity in New Zealand amounted to 9,133 MW and total electricity generation for the calendar year was 42,374 GWh.

The New Zealand electricity sector is unique in the sense that it has been getting *less* renewable overtime. The country generated 100 percent of its power from hydroelectric resources in the 1950s, but that number has dropped to about 55 percent in 2007, with fossil fuels (natural gas, oil, and coal) providing 34 percent of supply and geothermal and wind making up for most of the rest. In June 2008, 42 percent of output was generated by hydroelectric with 47 percent generated from thermal sources located in the North Island due to unexpected drought and shortfalls in hydroelectric supply.[30]

Still, the country is so awash in renewable resources that the government has already set a voluntary target of 90 percent renewable power supply by 2025 and renewable resources could meet almost double the country's electricity demand (**Table 4**). Table 4 likely *underestimates* the resource base because it excludes a number of potential small-scale wind, hydroelectric, and bioelectric resources. New Zealand has one of the best wind resources in the world, abundant sunshine hours, and a plethora of rivers, lakes, streams. It is generally always sunny, windy, or raining somewhere, with volcanic activity providing geothermal diversity to the renewable portfolio. New Zealand's hydroelectric storage capacity is also about 3,600 GWh or approximately five weeks of winter electricity demand, an additional resource that can be used to smooth out variable renewable power supply. The main barrier to greater renewables penetration is a bias towards large, centralized plants. Solar PV and smaller scale wind and hydroelectric developments are ideally suited to distributed generation, but solar PV remains languishing at 5 MW installed (as of 2007) and only 150 kW installed in 2008.

Table 4: Renewable Energy Potential (by Source) for New Zealand[31]

	Net Electricity Generation (Thousand kWh) in 2007	Estimated Generating Capacity (MW) in 2007	Potential (in MW)
Wind	928	321.7	3,600
Solar PV	5	N/A	31.5
Solar thermal	40	N/A	100
Geothermal	3,272	449.8	3,650
Biomass (wood)	528	80.3	N/A
Biogas (landfill gas)	198	35.4	1,370
Hydroelectric	23,283	5,366.2	12,000
Total	28,254	6,253.4	20,752

  doi:/10.1016/j.tej.2009.03.011

B. United States

The electricity sector in the United States is a curious mix of partially restructured and deregulated markets along with a collection of states that still adhere to the classic form of monopoly regulation. In 2007, total installed capacity was slightly more than 1,000 GW composed of about 16,000 power plants sending their power through 351,000 miles of high-voltage transmission lines and 21,688 substations. These power plants generated 4,157 million MWh of electricity, with roughly two-thirds coming from fossil-fueled units, 20 percent coming from nuclear units, and the remainder (about 10 percent) coming from renewable resources (including hydroelectric facilities).

Fortuitously, the United States has an enormous cache of renewable energy resources that it has only begun to utilize. While a bit dated, a comprehensive study undertaken by the U.S. Department of Energy calculated that 93.2 percent of all domestically available energy was in the form of just wind, geothermal, solar, and biomass resources. The amount of renewable resources found within the country, in other words, amounted to a total resource base the equivalent of 657,000 billion barrels of oil, more than 46,800 times the annual rate of national energy consumption at that point in time.[32] Perhaps an even more amazing feature of this estimate is that it was validated by researchers at the U.S. Geologic Survey, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratory, National Renewable Energy Laboratory, Colorado School of Mines, and Pennsylvania State University.

Table 5: Renewable Energy Potential (by Source) for the United States[33]

	Electricity Generation (Thousand kWh) in 2006	Grid-Connected Installed Capacity (MW) in 2007	Potential (in MW)
Onshore wind	25,781,754	12,600	1,497,000
Offshore wind	0	0	791,000
Solar PV	505,415	624	710,000
Solar thermal/CSP	N/A	354	98,000
Geothermal	14,842,067	3,100	2,800
Biomass (combustion)	50,064,892	9,733	465,000
Biomass (landfill gas)	5,509, 189	539	1,370
Hydroelectric	288,306,061	80,000	165,551
Total	385,009,378	106,950	3,730,721

Compiling data from a collection of peer-reviewed reports, the United States has 3,730,721 MW of renewable energy potential presuming the utilization of existing, commercially available technologies (**Table 5**). Two things pop out when looking at Table 5. First, the table shows that renewable resources have the capability to provide 3.7 times the total amount of installed electricity capacity operating in 2008. Second, the country has so far harnessed only a whopping 2.9 percent of this potential generation.

As Table 5 implies, the United States possesses an exceptional abundance of onshore wind resources. The fuel potential for wind energy, particularly in areas with frequent and strong winds, remains largely untapped. The Midwest and the Great Plains have been called the ''Saudi Arabia of wind'' and theoretically hold enough technical potential to fulfill the entire country's energy needs. The energy potential for offshore wind is even larger, as offshore wind turbines can harness stronger, more consistent winds than those that course through mountain passes or across open plains. An abundance of available roofs, parking lots, highway walls, and buildings are available for integrated solar PV systems and the West has immense solar thermal and geothermal potential. The Midwest has very large reserves of biomass fuel in the form of crop residues and energy crops, and every state has hydroelectric capacity that could still be developed after excluding national battlefields, parks, parkways, monuments, preserves, wildlife refuges, management areas, and wilderness reserves.

Table 6: Renewable Energy Potential (by Source) for the World[34]

Technology	Available Energy (TWh/year)	Electrical Potential (TWh/year)	Current Electricity Generation (TWh/year)	Worldwide Capacity Factor
Solar PV	14,900,000	3,000,000	11.4	10 to 20 percent
Concentrated solar power	10,525,000	4,425	0.4	13 to 25 percent
Wind	630,000	410,000	173	20.5 percent to 42 percent
Geothermal	1,390,000	890	57.6	73 percent
Hydroelectric	16,500	14,370	2840	41.6 percent

C. The world

Because New Zealand and the United States are not representative of all countries, the final part of this section lists the electrical renewable resource potential for the world. Solar, wind, and biomass resources exist in all countries, hydroelectric resources in most countries, and geothermal resources in many countries around the Pacific Rim. Excluding biomass, and looking at just solar, wind, geothermal, and hydroelectric, the world has roughly 3,439,685 TWh of potential—about 201 times the amount of electricity the world consumed in 2007 (**Table 6**). So far 3,082.4 TWh of that capacity is operational, less than 0.09 percent.

V. How Could They Do It?

This section lays out a seven-step policy agenda for how policymakers and regulators in New Zealand, the United States, and other countries could harness the world's vast renewable resources, and accomplish a 100 percent renewable power sector by 2020. When reading our list of seven policy recommendations relating to energy efficiency, elimination of subsidies, standardization, feed-in tariffs, grid interconnection, permitting, and information, three caveats must be mentioned. First, our list is not exhaustive and does not include every possible policy mechanism. However, it does highlight what we believe to be the combined tools most effective at promoting renewable power. Second, the sequence of the mechanisms is important. Promoting energy efficiency and eliminating subsidies for undesirable technologies augments the effectiveness of the mechanisms to follow. Third, the list is also noteworthy for what is excluded. It emphasizes that some mechanisms, such as investment tax credits or R&D expenditures, may be less important at promoting some renewables now that they have reached technological maturity and are cost-competitive with conventional resources.

A. Promote energy efficiency

Regulators should first aggressively implement demand-side management programs and maximize investments in energy efficiency. Almost all electric utilities can save electricity more cheaply than the cost of operating existing plants, meaning efficiency can improve cash flow, appease investors, and save consumers' money at the same time. For example, the average DSM program saves electricity at a cost of between 2.1 and 3.2¢/kWh, making it well below the cost of supplying electricity (regardless of the source). Investing in energy efficiency also means that less renewable supply has to be built to fulfill customer demand, and it displaces the need to build new transmission and distribution lines. Energy efficiency operates automatically through customers coincident with the use of underlying equipment, meaning it is always ''on'' and ''dispatched'' without delay or the needed intervention by system operators. One kWh saved can also be worth more than one kWh generated, since a kWh saved displaces reserve capacity along with dispatched generation (usually 1 kWh of energy efficiency offsets 1.18 kWh of total electricity capacity during peak times).[35] Lastly, targeted

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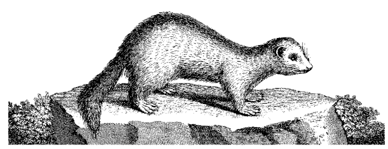
DSM programs can accrue huge savings. In many electric utility systems, about 10 percent of generation capacity is tapped only 1 percent of the time, and less than 1 percent of industrial customers constitute greater than 30 percent of total electricity demand. Relatively small DSM programs directed at a miniscule proportion of electricity customers or generators can produce mammoth benefits in terms of total demand reductions.

B. Eliminate subsidies

Subsidies should be eliminated for undesirable technologies and their fuels. Existing subsidies heavily favor natural gas, oil, coal, and nuclear resources—so much that in many countries 90 percent of existing subsidies go towards conventional technologies. Their repeal would send market signals to consumers and encourage more rational use and valuation of power resources, reduce the artificially low costs of conventional fuels, and make apparent the full risks and costs of different electricity fuel cycles. Subsidies become viciously self-replicating because, once enacted, they continue to shape energy choices through the long-lived infrastructure and capital stock they create. Coal and nuclear plants built 40 years ago, for example, still receive subsidies for coal mining and uranium enrichment. Ending them is absolutely essential towards leveling the playing field for renewable resources.

C. Standardize and certify

Standardization, accreditation, and certification of renewable power systems, especially small-scale, distributed, and residential models, must be encouraged. Rigorous comparative testing and certification can help prevent substandard technologies from entering the market, and also offer



a forum for useful information sharing and learning. Government-funded test stations can help evaluate technologies, and accreditation ensures better manufacturing and installation techniques.

D. Implement feed-in tariffs

Feed-in tariffs (FITs) pay renewable energy producers a fixed, premium rate for every kWh of electricity fed into the grid. Sometimes referred to as ''advanced renewable tariffs'' or ''renewable energy payments,'' FITs obligate power companies to purchase all electricity from eligible producers in their service area at this predetermined rate over a long period of time (usually 15 to 20 years).[36] FITs are empirically proven to be the most cost-effective and successful means to promote the rapid expansion of significant amounts of renewable generation. In Germany, the FIT was instrumental in increasing the power generated by renewable resources from 6.3 percent in 2000 to 15.3 percent in 2008—an increase of more than 200 percent in eight years. Despite the upfront cost to consumers to cover the expense of the tariff, FIT policies depress electricity prices after their first few years of operation. The German Federal Ministry of Environment estimates that while their FIT cost consumers $3.3 billion in higher electricity rates and administrative charges in 2007 (adding an average of €3 per month to the typical residential electricity bill), it saved them $9.4 billion in depressed fossil fuel costs and wholesale prices.[37] Unlike many forms of government subsidies, FITs are performance-based and also force customers, rather than taxpayers, to pay for cleaner forms of electricity supply.

E. Provide grid interconnection and metering

Regulators must also create an obligation for transmission and distribution operators to connect renewable electricity producers to the grid, and ensure that the power flowing into the grid is properly metered. In order to

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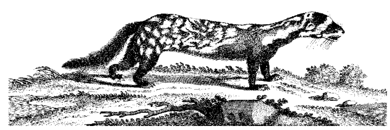
establish the best possible conditions for renewable power providers, regulations usually establish an immediate and priority obligation to connect them, then spreading the costs of building transmission and distribution infrastructure and interconnecting the units among all consumers. This means that the grid operator has to connect all new renewable electricity projects as soon as possible and at the same time give priority to the connection of renewable energy projects over conventional power plants. Similarly, effective support schemes tend to ensure that power providers taking advantage of FITs are able to use the existing transmission and distribution infrastructure to deliver their electricity.

F. Streamline permitting and planning

Streamlined permitting can harmonize the planning requirements for and expedite the construction of renewable power technologies, creating a ''one-stop-shop'' for renewable energy facility siting. Integrated permitting options that work best seem to give one agency exclusive jurisdiction over the tendering of bids for renewable energy construction, approval of pre-investigation of sites, environmental impact assessments, construction and operation, and licenses to produce electricity. Contrast this with the current situation in the United States, where approval for renewable energy planning is fragmented among several local, state, and federal agencies, and the U.S. Department of the Interior's Minerals Management Service has still not finalized its site permitting procedures for offshore wind turbines despite four years of discussion.



G. Distribute information

Finally, many investors and customers are woefully uninformed about energy policy, electricity technologies, and existing energy regulations. Thus, the final policy mechanism should inform the public and educate possible investors. A series of national electricity information and education campaigns could include grade-school classes on energy and the environment. Public demonstrations and tours of clean power facilities could be promoted. Mandatory disclosure of electricity usage for the construction of new buildings and the renting and leasing of existing ones could be required. Free energy audits and training sessions for industrial, commercial, and residential electricity customers could be offered. Improved labeling, rating, and certification programs for appliances and electricity-using devices could be provided. National information ''clearing houses'' consisting of Web sites, free books, indexing services, and libraries could be created to help consumers gather and process information in order to make more informed choices about their electricity use. These efforts would naturally be complemented by the use of smart meters and the removal of subsidies, which would improve the price signals and enhance the feedback available to electricity customers.

VI. Conclusion

First, a completely renewable power sector is technically feasible. There are no sound technical reasons why existing renewable power plants could not replace all conventional units. To quote just one of a plethora of recent studies, ''it is clearly feasible to replace the present fossil fuel energy infrastructure . . . with renewables.''[38]

Second, a renewable power sector would offer immense benefits to consumers, utilities, and society. Renewable power technologies reduce dependence on foreign sources of fuel, thereby

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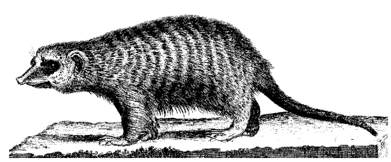
creating a more secure form of supply that minimizes exposure to economic and political changes abroad. Many forms of them decentralize electricity supply so that an accidental or intentional outage affects a smaller amount of capacity than one at a larger gas, coal, or nuclear facility. Renewable power technologies diversify the energy base, thereby providing more stable energy prices and insulating the industry from price spikes, interruptions, shortages, accidents, delays, and international conflicts. Unlike generators relying on oil, natural gas, uranium, and coal, most renewable generators are not subject to the rise and fall of fuel costs. They thus provide a hedge against future environmental regulations (such as a carbon tax) that could make the price of conventional power expectedly rise. The construction, installation, and operation of renewable power systems produce economic benefits such as more stable electricity rates, local sales dollars, and employment. Most significantly, clean power technologies have environmental benefits since their use tends to avoid air pollution and the dangers and risks of extracting fossil fuels and uranium. They displace or generate electricity without releasing significant quantities of CO_2 and other greenhouse gases that contribute to climate change as well as life-endangering nitrogen oxides, sulfur dioxides, particulate matter, and mercury. They also create power without relying on the extraction of fossil fuels and its associated digging, drilling, mining, transporting, storing, combusting, and reclaiming of land.

Third, a renewable power sector is achievable with the correct configuration of policy support and political leadership. To those that say the costs are too



great, let us remind them that we are already paying billions of dollars (and possibly trillions according to some estimates) in environmental damages, climatic changes, power outages, deteriorating public health, price spikes, and transfers of wealth. To those that express dismay, the history of the automobile, military aircraft, cell phones, and computers, along with the Cold War, might offer some perspective. Only a few thousand automobiles were on the road in the United States by 1900, yet more than 1 million existed by 1910, 6 million by 1930, and 74 million by 1960. In 1939, American wartime production of airplanes was thought to be limited to 2,000 per year until production increased to the point where 257,000 were in service by 1946, a feat achieved with 1940s technology in seven years.[39] The proliferation of personal computers and use of the Internet has doubled an average of every three to four *months* from 1995 to today.[40] The first commercial mobile phone service was launched by Bell Labs in Chicago in 1977 with only a few thousand subscribers, but within 10 years the number of cell phone users grew to more than 5 million and in 2007 surpassed 3.3 billion. The United States and former Soviet Union spent about $10 trillion on the Cold War, enough money to replace the entire infrastructure of the world. Every school, hospital, roadway, building, and farm could have been purchased for the cost of a political movement, one based on *possible* threats and *potential* destruction instead of the *real* risks already posed from climate change and environmental degradation (and partially addressed by renewable energy).[41]

These examples conclusively demonstrate that rapid technological diffusion can occur given the right mix of incentives. Compared to these momentous events the practicality of building tens of thousands of renewable power plants pales in comparison. It is not the technology that is lacking, but the political will, institutional inertia, and social awareness needed to bring it forward.■

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Endnotes:

1. For a tender summary of this argument, see Herman E. Daly, Beyond Growth: The Economics of Sustainable Development (Boston: Beacon Press, 1996), at 115.

2. See Benjamin K. Sovacool, *Renewable Energy: Economically Sound, Politically Difficult*, Elec. J., June 2008, at 18–29; and Benjamin K. Sovacool, The Dirty Energy Dilemma: What's Blocking Clean Power in the United States (Westport, CT: Praeger, 2008).

3. M. King Hubbert, *Energy Resources of the Earth*, Sci. Am., Sept. 1971, at 61.

4. One useful survey of these estimates is provided by Asia Pacific Energy Research Centre, *A Quest for Energy Security in the 21st Century: Resources and Constraints* (Tokyo: Institute of Energy Economics, 2007).

5. Quoted in Kate Connolly, *Endless Possibility*, The Guardian, April 16, 2008.

6. The world consumed about 17,000 TWh of electricity in 2007. A comprehensive study undertaken by the International Hydropower Association, the Implementing Agreement on Hydropower Technologies and Programmes of the International Energy Agency, the Canadian Hydropower Association and the International Commission Large Dams identified 14,370 TWh of remaining technical potential for hydroelectric facilities. Similarly, the International Geothermal Association surveyed a collection of studies and concluded that 22,400 TWh of geothermal power potential existed. See International Hydropower Association, *Hydropower and the World's Energy Future*, Nov. 2000, and R. Bertani, *What is Geothermal Potential*, International Geothermal Association, 2002.

7. The number of studies making this argument is truly immense and growing. However, for a good start, see C.L. Archer and M.Z. Jacobson, *Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms*, J. Applied Meteorology & Climatology 46 (2007), at 1701–1717; J. Smith *et al.*, *Utility Wind Integration and Operating Impact State of the Art*, IEEE Transactions on Power Sys. 22(3) (Aug. 2007), at 900–908; H. Holttinen *et al.*, State-of-the-Art of Design and Operation of Power Systems with Large Amounts of Wind Power, Presentation to European Wind Energy Conference & Exhibition in Milan, May 2007; and C.L. Archer and M.Z. Jacobson, *Spatial and Temporal Distributions of U.S. Winds*

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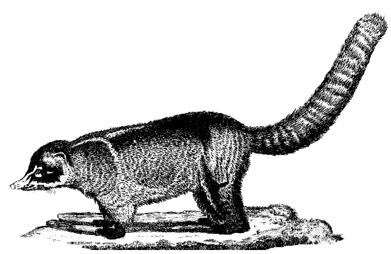
and Wind Power at 80m Derived from Measurements, J. GEOPHYSICAL RES. 108 (2003), at 4289. One recent survey of this literature is offered in Benjamin K. Sovacool, *The Intermittency of Wind, Solar, and Renewable Electricity Generators: Technical Barrier or Rhetorical Excuse?* UTIL. POLICY, forthcoming, 2009. That meta-survey concludes that ''claiming that the variability of renewable energy technologies means that the costs of managing them are too great has no factual basis in light of the operating experience of renewable in Denmark, Germany, the United Kingdom, Canada, and a host of renewable energy sites in the United States.''

8. For three interesting case studies of wind-hydrogen systems in Europe, see Benjamin K. Sovacool and Richard F. Hirsh, *Island Wind-Hydrogen Energy: A Significant Potential U.S. Resource*, RENEWABLE ENERGY, Aug. 2008, at 1928–1935.

9. Bonneville Power Administration, a large federal utility in the Pacific Northwest of the United States, already uses its existing 7,000 MW hydroelectric and pumped hydro storage network to transform intermittent renewable energy into baseload power. Starting in 2005, Bonneville offered a new business service to ''soak up'' any amount of intermittent output from wind and solar facilities, and sell it as firm output from its hydropower network one week later. Such storage technologies can have greater than 1,000 MW of capacity (depending on location), and operate according to fast response times and relatively low operating costs.

10. Compressed air energy storage (CAES) is economical for large bulk storage of electricity. Renewable-CAES systems use intermittently generated renewable energy to compress air and pump it into underground formations such as caverns, abandoned mines, aquifers, and depleted natural gas wells. The pressurized air is then released on demand to turn a turbine that generates electricity. Land and expertise are widely available for widespread renewable-CAES systems. While no studies have been done yet for New Zealand, sufficient CAES resources are available in 75 percent of the United States and operators already have an 80-year history of storing pressurized natural gas in underground reservoirs. Existing CAES plants still use small amounts of natural gas to heat compressed air, but consumption is 60 percent lower than single-cycle natural gas turbines. Natural gas fuel needs are set to be eliminated entirely in the newest designs relying on advanced adiabatic CAES, expected to be commercialized



as early as 2015. See Vasilis Fthenakis, James E. Mason and Ken Zweibel, *The Technical, Geographical, and Economic Feasibility for Solar Energy to Supply the Energy Needs of the U.S.*, ENERGY POLICY 37 (2009), at 387–399.

11. See Benjamin K. Sovacool and Richard F. Hirsh, *Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-Grid (V2G) Transition*, ENERGY POLICY, March 2009, at 1095–1103.

12. Solar thermal and concentrated solar power facilities can be made into a dispatchable resource by adding molten salt thermal storage. See Fthenakis *et al.*, *supra* note 10.

13. See Fthenakis *et al.*, *supra* note 10, as well as Paul Denholm, *Improving the Technical, Environmental and Social Performance of Wind Energy Systems Using Biomass-Based Energy Storage*, RENEWABLE ENERGY 31 (2006): 1356, and Paul Denholm, Gerald L. Kulcinski and Tracey Holloway, *Emissions and Energy Efficiency Assessment of Baseload Wind Energy Systems*, ENV. SCI. & TECH. 39 (2005): 1903–1911.

14. Again, while the literature on ELCC, solar energy, and peak demand is vast, readers are encouraged to read P. Denholm and R. Margolis, Very Large-Scale Deployment of Grid-Connected Solar Photovoltaics in the United States: Challenges and Opportunities, presentation at Solar 2006 Conference, NREL/CP-620-39683, April 2006; Chris Robertson and Jill K. Cliburn, Utility-Driven Solar Energy as a Least Cost Strategy to Meet RPS Policy Goals and Open New Markets, presentation at ASES Solar 2006 Conference, and R. Perez, R. Margolis, M. Kmiecik, M. Schwab and M. Perez, *Effective-Load Carrying Capability of Photovoltaics in the U.S.*, National Renewable Energy Laboratory, Golden, CO, NREL/CP-620-400GB), June 2006.

15. Capital costs for nuclear power taken from Benjamin K. Sovacool and Christopher Cooper, *Nuclear Nonsense: Why Nuclear Power is No Answer to Climate Change and the World's Post-Kyoto Energy Challenges*, WILLIAM & MARY ENV. LAW & POLICY REV., Fall 2008, at 1–119. Geothermal data taken from U.S. Department of Energy and Geothermal Energy Association, *Factors Affecting Costs of Geothermal Power Development*, 2005. Hydroelectric data taken from Debbie Stone, Hydroelectric Power: Untapped Resources, in *Report to the U.S. Hydropower Council for International Development*, July/Aug. 2002). Wind data taken from U.S. Department of Energy, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, 2008. Solar PV data taken from United Nations Environment Program, Division of Technology, Industry, and Economics, *Energy Technology Fact Sheet: Solar PV*, New York, 2003. Biomass data taken from U.S. Environmental Protection Agency, Representative Biomass CHP System Cost and Performance Profiles, *EPA Combined Heat and Power Partnership Biomass CHP Catalog*, 2007. Natural gas combined cycle data taken from

California Public Utilities Commission, *New Combined Cycle Gas Turbine (CCGT) Generation Resource, Cost, and Performance Assumptions*, Nov. 2007. MSW landfill gas, IGCC with carbon sequestration, solar thermal, scrubbed coal, and fuel cells data taken from U.S. Energy Information Administration, Cost and Performance Characteristics of New Central Station Electricity Generating Technologies, *Electricity Market Module,* DOE/EIA-0554, June 2008.

16. Nuclear power costs come from Pam Radtke Russell, *Prices Are Rising: Nuclear Cost Estimates Under Pressure*, ENERGYBIZ INSIDER, May/June 2008, at 22. All other figures come from Sovacool, *supra* note 2, at 115.

17. Fthenakis *et al.*, *supra* note 10.

18. See ''Technological Learning'' section of Sovacool's *Dirty Energy Dilemma*, *supra* note 2, at 89–92.

19. Andrew Mills, Ryan Wiser and Kevin Porter, *The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies*, Lawrence Berkeley National Laboratory, LBNL-1471E, Feb. 2009.

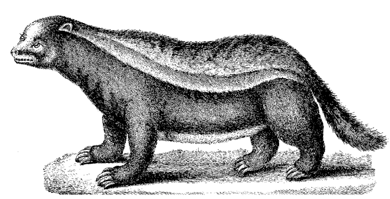
20. See Luc Gagnon, *Civilization and Energy Payback*, Energy Policy 36 (2008), at 3317–3322.

21. See ''Putting it All Together'' section of Sovacool's *Dirty Energy Dilemma*, *supra* note 2, at 113–121.

22. See U.S. Energy Information Administration, *Receipts, Average Cost, and Quality of Fossil Fuels for the Electric Power Industry, 1995 to 2006*, 2007, and International Energy Agency, *Key World Energy Statistics*, 2008.

23. Source is Mark Z. Jacobson, *Review of Solutions to Global Warming, Air Pollution, and Energy Security*, ENERGY & ENV. SCI., forthcoming, 2009.

24. Pacific Gas and Electric Company (PG&E), the largest investor-owned utility in California, built an entire power plant in 1993 to test the grid benefits of a 500 kW distributed solar power plant. PG&E found that the generator improved voltage support, minimized power losses, lowered operating temperatures for transformers on the grid, and improved transmission capacity. The benefits were so large that the small-scale generator was twice as valuable as estimated, with projected benefits of 14 to 20¢/kWh. See Howard J. Wenger, Thomas E. Hoff, and Brian K. Farmer, *Measuring the Value of Distributed Photovoltaic Generation: Final Results of the Kerman-Grid Support Project*, PROCEEDINGS OF FIRST WORLD CONFERENCE ON PHOTOVOLTAIC ENERGY CONVERSION, Waikaloa, HI, Dec. 1994, IEEE, 1994, at 792–796. Another study



conducted by Los Alamos National Laboratory compared coal-fired power stations in two different sizes: four plants each generating 750 MW, and 9 plants each only one-third as large. The study discovered that the larger plants needed one-third more reserve capacity, had higher forced outage rates, and took nine years to build, whereas the smaller plants were more reliable because of their distributed nature, took only five years to build, and had forced outage rates 60 percent lower. The researchers concluded that the money saved by these advantages more than offset any economic disadvantages of having to operate and maintain greater number of power plants. See Amory B. Lovins and L. Hunter Lovins, BRITTLE POWER: ENERGY STRATEGY FOR NATIONAL SECURITY (Andover, MA: Brick House Publishing Co., 1982, at 352.

25. After running thousands of simulations, they found that had distributed solar PV facilities been operating on Aug. 14, the blackout most likely would not have occurred. The researchers noted that the indirect cause of peak demand on that day—hot temperatures and greater air conditioning loads—are also the best source for solar PV generation. If a few hundred MW of solar PV had been operating, the researchers concluded that power transfers and losses would have been reduced, voltage support enhanced, and uncontrolled events would not have cascaded into a complete blackout. See Richard Perez, Marek Kmiecik, Tom Hoff, John G. Williams, Christy Herig, Steve Letendre, and Robert M. Margolis, *Availability of Dispersed Photovoltaic Resource During the August 14th 2003 Northeast Power Outage*, Univ. of Albany, Albany, NY, 2007.

26. See United Nations Environment Program, *Natural Selection: Evolving Choices for Renewable Energy Technology and Policy,* Geneva, 2000, and Daniel Kammen *et al.*, *Putting Renewables to Work: How Many Jobs Can the Clean Power Industry Create?* RAEL REPORT, Jan. 2004.

27. These figures come from two studies in California and Arizona, along with a survey conducted by Lovins & Lovins. See Black and Veatch, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California,* Los Angeles, April 2006; Arizona Dept. of Commerce Energy Office, *Energy Dollar Flow Analysis for the State of Arizona,* Phoenix, 2004; and Lovins & Lovins, *supra* note 24, at 306.

28. Up until 1993 New Zealand had a system of monopoly providers of generation, transmission, distribution, and retailing. Regulation of the newly restructured electricity market was managed by the companies themselves and the Electricity Commission (EC) was appointed in 2003 to monitor the industry. The EC was set up as an independent non-government organization, yet its independence has been brought into question of late with evidence implicating government intervention on EC directives that adversely impact state-owned electricity companies.

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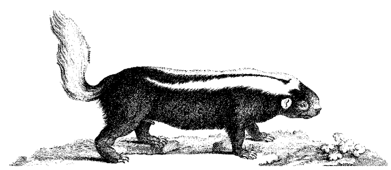
29. Up until 2008 legislation prevented a generation company owning or having an interest in a distribution company and a distribution company could not retail electricity. In a bid to encourage more competition, new legislation has allowed lines companies to invest in permitted generation, especially from renewable energy sources.

30. Generation by fuel type taken from the New Zealand Electricity Commission Centralised Data Set-Web interface.

31. Wind potential taken from David Parker, Wind Potential to Meet New Zealand's Energy Needs, Address to the New Zealand Wind Energy Conference, March 13, 2007, Wellington, NZ, and excludes low wind speeds and environmentally sensitive areas. Net generation and potential for solar PV and solar thermal taken from Energy Efficiency and Conservation Authority, *Solar Energy Use and Potential for New Zealand,* 2001. Geothermal potential taken from Jim Lawless, *Potential for Geothermal to Substitute for Fossil Fuels,* New Zealand Geothermal Assn., Dec. 17, 2001. Hydroelectric potential taken from WORKS Consultancy Services, *Hydro Resources of New Zealand,* April 1990. Data for all other sources taken from Ministry of Economic Development (MED), *New Zealand Energy Data File,* June 2008.

32. U.S. Department of Energy, Characterization of U.S. Energy Resources and Reserves (Washington, DC: DOE/CE-0279, 1989).

33. Electricity generation data taken from U.S. Energy Information Administration, *Electricity Net Generation from Renewable Energy by Energy Use Sector and Energy Source, 2002-2006,* 2007. Achievable onshore wind potential assumes class 1–7 wind regimes in all 50 states (and is based on the DOE estimate that onshore wind could supply ''more than one and a half times the current electricity consumption of the U.S.''). See Energy Efficiency and Renewable Energy Program at the U.S. Department of Energy, *Wind Energy Resource Potential,* 2007. Achievable offshore wind potential assumes water depths from zero to 900 meters. The estimate excludes 266,200 MW of offshore potential for waters currently deeper than 900 meters because such technology is not commercially available. Data taken from Walt Musial, *Offshore Wind Energy Potential for the U.S.,* NREL, May 19, 2005, at 9. Achievable solar photovoltaic potential assumes prices of $2 to $2.50 per installed watt. Data taken from Maya Chaudhari, Lisa Frantzis and Tom E. Hoff, *PV Grid Connected Market*



Potential, Energy Foundation, Sept. 2004. Achievable solar thermal potential includes parabolic troughs and power towers, and is taken from National Renewable Energy Laboratory, *Concentrating Solar Power Resource Maps,* Dec. 2007. NREL states that ''realistically, the potential of concentrating solar power in the Southwest could reach hundreds of gigawatts or greater than 10% of U.S. electric supply.'' Achievable geothermal potential taken from Bruce D. Green and R. Gerald Nix, *Geothermal—The Energy Under Our Feet*, National Renewable Energy Laboratory, NREL/TP-840-40665, Nov. 2006. Achievable biomass potential (combustion) converted from estimates provided in Oak Ridge National Laboratory and U.S. Department of Energy, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, DOE/GO-102995-2135, 2005. Achievable biomass potential (landfill gas) taken from U.S. Environmental Protection Agency, Landfill Methane Outreach Program, *An Overview of Landfill Gas Energy in the U.S.*, May 2007. Achievable hydroelectric potential excludes all nationally protected lands and areas, and is taken from U.S. Dept. of Energy, *Water Resources of the U.S. with Emphasis on Low Head/Low Power Resources,* DOE/ID-11111, April 2004.

34. Most estimates assume the exclusion of low-resource and environmentally sensitive areas. Some figures for concentrated solar power and geothermal derived from the mean of the given ranges presented. All figures taken from Mark Z. Jacobson, supra note 23, except for the electrical potential of hydroelectric power, which is taken from International Hydropower Assn., *supra* note 6.

35. Richard Cowart, *Efficient Reliability: The Critical Role of Demand-Side Resources in Power Systems and Markets,* National Association of Regulatory Utility Commissioners, Washington, DC, June, 2001.

36. Wilson Rickerson and Robert C. Grace, THE DEBATE OVER FIXED PRICE INCENTIVES FOR RENEWABLE ELECTRICITY IN EUROPE AND THE UNITED STATES: FALLOUT AND FUTURE DIRECTIONS (Washington, DC: Heinrich Boll Foundation, 2007).

37. Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, Prospects for Renewable-Generated Electricity, *Renewable Energy Resources Act (EEG) Progress Report 2007,* Berlin, 2008.

38. Fthenakis *et al.*, *supra* note 10, at 397.

39. Tracey Bryant, Mid-Atlantic Offshore Wind Potential: 330 GW, Univ. of Delaware Press Release, July 2, 2007.

40. K.G. Coffman and A.M. Odlyzko, *Growth of the Internet*, 2001.

41. Paul Hawken, THE ECOLOGY OF COMMERCE: A DECLARATION OF SUSTAINABILITY (New York: Harper Collins, 1993), at 58.

  doi:/10.1016/j.tej.2009.03.011