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Renewable Electricity Generation in the United States

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Abstract

This paper provides an overview of the use of renewable energy sources to generate electricity in the United States and a critical analysis of the federal and state policies that have supported the deployment of renewable generation. Particular attention is paid to the use of wind energy and to the contrasting experiences in Texas and California.

Thomas A. Edison's Pearl Street Station in New York, the first permanent, commercial electric generating plant, began operation on September 4, 1882.[2] Just 26 days later, the first commercial generating plant using renewable energy – a hydroelectric facility – began operation in Appleton, Wisconsin.[3] The United States has considerable hydroelectric potential and moved aggressively, particularly in the 1930s, to exploit it. By 1949 hydro power accounted for just under a third of U.S. electricity generation (EIA 2009 (Electric Power Annual, online), Table 1.1).[4]

Since then, however, the relative importance of hydro power has waned, as potential dam sites were of lower quality than those already utilized, the performance of other generating technologies improved, and the public became increasingly concerned about the environmental impacts of dams. In recent years more attention has been given to the possible demolition of hydroelectric dams than to their possible construction. Hydro power accounted for only about six percent of U.S. electricity generation in 2007 (EIA 2009, Table 1.1).

Renewable generation technologies other than hydroelectricity – what I will call non-hydro renewable or NHR technologies – began to attract significant attention from public and private decision-makers in the U.S. and abroad after the energy crises of the 1970s. As environmental concerns, particularly those related to climate change, have become more important, support for these technologies has generally increased. In the U.S. the result has been

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[1] This essay is a draft of a chapter in a forthcoming book, *Harnessing Renewable Energy*, being edited by Boaz Moselle, Jorge Padilla, and myself. I am indebted to Dhiren Patki for superb research assistance and to Boaz Moselle for exceptionally useful comments on an earlier draft. This chapter also benefitted from my participation in the MIT Future of Solar Energy study, in which I received excellent research assistance from Kevin J. Huang.

[2] IEEE, "IEEE Global History Network," *Pearl Street Station*,http://www.ieeeghn.org/wiki/index.php/Pearl_Street_Station (accessed September 3, 2009).

[3] IEEE, "IEEE Global History Network," *Milestones: Vulcan Street Plant, 1882,* http://www.ieeeghn.org/wiki/index.php/Milestones:Vulcan_Street_Plant,_1882 (accessed September 3, 2009).

a complicated saga of erratic and unfocused federal policy and widely divergent state policies, with results that have not surprisingly varied considerably over time and among the states.

Section 1, below, provides a brief quantitative overview of the actual and potential importance of non-hydro renewable energy in the United States over time. Until recently the US was a leader in NHR generation of electricity, but other nations have provided more effective support of these technologies and have accordingly taken the lead in utilizing them.

Section 2 outlines rationales and policy tools for supporting NHRs and examines policy at the federal level in the U.S. Section 3 considers state-level policies and their effects and provides brief discussions of experience in two major states that have played (very different) leadership roles in this area: California and Texas.

Section 4 discusses the most rapidly growing NHR technology in the U.S. – wind – and some of the issues and concerns that its growth has raised. Section 5 provides a few concluding observations.

1. Non-Hydro Renewables in the United States

Between 1949 and 2008, both total U.S. energy consumption and consumption derived from NHRs grew at about 1.95% annually on average.[4] In the first half of this period, from 1949 to 1978, total energy consumption grew at a 3.21% average annual rate, while energy from NHRs grew only about a third as fast – at a 1.06% annual rate. Thereafter, the growth of total energy consumption slowed dramatically to a 0.72% annual rate, while the growth of energy from NHRs accelerated to a 2.82% annual rate. Despite this impressive growth, however, NHRs have never accounted for more than 4.5% of total U.S. energy consumption.

Figure 1 gives a breakdown of total energy consumption from non-hydro renewables over the 1978-2008 period by source. In the early years the only important source in this category was biomass – mainly wood and wood waste – used to generate heat rather than electricity. In recent years, biofuels – mainly ethanol – have become of comparable importance. Together with a small contribution from “Other Solar” – the use of solar energy to produce heat, mainly to warm swimming pools – these three non-electric uses of renewable energy are much more important than the use of NHRs to generate electricity.

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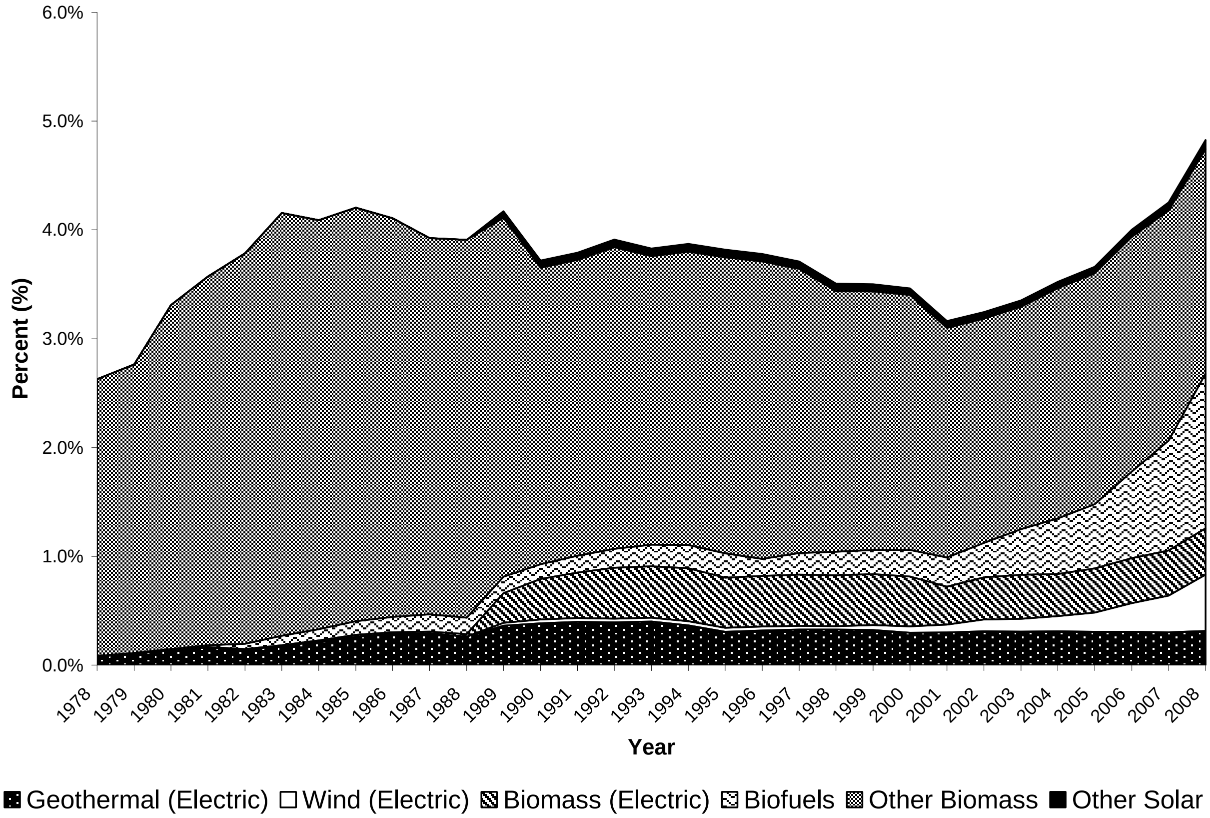
[4] The numbers in this paragraph are derived from Energy Information Administration, *Annual Energy Review 2008*, Table 1.3, http://www.eia.doe.gov/aer/overview.html.

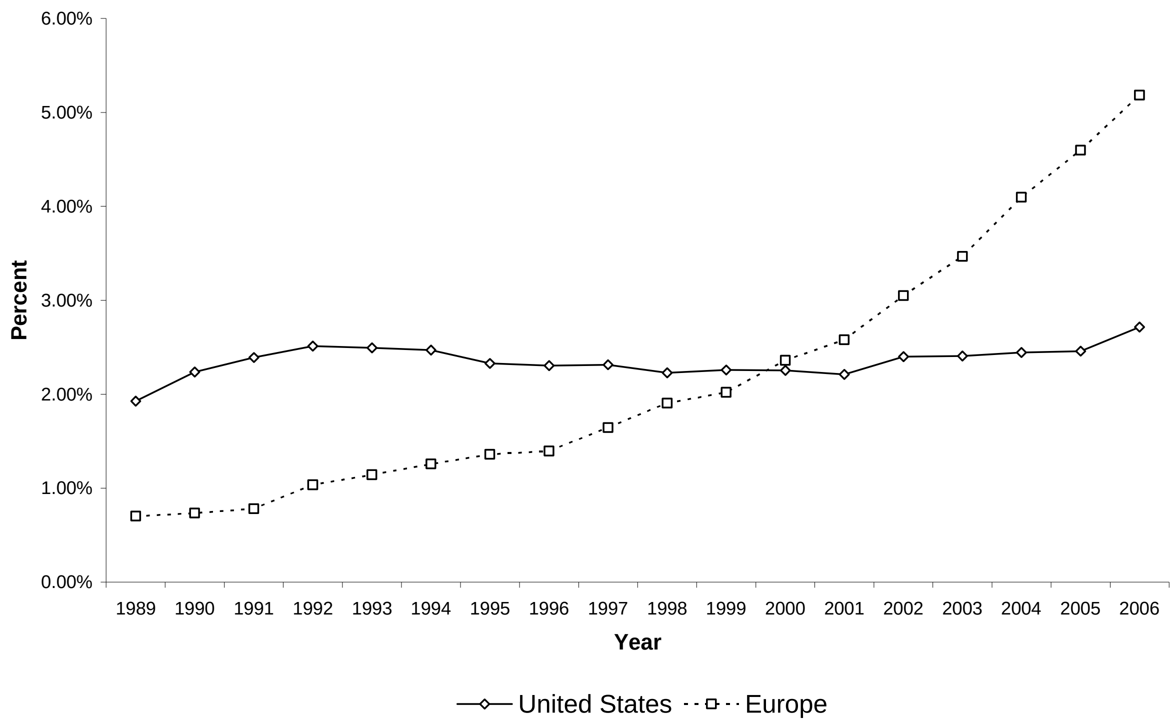
Figure 1: Non-Hydro Renewable Energy Consumption as a Percentage of Total US Energy Consumption



Source: EIA, *Annual Energy Review*, 2008.

Since the late 1970s, NHRs have been of interest to policy-makers primarily because of their perceived potential to displace fossil fuels (and, in some jurisdictions, nuclear energy) in electricity generation. Despite this interest, however, and a wide variety of policies aimed at encouraging the use of NHRs, these technologies have only accounted for between 2.0% and 2.5% of total U.S. electricity generation since 1989, as Figure 2 shows. For all of the 1990's NHRs played a more important role in generating electricity in the U.S. than in Europe. But major European nations, particularly Germany, were much more aggressive in promoting NHRs over most of this period, and the share of these technologies in European electricity generation has accordingly been rising. It is now almost double that in the U.S.

Figure 2: Share of Non-Hydro Renewable Electricity in Total Generation



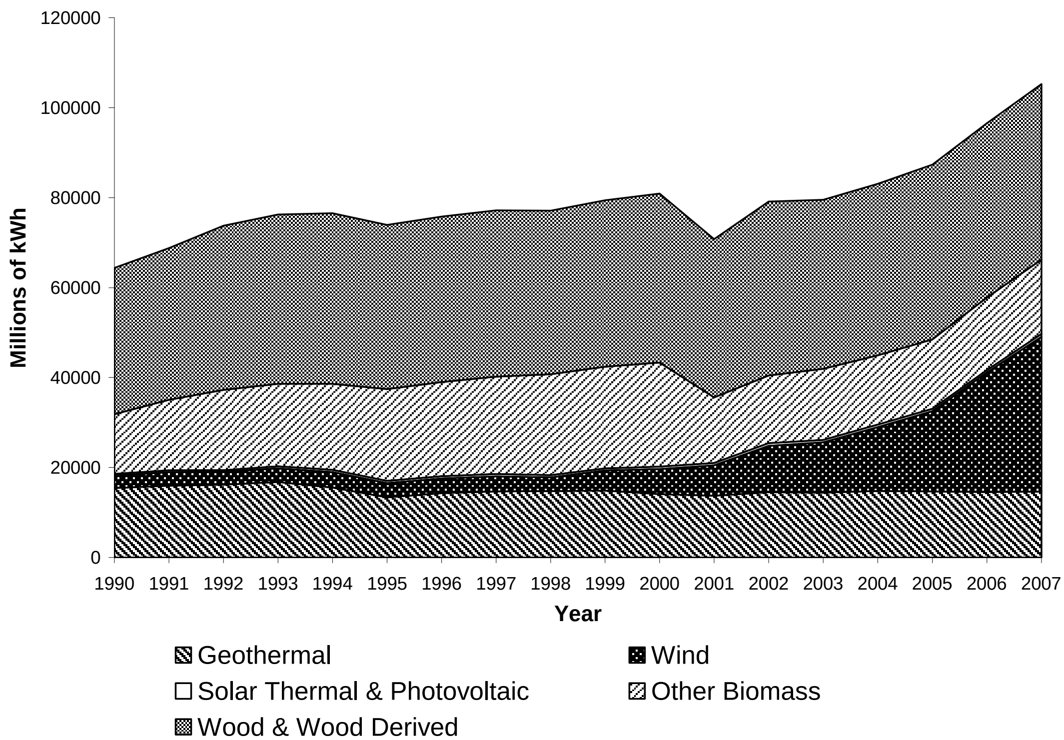
Source: EIA, International Energy Statistics.
http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=6&pid=29&aid=12

Figure 3 shows the contributions of the various NHR technologies to electricity generation since 1990. About 70% of biomass generation is fueled by wood and wood waste; the remainder is fueled by biogenic municipal solid waste, landfill gas, and a variety of other substances. Between 1990 and 2007, geothermal generation declined slightly, and biomass-fueled generation grew at only a 1.1% average annual rate. In these data, solar generation grew at an average annual rate of 3%, but from a tiny base. Because the U.S. Energy Information Agency only tracks generation from solar installations with capacities above 1 MW, it seems likely that solar generation at the end of this period was understated by at least 60%.[5] Even

[5] According to the International Energy Agency (*Renewables Information 2008* (Paris, France, IEA: 2008)), which bases its U.S. figures on data submitted by the U.S. Energy Information Agency, solar-thermal installations accounted for 97.4% of 2007 U.S. solar-electric generation, while according to the IREC (Larry Sherwood, *U.S. Solar Market Trends 2007* (Interstate Renewable Energy Council, 2008), which measures all grid-connected solar-electric capacity, solar-thermal units accounted for only 49.2% of average solar generating capacity in 2007 (taking the average of solar thermal and photovoltaic capacities at the end of 2006 and the end of 2007). If photovoltaic units had the same capacity factor as solar thermal units on average, total US solar generation was 98% above the

correcting for this bias, however, solar's share remains tiny. Wind, which grew at an average annual rate of 15.9%, accounted for the bulk of NHR growth over this period.

Figure 3: U.S. Electricity Generation from Non-Hydro Renewable Energy



Source: EIA, *Electric Power Annual*, 2007. Data Table EIA-906.

Many analysts contend that even with current technology, non-hydro renewables have the potential to play a much larger role in the U.S. than they do at present. Table 1 compares actual generation from non-hydro renewables in the US in 2007 with estimates by the International Energy Agency (IEA) of "total realizable potential by 2020."[6] These estimates are intended to reflect both natural endowments (e.g., average solar radiation) and the relative costs of current NHR technologies, but they are inevitably imprecise and should accordingly be treated with caution. It is worth noting, however, that even though the IEA believes that solar generation has

IEA figures. It was at least 60% above the IEA figures if photovoltaic units had at least 62% of the capacity factor of solar thermal units, and this seems a conservative assumption.

[6] Two clarifying observations are in order. First, as note in the preceding footnote, the IEA's data are based on reports submitted to them by national statistical agencies such as the EIA, so the IEA understates US solar generation just as the EIA does. Second, the IEA reports gross electricity generation, including estimated in-plant losses, while all EIA numbers are for net generation. Net generation is about 5% below gross generation for the US as a whole.

not even reached one percent of its potential despite decades of attention by policy-makers, it also estimates that its ultimate potential is much less than either biomass or wind.

Table 1: Actual and Potential NHR Generation in the US

Resource	Estimated Total Realizable Potential by 2020 (TWh)	Actual 2007 Gross Generation (TWh)	Actual as a Percentage of Potential
Biomass	501.6	58.6	11.7
Wind	300.4	32.3	10.8
Solar	85.2	0.7	0.8
Geothermal	36.0	16.9	47.0
Tidal & Wave	2.3	0.0	0.0
Total	925.5	108.4	11.7

Sources: Estimated potentials from IEA, *Deploying Renewables*, 65; generation from IEA, *Renewables Information 2008*, 396.

As noted in the introduction, there has been a great deal of variation in state-level experience with NHRs. In 2007, NHRs accounted for 2.53% of total US net generation but for more than 5% in seven states and for less than 1% in 11 states. Some of this variation reflects differences in the potential for various renewable technologies, and some reflects differences in state-level policies toward renewables. To shed quantitative light on the relative importance of these two sources of variation would require plausible estimates of state-level, technology-specific potentials comparable to the IEA estimates in Table 1, but no such estimates appear to exist.[7]

Table 2 provides information on the seven states for which NHR generation accounted for more than 5% of total generation, as well as the two states not in this set that were in the top five in terms of total NHR generation. These nine states accounted for 92% of US NHR generation in 2007. For most states one technology is the dominant contributor to NHR generation, but two were nearly tied in the cases of Hawaii and Florida. The importance of wood and wood waste is clear here, as it was in Figure 3, particularly in heavily forested states like Maine, Vermont, and Idaho. The so-called "wind belt," extending northward from Texas to the Canadian border, is visible here, though some states in that belt are conspicuous by their absence.

[7] Estimates of the state- and technology-specific potentials have been published by the Union of Concerned Scientists (UCS): Jeff Deyette, Steve Clemmer, and Deborah Donovan, *Plugging in Renewable Energy: Grading the States* (Union of Concerned Scientists, 2003). The UCS estimates did not take into account costs, however, and they imply total national potential roughly 20 times as large as the IEA's and with a very different pattern across technologies. The UCS's estimated solar potential was three times as large as the estimated biomass potential, and the estimated wind potential was 19 times as large.

(The wind belt is discussed further in Section 4). It is also interesting to note the unimportance of solar power, even in states like California, Hawaii, and Texas that have abundant solar resources.

Table 2: Leading NHR Generation States

State	2007 NHR Generation Percent of State Total	TWh	Main NHR Technology or Technologies
Maine	26.1	4.21	Wood/Wood Waste
California	11.8	24.85	Geothermal
Vermont	8.0	0.65	Wood/Wood Waste
Minnesota	7.2	3.93	Wind
Hawaii	6.6	0.75	Wind, Geothermal
Iowa	5.8	2.91	Wind
Idaho	5.7	0.65	Wood/Wood Waste
Texas	2.5	10.29	Wind
Florida	1.9	4.30	Wood/Wood Waste, Other Biomass

Source: EIA, *State Renewable Energy 2007*.

2. Federal Policies in Support of NHRs

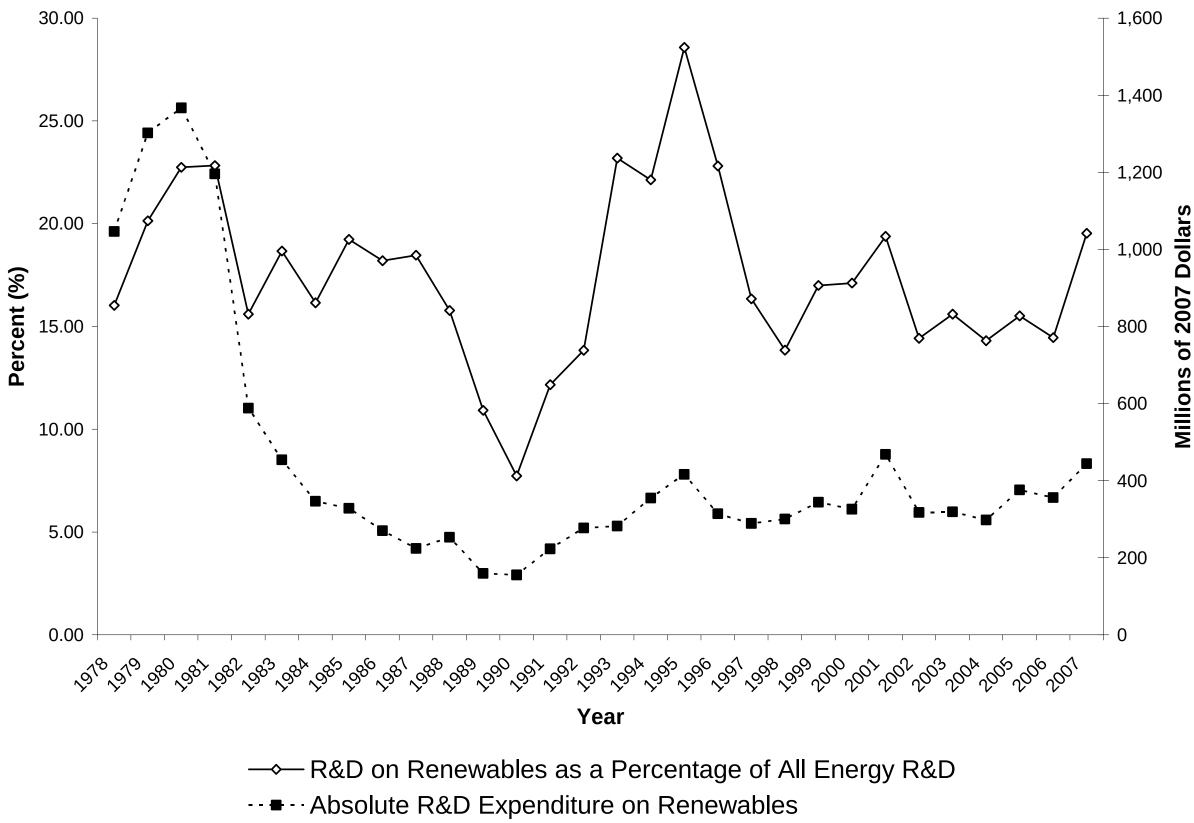
The US federal government has long supported R&D aimed at advancing NHR technologies and has more recently moved to subsidize their deployment. Motivations for such support have varied over time, with energy security being less important now than earlier, and environmental concerns – particularly associated with global climate change – more important in recent years.

2.1 Research and Development

Government financial support for basic research and pre-commercial development (R&D) aimed at advancing NHR technology – or almost any other technology – can be justified by the positive externalities that knowledge spillovers produce. Despite this rationale and strong rhetorical support for NHRs, however, the data reveal that U.S. policy-makers have historically allocated more generous R&D support to fossil-fuel and nuclear technologies, which are generally much more mature than NHRs. Between 1978 and 2007, federally sponsored R&D on renewable technologies amounted to 17.8% of total energy-directed R&D, while 39.3% was spent on nuclear technologies, and 32.1% was spent on fossil fuel technologies.[8]

[8] Energy Information Administration, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, (Washington, DC: GPO, 2008), 40. The remainder was devoted to end use technology (10.9 %).

Figure 4: Federal Expenditure on R&D in Renewable Technology



Source: EIA, *Federal Financial Interventions and Subsidies in Energy Markets 2007*.

Not only has federal R&D support for NHRs lagged support for more conventional technologies, it has varied substantially over time in both relative and absolute terms, as Figure 4 shows. R&D for NHRs – and for most other energy technologies – peaked in 1980, fueled by intense concerns over energy security and rapidly rising oil prices. As oil prices receded, so did energy-related R&D. Since the early 1980s, R&D funding in support of NHRs has been both modest and variable from year to year – hardly conducive to long-term, sustained efforts aimed at major breakthroughs.

2.2 Support for NHR Deployment: Conceptual Overview

Before examining actual federal and state policies to support the deployment of existing NHR technologies, it is worth noting that such policies are difficult to justify economically. In the presence of a binding cap on carbon dioxide emissions, for instance, a subsidy to NHR deployment will have no impact on total emissions but will raise the total social cost of meeting the cap. And while many claim that widespread deployment of NHRs will lower their costs through learning-by-doing, they rarely note that firm-specific learning that does not lower the costs of other firms does not justify subsidies. Rigorous empirical support for the importance or even existence of such spillover benefits is lacking. Other arguments for subsidizing NHR deployment, which include capital market imperfections (which, somehow, permit large, risky investments in other sectors), infant industry considerations (which, logically, should apply across the economy and have supported policies with a terrible historical record), and job creation (which lacks rigorous support and runs counter to historical progress by favoring labor-intensive over labor-saving technologies) are even less persuasive.

Nonetheless, subsidies of four basic sorts have been adopted in the U.S. and abroad: feed-in tariffs, output subsidies, investment subsidies, and output quotas. Feed-in tariffs, which guarantee a pre-determined, above-market price for power over a period of years, are the most popular policy device outside the US.[9] Feed-in tariffs provide strong incentives for minimizing costs and maximizing production. They generally do not provide stronger incentives for generating electricity when it is more valuable (e.g., by scheduling maintenance accordingly), however, and they provide an invisible subsidy by shifting all risk related to the supply of and demand for electricity to other market participants. An output subsidy, paid on top of market price, can eliminate both these shortcomings while retaining the other good incentive properties of a feed-in tariff. Output subsidies are not widely employed, however, and, like feed-in tariffs, can provide incentives to operate NHR facilities even when the marginal value of their generation is negative.[10] Investment subsidies are not particularly attractive economically because they provide weaker incentives for reducing initial cost than feed-in tariffs or output subsidies. Nonetheless, governments in the US and abroad that promote deployment of NHRs almost all use investment subsidies as part of their policy packages. Finally, output quotas,

[9] At least 16 of the 30 OECD nations have feed-in tariffs, as do 7 of the 8 EU member states that are not OECD members. International Energy Agency, "Global Renewable Energy: Policies and Measures," http://www.iea.org/textbase/pm/?mode=re (accessed September 3, 2009); Rogier Coenraads, et al., *Renewable Energy Country Profiles* (Utrecht, The Netherlands: European Commission, 2008); European Renewable Energy Council, "National Policy – Overview of EU Member States," http://www.erec.org/policy/national-policy.html (accessed September 3, 2009); Gröschel_ Geheeb_ Responsible Branding GmbH, EEG , *The Renewable Energy Sources Act: The Success Story of Sustainable Policies for Germany* (Berlin, Germany: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2007) http://www.gtai.com/uploads/media/EEG_Brochure_01.pdf (accessed September 3, 2009); Commission of the European Communities, Commission Staff Working Document SEC(2008) 57, *The Support of Electricity From Renewable Sources*, (Brussels, Belgium: EU,2008), http://ec.europa.eu/energy/climate_actions/doc/2008_res_working_document_en.pdf

[10] See the discussion of Texas in Section 3.4.

known in the U.S. as renewables portfolio standards or RPSs, typically require load-serving entities to generate or procure a minimum fraction of energy from NHRs. This approach is not as popular as feed-in tariffs abroad but is very popular at the state level in the U.S. and is part of legislation being actively debated at the federal level.[11] As we will see, not only has the US adopted a different mix of policies than most other wealthy nations, but it has implemented those policies in ways that significantly limit their efficiency and effectiveness.

2.3 Federal Support of NHR Deployment

Somewhat ironically in light of subsequent developments, the first federal initiative that supported deployment of NHRs did so almost unintentionally and led to the establishment of generous feed-in tariffs in several states. The Public Utilities Regulatory Policy Act of 1978 (PURPA), was primarily aimed at opening electric utilities to competition and increasing efficiency in electricity markets. PURPA required utilities to purchase electricity generated from certain defined "qualified facilities" at the utilities' avoided costs. "Qualified facilities" could be either cogeneration facilities (which produced both useful heat and electricity) or certain small NHR generators. Since electric utilities at that time were almost all vertically integrated, avoided costs were to be determined by state regulators rather than market prices, and regulators in some states (notably California, as discussed in Section 3) responded by establishing feed-in tariffs that were based on the expectation of high and increasing generation costs. As costs of conventional generation in fact came down, this system became unsupportable and was largely dismantled by the early 1990s (Borenstein and Bushnell 2000, 48).

Since then, federal policy has promoted NHR deployment primarily through favorable corporate income tax provisions: accelerated depreciation and tax credits for production and investment. Since 1986 most NHR generating assets, which had been depreciated over 15 years for tax purposes, could be written off over five years. (The list of eligible NHR technologies was

[11] Only seven EU members employ this device, three of which also use feed-in tariffs. Two non-EU OECD nations also employ this mechanism. International Energy Agency, "Global Renewable Energy: Policies and Measures," http://www.iea.org/textbase/pm/?mode=re (accessed September 3, 2009), Rogier Coenraads, et al., *Renewable Energy Country Profiles* (Utrecht, The Netherlands: European Commission, 2008), European Renewable Energy Council, "National Policy – Overview of EU Member States," http://www.erec.org/policy/national-policy.html (accessed September 3, 3009), and Commission of the European Communities, Commission Staff Working Document SEC(2008) 57, *The Support of Electricity From Renewable Sources*, (Brussels, Belgium: EU,2008), http://ec.europa.eu/energy/climate_actions/doc/2008_res_working_document_en.pdf.

expanded in 2005 and 2008.) This increased the present value of tax deductions for depreciation by around half.[12]

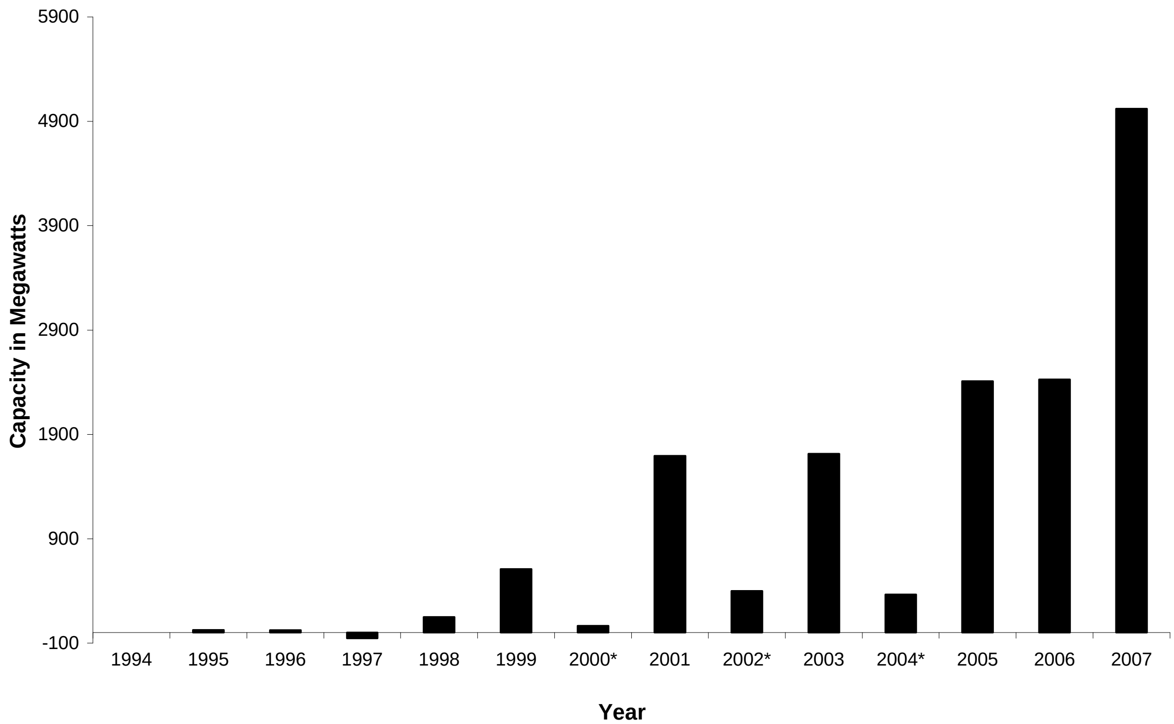
The Renewable Electricity Production Tax Credit (REPTC) was first established by the Energy Policy Act of 1992.[13] It provided for a corporate income tax credit of 2.1¢/kWh (1.5¢/kWh in 1993 dollars, indexed for inflation) for generation using some technologies and half that for others for (generally) the first 10 years of operation. Favored NHR technologies are currently wind, closed-loop biomass, and geothermal; other eligible technologies include open-loop biomass, landfill gas, municipal solid waste, and certain hydroelectric, marine, and hydrokinetic facilities. The legislation establishing the REPTC also established a Renewable Energy Production Incentive (REPI) program that authorized payments roughly equivalent to the PTC to entities such as state and local governments that were not corporate income tax payers.

This output subsidy policy has not been consistently or predictably implemented over time. Payments actually made under the REPI must be appropriated annually and are thus far from certain. Solar facilities were eligible for the REPTC only briefly – if they began operation in 2005. The REPTC expired at the end of 2001 and was then extended in March 2002. It then expired at the end of 2003 and was not renewed until October 2004, in legislation that extended it until the end of 2005. Legislation passed in 2005 extended it through the end of 2007; legislation passed in 2006 extended it through 2008; and laws passed in 2008 and 2009 revised and extended it through 2012 for wind and 2013 for other technologies. Figure 5 shows a surge in installation of wind capacity during 2001 before the REPTC expired, followed by a drastic drop-off during 2002, reflecting the uncertain status of the REPTC until March and the lag between project initiation and completion. Similarly, the unavailability of the REPTC during 2004 shows clearly in the Figure. If investors cannot rely on a subsidy's remaining in place, that subsidy provides at most weak incentives for long-term investments in such things as technology development and efficient production capacity.

[12] Conventional generation assets are depreciated using 150% declining balance over 15 years, with the option to switch to straight-line depreciation at any point. Qualifying NHR generating assets can be depreciated using 200% declining balance over 5 years, with the same option. The figure in the text was computed by assuming the switch occurs when it is most profitable and employing a 10% discount rate. For more details, see Metcalf (2009a, 2009b).

[13] Except where noted in what follows, all information on state and federal policies is from the U.S. Department of Energy's online Database of State Initiatives for Renewables and Efficiency: http://www.dsireusa.org/.

Figure 5: Wind Electricity Capacity Addition



Source: EIA, *Electric Power Annual*, 2007. Data Table EIA-860.

The Energy Tax Act of 1978, which was passed along with PURPA, established investment tax credits for a variety of NHR technologies. These were modified several times in the ensuing years (EIA 1999). Since 2005 the Residential Renewable Energy Tax Credit (RRETC) has provided personal income tax credits for up to 30% of investments in solar-electric systems, solar hot water systems, wind turbines, fuel cells, and geothermal heat pumps. Also since 2005, the Business Energy Investment Tax Credit (BEITC) has provided a 30% corporate income tax credit for investment in essentially all solar systems except those used to heat swimming pools, as well as for fuel cells and small wind turbines. It provides a 10% investment tax credit for certain other technologies. Both these provisions were initially scheduled to expire at the end of 2008, but legislation that year extended them to 2016.

For solar systems, the initial investment accounts for most of the life-cycle cost, so a 30% investment tax credit is a very large subsidy indeed. The Interstate Renewable Energy Council (Sherwood 2009) reports that the annual growth rate of photovoltaic capacity installed doubled in 2006, and capacity installed in 2008 was triple that installed in 2005. Similar dramatic growth occurred in solar hot water and space heating. It is important to note, however, that an investment tax credit is most valuable when it is less than current taxable income. This condition is probably satisfied for most homeowners who can seriously consider installing a solar system, but it is unlikely to be satisfied for any corporation specializing in grid-scale solar power. The need for such firms to use joint ventures and other devices to ensure that the full value of the investment tax credit is received can add significant friction to the process of financing solar projects.

The REPTC and REITC have been the most important sources of support for renewables deployment. In FY 2007, the reductions in tax revenue caused by subsidized financing of renewables facilities under other programs was $100 million, as compared to $690 million in such tax expenditures for the REPTC and REITC. But programs supporting fossil fuels were considerably more costly, resulting in $2.7 billion in tax revenue reductions (US Government Accountability Office 2007, 37).

The American Recovery and Reinvestment Act of 2009 (generally known as the stimulus bill) allows taxpayers eligible for the BEITC or the REPTC for facilities entering service or, generally, beginning construction in 2009 or 2010 to elect to receive a BEITC-equivalent cash grant instead. The rationale is that tax credits are of limited value during a period of unusually low corporate profits, but, on the other hand, entitlement to a grant is of no value if Congress does not appropriate sufficient funds.

Finally, there are several relatively small federal grant and loan guarantee programs, each targeted at certain classes of entities (e.g., municipal governments) and of technologies. These programs are modified from time to time, and the actual funding available is determined each year by the appropriations process. In FY 2006, excluding energy efficiency, the federal government only made $16.7 million in grants to support renewables and only guaranteed $23.8 million in loans (US Government Accountability Office 2007, 50).

As with R&D, it is interesting to compare federal subsidies for the utilization of NHRs to subsidies for other generation technologies. Table 3 shows EIA estimates of total subsidies and support by technology for 2007, both in absolute dollar terms and per MWh of generation. In absolute terms, coal (particularly clean coal) and nuclear power were the most heavily subsidized, while per unit of output solar and wind were much the biggest winners. It is interesting to note that wind, in particular, received more than 12 times as much support as

"Other NHR", even though the latter technologies accounted for more than twice as much generation.

Table 3: Subsidies and Support to Electricity Production by Technology, 2007

Fuel/End Use	2007 Net Generation (million MWh)	2007 Subsidy ($ Million)	Subsidy ($/MWh)
Coal & Refined Coal	2018	3010	1.49
Natural Gas & Oil	919	227	0.25
Nuclear	794	1267	0.16
Hydroelectric	258	174	0.67
Solar	1	14	24.34
Wind	31	724	23.37
Other NHR	70	59	0.84

Source: EIA, *Federal Financial Interventions and Subsidies in Energy Markets*, 2007, p.xvi. "Other NHR" includes biomass (and biofuels), landfill gas, municipal solid waste, and geothermal.

3. State Policies and Experience

This section begins with an overview of state policies in support of NHR deployment and then provides brief discussions of the California and Texas experiences. We focus initially on what is generally considered to be the most important state-level NHR policy and is certainly one of the most popular: renewables portfolio standards or RPSs[14].

3.1 Renewables Portfolio Standards

Renewables portfolio standards require that a minimum percentage of electricity generated or sold by a covered entity come from sources designated as renewable. Compliance is usually measured on an annual basis, and the required percentage typically increases over time. Iowa enacted the first RPS in 1983, and Nevada adopted the second in 1998. Since then the pace has increased dramatically, and 29 states plus the District of Columbia now have RPSs. These include all the states listed in Table 2 except Vermont (which has a voluntary standard), Idaho, and Florida, and states with RPSs accounted for 62% of U.S. net electricity generation in 2007. Table 4 lists these programs in order of their initial adoption and gives some of their most important current features. Five additional states have voluntary goals for renewable energy; these programs are listed in Table 5

[14] Rabe (2007) suggests that these policies are popular because they are seen to rely on market forces. A more cynical assessment would be that their costs are less visible than those of other subsidy types.

While all RPS programs have the common goal of increasing the share of renewable resources, they differ considerably along multiple dimensions. One important difference is how compliance is to be achieved. In states with organized wholesale markets, entities that distribute power are generally responsible for meeting RPS targets and are given considerable freedom to choose how to do so. In states that have regulated, vertically-integrated utilities, regulators oversee contracting and utility procurement. In New York and Illinois, a state agency has direct responsibility for the procurement of renewables under the RPS (Wiser and Barbose 2008). Some states have legislated explicit per-MWh penalties for non-compliance, while others allow the state's public utility commission to determine the appropriate penalty.

Differences also exist in the definition of resources that are deemed "renewable" and whether the RPS is applicable solely to investor owned utilities or whether it is extended to smaller retail suppliers with a lower target (as is the case in Colorado or Oregon). In some instances, the size of a facility has an important effect on whether its output counts toward RPS requirements. Maine, for instance, requires facilities to be 100 MW or smaller. In other states the age of a facility determines whether or not it is considered eligible – in Massachusetts only capacity installed after 1997 is considered eligible. Hydroelectric facilities are generally eligible subject to the capacity constraint that each state sets on facilities. Some states such as New Hampshire are explicit in their consideration of small hydroelectric facilities. A number of states have tiers or set-asides often with different timeframes or target levels. Fifteen states and the District of Columbia have provisions favoring solar power or distributed generation; nine have minimum solar requirements of various sorts, and the others give extra credit for solar or distributed generation. Illinois, on the other hand, requires that 75% of renewable generation come from wind. Nine of the RPS jurisdictions give at least some credit for solar hot water

Table 4 State Renewables Portfolio Standards

State	First RPS Adoption	Current Target	Other Requirements
Iowa	1983	105 MW	
Nevada	1997	6% by 2005, 20% by 2015	5% of RPS to be solar in each year
Massachusetts	November-97	15% by 2020 (Class 1) and 1 % each year thereafter, 3.5 % of sales each year starting in 2009 (Class 2)	To be determined
Connecticut	July-98	27% by 2020	20% Class 1, 3% Class 2, 4% Class 3
New Jersey	January-99	22.5% by 2021	2.12% solar by 2021
Texas	September-99	2280 MW by 2007, 5880 MW by 2015	500 MW from sources other than wind
Maine	1999	30% by 2000 (Class 2), 10% by 2017 (Class 1)	
Hawaii	2001	20% by 2020	
Wisconsin	October-01	10% by 2015	
California	2002	20% by 2010	
Maryland	May-04	20% by 2022 (Tier 1), 2.5% 2006-2018 (Tier 2)	2% solar by 2022
Rhode Island	June-04	16% by 2020	
New York	September-04	24% by 2013	Not specific
Colorado	November-04	20% by 2020	4% of RPS to be solar in each year
Pennsylvania	November-04	18% by 2020 (8% Tier 1, 10% Tier 2)	0.5% solar by 2020
DC	April-05	20% by 2020	0.4% from solar by 2020
Montana	April-05	5% in 2008, 10% in 2010, 15% in 2015	
Delaware	July-05	20% by 2019	2.005% photovoltaic by 2019
Arizona	November-06	15% by 2025	30% of RPS from distributed renewables after 2012
Washington	November-06	15% by 2020	
Minnesota	February-07	25% by 2025, Xcel Energy: 30% by 2020	Xcel Energy: 25% of RPS from wind in each year
New Hampshire	May-07	23.8% by 2025	0.3% solar, 6.5% existing biomass, 1 % existing small hydro
Oregon	June-07	25% by 2025	Varies by utility
Illinois	August-07	25% by 2025	75% from wind
North Carolina	August-07	12.5% by 2020	0.2% solar & thermal by 2018, 0.2% swine waste by 2018, 900,000 MWh from poultry waste by 2014
New Mexico	August-07	20% by 2020	4% solar, 4% wind, 2% geothermal & biomass, 0.6% distributed renewables
Michigan	October-08	10% by 2015	Varies by utility
Missouri	November-08	15% by 2021	0.3% solar by 2021
Ohio	January-09	12.5% by 2025	0.5% solar by 2025
Kansas	May-09	20% by 2020	

Source: Database for State Incentives for Renewable Energy (North Carolina Solar Center, 2009)
Notes:
Connecticut Class 1: solar, wind, fuel cell, landfill gas, small hydroelectric, wave, tidal and ocean thermal, sustainable biomass. Connecticut Class 2: trash to energy, biomass not included in Class I. Connecticut Class 3: customer sited cooling-heating-power systems, recent savings from conservation and load management, recycled energy from heat pipes.

Maine Class 1: RPS mandate to provide 30% of sales through renewables. Maine Class 2: portfolio Goal to increase new renewable capacity by 10% by 2017.

Maryland Tier 1: solar, wind, qualifying biomass, landfill gas, geothermal, wave, tidal and ocean thermal, small hydroelectric, fuel cells. Maryland Tier 2: trash to energy, hydroelectric other than pump storage.

Massachusetts Class 1: (in state, on-site) solar, wind, ocean thermal, wave, and tidal, fuel cells, landfill gas, qualifying hydroelectric, qualifying biomass, geothermal. Massachusetts Class 2: (in state, on-site) systems dating prior to Dec 1997 using the same technology as above.

Pennsylvania Class 1: new and existing solar, wind, small hydro, geothermal, biomass, fuel cells, qualifying gas. Pennsylvania Class 2: new and existing waste coal, large hydro, waste to energy, distributed generation, demand side management, certain biomass.

Table 5 State Voluntary Renewables Goals

State	Date Goal Adopted	Current Goal
North Dakota	August-07	10% by 2015
South Dakota	February-08	10% by 2015
Vermont	March-08	20% by 2017
Utah	March-08	20% by 2025
Virginia	July-09	15% by 2025

Source: Database for State Incentives for Renewable Energy (North Carolina Solar Center, 2009) systems as displacing non-renewable generation, and Hawaii, Nevada, and North Carolina have provisions that allow demand side efficiency to be used to meet a part of the RPS requirements (Wiser and Barbose 2008).

The most common mechanism for demonstrating compliance with RPSs is the purchase of "renewable energy certificates" or RECs (Corey and Swezey 2007). Renewable generators sell power at the market price and then also sell, in effect, a 1 MWh REC for each MWh of electricity they have sold. Distribution utilities and others obliged to obtain a minimum percentage of their electricity from NHRs demonstrate compliance by purchasing an appropriate number of RECs and surrendering these to the authorities. The ability to trade RECs assures that costs are minimized within the state, since there are economic incentives to, in effect, produce the certificates using the cheapest available NHR technology. (Though, of course, this regime does not create any incentive to favor technologies with large spillover benefits.) Since the potential for NHR generation differs widely among the states, even in the absence of a nationwide RPS nationwide trading of RECs would potentially be an important way of reducing the cost of meeting the states' goals. Unfortunately, as we have discussed, state RPS programs differ in so many dimensions—including the precise definition of an REC—that interstate trading is virtually impossible. Indeed, some state RPS programs prohibit it altogether.

At the federal level, in 2005 the Senate passed a bill containing a national RPS that would have required 10% of electricity in the country to be generated by renewables by 2020, but the bill died in the House. In 2007 the House passed legislation containing a national RPS of 15% by 2020; this bill died in the Senate. Most recently, the Waxman-Markey bill, passed by the House in June 2009 contains a national RPS with nationally tradable RECs. The bill's standard, which could be met with a combination of energy efficiency savings and NHR generation, would start at 6% in 2012 and rise to 20% by 2020. As this is written, the fate of this provision is yet to be determined.

A majority of state RPS programs have only recently become operational – 10 of them are less than three years old, while 19 are less than five years old. Furthermore, as discussed just below, RPSs are just one of the many state-level policies that have been adopted to promote renewable energy. As a consequence, it is difficult make confident statements about the effectiveness of RPSs in increasing NHR generation, let alone to assess their costs. A significant impact is suggested by the fact that in 2007, states with RPS programs accounted for an overwhelming 86% of new NHR generating capacity, as compared to just 22% of all new generating capacity.[15] In a multivariate statistical analysis, Menz and Vachon (2006) find that RPS programs effectively encourage cumulative renewable energy investment and capacity deployment. However, in a later analysis using additional control variables, including the environmental orientation of each state's legislators and the size of each state's agencies concerned with natural resources, Carley (2009) finds that the adoption of RPS mandates does not effectively increase the share of renewable electric generation. There are at least reasons to be concerned that some of these programs may fail to meet their goals.

3.2 Other State Policies

In addition to RPSs of various shapes and sizes, state governments have adopted a wide variety of other measures aimed at promoting NHR generation. Table 6 provides some information regarding their popularity. As with RPSs, no two state policies for, say, state income tax credits, are identical.

Table 6: Other State Policies to Promote NHR Generation

Type of Incentive	Number of States
Personal Tax: credits or other	21
Corporate Tax: credits or other	23
Sales Tax: exemption or deduction	25
Property Tax: exemption or special assessment	32
Rebates programs	19
Grant programs	22
Subsidized bond or loan programs	34
Production Incentives	9
Public Benefit Funds	18
Net Metering	43

Source: Database for State Incentives for Renewable Energy (North Carolina Solar Center, 2009). The District of Columbia is counted as a state in this table.

The IEA lists the three most important state policies promoting renewables as RPSs, public benefit funds, and tax incentives.[16] Public benefit funds are generally financed by a small surcharge on retail electric rates and are used to support renewable energy in a wide variety of ways. They are projected to total $7.3 billion by 2017 (DSIRE summary map). All states except

[15] Energy Information Administration, *Electric Power Annual 2007*, Data Table EIA-860, http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html.

[16] International Energy Agency, *Deploying Renewables: Principles for Effective Policies* (Paris, France: IEA, 2008), 329

Arkansas offer some subsidy for investment in NHR generation, but the design and impact of tax benefits, rebates, grant, and subsidized bond or loan programs vary enormously.

Beginning with Massachusetts and Wisconsin in 1982, 42 states and the District of Columbia have established net metering policies, and the Energy Policy Act of 2005 requires all utilities to provide net metering to customers that request it. Net metering allows utility customers with some NHR generators, generally only small residential or commercial installations, to sell electricity to the distribution entity that serves them at the retail rate the customer pays for electricity, not the typically much lower wholesale rate the distribution entity pays for other power. In Massachusetts in 2007, for instance, retail rates averaged $ 0.152 per kWh, while the average wholesale price in the New England market was only $0.068 per kWh.[17] A small part of this difference reflects power losses in transmission and distribution, but these losses average only about seven percent of net generation in the US.[18] Most of the wholesale-retail difference arises simply because regulated prices do not reflect incremental costs: retail rates are generally set to recover the fixed costs of distribution systems through a per-kWh charge added to wholesale electricity rates rather than through fixed charges of one sort or another.

While net metering programs are popular in state capitals, they are not yet widely utilized. Only 48,280 utility customers participated in net metering programs in 2007; 95% were residential, and 72% were in California (which established its program in 1995). But participation did grow at a 46% annual rate over the 2004-07 period.[19]

Ten U.S. states Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont – have recently signed the Regional Greenhouse Gas Initiative (RGGI) agreement.[20] The agreement obliges these states to cap their total CO_2 emissions from the electric power sector through 2015 and then reduce them by 10 percent by 2018. Beginning at the start of 2009, electric utilities in these states have had to obtain and surrender allowances equal to their CO_2 emissions. These allowances are mainly

[17] Energy Information Administration, http://www.eia.doe.gov/fuelelectric.html (accessed November 14, 2009) and Federal Energy Regulatory Commission, *Electric Power Markets: National Overview*, http://www.ferc.gov/market-oversight/mkt-electric/new-england.asp#prices (accessed November 14, 2009).
[18] See, for instance, Energy Information Administration, *Electric Power Annual*, http://www.eia.doe.gov/cneaf/electricity/epa/epates2.html (accessed November 14, 2009).
[19] Energy Information Administration, *Renewable Energy Annual 2007* (Washington, DC: EIA, 2008), and Energy Information Administration, *Green Pricing and Net Metering Programs*, 2005 (Washington, DC: EIA, 2007).
[20] A good source of information on this initiative is its website: http://www.rggi.org/home.

auctioned by the governments of the 10 states involved. In principle, this system caps utility CO_2 emissions in the affected region, but allowance prices have so far been quite low: $2 to $3 per ton of CO_2, a fraction of prices in the European Union's Emissions Trading System for CO_2. It thus seems unlikely that this system has so far had much effect on the deployment of non-hydro renewables.

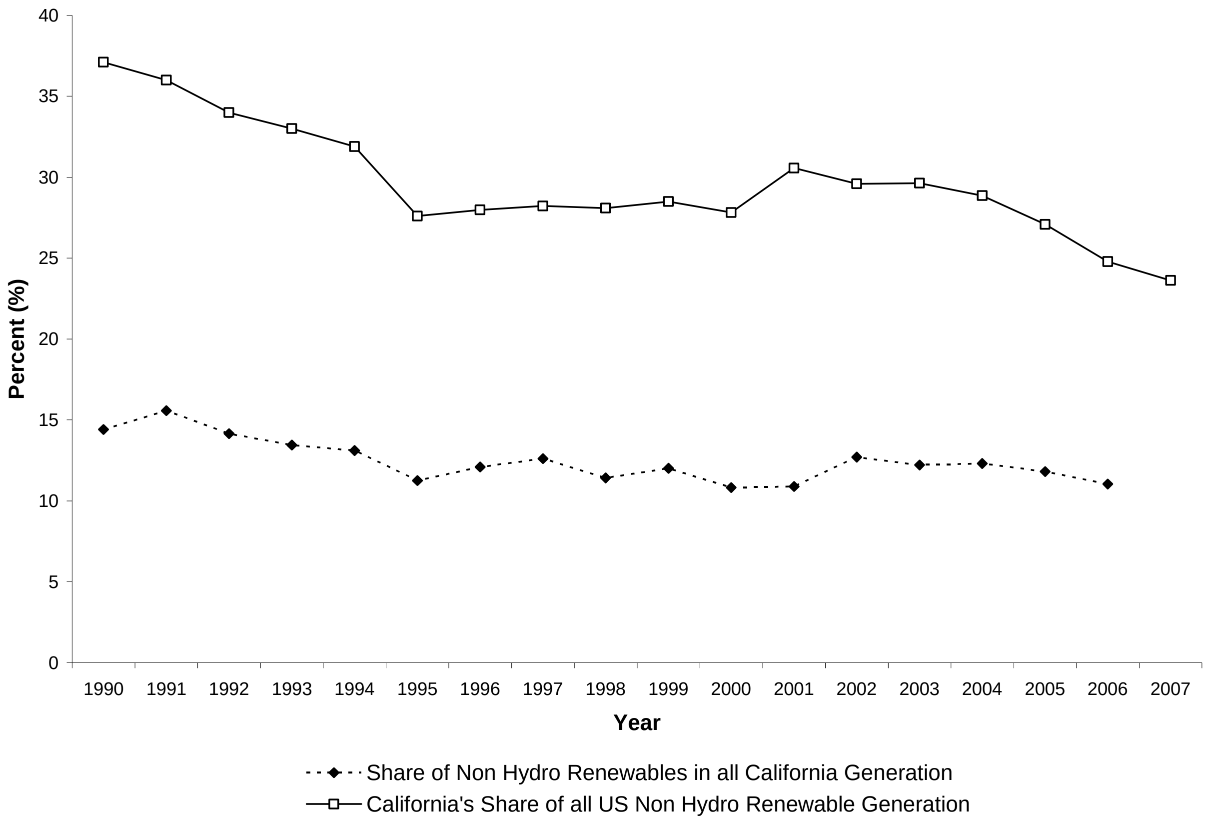
Finally, it is interesting to note the relative unpopularity of production incentives such as feed-in tariffs and output subsidies in the U.S. Perhaps the most important of these in the U.S. is the California feed-in tariff discussed below, but it is available only to small generators.

3.3 California: A Long History of Carrots

California was an important early leader among U.S. states in promoting NHR generation. Despite generating only 5.5% of U.S. electricity in 1990, California accounted for 37% of U.S. NHR generation that year. As Figure 6 shows, however, California's share of NHR generation has declined over time as other states have moved to promote renewables, but in 2007 California still accounted for just under 24% of national NHR generation.

California's early high share of national NHR generation is mainly due to its response to PURPA. In 1983, the California Public Utilities Commission (CPUC) developed policies that guaranteed qualifying facilities generous feed-in rates for a period of ten years. These policies were based on assumptions that oil prices (and therefore avoided costs) would continue to rise from what were then already high levels (Hirsh 1999). The result was a boom in construction of small NHR generators and other qualifying facilities. Even though the CPUC suspended further contracts for power generation in 1985, qualifying facilities that had already contracted with the CPUC were permitted to sell power at high rates. By 1986, California had nearly 90% of *global* wind generating capacity (US Department of Energy 2008, 6). Figure 7 shows that the bulk of the resulting NHR generation was powered by geothermal energy and biomass. It also shows that a number of these facilities shut down when their PURPA contracts expired between 1993 and 1995, though most continued to operate.

Figure 6: Non-Hydro Renewables in California

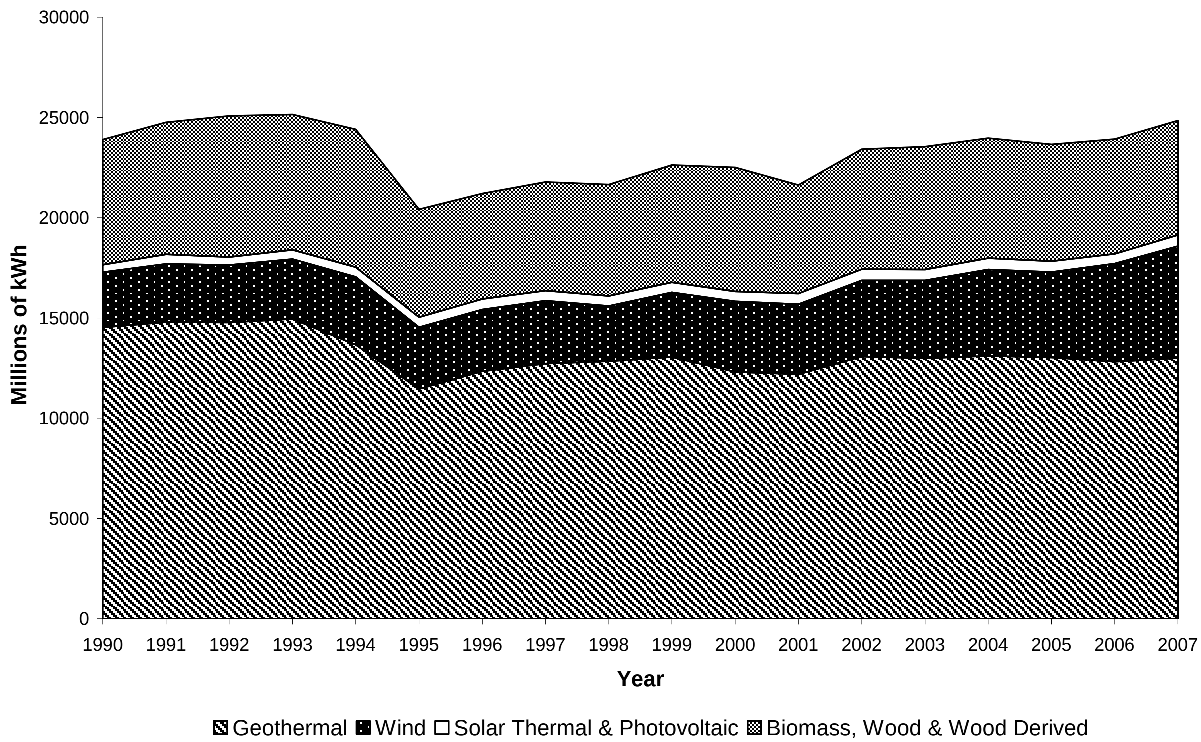


Source: EIA, *Electric Power Annual*, 2007. Data Table EIA-906.

In the ensuing years, California adopted a wide variety of policies to promote solar and other NHR generation, relying more heavily on subsidies of various sorts than on regulation or mandates, but Figures 6 and 7 show that these policies did not produce significant increases in the NHR share of total generation or even the absolute amount of NHR generation.[21] In 1995, for instance, the CPUC proposed an RPS regime to increase renewable generation, but in 1996 the legislature adopted a production-based auction funded by surcharges on electric utility bills instead (Wiser et. al 1996). This program ran from 1998 to 2001, provided between $540 and $640 million in funding each year, and supported 4400 MW of existing renewable capacity and 1600 MW of new renewable capacity (Ritschel and Smestad 2003, Wiser et. al, 1996).[22]

[21] For an interesting discussion, see Margaret Taylor, "Beyond technology-push and demand-pull: Lessons from California's solar policy," *Energy Economics* 30 (2008):2829-54.
[22] The surcharge has been estimated to have added between 2 and 3% to the price of a kWh. The proceeds were aimed at production credits for biomass, wind, solar, geothermal and small hydroelectric facilities.

Figure 7: Electricity Generation by Non-Hydro Renewable Sources: California



Source: EIA, *Electric Power Annual*, 2007. Data Table EIA-906.

Between 1998 and 2007, California's Emerging Renewables Program, funded by the ratepayers of California's four largest investor owned utilities, has funded roughly 130 MW of capacity additions from smaller wind, solar, and fuel cell facilities.[23] The Self Generation Incentive Program (SGIP), funded at roughly $83 million each year, supports customer generated renewable energy via wind, solar, and fuel cell sources. Between 2001 and 2007 the SGIP funded over 300 MW of total capacity additions.[24]

In 2006, California adopted the California Solar Initiative (CSI), a ten-year $3.2 billion program to fund the development of 3000 MW of solar capacity.[25] Part of the CSI is the New

[23] California Energy Commission, "Renewables," *Emerging Renewables Program*, http://www.energy.ca.gov/renewables/emerging_renewables/index.html (accessed July 17, 2009).
[24] Like the Emerging Renewables Program, funding for solar and PV projects for the SGIP was taken over by the California Solar Initiative in 2007.
[25] Database of State Incentives for Renewables and Efficiency, "California – Incentives/Policies for Renewables and Efficiency," *California Solar Initiative*, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA134F&re=1&ee=1 (accessed July 17, 2009).

Solar Homes Partnership, a ten-year $400 million incentive-based program aimed at constructing homes with solar energy systems with a focus on energy efficiency.[26]

Beyond the big-ticket subsidy programs described above, the state of California runs a slew of smaller more localized funding programs for renewable energy development. These include 5 utility specific grant programs, 11 utility specific loan programs, and 94 utility specific rebate programs and other smaller financial incentives. And solar systems are exempted from local property taxes.

In 2002 California followed eight earlier adopters and enacted an RPS. The California RPS requires electric utilities to acquire 20% of their electricity from renewable sources by 2010. More recently, the state has adopted a non-binding goal of 33% by 2020. Of the 7000 MW of contracts for renewable generation signed between 2002 and 2007, 53% is wind, 23% is solar, 12% geothermal, 7% biomass, and less than 1% is small hydro and ocean energy (Wiser and Barbose 2008). It should be clear from the foregoing, however, that the RPS is but one policy in a large set of policies aimed at promoting NHR generation in California.

Finally, in 2008 California established a feed-in-tariff for small renewable energy facilities with capacities of 1.5 MW or less. It has the efficiency-enhancing feature that rates are to vary by time of day. Facilities that sell power under this tariff are not eligible for additional state incentives and programs.[27]

3.4 Texas: RPS-Driven Wind Energy Development

In contrast to California, Texas was slow to embrace NHR generation, and it does not seem to have made much use of explicit subsidies. In 1990 Texas accounted for less than 2% of national NHR generation, even though it generated 9.3% of the nation's electricity. Dramatic changes began to occur in 1999, when Texas adopted an RPS program with binding obligations beginning in 2002 and extending (as amended) to 2015. As Figure 8 shows, the result was extraordinary growth in wind power, dwarfing the California growth shown in Figure 7.

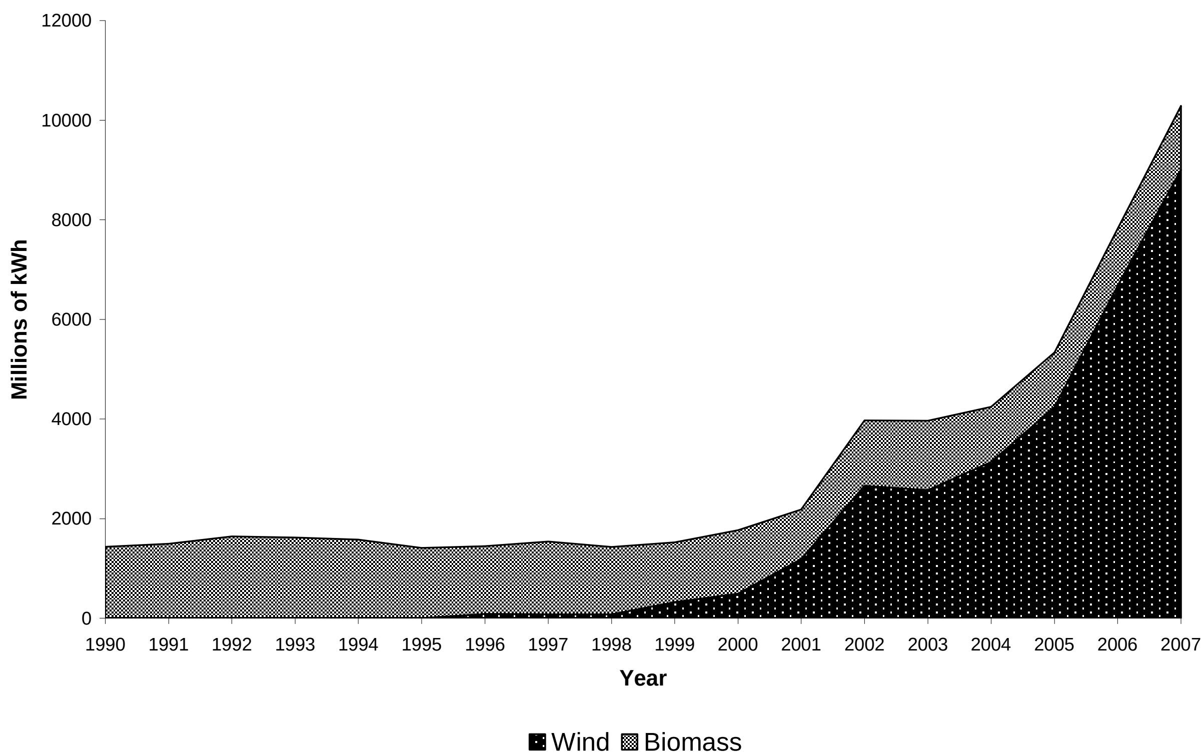
In 2007 Texas accounted for 9.8% of US electricity generation and an identical percentage of NHR generation. And in 2008, Texas accounted for 31% of new U.S. wind

[26] Database of State Incentives for Renewables and Efficiency, "California – Incentives/Policies for Renewables and Efficiency," *New Solar Homes Partnership*, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA150F&state=CA&CurrentPageID=1&RE=1&EE=1

[27] Database of State Incentives for Renewables and Efficiency, "California – Incentives/Policies for Renewables and Efficiency," *California Feed-In Tariff*, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA167F&re=1&ee=1

generation capacity, for more new capacity than any *country* except China and the U.S.[28] Texas currently has about 8,800 MW of wind generating capacity,[29] which is about 12% of total capacity, and is projected to have 18,500 MW of wind generating capacity by 2015.[30]

Figure 8: Electricity Generation by Non-Hydro Renewable Sources: Texas



Source: EIA, *Electric Power Annual*, 2007. Data Table EIA-906.
Note: Solar generated electricity accounted for up to 385,000 kWh of generation in 1990 but that number decreased to zero in 2001.

Observers who have analyzed Texas' RPS attribute its strong impact to several factors. At least initially the system was technology-neutral,[31] so that the most economical resource—wind in this case—could be used most intensively. As discussed in Section 4, Texas, along with a few other states, is blessed with excellent wind resources. This is particularly true of western Texas where wind speeds average 8m/s year-round, and wind power facilities can operate at

[28] American Wind Energy Association, *Annual Wind Industry Report: Year Ending 2008* (AWEA: 2009) http://www.awea.org/publications/reports/AWEA-Annual-Wind-Report-2009.pdf
[29] American Wind Energy Association, http://www.awea.org/newsroom/releases/10-20-09_AWEA_Q3_market_report.html, and http://www.ercot.com/news/press_releases/2009/nr05-29-09
[30] http://www.reuters.com/article/GCA-BusinessofGreen/idUSTRE59701B20091008.
[31] As noted above, Texas has given a premium for non-wind renewable generation since 2005. (DSIRE)

capacity factors of 40% or more (Langniss and Wiser 2003), at the upper end of the 25-40% range commonly cited for wind generators.[32] The remote location of these sites and the lack of transmission infrastructure initially inhibited exploitation of their potential. Subsequent legislation required utilities to upgrade their transmission systems as necessary to meet the state's RPS goals and allowed them to recover the costs in retail rates (DSIRE, Langniss and Wiser 2003). As discussed further below, however, transmission from these sites nonetheless remains a problem.[33]

It is also important that the Texas RPS program applies to most of the state's retail electricity load in a way that permits these remote sites to be fully exploited. While most RPS programs set generation requirements, Texas' RPS sets requirements for capacity and thus for capacity additions year by year. Owners of renewable generating capacity can sell both electricity and renewable energy credits (RECs) to any electricity retailer in the Texas market, and retailers can freely buy, sell, and bank RECs. A capacity conversion factor, now based on performance of renewable generating units in the two prior years, is used to convert capacity requirements into MWh requirements, which are allocated to retailers based on their shares of statewide electricity sales. The relatively large, organized, competitive (Potomac Economics 2009) wholesale power market in Texas has enabled an effective market for RECs.[34]

In addition, the structure of the Texas RPS enables renewable energy suppliers to sign long-term (10-25 year) contracts, which reduces their risk and makes it easier to raise capital, thus lowering costs. Because the law sets annual requirements, each retailer can forecast how many RECs it will need in the future and can thus confidently sign long-term contracts with renewable suppliers.[35]

Finally, the Texas RPS legislation provides strict, automatic penalties for non-compliance, while providing flexibility to electricity retailers through the ability to trade and bank RECs (Langniss and Wiser 2003). The California program, in contrast, seems to rely on

[32] See, e.g., American Wind Energy Association, *Wind Energy Basics*, http://www.awea.org/faq/wwt_basics.html.
[33] Observers have also noted that the use of a zonal pricing system within Texas rather than a nodal pricing system contributed to inefficient use of transmission capacity; see Potomac Economics (2009).
[34] Connecticut is one example of a state where the RPS applies to such a small section of the electricity market so as to be rendered marginal (Langniss and Wiser 2003).
[35] In contrast, in some states there is considerable uncertainty around the size and scope of the RPS as well as its end date. For instance, in Maine the RPS is slated to be reviewed every five years and in Connecticut and Massachusetts the end date of the RPS is unclear.

the general enforcement powers of the Public Utility Commission, and its discretion, to deal with any instance of non-compliance.

4. Wind Power in the United States

According to the IEA (Deploying Renewables, pp. 65-66), the potential for wind-powered electricity generation in the U.S. substantially exceeds that in any other OECD nation, as well in Brazil, Russia, India, and China. In 2008, the U.S. Department of Energy published a detailed analysis of a scenario under which wind would account for 20% of U.S. electricity generation by 2030 (U.S. Department of Energy 2008). And, as noted in Section 1, wind-powered generation grew at a 15.9% average annual rate during 1990-2007 and accounted for the bulk of NHR growth over that period. That growth has not been geographically uniform, however. And, because wind, like solar but unlike some other NHR technologies, is intermittent, that growth is raising new issues of power system design and operation.[36]

According to the American Wind Energy Association (AWEA), twelve states in the so-called wind belt, stretching northward from Texas to the Canadian border, have 93% of the wind energy potential in the U.S.[37] These states are listed in Table 7. The Table also provides information on three states on the Pacific coast that have substantial wind generation despite having considerably less potential than the wind-belt states. Together, the 15 states listed in Table 7 accounted for 30% of all U.S. electricity generation in 2007 and 92% of wind-powered generation. Table 7 also shows when the states that have RPSs initially enacted them.

Table 7: Leading Wind Generation States

		2007 Wind Generation			
State/Region	Estimated Wind Potential	TWh	% of Estd. Potential	% of Total Generation	Initial RPS Year
North Dakota	1210	0.62	0.05	1.99	
Texas	1190	9.01	0.76	2.22	1999
Kansas	1070	1.15	0.11	2.30	2009
South Dakota	1030	0.15	0.01	2.44	
Montana	1020	0.50	0.05	1.71	2005
Nebraska	868	0.22	0.03	0.67	

[36] These issues have also been encountered in other countries with high level of wind penetration. For an interesting discussion of the experience in four such countries, see Ackerman et al (2009).

[37] American Wind Energy Association, *Top 20 States with Wind Energy Resource Potential*, http://www.awea.org/newsroom/pdf/Top_20_States_with_Wind_Energy_Potential.pdf. The AWEA's total estimated U.S. potential is 36 times the IEA estimate, indicating the former includes sites not deemed economic by 2020 by the latter. We use the AWEA numbers here on the assumption that they are correlated with potentials that would be estimated using the IEA's assumptions and methods.

Wyoming	747	0.76	0.10	1.65	
Oklahoma	725	1.85	0.26	2.54	
Minnesota	657	2.64	0.40	4.84	2007
Iowa	551	2.76	0.50	5.65	1983
Colorado	481	1.29	0.27	2.40	2004
New Mexico	435	1.39	0.32	3.87	2007
Wind Belt	9984	22.33	0.22	2.58	
California	59	5.59	9.47	2.65	2002
Oregon	49	2.44	2.56	2.28	2006
Washington	37	1.25	6.52	2.26	2007
Pacific	161	9.27	6.39	2.49	
Wind Belt + Pacific	10129	31.60	0.31	2.55	
Rest of US	648	2.85	0.44	0.10	

Sources: Estimated potentials are from the American Wind Energy Association: http://www.awea.org/newsroom/pdf/Top _20_States_with_Wind_Energy_Resource_Potential.pdf and , for Washington and Oregon, telephonic communication. Generation data are from EIA, *State Renewable Electricity 2007*, and RPS dates are from Table 4

Table 7 reveals a number of interesting patterns. First, all these states look very different from the rest of the country in terms of their potential for and use of wind generation. Second, Texas and California stand out in terms of total wind generation: together they accounted for just over a third of the U.S. total. Third, there is enormous variation in the extent to which the potential for wind generation is exploited, with the three Pacific coast states generating much larger percentages of their estimated potentials than any of the wind-belt states. In the case of California this is clearly attributable to very generous early subsidies for renewable generation. Oregon and Washington are also notoriously "green" states, but they were not early adopters of RPSs, nor do they have subsidy programs with California-like levels of generosity. Part of the reason for their relatively intensive exploitation of their wind potential may be that California utilities have taken advantage of their ability to meet their RPS obligations by purchasing NHR power generated elsewhere.

Within this group of states there is also substantial variation in the share of total generation accounted for by wind. Here, though, neither Texas nor the Pacific states are outliers. On the high side, Iowa and Minnesota are the most reliant on wind generation. Iowa was an early RPS adopter, but Minnesota was not. On the low side, both in terms of reliance on wind generation and exploitation of wind potential, Nebraska, Wyoming, Montana, and North Dakota stand out. Among these four, only Montana had an RPS in 2007. Perhaps more importantly, all are relatively small in terms of population and total electricity generation, and all are distant from major population centers, so that the wind integration problems discussed below are unusually difficult. More generally, the wind belt suffers from the fact that only seven percent of the U.S. population lives in the top ten states for wind potential (NERC 2009).

As mentioned earlier, the rapid growth and significant penetration of wind power is raising important issues in power system design and implementation. Wind power is intermittent, meaning both that the output of wind-powered generators is *variable* over time and that it is *uncertain* – it cannot be perfectly forecast. The output of hydroelectric facilities is also variable and uncertain because rainfall cannot be perfectly forecast, but these features manifest themselves over time-scales of months or years. The output of wind facilities is variable and uncertain over time-scales of hours; the output of solar facilities can vary from minute to minute as clouds pass by overhead. Since residential, commercial, and industrial demands also vary over these time-scales, at small levels of penetration wind power poses no new issues. At large scales, however, an influential industry group has concluded that "reliably integrating high levels of variable resources [including wind and solar] into the North American bulk power system will require significant changes to traditional methods used for system planning and operations" (NERC 2009).[38]

Perhaps the most talked-about manifestation of the variability of wind power took place in Texas on February 26, 2008.[39] As the evening electricity load was increasing, wind generation dropped from over 1700 MW to 300 MW in a three-hour period because wind speeds decreased. This was roughly equivalent in magnitude to a single large fossil generating unit going offline – not a rare event – and it happened gradually. (Moreover, commercial forecasts, not available to the grid operators, had predicted the fall in wind speeds.) This emergency, which was exacerbated by the unforeseen unavailability of some fossil-fired capacity, was mainly handled by curtailing service to large industrial and commercial users who had contracted for interruptible power, reducing system loads by 1100 MW within a 10-minute period. While wind only provides a few percent of generation in Texas on average, winds in west Texas generally blow the strongest at night, when demand is low. As a result, wind can provide more

[38] For an illuminating recent discussion of wind integration issues, see Grant et al (2009) and Milligan et al (2009).
[39] This paragraph is mainly based on Electricity Reliability Council of Texas, "Press Release, "*ERCOT Demand Response Program Helps Restore Frequency Following Tuesday Evening Grid Event*, http://www.ercot.com/news/press_releases/2008/nr02-27-08 and Kate Galbraith, "Texas Adjusts its Grid For Wind," *New York* Times, November 13, 2008, Energy & Environment, Green Inc., http://greeninc.blogs.nytimes.com/2008/11/13/texas-adjusts-its-grid-for-wind/, and Grant et al (2009, pp. 51-52).

than 10% of power in Texas on some occasions, making its variability a potentially more serious issue. In the fall of 2008 the operators of the Texas grid increased backup power requirements, particularly at night.

With wind generation in Texas expected to more than double by 2015, wind's variability is projected to be a more serious concern going forward, and more flexible gas-fired capacity will likely be needed. Since power prices tend to be low at night, however, and the gas-fired units used to provide backup power tend to have high marginal costs, some observers worry that the Texas market may not provide sufficient backup capacity.[40]

Similar issues have confronted the Bonneville Power Administration (BPA), which operates the grid in the Pacific Northwest with about 41,000 MW of peak generating capacity.[41] During one 24-hour period in December, 2008, BPA received near-zero levels of wind generation early and late in the day, punctuated by nearly 1,600 MW around mid-day. Between January 5 and January 14, 2009, wind output varied from 500 MW to 1500 MW – followed by two weeks of zero output.[42] In part this high degree of variability has arisen because most of the relevant capacity is geographically concentrated along the Washington-Oregon border – just as much of Texas's wind generation capacity is concentrated in west Texas – and thus wind conditions are highly correlated within the generating fleet.

As wind power becomes more important, it will become more important to enhance the flexibility of the overall electric power system (IEA Empowering Variable Renewables 2008, NERC 2009, Grant et al 2009, Milligan et al 2009). The basic methods for doing this are well-known. One can, in principle, increase demand responsiveness to supply conditions and go well beyond what was possible in the Texas emergency discussed above. A variety of institutional, regulatory, and technological barriers make this far from straightforward, however. On the supply side, one can add generating units that can increase or decrease output rapidly (mainly gas-fired under current technology) or add grid-level storage (generally too expensive with

[40] See http://www.reuters.com/article/GCA-BusinessofGreen/idUSTRE59701B20091008 and J. Bushnell, "Building Blocks: Investment in Renewable and Non-Renewable Technologies," in this volume. A similar problem has recently been analyzed quantitatively in the German context; see Thure Traber and Claudia Kemfert, "Gone with the Wind? Electricity Market Prices and Incentives to Invest in Thermal Power Plants under Increasing Wind Energy Supply" (DIW Berlin Discussion Paper No. 852, January 2009), http://ssrn.com/abstract=1430905.

[41] This paragraph is based on Bobette Riner, "BPA Struggling with Vagaries of Wind Power," *Natural Gas Week*, July 29, 2009, 8.

[42] For an interesting discussion and graphical depiction of wind variability, see http://www.nerc.com/docs/pc/riccitf/BPA_supports_wind_power_for_the_Pacific_Northwest_Mar_2009.pdf

current technology). Alternatively, one can use transmission and operational integration to create large power systems, taking advantage of the fact that "the correlation between production from multiple wind plants diminishes as those plants are geographically farther apart" (Kirby and Milligan, 2008, p. 3). It is often difficult to get permission to build transmission capacity in this country, however, and geographic averaging is inherently expensive in areas that are thinly populated and distant from major load centers, like many of the states in the wind belt.

In addition, some utilities (and their regulators) have been reluctant for a variety of reasons to join the large integrated regional systems operated by regional transmission operators (RTOs) and Independent System Operators (ISOs) that currently meet about two-thirds of U.S. electricity demand.[43] The open, flexible wholesale electricity markets operated in those systems help to economically and reliability integrate wind generation (Kirby and Milligan 2008). In light of these advantages it is not surprising that as of the end of 2007 74% of U.S. installed wind generating capacity was located in ISO and RTO regions, even though those areas had only 44% of the nation's wind energy potential (Kirby and Milligan 2008). Nor is it surprising that Minnesota and Iowa, which have the highest levels of wind energy penetration (see Table 7) and do not appear to have experienced serious operational problems, are part of the Midwest ISO. So is North Dakota, but it has not actively promoted renewables generation, and it is distant from the major load centers in the Midwest ISO. On the other hand, Nebraska and Wyoming, which make conspicuously little use of their abundant wind resources, are not in an organized regional market, and neither is most of Montana.

Finally, a number of observers have commented on the fact that spot electricity prices in west Texas are often negative, particularly at night when the wind is strongest and demand is lowest.[44] This generally happens when the power lines connecting the wind generators in the west to the major load centers elsewhere in the state are operating at capacity, and spot prices in the rest of the state are positive. Negative prices would, of course, induce conventional thermal generating units to shut down, unless the energy cost of ramping up when demand rises would exceed the costs of paying the grid operator to take power. Wind units do not generally incur ramp-up costs, and when there is an excess of power it would commonly be more efficient for

[43] IRC, ISO/RTO Council, *Progress of Organized Wholesale Electricity Markets in North America: A Summary of 2006 Market data from 10 ISO's & RTO's*, (IRC, 2007), http://www.isorto.org/atf/cf/{5B4E85C6-7EAC-40A0-8DC3-003829518EBD}/IRC_State_of_the_Markets_Report_103007.pdf

[44] This paragraph is based on Wang (2008) and Lively (2009); see also Lawhorn et al (2009, pp. 86-87).

wind units to cease production rather than for, say, a baseload coal plant with significant ramp-up costs to do so. (There are currently no costs of CO_2 emissions to factor into this comparison in most of the U.S.) But if a wind-powered generator remains in operation it earns both the federal REPTC of 2.1¢/kWh and the value of the RECs to which its output entitles it. In Texas, it is apparently a better deal for wind generators to pay the grid operator 4¢/kWh to take their output rather than to shut down. In the case of Texas, adding transmission capacity seems the best way to deal with this problem, and Texas plans to add more than 2,300 miles of new transmission capacity by 2015, about a 6% increase.[45] More generally, output subsidies and feed-in tariffs can be expected to raise operating issues of this sort from time to time.

5. Concluding Observations

Though it is far from certain as this is written that the U.S. will soon adopt a cap-and-trade system to limit CO_2 emissions from the combustion of fossil fuels, there seems a fair chance that it will do so within, say, the next decade. Whether or not this happens, and even though supporting the deployment of NHR generation would make little economic sense if a CO_2 cap were in place, it seems close to certain that, as in Europe, U.S. governments will nonetheless continue to support both the development and the deployment of NHR technologies. And, absent a dramatic change in the nature of support policies, it also seems close to certain that wind will account for the dominant share of new NHR generating capacity in the U.S. for some years to come.

As this chapter's bibliography indicates, much attention is currently being paid, in the U.S. and abroad, to the challenges posed by large-scale integration of wind and other intermittent generation technologies. But almost no attention seems to be being paid to increasing the economic efficiency of state and federal policies that subsidize development and deployment of NHR technologies. Among the issues raised by the current U.S. regime and discussed above that would seem to deserve serious thought are the following:

- Federal R&D support has tended to favor relatively mature fossil and nuclear technologies, and support for NHR technologies has been far from steady over time.

[45] http://www.reuters.com/article/GCA-BusinessofGreen/idUSTRE59701B20091008 and http://www.ercot.com/content/news/presentations/2009/ERCOT_Quick_Facts_February_2009.pdf.

- Channeling federal support for NHR deployment primarily through the corporate income tax disadvantages small firms without substantial income streams and complicates project financing generally.
- The variability of federal subsidy programs over time discourages investments in long-lived tangible and intangible capacity by producers of NHR generating equipment.
- Subsidies tied to the level of initial investment provide weak incentives for cost-containment or for efficient and reliable operations.
- When transmission capacity is inadequate, output subsidies (and feed-in tariffs) can create perverse incentives to generate power when it is not needed.
- The variation in state-level renewables portfolio standards almost entirely prevents inter-state trading that would lower total national costs of meeting state-specific targets.
- Though states have adopted a variety of different RPS designs, there has been little systematic analysis of the performance implications of these design differences.
- Federal policy toward the electric power sector has ignored the evidence that organized ISO/RTO wholesale power markets facilitate deployment of NHR generation.
- The myriad state and federal (and other) NHR programs and policies confront a would-be NHR generator with unproductive complexity.

I do not expect the last of these issues to go away, since complete pre-emption of state and local authority in this area is hard to imagine. Nor do I think the ideal way forward would be simply to adopt some other nation's policy regime. Other chapters in this volume make it clear that no perfect solution to the problem of efficiently subsidizing NHR deployment has yet been implemented. But, as in other areas of public policy, I believe careful economic analysis could at least increase the returns from investments in deployment subsidies.

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