BASE-POWER ALTERNATIVES TO REPLACE BASE-LOADED COAL PLANTS, by Willem Post; 27 December, 2010
http://www.coalitionforenergysolutions.org/

INTRODUCTION

The purpose of this study is create “ballpark” estimates of the capital costs of deploying three base-power alternatives to replace East Coast base-power coal plants and to compare these alternatives regarding capital cost and the quantity and cost of CO2 reduction. The three alternatives considered are Gas, Wind and Nuclear.

The below table shows GDP and emissions for several major industrialized economies; China’s lbs of CO2/$ of GDP is high because its currency undervalues its GDP in dollars. Its purchasing power parity GDP is about $6,122 billion dollars.

	GDP, $billions	CO2 Emissions, billion metric tons/yr	lbs CO2/$ of GDP
China	2,658	6.54	5.06
US	13,178	5.84	0.96
Japan	4,363	1.25	0.65
Germany	2,914	0.79	0.61
France	2,271	0.37	0.37

http://en.wikipedia.org/wiki/List_of_countries_by_ratio_of_GDP_to_carbon_dioxide_emissions
http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions

US 2009 power production: 3,957 TWh; coal 44.9%, gas 23.4%, nuclear 20.2%, hydro 7%, wind 1.8%, biomass 1.35%, oil 1%,, geo 0.37%, solar 0.07%
France 2009 power production: 486 TWh; nuclear 75%, hydro 12%, fossil 11%, wind 1.5%, other renewables (mainly biomass) 0.8%.

At the end of 2009, the US had about:

310,000 MW of coal plants which produced 1,774 TWh and emitted about 1.61 billion metric tons of CO2.
440,000 MW of gas plants which produced 926.4 TWh and emitted about 0.43 billion metric tons of CO2.
101,000 MW of nuclear plants which produced 799 TWh
35,159 MW of wind farms which produced 70.8 TWh

Because of new drilling techniques, the US is able to extract vast quantities of gas from shale formations. As a result, the US is estimated to have about a 100-year supply of gas at current consumption rates. The plentiful gas supply has kept gas prices around $4/million Btu; future oil prices will be lower than they would be without the plentiful gas.

The percentage of power production from gas has been rising for more than 25 years. Utilities have moved away from adding new coal plants to adding new gas plants which have low capital costs per MW, are quick to build (less financing cost), have low owning and operating costs, require minimal air quality control systems and have emissions of less than 1.0 lb of CO2 per kWh vs about 2.25 lb of CO2 per kWh from older base-loaded coal plants. The low price of gas is a boon for these utilities. It confirms their decision.

The utility build-out of gas capacity largely is economics driven. The recent build-out of wind capacity is largely legislative mandate-driven and subsidy-driven.

The federal subsidies for renewables move power production into uneconomical directions which will increase electricity prices and divert scarce resources from more productive uses. This will adversely impact US competitiveness and standard of living at exactly the time it needs to become more competitive to reduce its trade and budget deficits and to create the savings to invest in restructuring its economy.

Reference: The Eastern Wind Integration and Transmission Study

EWITS considers four scenarios, three are for 20% wind penetration, Scenario 4 is for 30% penetration of the US portion of the Eastern Interconnect by 2024. Scenario 4 assumes all wind power will be from the Great Plains, East Coast land-based, and East Coast offshore wind farms, a total of 258,608 MW land-based (103,443 units @ 2.5 MW), plus 79,100 MW offshore (21,972 units @ 3.6 MW) equaling 337,708 MW (125,415 units). Scenario 4 wind power production is 337,708 MW x 8,760 hr/yr x average capacity factor 0.377 = 1,116 TWh in 2024. See EWITS pg. 79.

The Great Plains, East Coast and offshore wind farms would all be connected to three new grid “overlays” to minimize power variation. The power from the Great Plains grid overlay would be transmitted to the East Coast grid overlay via several HVDC lines. The power from the offshore grid overlay would be transmitted to the East Coast grid overlay via several HV lines.

By interconnecting all the wind farms the resulting geographical area would cover at least two moderate-size weather systems and the variability of the wind power would be reduced. The long string of offshore wind farms, about 1,000 miles from North Carolina to Massachusetts, would by itself cover at least two moderate-size weather systems. The thinking is the wind strength will vary on the Great Plains, on the East Coast and offshore, but the wind will blow somewhere.

EWITS estimates minimum wind power, on rare occasions, may be as low as 20% of installed capacity. Average wind power is at 37.7% of installed capacity. Peak wind power, on rare occasions, may be as high as 50% of installed capacity, as sometimes happens in Spain.

Weather extremes, such as snow, rain and ice storms, hurricanes and tornadoes may require the idling of many wind farms thereby increasing power variability on the overlay grids to unacceptable levels. This means an adequate percentage of wind power capacity must be available from other sources, likely CO_2 producing, to avoid brownouts or blackouts.

Scenario 4 capital cost of the new overlay systems and the modifications to the existing East Coast grids is estimated at $92.5 billion from the present to 2024. See EWITS pg. 39.

Scenario 4 reserve requirements would need to increase from 4,022 MW (Base Case) to 22,134 MW to integrate the wind power.

For example: If Scenario 4 (30% wind) of the EWITS study were applied to the ISO-NE grid conditions during 2006, CO_2 producing spinning reserves would have to increase from 202 MW to 1,789 MW. Other grids of the Eastern Interconnect would have similar increases. See EWITS pgs. 40 and 42.

Note: The New England Wind Integration Study, NEWIS, estimates ISO-NE total reserve requirements, TOR, of 2,250 MW at no wind; 2,270 MW at 2.5%; 2,600 MW at 14%; 2,780 MW at 20% and about 3,100 MW at 30% wind.

EWITS did not state that It would take 125,415 /(250 days/yr x 6/day) = 84 yrs to produce the wind turbines at current GE and Vestas production rates of 3 units each per day. The entire GE and Vestas production would need to be dedicated to the US Eastern Interconnect AND production rates would need to increase 6 times over a 14-year period to provide the 125,415 wind turbines by 2024.

EWITS did not provide a time schedule of major activities to implement the wind turbines and transmission systems by 2024.

EWITS did not provide a time schedule of capital expenditures to implement the project which impacts the methods and costs of long-term financing.

http://www.esrl.noaa.gov/research/events/seas/Sep2010/Corbus_NOAA.pdf
http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=16093
http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf
http://www.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/mtrls/2010/nov162010/newis_iso_summary.pdf
http://theenergycollective.com/willem-post/46977/impacts-variable-intermittent-power-grids

Study Methodology and Assumptions

For this study each of the three alternatives is assumed to generate 1,000 TWh/yr which will yield sufficient data for comparisons.

All alternatives are assumed to be implemented overnight to simplify the analysis and to avoid the complexities of financing.

The 1,000 TWh/yr is based on EWITS Scenario 4 that provides 30% of the US share of the Eastern Interconnect as wind power by 2024. This wind power would have been 944 TWh in 2006 and is estimated to be 1,116 TWh in 2024. See EWITS pgs. 46, 66 and 72

CCGT plant data:

Efficiency is assumed at 60% (Lower Heating Value), or about 54% (Higher Heating Value)
Capacity factor, CF, is assumed at 0.85
Capital costs are assumed at $1,250/kW
Heat rate = (3,413 Btu/kWh)/efficiency 0.60 = 5,688 Btu/kWh
CO_2 emissions/kWh = 117 lb of CO_2/(million Btu x 1kWh/5,688 Btu) = 0.67 lb of CO_2/kWh

In western Maine, an area with good winds, are located nine wind farms on ridge lines. Their average capital cost is about $2,500. The average CF of the five operating wind farms and the four under-construction wind farms is about 0.32. It is likely other East Coast ridge line wind farms in good wind locations will have similar CFs.

In the Great Plains, wind farms with good winds, such as in Kansas, have CFs of about 0.40. Offshore wind farms with good winds, such as in Nantucket Sound, have CFs of about 0.39.

For this study the wind CF is assumed at 0.377 = 1,116 TWh/(8,760 hr/yr x 337,708 MW), as calculated from EWITS pg. 79.

For this study wind capital costs is assumed at $2,500/kW for Great Plains and East Coast land-based wind farms, and $3,921/kW for East Coast offshore wind farms. See pg. 110 of NREL website.

Nuclear CF is assumed at 0.90
Nuclear capital costs are assumed at $7,000/kW

http://www.coalitionforenergysolutions.org/maine_wind_farms.pdf
http://www.nrel.gov/docs/fy10osti/40745.pdf
http://www.etsap.org/E-techDS/EB/EB_E02_Gas_fired%20power_gs-gct.pdf

STUDY SUMMARY

Replacing most of the older coal plants with a mix of base-loaded gas, wind and nuclear plants would significantly reduce CO_2 emissions and other pollutants.

The below table indicates a combination of gas and nuclear plants would have the lowest capital cost, would remove up to 0.90 billion metric tons of CO_2/yr and would reduce CO_2 emissions at the lowest cost per metric ton of CO_2/yr.

Wind plants should be built at only the locations with the most favorable conditions, i.e., excellent winds and relatively close to population centers, to maximize their economics. If wind farms are built in marginal locations because of subsidies and legislative mandates, their owners will likely press legislatures for long-term or permanent subsidies; an undesirable policy outcome.

	New Capacity(1)	Capital Cost (2) $trillion	CO2 Emissions Reduction (3) billion metric tons/yr	(2)/(3) $/metric ton of CO2/yr	Plant Life Years
Case -1	134,300 MW CCGT	0.22	0.64	344	30-35
Case -2	302,610 MW Wind	0.95+	1.029	923	20-25
Case -3	126,840 MW Nuclear	0.89	1.036	859	50-60

+ Annual cost of wind power regulation is $4.54 billion/yr. Annual cost of wind power O&M is $2.58 billion/yr.

After about 30-35 years, Case-1 will require a major investment for new gas turbines to about equal the life of Case-3.
After about 20-25 years, Case-2 will require a major investment for new wind turbines to about equal the life of Case-3.

A levelized cost of energy, LCOE, analysis is required to determine the most economical alternative. The LCOE, $/kWh, for an alternative is the total costs over the life of the project, such as capital investment and the costs of capital, O&M, power regulation, fuel, etc., divided by the total power production over the life of the project. Such analyses have shown offshore wind is about twice as expensive as land-based wind, which currently costs about 5-8 c/kWh in very good wind areas, such as Kansas where capacity factors are about 0.40, or greater. See pgs. 115 - 118 of NREL website.

STUDY ANALYSIS

Base-Loaded Natural Gas Replacing Base-Loaded Coal is Better

Natural gas from a well is a mixture of CH_4 and CO_2. The CO_2 is removed and released to the atmosphere.
For comparison: Land fill gas may be 50% CH_4 and 50% CO_2.

The production, processing, transmission and storage, and distribution of natural gas creates CH_4 (leakage) and CO_2 emissions (processing).

Natural gas industry emissions in 2006, million metric tons of CO_2 equiv: CH_4 261.00 CO_2 28.50
Petroleum industry emissions in 2006, million metric tons of CO_2 equiv: CH_4 27.74 CO_2 0.29

The US EPA calculates conversion factors at standard temperature (32F) and pressure (14.7 psia).
Per EPA, combustion of 1,000 standard cf of CH_4 yields 122 lb of CO_2.
The US petroleum industry calculates conversion factors at 60F and 14.7 psia.
Per US petroleum industry, combustion of 1,000 UPI cf of CH_4 yields 115 lb of CO_2
Adjustment factor is 115/122 = 0.9426

Natural gas industry leakage rate of CH_4 in 2006 was about {261 MMT CO2e/(Adjustment factor 0.9426 x 0.4045 MMT CO2e/bcf)}/19,410 bcf production in 2006 = 3.52%
Value of leakage in 2006 was about 3.52% x 19,410 bcf x $4.00/million Btu = $2.74 billion.

$CH_4 + 2 O_2 \rightarrow CO_2 + 2 H_2O$; as a green house gas CH_4 is about 21 times more potent than CO_2.
16 lb + 64 lb --> 44 lb + 36 lb; 1 lb of CH_4 becomes 44/16 = 2.75 lb of CO_2.
It is 21/2.75 = 7.64 times worse for CH_4 to be leaked than combusted.

Additional CO_2 equivalent emissions due to CH_4 leakage and processing is {(261 + 28.5)/261)} x 3.52% x 7.64 = 29.8%

The emissions of mining, transporting, storing and pulverizing of coal is about (1,700 grams of CH_4/MWh)/(454 gr/lb) = 3.75 lbs of CH_4/MWh, almost all of it during mining, which is equivalent to 7.64 x 3.75 = 28.65 lbs of CO_2e/MWh.
For comparison: combustion of coal yields about 2,250 lbs of CO_2/MWh.

Additional CO_2 equivalent emissions due to CH_4 and CO_2 leakage is (2,250 + 28.65)/2,250 = 1.27%

Base-loaded coal plants emit about 2.25 lb of CO_2/kWh, higher than any other power source. Older coal plants, with lower efficiencies and higher emissions than newer coal plants, will likely be replaced with new CCGT plants.

High efficiency, base-loaded CCGT plants have:
- low capital costs, short construction times (less interest during construction, earlier revenue streams).
- much less visible impact than 20-30% wind penetration scenarios that require highly visible and costly grid overlay systems.
- reduce CO_2 emissions quicker (a global warming plus), albeit by not as much as wind and nuclear which would take much longer to implement.

Coal plant boilers have solid waste emissions of bottom ash and gaseous emissions that contain SOx, NOX and flyash. The bottom ash and flyash emissions are toxic and contain heavy metals and radioactive compounds. The radioactive flyash emissions are spread over large areas and harm the fauna and flora. In just the US, these emissions cause various diseases in millions of people and 20,000 to 25,000 deaths each year.

The 50-60 year life cycle radioactivity emitted by a coal plant is many orders of magnitude greater than by a similar size nuclear plant.

For comparison: One aboveground, medium-size, nuclear bomb test released more radioactivity than the combined emissions of all nuclear plants, including Three Mile Island, during the past 50 years. There have been about 2,000 aboveground nuclear tests. The radioactive fallout was spread over large areas and harmed the fauna and flora. This fallout causes diseases in people and deaths each year.

http://www.epa.gov/climatechange/emissions/downloads10/Subpart-W_TSD.pdf
http://theenergycollective.com/david-lewis/48209/epa-confirms-high-natural-gas-leakage-rates#comments?utm_source=tec_newsletter&utm_medium=email&utm_campaign=newsletter
http://www.eia.gov/dnav/ng/hist/n9050us2a.htm
http://efile.mpsc.state.mi.us/efile/docs/15996/0186.pdf
http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html
http://www.scribd.com/doc/1822123/Environmental-Protection-Agency-unitconverter-final
http://www.carboncompany.com/statistics.htm
http://www.epa.gov/cmop/resources/converter.html
http://www.johnstonarchive.net/nuclear/atest00.html

The following three cases are analyzed regarding capital costs and the quantity and cost of CO_2 reduction.

CASE-1: NEW BASE-LOADED CCGT PLANTS TO REPLACE BASE-LOADED COAL PLANTS

The latest gas-fired CCGT generator sets have capacities up to about 570 MW (Siemens) and electrical efficiencies up to about 60%, produce steady, 24/7/365, low-cost power, and emit about 0.67 lb of CO_2 per kWh, or 0.67 billion lb of CO_2 per TWh. CCGT plants can have overall efficiencies up to about 85%, if combined with district heating and cooling, as is widely practiced in Europe and Japan.

Adding gas-fired CCGT capacity will require upgrading and expansion of the existing gas distribution systems. For this study the capital cost of the upgrading and expansion is assumed at $50 billion, about half of the capital costs of the transmission systems of Case 2.

- The new CCGT plants would be mostly located at existing coal plant sites.
- Relative to Case-2, minor transmission system changes would be required.
- Visuals of existing coal power plants would be improved, as unsightly coal plants are replaced by new CCGT plants.
- Regulatory issues will be minimal, as pollution and CO_2 from gas plants is much less than from the retired coal plants.

Calculations

Production: 134,300 MW x 1 TW/1,000,000 MW x 8,760 hr/yr x capacity factor 0.85 = 1,000 TWh/yr

Capital cost: 134,300 MW x $1,250,000/MW = $0.17 trillion
Capital cost of gas distribution system: $50 billion
Total capital cost: 0.17 + 0.05 = $0.22 trillion

CO_2 Emissions: 1.298 CH_4 leakage factor x 0.67 billion lb of CO_2/TWh x 1,000 TWh/yr = 870 billion lb of CO_2/yr, or 0.395 billion metric tons of CO_2/yr

The US has about 310,000 MW of coal plants. They are about 30% efficient, emit pollutants and CO_2.
Production in 2009: 310,000 MW x 8,760 hr/yr x CF 0.653 = 1,774 TWh
CO_2 emissions in 2009: 1.0127 CH_4 leakage factor x 2.25 billion lb of CO_2/TWh x 1,774 TWh/yr = 4,042 billion lb of CO_2 in 2009, or 1.837 billion metric tons of CO_2/yr

The new CCGT plants would enable retiring 1,000/1,774 x 310,000 MW = 174,700 MW of coal plants.
CO_2 emissions of 174,700 MW of coal plants: 1,000/1,774 x 4,042 billion lb of CO_2/yr/(2,200 lb/metric ton) = 1.036 billion metric tons of CO_2/yr.

Net CO_2 emissions reduction: (1.036 - 0.395) = 0.64 billion metric tons of CO_2/yr, would require a capital cost of $0.22 trillion, or 220/.64 = $344/(metric ton of CO_2/yr)

http://www.powergenworldwide.com/index/display/articledisplay/6029920807/articles/power-engineering-international/volume-18/Issue_3/features/CCGT_Breaking_the_60_per_cent_efficiency_barrier.html
http://www.jcmiras.net/surge/p130.htm
http://www.coalitionforenergysolutions.org/power_capacity_and_producti.pdf
http://www.eeb.cornell.edu/howarth/GHG%20emissions%20from%20Marcellus%20--%20November%202010.pdf

CASE-2: NEW BASE-LOADED WIND POWER SYSTEMS TO REPLACE BASE-LOADED COAL PLANTS

Land-based wind power is the lowest cost, CO_2-free renewable, if one looks at only the wind farm. If one looks at the wind farm as part of a system, then the economics and CO_2 emission reduction becomes less favorable. As most of the windy places are sparsely populated, transmission facilities are needed to bring power to the populations on the East Coast. This is a visual and economic negative for wind power.

The capital costs per MW of offshore wind farms are 1.5-2.0 times the costs of land-based wind farms. Offshore wind farms have about three times the variable O & M costs/MWh of land-based wind farms. See EWITS pg. 67.

Many state legislatures passed laws requiring utilities to have a significant percentage, usually 20% or more, of their power from renewables by a certain date. Wind power is variable and intermittent; it is absent at times when wind speeds are too high or too low, and varies at all other times. As this power is fed into the grids, operators of the grids are expected to deal with it. Wind power penetrations of less than 5% usually are not a big problem. Higher wind power penetrations are a problem in Germany (6.4% wind in 2009) and in Texas (4.9% wind in 2009).

Denmark, Portugal, Spain, the Bonneville Power Authority and Hydro-Quebec use pumped storage hydro plants to smooth incoming wind power. Currently, it is the most economical method of integrating wind power. The Bonneville Power Authority charges about $5.7/MWh to integrate wind power by using its hydro plants. The EWITS estimate for Scenario 4 is $4.54/MWh. See EWITS pg. 46

http://theenergycollective.com/willem-post/46977/impacts-variable-intermittent-power-grids

Cape Wind and Other Offshore Wind Farms

Cape Wind Associates, LLC, plans to build and operate a wind farm on the Outer Continental Shelf offshore of Massachusetts. The wind farm would have a rated capacity of 468 MW consisting of 130 Siemens AG turbines each 3.6 MW, maximum blade height 440 feet, to be arranged in a grid pattern in 25 square miles of Nantucket Sound in federal waters off Cape Cod, Martha's Vineyard, and Nantucket Island.

The Massachusetts Department of Public Utilities approved a 15-yr power purchase agreement, PPA, between the utility National Grid and Cape Wind Associates, LLC. National Grid agreed to buy 50% of the wind farm's power starting at $0.187/kWh in 2013 (base year), escalating at 3.5%/yr which means the 2028 price to the utility will be $0.313/kWh.

A household using 618 kWh/month will see an average wind power surcharge of about $1.50 on its monthly electric bill over the 15 year life of the contract; if the other 50% of power is sold on the same basis, it may add another $1.50 to that monthly bill.
Power production is estimated at 468 MW x 8,760 hr/yr x CF 0.39 = 1.6 GWh/yr.
The capital cost is estimated at $2.0 billion, or $4,274/kW. Federal subsidies would be 30% as a grant.

The 28.4 MW Block Island Offshore Wind Project has a 20-yr PPA starting at $0.235/kWh in 2007 (base year), escalating at 3.5%/yr which means the 2027 price to the utility will be $0.468/kWh. A State of Rhode Island suit is pending to overturn the contract; the aim is to negotiate to obtain a lower price.
Power production is estimated at 28.4 MW x 8,760 hr/yr x CF 0.39 = 0.097 GWh/yr.
Capital cost is estimated at $121 million, or $4,274/kW. Federal subsidies would be 30% as a grant.

The 200 MW Delaware Offshore Wind Project has a 25-year PPA starting at $0.0999/kWh in 2007 (base year), escalating at 2.5%/yr which means the 2032 price to the utility will be $0.185/kWh.
Power production is estimated at 200 MW x 8,760 hr/yr x CF 0.39 = 0.68 GWh/yr.
Capital cost is estimated at $855 million, or $4,274/kW. Federal subsidies would be 30% as a grant.

For comparison: TransCanada Power which owns the 132 MW Kibby Mountain Wind Facility in Maine has a 10-yr PPA with NStar, an electric utility, at a flat $0.105/kWh, plus the associated renewable energy certificates.
Power production is estimated at 132 MW x 8,760 hr/yr x CF 0.31 = 0.357 GWh/yr.
Capital cost is estimated at $320 million, or $2,424/kW.

The above PPA prices cannot be directly compared because they are influenced by factors other than generating costs. See pg 119 of the NREL website.

The 1,000 MW Deep Water Wind Project with 500 ft tall wind turbines @ 5-6 MW each is proposed to be located in Long Island Sound. Power is expected to be sold "in the mid teens", i.e., at about $0.15/kWh.
Production is estimated at 1,000 MW x 1,000 kW/MW x 8,760 hr/yr x CF 0.40 = 3.5 GWh/yr.
Capital cost, with interconnects to existing grids, is estimated at 4.5-5.5 billion dollars.

For comparison: Production by 471 MW of CCGTs: 471 MW x 1,000 kW/MW x 8,760 hr/yr x CF 0.85 = 3.5 billion kWh/yr.
Capital cost: 471 MW x $1,250/kW = $589 million.

http://green.blogs.nytimes.com/2010/12/09/wind-farm-would-link-northeastern-grids/
http://www.southcoasttoday.com/apps/pbcs.dll/article?AID=/20101123/NEWS/11230310
http://www.brighterenergy.org/15568/news/wind/rhode-island-offshore-wind-project-challenged-in-supreme-court/
http://theenergycollective.com/brighterenergy/47584/america-moves-step-closer-its-first-offshore-wind-farm
http://www.env.state.ma.us/dpu/docs/electric/10-54/73010tntst.pdf
http://www.nrel.gov/docs/fy10osti/40745.pdf
http://www.coalitionforenergysolutions.org/maine_wind_farms.pdf
http://finance.yahoo.com/news/Wanted-Buyer-for-apf-120662485.html?x=0&sec=topStories&pos=1&asset=&ccode=

Calculations

Production : 302,610 MW x 1 TW/1,000,000 MW x 8,760 hr/yr x CF 0.377 = 1,000 TWh/yr,

Capital cost of land-based wind farms: 231,730 MW x $2,500,000/MW = $0.58 trillion.
Capital cost of offshore wind farms: 70,880 MW x $3,921,000/MW = $0.28 trillion.
Capital cost of transmission systems: $92.5 billion. See EWITS pg. 39
Total capital cost: 0.58 + 0.28 + 0.093 = $0.95 trillion.

The CO2 emission reduction would be less because about (22,134 - 4,022) MW = 18,112 MW of additional CO2-producing spinning power plants are required to regulate the variability and intermittency of wind power. Such plants usually are gas-fired, simple-cycle, gas-turbine generators. Their efficiency at rated output is about 35%, or about 9,750 Btu/kWh, and at 50% rated output about 30%, or about 11,375 Btu/kWh. The spinning power plants usually operate at about 50% of rated output otherwise they cannot modulate as needed by demand.

Annual CO2 emissions of power regulation: (22,134 - 4,022) MW x 1,000 kW/MW x 8,760 hr/yr x (11,375 - 9,750) Btu/kWh x 50% rated output x 1.2 lb CO2/9,750 Btu = 15.5 billion lbs of CO2/yr, or 0.0072 billion metric ton/yr

Annual cost of power regulation: 1000 TWh/yr x 1,000,000 MWh/TWh x $4.54/MWh = $4.54 billion/yr. See EWITS pg 46.
Annual cost of offshore O&M: 70,880/302,610 x 1,000 TWh/yr x 1,000,000 MWh/TWh x $2.56/MWh = $0.60 billion/yr.
Annual cost of land-based O&M: 231,730/302,610 x 1,000 TWh/yr x 1,000,000 MWh/TWh x $1.28/MWh = $0.98 billion/yr.
See pg 118 of NREL website.

Net CO2 emissions reduction: (1.036 - 0.0072) billion metric tons of CO2/yr = 1.029 billion metric tons of CO2/yr, requires a capital cost of $0.95 trillion, or 950/1.029 = $923/(metric ton of CO2/yr)

http://www.reuters.com/article/idUSTRE69A4LP20101012
http://www.offshorewind.biz/2010/10/12/developers-confident-about-raising-funds-for-cape-wind-project-usa/
http://reason.com/blog/2010/04/29/costing-cape-wind-was-teddy-ri

http://en.wikipedia.org/wiki/Cape_Wind
http://www.vcerc.org/VCERC_Final_Report_Offshore_Wind_Studies_Full_Report_new.pdf
http://www.hnsboroesc.outlierproductions.com/Resources/CapacityFactorOfWind.pdf
http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power/chapter-2-offshore-developments/the-cost-of-energy-generated-by-offshore-wind-power.html
http://offshorewind.net/Other_Pages/Links%20Library/MarylandsOffshorewindPowerPotential-feb2010.pdf
http://en.wikipedia.org/wiki/Wind_power
http://en.wikipedia.org/wiki/Wind_power_in_the_United_States
http://www.wind-watch.org/documents/integrating-wind-power-in-portugal/

CASE-3: NEW BASE-LOADED NUCLEAR PLANTS TO REPLACE BASE-LOADED COAL PLANTS

- The new nuclear plants would be mostly located at existing nuclear and coal plant sites.
- Relative to Case-2, minor transmission system changes would be required.
- Visuals of existing coal power plant sites would be improved, as unsightly coal plants are replaced by new nuclear plants.

Modular Nuclear Reactor Alternative to Large-Capacity Nuclear Reactors

B&W has about 50 years of experience building small nuclear reactors for the US Navy and big reactors for power companies. Utility nuclear power plants take about 8 years to build; their reactors usually are 1,000 MW, or greater.

B&W has developed a 125 MW nuclear power module that will be built in US factories under controlled conditions to reduce costs and ensure quality. The modules can be transported by rail to a plant site. Several modules can be combined to create power plants of 1,000 MW, or greater. The plant can be arranged for water or air cooling of the condenser. B&W is planning to have a complete steam turbine generator module that can be transported by rail to a plant site. The modules use standard 5% enriched U-235 uranium and have a 4.5-year operating cycle between refueling.

B&W calculates over the 60-yr life of the reactor, each module will avoid about 125 MW x 1,000 kW/MW x 8,760 hr/yr x CF 0.90 x 60 yr x 2.12 lb of CO_2/kWh x 1 metric ton/2,200 lb = 57 million metric tons of CO_2 that would have been emitted by a coal plant.

B&W and Bechtel have formed a joint venture to build the modular power plants. Such standardized plants will be much quicker to license and build and less costly to own and operate. TVA is seeking approvals from the NRC to build a plant with up to 6 reactors at Oak Ridge, Tennessee.

If Boeing can build about thirty $150 million planes per month, then B&W could build about ten $375 million modules per month.

Calculations

Production: 126,840 MW x 8,760 hr/yr x CF 0.90 = 1,000 TWh/yr

Capital cost: 126,840 MW x $7,000,000/MW = $0.89 trillion

CO_2 emissions reduction: 1.036 billion metric tons of CO_2/yr, requires a capital cost of $0.89 trillion, or 890/1.036 = $859/(metric ton of CO_2/yr).

http://www.babcock.com/products/modular_nuclear/
http://www.bechtel.com/assets/files/news/bw/mPower.pdf
http://www.world-nuclear-news.org/NN-BandW_unveils_modular_reactor_design-1006095.html
http://www2.newsadvance.com/business/2010/nov/11/tva-seeks-regulatory-approval-build-bw-reactors-ar-647614/
http://www.cleanenergyinsight.org/tag/modular-reactors/
http://icapp.ans.org/icapp10/highlights/plenary%20stuff/p4/halfinger.pdf
http://en.wikipedia.org/wiki/Economics_of_new_nuclear_power_plants