CHALLENGES FOR HYBRID RENEWABLE ENERGY SYSTEMS

Brendan McNamara, July 2012

Environmentalists for Nuclear Energy www.efn-uk.org

Part II. The US National Renewables Energy Laboratory Study, 2012.

NREL has performed a study of a range of RE scenarios leading to 80% of electricity being provided by renewables by 2050. This would be a major step towards cutting global CO_2 and other greenhouse gas emissions by 80%. The NREL 2012 study (www.nrel.gov/analysis/re_futures)does not contemplate the use of CC&S. The NREL study does not mention the decline of conventional oil or discuss the production of biodiesel. Any thought of the expansion and electrification of railroads to replace long distance travel and trucking is absent. Nuclear power is allowed to die away to 5% by 2050 as existing nuclear plants are retired. The optimised High Demand results require a total capacity of 1930 GW to deliver 582 GW at a cumulative capital cost of about $4.5 trillion under their optimistic assumptions. More conservative estimates lead to a cost of about $6Tn. Nuclear power could replace all 308 GW of wind and solar electricity output for $2.0Tn with twice the service life.

Every State of the Union is expected to contribute to the RE production on a continent wide grid which has complete control of all resources. Electricity on demand cannot be guaranteed with 80% renewables so forced load reductions of up to 10% (60 GW) may be necessary for selected sets of industrial users, electric vehicles, home appliances, and others. The primary electricity generation will be from wind (200 GW) and solar (70 GW), partnered with equivalent energy storage by pumped Hydro, Compressed Air storage, molten salt thermal storage, and gas turbines and dispatchable renewables like Hydroelectricity and Biomass. Energy conservation would be pushed to its highest level to optimize each scenario.

The primary energy storage used in the modelling is Pumped Storage Hydro, followed by Compressed Air Energy Storage, CAES. The primary Solar energy is to come from Utility scale and rooftop Solar PV, followed by Concentrating Solar Power (CSP). The total spend on Solar is 30% more than that on wind but produces 1/3 of the wind energy.

The best geographical sites have been identified for each technology. These should be used first to get the highest performance, but this puts them far away from population centres. Actual performance is dependent on weather, which can also vary by up to 30% between wet and dry years. The overall schemes are very similar to the European DESERTEC scheme.

The Wind and Solar sources can produce 3 or 5 times their average output and sometimes simultaneously. The output can exceed the total load on the grid and so must be curtailed and energy discarded. On a regional basis, 6-10% of wind <u>energy</u> will be curtailed. These renewables can also produce less than 10% of their average and so <u>demand</u> may have to be curtailed on a regional basis by 16-24%. Lighting will not be deliberately curtailed.

NREL has amassed a large amount of data on a long list of technologies and the geographical possibilities for deployment. The model scenarios and working assumptions for various levels of penetration by renewables have been optimised to represent the best combinations. NREL has assumed that the continent wide system will indeed smooth out the delivery of power. This remains unverified with real time wind or solar data. Various averages are applied in the modelling and high, ideal performance for equipment is used, leaving concerns that reality may be far from these models. It is clear that the infrastructure needs for support of wind farms are far more elaborate than is ever presented by the wind farm industry. The NREL study does not promote the more contentious or even silly claims of parts of the renewables industry or its supporting academics.

Some of the systems may be unfamiliar so we will use their cartoons and data to illustrate them.

II.1 NREL Renewable Energy Technologies

II.1.1 Concentrating Solar Power

CSP technologies use mirrors or lenses to focus the 47% of thermal energy in sunlight on a receiver containing a working fluid. The mirrors use a 1 or 2 axis tracking to maximise the solar energy captured. Parabolic trough and linear Fresnel systems use oil based fluids. Dish concentrators may use air to drive a Stirling cycle engine. The tower concentrators use molten salt, at much higher temperatures, for higher conversion efficiency of heat to electricity.

Figure 9. Cartoon of 4 CSP systems: Parabolic trough, Tower, Dish, and Fresnel concentrators.

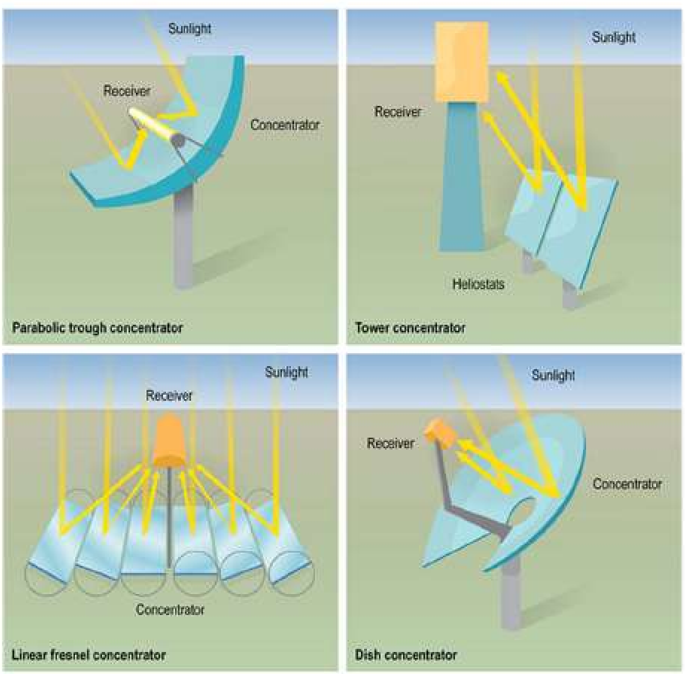
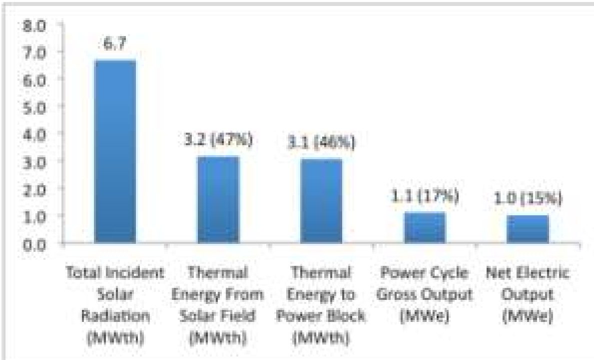


Figure 10-5. Solar-field components of a CSP system

The South West of the USA is virtually uninhabited and has vast acreage for solar plants. Los Angeles and Phoenix are on the same latitude as Baghdad, so there is up to 13 hours of sunshine in the summer. An MIT presentation (Anderson) evaluates the performance of a 100 MWe CSP plant, Figures 10,11,12. The power output is a useful 15% of the total concentrated sunlight.

Figure 10. Energy conversion from sunlight to electricity by a 100MWe CSP plant. A fraction of the power is used to rotate mirrors and pump the working fluid.



The daily and seasonal variations of solar energy mean that the CSP plants have a low annual load factor, though it does match with local daytime air conditioning demand. The levelised cost of electricity is 12 cents/kWh, about 2.5 the cost from conventional sources. The low load factor and high capital investment has made CSP plants uneconomic and few have been built. The largest in the world is a group of 9 plants in the Mojave desert with an total capacity of 354 MW, using 6.5 km^2 of land.

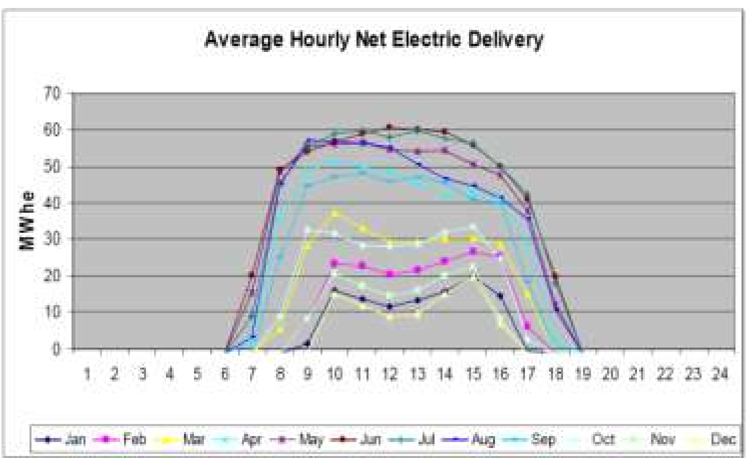


Figure 11. The net electric delivery by Nevada Solar one, 2006, is zero at night and varies from a peak 60 MW in summer to 10 MW in winter. The daytime dips correspond to hazy or cloudy conditions during those months.

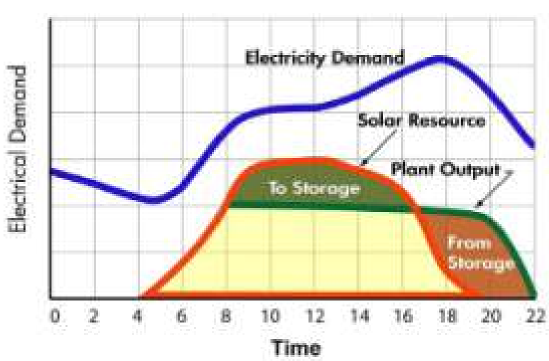
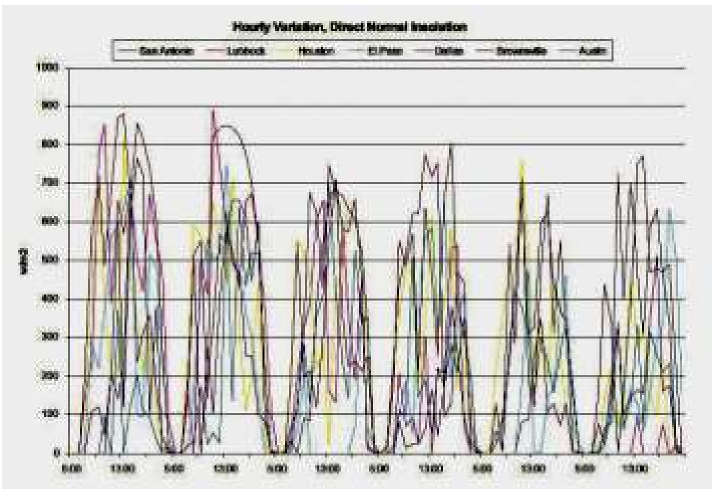


Figure 12. The output time can be extended by a about 8 hours by attached thermal energy storage. This capacity cannot extend across weeks and seasons.

Figure 13. Solar output is often as erratic as wind as shown by this chart of incident solar energy over 6 days at 7 locations in Texas, 2006 (http://www.seco.cpa.state.tx.us/publications/renewenergy/solarenergy.php).



This is data from the National Solar Radiation Data Base. Solar energy presents similar problems to the grid as does wind on an hourly, daily, seasonal, and yearly basis. Wet and cloudy years can be down by 30% from dry years. This is not included in NREL models.

Figs. 14-15. NREL maps of the best locations for Solar PV and CSP Plants. The broader availability of PV energy means that their optimization reduces the CSP contribution even though it is significantly cheaper.

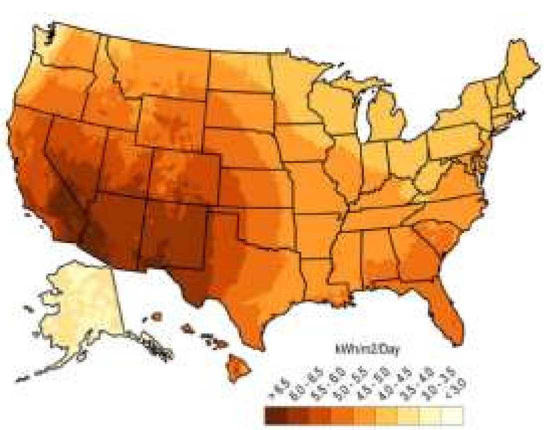


Figure 10-2. Map of the mean solar resource available to a PV system that is facing south and is tilted at an angle equal to the latitude of the system

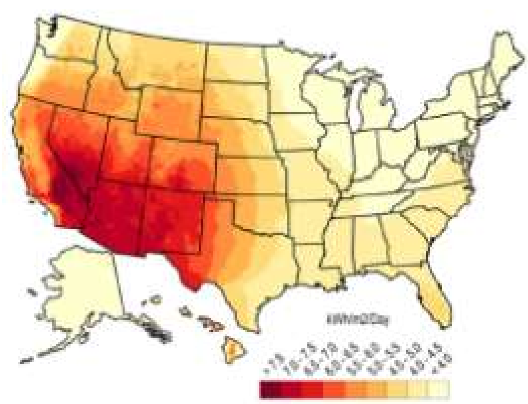


Figure 10-3. Map of mean U.S. solar resource available to concentrating solar power systems with 1-axis tracking that follows the daily trajectory of the sun from east to west

II.1.2 Hydro Electric Plants

Very large hydro electric plants, like the Hoover Dam in Arizona or the Aswan Dam in Egypt store water from major rivers or large catchment areas and deliver great amounts of cheap electricity on demand. The capital investment and drowning of large areas are proportionally huge. Small Hydro plants, down to 1-2 MW capacity, can be installed wherever there is a lake or running river to drive them. They require such geological features and are dependent on seasonal rainfalls. They can be used on a seasonal basis, storing water in winter and making power in the summer.

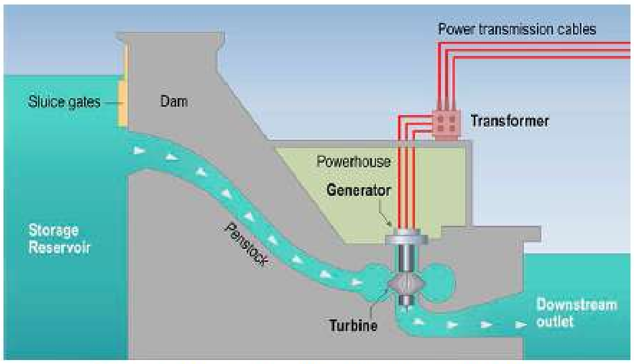


Figure 8-6. Cross section of a large hydroelectric plant

Figure 16. NREL cartoon of a large Hydroelectric plant.

Figure 8-5. An advanced modern hydropower turbine being lowered into position

Courtesy of Grant County Public Utility District

Hydroelectricity output around the world has dropped by up to 20% in the last decade due to continued droughts or low rainfall.

Figure 17. One of the world's largest water turbines being installed in a Hydroelectric plant.

Figure 8-3. Map of hydroelectric plant locations in the United States

Figure 18. Most of the large hydroelectric plants are and will be in the northwest of the USA. Most of the best sites are already occupied and others need new regulations to allow construction in protected places like National Parks.

II.1.3 Pumped Hydroelectric Storage, PHS

Electrically pumped storage needs only an upper and lower lake or reservoir with a 50-100m height between them. The size of the upper reservoir can be built to provide a fixed amount of power, say 500MW for 12 hours. The lower reservoir can be artificial, providing a closed cycle, or any other reliable source of water, even seawater. Typically, the plant will return 80% of the electric input to the grid.

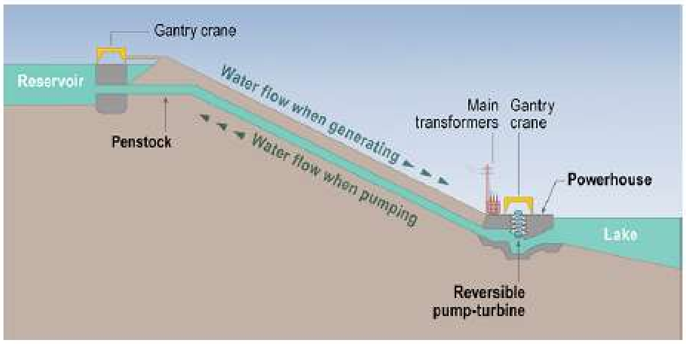


Figure 12-3. Simplified pumped-storage hydropower plant configuration

Figure 19. NREL cartoon of a pumped storage hydroelectric plant.

II.1.4 Compressed Air Energy Storage, CAES

Air may be pumped into a large cavern, increasing the air temperature and providing a high pressure. Caverns could be existing caves or mines, or constructed by washing out salts in a salt bed, or cut from hard rock. Being underground, the systems occupy little land area and can be deployed more easily than pumped Hydro. The energy is to be recycled in 15hrs. The hot air can be efficiently supplemented with natural gas to give a higher power output when needed, at the cost of some CO_2 emissions.

In the highest demand scenarios the US system needs up to 120 GW of PSH and 15 GW CAES as the principal partners for excess Wind and Solar. There are only 2 large, working CAES systems in the world today. The American one at McIntosh, Alabama produces 110 MW from compressed air to pressurize natural gas for a further 240 MW. The plant can run for 26 hours on a full or charge, or more normally for 10 hours on a daily basis.

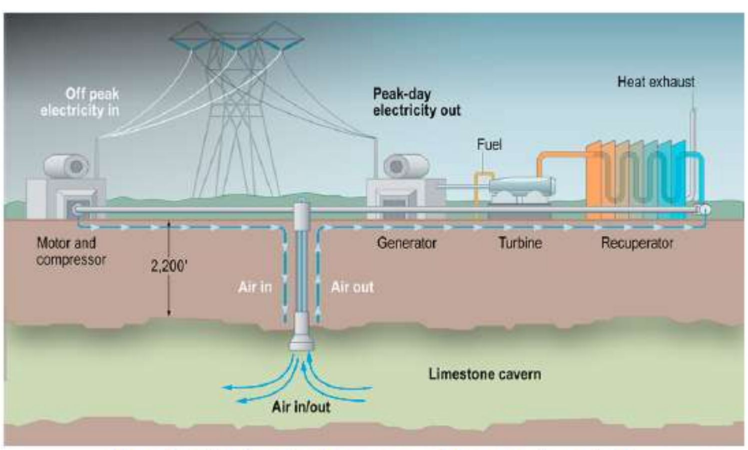


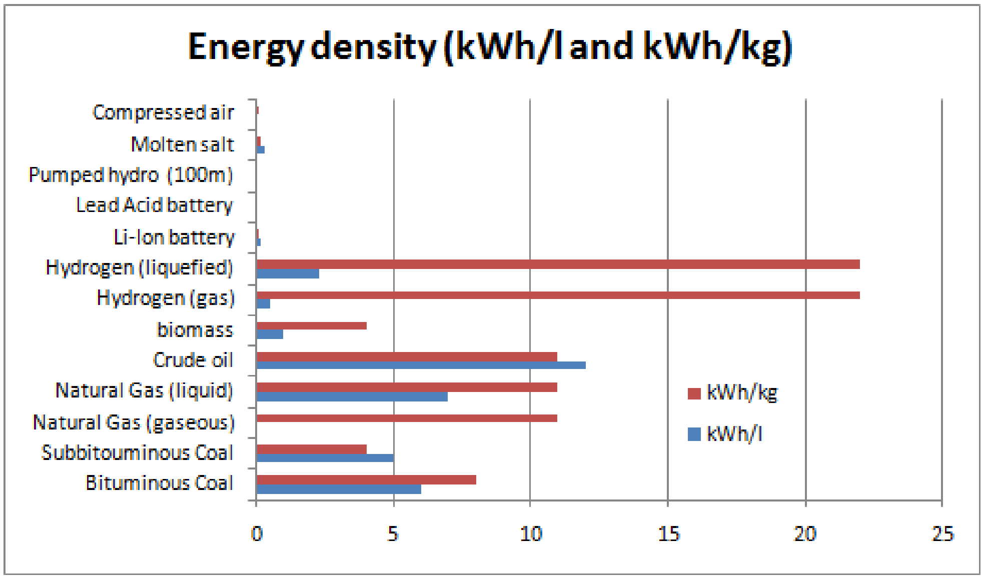
Figure 12-4. Configuration of a compressed air energy storage plant

Figure 20. NREL cartoon of a Compressed Air Energy Storage plant using an artificial limestone cavern. The power output is enhanced by a gas turbine and the exhaust heat returned to the cavern.

II.1.5 Battery and other Energy Storage

Electricity can be stored in chemical batteries based on lead-acid, Li-ion, reduction/oxidation of Vanadium salt, Sodium-Sulphur and others, but the amount stored per kg or per litre is small. Large Vanadium salt batteries have been proposed to smooth the most rapid fluctuations of wind energy at multi MW levels. Millions of electric vehicles will carry millions of tonnes of Li-ion or other such batteries and are regarded by NREL as a potentially time shiftable load. The vehicle owners may not see it that way when their batteries have not been charged.

Figure 21. A comparison of energy density for various storage systems.



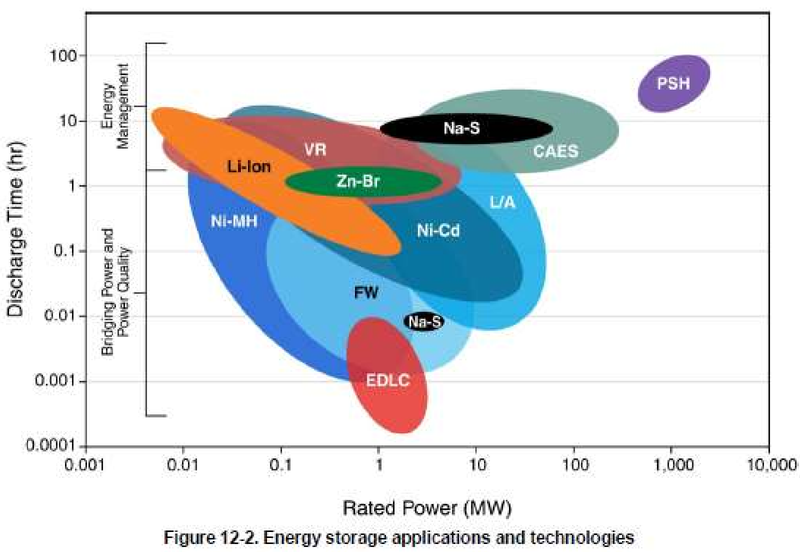


Figure 22. NREL comparison of the capacity of storage systems to deliver a rated power for some discharge time. The most suitable systems to support massive amounts of wind and solar energy are clearly Pumped Hydro and Compressed Air.

II.1.5 The USA Super Grid.

The Wind, Solar and Hydro power resources are widely spread and mostly far from population centres. The highest onshore wind resource arises in the Central states, Figure 23. More expensive Offshore wind is available on the East and West coasts and around the great lakes. The most favoured regions for offshore wind are the Great Lakes and the North West.

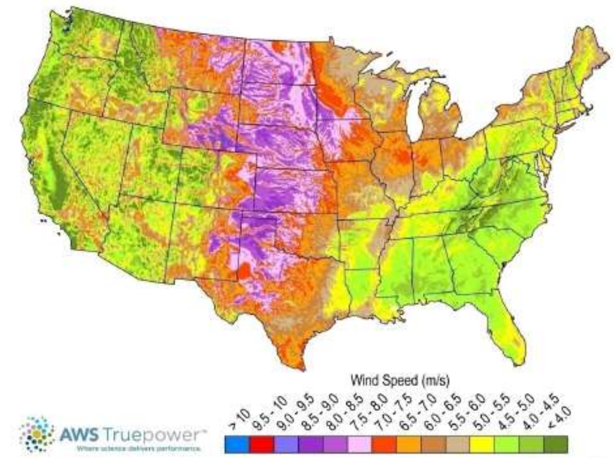
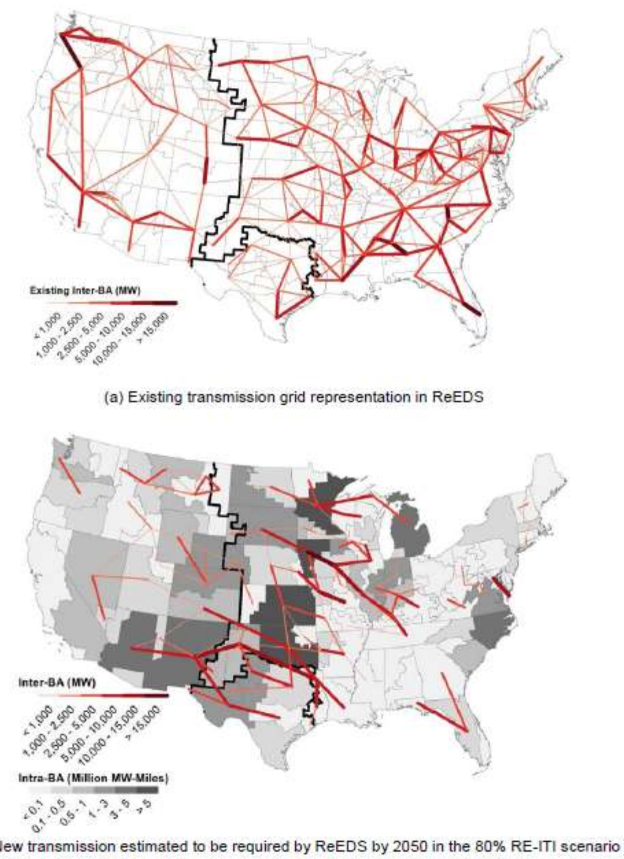


Figure 11-2. Onshore wind resource (annual average wind speeds) at 80-m hub height in the contiguous United States

Figure 23. NREL map of wind speeds in the USA.



(a) Existing transmission grid representation in ReEDS

(b) New transmission estimated to be required by ReEDS by 2050 in the 80% RE-ITI scenario

Figure 3-9. Existing and new transmission required in the 80% RE-ITI scenario

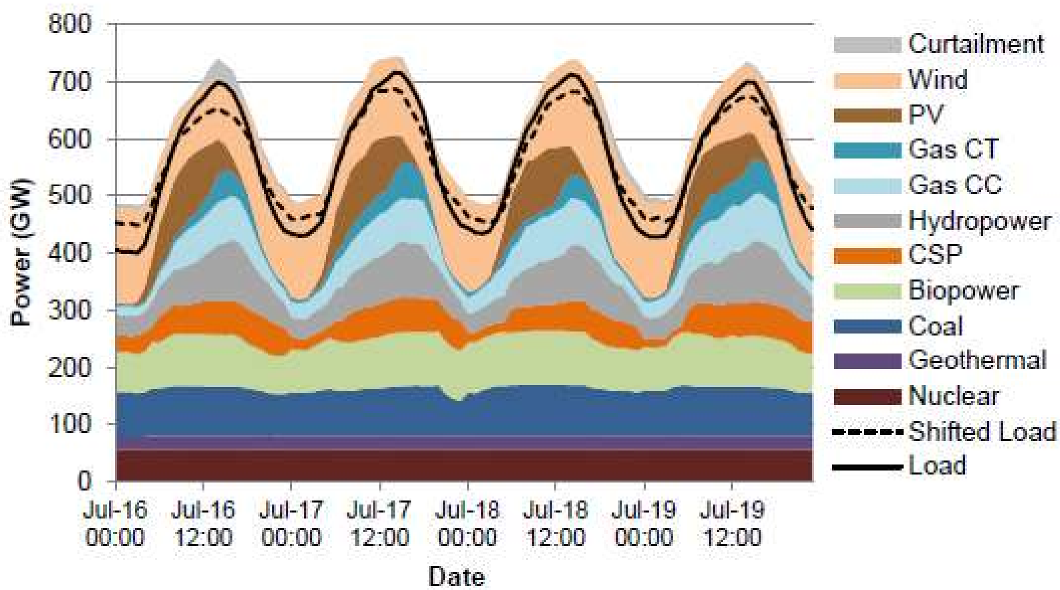
The NREL scenarios require that all resources be equally visible and controllable all across the continent. These maps show the main transmission lines today with little connection between East and West coasts. All of this must be strengthened to carry much larger power flows. New connections are needed by 2050 to link State or regional grids. Grid control will be managed by an equivalent computer network. Most of the cost of this work is in support of the dispersed wind and solar systems.

Figure 24. Maps of the 2010 and 2050 high power grid connections. For distances above 250 miles a High Voltage DC line may be considered. The DC motor to AC generator convertor sets at each end can match different phases for the local grid but are also very expensive. These convertors, on a smaller scale are needed to connect every onshore and offshore wind farm to the grid. Low voltage convertors are part of every solar rooftop installation.

II.2 NREL Energy Scenarios for 2050.

NREL has explored combinations of all the renewable energy sources which can optimize an 80% renewable energy future. The remaining 20% of carbon based electricity generation is from coal and gas. They have ignored Carbon Capture & Storage as a way of rehabilitating more coal and gas which leaves the questions open their view on the successful implementation of CC&S on a large scale. Nuclear power is allowed to die away in all scenarios as plants reach the end of their service lives. This is, of course, a primary goal of the renewables movement.

The model requires a total capacity of 1930 GW from all sources to deliver an average of 582 GW. The modelling is done on an hourly basis but using averaged outputs from the erratic wind and solar sources.



(a) Summer peak load in 2050

Figure 25. Matching output to load over 4 days of a summer peak. The peak is due partly to extensive use of air conditioning of homes and offices. Solar sources are at their summer peak with 1/3 from the from uncontrolled rooftop PV installations, and 2/3 from CSP utilities. The CSP output shows the extended production from thermal or molten salt storage. Coal makes a substantial contribution to the base load, and gas partners much of the wind variation. Some excess wind is simply curtailed. The annual wind curtailment is about 10%.

We have not discussed Biomass energy, using materials like wood wastes and domestic or industrial wastes to be burned alone or with other fuels like coal. Greater use of Biomass fuels would impact agriculture, endanger large forests, and impact local ecologies as is clearly seen in parts of Africa dependent on firewood for cooking. Biomass does play a role in all NREL scenarios.

A basic assumption is that energy conservation will reduce the 2050 demand by 30% from the direct increase due to a 50% population growth. All environmentalists agree that this is necessary for any sustainable future, but the USA has so far been the least willing to cut waste and energy consumption. Californians, on a personal level, seem to have no interest or understanding of energy conservation. Progress to more efficient homes is largely left to 'inter-fuel competition' between natural gas and electricity. Ultra-efficient homes can cut consumption by 70% with good insulation, solar panels, air pumps for cooling, ground pumps for heating, air circulation without leakage, and large south-facing windows. The costs for ultra-efficiency are high. For these reasons, we only look at the high demand NREL scenario for 2050.

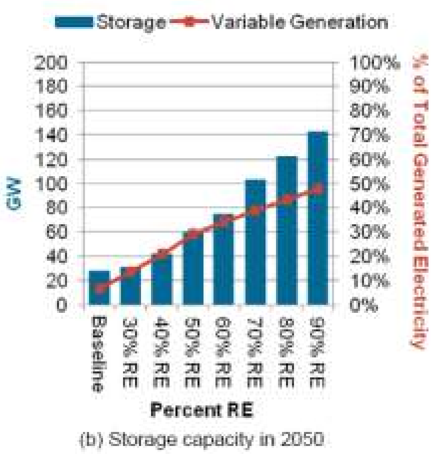


Figure 26. Storage of excess wind and solar energy is the main Hybrid partner on an annual basis in all scenarios. Storage matches or exceeds variable generation, not the variable nameplate capacity.

The NREL study may well be used worldwide as a basis for driving the growth of renewables in rich countries. The scenarios presented are the best found by optimising among many parameters and choices, using the most favourable assumptions that are not obviously wrong.

The highest load prediction is for an average 582 GW in the RE-80%-HD scenario. The US electricity consumption in 2011 was about 4000 Twh, or 456 GW. However, the product of 30% conservation, a 50% increase in population, and at least a 50% increase in electricity for transport and heating uses leads us to expect an average demand above 700 GW.

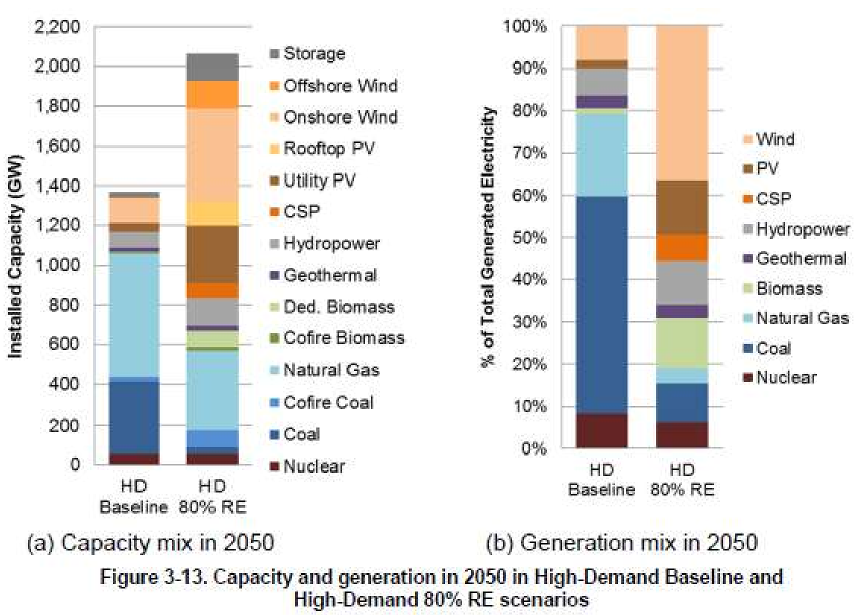


Figure 27. The capacity and generation mix for the High-Demand 80% RE scenarios with a comparison to a fossil fuelled baseline. The % Generated stacks conceal both the total generation of 582 GW and the generation from each source.

Wind is the largest and most erratic generator but, under the smoothing assumptions of the model, only a small amount of gas, the modest amount of CAES shown, and the Hydroelectric plants seem sufficient to steady the supply. However, a large amount of gas capacity is still available as reserve or standby power. Coal and co-fired coal with some biomass are used to add base load power when the wind is predicted to drop or continue low on a following day. **Good weather prediction is a necessary part of the overall management of supply and demand.**

Unpacking the stacks gives a more informative presentation: The capacity (blue) and actual generation (red) from each source are shown in Figure 28. The wind capacity could be 200GW short if the real average performance of the wind farms was 20-30% lower than the theoretical. Year on year weather variations or large scale climate change could have a similar impact. The comprehensive NREL modelling says nothing about these possibilities.

The capacity and generation for the Hybrid partners - gas, coal and storage – are superposed in green for easy comparison. The total of all this Hybrid backup capacity and the total renewable capacity are shown to be comparable. The RE Total is indeed about 80% of 582 GW generation and would be 90% emissions free if the Nuclear contribution were included.

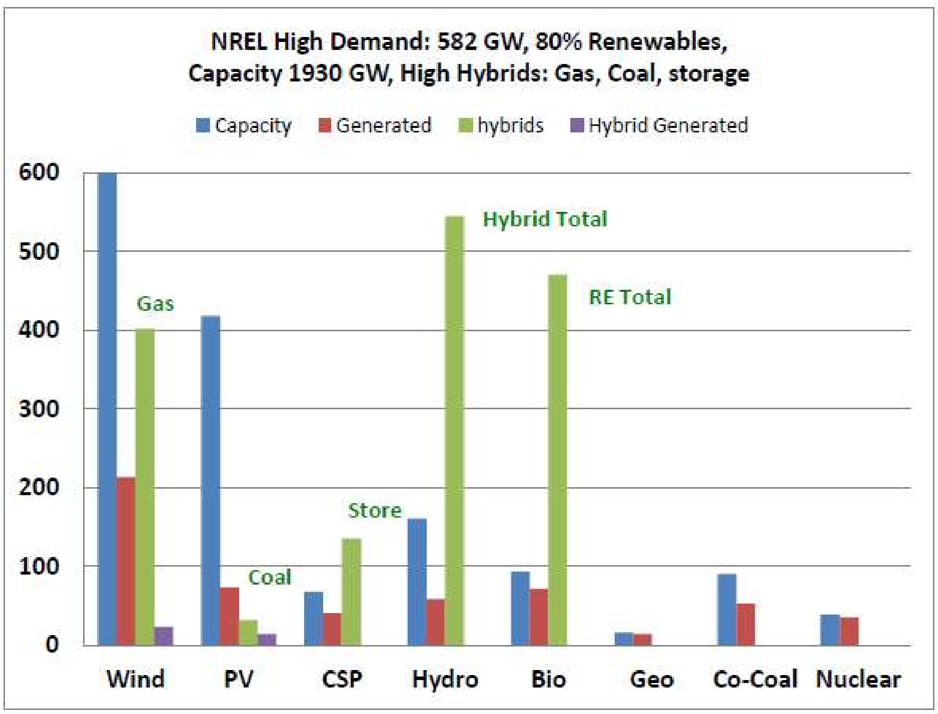


Figure 28. Capacity and generation for all the electricity sources in the NREL 80% Renewables scenario for 2050.

The electricity from storage came from excess wind or solar and is therefore not an originating source. The very large amount of gas fired capacity in the system can be used for major lows in renewable production and cannot be taken out of service. The NREL assumptions about continental averaging required very little gas to be used in this case.

It remains to discuss the real cost of electricity in this 2050 scenario. The costs have been estimated by Black and Veatch with fair assumptions about future improvements and reductions in cost by 2050. We have mostly used the lower 2050 costs and the average of the 2015 and 2050 costs for

Solar PV. There is not enough information in the reports to make a good estimate of the costs for the grid expansion, but a range of $Bn100-200 seems appropriate. The cumulative capital cost of the RE-80% systems is about $4.5 trillion for the NREL assumptions or up to $6Tn on more conservative performance assumptions. Nuclear power to deliver the same electricity as wind +solar would cost about $Tn2.0 with double the service life, locally managed grids, and no demand curtailment.

Our last chart, Figure 29, shows the capital cost of electricity actually delivered from each component of the system in $Bn/GW – or $M/MW. This is not the same as the Levelized Cost of Electricity, LCOE, which also depends upon the various running costs, the interest rate charged for capital loans - a factor of 1.5 to 2 in bank interest over 20 years - , and plant service life. All the carbon free systems have little or no fuel costs so the price of electricity is mostly set by the capital cost and service life. Nuclear power has 2-3 times the service life of wind and solar plants and electricity is proportionally cheaper. Using cost per MW delivered reflects the true economics of the system, unlike the usual cost per MW of peak capacity.

Wind, Solar and their hybrid partners, pumped Hydro, CAES, and gas and coal are shown in as one group (orange). The controllable renewables of Hydroelectricity, Geothermal, and Biomass are another group (red). New Nuclear is shown for comparison. The actual nuclear power used in the NREL scenarios is old nuclear, providing the cheapest electricity at its very low marginal cost after 20 years.

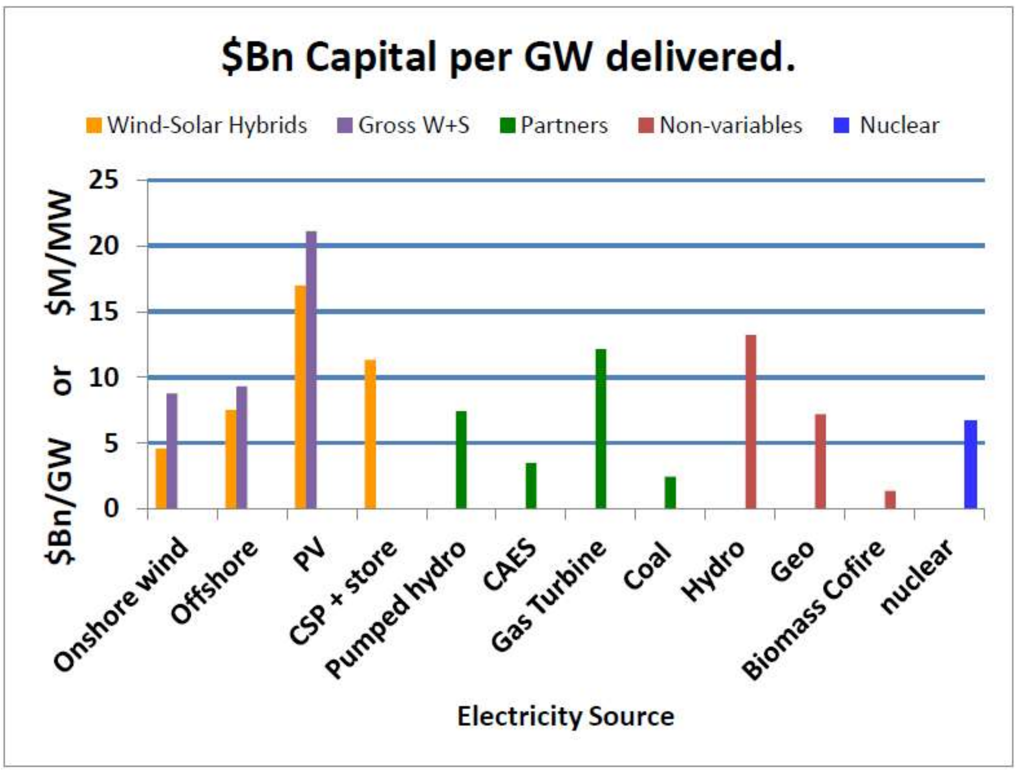


Figure 29. Capital costs per average Gigawatt of electricity delivered.

The real capital cost of wind and solar energy should include the investments in all the backup or partner systems and in the elaborate national grid. A simple proportional division of the storage costs between the wind and PV sources gives an estimate of the Gross cost of each with storage as shown (purple). By all measures, solar power is by far the most expensive source of electricity, especially the rooftop panels. Its value is that it is independent of wind and provides its power regardless.

Corporations, governments and their agencies seem never to ask this titanic question: how close to disaster are our rosy predictions?

The biggest challenge to the NREL is to extrapolate real performance data from existing installations, using a wider set of weather assumptions and other parameters, to map the boundaries of acceptable energy supply.

Final Observations

The friendly looking local windmills or rooftop solar panels are not what our society is buying into with renewable energy. These are just the first step towards the vast DESERTEC or NREL RE80% scenarios, their continental spread of high voltage networks, and centralised control of every energy source and every user, and overriding authority over land use. This level of control is a major political obstacle as every person, industry and state must yield sovereignty to this version of the common cause.

Only the Olympic Games has achieved the dream of such agreement among 204 nations to play by the rules, be fair and honest in competition, not be violent, treat every race, religion or state with respect, and accept women as competitors in all sports. Energy supply is not a game.

The USA is thinly populated in the central states where wind and solar sources are at their best. This is not true in densely populated Europe and these systems represent a huge assault on our landscapes, seascapes, and natural environment. Planning regulations are becoming more dictatorial in the EU to force the systems into place and the subsidies offered have produced excessive profits for many players. Governments are providing extreme funds to establish these industries, whose promotional spending then vastly exceeds the cash available for any balanced debate about the plan. It is clear that wind farms are being built much faster in Europe than even the planning for the required infrastructure and partner systems.

Not all dollars are equal. The cost of a new energy system is for resources to make things and for people to build things, things that everybody needs. These are 'real' dollars, not virtual dollars created by legislation or loans to be repaid indefinitely to the financial industry. Companies who do things and make things outperform the stock markets which live on margins from high volume trading. The real dollars are harder to come by, but they create real lasting wealth.

The cost of electricity will be at least double what it is today for the EU and the USA. The systems are too expensive for wide deployment in the rest of the world and so the goal of controlling global warming is still highly doubtful. If the EU and the USA manage to drop gas and coal we may expect them to be cheaper so the rest of the world will use it.

You may view the NREL study as proof that an 80% renewables future is possible, that all the defects of a 2012 study can be overcome by 2050, and that it should be pursued regardless of cost. Others may see it as a promotion for an ever more complex and risky scheme, with 10-20 energy technologies, all with large uncertainties. The cost and impact on your life will certainly be very large.

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