Is Renewable Energy Viable?

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The issue of climate change has stimulated considerable controversy over whether conventional energy sources–fossil fuels and nuclear–should be curtailed or even eliminated in favor of so-called "renewable" energy sources. Of course, this could not be accomplished overnight, but should it be attempted at all? An analysis of the costs and effects of utilizing renewable energy as a partial or complete replacement to supplant conventional energy sources can help determine what conditions would be necessary to make such changes and whether the cost would be worth it.

"Renewable" energy means energy that is always available, i.e., it does not have finite reserves that will someday run out. Here, renewable energy sources will include wind and solar for electricity and ethanol for transportation fuel. Hydro and geothermal can also be utilized for electric power generation, but because of limitations on the ability to scale up these alternatives, they cannot contribute more than a small segment of the overall portfolio of energy sources. Wind and solar power also have the perceived advantage of producing no carbon dioxide during their operation.

A good definition of "viable" would be: capable of working or functioning, i.e., something that works. If renewable energy truly "works," then by definition it is good enough to replace conventional energy sources. If not good enough to be a replacement source, then regardless of its other desirable attributes, renewable energy is not truly viable. Whether a renewable energy source might be viable at a future time will also be considered. Conventional energy sources will include those being currently used on a large scale such as coal, natural gas, and nuclear for electricity, and oil and natural gas for transportation fuels.

Energy Imperatives

Robert Bryce, in his book *Power Hungry*, lists four imperatives for energy sources that work in the marketplace: power density, energy density, cost, and scalability.[1] *Power Density* refers to how compact or spread out power generation stations are using different energy sources. Fossil fuel and nuclear plants tend to be compact while wind and solar tend

[1] Robert Bryce, *Power Hungry* (PublicAffairs 2010), 4.

to take lots of space. *Energy Density* refers to how much energy per weight or unit volume is characteristic of different sources, an important consideration for transportation fuels. Oil, for example, is much more energy dense than hydrogen. *Cost* refers to the capital and operating costs of facilities for electric power generation and, in the case of transportation fuels, the cost per unit of energy yield. *Scalability* considers whether a source of energy can be efficiently scaled up to a useful size or percentage of the energy sector. For example, hydropower and geothermal meet most of the imperatives, but only certain sites are suitable for these types of power so they are limited in scalability.

To the four imperatives listed above, a fifth imperative should be added—*Reliability*. If an energy source cannot be depended upon to produce power when it is needed, it is not acceptable as a major player. Wind only produces useful power when the wind is blowing in an acceptable range. Solar power only produces electricity when the sun is shining and only at full power with a clear sky and an optimum angle of the sun.

Evaluating Electricity Costs

Evaluating all energy sources for electric power generation cost on a precise basis is difficult because of the many variations in technologies, locations, plant sizes, and so on. Nevertheless, a range of costs from various projects can show a relative comparison between different electric power generation technologies.

A number of data sources were generally reviewed for comparative costs of generating electricity. A list of these sources is provided in the Bibliography at the end of the article following the Reference list which lists footnoted references.

The IEA/OECD report was the most useful of those reviewed and is referenced in this article. In this report, cost data were analyzed for more than 130 power plants using the various fuels and technologies under consideration.

The IEA/OECD analysis uses a single cost metric, "Levelised Lifetime Cost" (similar to life cycle cost analysis), which includes both capital cost and operating costs for a 40 year plant life at a 5% discount rate and a typical average load factor. The levelised costs of electricity (LCOE) production approach has the advantage of combining all costs into a single project lifetime cost factor that allows direct comparison between different energy sources. LCOE values are provided over the expected range for each energy source. Calculated costs of electricity are at the power station and do not include transmission and distribution costs.

Not including the costs of transmission and distribution is a necessary condition to keep comparison of alternatives simple, but it does give a cost advantage to both wind and solar. Conventional electric power plants can be located more proximate to the areas they serve which minimizes transmission and distribution costs, i.e., shorter and fewer lines. Wind and solar facilities should be located in areas that produce the most power (stronger and more frequent winds, and optimum sites for sun) and these areas may not be proximate to areas they serve. The need for more high-voltage transmission lines for wind and solar power facilities is one of the biggest disadvantages to renewable power alternatives, and it is often overlooked.[2]

Capacity Factor measures a generating plant's ability to produce power over a period of time at its maximum output. Conventional power sources have very high capacity factor ratings, i.e., they can run hour after hour, day after day, at maximum rated output, while renewable sources are unable to produce steady maximum output because of the variability of the wind and full sunlight.

Table 1
Electricity Generation Alternatives

	Construction Cost $/KW	LCOE $/MWh	Capacity Factor %
Coal-fired	1000-1500	25-50	85%
Gas-fired	400-800	37-60	85%
Nuclear	1000-2000	21-31	85%
Wind, onshore	1000-2000	35-95	17-38%
Wind, offshore*	1000-2000	35-95	40-45%
Solar PV	3640+	150-300	9-24%

*Principal data provided for wind did not differentiate between onshore and offshore technologies as to LCOE costs, but supplementary data indicated offshore wind generation construction cost is some 15-40% higher.

[2] Smil, V., "A Reality Check on the Pickens Energy Plan". Environment360 (2008): (accessed August 25, 2008). e360.yale.edu/…/a-reality-check-on-the-pickens…plan/2058.

Table 1. Ranges of costs for the various power generation technologies (IEA/OECD 2010). Costs include Construction Cost (overnight construction cost) in U.S. dollars per kilowatt-hour, LCOE (Levelised Cost of Electricity) in U.S. dollars per megawatt-hour, and Capacity Factor expressed as a percentage.

Summary of Electricity Generation Technologies

As shown in Table 1, the main conventional electric power generation methods (coal, natural gas, and nuclear) are in the range of 25-60 dollars per megawatt-hour. At current coal and natural gas fuel prices, costs may be even lower, in the range of 25-45 $/MWh. There are some differences in costs between the conventional sources, but they are in the same general cost range. Because of varying conditions between projects, no one method will be cheapest in all circumstances.

Compared to conventional electrical power generation costs, renewable technologies are always more expensive. Wind is 40-100% more costly, and solar is higher than conventional sources by a factor of 3 to 10 times.

Costs are a major consideration, but perhaps the most important comparison is that of *reliability*. Note that conventional power sources are rated at 85% capacity factor, but for all practical purposes, they may be regarded as 100% reliable. To provide wind power, wind speed must be an acceptable range, neither too high nor too low and, because wind power varies as the cube of the wind velocity, a wind speed of 10 m.p.h. produces only one-eighth as much power of wind at 20 m.p.h. Solar cannot provide power at night, and only at reduced power on cloudy days. Full solar output is only achieved on a clear day when the sun is at maximum incidence, i.e., near mid-day during summer months.

Because of these limitations on power output, wind and solar have low capacity factors, i.e., they can only provide full power at relatively low percentages of the time.

Can Renewable Power Sources "Stand Alone?"

It is obvious that because of the variability of wind and sun, renewable energy plants cannot be relied upon as an uninterrupted source of electricity. They must have backup from conventional energy plants to provide constant and reliable electricity to meet the demands of the grid. If renewable energy is proposed as an alternative source of electricity to replace fossil fuels and nuclear power, it should not have to rely upon those sources. To "stand alone" renewable energy must be able to provide reliable power independent of the energy sources it proposes to replace. So to "stand alone," power from renewable sources must have some method of energy storage, e.g., batteries, which can be turned on to meet demand when wind and sun are not available. The renewable energy sources must provide additional power to charge those backup facilities when the wind is blowing and the sun is shining.

There are conceptual alternatives for electrical power storage, including pumped hydroelectric, flow batteries, flywheels and compressed air. These backup power storage facilities would require significant expenditures to build and maintain, in addition to the cost of the wind/solar generating plants. Also, to be able to supply electricity both to the grid when the wind and sun are available and additional electricity to charge the power storage facilities for later use, would require building generating capacity several times the size of the demand needed to simply feed into the grid at maximum output.

If, for example, the capacity factor of a given wind/solar power plant were 33%, then facilities must be built to provide at least three times the output otherwise required. Why? Because sufficient wind power must be generated to provide for the demand from the grid plus twice the power to charge the storage facilities to provide for the 67% of the time the wind power is not available. This does not include energy loss that invariably occurs when charging the storage facilities and then again when the stored electricity is released for use.

An example can illustrate this requirement. For a stand-alone wind generation facility a pumped hydroelectric backup power facility could be incorporated. (Pumped hydroelectric power has been utilized on a limited demonstration plant scale and is relatively efficient). Pumped hydroelectric facilities utilize excess power from the base source (wind power) to power pumps that lift water into an elevated reservoir. Later, when wind power is insufficient, the water can be released through turbines to generate electricity as a backup source. Pumped hydroelectric is relatively efficient, losing only about 20% of the energy in the conversion process of lifting water and another 20% or so when the water is released to generate electricity. The total efficiency loss for charge and release is in the neighborhood of 40%.

Obviously, this loss of energy must be additionally compensated for with more excess generating output from the wind power source. This added capacity is, in addition to the oversized generation requirement, already required for charging the backup power generating facilities.

In this example of a conceptual stand-alone wind energy system, the wind energy output could easily require four times the output of a comparable conventional plant using coal, natural gas, or nuclear energy. Because wind (and solar) power are not power dense, i.e., they require many times more space for the same amount of electric output, the space required would be multiplied by some four times over the already extensive space required. It should be noted that a capacity factor of 33% used in the above example is generous: the capacity factor of wind power projects usually claimed by proponents as 30% or higher, when actual world average data shows it to be 20% or lower.[3] Additionally, the project life of conventional electric power generation facilities is on the order of 40 years or more, but realistic analysis of industrial wind turbines indicates a life of 20 years, only half as long. Also, while 90% of all wind turbines are located in the Great Plains regions because of more favorable winds, transmitting their energy long distances to high population centers further increases infrastructure costs while further reducing the capacity factor available at the customer's electric meter.[4]

The example provided is for wind energy, but solar power facilities have many of the same inherent limitations requiring massive oversizing to compensate for a low capacity factor for stand-alone systems in both output and space. Renewable energy power facilities typically require as much as ten times more space than conventional power sources.[5] It can be seen from the example that without conventional power plants to back them up, renewable energy power facilities cannot be economically justified as a source of continuously reliable electricity.

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[3] De Wachter, Bruno, "The Capacity Factor of Wind Power," Leonardo Energy, Last modified December 6, 2008. www.leonardo-energy.org/capacity-factor-wind-power.

[4] Post, Willem, "Energy from Wind Turbines Actually Less Than Estimated?" The Energy Collective. Last modified January 10, 2013. http://theenergycollective.com /willem-post/169521/wind-turbine-energy-capacity-less-estimated.

[5] Ausubel, J., "The Future Environment for Energy Business." *Presentation to Australian Petroleum Production and Exploration Association* (April 2007), 94. http://phe.rockefeller.edu/docs/ausubelappea.pdf

Stand-alone electric power generation using renewable energy technology is not economic or scalable on a reliable basis. Clearly, stand-alone electric power from renewable sources does not work, i.e., it is not viable.

Does Wind/Solar Power Reduce Capital Investments?

As pointed out, because of its intermittent nature, for the power grid to provide reliable power every hour of every day, wind and solar must be backed up–every megawatt of wind/solar power must have a matching conventional source. For this reason, it is obvious that wind/solar power sources do not reduce the amount of installed conventional capital investment but add to it. Wind/solar sources do not provide a reduction in capital investment but generate an increase while adding nothing to the overall power supply capacity.

Can Wind or Solar Power Reduce CO_2 Emissions?

The case could be argued that even though renewable energy is not viable as a stand-alone system and does not reduce capital cost it could be used in tandem with conventional power sources to reduce CO_2 emissions. To justify the use of renewable power on this basis would require acceptance of the belief that CO_2 emissions are sufficiently harmful to compensate for the additional expenditures that would be required. The net benefit or harm of additional CO_2 notwithstanding, this argument to justify the viability of renewable power should be examined on its own merits.

Although both wind and solar are considered as renewable energy power supplies for electricity, because of the far higher cost of solar power as compared to wind power, most of the installed renewable electric power generation capacity has been from wind. Consequently most available data comparing renewable sources to conventional sources refers to installed capacity from wind. Solar power is expected to remain small compared to wind power as a supply for the electric grid for the foreseeable future.

When wind power becomes unable to meet the demands of the grid, conventional power must be ready to take up the slack. Conventional power plants that normally provide reliable base load electricity tend to be more efficient, but have higher capital costs. These plants typically require lead times of as much as 24 hours to be ready to provide power, or alternatively they must be kept on line in "hot spinning reserve." It should be noted that in hot spinning reserve, a power plant is using fuel to be ready, but is producing no electricity.

Power sources that can be quickly turned on to meet power demands are called "dispatchable." Two types of highly dispatchable electric power generation are hydro-power and natural gas fired turbine generators. Both these sources can be brought to full power within minutes. But hydro-power is quite limited as a source–there is not enough of it–and used solely as a power source, it takes an enormous amount of land space so it can only supply back-up power in a small percentage of cases.[6]

With the far greater supply of low-cost natural gas in recent years, gas-fired turbine generators have been increasingly utilized as peaking power stations. These gas turbine generators make ideal backup power sources for wind because they can be quickly brought to full power and subsequently shut down as wind power rises and falls.

Power plants specifically intended as backup sources typically have lower capital costs–an advantage–but they are considerably less efficient. The frequency of cycling gas turbine generators on and off to back up wind generators adds to their already lower power efficiency and results in more gas consumption than if there were no wind turbines at all. In an analysis of gas turbines for backup of wind power systems, Kent Hawkins found that "wind power is not an effective CO_2 mitigation strategy because of the inefficiencies introduced by fast-ramping (inefficient) operation of gas turbines."[7]

So while natural gas-fired turbine generators are the most suitable back-up power supply available for wind generators because of their economics and dispatchability, they are unable to reduce the amount of CO_2 emissions. Other more efficient power supplies are not suitable because of the far higher capital costs and lack of dispatchability.

It is a basic assumption of the Intergovernmental Panel on Climate Change that each unit of energy supplied by non-fossil-fuel sources takes the place of a unit of energy supplied by fossil fuel sources, but is this true? A study specifically addressed this assumption and found that for electricity,

[6] Ausubel, J. "The Future Environment for Energy Business."

[7] Hawkins, Kent. "Wind Integration: Incremental Emissions from Back-Up Generation Cycling, Part 1," *MasterResource.org* (November 13, 2009).

non-fossil-fuel sources displaced less than one-tenth of a unit of fossil fuel generated electricity.[8]

Wind power utilization is not an effective strategy for reducing CO_2 emissions. Solar power would have the same limitations as shown above, but at significantly higher cost than wind power.

Load Balancing

Operating electric power generation requires constant monitoring of electric power demand in the grid. Power supply must be adjusted to meet the rise and fall of demand—hourly, daily, seasonally, and when unusual demand occurs. The grid voltage must constantly be maintained within a certain range to avoid "brown-outs" from low voltage as well as damage caused by too-high voltage. If the power supply is not adequate to maintain voltage in the system the utility operators must shut down part of the grid, producing "rolling blackouts."

For the system to have reliable capacity at all times it must be able to promptly ramp up generating power to meet demand. Matching the power supply to the power demand is called "load balancing" and it is an essential requirement of a reliable power supply system.

Load balancing is not difficult as long as the power supply is ample and reliable. To a degree, the demand of an electric grid can be predicted from knowledge of daily and seasonal records and from weather predictions, so operators can anticipate upcoming high and low demands.

Unpredictability on the power supply side of the equation is more difficult to manage. When a given power supply source is intermittent and somewhat unpredictable, as with wind, its variations can be compensated for as long as that source is a small segment of the overall supply network. Reliance upon wind power tends to introduce more chaos into the system's operation as its share of the total power input increases. With an unreliable source as a major portion of a system's power supply, consistent load balancing becomes virtually impossible without corresponding installed dispatchable backup power. As we have seen above, having these dispatchable backups on standby, available to quickly phase in and out,

[8] York, R., "Do Alternative Energy Sources Displace Fossil Fuels?" *Nature Climate Change* 2 (2012): 441-443.

eliminates any energy saving economics, and operation of such a system does not reduce the overall amount of CO_2 emitted.

Although wind and solar power are promoted as acceptable alternatives for electric power generation, they do not meet the imperatives of power density, cost, scalability, and reliability. These renewable energy sources do not save on capital costs or reduce carbon dioxide emissions serving the demand of the grid, either on a small or large scale. Renewable energy for electricity from wind or solar is not viable.

Evaluating Renewable Energy for Transportation

As previously stated, if renewable energy is truly viable, then it must be good enough to replace conventional energy sources. If it cannot do this, then it is not viable. Conventional transportation energy sources are gasoline, diesel, jet fuel, and compressed natural gas. All these fuels are derived from oil and gas.

Renewable fuels are those that have, at least in theory, an unlimited supply. These include ethanol, biodiesel, and hydrogen.

Similar to the evaluation of electric power generation, there are certain imperatives that any "viable" energy source must meet. Energy density, cost, and scalability are three such imperatives. The conventional transportation fuels listed above obviously meet these imperatives because they are currently in wide use, but several of the renewable sources do not.

Hydrogen, the lightest element, does not meet the requirement for energy density. In theory, a high pressure tank could be proposed for vehicles, but cost and safety factors are questionable. The principal current source for hydrogen is by synthesis from natural gas, but using this source would eliminate hydrogen as a "renewable" inasmuch as natural gas is a fossil fuel and is itself finite. Hydrogen can be produced from water by electrolysis, but the process is very energy intensive. Reliable cost data for hydrogen as a transportation fuel are not readily available, but its inability to meet the imperative of energy density eliminates hydrogen as a viable candidate to replace or supplant fossil fuels in the foreseeable future.

Bio-diesel has been produced from waste vegetable oils and on a small pilot plant scale from algae. Aside from its questionable cost competitiveness, bio-diesel as a viable transportation fuel is eliminated by scalability: there is not a sufficient supply of waste vegetable oil (or even waste petroleum oil) to provide the feedstock necessary to produce the millions of barrels per day that would be required to replace even a partial segment of conventional fuels. Producing bio-diesel from algae has been done on an experimental basis, but it is far from proven as cost effective or scalable.

This leaves ethanol as the remaining renewable transportation fuel candidate. Ethanol obviously has some capabilities as a transportation fuel inasmuch as it is widely used as an additive to gasoline in today's motor fuels.

Despite its use as an additive to gasoline, ethanol has some significant disadvantages. The first disadvantage has to do with energy density. Ethanol has about two-thirds the energy density of gasoline, so for the same size fuel tank it has a shorter range before refueling is necessary.

Cellulosic ethanol can be produced from switchgrass, and organic wastes from forestry and agriculture, but these feedstock sources are simply too limited to produce sufficient quantities to meet a significant portion of transportation energy needs. Switchgrass planted on less desirable land has been proposed as an ethanol feedstock, but ethanol from corn planted on prime farmland produces a much higher output per acre of land.[9]

It takes energy to produce energy. The production of fossil fuel energy is very efficient in that it requires the equivalent of 1 barrel of oil to produce up to 10 barrels of refined products.[10] Other fossil fuels are similarly highly efficient in producing much more energy than they consume.

Biofuels, on the other hand, do not appear to be energetically very efficient.[11] There is considerable debate over whether biofuels can yield significantly more energy than they consume to be produced or whether

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[9] Bryan B., D. King, and E. Wang. "Biofuels Agriculture: Landscape-Scale Trade-Offs between Fuel, Economics, Carbon, Energy, Food, and Fiber," *Global Change Biology Bioenergy* 2 (2010): 330-345.

[10] Energy Information Administration. "Performance Profiles of Major Energy Producers." 2009. *Independent Statistics and Analysis, Tables 10, 11, 12,* (reviewed January, 2014).

[11] Gomiero, T., M. G. Paoletti, and D. Pimentel, D., "Biofuels: Efficiency, Ethics, and Limits to Human Appropriation of Ecosystem Services," *Journal of Agricultural and Environmental Ethics* 23 (2010): 403-434.

they are actually net energy consumers. Corn ethanol in particular may require 70% more nonrenewable energy consumed than the energy content of ethanol produced.[12] It should be kept in mind that corn ethanol is produced largely by using fossil fuels–diesel, gasoline, and non-renewable generated electricity–not by using ethanol.

Within engines, fossil fuels are mechanically friendly in that they tend to lubricate the metal surfaces they contact. By contrast, ethanol is very corrosive and this produces added degradation, wear and tear on the metal parts they contact.

Because ethanol is semi-polar, it is very hydrophilic and will readily dissolve in, or absorb water. This condition greatly adds to its transport and storage costs. It cannot be transported by pipeline because it absorbs water as it moves along, which dilutes the ethanol and corrodes the pipe. It must be transported by special trucks and its handling and storage are more complex. Ethanol is only blended into gasoline as a final step before delivery to service stations.

Corn ethanol competes with corn produced for food. Inasmuch as the U.S. produces some 40% of the world's corn, this has important implications. But the fuel versus food competition problem extends far beyond just the impact upon corn production. To produce more fuel from biomass would cause a severe impact on other food commodities.[13] Biofuel production cannot, in any significant degree, improve the energy security of developed countries because it would require so vast an allocation of land that it would crowd out a multitude of land uses.[14]

Ethanol is limited in its role as a transportation fuel. Although it is proposed as a replacement fuel for gasoline, growth in gasoline consumption is essentially flat because of steadily increasing efficiency in fuel economy in passenger autos. The two fastest growing sectors of transportation fuels are diesel and jet fuel. Over 90% of the goods shipped

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[12] Yang, Q. and G. Q. Chen. "Nonrenewable energy cost of corn ethanol in China." *Energy Policy* 41 (2012): 340-347.

[13] Johansson, D., and C. Azar. "A Scenario Based Analysis of Land Competition between Food and Bioenergy Production in the U.S." *Climatic Change* 82 (2007): 267-291.

[14] Gomiero, T., M. G. Paoletti, and D. Pimentel, D., "Biofuels: Efficiency, Ethics, and Limits to Human Appropriation of Ecosystem Services."

in the U.S. are transported by diesel-powered vehicles.[15] Jet aircraft can fly higher and faster than gasoline-powered aircraft because of the energy density of jet fuel. Ethanol cannot replace these two fuels.

As with wind energy for electricity, ethanol has been promoted as a means of reducing greenhouse gases. But similar to the case of wind energy for electricity, it does not. Ethanol as a transportation fuel does not reduce greenhouse gas emissions, and its use may actually increase emissions.[16]

A level playing field cost comparison of ethanol with conventional fuels is very difficult to obtain. Because of government subsidies and mandates for ethanol its true market cost is distorted. Nevertheless, because of its many disadvantages, ethanol is considered very expensive compared to gasoline.[17]

For the numerous reasons cited above it is clear to see that ethanol, the leading contender as a renewable transportation fuel, is not viable. Compared to gasoline it is more expensive, corrosive, more difficult to transport and store, less energy dense, and its scalability is limited.

Only conventional transportation fuel sources are viable, i.e., those derived from fossil fuels. Despite the determined efforts of environmental advocates to reduce or eliminate their use, these conventional fuels will continue to be the dominant choices to power the needs of human beings for the foreseeable future.

Googling Renewable Energy

In 2007 Google corporation undertook an in-depth program known as RE<C to make renewable energy viable, but after four years their engineers declared it a complete failure. "At the start of RE<C, we had shared the attitude of many stalwart environmentalists: We felt that with steady improvements to today's renewable energy technologies, our society could

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[15] U.S. Energy Information Administration, "Diesel–A Petroleum Product," *Encyclopedia of Energy Basic,* U.S. Energy Information Administration (2009).

[16] Jaeger, W. and T. Egelkraut. "Biofuel Economics in a Setting of Multiple Objectives and Unintended Consequences." *Renewable and Sustainable Energy Reviews* 15 (2011): 4320-4333.

[17] Dirksen, J., "Ethanol: Bumper Crop for Agribusiness, Bitter Harvest for Taxpayers," *Policy Paper #121,* National Taxpayers Union (2006).

stave off catastrophic climate change. We now know that to be a false hope." Google engineers Ross Koningstein and David Fork observed that renewable energy sources were not economically competitive or continuously reliable, and "can't provide power that is both distributed and dispatchable." They also noted: "Trying to combat climate change exclusively with today's renewable energy technologies simply won't work; we need a fundamentally different approach".[18]

Being Green

This article's title asks, "Is Renewable Energy Viable?" but another relevant question should be, "Is Renewable Energy Really Green?" Being "green" means leaving a small and lightweight footprint on the earth, i.e., minimally intrusive on the landscape, leaving more of the land undisturbed and unoccupied by energy production. But the energy options that are most actively promoted–wind, solar, and ethanol–are incredibly invasive in terms of land sprawl.

Gomiero points out, "there is not enough readily available land to produce much fuel from biomass without causing a severe impact on global food commodities" and continues, "…even allocating the entire USA cropland and grassland to biofuels production, the energy supply will account for only a few percentage points of the USA energy consumption."[19] Choosing to devote a major portion of our cropland to biofuels means we will not have much left to raise food.

Photovoltaic cells sufficient to power New York City would require an area the size of Connecticut.[20] If wind power were used instead, the area would be over five times bigger. This is without including backup power for the inevitable periods of insufficient sunlight and/or wind.

Conventional energy sources have very high power density and energy density factors. They produce a lot of energy, but require only a relatively

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[18] Koningstein, Ross, and David Fork. "What It Would Really Take to Reverse Climate Change," Last modified Nov 18, 2014. http://spectrum.ieee.org/energy/renewables/what-it-would-really-take-to-reverse-climate-change

[19] Gomiero, T., M. G. Paoletti, and D. Pimentel, D., "Biofuels: Efficiency, Ethics, and Limits to Human Appropriation of Ecosystem Services."

[20] Ausubel, J. "The Future Environment for Energy Business."

small amount of land. Renewable energy takes up a lot of space. It is not viable and is not even green.

How Long Can Conventional Energy Last?

Regardless of the current viability of today's store of energy reserves, all conventional energy sources are finite and will eventually be consumed to economic extinction.

"Peak Oil" is a term that describes the point at which oil production has been surpassed by demand, and the price of oil begins to rapidly escalate as its use inevitably declines. "Peak Oil" was first predicted to occur in the late 1970's, yet technology has repeatedly pushed this date back again and again as better ways were discovered to find and extract oil reserves. With U.S. oil supply currently rising, Peak Oil is not on the immediate horizon, but undeniably it will someday arrive. What will happen then?

Oil yields most of our liquid fuels, but there are similar liquid fuels that can be produced from coal, natural gas, and oil shale. Natural gas-to-liquids (GTL) and coal-to-liquids (CTL) technology can produce diesel and jet fuel from these resources. Kerogen-derived synthetic oil can be produced from oil shale reserves. Current U.S. estimated recoverable oil shale resources are 982 billion barrels exceeding the oil reserves of Saudi Arabia by over three times.[21]

In energy equivalents, traditional oil–although the most useful–is the least abundant of all fossil fuels. There is at least a 200 year supply of natural gas and perhaps as much as ten times as much coal as oil reserves.[22] Coal reserves can be greatly augmented beyond current reserves by the use of underground coal gasification (UCG). This technology extracts energy from coal deposits too deep or dispersed to otherwise be economically useful and can expand the already massive coal reserves by 3-4 times.

[21] U.S. Geological Survey. "Oil Shale and Nahcolite Resources of the Piceance Basin, Colorado," (Oct. 2010): 1. http://pubs.usgs.gov/dd/dds-069/dds-069-y/; Whitney, Gene, Carl E. Behrens, Carol Glover., "U.S. Fossil Fuel Resources: Terminology, Reporting, and Summary." Congressional Research Service report 7-5700, R40872. (Nov.30, 2010):10-11.

[22] Yang, Q. and G. Q. Chen. "Nonrenewable energy cost of corn ethanol in China." *Energy Policy* 41 (2012): 340-347; Smith, Robert P. "ENERGY–Present and Future: Common Sense for Concerned Americans. (2009). http://icecap.us/images /uploads/Energy_Final_5-1-09.pdf

There are sufficient "proved" fossil fuel reserves at current usage rates to supply the world for at least several hundred years, and sufficient "economically recoverable resources" for at least 500 years or more.[23]

When those fossil fuels have been exhausted, there remains even more hydrocarbon reserve, methane hydrate. Methane hydrates exist in the seabed along coastlines around the world. Technology does not currently exist for the economic recovery of methane hydrates, but there are hundreds of years of time for the necessary discoveries. Japan, Germany, China, India, and the U.S. have small research efforts underway to explore and research methane hydrate technology. Methane hydrate reserves are massive and estimated to equal a 2,000 year supply of natural gas.[24]

It can be seen that, although the mix and formulation of liquid transportation fuels may change in future decades, with more reliance upon diesel instead of gasoline, continued improvements in vehicle efficiency, greater use of electric autos, etc., fossil fuels are still going to be with us for a long, long time. The cost of conventional fuels may continue to increase, but even at higher cost, conventional liquid fuels will still be the best option for a large segment of transportation and the hydrocarbons required for petrochemical feedstock.

What about Electricity?

In time, probably several generations into the future, the cost of traditional oil will inevitably rise as it is depleted forcing increasing use of synthetic liquid fuels from coal and natural gas for transportation and petrochemical feedstock. Also, economics will push toward greater and greater use of electricity in order to conserve fossil fuels for our transportation energy needs.

How can electric power generation be increased even as electricity from fossil energy is decreased? The answer is that nuclear power will have to be stepped up to provide that electricity. So we must ask, "Is nuclear power viable as our principal producer of electricity?" Indeed it is.

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[23] Institute for Energy Research, "North American Energy Inventory," December 2011, pp III, VI, 5. www.energyforamerica.org/inventory.

[24] Margonelli, L., "An Inconvenient Ice," *Scientific American* (October 2014): 83-89.

Nuclear power plant construction cost is expensive–more so than either highly efficient coal or natural gas plants. Long term, however, there is an inevitable tradeoff. Fuel for nuclear reactors is but a fraction of the cost of coal or gas.[25] Over an extended project life cycle, nuclear power is as cheap as current fossil fuel plants.[26]

One reason nuclear power is more expensive in the U.S. is the failure to standardize both reactor design and specifications for site construction. When each plant is a "one-off" design, construction costs are far higher, and the time and expense of securing construction permits and operating licenses from government agencies is significantly greater. France, which has been a world leader in nuclear power utilization, has greatly reduced its construction and operation costs by standardization. As nuclear power expands its role in electricity generation and design standardization becomes standard practice, the overall life cycle cost per megawatt of power will come down.

The deadly tsunami in Japan and the resulting damage to the Fukushima nuclear plant caused its failure and became a widely reported story. Despite the high cost to Japan to clean up the site, no deaths were attributed nor are any additional radiation illnesses or deaths anticipated.[27] The Fukushima plant was old and had never been refurbished or modernized. New nuclear plant designs, such as the Generation III technologies, include advanced safety features. These are designed to prevent a meltdown or any loss of radiation products even in the case of significant damage or sudden power interruption.

Questions might be posed as to the extent of nuclear fuel reserves and how spent nuclear fuel is managed. Spent nuclear fuel does not require much storage space. It can be safely stored under several feet of water, and the entire volume of spent fuel in the U.S. to date would only fill the space of a football field several feet deep.

Spent nuclear fuel can be reprocessed into usable fuel and consumed in reactors designed for this purpose. For conventional nuclear reactors, there

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[25] Robert Bryce, *Power Hungry* (PublicAffairs 2010), 4.

[26] "Projected Costs of Generating Electricity," IEA/OECD (2010):12-14.

[27] Brumfiel, Geoffrey. "World Health Organization Weighs in on Fukushima." *Nature Journal* Last modified May 23, 2012. blogs.nature.com/news/2012/05/world-health-organization-weighs-in-on-fukushima.html.

is sufficient reserve for several hundred years from known deposits. A virtually limitless supply of uranium is contained in seawater, from which it can be extracted. For fast reactors utilizing reprocessed spent nuclear fuel, there are reserves for thousands of years.[28]

Nuclear power has versatility for expanded applications. The use of nuclear powered submarines and warships over many decades has proven that smaller reactors in ocean vessels can safely utilize nuclear power for industry and commerce. Small Modular Nuclear Reactor (SMNR) technology has been developed to provide for much smaller power plants. SMNR reactors are compact enough for the components to be manufactured at a central site and delivered to the operating site on a conventional tractor-trailer rig. For safety and efficiency the entire power plant can be installed underground. These SMNR units can be used for powering remote industrial sites or for distributed installation throughout metropolitan or suburban service areas.[29] They are designed to be fail-safe. One of the main advantages of the SMNR concept is that, with distributed power generation throughout the service area, a total power failure over a large area is less likely than when populations are served from a single large centralized power plant.

Finally, as a potential solution to the continuing need for hydrocarbons when all earth's economically-recoverable reserves have been extracted, nuclear power may come to the rescue. Researchers at the U.S. Naval Research Laboratory (NRL) have demonstrated a process for recovery of CO_2 and hydrogen from seawater and its subsequent conversion to liquid hydrocarbon fuel. The NRL has developed a "carbon capture and hydrogen stripper" device to extract CO_2 and hydrogen from seawater. The concentration of dissolved carbon dioxide in seawater is 140 times that of the atmosphere, so harvesting CO_2 is far more efficient than from air. Following capture of the gases, a patented catalytic process is used to produce longer-chain unsaturated hydrocarbon by-products which become feedstock for the subsequent formation of industrial petrochemicals and designed liquids including jet fuel. This pilot plant scale facility is producing fuel that has successfully powered an internal combustion model airplane. Predicted cost of jet fuel from this process is in the range of $3-$6

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[28] Hopf, J., "World Uranium Reserves." *American Energy Independence*. (November 2004): 3-4. www.americanenergyindependence.com/uranium.aspx/uranium.aspx.

[29] "Small Modular Nuclear Reactors." http://energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors.

per gallon. The entire process can be powered by the nuclear power plant on an aircraft carrier. The research project was initially conducted to develop a process to self-provide fuel for aircraft on board an aircraft carrier.[30]

While the goal of the process was to be able to self-provide aircraft fuel on carriers at sea, it has very important implications for much wider application to the ongoing production of hydrocarbons in the future. The process appears to offer a cost-effective method for production of hydrocarbons for transportation needs at a future time when all earth's economically-recoverable fossil fuels have been extracted and consumed. If the process continues to improve in efficiency and cost-effectiveness, it may supplant and replace traditional oil and gas production before those fossil fuels are even exhausted.

At the very least, this fuel-from-seawater process, paired with nuclear power, could provide the means for generating of electricity and producing liquid fuels and petrochemical feedstock almost without limit into the future. Both of these alternatives appear to meet the imperatives of energy density, power density, cost, scalability, and reliability. That is to say, they are viable.

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[30] NRL. "Scale Model WWII Craft Takes Flight With Fuel From the Sea Concept." U.S. Naval Research Laboratory. April 7, 2014. Accessed December 10, 2014. http://www.nrl.navy.mil/media/news-releases/2014/scale-model-wwii-craft-takes-flight-with-fuel-from-the-sea-concept.

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