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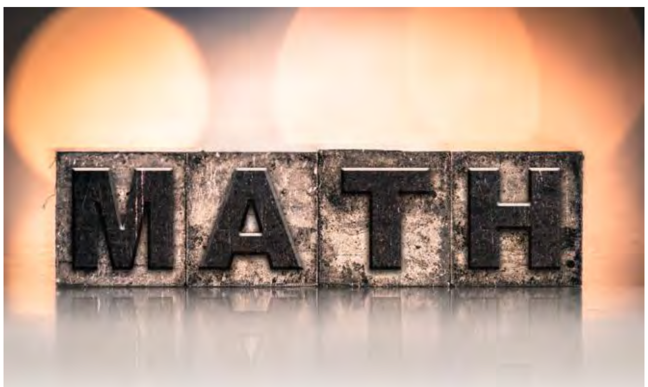

WHY RENEWABLE ENERGY CANNOT REPLACE FOSSIL FUELS BY 2050

A REALITY CHECK

BY ROBERT LYMAN

ENERGY ECONOMIST

Humanity is owed a serious investigation of how we have gone so far with the decarbonization project without a serious challenge in terms of engineering reality.

– Michael Kelly, Prof. Electrical Engineering, Cambridge

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May 30, 2016

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WHY RENEWABLE ENERGY CANNOT REPLACE FOSSIL FUELS BY 2050

Contributed by Robert Lyman © May 2016

EXECUTIVE SUMMARY

Robert Lyman is an energy economist with 27 years' experience and was also a public servant and diplomat.

A number of environmental groups in Canada and other countries have recently endorsed the "100% Clean and Renewable Wind, Water and Sunlight (WWS)" vision articulated in reports written by Mark Jacobson, Mark Delucci and others. This vision seeks to eliminate the use of all fossil fuels (coal, oil and natural gas) in the world by 2050. Jacobson, Delucci et. al. have published "all-sector energy roadmaps" in which they purport to show how each of 139 countries could attain the WWS goal. The purpose of this paper is to examine whether the 100% goal is feasible.

While a range of renewable energy technologies (e.g. geothermal, hydroelectric, tidal, and wave energy) could play a role in the global transformation, the world foreseen in the WWS vision would be dominated by wind and solar energy. Of 53,535 gigawatts (GW) of new electrical energy generation sources to be built, onshore and offshore wind turbines would supply 19,000 GW (35.4%), solar photovoltaic (PV) plants would supply 17,100 GW (32%) and Concentrated Solar Power plants (CSP) would supply 14,700 GW (27.5%). This would cost $100 trillion, or $3,571 for every household on the planet.

Western Europe has extensive experience with investments in renewable energy sources to replace fossil fuels. By the end of 2014, the generating capacity of renewable energy plants there was about 216 GW, 22% of Europe's capacity, but because of the intermittent nature of renewable energy production, the actual output was only 3.8% of Europe's requirements. The capital costs of renewable energy plants are almost 30 times as high as those of the natural gas plants that could have been built instead; when operating costs are also taken into account, onshore wind plants are 4.6 times as expensive as gas plants and large-scale PV plants are 14.1 times as expensive as gas plants. Wind and solar energy is not "dispatchable" (i.e. capable of varying production quickly to meet changing demand), which results in serious problems – the need to backup renewables with conventional generation plants to avoid shortfalls in supply, and the frequent need to dump surplus generation on the export market at a loss. The current energy system in the United States, Canada and globally is heavily dependent on fossil fuels – they generally supply over 80% of existing energy needs in developed countries and over 87% in the world as a whole. Currently, wind and solar energy sources constitute only one-third of one per cent of global energy supply.

The financial costs of building the 100% renewable energy world are enormous, but the land area needed to accommodate such diffuse sources of energy supply is just as daunting.

Accommodating the 46,480 solar PV plants envisioned for the U.S. in the WWS vision would take up 650,720 square miles, almost 20% of the lower 48 states. This is close in size to the combined areas of Texas, California, Arizona, and Nevada.

A 1000-megawatt (MV) wind farm would use up to 360 square miles of land to produce the same amount of energy as a 1000-MV nuclear plant.

To meet 8% of the U.K.'s energy needs, one would have to build 44,000 offshore wind turbines; these would have an area of 13,000 square miles, which would fill the entire 3000 km coastline of the U.K. with a strip 4 km wide.

To replace the 440 MW of U.S. generation expected to be retired over the next 25 years, it would take 29.3 billion solar PV panels and 4.4 million battery modules. The area covered by these panels would be equal to that of the state of New Jersey. To produce this many panels, it would take 929 years, assuming they could be built at the pace of one per second.

The WWS roadmap for the U.S. calls for 3,637 CSP plants to be built. It would be extremely difficult to find that many sites suitable for a CSP plant. Packed together, they would fill an area of 8,439 square miles, about the area of Metropolitan New York. They would require the manufacture of 63,647,500 mirrors; if they could be manufactured one every ten seconds, it would take 21 years to build that many mirrors.

A central component of the WWS vision is the electrification of all transportation uses. This is technically impossible right now, as the technologies have not yet been developed that would allow battery storage applicable to heavy-duty trucks, marine vessels and aircraft. Even in the case of automobiles, despite taxpayer subsidies of $7,500 per vehicle and up, the number of all-electric vehicles sold has consistently fallen far short of governments' goals.

The costs of electrifying passenger rail systems are so high that no private railway would ever take them on. Electrification of a freight railway system makes even less sense, and would cost at least $1 trillion each.

The diversion of crops to make biofuels already is raising the cost of food for the world's poor. The World Resources Institute estimates that if this practice is expanded, it will significantly worsen the world's ability to meet the calorie requirements of the world's population by 2050.

Scientists and governments have been guilty of the "Apollo Fallacy"; i.e. of thinking that the space race is a model for the development of renewable energy. The Apollo program cost billions of dollars to demonstrate U.S. engineering prowess during the Cold War; costs, and commercial considerations, were secondary considerations, if they counted at all.

The proponents of WWS grossly under-estimate the costs of integrating renewable energy sources into the electricity system. The additional costs of backup generation, storage, load balancing and transmission would be enormous.

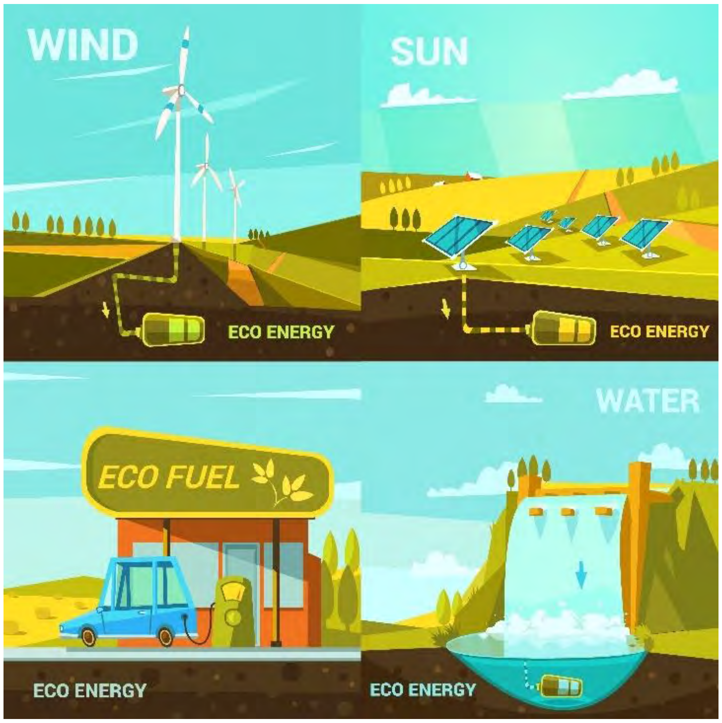
The WWS scenario calls for 39,263 5-MW wind installations in Canada at a cost of $273 billion for the onshore wind generation alone. Building a national backbone of 735 kV transmission lines would cost at least CDN $104 billion and take 20 years to complete.

The WWS includes a call to shut down all coal, oil and natural gas production. It implies the closing of all emissions intensive industries, such as mining, petrochemicals, refining, cement, and auto and parts manufacturing. The political and regional backlash against such policies in a country like Canada would threaten Confederation. In short, the WWS vision is based on an unrealistic assessment of the market readiness of a wide range of key technologies. Attaining the vision is not feasible today in technological, economic or political terms.

WHY RENEWABLE ENERGY CANNOT REPLACE FOSSIL FUELS BY 2050

1 INTRODUCTION

Several prominent environmental groups in Canada and the federal New Democratic Party have endorsed the view that Canada should adopt the goal of "100% Clean and Renewable Wind, Water and Sunlight (WWS) by 2050". This view is shared by environmental groups in other countries.



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Is this goal feasible? Studies by academics and think tanks in the United States and elsewhere have examined the potential for and costs of replacing fossil fuels. The most widely cited of these, and the probable bases for the view that 100% renewables is possible, are the reports done by Mark Jacobsen, Mark Delucci and others at Stanford University. Their studies examine both the United States and the global situation, using similar models and methodologies. Jacobson and Delucci also published a series of "all-sector energy roadmaps" that purport to show how each of 139 countries in the world could attain the WWS goal.

The purpose of this paper is to examine the likely implication of the 100% renewables goal for countries like the United States and Canada.

2 THE CHALLENGE OF REPLACING HYDROCARBONS

Most people are unaware of the vast scope of energy use in the world. The term "cubic mile of oil equivalent energy" (CMO) has become a way of expressing how much energy people use, globally, every year. Today we use about 3 cubic miles of oil equivalent energy per year. Here is a graphic from IEEE Spectrum[1] that sets a context for the following conversation on whether renewables-are-doable.

> *"To obtain in one year the amount of energy contained in one cubic mile of oil, each year for 50 years we would need to have produced the numbers of dams, nuclear power plants, coal plants, windmills, or solar panels shown here."*

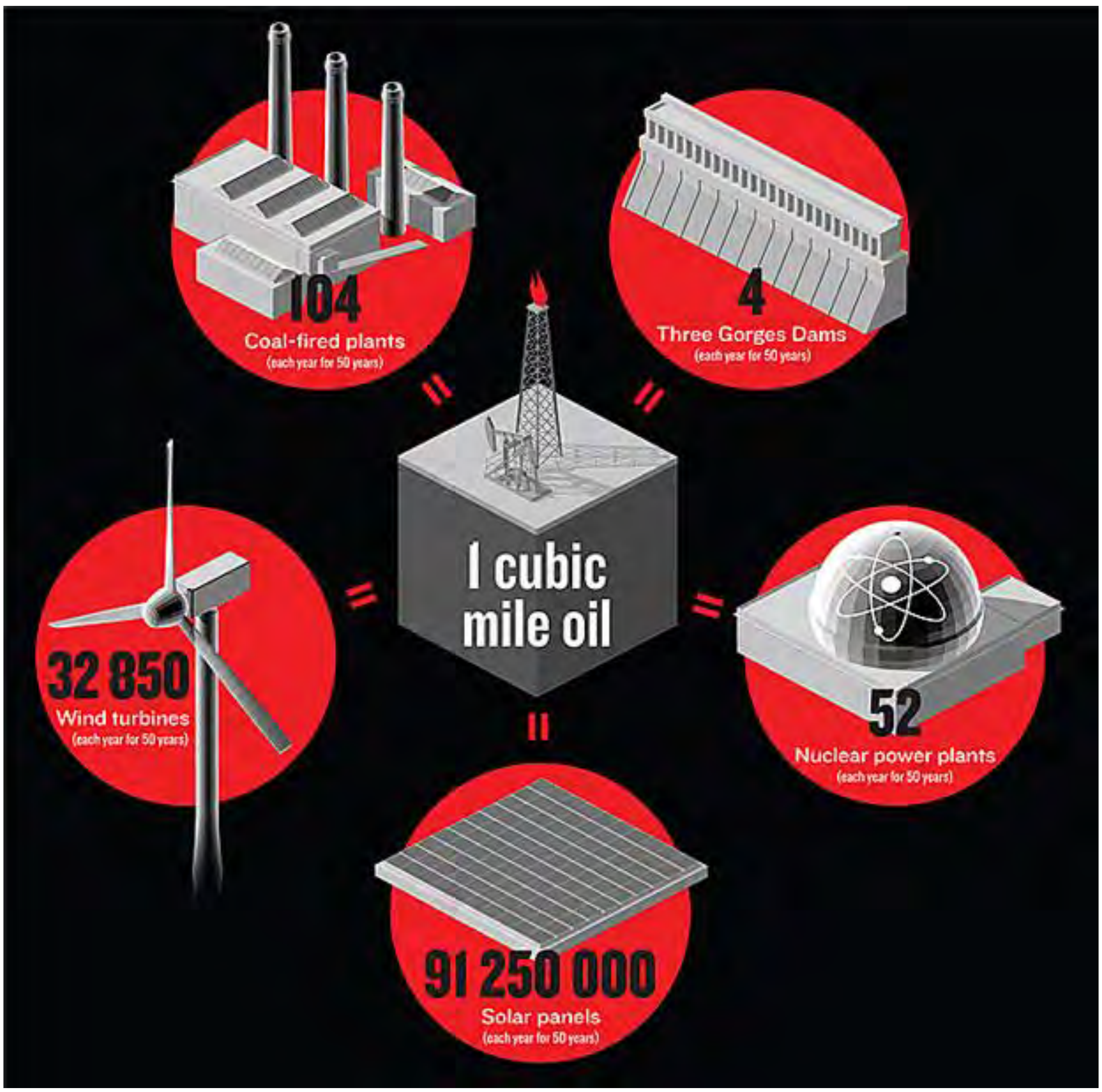

Illustration: Bryan Christie Design

[1] http://spectrum.ieee.org/energy/fossil-fuels/joules-btus-quads-lets-call-the-whole-thing-off

> ***Assumptions:*** *The Three Gorges Dam is rated at its full design capacity of 18 gigawatts. A nuclear power plant is postulated to be the equivalent of a 1.1-GW unit at the Diablo Canyon plant in California. A coal plant is one rated at 500 megawatts. A wind turbine is one with a 100-meter blade span, and rated at 1.65 MW. A solar panel is a 2.1-kilowatt system made for home roofs. In comparing categories, bear in mind that the average amount of time that power is produced varies among them, so that total energy obtained is not a simple function of power rating.*

Since hydrocarbons (oil, natural gas, coal) are energy dense, portable and storable, and they have many useful byproducts that create thousands of spin-off industries, there is no simple way to move from oil, coal and natural gas to 'renewables' – partly because the manufacturing of all renewables also requires massive amounts of fossil fuels and natural resources[2] with proportionately little energy return.

Some basic comparisons of energy density help put things in perspective. Aside from being an intermittent source of energy, wind has very low energy density.

Table 1. Energy densities of different fuels.

Fuel type	Energy density MJ/kg
Wind	0.00006
Battery	0.001
Hydro	0.72
TNT	4.6
Wood	5.0
Petrol	50
Hydrogen	143
Nuclear fission	88250000
Nuclear fusion	645000000

In terms of manufacturing wind and solar devices, development may be constrained by the availability of materials, the cost of mining them, or the reclamation/decommissioning costs. An additional challenge is that even if unit prices of wind and solar devices drop, the costs of integrating wind and solar to the conventional grid and necessary build-out of new transmission lines runs into the billions,

[2] https://openaccess.leidenuniv.nl/bitstream/handle/1887/19740/04.pdf?sequence=27

even for short regional lines. Further, the planning and implementation of transmission lines take time, ranging from 12 to 20 years in the US,[3] suggesting that the WWS vision faces some hard realities.

3 The WWS Vision

The WWS vision calls for converting all energy use (electricity, transportation, heating/cooling, industry, and agriculture/forestry/fishing) to be powered by wind, water and sunlight. It further seeks the closing of all energy production and consumption associated with fossil fuels (i.e. coal, oil and natural gas) and nuclear energy.[4] Jacobson and Delucci propose several measures that governments could take to begin the process of converting the world energy system to WWS starting immediately. As of the end of 2014, they estimate that 3.6% of the WWS energy generation needed for a 100% world has already been installed. Constructing the remaining 96.4% would be an immense task. Their breakdown of the additional global generation capacity needed, in terms of gigawatts (GW), is shown in Table 1. For clarity, "Solar PV" refers to photovoltaic panels, often installed on rooftops or in open areas. "Solar CSP" refers to large concentrated solar power plants.

Table 1

Additional Global Generation Capacity Required (GW)

Technology	**Capacity**
Geothermal	535
Hydroelectric	1,170
Solar (PV)	17,100
Solar (CSP)	14,700
Tidal	490
Wave	540
Wind	19,000

[3] http://geospatial.blogs.com/geospatial/2012/08/transmission-and-cost-could-inhibit-the-continued-expansion-of-renewable-energy-generation.html
[4] https://friendsofsciencecalgary.wordpress.com/2016/05/21/ontarios-climate-plan-vis-a-vis-wws/

The exclusion of nuclear energy from the list of "clean" energy sources cannot be explained by its role in potentially reducing greenhouse gas (GHG) emissions; nuclear energy is emissions-free. The exclusion appears to be based on a political rather than analytical judgment.

Jacobson and Delucci assessed the cost of their projected scenarios in various ways. These are summarized in table 2.

Table 2
ESTIMATED COST OF ADDITIONAL GENERATION CAPACITY
BETWEEN 2013 AND 2030

Level	Total Cost	Cost per Household per year	Loss to GDP
United States	$13 trillion	$5,664	$15.7 trillion
Global	$100 trillion	$3,571	$71.6 trillion

Jacobson and Delucci suggest that one simple way to calculate the costs of adding power generation capacity is to consider that every megawatt (MW) of installed capacity costs an average of about U.S. $2.1 million, across all renewable technologies. For reasons I will explore later in this paper, these estimates are, in fact, quite conservative.

4 Organization of This Paper

To assess the feasibility of attaining a transition to an all-renewable electrical energy system by 2050, this paper will answer the following questions in order.

- What has been the experience to date of countries in Europe that are most advanced in terms of building renewable energy capacity?
- How large a change from the current energy system is being proposed?
- What would be the cost and spatial implications of replacing fossil fuels with current renewable energy technologies?
- Which other factors are likely to limit the feasibility of the WWS vision?
- What would be the consequences for Canada?

5 EXPERIENCE WITH RENEWABLE ENERGY USE IN ELECTRICITY

No region of the world has made larger investments in constructing renewable energy plants to replace fossil fuels than Western Europe. **By the end of 2014, European Union countries had invested approximately 1.1 trillion Euros (CDN $1.63 trillion at current exchange rates) in large-scale renewable energy installations.** This has provided a nominal nameplate electrical generating capacity of about 216 GW, or about 22% of the total European generation needs of about 1000 GW. Nameplate capacity, however, is quite different from electricity generation. Generation is the result of total capacity multiplied by the actual capacity factor achieved. According to the renewables industry itself, the measured output from renewable generation in Europe in 2014 was 38 GW, or 3.8% of Europe's electricity requirement, at a capacity factor of about 18% overall.

Adjusting for capacity factors, the capital costs of these renewable energy installations has been about 29 billion Euros ($CDN $43 billion) per Gigawatt. That capital cost should be compared with conventional natural gas-fired electricity generation costing about one billion Euros (CDN $1.48 billion) per GW. In other words, the capital costs of the renewable energy plants were almost 30 times as high as the capital costs of natural gas plants that could have been built instead.

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Renewable energy generally has lower operating costs than conventional energy generation because of the higher fuel costs of the conventional facilities. If one includes both capital and operating costs, however, renewable energy plant costs are still multiples of what natural gas plants would cost; onshore wind plants are 4.6 times, offshore wind plants are 12.3 times and large scale photovoltaic plants are 14.1 times as expensive as gas plants.

These costs have been imposed on electricity consumers through a variety of means. In almost all cases, European governments provide direct taxpayer subsidies. In some cases, they require electrical utilities to pay higher-than-market rates for renewable energy generation through "feed-in-tariffs". They use regulations to impose mandatory minimum purchases or "first-to-the-grid" rights. The costs of these measures have raised electricity rates for European residential, commercial and industrial consumers to some of the highest in the world, leading to an exodus of some heavy industry and hundreds of thousands of cases of "energy poverty".

The western press often focuses on announcements concerning the growth in nameplate capacity in Europe, but as noted previously, this is a less useful measure than the actual output and the capacity factor. There are simple reasons for the discrepancy between the two measures: night, cloud, and calm. The output of wind and solar generators varies wildly with weather and the time of day; during most hours they produce a small fraction of their nameplate power—or nothing at all.

German solar plants typically operate at a capacity factor of 11%. Production from wind power, despite the construction of hundreds of new turbines, actually declined to 46 TWh in 2012 from the 2011 figure of 48.9 TWh. The capacity factor of German wind is 17 percent. By comparison, fossil-fueled plants can achieve capacity factors of 80 percent or more. And electricity production from Germany's 12 GW of nuclear capacity in 2012 was 99 TWh, a capacity factor of 94 percent. Even though Germany's nuclear nameplate capacity was just one-fifth the size of its solar and wind nameplate capacity, those nuclear plants produced 35 percent more watt-hours of electricity than did all the wind and solar generators put together.

Aggregate generation—the total amount of electricity churned out during a whole year – is only one measure of performance when it comes to electricity. To avoid blackouts and overloads, the electrical grid has to match generation with consumption on a moment-to-moment basis, not on a yearly basis. Since it is difficult and expensive to store electricity on a significant scale, the grid cannot bank much excess electricity production to draw on later during shortfalls; it has to reliably produce all the power demanded each moment, largely from generators then on line.

The difference lies in "dispatchable" generation versus the intermittent energy of wind and solar. "Dispatchable power" provides "on-demand" power from sources like nuclear, coal, gas, hydro, and biomass. These can be command to match output with current electricity demand because they have a consistent fuel source that is controlled at the facility. Wind turbines and photovoltaic panels rely on Mother Nature's whims. The wind is not "always blowing somewhere"[5] [6]as Europe has discovered in a very costly experiment. Wind and solar often go dead when electricity is needed. Often worse, they

[5] http://euanmearns.com/wind-blowing-nowhere/ and http://euanmearns.com/wind-blowing-nowhere-again/
[6] https://friendsofsciencecalgary.wordpress.com/2015/09/29/power-generation-information-on-difficulties-of-instituting-the-proposed-wind-hydro-national-grid-network-in-acting-on-climate-change/

then overproduce when power is not needed. *"These "intermittent" generators result in "common-mode failure": night, winter, summer, and passing weather fronts cause swathes of generators to cease producing all at once, for weeks on end, on a continental and even hemispheric scale. Grid managers dread that kind of catastrophic unreliability, but it is a daily reality for wind and solar."*[7]

Statistics from the pro-renewables Fraunhofer Institute show how dire those common-mode failures can get. Had they been running constantly at nameplate capacity, solar and wind would have produced from 9 to 10.5 terawatt hours (TWh) each week. As reported in Dissent Manage of August 2013, *"during six separate weeks in 2012 they produced less than 9 percent of that nameplate generation for the entire week, and less than 7 percent during three of those weeks. During the week of November 12 to 18, all the wind turbines and solar panels in Germany together produced just 0.51 TWh, generating a mere 3 GW of power on average out of their 63 GW of nameplate capacity—a weeklong capacity factor of just 4.8 percent. And these weekly aggregates leave out many two- and three-day periods when wind and solar slumped even further, generating essentially no electricity at all."*[8]

These numbers raise a sobering question: how would any nation survive – especially Canada with our long winters, short days and desperate cold spells with biting winds and often deep snows or ice storms – how would we survive with wind/solar shut down completely in the dead of winter?

A lake effect snow storm brought five feet of snow to Lancaster, New York on November 18, 2014. Image credit: Melinda Stoldt, via Facebook. https://www.wunderground.com/blog/JeffMasters/buffalo-belted-with-five-feet-of-snow-is-jet-stream-weirdness-to-blam

[7] https://www.dissentmagazine.org/article/green-energy-bust-in-germany
[8] https://www.dissentmagazine.org/article/green-energy-bust-in-germany

The Dissent Magazine article explains that overbuilding capacity won't solve the problem. At the time of writing Germany's annual total electricity consumption was 594 TWh. To try and serve this with renewables, "*Germany would need about 484 GW of wind and solar nameplate capacity, almost eight times as much as it has now. But even this gargantuan over-capacity would have been insufficient during that moribund week in November 2012, when it would have produced just 3.4 percent of Germany's 68 GW or so of electric-power demand."* Expanding capacity creates new problems as trying to fill the slumps with more renewables, means those renewables must have equivalent conventional back-up power from coal, gas, nuclear or hydro. Construction and overhead costs per usable kilowatt-hour will therefore skyrocket.

There are some so-called "dispatchable renewables." These are hydro, geothermal and biomass plants. However, they cannot be scaled up sufficiently, reaching a maximum at about 5 GW each, biomass at perhaps 8 GW. Talk of pumped storage as a savior is also misleading in terms of scale. Dissent reports: "*Germany has about 5 GW of pumped-hydro storage stations, maybe rising to 10 GW over the next few decades, but even generating at full power their small reservoirs would run dry in a day at most. If Germany stays with its current policy of phasing out all nuclear power, that leaves only dispatchable coal- and gas-fired generators to bridge the gap when wind and solar fail to produce."*

In this situation, the risk of repeating cycles of long blackouts throughout the year is very high. Thus every gigawatt of wind and solar average capacity must be backed-up with another gigawatt of gas or coal. Once dispatchable nuclear generators could have backed up this intermittent power, but they are being shuttered. Therefore, coal and natural gas plants cannot be phased-out; more coal plants are being built. The expensive and ironic situation develops of parallel, redundant systems; one designed allegedly to reduce greenhouse gas emissions and be 'clean' – that can only be operated on the grid thanks to the consistent, on-demand power of coal and gas, of which the gas plants emit even more carbon dioxide and other greenhouse gases when 'peaking' to keep up with the sudden surges or drops in renewable wind and solar generation. Thus wind and solar become effectively redundant – an extra layer on a grid that could manage all demand as is, more cost-effectively, reliably, affordably, and with little need for sudden emissions-laden peaking. That is one reason why wind and solar are the highest-cost options available for generating power.

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6 WHAT IS THE SCALE OF CHANGE FROM THE CURRENT ENERGY SYSTEM AS PROPOSED?

To consider this question, we first have to measure the size of the challenge. The U.S. Lawrence Livermore National Laboratory has produced a detailed breakdown, in the form of a flow chart, of the current sources and uses of energy in the United States in 2013. The Laboratory produced a similar flow chart for the world in 2011. The flowing tables summarize current sources of energy use in terms of quadrillion BTU's ("quads") according to these charts.

Table 3
ENERGY SOURCES FOR THE UNITED STATES 2013 (Quads)

Energy Source	Use	Percentage
Petroleum	35.1	36
Natural gas	26.6	27.3
Coal	18	18.5
Nuclear	8.27	8.5
Biomass	4.49	4.6
Hydro	2.56	2.6
Wind	1.6	1.6
Solar	0.32	0.2
Geothermal	0.2	0.2
Totals	**97.4**	**100**

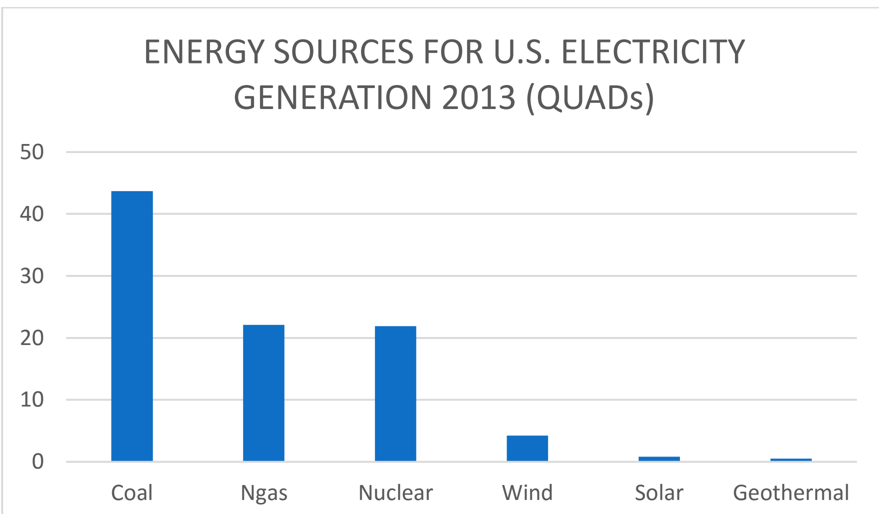
Note that fossil fuels (oil, natural gas and coal) constitute 81.8 %, or more than four fifths, of U.S. energy use, compared to 2.1% (one fiftieth) for the renewable energy sources favoured by environmentalists. Wind, solar and geothermal energy sources barely register today.

The Lawrence Livermore National Laboratory also provides a breakdown of the sources of energy used for electricity generation in the United States. See the results in Table 4.

Table 4
ENERGY SOURCES FOR U.S. ELECTRICITY GENERATION 2013
(QUADs)

Energy Source	Use	Percentage
Coal	16.5	43.7
Natural Gas	8.34	22.1
Nuclear	8.27	21.9
Wind	1.60	4.2
Solar	0.32	0.8
Geothermal	0.20	0.5
Totals	**37.76**	**100**

Note here that fossil fuels (coal and natural gas) constitute 65.8 % of the energy for electricity generation, whereas wind, solar and geothermal sources combined constitute only 5.5%. Reversing this relationship is a tall order indeed.



By percentage

Jacobson and Delucci set out an energy roadmap for the United States that shows the present and proposed capacity of renewable energy generation plants or devices needed to meet the WWS vision.

According to this roadmap, by 2050 almost 90% of energy supply would come from wind and solar energy. The WWS projections are summarized in Table 5.

Table 5
WWS Proposed U.S. Generation System

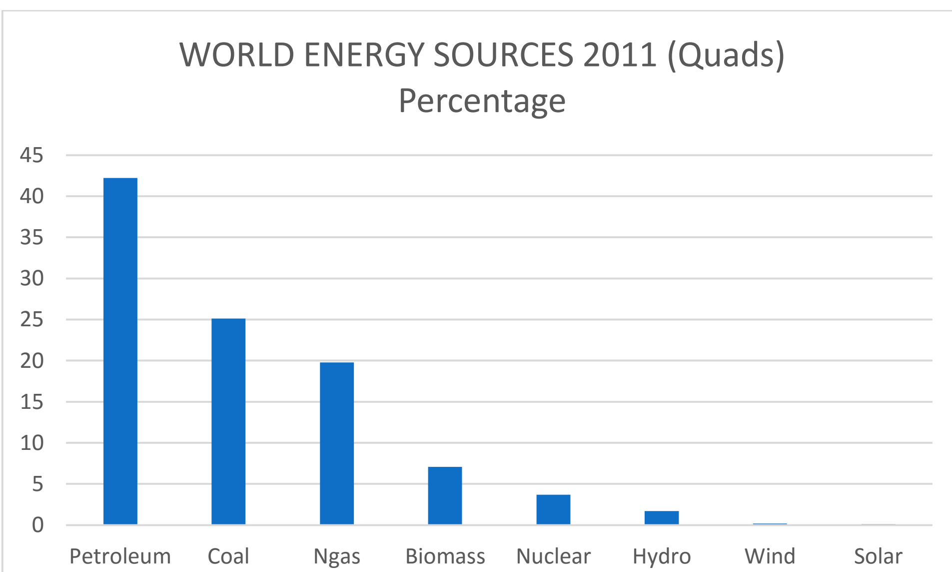
Technology	Target Capacity (MW)	Plants Needed	% of 2050 Load
Onshore wind	1,701,000	328,000	30.9
Offshore wind	780,900	156,200	19.1
Wave device	27,040	36,050	0.4
Geothermal	23,250	208	1.3
Hydroelectric	91,650	3	3.0
Tidal turbine	8823	8823	0.1
Res, roof PV	379,500	75,190,000	4.0
Comm./gov roof PV	276,500	2,747,000	3.2
Solar PV plant	2,326,000	46,480	30.7
Utility CSP plant	227,300	2273	7.3
Sub-total	5,841,000		100
Peaking/Storage			
Additional CSP	136,400	1364	
Solar thermal	469,000		
Total	**6,447,000**		

Table 6 shows the current breakdown of energy uses at the global level. Here, it is important to note that much of the developing world remains dependent on the use of traditional biofuels (wood, peat, and dried animal dung) for heating, lighting and cooking.

Table 6
WORLD ENERGY SOURCES 2011 (Quads)

Energy Source	**Use**	**Percentage**
Petroleum	320	42.2
Coal	190	25.1
Natural Gas	150	19.8
Biomass	54	7.1
Nuclear	28	3.7
Hydro	13	1.7
Wind	1.6	0.2
Solar	1.0	0.1
Totals	**757.6**	**100**

The data on energy use at the global level shows an even more daunting picture of the change being advocated. **Fossil fuels represent fully 87.1% (7/8) of all current energy use, while the renewables favoured in the WWS vision are a miniscule 0.3 %.**



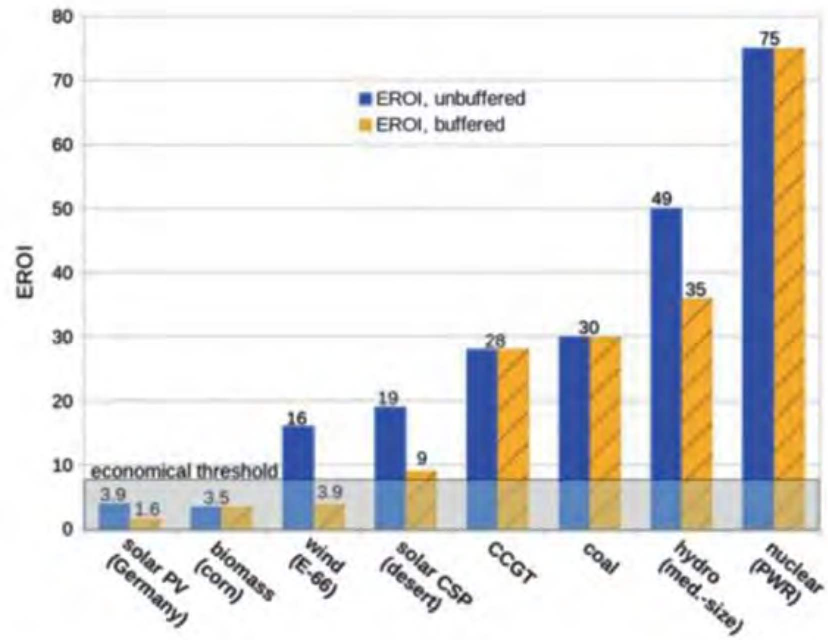


Figure 2. The energy return on energy invested for various forms of energy generation with the threshold for supporting a modern economy indicated across the bottom.[23] The advantages of fossil fuels and nuclear energy are very clear. Reprinted from Ref. 23, with permission from Elsevier.

The above table is taken from *"Lessons from technology development for energy and sustainability"* by M.J. Kelly, Electrical Engineering Division of the University of Cambridge.[9] He points out that to operate a modern society with "international travel and high culture" we need an Energy Return on Investment (EROI) of 10 or more. He gives the example that an Energy Return on Investment of 1 means that we could mine fuel, but then only 'look at it.' As you can see above, four pillars of the WWS proposal do not make the grade. ("Buffered" includes maintenance and all externalized costs.)

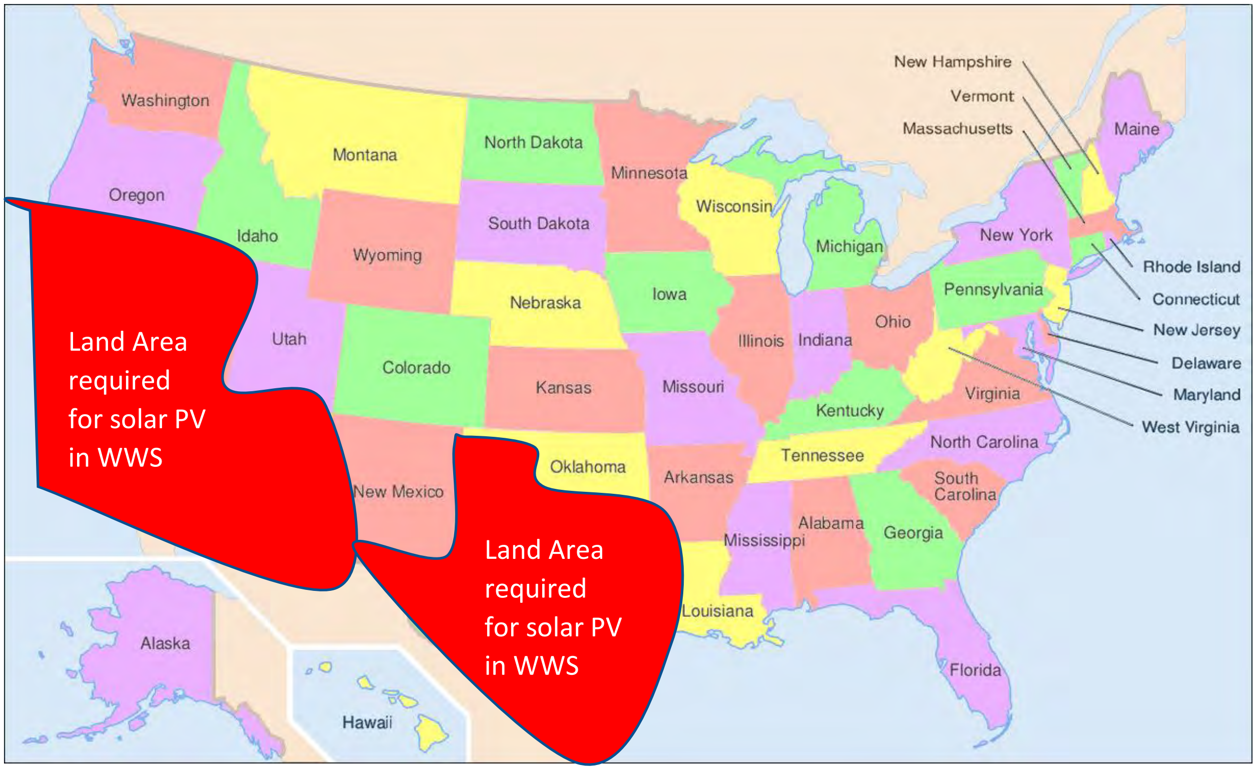
7 Cost and Spatial Implications of Building an All-Renewables Future

In this section, we will examine the physical and area requirements associated with wind, solar and biomass energy sources, first in general and then with reference to specific energy sources or uses.

A 1000-MW solar photovoltaic (PV) facility would require about 8,000 acres (approximately 14 square miles) according to the U.S. Department of Energy. Accounting for a range of capacity factors (17-28 percent), between 3,300 MW and 5,400 MW of solar PV capacity is needed to produce the same

[9] http://journals.cambridge.org/download.php?file=%2FMRE%2FMRE3%2FS2329222916000039a.pdf&code=25627d5064779b86e051a6bcc1b17fc3#xml=http://journals.cambridge.org/data/userPdf/

amount of electricity as a 1,000-MW nuclear plant in a year. The amount of land needed by solar PV to produce the same generation as 1,000 MW of nuclear capacity in a year is between 45 and 75 square miles.[10] **The amount of land needed to accommodate the 46,480 solar PV plants envisioned for the U.S. in the WWS vision is 650,720 square miles, almost 20% of the U.S. lower 48 territories. This is close in size to the areas of Texas, California, Arizona and Nevada combined.**



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Solar PV is commonly used in distributed (i.e. widely diffuse) applications rather than in large central plants. The power density problem for solar PV can be illustrated in this way. In order to supply a house with electricity, PV cells would have to cover the entire roof; the house would also need a large battery pack (costing at least U.S. 8,000 uninstalled) to store electricity when the sun does not shine. A supermarket would need a photovoltaic field roughly 10 times larger than its own roof. A high-rise building would need one 1,000 times larger than its own roof.

A 1,000-MW wind farm would require approximately 85,240 acres of land (approximately 133 square miles), again as calculated by the U.S. Department of Energy. Accounting for a range of capacity factors (32-47 percent, much higher than observed in practice in Canada), between 1,900 MW and 2,800 MW of wind capacity would be needed to produce the same amount of electricity as a 1000-MW nuclear

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[10] Land Requirements for Carbon-Free Technologies. (n.d.). Retrieved from http://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Land_Use_Carbon_

plant in a year. The land area needed for wind energy to produce the same amount of electricity as a 1000-MW nuclear plant is between 260 square miles and 360 square miles.

The WWS vision foresees the construction in the U.S. of 328,000 5 MW onshore wind farms with a name plate capacity of 1,701,000 MW. This is significantly larger than the typical 3.5 MW offshore wind farms built today. Onshore facilities of this size only exist at the prototype stage, so there are no publicly available estimates of how much land area such facilities would occupy.

At sea, winds are stronger and steadier than on land, so offshore wind farms deliver a higher power per unit area than onshore wind farms.[11] Due to strenuous opposition from people who live near potential offshore wind farm sites, there currently are no offshore wind farms in the United States. There are some operating in the United Kingdom and in Norway, so we now have some estimates of the areas of sea that might be covered by such installations, especially in the shallow offshore (depths less than 25-30 metres) regions. These industrial wind turbines are huge. Each rotor has a diameter of 90 metres centered on a hub height of 70 metres. Each 3 MW turbine weighs 500 tons, half of which is in its foundation.

Danish offshore wind farm – Image Wikipedia

The highest-producing offshore wind turbine installation in operation, Nysted Wind Farm in Denmark, has 72 turbines and a capacity of 165.6 megawatts. Assuming that 40 percent of that capacity can actually be realized, one can estimate that those turbines put out an average of about 66 megawatt hours in an hour. **Producing enough power just to account for all of what is now put out by coal-fired plants in the U.S. would require 3,540 installations of that size, comprising well over 250,000 individual turbines.**[12]

[11] Ch 10 Page 60: Sustainable Energy - without the hot air ... (n.d.). Retrieved from http://www.withouthotair.com/c10/page_60.shtml
[12] DEBUNKED: The Danish "20 Percent" Wind Energy Canard ... (n.d.). Retrieved from http://instituteforenergyresearch.org/media/denmark/Denmark_DEBUNKED.pdf

David MacKay is a British engineer, believer in the theory of catastrophic global warming, and author of *Sustainable Energy: Without the Hot Air*, a book in which he examines in great detail the sources and uses of energy in the United Kingdom to determine whether it would be feasible to replace all current energy requirements by renewable energy sources. He ignores altogether the economic costs of renewable energy sources. Using a rather unique approach, he estimates that the U.K's total energy needs are equal to 195 kWh per person per day. He then examines each potential source of renewable energy to determine how much of that total could be met. To meet 16 kWh per person per day, or 8.2% of the total needs, he estimates that one would have to take the total coastline of Britain (with a length of 3000 km.), and put a strip of wind turbines 4 km wide all the way around. That strip would have an area of 13,000 square km. 44,000 turbines would be needed, which works out to 15 per kilometer of coastline, if they were evenly spaced around the 3000 km of coast. To say the least, this would give rise to major land use conflicts between the shipping, fishery and energy industries.

In summary, renewable energy sources would occupy very large land areas by comparison with conventional generation sources like nuclear, coal or natural gas. The costs of acquiring this land would be extremely high and the problems involved in obtaining rights-of-way alone are beyond anything we have ever experienced.

Let us now take a closer look at what an all-renewable energy future would mean in terms of each energy source.

Image licensed from Shutterstock.

7.1 Solar Energy

A number of prominent solar energy advocates have made optimistic claims lately about the potential for solar energy to replace the energy now produced by fossil fuels (i.e. coal, oil and natural gas) in the

United States. Peter Diamonds recently wrote an article in the online Forbes magazine entitled "Solar Energy Revolution: A Massive Opportunity". Ray Kurzweil, a co-founder of Google, projects that the U.S. will meet 100% of its electrical energy needs from solar in twenty years. Elon Musk, Chairman of Tesla Motors, expects "solar power to produce 50% of America's electricity in 20 years". On July 29 2015, Tom Tamarkin, the President of a California-based company that sells energy efficiency products, published an on-line review of these claims.

To produce this number of panels, it would take 929 years, assuming they could be built at the rate of one per second. The estimated cost of this, including the costs of the panels, the battery modules, the materials, electronic controls and transformers, land acquisition and equipment changes over 20 years is U.S. $15.93 trillion.

Tamarkin analyzed what would be required under scenarios in which solar power were used to replace 440 megawatts (MW) of electricity generation capacity that is now projected to be retired due to age over the next 25 years and one in which solar electricity were required to meet 1100 MW of electricity demands, including those for transportation, industrial processes, commercial businesses and agriculture.

An important starting point was to define how much electricity solar PV panels could generate on average per square meter. This is 37.5 watts, averaged over 365 days, 24 hours a day a year, factoring in historical weather factors such as cloud cover, fog, etc. in extremely well suited areas in the southwest United States (Arizona and the desert areas of California). [13]

To meet the 440 MW target, one would need 29.3 billion solar panels and 4.4 million battery modules. The area covered by these panels and modules would be 29,332 square kilometers, or 18,226 square miles (nearly equal to the area of the state of New Jersey), with zero space between the panels and modules. **To produce this number of panels, it would take 929 years, assuming they could be built at the rate of one per second. The estimated cost of this, including the costs of the panels, the battery modules, the materials, electronic controls and transformers, land acquisition and equipment changes over 20 years is U.S. $15.93 trillion.** This does not include the costs of labour or the electrical invertors required to convert the power from low voltage DC to 240-120 volts AC required by electricity users. For comparison, the 440 MW generation capacity with a 20% margin for security could be met with 212 nuclear power plants for a present day cost of $528 billion, or 3% of what the all-solar option would cost.

[13] The Green Mirage | Fusion 4 Freedom - Fuel R Future. (n.d.). Retrieved from http://fusion4freedom.us/review-of-forbes-on-line-magazine-article-solar-energy-

In addition, according to a U.S. National Renewable Energy Laboratory study that assumed zero growth in electricity demand for the next 35 years (i.e. permanent recession), **going completely solar would require the deployment of 28-48 GW of additional load balancing by 2050, compared to 15.6 MW in 2009, and installing 30 million to 180 million new MW-miles in electricity transmission lines, which would effectively double current U.S. capacity and cost between U.S. $6.4 billion and U.S. $8.1 billion per year from 2015 to 2050**. This ignores the siting issues that would inevitably arise.

The leading solar energy candidate technology to produce significant amounts of power is Concentrated Solar Power (CSP) with integrated storage (molten salts.) The largest American CSP plant currently built is the Crescent Dune plant in Tonopah Nevada. This plant uses a 540-foot-high tower surrounded by 17,500 computer-controlled mirrors, each 64 square meters in size, to precisely track the sun and focus the sun's energy on the solar tower to convert that energy into 1,050 F degree heat to melt sodium nitrate based salts to turn an electro-magnetic generator. The facility takes up 1,600 acres, or 6 square kilometers (2.32 square miles) of land. It cost about $1 billion to build and it has a nameplate capacity of 125 MW and a capacity factor of 52%. It can only produce about 485 GWh of power annually at a system cost of U.S. 48.5 cents per kWh (about eight times the cost of a conventional power plant). This plant garnered some unwanted publicity when, during a test of the system, it incinerated 150 birds that happened to fly over during the test.[14]

Crescent Dunes Concentrated Solar Power Facility. Source unknown

Critics of the Crescent Dune plant have observed that, even though located in the Nevada desert, it is still located too far north to make optimal use of the sun's rays. The WWS roadmap envisioned that 3,637 CSP plants would be built, 227,300 MW to meet base load requirements and 136,400 MW to

[14] Can Solar Energy Replace All U.S. Hydrocarbon Production ... (n.d.). Retrieved from https://friendsofsciencecalgary.wordpress.com/2015/12/18/can-solar-energy-replac

serve as peaking plants. It would be very difficult to find 3,637 sites in the southern United States that would make sense. The plants would cover an area of 8,439 square miles if all packed together, about the area of metropolitan New York. 3,637 plants with 17,500 mirrors each would require the manufacture of 63,647,500 mirrors. If we could manufacture one every ten seconds, starting right now, it would take 21 years to build that many mirrors.

Ivanpah CSP Facility By Aioannides - Taken from side of the Road near I15Previously published: None, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25841974

7.2 Wind Energy

Between 1985 and 2012, global electricity production increased by about 450 terawatt-hours per year. That's the equivalent of adding about one Brazil (which used 554 terawatt-hours of electricity in 2012) to the global electricity sector every year. And the International Energy Agency expects global electricity use to continue growing by about one Brazil per year through 2035.

Pincher Creek area wind farms – Clive Schaupmeyer

Robert Bryce is a senior fellow at the Manhattan Institute in the United States and the author of several books on energy and environmental issues. In his book entitled *Smaller Faster Denser Lighter Cheaper,* he recently addressed the question of what it would take just to meet world electricity demand growth with renewable energy.

In 2012, the world's wind turbines – some 284,000 megawatts of capacity – produced 521 terawatt hours of electricity. The United States has more wind capacity than any other country, about 60,000 megawatts at the end of 2012. Thus, just to keep pace with electricity demand growth, the world would have to install about four times as much wind-energy capacity as the United States has right now, *and it would have to do so annually.*

Now let's look at carbon dioxide emissions. *"The American Wind Energy Association claims that wind energy reduced US carbon dioxide emissions by 80 million tons in 2012. That sounds significant. But consider this: global emissions of that gas totaled 34.5 billion tons in 2012.* ***Thus, the 60,000 megawatts of installed wind-generation capacity in the United States reduced global carbon dioxide emissions by less than two-tenths of one percent. "*** [15]

To make the point even clearer, let us look at the history of global carbon dioxide emissions. Since 1982, "*carbon dioxide emissions have been increasing by an average of about 500 million tons per year. If we take the American Wind Energy Association's claim that 60,000 megawatts of wind-energy capacity can reduce carbon dioxide emissions by 80 million tons per year, then simple math shows that if we wanted* ***to stop the growth in global carbon dioxide emissions by using wind energy alone"*** [16]**– and remember that doing so will not reduce any of the existing demand for coal, oil and natural gas – we would have to install about 375,000 megawatts of new wind-energy capacity every year.**

How much land would all those wind turbines require? Recall that the power density of wind energy is about 1 watt per square meter. Therefore, merely halting the rate *of growth in carbon dioxide emissions with wind energy would require covering a land area of about 375 billion square meters or 375,000 square kilometers*.[17] That's an area the size of Germany. *And we would have to keep covering that Germany-sized piece of territory with wind turbines every year.*

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[15] "Killing Wildlife In the Name of Climate Change" (Part II ... (n.d.). Retrieved from https://www.masterresource.org/energy-density/killing-wildlife-in-the-name-of-cl

[16] Wind turbines are climate-change scarecrows - Wind Watch. (n.d.). Retrieved from https://www.wind-watch.org/news/2013/11/26/wind-turbines-are-climate-change-scar

[17] "Killing Wildlife In the Name of Climate Change" (Part II ... (n.d.). Retrieved from https://www.masterresource.org/energy-density/killing-wildlife-in-the-name-of-cl

What would that mean on a daily basis? Using wind to stop the growth in carbon dioxide emissions would require us to cover "*1,000 square kilometers with wind turbines – a land area about 17 times the size of Manhattan Island – and we would have to do so every single day.*" [18]

8 TRANSPORTATION

8.1 ELECTRIFYING VEHICLES

Oil provides 95% of the fuel demands of the transportation sector both at the global level and in the Canadian economy. Every transport mode – cars, trucks, trains, buses, marine vessels, and aircraft – relies almost entirely on petroleum fuels. Only natural gas liquids and, in recent years as the result of regulated fuel mandates, ethanol - have made small inroads in the dominant share held by oil. Further, on the basis of the projections by all major agencies that analyze energy supply and demand trends to 2035 and 2040, this will continue to be the case for the foreseeable future.

This is not by accident or the result of some evil conspiracy by the major oil companies. It is largely due to the unique advantages that oil products have as transportation fuels; their energy content is extremely high for their mass, and they can be easily and safely transported and stored. For many important modes – including aircraft, marine vessels and truck transport – there simply are no technologically proven and reasonable cost options.

The claim that the world, and especially countries like Canada, can move to completely displace fossil fuels by 2050 thus includes the implicit assumption that much of the transportation sector can be electrified, that people can be persuaded to forego personal vehicles, and that new agriculture-based fuels can be supplied in quantities that will displace the existing liquid fuels. Let us examine, then, the prospects for significantly increased use of electric vehicles and for electrification of freight movement.

Many western governments have sought to reduce greenhouse gas emissions in transportation by subsidizing the sale of partially electric (i.e. hybrid) vehicles and all-electric (plug-in) vehicles and by embracing ambitious targets for the market penetration of these vehicles. In the United States, for example, President Barack Obama introduced programs that provided billions of dollars in subsidies for the manufacturers of the vehicles and the electric storage batteries that power them and offered consumer subsidies of $7500 per vehicle to those who would buy them. The Administration's goal was

[18] "Killing Wildlife In the Name of Climate Change" (Part II ... (n.d.). Retrieved from https://www.masterresource.org/energy-density/killing-wildlife-in-the-name-of-cl

to have one million all-electric vehicles (plug-ins) on U.S. roads by the end of 2015. In Germany, Chancellor Angela Merkel similarly offered large industry and consumer subsidies and declared a goal of having one million all-electric vehicles on German roads by 2020. While Canadian governments have not published such lofty goals, buyers of all-electric vehicles qualify for taxpayer subsidies of CDN $8500 each.

Along with these well-publicized commitments by governments, the manufacturers of all-electric vehicles have made many announcements of technological advances and of new research initiatives (almost always partially or totally funded by taxpayers) that they confidently predicted would lead to increased sales and consumer acceptance. Perhaps the most widely publicized claims were made by Tesla and its charismatic President, Elon Musk. Tesla has produced a number of high-performance expensive luxury cars that are powered entirely by electricity. Famously, Tesla has claimed that it is on track to produce a U.S. $35,000 to $40,000 all-electric car with a range of roughly 200 miles by 2017. Many young people accept Tesla's prediction that, with the introduction of a mid-priced all-electric vehicle, the days of the internal combustion engine are soon coming to an end.

The reality of the marketplace is strongly at odds with these perceptions.

In a December 2015 program entitled "Electric Cars Running on E", U.S investigative reporter Sharyl Attkisson delved into this subject. The program can be viewed here:

http://fullmeasure.news/news/politics/electric-cars-12-04-2015

She found the U.S. electric vehicle program's achievements are actually way behind its targets, and that the goal of putting one million electric cars on the road by the end of 2015 had fallen woefully short. Only about one-third that many all-electric cars, heavily subsidized with tax incentives, have been sold. Further, six of the 11 main manufacturers have gone belly up or stopped manufacturing.

By Ludhiana E. Moreira Sales and Mario Duran (Mariordo) - This file was derived from Amsterdam 06 2015 1616.JPG:, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=41278454

Tesla Motors got half a billion dollars to make the Model 2 electric vehicle. It was one of the few success stories. The Model 2 went from 0 to 60 in 2.8 seconds, and strong sales helped it pay back its $10 million government loan early. Others, like the Volkswagen E Golf, and the Chevy Volt, have not been so successful.

One of the most serious problems concerns the limitations of current battery technology. In the 1990s, GM used cheaper lead-acid batteries for its electric EV-1; each battery weighed a bulky 600 kilograms and delivered only 55 to 95 miles before it had to be recharged. When Tesla Motors introduced one of the first lithium-ion-powered electric cars in 2008, it could go 250 miles on a charge, roughly three times farther than the EV-1. But the vehicle cost over $100,000, in large part because the batteries were so expensive. To cut costs, the lithium-ion-powered electric cars made today by companies such as Nissan and GM use small battery packs with a range of less than 100 miles.

While countless breakthroughs have been announced over the last decade, time and again these advances failed to translate into commercial batteries. One difficult thing about developing better batteries is that the technology is still poorly understood. Changing one part of a battery—say, by introducing a new electrode—can produce unforeseen problems, some of which can't be detected without years of testing.

Yet for electric cars to account for a significant portion of the roughly 60 million cars sold each year around the world, batteries will probably need to get considerably better. After all, 200 miles is far short of the 350-plus miles that people are used to driving on a tank of gasoline, and $35,000 is still quite a bit more than the $15,000 price of many small gas-powered cars.

So what has been the actual experience of electric vehicle sales in North America? What have billions of dollars in taxpayer subsidies achieved?

In the United States, by the end of 2015 there were about 320,000 all-electric vehicles on the roads, less than a third of Obama's goal. In 2015, total electric drive vehicle sales were 498,000, of which plug-ins constituted 114, 000, or 23%. By comparison, total light duty vehicle sales in the United States in 2015 were almost 17,400,000. Electric vehicles (hybrids and all-electric) represent only 2.87% of total light duty vehicle sales. Worse, electric vehicle sales in 2015 were actually down from the 571,000 (including 119,000 plug-ins) achieved in 2014.

In Canada, there are about 150,000 hybrid light duty vehicles on the roads. The most recent data on electric vehicles sales are to the end of June 2015. At that point in time, there were 14,300 plug-in vehicles registered in Canada, half of which were plug-in hybrids and the other half battery powered all-electric vehicles. The sales of plug-ins during the first half of 2015 were 2,779. Of the total number on the roads, most were small vehicles like the Chevrolet Volt or the Nissan Leaf; there were only 394 Teslas. As of the end of 2014, plug-in electric vehicles had 0.27 of total vehicle market share in Canada — roughly speaking, one out of every 300 cars sold in Canada is an EV. By comparison, in 2015, total light duty vehicle sales in Canada in 2015 were 1,900,000. Plug-ins barely register.

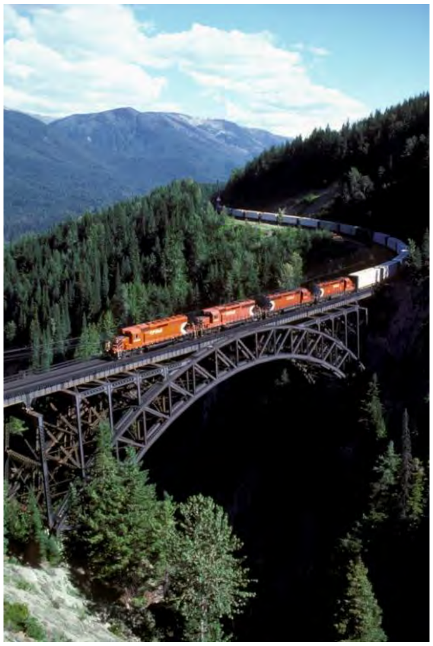
What about the much hyped "affordable" Tesla coming in 2017? The lower price will help, but it will not change the fact that American and Canadian buyers are showing considerable resistance to all-electric vehicles, preferring the more user-friendly hybrids. Factors such as high prices, uncertain resale values, the inconvenience of plugging the vehicle in, the recharge time and limited range are difficult for consumers to ignore.

For all the hype, and even assuming that the taxpayer subsidies will continue indefinitely, it seems highly unlikely that electric vehicle sales will rise to even 5% of total light duty vehicle sales for several years. In other words, the internal combustion engine will be the norm for the foreseeable future.

This is illustrated by the situation in Canada. The National Energy Board produces the best publicly available projection of Canada's use of fuels in transportation. The Board's last report, in 2013, projects that energy use will decline by an annual average of 0.6% over the period from 2011 to 2035 as a result of continuing increases in vehicle fuel efficiency and some changes in passengers' travel demands. The demand for fuels for freight transportation, in contrast, is projected to grow by an annual average of 2.0% over the period, driven by growth in the goods producing industries. Overall, the demand for transportation fuels (i.e. oil) will grow as the Canadian economy grows. The NEB also is not expecting to see a significant trend towards electrification of Canadian vehicles either for passengers or for freight.

8.2 Electrifying Railways

Occasionally, there are speculative articles in the popular press about the possibility of electrifying passenger trains. In theory, electrification makes some technical sense for passenger trains, as electricity is good for high speeds, acceleration, and frequent stops. No privately owned passenger rail company will touch it, however, and most governments shy away from the enormous costs.



According to the article "Can Freight Trains be Electrified" freight trains are very different from passenger trains– "*they are slow, rarely stopping, and need power, not acceleration. Above all, speeding up freight trains wastes energy. Since most of what's being hauled"* does not spoil, freight doesn't need to get anywhere fast. Increasing the speed of freight trains would also raise safety problems. "*There are about five derailments a day in North America. Imagine the damage an 80-million-pound electric train derailing at 100 mph would cause, plus the added costs of the overhead wires being pulled down."* High speeds would also wear out tracks out faster, requiring expensive maintenance.

[19] By Photograph by David R. Spencer. Please retain this attribution. - http://www.scenic-railroads.com , CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=84266

Alice Friedeman, a well-known transportation economist and author of *When Trains Stop Running – Energy and the Future of Transportation*, has written an analysis of the arguments for and against the electrification of freight rail transportation. The following summarizes her work.

The main considerations that today govern investment in the rail industry in North America are economic. The railways are private companies, and do not invest in something because it is "green"; they do so because the projected revenue from sales is greater that the capital and operating costs of providing the service.

Most estimates for electrification are for passenger rail, which can be quite expensive. California's 520 miles of high-speed rail is estimated to cost $68 billion, which is $130.7 million per mile. To estimate the cost of electrifying freight trains is difficult as the parameters of weight and the content of load are very different.

Freight trains are much heavier than passenger trains so the electrification of a single freight rail system would cost at least a trillion dollars. *"A coal train often weighs over 20,000 tons, but a passenger train is likely to weigh less than 1,000 tons. The extra weight of a freight train would require 6 to 24 megawatts (MW) of power (8,000-32,000 Horse Power). This is 4 to 24 times more power than passenger trains need. Light rail can get by on 1 MW or less, a heavy commuter train 3 to 4 MW, and a*

[19] Can Freight Trains Be Electrified? | Peak Energy ... (n.d.). Retrieved from http://energyskeptic.com/2014/electrification-of-freight-rail/

high-speed intercity train 4 to 6 MW. And passenger trains need only 25kV lines, but one would want to have at least 50kV for freight trains to minimize the number of substations."[20]

When you multiply out the power for just one freight train to many trains over long distances, you'd need a huge amount of power. *"For example, you would need 1,500 MW to go the 2,000 miles between Chicago to Los Angeles, equal to three large conventional power plants. So with 160,000 miles of tracks, you'd need the equivalent of 240 power plants. Of course, some of this power already exists, but it's likely new power plants, over-sized substations, transmission lines, and so on would be need to be built since railway electrification load is one of the most difficult for an electric utility to cope with."*[21]

According to "Can Freight Trains Be Electrified," some of the costs to electrify the U.S. freight rail system would include:

- $125 to $250 billion to replace 25,000 locomotives with $5 million all-electric locomotives or $10-million-dollar ALP-45DP dual-mode locomotives, since these passenger locomotives aren't powerful enough to haul freight trains.
- $800 billion to electrify 200,000 miles of railroad tracks with overhead wires, which need to be much higher than anywhere else in the world because of America's highly energy-efficient double stack trains, which carry twice as much cargo per gallon of fuel. The average cost of three passenger rail projects was $3,980,000: $3.96 million (SCRRA), $4.55 million (Caltrain), $3.42 million (Metrolinx).
- Unknown billions to add new power plants, transformers, substations, new infrastructure to unload and load containers now that overhead wires are in the way, raise bridges and tunnels for overhead wires, and so on.

Electrification of the entire rail system would raise many other major problems.

One is that it would create a possible failure of energy supply for the whole system at a single point. Electricity flow can suddenly stop for many reasons – which would affect the entire overland shipping by rail (whereas single diesel engines may have trouble, but only one train would be affect). Many natural weather events cause individual train stoppages – like heavy winter snow, spring runoff landslide, but if the entire system were electrified, a single such event could paralyze all traffic. Electric-only locomotives could be stuck wherever they are and need to be rescued by diesel locomotives, creating costly and severe congestion on many heavily traveled routes.

Finally, diesel locomotives can't be beat for performance and durability. *"Diesel engines keep getting better, last a long time, are rugged enough to handle rough patches of rail, and can be rebuilt. Many locomotive engines achieve the equivalent of one million miles before overhaul, equal to 36,000 megawatt-hours."* [22]

[20] Ibid.
[21] Ibid.
[22] Ibid.

The cost of completely electrifying the passenger and freight rail systems in North America would almost certainly run into trillions of dollars. In fact, no one has yet done a study of what it would cost here, let alone in all countries. It is an environmentalist's dream without a price tag, not a serious proposition.

8.3 Biofuels for Transportation

The other approach to reducing transportation emissions sometimes touted by advocates is the use of so-called biofuels – ethanol and biodiesel.

In a 2011 report, AltaCorp Capital, a Canadian investment firm that specializes in energy investments, analyzed the effects of increasing biofuels production as a means to reduce GHG emissions. The following information is from the AltaCorp report.

The production and use of ethanol is today promoted by many governments through extensive direct and tax subsidies and by regulations that require oil refiners to include some minimum percentage of ethanol in gasoline, with the percentage varying from 5% to 15%. According to "The Case Against Biofuels" – *"Most ethanol today is produced from corn. In the United States in 2007, energy legislation raised mandated production of biofuels to 36 billion gallons by 2022. These mandates shelter biofuels investments by guaranteeing that the demand will be there, thus encouraging oversupply."* [23]

Looking at one country, if all the arable land in the United States were converted for ethanol production – *"leaving no land for growing food – the total amount of ethanol would only replace 74% of U.S. oil imports."* [24] In 2009, 4,968 million bushels (38.7 million tons) of corn grown in the U.S. were used to produce ethanol. That is 38% of the total corn crop of 13,110 million bushels grown that year.

[23] The Case Against Biofuels: Probing Ethanol's Hidden Costs ... (n.d.). Retrieved from http://e360.yale.edu/feature/the_case_against_biofuels_probing_ethanols_hidden_c
[24] Ibid.

Daily Mail story “Record One Billion People in the World are Hungry, says UN as parents fight to give their child just one meal a day” 2009
http://www.dailymail.co.uk/news/article-1220911/Record-billion-people-world-hungry-says-UN-parents-fight-children-just-meal-day.html

“149 million people could be fed for a year with the 38.7 million tons of corn that is annually used to make ethanol in the United States.”[25]

Moving to significantly increase the use of ethanol in transportation fuels would reduce the land available for food, thereby reducing food production, raising food prices, and making life that much more difficult for the poor.

To replace 54 million barrels per day (about 60%) of global oil production with corn ethanol, it would take a cornfield the size of the United States, China and India combined. Actually, this is an area larger than the currently used arable land in the world. That would eliminate that land for food production and the world would, of course, starve.

The World Resources Institute recently published a series of working papers that examined the question of how to address the potential gap of 6,500 trillion kilocalories (kcal) per year between the food available in 2006 and the likely demand in 2050 – roughly a 70% increase in food crop calories from 2006 levels. One working paper, published in January 2015 was entitled, *Avoiding Bioenergy Competition for Food Crops and Land*. [26]The report notes that biofuels from food crops today – such as corn, vegetable oils, and sugarcane – provide about 2.5% of the world’s transportation fuel. Yet even

[25] Ibid.
[26] Avoiding Bioenergy Competition for Food Crops and Land ... (n.d.). Retrieved from http://www.wri.org/publication/avoiding-bioenergy-competition-food-crops-and-lan

this small share of transportation fuel in 2050 would have substantial implications for the crop calorie gap. If crop-based biofuels were phased out, the 2050 crop calories gap would decrease from 70% to about 60%, a significant step towards a sustainable food future.

However, some major countries including the United States, Canada and much of Europe have established high biofuel targets that amount to at least 10% of transportation fuel by 2020. If such targets were to go global by 2050, meeting them would increase the calorie gap from 70% to 90%, making a sustainable food future even more difficult to achieve. The report concludes that "*Overall, phasing out the use of crop-based biofuels instead of meeting an expanded 10% target is likely to mean the difference between a 90% crop calorie gap and a 60% gap. It is therefore a potent strategy for sustainably meeting future food needs.*"

The World Resources Institute working paper can be found here:

http://www.wri.org/sites/default/files/avoiding_bioenergy_competition_food_crops_land.pdf

9 Other Considerations Call into Question The 100% Renewables Future

There are five additional important considerations that should cause people to question the thesis that completely replacing hydrocarbons by renewable energy sources by 2050 is desirable or achievable. Some of these are documented in the October 2013 report of the Information Technology and Innovation Foundation entitled *Challenging the Clean Energy Deployment Consensus*, which can be seen here:

http://www2.itif.org/2013-challenging-clean-energy-deployment-consensus.pdf

9.1 Excessive Confidence in Science and Technology

Scientists and engineers often express a quite remarkable belief in the ability of science and technology to transform the world, and specifically energy supply and demand, quickly. Their extraordinary optimism extends throughout the phases of the science to technology spectrum. That includes the rate at which breakthroughs will be made in the basic science, the rate at which scientific discoveries will be demonstrated to be technically applicable, the rate at which technically demonstrated technologies can be used to develop commercially viable products and services, and the success that companies will have in achieving initial market penetration and then mass production through broadly-based consumer acceptance. They seem to think that, if something can be done and it has alleged environmental benefits, all that stands in the way of its mass commercialization is "friction" in the system, and therefore the answer is for governments to subsidize or regulate so as to achieve their preferred outcome.

In reality, scientific breakthroughs do not come on a fixed schedule, and there is no direct relationship between the amount of money that society spends on research and the likelihood or timing of a discovery. If there were, cancer would have been cured long ago.

Dr. Peter Grossman, one of the foremost experts in the history of U.S. energy policy, has coined a phrase to describe the tendency to think that government-directed funding will lead to technological gains. He calls it the "Apollo Fallacy".[27] In his books and in a famous 2009 essay, he described how over the past fifty years U.S. policy makers have made continual references to the Apollo program (or the Manhattan Project) as a model for the development of alternative energy technologies. Just as President John Kennedy announced early in the 1960's that the U.S. would put a man on the moon by the end of the decade, so other U.S. presidents have embarked on grand alternative energy schemes to achieve it by time *y.* These efforts have never succeeded and have cost many billions of dollars. The technologies promoted are the same ones being advocated today in the name of addressing alleged global warming – solar energy, wind energy, cellulosic ethanol, electric vehicles, etc. The goal of the Apollo program, in fact, was the demonstration of U.S. engineering prowess as part of a space race waged for propaganda purposes as part of the Cold War with the former Soviet Union; costs, and indeed commercial viability, were at best secondary considerations, if relevant at all. The Apollo fallacy, as applied to alternative energy technologies, conflates an engineering problem with a commercial problem, and it actually deflects efforts (and funds) away from scientific research and advance and focuses them instead on grandiose social results. Among other things, programs to accelerate the increased demonstration and use of specific technologies have amounted to picking winners over losers, and governments have proved again and again that they are remarkably bad at that game. Dr. Grossman's essay can be read here:

http://digitalcommons.butler.edu/cob_papers/171/

The excessive optimism is manifested in the way the WWS projections are presented. Jacobson, Delucci et. al. do not stop at setting out a list of promising technologies and visualizing the amount of renewable energy generation capacity needed to meet future demand. They presume to set out detailed, quantified "roadmaps" of exactly which steps governments should take by which dates and of the resulting generation levels by 2050. All they succeed in doing is in showing how economically infeasible reaching high renewable penetration levels is using today's expensive renewable technologies.

[27] The Apollo Fallacy and its Effect on U.S. Energy Policy. (n.d.). Retrieved from http://digitalcommons.butler.edu/cgi/viewcontent.cgi?article=1171&context=co

9.2 The Presumption that Deployment Alone Will Make Technology Competitive

It is not clear that proponents of the all-renewables future care about whether consumers will freely choose to purchase their favoured products (a point to which I will return). Realistically, however, new renewable energy technologies must at some stage be able to compete with conventional alternatives on both a cost and performance basis without relying on subsidies and government mandates. (At some stage, the taxpayers and the voters will react.)

The inherent presumption in the WWS analysis is that forcing the deployment of new renewable energy technologies through government action will provide sufficient impetus for both innovation and the widespread commercialization and dissemination of the technologies. University of Wisconsin-Madison professor Gregory Nemet has conducted substantial research on the relative effects of "technology push" policies, such as R&D investment, and "demand pull" policies, a proxy for deployment policies such as pricing and adoption subsidies, with the conclusion being that "demand-pull ignores technological capabilities." Specifically, Nemet finds investment in R&D to be a far more effective driver of renewable energy development than subsidies.

Even those who support subsidies and mandates on the grounds that scaling up the production of renewable technologies might move them down the cost curve acknowledge that the more significant problem is that these cost curves are still much higher than those of fossil fuel alternatives. The incremental improvements of deploying technologies at a massive scale will not lead to breakthroughs in cost or performance competitiveness – in other words, they will not lead to new and cheaper cost curves.

9.3 The Failure to Acknowledge that Prices Matter

Proponents of the all-renewable future seem to be stuck in a time warp. For them, it is still 2014, oil prices are still close to $130 per barrel, and natural gas and coal prices are surging. In such a world, it may be easier to make the case that renewables will become far more competitive sooner. The reality, of course, is that the decline of international oil prices to the range of $40 per barrel and the dramatic slumps in natural gas and coal prices in many areas (especially North America), has meant that these hydrocarbons are far better placed to compete with alternative energy sources. The demand for them has not increased in the OECD countries because of continuing economic recession, but it has increased significantly in China, India and the other burgeoning economies of Asia. While it is difficult to judge the future trajectory of international oil prices, the consensus of experts today is that it will be several years before they return to 2014 levels.

Especially in developing countries that face difficult choices between economic development and the wellbeing of their citizens on one hand and reducing greenhouse gas emissions on the other, the choice between fossil fuels and renewables will more likely be based on which are cheaper. Renewables are unlikely to win that competition for many years, if ever, a fact that will weigh heavily of the situation in 35 years' time.

9.4 The Under-estimation of the Impacts of Renewables on Reliability and System Costs

The claim that renewable energy will rapidly expand its share of electricity generation is partly based on the assumption that renewables will benefit from falling levelized costs. Levelized cost is a measure of the cost of an energy generation system over the course of its lifetime, which is calculated as the per-unit price at which energy must be generated from a specific energy source in order to break even. The levelized cost of an energy generation system (LCOE) reflects capital and operating and maintenance costs, and it serves as a useful measure for comparing the cost of, say, a solar photovoltaic plant and a natural gas-fired plant.

The U.S. Energy Information Administration periodically publishes forecasts of the range of levelized domestic electricity generation costs for different energy sources. The most recent forecast uses data based on a 30-year cost recovery for different sources beginning in 2017. It indicates that a natural gas fired-plant with conventional combined cycle technology would be among the lowest cost sources, with an LCOE of U.S. $63-67/MWh. A coal-fired plant would follow at U.S. $89-$118/MWh. Of the renewable energy sources, only wind – in certain situations – can be considered cost-competitive with coal. The costs of solar and other renewable sources are much higher but are falling.

The proponents of an all-renewables future see this as a sign that renewable energies are becoming cheap enough to be cost-effectively deployed. The report of the Information and Technology Foundation previously cited points out the flaw in this.

"*Levelized cost is an incomplete measure of cost-competitiveness, as it does not account for regional variation in costs and does not factor in storage and integration costs of renewables. The former is important because the EIA indicates that energy policymakers and stakeholders can continue to expect substantial regional variation in the levelized cost of wind and solar. The latter is important because storage, load balancing, and grid integration technologies are obviously critical to ensuring electricity reliability. Many of these technologies are still in development and continue to have significantly high costs."*

"The National Renewable Energy Laboratory's (NREL) Futures Study, which models 80 percent renewable penetration in the United States by 2050, requires increasing existing storage capacity by at least seven times current capacity, from around 29 GW in 2010 to 140 GW in 2050. A recent study by the U.S. Department of Energy and the Electric Power Research Institute (EPRI) calculates that, depending on system size, levelized costs of pumped hydro and compressed air energy storage systems are over $200/MWh. In its 'low-demand' scenario, which assumes that national electricity demand does not increase between now and 2050, the Futures Study also requires the deployment of 28 GW-48 GW of additional load balancing by 2050, compared to 15.6 GW in 2009. Additionally, the Futures Study requires installing 30 million to 180 million new MW-miles in transmission capacity, which would effectively double current capacity and cost between $6.4 billion and $8.1 billion per year between 2010 and 2050. "

The *Futures Study*, of course, does not assess whether electricity consumers would be willing to pay for all these infrastructure additions to the electrical energy system nor to what kinds of siting controversies they would give rise.

9.5 The Political Dimension

The complete transformation of the world's energy economies, at the extraordinarily high costs indicated in this note, would not be possible without the general consent of the people affected. Even in the many countries of the world that are ruled by authoritarian regimes, it seems highly unlikely that governments could double or triple energy costs and significantly constrain citizens' choices as to their sources of energy supply and services without incurring strong opposition and perhaps revolt.

The all-renewables future that environmentalists prescribe will most certainly not be welcomed among the world's poorest countries, in which millions of people strive to make do without even the barest of modern energy services, including electricity. This is why all of the projections of world energy supply, demand and emissions made by authoritative sources today (e.g. the International Energy Agency, the U.S. Energy Information Administration, Exxon/Mobil and British Petroleum, among others) project that, in the period to 2035-2040, almost all the growth in GHG emissions will occur in the non-OECD countries. This is virtually inevitable; whatever notional commitments the governments of the less developed countries may have made at the last Climate Change Conference of the Parties in Paris.

The prescriptions contained in the WWS energy roadmaps, therefore, are only likely to be taken seriously in the wealthier countries, where people are not struggling to make their energy ends meet, and can afford the luxury of partial self-denial.

10 Implications for Canada

Let us look specifically at what the all-renewables future would mean for Canada. The WWS roadmap provides a breakdown of what energy sources Canada should use by 2050. These would include:

- **Renewable Source** **%**
- Onshore wind 37.5
- Offshore wind 21
- Solar PV 17.7
- Hydroelectric 16.5
- Wave energy 2
- Residential rooftop solar 1.5
- Commercial/gov't rooftop solar 1.7
- Geothermal 1.9
- Tidal turbine 0.2

One the things that stands out immediately to those familiar with Canada's energy scene is the expectation concerning hydroelectric production. According to Natural Resources Canada, hydro now constitutes 8% of Canada's primary energy production. The WWS road map foresees that share more than doubling to 16.5% by 2050.

According to the National Energy Board 2016 report on Canadian energy supply and demand projections to 2040, hydro-based generating capacity, including small hydro and run-of–river facilities, will increase from 77 GW in 2014 to 87 GW in 2040. This capacity expansion reflects a number of large hydro projects currently under construction such as La Romaine in Quebec, Muskrat Falls in Labrador, and Keeyask in Manitoba as well as projects in the planning and development stages such as Site C in B.C., Petit Mécatina in Quebec, and Conawapa in Manitoba.

As a result of these capacity expansions, the NEB projects annual hydroelectricity production to increase from 381 TWh in 2014 to 452 TWh in 2040. Due to faster growth in other forms of generation, such as wind and natural gas fired generation, the share of hydroelectricity generation is expected to decline from 59 per cent in 2014 to 57 per cent in 2040. The question is, "Where in the world do Mark Jacobson and his colleagues think the additional hydro generation is supposed to come from?"

Blair King, a commentator on renewable energy issues in Canada, reviewed these WWS plans in his online blog *A Chemist in Langley*. He points out that, **according to Dr. Jacobson, in the next 34.5 years, Canada will have to install 60,000 wind turbines.** That means 1,764 per year or 5 units a day every day between now and January 1, 2050. The prominent role assigned to offshore wind turbines is striking; to meet the WWS goal, Canada would have to build 21,155 offshore wind turbines. As of today, it has precisely none.

Dr. Jacobson estimates that the costs of the onshore wind facilities will range from $1.35 million to $1.8 million per MW and considerably more for offshore turbines. **As the 100% WWS scenario calls for over 100,000 MW of new capacity in Canada (39,263 5-MW wind installations), the cost (using Jacobson's discounted rate for these installations) would be $273 billion.** That is for the onshore facilities alone, before considering the costs for transmission lines, grid upgrades or roads to access the facilities. The costs for offshore wind, wave devices, solar facilities and geothermal plants would be in addition to this. How much is $273 billion? By comparison, Canada's total expenditure on health care by all levels of government in 2014 was $215 billion.

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The prescribed levels of wave and tidal power are equally problematic. According to the WWS plan, Canada will need 27,323 wave power devices and 1,980 tidal turbines. There are zero wave devices installed in Canada at the end of 2015; indeed, there are only a few small wave power devices installed worldwide because the technology is so immature. We have not yet even begun to design or test such systems commercially in Canada. **Further, according to British Columbia Hydro, the estimated unit energy cost for wave energy ranges from $440 to $772 per MWh, nine to fourteen times the cost of conventional electricity generation.**

As Blair King notes, one of the biggest Achilles' heels of the WWS plan for Canada concerns power transmission. The transmission costs would be immense, as the generation facilities would all be located hundreds, if not thousands, of kilometers from the main centres of electricity consumption. Building transmission lines in Canada can be very expensive. As an example, Northwest Transmission's Line project in British Columbia will probably cost over CDN $2 million a kilometer to build. 100% renewable energy in 2050 means that virtually every community in Canada, including the many quite remote towns and cities, would have to import a lot of power to continue to exist. **Even the most optimistic view puts the cost of a national backbone of 735 kV transmission lines at around CDN $104 billion and taking 20 years to complete.** Once that were built, we would have to start on an equally, if not more, expensive network of collector and feeder transmission lines to every city, town and hamlet. This simply could not be done in 35 years.

Canada's case illustrates well the limitation that may be placed by political factors on the attainment of the WWS vision.

As noted previously, the cost of building 60,000 wind turbines alone could cost $273 billion, which equates to 2.4% of Canada's GDP per year for the next 34 years. The astounding cost of the solar PV plants, the wave and tidal facilities, plus the electricity storage, load balancing and transmission infrastructure provide clear evidence of the complete non-feasibility of the WWS roadmap. Even proceeding partway along this path would entail costs so enormous that attempting to meet them would crowd out the funding of many essential public programs in the health, education and social fields, at a time when Canada is already facing serious financial problems due to high and rising indebtedness by the federal and provincial governments.

These costs, while immense, however, would be only part of the problem. The WWS roadmap calls for the shutting down of all coal, oil and natural gas production, preferably before 2030. Coal, oil and natural gas are extremely important components of the economies of Alberta, Saskatchewan, Nova Scotia and Newfoundland and Labrador. Shutting down these industries, with the employment, investment, government revenue and balance of trade benefits that they now provide, would strike like a dagger to the heart of Canada's present economy. Among other things, these sectors are some of the few that consistently show significant improvements in productivity that sustain higher incomes for Canadians.

Canada's economy has long benefitted from access to relatively low cost and plentiful energy sources. It is a central element of Canada's international competitiveness and ability to attract external investment. Without this, Canada's entire economy and future prospects would dim substantially. Canada is especially vulnerable to losing industry and employment to countries that do not follow the WWS vision.

The complete electrification of all sectors of the economy, and especially the transport sector, is in fact impossible, especially in the time frame established by the WWS vision. That being the case, the only way to attain the targeted reductions in emissions from transportation would be through severe restrictions on the use of private vehicles, aircraft and trucking. This is surely unthinkable in a country of Canada's size and cold climate. Similar restrictions on hydrocarbon use in the emissions-intensive industries would cause significant declines in the mining, refining, petrochemicals, cement, and vehicle manufacturing industries, to name only a few.

It is difficult to imagine that moving even partially in the direction proposed by the WWS would be accepted without enormous political resistance in Canada. Business and labour groups would unite to fight against the existential threat to their incomes and future wellbeing. Consumers and taxpayers would confront governments over the high costs imposed by carbon taxes and the limitations imposed on choice. Canada's regional divisions, already aggravated due to the uneven effects of economic recession and globalized trade, might not be containable. In these circumstances, one wonders how Confederation would survive.

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11 Conclusion

The WWS vision is not feasible in economic, technological or political terms. Its only purpose, it seems, is to offer the pretense that a credible path to a non-carbon world exists in the period to 2050. The sooner this reality is exposed and confronted, the better.

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FRIENDS OF SCIENCE
Providing Insight into Climate Science

About

Friends of Science has spent a decade reviewing a broad spectrum of literature on climate change and have concluded the sun is the main driver of climate change, not carbon dioxide (CO2). Friends of Science is made up of a growing group of earth, atmospheric and solar scientists, engineers, and citizens.

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