A review of solutions to global warming, air pollution, and energy security
A path to sustainable energy in Canada

Briefing to: Standing Senate Committee on Energy, the Environment and Natural Resources
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Good afternoon Senators, my name is Matthew McCarville. I have a keen interest in understanding global warming issues and energy solutions. My research background is in the ecological forestry, bioscience and energy sectors. From 2007-2010, I was Coordinator for the ECOPEI Energy Project. In 2008, I completed a training seminar led by former Vice President of the United States Al Gore, for The Climate Project Canada, and since deliver presentations to raise awareness about climate change and energy solutions. I have some consulting experience in the energy sector and am currently beginning research for a marine renewable energy infrastructure assessment for the Nova Scotia Department of Energy.

So, today I want to talk about a plan – to covert Canada's energy system to 100% wind, solar, geothermal, tidal, wave and hydroelectric power for all purposes. I will motivate this by asking, what's the problem? Why do we even care? Why act quickly? Why can't we act in 100 years?

Aside from the 2.5-3 million air pollution deaths a year, the hidden medical and insurance costs, etc… well, temperatures are rising rapidly. In Atlantic Canada, from September to December in 2010, 89 new temperature records were set, including 3 new lows and 86 new highs[1]. In the 2000's we had 9 of the 10 hottest years in recorded history. Not to say that these are the hottest years ever during the evolution of the earth. There have been hotter years 100 million years ago, but nobody lived at that time, so we didn't have to deal with it. Now we have huge populations to support and we have infrastructure and we want to be sustainable for a while.

Arctic sea ice is decreasing very rapidly, ~15% in the last decade alone. Because the arctic ice is very thin, only a couple of meters, sometimes 3 or 4 meters, when it decreases you uncover the lower albedo ocean below, ~5-6% albedo vs. ~67% for sea ice, and so there's a rapid positive feedback. So as sea ice disappears it's much more difficult for it to recover. Once the sea ice is gone, the climate can warm even more rapidly. So this is really important when we're looking at the solutions because we need solutions that can be implemented quickly. Thus, we can't rely on solutions that might be available in 15-20 years, or 30 years, because even if you have a new technology that will be 20 years coming, it will still take decades after that to implement that technology, so we have to rely on the best technologies that exist today to solve this problem.

Next, we'll look at a "Review of solutions to global warming, air pollution, and energy security", by Mark Z. Jacobson, which was the top downloaded article in March 2009 in Energy & Environmental Science journal.

In sum, the paper reviews and ranks major proposed energy-related solutions to global warming, air pollution mortality, and energy security while considering other impacts of the proposed solutions, such as on water supply, land use, wildlife, resource availability, thermal pollution, water chemical pollution, nuclear proliferation, and undernutrition. The use of wind, concentrated solar power, geothermal, tidal, solar PV, wave, and hydro to provide electricity for BEVs and HFCVs and, by extension, electricity for the residential, industrial, and commercial sectors, will result in the most benefit among the options considered. The combination of these technologies should be advanced as a solution to global warming, air pollution, and energy security. Coal-CCS and nuclear offer less benefit thus represent an opportunity cost loss, and the biofuel options provide no certain benefit and the greatest negative impacts[2].

Next, we'll discuss, "Providing all global energy with wind, water and solar power", by Mark Z. Jacobson and Mark Delucchi, published in Energy Policy journal (2010).

In abstract, the paper analyzes the feasibility of providing worldwide energy for all purposes (electric power, transportation, heating/cooling, etc.) from wind, water, and sunlight (WWS). In Part I, authors discuss WWS energy system characteristics, current and future energy demand, availability of WWS resources, numbers of WWS devices, and area and material requirements. In Part II, they address variability, economics, and policy of WWS energy. They estimate how many wind turbines, concentrated solar plants, solar PV power plants, rooftop PV systems, geothermal power plants, new hydroelectric power plants, wave devices, and tidal turbines can power a 2030 WWS world that uses electricity and electrolytic hydrogen for all purposes. This WWS infrastructure reduces world power demand by 30% and requires only ~1% more of the world's land for footprint and spacing. Authors suggest producing all new energy with WWS by 2030 and replacing the pre-existing energy by 2050. Barriers to the plan are primarily social and political, not technological or economic. The energy cost in a WWS world should be similar to that today[3].

So, next I assess converting Canada to WWS infrastructure for all purposes. Using Natural Resources Canada data on total energy use in Canada (2008)[4], I convert Canada's energy use from petajoules (PJ) to terawatt hours (TWh)[5]. Total energy use in Canada converted to electricity is ~2,424 TWh/yr. Reducing this figure by 30 percent due to electricity and hydrogen conservation measures mainly from replacing inefficient combustion processes (Jacobson and Delucchi, 2010), results in ~1,697 TWh/yr.

To determine whether this amount of power can be generated using technologies recommended by Jacobson and Delucchi, I assess Canada's wind[6], solar[7], geothermal[8], tidal[9], wave[10], and hydro[11] energy resources using available data. A Statistics Canada map[12] shows the country's population is mostly distributed in southern areas, which I use as an overlay to roughly assess transmission and interconnection requirements. For these recommended energy sources, I draw assumptions about capacity factors from data to calculate how much power can be generated from installations[13]. Thus, I estimate that ~55,000 5 MW wind turbines, ~500 300 MW concentrated solar plants, ~500 300 MW solar PV power plants, ~ 3 million 3 kW rooftop PV or wind power systems, ~150 100 MW geothermal power plants, ~10 new 1300 MW hydroelectric power plants, ~5000 0.75 MW wave devices and ~5000 1 MW tidal turbines plus 70,000 MW existing hydroelectric power plant capacity can power a future Canada that uses electricity and electrolytic hydrogen for all purposes.

Vehicles, ships and trains would be powered by electricity and hydrogen fuel cells. Aircraft would run on liquid hydrogen. Homes would be cooled and warmed with electric heaters – no more oil, natural gas, coal or even nuclear – and water would be preheated by the sun.

100 passenger hydrogen ship[14]

Hydrogen tractor[15]

Liquid hydrogen aircraft (concept)[16]

If Canada converts all personal vehicles to battery electric vehicles powered by wind, the footprint would be <0.2 km^2, twice the area of Parliament Hill. Land area for turbine spacing can still be used for agriculture.

Space heating is a key service representing 62.8% of end-use energy in Canada's residential sector[17]. Fortunately wind, the best resource option in general, tends to be almost doubly as powerful in the coldest month compared to the warmest. Electric thermal storage (ETS) devices such as dense, ceramic bricks can thus be installed to supply Canadians with wind for space heating with reliability. For PEI, the average household using ETS for space heating and a 95% wind and 5% hydro supply mix, results in lifecycle CO_2 equivalent emissions of ~200 kg/yr.[18].

Aside from cryogenic hydrogen for aircraft, which you have to combust, along with some high temperature processes that would replace steel production, there would be no need for any combustion except in some very remote circumstances. In sum, this path to sustainable energy in Canada achieves more than a 90% reduction in CO_2e from total energy use, down from ~488 Mt CO_2e in year 2008 to ~32 Mt per year[19].

I encourage people to review these energy solutions carefully, using the sources and calculations in this testimony as a starting point. More detailed information and analysis can be supplied upon request. I am available to respond to any questions, comments or concerns you may have.
Thank you.

Sources and Calculations:

1. Environment Canada data: http://www.youtube.com/user/CarlDuivenvoorden#p/a/u/1/cLfIgXuzTnU
2. http://www.stanford.edu/group/efmh/jacobson/Articles/I/revsolglobwarmairpol.htm
3. http://www.stanford.edu/group/efmh/jacobson/Articles/I/susenergy2030.html
4. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/aaa_ca_1_e_4.cfm?attr=0
5. One quadrillion joules = One petajoule (PJ) = 0.277778 terawatt hours (TWh), thus assume 0.278 TWh
6. http://www.windatlas.ca
7. https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php
8. http://www.cangea.ca/images/uploads/Islandsbanki_CanadaGeoReport2010.pdf
9. http://www.oreg.ca/web_documents/tritoncanadatidalpowermay2006.pdf
10. http://www.oreg.ca/web_documents/chc-tr-041.pdf
11. http://www.canhydropower.org/hydro_e/pdf/Speaking_notes_TransAmerica_Conference_3.pdf
12. http://www.statcan.gc.ca/pub/91-214-x/2007000/4121648-eng.htm
13. Calculation of number of plants and devices to power Canada:
    55,000 5 MW wind turbines x .36 x 8,760 = 867.2 TWh/yr
    150 100 MW geothermal power plants x .95 x 8,760 = 124.8 TWh/yr
    5000 1 MW tidal turbines x .3 x 8,760 = 13.1 TWh/yr
    5000 0.75 MW wave devices x .25 x 8,760 = 8.2 TWh/yr
    500 300 MW concentrated solar plants x .11 x 8,760 = 144.5 TWh/yr
    500 300 MW solar PV plants x .11 x 8,760 = 144.5 TWh/yr
    3 million 3 kW rooftop PV systems x .11 x 8,760 = 8.7 TWh/yr
    Total electricity production without hydro (load balancer) is 1,311 TWh/yr
    Add 368.2 TWh/yr of existing hydroelectricity to fill in the supply gaps
    Add 10 new 1300 MW hydroelectric power plants x .6 x 8,760 = 68.3 TWh/yr
    Total electricity production = 1,747.5 TWh/yr
14. http://www.zemships.eu/en/project/introduction/index.php
15. http://agriculture.newholland.com/uk/en/WNH/hydrogen/Pages/Hydrogen.aspx
16. http://ec.europa.eu/research/growth/gcc/projects/in-action-cryoplane.html
17. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/res_ca_2_e_4.cfm?attr=0
18. Average space heating demand per PEI home is 18,500 kWh/yr. Assume 95% wind + 5% hydro backup supply:
    17,575 kWh wind x 8 g CO_2e/kWh + 925 kWh hydro x 65 g CO_2e/kWh = 140.6 kg + 60.1 kg =
    The result is 200.7 kg CO_2e per home/yr.
19. Calculation of total lifecycle CO_2 equivalent emissions for energy use in Canada:
    (Including all-source GHGs and background GHGs from existing system due to planning-to-operation delays)
    867,200,000,000 kWh of wind x 8 g CO_2e/kWh = 6.9 megatonnes (Mt) CO_2e/yr.
    124,800,000,000 kWh of geothermal x 30 g CO_2e/kWh = 3.7 Mt CO_2e/yr.
    13,100,000,000 kWh of tidal x 45 g CO_2e/kWh = 589.5 kilotonnes (kt) CO_2e/yr.
    8,200,000,000 kWh of wave x 50 g CO_2e/kWh = 410 kt CO_2e/yr.
    144,500,000,000 kWh of CSP x 23 g CO_2e/kWh = 3.3 Mt CO_2e/yr.
    144,500,000,000 kWh of solar PV x 85 g CO_2e/kWh = 12.3 Mt CO_2e/yr.
    8,700,000,000 kWh of rooftop PV & small wind x (24 + 85)/2 g CO_2e/kWh = 474.2 kt CO_2e/yr
    368,200,000,000 kWh of existing hydro x 65 g CO_2e/kWh = 23.9 Mt CO_2e/yr.
    68,300,000,000 kWh of new hydro x 65 g CO_2e/kWh = 4.4 Mt CO_2e/yr.

    Note – the above estimates of lifecycle g CO_2e/kWh are derived from ranges of data (Jacobson, 2009). The solar estimate is then increased by a factor of 2.5 to reflect resource availability in Canada. The small wind estimate is increased by a factor of 3.

    Total CO_2e ~ 56.0 Mt CO_2e/yr. Assuming you do not include any emissions for existing hydroelectric generating capacity, as construction of plants are completed and vegetation areas flooded, total CO_2e ~ 32.1 MT CO_2e/yr.

    Total GHG emissions in Canada (2008) ~ 487.8 Mt of CO_2e * not accounting for GHGs from outside Canada (ie. – manufactured components) or for background GHGs due to delays (ie. – 10-19 years delay for new nuclear relative to new wind capacity).

    This path to sustainable energy in Canada achieves more than a 90% reduction in GHGs.

Moving Canada forward – energy policy options

A recent McKinsey&Company report estimates if the United States invests $520 billion in energy efficiency by 2020, it reduces non-transportation end-use energy by 23 percent, saving $1.2 trillion dollars.

Bill Clinton once said, "the least sexy topic is where the most jobs are."

According to Clinton's sources, on balance, $1 billion invested in a coal fired power plant creates 870 jobs, in solar PV 1800 jobs, concentrated solar power 1900 jobs, in wind energy 3300 jobs, every $1 billion invested in building retrofits creates 6000 jobs.

Canada and US economies, energy systems and exchange rates are similar, and Canada is ~0.1 of US population, so perhaps Canada could invest ~$50 billion, saving ~$110 billion. If Canada invested ~$50 billion in retrofits, the result is ~300,000 jobs.

If Canada installs 275,000 MW of wind capacity at $2 million per MW (mean cost of onshore wind development in Eastern Canada, 2009), $550 billion invested creates ~1.8 million jobs.

These are very rough calculations to start, but the point is that Canada should start with the low-hanging fruit – unlocking energy efficiency in Canada, creating jobs and boosting the economy. Wind is relatively economical today, without even considering the externalities associated with conventional energy sources, and so wind also represents vast opportunities. All renewables offer price stability over the long-term and create plenty of jobs.

Policy measures should be, for example, a system-benefit charge on energy to create funds for reinvestment in energy efficiency, a revenue-neutral pollution tax (e.g., tax polluters, use funds to pay for renewables), a stronger renewable portfolio standard, incentives for electric vehicles etc. A tax credit up to $7,500 for automotive grade lithium batteries should be offered and revised down to $0 as battery costs are expected to decline. New building codes should have EV charging provisions, like Vancouver. Support should be provided to retool the automotive industry, as these costs can be several hundred million dollars. These are some great approaches, and there are many others.

We have a National Energy Board, helpful to build pipelines, but who handles overall transmission planning for the electricity system if it is the best way to move forward dealing with global warming, etc.? Why does PEI have no smart meters but Ontario does, when we could actually use them for something tangibly valuable today – storing our excess wind power? These kinds of questions are worth considering.

On PEI, we have a new oil furnace incentive but no wind heating incentive, thus we should replace the old incentive with the new one at little or no additional program cots. Otherwise, governments help pay for energy systems that will need to be replaced before end-of-life to meet GHG reductions.

So, time to stop playing around with this – time to move forward.
No sources are referred to as this is a brief supplemental section. More detailed information can be provided to the Committee upon request.