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GREENHOUSE GAS EMISSIONS AND FUTURE ENERGY REQUIREMENTS

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INTRODUCTION

International concern over global warming and greenhouse gases (GHGs) led to the ratification of the United Nations Framework Convention on Climate Change (FCCC) which called for the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[1] The FCCC's Kyoto Protocol[2] of 1997 calls for reductions in global GHG emissions to 5.2% below 1990 levels, to be reached between 2008 and 2012. Given future energy needs, reversing the trend of increasing CO_2 concentrations will require reductions beyond those called for by the Kyoto Protocol as well as the uncoupling of energy use and carbon emissions. The development of non-carbon-emitting energy sources will thus be a key component of any plan that hopes to tackle the GHG issue. This paper briefly explains the increasing need for carbon-free energy sources and reviews some of the alternatives available as well the advantages and drawbacks of each.

HOW MUCH CARBON-FREE ENERGY DO WE NEED?

Given current projections for global economic and population growth, energy requirements are expected to increase considerably over the coming decades. If the proportion of energy derived from fossil fuels remains constant at approximately 75%, roughly 10 terawatts (10 TW is equivalent to 10 billion kilowatts, kW) of carbon-emission-free power will be required

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(1) "Article 2, Objective," *The United Nations Framework Convention on Climate Change*, www.unfccc.de/resource/conv/conv_004.html.

(2) http://www.unfccc.de/resource/conv/index.html.

by the year 2050 to make up the other 25% of energy requirements.(3) To put this into perspective, 10 terawatts of electricity is the amount of energy used globally in 1990 and would require the equivalent of 10,000 nuclear power stations to produce. Under this scenario, atmospheric CO_2 levels would rise to double pre-industrial levels by 2070, and would continue to rise beyond this date. If we want to try to stabilize atmospheric CO_2 levels, at or below this level, *tens* of (rather than ten) terawatts of carbon-emission-free energy will be needed.

In order to meet the reductions called for at Kyoto, as well as our own increasing demand for energy, non-carbon-emitting energy sources must be developed. Possible energy sources that may be explored include: hydro, tidal, wind, solar, nuclear, biomass and geothermal energy (see below for a discussion of each of these sources). Additionally, CO_2 emissions may be reduced by improving the efficiency with which fossil fuel resources are utilized, or by capturing and sequestering CO_2, thereby preventing it from accumulating in the atmosphere. According to the Pembina Institute,(4) Canada lags behind many industrialized nations in both the amount of energy it derives from renewable sources as well as in spending on renewable energy research and development.

FOSSIL FUELS

Decreasing the amount of carbon released from each unit of energy derived from fossil fuels can help decrease CO_2 emission rates. One way to accomplish this is to switch from coal and oil to natural gas,(5) which is the cleanest-burning and least carbon-intensive of the fossil fuels.(6) There has been a significant shift in this direction over the past decade; however, with the rise in natural gas prices in recent years, this trend has slowed. The average price quoted for electricity derived from fossil fuels is about 3¢ (U.S.) per kilowatt-hour (kWh), in the absence of health and environmental costs. But when these costs are included (internalized), the real price

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(3) Martin I. Hoffert *et al.*, "Energy implications of future stabilization of atmospheric CO2 content," *Nature*, 395, 28 October 1998, pp. 881-884.

(4) http://www.pembina.org/pubs/pdf/cre.pdf.

(5) http://www.gastechnology.org/pub/oldcontent/pubs3/e+s/f96e-s-featr.html.

(6) President's Committee of Advisors on Science and Technology, Panel on International Cooperation in Energy Research, Development, and Deployment, *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, June 1999, pp. 1-7, 5-2.

of coal has been estimated to be closer to 7¢/kWh (U.S.).(7) (A single kWh can run a 100-watt bulb for 10 hours.) New "clean coal" technologies have also emerged in recent years, such as integrated gasification combined cycle (IGCC) electric power generation, whose high efficiencies require less coal per unit of energy output, resulting in significantly lower CO_2 emissions. The synthesis gas produced by IGCC can also be converted to transportation fuels that boast significantly lower emissions than do traditional fuels.(8) Although these systems are relatively expensive, their costs are expected to decline in the coming years.

The capturing and sequestration of carbon,(9) either in the deep ocean or underground in depleted oil and gas reservoirs, is now being investigated as a means of preventing CO_2 accumulation in the atmosphere. Although probably technically feasible, the long-term stability of such reservoirs is largely unknown and it has been estimated that they would likely increase the cost of electricity generation by about 30%.

In the final analysis, however, it is necessary to move away from dependence on fossil fuels. If all of the world's fossil fuel reserves were burned, atmospheric CO_2 levels would jump to 4-8 times their pre-industrial levels; the predicted increase in temperature would be between 3 and 15ºC.(10)

HYDRO/TIDAL

Hydroelectric power currently provides more electricity than any other renewable energy source. It accounts for almost 19% of the world's electrical output, and in Canada it contributes roughly 67,000 MW of electricity (1 MW equals 1,000 kW).(11) Although hydropower typically costs more per kWh than fossil fuel energy, no combustion gases or solid wastes are produced. In addition, the operating costs of hydro plants are usually low for

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(7) Mark Z. Jacobson and Gilbert M. Masters, "Exploiting Wind Versus Coal," *Science*, Vol. 293, 24 August 2001, p. 1438.

(8) National Laboratories Directors for the U.S. Department of Energy, *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions*, October 1997, www.ornl.gov/climate_change/climate.htm.

(9) http://www.nrcan.gc.ca/es/oerd/publications/publications/CO2%20Capture%20&%20Storage_e.PDF.

(10) James F. Kasting, "The Carbon Cycle, Climate, and the Long-Term Effects of Fossil Fuel Burning," *Consequences: The Nature and Implications of Environmental Change*, Vol. 4, No. 1, 1998, www.gcrio.org/CONSEQUENCES/vol4no1/carbcycle.html.

(11) Canadian Hydropower Association, "Quick Facts," www.canhydropower.org/hydro_e/pdf/Quick_Fact.pdf.

two reasons: there are no fuel costs, and maintenance requirements are minimal. However, hydropower is not without environmental impacts. By significantly altering water levels, disrupting water flow patterns, and usually requiring the flooding of large areas, dam and reservoir construction can have very negative effects on the flora and fauna that inhabit the surrounding areas, as well as the local human population. In addition, the world's total potential hydropower capacity has its limits. About 700,000 MW is currently produced, and if all economically feasible developments were pursued, this number could be expected to triple.[(12)] However, this would amount to only 2.15 TW; although helpful, other carbon-free energy sources would still be necessary to fulfil future energy needs.

Another source of energy that harnesses power from the flow of water is tidal energy. Exploiting the daily cycle of water movement, created by the gravitational pull of the moon, is limited to a select number of coastal areas where the topography allows for an economically feasible plant. Only one tidal plant currently operates in North America; the Annapolis Royal[(13)] plant in Nova Scotia profits from the highest tides in the world in the Bay of Fundy, and has a peak production capacity of 20 MW. Nevertheless, tides are ultimately periodic, and adequate techniques for the retiming of energy output are still lacking.

WIND

Among renewable energy sources, wind is the closest to being cost-competitive with fossil fuels. In Canada, the cost of electricity derived from wind power has dropped from 30¢ to 5.8¢ (Can.)/kWh in the past decade.[(14)] American estimates put the cost between 3¢ to 4¢ (U.S.).[(15)] In the spring of 2001, the world's wind energy capacity hit 10,000 MW; by the end of 2010, it is estimated that Canada alone will be producing 10,000 MW of wind power annually.[(16)] According to a 1997 U.S. study, 34 of the 50 states have high-quality wind

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(12) International Hydropower Association, International Energy Agency, Canadian Hydropower Association, *Hydropower and the World's Energy Future: The role of hydropower in bringing clean, renewable, energy to the world*, November 2000, p. 1.

(13) http://www.nspower.ca/AboutUs/OurBusiness/PowerProduction/HowWeGeneratePower/TidalPower.html.

(14) Canadian Wind Energy Association, *Quick Facts*, 2001, www.canwea.ca/quickfacts.htm.

(15) Jacobson and Masters (2001).

(16) "Wind Power Projects Covering More Landscape," *Energy Analects*, Vol. 30, No. 18, 4 September 2001, pp. 1-3.

resources, and wind power could contribute significantly to a reduction in U.S. greenhouse gas emissions.(17) Canada has extensive wind energy resources, and the best areas for wind turbines are in the Gaspésie (Quebec), the Maritime provinces, southern Alberta and Saskatchewan, and the far North. However, because wind speed is greatly influenced by topography, suitable wind speeds can be found in many parts of Canada.(18) Although wind power and many other renewable power sources are intermittent resources, diversifying the suite of energy sources used can largely accommodate this problem.

SOLAR

At about 12¢/kWh (U.S.), solar photovoltaic (PV) electricity from the most cost-efficient large-scale plants is still more expensive than fossil fuel-generated power.(19) However, the cost of PV electricity has already declined dramatically and is predicted to continue to do so for the next 20 years. By then, prices are expected to reach competitive levels. In fact, solar power is already competitive in niche markets, i.e., mainly remote areas and developing communities that lack connections to established electrical grids. It is estimated that an area 26,000 Km^2 in size, covered with PV panels using current technology, could produce enough energy to fulfil the current power needs of the United States. This is equivalent to one-quarter of the area covered by U.S. roads. Of course, the total area required would be substantially reduced if other energy technologies were used in concert with solar power.(20)

Over the past decade, PV technology has succeeded in meeting the needs of a growing number of remote off-grid markets in Canada.(21) However, it is not yet cost-competitive with the industrial power generators that service grid-tied customers. In 1999, Canada's installed PV power capacity reached 5.8 MW.(22) Although the production of PV

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(17) National Laboratories Directors for the U.S. Department of Energy (1997).

(18) Canadian Renewable Energy Network, *Wind Energy: Resource Assessment*, 13 April 2000, www.canren.gc.ca/icmtmpl/en_resource.asp?ca=56.

(19) Energy Efficiency and Renewable Energy Network, *Concentrating Solar Power: Energy from Mirrors*, Consumer Energy Information: EREC Fact Sheets, March 2001.

(20) J.A Turner, "A Realizable Renewable Energy Future," *Science*, Vol. 285, 1999, p. 687.

(21) http://cedrl.mets.nrcan.gc.ca/pubs/cedrl_2001_45_tr_411_pvpstr_2000_report_e.pdf.

(22) Lisa Dignard-Bailey, *Photovoltaic Technology Status and Prospects: Canadian Annual Report 2000*, CANMET Energy Diversification Research Laboratory, Natural Resources Canada, 2000, http://cedrl.mets.nrcan.gc.ca/pubs/cedrl_2001_45_tr_411_pvpstr_2000_report_e.pdf.

panels would require an energetic investment, this would likely be paid back within 3-4 years, and the CO_2 savings would far exceed the emissions produced from panel manufacturing.

NUCLEAR

Nuclear fission power generation produces far fewer greenhouse gases than equivalent fossil fuel generation. Any initial emissions produced from power plant construction are quickly overwhelmed, as in the case of PV panel production. Assuming it replaces electricity derived from fossil fuels, current levels of nuclear power use are said to reduce global carbon emissions by up to 17% in the electricity-generating sector.(23) Between the late 1970s and early 1990s, France decreased CO_2 emissions in its electricity-generating sector by 80% when it switched to mainly nuclear power.(24)

More than 400 nuclear power plants are currently in operation throughout the world. The bulk of these were constructed in the 1970s and 1980s, and will soon reach the end of their initial 40-year life spans. Although lifetime extensions of ten or more years are expected, many new reactors will soon be required, at an average cost of over $2 billion (U.S.) each. In order for nuclear power to make a significant contribution to cutting CO_2 emissions in the coming years, roughly ten times the current number of reactors would be required. Apart from the cost, the logistical problems associated with the construction of such a great number of plants would be enormous.

As with fossil fuels, there is a finite supply of nuclear fuels. At our current rate of consumption, the world has about 25-30 years worth of inexpensive uranium resources, and uranium development beyond this date is difficult to predict.(25) However, fast breeder reactors, which produce more fissionable material than they consume, offer the possibility of essentially renewable nuclear power. Although this may help extend the world's nuclear fuel supply, many believe the concomitant production of weapons-grade plutonium may increase the risk of nuclear weapons proliferation. Another possible solution to the nuclear fuel problem is the harvesting of uranium from the sea, which contains enough uranium to supply energy needs for thousands of

(23) Nuclear Energy Agency, *Nuclear Power and Climate Change*, 1998, www.nea.fr/html/ndd/climate/climate.pdf.

(24) National Laboratories Directors for the U.S. Department of Energy (1997).

(25) International Energy Agency, Organisation for Economic Co-operation and Development, *World Energy Outlook* 2000, 2000, p. 289.

years; however, current technology makes this impractical. Nuclear fusion has the potential to produce a near-limitless supply of clean energy by imitating the reactions that occur in the sun. However, the technology to make fusion a feasible source of energy is still in the distant future.

For many people, the hazards associated with nuclear technologies represent the greatest concern. Reactor safety and nuclear waste disposal both present challenges that must be adequately confronted if nuclear technology is to overcome its negative reputation.

BIOMASS

Biomass resources – including agricultural and industrial wastes, municipal solid waste, and energy crops – may be used as fuel alone, co-fired with coal, or gasified for use in lieu of natural gas. Biomass products may also be converted to liquid fuels – such as methanol, ethanol and hydrogen – in order to replace petroleum products for use in internal combustion engines. Many developing countries rely heavily on biomass fuel sources. In Asia and India, biofuels account for one-quarter and one-half of energy use, respectively.(26)

Currently, the cost of biomass energy ranges from 8¢ to 12¢/kWh (U.S.).(27) In addition to the cost, biomass only provides emission savings if the CO_2 released by their burning is recycled into the production of new biomass products. A further concern with the burning of biomass products is the release of particulate emissions, and consequent degradation of air quality. As well, the production of dedicated crops for biomass has the potential to compete for agricultural land. As a result of these factors, this resource must be approached with caution to ensure its use is effective and sustainable.

GEOTHERMAL

Hot magma from the Earth's core is continually radiating outwards, occasionally reaching beyond the crust, in the form of lava. Usually, however, the magma remains below, where it heats up rock and water deposits. The water and/or steam from these hydrothermal

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(26) J. Lelieveld *et al.*, "The India Ocean Experiment: Widespread Air Pollution from South and Southeast Asia," *Science*, Vol. 291, No. 5506, 9 February 2001, pp. 1031-1036.

(27) Electric Power Research Institute, as cited by John A. Turner, "Biomass in the Energy Picture," *Science*, Vol. 285, No. 5431, 20 August 1999, p. 1209.

reservoirs can be used to power turbines and thereby produce electricity. One of the obstacles preventing the full exploitation of geothermal resources is the difficulty of predicting reservoir performance and lifetime. The majority of hydrothermal resources in the United States is located in Alaska, Hawaii and the western states; California and Nevada currently lead the nation in generation of electricity from hydrothermal sources.(28) At present, about 8,000 MW of energy is produced worldwide using hydrothermal reservoirs. Canada's potential for geothermal energy production is estimated to be over 400 GW.(29) However, with current technology, only a fraction of the world's huge geothermal resources could be used economically.(30)

Alternatively, hot air and water can be cycled through a system of underground pipes or through buildings to provide heat. These "heat pump" systems may also be reversed during warm seasons to provide cooling. Exploiting this "earth energy" could replace the use of traditional combustion furnaces.(31) This would be especially useful in Canada where one-quarter of our total energy consumption is used for the heating and cooling of water and buildings.

HYDROGEN

No discussion regarding the future of the world's energy supply can be complete without a mention of hydrogen which is high in energy. The burning of pure hydrogen produces nearly no pollution of any kind; however, it does not naturally exist in a useable form and so must be produced either from hydrocarbons or from electrolysis of water. Hydrogen is, therefore, only as "clean" as the energy used to produce it; unless renewable sources of energy are used for its production, hydrogen cannot help to reduce CO_2 emissions.

Currently, hydrogen is used in a limited number of applications; notable among these is its use as fuel for spacecraft propulsion. Fuel cells(32) allow useful energy to be extracted

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(28) Energy Efficiency and Renewable Energy Network, "Frequently Asked Questions," *What is Geothermal Energy?* U.S. Department of Energy's Geothermal Energy Program, 2001, www.eren.doe.gov/geothermal/geofaq.html.

(29) D.K. Blamire, *Utility Perspective on Technology related to Greenhouse Gas Abatement*, Nova Scotia Power Inc., March 1999.

(30) National Laboratories Directors for the U.S. Department of Energy (1997).

(31) Energy Efficiency and Renewable Energy Network (2001).

(32) http://www.nrcan.gc.ca/es/etb/cetc/cetc01/htmldocs/factsheet_fuel_cells_e.html.

from hydrogen and can be adapted for use in transportation vehicles, homes, or for industrial purposes. Despite the technological, safety and cost issues associated with hydrogen, many foresee a time when its use will dominate throughout the world because of its ability to act as an energy carrier, allowing energy to be stored and delivered where it is needed. Given the intermittency of many renewable energy sources, hydrogen could be the missing link that will allow these technologies to realize their full potential. To reach this goal, however, scientists will have to overcome many technical aspects regarding hydrogen, such as the current requirement for large portable storage units and a lack of transportation infrastructure.

CONCLUSION

In order to achieve stable and safe atmospheric levels of greenhouse gases, it is clear that energy use must be uncoupled from carbon emissions. Although this will not require the complete elimination of carbon-based energy, it will demand the development of alternative emission-free sources. There will not be, however, a "magic bullet" solution to the problem of rising energy requirements and our competing desire to reduce greenhouse gas emissions. No single alternative will be sufficient to supply our future energy needs, and many of the energy alternatives discussed here are still in a fairly nascent stage of technological development. Thus, research and development are needed in all areas to meet the goal of stabilized CO_2 levels.

MORE INTERNET LINKS OF INTEREST

For more information on:

- the Kyoto Protocol and Canada's response to global warming – see: Global Warming, Greenhouse Gases and the Kyoto Protocol (http://lpintrabp/apps/tips/tips-cont.asp?Language=E&Heading=7&TIP=61)
- renewable energy from Natural Resources Canada – see: Canadian Renewable Energy Network (http://www.canren.gc.ca/)
- specific sources of renewable energy – see:
  - Hydro/Tidal (http://www.canren.gc.ca/hydro/index.asp)
  - Wind (http://www.canren.gc.ca/wind/index.asp)
  - Solar (http://www.canren.gc.ca/solar/index.asp)
  - Nuclear (http://nuclear.nrcan.gc.ca/english.pdf)

- Biomass (http://www.canren.gc.ca/bio/index.asp)
- Geothermal (http://www.canren.gc.ca/earth/index.asp)

- organizations – see:
  - Pembina Institute for Appropriate Development (http://www.pembina.org/)
  - Canadian Hydropower Association (http://www.canhydropower.org/hydro_e/p_cha.htm)
  - Canadian Wind Energy Association (http://www.canwea.ca/indexen.htm)
  - Solar Energy Society of Canada (http://www.solarenergysociety.ca/)
  - Canadian Nuclear Society (http://www.cns-snc.ca/home_eng.html)
  - Canadian Gas Association: Natural Gas & the Environment (http://www.cga.ca/natural.html)
  - Energy Efficiency and Renewable Energy Network (U.S. Department of Energy) (http://www.eren.doe.gov/)