The Next Generation of CANDU Technologies: Profiling the Potential for Hydrogen Fuel

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EACL Énergie atomique du Canada limitée

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Reliable, clean and affordable energy is key to human progress and to attaining a better quality of life for all people. It is needed to run our industry, our businesses and our homes, and it is critical for our transportation requirements. Around the world today, balancing society's needs for energy with the imperative to protect our air, water and climate is a key business and social challenge, and a significant opportunity.

In the last years of the 20th century, and at the beginning of the 21st, there have been tremendous changes in the energy marketplace. During the last twelve months we have seen the continuing efforts to implement the Kyoto Protocol, price surges for oil and natural gas, and painful transitions to deregulation, leading to blackouts and near-bankrupt utilities in California. Unpredictability has been the key characteristic of the emerging energy economy. However, through these complex signals, two needs are clearly and consistently expressed:

- the need for clean energy with zero, or minimal, air emissions to support healthy communities
- the need for a reliable energy supply with stable prices, to support people's standard-of-living expectations.

Vision for a Zero-Emission Future

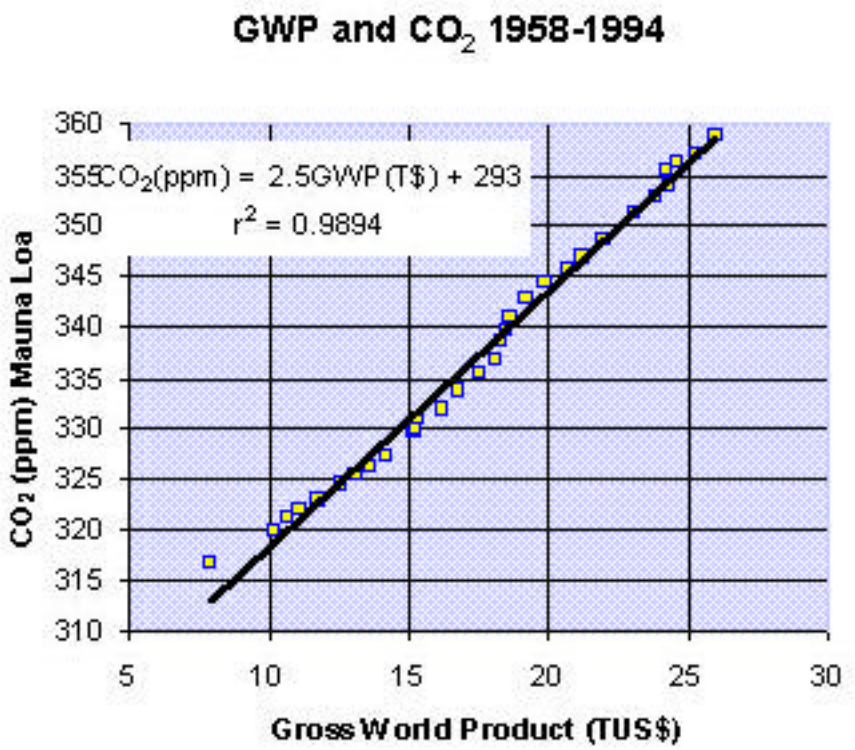
At such a time, the need for new technologies and new processes is critical. Emerging 21st century technologies will change how energy is generated and delivered to the end-user. At the same time, they can help to drastically reduce environmental impacts, while providing affordable energy. The best option is a sound mix of different energy sources, providing reliability of supply, making the best use of our resources, and limiting environmental and health effects.

When we take a historical look at electricity, in particular, we see that an increase in production always corresponds with gains in economic growth and energy efficiency (lower energy use per unit of economic activity). Traditionally, it has also meant an increase in the emission of greenhouse gases (GHGs), acid rain and smog. However, when clean generating technologies such as nuclear power are used, electricity can be produced in an environmentally responsible manner—without adding to these emissions.

AECL's MACSTOR™ units provide environmentally safe, above-ground storage of used fuel.

Nuclear power is the largest proven non-carbon energy source available. Nuclear plants require a smaller land area than any other commercial energy source. They also use a smaller amount of fuel and generate a smaller amount of waste

than fossil-fuelled generating stations. The waste satisfies the goal of "sustainability" because its radioactivity decays naturally, in 300-400 years, to the level of the original uranium. The relatively small amount of waste is safely stored at the reactor sites and is closely monitored to ensure that there are no impacts on workers, the public or the environment. The nuclear industry has developed options for disposal, but continues to look for and incorporate the most current technologies to optimize storage and disposal management systems.



Canada has the technological capability and expertise to lead the way to a zero-emission future. Included in the mix of possible solutions for achieving this is the opportunity to exploit the synergies between two clean, safe and reliable energy sources: next-generation CANDU® nuclear power reactors, as a large-scale source of electricity for our homes, businesses and industry, and hydrogen (another non-carbon source) to fuel our transportation sector. This paper will describe the contributions nuclear technology can provide to meet global energy demands while, at the same time, addressing environmental challenges such as clean air and climate change.

Clean, Affordable CANDU Electricity for Homes, Businesses and Industry

Atomic Energy of Canada Limited (AECL) is the developer of CANDU nuclear power reactors, which provide clean, reliable electricity on four continents. Founded in 1952 as a Crown corporation of the Government of Canada, AECL has also developed important advances in nuclear medicine, and is currently the largest producer of medical radioisotopes in the world—supplying them to the world's leading radiopharmaceutical company, MDS Nordion.

CANDU power reactors have design features that are different from other commercially available nuclear power plants. For example, current CANDU plants use natural uranium instead of slightly enriched uranium fuel, and use heavy water instead of light water as moderator and coolant. They have a number of significant advantages including the ability to refuel while operating and their inherent passive safety features. There are 20 CANDU nuclear power reactors in Ontario. As well, AECL has built eight 700 MWe-class CANDU 6 power plants in Québec, New Brunswick, Argentina, Korea and Romania, and is currently constructing three more units in Romania and China.

The CANDU 6 has an outstanding, consistent record of success. Operating units have achieved lifetime average capacity factor of almost 85 per cent. Construction time has been minimized, with the most recently completed (1997-99) units in Korea being built on time to the day, in demanding 55-month construction schedules. Unit 4 at the Wolsong station in South Korea had the highest capacity factor (102.9 per cent) in the world for the year ending September 2000.

Four CANDU units at the Wolsong site in Korea—built in 1983, 1997, 1998 and 1999.

Due to its reliability, and improved safety and economics, nuclear power is now starting to be seen once more as an important clean energy source in many countries. In 2000, the number of operating nuclear power plants worldwide increased to 438, with 36 new plants under construction. At the same time, electricity generation from the existing plants has increased. This is due to improved operating practices, which has resulted in improved plant performance. This was seen dramatically in the U.S., where average plant capacity factor increased from 53.5 per cent in 1973 to 84.8 per cent in 1999. A recent U.S. report shows that nuclear energy is now the cheapest form of electricity production in that country.

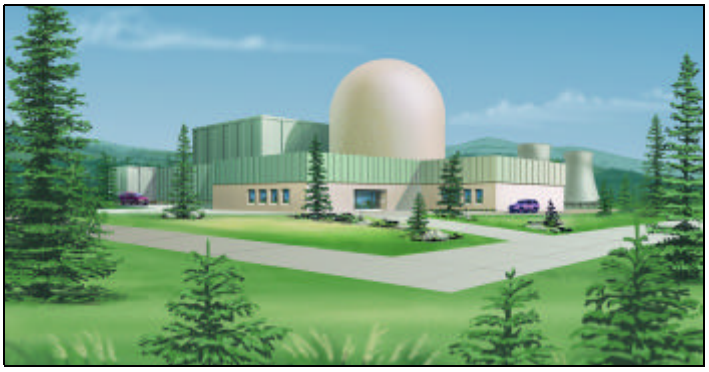
Restoring nuclear operation will have significant benefits in terms of air quality and climate change. Nuclear power plants generate zero emissions of sulphur dioxide (SO_2), nitrogen oxides (NOx), heavy metals and particulates. Each year, a 700 MWe nuclear power plant avoids emissions of about five million tonnes of CO_2, the amount that would be generated by a coal-fired power plant of the same size. Between 1971 and 1999, OPG's nuclear power plants in Ontario avoided 11 million tonnes of SO_2, 2.5 million tonnes of NOx and 1.2 billion tonnes of CO_2.

In the U.S., Canada and many other countries, utilities recognize the environmental and economic benefits of nuclear generation and are refurbishing existing plants to extend their operating life for these reasons. This approach will help to avoid large potential emissions in the future.

Next-generation CANDU Power Reactors: Responding to Economic Expectations

As the energy marketplace evolves, the challenge for nuclear utilities and vendors is to respond to new economic expectations while demonstrating that safety and performance standards are fully met. AECL is meeting this challenge by developing a series of new technologies as building blocks for a next generation of CANDU power plant designs. AECL is continually advancing CANDU technology, building on our in-depth knowledge of CANDU materials, components and systems, and on feedback from utilities about their operating experience. Currently, we are establishing the conceptual design for a next-generation medium-sized CANDU plant. We will keep proven elements of the CANDU design, while making significant innovations, including:

- compact reactor core design, reducing size by a factor of one third for the same power output
- improved thermal efficiency through higher-pressure steam turbines
- reduced use of heavy water (one quarter of the heavy water required for existing plants), thus reducing cost and eliminating many material handling concerns
- use of slightly enriched uranium to extend fuel life to three times that of existing natural uranium fuel
- further additions to CANDU's inherent passive safety



Next-Generation CANDU—responding to new economic expectations while demonstrating that safety and performance standards are fully met.

With these advanced features, the capital cost of constructing the plant can be dramatically reduced by up to 40 per cent compared with existing designs. AECL is developing improvements to project engineering, manufacturing and construction technologies. This will allow streamlined projects with shorter schedules, an extremely high-quality as-built design, and reduced delays due to rework.

Many of these construction project improvements have already been successfully demonstrated in AECL's recent CANDU construction projects in Korea (Wolsong 2, 3 and 4—completed 1997-99) and in China (Qinshan Phase III—completion date 2003). Improved modularization techniques, where power plant systems are pre-fabricated and lifted into place ready-built, are saving money and improving the quality of the finished product. AECL has also been a pioneer in the application of 3D-CADD computer aided design techniques. These help to integrate all

project activities including: equipment specification and procurement; construction and installation; inventory management; plant commissioning, and operation. Applying these practical advancements to the next-generation CANDU design will enable construction schedules to be further reduced. For replicated plants, AECL's target is to deliver a next-generation CANDU in 48 months, from the main contract signing through to commercial operation.

Two 728 MWe CANDU reactors at the Qinshan Phase III site in China will begin producing electricity in 2003.

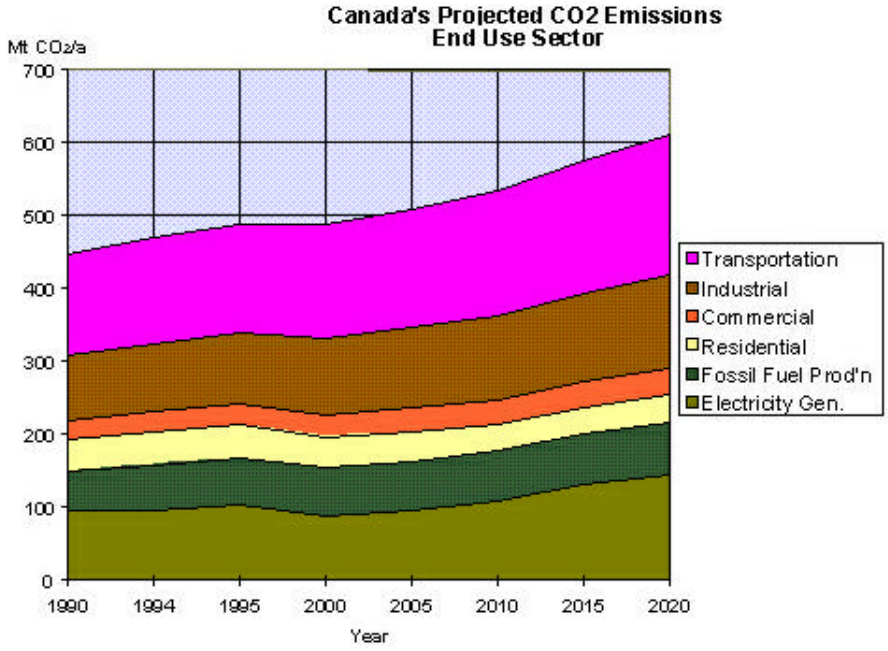
AECL's targets for this power plant are ambitious, but the conceptual design shows that they are achievable. The next generation of plants will build on CANDU's clean-power record by further improving environmental performance. They will

- reduce spent fuel quantities to one third of current plant quantities
- further decrease already-minimal radioactive emissions by more than a factor of two
- generate more energy per unit of uranium mined
- incorporate further passive safety characteristics.

Innovative CANDU design can make a positive clean-energy impact in the electricity market, as we know it today. The ultimate vision, however, is to extend this impact to the Transportation Sector.

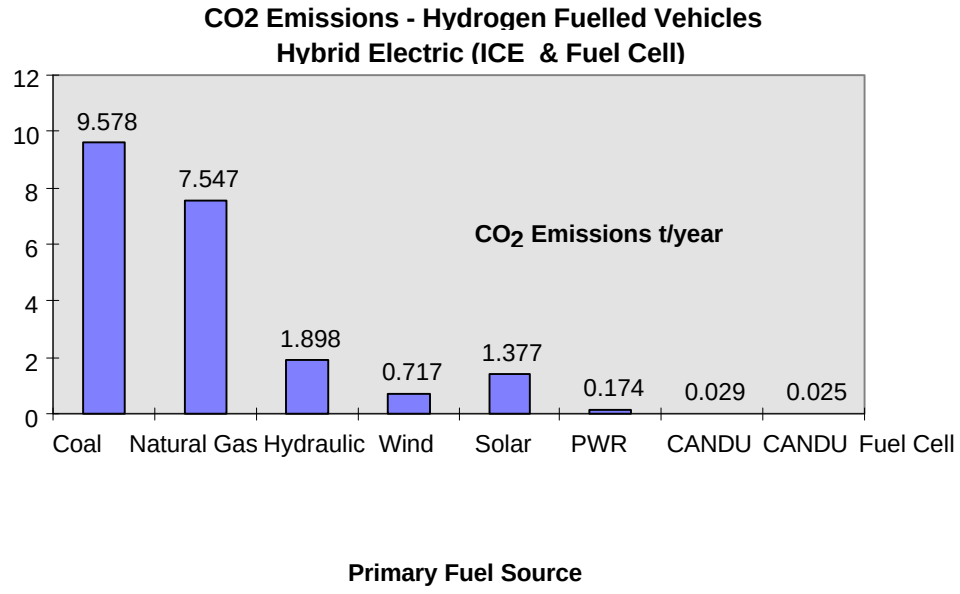
Reducing Emissions in the Transportation Sector

The importance of improving transportation efficiency and lowering associated emissions is gaining ever-increasing recognition. The transportation sector represents 35 per cent of total energy use in Canada and this energy represents four per cent of total Gross Domestic Product. Since most transportation fuels are hydrocarbon-based, emissions of by-products that affect air quality are an issue in high-use, high-population areas. Sixty per cent of smog-causing compounds are generated from Canadians' use of transportation. Contribution to greenhouse gas emissions, which cause climate change, is high, too—about 150 million tonnes of CO_2 per year. This is about 25 per cent of Canada's climate-change gas emissions.



Hydrogen: A Clean Transportation Fuel

Hydrogen can be readily stored, distributed, and used as a transportation fuel—and it can provide a solution in reducing Canada's environmental emissions. Conversion of hydrogen into energy, whether by combustion or by fuel cell, is an exceptionally clean process. If pure hydrogen is used, the only by-product is water. Hydrogen thus offers the potential of a transportation fuel completely free of all airborne emissions, whether NOx, particulates, or greenhouse gases. If hydrogen is produced from electrical energy (electrolysis), then no CO_2 or other emissions are generated.



Large amounts of electricity, however, are required to operate the industrial plants that use electrolytic methods to produce the hydrogen. This means that, in order to achieve the objective of reducing emissions from *all* sources, the electricity required to power hydrogen production plants must also be produced using technology that does not emit such gases itself. Hydrogen, when produced by plants powered by nuclear or renewable energy sources, offers us, and future generations, an important "sustainable" fuel. An extensive U.S. study states that: *As the ultimate fuel, hydrogen, once established, will provide a single alternative fuel, which……would last for the foreseeable future*. (Berry, 1996)

Photo courtesy of Ballard Power Systems

CANDU-Hydrogen Synergy: A Powerful Vision

The use of clean CANDU-generated electricity to run hydrogen-producing plants would ensure that the full cycle of hydrogen production was emission-free. Current electrolysis technology delivers pure hydrogen, thus eliminating even trace by-product emissions when used for transportation. Hydroelectric power, along with more intermittent renewable energy sources—such as solar and wind farms—could supplement reliable, baseload CANDU electricity for this purpose.

Recent improvements in electrolysis technology mean that hydrogen production using electricity as a power source is increasingly cost-effective. As well, hydrogen distribution can be handled from one large centre or, alternatively, distribution corridors with many smaller distribution centres can be established. Production scale can be tailored to the size of the application, because the modular nature of electrolysis equipment means that cost is not significantly affected by size.

At the same time, recent developments in fuel cell technology are beginning to allow efficient, cost-effective conversion of hydrogen into electricity as an on-board power source for transportation. Fuel cell conversion efficiency of 50 per cent for hydrogen fuel is well established, as are commercially competitive reliability and cell life. Prototype demonstrations of fuel-cell-powered vehicles are building an experience base to launch this technology. For example, fuel-cell-powered buses are successfully operating in Vancouver and elsewhere. A recent prototype (100-kilowatt) fuel cell, sponsored by the U.S. Department of Energy, as part of their advanced power technology program, passed its two-year operating test with flying colours. In this way, the clean electricity-hydrogen-fuel-cell cycle powers emissions-free transportation, with substantially greater end-use efficiency than traditional internal combustion power sources.

A final strength of this unique energy system is the synergy between hydrogen production and the generation of heavy water, which is needed to sustain the required neutron chain reaction in CANDU reactors. While producing an industrial stream of hydrogen from electrolysis would be the main objective of a hydrogen plant, a side-stream generation of heavy water could also be produced, with virtually no additional energy expenditure. This can be achieved by using AECL's CECE (Combined Electrolysis and Catalytic Exchange) technology. In a production setting, this would earn additional revenue for the hydrogen production process, thus improving the economics of hydrogen supply while, at the same time, producing essential heavy water for CANDU reactors.

Conclusion

Emerging technologies will be invaluable in providing clean, efficient, reliable energy sources to drive Canada's growth in the 21st century. Next-generation CANDU reactors, combined with mobile hydrogen fuel, provide us with a vision of affordable electricity to power our homes, businesses, industries and transportation vehicles, while offering future generations of Canadians clean air, reduced health problems and a better overall quality of life.

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