Nuclear Power and Carbon Dioxide Free Automobiles

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Abstract

Nuclear energy has been developed as a major source of electric power in Canada. Electricity from nuclear energy already avoids the emission of about 100 million tonnes of carbon dioxide to the atmosphere in Canada. This is a significant fraction of the 619 million tonnes of Canadian greenhouse gas emissions in 1995. However, the current scope of application of electricity to end use energy needs in Canada limits the contribution nuclear energy can make to carbon dioxide emission reduction.

Nuclear energy can also contribute to carbon dioxide emissions reduction through expansion of the use of electricity to less traditional applications. Transportation, in particular contributed 165 million tonnes of carbon dioxide to the Canadian atmosphere in 1995. Canada's fleet of personal vehicles consisted of 16.9 million cars and light trucks. These vehicles were driven on average 21,000 km/year and generated 91 million tonnes of greenhouse gases expressed as a CO2 equivalent.

Technology to improve the efficiency of cars is under development which is expected to increase the energy efficiency from the 1995 level of about 10 litres/100 km of gasoline to under 3 litres/100km expressed as an equivalent referenced to the energy content of gasoline.

The development of this technology, which may ultimately lead to the practical implementation of hydrogen as a portable source of energy for transportation is reviewed. Fuel supply life cycle greenhouse gas releases for several personal vehicle energy supply systems are then estimated.

Very substantial reductions of greenhouse gas emissions are possible due to efficiency improvements and changing to less carbon intensive fuels such as natural gas. CO2 emissions from on board natural gas fueled versions of hybrid electric cars would be decreased to approximately 25 million t/year from the current 91 million tonnes/year. The ultimate reduction identified is through the use of hydrogen fuel produced via electricity from CANDU power plants, reducing total emissions from these personal vehicles to an insignificant total of about 0.5 million t/year.

Introduction

Nuclear energy has been developed as a major source of electric power in Canada. Electricity from nuclear energy already avoids the emission of about 100 million tonnes of carbon dioxide to the atmosphere in Canada. This is a significant fraction of the 619[1] million tonnes of Canadian greenhouse gas emissions in 1995. However, the current scope of application of electricity to end use energy needs in Canada limits the contribution nuclear energy can make to carbon dioxide emissions reduction. Nuclear energy can also contribute to carbon dioxide emissions reduction through expansion of the use of electricity to less traditional applications. Transportation contributed 165 million tonnes of carbon dioxide to the Canadian atmosphere in 1995. Canada's fleet of personal vehicles consisted of 16.9 million cars and light trucks in 1995[2]. These vehicles were driven on average 21,000 km/year and generated 91 Mt of GHG expressed as CO2 equivalent. This paper reviews life cycle greenhouse gas emissions related to personal vehicles. The development of low emission vehicles is reviewed. The magnitude of releases for several personal vehicle energy supply systems is estimated. It is concluded that CANDU reactors can, ultimately, nearly eliminate greenhouse gas emissions from personal transportation.

Background

Fossil fuels have turned out to be a most convenient form of energy for mobile systems used for transportation. Many forms of fossil fuel are available in liquid form and contain a lot of energy in a small package. In fact their availability in abundance and the relative ease of transformation to usable energy for propulsion underlies the development of our current transportation systems.

Scientists, engineers and inventors have long been intrigued with the idea of using hydrogen in a similar capacity. The primary goal is to have a replacement on hand in anticipation of the eventual exhaustion of cheap and abundant liquid fossil fuel. Hydrogen can be produced by large central plants which are not so amenable to mobile applications. For example, water can be converted to hydrogen using electricity produced from coal, nuclear, hydraulic, solar and wind power plants. The hydrogen can be stored and then used as fuel for mobile equipment. The electricity from such plants can also be used to charge batteries, which in turn can power vehicles. Batteries developed thus far have shortcomings with respect to their size and weight. They are simply too heavy or expensive to power vehicles with the range and power to which we are accustomed. Another route to the use of hydrogen as an energy carrier involves the use of fuel cells which efficiently convert hydrogen and oxygen from the air into electricity and water. Development of this technology has been progressing for several years under the impetus provided by high oil prices and shortages of fossil fuels in the early eighties.

The climate change issue has brought renewed urgency to this development. Research and development related to the use of electricity and hydrogen for transport has jelled to the point that a credible path of evolution to the use hydrogen as a replacement for fossil fuels in personal transportation can be seen.

The Evolutionary Path

The news has recently been filled with stories about the use of hydrogen as an emissions free source of energy. The ultimate expression of the technology is the application of fuel cells which can efficiently convert hydrogen and oxygen from the air into electricity. However, hydrogen is not freely available, and must be produced from other sources. The primary sources at present are fossil fuels such as natural gas or by the separation of water into it's components, hydrogen and oxygen, using electricity. Hydrogen thus produced serves as a form of energy "carrier" which can be stored and used as needed. The centralized production of hydrogen is an enabling technology allowing the application of nearly carbon dioxide free energy sources such as nuclear, hydro, solar and the wind to transportation. There are a number of inefficiencies in the production and use of hydrogen which have precluded rapid adoption of the technology. The need to develop highly efficient transportation technology in order to reduce carbon dioxide emissions seems to have opened a new window of opportunity to introduce hydrogen technology and achieve emissions free transportation.

Research and development effort is currently focusing on so-called hybrid electric vehicles. Gasoline powered vehicles tend to be inefficient as a very large engine is needed to provide power for acceleration to highway speeds and emergency situations. Cars powered by batteries and electricity are highly efficient but limited in range and performance by heavy battery installations. Hybrid electric vehicles take advantage of the best of both worlds by combining a small internal combustion engine (ICE) with a small battery set and an electric motor. Although there are many variations of this basic design theme, it is possible to use both engines for acceleration and other brief high load conditions. The ICE operates only under highly efficient full load conditions when accelerating, cruising on the highway or to charge the batteries. The batteries and electric motor are capable of efficiently powering the car at low speeds around town. Smart use of these two types of motor allows for double the mileage of current ICE only cars. This efficiency cuts the carbon dioxide emissions roughly in half. In addition the batteries may be charged directly from household electricity. Should that electricity come from emission free sources such as hydro or nuclear power, carbon dioxide emissions can be cut still more.

Another evolutionary step is possible along the way toward emission free cars. Natural gas releases substantially less carbon dioxide per unit of energy released by combustion than gasoline or diesel fuel. This is due to it's higher hydrogen content. Internal combustion engines can also be made somewhat more efficient with natural gas fuel. Carbon dioxide releases can thus be further reduced by using natural gas as the fuel for a hybrid car.

Pure hydrogen can also be utilized as an ICE fuel source. Carbon dioxide emissions at the point of use are thus eliminated although there will still be some emission of nitrous oxides resulting from high temperature combustion. The ultimate source of power for a hybrid vehicle would be a hydrogen fuel cell. Although very expensive to produce at present, fuel cells are very efficient in producing electricity and operate at low temperature avoiding the production of nitrous oxides and other emission products. Fuel cells also become more efficient at part load, unlike internal combustion engines, and are thus well suited to powering vehicles which usually only require a fraction of maximum power needs. A relatively small fuel cell may be employed in combination with batteries to counter the high cost of the fuel cell. It replaces the ICE of earlier generation hybrid vehicles.

A clear path toward the development of an emissions free transportation system is in sight. A smooth progression from our current system, which depends on fossil fuels with large carbon dioxide emissions, to a emissions free system which derives primary energy from carbon dioxide free sources such as nuclear power or emissions free renewable sources including hydro, wind and solar energy is envisaged.

Carbon Dioxide Emissions

Substantial quantities of hydrogen are already produced and used in Canada. Almost all of it is produced from hydrocarbons through a process known as reforming. This is accomplished by heating hydrocarbons, by burning some, to separate the hydrogen and carbon components. The products are hydrogen, and you guessed it, carbon dioxide. The hydrogen generated is primarily used to produce fertilizer (ammonia) or is added to heavy oils to make useable gasoline and other liquid hydrocarbon products.

Hydrogen can also be produced by the electrolysis of water, and if the energy source used to produce electricity is free of GHG emissions, the entire energy supply and use system will be GHG free. However, all systems currently use some energy derived from fossil fuels. A life cycle analysis which establishes all of the CO2 emissions involved in preparation of materials, transportation, construction, operation and decommissioning of facilities is needed to establish an objective evaluation of competing technologies. Information on life cycle analyses is applied to estimate CO2 emissions from factors which are involved in the production and use of a typical Canadian car. This is ultimately expressed in metric tonnes of carbon dioxide emissions per vehicle year in Figures 1 and 2.

A recent United States Department of Energy sponsored study[3] provides a great deal of relevant information. This study establishes emissions of greenhouse gases from cars which are under progressive development to reduce greenhouse gas emissions. Emissions for current practice ranging to very low emission vehicles using hydrogen as fuel are considered. The study concludes, that if hydrogen fuel is to make a contribution to GHG reduction, primary energy sources for hydrogen production must be emissions free themselves. The use of fossil fuels to produce hydrogen is irrational as the inefficiencies of energy conversion simply increase GHG emissions relative to direct use of fossil fuels in vehicles. Figure 1 shows GHG emissions established by the study. Minor adjustments have been made to adapt the information to Canadian vehicle use. The actual Canadian data for emissions is shown on the chart as well for reference. The chart shows that the hybrid cars now under development can effect dramatic improvements relative to the current Canadian emissions and "30mpg" reference car of the US DOE study. The hybrid gasoline car with less than half the fuel consumption "65MPG" also cuts GHG emissions in half. This kind of vehicle is represented by the Toyota Prius which is already available in Japan and will be sold in the USA in 2000[4]. Press reviews have indicated the Prius is a very satisfactory car to drive with performance comparable to current cars of similar size. Further development of the hybrid - electric concept to use natural gas as the primary on board fuel reduces emissions to less than a third of current emissions from Canadian cars. Natural gas and hydrogen allow for higher efficiency internal combustion engines so that the reference vehicle is expected to achieve "70MPG" and "80mpg" equivalent , respectively, with natural gas and hydrogen fuel. The last example on Figure 1, the vehicle utilizing hydrogen on board fuel derived from the reforming of natural gas, indicates an increase in GHG emissions per vehicle. Although the emissions at the tailpipe are eliminated the plant needed to produce hydrogen introduces additional inefficiencies which increase full fuel cycle emissions. Additional GHG reduction depends on the production of

> ***Sequestration*** *- Carbon dioxide discharged from mobile equipment is particularly difficult to deal with. It is dispersed from the exhaust pipes of vehicles and mixed with the atmosphere.*
>
> *There is a potential GHG advantage to centrally producing hydrogen by reforming fossil fuels or other processes for use in vehicles. The advantage is that the carbon dioxide resulting from hydrogen production is localized. It is thus conceivable that the carbon dioxide could be collected and converted to a form which could be sequestered from the atmosphere. It is essentially impossible to collect the exhaust from millions of vehicles for sequestration.*

hydrogen using relatively GHG free primary energy sources such as solar, wind and nuclear energy.

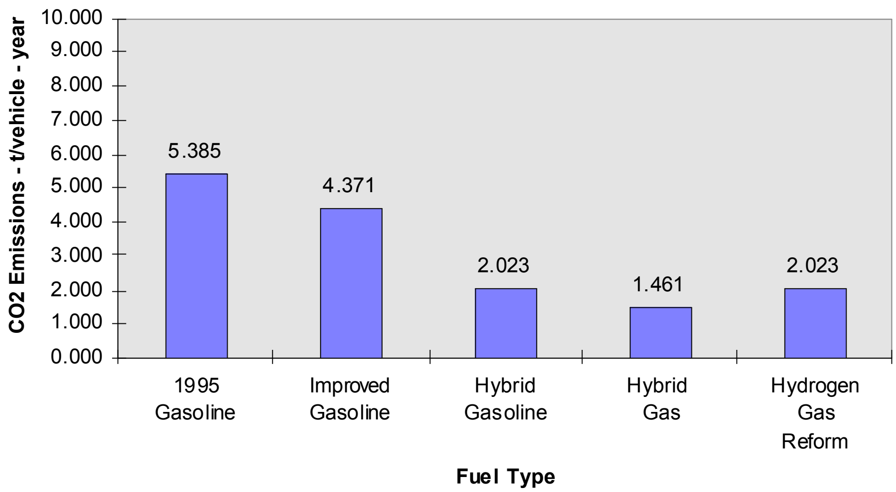

Figure 1: CO2 From Conventional and Hybrid-Electric Fossil Fuel Vehicles

There are many ways to accomplish this end. One approach is to generate electricity and then use electrolysis units to separate water into hydrogen and oxygen. The electrolysis process is relatively efficient and over 70% of the electrical energy can be retained in the hydrogen produced. Even relatively small units designed for home use can achieve this high efficiency. A unit designed for home refueling is expected to produce one kgm of hydrogen from 55 kWh of electricity. A typical Canadian vehicle, traveling 21,000 km year with an efficiency equivalent to an 80mpg gasoline car would require 162 kgm/year requiring 9,000 kWh of electricity. This is the level of efficiency expected for hybrid electric vehicles utilizing a hydrogen fueled internal combustion engine.

Somewhat higher overall efficiencies are anticipated from cars powered by electricity derived from fuel cells. Fuel cells are relatively expensive compared with internal combustion engines at present. An advantage is that their efficiency is high at part loads, in direct contrast to internal combustion engines which are most efficient at full load. Thus the complexity associated with hybrid electric vehicles might be reduced with vehicles powered by fuel cells. This reduced complexity could encourage the use of fuel cells even if their price is not quite as low as internal combustion engines.

Life cycle carbon dioxide emissions from electricity production are relatively well established. Emissions can vary substantially depending on plant design and local conditions as shown in Figure 2[5].

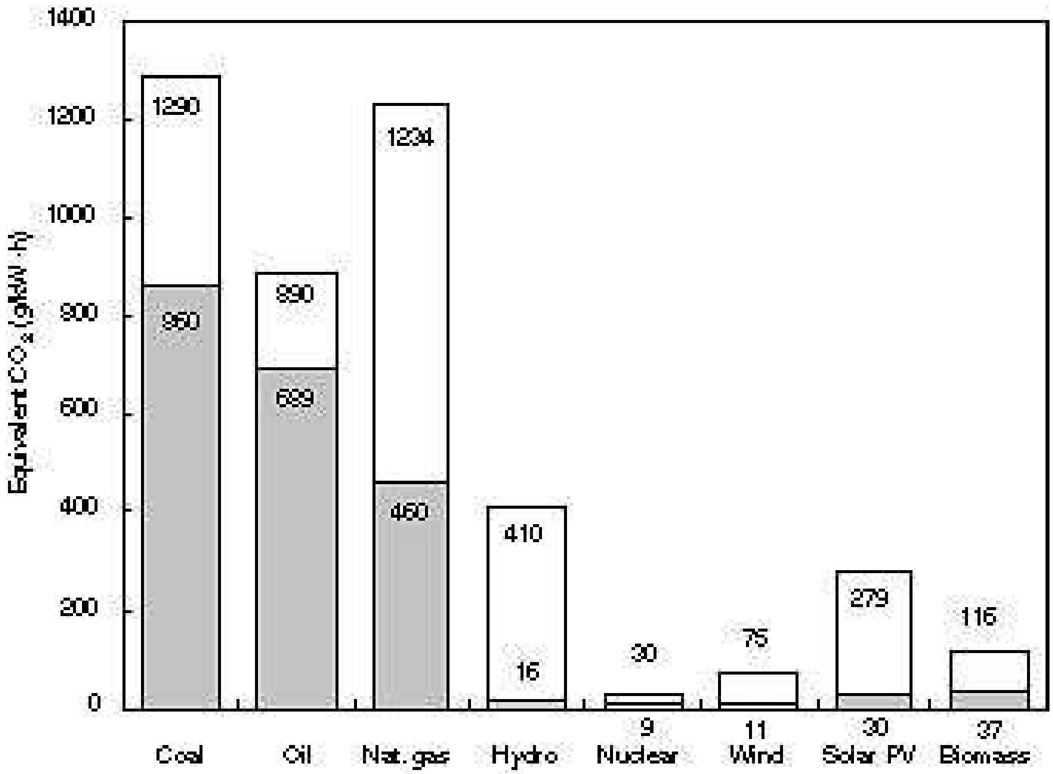

Figure 2: CO2 Emissions From Electricity Generation

Figure 3 show annual life cycle emissions from hydrogen vehicles deriving hydrogen from electricity generated from several primary energy sources where emissions from the non-CANDU primary sources are taken as the mean of high and low values presented in Figure 3. It is apparent that emissions can be greatly reduced if emissions free primary energy sources are used to supply electricity. It is also apparent, by comparison with Figure 1, that emissions from fossil fuel primary energy sources are higher than if the fossil fuel is used directly as a mobile fuel source. The possible advantage that the emissions are produced at a central location, and thus are subject to sequestration is not accounted for in this estimate. Finally, it is noted that vehicles which derive their primary energy for hydrogen production from CANDU reactors[6] would release only about 25 to 30 kgm of carbon dioxide per year when the full fuel cycle is taken into account.

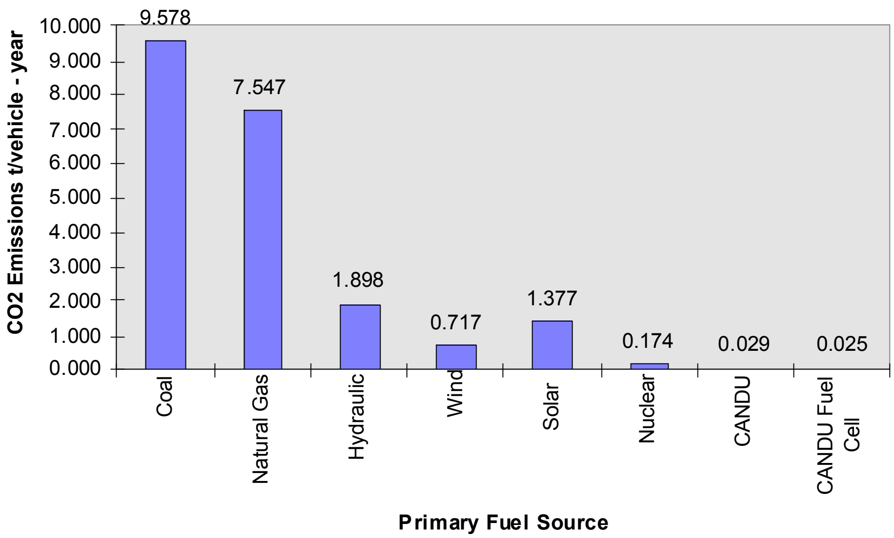

Figure 3 : **CO2 Emissions - Hydrogen Fuelled Vehicles Hybrid Electric (ICE & Fuel Cell)**

Summary and Conclusions

Canadian personal vehicles released 91 million tonnes of greenhouse gases to the atmosphere in 1995. Technology to improve the efficiency of cars is under development which is expected to increase the energy efficiency from the 1995 level of about 10 l/100 km of gasoline to under 3 l/100km equivalent to gasoline. CO2 emissions from on board natural gas fueled versions of these hybrid electric cars would be decreased to approximately 25 million t/year. These high efficiency vehicles can also be powered by hydrogen derived from electricity. Generation of the electricity from nuclear energy using CANDU reactors would further reduce total emissions from these personal vehicles to an insignificant total of about 0.5 million t/year.

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