Energy Independence for North America – Transition to the Hydrogen Economy

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Background

The U.S. transportation sector is almost totally dependent on liquid hydrocarbon fuels, primarily gasoline and diesel fuel from conventional oil. In 2002, the transportation sector accounted for 69 percent of the U.S. oil use; highway vehicles accounted for 54 percent of the U.S. oil use. Of the total energy consumed in the U.S., more than 40 percent came from oil. More significantly, more than half of this oil is imported and is projected by the Energy Information Agency (EIA) to increase to 68 percent by 2025 [1].

The supply and price of oil have been dictated by the Organization of Petroleum Exporting Countries (OPEC). In 2002, OPEC accounted for 39 percent of world oil production and this is projected by the EIA to increase to 50 percent in 2025. Of the world’s oil reserves, about 80 percent is owned by OPEC members. Major oil price shocks have disrupted world energy markets four times in the past 30 years (1973-74, 1979-80, 1990-1991, and 1999-2000) and with each came either a recession or slowdown in the GDP (Gross Domestic Product) of the United States. In addition, these market upheavals have cost the U.S. approximately $7 trillion (in 1998 dollars) in total economic costs [2]. Finally, it is estimated that military expenditures for defending oil supplies in the Middle East range from $6 billion to $60 billion per year [3] and do not take into account the costs of recent military operations in Iraq (i.e., Operation Iraqi Freedom, 2003).

At the outset of his administration in 2001, President George W. Bush established the National Energy Policy Development (NEPD) Group to develop a national energy policy to promote dependable, affordable, and environmentally sound energy for the future in order to avert potential energy crises. In the National Energy Policy report [4], the NEPD Group urges action by the President to meet five specific national goals that America must meet - “modernize conservation, modernize our energy infrastructure, increase energy supplies, accelerate the protection and improvement of the environment, and increase our nation’s energy security.” It is generally recognized that energy security can be achieved partially by reducing importation of oil from sources that are less politically stable.

Pathways to Energy Independence

There are pathways that could lead to dramatic reduction in transportation energy use and less reliance on imported oil, ultimately. These pathways include the following:

- Transportation energy demand reduction.
- Greater use of non-conventional resources.
- Transition to a hydrogen economy.

Transportation Energy Demand Reduction. The use of more efficient vehicle propulsion systems would definitely slow the growth of transportation energy demand even as vehicle-miles traveled increase with population expansion. This is recognized by the NEPD Group which
recommends that the President “direct the Secretary of Energy to establish a national priority for improving energy efficiency.” Vehicle propulsion systems that could increase fuel efficiency include: a) for the near term – direct injection diesel, gasoline direct injection, and gasoline hybrid; b) for the intermediate term – direct injection diesel hybrid, homogeneous charge compression ignition combustion engines, and low temperature combustion engines; and c) for the far future – hydrogen combustion engines and hydrogen fuel cells.

Between the two internal combustion engines currently in mass production, diesel engines are inherently more efficient than gasoline engines. Diesels are already the engine-of-choice for class 3-8 trucks and vans which are primarily for commercial use and for which the cost of fuel is important for profitability. Penetration of diesel engines in the light-duty vehicle market (personal cars and trucks including pickup trucks, sport utility vehicles and vans) would result in an overall reduction of transportation fuel consumption. R&D efforts being funded by the Department of Energy with its industry partners on diesel engines for light trucks have shown as much as a 60 percent improvement in light truck fuel economy (miles per gallon) by replacing the current gasoline engines with diesel engines (comparable over a set of performance criteria). Figure 1 shows that dieselization could potentially lead to a significant light truck fuel use reduction (assuming a 60 percent fuel economy improvement and the same diesel penetration rate [5] experienced in the heavier Class 2b light trucks).

Hybridization of the U.S. light-duty vehicle fleet (i.e., automobiles and light trucks) is another pathway to reducing transportation fuel use. Hybrid electric vehicles combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle, to achieve as much as twice the fuel economy of conventional vehicles. This combination offers extended vehicle range and standard refueling capabilities of a conventional vehicle, with low emissions and energy efficiency similar to an electric vehicle. Hybrid propulsion technologies are being developed for vehicles of all types and weight classes, from small sub-compacts to Class 8 diesel-electric hybrid trucks and military vehicles.

Greater Use of Non-Conventional Resources. Improving energy efficiency alone is not sufficient to dramatically reduce transportation energy use, nor reduce oil imports. The U.S. imports of crude oil and refined products in 2002 [6] are shown in Figure 2. The EIA [1] projects a continued increase in oil imports to almost 15 million barrels of oil per day by 2025.
Other energy sources need to be developed to reduce the widening gap between U.S. oil consumption and domestic oil production. Besides conventional crude oil or petroleum, liquid hydrocarbon fuels for transportation could also be produced from non-conventional resources which include heavy oil, oil sands (bitumen), shale oil, bio-renewables, and through the gas-to-liquid (GTL)/Fischer-Tropsch route. In Canada, for instance, there is a vast oil sands resource which is beginning to provide substantial quantities of liquid fuels (several hundreds of thousands of barrels per day of synthetic crude from oil sands) for the U.S. transportation sector. About 17 percent of total U.S. oil imports (see Figure 2) already come from Canada. These come through a network of crude oil pipelines that serve areas called Petroleum Administration Defense Districts or PADDs [7] as shown in Figure 3. The infrastructure, therefore, is already in place for closer energy integration of North America, achieving energy independence for North America and the United States through the Canadian oil sands resource.

Alberta, Canada holds the world’s single largest hydrocarbon resource in its oil sands deposits [8]. The Athabasca, Wabasha, Cold Lake, and Peace River oil sands deposits cover an area of nearly 77,000 sq. km. (see Figure 4). The Athabasca deposit, which is the largest, contains 213 billion cubic meters of oil sand and is almost the size of Lake Huron (58,880 sq. km).

The NEP recognizes the potential contribution of Canada to the energy security of North America; it reports that [4] “Estimates of Canada’s recoverable heavy oil sands reserves are substantial... Their continued development can be a pillar of sustained North American energy and economic security.”

Canada’s oil sands deposits contain 2.5 trillion barrels of oil, of which approximately 300 billion barrels are considered “recoverable” with today’s technology. It is estimated that, if all of the oil could be recovered from the deposit it could satisfy the global oil demand for the next one hundred years. The 12 percent that is considered recoverable could ensure energy independence for the North American continent. A comparison of world heavy oil and bitumen resources is shown in Figure 5.
Estimates of the Canadian oil sands resource vary and have been featured in several news articles and technical papers over the past couple of years [9, 10, 11, 12, 13, and 14]. It can be surmised, however, that the amount is substantial based on what energy companies have, so far, invested and are continuing to invest in developing the oil sands resource. Companies involved to date have invested more than Can$17 billion and an additional Can$56 billion are planned to be invested.

President Bush is well aware of Canada’s oil sands resource as indicated in his remarks when he visited Quebec in 2001. As cited in a recent article in *Time* magazine [15], the President said, “There is some very good news in our hemisphere, at least as far as Americans are concerned, and that is, that because of technologies – the Canadians have developed vast crude-oil resources … in what they call tar pits … That’s good for our national security; it’s good for our economy.” The NEPD Group recommended that the President “direct the Secretaries of State, Commerce, and Energy to engage in a dialogue through the North American Energy Working Group to develop closer energy integration among Canada, Mexico, and the United States and identify areas of cooperation, fully consistent with the countries’ respective sovereignties.”

What are oil sands? Oil sands (see Figure 6) are a combination of clay and sand (70-80%), water (<10%), and bitumen (0-18%). Unlike conventional oil which is recovered by drilling wells into deposits at varying depths of the earth’s crust, oil sands are “mined” from the earth’s surface. Bitumen is separated from the sand, clay, and water prior to further processing. Bitumen, which has been described as hydrogen-deficient oil, is composed of two major fractions, 85 percent maltenes and 15 percent asphaltenes [16].

Bitumen (see photo from Syncrude Canada Ltd. in inset) is highly viscous at 10,000 cP at reservoir conditions (compared to viscosity of water at 1 cP). It consists of extremely long hydrocarbon molecules (which can be as high as C_{2000}). As a result of the long hydrocarbon chains, bitumen needs to be upgraded to syncrude (or synthetic crude) either by coking (removing carbon) or by hydrocracking (breaking the long carbon molecule chains and adding hydrogen) before it can be used as a high quality fuel product.

The cost of mining bitumen and producing syncrude (currently at about US$12-16 per barrel of syncrude) has progressively been improving and becoming cost competitive and profitable compared to conventional oil which is currently US$26-28 per barrel (September 2003) on the world market. More advanced mining and upgrading methods are projected to lower the production cost of syncrude to US$6-9 per barrel, making it a very attractive investment.

Potential U.S. markets have been identified for synthetic crude and bitumen from the Canadian oil sands. Additional pipelines are expected to serve Petroleum Administration Defense Districts (PADD) II and IV based on estimated increased production of
synthetic crude and bitumen over the next 15 years. The additional market in PADD V will be mainly the state of Washington as Alaska North Slope supplies decline [7].

The current process of upgrading bitumen to syncrude uses natural gas as the source of hydrogen for hydrocracking and hydrotreating. About 1,500 scf of hydrogen is required for upgrading one barrel of bitumen [17]. As more syncrude is produced from the oil sands, the upgrading process could very well serve as a major precursor market for hydrogen to provide a “market pull” for the transition to a “hydrogen economy.”

Transition to a Hydrogen Economy. The long term vision to achieve energy independence is the transition to a hydrogen economy. However, hydrogen is not a true energy source, it is an “energy carrier” similar to a battery where energy can be stored. Hydrogen will need to be extracted from hydrocarbon fuels or from the electrolysis of water. Both of these processes require the expenditure (input) of energy to produce pure hydrogen.

How much hydrogen is needed by the transportation sector? The EIA estimates that by 2025, about 13 million barrels of oil equivalent per day would be needed to supply the energy needs of all light-duty gasoline highway vehicles (cars and light trucks). Assuming efficiencies in the hydrogen production chain as reported in literature [18] and hydrogen fuel cell vehicles achieving double the fuel efficiency of gasoline internal combustion engines, 647 thousand tons of hydrogen per day would be needed.

The next question is how this huge quantity of hydrogen will be produced and how much will it cost. Assuming that hydrogen will be produced by electrolysis of water only, it is estimated that about 1,300 GW of electricity would be required to produce enough hydrogen to fuel all of the light-duty vehicles. This would require the generating capacity of nearly 1,500 additional 1GW nuclear power plants operating at an 88 percent capacity factor or 3.7 million 1MW wind turbines at a 35 percent capacity factor, or a combination of these and other alternatives such as hydrogen from biomass and solar generated electricity. This is a tremendous amount of additional electric generating capacity which would need to be put in place for a hydrogen economy to materialize just for light-duty vehicles.

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Summary

The NEP supports improving energy efficiency as well as integrating the energy
interests of North American countries for regional energy security. Direct injection “clean” diesels promise to moderate the rate of increase in light-duty vehicle energy demand in the immediate future. Dieselization of the light truck fleet will have a significant impact on total U.S. fuel consumption. Hybrids and engines operating in new combustion regimes promise even higher efficiency and lower emissions. Reducing transportation energy demand will not be sufficient to significantly reduce the amount of imported oil. Alternative energy resources will need to be developed as well to improve energy security. For North America, there is a vast resource in Canada’s oil sands of non-conventional petroleum hydrocarbon fuels for combustion engines. The hydrogen requirements for removing sulfur from petroleum fuels plus “upgrading” bitumen from the oil sands to syncrude will serve to stimulate the development of a hydrogen infrastructure which will provide a “market driven” transition of the light-duty vehicle transportation sector into a hydrogen economy.

References
8. Canada’s Oil Sands and Heavy Oil, Petroleum Communication Foundation, April 2000.