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Synthesis of Hydrocarbon Fuels Using Nuclear Energy

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INTRODUCTION

Production of synthetic hydrocarbon fuels ("synfuels") can help with the growing shortage of petroleum. Refined petroleum products or synfuels are generically $[CH_2]_n$. Currently, synfuels are made from fossil resources, primarily coal and natural gas. With increasing natural gas prices, coal will be increasingly emphasized. In this process, one atom of carbon is produced as CO_2 for every atom produced as CH_2 in the synfuel. Substitution of coal-based synfuels for petroleum-based fuels would thus double the amount of CO_2 produced by our transportation sector. We have investigated how nuclear energy could help this problem.

ANALYSIS

The leading synfuel process is the Fischer Tropsch (F-T) process which uses synthesis gas — hydrogen and carbon monoxide — as its feed and produces a synthetic "crude" that undergoes further processing to a range of commercial finished products [1]. The synthesis gas is produced by coal gasification. The Water-Gas Shift reaction can be used to produce additional H_2 from CO and water:

Gasification: $2C + {}^1/_2O_2 + H_2O \rightarrow 2CO + H_2$
Water gas shift: $CO + H_2O \rightarrow H_2 + CO_2$
F-T reaction: $CO + 2H_2 \rightarrow CH_2 + H_2O$
Net reaction: $2C + H_2O + {}^1/_2O_2 \rightarrow CH_2 + CO_2$

Note that two carbons are required to produce one Fischer-Tropsch CH_2 product; the other carbon being emitted as carbon dioxide.

If hydrogen is provided by nuclear production of hydrogen from water, the synfuel production process need not produce any CO_2.

Gasification: $C + {}^1/_4O_2 + {}^1/_2H_2O \rightarrow CO + {}^1/_2H_2$
Water-splitting: ${}^3/_2H_2O + \text{Energy} \rightarrow {}^3/_2H_2 + {}^3/_4O_2$
F-T reaction: $CO + 2H_2 \rightarrow CH_2 + H_2O$
Net reaction: $C + H_2O + \text{Energy} \rightarrow CH_2 + {}^1/_2O_2$

However, the synfuel, when burned for transportation will produce and release the contained carbon as CO_2. Since the synfuel would be a replacement for petroleum-based fuel, there would be no net increase in the production of CO_2.

If the hydrogen is provided from nuclear water-splitting, and if the carbon is provided by capture of CO_2 from the exhaust of existing coal-fired power plants, CO_2 would be consumed while making synfuel. Hydrogen would be used to produce CO from CO_2 in the reverse water gas shift reaction and to produce $[CH_2]_n$ from CO and H_2 in the Fischer-Tropsch reaction:

Rev. Water Gas Shift: $CO_2 + H_2 \rightarrow CO + H_2O$
F-T reaction: $CO + 2H_2 \rightarrow CH_2 + H_2O$
Water-splitting: $3H_2O + \text{Energy} \rightarrow 3H_2 + {}^3/_2O_2$
Net: $CO_2 + H_2O + \text{Energy} \rightarrow CH_2 + {}^3/_2O_2$

Three molecules of H_2 would be needed for every moiety of CH_2 produced.

Our current technology choice for CO_2 recovery from flue gas is a membrane system using gas absorption by chemical means with either amine or inorganic solvents. The common name for such systems is Membrane Gas Absorption (MGA) which is being investigated mainly by European organizations such as TNO Environment, Energy and Process Innovation (Netherlands) [2]. Our analysis indicates that these MGA systems can be cost effective, and might even be extended to recovery of CO_2 from the atmosphere in the future. If new coal plants are built or older plants can be retrofit with coal gasification or oxygen-fired combustion using the oxygen produced as a by-product of nuclear hydrogen production, CO_2 recovery can be easier and cheaper yet.

We did some simple economics analyses to explore the economics of nuclear synfuel production. A leading developer of coal-based synthetic hydrocarbon production is Rentech, Inc. of Denver, Colorado. They carried out a scoping study for the state of Wyoming of synthetic diesel fuel production from Powder River Basin coal using coal gasification and the Fischer-Tropsch synthesis process [3]. Using their methodology with values of \$30/ton for coal and 10% interest we estimated the cost of synfuel at ~\$1.85/gallon. We then estimated the impact of getting the hydrogen needed for the

F-T process from nuclear power and the CO from flue gas followed by reverse water gas shift. The cost of the hydrogen was estimated for production using the Sulfur-Iodine thermochemical water-splitting process coupled to the Modular Helium Reactor [12], and also for production by standard low temperature electrolysis using electricity from a Light Water Reactor. The production costs at a 10% interest rate are ~\$2.75/gallon and ~\$3.30/gallon for hydrogen from the MHR and LWR, respectively. If we get \$30/ton credit for CO_2 not produced or consumed, these costs fall to ~\$1.70/gallon and ~\$2.30/gallon, respectively. These costs are competitive with those of coal-based synfuel.

RESULTS

The production rate of CO_2 from coal power plants in the US is ~1900 million metric tons/year, >30% of our total CO_2 production. If this CO_2 were captured from coal-fired power plant flue gas and used with hydrogen produced by nuclear energy to make synfuel, it would provide all the hydrocarbon fuel needed for our transportation economy and would cut our total CO_2 production by 32%. We could shift from a petroleum-based transportation economy to a "recycled coal" plus nuclear hydrogen synfuel transportation economy. This would reduce our petroleum use by ~75%, and reduce our CO_2 production by >30% with no increase in coal use. It would require significant quantities of hydrogen (~260 million metric tons/year, or ~25 times our current production) that would be produced from water using nuclear energy.

CONCLUSIONS

The nuclear hydrogen synfuel concept would allow us to significantly reduce our use of petroleum, and cut our CO_2 emissions by a third, while still using our existing hydrocarbon-based transportation infrastructure, with a reasonable cost of fuel. It could provide a bridge to a pure hydrogen economy.

ACKNOWLEDGMENT

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