Meeting U.S. Liquid Transport Fuel Needs with a Nuclear Hydrogen Biomass System

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Outline

Need to Get Off Crude Oil
Electrification of Transportation
Fuel Cycles for Liquid Fuels
Biomass Resources and Limitations
Nuclear Biomass Liquid Fuels
Need to Get Off Crude Oil
There is a Need to Replace Crude Oil in the Transport System

Unstable Supplies

Risk of Climate Change

Athabasca Glacier, Jasper National Park, Alberta, Canada
Photo provided by the National Snow and Ice Data Center
Transportation is the Primary Use for Crude Oil in the United States

Electrification of Transportation
Electrification Could Reduce Transport Fuel Demand in Half

- Nuclear electricity could become the major transport fuel
- Technology pathways
  - Plug-in hybrid electric cars and light trucks
    - Cut gasoline demand in half
    - Price equivalent to ~$1.20/gasoline [$0.10/kw(e)]
  - Electrification of railroads with better inter-modal transport (10% reduction in total oil consumption)
  - High-speed rail replacement of airplanes along high-density routes
- With current oil prices, many of these technologies are economic; however, there are long transition times
Fuel Cycles for Liquid Fuels
Fuel Cycle for Liquid Fuels from Crude Oil

1. Oil Well
2. Crude Oil
3. Transport
4. Refinery
5. Liquid Fuel
6. Atmosphere
7. Carbon Dioxide

\((\text{CH}_2)_n\)
Conversion of Fossil Fuels to Liquid Fuels Requires Energy

Greenhouse Impacts (g CO₂-eq/mile in SUV)

- Transportation/Distribution
- Conversion/Refining
- Extraction/Production
- End Use Combustion

Business As Usual

Source of Greenhouse Impacts

Making and Delivering of Fuel

Using Fuel

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Fuel Cycle for Liquid Fuels from Biomass

\[ C_xH_y + \left( X + \frac{y}{4} \right)O_2 \rightarrow CO_2 + \left( \frac{y}{2} \right)H_2O \]

Atmospheric Carbon Dioxide

Biomass

Fuel Factory

Liquid Fuels

No Net Greenhouse Gas Emissions

Cars, Trucks, and Planes
Like Liquid Fuels from Fossil Fuels, Biomass Production, Transport, and Fuel Factories Use Energy

\[ C_xH_y + (X + \frac{y}{4})O_2 \rightarrow CO_2 + (\frac{y}{2})H_2O \]

Energy
- Biomass
- Nuclear
- Other

Biomass → Fuel Factory → Liquid Fuels → Cars, Trucks, and Planes

Atmospheric Carbon Dioxide
The Nuclear-Hydrogen-Biomass Liquid-Fuel Cycle

\[ C_xH_y + (X + \frac{Y}{4})O_2 \rightarrow CO_2 + \left( \frac{Y}{2} \right)H_2O \]

Nuclear Reactor

Atmospheric Carbon Dioxide

Biomass

Fuel Factory

Liquid Fuels

Heat Hydrogen Electricity
Biomass Resources and Limitations

Corn Stover

Fuel Ethanol
Biomass: 1.3 Billion Tons per Year

Available Biomass without Significantly Impacting U.S. Food, Fiber, and Timber

Agricultural Residues
Logging Residues
Urban Residues
Energy Crops
Different Processes can Convert Biomass into Different Fuels

- Ethanol
- Gasoline
- Diesel
- Biodiesel
- Jet fuel
Energy Value of 1.3 Billion Tons/year of Biomass as Liquid Fuel
Measured in Equivalent Barrels of Diesel Fuel/Day

Like coal, conversion of solid biomass into liquid fuels is energy intensive.
Biomass, Nuclear Heat, and Nuclear Hydrogen can Create Abundant Greenhouse-Neutral Liquid Fuels

Sufficient Biomass to Meet Liquid Fuel Needs if Outside Energy Sources for Biomass Processing

\[ C_xH_y + (X + \frac{Y}{4})O_2 \rightarrow \text{CO}_2 + (\frac{Y}{2})H_2O \]

Atmospheric Carbon Dioxide

Fuel Factory

Heat and Hydrogen

Liquid Fuels

Biomass
Nuclear Biomass Liquid Fuels

the Details
Three Step Strategy to a Nuclear-Biomass Liquid-Fuels Economy

- **Steps**
  - Starch (corn, potatoes, etc.) to ethanol
  - Cellulose to ethanol and diesel
  - Biomass to diesel

- **Basis of implementation strategy**
  - Economics and ease of implementation
  - Each step implies use of a larger biomass resource and a large increase in liquid fuel production
  - Each step increases liquid fuel yield per unit of biomass
The Biotech Revolution

Sugar (Sugarcane and Sugar Beets)
Sugar → Ethanol (Traditional Technology)
Process has been Used for Millennia

Starch (Corn, Barley, etc.)
Starch → Sugar → Ethanol
Process has been Used for Millennia
New Low-Cost Enzymes for Rapid Starch-to-Sugar Conversion (Corn-to-Ethanol Boom)

Cellulose (Trees, Agricultural Waste, Etc.)
Cellulose → Sugar → Ethanol
Enzyme Costs Dropping Rapidly;
Precommercial Plants Operating
Starch to Ethanol Requires Low-Temperature Steam

- Energy input to grow corn and convert it to ethanol is 70% of the energy value of the ethanol
- Low-pressure (150 psi) steam for distillation and other uses is half the nonsolar energy input
- Nuclear plants can provide this steam
  - Cuts fossil inputs and greenhouse gas releases from ethanol production in half
  - Cost of nuclear heat is about half that of natural gas
- Production of one billion liters of ethanol/year requires 260 MW(t) of steam
- Ethanol production limited by availability of corn, potatoes, and other feedstocks
**Starch to Ethanol**

Starch (corn, potatoes, etc.)

- Ethanol Plant
- Steam Plant
- Nuclear Reactor

- Natural Gas/Biomass
- Nuclear/Biomass

- Animal Protein
- Ethanol

**Fossil Energy Input** 70% of Energy Content of Ethanol

**50% Decrease in CO₂ Emissions/Gallon Ethanol**

**50% Reduction in Steam Cost**

**Economics are favorable and no new technology is required**
One-Third of U.S. Liquid Fuel Demand Could be Met with Ethanol By 2030

Most of the Ethanol is from Cellulose

Projected Ethanol Production

Cumulative Ethanol Production

Source: NREL – Bob Wooley
Cellulosic Liquid Fuel Yields Increased by 50% Using Nuclear Heat and Hydrogen

Cellulose (65-85% Biomass)

Lignin (15-35% Biomass)

Biomass (1.3 billion tons/year)

Ethanol Plant

Steam Plant

Lignin Plant

Nuclear Reactor

Ethanol Plant

Ethanol

Steam

Hydrogen (small quantities)

Heat

Gasoline/Diesel

Electricity

Biomass

50% Increase Liquid Fuel/Unit Biomass
Cellulosic Biomass Challenges

- Processes are in the pilot-plant stage
- Nuclear Cellulose R&D challenge
  - Economic use of nuclear energy requires conversion of lignin to liquid fuel
  - Nuclear steam is an option for cellulose feedstock only if a use is found for lignin
  - Lignin conversion methods are under development
- Nuclear requirements
  - Large quantities of steam
  - Limited hydrogen demand
  - Economics likely to be very favorable because of low nuclear-steam costs
Conversion of Biomass to Diesel Fuel

- Biomass is a carbon feedstock
- Full conversion to hydrocarbon fuels to maximize liquid fuels production per unit of biomass
- Requires large quantities of hydrogen
- Economics depends upon hydrogen costs

Biomass (1.3 billion tons/year)

Liquid Fuels Plant

Gasoline/Diesel

Nuclear Reactor

Hydrogen (large quantities)

Steam

Electricity

3-4X Fuel Output/Unit Biomass
Two Methods for Converting Biomass and Hydrogen to Diesel Fuel

Fischer-Tropsch

- Process
  - Biomass + O₂ ➞ CO + H₂
  - CO + H₂ ➞ Diesel
- Indirect process
- Industrial technology (basis for coal liquefaction)

Direct Hydrogenation

- Process
  - Biomass + H₂ ➞ Diesel
- Direct process
- Laboratory process

Liquid fuel production exceeds U.S. liquid fuel needs for transportation

Hydrogen can be produced by electrolysis and other processes
Conclusions

• We need greenhouse-neutral replacements for liquid fuels from crude oil
• Electrification of transportation can cut the liquid fuel demand in half
• Biomass plus nuclear energy can meet the demand for liquid fuels
• Multiple greenhouse-neutral pathways off of crude oil
Questions?

Nuclear Hydrogen Biomass Liquid-Fuel Goals

No Crude Oil  No Climate Change

Athabasca Glacier, Jasper National Park, Alberta, Canada
Photo provided by the National Snow and Ice Data Center
Backup Slides

Backup Slides

Backup Slides
Biography: Charles Forsberg

Dr. Charles Forsberg is a Corporate Fellow at Oak Ridge National Laboratory, a Fellow of the American Nuclear Society, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design and the Oak Ridge National Laboratory Engineer of the Year Award. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 10 patents and has published over 200 papers.
The two major energy challenges for the United States are (1) replacing crude oil in our transportation system and (2) eliminating greenhouse gas emissions. A strategy is proposed to meet the total liquid-fuel transport energy needs within 30 years by producing greenhouse-neutral liquid fuels using biomass as the feedstock and nuclear energy to provide the heat, electricity, and hydrogen required for operation of the biomass-to-fuels production facilities. Biomass is produced from sunlight, atmospheric carbon dioxide, and water. Consequently, using liquid fuels from biomass has no net impacts on carbon dioxide levels because the carbon dioxide is being recycled to the atmosphere when the fuel is burnt. The U.S. could harvest about 1.3 billion tons of biomass per year without major impacts on food, fiber, or lumber costs. The energy content of this biomass is about equal to 10 million barrels of diesel fuel per day; however, the actual net liquid-fuels production would be less than half of this amount after accounting for energy to process the biomass into liquid fuel. If nuclear energy is used to provide the energy in the form of heat, electricity, and hydrogen to support biomass growth and conversion to liquid fuels, the equivalent of over 12 million barrels of greenhouse-neutral diesel fuel per day can be produced. The combination of biomass and nuclear energy may ultimately meet the total U.S. transport fuel needs.
The Age of Oil for Fuels is Closing

Discoveries (billion bbl/year)

Consumption

Oil and Gas J.; Feb. 21, 2005
Climate Change may Restrict Carbon Dioxide Releases from Transportation

Carbon Emissions

CO₂ in Atmosphere

Global Warming

Global Economic Effects

Source: Intergovernmental Panel on Climate Change

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The United States Runs on Oil: A National Security Threat

- Oil provides 39% of U.S. energy
  - Two-thirds of the crude oil is imported
  - Major component of the U.S. trade deficit
- World oil reserves dominated by four countries
  - Saudi Arabia
  - Iraq
  - Iran
  - Kuwait
- No historical basis to assume political stability of oil producers
Transportation Fuels Make Up 1/3 of Total GHG Carbon Emissions

Sources:
- Coal 498
- Gas 317
- Petroleum 594
- 80 A/F
- 85 OI
- 60 MSW

Emissions (MtC)
- Nuclear 140
- Renewable 70
- Buildings 489
- Industry 549
- Transportation 457
- A/F 80
- MSW 60

End Use Sectors:
- 28% Must Be “Portable”
- 64% Theoretically Replaceable by “Immobile”

U.S. Energy System

MSW = Municipal Solid Waste
A/F = Agriculture and Forestry
OI = Other Industrial

(EIA, 2002)
Newest Ethanol Plants Obtain Steam from Fossil Electric Plants

Elk River Ethanol and Lignite-Fired Electric Plants
North Dakota, United States
Existing Nuclear Plants can Provide Much of the Needed Steam

The First Large Cogeneration Steam Market Located in Rural Areas Where Nuclear-Electric Plants are Located

A Biotech Revolution Within the Last Several Years
France Runs on Nuclear Electricity

- France ran on oil with cold houses
  - WWII
  - Suez crisis
  - Algerian wars
  - 1973 Oil Embargo

- 1975: Consensus decision on oil
  - Replace electrical generation (oil based) in 20 years with nuclear electricity
  - TGV super trains using electricity replace aircraft
  - Conservation effort with real teeth

- Result: Cut oil consumption market share in half in about 30 years with some of the cleanest air and lowest-cost electricity in Europe
The United States Runs on Oil

- Oil provides 39% of U.S. energy
- World oil reserves dominated by four countries
  - Saudi Arabia
  - Iraq
  - Iran
  - Kuwait
- The U.S. could chose to get off oil
  - U.S. is 39% dependent on oil versus France that was 90+% dependent on oil
  - Challenge about equal to the French decision to reduce oil share of energy demand by half
Energy Value of U.S. Biomass

Measured in Equivalent Barrels of Diesel Fuel/Day* from Harvesting 1.3 Billion Tons of Biomass/Year

- Energy value if burned: 9.8 million barrels/day*
- Energy value if converted to ethanol: 4.7 million barrels (diesel equivalent)/day*
  - Fraction of biomass converted to ethanol
  - Remaining biomass powers the conversion process
- Energy value if converted to diesel fuel: 12.4 million barrels/day*
  - Biomass fully converted to diesel fuel
  - Use non-biomass energy source to operate biomass-to-fuel plants
  - Use non-biomass energy source to make hydrogen for diesel

Conclusions
- Insufficient biomass to (1) meet U.S. liquid-fuel needs and (2) power biomass-to-liquid fuel plants
- Sufficient biomass to meet liquid-fuel needs if non-biomass energy and hydrogen inputs for biomass-to-fuel plant
American Agricultural History Suggests Major Advances will Occur in Biomass Crops for Fuel

History of American Corn Yields
Corn Yields Still Increasing

USA Corn Yield Trends, 1966-2005
(embodies tremendous technological innovation)

Historic and projected corn yields

\[
y = 112.4 \text{ kg/ha-yr} \\
[1.79 \text{ bu/ac-yr}] \\
R^2 = 0.80
\]

- Conservation tillage, soil testing, NPK fertilization
- Double-X to single-X hybrids
- Expansion of irrigated area, increased N fertilizer rates
- Integrated pest management
- Transgenic (Bt) insect resistance
- Reduced N fertilizer & irrigation?
- Higher density plantings and selection for stress resistance also a factor in 1995-2005 period

Source - W. Wilhelm, 2006

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