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

Charles Forsberg

Corporate Fellow
Nuclear Science and Technology Division
Oak Ridge National Laboratory
forsbergcw@ornl.gov; 865-574-6783

Nuclear Engineering Department Colloquium
University of Tennessee at Knoxville
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Outline

Need to Get Off Crude Oil

Fuel Cycles for Liquid Fuels

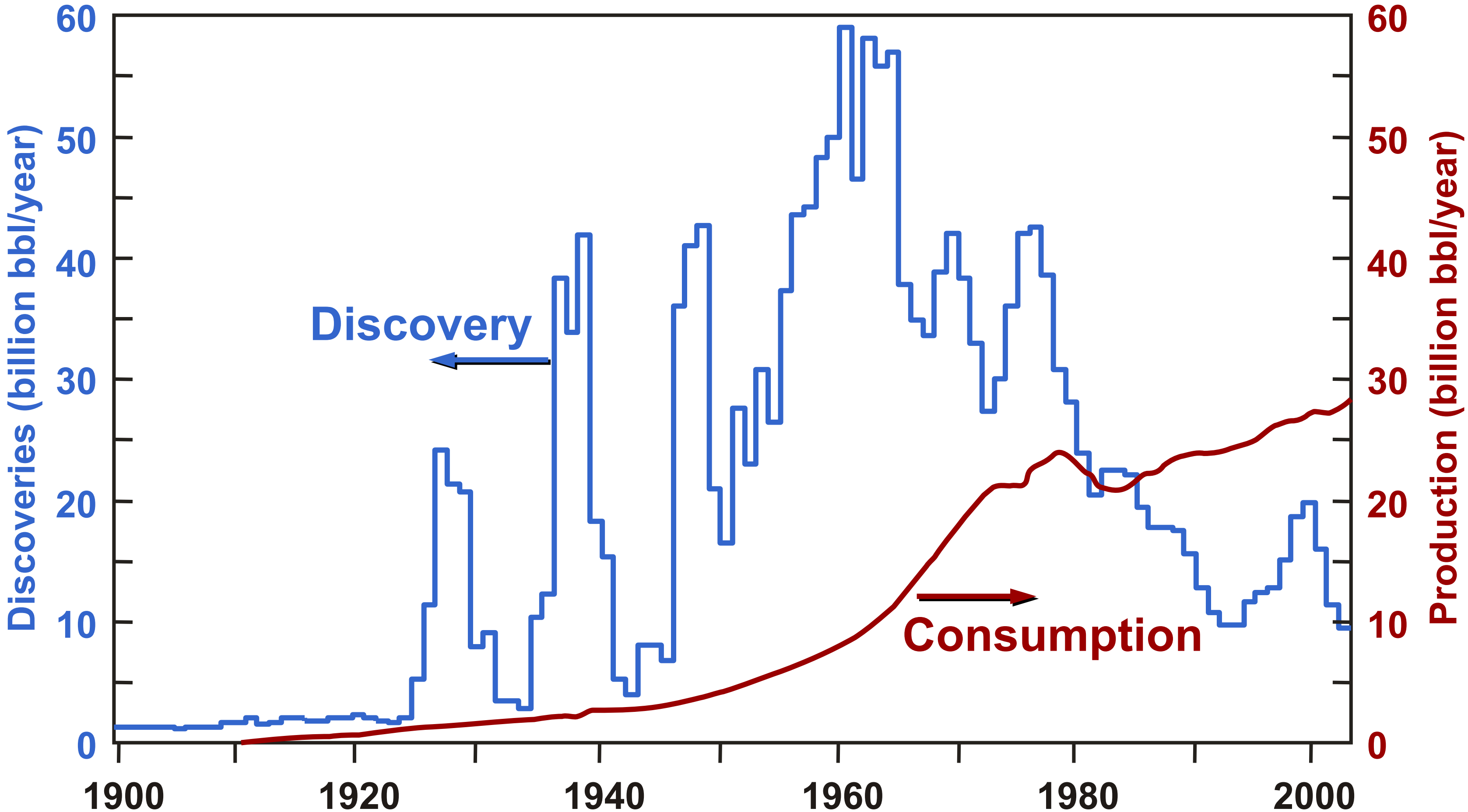
Biomass Resources and Limitations

Nuclear-Hydrogen Biomass Fuels

The Future of Nuclear Energy

Need to Get Off Crude Oil

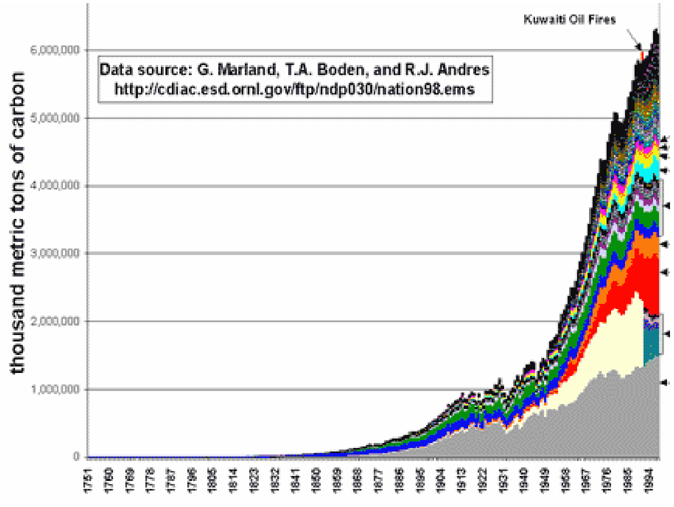
The Age of Oil for Fuels is Closing



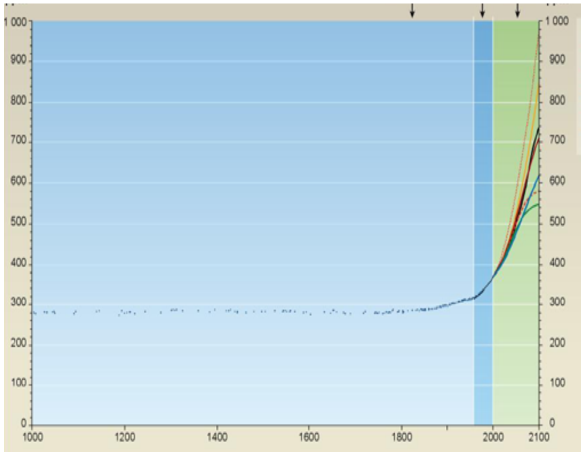
Oil and Gas J.; Feb. 21, 2005

Climate Change May Restrict Carbon Dioxide Releases from Transportation

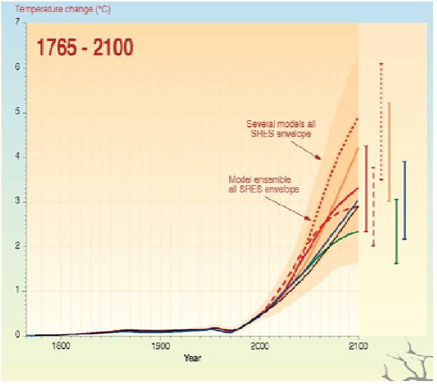
Carbon Emissions



CO_2 in Atmosphere



Global Warming



Global Economic Effects

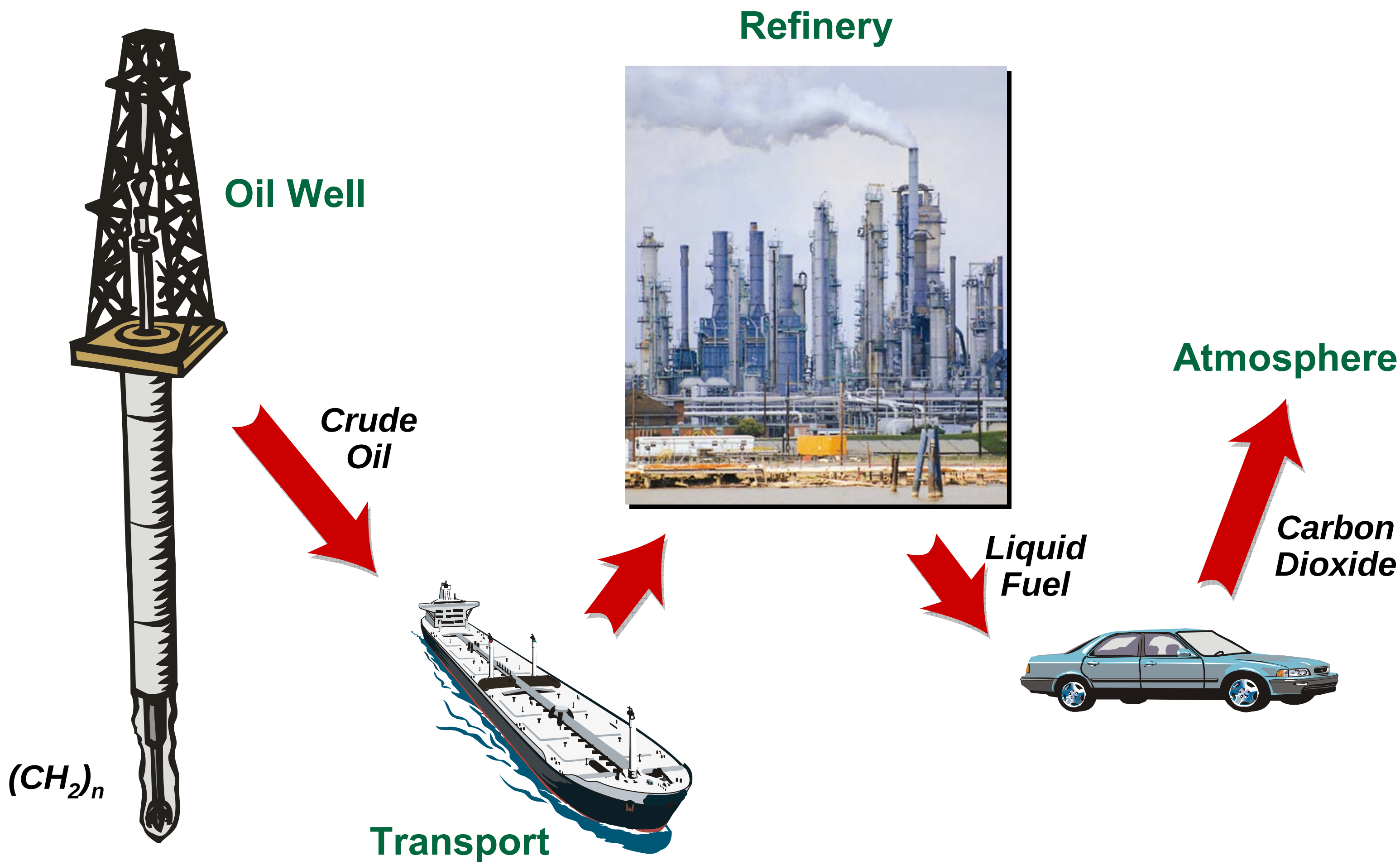
Source: Intergovernmental Panel on Climate Change

The United States Runs on Oil: A National Security Threat

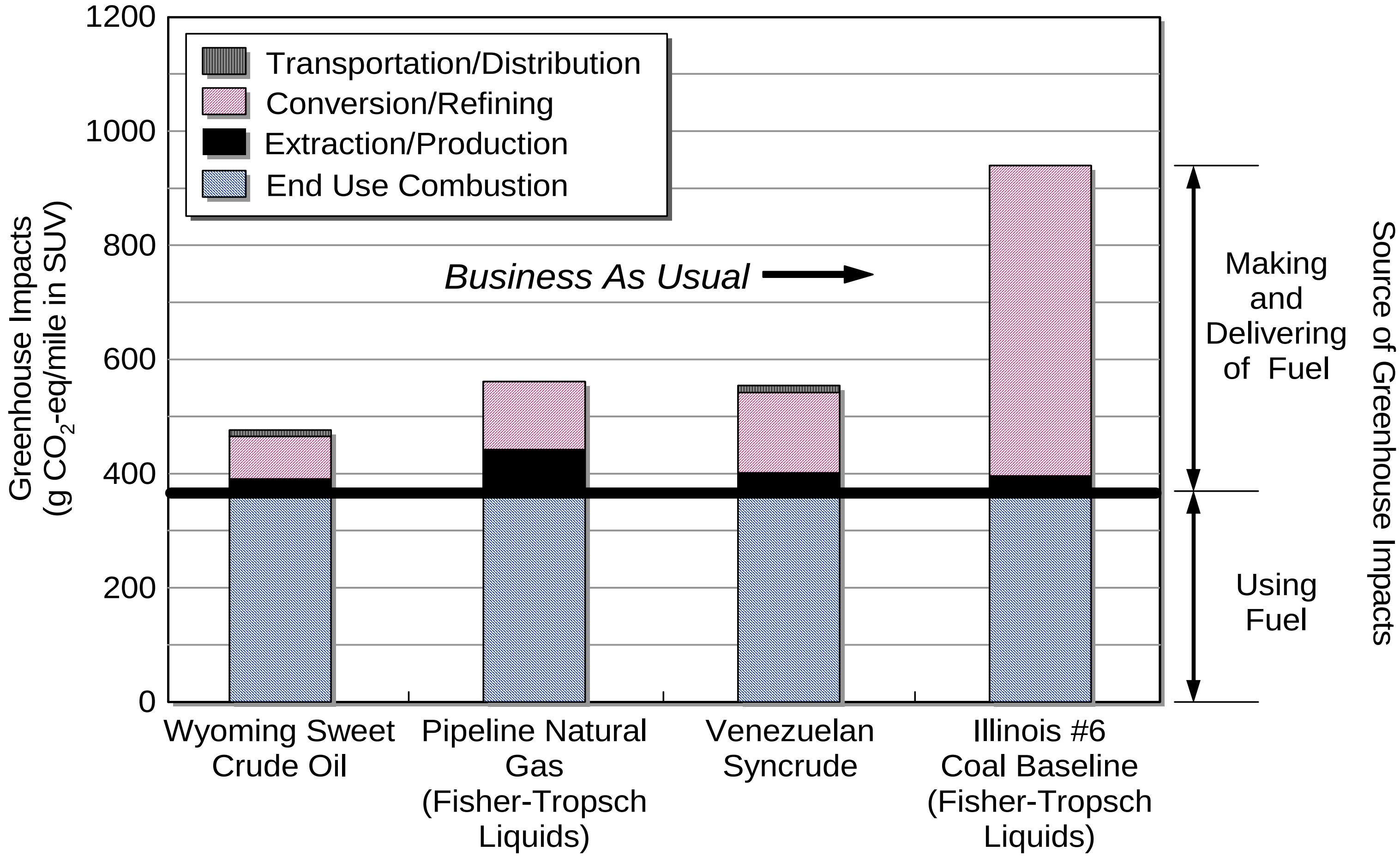
- Oil provides 39% of U.S. energy
  - Over half the crude oil is imported
  - Major component of the U.S. trade deficit
- World oil reserves dominated by four countries
  - Saudi Arabia
  - Iraq
  - Iran
  - Kuwait
- No historical basis to assume political stability of oil producers

Fuel Cycles for Liquid Fuels

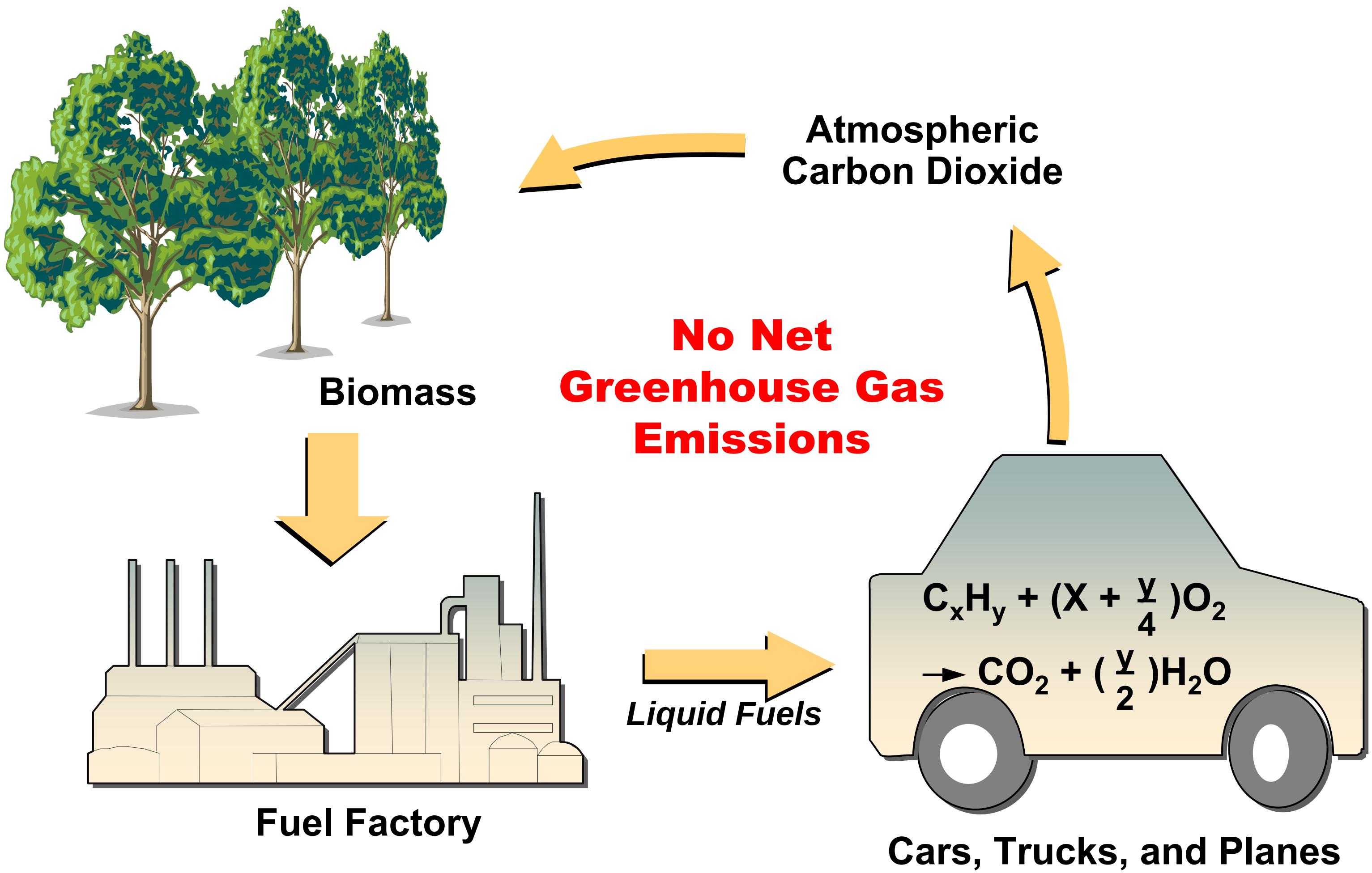
Fuel Cycle for Liquid Fuels from Crude Oil



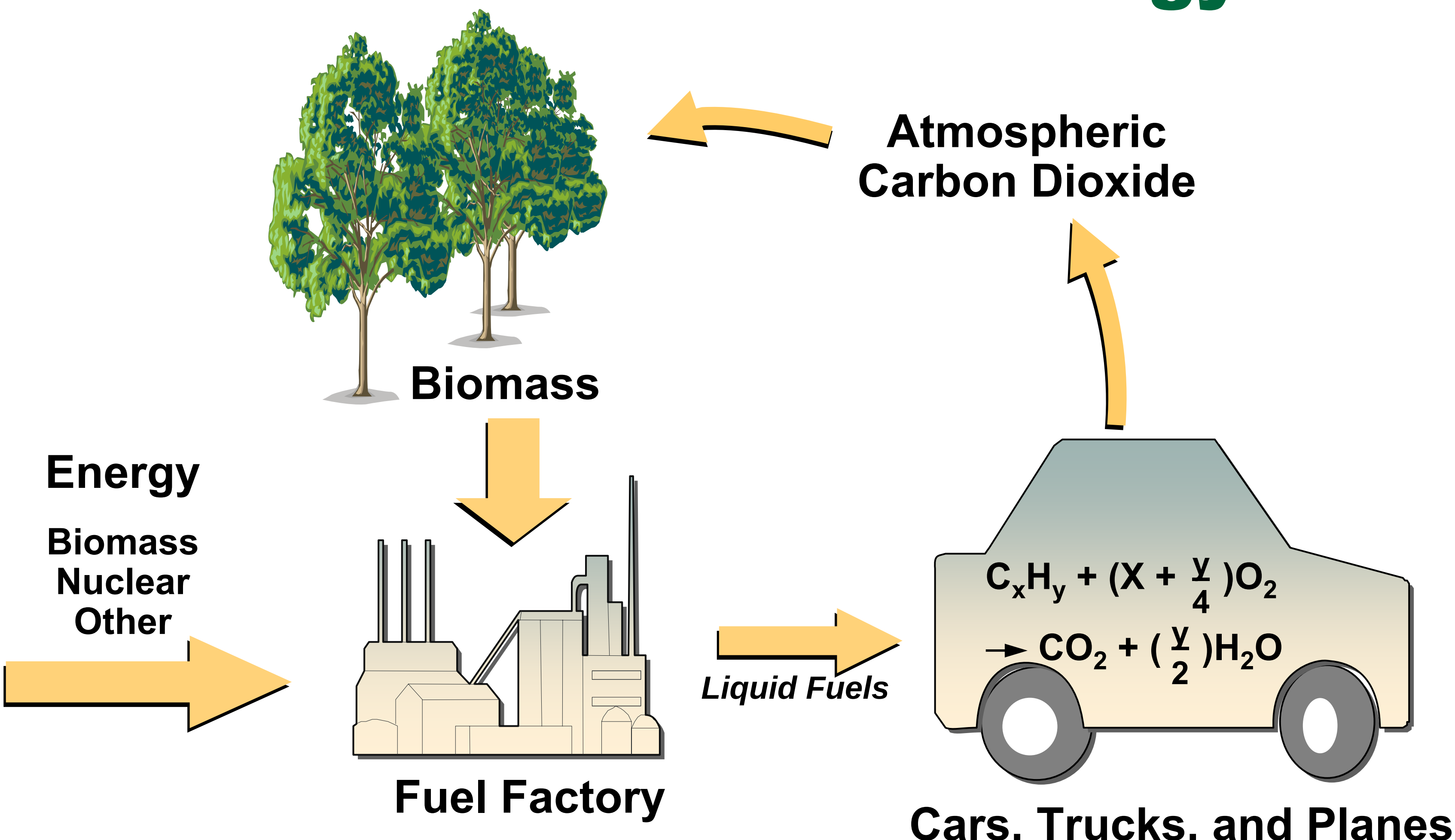
Conversion of Fossil Fuels to Liquid Fuels Requires Energy



Fuel Cycle for Liquid Fuels From Biomass



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



Biomass Resources and Limitations

Corn Stover

Fuel Ethanol

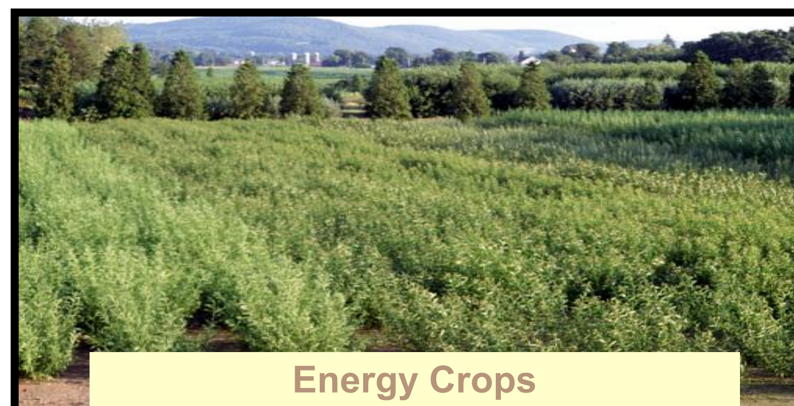
Biomass: 1.3 Billion Tons per Year

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

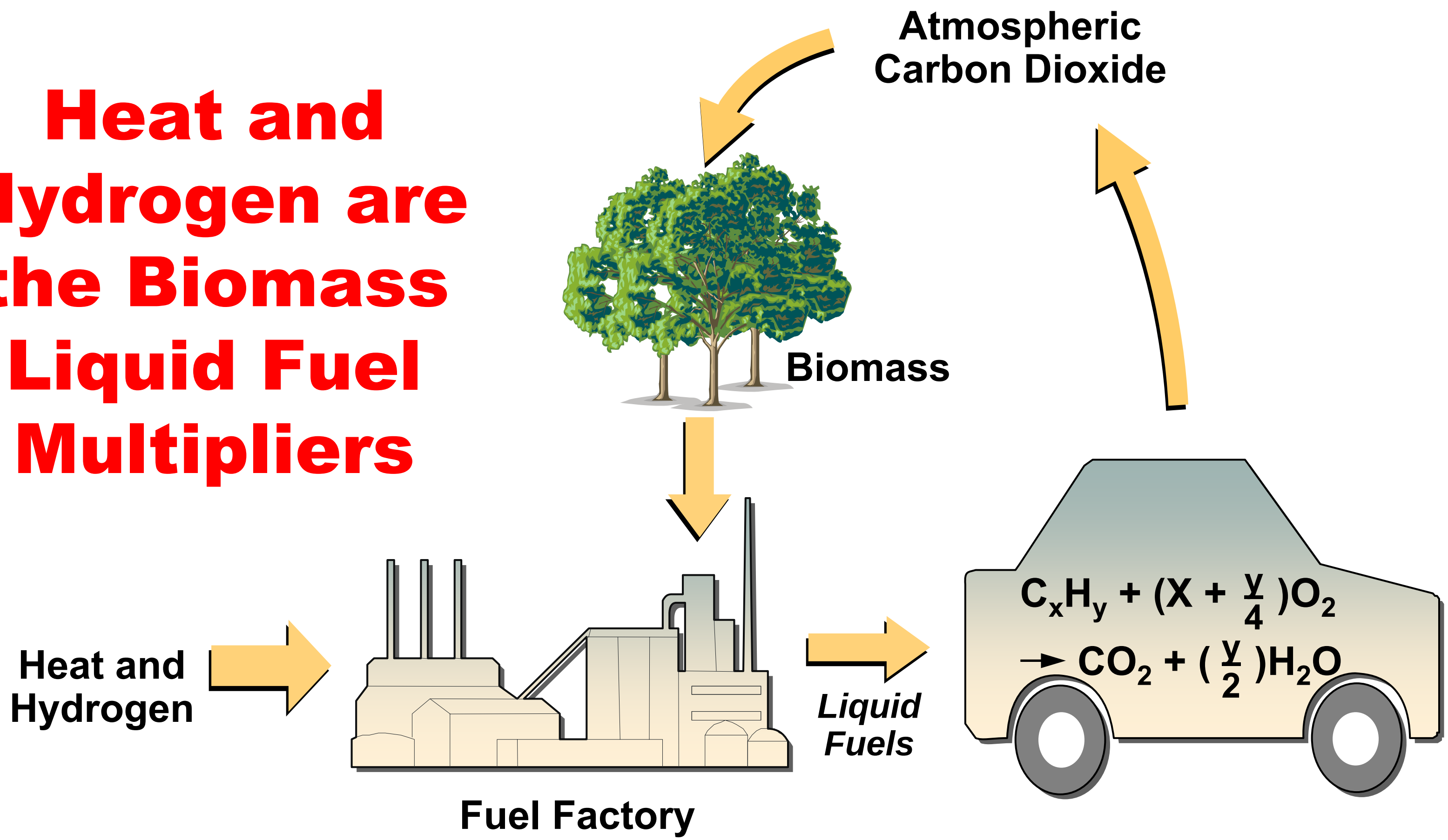
Energy Value of U.S. Biomass

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

Biomass, Nuclear Heat, and Nuclear Hydrogen can Create Abundant Greenhouse-Neutral Liquid Fuels

Heat and Hydrogen are the Biomass Liquid Fuel Multipliers



Nuclear-Hydrogen Biomass Liquid Fuels

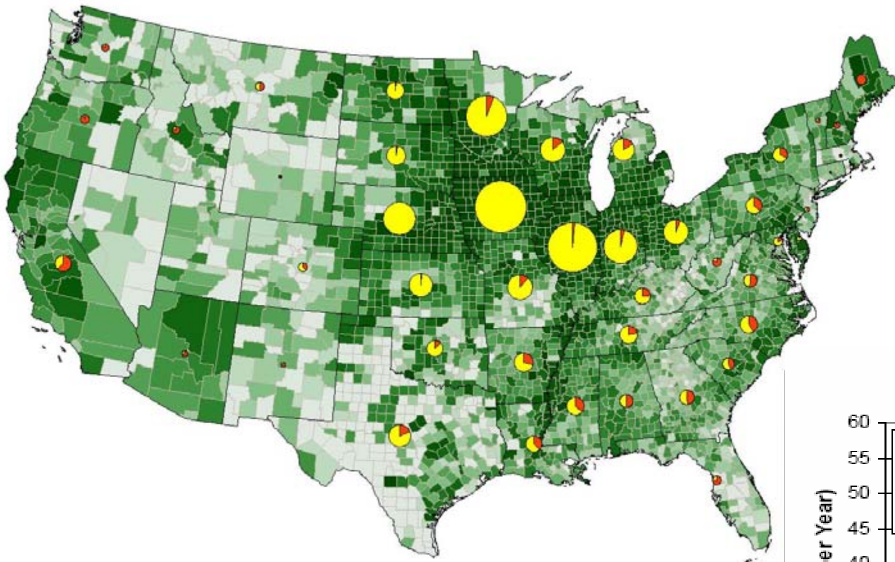
A Revolution in Biotechnology is Creating a Biofuels Industry

Fuel Ethanol is the First Step

Corn

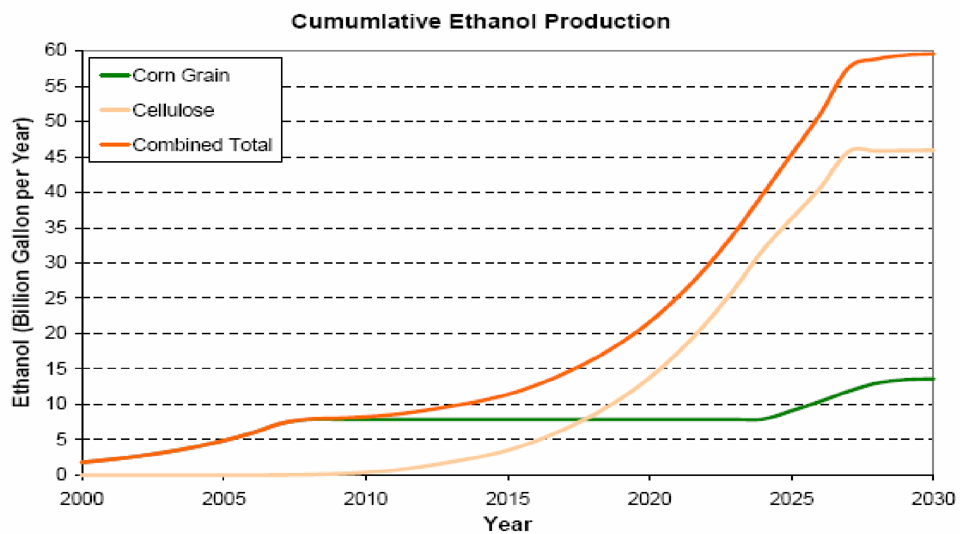
Corn to Ethanol

One-Third of U.S. Liquid Fuel Demand Could be Met with Ethanol By 2030



Distribution of Biomass Sources

Projected Ethanol Production



Source: NREL – Bob Wooley

What Happened? Why the Explosive Growth?

Distillation: The Energy Intensive Step

Ethanol Plant

Three Forms of Biomass can be Converted to Fuel Ethanol

- Sugar
- Starch (carbohydrates)
  - A polymer of sugars
  - Can be converted to sugars with enzymes
- Cellulose
  - A polymer of sugars
  - Can be converted to sugars with enzymes

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

Cellulose is the Primary Biomass on Earth

Economic Conversion of Low-Cost Cellulose to Fuel Ethanol Implies a Liquid-Fuel Revolution


Agricultural Residues


Logging Residues


Urban Residues


Energy Crops

The Other Biomass Challenge: Energy for Biomass Processing

- Biomass processing is energy intensive
- Example: Corn to ethanol
  - Nonsolar energy inputs to produce ethanol equal 70% of the energy from the ethanol
  - A high-quality liquid fuel is produced from less valuable forms of energy (natural gas, biomass)
- Current energy sources
  - Biomass (Sugarcane)
  - Fossil fuels (Corn)

Ethanol Production Requires Massive Quantities of Low-Temperature Steam

- **Distillation columns use low-pressure steam to separate ethanol from fermentation mash**
- **<u>Steam is one-half the nonsolar energy input in growing corn and converting it to fuel ethanol</u>**
- **Production of one billion liters of ethanol/year requires 260 MW(t) of steam**
- **By 2030, the United States could require 50 GW(t) of low-pressure steam**

Different Sources of Energy for Ethanol-Plant Steam Production

Sugar (Sugarcane and Sugar Beets)
Burn Sugarcane Residue (Bagasse)

Starch (Corn, Barley, etc.)
Burn Natural Gas or Coal

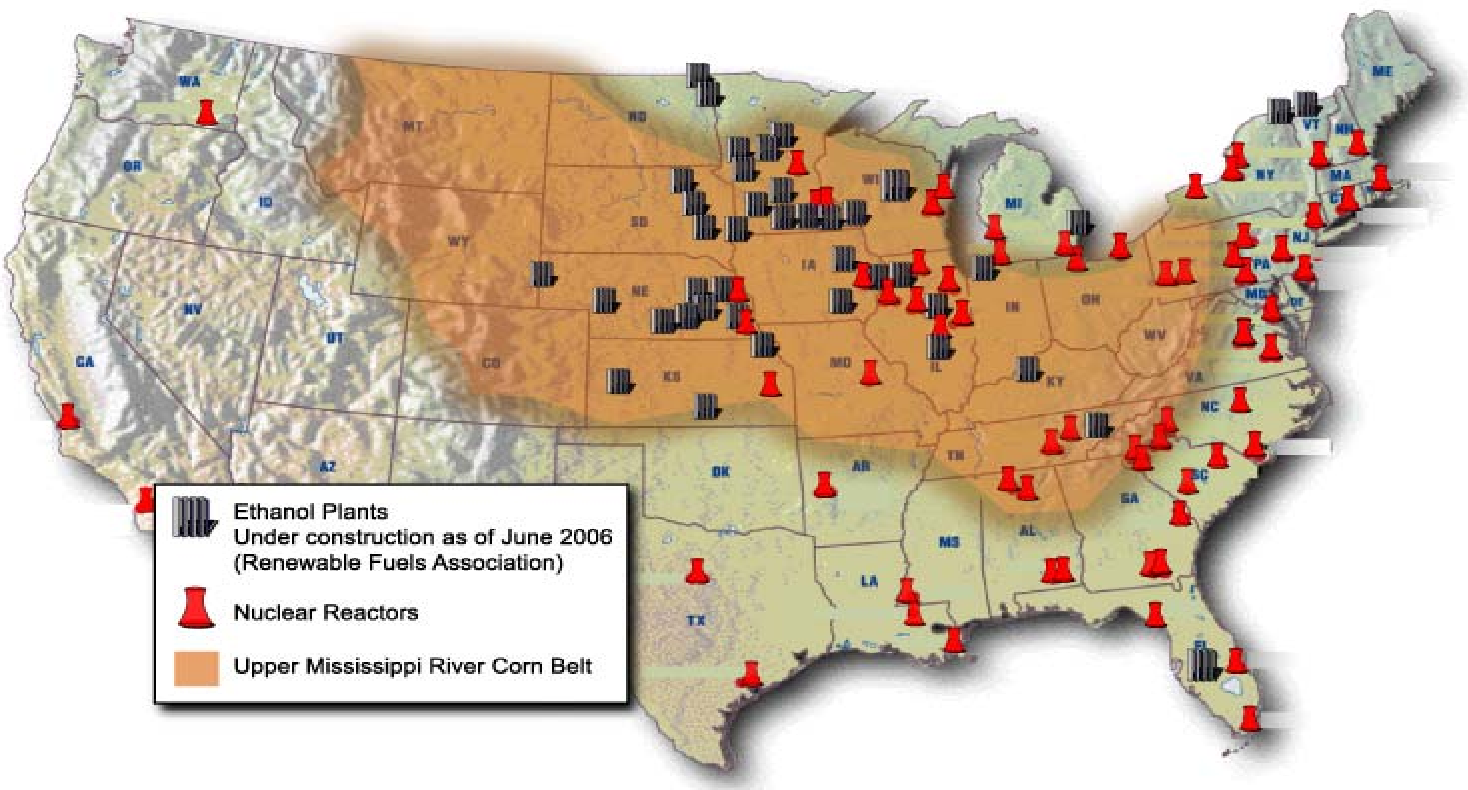
Cellulose (Trees, Agricultural Waste)
Burn Lignin (Nonfermentable Biomass)

Incentives to Use Nuclear Energy to Produce Ethanol-Plant Steam

- ***Environment:*** **Net CO_2 emissions can be reduced by one-half per liter of ethanol by using nuclear heat rather than fossil fuels**
- ***Economics:*** **U.S. nuclear steam costs are one-half those of natural gas (corn-to-ethanol plants)**
- ***Liquid fuel production:*** **Replacing biomass used for steam production enables use of that biomass to produce more liquid fuels (e.g., plants using sugarcane and cellulose to produce ethanol)**

Existing Nuclear Plants Can Provide Much of the Needed Steam

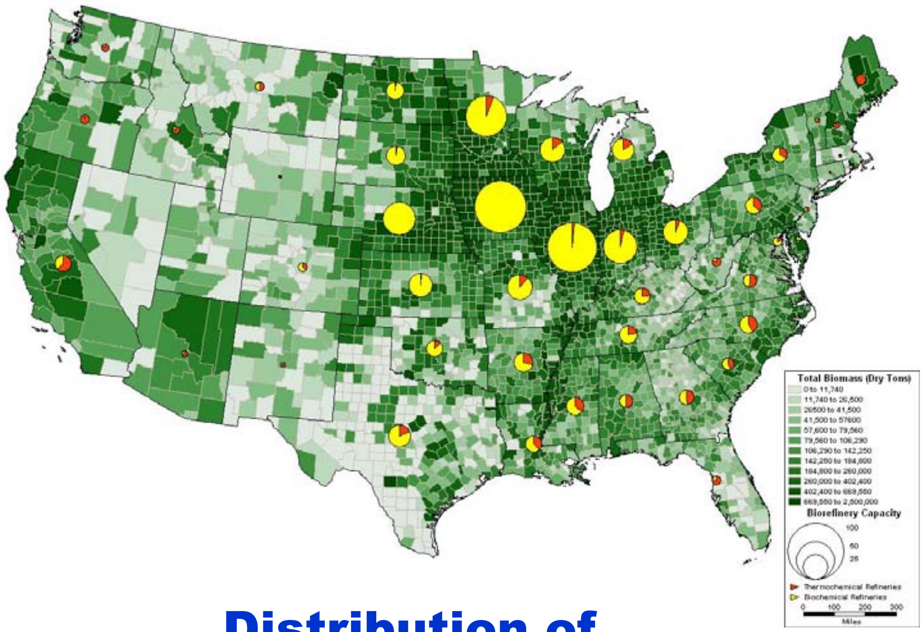
The First Large Cogeneration Steam Market will be Located in Rural Areas Where Nuclear-Electric Plants are Located



Nuclear-Specific Biomass Challenges

- Cellulose R&D challenge
  - Current plans: Steam is to be produced from burning lignin, the non-fermentable biomass residue
  - Methods to convert lignin to liquid fuels are under development
  - Nuclear steam is an option for cellulose feedstock only if a use is found for lignin
- Business model
  - Current ethanol plants need ~100 MW of steam
  - What are the advantages and disadvantages of much larger ethanol plants?

Further Growth In Biomass Liquid Fuels Requires Hydrogen



Distribution of Biomass Sources

- **Insufficient biomass to meet U.S. liquid fuel demands with ethanol**
- **Triple liquid-fuel production per ton of biomass by making diesel fuel $(CH_2)_n$ rather than ethanol (CH_3CH_2OH)**
  - **Ethanol can be considered a partly oxidized hydrocarbon**
- **Biomass + Hydrogen → Gasoline and Diesel fuel**

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Two Methods For Converting Biomass and Hydrogen to Diesel Fuel

Fischer-Tropsch

- Process
  - Biomass + $O_2 \rightarrow CO + H_2$
  - $CO + H_2 \rightarrow$ Diesel
- Indirect process
- Industrial technology (basis for coal liquefaction)

Direct Hydrogenation

- Process
  - Biomass + $H_2 \rightarrow$ Diesel
- Direct process
- Laboratory process

Required Energy Inputs to Produce Hydrogen Exceed Existing Nuclear Energy Production

Hydrogen can be produced by electrolysis and other processes

Are Liquid Fuels the Future of Nuclear Energy?

Nuclear Energy has Several Characteristics

Centralized Technology

Large Economics of Scale

Laws of Physics Favor Large Machines
Waste Management
Security

Technological Sophisticated User Required

Electricity is not Intrinsically a Large-Scale Centralized Technology

Electricity is Produced on Many Scales with Different Technologies

Nuclear Energy does not have an Intrinsic Advantage for Electricity Production

Hydrogen and Nuclear Energy

Hydrogen Production, Storage, and Transport are Centralized Technologies

+

Energy is Required to Make Hydrogen

↓

Nuclear Energy Characteristics (A Centralized Energy Source) Match the Hydrogen Production Needs

There is Only One Low-Cost Hydrogen Storage Technology: Underground

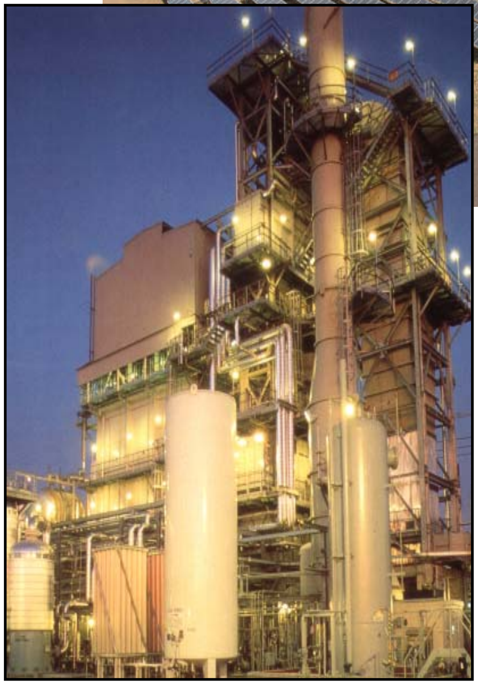
- **Hydrogen storage is required**
- **Low-cost storage is possible only on a large scale**
- **Centralized hydrogen storage favors centralized hydrogen production to avoid transport costs**

Hydrogen Collection and Distribution are Different than for Electricity

- Electricity transport
  - Two-way systems with transformers
  - Highly efficient methods to change voltage (electrical pressure)
- Hydrogen transport: similar to natural gas
  - Hydrogen transmits one way: high to low pressure
  - Large economics of scale associated with hydrogen compression
- Hydrogen transport characteristics favor centralized production, storage, and transport

Hydrogen Production Favors High-Capacity Centralized Systems

- **Hydrogen properties favor large systems**
  - **Hydrogen leakage**
  - **Hydrogen compression**
- **Economics of Scale**
  - **Electricity (<u>Electrons</u>):**
    - **Multiple production methods (wind, nuclear, coal, etc.)**
    - **Plant sizes vary by over 3 orders of magnitude**
    - **Electricity production costs vary by a factor of 3**
    - **Not intrinsically a large-scale technology**
  - **Hydrogen (<u>Atoms</u>):**
    - **Large economics of scale**
    - **Chemical industry experience**



Economics have Driven the Largest Natural Gas-to-Hydrogen Plant Outputs to Match Three 1000-MW(e) Nuclear Power Plants

Browns Ferry Nuclear Power Plant (Courtesy of TVA)

*Natural gas-to-H_2 plant with total output from four trains of $15.6 \cdot 10^6$ m^3/day

A Primary Future Role of Nuclear Energy may be Liquid Fuels Production

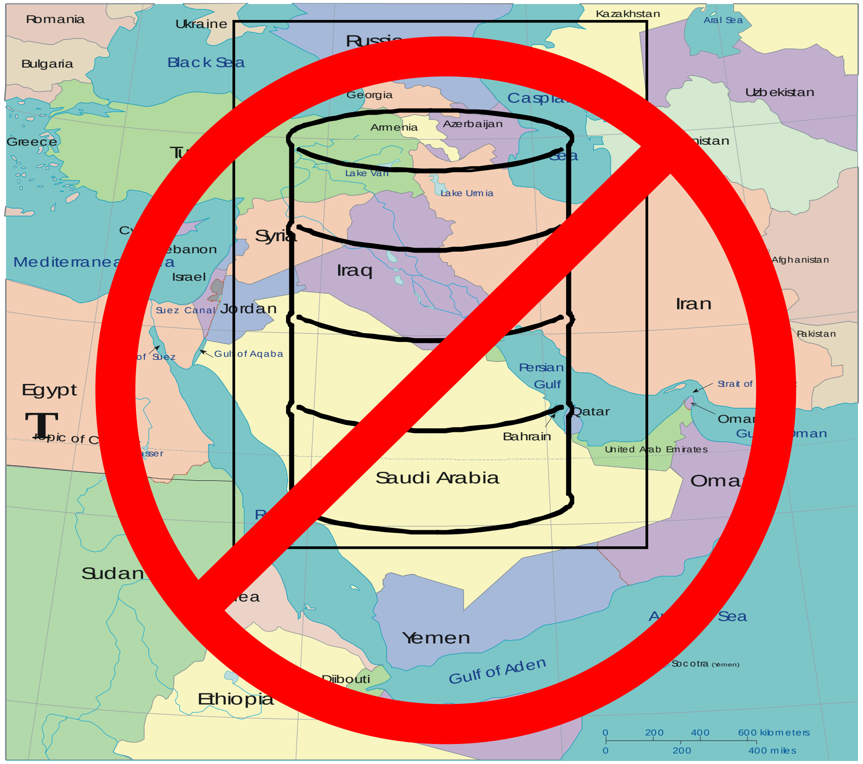
(In the Forms of Hydrogen and Heat)

Conclusions

- Need replacements for liquid fuels from crude oil
- The U.S. has large biomass resources
- Biomass plus nuclear energy could meet the nation's demand for liquid fuels
- Fuel production may be the future of nuclear energy

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.

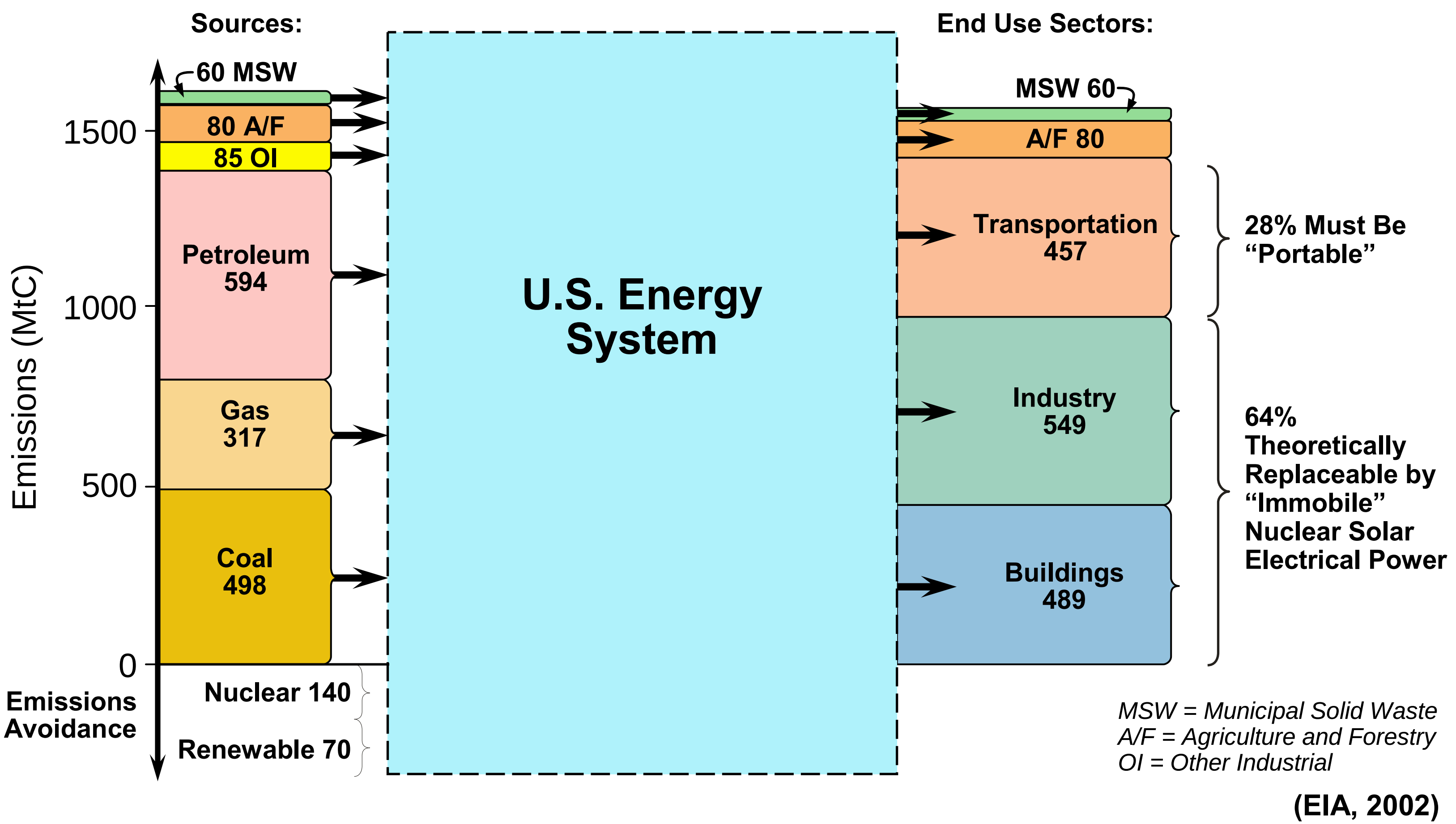
—ABSTRACT—

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

Charles Forsberg

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. That would meet the nation's liquid-fuel demand. The combination of biomass and nuclear energy can meet the total U.S. liquid fuel demand.

Transportation Fuels Make Up 1/3 of Total GHG Carbon Emissions



Newest Ethanol Plants Obtain Steam from Fossil Electric Plants

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