



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

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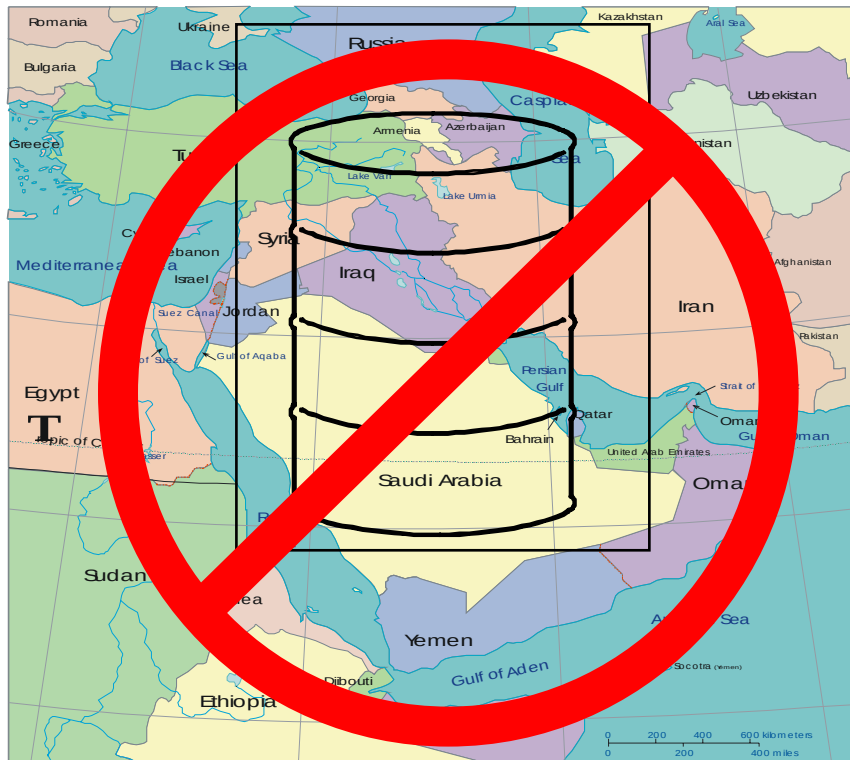
Outline

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

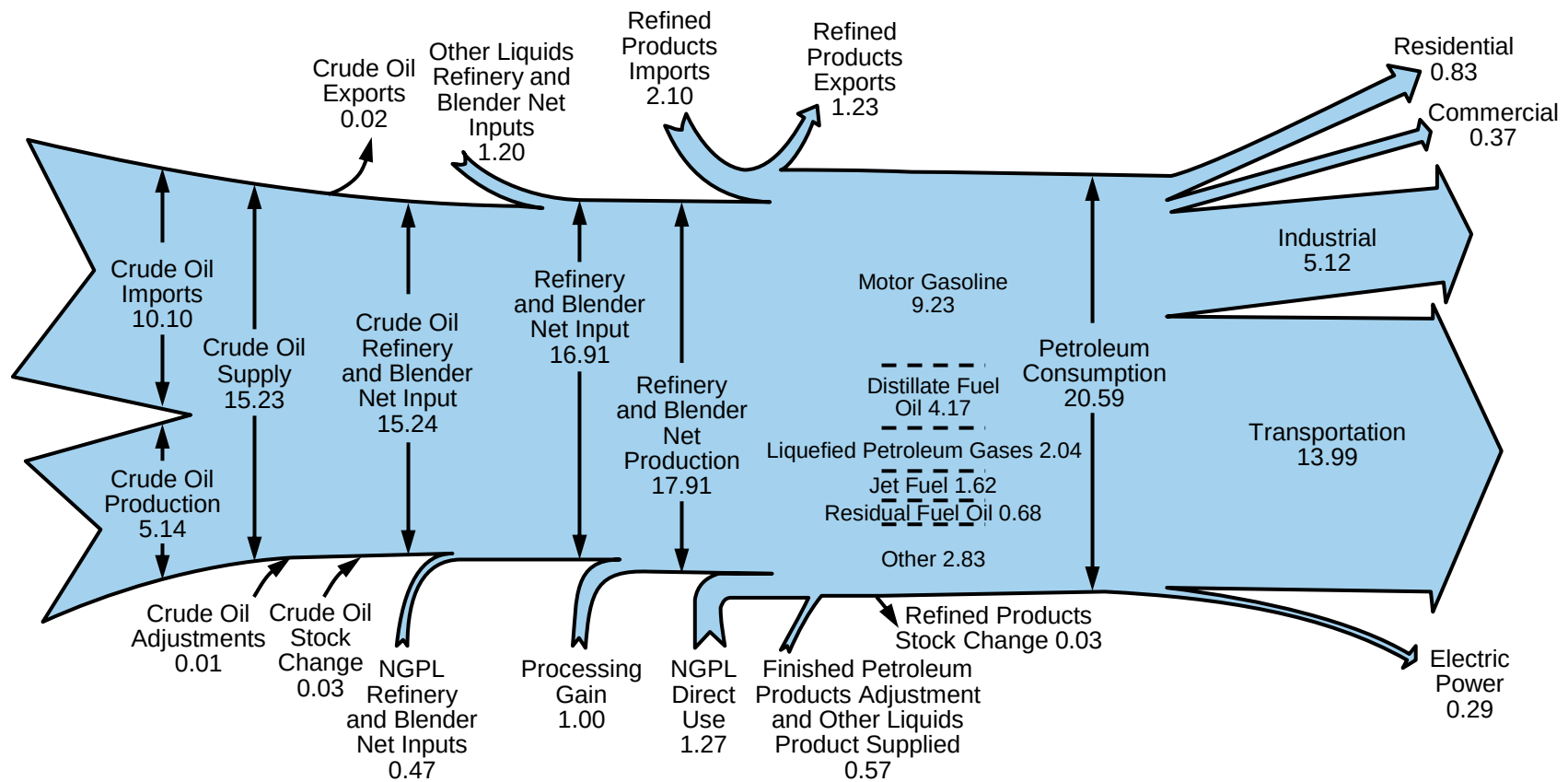


Risk of Climate Change



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



U.S. Energy Information Agency: Annual Energy Review 2006

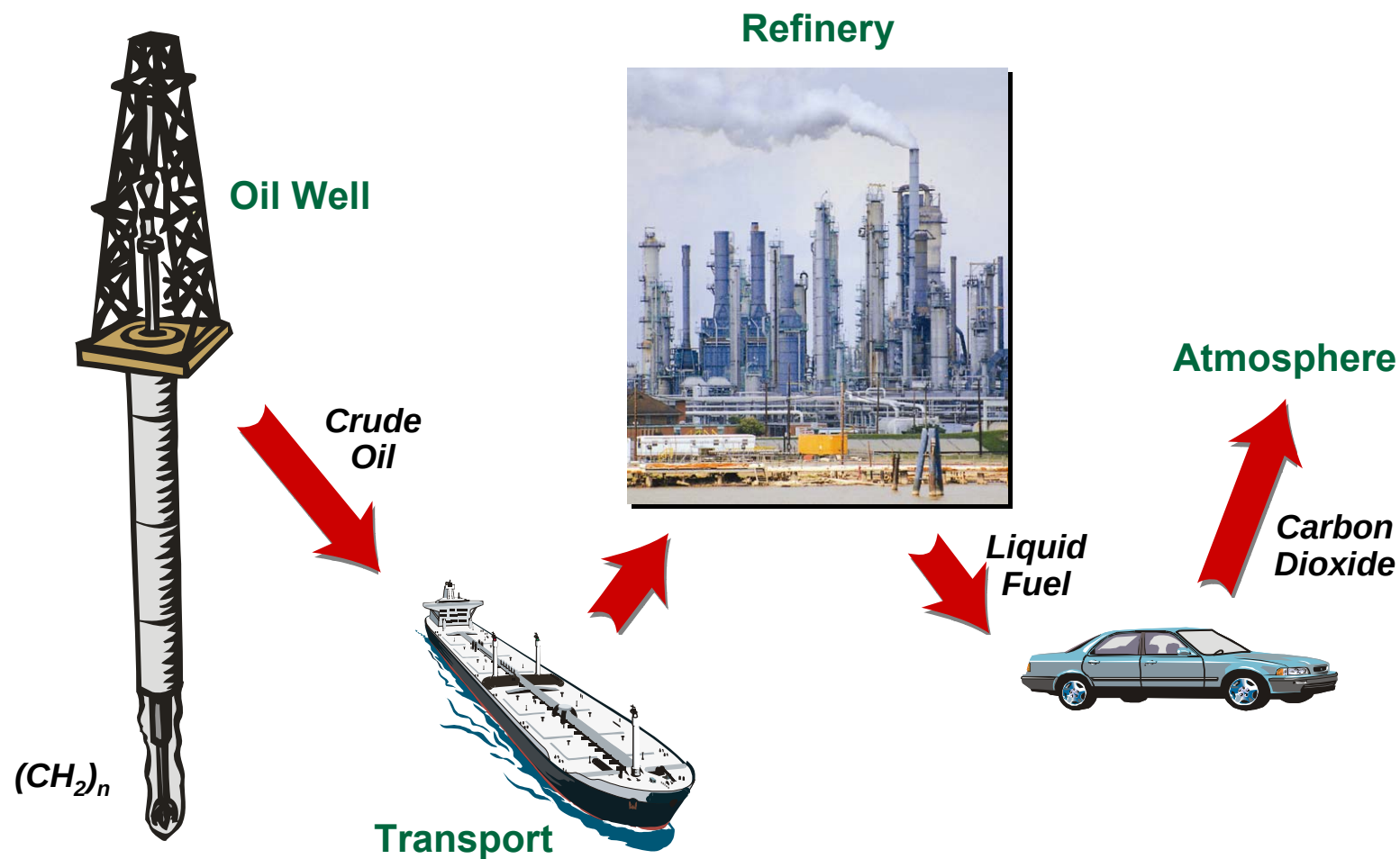
Electrification of Transportation

Electrification Could Reduce Transport Fuel Demand in Half

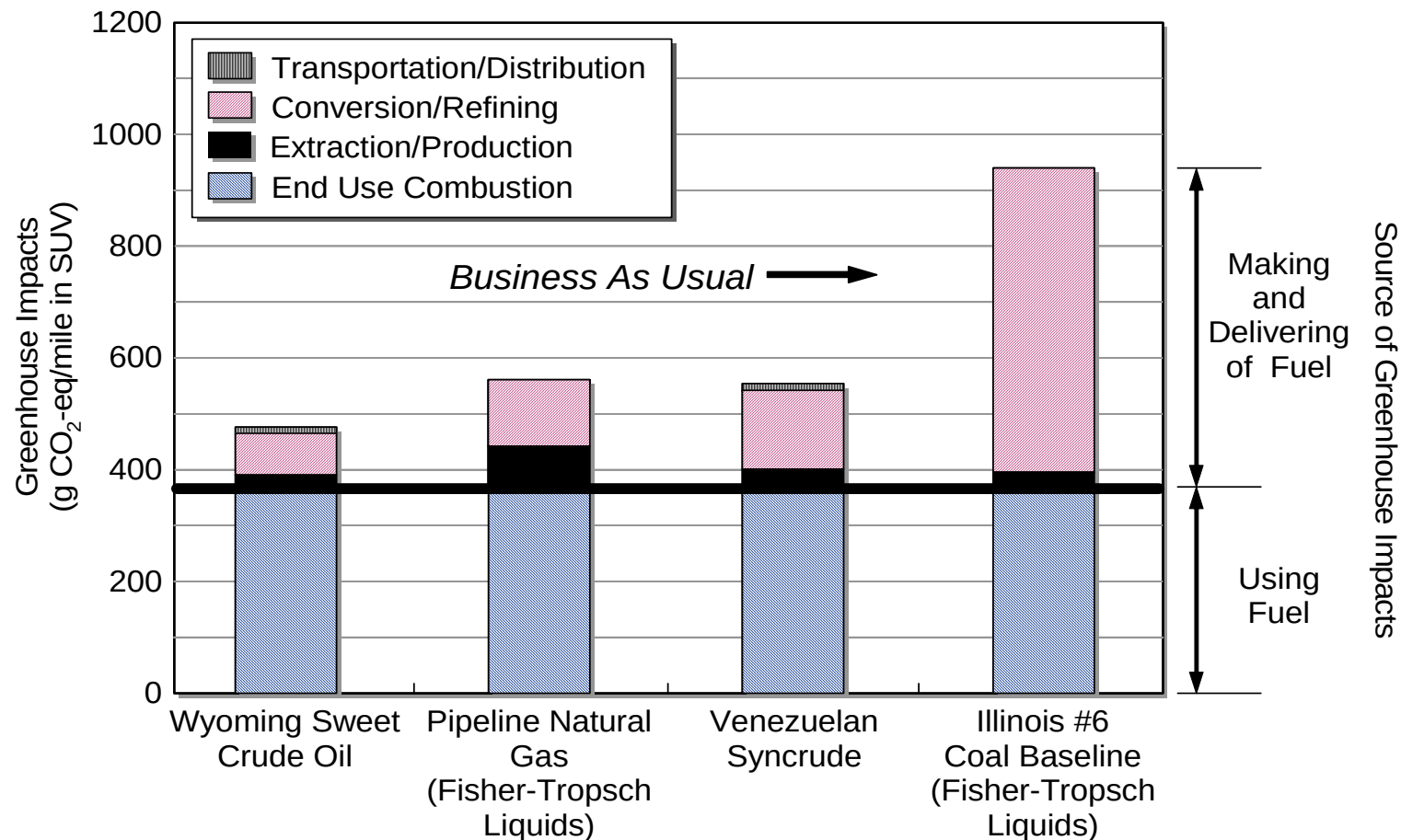
- **Nuclear electricity could become the major transport fuel**
- **Technology pathways**
 - **Plug-in hybrid electric cars and light trucks**
 - **Cut gasoline demand in half**
 - **Price equivalent to ~\$1.20/gasoline [\$0.10/kw(e)]**
 - **Electrification of railroads with better inter-modal transport (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

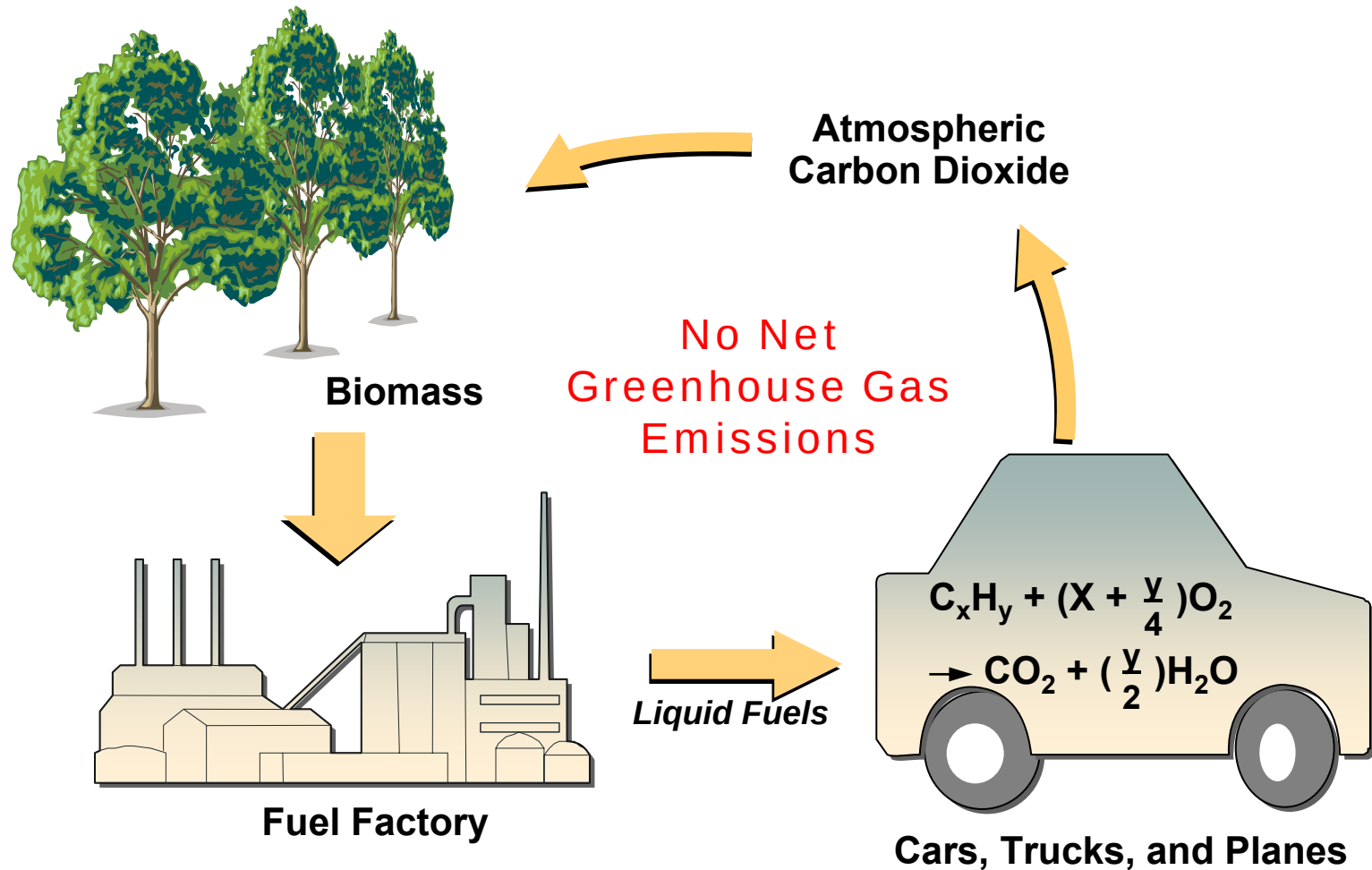
Fuel Cycle for Liquid Fuels from Crude Oil



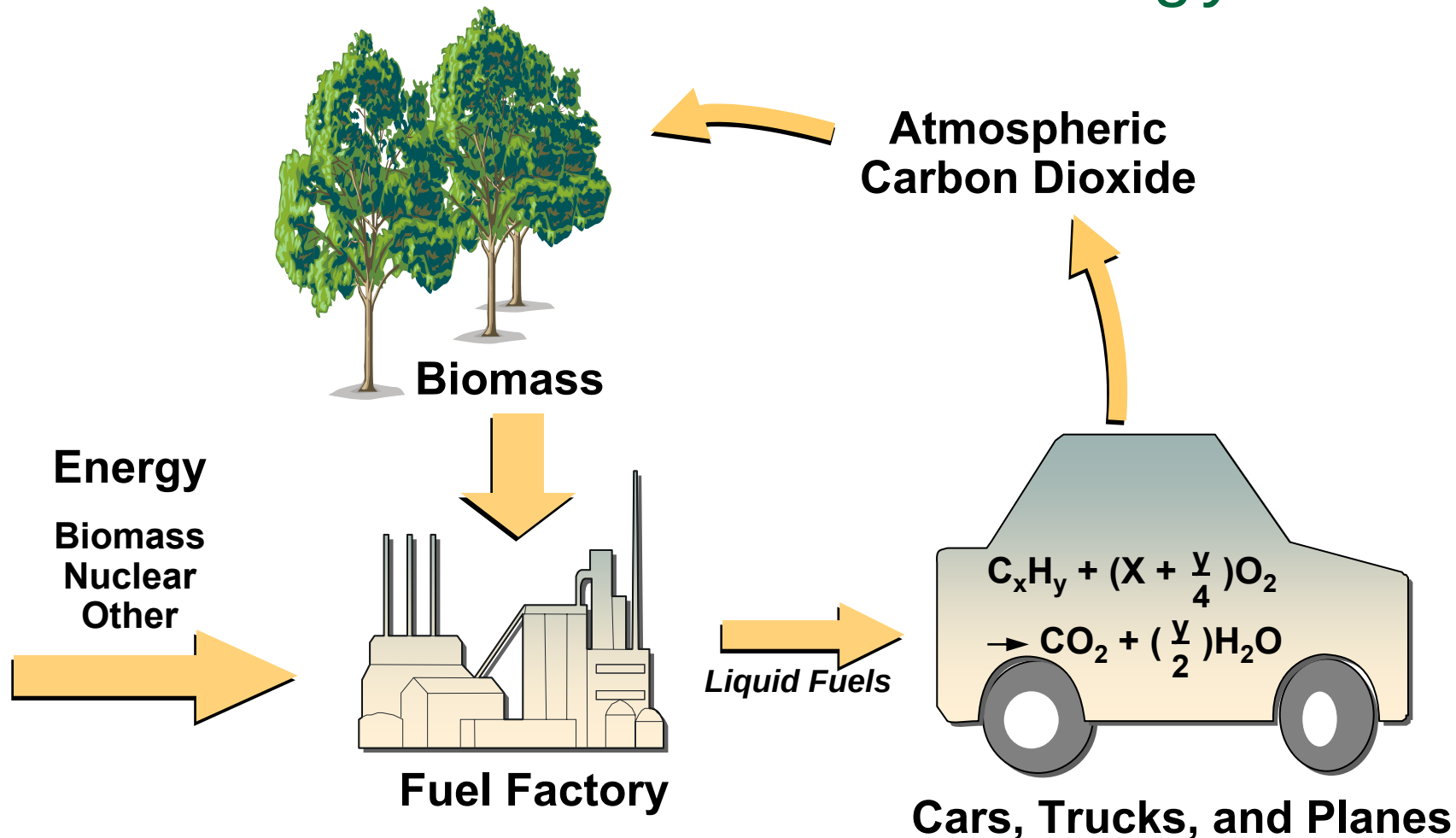
Conversion of Fossil Fuels to Liquid Fuels Requires Energy



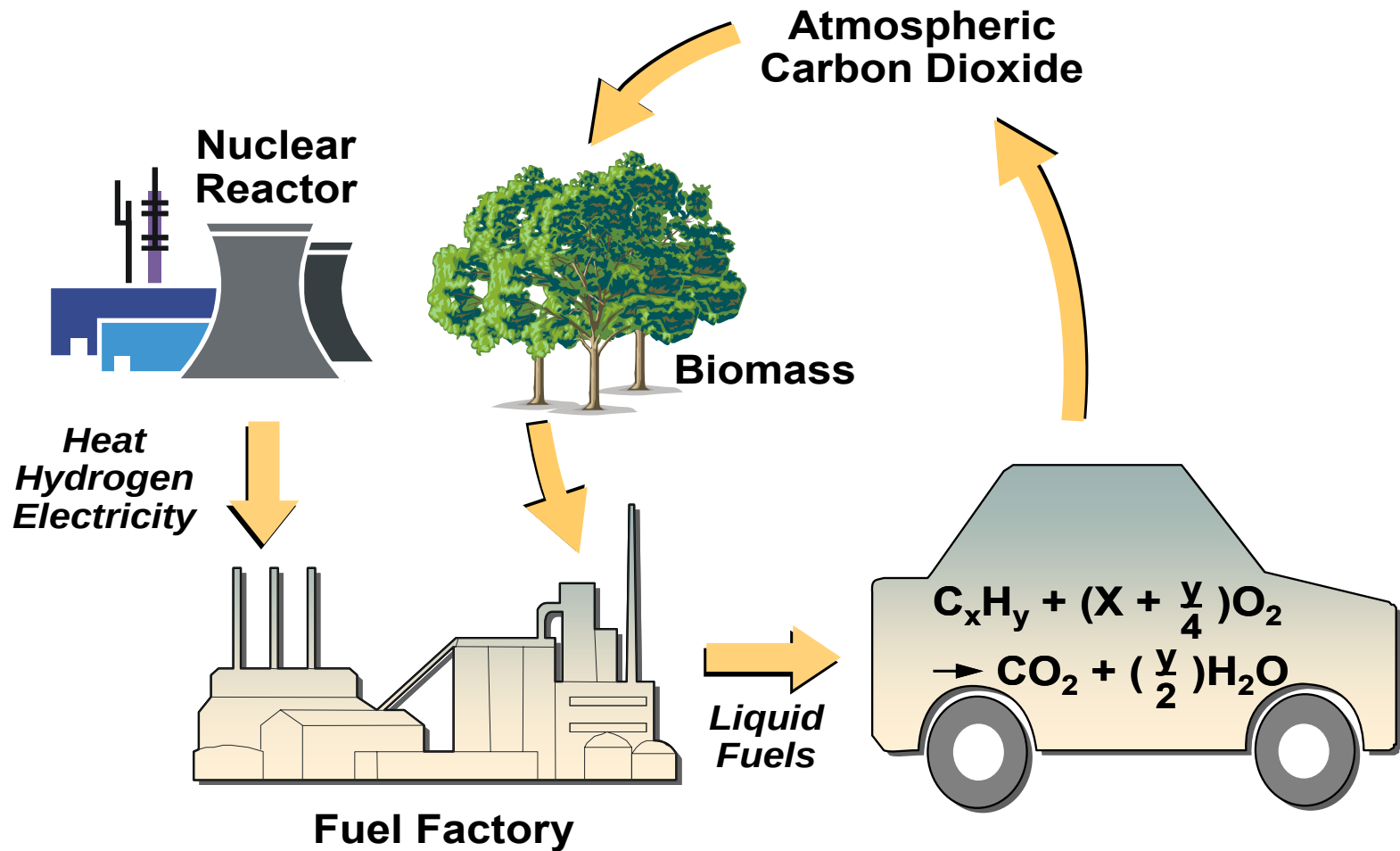
Fuel Cycle for Liquid Fuels from Biomass



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



The Nuclear-Hydrogen-Biomass Liquid-Fuel Cycle



Biomass Resources and Limitations



Corn Stover



Fuel Ethanol

Biomass: 1.3 Billion Tons per Year ¹⁵

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

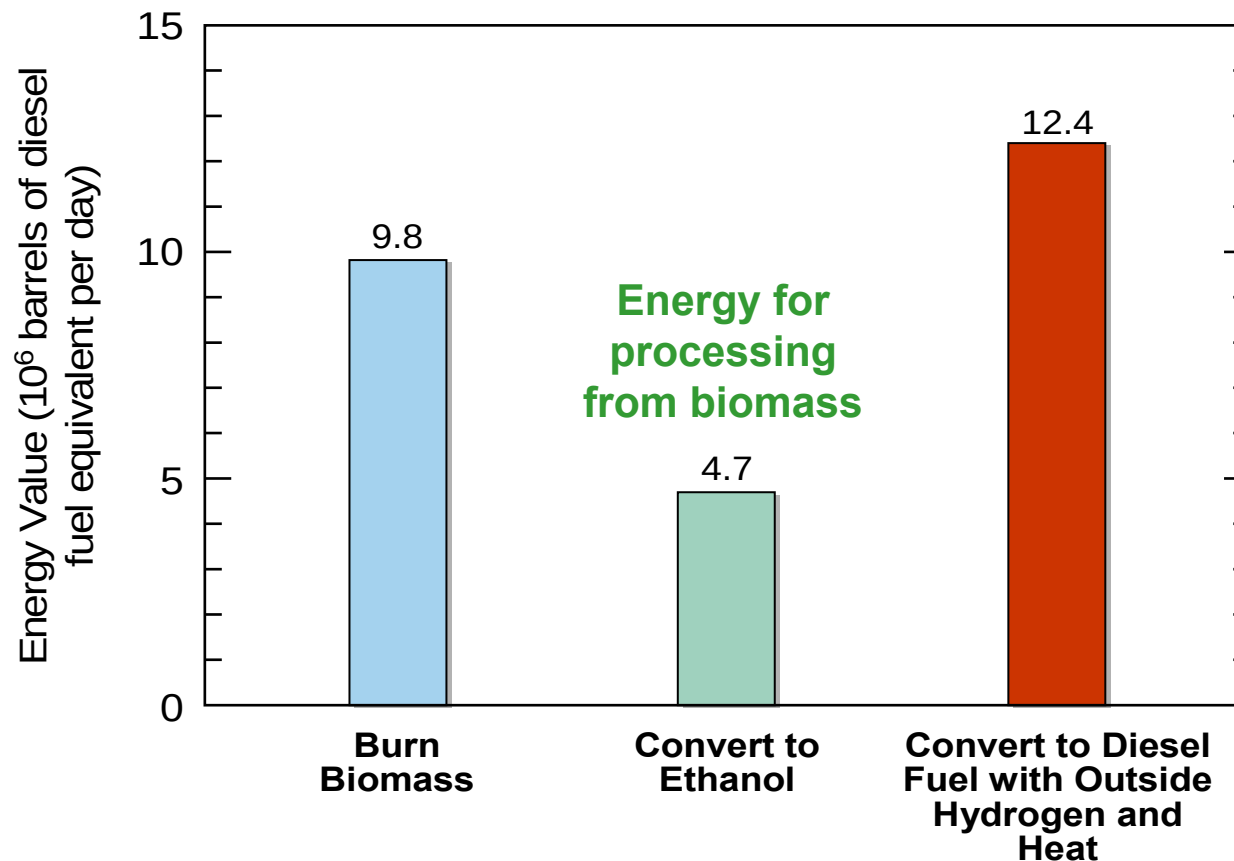


Different Processes can Convert Biomass into Different Fuels

- **Ethanol**
- **Gasoline**
- **Diesel**
- **Biodiesel**
- **Jet fuel**

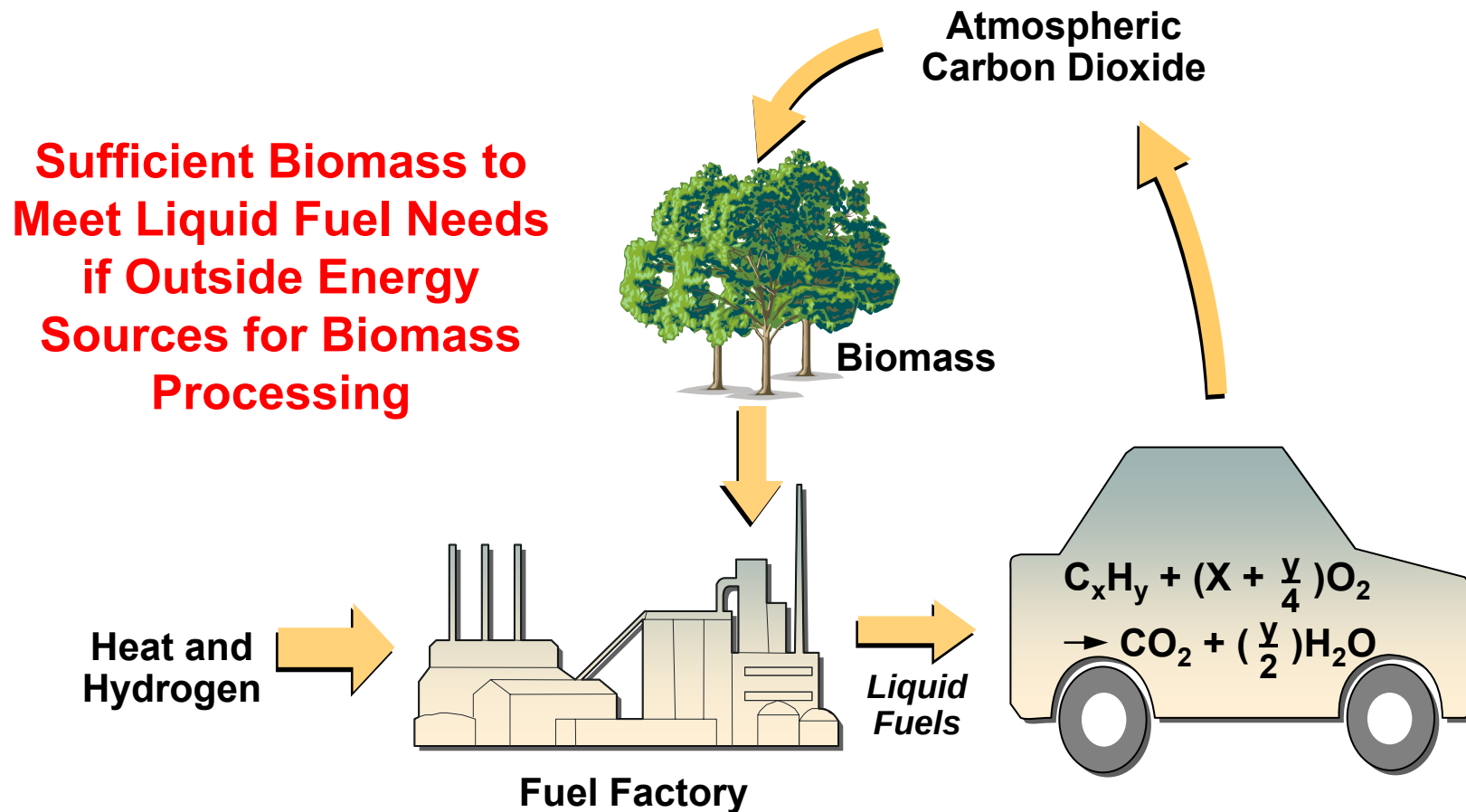
Energy Value of 1.3 Billion Tons/year of Biomass as Liquid Fuel

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



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



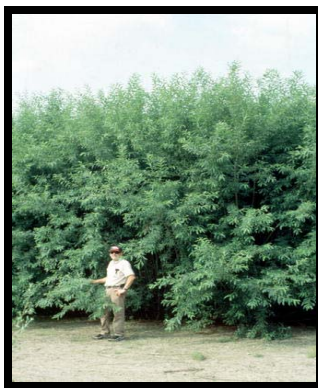
Sugar (Sugarcane and Sugar Beets)
Sugar → Ethanol (Traditional Technology)
Process has been Used for Millennia

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

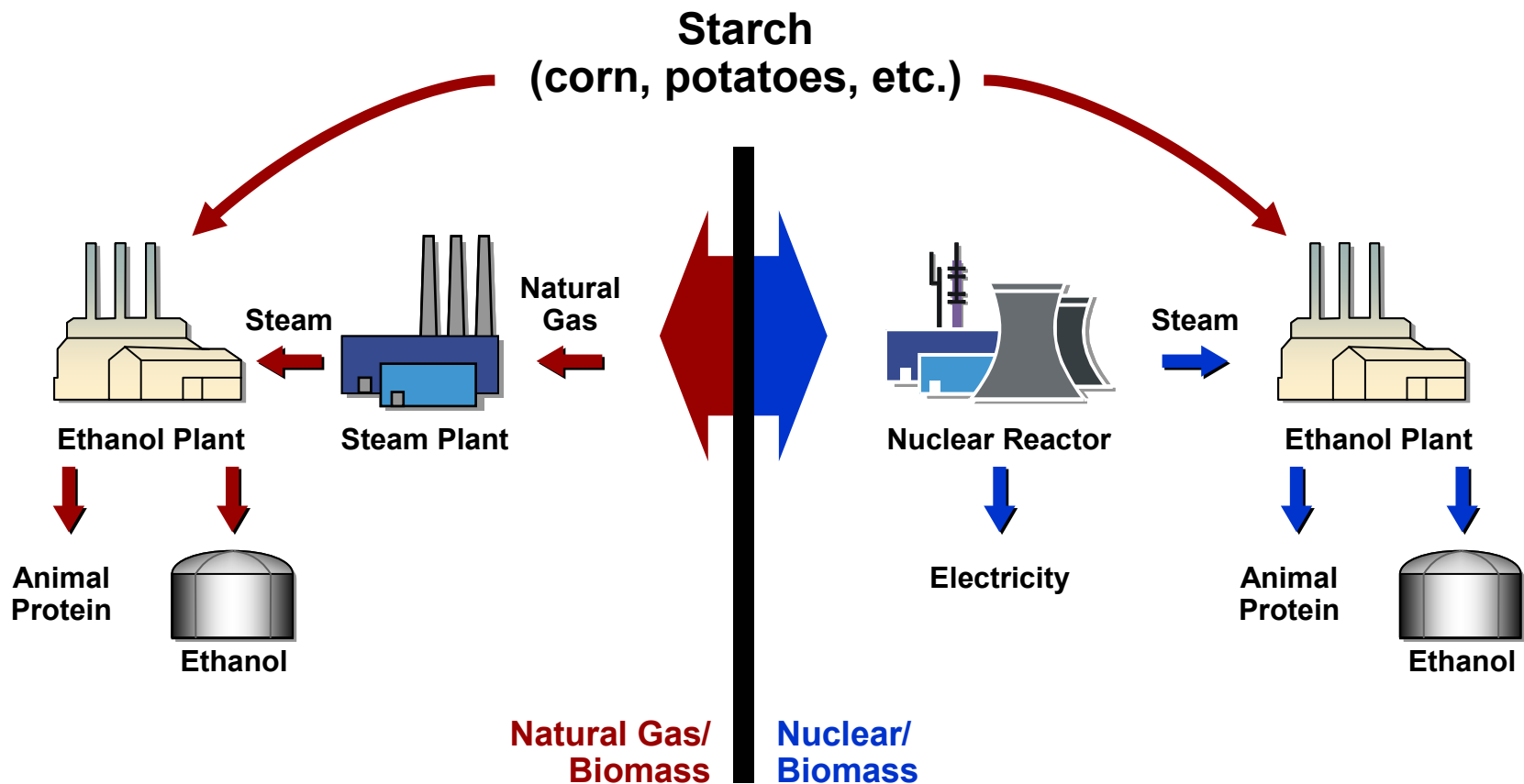
**Enzyme Costs Dropping Rapidly;
Precommercial Plants Operating**

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



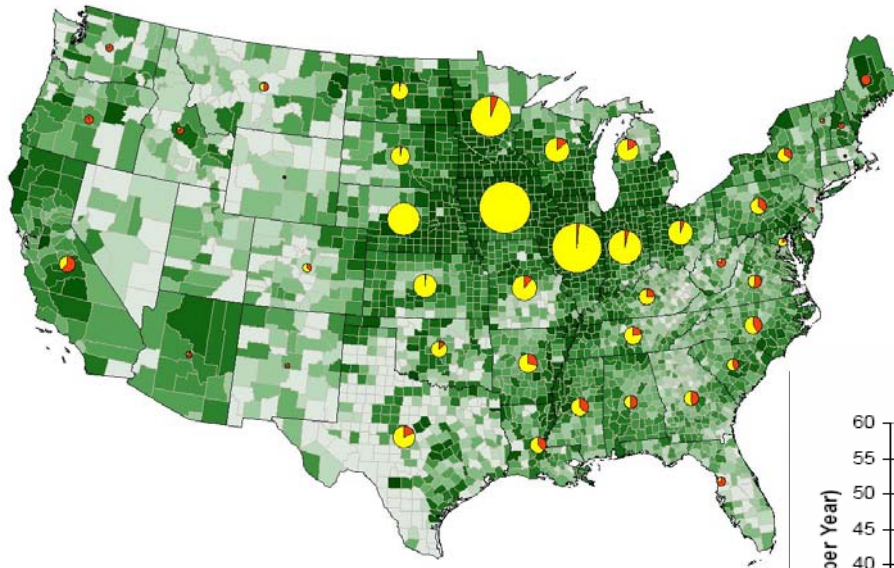
*Fossil Energy Input 70% of
Energy Content of Ethanol*

*50% Decrease in CO₂ Emissions/Gallon Ethanol
50% Reduction in Steam Cost*

Economics are favorable and no new technology is required

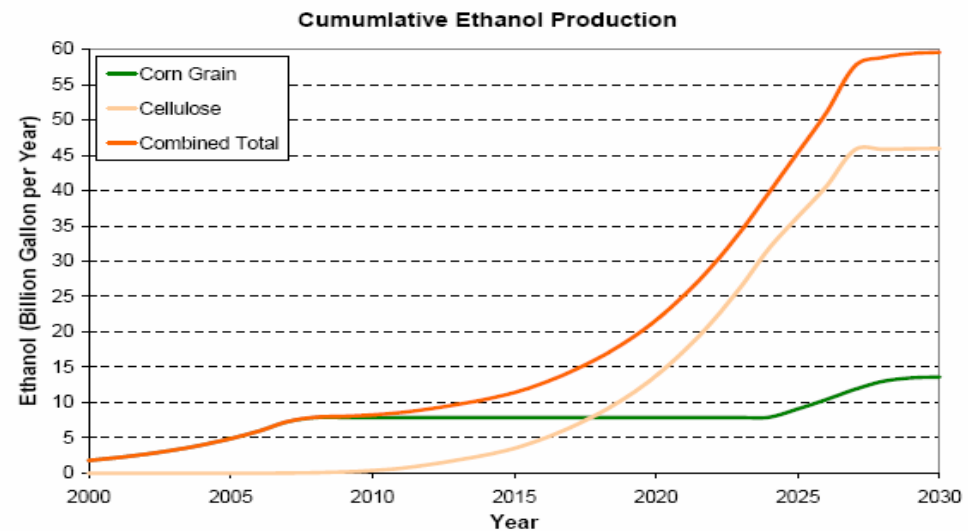
One-Third of U.S. Liquid Fuel Demand Could be Met with Ethanol By 2030

Most of the Ethanol is from Cellulose

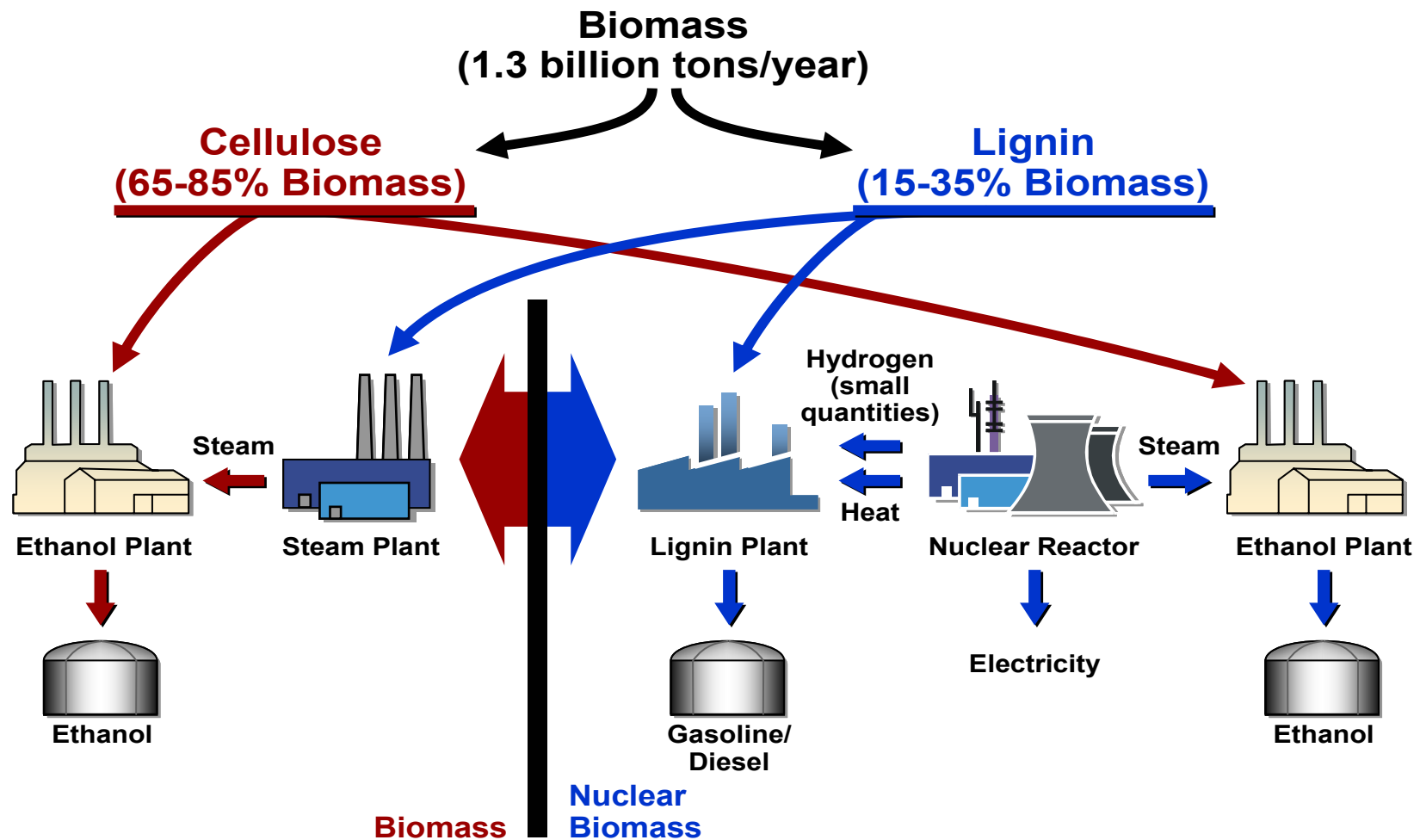


Distribution of
Biomass Sources

Projected Ethanol Production



Cellulosic Liquid Fuel Yields Increased by 50% Using Nuclear Heat and Hydrogen



Cellulosic Biomass Challenges

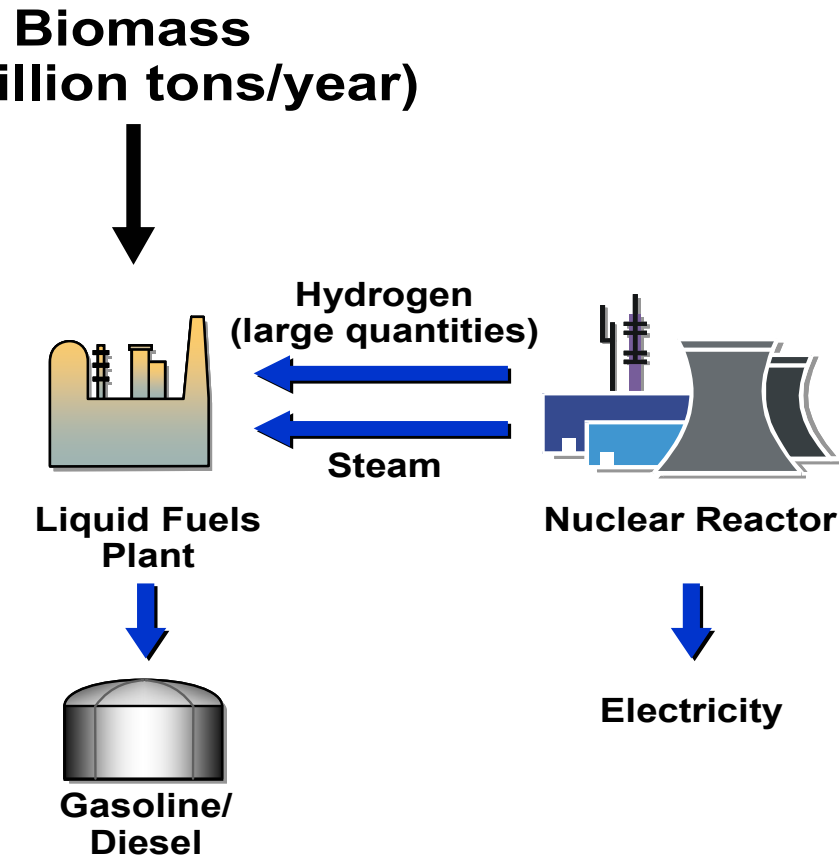


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- **Processes are in the pilot-plant stage**
- **Nuclear Cellulose R&D challenge**
 - Economic use of nuclear energy requires conversion of lignin to liquid fuel
 - Nuclear steam is an option for cellulose feedstock only if a use is found for lignin
 - 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



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

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

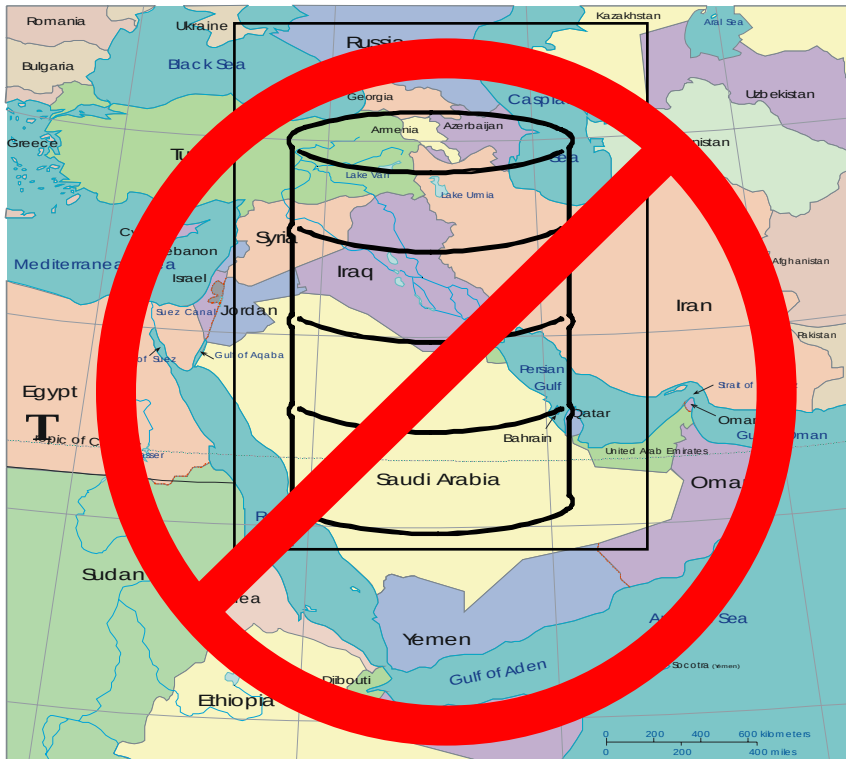


Questions?

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.

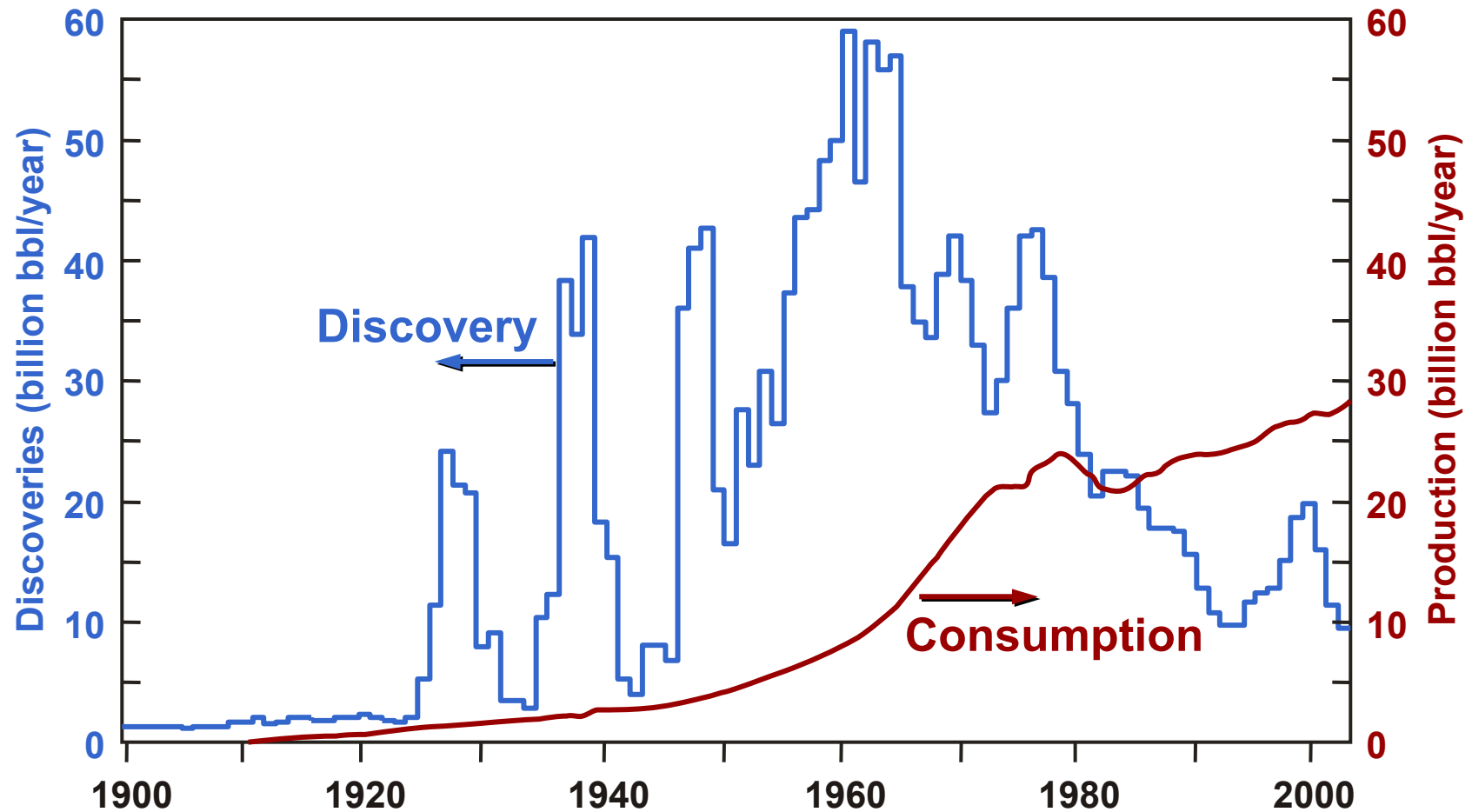
—ABSTRACT—

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

Charles Forsberg

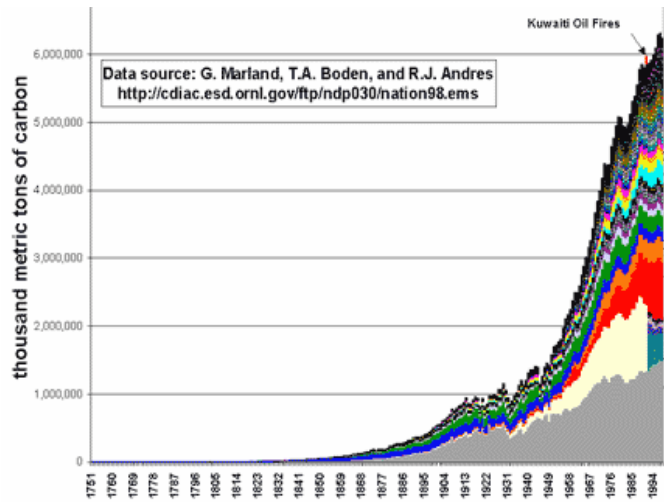
The two major energy challenges for the United States are (1) replacing crude oil in our transportation system and (2) eliminating greenhouse gas emissions. A strategy is proposed to meet the total liquid-fuel transport energy needs within 30 years by producing greenhouse-neutral liquid fuels using biomass 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. 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

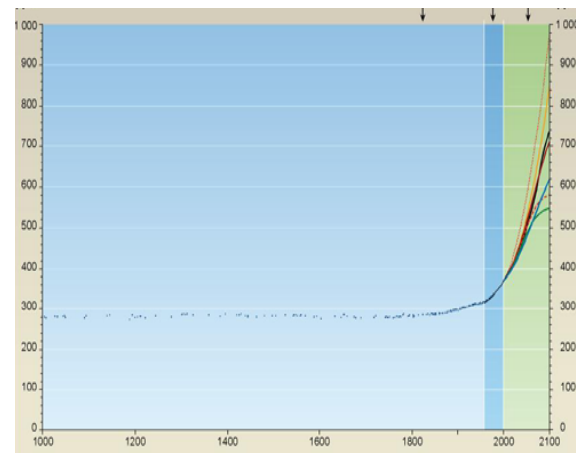


Climate Change may Restrict Carbon Dioxide Releases from Transportation

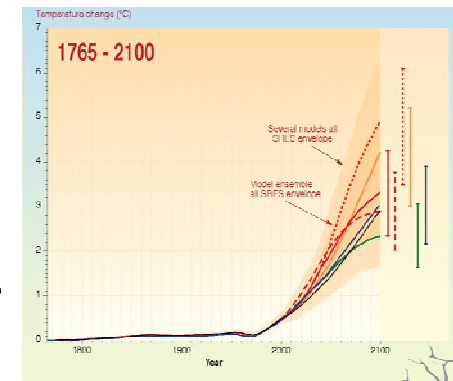
Carbon Emissions



CO₂ in Atmosphere



Global Warming



Global Economic Effects

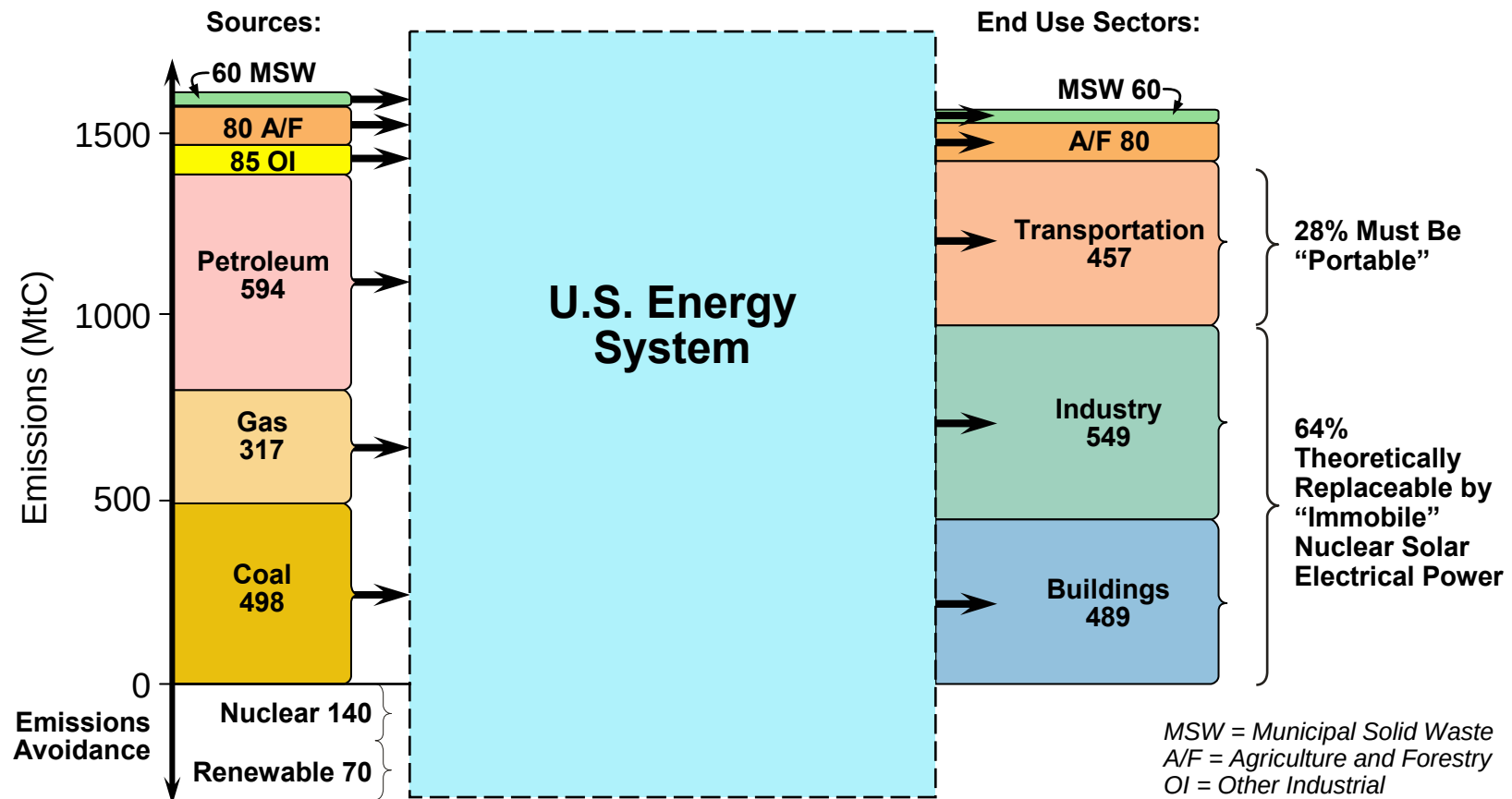
Source: Intergovernmental Panel on Climate Change

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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



(EIA, 2002)

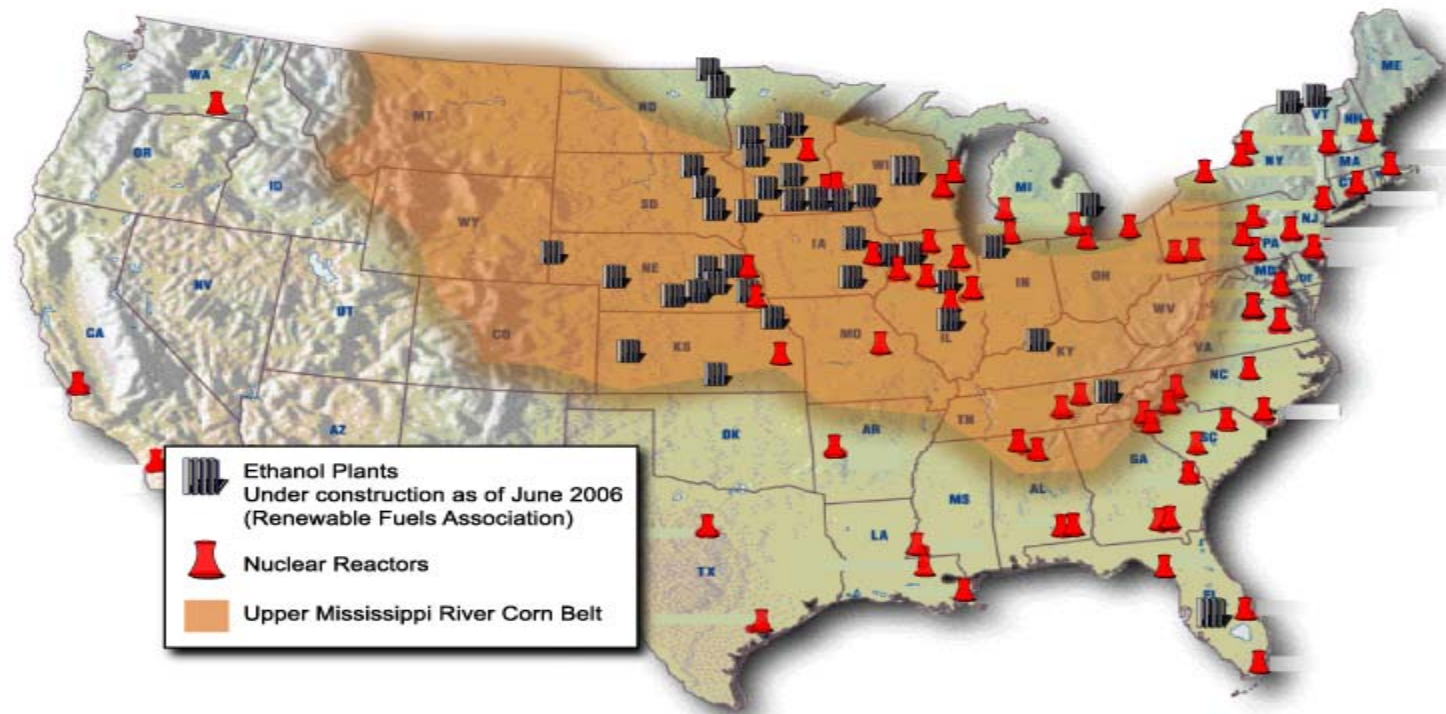
Newest Ethanol Plants Obtain Steam from Fossil Electric Plants



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

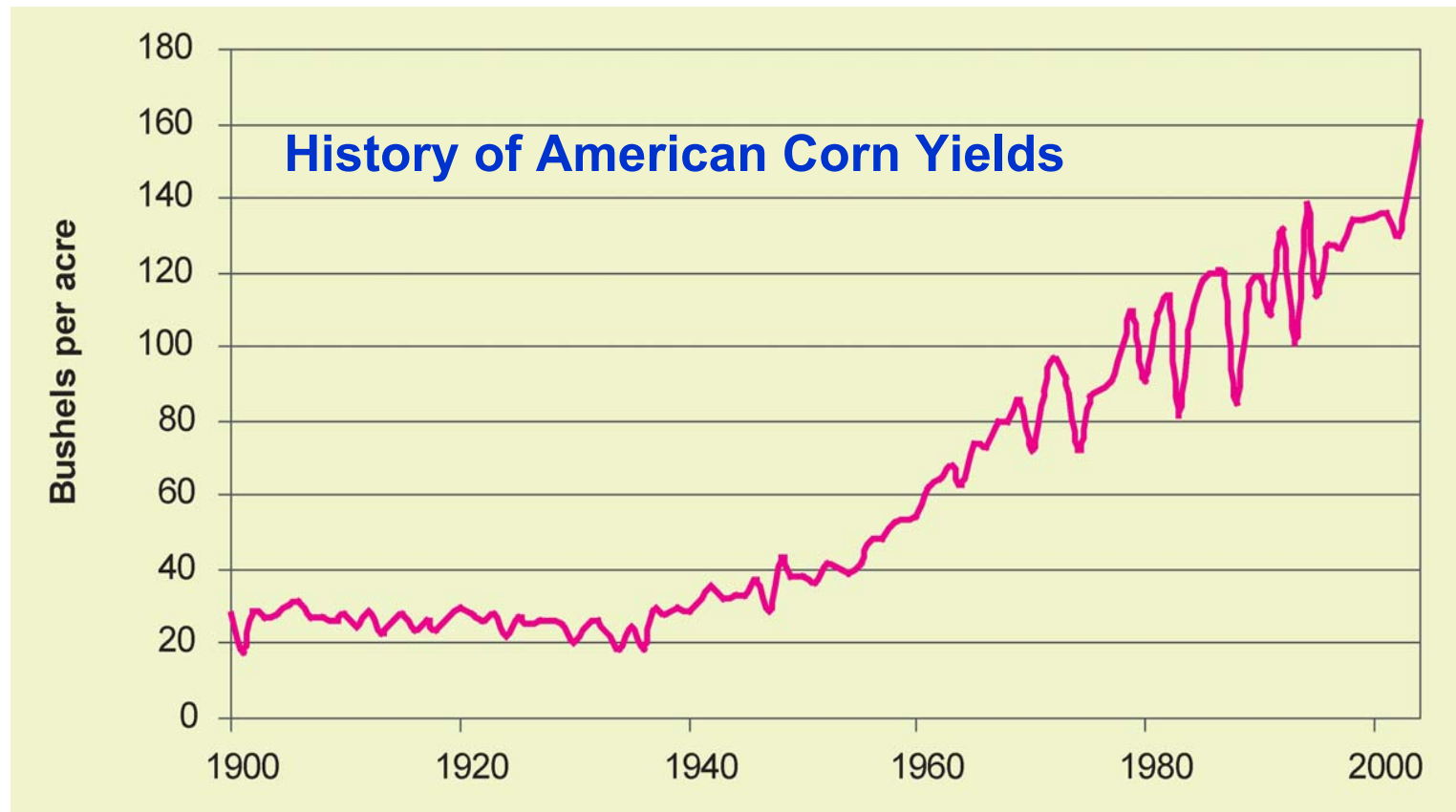
- **Oil provides 39% of U.S. energy**
- **World oil reserves dominated by four countries**
 - Saudi Arabia
 - Iraq
 - Iran
 - Kuwait
- **The U.S. could chose to get off oil**
 - U.S. is 39% dependent on oil versus France that was 90+% dependent on oil
 - Challenge about equal to the French decision to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

Energy Value of U.S. Biomass

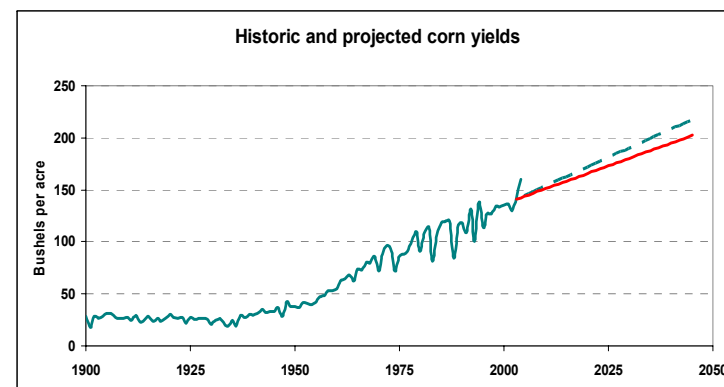
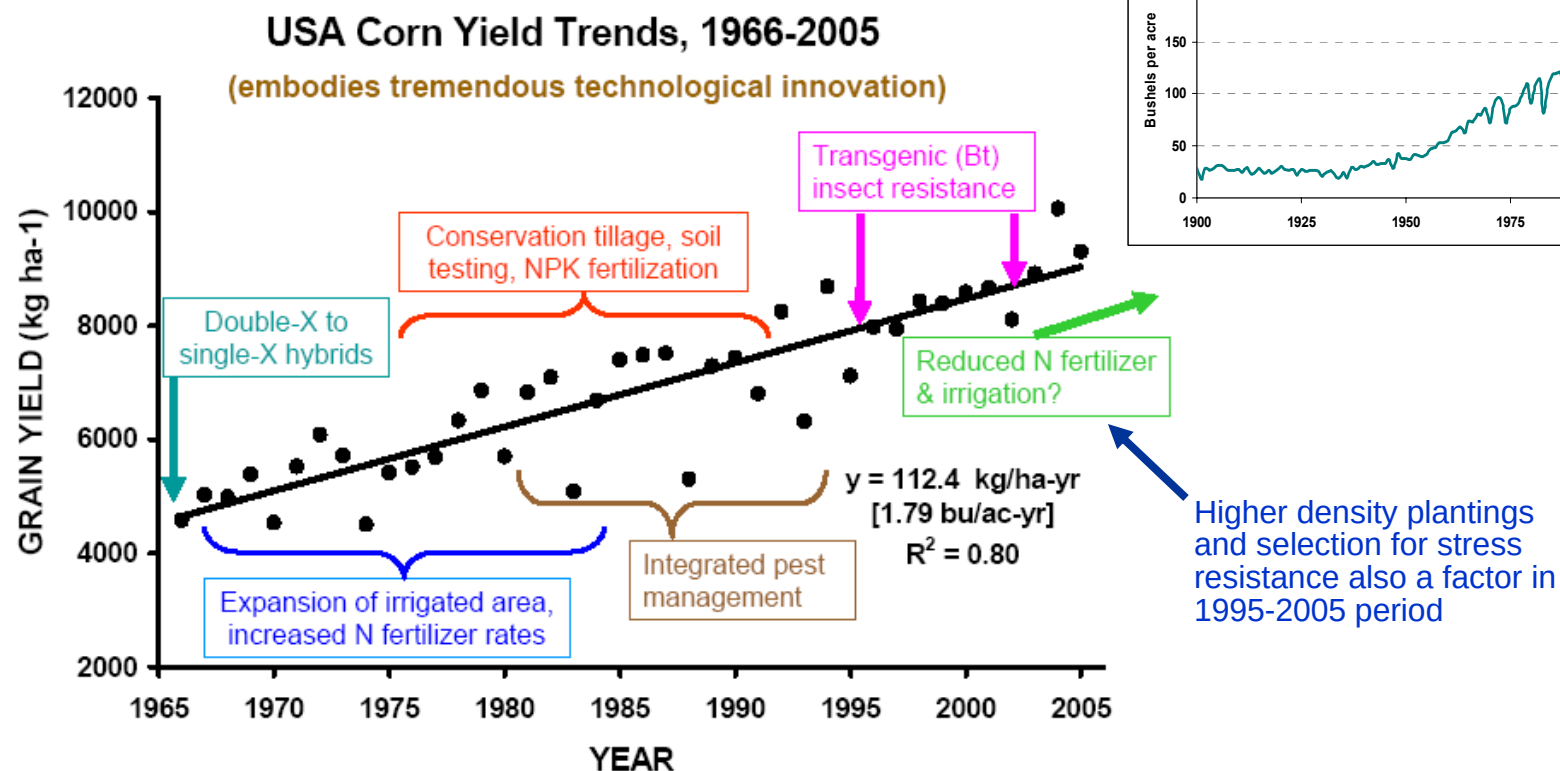
Measured in Equivalent Barrels of Diesel Fuel/Day*
from Harvesting 1.3 Billion Tons of Biomass/Year

- **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



Corn Yields Still Increasing



Source - W. Wilhelm, 2006