Fuel Ethanol Production Using Nuclear Plant Steam

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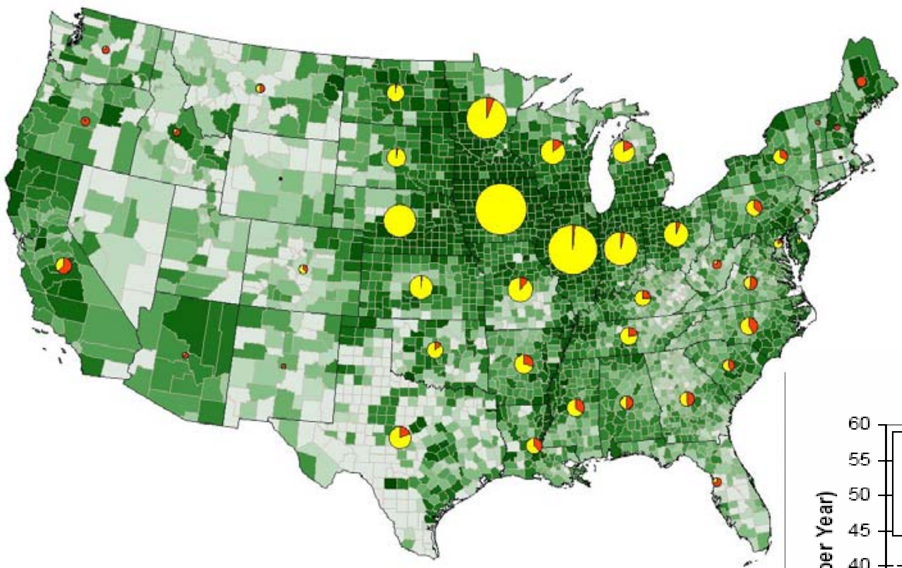
A Revolution in Biotechnology is Creating a Biofuels Industry

Corn to Fuel Ethanol is the First Step

Corn

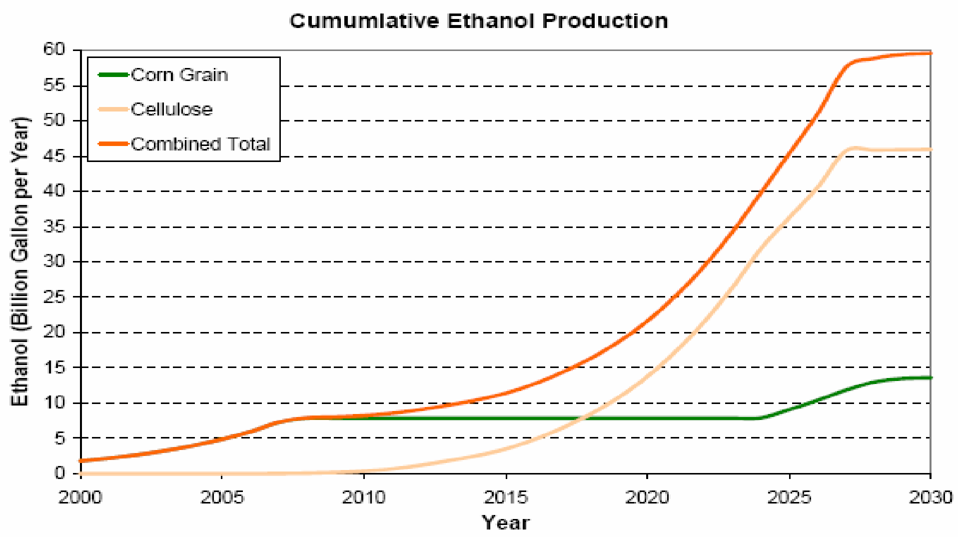
Corn to Ethanol

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**
- **Steam is one-half the nonsolar energy input in growing corn and converting it to fuel ethanol**
- **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)

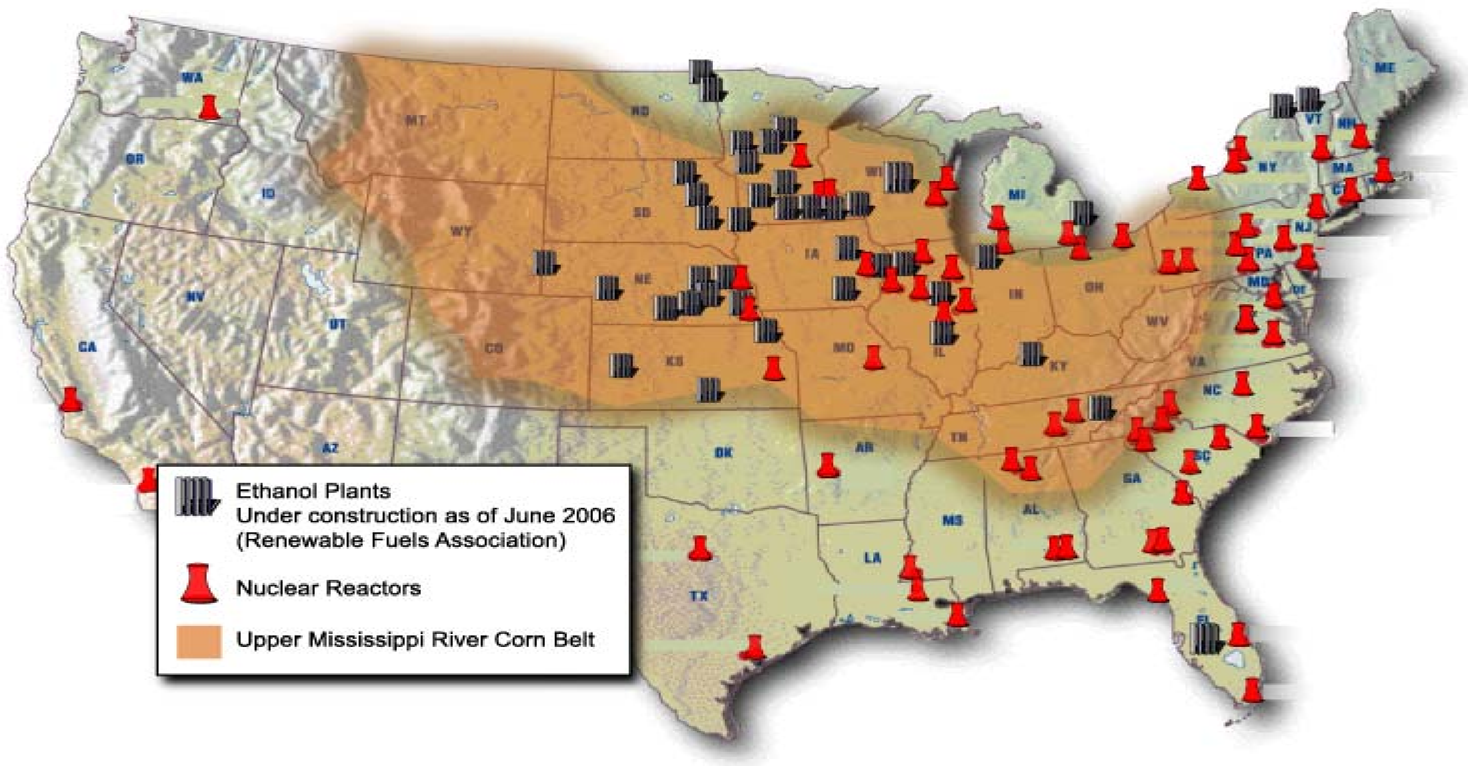
Incentives to Use Nuclear Energy to Produce Ethanol-Plant Steam

- **Environment: Net CO_2 emissions can be reduced by one-half per liter of fuel 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)**

Newest Ethanol Plants Obtain Steam from Fossil Electric Plants

Fuel Ethanol will be a Megamarket for Low-Pressure Steam [100+ GW(t)]

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?

Conclusions

A Revolution in Biotechnology will Allow Most Types of Biomass to be Converted to Fuel Ethanol

Ethanol and Most Other Bioprocessing Technologies Require Massive Amounts of Low-Temperature Steam

For the First Time, a Large Potential Worldwide Nuclear-Steam Market Exists Where Nuclear Plants are Located

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. After working for Bechtel Corporation, he joined the staff of Oak Ridge National Laboratory, where he is presently the Senior Reactor Technical Advisor. Dr. Forsberg has been awarded 10 patents and has published over 200 papers in advanced energy systems, waste management, and hydrogen futures.

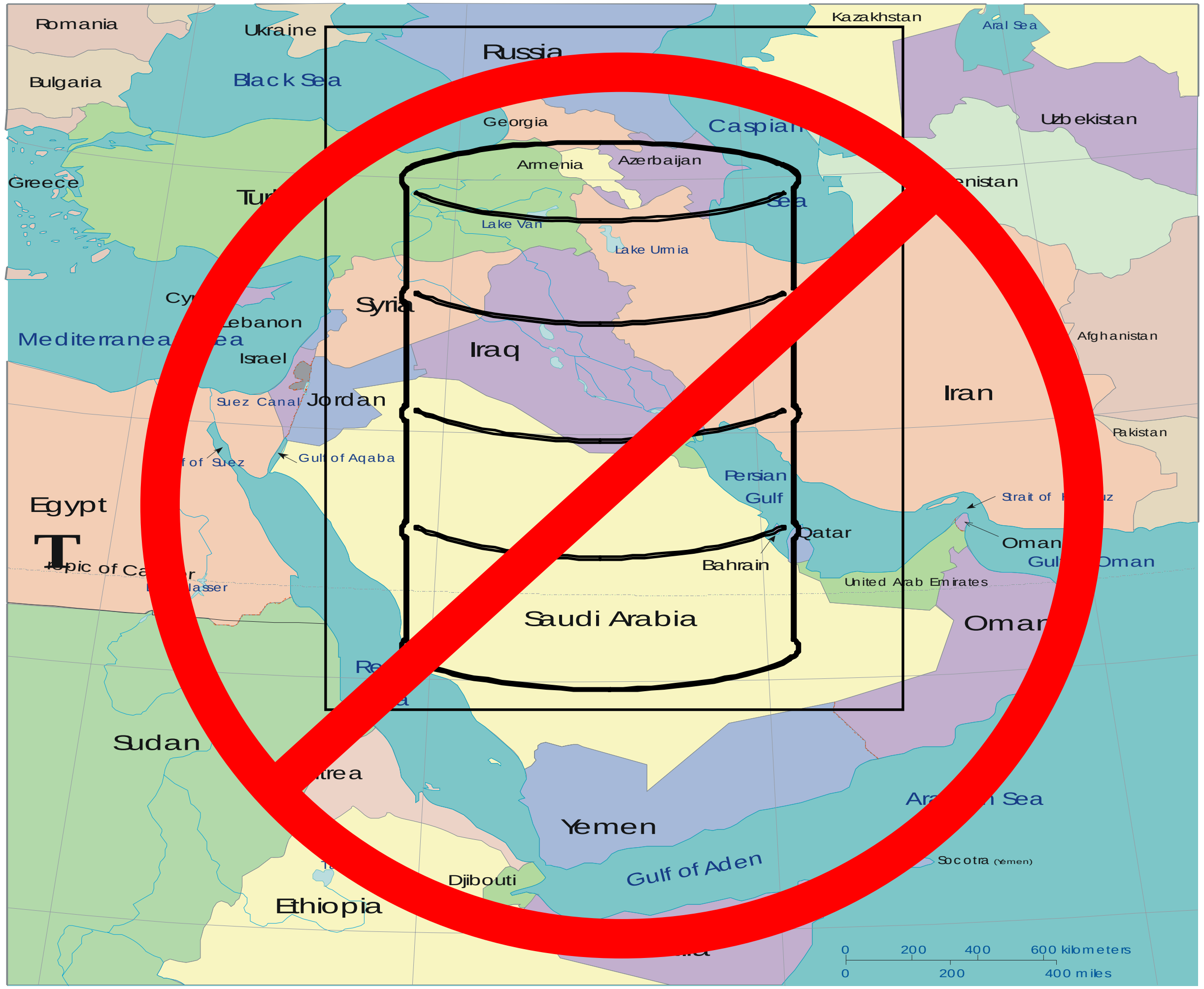
Abstract: Fuel Ethanol Production Using Nuclear Plant Steam

In the United States, the production of fuel ethanol from corn for cars and light trucks has increased from about 1.6 billion gallons per year in 2000 to 5 billion gallons per year in 2006. It is projected that by 2030 up to 30% of the liquid fuels consumed in the United States could be made from biomass with an ultimate production capability twice as large. Long-term studies indicate that biofuels could provide about 30% of the global demand in an environmentally acceptable way without impacting food production. Rapid expansion of liquid fuels production from biomass is predicted for many other parts of the world as well. Sugarcane and corn are the primary feedstocks today, but future plants are expected to also use abundant cellulose. The rapid growth in biomass-to-ethanol plants is a result of three factors: new biotechnologies that are dramatically improving the economics; increased concern about global warming, which generates renewed interest in renewable liquid fuels; and the high cost of oil.

The production of fuel ethanol from biomass requires large quantities of steam. For a large ethanol plant producing 100 million gallons of fuel ethanol from corn per year, about 80 MW(t) of 150-psi (~180ºC) steam is required. Within several decades, the steam demand for ethanol plants in the United States is projected to be tens of gigawatts, with the worldwide demand being several times larger.

There are strong incentives to use steam from nuclear power plants to meet this requirement. The cost of low-pressure steam from nuclear power plants is less than that of natural gas, which is now used to make steam in corn-to-ethanol plants. The use of steam from nuclear power plants reduces greenhouse gases compared with the generation of steam from fossil fuels. Last, in cellulose-to-ethanol plants, the liquid fuel produced per unit of biomass can be substantially increased if the ethanol plants also have the capability to convert lignin to liquid fuels. Lignin is the primary non-sugar-based component in cellulosic biomass that cannot be converted to ethanol. It is planned to use this lignin as boiler fuel in these ethanol plants. However, if there are other sources of steam it may be feasible to also convert the lignin to liquid fuels and thus increase the yield of liquid fuels per unit of cellulosic biomass. In several decades, this may become the largest market for cogeneration of steam from nuclear-electric power plants.

Fuel Ethanol Incentive: Get Off Oil



Fuel-Ethanol Incentive: Reduce Greenhouse Impacts

Athabasca Glacier, Jasper National Park, Alberta, Canada

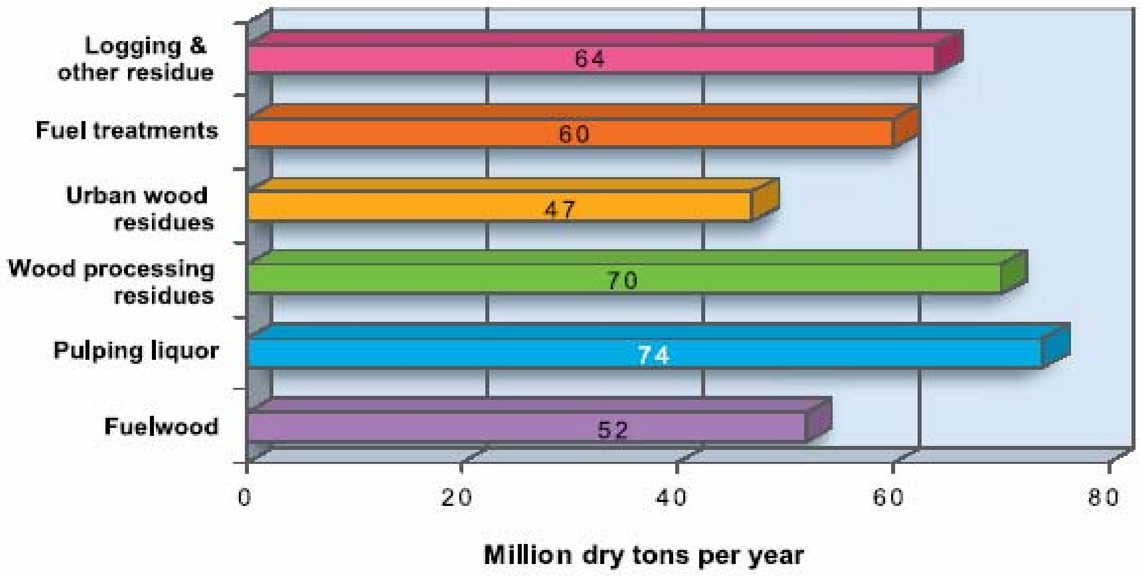
Photo provided by the National Snow and Ice Data Center

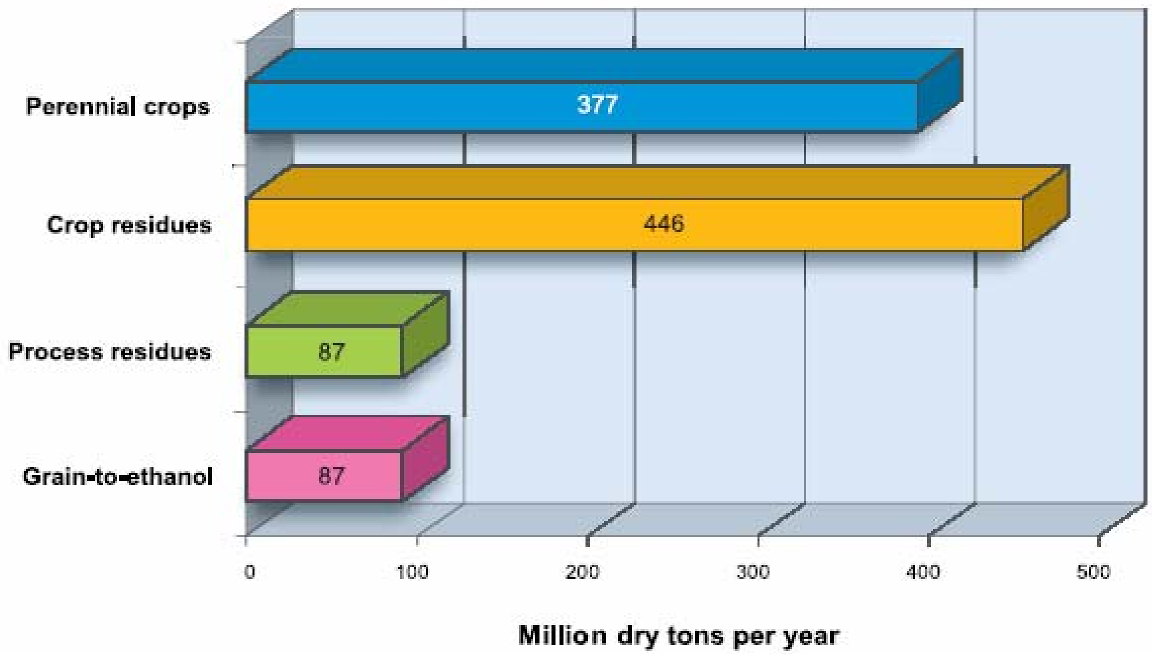
In the United States, Existing Nuclear Plants can Provide Low-Cost Steam at One-Half the Price of Natural Gas

Ethanol Plant

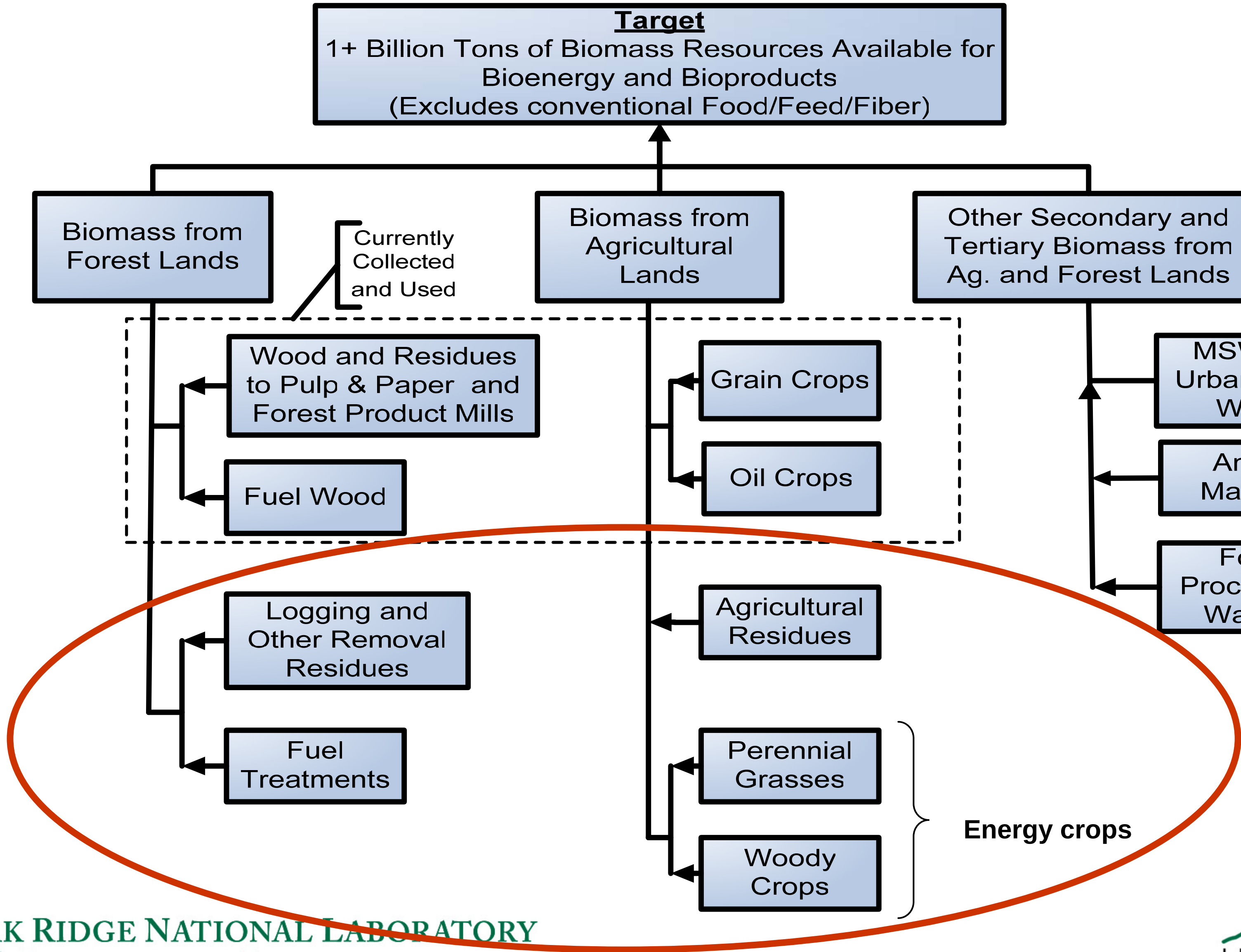
Distillation: The Energy-Intensive Step

U.S. Biomass-to-Ethanol Resource Base





The U.S. Biomass Resource Base



Biorefinery Deployment Pathways

Pathways are tied to the resource base and existing industry market segments