A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

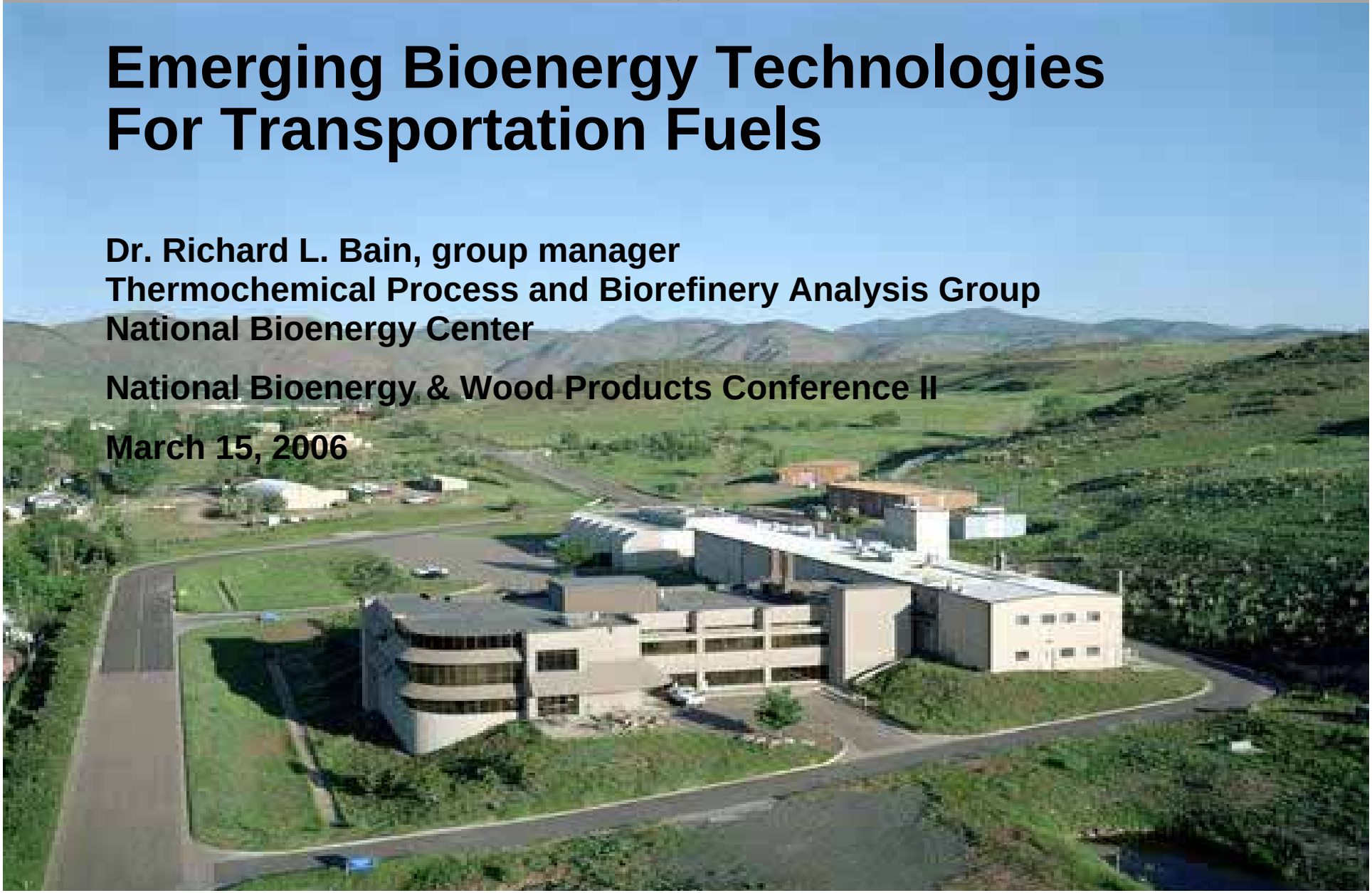
Innovation for Our Energy Future

Emerging Bioenergy Technologies For Transportation Fuels

Dr. Richard L. Bain, group manager
Thermochemical Process and Biorefinery Analysis Group
National Bioenergy Center

National Bioenergy & Wood Products Conference II

March 15, 2006



National Bioenergy Center

Sponsored by DOE - EERE Office of the Biomass Program

Purpose:

- Help achieve DOE goals:
  - Reduce U.S. dependence oil
  - Build U.S. bioenergy industry
  - Reduce global warming
- Provide one-stop shopping for DOE's industrial partners
- Coordinate multi-year planning and execution of R&D at all DOE Labs
- Fully leverage tax-payer investment in federal facilities

"Virtual Center" created to improve DOE Lab collaboration in bioenergy research

NREL

ARGONNE NATIONAL LABORATORY
OPERATED BY THE UNIVERSITY OF CHICAGO

INEEL
Home of Science and Engineering Solutions

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

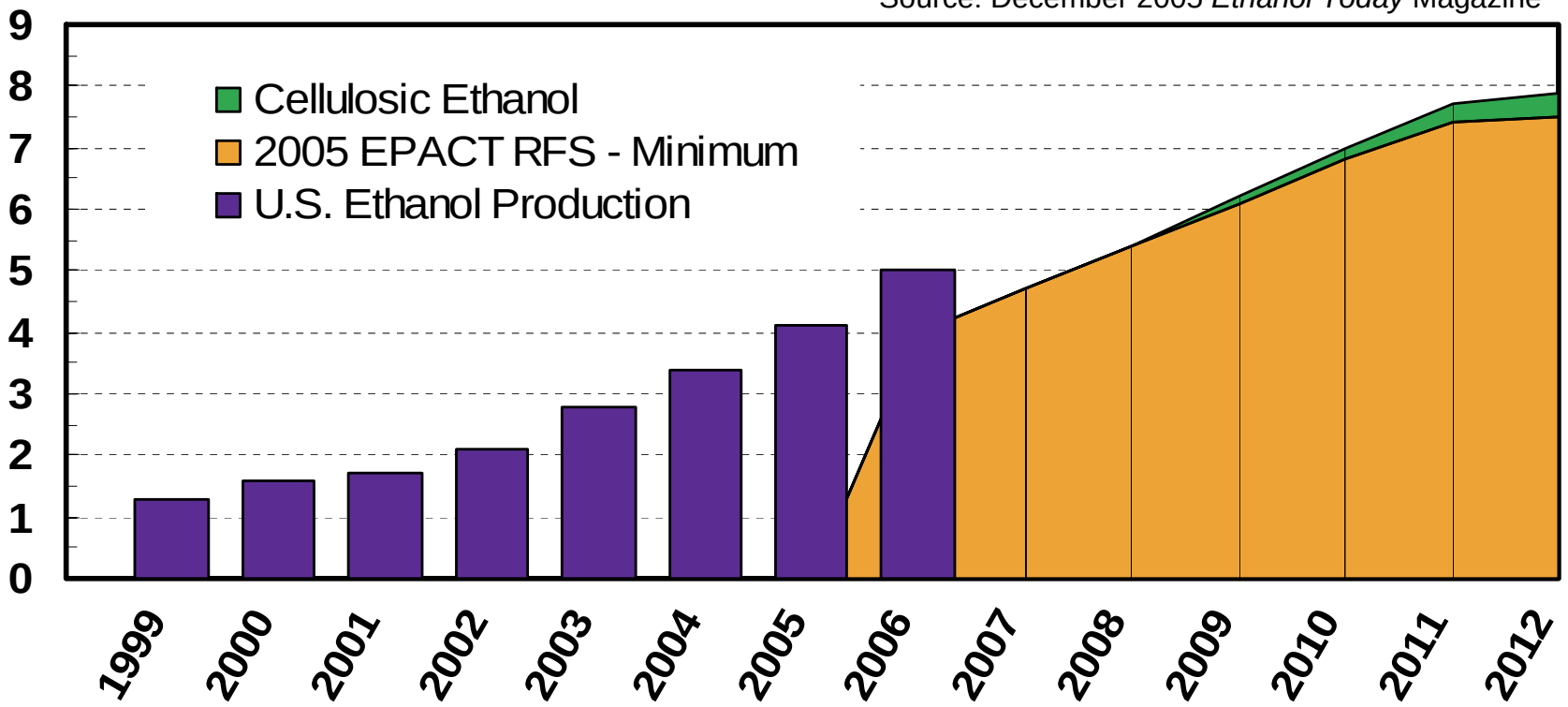
OAK RIDGE NATIONAL LABORATORY

Ethanol Production

Actual and Projected U.S. Ethanol Production 1999-2012

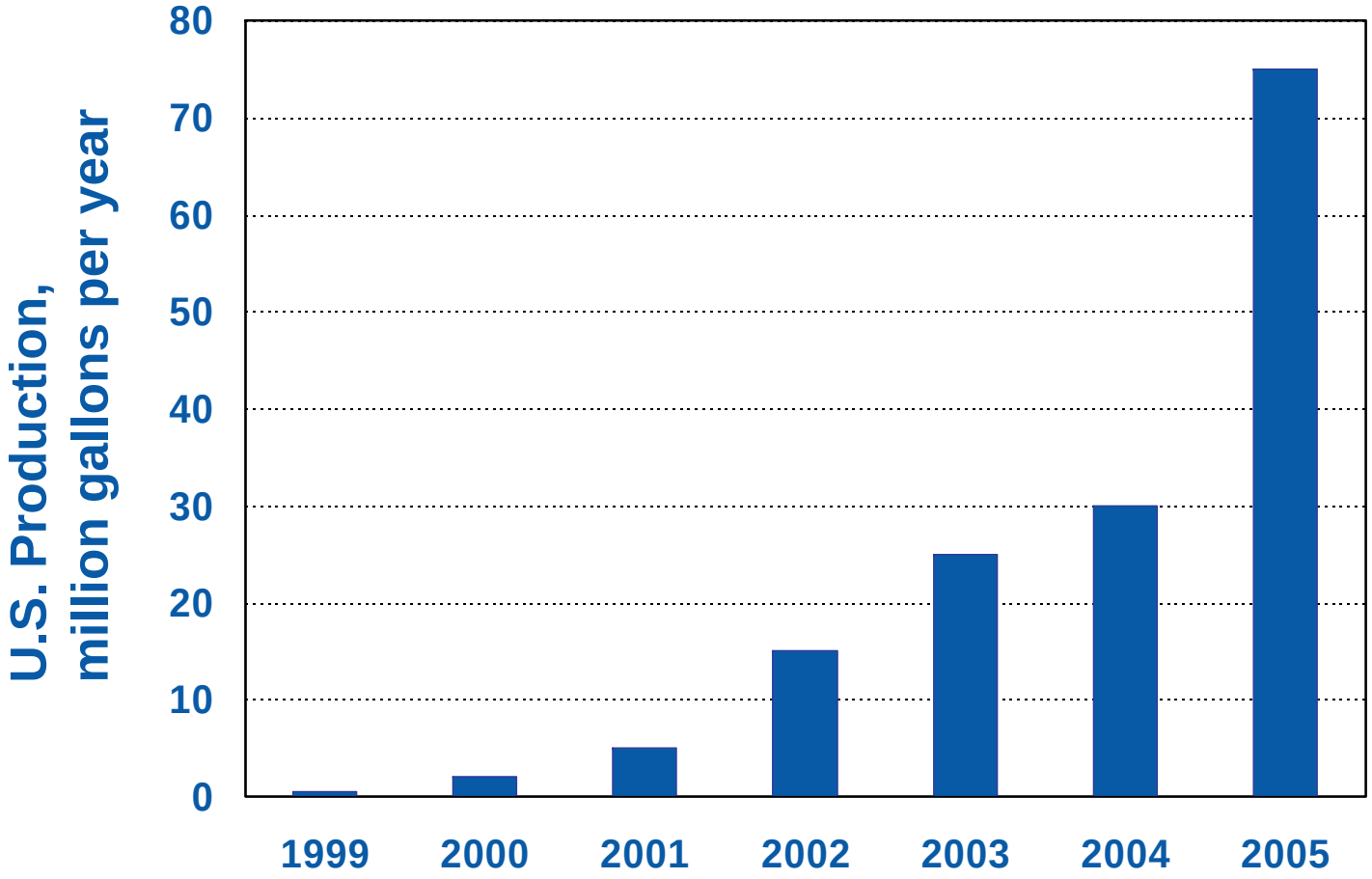
Billion Gallons of Production

Source: December 2005 *Ethanol Today* Magazine



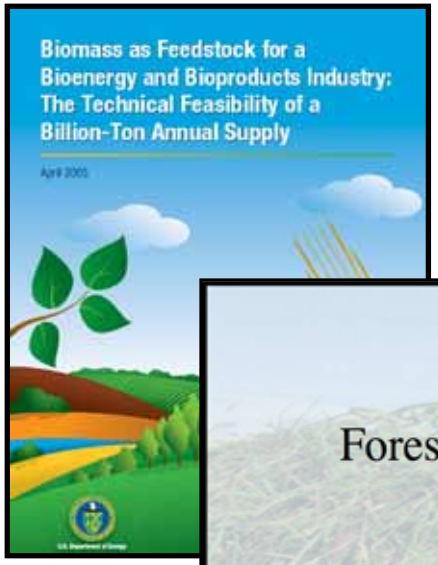
- Renewable Fuels Standard mandates 7.5 billion gallons by 2012
- Total US gasoline market ~140 billion annual gallons

U.S. Biodiesel Production

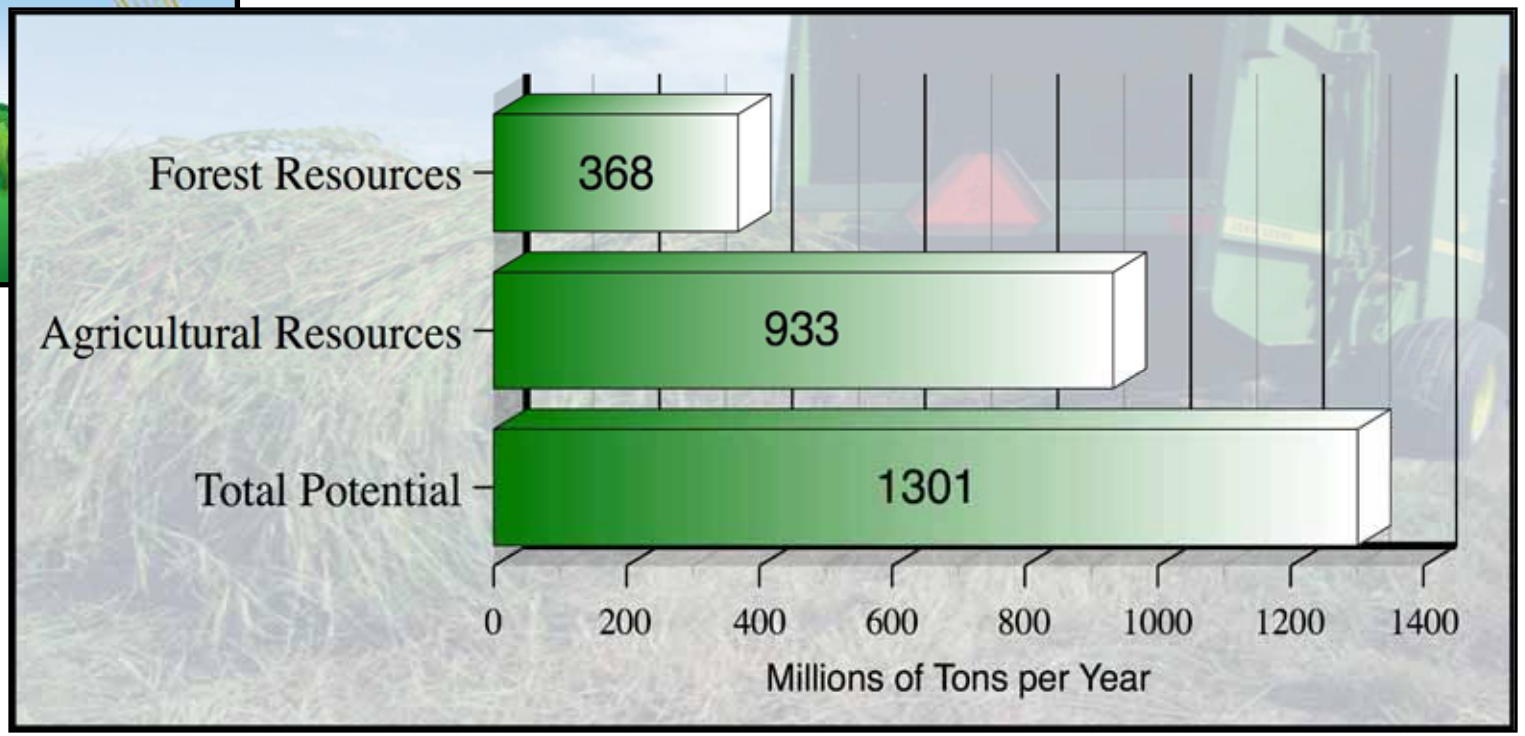


Total US distillate fuels market is approximately 60 billion gallons per year

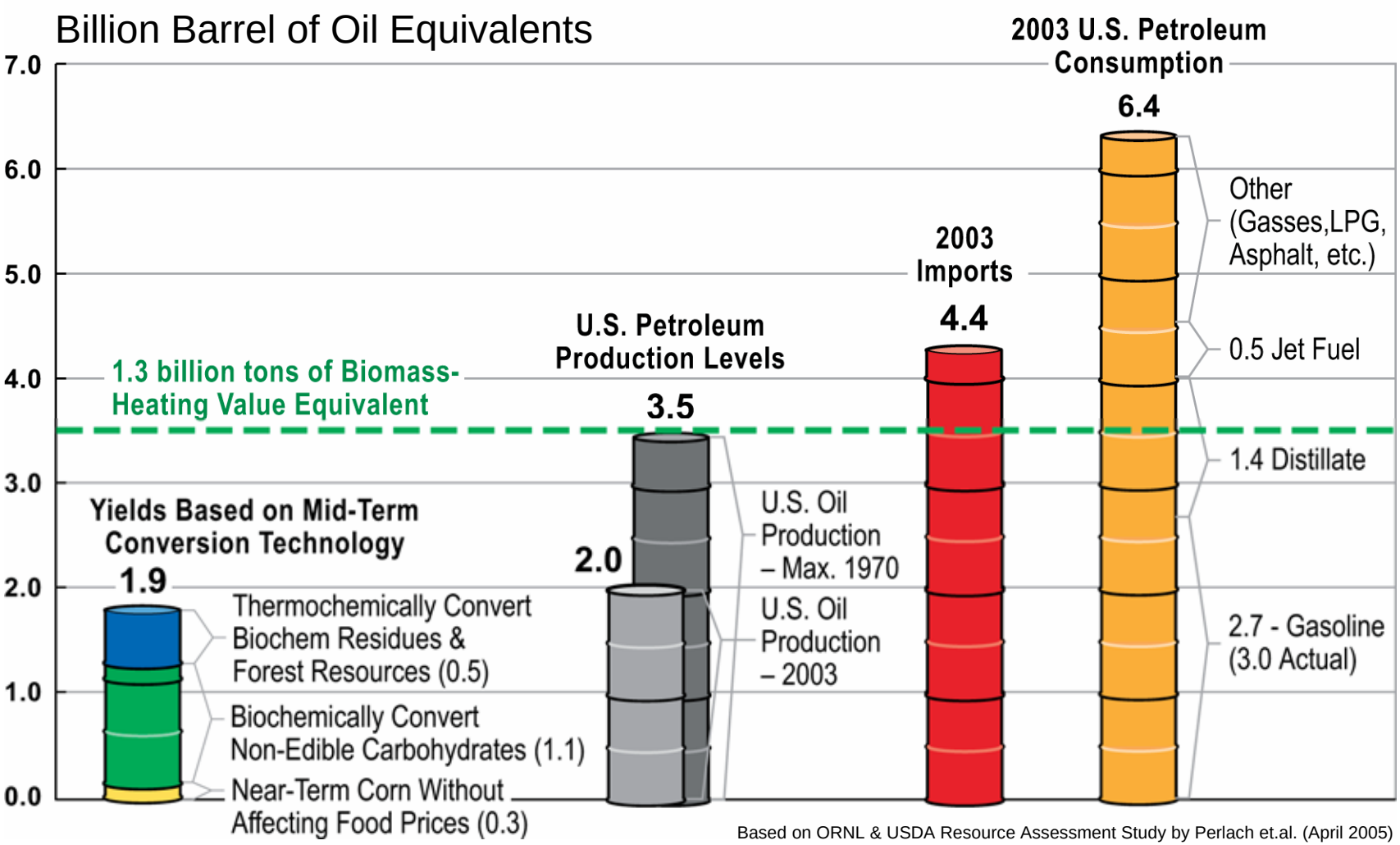
U.S. Biomass Resource Assessment



- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the “Billion Ton Study”



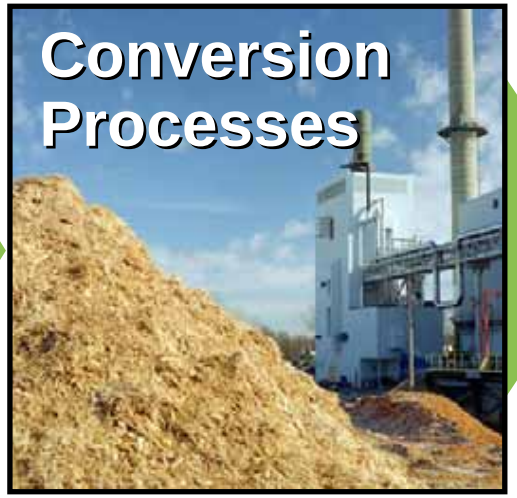
The 1.3 Billion Ton Biomass Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Range of Biorefinery Concepts

- Trees
- Grasses
- Agricultural crops
- Residues
- Animal wastes
- Municipal solid waste



- Enzymatic fermentation
- Gas/liquid fermentation
- Acid hydrolysis/ fermentation
- Gasification
- Combustion
- Co-firing
- Pyrolysis

Uses

Fuels
- Ethanol
- Renewable diesel
- Renewable gasoline

Power
- Electricity
- Heat

Chemicals
- Plastics
- Solvents
- Chemical intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty acids
- Acetic acid
- Carbon black
- Paints
- Dyes, pigments, and ink
- Detergents

Food and Feed

Ethanol

- Ethanol industry at 4 billion gal/yr based on corn starch
- Corn mills investing in process improvements and higher value products
  - ADM
  - Broin
  - Abengoa

Chemical industry investing in higher value products from glucose

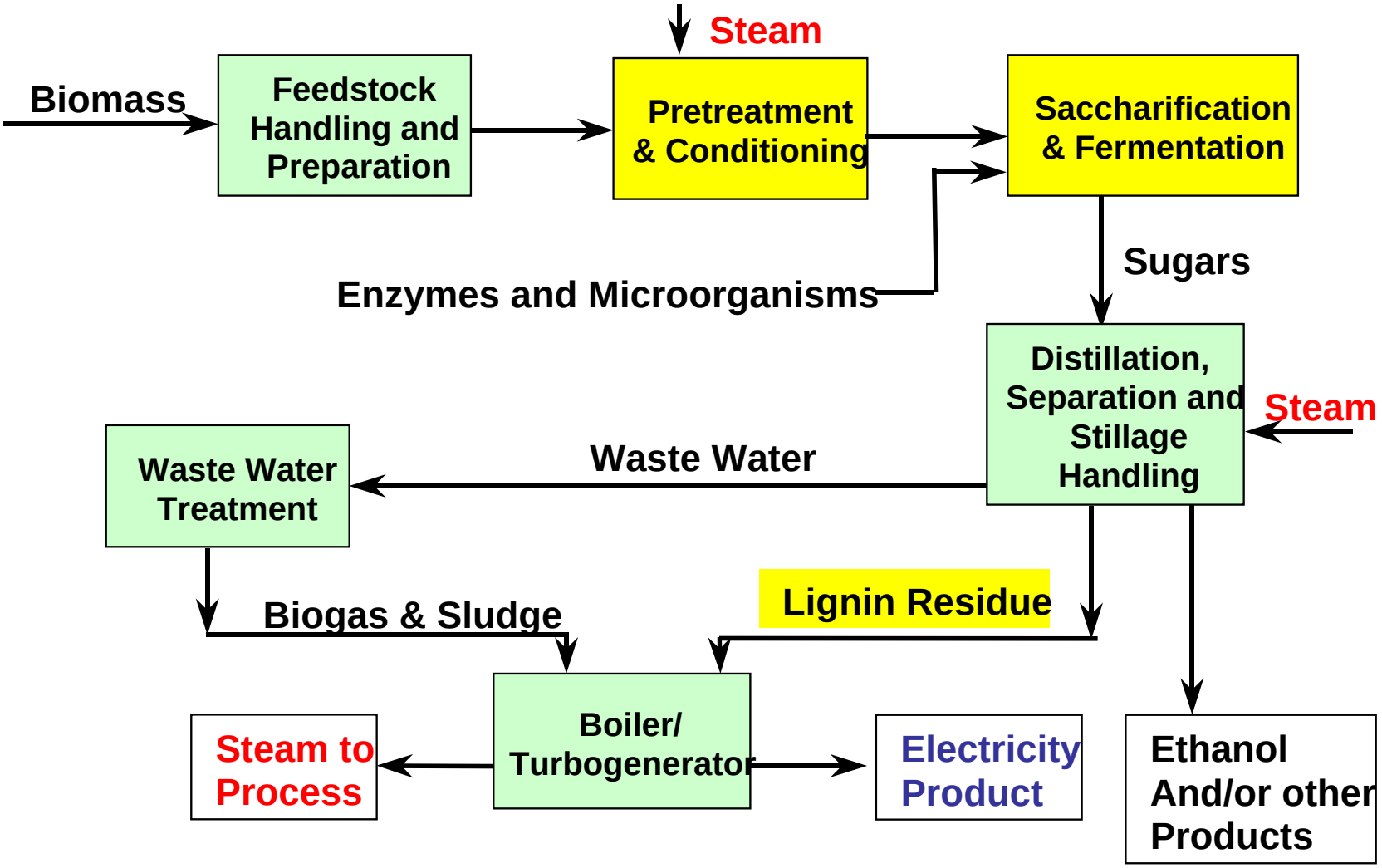
- NatureWorks LLC
- duPont

Both corn ethanol and chemical industries are investigating biomass to extended sugar resources

Shell investing in biomass ethanol technology (Iogen, Canada)

Cargill Dow Dedicates PLA Refinery April 2002

Ethanol Production



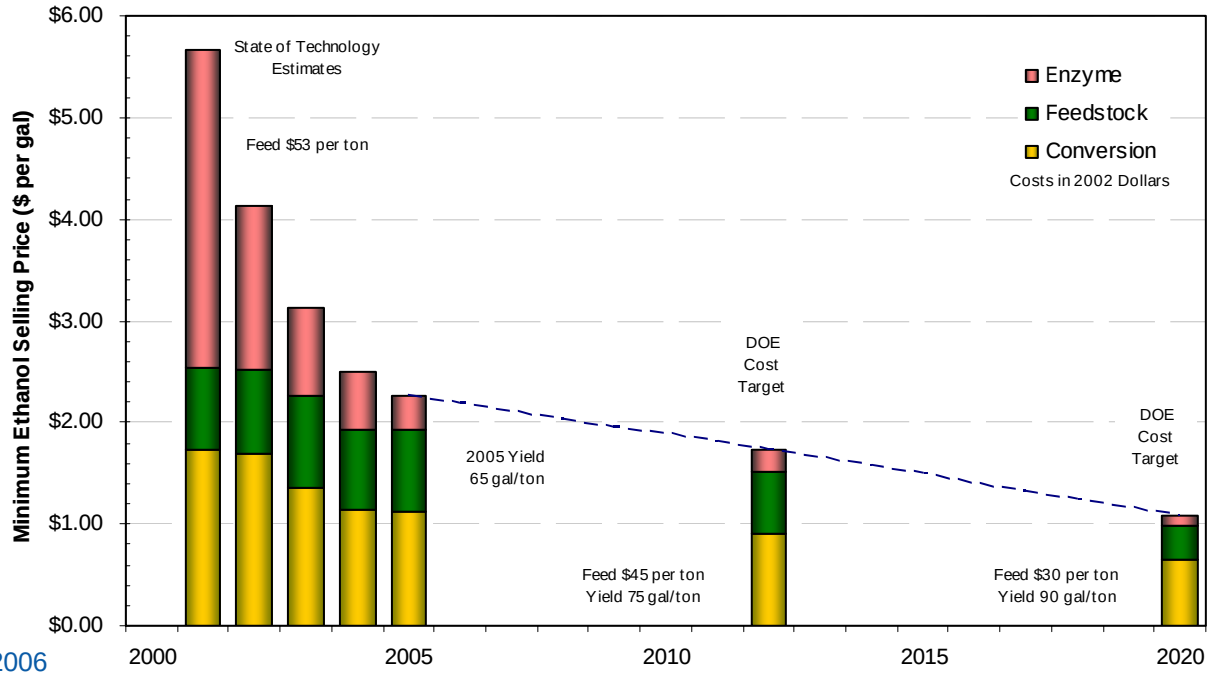
Cost Goals – Ethanol from Lignocellulosic Biomass

Mid-term:

- Ethanol from lignocellulosic agricultural residues (e.g.. corn stover)
  - •$1.07/gal by 2020 (Accelerated Case - 2012)
  - • Competitive with starch-based ethanol

Long term:

- Production Cost $0.59/gal by 2030 (Accelerated Case – 2020)

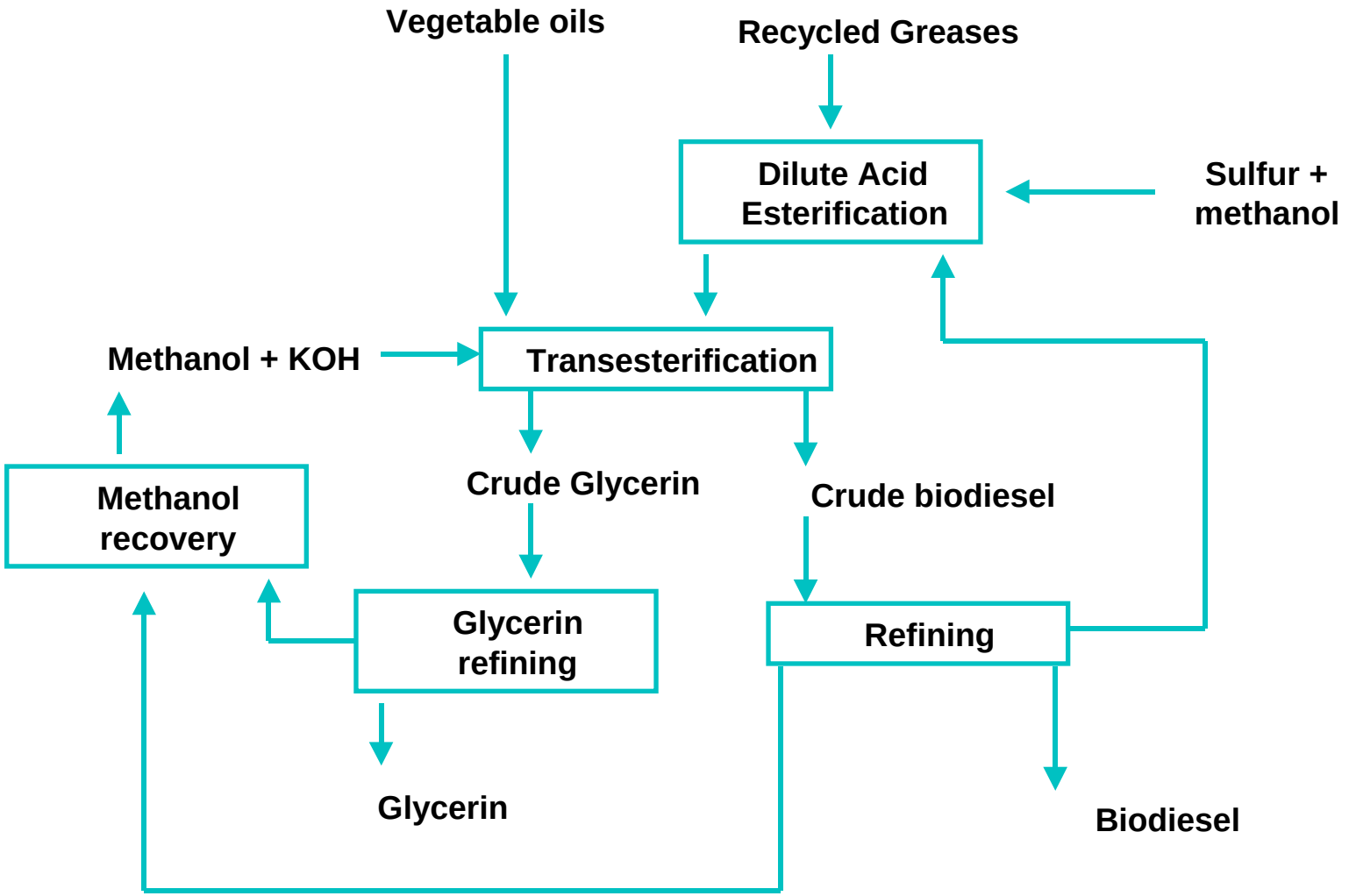


Biodiesel

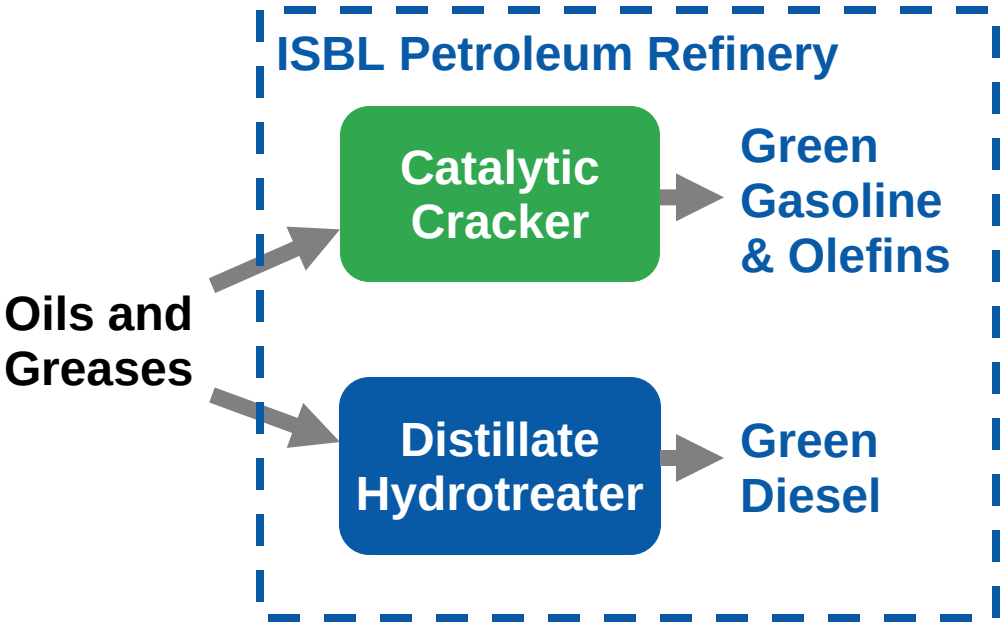
Griffin Industries, USA and
Bruck Industries, Austria

Sep 2004: 60 Mil gal/yr dedicated capacity in U.S.

Biodiesel - Basic Technology



Oils, Fats & Greases as Bio-renewable Petroleum Refinery Feedstocks



- **Co-processing of oils and greases with petroleum fractions**
- **Utilize existing process capacity**
- **Potential for lower conversion costs (than FAME)**
- **Higher quality diesel blending component**
- **G/D flexibility**

Based on Presentations at 1st International Biorefinery Workshop, Washington DC, July 20-21, 2005

- ***Future Energy for Mobility***, James Simnick, **BP**
- ***From Bioblending to Biorefining***, Veronique Hervouet, **Total**
- ***Opportunities for Biorenewables in Petroleum Refineries***, Jennifer Holmgren, **UOP**

Green Diesel and Biodiesel Yields

Feed	Biodiesel	Green Diesel
% Oil or Grease	100	100
% H2		1.5-3.8
% methanol	8.7	
Products		
% water,C02		12-16
% Lt HC		2-5
% diesel	96	83-86
% glycerol	12	
Operating cost $/gal	.05	.025

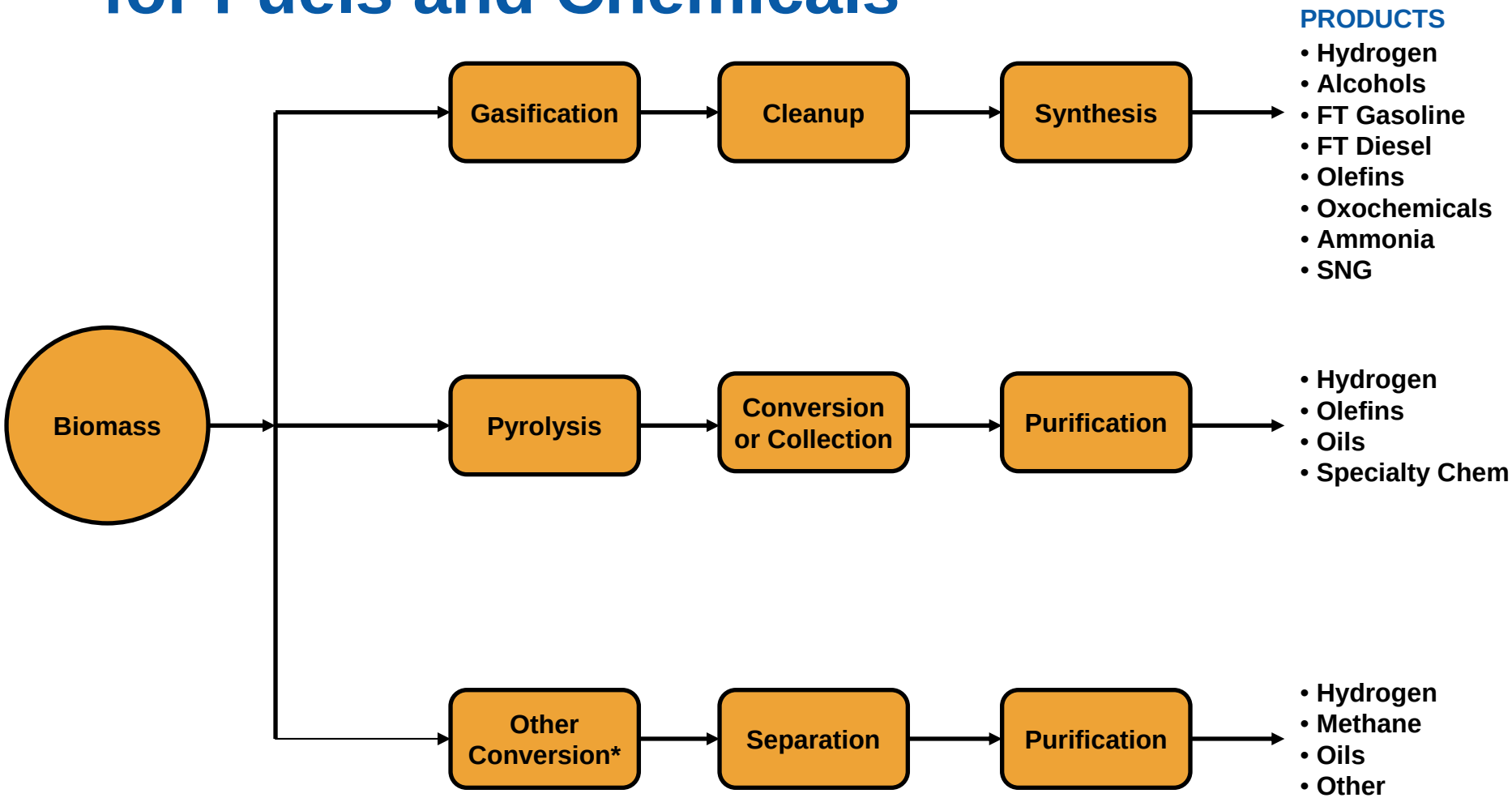
Marinangeli, R., et.al. (2005). "Opportunities for Biorenewables in Oil Refineries: Final Technical Report," UOP, Des Plaines, IL; DOE Report No. DE-FG36-05GO15085.

Diesel Properties

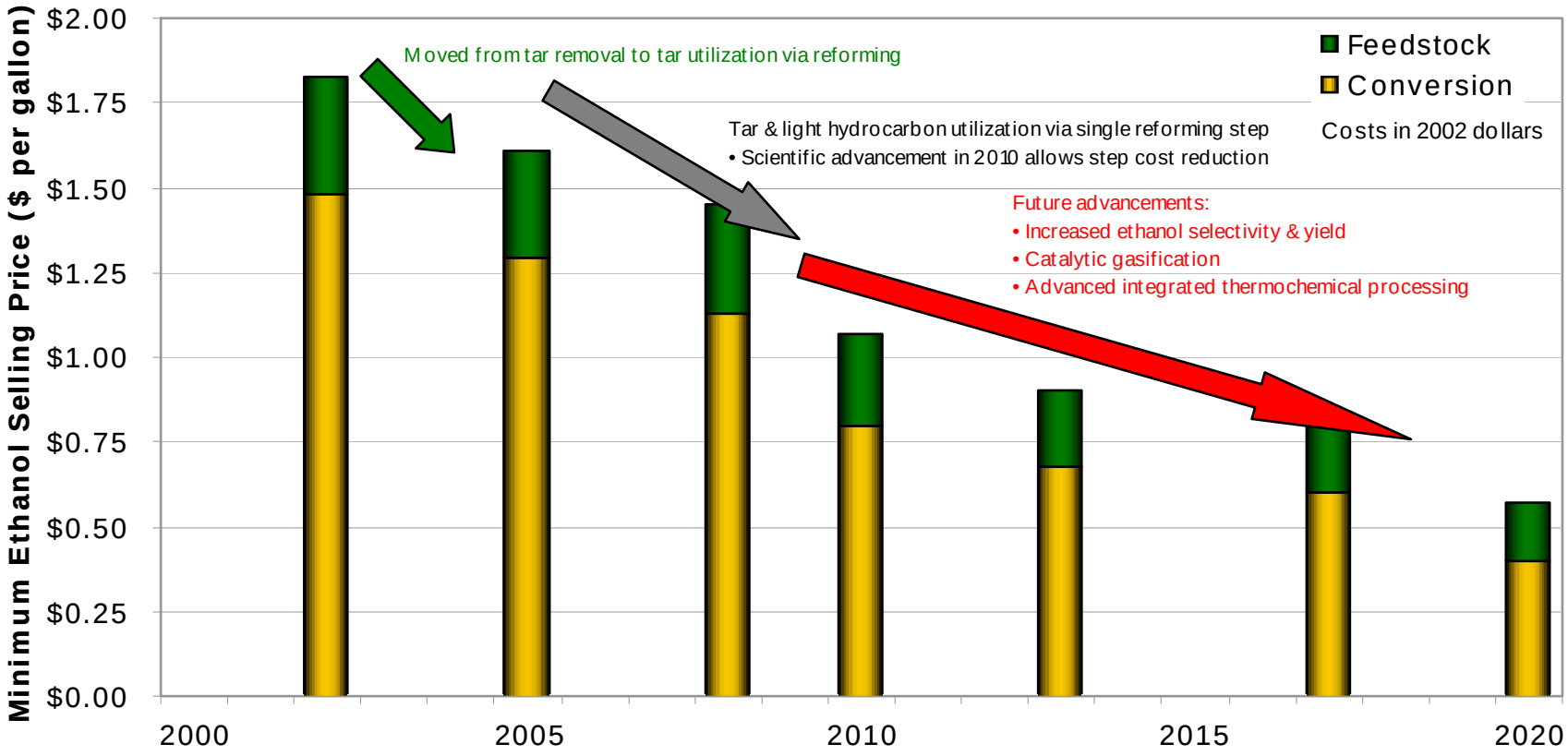
	Biodiesel (FAME)	Green Diesel
% Oxygen	11	0
Density g/ml	.883	.78
Sulfur content	<10ppm	<10ppm
Heating Value (lower) MJ/kg	38	44
% change in NOx emission	0 to +10	0 to -10
Cloud Point °C	-5	-5 to -30
Distillation 10-90% pt	340-355	265-320
Cetane	50	80-90

Marinangeli, R., et.al. (2005). "Opportunities for Biorenewables in Oil Refineries: Final Technical Report," UOP, Des Plaines, IL; DOE Report No. DE-FG36-05GO15085

Biomass Thermochemical Conversion for Fuels and Chemicals



Ethanol From Thermochemical Mixed Alcohols



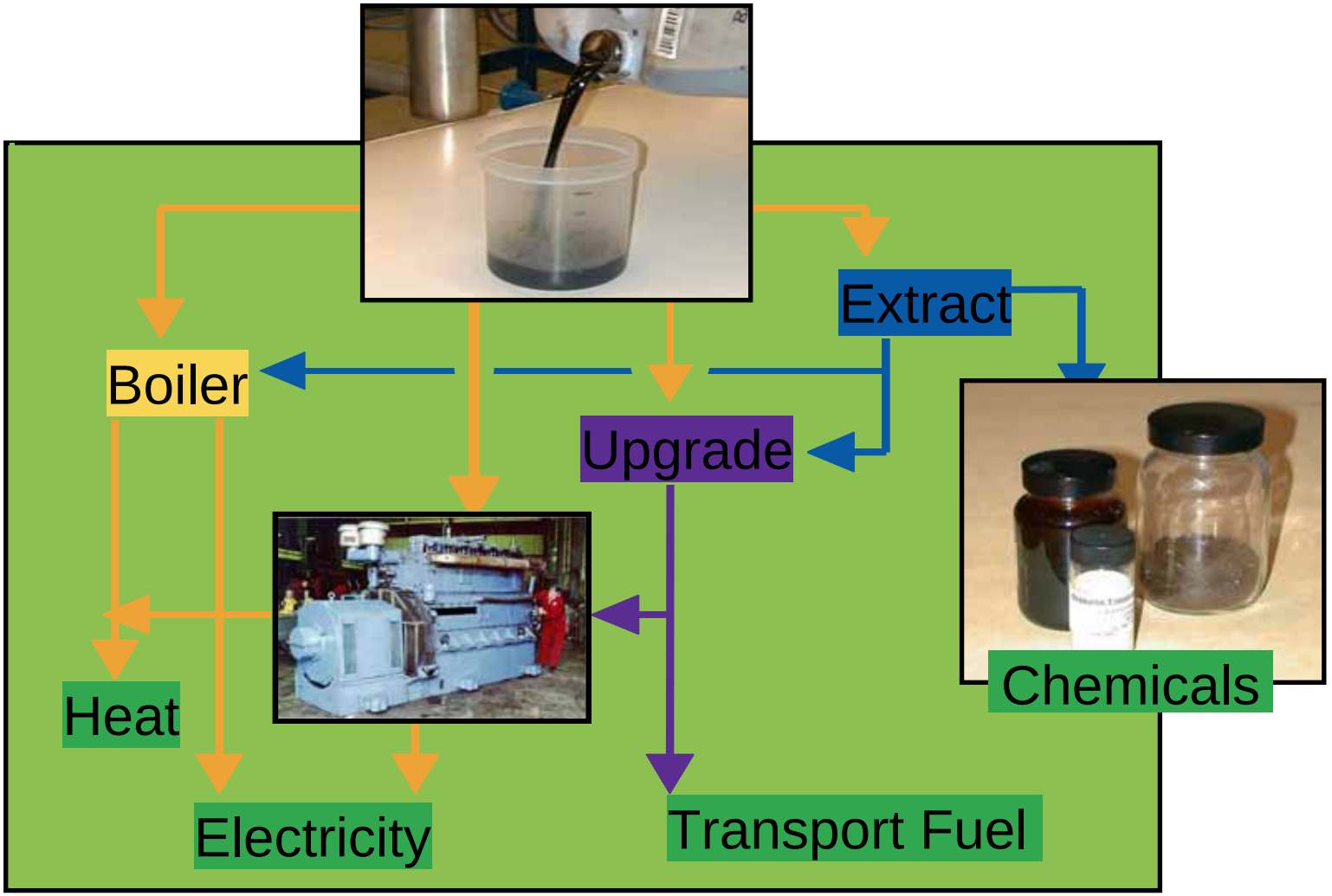
Fast Pyrolysis of Biomass

Fast pyrolysis is a thermal process that rapidly heats biomass to a carefully controlled temperature (~500°C) and then very quickly (<2 sec) cools the volatile products formed in the reactor.

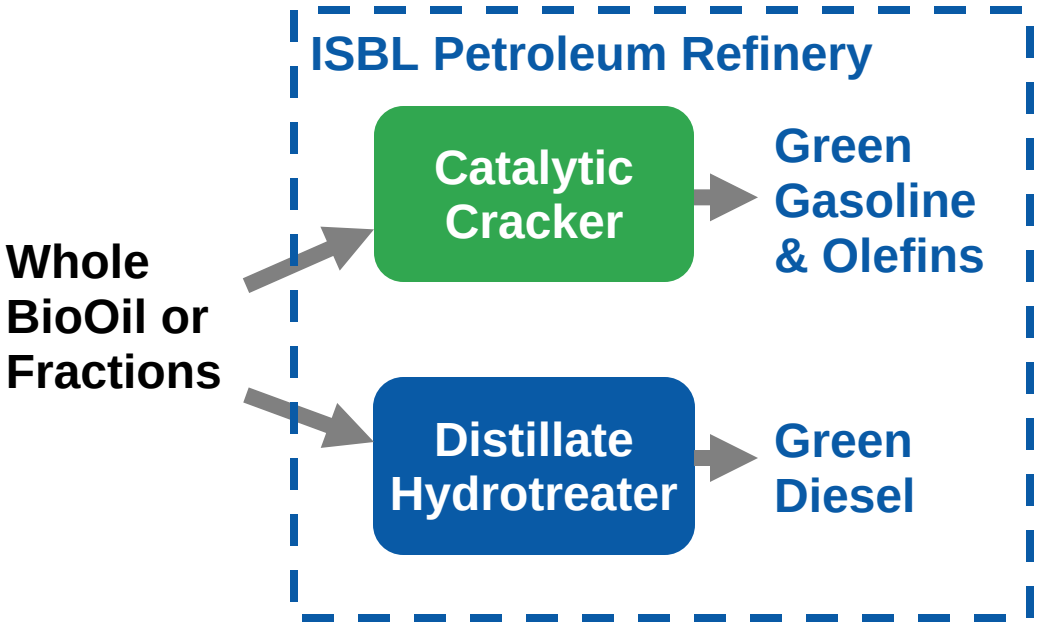
Fast pyrolysis:

- Offers the unique advantage of producing a liquid that can be stored and transported
- Has been developed in many configurations
- At present is at relatively early stage of development.

Applications of Bio Oils



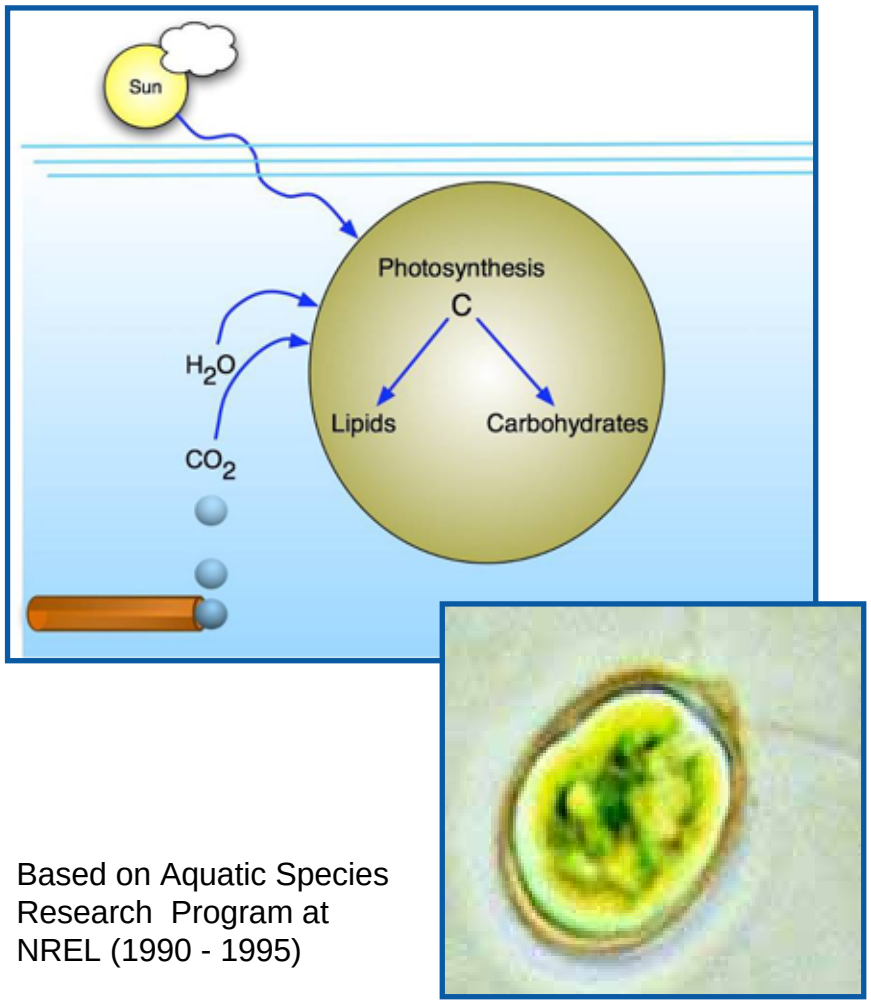
Bio-oil Processing Scenarios



- **Must reduce acidity, improve stability and bio-oil miscibility with petroleum**
- **Deoxygenation may be required on either side of battery limits**
- **Fractionation could be beneficial, and may be performed outside the petroleum refinery**
- **Other processing options exist ISBL of the petroleum refinery**

Based on UOP/NREL/PNNL R&D Project DOE-FG36-05GO15085 (2004 - 2005), and Colin Schaverien's (Shell) Biorefining presentation at 1st International Biorefinery Workshop, July 20-21, 2005, Washington D.C.

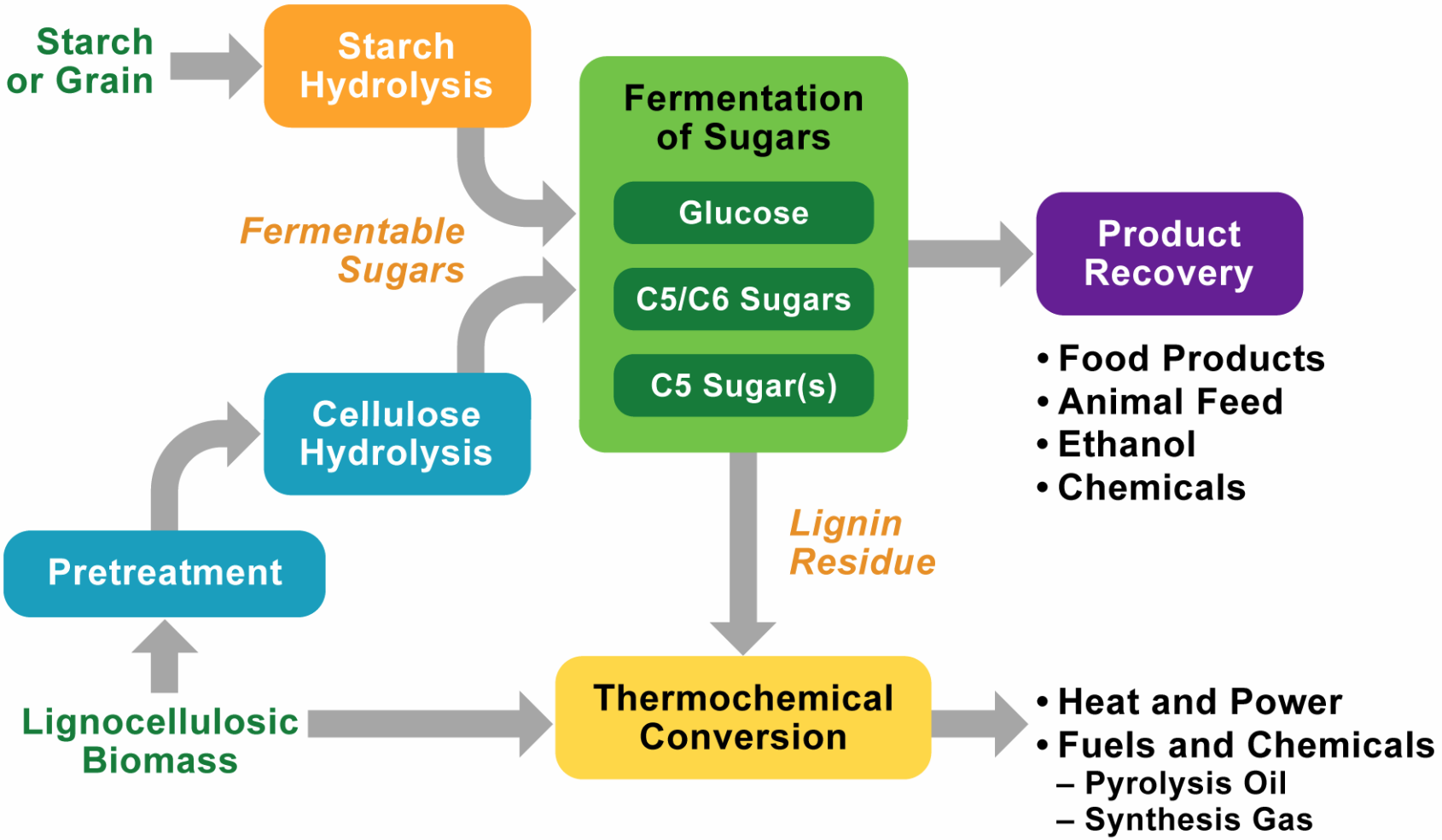
Algae as a Source of Biofuels



Based on Aquatic Species Research Program at NREL (1990 - 1995)

- Source of additional lipids and/or carbohydrates
- Complements terrestrial biomass production
  - Reduces pressure on land use
  - Avoids food vs fuel debate
  - Option to utilize large waste CO_2 resource (e.g. Coal-fired Power Plants)
- Potential for greater productivity than their terrestrial cousins
  - Up to 50 times more productive than traditional oilseed crops
  - Very large resource potential for producing additional biodiesel

Integrated Biorefinery Elements



Technology Synergies