Biofuels:
Trends, Specifications, Biomass Conversion, and GHG Assessments

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Outline (Emphasis on U.S. Situation)

A. Policy and Regulatory Drivers for Biofuels

B. Biofuel Trends and Projections

C. Feedstocks for Biofuels

D. Biomass Conversion Technologies

E. Environmental Considerations

F. Fuel Commercialization Requirements

G. Summary and Conclusions

Policy and Regulatory Drivers for Biofuels in the U.S.

- "America is addicted to oil."
  - President G. W. Bush; January 2006
- Federal Executive Actions:
  - Advanced Energy Initiative (AEI) (2006)
  - 20-in-10 Plan (2007)
- Federal Legislative Actions:
  - Energy Policy Act of 2005
  - Energy Independence and Security Act of 2007
- State Actions:
  - California Low Carbon Fuel Standard
  - California AB-32 (GHG reduction)

State of the Union Address (1/31/07)

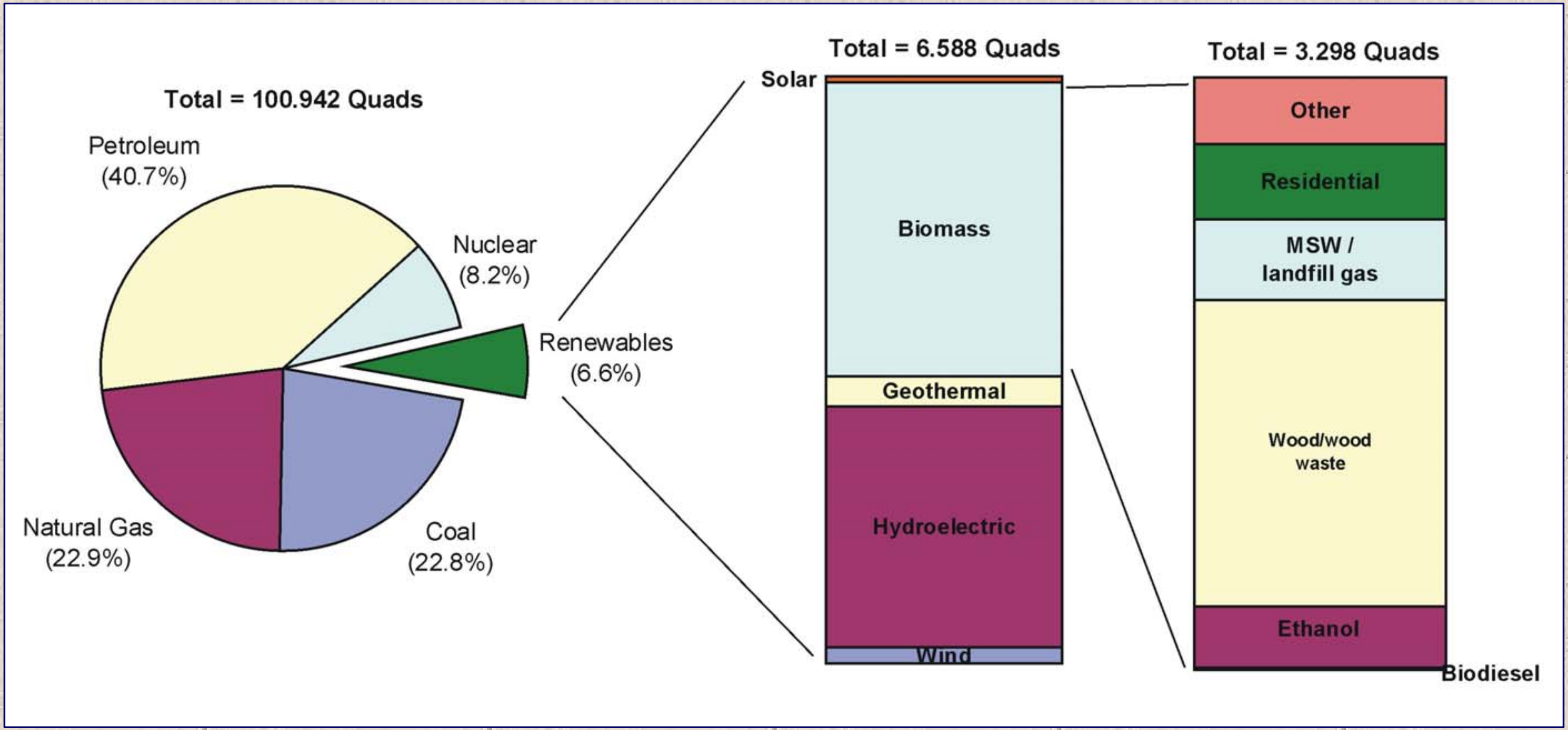
Terminology for Liquid Transportation Fuels
(Common terms, but not universally accepted)

1. **Conventional Fuels**: produced from petroleum
2. **Alternative Fuels**: produced from non-petroleum sources, including other fossil sources (coal, natural gas)
3. **Renewable Fuels**: produced from modern biological precursors (plants and animals)
4. **Biofuels**: synonymous with "Renewable Fuels"
5. **Biodiesel**: methyl esters produced from fats and oils
6. **Renewable Diesel**: non-fossil hydrocarbon fuel produced via hydroprocessing of fats and oils;
7. **Cellulosic Fuels**: produced via biochemical or thermochemical conversion of lignocellulosic materials
8. **Clean Fuels**: ??

Potential Benefits and Challenges of Biofuels

Improved Energy Security	Economic Productivity	Environmental Impacts (pros and cons)
• Domestic supply • Distributed resources • Supply reliability • Petroleum reduction	• Price stability • Increased rural development • Reduced trade deficit • Improved global competitiveness	• GHG reduction • Carbon sequestration • Land and water use • Criteria air pollutants • Wildlife habitat • Biodiversity

Annual U.S. Energy Consumption
(Quads*, 2005)



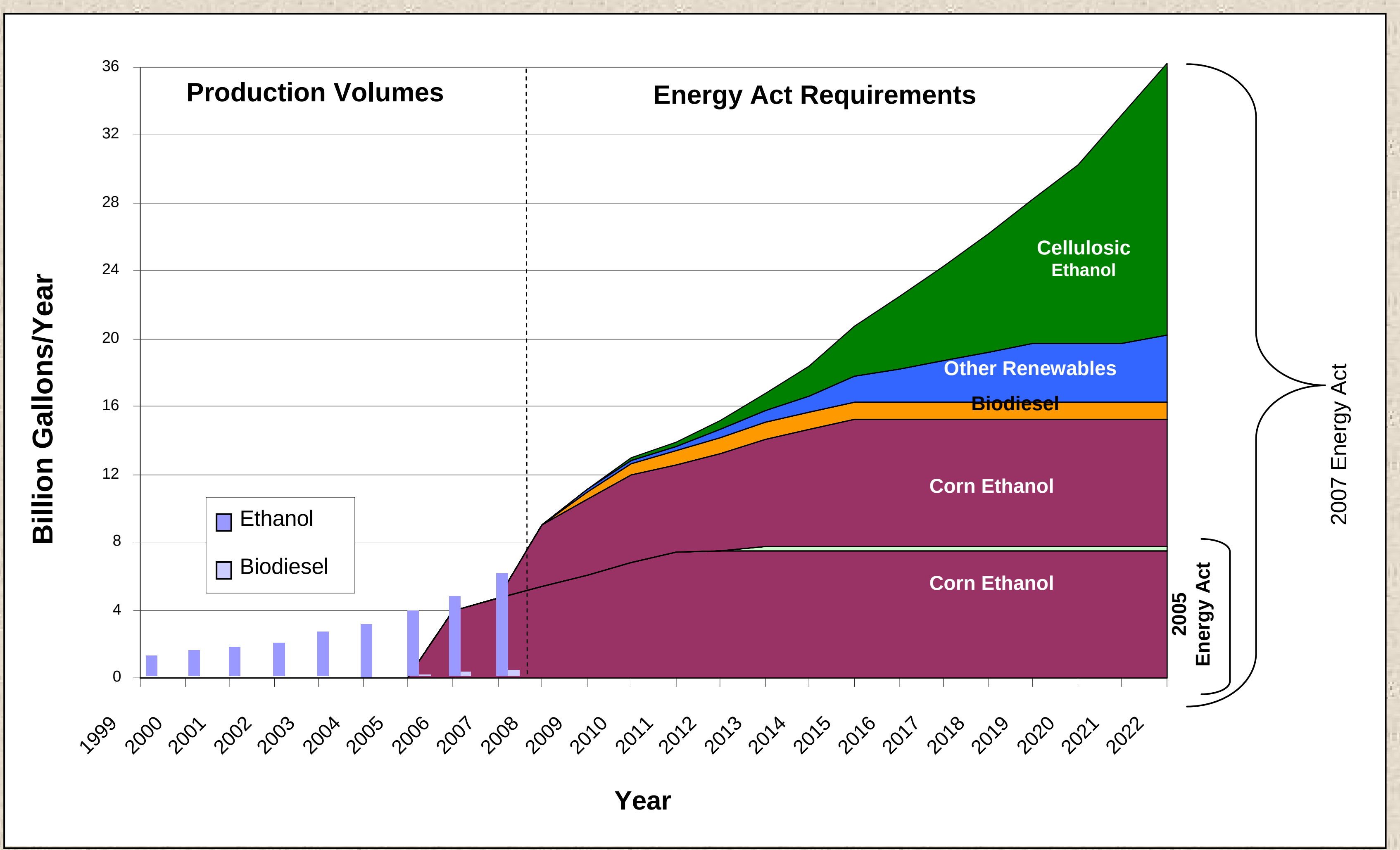
Source: *DOE Renewable Energy Annual 2005* (July 2007)

* 1 Quad = 1.055 Exajoules (1 Exajoule = 10^{18} joules)

Growth of Biofuels in the U.S.

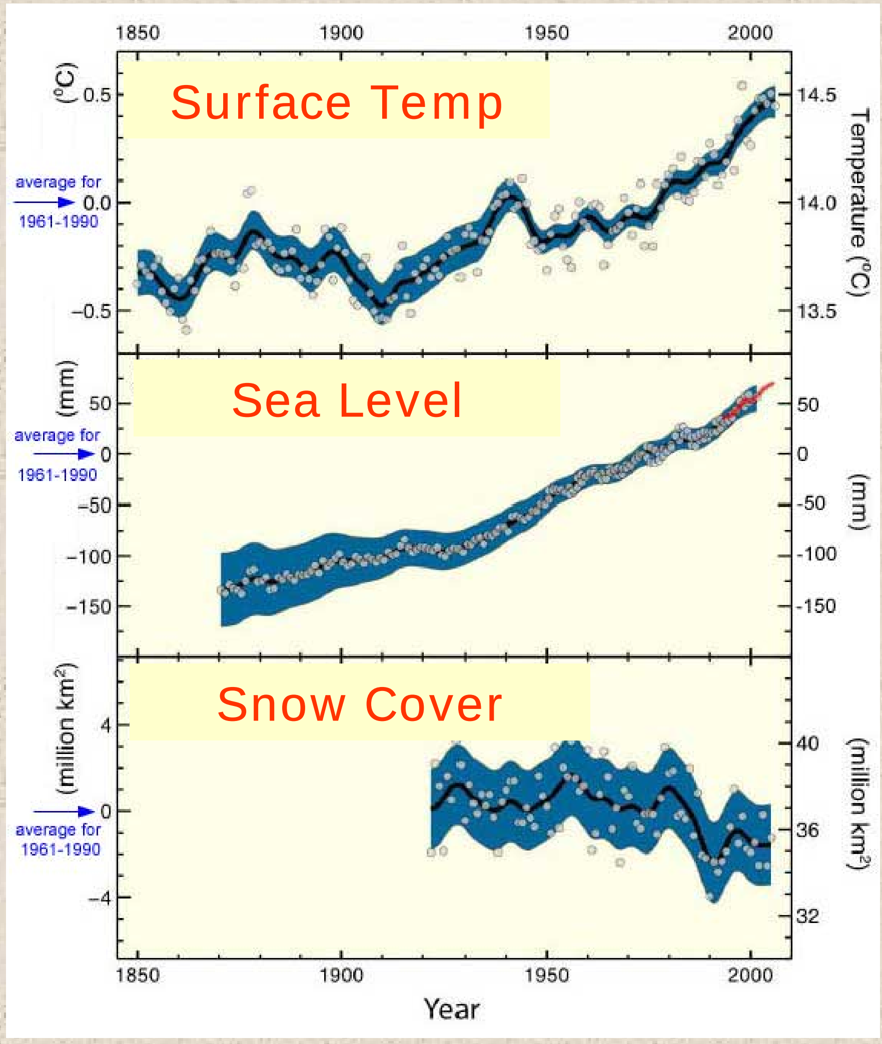
- **Currently dominated by corn-based ethanol**
  - 6.4 billion gallons in 2007
  - Supplies about 4% of U.S. gasoline demand
  - Requires about 15% of U.S. corn crop
- **Biodiesel is growing, but still small**
  - 0.35 billion gallons in 2007
  - Supplies <1% of U.S. diesel demand
  - Main U.S. feedstocks are soy oil and waste oils

U.S. Renewable Fuels Production and Volume Requirements, bg/y



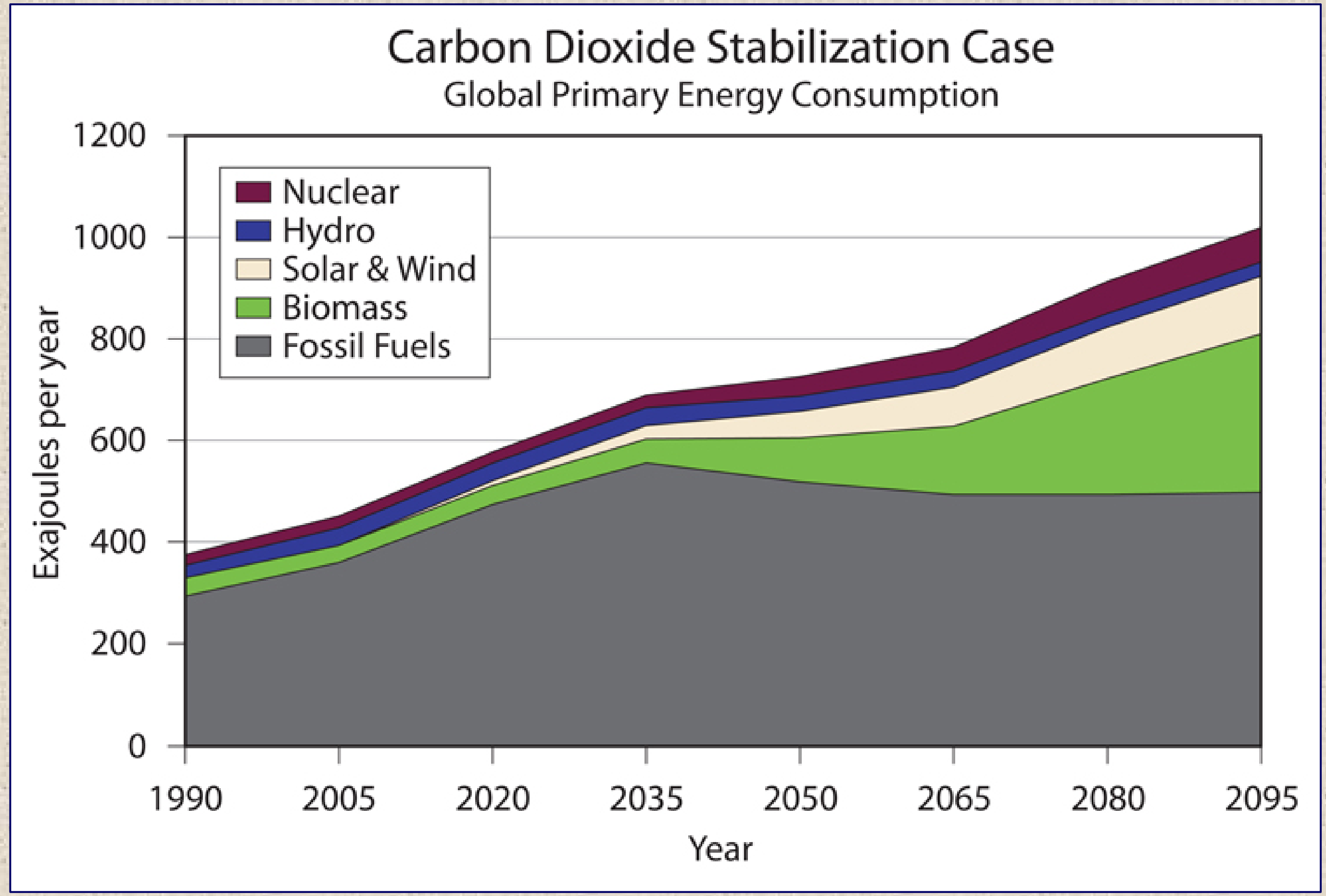
Importance of Continued Biofuels Growth

- Biofuels are a critical component of GHG stabilization strategies
- Increased biofuels could help satisfy growing global demand for fuels
- Continued increase in biofuels requires use of cellulosic feedstocks



Source: IPCC 4th Assessment Report (2007)

Potential Role of Biomass Fuels in Stabilizing Global CO_2 at 550 ppmv

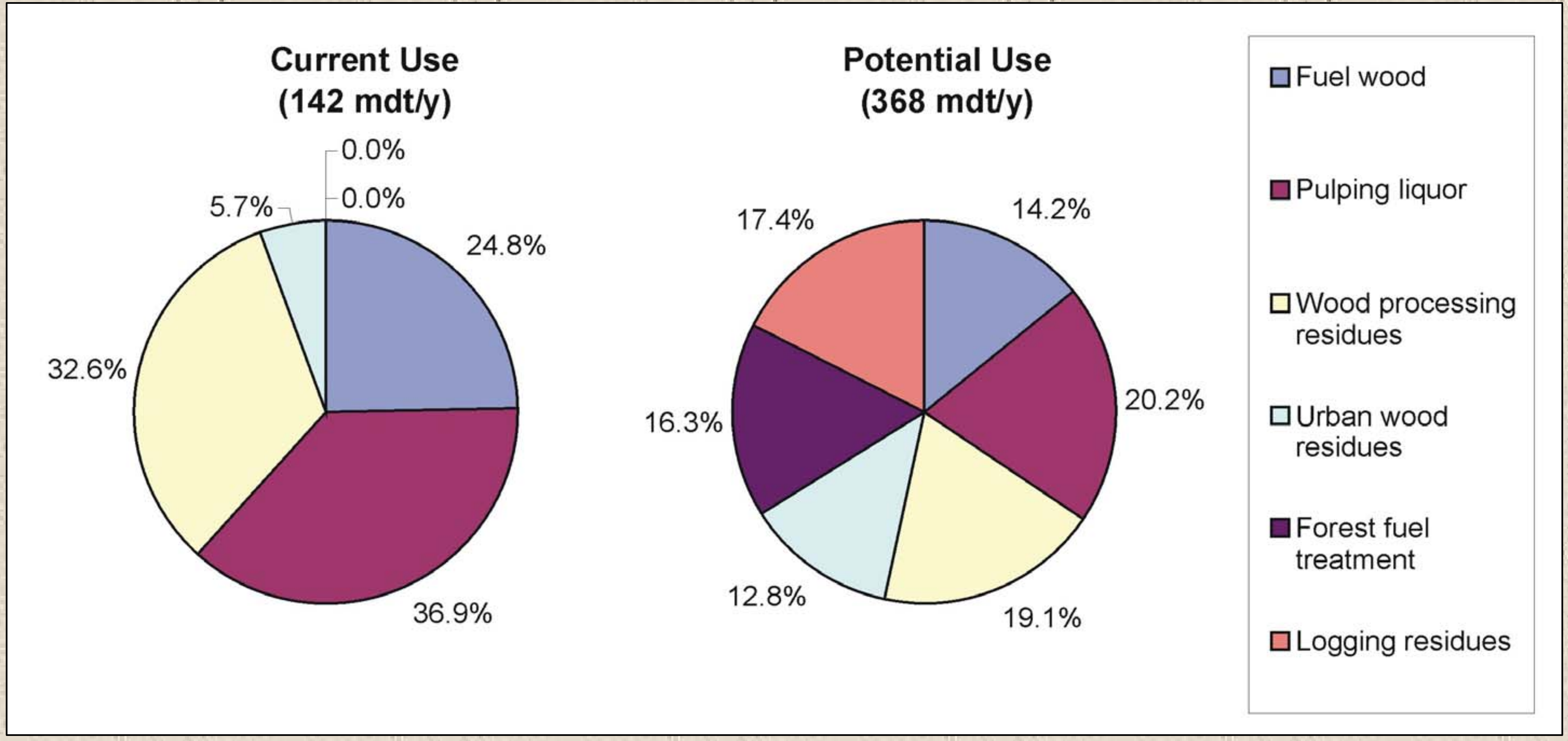


Source: *US DOE Genomics-to-Life (GTL) Roadmap* (Aug. 2005)

Biomass Resource Base in U.S.

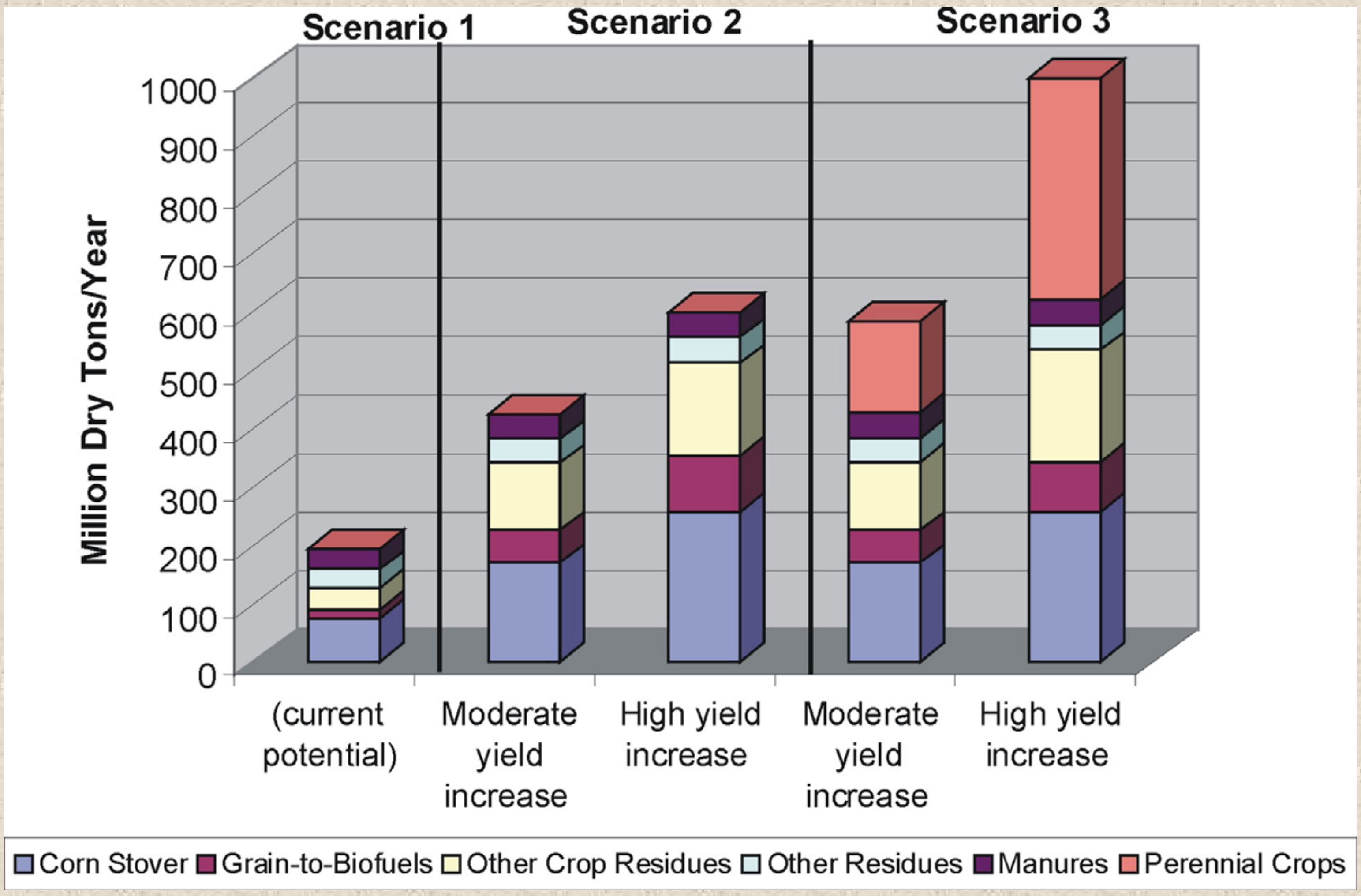
	Forest Resources	Agricultural Resources
Primary	• Logging residues • Forest fuel treatment • Fuel wood	• Crop residues • Grain • Perennial grasses • Woody crops
Secondary	• Mill residues • Pulping liquors • Wood processing residues	• Animal manures • Food/feed processing residues
Tertiary	• Construction debris • Demolition debris • Urban tree trimmings • Packaging waste	• Municipal solid waste (MSW) • Landfill gases

U.S. Forest Biomass Resources,
million dry tons/year (mdt/y)



Source: DOE/USDA, *The Technical Feasibility of a Billion-Ton Annual Supply* (April 2005)

Potential U.S. Agricultural Biomass Resources (mdt/y)



Source: DOE/USDA, *The Technical Feasibility of a Billion-Ton Annual Supply* (April 2005)

U.S. Agricultural Land Allocation under Biomass Scenarios, million acres

	Scenario 1 (current allocation)	Scenario 2 (Mod. & high yield increase)	Scenario 3 (Mod. yield increase)	Scenario 3 (High yield increase)
Active cropland	344	344	339	319
Idle land	37	37	27	27
Pasture	68	68	43	43
Perennial crop	0	0	40	60
Total	449	449	449	449

Source: DOE/USDA, *The Technical Feasibility of a Billion-Ton Annual Supply* (April 2005)

Biomass Conversion Technologies
Production of "2nd Generation" Fuels

A. Lignocellulose-to-fuels
1. Biochemical processes
2. Thermochemical processes

B. Triglycerides-to-fuels
1. Transesterification
2. Hydroprocessing
3. Thermal depolymerization

C. Other Processes
1. Gas-to-liquids (GTL)
2. Waste digesters
3. Direct microbial production

Conversion of Lignocellulosic Materials

1. Biochemical Processes

- Typical Process
  - Pre-treatment (heat and/or acid)
  - Enzymatic hydrolysis to form sugars
  - Fermentation to form ethanol
- Challenges/barriers:
  - Variability of feedstocks
  - Recalcitrance of lignocellulosic feedstocks
  - Effectiveness/robustness of enzymes
  - Slow speed of processes
  - Cost

Conversion of Lignocellulosic Materials

2. Thermochemical Processes

a. Gasification

- High temperature decomposition of lignocellulose
- Partial oxidation to produce synthesis gas
- Catalytic reaction of syngas to produce alcohols and/or hydrocarbons

b. Pyrolysis

- Moderate temp decomposition of lignocellulose in absence of O_2
- Produces pyrolysis oil – oxygenated hydrocarbon feedstocks requiring further refining

Challenges/barriers:

- Pre-treatment of lignocellulosic feedstocks
- Minimization of tars from gasification
- Effective catalysts for syngas conversion
- Stability of pyrolysis oil

Conversion of Triglycerides

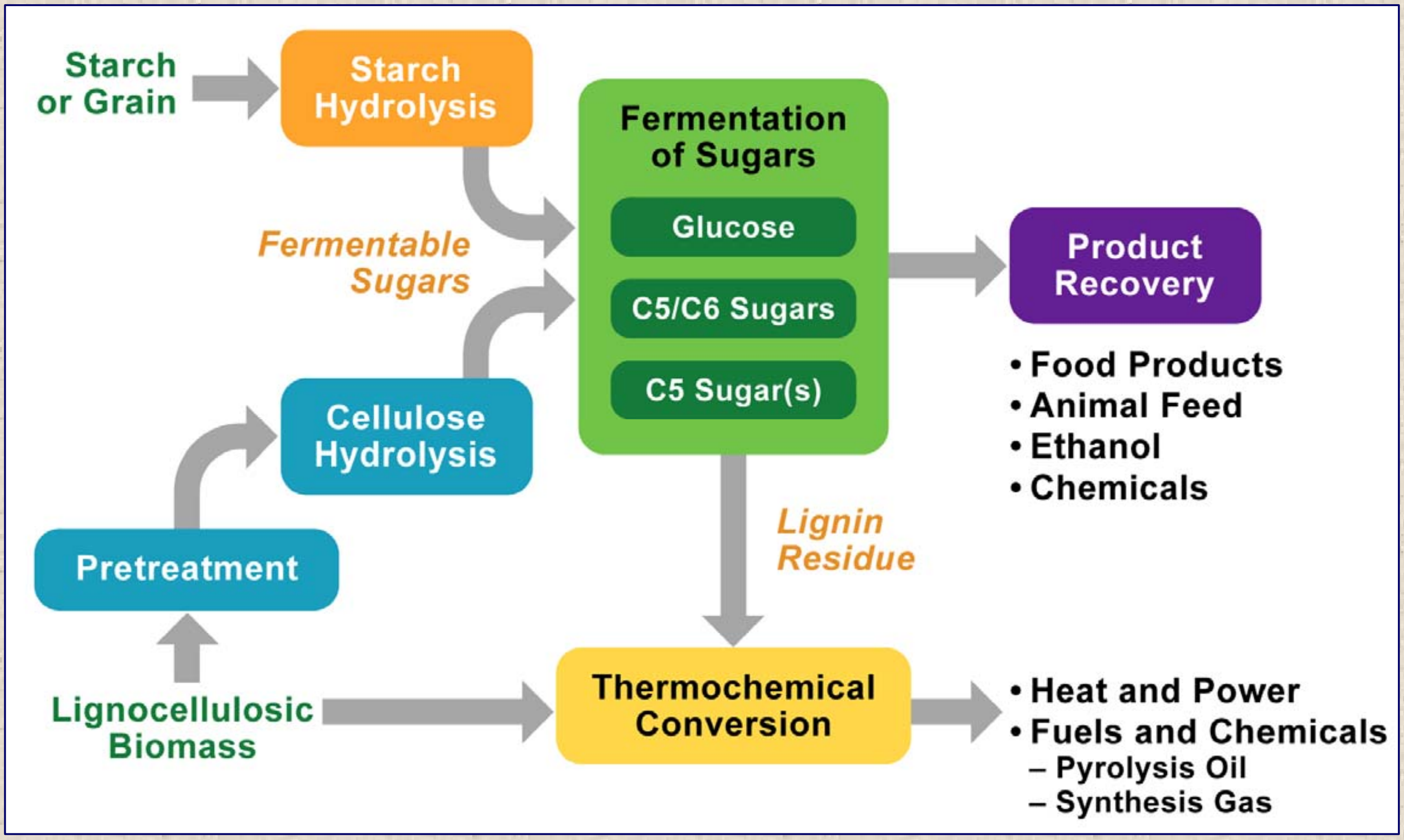
1. Transesterification to produce biodiesel
   - Feedstocks:
     - Seed oils (soy, canola, palm, jatropha, etc.)
     - Animal fats and waste oils
     - Algal oils
   - Products are methyl esters of fatty acids (FAME)
   - Glycerol is major by-product

2. Hydroprocessing to produce renewable diesel
   - Feedstocks: same triglycerides as above
   - Catalytic hydroprocessing produces free hydrocarbons
   - Product is virtually identical to petroleum diesel
   - No glycerol by-product

U.S. DOE-Supported Biomass-to-Ethanol Small Scale Commercial Plants

Process Category	Lead Company	Feedstocks	Process Details	Project Location
Bio-Chemical	Abengoa Bioenergy	Ag. Residues (corn stover, wheat straw, switchgrass)	Enzymatic Hydrolysis, saccharification, fermentation	Kansas
	BlueFire Ethanol	Landfill green waste and wood waste	Concentrated acid hydrolysis, fermentation	California
	Broin (now called Poet)	Ag. Residues (corn fiber, cobs, and stalks)	Hydrolysis, saccharification, fermentation	Iowa
	Iogen Biorefinery	Ag. Residues (wheat and barley straw, corn stover)	Hydrolysis, saccharification, fermentation	Idaho
Thermo-Chemical	Alico	Yard waste, wood waste, and vegetative waste	Gasification, fermentation of syngas	Florida
	Range Fuels	Wood residues, woody crops	Gasification, catalytic reaction of syngas	Georgia

DOE's Integrated Biorefinery Concept



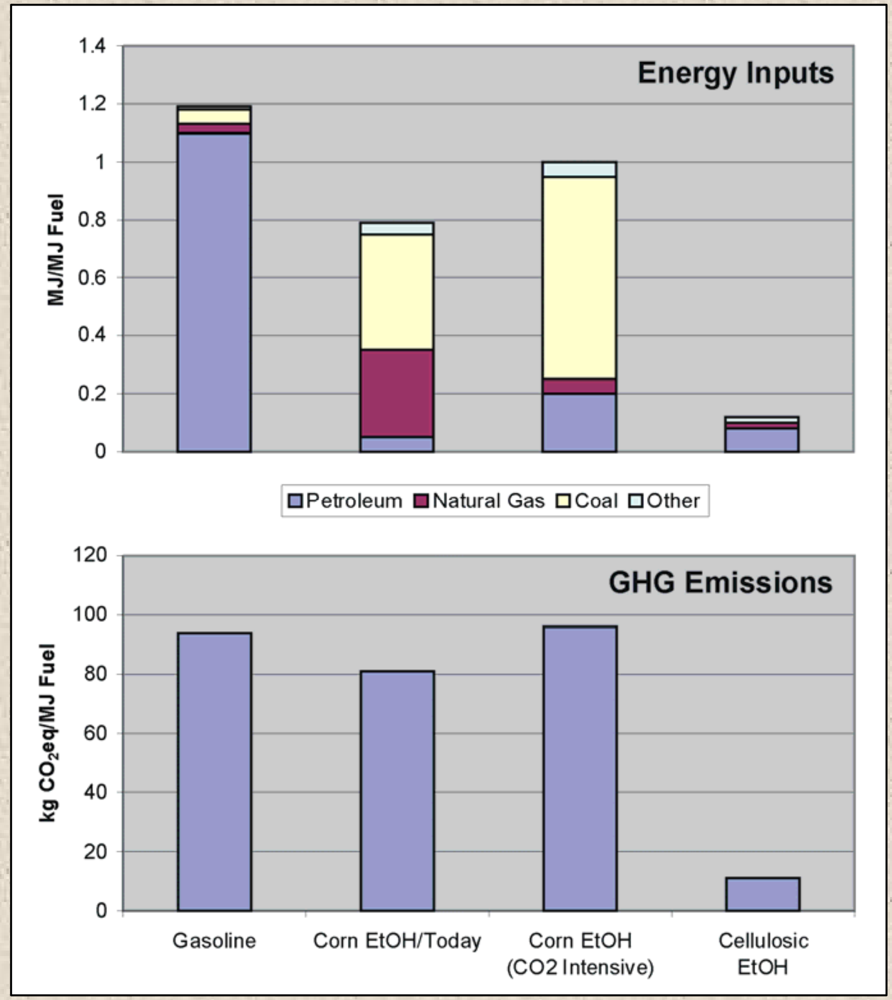
Source: NREL (2006)

Environmental Concerns with Biofuels

- Water quantity and quality
- Runoff of nutrients and agricultural chemicals
- Long-term impacts of crop residue removal
- Disruption of habitat
- Effects on biodiversity
- Sustainability of agricultural and forestry practices

Life-Cycle Energy and GHG Impacts of Ethanol

- Many different life-cycle assessments (LCA) have been conducted.
- Controversial area. Results depend upon assumptions used.
- In general:
  - Small energy and GHG benefits from corn-derived ethanol
  - Large benefits from cellulosic ethanol
- Changes in land use can have significant GHG impacts



Source: Farrell et al, *Science,* 311, 506-508 (2006)

Biomass-to-Biofuels Supply Chain

Feedstock Production → Feedstock Logistics → Biofuels Production → Biofuels Distribution → Biofuels End Use

- All steps in supply chain are important, and must be integrated
- Entire chain must be economically sustainable

Source: *DOE Biomass Multi-Year Program Plan* (2007)

Summary and Conclusions

1. U.S. biofuels industry is currently undergoing rapid growth and transformation
2. Technological emphasis is on 2nd Generation biofuels
   - Both biochemical and thermochemical technologies are advancing rapidly
   - No single “best approach” is likely to emerge
3. U.S. has abundant natural resources to support production of 2nd Generation biofuels
   - Could potentially displace 30-50% of conventional fuels
   - Must be careful to maximize sustainability and minimize environmental harm
4. For widespread acceptance, biofuels must be conveniently available, affordable, and compatible with conventional fuel/vehicle systems

Thank You!