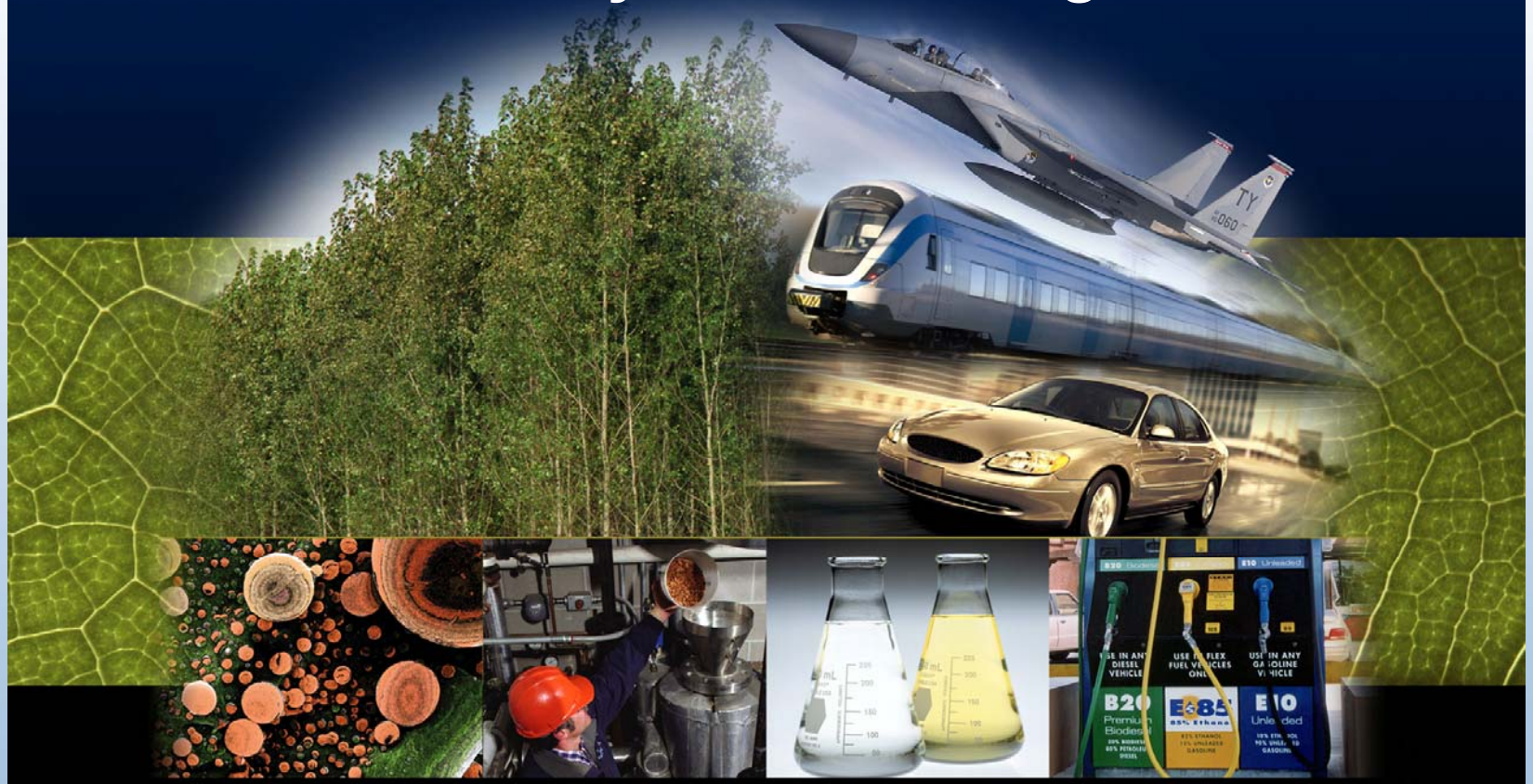
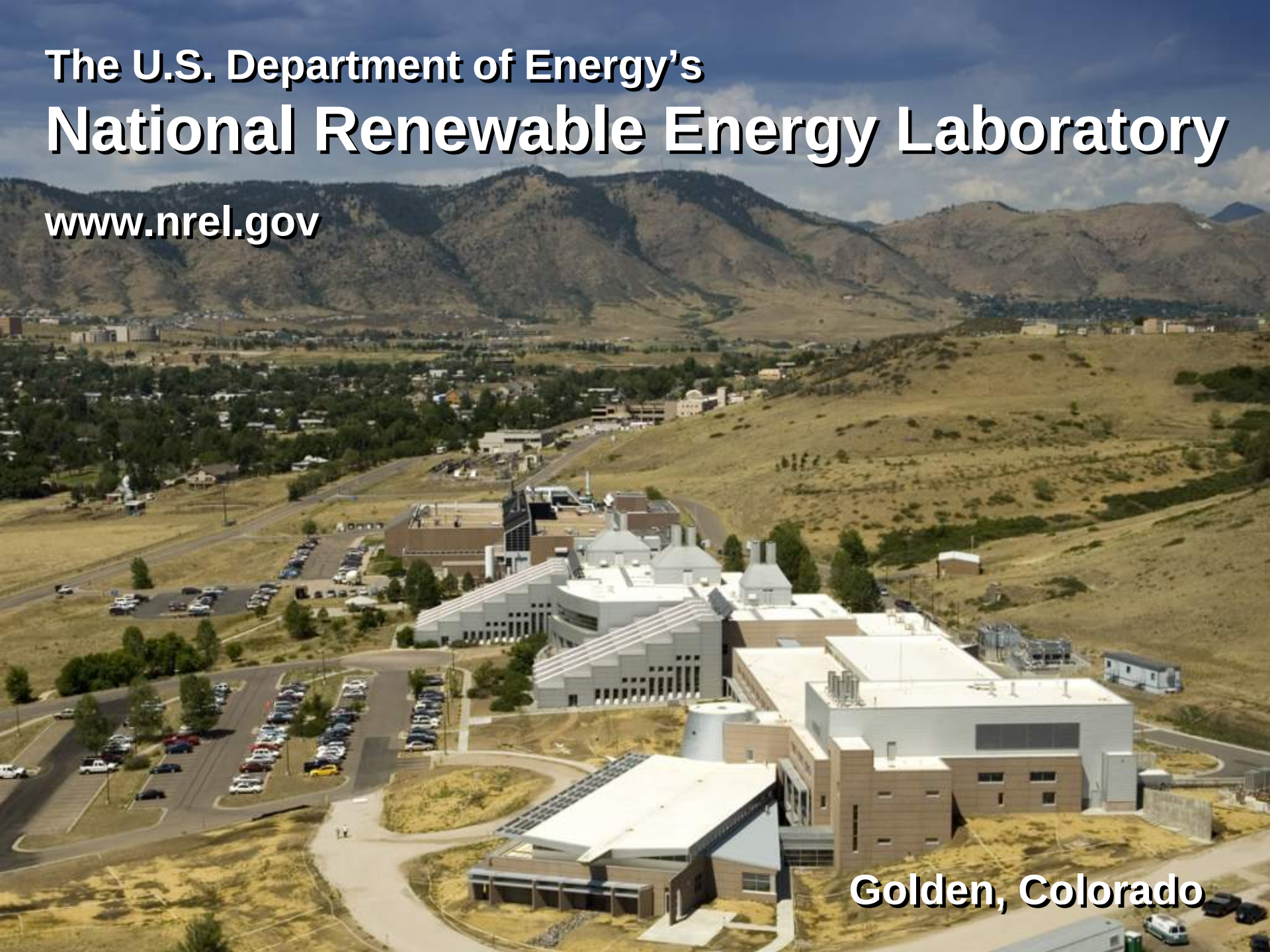
Biofuels R&D: Process Options, Economics, Sustainability and Pressing Issues



July 24, 2008
Dr. Joseph M. (Mike) Cleary
Center Director, The National Bioenergy Center


The U.S. Department of Energy's
National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado

National Renewable Energy Laboratory

What Makes It Unique?

- Only DOE national laboratory funded by and specifically dedicated to EERE RDD&D
- Projects span targeted fundamental science to technology solutions
- Collaboration with industry and university partners is a hallmark
- Cost driven R&D that based on market relevancy
- and systems focus

NREL's National Bioenergy Center

- **Mission**: Foster R&D capabilities and advance technologies used to produce fuels, chemicals, materials, and power from biomass.

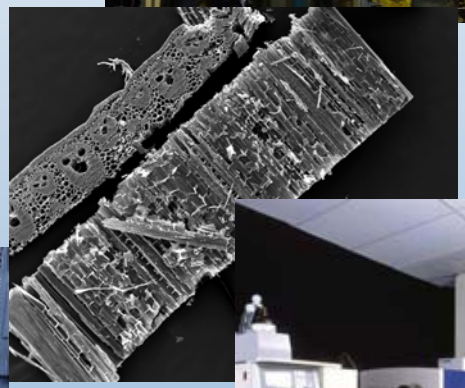
- **DOE Goals**: 1) Reduce U.S. dependence on oil, 2) Build a U.S. bioenergy industry, 3) Reduce global warming

- **Organization**: Established in 2000 to support the science and technology goals of DOE's EERE Biomass Program by working with a multi-laboratory consortium of:
  - **Argonne National Laboratory** – Reaction Engineering & Separations
  - **Idaho National Laboratory** – Biomass Harvesting Technology
  - **National Renewable Energy Laboratory** – Biorefinery R&D
  - **Oak Ridge National Laboratory** – Feedstock Development
  - **Pacific Northwest National Laboratory** – Syngas and Catalysis

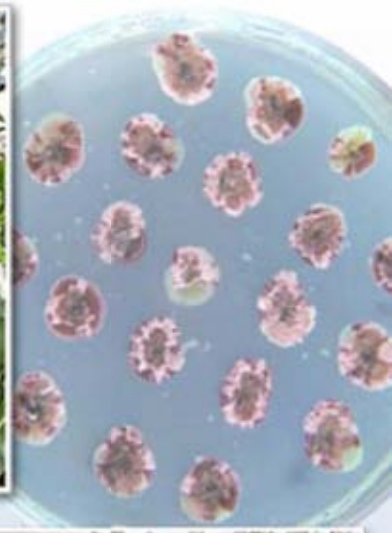
- **Primary Roles for DOE Labs in Bioenergy**:
  - Lignocellulose conversion to intermediates and biofuel
  - Integrated biorefinery concepts and design
  - Accurate process and life-cycle analysis modeling
  - Partnerships with and support of near-term industrial commercialization projects
  - Longer-term **core** bioenergy research

NREL Biofuels R&D Capabilities

- Biomass to Biofuel (Ethanol) Conversion
  - Biochemical & Thermochemical process capabilities
  - Micro Reactors to ton/day Pilot Plants
- Biomass Analysis, Characterization & Spectroscopy
  - Wet chemical analysis and NIR
  - NMR, IR, LIBS, MBMS
  - Microscopy - SEM, TEM, confocal, AFM
- Microbial R&D
  - Bacterial genetic engineering, algal microbiology, FACS
- Biorefinery Techno-economic and Life Cycle Analysis
- Systems Biology and Protein characterization
  - Microarray analysis, HTP robotics, XRD crytallography



Biofuels



Current Biofuels Production status

- Biodiesel – 1.3 billion gallons/yr capacity[1]
- Corn ethanol
  - 121 commercial plants[2]
  - 6.3 billion gal/yr. capacity[2]
  - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
  - Projected commercial cost ~$3.50/gge

Key DOE Biofuels Goals

- 2012 goal: cellulosic ethanol ~$1.89/gge
- 2022 goal: 36 billion gal
  - **EISA Renewable Fuels Standard – 21 Billion gal "advanced"**
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

NREL Research Thrusts

- Integrated biorefineries and cellulosic ethanol
- Solutions to under-utilized waste residues
- Alternative bioenergy crops

A NEW DIRECTION FOR ENERGY SECURITY
OFFICE OF THE SPEAKER

Updated July 2007
Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, all other information based on DOE and USDA sources

Major DOE Biofuels Project Locations

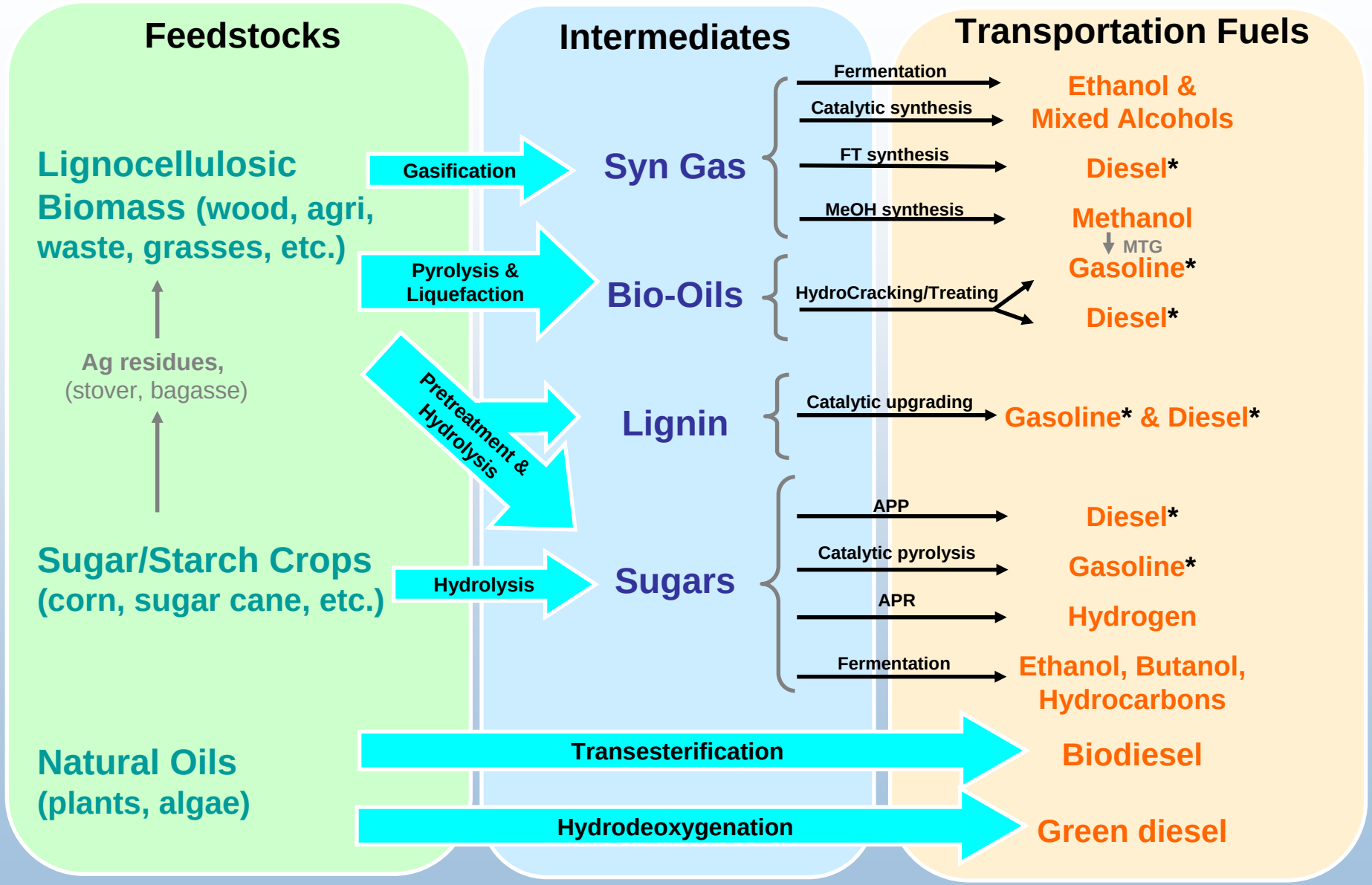
Geographic, Feedstock and Technology Diversity

- Four Commercial-Scale Biorefinergy Projects: up to $305 million
- Nine Small-Scale (10%) Biorefinery Projects: up to $240 million
- Three Bioenergy Centers: up to $405 million
- Four Thermochemical Biofuels Projects: up to $7.7 million
- Four Improved Enzyme Projects: up to $33.8 million
- Five Projects for Advanced Ethanol Conversion Organisms: up to $23 million

Regional Partnerships

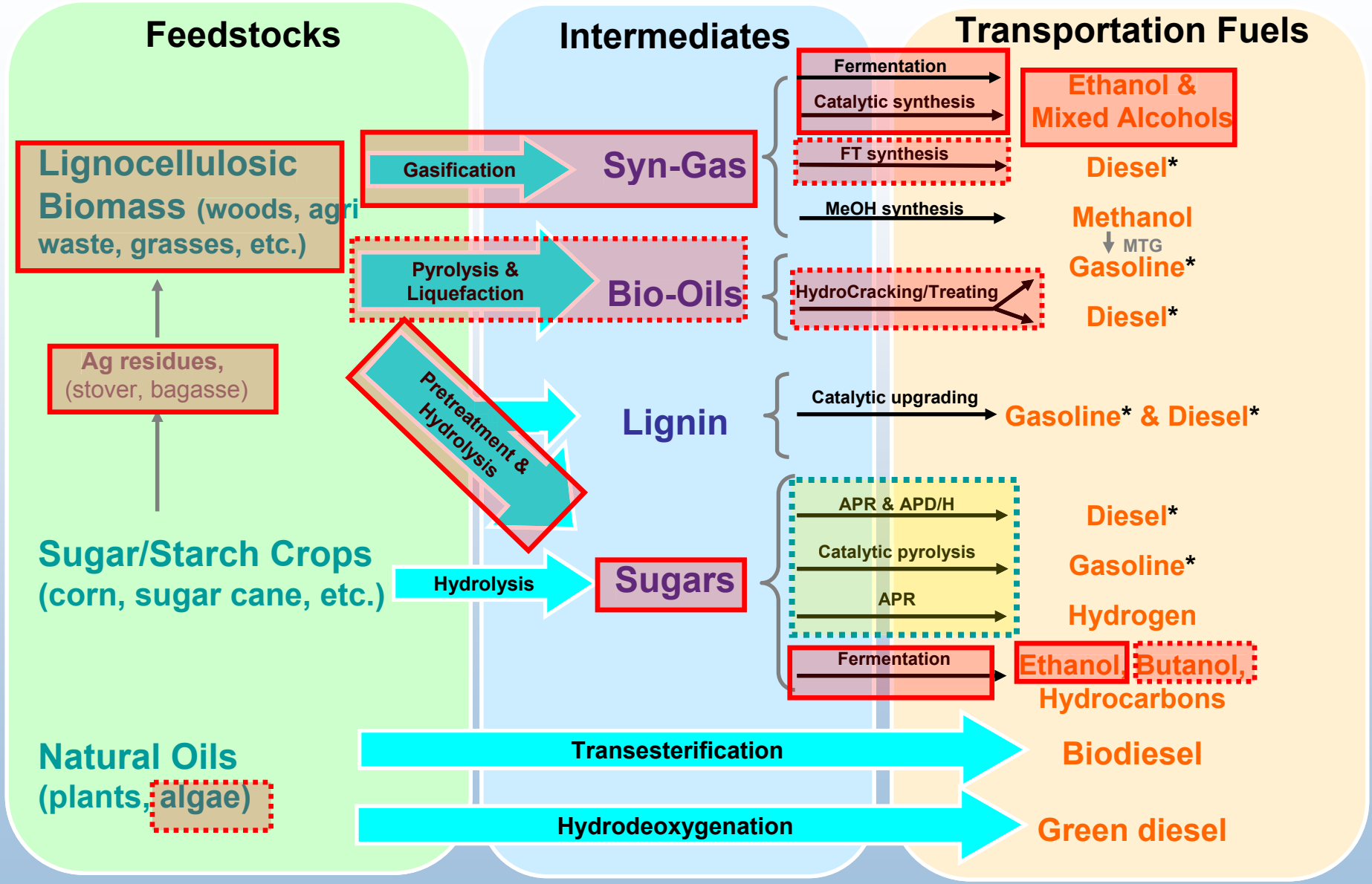
South Dakota State Univ., Brookings, SD
Cornell University, Ithaca, NY
Univ. of Tennessee, Knoxville, TN
Oklahoma State Univ., Stillwater, OK
Oregon State Univ., Corvallis, OR

Pathways to Biofuels



* Blending Products

Current Biomass Program (& NREL) Focus



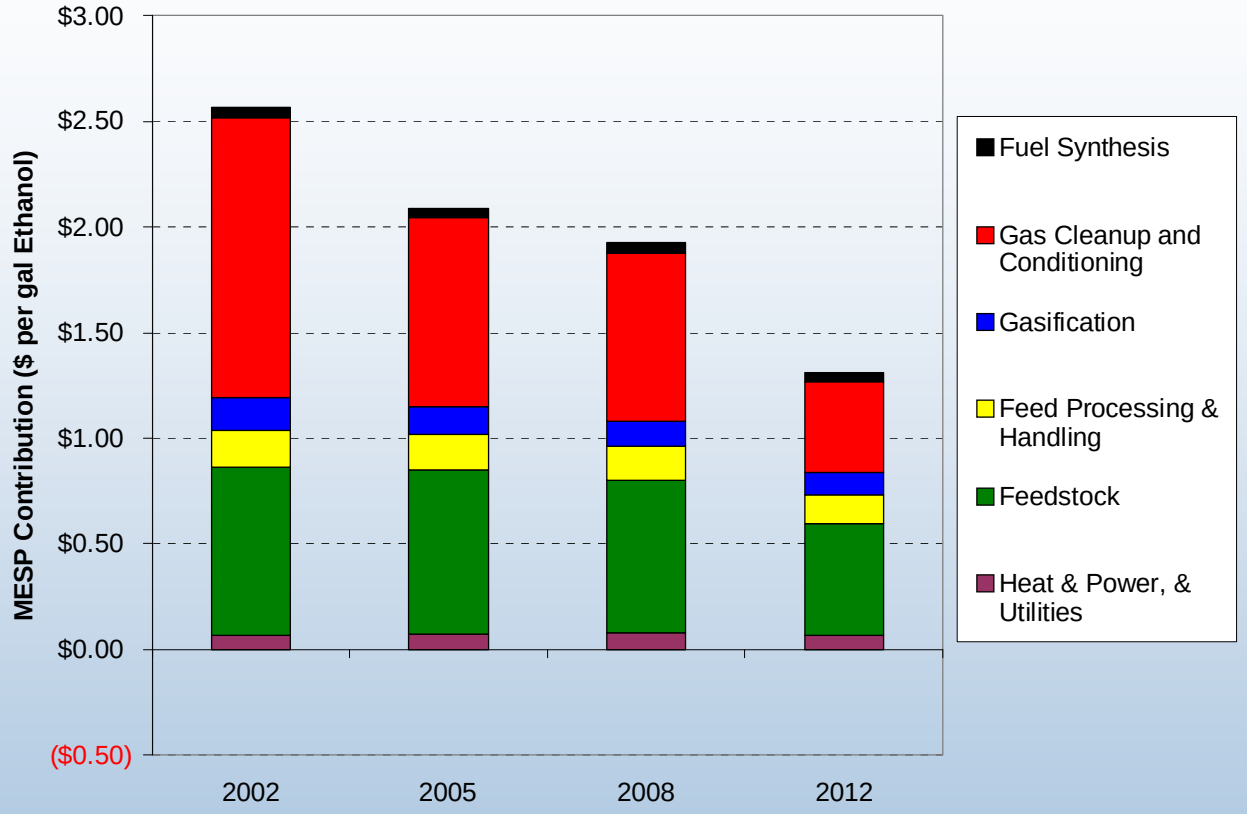
= Primary cellulosic ethanol RD&D areas

= Alternative biofuels RD&D activity areas

* Blending Stock

NREL National Renewable Energy Laboratory

Thermochemical Process Cost Analysis



- Unit operation cost estimates used to gauge progress and guide thermochemical research efforts
- Benchmark for comparing other approaches to thermochemical ethanol
- Model available for use by industry

Sustainability Challenges
Biomass to Biofuels Systems

Greenhouse Gas Emissions

Biofuels/Biomass Production
- *Supply infrastructure*
- *Fuel production*
- *Distribution and use*

Land Use
- *Indirect Effects*
- *Competition with food*
- *Soil*

Economic Prosperity
- *Rural and urban communities*
- *Industry*

Biodiversity

Water Use
- *Use*
- *Quality*
- *Efficiency of use*

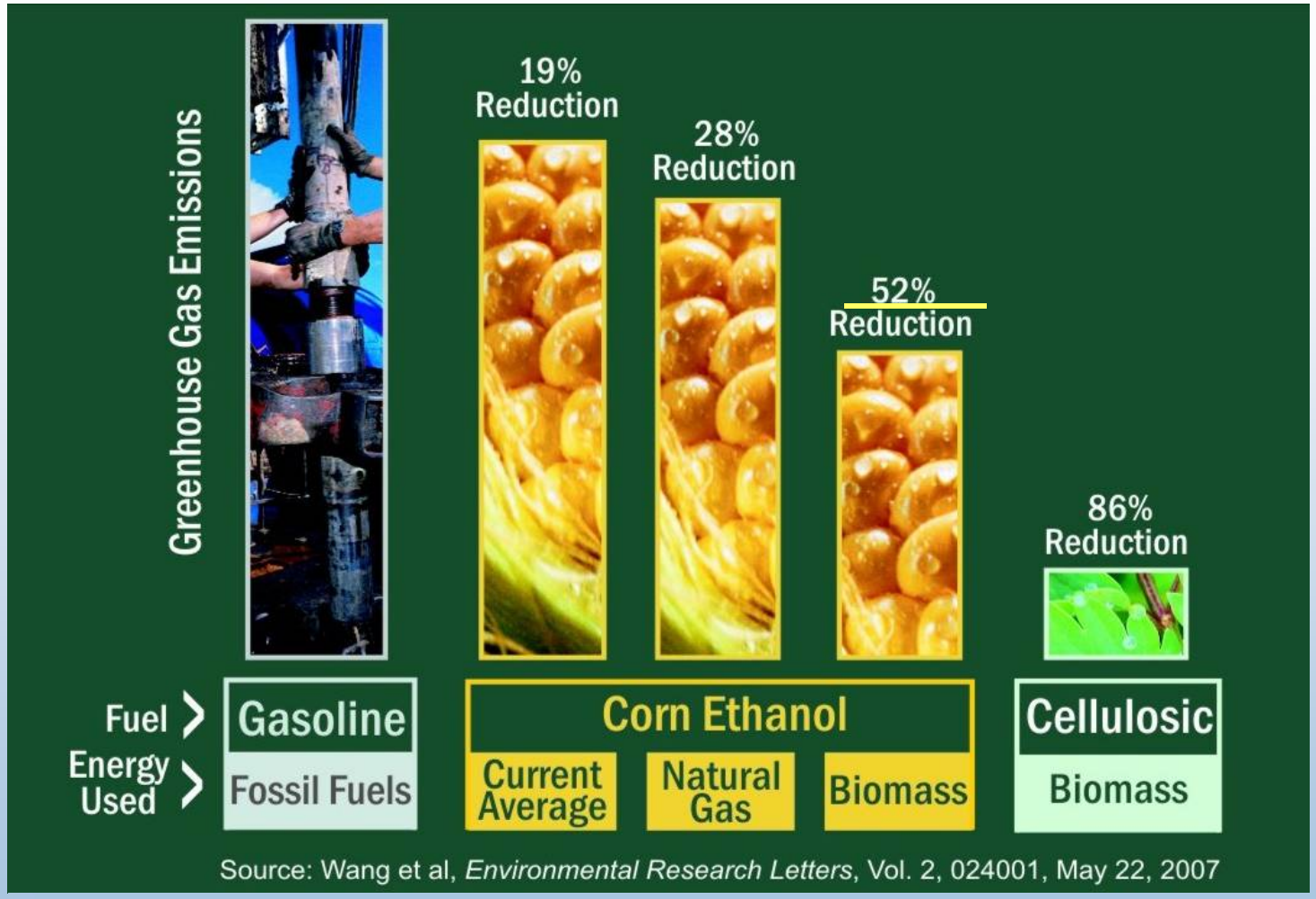
Social Well-being

Environmental Impacts

Increase Food and Energy Security

while safeguarding soil, water and biodiversity

Relative Emissions Impacts



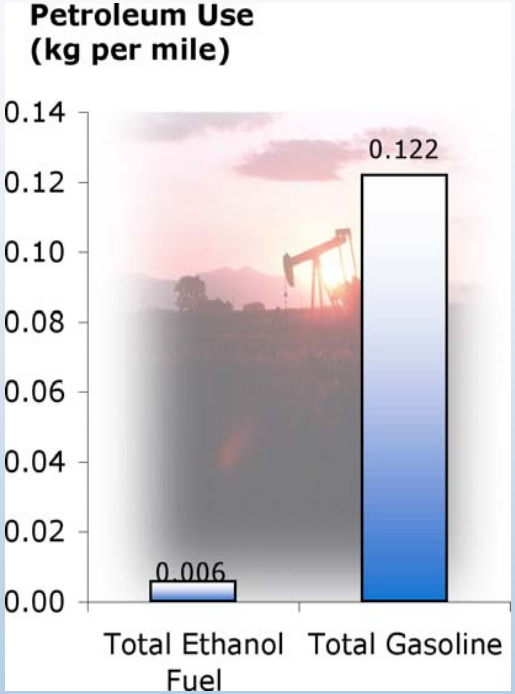
Greenhouse gas emissions of fuels vary by feedstock and by type of energy used for processing.

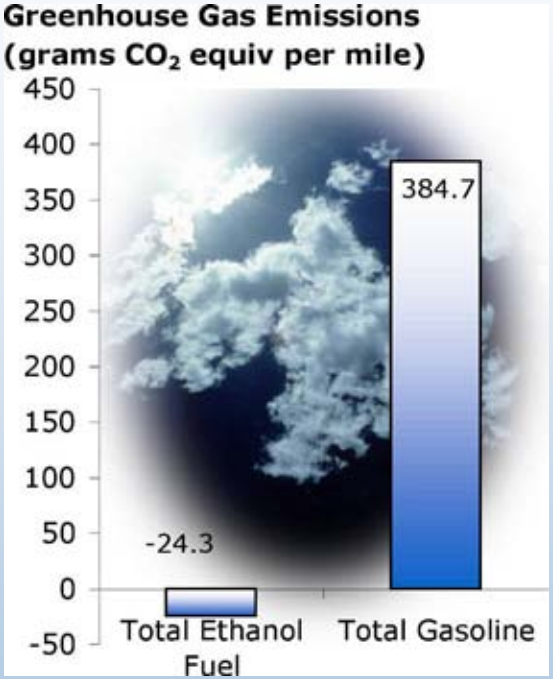
New Lifecycle GHG Criteria

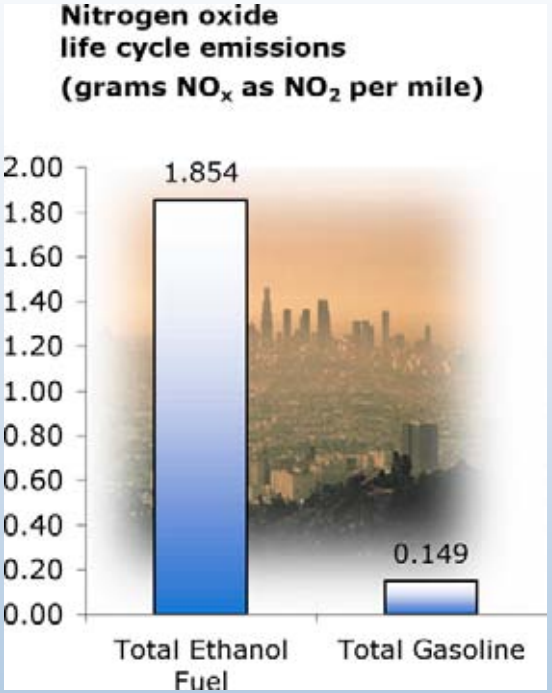
- All renewable fuels are required to meet a 20% lifecycle GHG threshold relative to the gasoline or diesel fuel they displace
  - EPA must determine lifecycle performance
  - Evaluation includes GHG emissions resulting from international land-use changes (“significant indirect emissions”)
- Facilities that “commenced construction” prior to EISA are grandfathered
  - No clear guidance on what this means
  - Products from such facilities automatically comply, however…
- EISA language permits EPA to adjust the lifecycle GHG thresholds by as much as 10%

Cellulosic Ethanol – Air Quality

Overall GHG emissions are lower than gasoline, but NOx is higher







95% less oil use

(every mile traveled requires 5% of crude oil compared to conv gasoline)

106% lower GHG

CO2, CH4, N2O

12x higher NOx

Most from soil emissions

Tradeoff Areas -Nothing is ever a "slam dunk"

Water use

Fresh Water Demands	Corn Ethanol: Dry Grind	Cellulosic Ethanol: Biochemical	Cellulosic Ethanol: Thermochemical
Cooling tower makeup (percent)	68	71	71
Boiler and process makeup (percent)	32	29	29
Overall water demand (Gal H_2O / Gal EtOH)	3–4	6	1.9

Summary of ethanol production process water demands. Corn ethanol values are from commerically operating plants; cellulosic values are model-based.

The Numbers

96% of corn used for ethanol production is not irrigated
785 gallons water per gallon of ethanol (average crop irrigation)
3-4 gallons water per gallon ethanol (dry grind production)
1.9-6 gallons water per gallon ethanol (conceptual cellulosic production)
2-2.5 gallons water per gallon gasoline (petroleum refining)
0.6 gallons water per kilowatt-hour* (coal-fired power plant)

***15 gallons of water per gallon of ethanol equivalent energy**

A. Aden, 2007. Water Usage for Current and Future Ethanol Production, Southwest Hydrology, September/October Issue, p. 22-23

Land Use

- Many uncertainties and challenges to accurate predictions
  - LUC <> land use change (relies on remote sensing data)

- Modeling results are highly sensitive to LUC assumptions, baseline projections, scale

- Research and data – very different perspectives!
  - LUC impact postulated by Searchinger et al.:
    - **108 thousand Sq Kilometers**
    - "Conventional wisdom" - if an acre is taken out of food production in one place, it must be replaced somewhere else

  - Underutilized, non-forest, "available/suitable" agricultural lands:
    30 - 40 million Sq Kilometers

- "Indirect impact" argument assumes that land is not available for expansion without clearing new forests or grasslands.

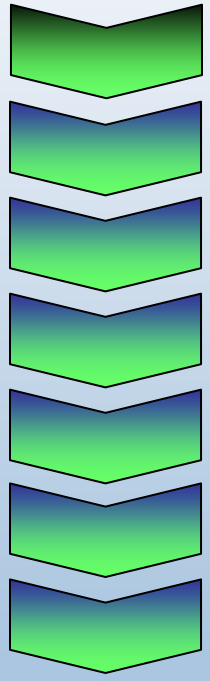
- Much more data and analyses are being generated – impacts from fire, climate change

Pressing R&D Issues

- **Biochemical Processes**
  - **More efficient and inhibitor tolerant strains**
  - **More efficient enzymes**
- **Thermochemical Processes**
  - **Improved syngas catalysts, e.g, tar reforming**
  - **Better catalysts for mixed alcohol synthesis**
- **Biorefineries**
  - **Process water recycle integration**
- **Sustainability**
  - **More thorough and accurate Life Cycle Analysis**

Ethanol is the 1st of Many Possible Biofuels

Near Term



Long Term

- **Ethanol** – from grain, sugar, or cellulosic material
- **Biodiesel** – transesterified vegetable oils, fats, and greases
- **Green Diesel** – vegetable oils, fats, and greases converted to diesel by hydroprocessing
- **Other Fermentation Fuels** – includes: butanol, higher alcohols, novel microbial hydrocarbons
- **Pyrolysis Liquids** – low quality, higher density liquid made by thermal processing ("thermal cracking") of biomass
- **Synthesis Gas** – for conversion to F-T liquids, methanol, dimethyl ether, or mixed alcohols
- **Algae-derived Fuels** – alternative source of triglycerides and carbohydrates for biodiesel and fermentation fuels, respectively
- **Hydrocarbon Fuels** – from hydrogenation of biomass constituents

Acknowledgments

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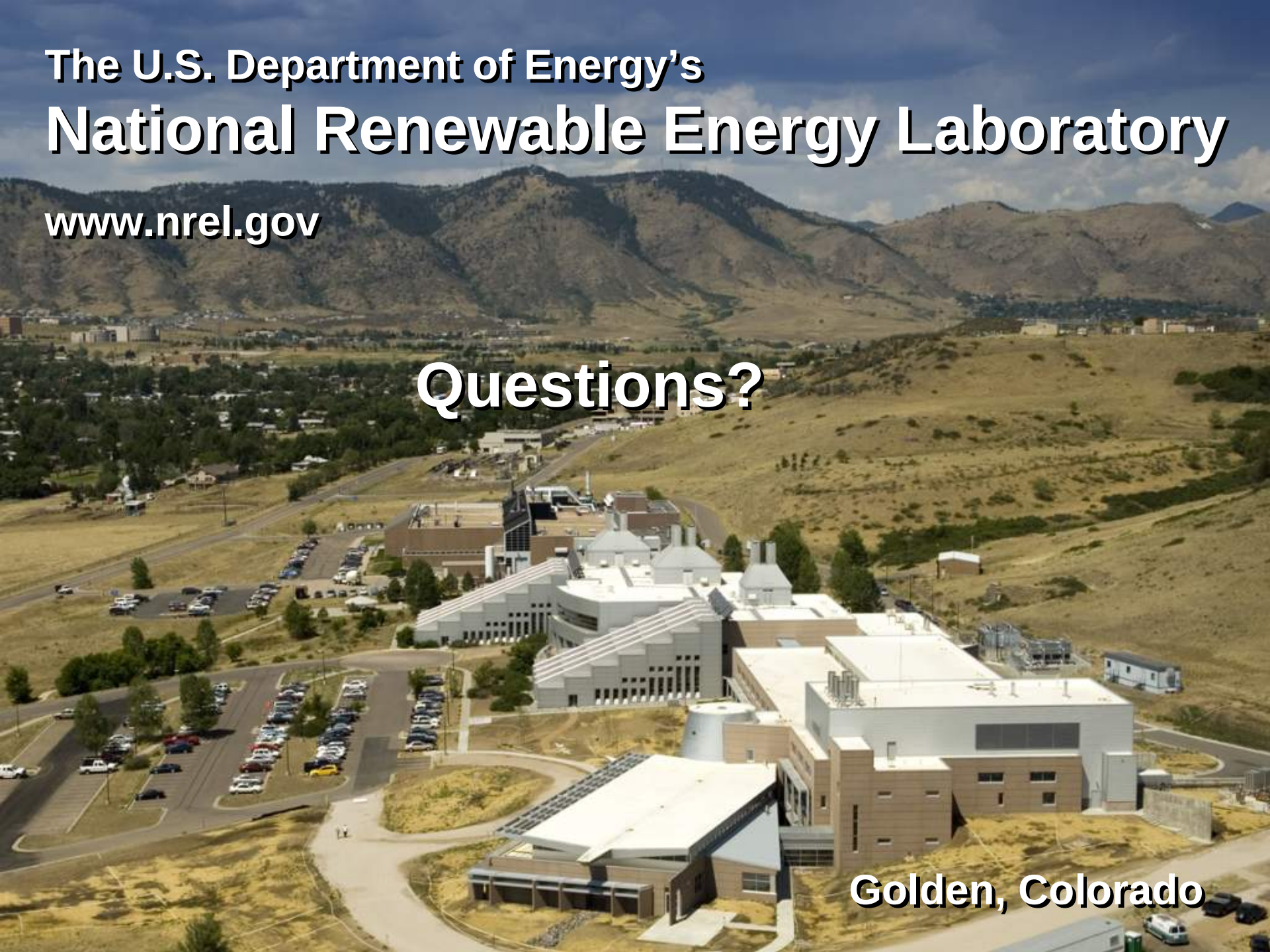
Additional Information

- DOE Biomass Program Web Site
  http://www.eere.energy.gov/biomass/

- NREL Biomass Web Site
  http://www.nrel.gov/biomass/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