U.S. DOE Biofuels Program

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U.S. DOE Vision

Realize a viable, sustainable biomass industry

- Producing renewable biofuels, bioproducts and biopower
- Enhancing energy security
- Reducing petroleum dependence
- Providing environmental benefits, including reduced GHG emissions
- Creating widespread economic opportunities

Social **Environmental** **Economic**

Ambitious Goals Established

2012 Cost-competitive cellulosic ethanol

2017 **"20 in 10":** Reduce U.S. gasoline use* by **20%**

- **15%** by producing/using **35 B** gallon/yr of alternative fuels (AFS)
- **5%** through higher vehicle* efficiency standards (CAFÉ)

2022 Energy Independence and Security Act (EISA 2007)

- Produce 36 B gal/yr biofuels; increase CAFÉ standards to 35 mpg
- Produce >21 B gal/yr advanced biofuels (>16 B gal/yr cellulosic ethanol)

2030 **"30 in 30"**

- Displace **30%** of U.S. gasoline consumption*
- Ramp up biofuels production to **60 B** gallons/year

* light-duty vehicles only 1 Billion (B) = 1000 Million = 10^9

Strategic Focus: Biofuels

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



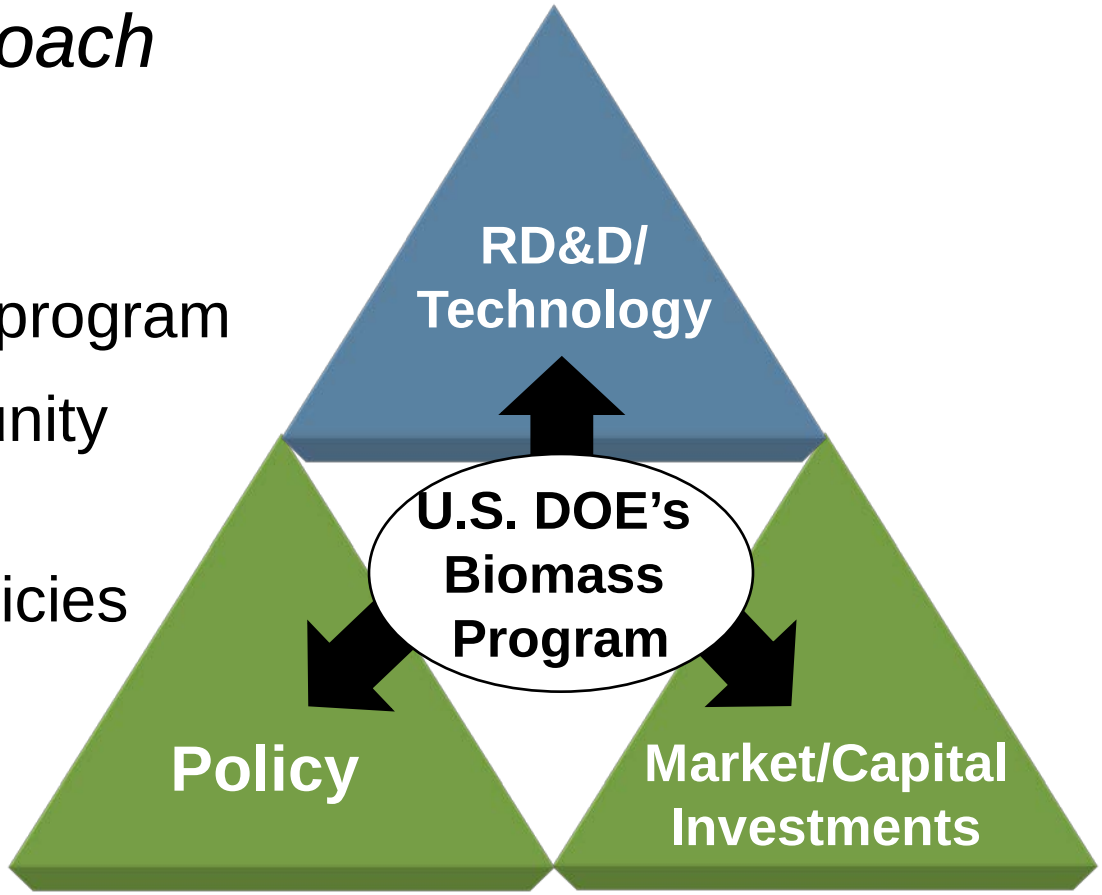

- **Cellulosic ethanol is main focus of U.S. DOE's Biomass Program**
- **Currently scoping other alternative / renewable fuels to help prioritize work on fuels "beyond" ethanol**
  - **Focus on replacement fuels for light-duty and diesel vehicles**

Out of Scope: Commercially viable biofuel production technologies e.g., conventional starch- and sugar-based ethanol and plant oil (soy, palm, canola, etc.)-based biodiesel

Leveraged Strategy to Achieve Goals

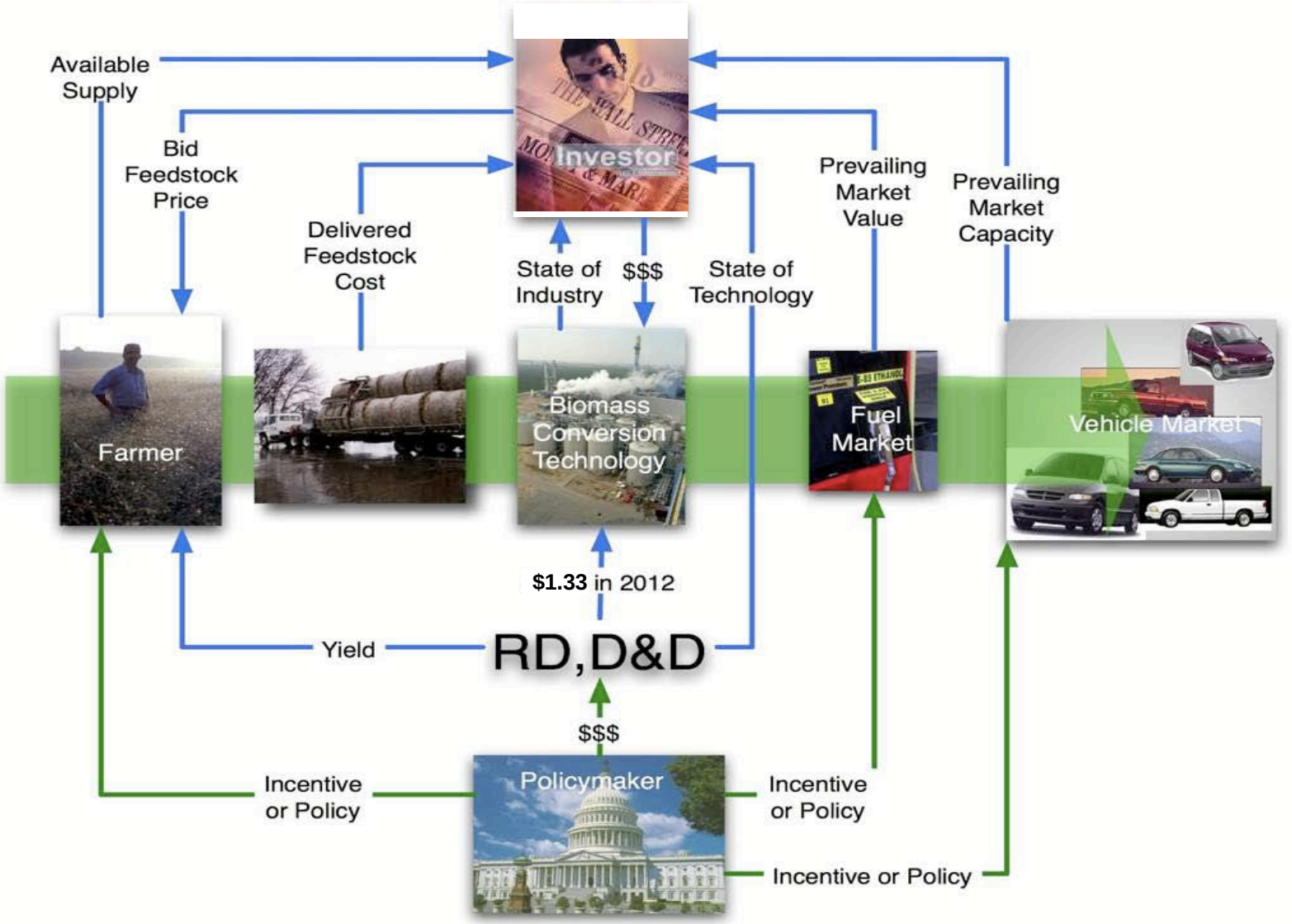
Three-pronged approach

- Accelerate Research, Development and Deployment (RD&D) program
- Spur financial community investment
- Create supportive policies



Rigorous Economic Modeling Guides R&D Targets

The Biomass Scenario Model



Six Main Challenges to Achieving National Goals

1. Availability of Biomass
2. Economic Viability
   - Biochemical
   - Thermochemical
3. Sustainability
4. Industry engagement
5. Policy drivers
6. Infrastructure and vehicles

Bioenergy Research Centers Continue Critical R&D

DOE Bioenergy Science Center

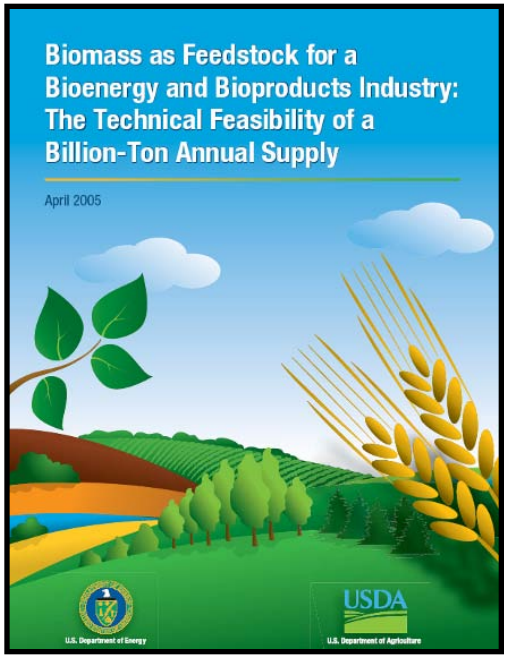
ORNL, U. Georgia, U. Tenn, NREL, Georgia Tech,
Noble Foundation, Dartmouth, ArborGen, Verenium, Mascoma

DOE Great Lakes Bioenergy Research Center

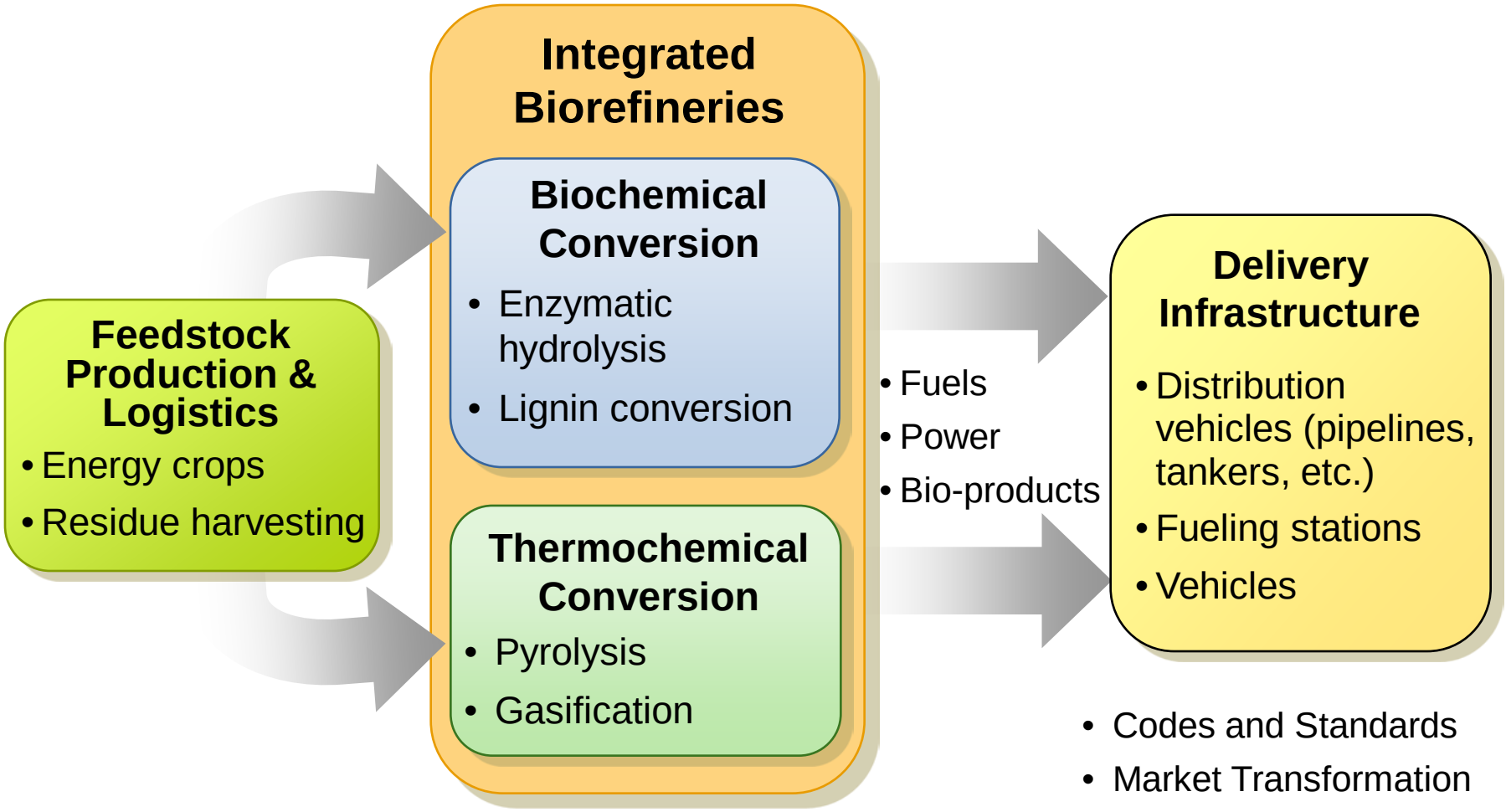
U Wisconsin, MSU, Illinois State, Iowa State, Lucigen,
U Florida, PNNL, ORNL

DOE Joint Bioenergy Institute

LBNL, LLNL, SNL, UC Davis, UC Berkeley, Carnegie Institute



Two Major Paths to Success



Success relies on simultaneous development of the supply, conversion, and demand infrastructures for biofuels.

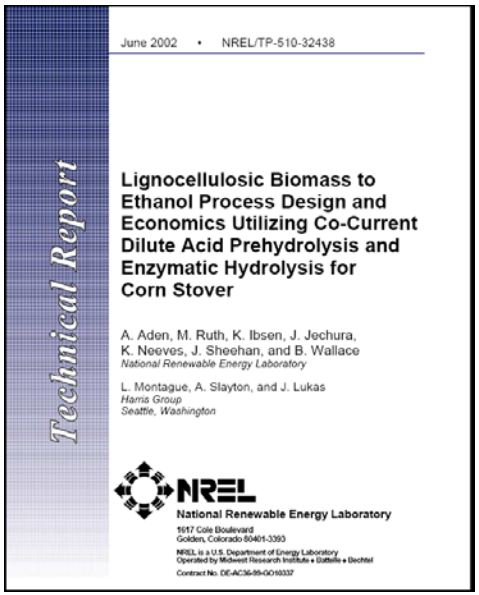
Biochemical Conceptual Design Report Drives R&D Direction

Enzyme Production

Pretreatment → Conditioning → Enzymatic Hydrolysis → Co-fermentation of C5 & C6 Sugars → Product Recovery → Ethanol

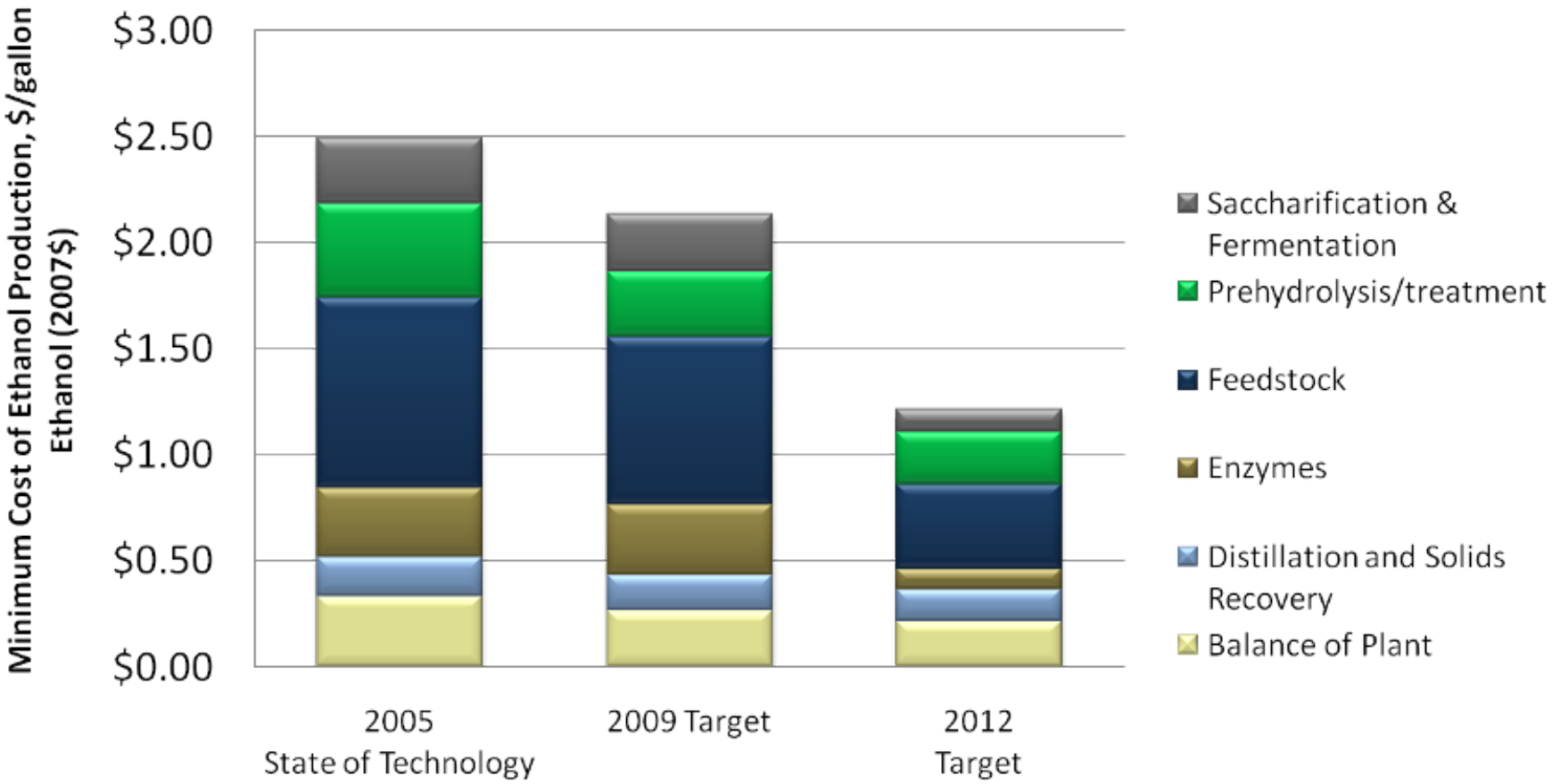
Hybrid Saccharification & Fermentation - HSF

Residue Processing → By-products



- **Conceptual design of a 2,000 tonnes/day commercial plant**
- **NREL pilot plant based on this process**
- **Basis for connecting R&D targets to cost targets**
- **Has undergone rigorous peer review**

Cellulosic Ethanol Cost Goals



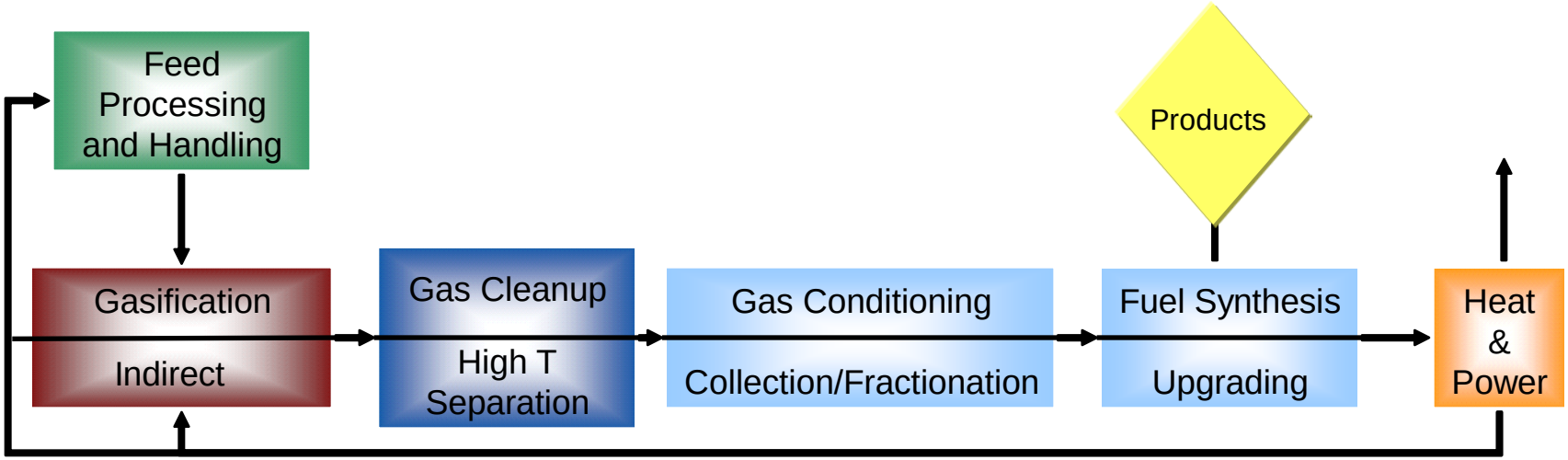
DOE efforts will lead to a substantial cost decline in the production of cellulosic ethanol

Biochemical Conversion FY07 State of Technology

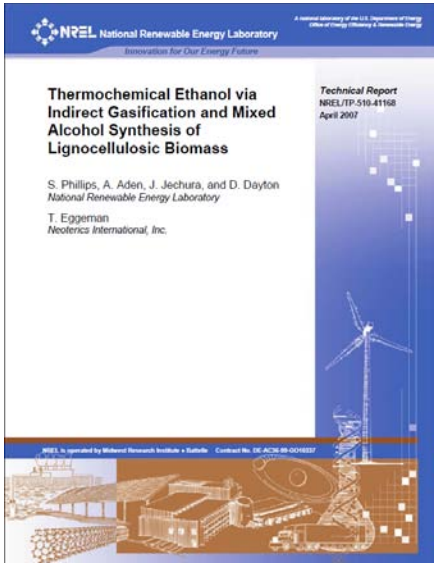
All FY07 targets were met or exceeded

	2005 Post Enzyme Subcontract	2007 Target	2007 Result	2008	2009	2010	2011	2012 Market Target
Minimum ethanol selling price	$2.47	**$2.40**	**$2.29**	$2.25	$2.07	$1.60	$1.43	$1.31
Installed capital per annual gallon	$2.94	**$2.57**	**$2.57**	$2.62	$2.57	$2.22	$2.04	$1.83
Yield (gallon/dry ton)	65	**68**	**72**	72	74	82	87	90
Pretreatment								
Solids loading (wt%)	30%	**30%**	**30%**	30%	30%	30%	30%	30%
Xylan to xylose	63%	**75%**	**75%**	75%	85%	85%	90%	90%
Xylan to degradation products	13%	**13%**	**13%**	8%	6%	6%	5%	5%
Conditioning								
Xylose sugar loss	13%	**11%**	**2%**	2%	2%	2%	1%	1%
Glucose sugar loss	12%	**12%**	**1%**	1%	1%	1%	1%	0%
Enzymes								
Enzyme contribution ($/gal EtOH)	$0.32	**$0.32**	**$0.32**	$0.32		$0.16		$0.10
Saccharification & Fermentation								
Combined saccharification & fermentation time (d)	7	**7**	**7**	7		5		3
Overall cellulose to ethanol	86%	**86%**	**86%**	86%		86%		86%
Xylose to ethanol	76%	**76%**	**76%**	80%		80%		85%
Arabinose to ethanol	0%	**0%**	**0%**	40%		80%		85%

Thermochemical Conceptual Design Report Drives R&D Targets



Indirect Gasification and Mixed Alcohol Synthesis



- **Conceptual design of a 2000 tonnes/day commercial plant**
- **NREL pilot plant based on this process**
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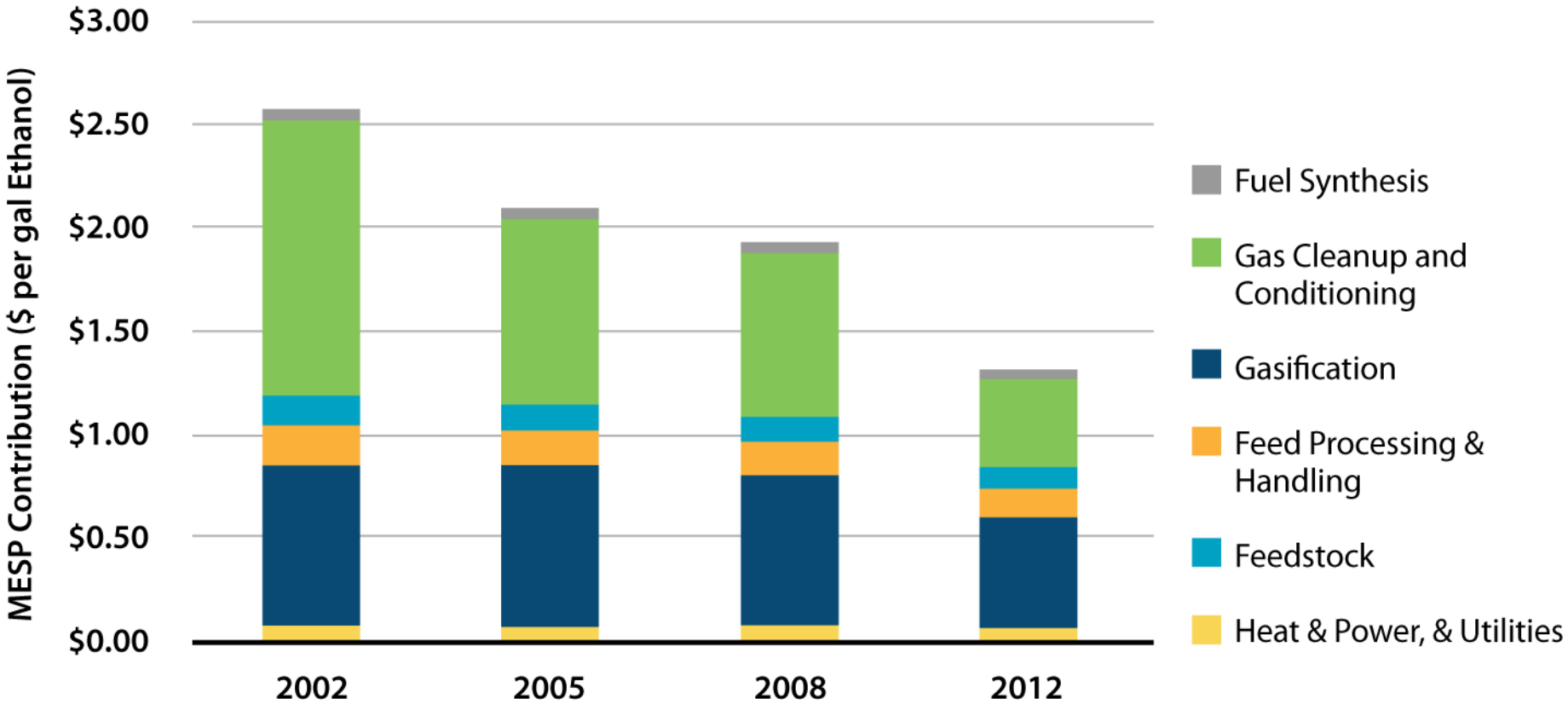
Costs on Target to Meet Goal

Thermochemical Conversion Cost Target Goal



Thermochemical Conversion FY07 State of Technology

All FY07 targets were met

	2002	2005	2007	2008	2009	2010	2011	2012
Minimum ethanol selling price ($/gal ethanol)	$2.56	$2.09	**$2.08**	$1.92	$1.65	$1.57	$1.33	$1.31
Installed capital cost ($/annual gal MA)	$4.79	$3.22	**$3.22**	$2.98	$2.55	$2.46	$2.21	$2.21
Mixed alcohol yield (gal/dry ton)	55.5	74.0	**74.0**	76.7	82.7	83.8	86.2	86.2
Feedstock								
Feedstock cost ($/dry ton)	$53	$53	**$53**	$51	$49	$48	$46	$44
Thermochemical Conversion								
Raw syngas methane (mol % - dry basis)	15.09	15.09	**15.09**	15.09	15.09	15.09	15.09	15.09
Cleanup and Conditioning								

Sustainability Challenges for Biomass to Biofuels Systems

Greenhouse Gas Emissions

Economic Prosperity
- Rural and urban communities
- Industry

Land
- Use and change
- Competition with food
- Soil carbon, health
- Erosion

Social Well-Being

Biodiversity

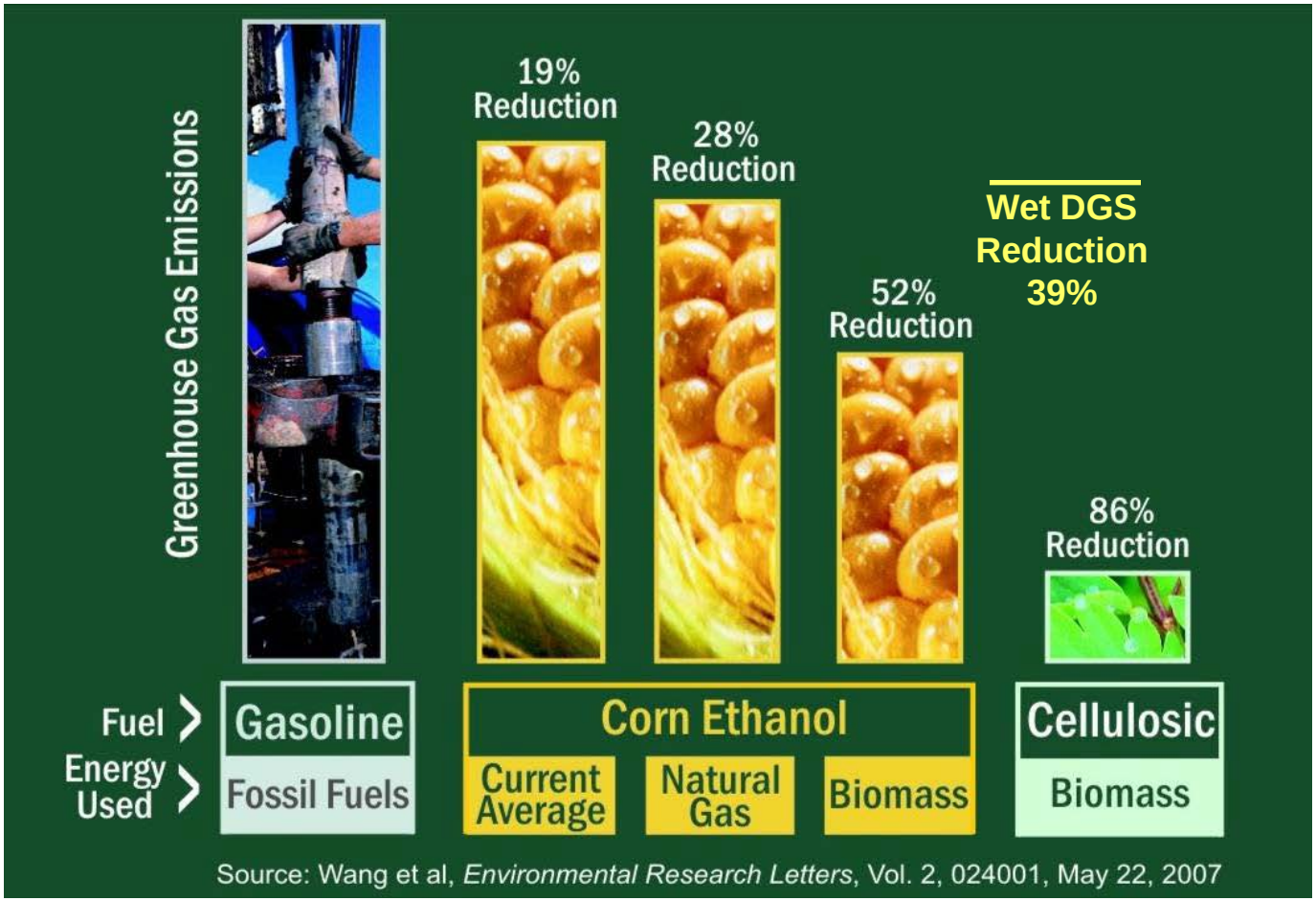
Air Quality
- Criteria Emissions
- Urban air backsliding
- Biofuels blending standards

Water
- Use
- Quality
- Efficiency of use

Environmental Impacts

Increase food and energy security while safeguarding soil, water, and biodiversity

GHG - Relative Emissions Impacts



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

Land Use Changes

- Global development of biofuels can result in significant land use change both regionally and globally (*Searchinger, 2008; Fargione, 2008*)
- Land use change can incur a carbon debt that can take decades or centuries to repay
- Biofuels is one driver in a complex global agronomic system that can affect land use change
- More detailed studies on biofuels development and the resulting effects on land use change necessary

Major DOE Accomplishments
(2007 – To Date)

The U.S. DOE has announced funding commitments totaling over $1 billion for biofuels-related projects since 2007.

These multi-year investments include:

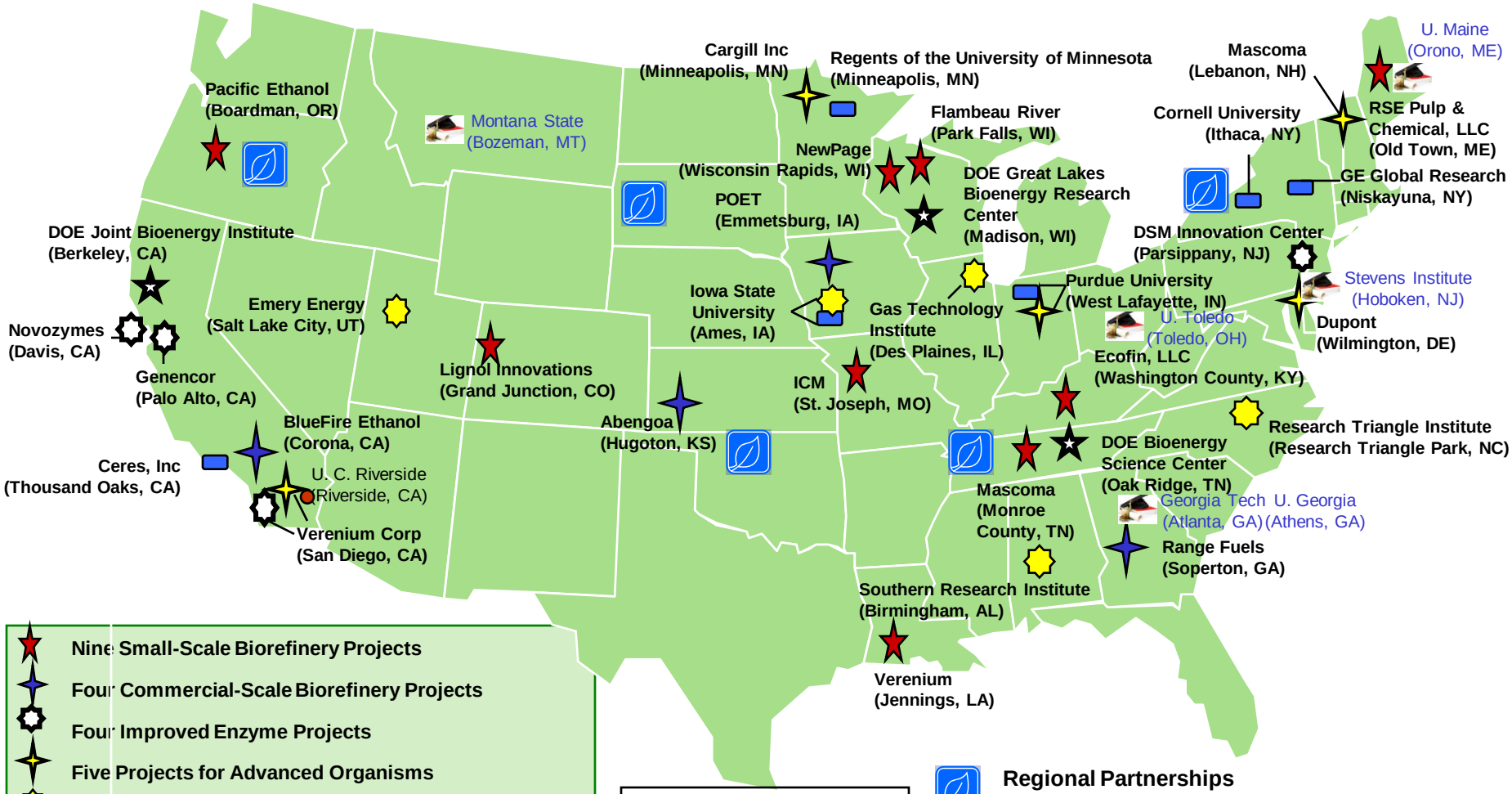
- $385 for commercial-scale biorefineries (6)
- $200 million for pilot-scale (10%) biorefineries (7)
- $23 million for more efficient fermentation microbes (5)
- $34 million for more efficient enzymes (4)
- $405 million for new bioenergy centers (3)

Many are being cost-shared by industry.
Some include foreign participants/technology.

U.S. Department of Energy
Energy Efficiency and Renewable Energ
Bringing you a prosperous future where energy is clean, abundant, reliable, an

Major DOE Biofuels Project Locations

Geographic, Feedstock, and Technology Diversity



- Nine Small-Scale Biorefinery Projects
- Four Commercial-Scale Biorefinery Projects
- Four Improved Enzyme Projects
- Five Projects for Advanced Organisms
- Five Thermochemical Biofuels Projects
- Three Bioenergy Centers
- DOE Joint Solicitation Biomass Projects
- Six University Projects (Biochem, thermochem, algae)

2002 Biorefinery Projects

DuPont – Wilmington, DE
Abengoa- York, NE
Cargill – Minnetonka, MN

Regional Partnerships

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

Legislative Incentives

- Incentives for cellulosic biomass suppliers
- Improve Loan Guarantee program for biofuel facilities and expand to pipelines
- Offer tax investment credits for state of the art biofuels production facilities
- Remove barriers to E10 nationwide (e.g. specs, logistics)
- Enable blends between E10 and E85
- Rethink E85 incentives
- Target full Flexible-Fuel Vehicle fleet penetration
- Extend ethanol subsidies to 2015 – rethink fixed credit model
- Alternative Fuel Standards legislation with defined cellulosic contribution
- Develop infrastructure codes and standards

Biofuels Beyond Ethanol

Today

Ethanol – as a blending agent from either grain or cellulosic material from Ag and/or Forestry industry

Biodiesel – Transesterified vegetable oils blended with diesel

Green Diesel – fats, algal oils, waste oils, or virgin oils converted to low-sulfur diesel in petroleum refinery

Higher alcohols – examples include: butanol, mixed alcohols, higher carbon alcohols (C5- and greater)

Fischer-Tropsch Liquids – and other products from syn gas including methanol, dimethyl ether, etc

Pyrolysis Liquids – alternative feedstock to petroleum refinery or gasification facility

Methanol derived fuels – Methanol to gasoline technology, dimethyl ether and other products

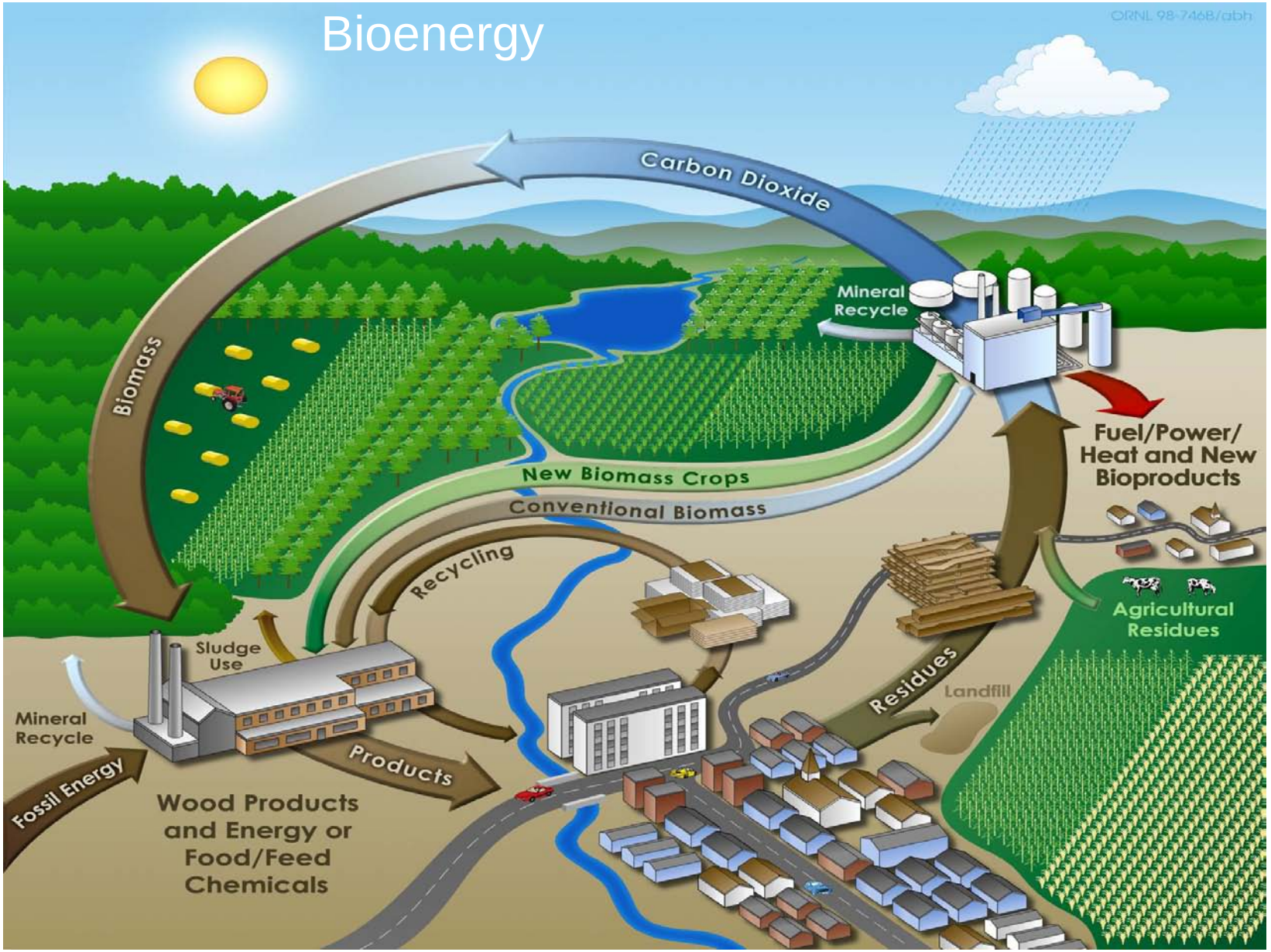
Other fuels – Liquid transportation fuels from sugars/oils refinery not discussed or yet envisioned

Future

Additional Information

- EERE Biomass Program
  - http://www.eere.energy.gov/biomass/
- NREL Biomass Research
  - http://www.nrel.gov/biomass/
- USDOE-USDA Biomass R&D Initiative
  - http://www.brdisolutions.com/

Questions?


Bioenergy
ORNL 98-7468/abh
Carbon Dioxide
Biomass
Mineral Recycle
Fuel/Power/ Heat and New Bioproducts
New Biomass Crops
Conventional Biomass
Recycling
Agricultural Residues
Sludge Use
Residues
Landfill
Mineral Recycle
Products
Fossil Energy
Wood Products and Energy or Food/Feed Chemicals