Production Economics and Environmental Sustainability of Advanced Biofuels

Transportation Research Board (TRB) 90th Annual Meeting

Andy Aden, PE

National Renewable Energy Laboratory (NREL)

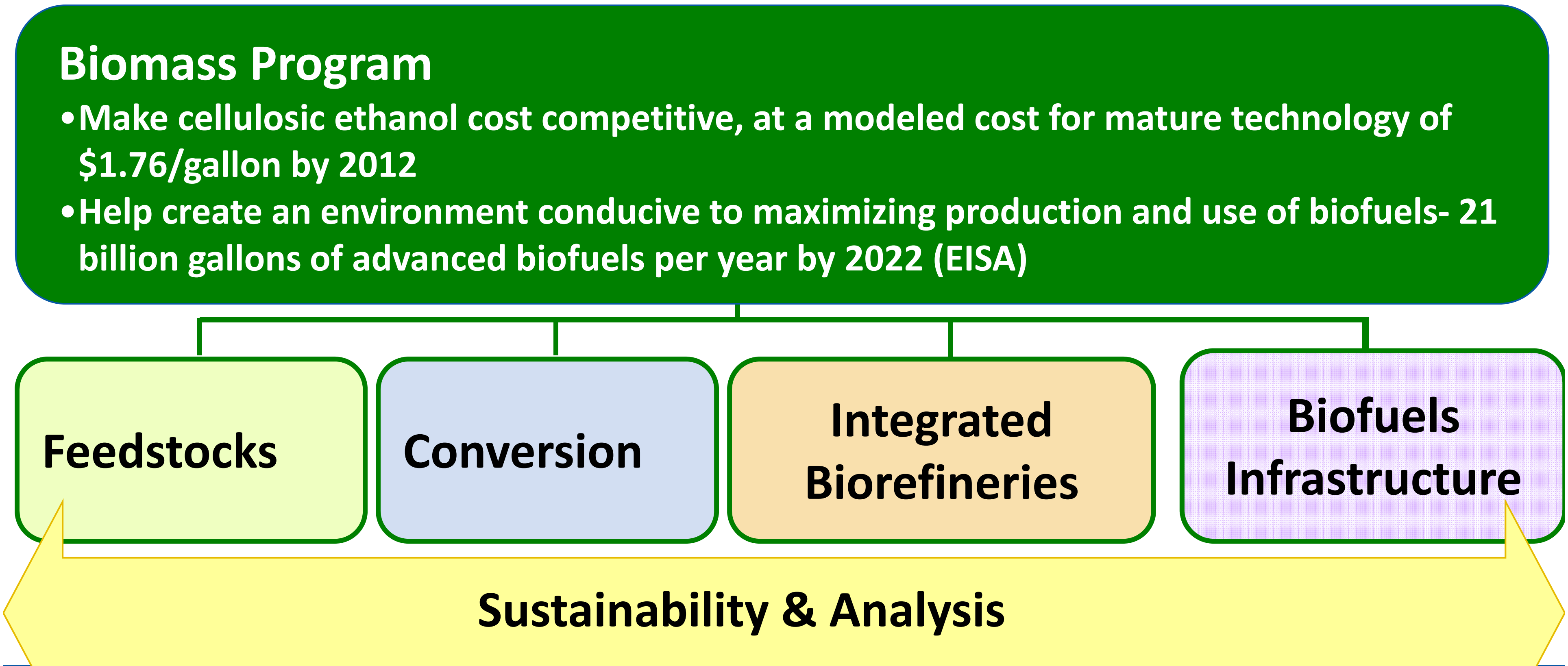
January 26, 2010

Biomass Program Mission and Objectives

Develop and transform our renewable and abundant, non-food, biomass resources into sustainable, cost-competitive, high-performance biofuels, bioproducts and biopower.

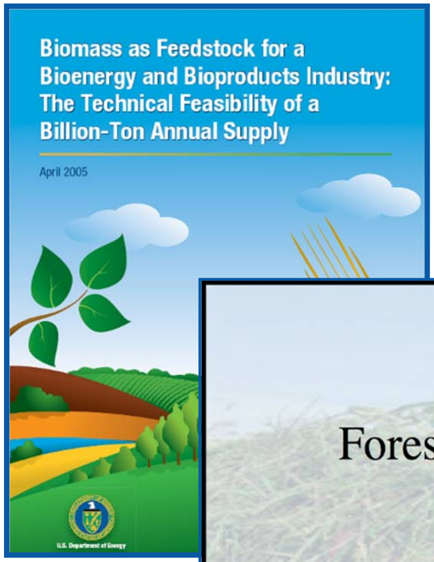
Focus on targeted research, development, and demonstration

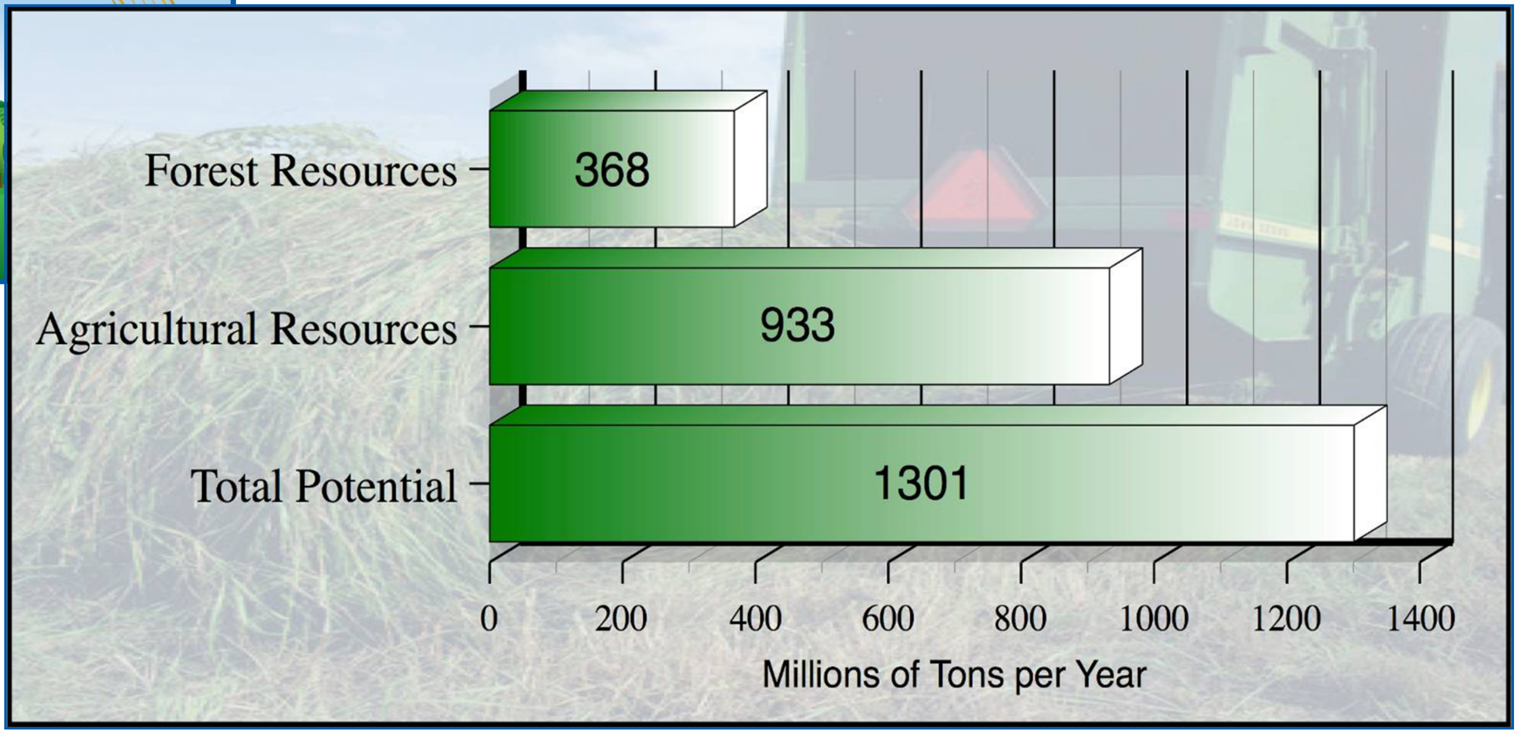
- Through public and private partnerships
- Deploy in integrated biorefineries



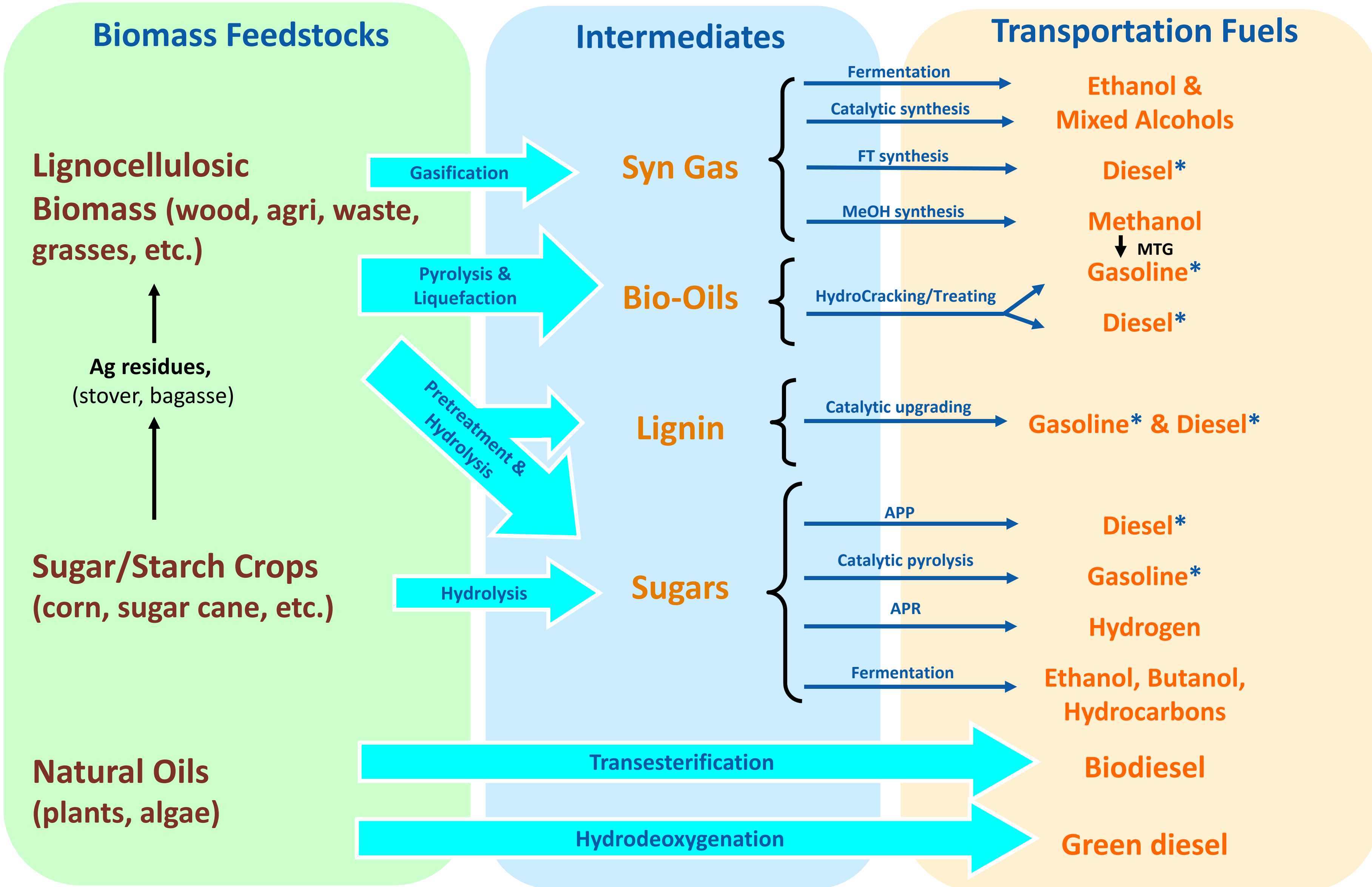
U.S. Biomass Resource Assessment

- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the "Billion Ton Study"
- Updated, release "imminent"





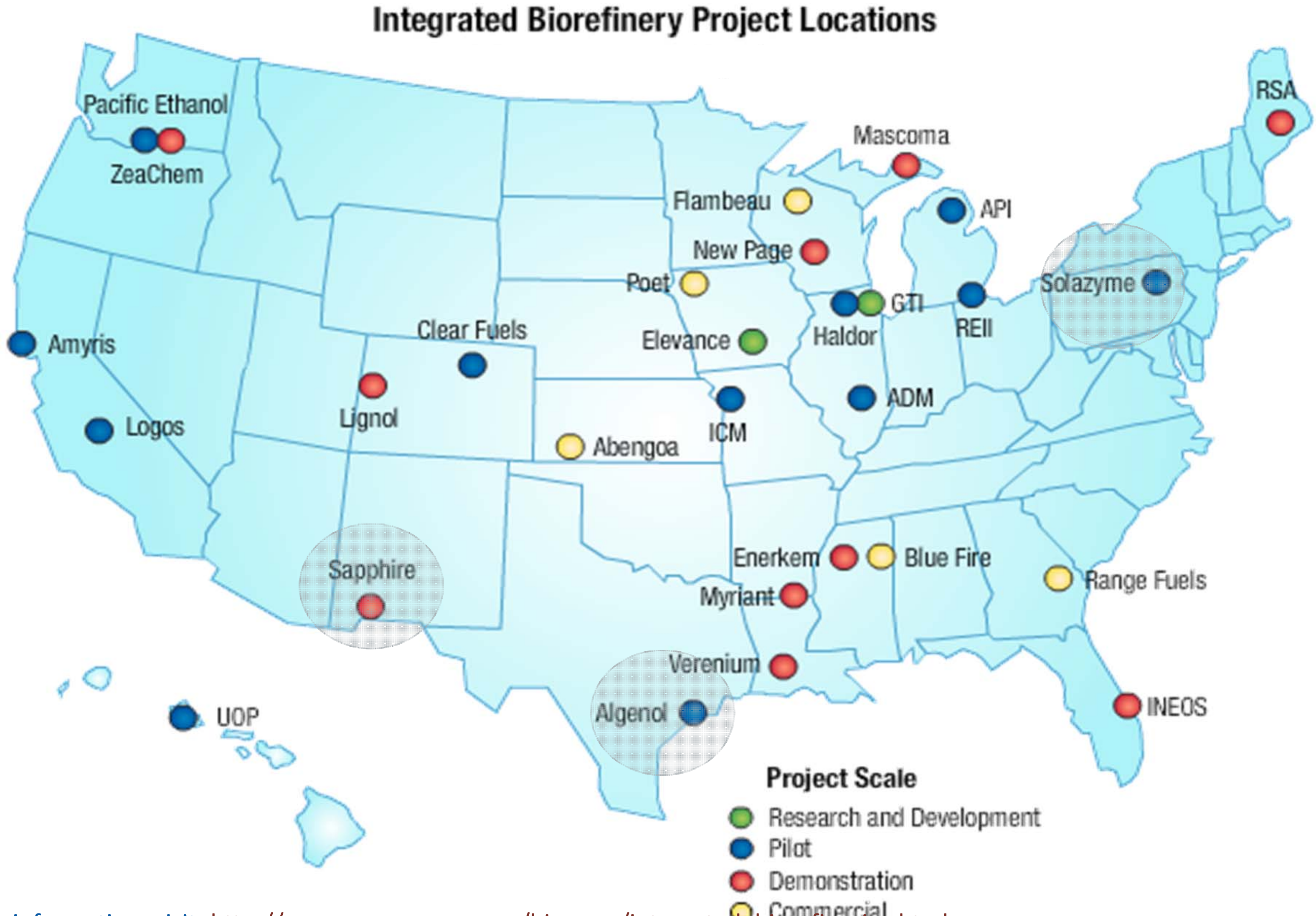
Biofuels Transportation Options



* Blending Products

Locations of DOE Integrated Biorefinery Projects

Does not include non-DOE funded projects



For more information, visit: http://www.eere.energy.gov/biomass/integrated_biorefineries.html

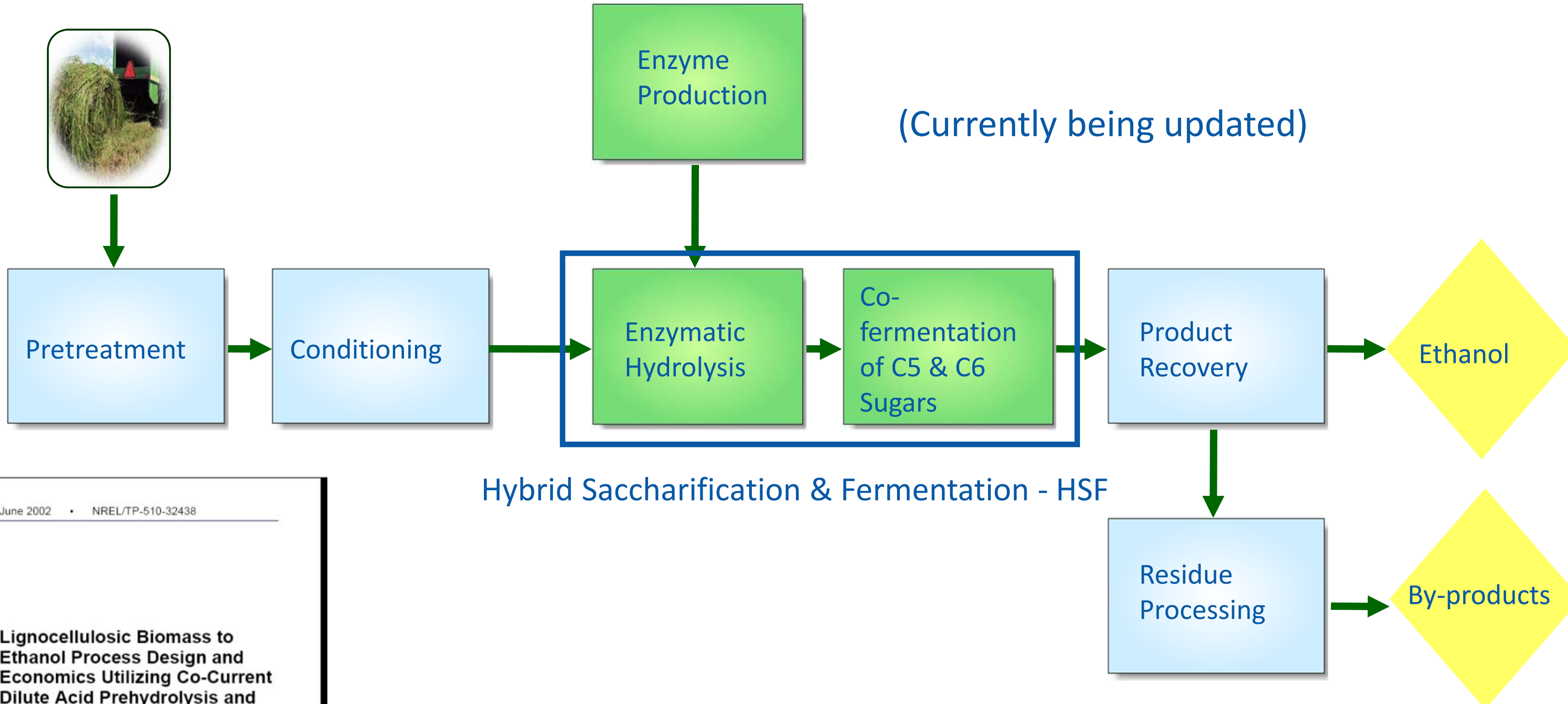
Integrated Biorefinery Research Facility

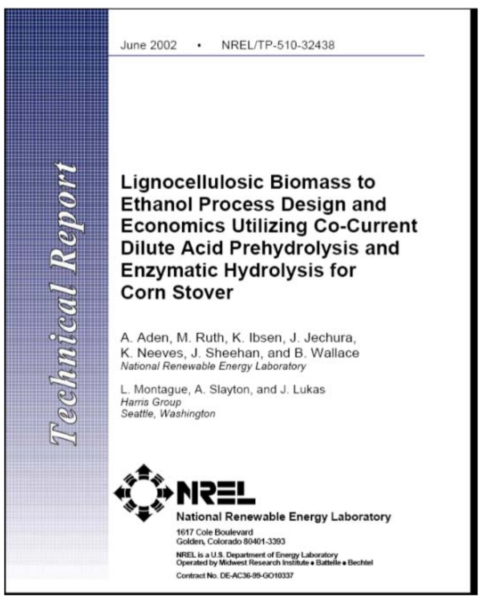
Capabilities

- State of the Art Pilot Scale Pretreatment Equipment Capable of Demonstrating 2012 Core Research Program Targets
- 2 Parallel Processing Trains Enabling a Focus on Cost Reduction Areas for 2012 & Beyond
- Provides Multiple Biomass Pretreatment/Feedstock Options for R&D and Demonstration Support (unparalleled flexibility)
- Significantly Improves the Capability and Probability for Industry Partnerships and Commercialization Support
- Positioned as Prime DOE Facility for Pilot Scale Pretreatment and Enzymatic Saccharification R&D for the Future

March 2010

Biochemical Conceptual Design Report Drives R&D Direction





June 2002 • NREL/TP-510-32438

Technical Report

Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover

A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace
National Renewable Energy Laboratory

L. Montague, A. Slayton, and J. Lukas
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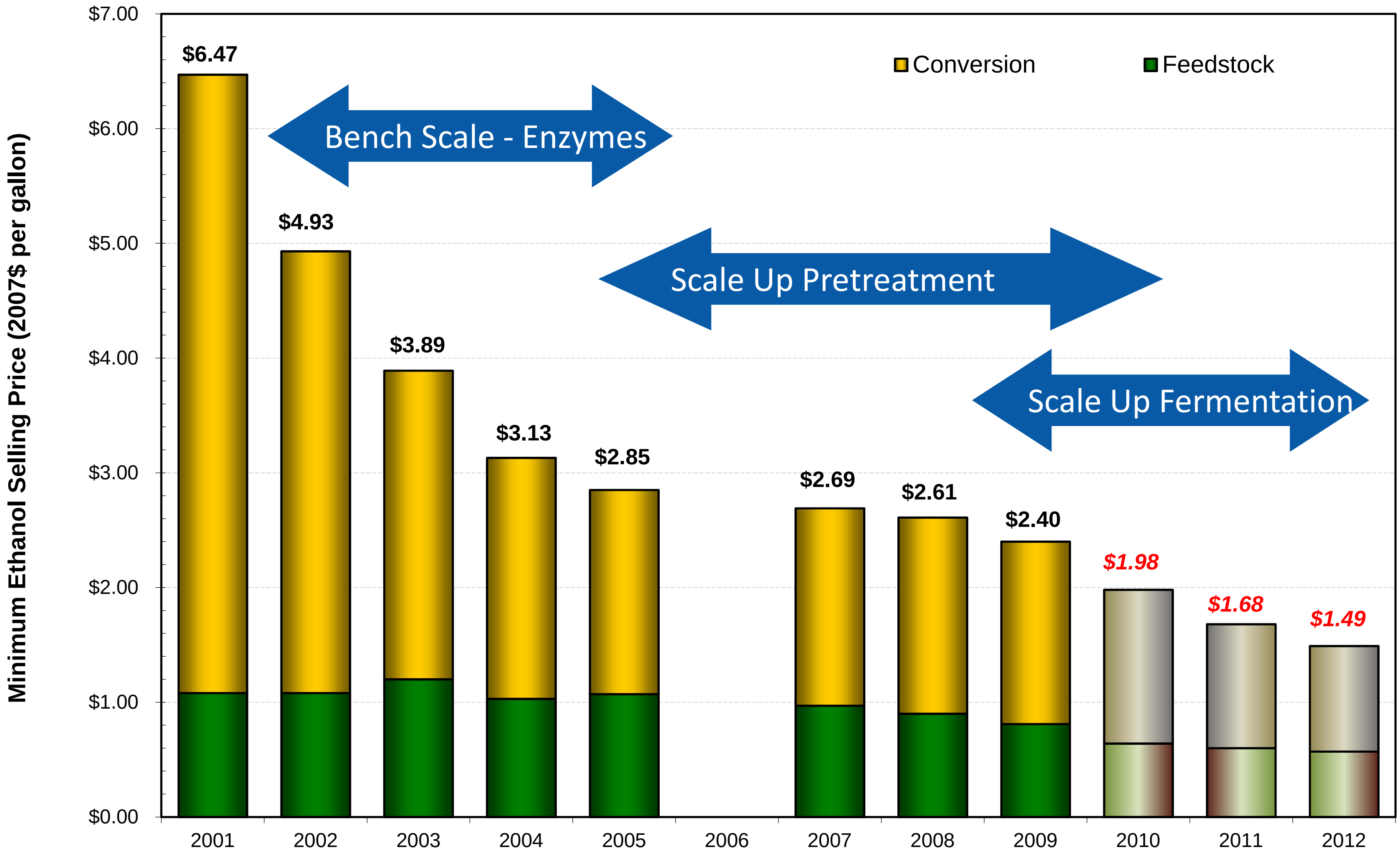
- **Conceptual design of a 2,000 tonnes/day commercial plant – one possible tech package, not optimized**
- **NREL pilot plant based on this process**
- **Basis for connecting R&D targets to cost targets**
- **Has undergone rigorous peer review**
- **Basis for comparison against other technology options**

Biochemical Conversion: *State of Technology*



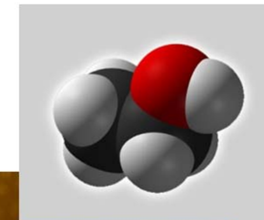
Technical Achievements Translate into Cost Savings

	2005	2008	2009	*2010 Target*	*2012 Target*
Minimum Ethanol Selling Price ($/gal)	**$2.86**	**$2.61**	**$2.40**	***$1.98***	***$1.49***
Feedstock Contribution ($/gal)	$1.07	$0.90	$0.82	*$0.65*	*$0.57*
Conversion Contribution ($/gal)	$1.79	$1.72	$1.58	*$1.33*	*$0.92*
Yield (Gallon/dry ton)	65	73	77	*83*	*90*
Feedstock					
Feedstock Cost ($/dry ton)	$69.60	$65.30	$62.05	*$53.70*	*$50.90*
Pretreatment					
Solids Loading (wt%)	30%	30%	30%	*30%*	*30%*
Xylan to Xylose (including enzymatic)	63%	75%	84%	*85%*	*90%*
Xylan to Degradation Products	13%	11%	6%	*6%*	*5%*
Conditioning					
Ammonia Loading (mL per L Hydrolyzate)	N/A (lime)	50	38	*50*	*25*
Hydrolyzate solid-liquid separation	Yes	yes	yes	*Yes*	*no*
Xylose Sugar Loss	13%	2%	2%	*2%*	*1%*
Glucose Sugar Loss	12%	1%	1%	*1%*	*0%*
Enzymes					
Enzyme Contribution ($/gal EtOH)	$0.35	$0.35	$0.35	*$0.17*	*$0.12*
Enzymatic Hydrolysis & Fermentation					
Total Solids Loading (wt%)	20%	20%	20%	*20%*	*20%*
Sugar loss to contamination	7%	7%	7%	*7%*	*3%*
Combined Saccharification & Fermentation Time (d)	7	7	7	*5*	*3*
Corn Steep Liquor Loading (wt%)	1%	1%	1%	*1%*	*0.25%*
Overall Cellulose to Ethanol	86%	85%	84%	*85%*	*85%*
Xylose to Ethanol	76%	80%	82%	*80%*	*85%*
Minor Sugars to Ethanol	0%	0%	51% (arab)	*80%*	*85%*

Thermochemical Platform: *Gasification and Mixed Alcohols Synthesis*

Biomass via synthesis gas to fuels

- Deconstruct biomass all the way to light gases (CO & H_2)
- Convert syngas to liquid fuels



Biomass

↓

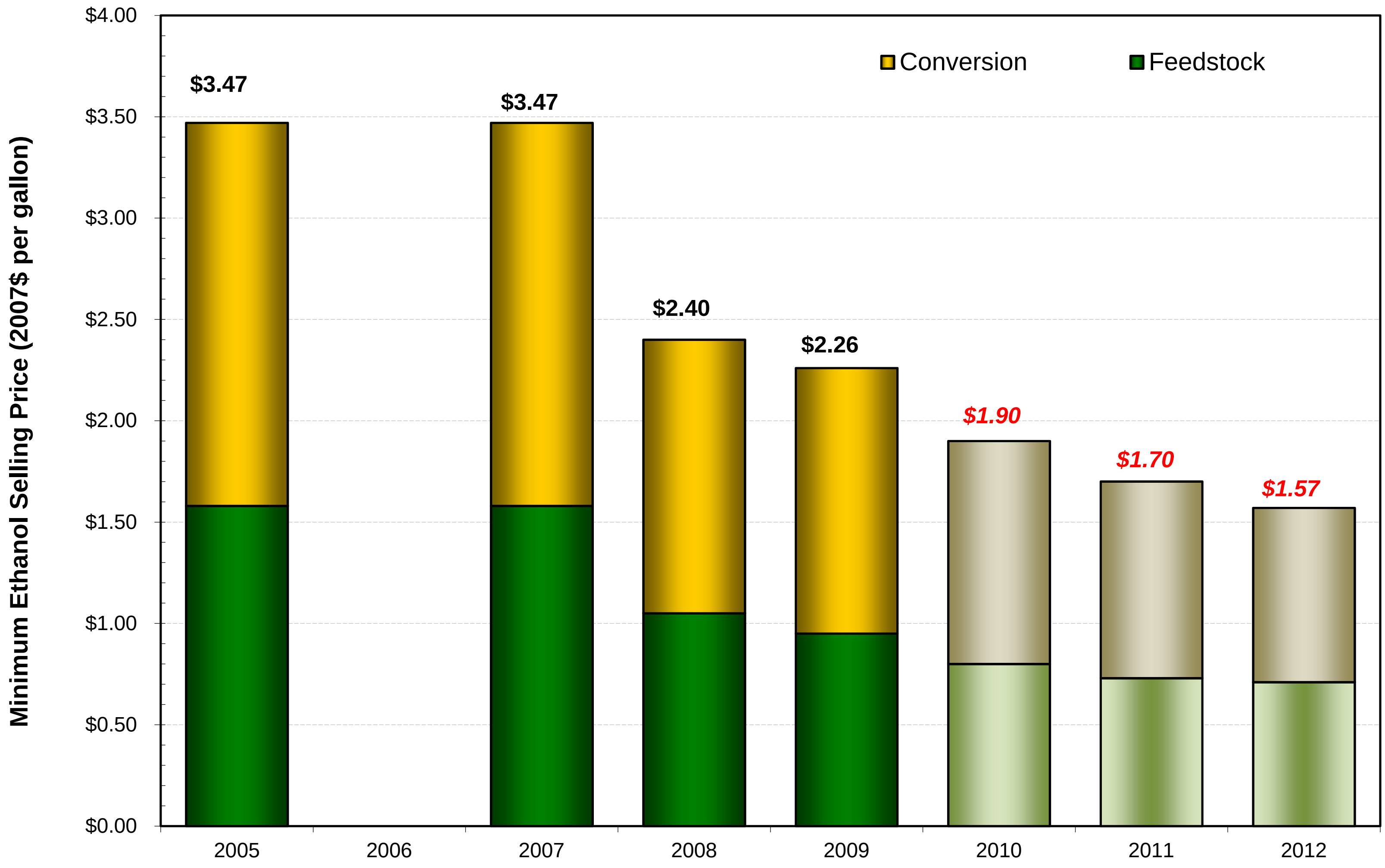
Feed Processing → Gasification → Syngas Cleanup & Conditioning → Fuel Synthesis

↑

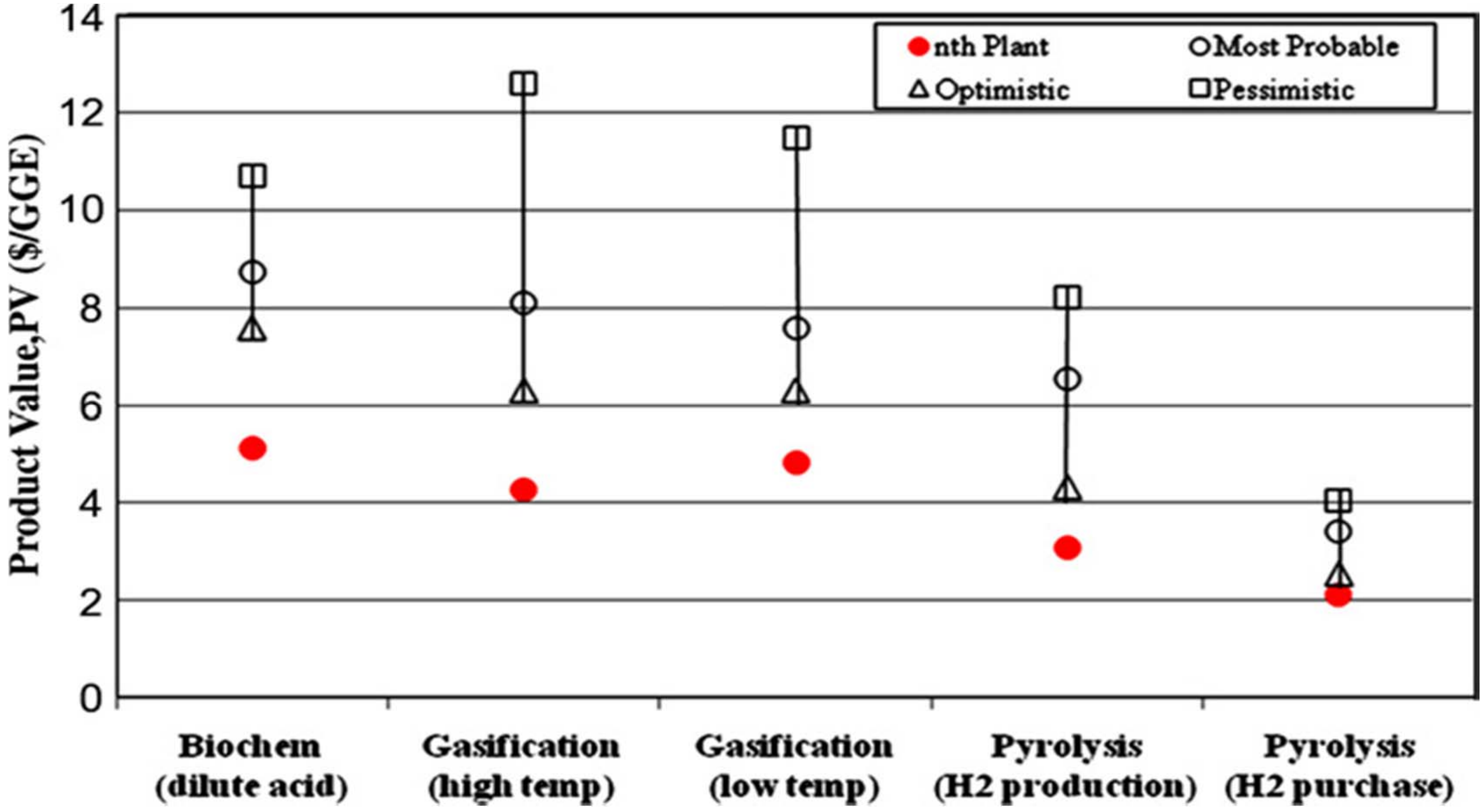
Transportation Fuels

- Feed Processing: *Minimize ash and moisture as needed*
- Gasification: *Limit tar formation*
- Syngas Cleanup & Conditioning: *Reform methane and tar, mitigate S as necessary*
- Fuel Synthesis: *Catalytic conversion of syngas*

Thermochemical Conversion: *State of Technology*



Understanding First-of-a-kind Economics vs. n^{th}-of-a-kind



ConocoPhillips / Iowa State / NREL Collaboration

Anex, et.al. "*Techno-economic Comparison of Biomass to Transportation Fuels via Pyrolysis, Gasification, and Biochemical Pathways*", 2010, FUEL, doi:10.1016/j.fuel.2010.07.015

National Advanced Biofuels Consortium

Project Objective – Develop cost-effective technologies that supplement petroleum-derived fuels with advanced “drop-in” biofuels that are compatible with today’s transportation infrastructure and are produced in a sustainable manner.

ARRA Funded:

- 3 year effort
- DOE Funding $35.0M
- Cost Share $12.5M

Total $47.5M

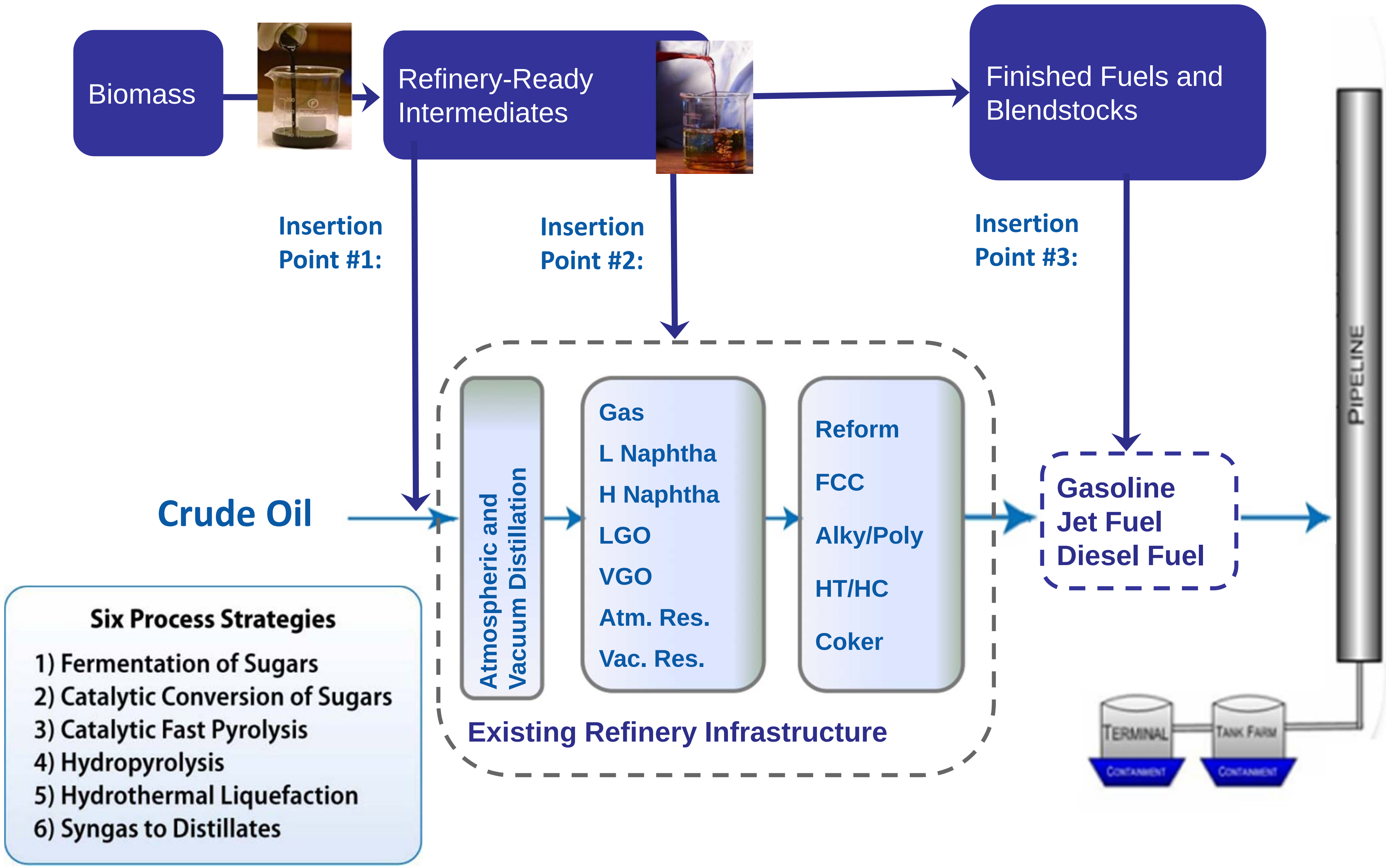
Consortium Leads

National Renewable Energy Laboratory
Pacific Northwest National Laboratory

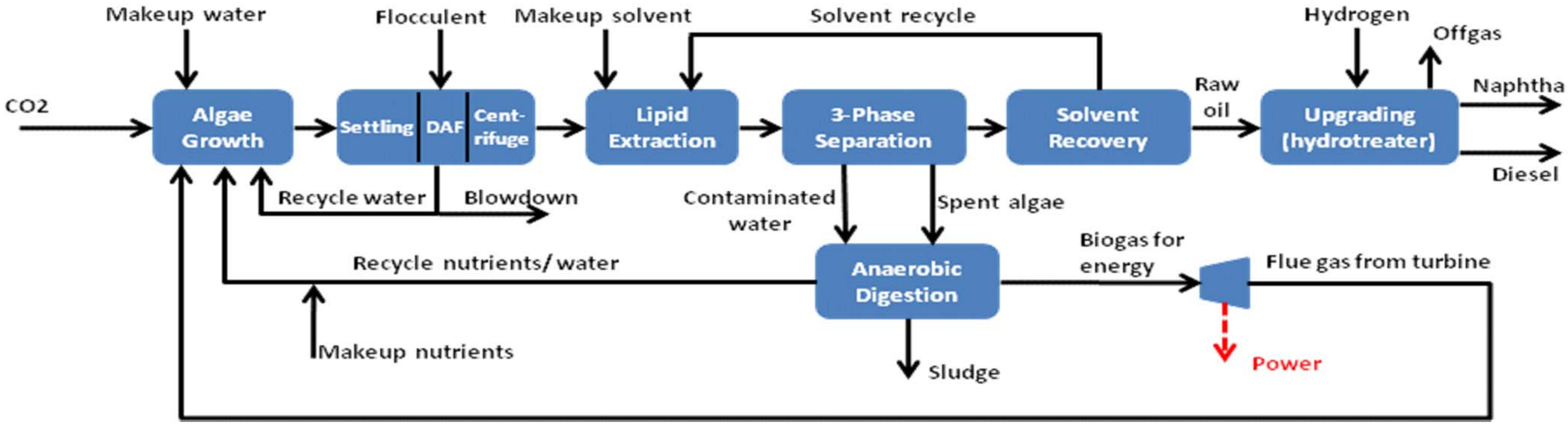
Consortium Partners

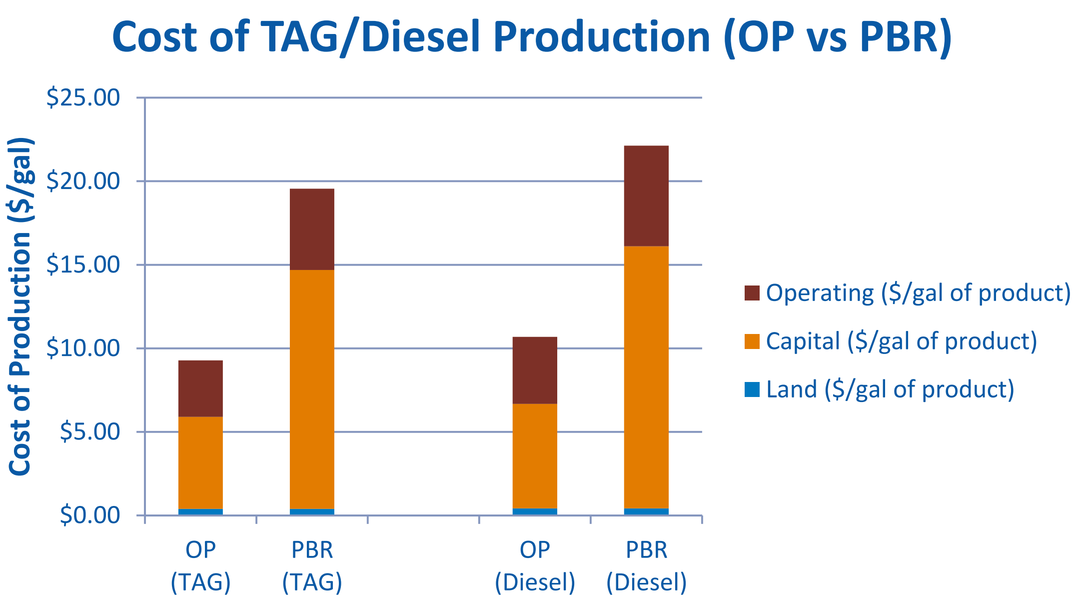
Albemarle Corporation
Amyris Biotechnologies
Argonne National Laboratory
BP Products North America Inc.
Catchlight Energy, LLC
Colorado School of Mines
Iowa State University
Los Alamos National Laboratory
Pall Corporation
RTI International
Tesoro Companies Inc.
University of California, Davis
UOP, LLC
Virent Energy Systems
Washington State University

NABC Infrastructure Compatibility Strategy



Algae Technoeconomics and Dashboard Tools





NREL has developed for DOE baseline economics for 3 algae pathways:

- Open pond (autotrophic)
- Closed photobioreactor (autotrophic)
- Heterotrophic

NREL has also created simple spreadsheet dashboard tools

Sustainability across the Biomass Program

Strategic Objectives: Toward Sustainable Biofuels

Feedstock Production → Conversion Technologies → Integrated Biorefineries → Infrastructure

Feedstocks

Field-based research to evaluate nutrient and carbon cycling; Collecting biomass physical and chemical properties impacting land use sustainability

Biochemical Conversion

Minimizing water consumption and air pollution, maximizing efficiency

Thermochemical Conversion

Minimizing water consumption and air pollution, maximizing efficiency

Integrated Biorefineries

Monitoring and improving the carbon footprint of new facilities; promoting co-product utilization and fully integrated systems

Biofuels Infrastructure

Ensuring minimal greenhouse gas emissions and avoidance of negative impacts on human health

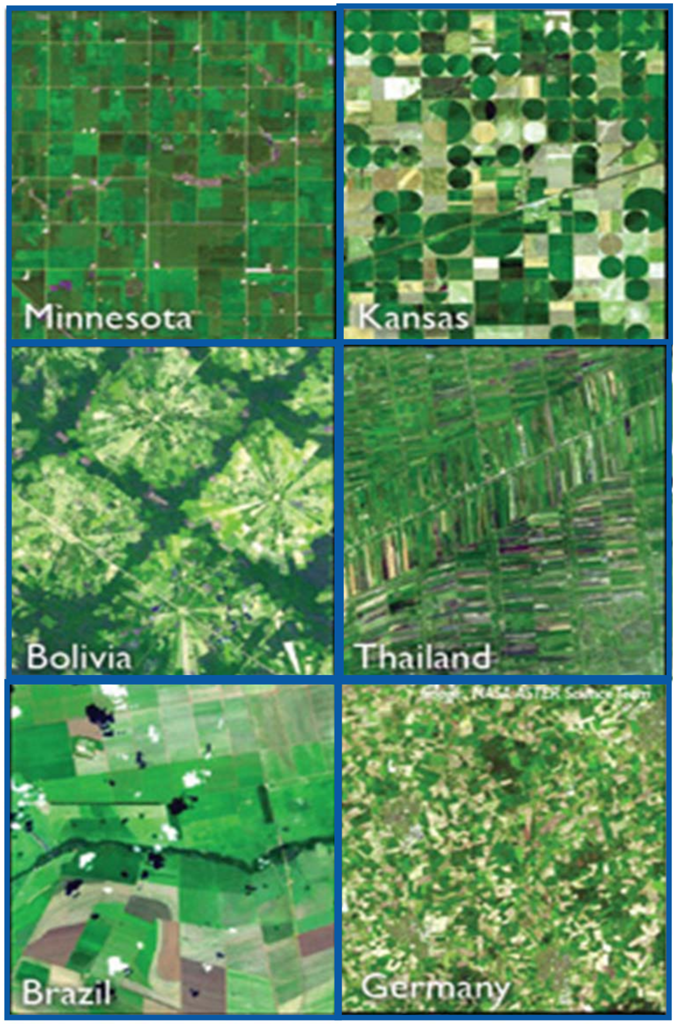
Cross-cutting

Life cycle analysis of water consumption and greenhouse gas emissions; land use change modeling; water quality analysis of biofuels

Projects in Progress: Land-use change

Indirect Effects of Biofuels

- Defining sustainability and its metrics
- Evaluation of assumptions and definitions used in current analysis of land-use effects of bioenergy
- Determination of key drivers of land-use change
- Identification of factors not in current analysis of indirect effects
- Refining models to help study international land-use change issues due to growth of biofuels



Land-Use Change and Bioenergy Workshop (May 2009)

- Experts in the field gathered to prioritize next steps for research needed to address key land-use issues
- Final report is available

Conclusions

Biofuels have significant potential to provide environmental sustainability and energy security benefits beyond today's current transportation picture

Conventional biofuels are facing limitations

Advanced biofuels are on the brink of commercial reality, however, challenges remain (technical, financial, market)

Competition for biomass resources is likely, there is no "optimal" use of biomass

Increased sustainability (economic, environmental, social) is possible if developed correctly

Thank you!!

DOE's Office of the Biomass Program

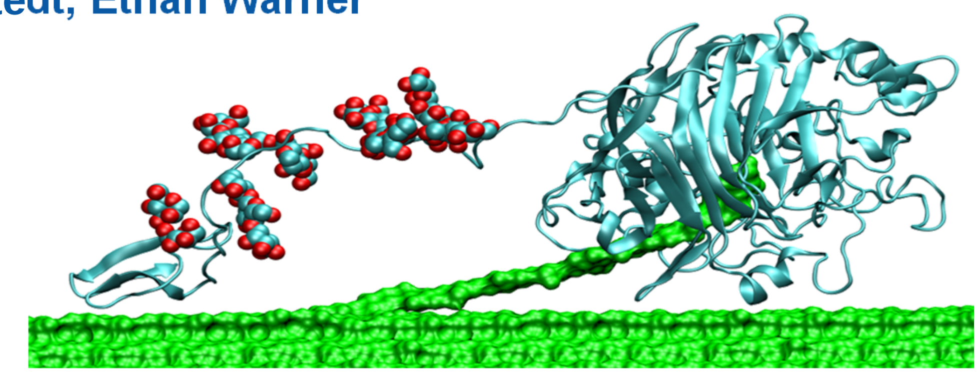
http://www.eere.energy.gov/biomass

NREL Biorefinery Analysis Team

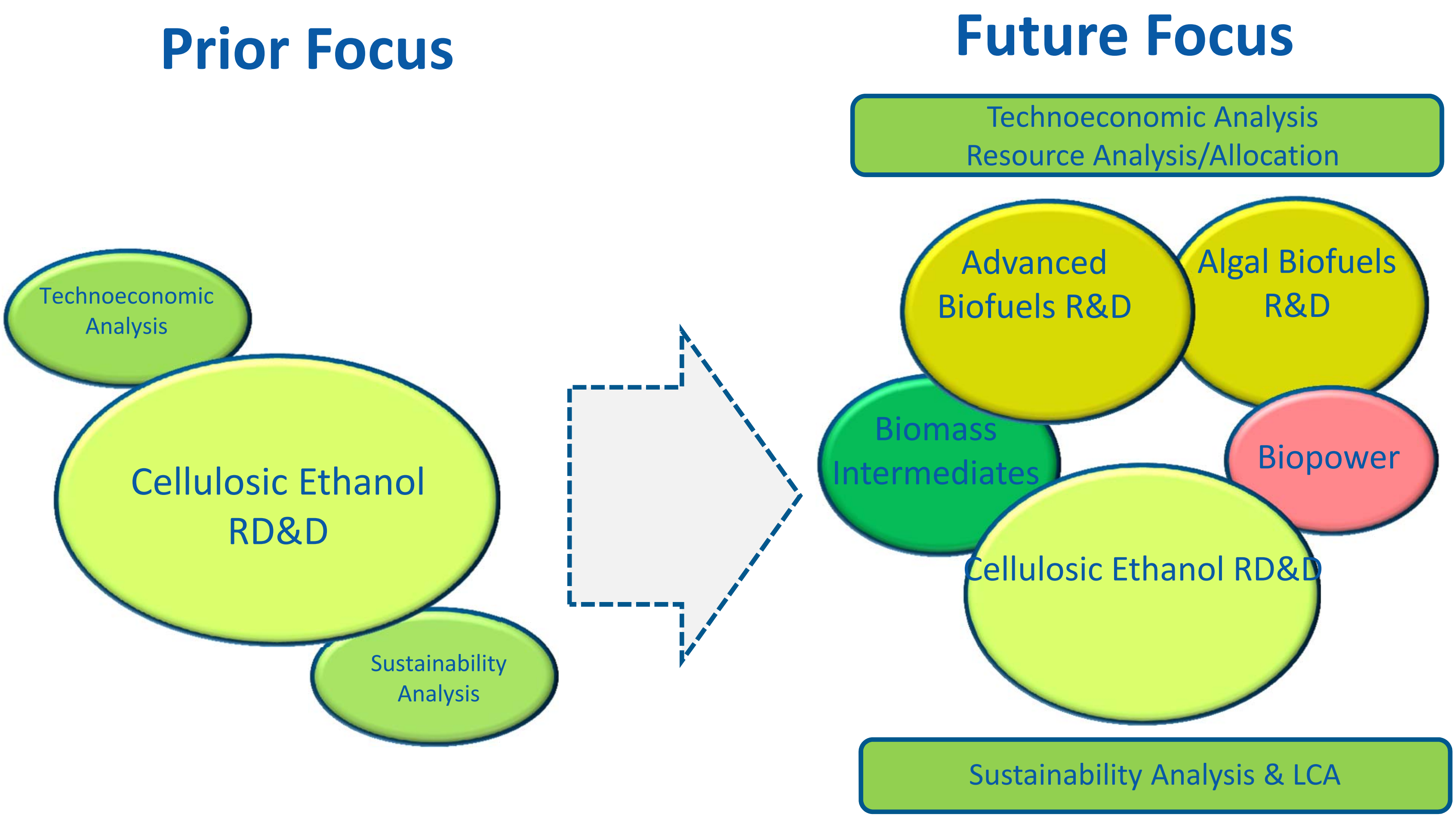
– Andy Aden, Mary Biddy, Ryan Davis, Abhijit Dutta, Dave Humbird, Danny Inman, Chris Kinchin, Mike Talmadge, Eric Tan, Ling Tao

Other NREL analysts

- Brian Bush, Helena Chum, Garvin Heath, David Hsu, Jordan Macknick, Margaret Mann, Anelia Milbrandt, Kristi Moriarty, Mark Ruth, Laura Vimmerstedt, Ethan Warner



Biomass R&D Evolution



The Consumer Standpoint

Conflicting Information and Misinformation has Led to Significant Confusion

Conventional biofuels:
Corn ethanol, Sugarcane ethanol, Biodiesel

Corn Ethanol As of January 2010:

- 187 operating plants
- Installed Capacity: 13 billion gallons per year
- Annual Production: 10.6 billion gallons per year (2009)

Two major markets facing market challenges:

- Blend market (up to E10) – facing market saturation
- Flex-fuel market (E-85) – very slow growth

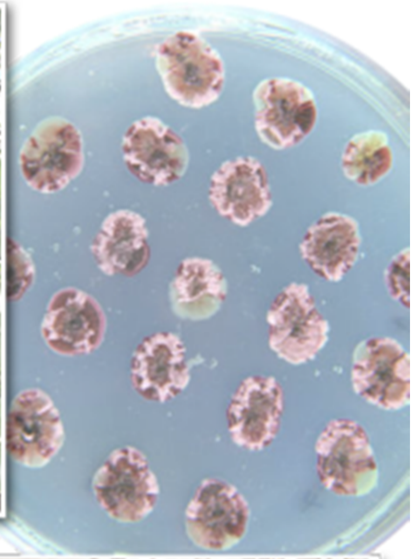
October 2010, EPA partially grants E-10 waiver to allow E-15 in cars manufactured in year 2007 and beyond.

VEETC credit exists ($0.45/gallon) but is being debated

Sugarcane ethanol (Brazil):
-Subject to tariff ($0.54/gallon)

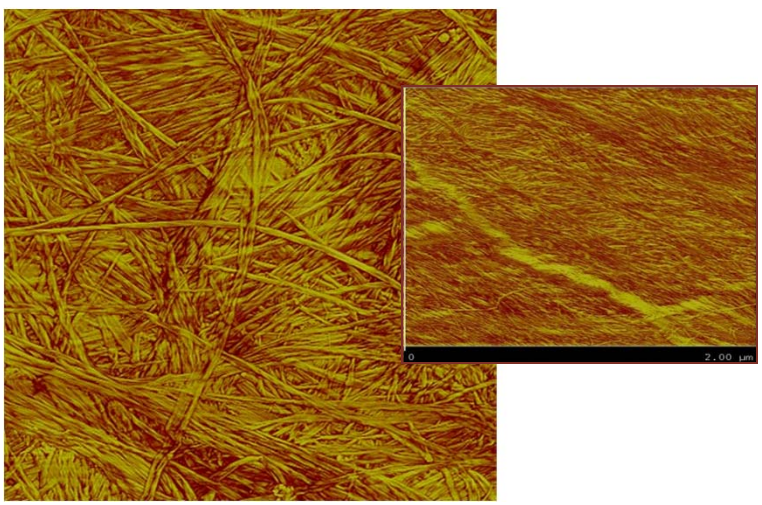
Biodiesel

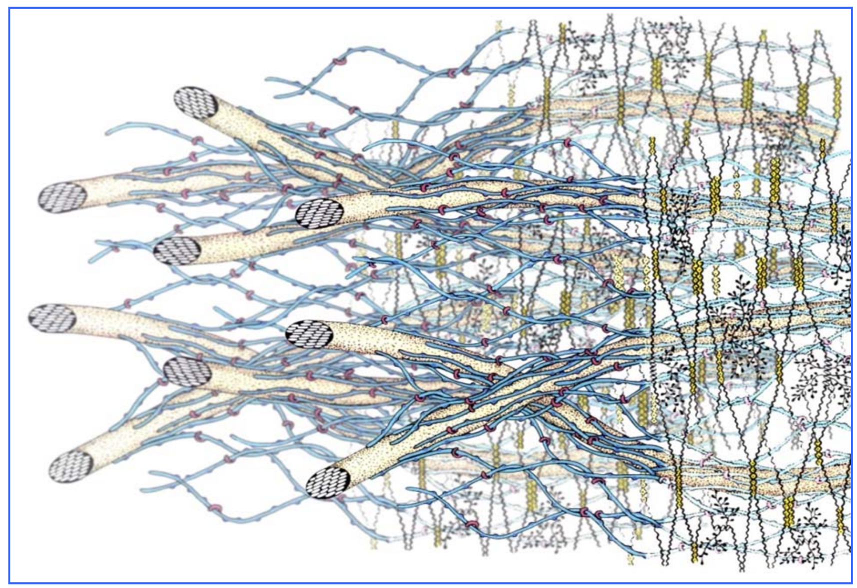
- Industry suffered from lack of federal tax credit



Cellulosic Conversion Technology Significantly More Challenging than Conventional

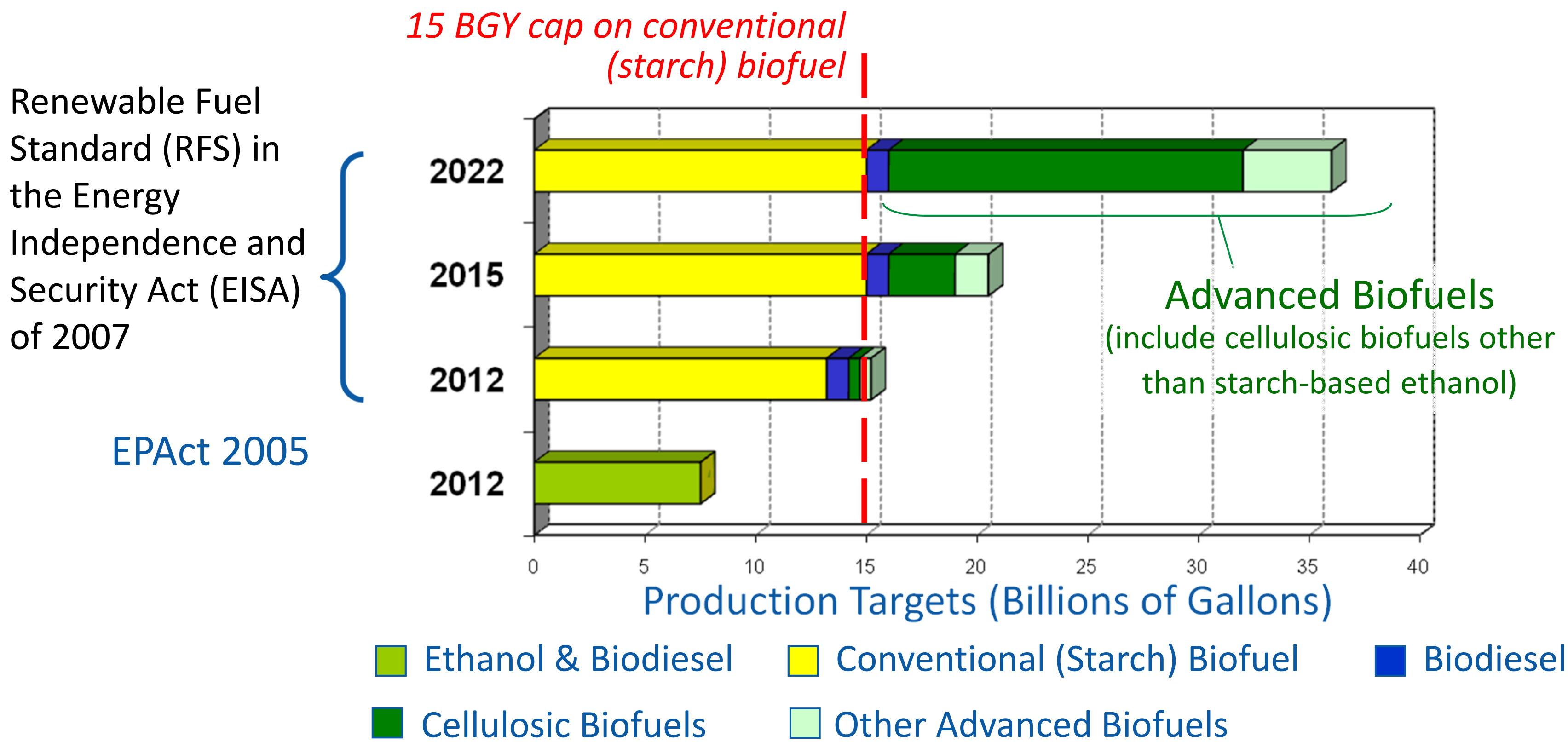
- Cellulose sugars more tightly bonded than starch
- Matrix of hemicellulose, cellulose, and lignin polymers
- Multiple sugars in biomass
- Feedstock heterogeneity





Carpita, N.C. & Gibeaut, D.M. 1993. Structural models of primary cell walls in flowering plants: consistency of molecular structure with the physical properties of the walls during growth. The Plant Journal **3** (1), 1-30.

Energy Independence and Security Act Mandated Production Targets



EISA defines *Advanced Biofuel* as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are *at least 50 percent less* than baseline lifecycle greenhouse gas emissions."

Cellulosic ethanol technology is important to reaching the 2022 EISA target, however, other advanced biofuels will be needed to aid in this endeavor.