Technology Commercialization Showcase 2008
Office of the Biomass Program

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Agenda

- Industry Landscape
- Program Objectives
- Technology Commercialization Opportunities

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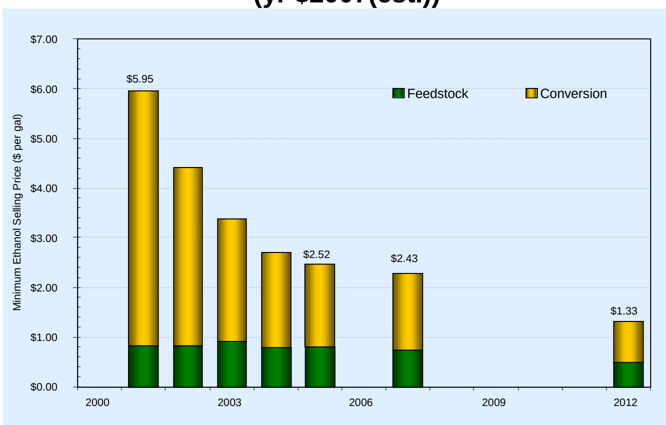
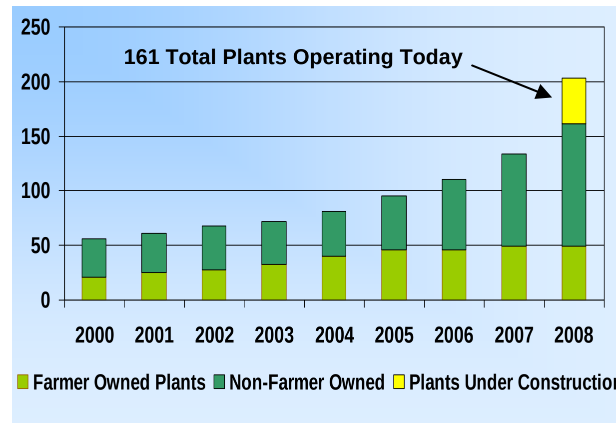
The Industry Landscape

- The growth in the existing ethanol and biofuels industry has been over 50% per year
- Current corn ethanol capacity and including plants under construction will easily meet the EISA corn ethanol cap
- The combination of cellulosic biofuels cost reduction and current demonstration projects are poised to spur investment in advanced biofuels helping to achieve the RFS objectives of EISA

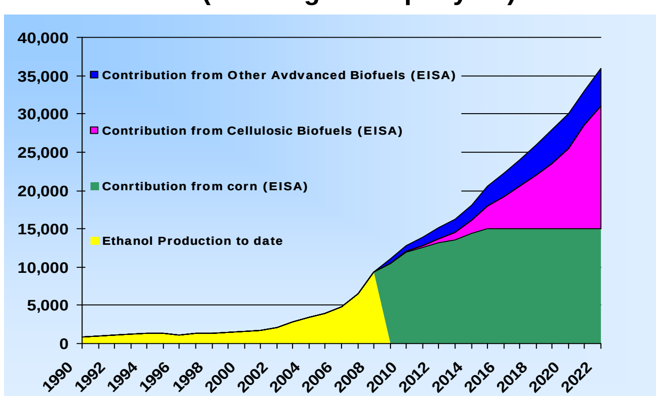
State of Technology (yr $2007(est.))



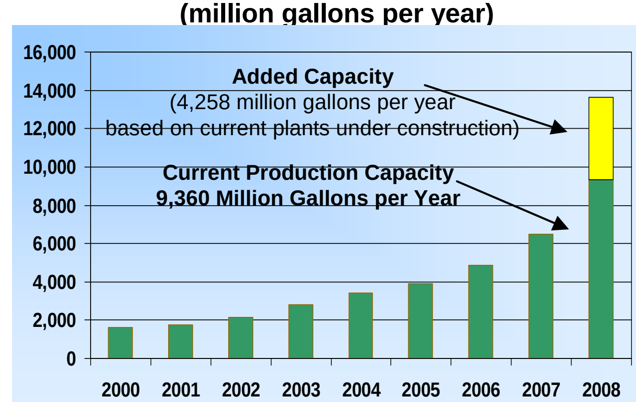
U.S. Ethanol Production Facilities 2000 - 2008



U.S. Biofuels Production and EISA Requirements (million gallons per year)

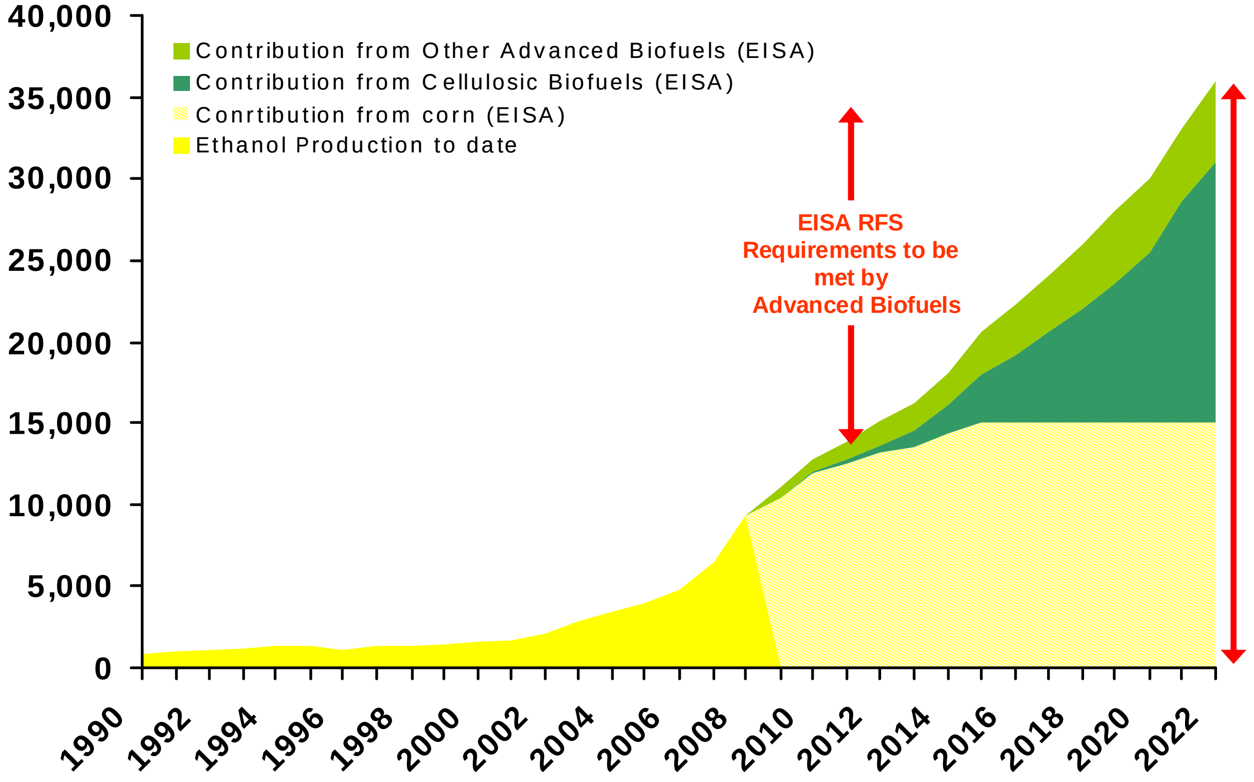


U.S. Ethanol Production Capacity (million gallons per year)



Sources: Renewable Fuels Association, EISA, NREL

Biofuels Production, EISA Requirements and Opportunities (Million Gallons/Year)



Sources: EISA & Renewable Fuels Association (As of July 14, 2008)

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Program Overview

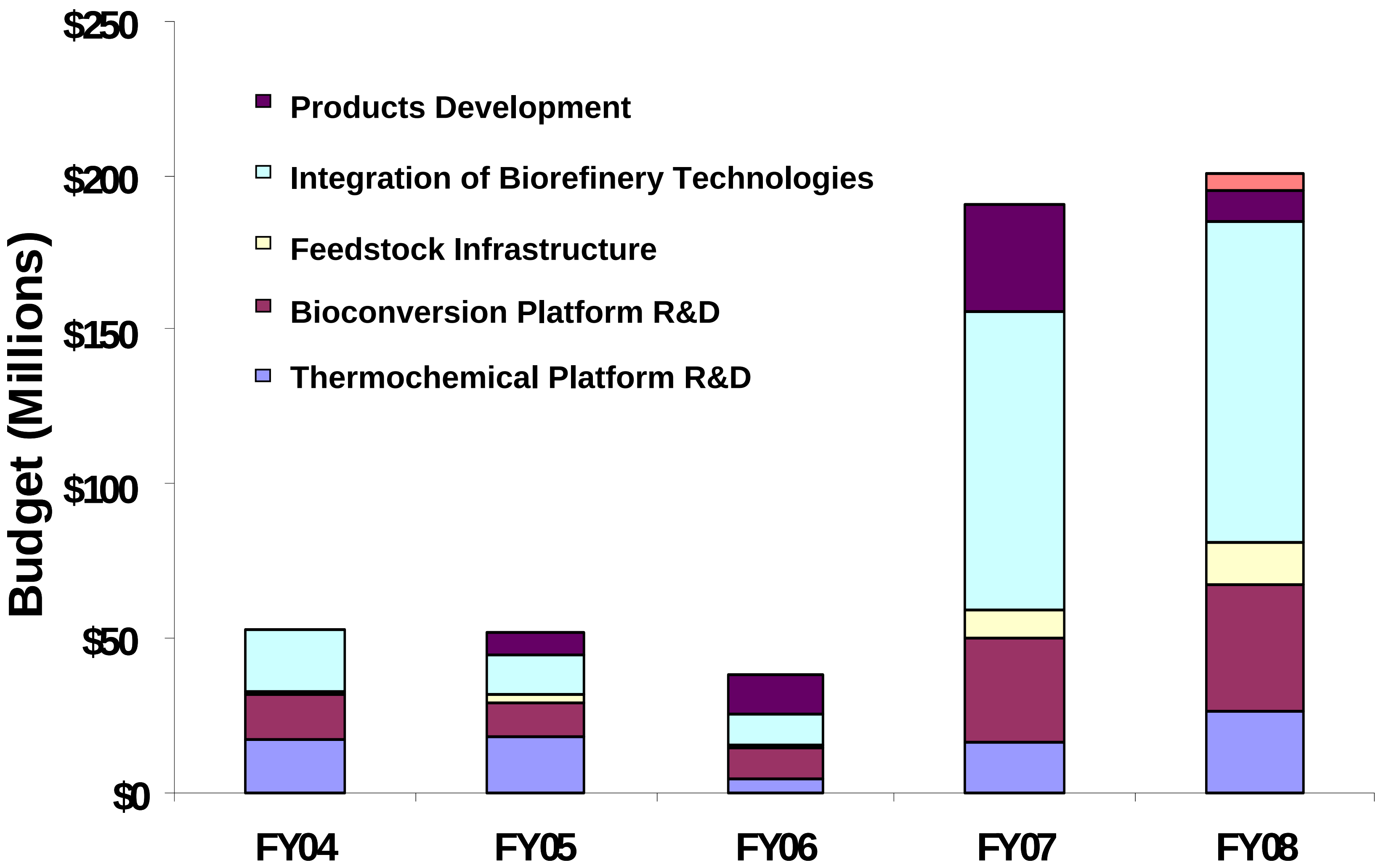
Mission Statement

Develop and transform our renewable and abundant biomass resources into cost competitive, high performance biofuels, bioproducts, and biopower. This will be achieved through targeted research, development, and demonstrations leading to deployment in integrated biorefineries, supported through public and private partnerships.

Program's Goals

- **Short Term:** Foster breakthrough technologies needed to make cellulosic ethanol cost competitive by 2012 (cost target: $1.33/gal).
- **Mid Term:** Help create an environment conducive to maximizing the sustainable production of biofuels by 2017, including cost-effective technology, sufficient infrastructure, appropriate policies, and supportive consumers (cost target: $1.20/gal).
- **Long Term:** Increase the supply of renewable fuels to 36 billion gallons by 2022 - especially contributing to the 21 billion gallons of cellulosic and advanced biofuels (EISA, RFS)

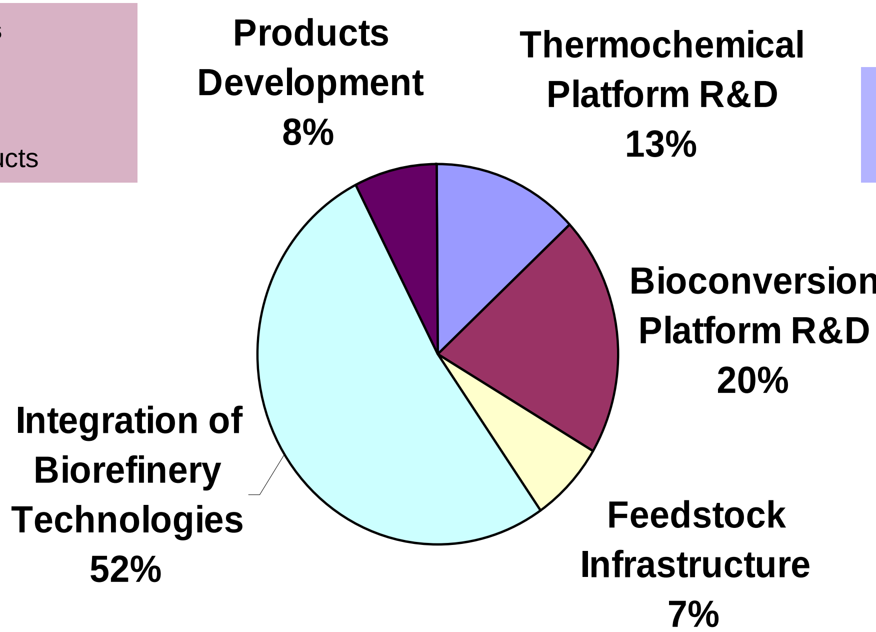
The FY07 & FY08 appropriations enabled the Biomass program to substantially enhance its impact



DOE Technology Funding Breakdown

FY08 Appropriations by Technology Area

Develop Biorefinery Outputs
- Fuels
- Chemicals
- Materials
- Other Value Added Products



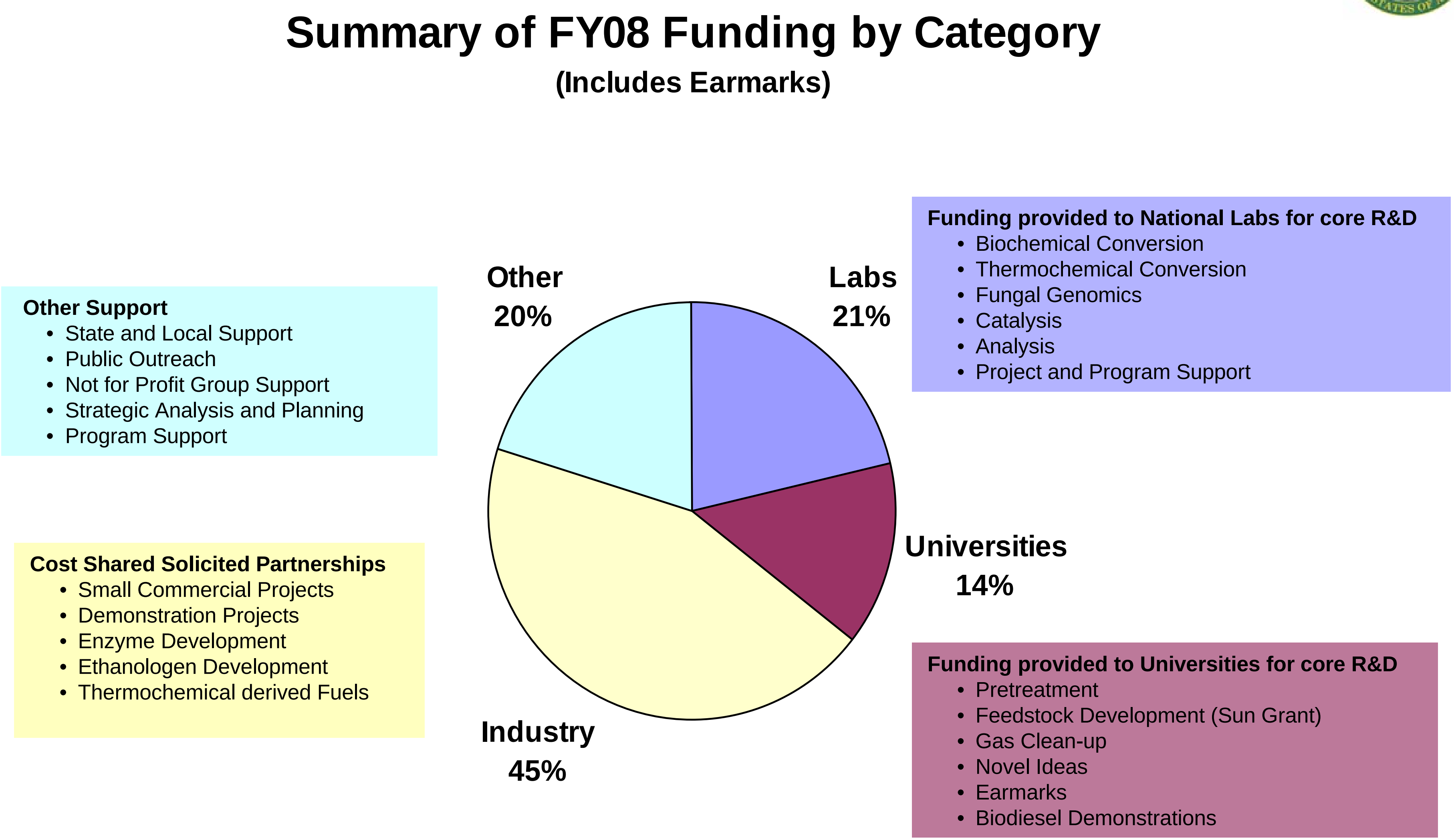
Production of Syngas and Bio-oils
- Gasification & Gas Clean-up
- Pyrolysis & Oil Stabilization

Production of Low Cost Sugars
- Pretreatment
- Enzymes
- Fermentation

Develop Economically Viable Integrated Biorefineries
- Small commercial scale
- Demonstration scale
- Pilot Scale

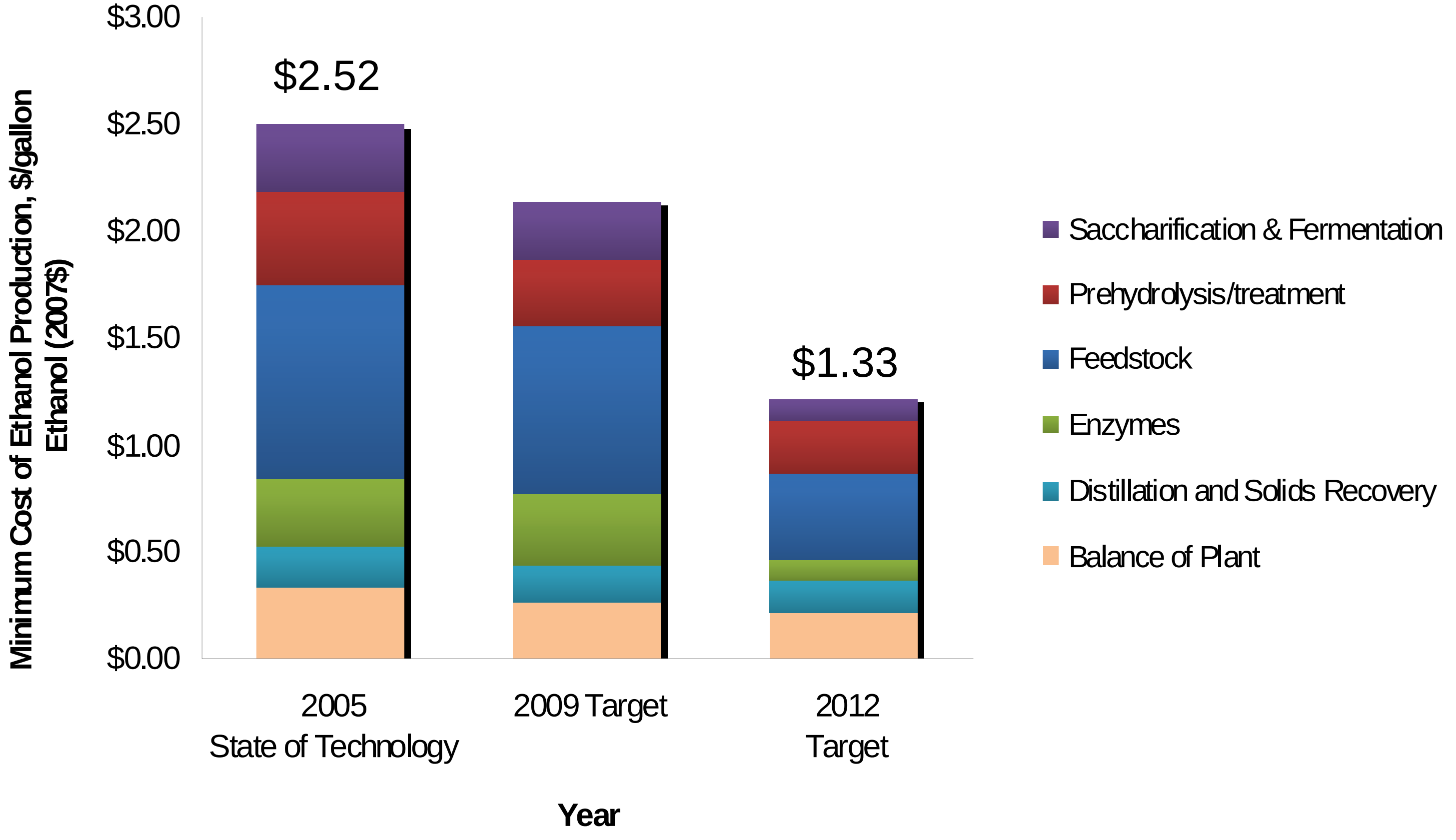
Production & Deliver of Low Cost Biorefinery Feedstocks
- Production
- Harvesting
- Collection
- Storage
- Sustainability

DOE Budget Allocation across Partners



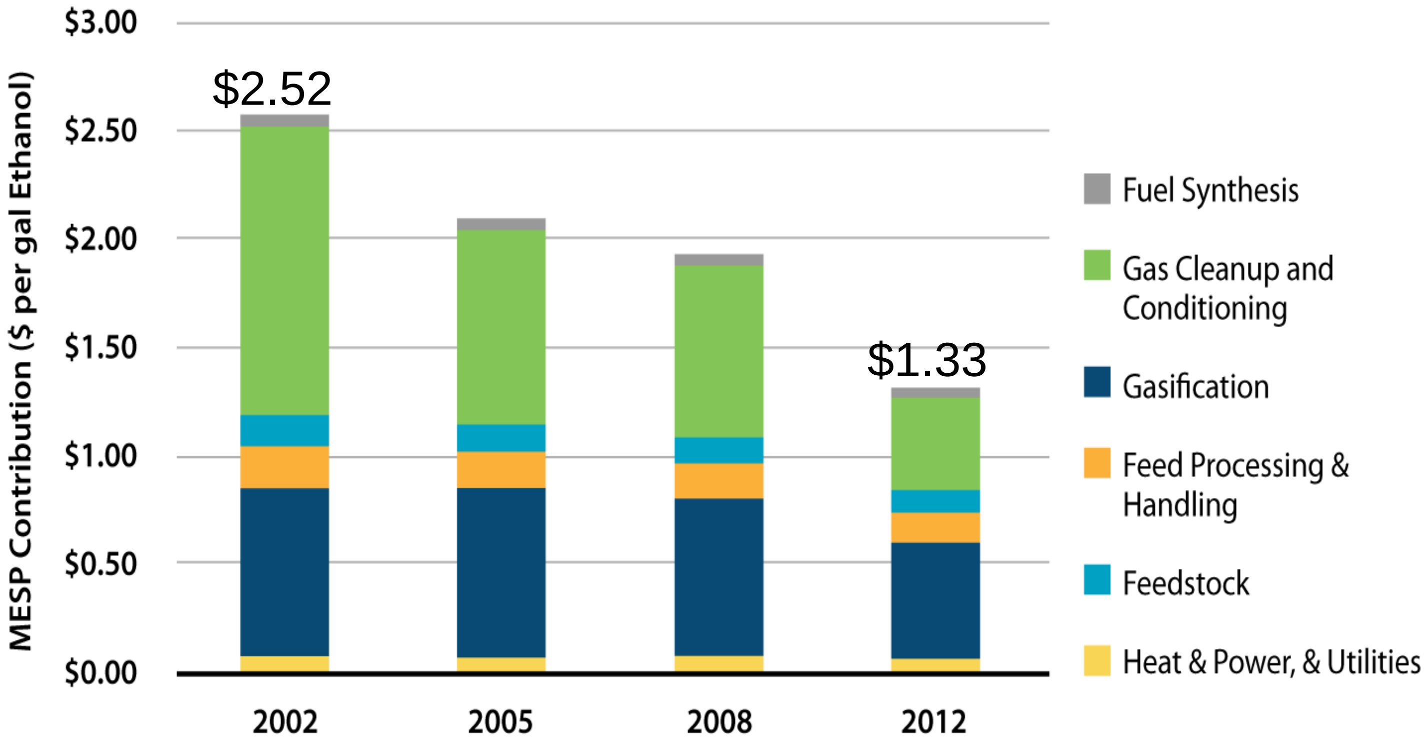
Biochemical R&D Opportunities

Reductions in cost due to Biochemical R&D improvements are one of the areas of profit potential through biorefinery R&D Investment



Thermochemical R&D Opportunities

Reductions in cost due to Thermochemical R&D improvements are one of the areas profit potential through biorefinery R&D Investment



Solicitations: Leveraging Partnerships to Achieve Goals

Commercial-Scale Biorefineries (up to $272 million)

- Four cost-shared, integrated biorefinery demonstration projects to produce 130 million gallons of cellulosic ethanol in 5 years using variety of conversion technologies and cellulosic feedstocks

10%-Scale Biorefinery Validation (up to $240 million)

- Cost-shared, integrated biorefinery demonstrations using cellulosic feedstocks to produce renewable fuels; one-tenth of commercial scale
- Nine selectees announced for a total investment of $240 million

Ethanologen Solicitation (up to $23 million)

- Five selected research teams working on microorganisms

Enzyme Solicitation (up to $33.8 million)

- Four selected research teams working on inexpensive enzyme systems for commercial biomass hydrolysis

Thermochemical Solicitation (up to $16.7 million)

- Integration of gasification and catalyst development
- Pyrolysis oil stabilization

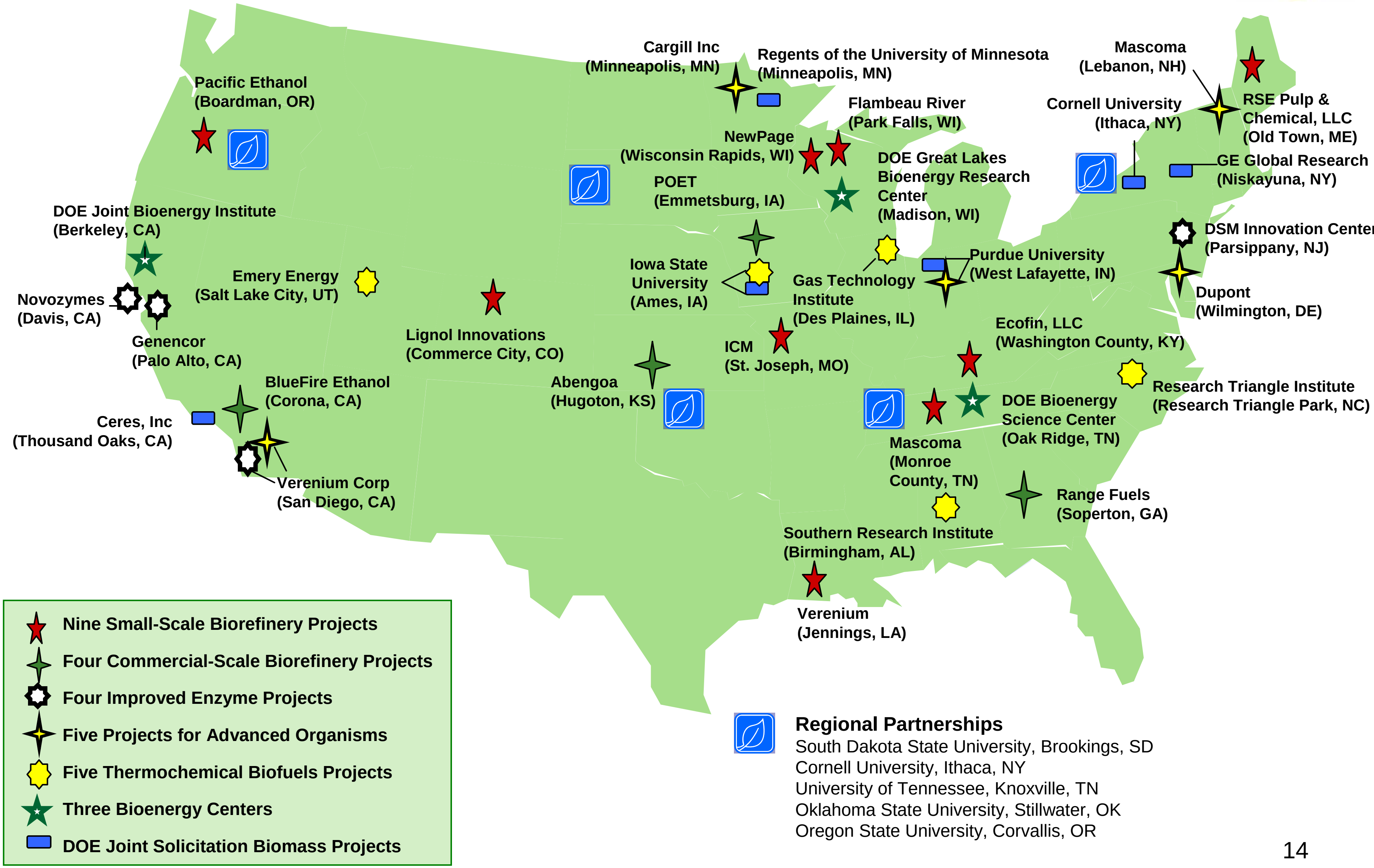
Joint DOE-USDA Solicitation ($5.2 million of $18 million funded by DOE)

- Biomass R&D Initiative: 20 awards announced March 2008

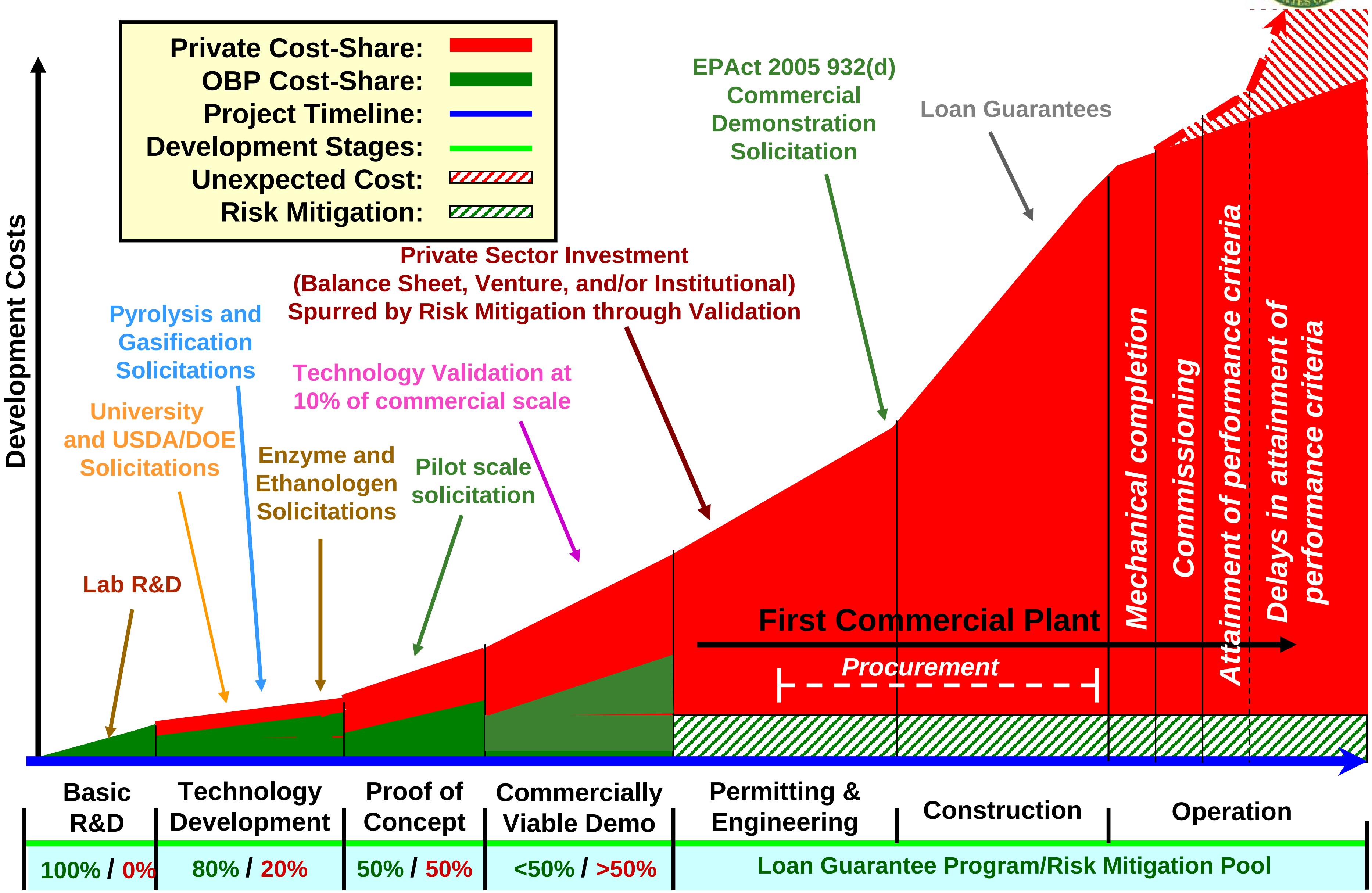
POTENTIAL FUTURE SOLICITATIONS

- Integrated Pilot Sale Biorefinery
- Integrated Demonstration Scale Biorefinery
- Lab Call
- Annual USDA/DOE Joint Solicitation

Major DOE Biofuels Project Locations
Geographic, Feedstock, and Technology Diversity



Deployment Barriers and Solutions



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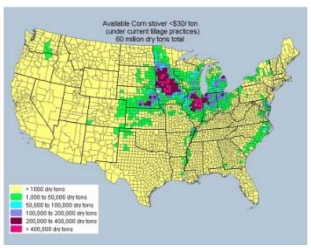
Mechanisms for Utilizing Lab Expertise and Capabilities to Develop Available Technologies (whether theirs or yours)

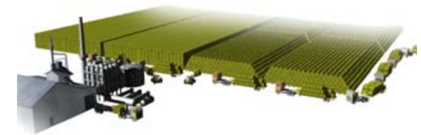


Technology Licensing

- License and further develop Lab IP
- Can be for sole use or for broad dissemination and further licensing

Work for Others

- Avoids IP Issues
- Have Labs develop technology to suit your needs
- Have Labs develop your idea
- Developmental work can be very specific



CRADA's

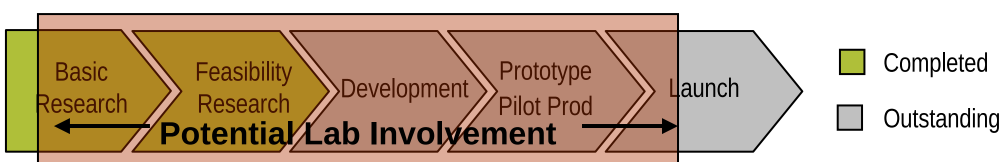
- Jointly develop lab IP for specific application
- May be one or a suite of technologies
- May partner with different labs
- IP developed is protected
- Useful when developing or improving technology that's part of an integrated system

User facilities

- Link lab technologies test and develop as a system
- Test and improve independently developed system
- May avoid construction of costly bench and pilot facilities

Project support

- Can leverage technology development in solicited projects
- Allows specific technological gaps to be addressed
- Optimizes synergies of DOE and industry developed technologies
- Can utilize either CRADA's or work for other arrangements



National Laboratory Core Capabilities

Oak Ridge

- Feedstock Supply
- Multiple programs focused on establishing energy crops ★
  - Analysis
  - Transition Modeling
  - Feedstock Cost Curves
  - NEPA Support
  - Engine Testing
  - Separations

Idaho

- Feedstock Logistics
- Multiple technologies focused on developing feedstock harvesting and delivery systems ★
  - Harvesting and collection
  - Storage Studies
  - Depot concept development
  - Pre-processing

★ Lab Core Competency

National Laboratory Core Capabilities - continued

NREL

- Alternative Fuels User Facility/Integrated Biorefinery Facility
  - Pretreatment
  - Clean Fractionation ★
  - Enzymatic hydrolysis ★
  - Fermentation ★
- Thermochemical User Facility
  - Gasification
  - Syngas clean-up
- Algal Development ★
- Biomass Characterization Laboratory

PNL

- Biochemical Conversions
  - Fungal Fermentations ★
  - Genomics and Proteomics
- Thermochemical Conversion
  - Pyrolysis ★
    - Pyrolysis oil stabilization and upgrading to fuels via catalyst development
    - Fast Pyrolysis and Hydrothermal Liquefaction
  - Gasification
    - Catalyst development for syngas clean-up and fuels synthesis ★
    - Catalyst development for mixed alcohols ★
  - Aqueous Phase Processing of Biomass to Chemical

★ Lab Core Competency

National Laboratory Core Capabilities - continued

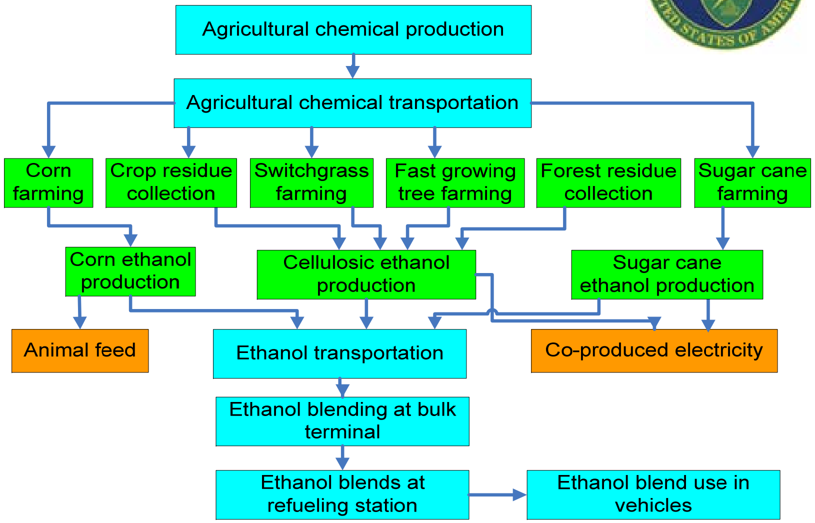
ANL

- Unit Operation Development
- Life Cycle Analysis ★
- Multiple programs focused on Engine testing, Life cycle analysis and Unit operation development
  - Greet Model Analysis (GHG) ★
  - Analytical Program Support
  - Separations/Fermentation Technologies (membranes) ★
  - Engine and fuel testing

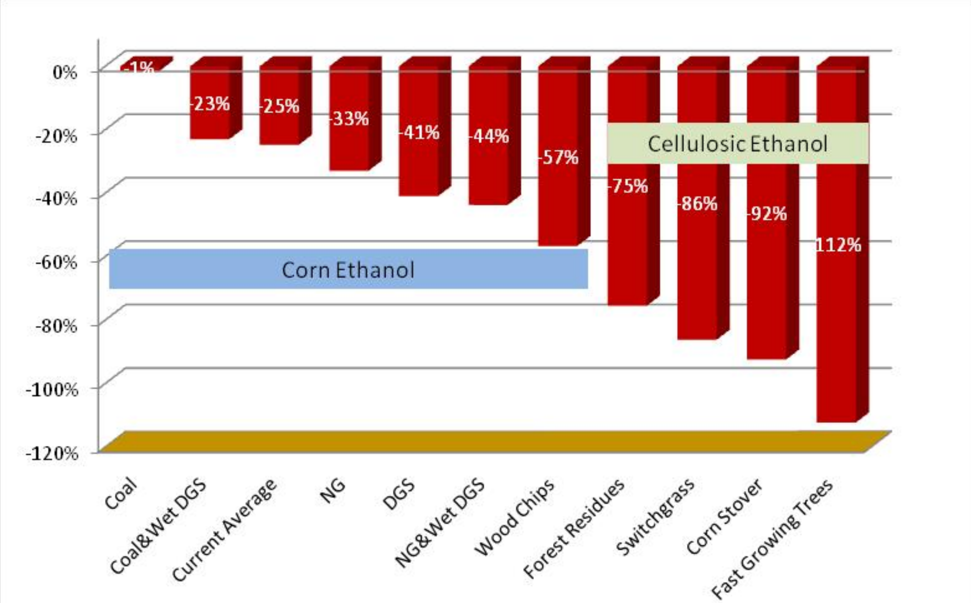
★ Lab Core Competency

Tool Development
GREET Life-Cycle Analysis for Biofuels

- GREET development at Argonne has been supported by DOE
- GREET and its documents are available at Argonne's website at *http://www.transportation.anl.gov/software/GREET/*
- The most recent GREET version (GREET 1.8b) was released in May 2008
- As of April 2008, there were 7,500 registered GREET users worldwide



GHG Emission Reductions By Ethanol Relative to Gasoline



(Land use change effects are not included for corn ethanol results)

- Without accounting for effects of direct and indirect land use changes, corn ethanol is shown to have GHG reductions
- Cellulosic ethanol will achieve significant GHG reductions
- DOE is funding efforts of simulating land use changes for biofuel production; methodologies are still evolving and current results are subject to great uncertainty
- Other sustainability issues of biofuels are currently being addressed by DOE; DOE is funding efforts on analyzing water requirements for biofuel production

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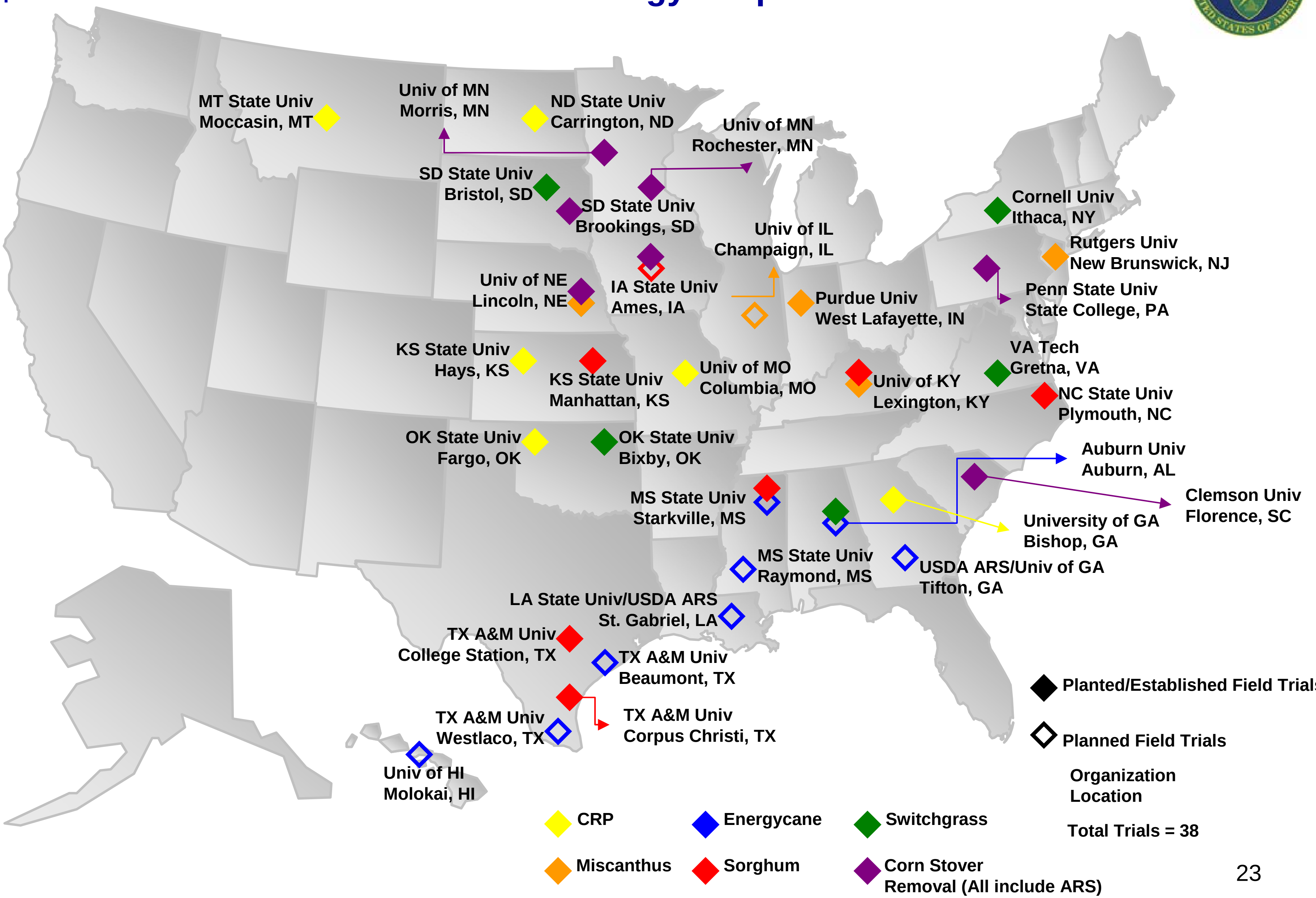
Feedstock Opportunities

The Supply of Feedstock for Biofuels

- Improved Harvesting
  - Large scale collection equipment
  - Lowers feedstock contribution cost
- Improved Storage
  - Minimizes degradation
- Densification
  - Minimizes transportation costs
- Pre-processing
  - Minimizes at facility processing
- Improve Energy Crops Yields ★
  - Grow on marginal land with minimal water
  - Not competing with food crops
  - Lowers costs
- Established Supply Chain
  - Least developed part of the production process
  - Need to define regional advantages
  - Diversify feedstocks
  - Improve reliability – quantity, quality
  - Prove sustainability

★ VC Opportunity

Regional Biomass Energy Feedstock Partnership
2008 Bioenergy Crop Trials



Biochemical Opportunities

The Biochemical Production of Biofuels

- Pretreatment
  - Increased solids loadings
    - Capex reduction
    - Lower water usage
  - Milder conditions
    - Less expensive materials of construction (Capex)
  - Clean Fractionation ★
- Hydrolysis
  - Improved enzymes ★
    - Higher conversions
    - Lower operating costs
- Fermentation ★
  - Improved fermentative organisms for mixed sugars
    - Higher yields
    - Decreased fermentation time (Capex)
    - Improved robustness (operating costs)
- Balance of Plant
  - Improved heat exchange
    - Improved efficiency (operating costs and capex)
  - Improved separations ★
    - Higher yields
    - Capex reduction
    - Lower water usage
- Applications
  - Niche stand-alone greenfield plants ★
  - Coupled with existing facilities to leverage and improve operations
    - Forest Products
    - Existing biofuels facilities

★ VC Opportunity

Clean Fractionation

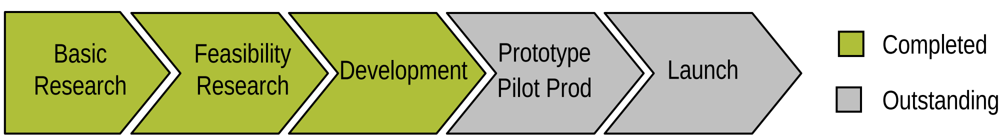
Description

Clean fractionation is a process for upgrading feedstocks for a biorefinery by separating the cellulose, hemicellulose, and lignin into pure streams for conversion into value added products.

Impact

- Ethanol production costs lowered by significantly reducing fermentation times
- Hemicellulose can be used for production of other value added chemicals

Technology Readiness



Estimated Time to Market

- 3 to 5 years

Estimated Commercialization Cost

- $10 M

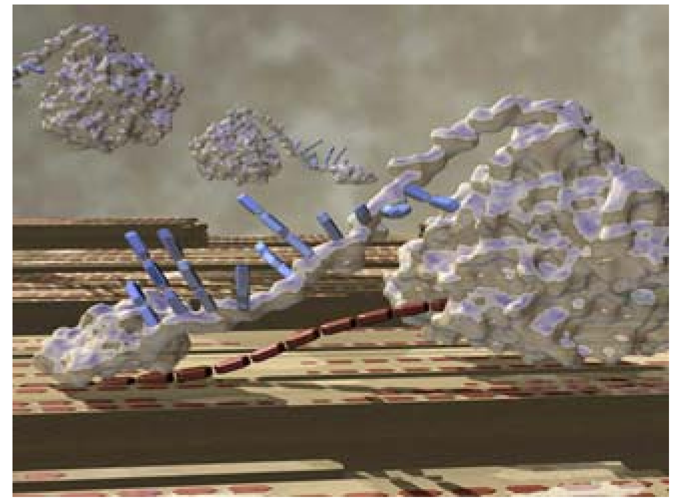
Enzymes to Convert Cellulosic Feedstocks into Sugars

Description

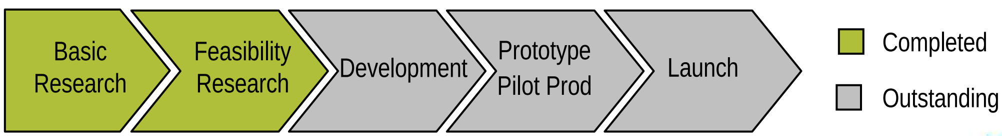
- Enzymes to Convert Cellulosic Feedstocks into Sugars

Impact

- Enzymes to convert biomass to simple sugars for biofuels production are too expensive.
- Enzymes developed must prove durable and effective in the conditions at which biorefineries would operate



Technology Readiness



Reduction of Enzyme Cost per Gallon

Goal
Reduce the cost contribution from enzymes for cellulose hydrolysis

$$\text{Effective cellulase cost}\left(\frac{\$}{\text{gal EtOH}}\right)=\left(\frac{\$}{\text{gm enzyme}}\right)\cdot\left(\frac{\text{gm enzyme}}{\text{gal EtOH}}\right)$$

Estimated Time to Market

- 3 to 4 years

Estimated Commercialization Cost

- Recent solicitation funding totals nearly $68 million, with 50% of the cost shared by industry

Improved Fermentation

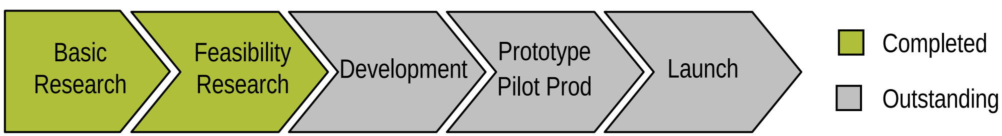
Description

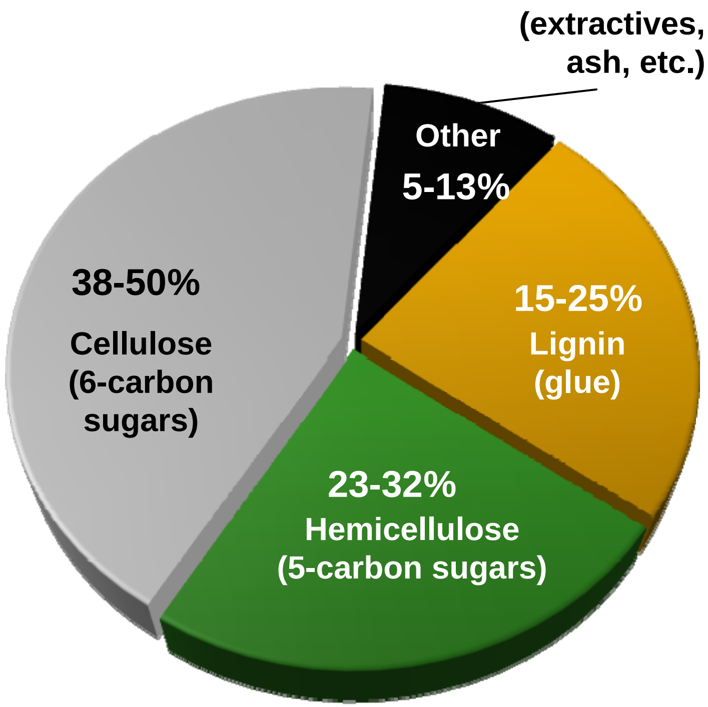
- Decrease Ethanol Cost by Fermenting 5-Carbon Sugars

Impact

- Need to develop robust, efficient fermentation organisms to convert both 5- and 6-carbon sugars to ethanol at high yields, high ethanol concentration, and low toxicity for cost effective products and prove performance in an integrated biorefinery.

Technology Readiness





Components of Biomass

Estimated Time to Market

- 3 to 4 years

Estimated Commercialization Cost

- Recent solicitation at nearly $37 million total investment in five projects to commercialize multi-sugar fermenting organisms.

Separative Bioreactor

Problem: Biobased co-products are critical components of economically successful integrated biorefineries. Improved process and separations efficiency is required for biobased products to compete with petrochemicals.

Technology: The invention integrated bioconversion and recovery of charged biobased products such as organic acids.

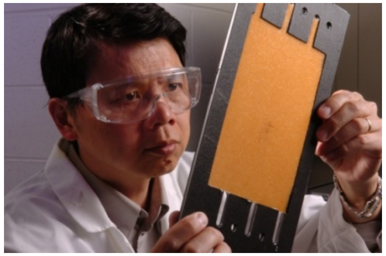
Impact: The technology provides a pathway to commercialization on many of the identified "top chemicals from biomass" by reducing operating costs and waste streams. The process could expand the product portfolio in integrated biorefineries.

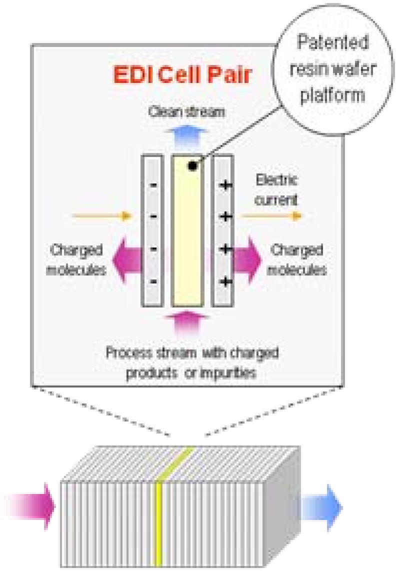
- The technology has other potential applications including clean-up and conditioning of cellulosic sugar streams after pre-treatment.

IP: ANL has a portfolio of 8 issued and pending patents. ANL applied for patents in several international markets. The IP protects the devices, fabrication methods, processes and applications.

Status:

- The technology is currently being field tested at the pilot scale at the ADM's facility.
- Argonne is negotiating license options. Argonne is also evaluating investors requests to fund a start-up to become the commercial technology provider.





Commercial EDI "stack" contains 100+ cell pairs

Seth	Snyder	ANL
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Thermochemical Opportunities

Gasification

- Improved Gas Clean up
  - Capex reduction
  - Longer catalyst life
  - Increase syngas usage options
- Improved feeder system
  - More diverse feedstock adaptability
  - Improved operating time

Pyrolysis

- Improved Oil stability
  - Increase pyrolysis oil usage options
  - Lower capex
  - Higher operating efficiency
- Char collection and beneficial use

Catalysis

- Improved catalysts ★
  - Higher yields and conversions
  - Less by-products
  - Improved robustness and longer catalyst life (operating costs and capex)

Applications

- Existing biofuel industry
  - Improved carbon footprint
  - GHG mitigation
  - Energy cost reduction
  - Lower operating costs
- Coupled with biochemical operations
  - CHP potential for non-converted streams
  - Additional biofuels and/or product production

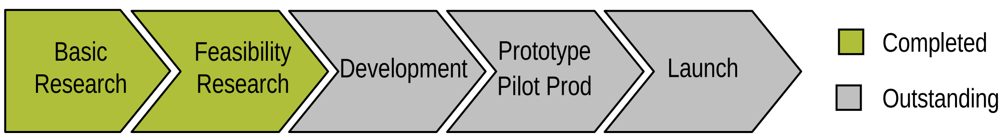
★ VC Opportunity

Catalyst Development From Biomass Derived Oils

Description
- Fast Pyrolysis and Hydrothermal Liquefaction
- Pyrolysis oil stabilization and upgrading to fuels

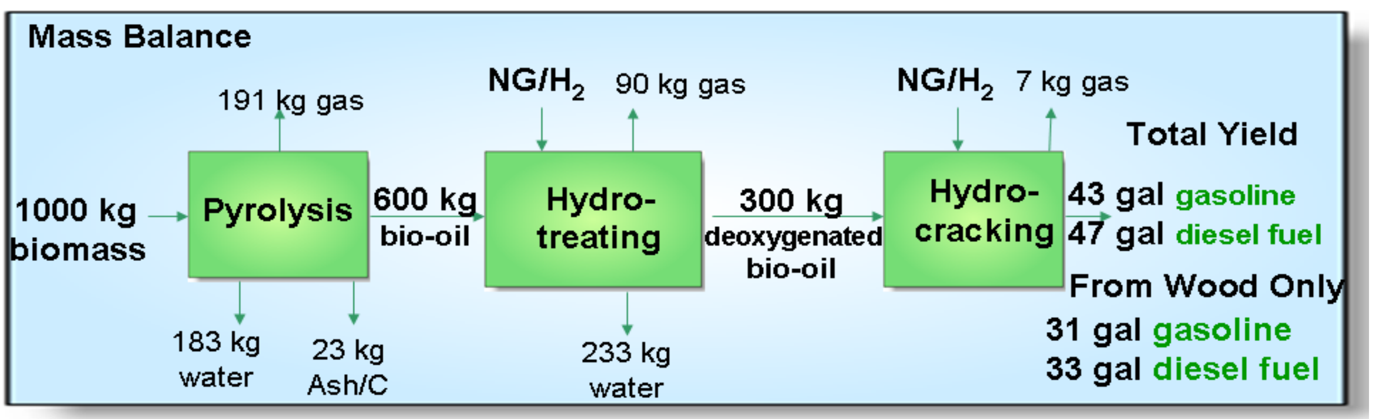
Impact
- Infrastructure compatible hydrocarbon fuels from whole biomass

Technology Readiness



Estimated Time to Market
- 2-5 years

Estimated Commercialization Cost
- Dependent upon existing infrastructure



Advanced Biofuels Opportunities

- Algal Based Biofuels ★
- Higher Alcohols ★
- Green Gasoline ★
- Renewable Diesel ★
- Renewable Jet Fuel Formulations ★
- Other Advanced Biofuels ★

★ VC Opportunity

Increase Yields of Algal Oils for Biofuels

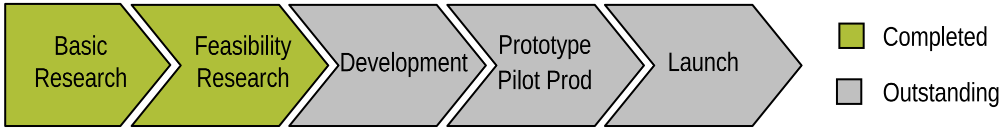
Description

- Increase Yields of Algal Oils for Biofuels

Impact

- More biodiesel to meet RFS volumetric requirements

Technology Readiness

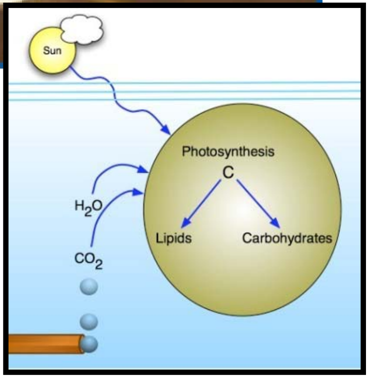


Estimated Time to Market

- Unknown - 5-10 years

Estimated Commercialization Cost

- Unknown - $25 million for OBP to develop Program in FY09 House Mark appropriations



NREL patented genes could be used to direct fixed carbon to lipids (oil) *vs.* carbohydrates

Agenda

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- Appendix

Intensified Reaction/Product Recovery Process for the Continuous Production of Biodiesel

Problem: Conventional reaction and separations used in biodiesel production are commonly done in time-consuming batch processes, which increases the size and cost of equipment and restricts the rate of production.

Technology: ORNL researchers have developed a method for continuous conversion that yields an order-of-magnitude increase in production rates, while decreasing plant size and processing requirements This method is faster, more compact, and allows reaction and separation in one process step in the reactor.

Effective mixing and separation in a laboratory device.

Impact: Continuous biodiesel processing is projected to reduce investment cost by 40%. (G. Keller, MATRIC)

IP: Invention disclosure filed

Status: EERE Technology Commercialization and Deployment Fund (TCDF) project selected for funding and in CRADA negotiation

- ORNL and Nu-Energie, LLC

Joseph	Birdwell	ORNL-Technical Lead
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Clean Fractionation

PROBLEM: Ethanol production costs are driven by efficient pretreatment and fermentation processes

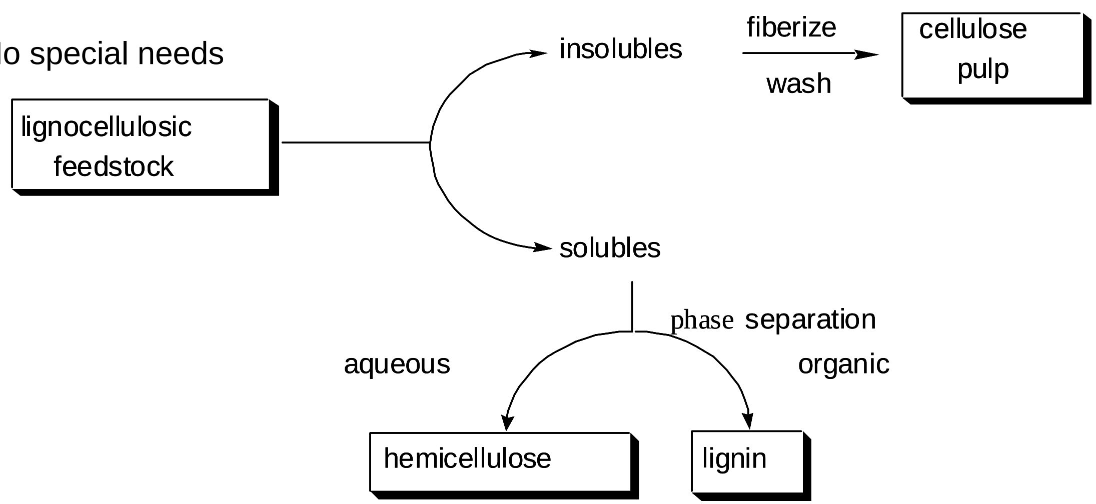
DESCRIPTION: Extraction efficiency is improved by a solvent fractionation technique applied to the biomass. The resulting pure streams of cellulose, hemicellulose, and lignin are separated, and can be processed more efficiently and economically. Conversion times and efficiencies have been significantly reduced and increased. The hemicellulose can either be converted into ethanol or other value added chemicals (ex. Xylitol).

IMPACT: Potentially very large since this can be used to improve the efficiency of all cellulosic to ethanol biorefineries

IP POSITION: 1 patent issued, additional intellectual property

TECHNOLOGY STATUS: Currently available. Ethanol production costs lowered by significantly reducing fermentation times

- **Reduction to practice**: The process has been successfully used on a number of feedstocks and data indicates that it is scalable
- **Special needs to implement**: No special needs



Tom Williams | NREL | Phone: 303-275-4485 | tom_williiams@nrel.gov

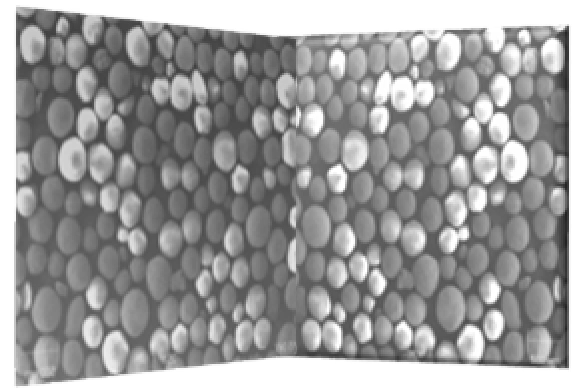
Improved Syngas Clean-up

Description

- Creating Clean Biomass Syngas for Liquid Biofuels

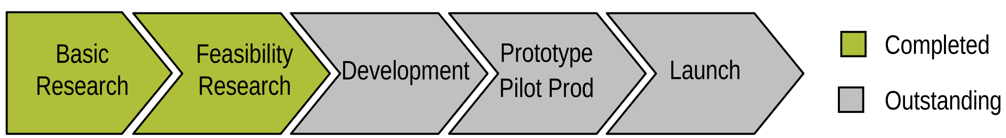
Impact

- Biomass-derived syngas from gasification requires fluidizable catalysts for efficient tar reforming and catalyst regeneration.



SEM (1000x) of NREL fluidizable catalyst

Technology Readiness



Estimated Time to Market

- 3 to 4 years

Estimated Commercialization Cost

- Recent solicitation at nearly $9.2 in DOE cost share to develop integrated syngas clean up systems for liquid biofuels.

Enzymes to Convert Cellulosic Feedstocks into Sugars

Problem

- Enzymes to convert biomass to simple sugars for biofuels production are too expensive today
- Subject of recent Solicitation

Description of the Technology:

- Enzymes are needed to produce sugars from cellulosic feedstocks. Sugars can be fermented to ethanol, other biofuels, and products. “Cellulase” enzymes are industrial products, used in cleaning products and foods

Impact to Biorefineries:

- Cost reduction of cellulosic ethanol, biofuels, and products
- Current cellulase enzyme cost is ~$0.30-$0.50/gal with a goal of $0.10/gal by 2017 and $0.05/gallon by 2030
- A 2-5 billion gal cellulosic ethanol by 2017 would generate enzyme value of $400 million to $1 billion with 100% margin
- Some enzymes have other commercial applications that need further development. Could contribute to this $1.6 billion U.S. enzyme industry growing at 6.9%/year

Enzymes to Convert Cellulosic Feedstocks into Sugars (cont'd)

IP and Status:

- NREL has a portfolio of enzymes derived from the leading edge organisms such as Acidothermus cellulolyticus, fungal sources, and others
- 11 issued patents and several in filing. 50% of all A. cellulolyticus patents (remainder by industry)
- Industry using NREL patented enzymes
- Reduced cost in practice but need additional development for commercial viability
- Available for licensing. Could enhance a VC biotech company's enzyme portfolio
- NREL's technology experts and facilities are available for partnerships

Estimated Future Markets and Value

Estimated Year of Production		2007	2017	2030
Estimated annual ethanol prodn	B gallons	-----	5	60
Estimated enzyme cost contribution	**$/gal ethanol**	**$0.30 - $0.50**	**$0.10**	**$0.05**
	MM$ year	-----	$500	$3,000
Estimated enzyme revenue	**MM$/year**	-----	**$1,000**	**$6,000**
Estimated enzyme loading	g//kg carb	20	10	5
Avg. feedstock carbohydrate content	kg carb/kg biomass	0.75	0.75	0.75
	g protein/ton biomass	13,605	6,803	3,401
Estimated ethanol yield	gal/ton feedstock	60	90	100
Estimated enzyme requirement	g protein/gal ethanol	227	76	34
Estimated annual enzyme production	**ton protein**	**NA**	**417,000**	**2,250,000**

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Improved Fermentation

Problem: Develop robust, efficient fermentation organisms

- Both 5- and 6-carbon sugars have to be converted to ethanol at high yields, high ethanol concentration, and low toxicity for cost effective products.

Technology: Demonstrated successful metabolic and genetic engineering of *Zymomonas*

- 5-carbon sugars xylose and arabinose fermented with improved tolerance to acetic acid.
- Glucose and the C-5 sugars can be co-fermented.
- One of four major approaches worldwide under investigation. NREL's uses recombinant techniques.

Impact on Biorefineries

- New routes for simultaneous utilization of all sugars to produce ethanol or bioproducts.
- Competition (top, near-term candidates)
  - Separate fermentations with known organisms
  - Saccharomyces cerevisiae (yeast)
  - E. coli (bacteria)
  - Thermoanaerobacterium saccharolyticum (bacteria)

- *Zymomonas* industry total revenue value of $200 million to $500 million for a 2-5 billion gallon ethanol industry by 2017.

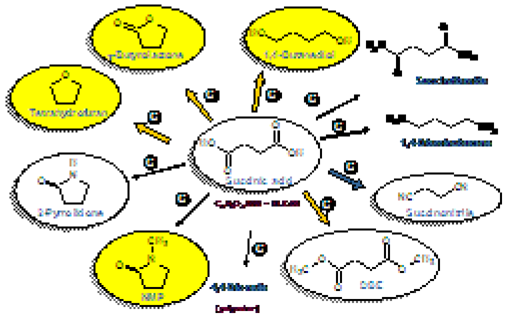
Catalysts Development for Sugars

Description

- Production of commodity chemicals from biomass
  - Catalyst Development
  - Process Development

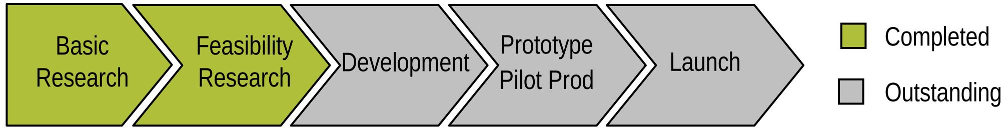
Impact

- Chemical manufacturers seek low cost renewable feedstocks and processes to maintain competitive advantage in the market place.



Technology Concept

Technology Readiness

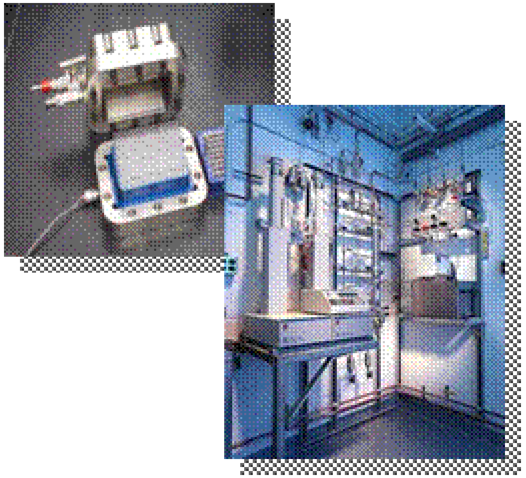


Estimated Time to Market

- Dependent on specific applications (1-5 yrs)

Estimated Commercialization Cost

- Depends on specific application and if use of existing infrastructure



Technical tools at PNNL

Bioproducts through Fungal Biotechnology

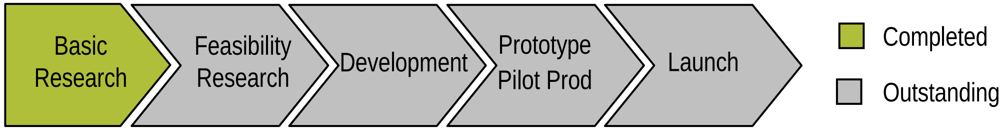
Description

- Enabling tools for fungal biotechnology (includes fuels, chemicals, and enzymes)

Impact

- There are aggressive goals for biofuel production in both near and long term timeframes. Bioproducts produced by fungi aid in the economic viability of biofuels.

Technology Readiness

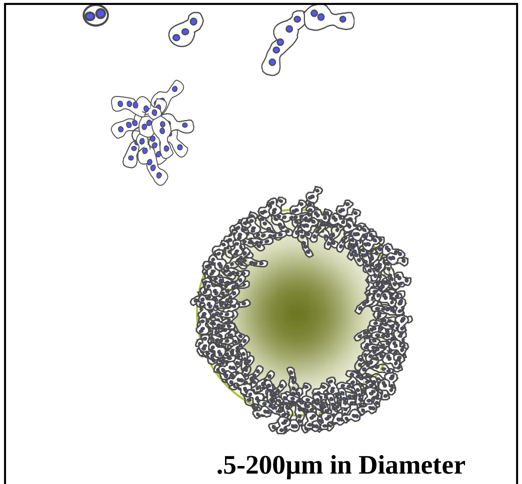


Estimated Time to Market

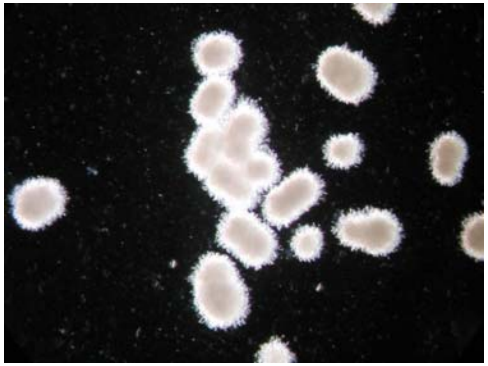
- Tied to the specific bioproducts application (3-10 yrs)

Estimated Commercialization Cost

- Tied to the specific application



Genetic control of fungal fermentation morphology



Molecular genetic tools for correct fermentation morphology

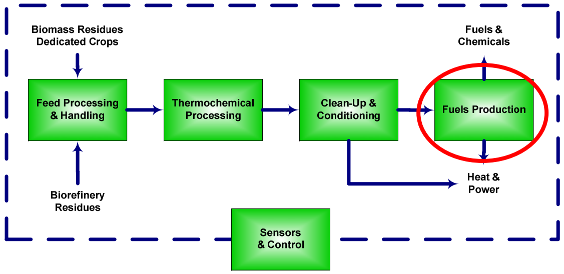
Catalyst Development From Biomass Syngas

Description

- Improved Catalysts for Mixed Alcohol Fuels from Biomass Syngas

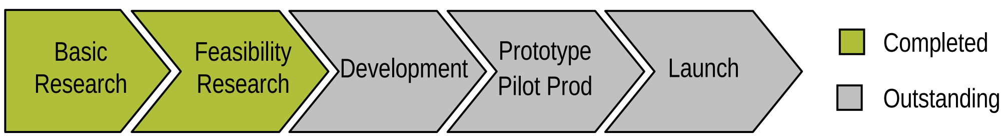
Impact

- The current low-productivity catalysts require higher capital cost investments that limit this technology options.



Technology Concept

Technology Readiness



Estimated Time to Market

- 2-5 years

Estimated Commercialization Cost

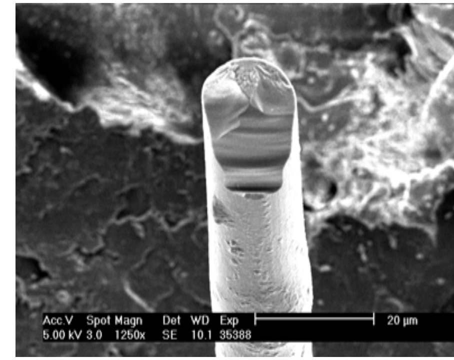
- Dependent upon existing infrastructure

Improved catalysts

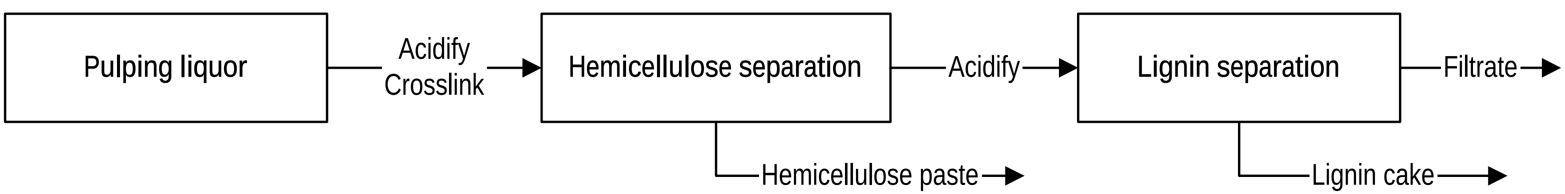
Improving Separation of Lignin from Carbohydrates in Wood Pulp and Biomass Hydrolysis Liquors

Problem: Lignin from biomass and pulping streams is potentially the most valuable product. However, use has been limited by carbohydrate contaminants.

Technology: Use of a double-step precipitation process with cross-linking separates carbohydrate from lignin. This produces both a clean lignin, and a hemicellulose carbohydrate that is useful in paper sheet or as fermentation feedstock. “Clean” lignin can be used to make industrial aromatic chemicals, carbon fiber feedstocks, molding compounds, etc.



Microscopy of lignin-based carbon fiber



Process for stripping hemicellulose from black liquor

Improved Fermentation

IP and Status:

- NREL's portfolio of bacterial *Zymomonas* strains is a lead contender
  - Five issued patents, several filings in process.
  - Reduced to practice but need additional development for commercial viability.
  - Available for non-exclusive licensing. Could enhance a VC biotech company's portfolio in ethanol, other biofuels, or bioproducts.
  - NREL's *Zymomonas* experts and facilities are available to help develop commercial strains.

Estimated Future Markets and Value

Estimated Year of Production		2017	2030
Annual ethanol production	B gallons	5	60
Zymo contribution	$/gal ethanol	$ 0.05	$ 0.01
	MM$ year	$ 250	$ 600
Estimated Total Revenue	**MM$/year**	**$ 500**	**$ 1,200**
Zymo loading	g//kg carb	100	50
Feedstock carb content	kg carb/kg biomass	0.75	0.75
	g protein/ton biomass	68,027	34,014
Yield	gal/ton	90	100
	g protein/gal ethanol	756	340
Annual Zymo production	**ton protein**	**4,167,000**	**22,500,000**

5-6% titers obtained with NREL base strains. Additional development could lead to 13% titer of commercial interest

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Increase Yields of Algal Oils for Biofuels

Problem: Need for high oil yielding microalgae for renewable diesel and aviation fuel production

Technology: Tools for metabolic engineering of microalgae to enhance rates and yields of triglyceride biosynthesis

Impact

- Increased yields needed to facilitate large-scale production of triglyceride oils for biofuels using microalgae grown on low-value land with saline water and waste CO_2 streams
- Could enable major impact on diesel and aviation fuel markets using resources not currently being tapped for food/feed/fuel production

IP and Status: NREL has a portfolio of intellectual property and know-how from 18 years of research on microalgae

- 2 issued patents relating to genes thought to control the flow of carbon into lipids (oil) in a microalgal species (*Cyclotella cryptica*); other NREL IP could apply to algal residue use (fermentation, anaerobic digestion, *etc*.)
- Expertise in microalgal metabolic engineering and algal processing stemming from DOE's investment of $25M in the Aquatic Species Program at NREL
- Further development could lead to commercially viable strains
- NREL IP is available for non-exclusive licensing; could enhance a VC biotech company portfolio in the blossoming fuels-from-algae field

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Bioproducts through Fungal Biotechnology

Problem: Fungi are a promising set of organisms for bioprocesses within the biorefinery industry. However, there are barriers to widespread usage of fungi for the production of bioproducts such as organic acids.

- There are aggressive goals for biofuel production in both near and long term timeframes. Bioproducts produced by fungi aid in the economic viability of biofuels

Description: Fungi are capable of low pH fermentation, producing high titers of end products and co-production of ethanol with products.

Impact: Potentially large, given that fermentations producing acids by organisms other than fungi require neutralization.

IP: 2 patent applications for fungal genes and regulatory sequences involved in control of morphology

Technology Status:

- Inventions: Related to fungal gene expression and control of morphology
- Reduction to practice: Evidence that *Aspergillus niger* citric acid fermentation morphology can be modified genetically, evidence for control of gene expression
- Time constant to availability: Currently available

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Improved Syngas Clean-up

Problem: High Temperature Catalytic Tar Conversion

- Biomass-derived syngas from gasification requires fluidizable catalysts for efficient tar reforming and catalyst regeneration

Technology: Demonstrated Tar and Light Hydrocarbon Conversion

- Simultaneously convert tar and methane to additional syngas
- Use can be expanded to petroleum refining (steam reforming and hydrotreating) and hydrogen production from biomass

Impact on Biorefineries: Capital cost reduction and higher thermochemical biomass conversion efficiency to liquid fuels

- At 5 billion gallons of thermochemical EtOH production, industry would use 5 to 10 million lbs of catalyst per year or about $25-$50 million per year.
- This represents an addition of $50 to $100 million revenue to a catalyst manufacturer (100% margin).
- If in 2030 the size of ethanol production increases to 30 billion gallons, the revenue would increase by a factor of six.
- The U.S. catalyst market size is estimated at $2.8 billion in 2005 with a projected growth rate of 4.5% through 2007

IP and Status: NREL developed attrition-resistant fluidizable tar reforming catalyst

- Patent application filed jointly with CoorsTek, supplier of supports.
- U.S. Patent Application Serial No. 11/576,422 (NREL 03-26) and published in WIPO under No. 2007/0444009.
- Available for licensing. Could enhance a VC company's portfolio in thermochemical biomass-derived ethanol and other biofuels.
- Competing technologies are wet and dry scrubbing with many associated environmental impacts.

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Catalysts Development for Sugars

Problem: Increasing cost and price volatility of petroleum has impacted the economic margins of US based commodity chemicals.

Description: PNNL has intellectual property in the form of chemical catalysts for production of numerous commodity chemicals from sugars including: acrylates, 1,4-butanediol, tetrahydrofuran, pyrrolidinones, and others.

Impact: Low cost bioproducts can replace many chemicals made from petroleum. Preliminary process economic demonstrate cost savings of approximately 20% versus petroleum. PNNL's technology uses water without organic solvents.

IP Position: Patents Available for license

- US 7,199,250 (low cost route to NMP)
- US 6,706,893; US 6,670,483; US 6,632,951; US 6,603,021 (catalytic production of pyrrolidinones)
- US 7,049,446 (production of new N-containing compounds from amino acids)
- US 6,992,209 (low cost route to acrylic acid)
- US 6,545,175; US 5,252,473 (additional routes)

Technical Status:

- Concept has been demonstrated at laboratory scale
- Technologies in most advanced stage are chemical catalysts and conditions for producing n-methyl pyrrolidinone and acrylic acid; others are in progress

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Production of Commodity Chemicals From Sugars

Problem: The increasing cost and volatility of petroleum building blocks has impacted the economic margins of commodity chemicals

- Chemical manufactures need renewable low cost processes to maintain competitive advantage in the market place

Description: PNNL has intellectual property for the production of 3- and 4-carbon molecules derived from biomass that are direct displacement for chemicals produced from propylene and maleic anhydride. Examples include: acrylates, 1,4-butane diol, tetrahydrofuran, and N-methylpyrrolidinone.

Impact: Biorenewables offer new low cost options for raw materials. Propylene derived chemicals exceeds 26 billion pounds (US) and maleic anhydride is ~ 2 billion pounds. Biorenewable competitive technologies are now very cost competitive with petroleum.

- Beyond PV

IP Position: Numerous patents and invention disclosures on acrylates, pyrrolidinones, furan derivatives, diols, and other chemicals

Technical Status:

- Dozens of patents or patent applications
- Reduced to practice at the laboratory scale
- Many technologies ready for scale-up development today
- No special needs other than interest in renewables
- Additional continuous reactors and combinatorial reactors would increase rate of research

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Improving Separation of Lignin from Carbohydrates in Wood Pulp and Biomass Hydrolysis Liquors (cont'd)

Impact to Biorefineries: Makes it economically feasible to use biomass lignin as a chemical feedstock (future) and also, to increase yield and throughput of existing pulp mills (now).

- 10% of lignin from woody biomass from a 50 million gal ethanol/yr biorefinery could be converted to >$90M/yr of carbon fiber @$5/lb
- Opportunity for production of high-volume chemical feedstocks from lignin, such as phenol ($0.75/lb)

IP and Status:

- One patent filed, three invention disclosures
- Three funded projects specifically developing high-volume, high-valued products from cleaned lignin
  - USDA/DOE biomass-based carbon fiber
  - ORNL LDRD polymer feedstocks
  - One industrial proprietary

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Single-Pass Multi-Component Harvester

Problem: Existing technologies for harvesting crop residues for biofuels feedstocks require multiple operations increasing harvesting costs and contributing to soil compaction. Single-Pass Multi-Component Harvester can remove biomass fraction most valuable to biorefinery, leaving fraction most agronomically valuable for soil health. Current commercial harvesters cannot selectively harvest in accordance with this criteria.

Technology: Enables simultaneous harvest and collection of crop residues with grain harvest. Includes integration two major components: a residue separation system, and a densification system into a conventional combine harvester. Integration would eliminate post collection and densification processes as separate operations.

Impact: Implementation will reduce the cost of corn stover collection by 50% from $20/ton to $10/ton (2007$). Given that more than 200 harvesters will be needed to support a single 50 Mgal biorefinery, there is considerable market potential for this product.

IP: INL has developed suite of technologies to address issues of single-pass harvester development. Intellectual property suite is composed of one issued patent, and two pending patents available for worldwide exclusive or nonexclusive licenses. Other harvesting systems in development by industry and academia do not adequately address densification and selective harvest requirements.

Single-Pass Multi-Component Harvester (cont'd)

Status:

Residue Separation – System has been designed, prototyped and tested; consists of a residue separator device that can be retrofit into existing combine harvesters or implemented into new designs for separating cereal straw anatomical fractions in a biomass residue stream for various downstream purposes.

- Separates straw and chaff residue streams, producing a straw stream with a potential ethanol yield 10 gallons ethanol production per ton of biomass greater than the remaining chaff fraction.
- Produces a chaff stream high in inorganics, making it valuable soil amendment. Technology allows 20% more nutrient-rich residue fractions to be returned to the soil as compared to conventional systems.
- Economic value of the straw stream is $5.00/ton greater than the residue.

Densification System – Bulk densities greater than 14 dry matter pounds per cubic feet are needed to optimize biomass transportation costs. System is in testing phase. Expected benefits:

- Bulk densities greater than 20 pounds per cubic feet.
- Low power requirements facilitate implementation on harvesting machine.
- Improved handling and storage compared to bulk biomass.
- Reduced feedstock costs of $5.00/ton due to lower handling, transportation & storage costs.

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Single-Pass Multi-component Harvester – Densification System

Technology: This technology addresses the densification need of single-pass harvest. The Single-Pass Multi-component Harvester densification system is a key requirement of single-pass harvest and a significant barrier to single-pass development to date. Bulk densities greater than 14 dry matter pounds per cubic feet are needed to optimize biomass transportation costs.

- Single-pass harvester development to date has focused on bulk density improvements through size reduction (i.e., chopping) alone. Research to date has achieved gains from 2-4 lbs/ft3 of as-harvested biomass to 6-8 lbs/ft3, limited mainly by available horsepower.

- This invention integrates a mechanical compaction operation into a combine harvester, to form the biomass into compressed masses during the harvest operation. The compaction process has been successfully developed by others in a stationary system, but this invention adapts this technology to a mobile platform on a harvesting machine.

Benefits: This technology is currently being tested, but the following benefits are expected:

- Bulk densities greater than 20 pounds per cubic feet.
- Low power requirements facilitate implementation on harvesting machine.
- Improved handling and storage compared to bulk biomass.
- Feedstock costs are reduced by $5.00/ton as a result of reduced handling, lower transportation and storage costs.

Catalysts Development From Biomass Syngas

Problem: Current catalysts for converting biomass syngas to mixed alcohol fuels have low productivities that limit process economics

Description: Catalysts with significantly improved productivities for mixed alcohols based on space-time yields. have been developed. These are metal catalysts on solid supports

Impact

- Improved catalysts result in lower capital requirements for thermal conversion processes
- Efficient thermal conversion processes can help meet rapid growth in the demand for ethanol from cellulosic feedstocks

IP position: Invention disclosures and other IP related to catalyst development

Technology Status: PNNL has a family of metal catalysts with various promoters for alcohol fuels

- Reduction to practice possible in approximately 1 year
- Catalyst lifetime studies needed prior to implementation

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Catalysts Development for Pyrolysis Oils

Problem: Pyrolysis oils are thermally less stable than petroleum, have a high oxygen content and low pH.

Description: Catalysts with significantly improved productivities for the upgrading of pyrolysis oil to a petroleum ready refinery feedstock that can be hydrocracked to gasoline and diesel.

Impact

- Lowering processing costs of converting biomass to hydrocarbons
- Efficient thermal conversion processes can help meet rapid growth in the demand for biofuels from cellulosic feedstocks

IP position: Invention disclosures and patent pending.

Technology Status: PNNL has expertise in production of catalysts and process conditions for upgrading and hydrocracking pyrolysis oils.

- Reduction to practice possible in approximately 1 year
- Catalyst lifetime studies needed prior to implementation

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Biomass Preprocessing & Separation System for Harvesters

Problem: Preprocessing and separation of biomass residues for use in a biorefinery is limited by capacity and efficiency of grinding systems.

Technology: Axial flow grinding system made up of rotating drum within a cylindrical set of screens. Biomass material enters the system along the axis of the drum and flows through the cylinder between the drum and the screen with an auger type action due to the orientation of the hammers/knives on the surface of the drum. The biomass moves into the grinding chamber and is sheared in to small participles that fall through the screens and are collected.

Impact: Will reduce the cost of the grinding cellulosic biomass by 40% from $10/ton to $6/ton (2007$). Large market potential with approximately 10 grinders needed to support a single 50 Mgal biorefinery.

IP: This system is a new design and not yet commercially available. The INL has one (1) invention record available for exclusive or nonexclusive license and a patent application in process.

Status:

- Technology is at conceptual stage of development supported by INL experience and experimental data.
- The technology requires further development and optimization (12-24 months).
- The INL is seeking collaboration with industrial participants.

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