

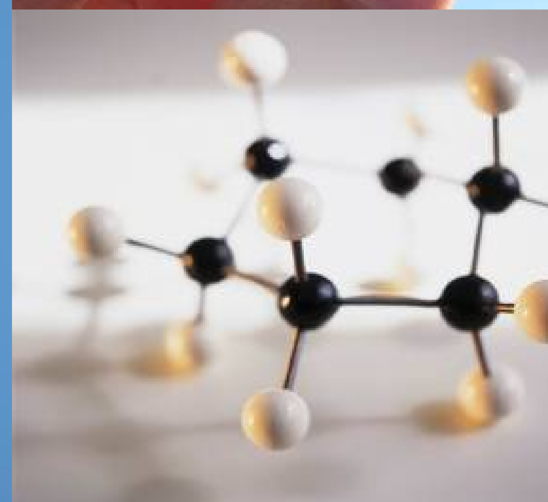


U.S. Department of Energy Biomass Program

Growing A Robust Biofuels Economy

Venture Capital Forum
August 21-22, 2007

Jacques Beaudry-Losique, Program Manager

U.S. Presidential Commitment to Ambitious Biofuels Goals

- Cost-competitive cellulosic ethanol" by 2012
- **"20 in 10"**
  - Reduce U.S. gasoline* use by **20%** by 2017 through…
    - **15%** reduction from new Alternative Fuels Standard at **35 billion** gallons/year
    - **5%** reduction from enhanced efficiency standards (CAFE)
- **"30 in 30"**
  - Longer-term DOE biofuels goal
  - Ramp up the production of biofuels to **60 billion** gallons
  - Displace **30%** of U.S. gasoline consumption* by 2030
- FY08 Office of Biomass Program budget request of $179 million: House and Senate marks exceed $240 million

* light-duty vehicles only

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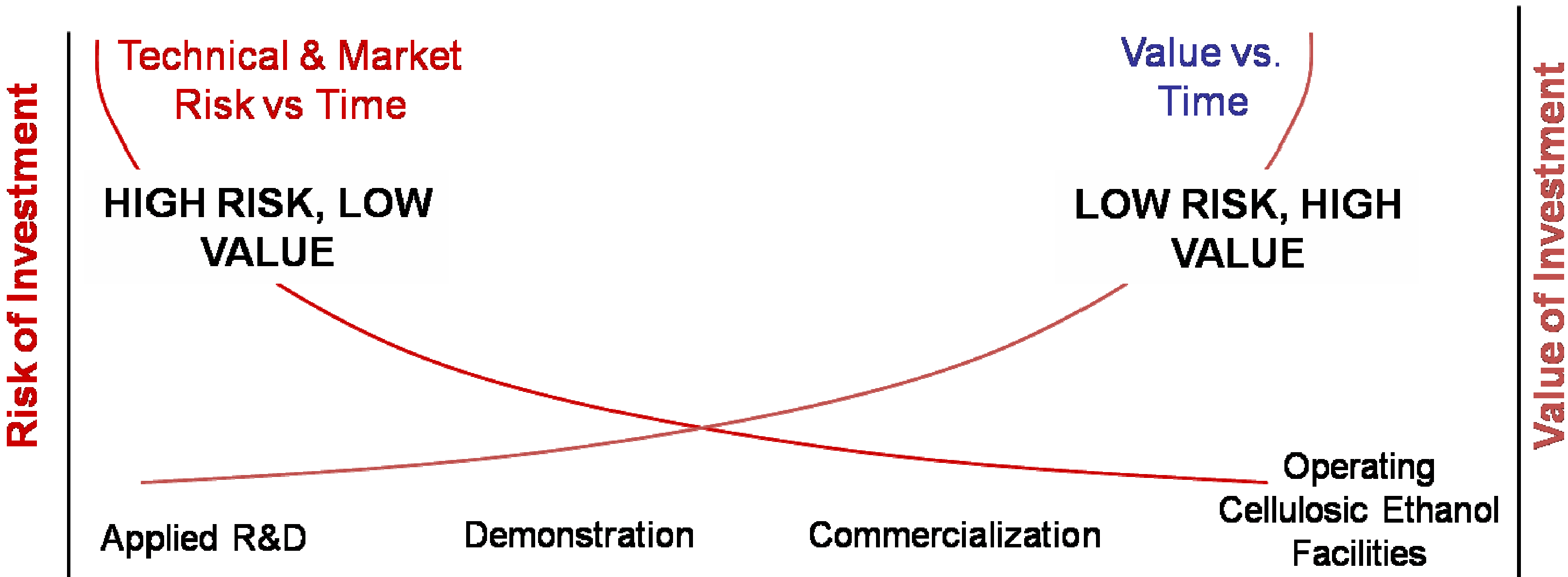
DOE Absorbs Some Of The Risk Through Focused RD&D Program



RD&D Timeline

2006	2007	2011	2012	2014	2018	2025
Loan Guarantee Program; Section 932 Demonstrations	Ethanologen Solicitation	Operation of 932 and 10% Scale Facilities	Reduced Enzyme and Feedstock Costs ($1.31/gallon cost target)	Repeatable Plant Design Packages	Genomics-Improved Feedstocks	Integrated Ethanol/ Bioproduct Facilities

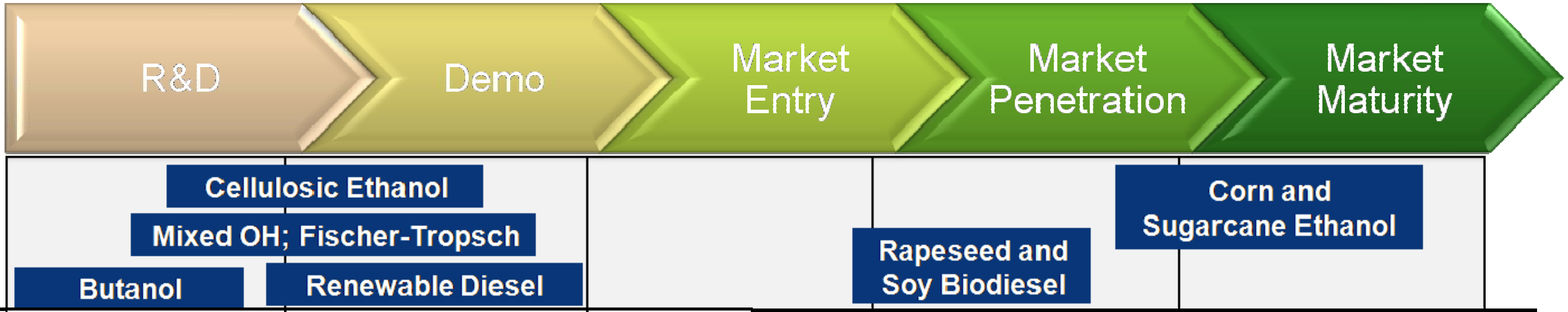
DOE focuses on investment risk reduction to drive market

Targeted RD&D: Overcoming Barriers

Barriers		**Solutions**
High cost of enzymatic conversion	→	R&D to improve effectiveness and reduce costs of enzymatic conversion
Inadequate technology for producing ethanol from sugars derived from cellulosic biomass	→	R&D on advanced micro-organisms for fermentation of sugars
Limitations of thermochemical conversion processes	→	Re-establish thermochemical conversion as a second path to success
Demonstration/integration of technology in biorefineries	→	Fund loan guarantees, commercial biorefinery demonstrations, and 10% scale validation projects
Inadequate feedstock and distribution infrastructure	→	Form interagency infrastructure and feedstock teams

Future efforts will address obstacles to biochemical and thermochemical routes to biofuels, support demonstrations, and resolve infrastructure issues.

"First generation" biofuels are commercially developed technologies, but have high costs and limited scalability…



2nd Generation Biofuels

- **R&D efforts are focused on:**
  - Increasing the range of feedstocks to produce biofuels
  - Reducing biomass-to-liquid conversion costs
- **Two main technology platforms in development:**
  - *Biochemical pathway* - conversion of cellulose to sugars and fermentation to alcohol fuels
  - *Thermochemical pathway* - gasification of biomass to syngas and synthesis to fuels
- **Commercial renewable diesel plants are under construction (e.g., Neste oil "NexBTL")**

1st Generation Biofuels

- **Ethanol** - clean burning, high-octane alcohol fuel used as a replacement and extender for gasoline
  - Has been commercially produced since the 70s in the US and Brazil, still the market leaders
  - Corn ethanol is cost competitive (with no subsidies) with gasoline when crude oil is above $50/barrel ($30/bbl from sugar cane)
- **Biodiesel** - high-cetane, sulfur-free alternative to (or extender of) diesel fuel and heating oil
  - Commercialized in Europe in the 90's
  - Worse economics (and smaller market) than ethanol

DOE focuses on second generation technologies aimed to resolve these limitations

Source: Navigant

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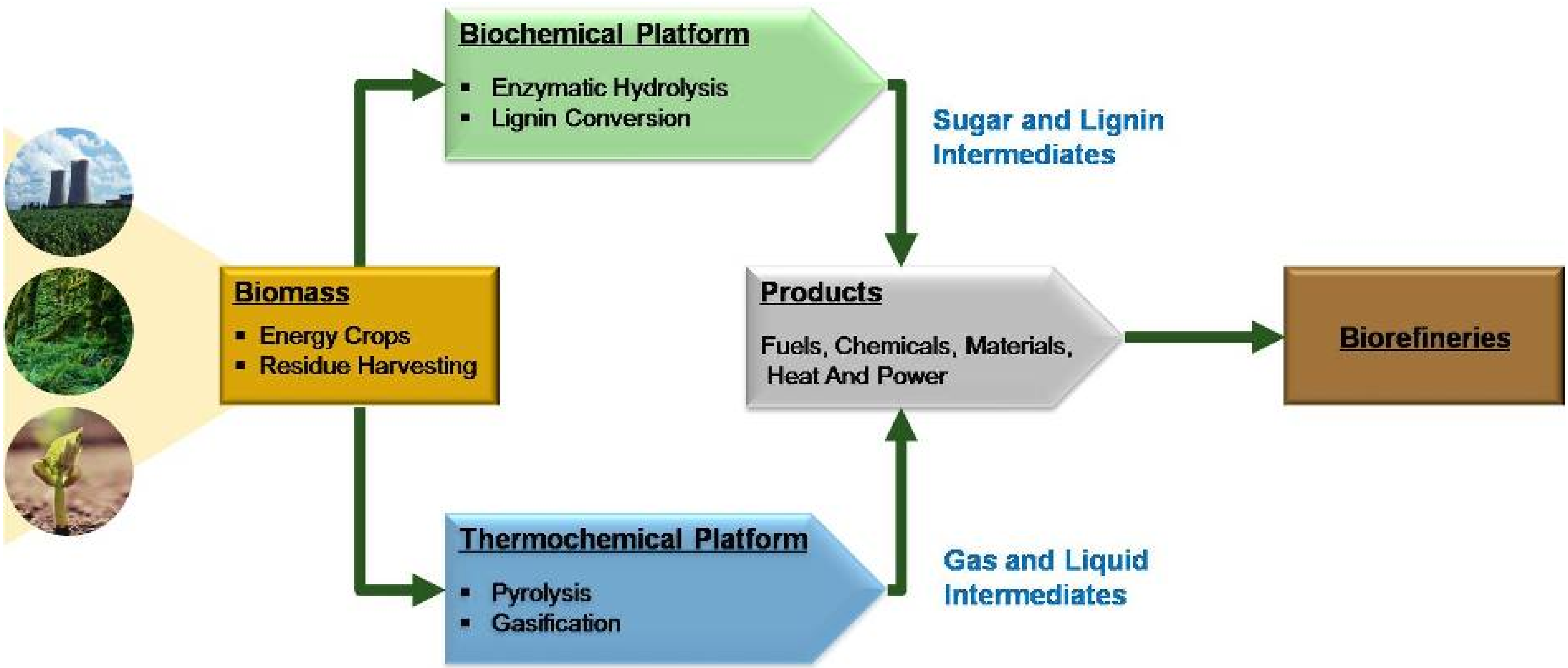
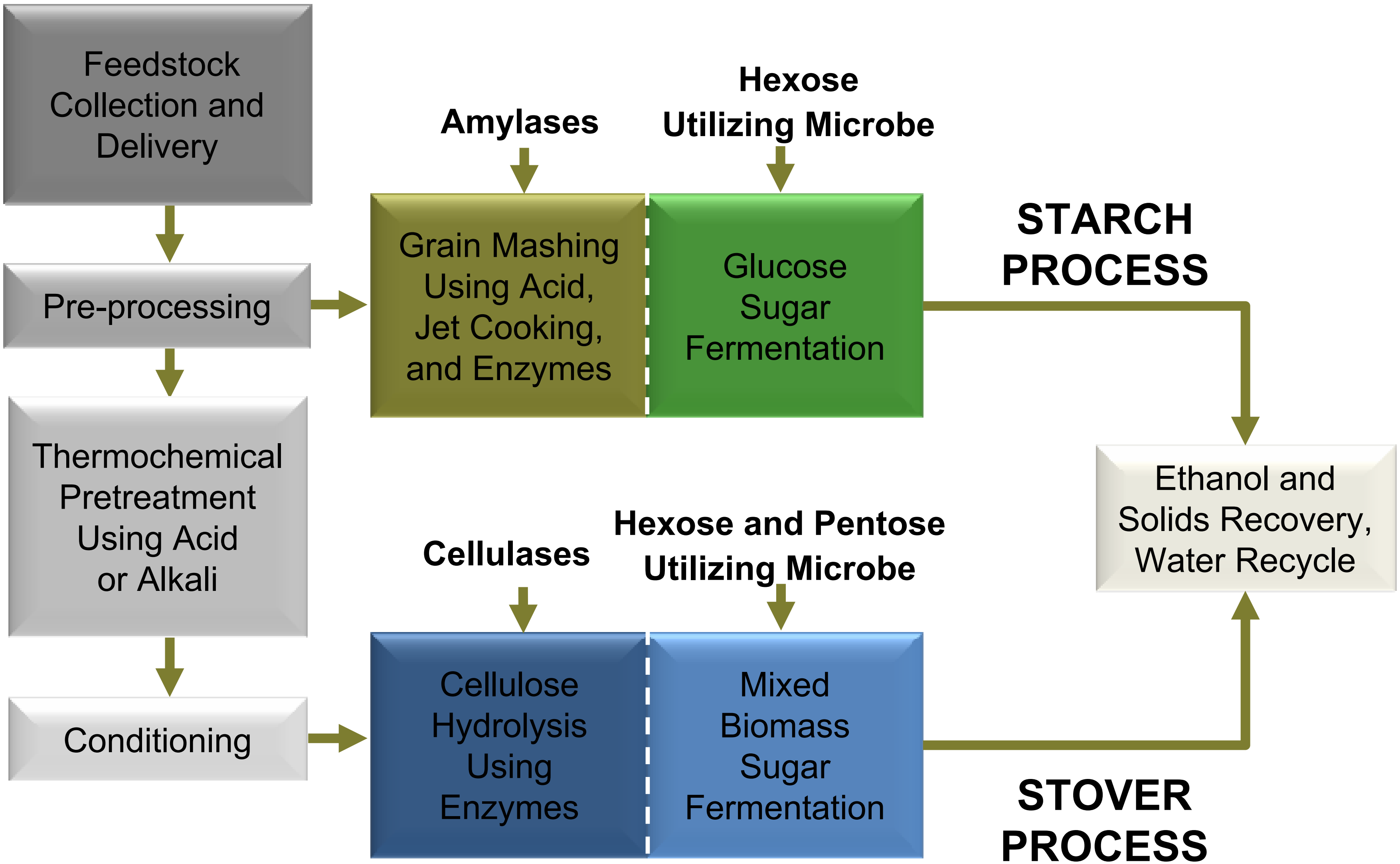
The Biomass Program Is Working On Two Major Routes To Produce Biofuels



Biochemical Processes (1)



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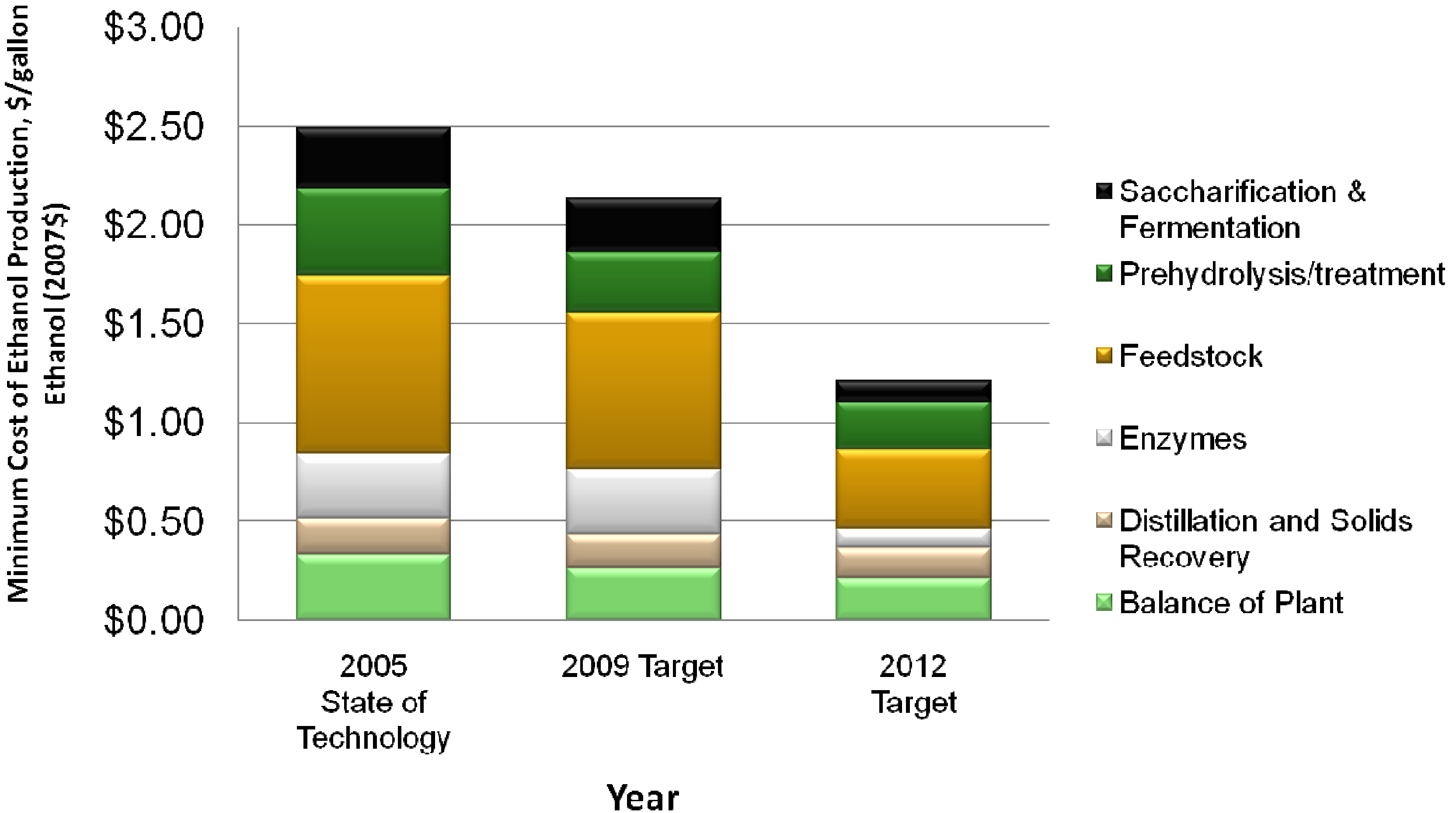
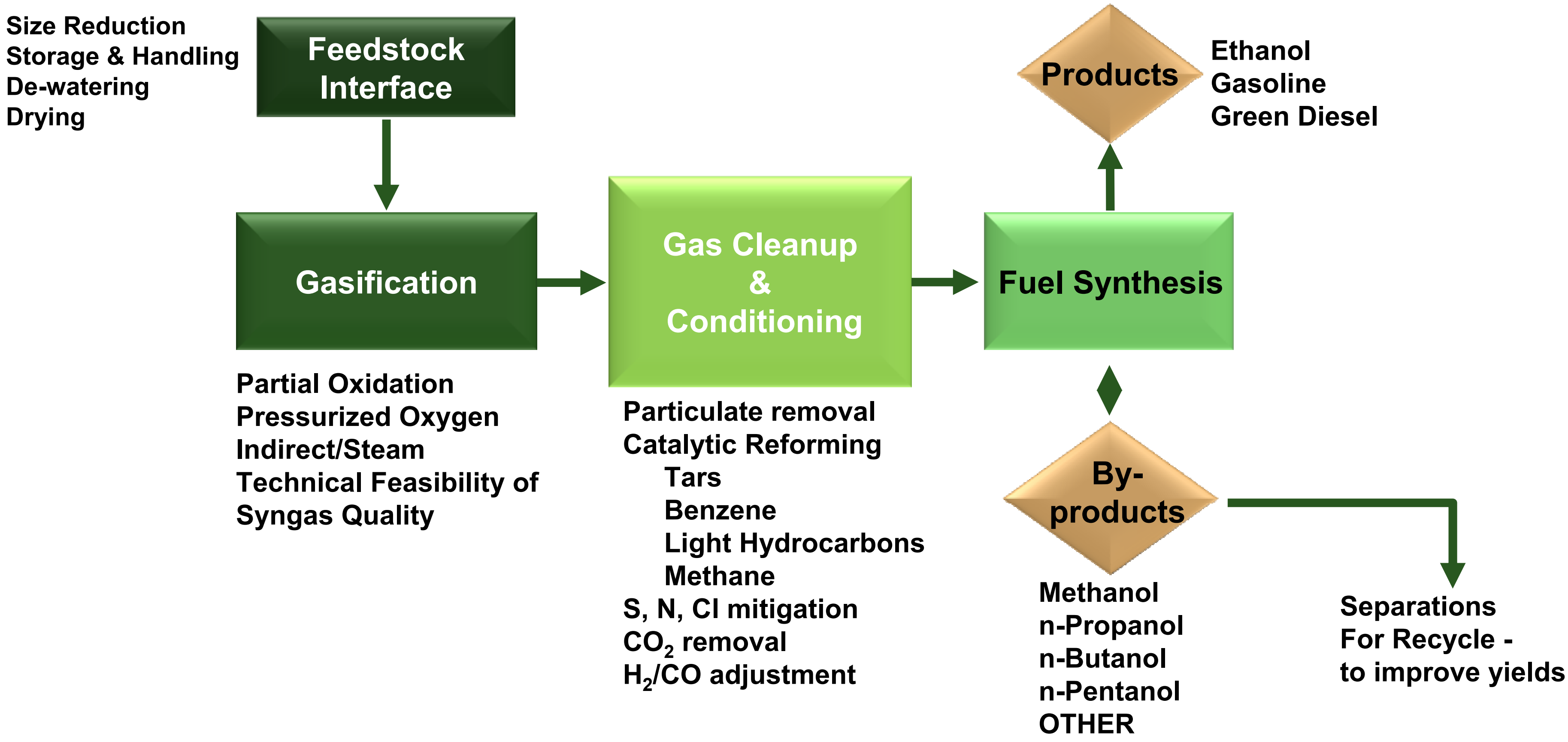
Biochemical Processes (2)



DOE efforts aim to trigger a substantial cost decline in the production of cellulosic ethanol

Thermochemical Processes



Examples of Biomass Program Technology RD&D

Enzymes to Convert Cellulosic Feedstocks into Sugars

Problem:

- Enzymes to convert biomass to simple sugars for biofuels production are too expensive today.

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 industry by 2017 would generate an enzyme market of $400 million to $1 Billion.
- 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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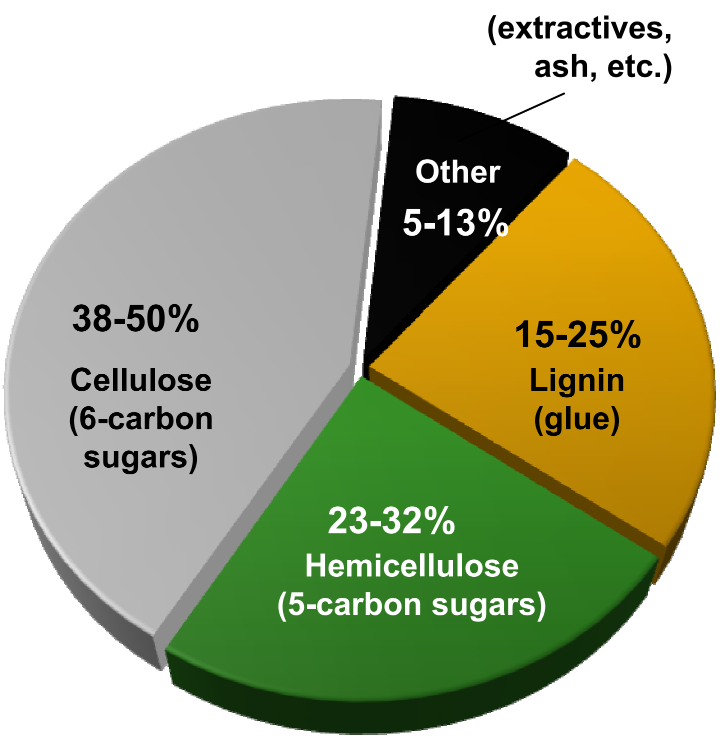
Decrease Ethanol Cost by Fermenting 5-Carbon Sugars

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.



Decrease Ethanol Cost by Fermenting 5-Carbon Sugars (cont'd)

Impact on Biorefineries:

- New routes for simultaneous utilization of all sugars to produce ethanol or bioproducts.
- Competition (top, near-term candidates)
  - Saccharomyces cerevisiae (yeast)
  - E. coli (bacteria)
  - Thermoanaerobacterium saccharolyticum (bacteria)
- Zymo industry total market of $200 to $500 million for a 2-5 billion gallon ethanol industry by 2017.

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

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.

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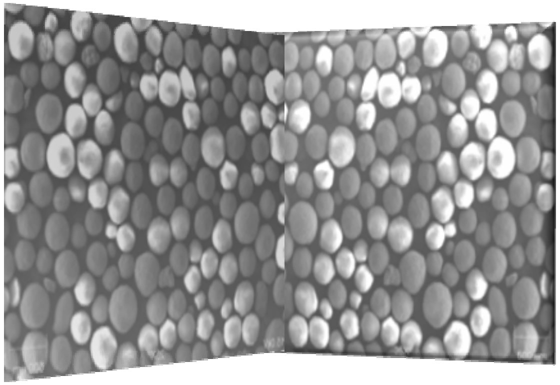
Creating Clean Biomass Syngas for Liquid Biofuels

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.



SEM (1000x) of NREL fluidizable catalyst

Creating Clean Biomass Syngas for Liquid Biofuels (cont'd)

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 a potential market of $50 to $100 million to a catalyst manufacturer.
- 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 To Produce Commodity Chemicals From Sugars

Problem:

- Increasing cost and price volatility of petroleum has impacted the economic margins of US based commodity chemicals.
  - Chemical manufacturers seek low cost renewable feedstocks and processes to maintain competitive advantage in the market place.

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:

- Biorenewables offer new low cost raw materials that can replace many chemicals made today from petroleum. PNNL's technology done in water without organic solvents. Preliminary process economic demonstrate cost savings of approximately 20% versus petroleum.

Catalysts To Produce Commodity Chemicals From Sugars (Cont'd)

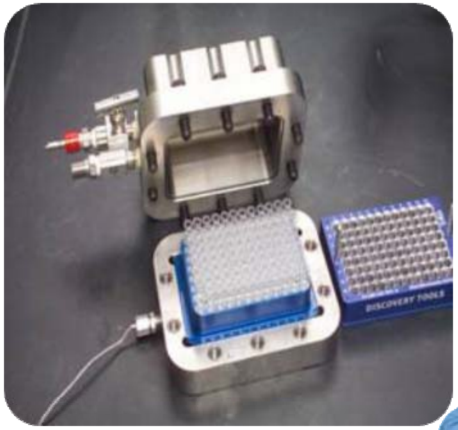
IP Position:

- 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)
- Patents Available for license
  - 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.

Technical tools at PNNL



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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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Biomass

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:

<u>Residue Separation</u> – 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.

<u>Densification System</u> – 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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Biomass

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.

Systems & Methods for Autonomous Control, Automated Guidance, and Global Coordination of Moving Process Machinery

Problem:

- Combine harvesters must be able to operate within physical and geographic bounds, communicate with and cooperate with other autonomous machines also, negotiate problem solutions, and make decisions to optimize the conduct of the work. This requires that the autonomous machines, devices or components be intelligent independent agents, able to collaborate on the conduct of the work, and able to compensate for failures or reduced capabilities of individual agents.

Technology:

- The technology is an integration of three different software programs that enable real-time decision-making, guidance and path-planning jointly. It also includes sensors to acquire and input data. The technology can be retrofitted on existing combines or other industrial machinery as an after-market feature or offered as a standard feature on new equipment.

Impact:

- The technology improves efficiency of the operation of combine harvesters by optimizing unit operations. Given that more than 200 harvesters will be needed to support a single 50 Mgal biorefinery, there is considerable market potential for this product.

Systems & Methods for Autonomous Control, Automated Guidance, and Global Coordination of Moving Process Machinery (cont'd)

IP:

- The IP consists of software algorithms and sensors that integrate decision-making, guidance and path-planning for the operation of a combine harvester or other industrial equipment. Trimble Navigation and Deere both have commercial products that offer one or more features of the above technology. However, no university or industrial company is working on an integrated system as described. The INL has one (1) pending patent that is available for worldwide exclusive or nonexclusive license.

Status:

- The technology has been demonstrated multiple times on prototype combine harvesters on a wheat production field during harvest for multiple years.
  - This system requires additional integration and optimization through a 24 month public/private collaboration.
  - The INL is seeking collaboration with qualified integrated agricultural equipment manufacturers to complete commercial development.

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Laboratory Patents and Contacts

Lab	Title	IP Position	Contact
ORNL	Improving Separation of Lignin from Carbohydrates in Wood Pulp and Biomass Hydrolysis Liquors	One patent	Alicia Compere 865-574-4970 compereal@ornl.gov
INL	Biomass Preprocessing & Separation System	A patent application is in preparation	David Anderson 208-526-0837 David.Anderson@inl.gov
INL	Single-pass Multi-component Harvester	One issued patent, and two pending patents	David Anderson 208-526-0837 David.Anderson@inl.gov
INL	Systems & Methods for Autonomous Control, Automated Guidance, and Global Coordination of Moving Process Machinery	One pending patent	David Anderson 208-526-0837 David.Anderson@inl.gov
NREL	Enzymes to Saccharify Cellulosic Feedstocks into Sugars	11 issued patents	Rich Bolin 303-275-3028 richard_bolin@nrel.gov
NREL	Decrease Ethanol Cost by Fermenting 5-Carbon Sugars	5 issued patents	Rich Bolin 303-275-3028 richard_bolin@nrel.gov
NREL	Creating Clean Biomass Syngas for Liquid Biofuels	Patent application filed jointly with CoorsTek, supplier of supports	Rich Bolin 303-275-3028 richard_bolin@nrel.gov
PNNL	Improved Catalysts for Mixed Alcohol Fuels from Biomass Syngas	PNNL has invention disclosures and other IP related to catalyst development.	Don Stevens 509-372-4603 Don.Stevens@PNL.gov
PNNL	Enabling tools for fungal biotechnology	Two patent applications	Mark Butcher 509-375-6894 Mark.butcher@pnl.gov
PNNL	Production of commodity chemicals from sugars	Dozens of patents and many additional invention disclosures.	John Holladay 509-375-2025 John.holladay@pnl.gov
ORNL	Improving Separation of Lignin from Carbohydrates in Wood Pulp and Biomass Hydrolysis Liquors	One patent	Alicia Compere 865-574-4970 compereal@ornl.gov
INL	Biomass Preprocessing & Separation System	One patent application is in preparation	David Anderson 208-526-0837 David.Anderson@inl.gov
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INL	Systems & Methods for Autonomous Control, Automated Guidance, and Global Coordination of Moving Process Machinery	One pending patent	David Anderson 208-526-0837 David.Anderson@inl.gov

Biomass

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- EERE INFO CENTER - http://www1.eere.energy.gov/informationcenter/

Thank You