Cross-cutting Technologies for Advanced Biofuels

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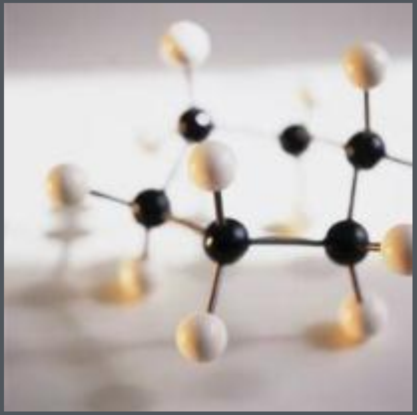

Report-Out Webinar

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Adam Bratis, Ph.D.

NREL

Cross-cutting Technology Areas:

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Dr. Adam Bratis
Biomass Program Manager
National Renewable Energy Laboratory
Golden, CO

Feedstock Supply and Logistics

- growth, harvesting, delivery

Analysis

- economic, life-cycle, resource assessment

Catalysis

- design, characterization, testing

Separations

- contaminant removal, product recovery

Current activities include R&D led by the [Sun Grant Initiative](), a network of land-grant universities, in partnership with industry, DOE National Laboratories, and USDA, to establish biomass feedstock productivity baselines. The 2010 regional bioenergy crop trials were located across the nation.

Cross-cutting: *Feedstock Logistics*

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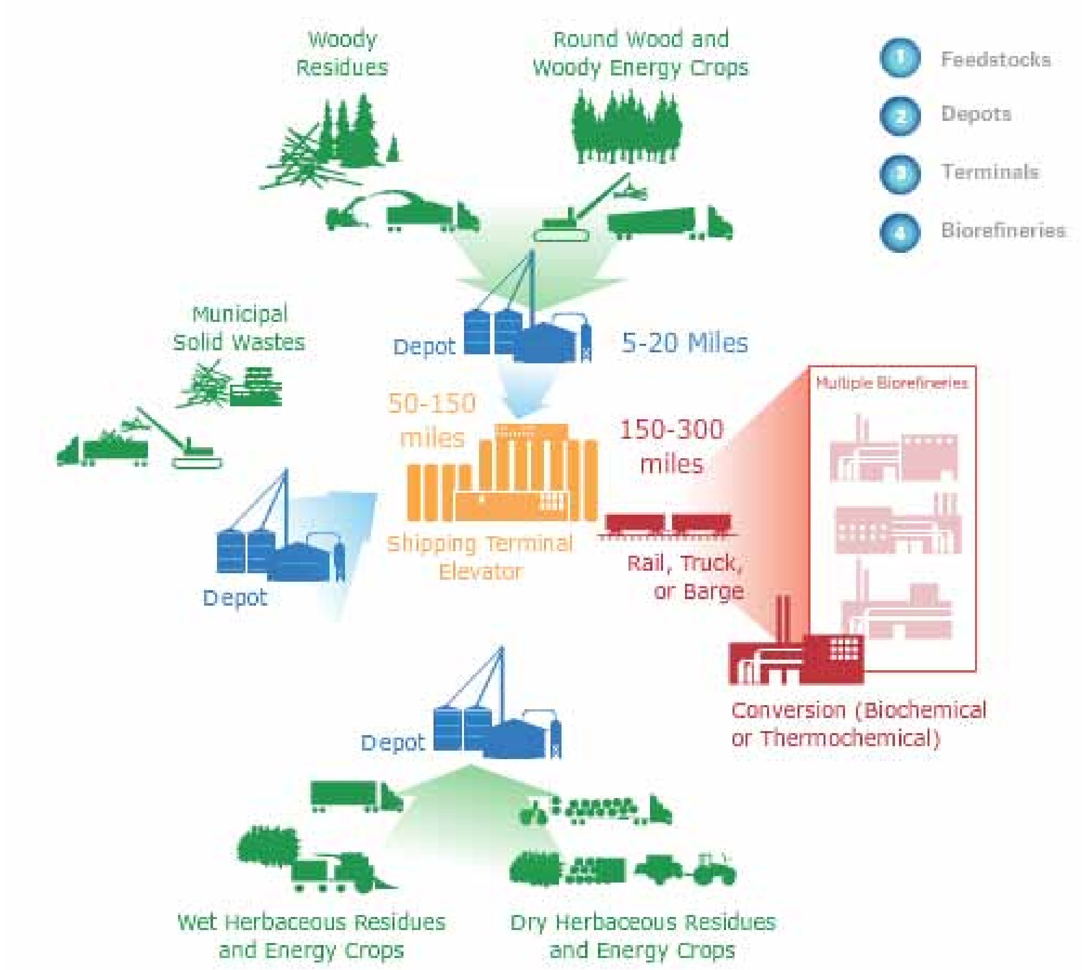
Current activities deal with major RD&D challenges associated with developing logistics systems for woody and herbaceous feedstock materials that are capable of supplying biorefineries with lower cost, high density, aerobically stable, and high-quality biomass material.



Existing Supply Systems	Depot Supply Systems
Nearer-term Platform Focus (through 2012)	Longer-term Platform Focus (2013+)
Access to a niche or limited feedstock resource	Access to a broader resource
Based on a dry supply system design (field-dried feedstocks)	Allows higher-moisture feedstocks into supply system
Designed for a specific feedstock type (dry corn stover)	Design addresses multiple feedstock types

Cross-cutting: *Feedstock Challenges and Activities*

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Ongoing Work:

- Billion Ton Study Update
- Sun Grant Initiative
- Uniform Format Feedstock Approach

Barriers:

- Low Energy Density
  - *Current model is small, decentralized plants*
  - *Difficulty maximizing economies of scale*
- Compositional Reliability/Variability
  - *Inter-crop, inter-variety, seasonal,*
  - *Geographical, storage effects, etc.*
  - *Moisture, ash, sugar content, etc.*
- High Relative Cost
  - *Largest cost contributor to biofuels production*
- Impact of Harvesting/Storage on
- Downstream Conversion
  - *Densification and product uniformity strategies*

Critical R&D Activities:

- Explore densification strategies to lower feedstock cost
- Define specifications at Feedstock/Conversion Interface
- Develop genetically modified feedstocks with higher sugar composition and lower recalcitrance
- Develop harvesting, collection and storage methods that minimize contamination and sugar degradation
- Determine impact of harvesting/logistics strategies on downstream conversion
- Understand and optimize the sustainability aspects of feedstock harvesting, logistics and storage operations

Cross-cutting: *Analysis*

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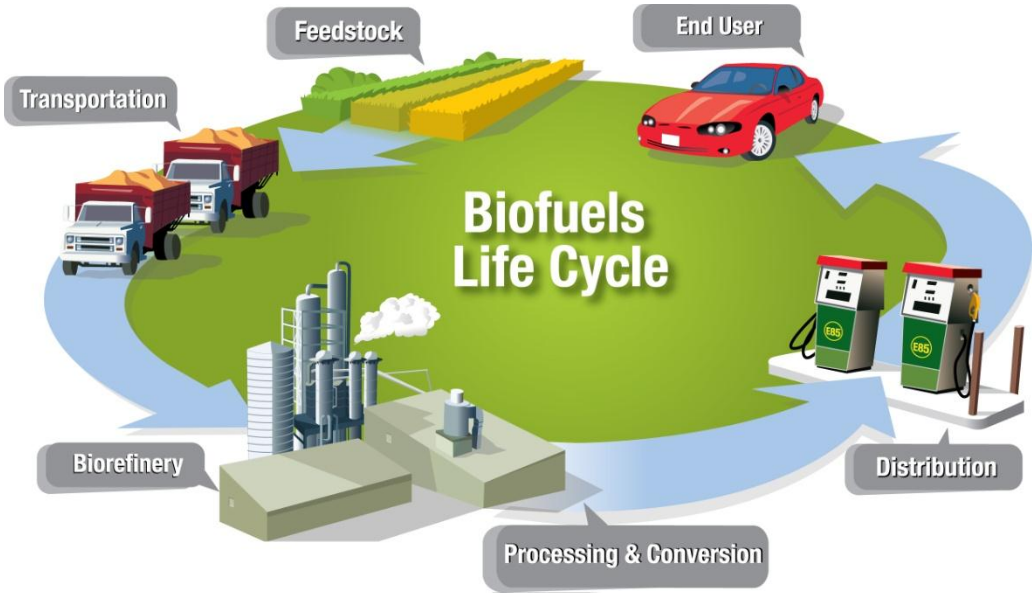
Current activities provide the analytical basis for Biomass Program planning, identify areas of high impact research, and progress assessments, define and validate performance targets for biomass technologies and systems, review and evaluate external analysis and studies, and contribute engineering analyses.

State-of-technology techno-economic assessments

Land-use change model development



GIS-based assessment of optimal feedstock resource potential

Well-to-wheels analysis and expansion of GHG Emissions and Energy Use in Transportation (GREET) model for emerging biofuels production pathways

	2007	2008	2009	2010	2011 Targets	2012 Targets
Minimum Ethanol Selling Price ($/gal)	**$3.64**	**$3.56**	**$3.19**	**$2.77**	**$2.56**	**$2.15**
Feedstock Contribution ($/gal)	$1.12	$1.04	$0.95	$0.82	$0.76	$0.74
Conversion Contribution ($/gal)	$2.52	$2.52	$2.24	$1.95	$1.80	$1.41
Yield (Gallon/dry ton)	69	70	73	75	78	79
Feedstock						
Feedstock Cost ($/dry ton)	$77.20	$72.90	$69.65	$61.30	$59.60	$58.50
Pretreatment						
Solids Loading (wt%)	30%	30%	30%	30%	30%	30%
Xylan to Xylose (including enzymatic)	75%	75%	84%	85%	88%	90%
Xylan to Degradation Products	13%	11%	6%	8%	5%	5%
Conditioning						
Ammonia Loading (mL per L Hydrolyzate)	50	50	38	23	25	25
Hydrolyzate solid-liquid separation	yes	yes	yes	Yes	Yes	no
Xylose Sugar Loss	2%	2%	2%	2%	1%	1%
Glucose Sugar Loss	1%	1%	1%	1%	1%	0%
Enzymes						
Enzyme Contribution ($/gal EtOH)	$0.39	$0.38	$0.36	$0.36	$0.34	$0.34
Enzymatic Hydrolysis & Fermentation						
Total Solids Loading (wt%)	20%	20%	20%	17%	17%	20%
Combined Saccharification & Fermentation Time (d)	7	7	7	5	5	5
Corn Steep Liquor Loading (wt%)	1%	1%	1%	1%	0.60%	0.25%
Overall Cellulose to Ethanol	86%	86%	84%	86%	86%	86%
Xylose to Ethanol	76%	80%	82%	79%	85%	85%
Arabinose to Ethanol	0%	0%	51%	68%	80%	85%

Cross-cutting:
Sustainability

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Current efforts are developing and integrating the resources, technologies, and systems across the supply chain needed to grow a biofuels industry in a way that protects the environment and enables sustainable future resources

Feedstock production and logistics

- Evaluate nutrient and carbon cycling
- Assess impact on land and resource use

Conversion

- Minimize water consumption, air pollution, and carbon footprint
- Utilize co-products and fully integrate systems
- Maximize efficiency

ethanol
diesel
gasoline
jet fuel
biopower
bioproducts

End use

- Minimize GHG emissions
- Avoid negative impacts on human health

Cross-cutting

- Life-cycle analysis of water consumption and GHG emissions
- Land-use change modeling
- Water quality analysis
- Environmental, economic, and social factors

Cross-cutting:
Analysis and Sustainability

Ongoing Work:

- Peer Reviewed techno-economic analyses
- WTW GHG Emission Modeling
- GIS based Resource Assessments

Barriers:

- Availability of High Quality, Public Data
- Still "Developing" Process Strategies
  - *many potential pathways/intermediates to hydrocarbon fuels/products*
  - *some ill-defined unit operations relative to cellulosic ethanol*
  - *New separation/product recovery strategies and lignin utilization strategies needed*
- Lack of Consistent Analytical Approach
  - *assumptions drive recommendations*

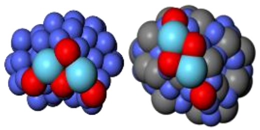
Critical R&D Activities:

- High level Hydrocarbon Fuel Scoping Study
  - *compare a variety of bio-oil and sugar intermediate routes to HC fuels; identify baselines and/or gaps in experimental information, guide R&D opportunities*
- Refinery Integration and Co-location Study
  - *evaluate economic impact of refinery integration, perform comprehensive TEA to guide selection of feasible intermediates, examine trade-offs between economy of scale advantages in refinery and transportation*
- Lignin Utilization Study
  - *evaluate fuel and value added product options that could be generated from lignin or lignin monomers/oligomers*

Cross-cutting: *Catalysis*

Chemical Catalysis

Fundamental Science

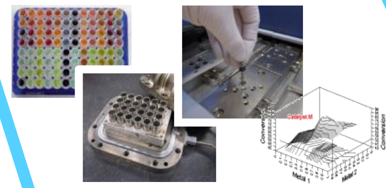


Computation is helping to shape our understanding of metal-metal and metal-support interactions in catalytic materials.

The design of new catalytic materials with precise active sites for selective deoxygenation.

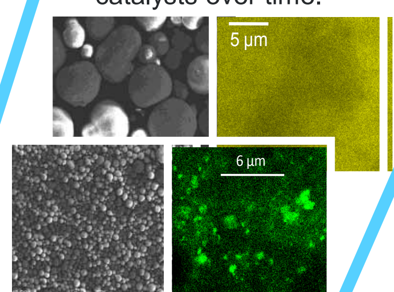
Applied R&D

Developing robust catalysts for biomass-derived process streams



Tools available are accelerating catalyst discovery and testing.

Surface science tools are providing details on changes to catalysts over time.



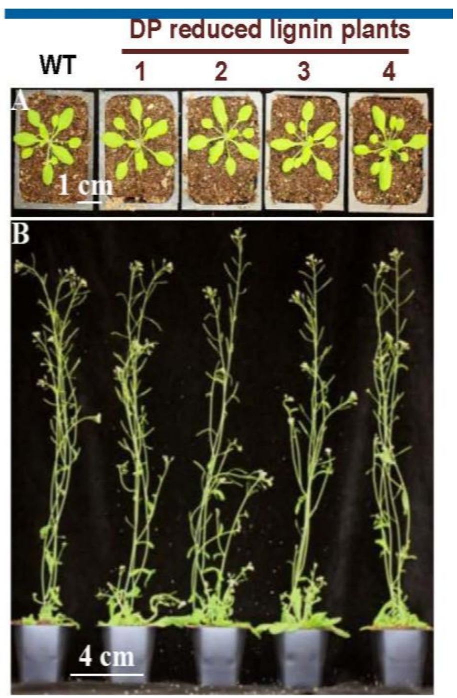
Integration and Demonstration

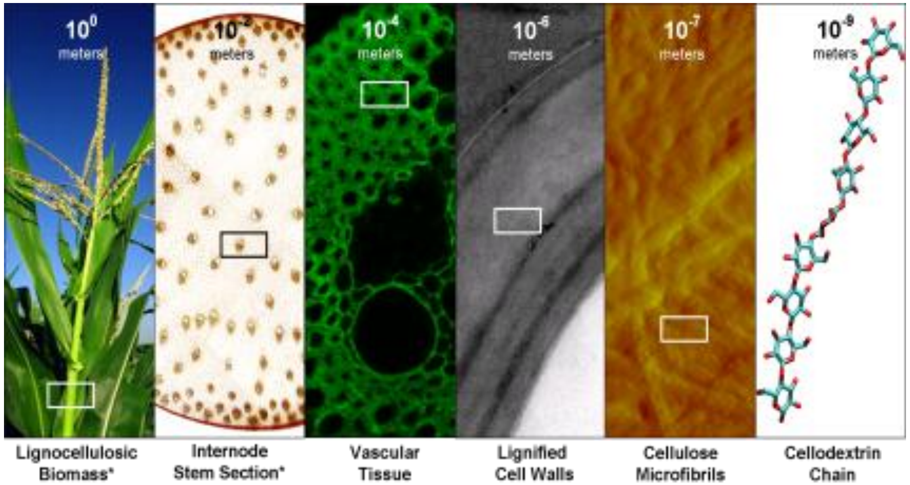
Validating and piloting

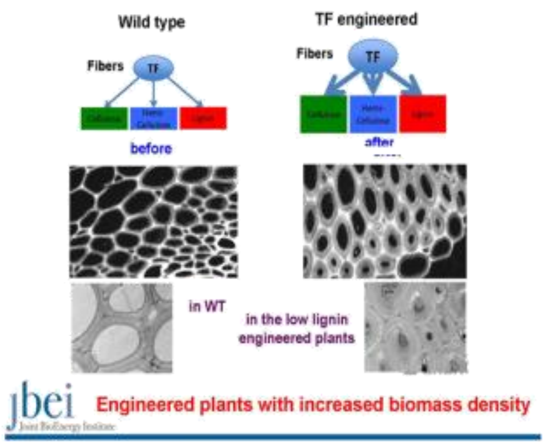
Catalysts are validated through thousands of hours of operation in continuous reactors. Integrated process can be demonstrated.

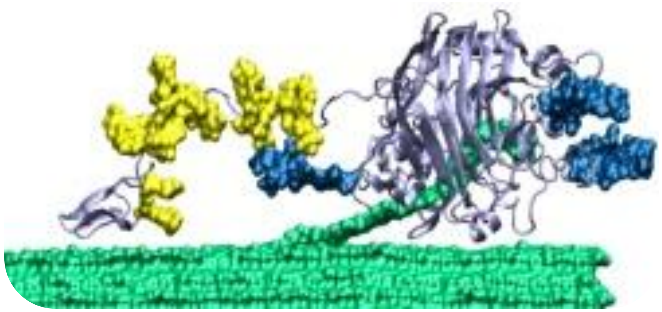
Biotechnology and Biocatalysis

Research provides insight into the cell wall. The insight is used to develop new plant species, improved enzymes for deconstruction, and advanced organisms for converting sugars/carbohydrates into organic acids, alcohols, and hydrocarbons.









Cross-cutting: *Catalysis*

Ongoing Work:

- **Catalyst Design, Characterization and Testing**
- **Enzyme/Organism Characterization and Development**
- **Biomass/Catalyst Surface Characterization**

Barriers:

- **Poor Selectivity Towards Desired Reactions**
  - *Decreases process/carbon efficiency*
  - *Increases coke formation/volatiles formation/catalyst deactivation*
  - *Low sugar utilization in fermentation*
- **Poor Understanding of Rxn Fundamentals**
  - *Kinetics, mechanisms, competing reactions, surface interactions in complex mixtures*
- **Limited Catalyst Lifetime Data**
  - *Catalyst deactivation and organism/enzyme inhibition an issue*
  - *Catalyst stability and regenerability*

Critical R&D Activities:

- **Enhance selectivity towards desired reactions**
  - *Better understanding of catalyst-biomass surface interactions through modeling, spectroscopy, and empirical relationships*
- **Investigate novel processes and catalysts**
  - *H_2 addition during pyrolysis, hydrogen*
  - *Donor/shuttle molecules, consolidated*
  - *Bioprocessing, thermo-tolerant enzymes,*
  - *Genetically improved organisms*
- **Improve catalyst lifetimes**
  - *Develop more robust catalysts and inhibitor tolerant organisms*
  - *Improve aqueous phase catalysts (stability and selectivity) in presence of hydrolyzates*
- **Industrially Relevant Long Term Testing**

Cross-cutting:
Separations

Ongoing Work:

- **Inhibitor Mitigation/Removal from Slurries**
  - *De-acetylation*
- **Gas/Liquid Filtration of Pyrolysis Vapors/Oils**

Barriers:

- **Product Recovery for HCs Different than EtOH**
  - *Potentially less energy intensive but more complex than fractional distillation*
- **Poor Understanding of Purification Needs**
  - *Emerging organisms/catalysts will have own set of tolerances to inhibitors/contaminants*
  - *Extensive concentration of intermediates?*
  - *Solid/liq. separation in intermediates/products*
- **Economic Routes to Reagent Recycling and Product Recovery**
- **Membrane/Filter Durability for Biofuels**

Critical R&D Activities:

- **Explore Feasibility of Current Technology to Biomass Applications**
- **Identification and Mitigation of Key Inhibitors/Contaminants**
- **Development of Novel Separation Techniques/Materials**
- **Integrate Separations and Conversion**
  - *Product removal during fermentation*
  - *Catalysis during filtration*
  - *Reactive distillation*
- **Explore Reagent Recycling Strategies**
- **Industrially Relevant Long Term Testing**