Penn State BioEnergy Bridge™ Partnership

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- Penn State Institutes of Energy and the Environment
- Environment and Natural Resources Institute
- EMS Energy Institute
- Huck Institutes of the Life Sciences
- Materials Research Institute
- Larsen Transportation Institute
- USDA-ARS Pasture Systems and Watershed Management Unit
Penn State Presents the BioEnergy Bridge™

• A university-industry-public partnership to address the critical need for integrated research and technology in the area of biomass fuels and power research

• The BioEnergy Bridge™ will address the full spectrum of challenges to our national priority of reducing dependence on foreign oil as well as decreasing environmental impact of fossil fuels
Penn State Presents the BioEnergy Bridge™

• The BioEnergy Bridge™ will build upon the University’s well established R&D pillars throughout the biomass supply chain to address the larger, systems issues that are critical to successful bioindustry development.
  – Diverse Feedstock Assessment
  – Feedstock Supply Chain and Delivery Infrastructure
  – Technoeconomic Analysis
  – Environmental Assessment
  – Economic and Workforce Development
  – Policy
  – Community Outreach
Penn State BioEnergy Bridge™

Systems

- Sustainable Agricultural Systems
- Integrated Process Analysis
- Supply Chain Research
- Socio-economic and Ethical Dimensions

The BioEnergy Bridge™

Processes

- Plant Production
- Biomass Harvest and Transport
- Biomass Storage and Pretreatment
- Saccharification and Fermentation
- Separations
- Combustion, Pyrolysis, and Gasification
- Chemical Catalysis
- Bioenergy Production – Electricity and Hydrogen
- Byproduct Recovery and Utilization

Services

- Field Trials
- Onsite Saccharification and Fermentation Facilities
- Techno-Economic Analysis
- Life Cycle Assessment
- Sustainability Analysis
- Engine and Vehicle Testing
- Outreach
Penn State BioEnergy Bridge™

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- Partnering to perform world class R&D at the bench and pilot scale
- Utilizing PSU’s vast intellectual capabilities to solve the technical issues related to fuels, power and products from biomass

The BioEnergy Bridge™

Processes
Penn State BioEnergy Bridge™

Penn State will provide scale-up capabilities to commercialize innovative technologies from both academic and industrial research.

Penn State will serve as a proving ground for companies that wish to test:

- Plant varieties
- Engineered organisms
- Biocatalysts
- Combustion and gasification technologies
- Fuels for car and truck engine testing

Services

- Field Trials
- Onsite Saccharification and Fermentation Facilities
- Techno-Economic Analysis
- Life Cycle Assessment
- Sustainability Analysis
- Engine and Vehicle Testing
- Outreach
Penn State BioEnergy Bridge™

Connecting the laboratory bench with industrial implementation in the areas of:

• Diverse Feedstock Assessment
• Feedstock Supply Chain and Delivery Infrastructure
• Technoeconomic Analysis
• Environmental Assessment
• Economic and Workforce Development
• Policy
• Community Outreach

Systems

The BioEnergy Bridge™

• Sustainable Agricultural Systems
• Integrated Process Analysis
• Supply Chain Research
• Socio-economic and Ethical Dimensions
Diversified Biomass Production Resources

• Penn State has over 14,000 acres of land
  – 3,000 + acres of crop land
  – 10,000 + acres of forest land
Penn State Fermentation Test Facilities

• Penn State has a fully functional fermentation facility
  – Sixfors 6 x 500ml research fermentor
  – Bioflow 1L to 5L benchtop fermentor
  – New Brunswick 15L cell culture bioreactor
  – New Brunswick 30L fermentor
  – Bio Services 60L bioreactor
  – 2 x New Brunswick 80L fermentors
  – ABEC 100L Bioreactor
  – Bio Service 150L fermentor
  – Bio Service 300L fermentor
  – Sharples T-1-P tube bowl centrifuge
  – Sharples AS-16 centrifuge

10+ yr track record of industry short courses
EMS Energy Institute Biofuels Initiatives

• Stationary
  – Combustion: Watertube Boiler, Fluidized-Bed Combustor
  – Gasification

• Transportation
  – Engine combustion performance and emissions characterization

• Biomass processing
Stationary Biofuels: Feedstocks

- Grasses/Wood Chips
- Animal Tissue
- Proteins
- Fats/Oils

Feedstocks include various materials like grasses, wood chips, animal tissue, proteins, and fats/oils.
Combustion: Fuel-Flexible Boilers

Hatfield Quality Meats, Cargill Taylor Beef, Keystone Protein Co., Monona Farms
Gasification: Wood

Gasification Reactor

Temp: 900 - 1,000°C
Input: Fuel, N₂ and Steam
Output: Gas and Char

Starting Material (Poplar)

End Product: Char

Red Maple Wood

- Hydrogen
- Methane
- Ethane
- Carbon Monoxide
- Carbon Dioxide
- Ethylene
- Acetylene
Transportation: Facilities

Engines
- 3 Light duty common-rail CI
- 1 Single cylinder marine CI
- Variable CR (Octane Rating)
- 1 Single cylinder SI
- All fully instrumented

Vehicles
- Entire fleet for testing
- Test track and dynamometer

Emissions
- Gas
  - AVL Diesel Emissions Bench
  - AVL Gasoline Emissions Bench
  - CA Emissions Bench
- PM
  - TSI SMPS
  - TEOM
  - Sierra BG-3
Biodiesel: Spray and Combustion

ULSD

B40

B100

10% Load and 1800 RPM in Cummins 5.9L ISB

Conoco-Phillips, Ultra Clean Fuels
Biodiesel: Soot Reactivity

Particulate Filter

Requires periodic burn-off of the filtered diesel particulates to prevent excessive “backpressure”

“Wall flow filtration”
Butanol: A Multi-Use Biofuel

- Reduced sooting tendency in diesel engines
- Alternative gasoline fuel
- More easily separated from water than ethanol
Alternative Fuels

- Butanol
- Dimethyl Ether (DME)
- Fischer-Tropsch (FT)
- Hydrogen
- Jet Fuel
- SVO
Biomass Feedstock Production

- Feedstock Production
- Harvest and Storage Technologies
- Plant Biotechnology
Ecological Intensification of Agriculture
Integrating bioenergy crops in food crop rotations

• Winter canola, camelina and soy biodiesel
  – Canola: 115 gal/A @ 50 bu/A vs.
  – Soybeans: 71 gal/A @ 50 bu/A

• Winter barley for ethanol
  – cover crop for soil protection
  – summer ethanol feedstock
21st Century Forestry

- Forest thinning for timber and wildlife
- Harvest small diameter, low use wood
- Logging residue recovery and use
Biomass Harvest and Value-added Storage

- Minimize dry matter loss
- Facilitate densification and transport
- Reduce pretreatment severity, minimizing energy and chemical inputs and costs
Plant Biotechnology

- Modify lignin synthesis
- Modify cell wall linkages
- Expansin synergies with cellulases
- Oil and starch metabolism
Identifying Feedstock Potential

75 million ha once farmed, no longer in production (or developed)
@ 50% re-conversion, 20 tons/ha = 750M tons
Land-use Change Decision Support

http://i-farmtools.org
Evaluating Cropping System Alternatives
Soy-Corn/Rye

Energetic Inputs

- Biodiesel Processing, 16%
- Cellulosic Ethanol Processing, 18%
- On-Farm Fuel Use, 19%
- Insecticide, 1%
- Herbicide, 3%
- Seed, 5%
- K, 6%
- P, 5%
- N, 27%

Energetic Outputs

- Cellulosic Ethanol, 64%
- Biodiesel, 12%
- Soymeal, 8%
- Glycerine, 2%
- Cellulosic Ethanol Coproduct, 14%

Energy Inputs: 24,368 MJ/ha
Energy Outputs: 84,554 MJ/ha
Net Energy Value: 60,187 MJ/ha
Net Energy Ratio: 3.47
Evaluating Cropping System Alternatives
Corn-Soy

Energetic Inputs
- Corn Ethanol Processing, 64%
- Biodiesel Processing, 12%
- Drying, 2%
- P, 1%
- K, 1%
- Seed, 3%
- Herbicide, 1%
- On-Farm Fuel Use, 5%

Energetic Outputs
- Corn Ethanol, 55%
- Biodiesel, 19%
- DDGS, 11%
- Glycerine, 3%
- Soymeal, 12%

Energy

<table>
<thead>
<tr>
<th>Energy</th>
<th>Value</th>
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<tbody>
<tr>
<td>Energy Inputs</td>
<td>38,655 MJ/ha</td>
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<tr>
<td>Energy Outputs</td>
<td>62,187 MJ/ha</td>
</tr>
<tr>
<td>Net Energy Value</td>
<td>23,532 MJ/ha</td>
</tr>
<tr>
<td>Net Energy Ratio</td>
<td>1.61</td>
</tr>
</tbody>
</table>
Addressing Stakeholder Concerns

• Will trade-offs be necessary between environmental benefits and economic growth?
• Who will invest in processing and biorefineries?
• What role will farmers have in the coming ‘bioeconomy’?
• Will CRP and other governmental regulations/policies help facilitate switchgrass production for energy?
Supply-Chain Operations

Suppliers of construction waste, woody biomass, and agricultural biomass

Biomass Conversion Facility

Downstream Operators

Source: SCOR 9.0, Supply-Chain Council (2008)
Feedstock Supply Elements

Biomass Production → Harvest & Collection → On-Site Storage

Handling & Transportation

- Cutting & hauling
- Densification (baling, bundling or chipping)

Farm gate

Handling & Off-site transport → Handling & Queuing

Plant gate

Pre-processing

- Grinding and formatting for increased density
- Fractionation, tissue separation, drying, or blending for improved feedstock quality

Conversion Plant

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Feedstock Supply Elements

Biomass Production → Harvest & Collection → Off-site pre-processing → Long-haul transport to plant → Handling & Queuing → Conversion Plant

- Cutting & hauling
- Densification (baling, bundling or chipping)

Handling & Transportation:
- Grinding and formatting for increased density
- Fractionation, tissue separation, drying, or blending for improved feedstock quality
- Loads directly to transport vehicle

Farm gate

Plant gate
Feedstock Supply Elements

Biomass Production → Harvest & Collection → On-site pre-processing → Long-haul transport to plant → Handling & Queuing → Conversion Plant

- Cutting & hauling
- Densification (baling, bundling or chipping)
- Field drying
- Grinding and formatting for increased density
- Fractionation, tissue separation, drying, or blending for improved feedstock quality
The Uncertainty Framework

Demand uncertainty

Low (Functional Products)  High (Innovative Products)

Low (Stable Process)  High (Evolving Process)

- **Efficient Supply Chains**: Grocery, basic apparel, food, oil and gas
- **Responsive Supply Chains**: Fashion apparel, computers, pop music
- **Risk-Hedging Supply Chains**: Hydro-electric power, some food produce
- **Agile Supply Chains**: Telecom, high-end computers, semiconductor

Source: Lee (2002)
Life Cycle Assessment

- Extraction process
  - raw materials
  - non-renewable energy
  - emissions
  - energy

- Process
  - Intermediate feedstock
  - energy
  - emissions

- Process
  - Intermediate feedstock
  - energy
  - emissions

- Process of Interest
  - energy
  - emissions
  - final product
  - net emissions

- Waste disposal
  - energy
  - emissions

- Extraction process
  - raw materials
  - non-renewable energy
  - emissions
  - energy
Technoeconomic Analysis

- Engineering Co. Consulting on Process Configuration
- Estimates of Other Commercial Technology
- ICARUS - Cost Estimation Software
- Engineering Company Cost Estimations

Process Flow Diagrams

Rigorous Material & Energy Balance
- ASPEN +

Capital & Project Cost Estimation

Discounted Cash Flow Economic Model

Product Minimum Selling Price

Sponsored Research Results

Outside Engineering Studies, e.g., WWT, Burner, EtOH Recovery

Vendor Cost Quotations

Environmental (Life Cycle) Analysis

Model terminology depends on process values used:
- Target/Goal - future
- Base - mixed
- State of Technology – current
The Penn State Research Engine

• Penn State’s diverse research portfolio and interdisciplinary programs make it the ideal institution to lead this BioEnergy Bridge initiative
• Penn State is a national leader in industry – university research
• Penn State has an excellent reputation for speed and ease of doing business with the University through our customer friendly Industrial Research Office
Industry and Private Research
Expenditures: 10-Year History

$105 Million in Industry-Sponsored Research
Ranks 3rd Nationally by the NSF*

*Rankings based on FY 2007, the most recent rankings available by the NSF
Research Expenditures:
Total by Source of Funds

Federal $411,444,000
Industry and Other $106,420,000
Commonwealth of Pennsylvania $88,690,000
University $110,690,000

FY 2008 Total
$717,244,000
Ranks 11th Nationally by the NSF*

*Rankings based on FY 2007, the most recent rankings available by the NSF
Penn State Industrial Research Office

• Industrial Research Office Mission
  – To create and grow lasting relationships between business and the Penn State research community, leading to solutions that enhance our industry partners’ competitive position in the global marketplace while preserving our role as a premiere educational and research institution.

• IRO Services
  – Identify Penn State research expertise to meet your needs
  – Arrange meetings with faculty
  – Answer IP concerns

www.iro.psu.edu
Penn State Operates Many Research Centers and Consortia

- Several models operating at the University for multi-member centers or consortiums (industry – government – multi-university, etc.)
- The IRO will develop a contract model to fit the operating model for the center
Some of our Bioenergy Industrial Partners

- ADM
- Air Products
- Bioenergy International
- DuPont
- Ernst Conservation Seeds
- Foster Wheeler
- Expansin Technologies
- Freedom Energy
- Genencor International

- General Electric
- Keystone Biofuels
- Lake Erie Biodiesel
- Mascoma
- New Holland
- North Shore Energy
- Volvo
- And you!
Penn State BioEnergy Bridge™

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