



Penn State BioEnergy BridgeTM Partnership

The Pennsylvania State University
Bob Wallace, Director

Biomass Energy Center

Tom Richard, Director

814.863.0291

trichard@psu.edu

Bob Wallace, Assoc. Director

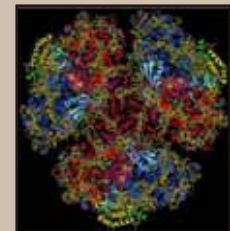
412.241.9322 ext 4#

rtw103@psu.edu

www.bioenergy.psu.edu



- 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™

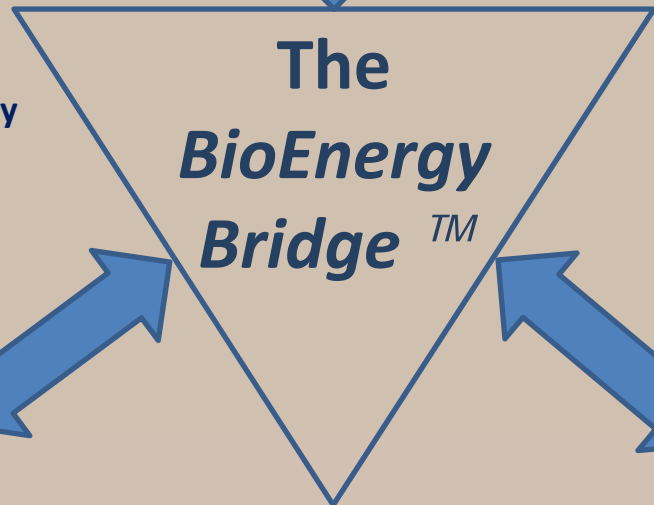
- The BioEnergy Bridge™ will build upon the University's well established R&D pillars throughout the biomass supply chain to address the larger, systems issues that are critical to successful bioindustry development.
 - Diverse Feedstock Assessment
 - Feedstock Supply Chain and Delivery Infrastructure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

Penn State BioEnergy Bridge™

- 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



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



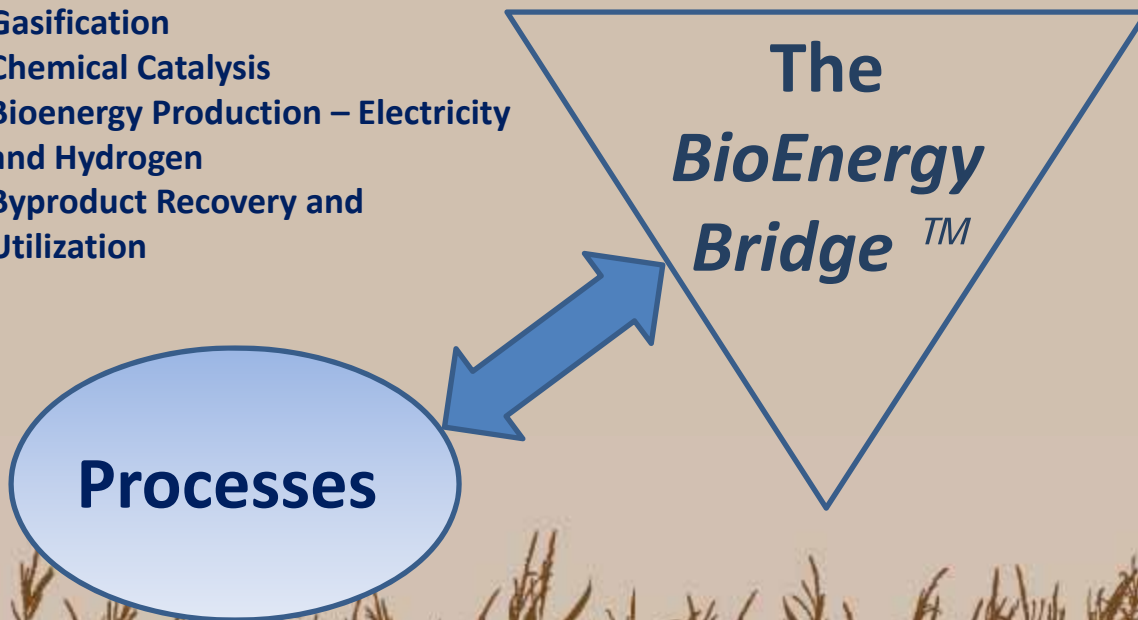
- Field Trials
- Onsite Saccharification and Fermentation Facilities
- Techno-Economic Analysis
- Life Cycle Assessment
- Sustainability Analysis
- Engine and Vehicle Testing
- Outreach



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

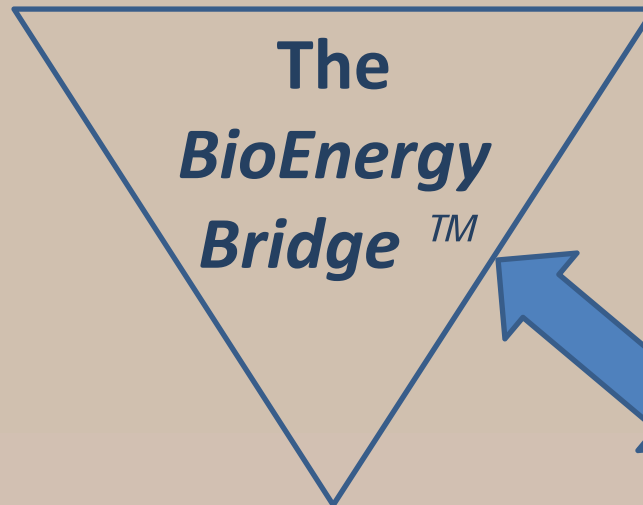


Penn State BioEnergy Bridge™

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



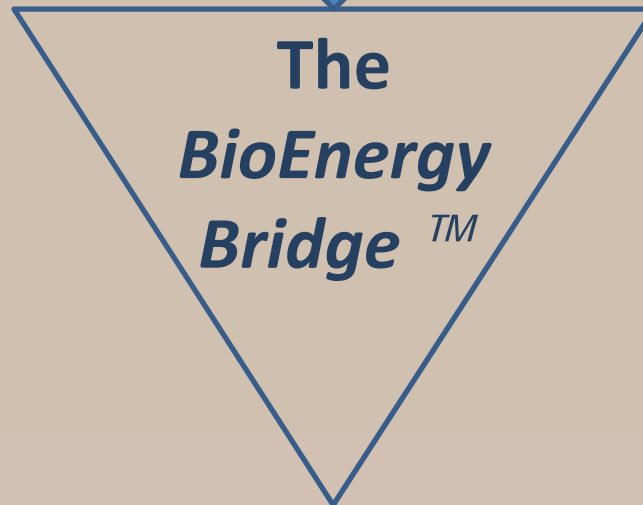
- Field Trials
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Penn State BioEnergy Bridge™

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



- 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



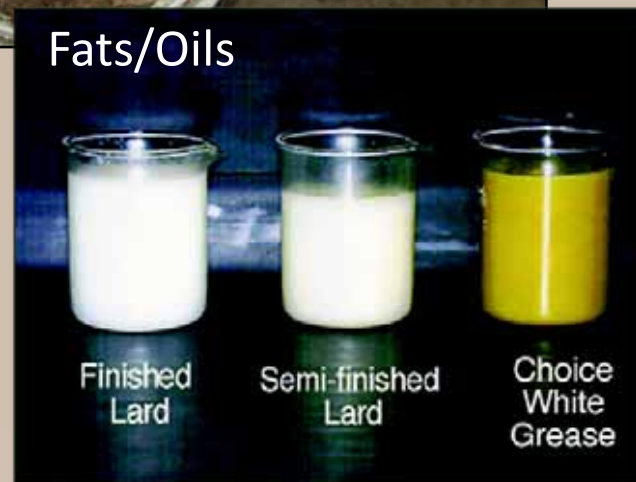
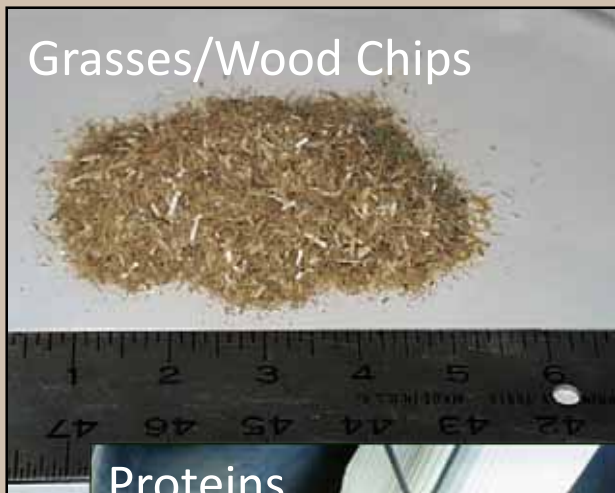
**10+ yr track record of
industry short courses**

EMS Energy Institute Biofuels Initiatives

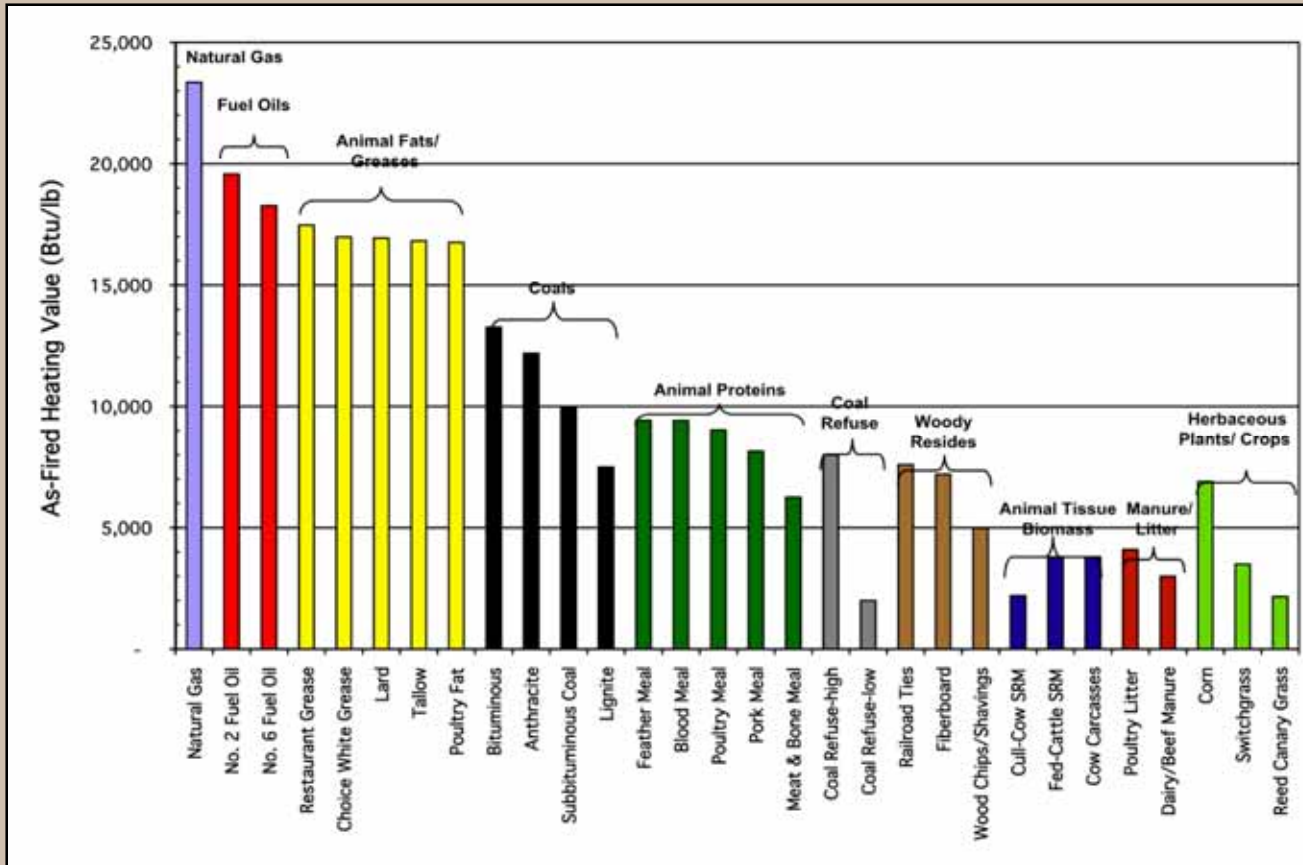
- Stationary
 - Combustion: Watertube Boiler, Fluidized-Bed Combustor
 - Gasification
- Transportation
 - Engine combustion performance and emissions characterization
- Biomass processing



Stationary Biofuels: Feedstocks



Combustion: Fuel-Flexible Boilers



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

Gasification: Wood



Gasification Reactor

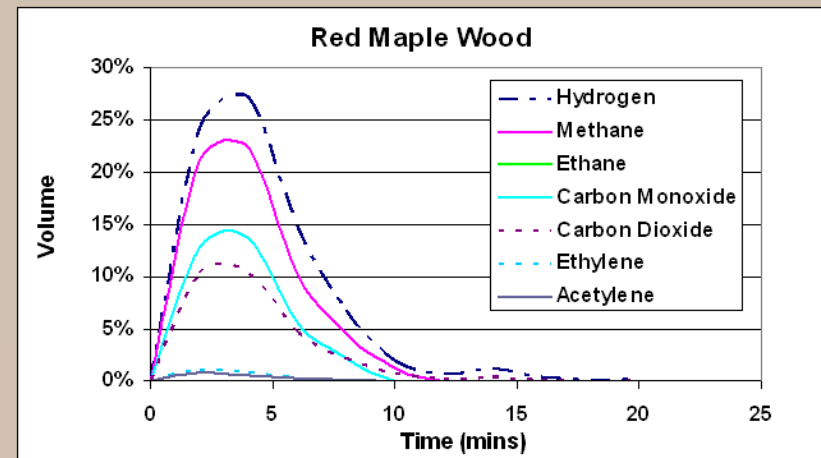
Temp: 900 - 1,000°C
Input: Fuel, N₂ and Steam
Output: Gas and Char



**Starting Material
(Poplar)**



End Product: Char



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

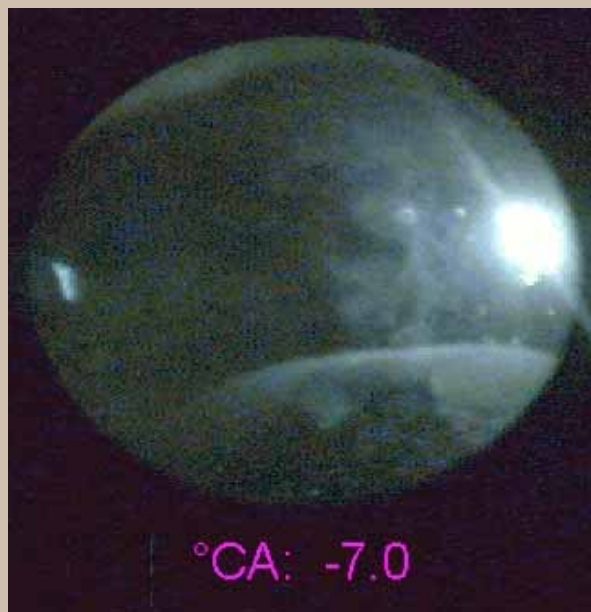
- Gas
 - AVL Diesel Emissions Bench
 - AVL Gasoline Emissions Bench
 - CA Emissions Bench
- PM
 - TSI SMPS
 - TEOM
 - Sierra BG-3

Biodiesel: Spray and Combustion

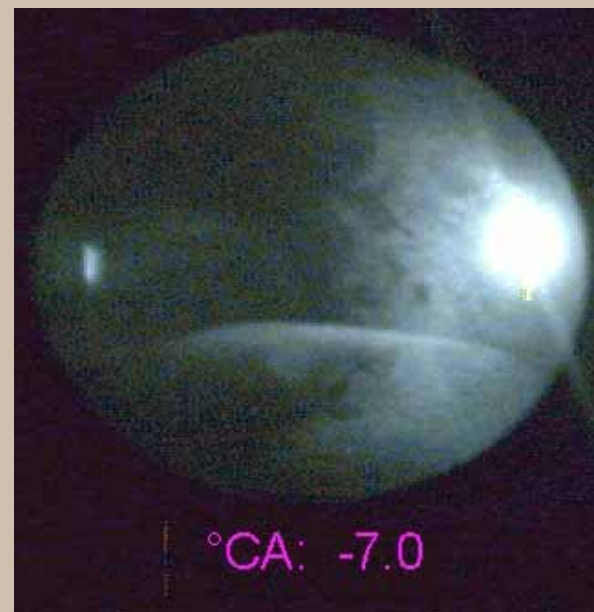
ULSD



B40



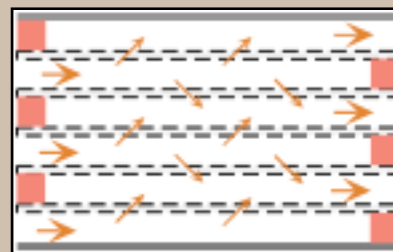
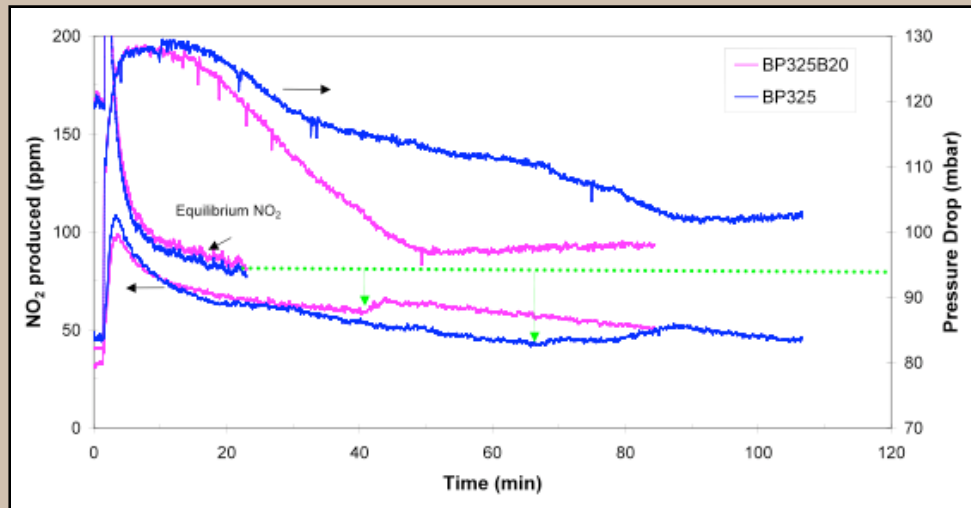
B100



10% Load and 1800 RPM in Cummins 5.9L ISB

Conoco-Phillips, Ultra Clean Fuels

Biodiesel: Soot Reactivity

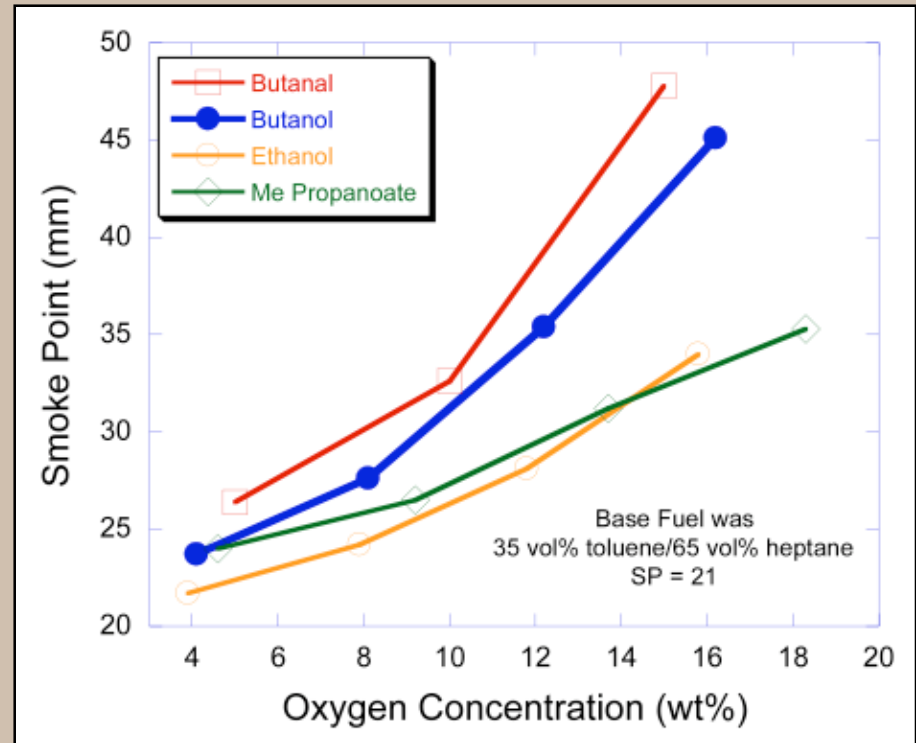


“wall flow filtration”

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

Butanol: A Multi-Use Biofuel

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



SRI, Stanford University, Stanford Global Climate Energy Program

Alternative Fuels

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



Air Products, US DOE, PA DEP, Conoco Phillips

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



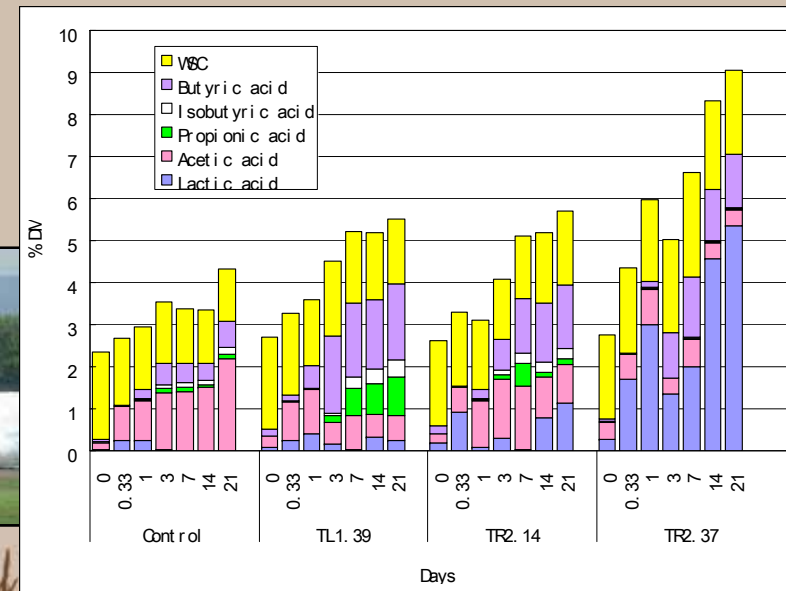
21st Century Forestry

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



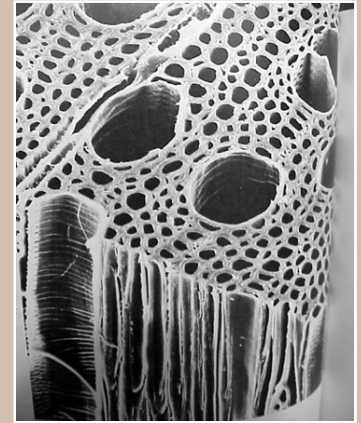
Biomass Harvest and Value-added Storage

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

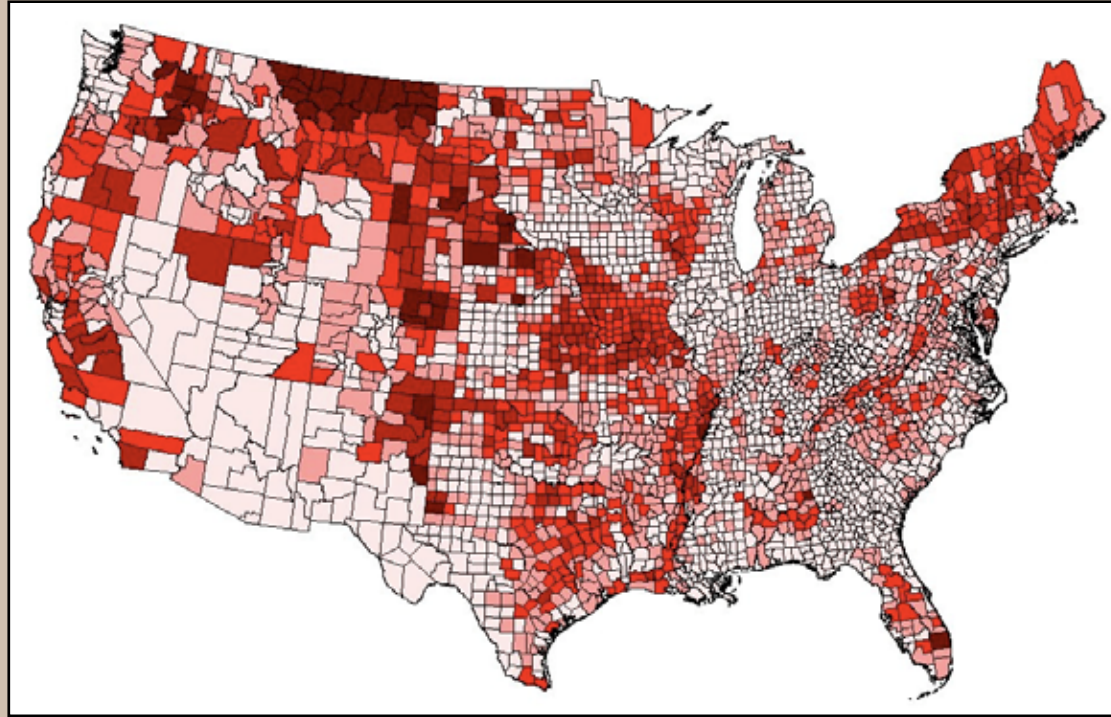


Plant Biotechnology

- 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>

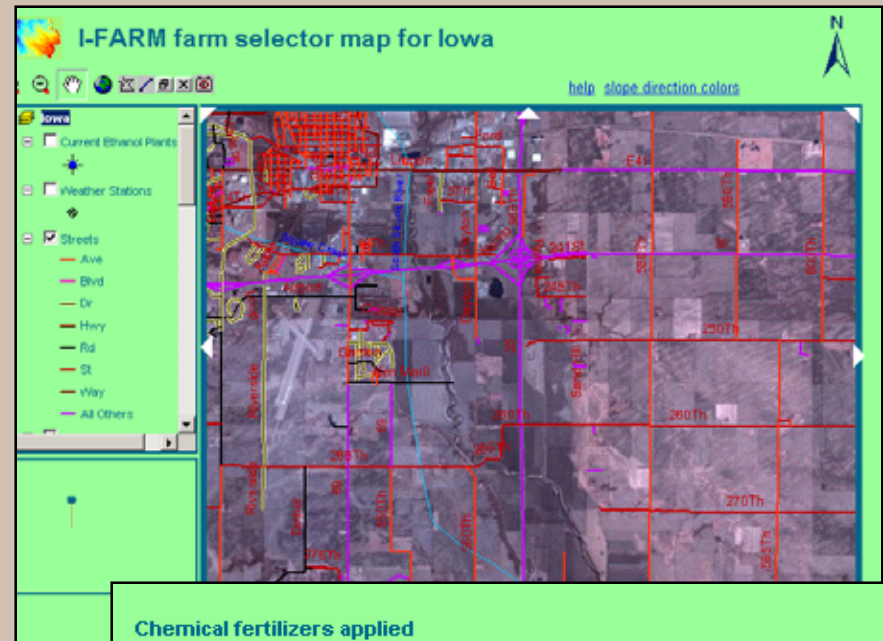
Soil erosion status of RUSLE modules in I-FARM
rainfall-runoff erosivity factor (R) for Adair-county, IA is: 160
Soil Conditioning Index SCI
organic matter growth rate for city: Des Moines (Polk-county, IA)

	units	field 1 sequence	farm
field area	acres	1,000	1,000
soil name		ACKMOREACKMORE	Info
soil surface texture		silt loam	
hill slope	percent	4.0	
slope length	feet	150	
tolerable soil loss (T)			
field specific soil loss			
Soil Conditioning Index			

I-FARM - Microsoft Internet Explorer

Farm bottom line (\$/year)

	Revenues	Expenses
Crops	374,410	324,588
Hired labor		7,080
Custom farming		9,726
Government payments*	44,795	
Bank loan payments		45,703
	419,205	387,097



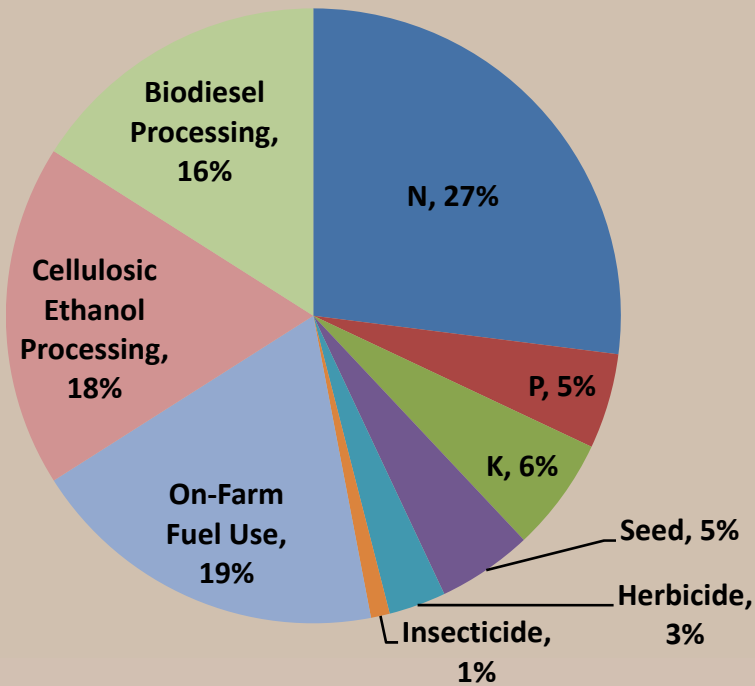
Chemical fertilizers applied

fertilizer name	bruto fertilizer use (lbs/year)	where		
		N (lbs/year)	P ₂ O ₅ (lbs/year)	K ₂ O (lbs/year)
anhydrous ammonia	241000	197620		
murate of potash	165945			99567
concentrated superphosphate	79000		35550	
total farm		197620	35550	99567
total per acre		198	36	100

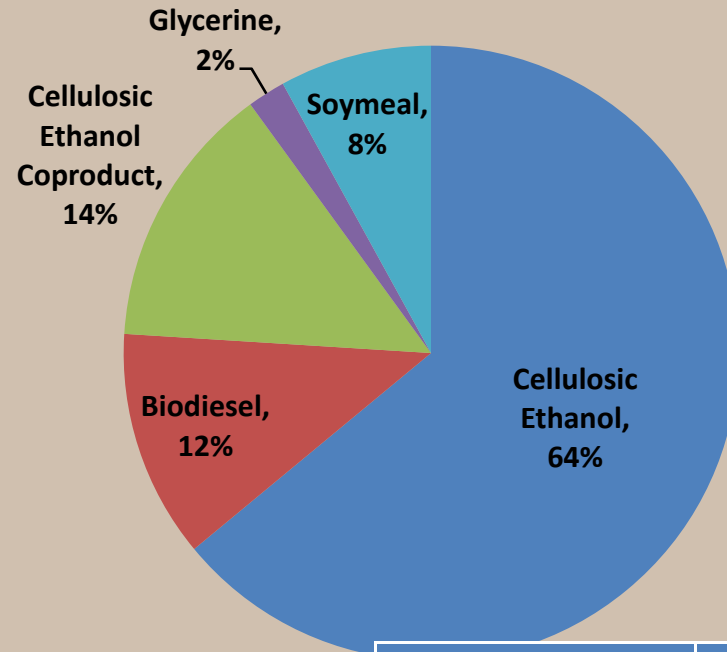
Evaluating Cropping System Alternatives

Soy-Corn/Rye

Energetic Inputs



Energetic Outputs

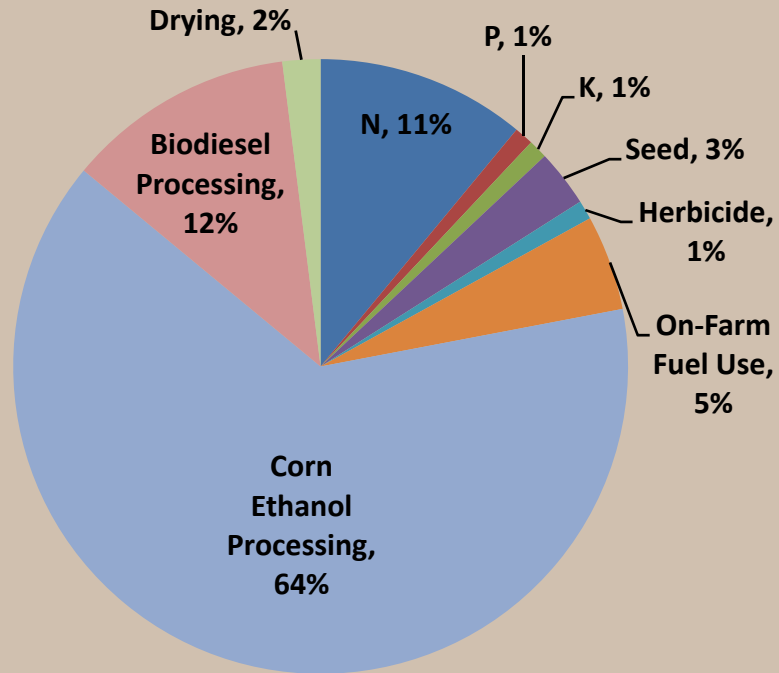


Energy	
Energy Inputs	24,368 MJ/ha
Energy Outputs	84,554 MJ/ha
Net Energy Value	60,187 MJ/ha
Net Energy Ratio	3.47

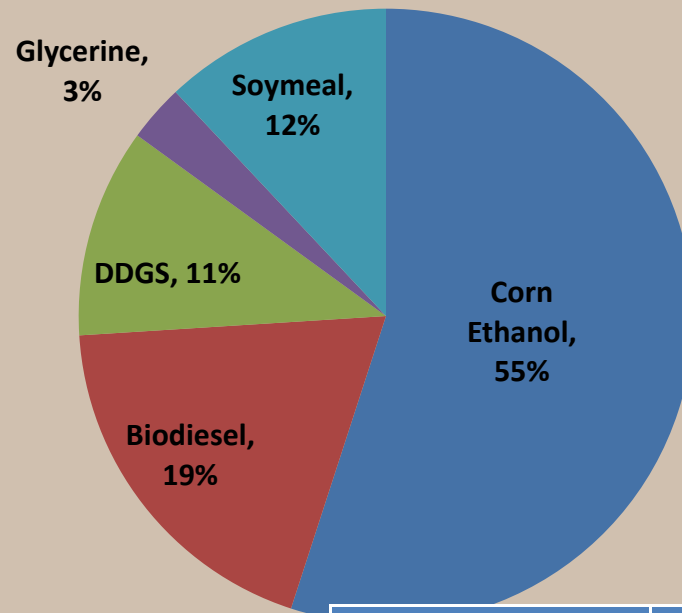
Evaluating Cropping System Alternatives

Corn-Soy

Energetic Inputs



Energetic Outputs



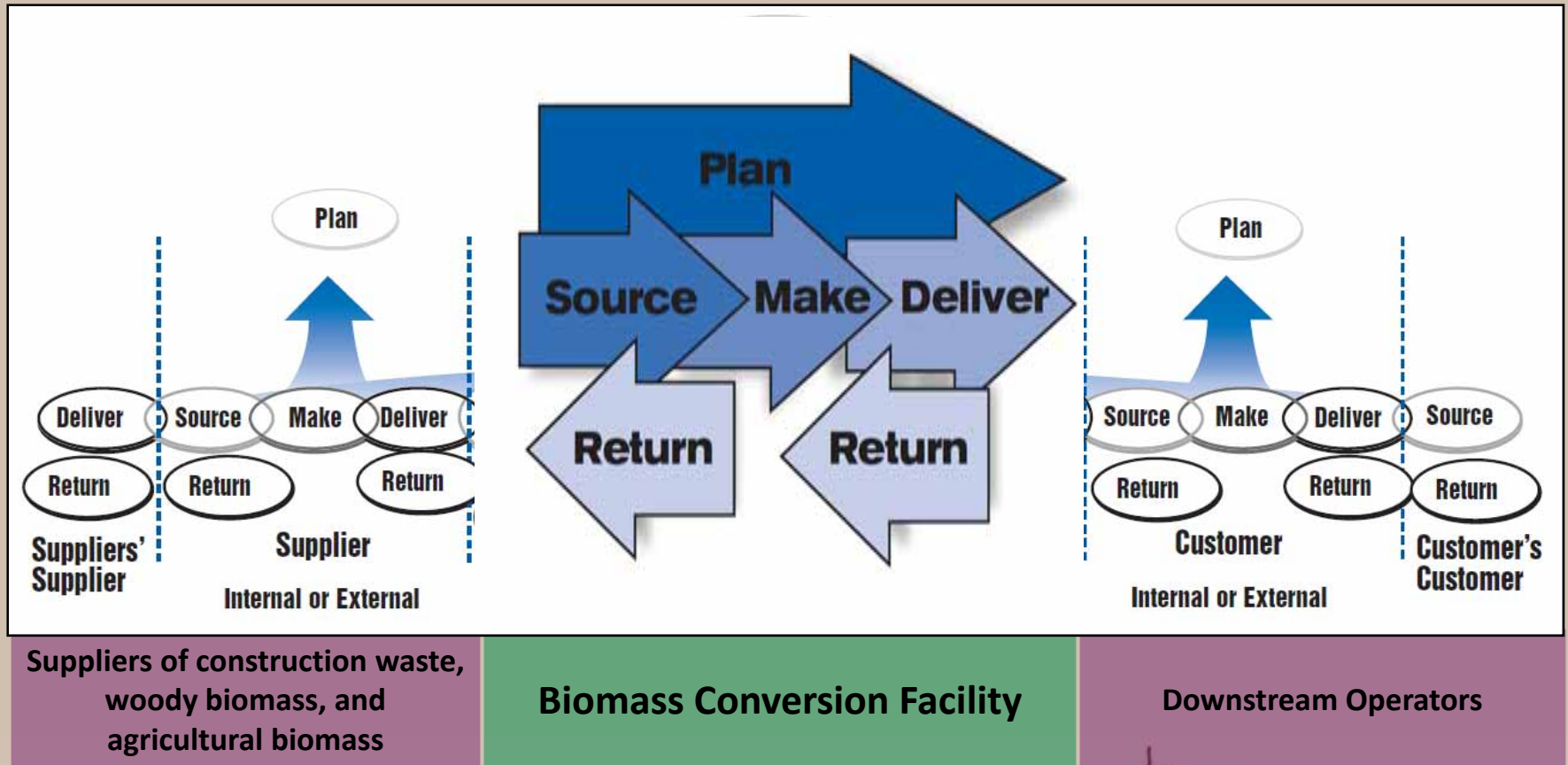
Energy	
Energy Inputs	38,655 MJ/ha
Energy Outputs	62,187 MJ/ha
Net Energy Value	23,532 MJ/ha
Net Energy Ratio	1.61

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?

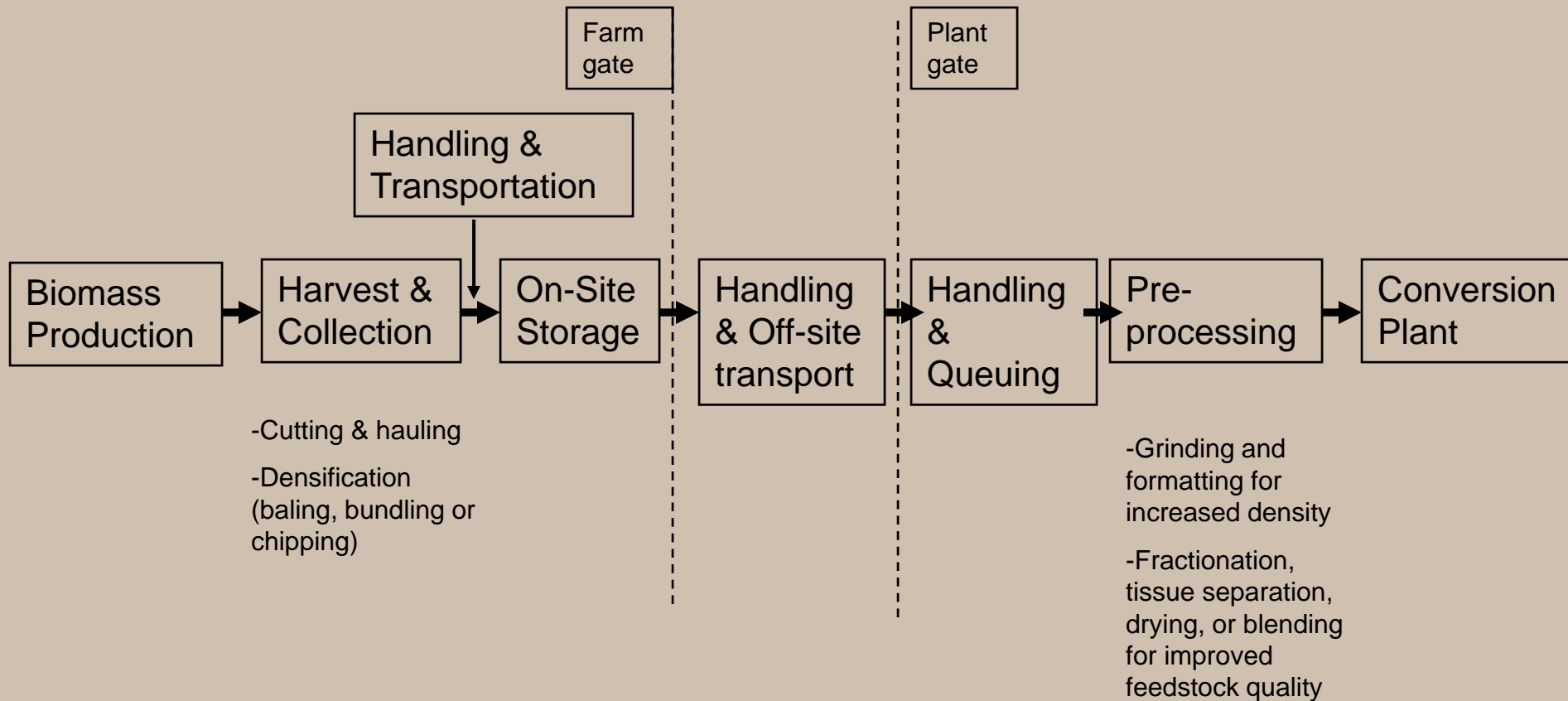


Supply-Chain Operations

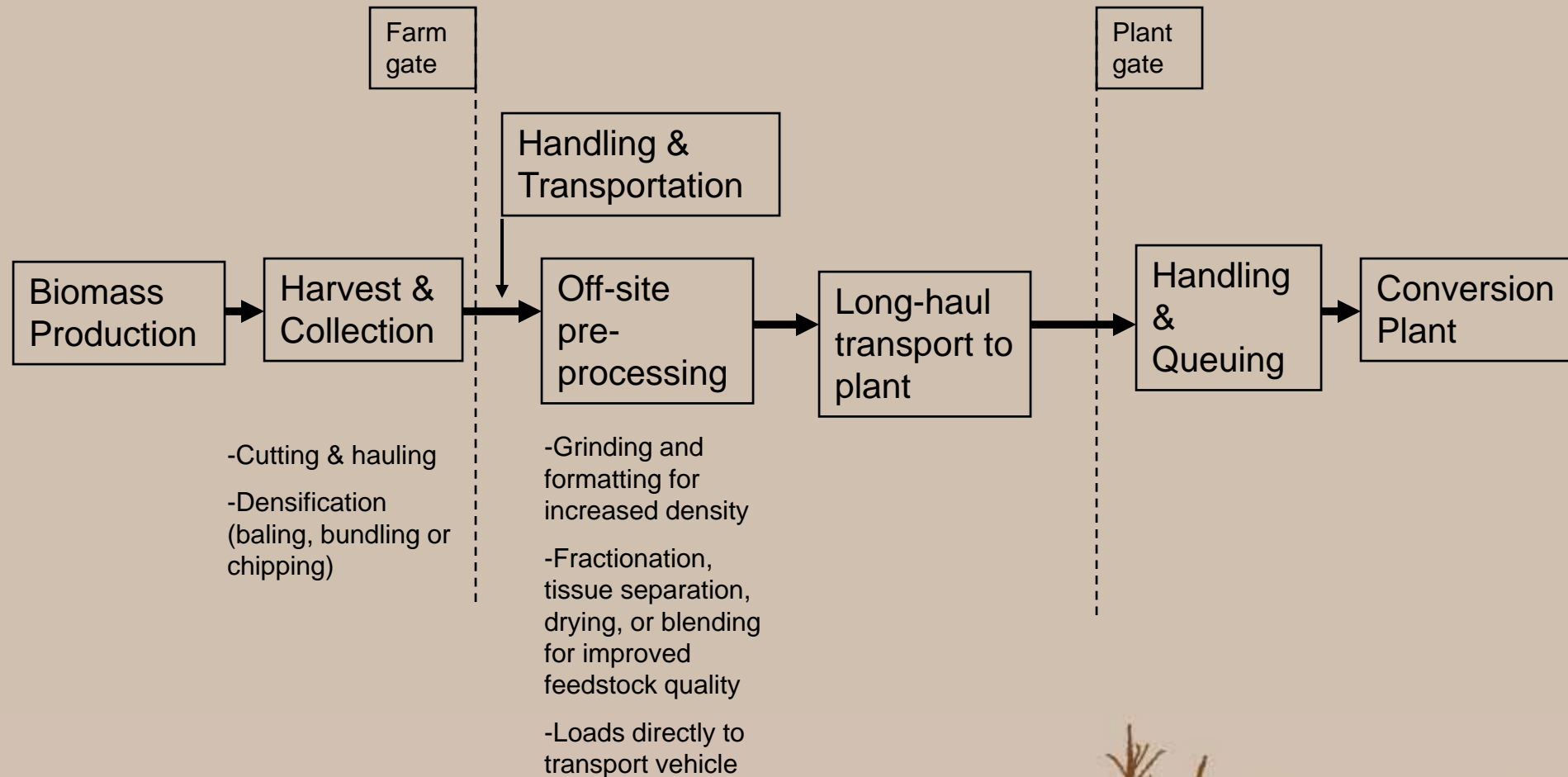


Source: SCOR 9.0, Supply-Chain Council (2008)

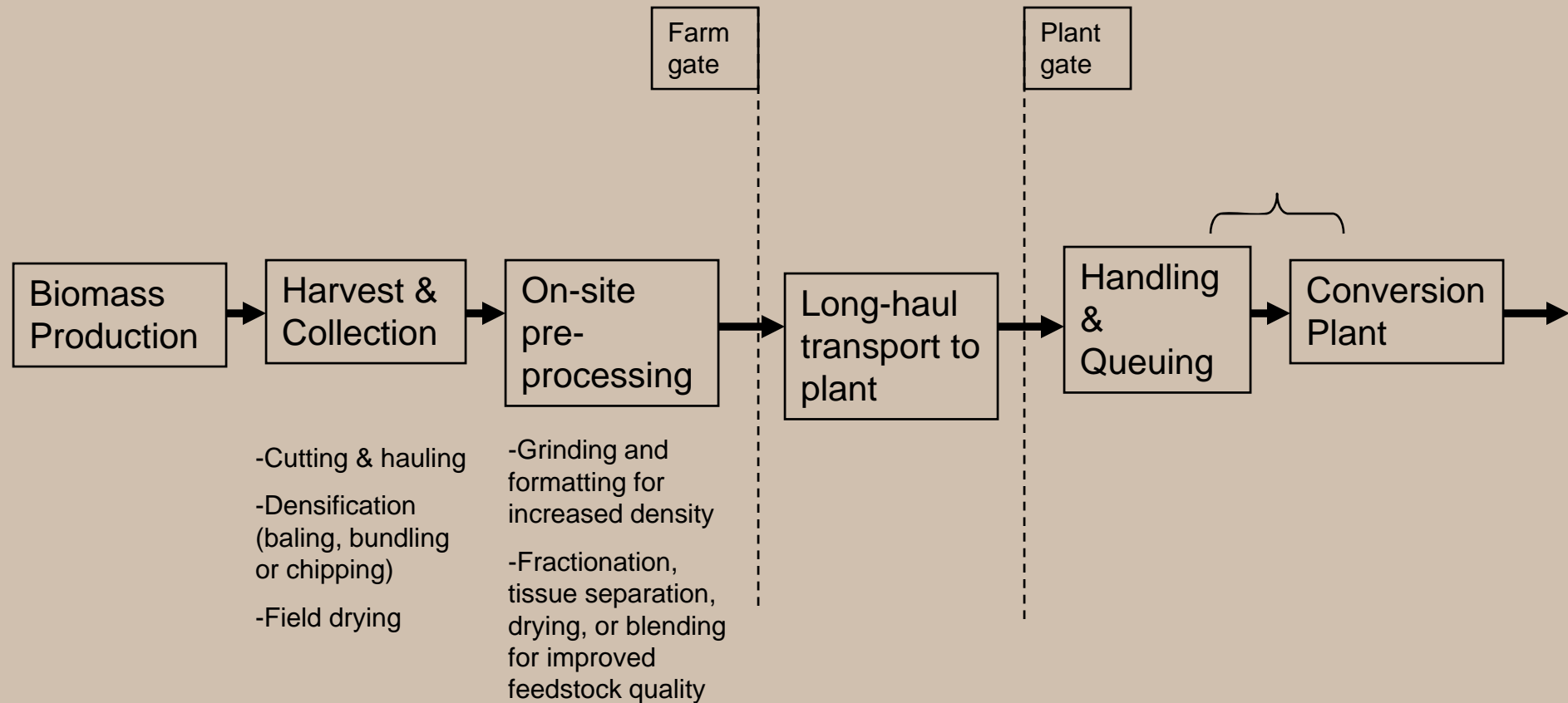
Feedstock Supply Elements



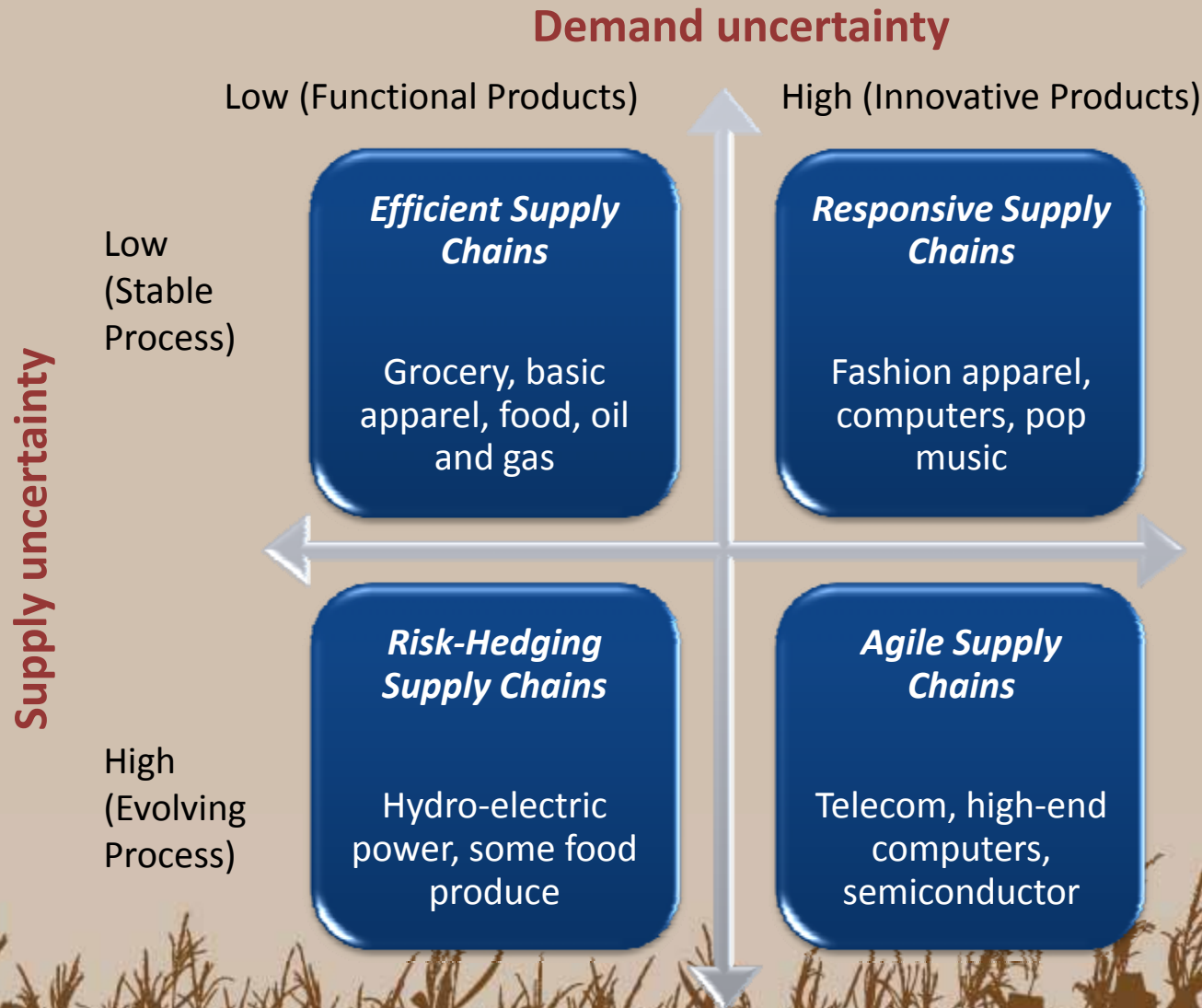
Feedstock Supply Elements



Feedstock Supply Elements

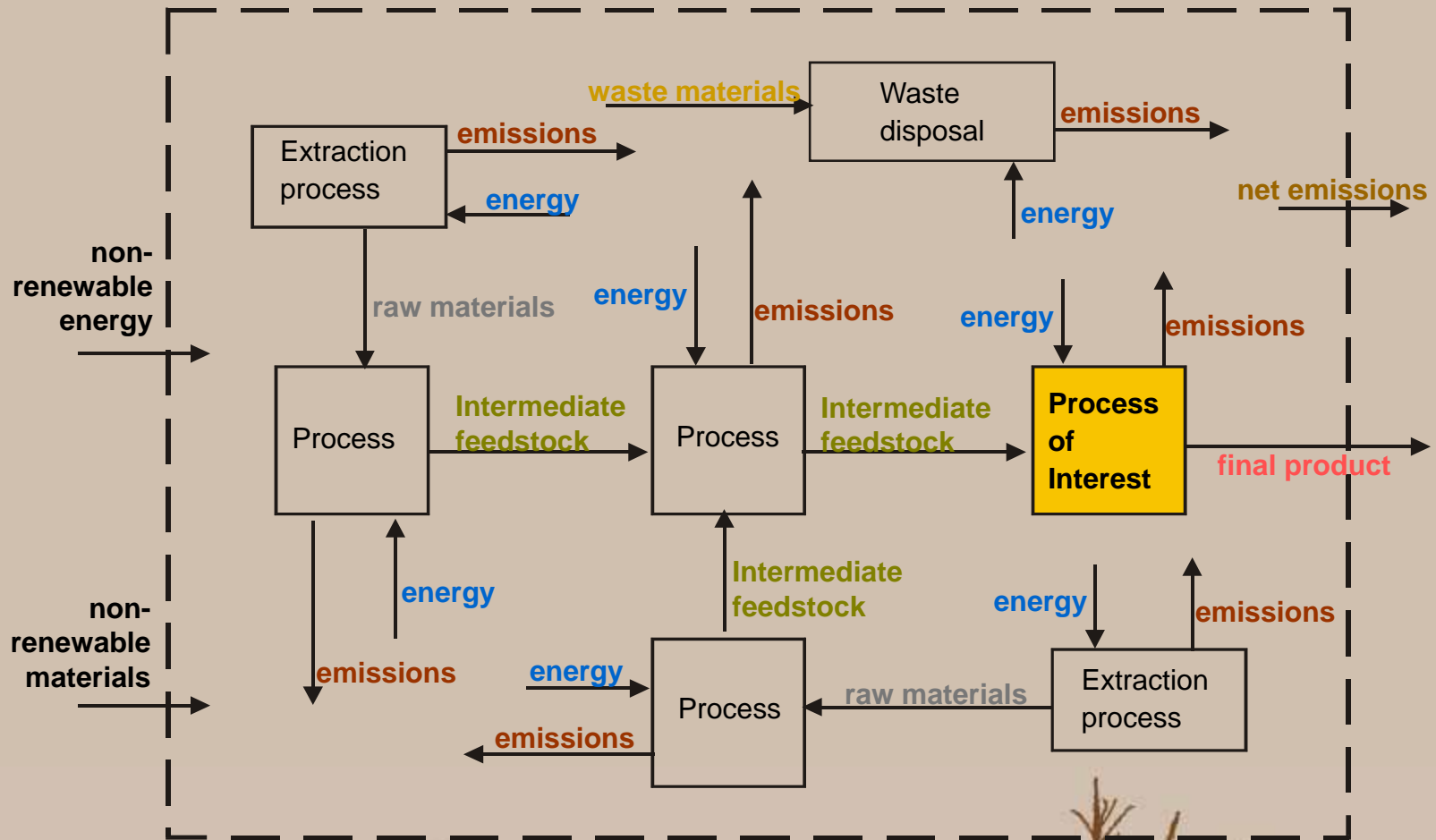


The Uncertainty Framework

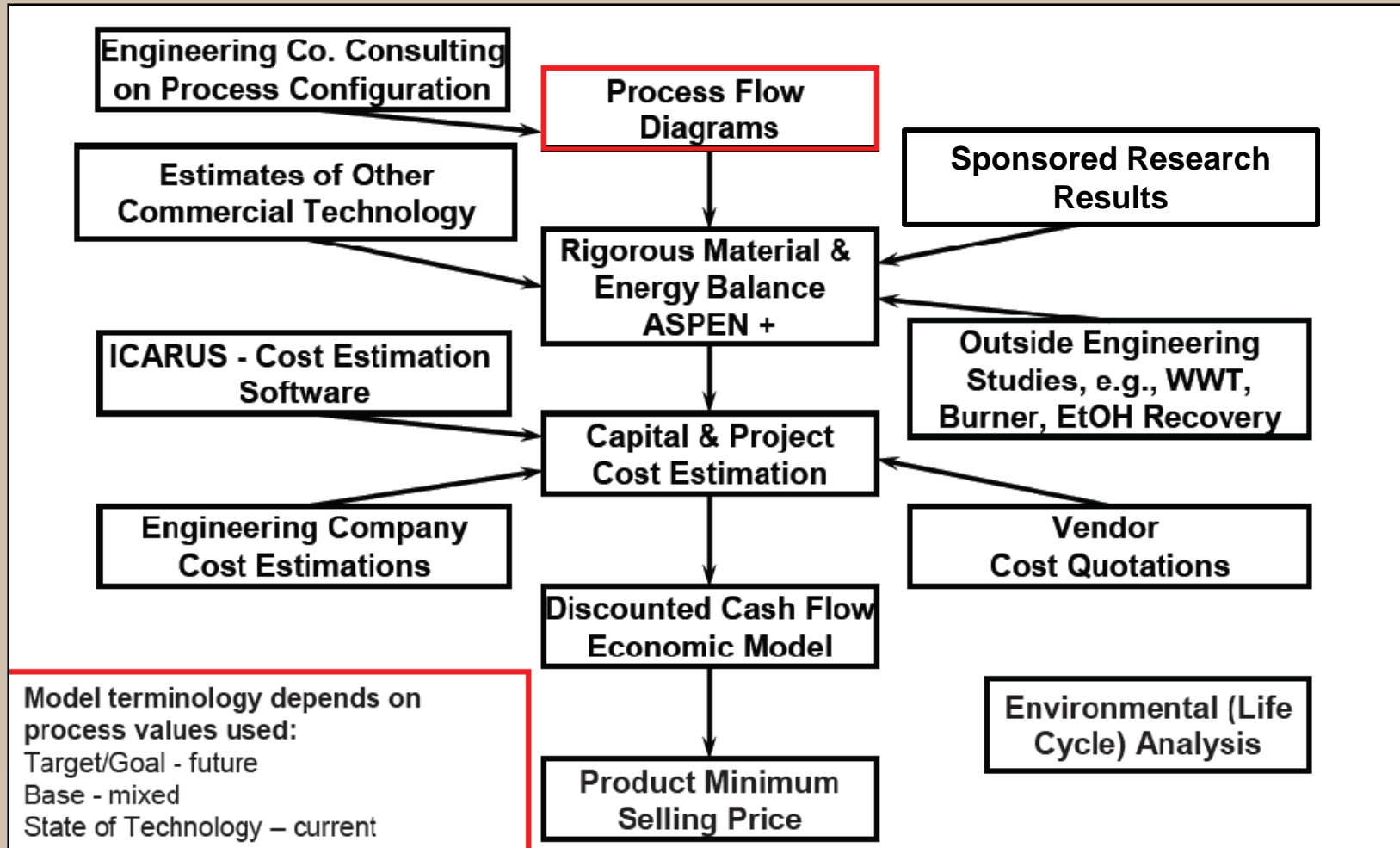


Source: Lee (2002)

Life Cycle Assessment



Technoeconomic Analysis



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

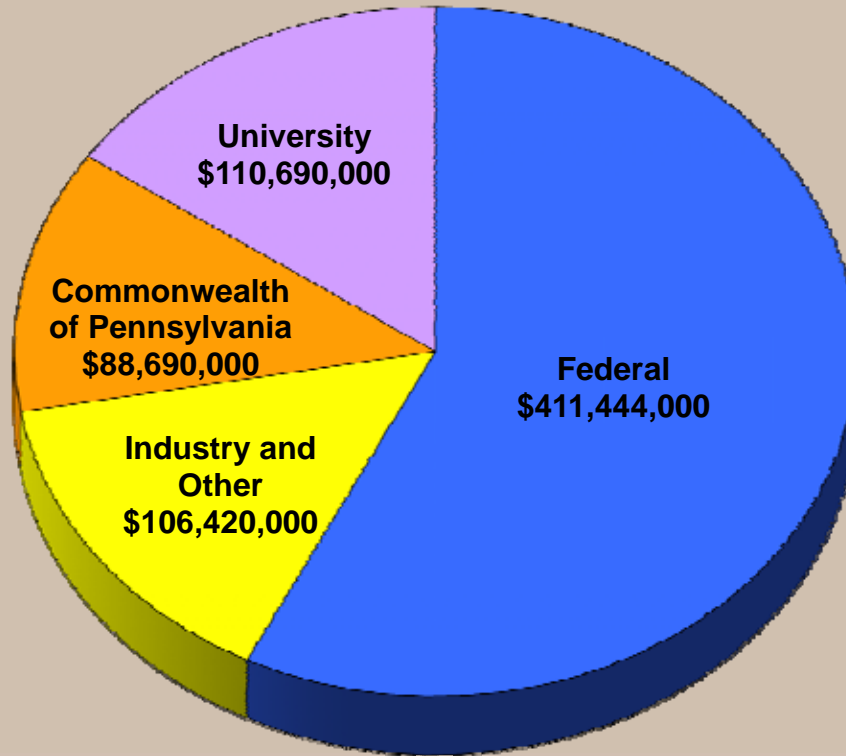
Expenditures: 10-Year History

\$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



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

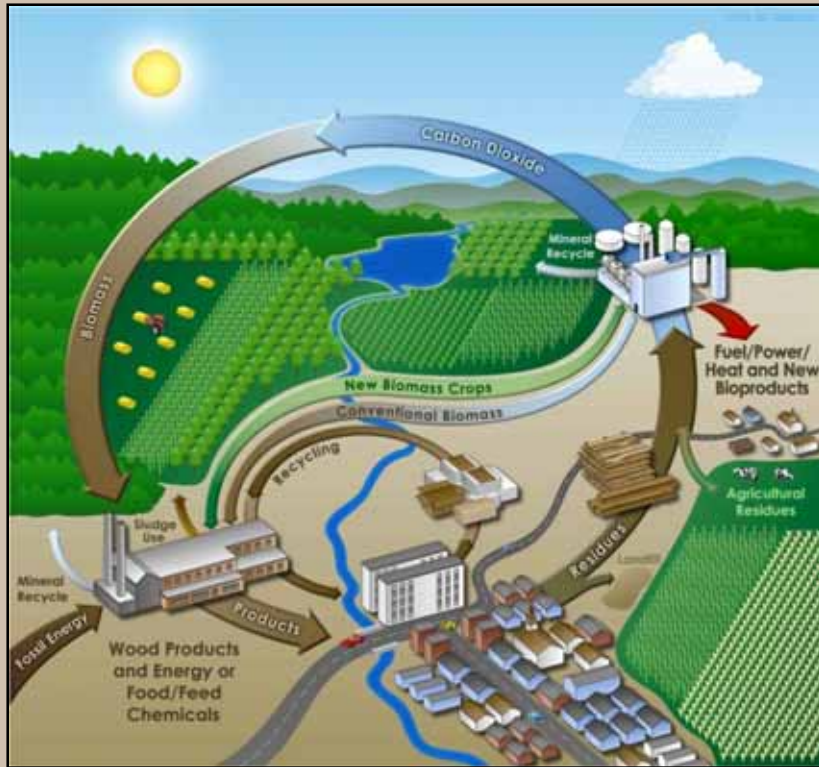
www.iro.psu.edu

Penn State Operates Many Research Centers and Consortiums

- 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!



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