IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

An Overview on ISU's Bioeconomy Initiative and Thermochemical Research Program

Dr.Justinus A. Satrio
Center for Sustainable Environmental Technologies (CSET)
Iowa State University
Ames, IA 50011
U.S.A

"Research Workshop on Sustainable Biofuel Development in Indonesia, Progress So Far and Future Applied Research Opportunities"

Sultan Hotel, Jakarta, Indonesia
February 4-5, 2009

1

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

What is the Bioeconomy?

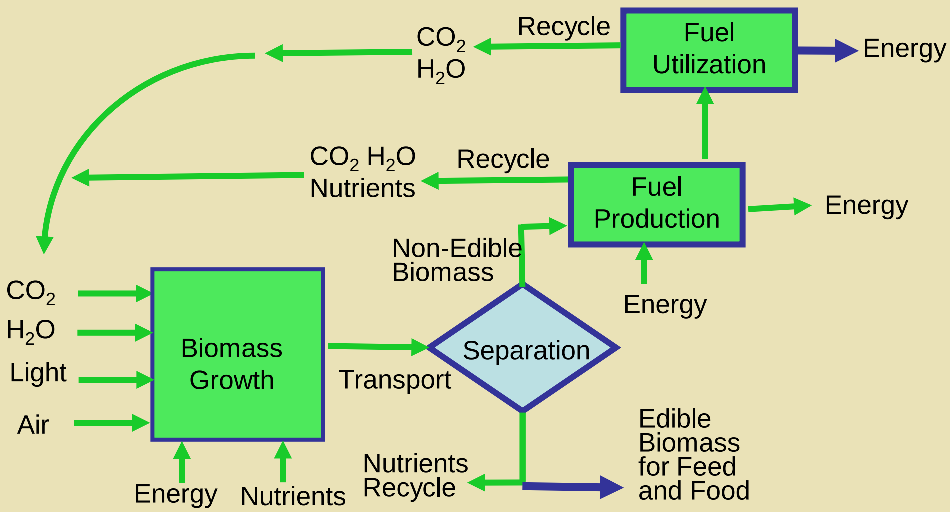
The bioeconomy is nothing less than a revolution in the way society will obtain vital sources of carbon and energy, in the process dramatically reducing our dependence on imported petroleum. Agriculture will make this transformation possible by providing biorenewable resources for the production of biobased products.

2

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

The Three Primary Needs for Bio-fuel Economy

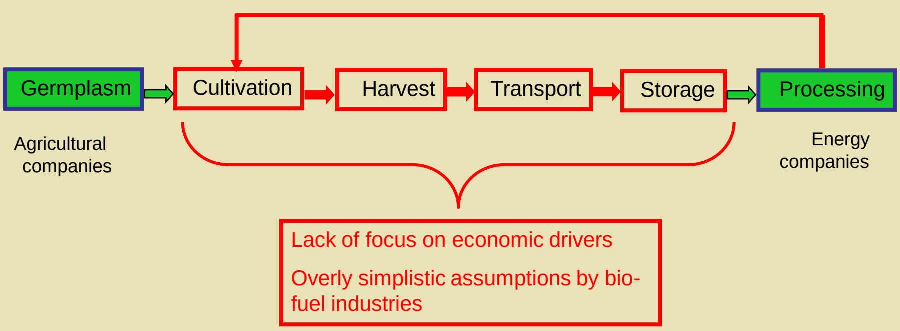


Source: Huber, et al. 2006

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Agricultural and Bio-energy Value Chain



"If one step of the value chain does not work, the entire value chain does not work"

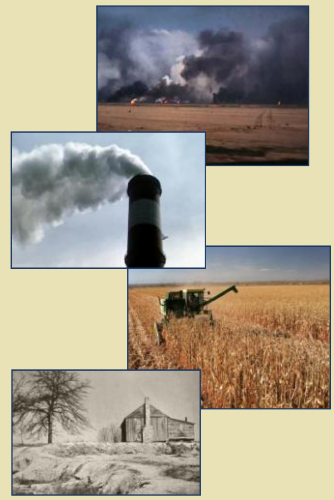
Credit: Jill Euken (jeuken@iastate.edu), ISU Extension

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

The Goals of Bioeconomy

- Enhanced national security
  - Reducing dependence on imported petroleum
- Improved environmental quality
  - Including mitigation of global climate change
- Increased markets for agricultural crops
  - With the benefit of reducing need for crop support programs
- Advances in rural development
  - Creating economic opportunities where the resource is located



Courtesy USDA NRCS

5

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

The goal is not ethanol and/or biodiesel!

6

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

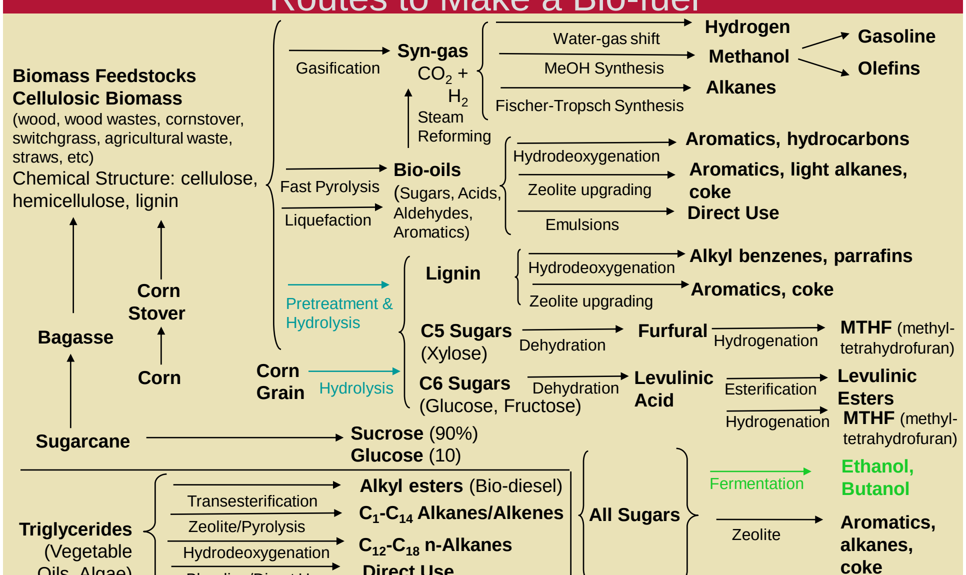
Ethanol/biodiesel is just one pathway to our goals

Fuel	Specific Gravity	LHV (MJ/kg)	Octane Number	Cetane Number
Ethanol	0.794	27	109	-
Biodiesel	0.886	37	-	55
Methanol	0.796	20.1	109	-
Butanol	0.81	36	96 - 105	-
Mixed Alcohols	~0.80	27-36	96-109	-
Fischer-Tropsch Diesel	0.770	43.9	-	74.6
Hydrogen	0.07 (liq)	120	>130	-
Methane	0.42 (liq)	49.5	>120	-
Dimethyl Ether	0.66 (liq)	28.9	-	>55
Gasoline	0.72-0.78	43.5	91-100	-
Diesel	0.85	45	-	37-56

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Routes to Make a Bio-fuel



IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Approaches to Biorefineries

- Biochemical (sugar platform)
- Thermochemical
  - Gasification
  - Fast pyrolysis
- Hybrid thermochemical/biochemical
  - Syngas fermentation
  - Bio-oil fermentation

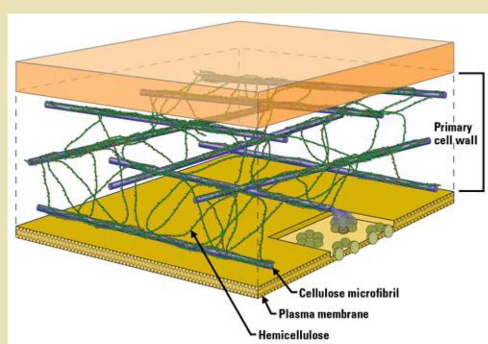
9

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Cellulosic Materials as Resources

Why is cellulose so difficult to turn into fermentable sugars?



- Starch is a storage polysaccharide designed by nature as a food reservoir
- Cellulose is part of a lignocellulosic composite designed by nature to resist degradation

10

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

ISU's Bioeconomy Initiative

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Iowa State University

- Iowa State University of Science and Technology (ISU), established in 1858, is the first land grant university in the USA.
- It is one of three state universities in the state of Iowa.
- Profiles:
  - 26,167 Students (Fall 2007)
  - 21,004 Undergraduate Students
  - 5,156 Professional/Graduate students
  - 2,124 International Students from 106 countries
  - 6,026 Faculty/Staffs
  - 2,473,075 Library Volumes
  - $580,000,000 Endowment
  - 1984 Acre campus
- The mission of ISU is to "Create, share and apply knowledge to make Iowa and the world a better place.

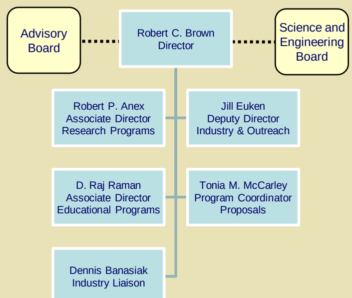
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Bioeconomy Institute

Centers and Institutes:

- Ames Laboratory Biorenewable Resources Consortium
- Biosafety Institute for Genetically Modified Agricultural Products
- Center for Agricultural & Rural Development
- Center for Catalysis
- Center for Crops Utilization Research
- Center for Designer Crops
- Center for Industrial Research & Service
- **Center for Sustainable Environmental Technologies**
- Center for Plant Breeding
- Center for Plant Genomics
- Center for Plant Transformation
- Institute for Food Safety & Security
- Institute of Science & Society
- Leopold Center for Sustainable Agriculture
- NSF-IMI CoSMIC International Materials Institute



Academic Departments:

Agricultural & Biosystems Engineering -
Agricultural Economics -
Agronomy -
Biochemistry, Biophysics & Molecular Biology -
Chemical & Biological Engineering -
Chemistry -
Civil, Construction, & - Environmental Engineering
Community & Regional Planning -
Economics -
Food Science & Human Nutrition -
Genetics, Development & Cell Biology -
Industrial & Manufacturing - Systems Engineering
Logistics Operations & - Management Information Systems
Materials Science & Engineering -
Mechanical Engineering -
Natural Resource Ecology & Management -

13

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Research / Discovery

- Over 160 faculty and scientific staff involved in R&D activities
- Research activities currently organized around technology platforms
- Incremental ISU funding helped leverage over $51 million in extramural funding over the last five years

14

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

ISU Advances in Biorenewables

PLANT SCIENCE

- Genetically engineered plants that produce polymers
- Maize breeding for improved cellulose conversion
- Elucidation of carbon flux in soybean metabolism
- Modification of lignocellulose synthesis to simplify fractionation of biomass

PRODUCTION

- New crops and cropping systems for improved biomass yield
- Integrated wet storage and biological pre-treatment of stover
- Feedstock supply systems for large-scale bioenergy production
- Green mulching systems to reduce soil loss under cultivation of biomass crops
- Agronomic systems that sequester carbon from the atmosphere
- Recycling of nutrients between biorefineries and fields

PROCESSING

- Conversion of glycerol into 1,3 propanediol
- Catalysts that hydrolyze oligosaccharides to fermentable sugars
- Sonication to increase starch conversion rates
- Isoamylase conversion of starch to increase yield of fermentable sugars and ethanol
- Enzyme-assisted, water-based process to recover oil from soybeans
- Heterogeneous catalysts to convert soybeans to biodiesel
- Syngas to ethanol catalysts
- Thermochemical alternatives to enzymatic hydrolysis

UTILIZATION

- Soybean oil with superior cold-tolerance and tribological characteristics for fuels
- Plastics from vegetable oils with shape-memory and noise-dampening properties
- Soy protein-based adhesives and plant-derived biocomposite materials
- Analysis of changing markets as a result of biofuels production

15

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Current Emphasis in Building Research Programs

- **Biomass production**
  - In collaboration with ISU's Plant Sciences Institute
- **Thermochemical biofuels**
  - In collaboration with ISU's Institute for Physical Research and Technology (IPRT)

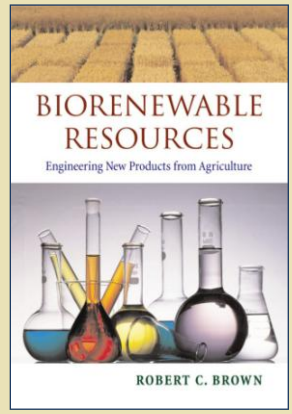
16

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Learning: ISU Program

- Established the Biorenewable Resources and Technology graduate program
  - Ph.D. and M.S. degrees offered (plus Ph.D. minor)
  - 24 students currently enrolled
- Textbook published April 2003 by Blackwell Publishing
- Offering fundamentals course through Engineering Distance Education
  - www.biorenew.iastate.edu



IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Examples of Recent Successes in Program Development

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Biorenewables Complex

This three building complex includes a 1150 m^2 Biorenewables Laboratory building dedicated to biorenewables research and two buildings to house the Agricultural and Biosystems Engineering Department.

19

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Biobased Industries Center

Goal: interdisciplinary research and education programs in support of biobased industries

- **economic analysis**
- **marketing**
- **policy**
- **infrastructure**
- **workforce**

20

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Industrial Partnership with Conoco Phillips

- Goal is to develop second generation biofuels
- Focus is on thermochemical processing
- $22.5 million, seven year partnership
- Basis for additional partnerships with other companies and national laboratories

21

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

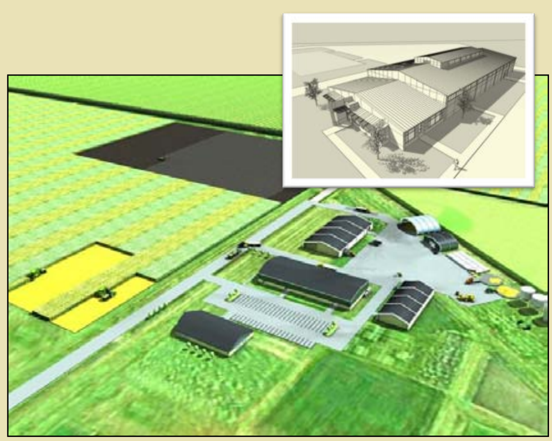
Transforming Agriculture to be Feedstock Ready…

…by establishing a New Century Farm

Research: biomass cropping, biofuel processing, the logistics of biomass supply, and recycling nutrients back to the land

Education: Laboratory and extension resource for training future scientists, producers, and extension experts

Extension: Demonstrate the economic, social and environmental viability of bioenergy production to producers, the public, and policy makers



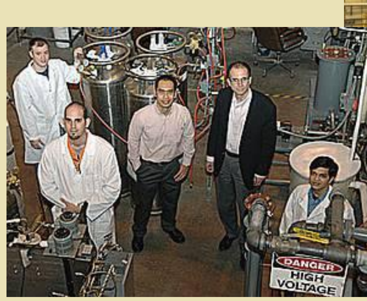
"The New Century Farm (NCF) would be the first integrated, sustainable biofuel feedstock production farm in the USA."

22

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Thermochemical Conversion of Biomass to Biofuels Program



23

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Thermochemical Program at ISU

- Research Areas:
  - Biorenewable materials pre-processing
  - Gasification
  - Fast pyrolysis
  - Gasification and fast pyrolysis products upgrading to produce final products
  - Techno-economic evaluations

24

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Facilities

Lab-Scale Fluid-Bed Systems

- Gasifier

- Used for synthesis gas production
- Rating of 6 lb/hr
- Equipped with down-draft combustor

- Fast Pyrolyzer

- Used for bio-oil production
- Rating of 12 lb/hr

Pilot-Scale Fluid-Bed System

Multi-mode operation
- Gasifier or combustor
- Bubbling or circulating fluid bed
- Atmospheric to 50psig
- Up to 5 tons/day operation

25

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Facilities

Bench-scale Fast Pyrolysis Reactor Systems

Drop-Tube Reactor System

Auger Reactor System

Micropyrolyzer+GC/MS

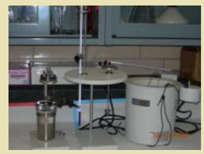
26

Instrumentation Facilities

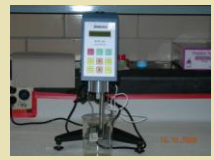
- CSET laboratories are well equipped for performing physiochemical analysis and characterization of biomass and its products, such as bio-oil, chars, and syngas.

GC/MS

KF Titrator



Calorimeter



Viscometer

Furnaces

AAS

- CHNS-O Analyzer
- Centrifuge
- Mercury Porosimeter
- Micro GC
- Ion chromatograph
- Mercury porosimeter

Gasification Approach

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Gasification

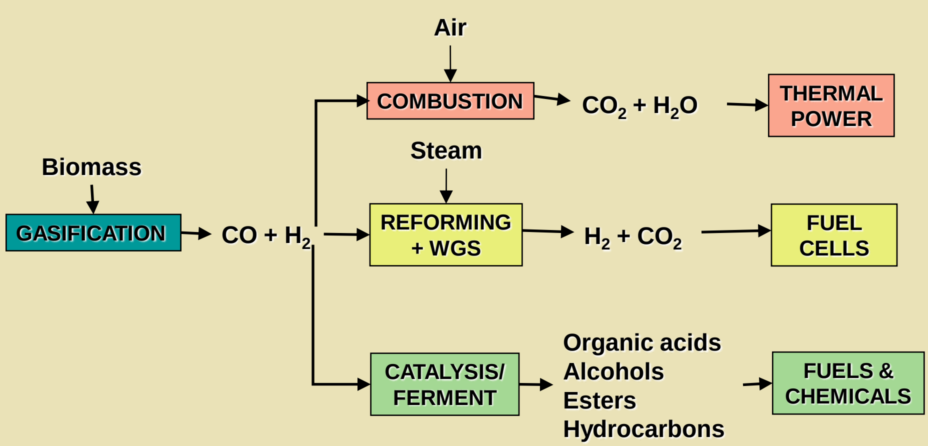
- Gasification - high temperature (750 – 1800 °C) conversion of solid, carbonaceous fuels into flammable gas mixtures
  - Carbon monoxide (CO), hydrogen (H2), methane (CH_4), nitrogen (N_2), carbon dioxide (CO_2), and smaller quantities of higher hydrocarbons
  - Gas mixture called producer gas or syngas
- Gas production is endothermic
  - Requires either the simultaneous burning of part of the fuel or the delivery of an external source of heat to drive the process

5 tpd biomass gasifier at BECON facility in Nevada, IA

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Why Gasification?



Synthetic Fuels from Syngas

Process	Products
Steam Reforming	Hydrogen
Methanol synthesis	Methanol, acetic acid, ethanol, diethyl ether, olefins
Fischer Tropsch Synthesis	Synthetic diesel and gasoline
Alcohols from Syngas	Ethanol, mixed alcohols
Syngas Fermentation	Ethanol, esters, and other metabolic products

Fast Pyrolysis Approach

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Fast Pyrolysis

- Rapid thermal decomposition of organic compounds in the absence of oxygen to produce liquids, char, and gas
  - Small particles: 1 - 3 mm
  - Short residence times: 0.5 - 2 s
  - Moderate temperatures (400-500 ^{o}C)
  - Rapid quenching at the end of the process

- Typical yields
  - Oil: 60 - 70%
  - Char: 12 -15%
  - Gas: 13 - 25%

33

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Bio-Oil

Pyrolysis liquid (bio-oil) from flash pyrolysis is a low viscosity, dark-brown fluid with up to 15 to 20% water

	Spruce	Poplar
Product Yields, wt %, m.f.		
Water	11.6	12.2
Gas	7.8	10.8
Bio-char	12.2	7.7
Bio-oil	66.5	65.7
Bio-oil composition, wt %, m.f.		
Saccharides	3.3	2.4
Anhydrosugars	6.5	6.8
Aldehydes	10.1	14.0
Furans	0.35	--
Ketones	1.24	1.4
Alcohols	2.0	1.2
Carboxylic acids	11.0	8.5
Water-Soluble – Total Above	34.5	34.3
Pyrolytic Lignin	20.6	16.2
Unaccounted fraction	11.4	15.2

34

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Bio-Oil

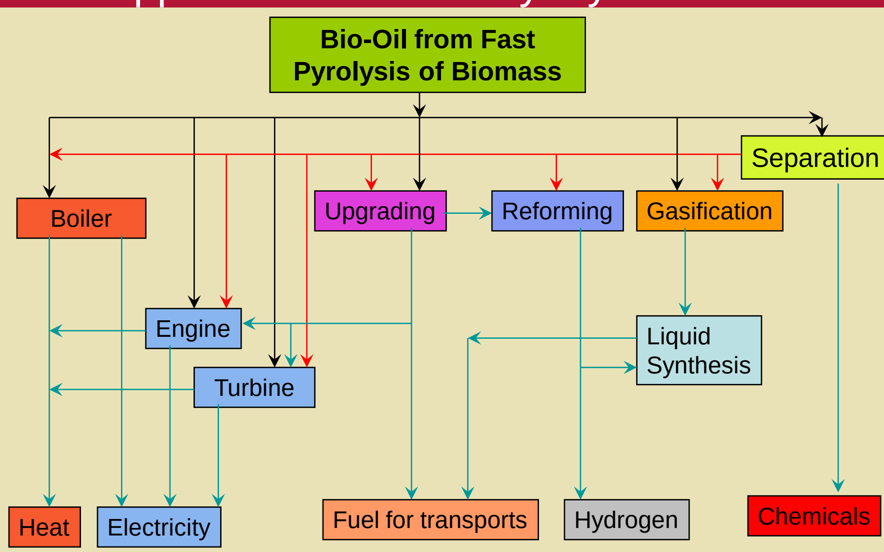
- Advantages include:
  - Liquid fuel
  - Decoupled conversion processes
  - Easier to transport than biomass or syngas
- Disadvantages
  - High oxygen and water content makes bio-oil inferior to petroleum-derived fuels
  - Phase-separation and polymerization and corrosiveness make long-term storage difficult

35

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Applications of Fast-Pyrolysis Oils



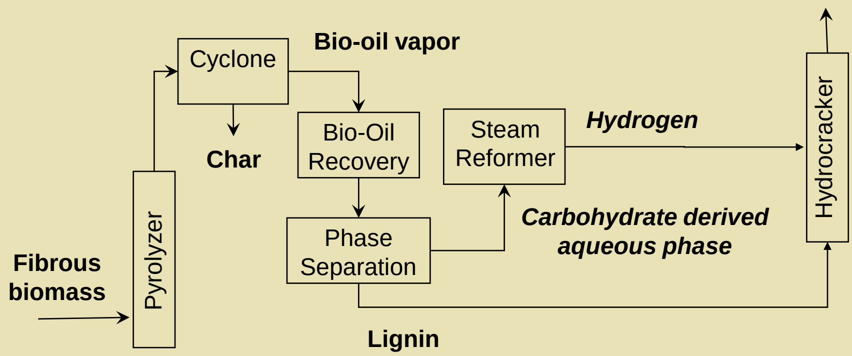
36

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Synfuels from Bio-oil: Hydrocracking

- Directly converts biomass into liquid bio-oil (lignin, carbohydrate derivatives, and water) and char
- Bio-oil catalytically converted into hydrocarbon fuel (green diesel)

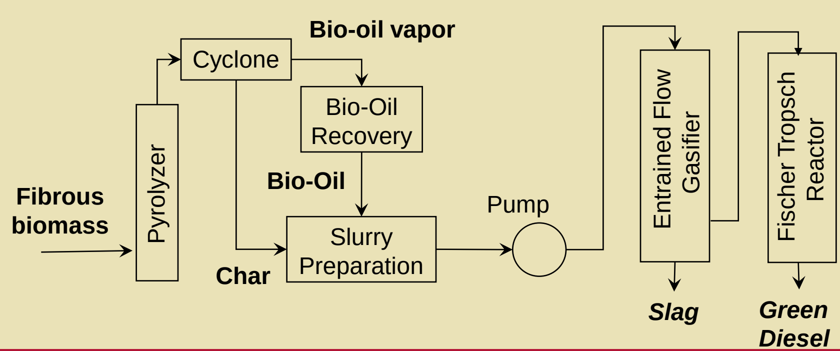


IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Synfuels from Bio-oil: Gasification

- Bio-oil and char slurried together to recover 90% of the original biomass energy
- Slurry transported to central processing site where it is gasified in an entrained flow gasifier to syngas
- Syngas is catalytic processed into F-T liquids



IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

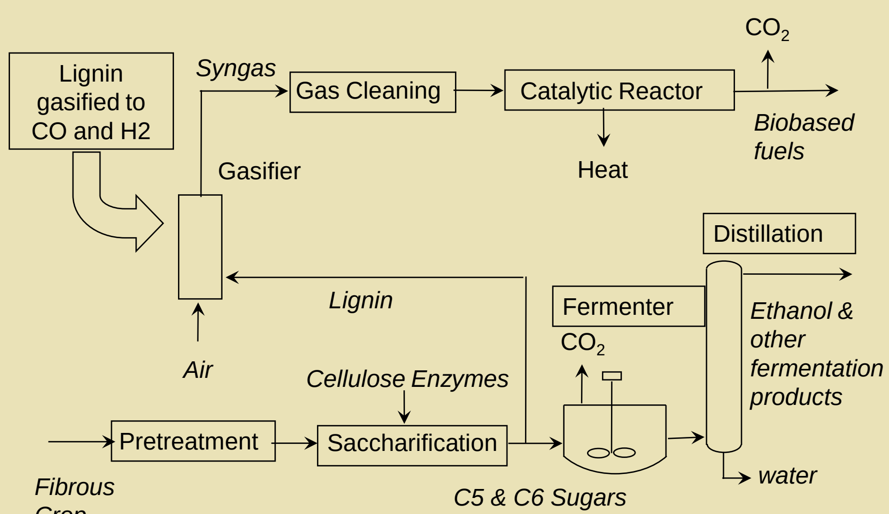
Hybrid Thermochemical-Biological Approach

39

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Hybrid Biochemical/Thermochemical Biorefinery



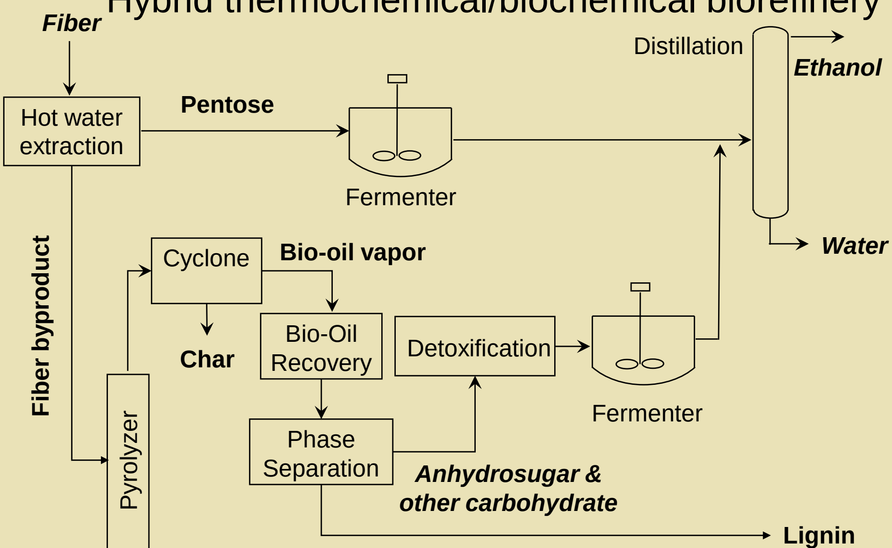
40

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Bio-oil Fermentation

Hybrid thermochemical/biochemical biorefinery



IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Summary

- ISU’s biorenewables research program is a comprehensive program in biorenewable resources and biobased energy, fuels and products.
- Research projects are built around research platforms, including a thermochemical conversion platform
- Several thermochemical options are under development:
  - Gasification/catalysis
  - Fast pyrolysis/catalysis
  - Syngas fermentation
  - Bio-oil fermentation

Contacts:

Dr. Robert C. Brown
Bioeconomy Institute and CSET, Director
rcbrown@iastate.edu

Dr. Justinus A. Satrio
CSET, Scientist & Program Manager
jasatrio@iastate.edu

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Thank you for listening!

Questions?

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Biomass-to-Fuels Efficiencies

Fuel Production Efficiencies		
Grain Ethanol[1]	38%	Biochemical
Lignocellulosic Ethanol[2]	35%	Biochemical
Methanol[3]	45%	Thermochemical
Hydrogen[3]	50%	Thermochemical
Fischer-Tropsch[4]	45%	Thermochemical

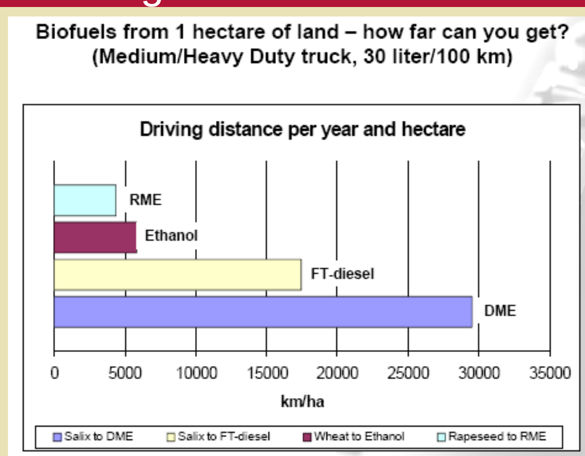
*BPD – barrels per day **MMGPY – million gallons per year (gasoline equivalent)
Note: Efficiencies do not account for byproduct value or power production although production costs do.

References:
1. A. McAloon, F. Taylor, W. Yee, K. Ibsen, and R. Wooley, "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks," National Renewable Energy Laboratory Report, October 2000.
2. C. N. Hamelinck, G. van Hooijdonk, and A. PC Faaij, "Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-, and long-term," Biomass and Bioenergy. 22, 384-410, 2005
3. C. N. Hamelinck, and A. Faaij, "Future prospects for production of methanol and hydrogen from biomass," Journal of Power Sources 111, 1-22, 2002.
4. M. J.A. Tijmensen, A. P.C. Faaij, C. N. Hamelinck, and M. R.M. van Hardeveld, "Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification," Biomass and Bioenergy 23, 129-152, 2002.

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Yield Advantage of Thermochemical synfuels



Source: Röj, A.*, Automotive Fuels from Biomass – What is the best road forward, First International Biorefinery Workshop, Washington, D.C., July 20-21, 2005, http://www.biorefineryworkshop.com/presentations/Roj.pdf
* Volvo Technology Corporation, anders.roj@volvo.com

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Comparing Costs

150 MMGPY* Capacity (2005 basis)	Capital Cost ($/bpd)*	Operating Cost ($/gal)	Feedstock Cost
Grain Ethanol[1]	13,000	$1.74/gal	$3.00/bu
Lignocellulosic Ethanol[2]	76,000	1.76	$50/ton
Methanol[3]	66,000	1.19	$50/ton
Hydrogen[3]	59,000	1.07	$50/ton
Fischer-Tropsch[4]	86,000	1.87	$50/ton

*BPD – barrels per day **MMGPY – million gallons per year (gasoline equivalent)
Note: Operating costs include credit for byproduct utilization.

References for Base Case Data:
1. A. McAloon, F. Taylor, W. Yee, K. Ibsen, and R. Wooley, "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks," National Renewable Energy Laboratory Report, October 2000.
2. C. N. Hamelinck, G. van Hooijdonk, and A. PC Faaij, "Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-, and long-term," Biomass and Bioenergy. 22, 384-410, 2005
3. C. N. Hamelinck, and A. Faaij, "Future prospects for production of methanol and hydrogen from biomass," Journal of Power Sources 111, 1-22, 2002.
4. M. J.A. Tijmensen, A. P.C. Faaij, C. N. Hamelinck, and M. R.M. van Hardeveld, "Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification," Biomass and Bioenergy 23, 129-152, 2002.

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Bioeconomy Instititute
Center for Sustainable Environmental Technologies

Biochemical Biorefinery

"Back-end" gasification can provide efficiency boost