

# Environmental Life Cycle Assessments of Biofuels

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**David R. Shonnard, Ph.D.**

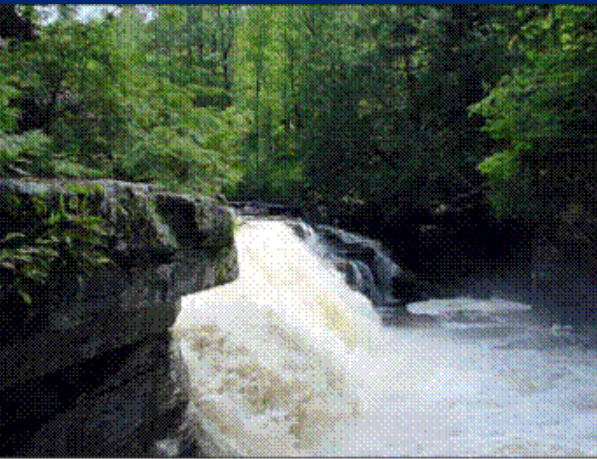
**Robbins Chair Professor  
Department of Chemical Engineering  
Michigan Technological University  
Director, Sustainable Futures Institute**

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***MichiganTech***

# Michigan Tech



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# Michigan Tech Statistics

- ❖ Established in 1885 to support the Mining Industry
- ❖ 7000 students (~1300 grad students)
- ❖ ~60% engineering students – one of the largest engineering Colleges in U.S.
- ❖ 1<sup>st</sup> Tier of US National Universities (US News, 2012)
- ❖ 64<sup>th</sup> Best in Engineering (US News, 2012)
- ❖ Top 10 Technological Universities (Money)
- ❖ Top 10 Safest University in USA
- ❖ 95% Placement Rate for Graduate Employment
- ❖ Intellectual Property – 3x national average in generating licenses



# Overview of Presentation

- ❖ Introduction to Energy Sustainability
- ❖ Sustainability Issues for Biofuels and Bioenergy
- ❖ Biomass Feedstock Availability (USA and China)
- ❖ Conversion Pathways for Biofuels
- ❖ Introduction to Biofuel Life Cycle Assessment (LCA)
- ❖ Overview of LCA Results
- ❖ Integrated Biofuel Research with Examples

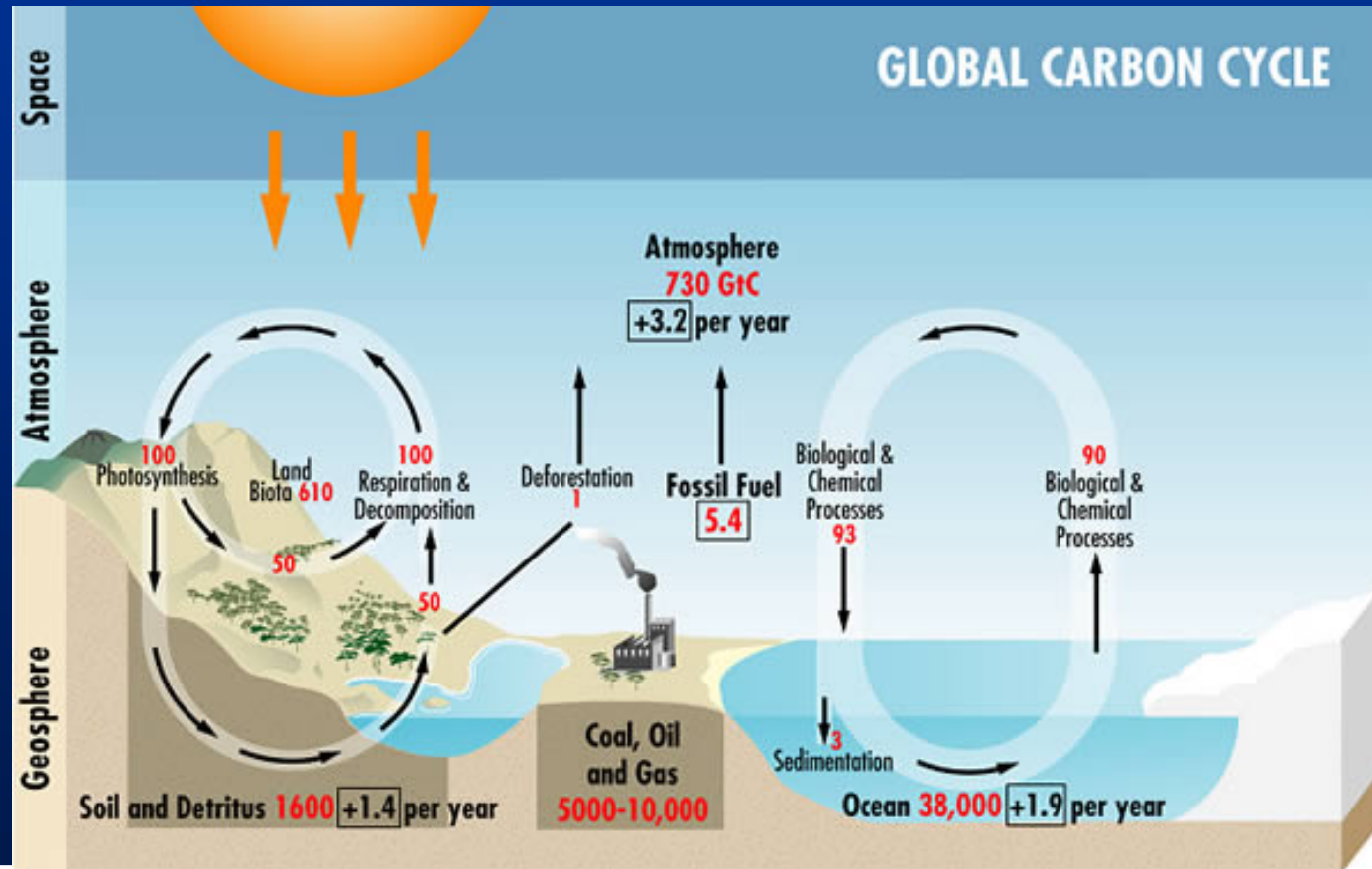




# Managing the Carbon Cycle: A Sustainable Energy Challenge

From <http://www.bom.gov.au/info/climate/change/gallery/index.shtml>

**Combustion of Fossil Fuels acts as a Carbon Pump**



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# CO<sub>2</sub> and Temperature in the Northern Hemisphere are Rising

## Temperature rising

Temperature and CO<sub>2</sub> records >>>>>>

### ■ Warming trends

The concentration of carbon dioxide in the atmosphere helps determine Earth's surface temperature. Both CO<sub>2</sub> and temperature have risen sharply since 1950.

Average Northern Hemisphere surface temperature

60°F -  
59 -  
58 -  
57 -  
56 -

Temperature data from ice-core, tree-ring, and lake-sediment samples

CO<sub>2</sub> data from ice-core samples

CO<sub>2</sub> ppm  
(parts per million)

400  
350  
300  
250

A.D. 1000 1200 1400 1600 1800 2004

*National Geographic, September 2004, pg 20, National Geographic Society, Washington, D.C.*



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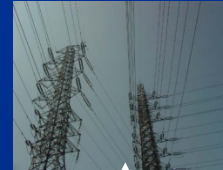
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# Wood-to-Wheels (W2W) Concept

## Research Thematic Areas



Sustainability  
Assessments /  
Decision-Making



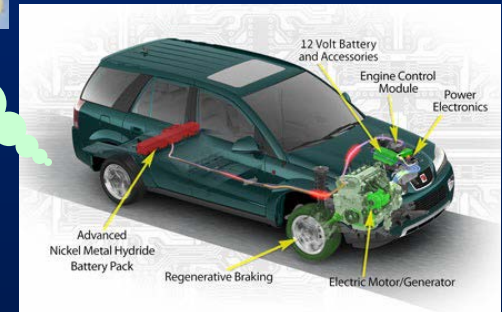
Bio-Processing Research  
*Photo: Glacial Lakes Energy*



Woody Biomass Resource Research



CO<sub>2</sub>



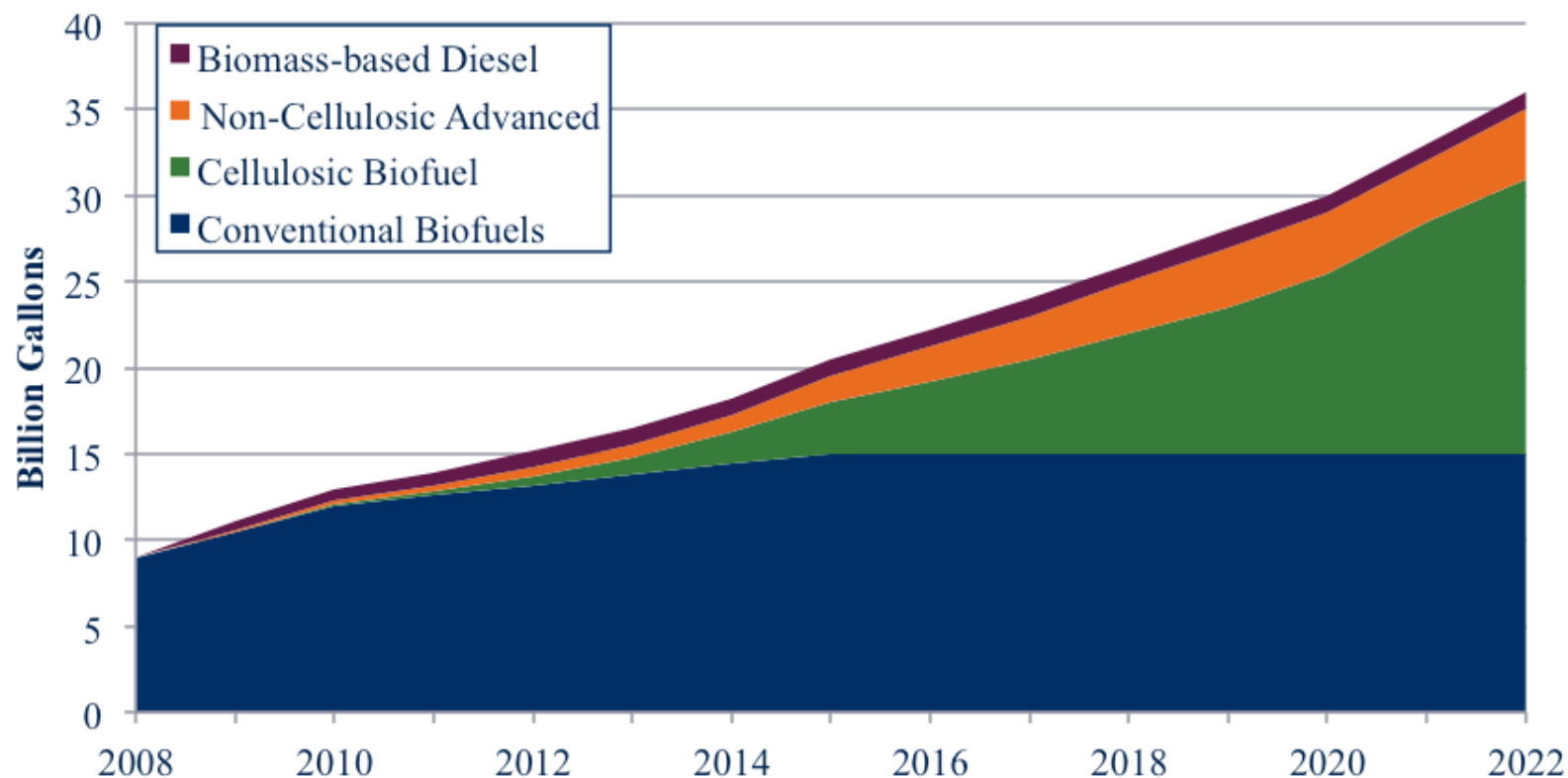
Vehicle Systems Research



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# Renewable Fuel Standard in USA



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AND ENERGY SOLUTIONS

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# But, How Much Biomass is Available on an Annual Basis in the USA?

**Table ES.1** : Summary of Currently Used and Potential Forest and Agriculture Biomass at \$60 per Dry Ton or Less, under Baseline and High-Yield Scenario Assumptions

Feedstock	2012	2017	2022	2030
Million dry tons				
<b>High-yield scenario (2%–4%)</b>				
Forest resources currently used	129	182	210	226
Forest biomass & waste resource potential	97	98	100	102
Agricultural resources currently used	85	103	103	103
Agricultural biomass & waste resource potential <sup>b</sup>	244	310	346	404
Energy crops	0	139–180	410–564	540–799
<b>Total currently used</b>	<b>214</b>	<b>284</b>	<b>312</b>	<b>328</b>
<b>Total potential</b>	<b>340</b>	<b>547–588</b>	<b>855–1009</b>	<b>1046–1305</b>
<b>Total high-yield (2-4%)</b>	<b>555</b>	<b>831–872</b>	<b>1168–1322</b>	<b>1374–1633</b>



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- Oil seed crops (rapeseed, etc.)
- Corn stover (stalk of the plant)
- Wheat straw



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Switchgrass, miscanthus  
Hybrid poplar and willow



# And, How Much Biomass is Available on an Annual Basis in China?

## The Renewable Energy Law of China

### Bio-ethanol

10 Mt/yr by 2020

Sweet Sorghum  
Sugarcane  
Maize  
Wheat  
Sweet Potato  
Cassava

### Bio-diesel

2 Mt/yr by 2020

Jatropha  
Oil Vegetable  
Cottonseed  
Coptistree  
Yellowhorn

35 million hectares total area for potential biofuel production – Type I-III lands  
175 million tons ethanol assuming 5 t ethanol/ha (sweet sorghum)

*Biomass Initiative Inventory in China, Task Force on Sustainability of GBEP, Wang and Ma, 2008*



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# Biofuel Conversion Pathways

Shonnard, D.R., Campbell, M. Brodeur-, Martin-Garcia, A.R., Kalnes, T.K., (2012), *Chemical Engineering of Bioenergy Plants: Concepts and Strategies*, in Vol. 1 *Handbook of Bioenergy Crop Plants*, Kole, C., Joshi, C., Shonnard, D.R. Eds., CRC Press-Taylor and Francis, Boca Raton, FL, 133-164

## Conventional Biofuels

### Biochemical

Corn,  
Sugar beets  
Sugar cane

Enzymatic  
Hydrolysis

Glucose,  
Sucrose

Fermentation

Ethanol,  
DDGS

### Thermochemical

Triglycerides:  
soybean, rape  
seed, palm

Solvent  
Extraction

Plant Bio-oil

Transester-  
ification

Biodiesel,  
Glycerol,  
Soymeal...

## Advanced Biofuels

### Biochemical

Lignocellulosic  
Feedstocks

Chemical  
Hydrolysis

Glucose  
Xylose  
Galactose  
Arabinose  
Mannose

Enzyme  
Hydrolysis,  
Fermentation

Ethanol,  
Butanol,  
Hydrocarbons

### Thermochemical

Triglycerides:  
camelina, algae,  
tallow, jatropha

Solvent  
Extraction

Bio-oil

Hydrotreatment

Hydrocarbon  
Biofuels

Lignocellulosic  
Feedstocks

Gasification

Synthesis Gas

Fischer-Tropsch

Hydrocarbon  
Biofuels

Pyrolysis,  
Hydropyrolysis

Py-Oil  
HydroPy-Oil

Hydrotreatment

Biomass

Pretreatment

Intermediates

Conversion

Biofuels



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# Categories for indicators of environmental and socioeconomic sustainability

Greenhouse gas emissions

Productivity

Soil quality

Biological  
diversity

Water quality  
and quantity

Air quality

**McBride et al. (2011)**  
***Ecological Indicators***  
**11:1277-1289**



Oak Ridge National Laboratory  
<http://www.ornl.gov/sci/ees/cbes/>

Social well being

Social  
acceptability

External  
trade

Resource  
conservation

Energy  
security

Profitability

**Dale et al. (In review)**  
***Ecological Indicators***

**Example of one category: soil quality**

<u>Indicator</u>	<u>Units</u>
Total organic carbon (TOC)	Mg/ha
Total nitrogen (N)	Mg/ha
Extractable phosphorus (P)	Mg/ha
Bulk density	g/cm <sup>3</sup>

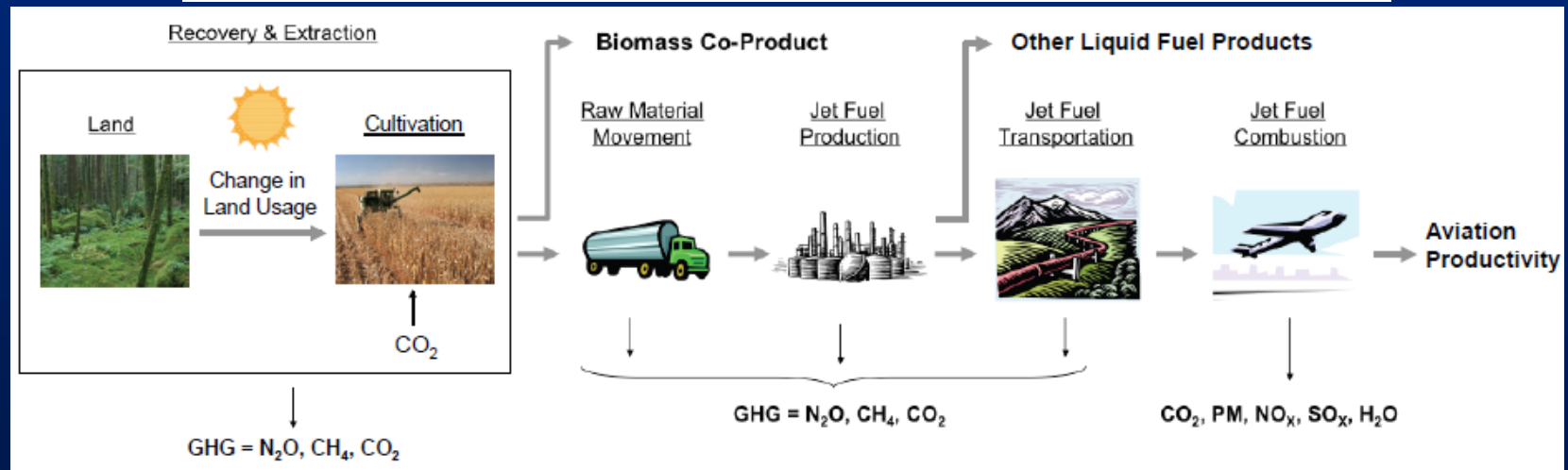
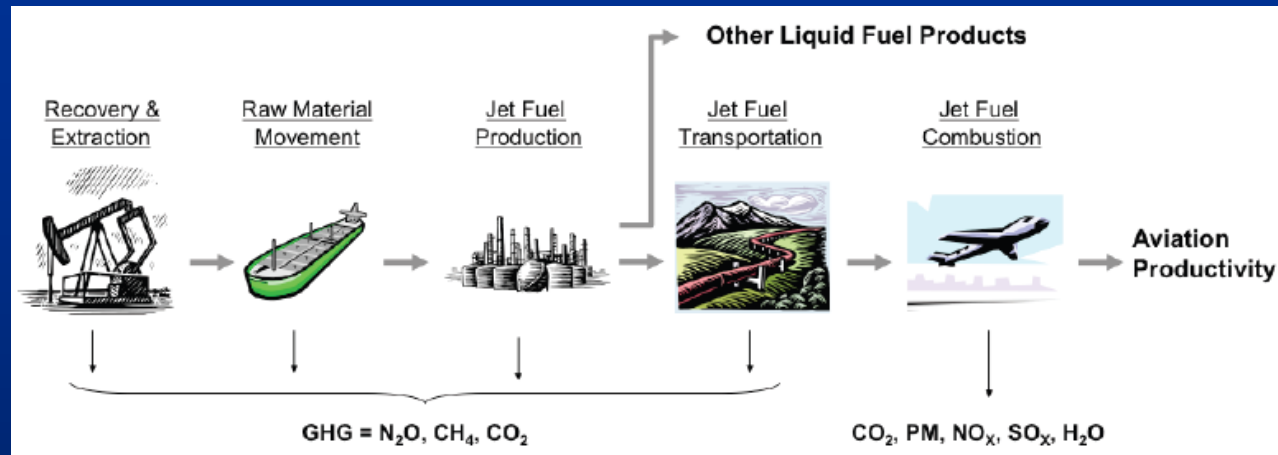


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# Introduction: Biofuel Environmental LCA

Stratton, Wong, and Heilman, MIT, PARTNER Project 28 Report: Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels

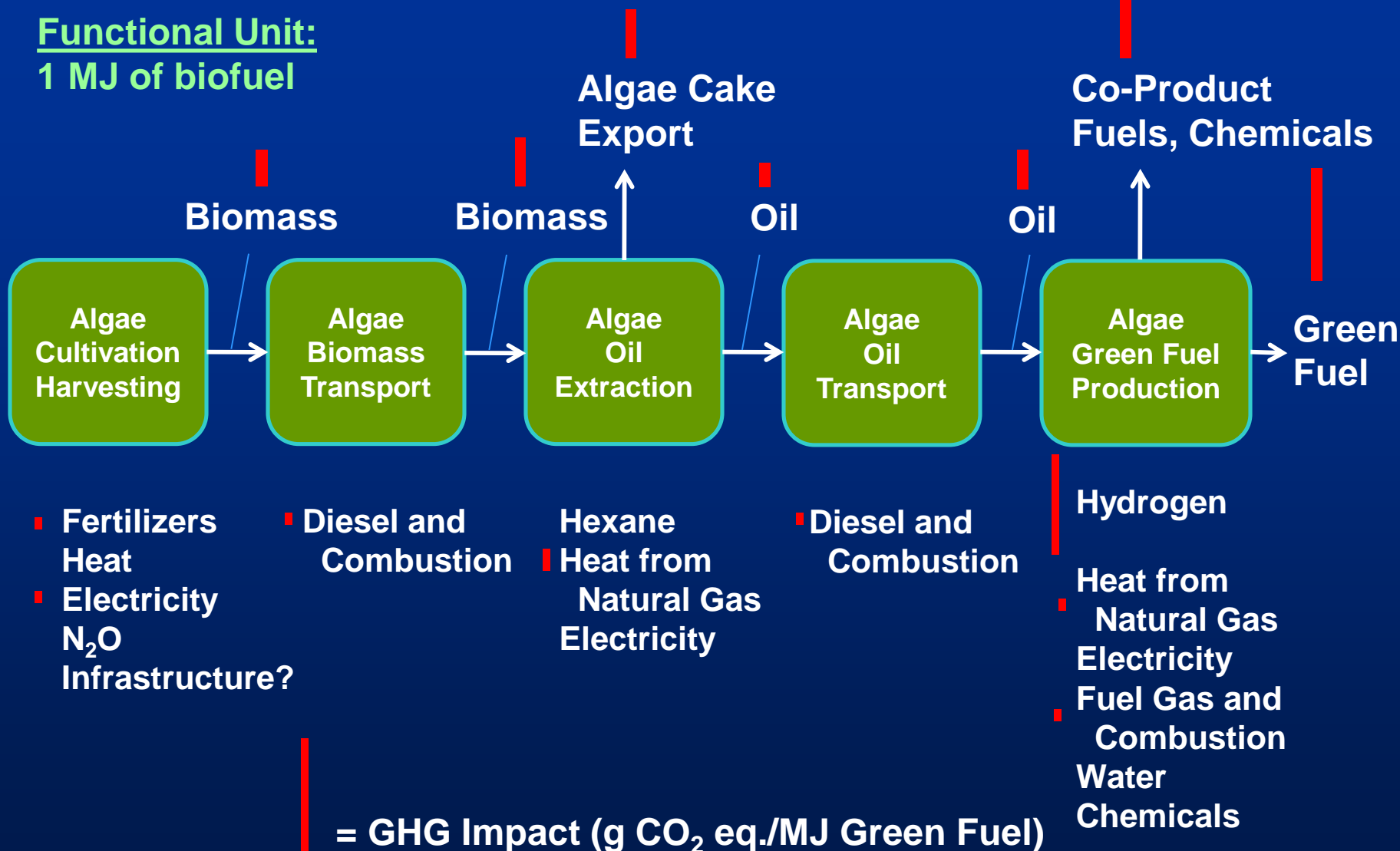


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# Energy Allocation Method (DOE, EC)

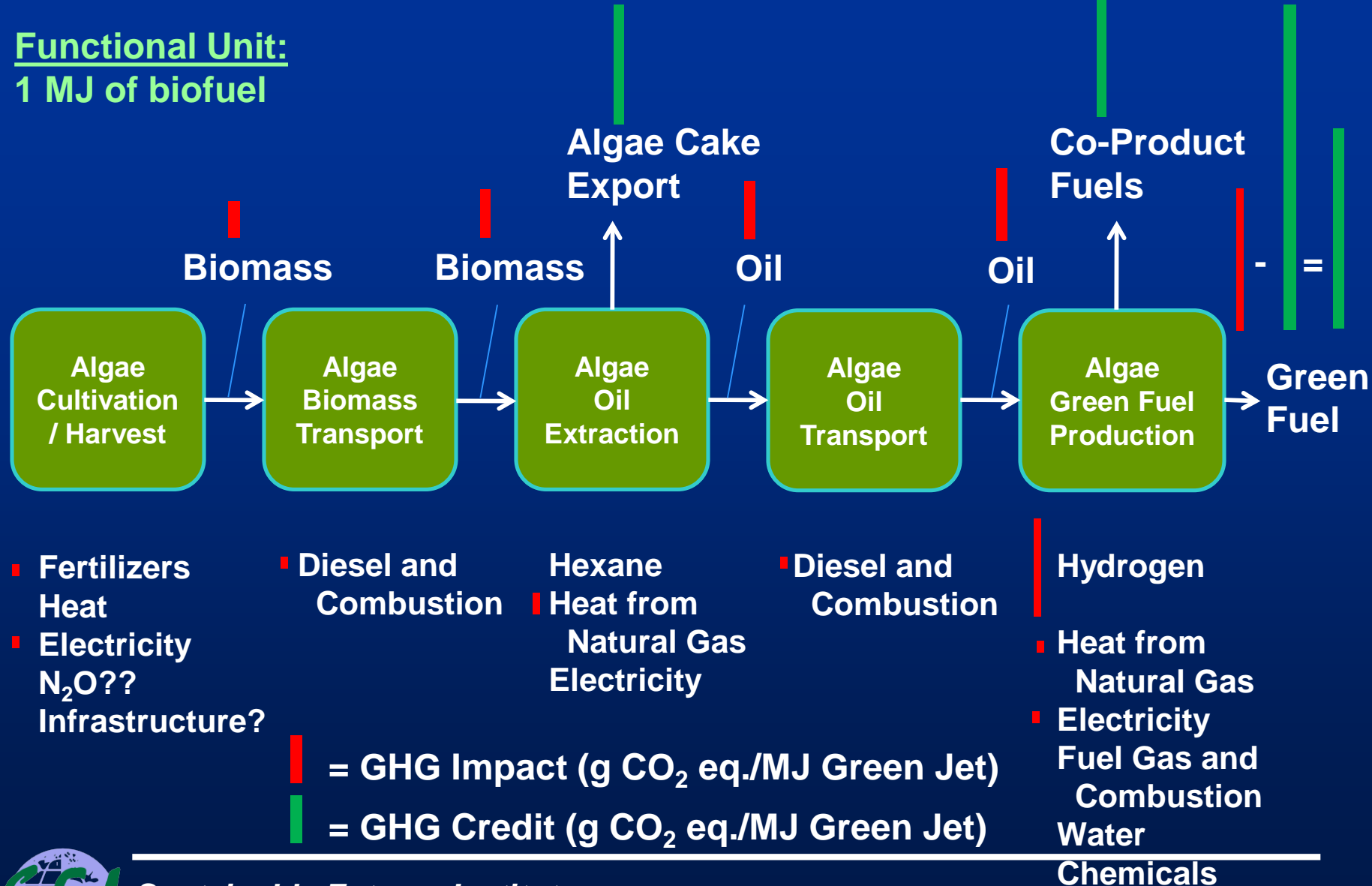
Functional Unit:  
1 MJ of biofuel





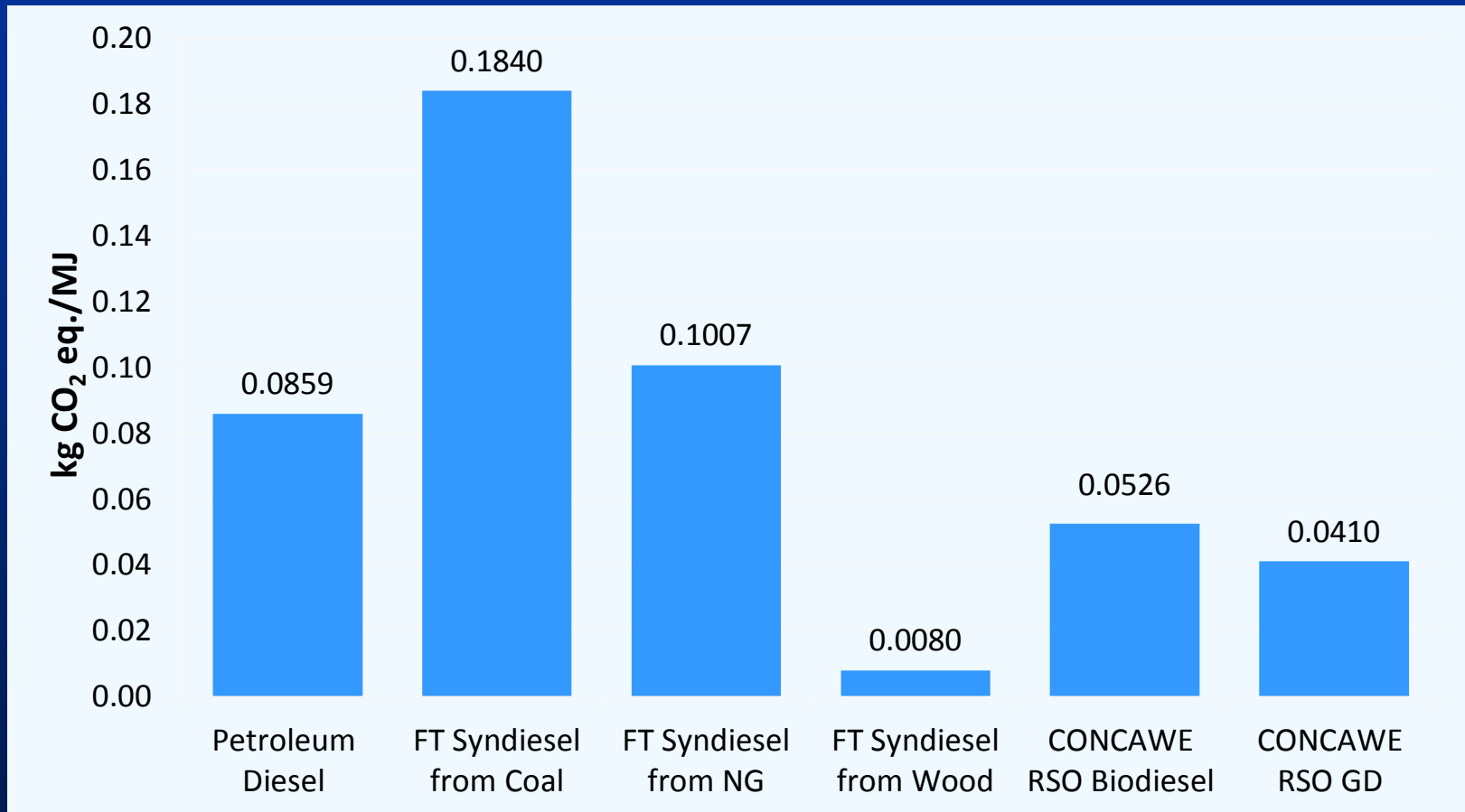
# Displacement Allocation Method (EPA)

Functional Unit:  
1 MJ of biofuel



# Some Biofuel LCA Results

## *Greenhouse Gas (GHG) Emissions*



Koers, K.P., Kalnes, T.N., Marker, T., Shonnard, D.R. (2009), *Green diesel: A technoeconomic and environmental life cycle comparison to biodiesel and syndiesel*, *Environmental Progress & Sustainable Energy*, 28(1), 111-120

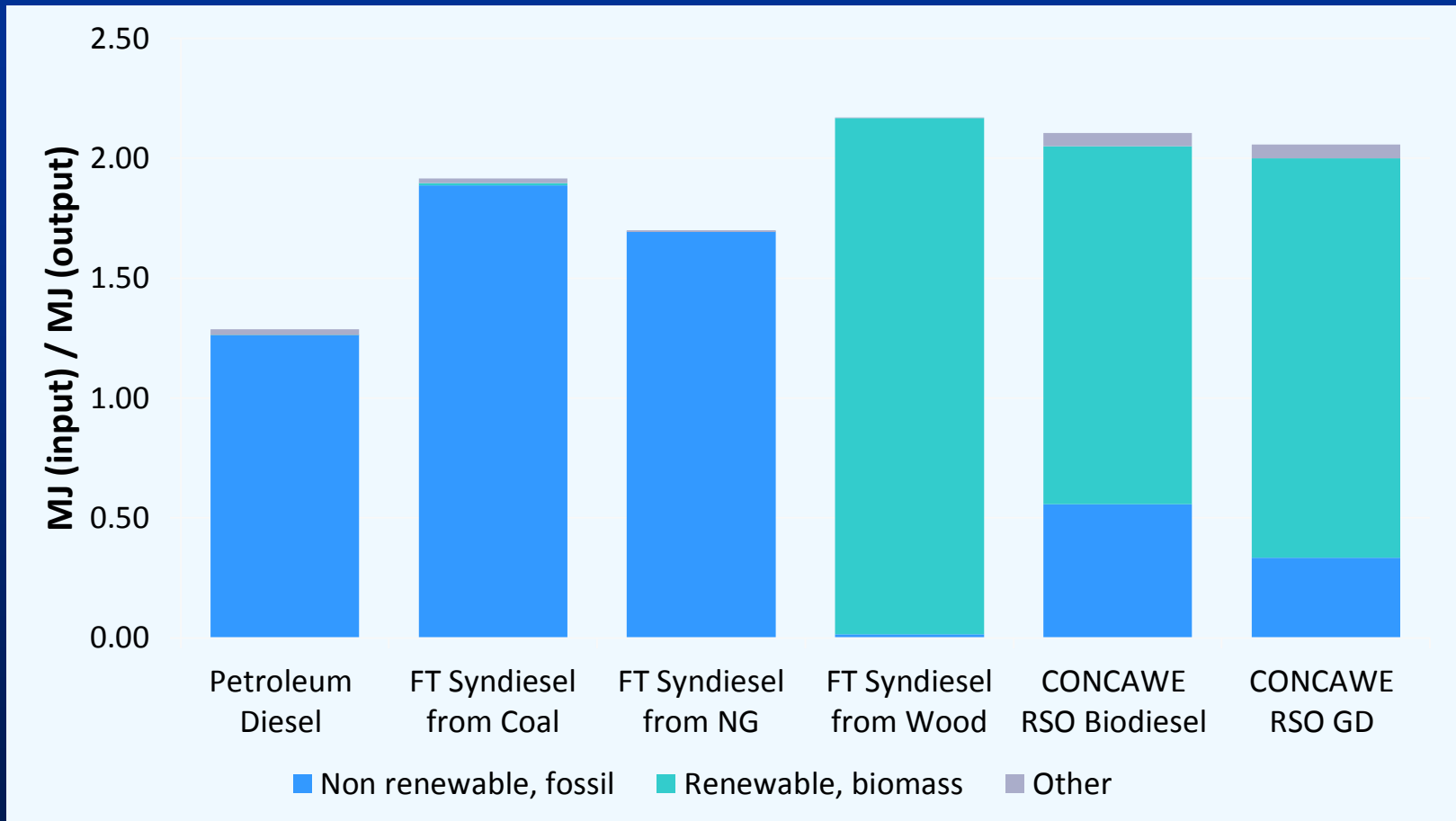


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# Some Biofuel LCA Results

## *Cumulative Energy Demand*



Koers, K.P., Kalnes, T.N., Marker, T., Shonnard, D.R. (2009), Green diesel: A technoeconomic and environmental life cycle comparison to biodiesel and syndiesel, *Environmental Progress & Sustainable Energy*, 28(1), 111-120



# Integrated Biofuels Research

## *Potential Benefits to Society*

❖ Current technology: 30% gasoline displacement

❖ Improved technology: > 60% displacement

Achievable Using Existing  
Cell. EtOH Technologies

X

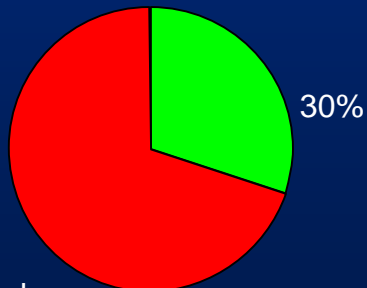
Improved  
Biomass Productivity

X

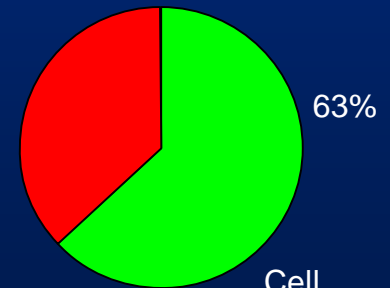
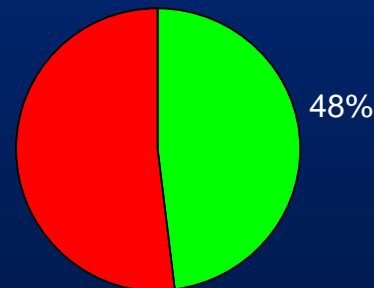
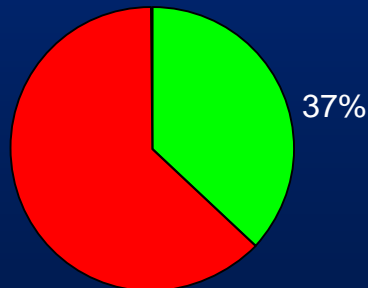
Improved  
Bioprocessing Efficiency

X

Improved Engine/  
Vehicle Efficiencies



Petroleum  
Gasoline



Cell.  
EtOH



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# NSF Sustainable Energy Pathways

Wood-to-Wheels: Forest-Based Biofuels (Green Diesel)

Research driven by the need to **understand** and **manage** molecular identity

Integrated Sustainability Assessment  
SS, ECM : Mayer, Shonnard, Zhou

Information ↔ Guidance

**Sustainable  
Forest  
Systems  
SFRES:  
Burton,  
Froese, Joshi,  
Gailing**

Prescribed  
biomass  
composition  
profiles

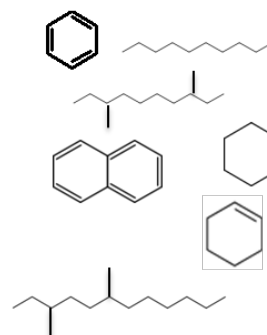
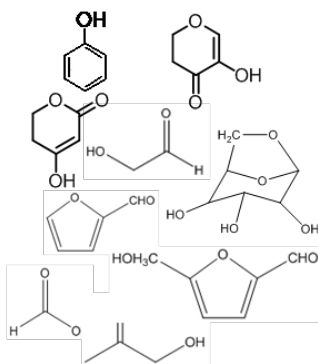
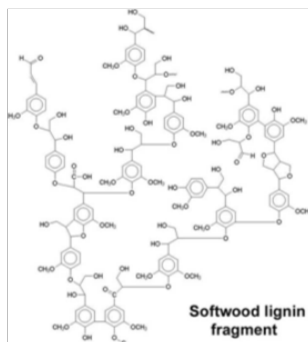
Information ↔ Guidance

**Conversion  
Processes  
ECM, MEEM:  
Bar Ziv,  
Mullins,  
Shonnard**

Prescribed  
GD make-  
up for clean  
combustion

Information ↔ Guidance

**Energy  
Utilization:  
MEEM: Naber,  
Lee, Johnson**



CO<sub>2</sub>  
CO  
NO<sub>x</sub>  
PM



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# Pan American Biofuels and Bioenergy Sustainability Research Coordination Network (RCN)

D. Shonnard, R.P. Donovan, K. Halvorsen, B. Solomon, S. Sweitz, (50 others)  
*National Science Foundation: CBET-1140152, 01/01/12 - 12/31/15*



- a. Community impacts,
- b. water / energy nexus,
- c. biodiversity / ecosystems
- d. energy policy,

Research  
Coordination  
Network

Workshops /  
Conference

Research Roadmap Report on  
Sustainability of Pan American  
Biofuels and Bioenergy

- e. life cycle assessment,
- f. food and other systems,
- g. biogeochemical cycles, and
- h. biomass supply transportation logistics.

Education:  
Graduate Course on Biofuels  
and Bioenergy Sustainability



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# Funding Sources



Colcom Foundation



Shonnard Research Group, 2010

Richard and Bonny Robbins Endowment



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# Thank You!



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