Environmental Life Cycle Assessments of Biofuels

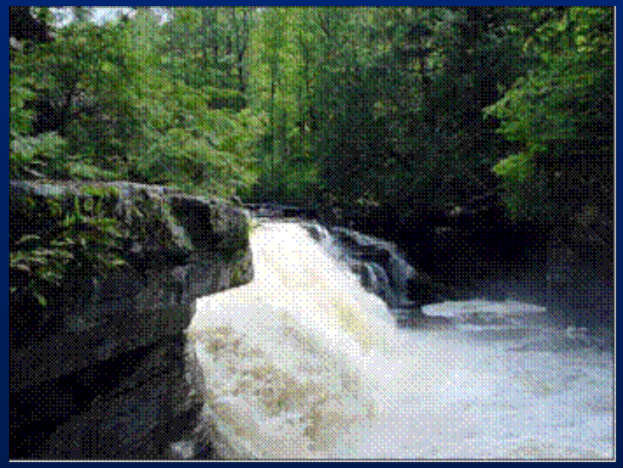
www.sfi.mtu.edu

David R. Shonnard, Ph.D.

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

drshonna@mtu.edu

Michigan Tech



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.

- 1st Tier of US National Universities (US News, 2012)
- 64th 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

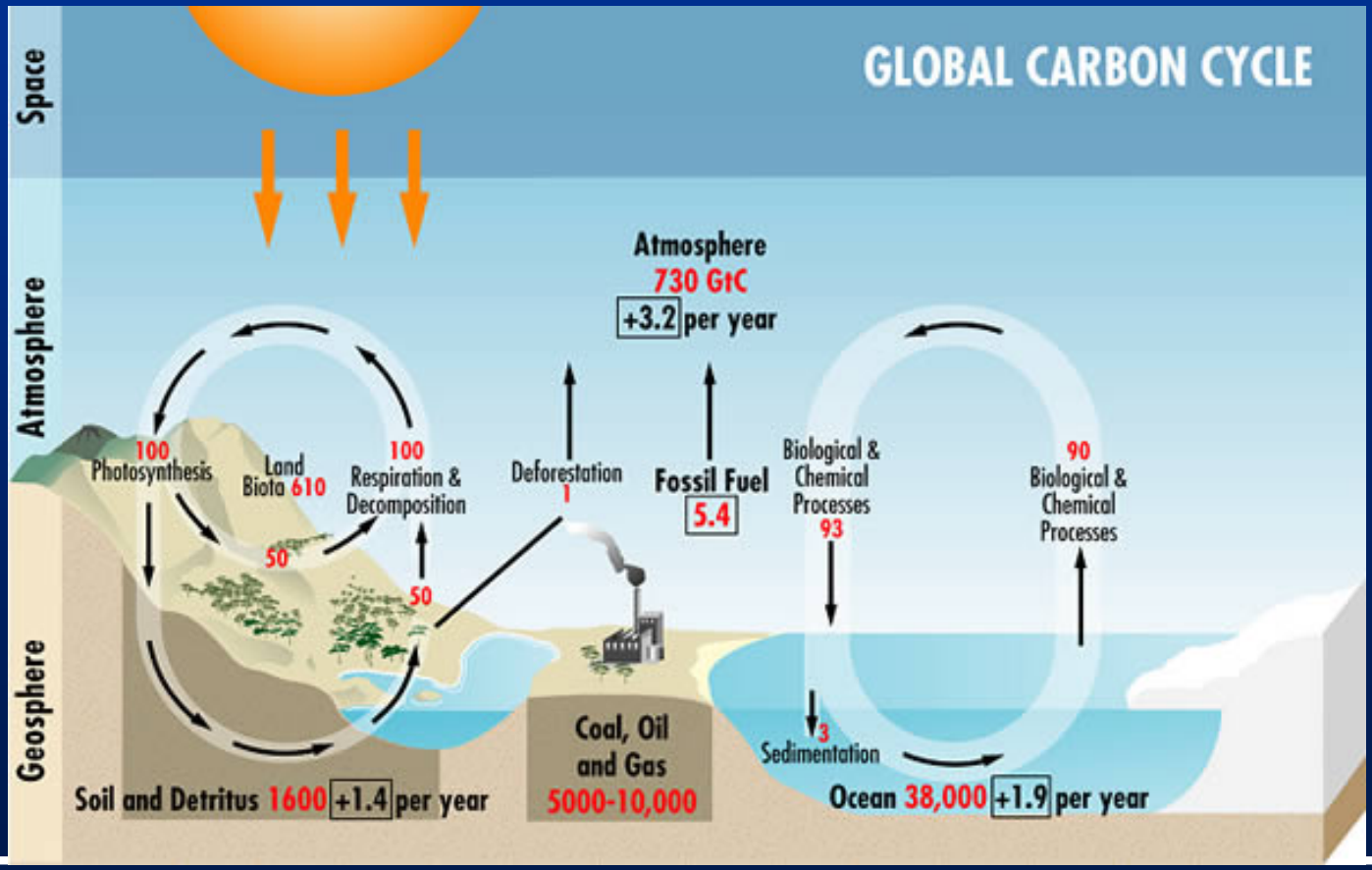
- Introduction to Energy Sustainability
- Sustainability Issues for Biofuels and Bioenergy
- Biomass Feedstock Availability (USA and China)
- Conversion Pathways for Biofuels
- Introduction to Biofuel Life Cycle Assessment (LCA)
- Overview of LCA Results
- Integrated Biofuel Research with Examples

Managing the Carbon Cycle:

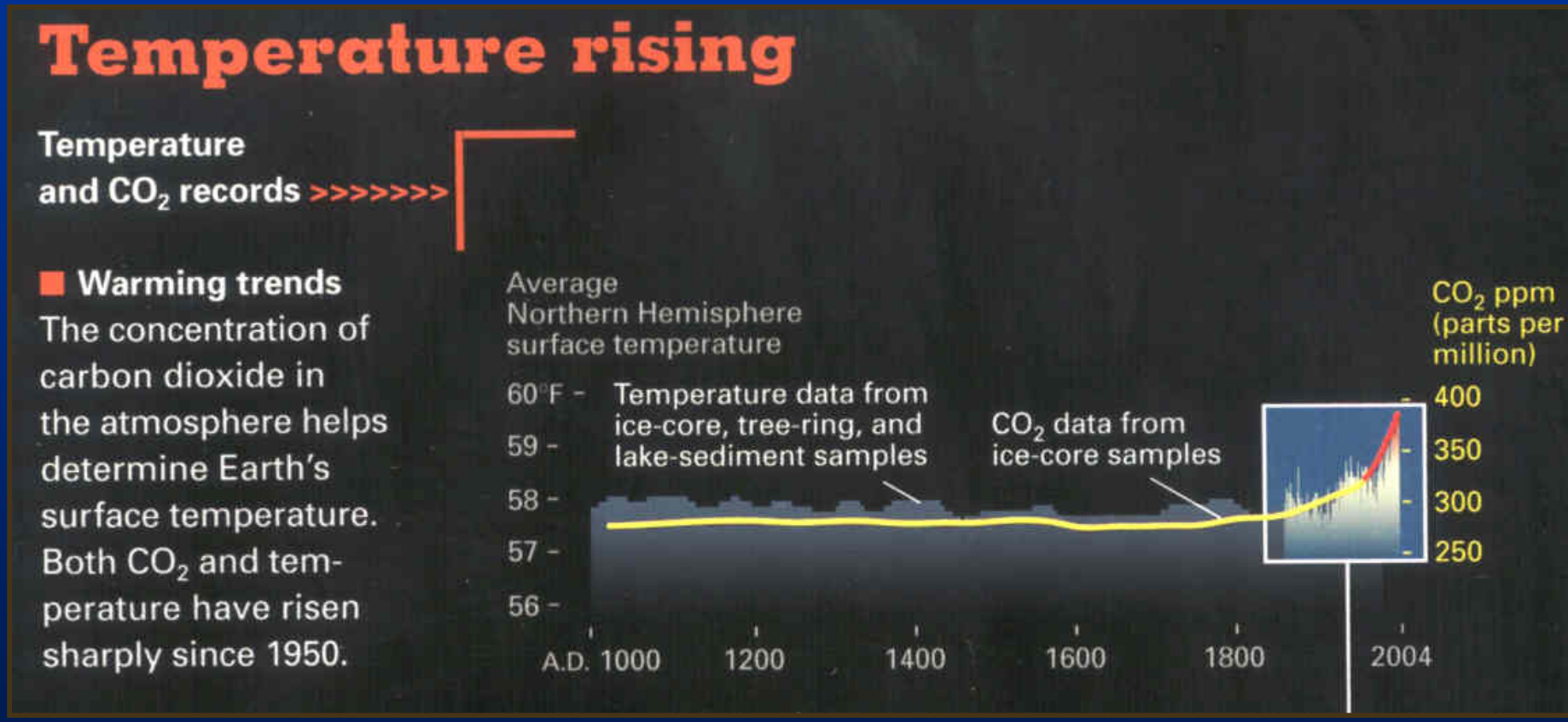
A Sustainable Energy Challenge

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

Combustion of Fossil Fuels acts as a Carbon Pump



CO_2 and Temperature in the Northern Hemisphere are Rising



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

Wood-to-Wheels (W2W) Concept

Research Thematic Areas

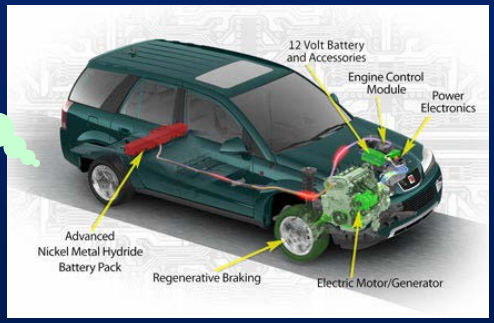
Sustainability Assessments / Decision-Making

Bio-Processing Research

Photo: Glacial Lakes Energy

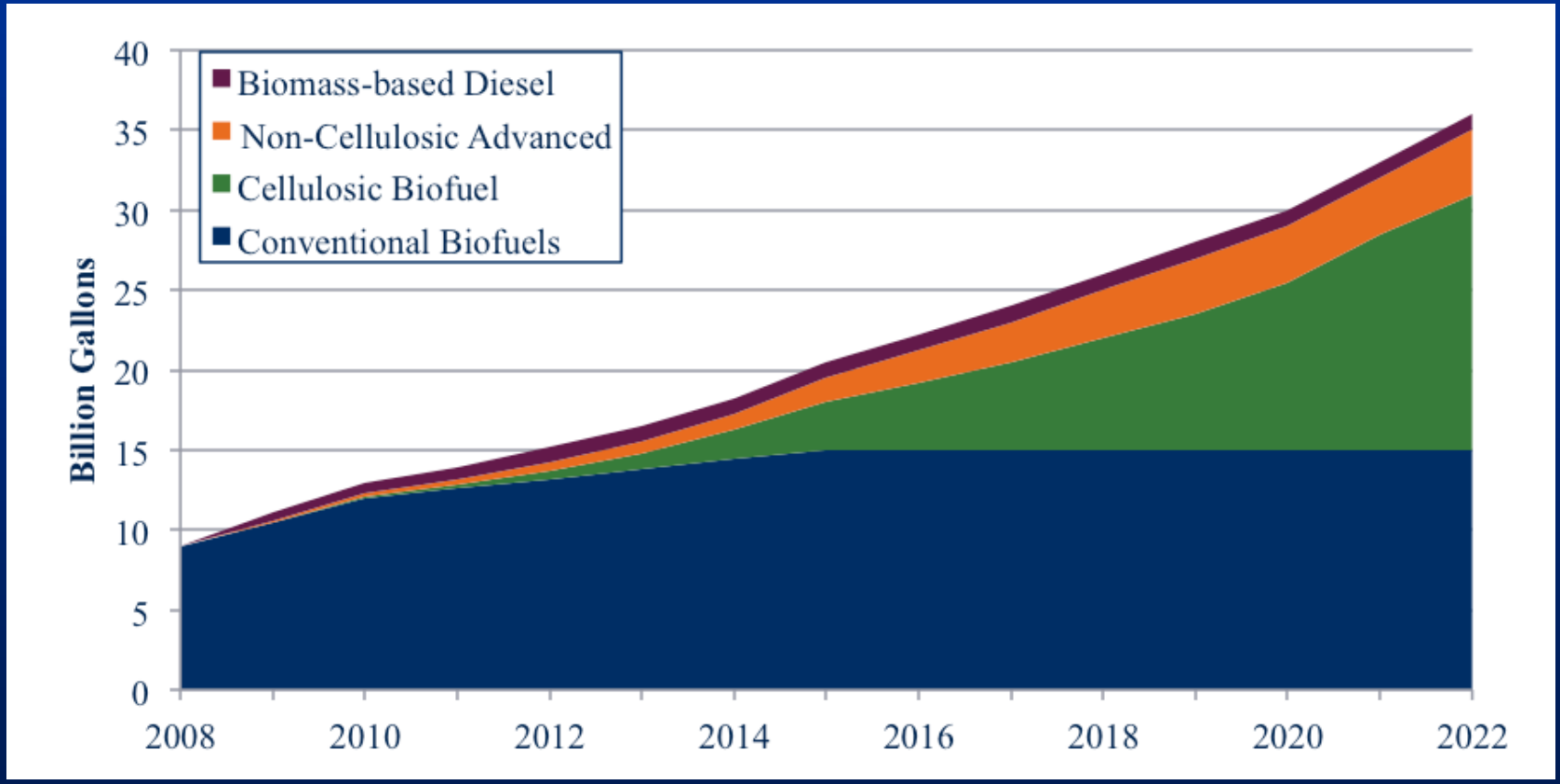
Woody Biomass Resource Research

CO_2



Vehicle Systems Research

Renewable Fuel Standard in USA



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		
High-yield scenario (2%–4%)				
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[b]	244	310	346	404
Energy crops	0	139–180	410–564	540–799
Total currently used	**214**	**284**	**312**	**328**
Total potential	**340**	**547–588**	**855–1009**	**1046–1305**
Total high-yield (2-4%)	**555**	**831–872**	**1168–1322**	**1374–1633**

U.S. Department of Energy. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes , ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.*

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		
High-yield scenario (2%–4%)				
Forest resources currently used			210	226
Forest biomass & waste resource potential			100	102
Agricultural resources currently used		103	103	103
Agricultural biomass & waste resource potential[b]	244	310	346	404
Energy crops	0	139–180	410–564	540–799
Total currently used	**214**	**284**	**312**	**328**
Total potential	**340**	**547–588**	**855–1009**	**1046–1305**
Total high-yield (2-4%)	**555**	**831–872**	**1168–1322**	**1374–1633**

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

U.S. Department of Energy. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes , ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.*

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		
High-yield scenario (2%–4%)				
Forest resources currently used	129	182	210	226
Forest biomass & waste resource potential			100	102
Agricultural resour			103	103
Agricultural bioma resource potential[b]			346	404
Energy crops	0	139–180	410–564	540–799
Total currently used	**214**	**284**	**312**	**328**
Total potential	**340**	**547–588**	**855–1009**	**1046–1305**
Total high-yield (2-4%)	**555**	**831–872**	**1168–1322**	**1374–1633**

Switchgrass, miscanthus
Hybrid poplar and willow

Sustainable Futures Institute
www.sfi.mtu.edu

U.S. Department of Energy. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes , ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.*

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

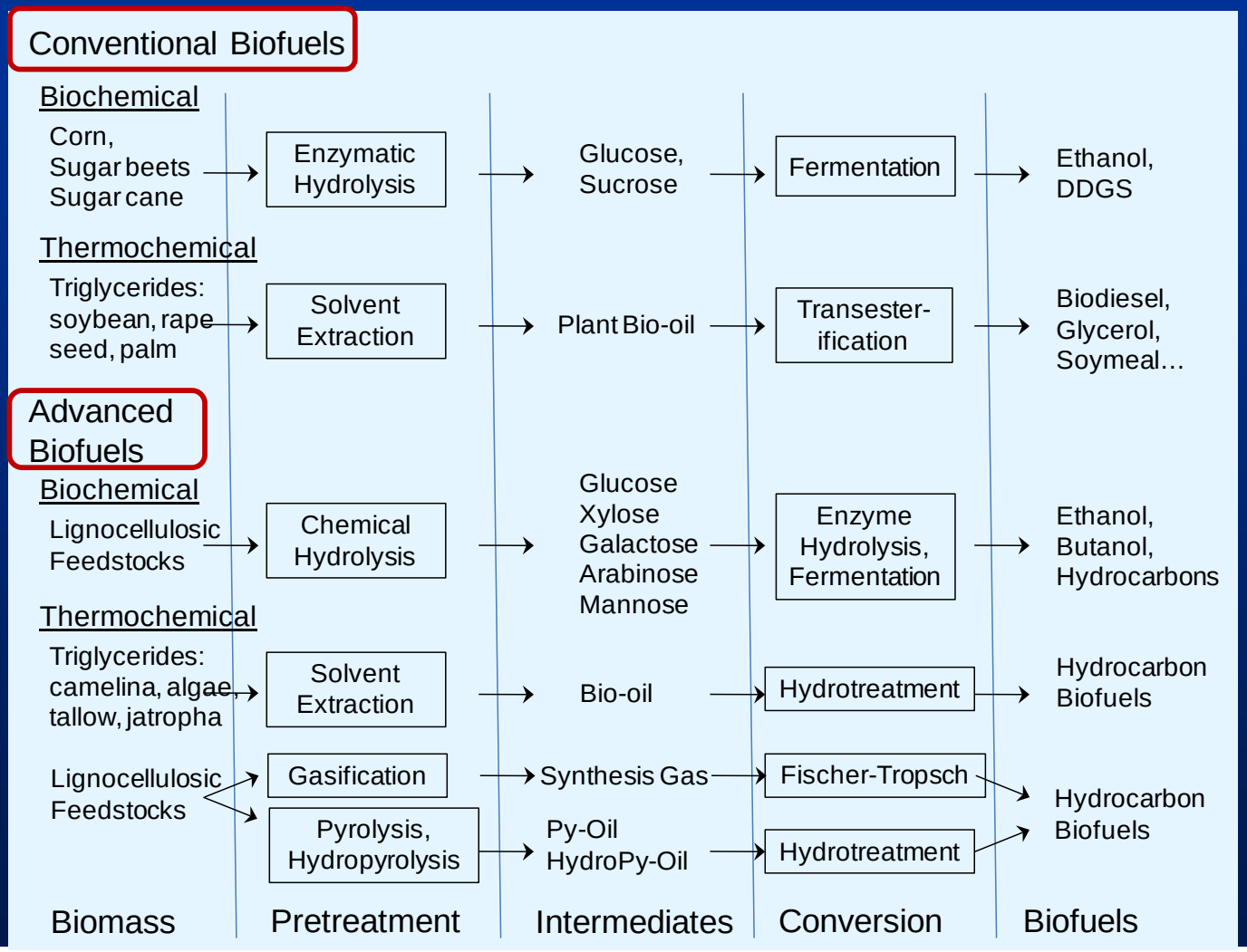
Jatropha
Oil Vegetable
Cottonseed
Coptistree
Yellowhorn

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

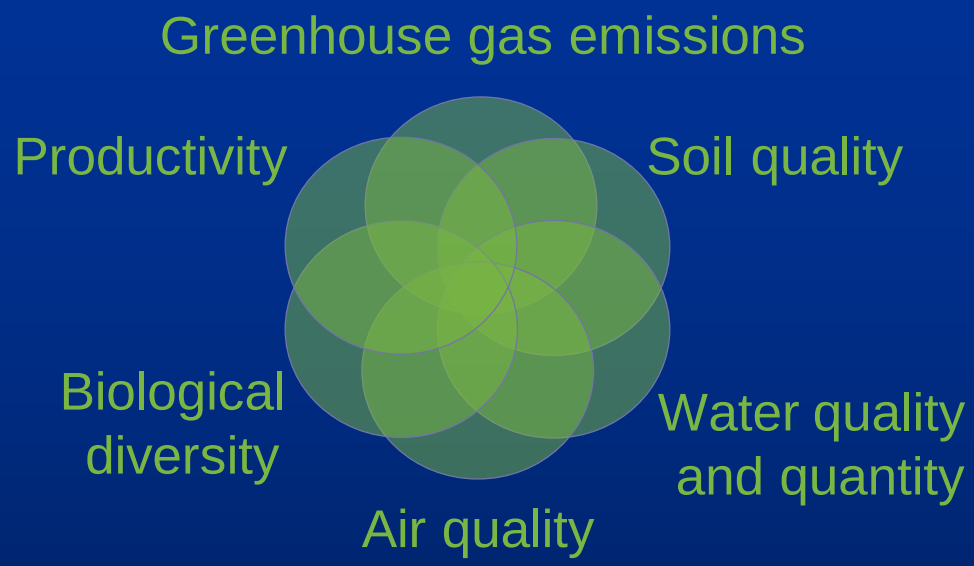
Biomass Initiative Inventory in China, Task Force on Sustainability of GBEP, Wang and Ma, 2008

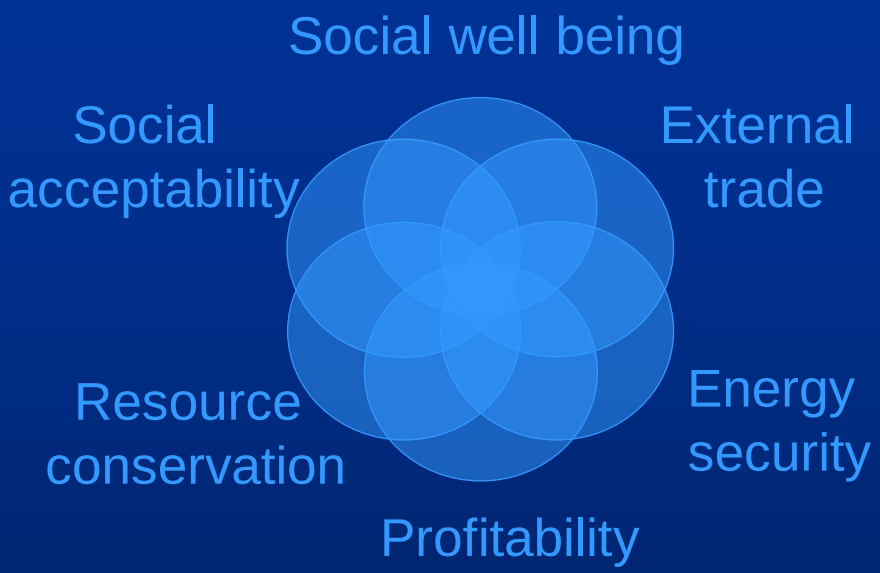
Biofuel Conversion Pathways

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



Categories for indicators of environmental and socioeconomic sustainability





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

Dale et al. (In review)
Ecological Indicators

Example of one category: soil quality

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

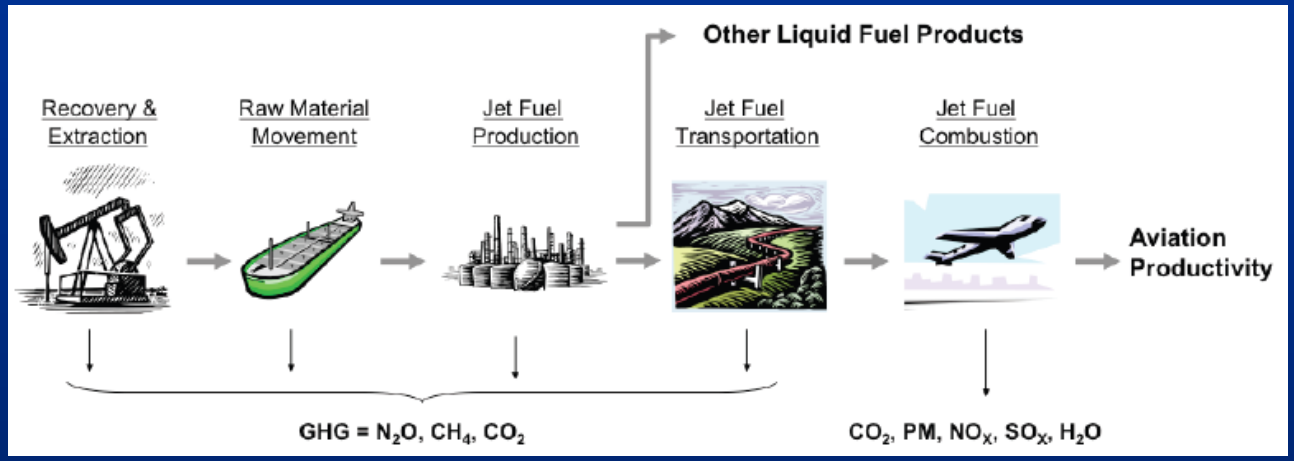
Oak Ridge National Laboratory
http://www.ornl.gov/sci/ees/cbes/

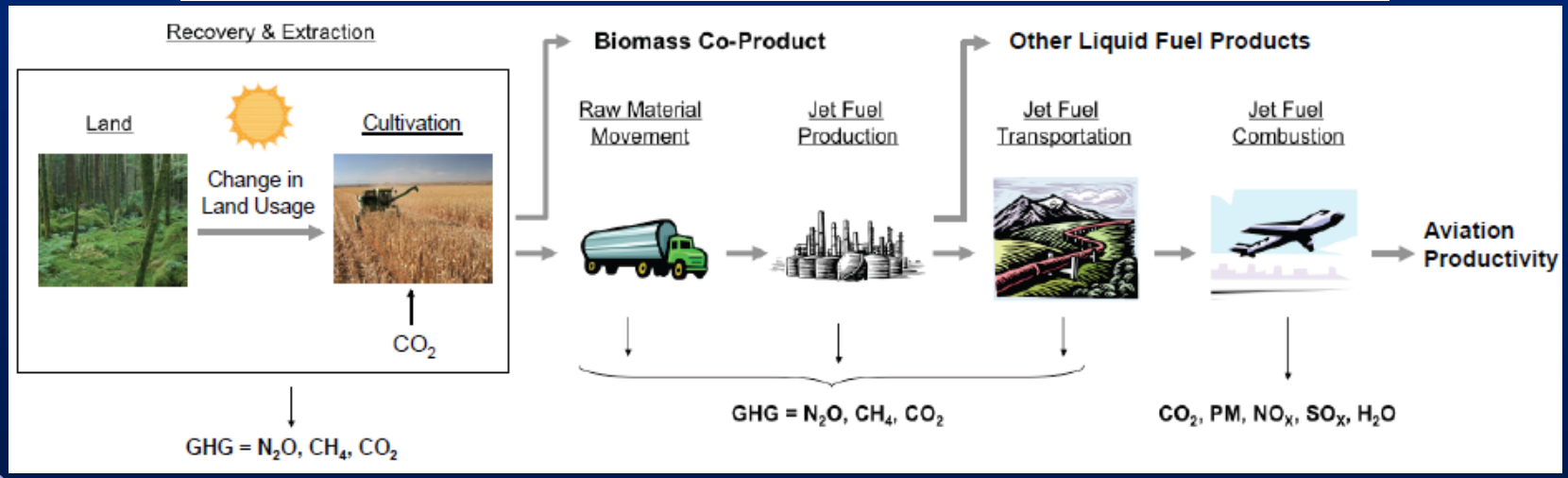
Sustainable Futures Institute
www.sfi.mtu.edu

MichiganTech

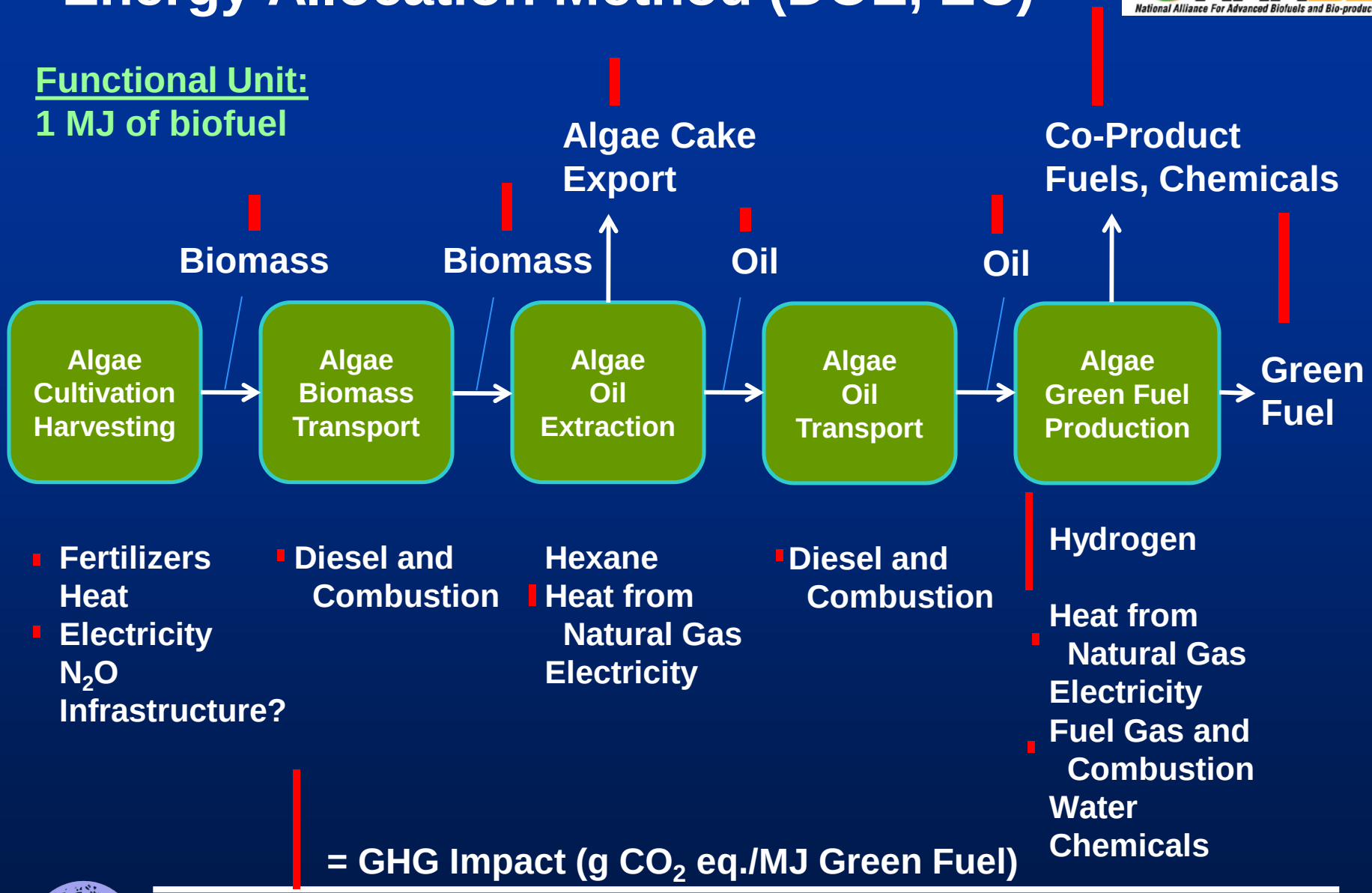
Introduction: Biofuel Environmental LCA

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



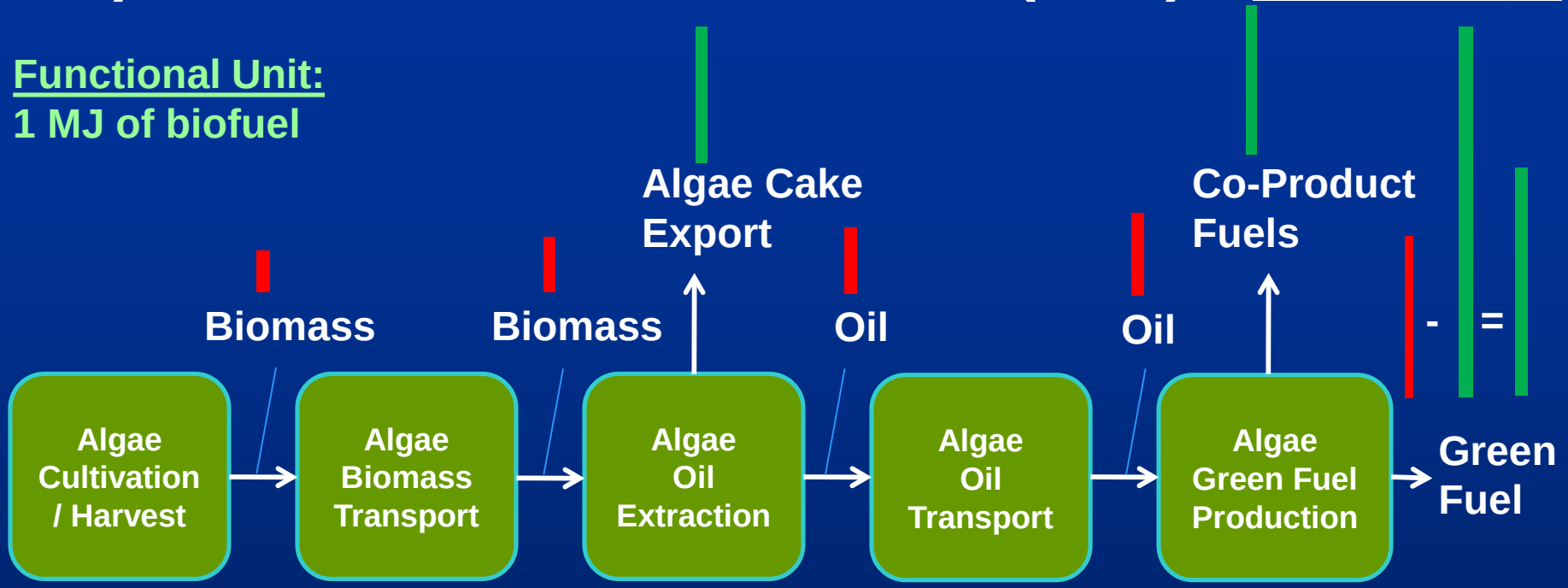


Energy Allocation Method (DOE, EC)



Displacement Allocation Method (EPA)

Functional Unit:
1 MJ of biofuel



- Fertilizers
  Heat
- Electricity
  N_2O??
  Infrastructure?

- Diesel and Combustion

Hexane
- Heat from Natural Gas

Electricity

- Diesel and Combustion

- Hydrogen
- Heat from Natural Gas
- Electricity

Fuel Gas and Combustion
Water
Chemicals

= GHG Impact (g CO_2 eq./MJ Green Jet)

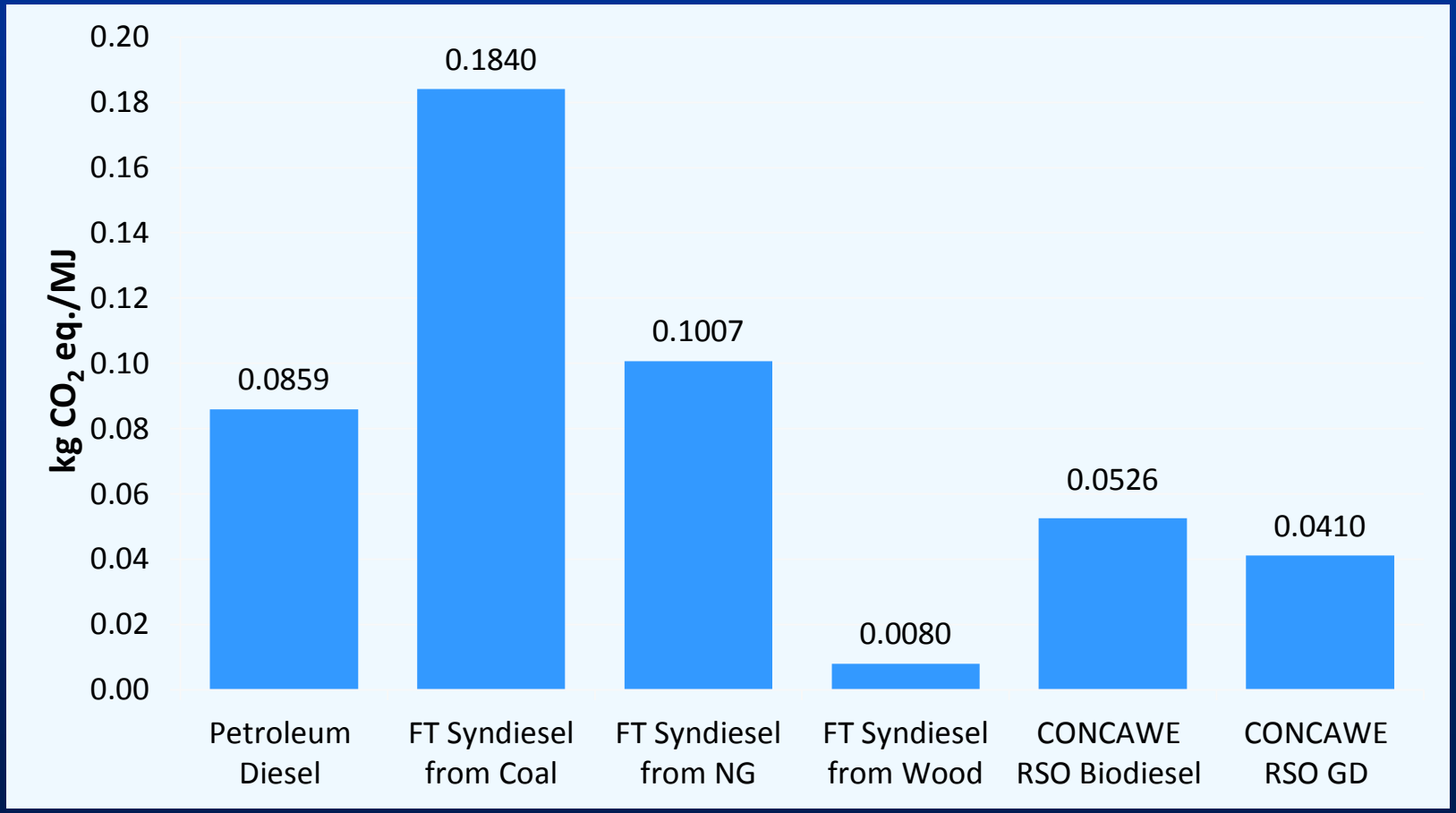
= GHG Credit (g CO_2 eq./MJ Green Jet)

Sustainable Futures Institute
www.sfi.mtu.edu

Michigan Tech

Some Biofuel LCA Results

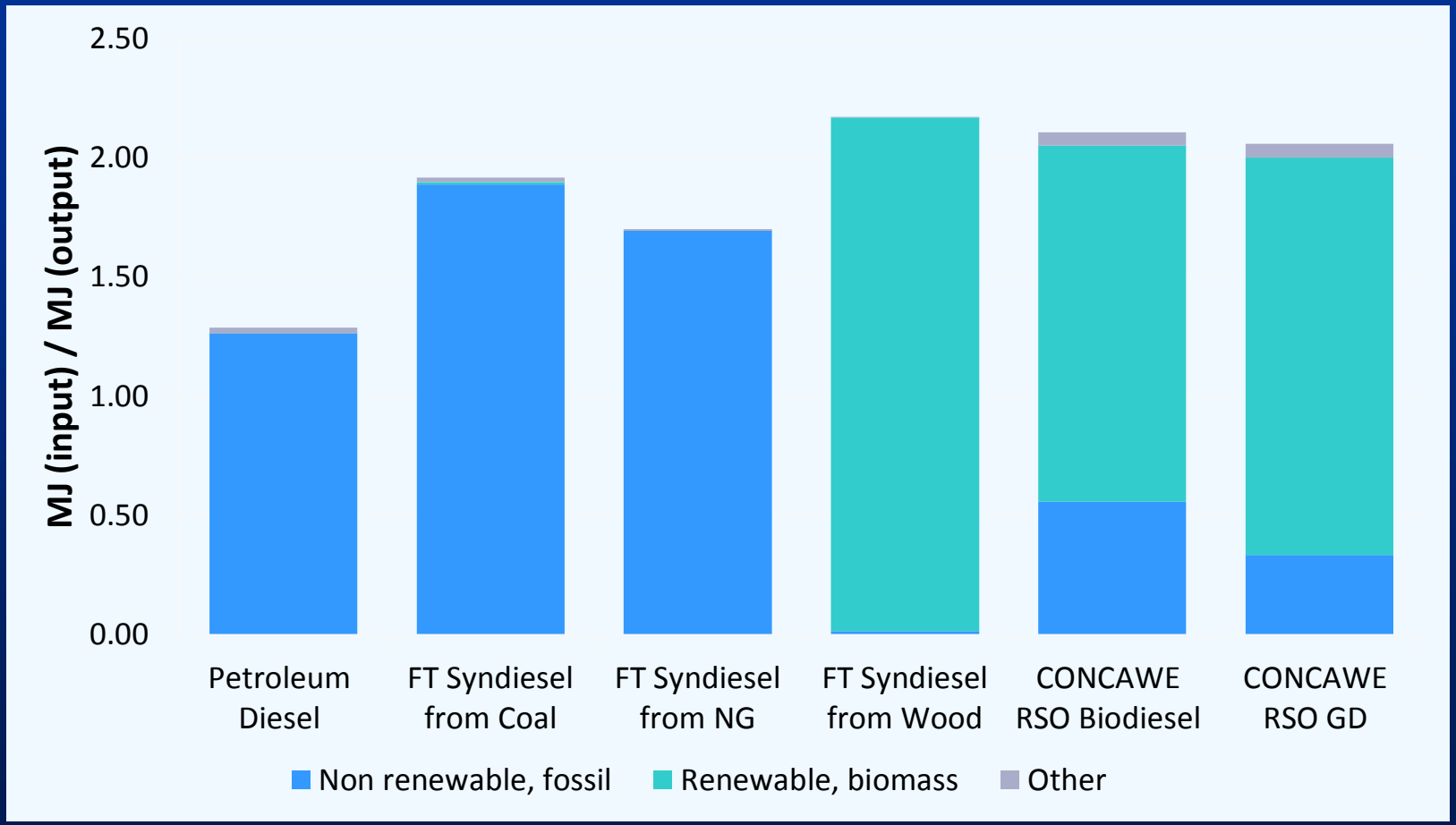
Greenhouse Gas (GHG) Emissions



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

Some Biofuel LCA Results

Cumulative Energy Demand

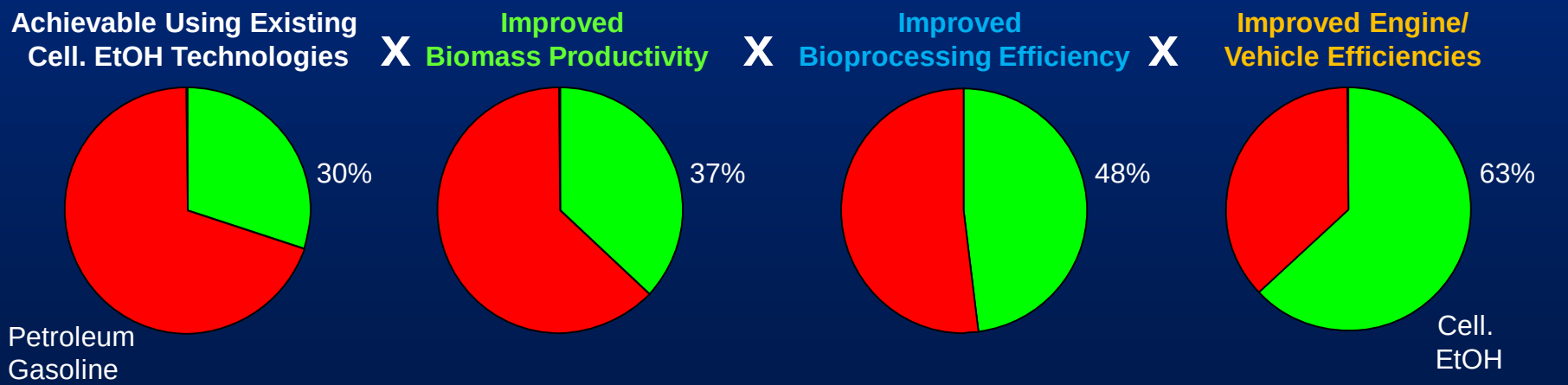


Koers, K.P., Kalnes, T.N., Marker, T., Shonnard, D.R. (2009), Green diesel: A technoeconomic and environmental life cycle comparison to biodiesel and syndiesel, Environmental Progress & Sustainable Energy, 28(1), 111-120

Integrated Biofuels Research

Potential Benefits to Society

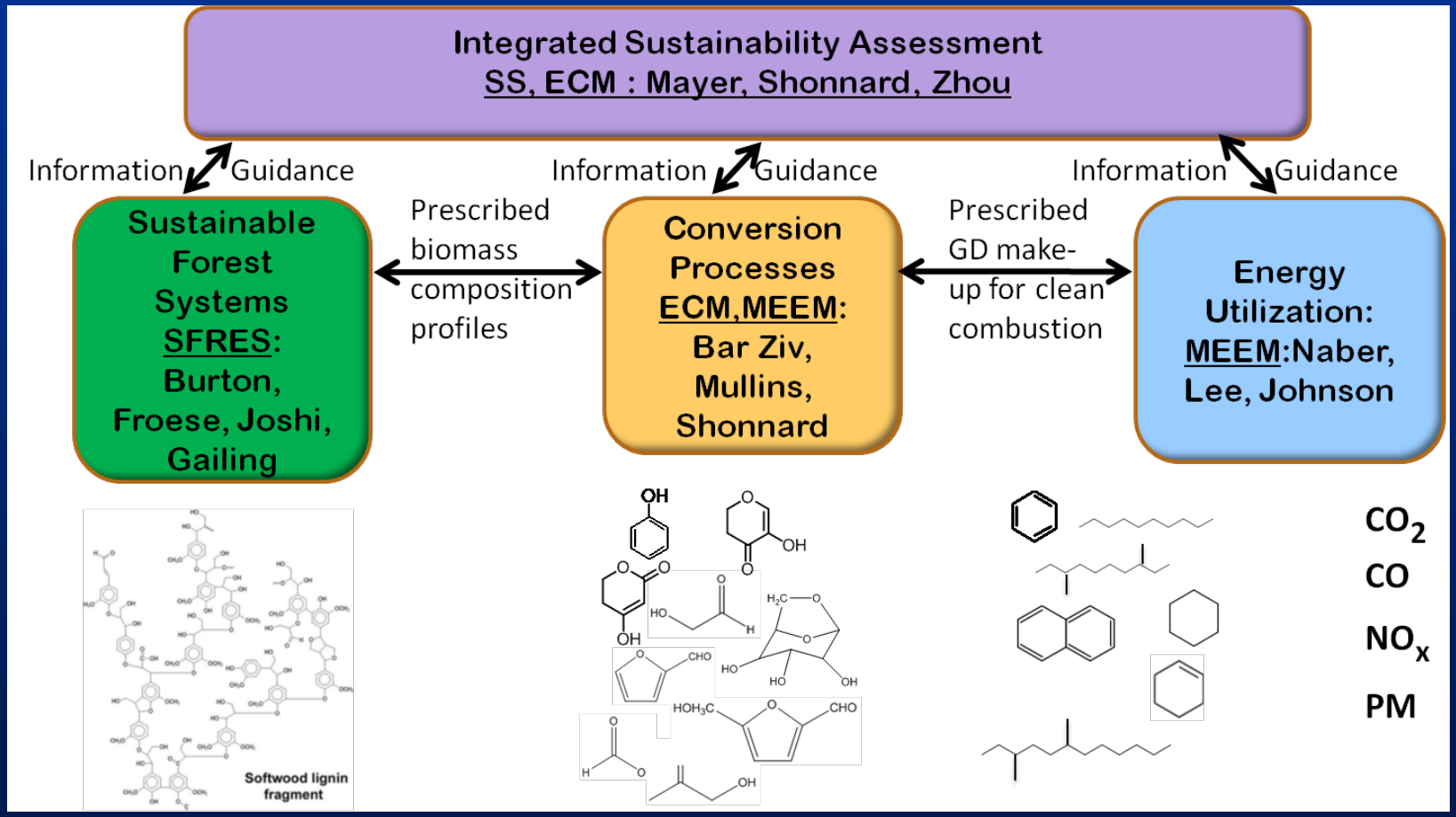
- **Current technology: 30% gasoline displacement**
- **Improved technology: > 60% displacement**



NSF Sustainable Energy Pathways

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

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



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

Research Coordination Network

Workshops / Conference

Research Roadmap Report on Sustainability of Pan American Biofuels and Bioenergy

Education: Graduate Course on Biofuels and Bioenergy Sustainability

Sustainable Futures Institute
www.sfi.mtu.edu

Michigan Tech

Funding Sources

Richard and Bonny Robbins Endowment

Shonnard Research Group, 2010

Thank You!