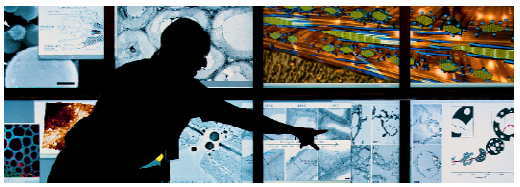
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Renewable Fuels

5th Annual Green Technologies Conference

IEEE

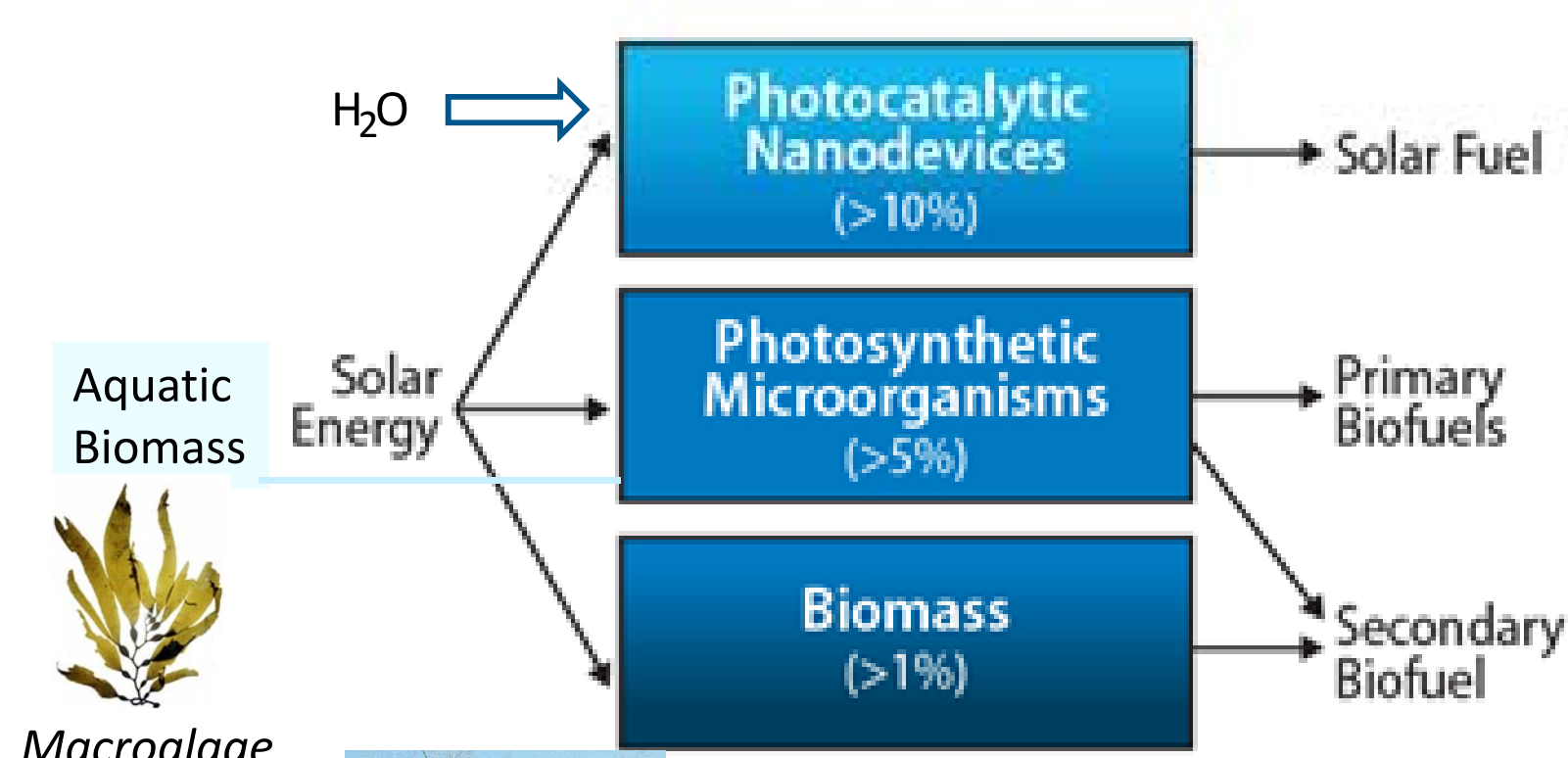
Helena L. Chum

April 5th, 2013

Outline

- Renewable Fuels
- Biomass and Bioenergy Today
- Commoditization existing/developing
- Sustainability Considerations to Improve Agriculture and Forestry and integrate bioenergy
- Lignocellulosic Biofuels Integrated Systems Research at DOE's Laboratories and partners
- Global Considerations

Renewable Fuels



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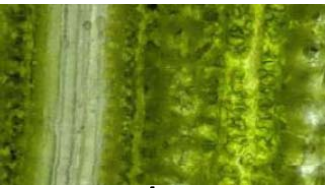
Early stage R&D

Developing Technologies

Aquatic Biomass

Macroalgae



Cyanobacteria

Microalgae

Grasses

Lignocellulose

Short Rotation Woody Biomass

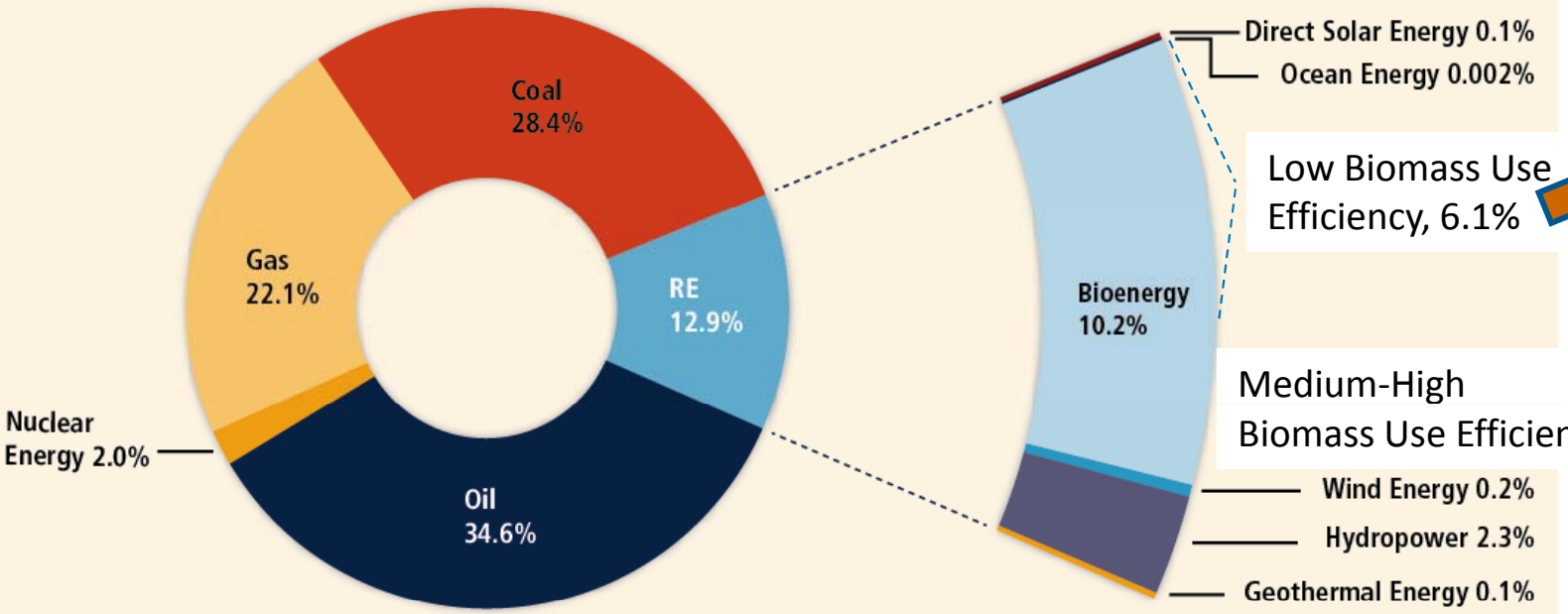
Crop residues and MSW

Commercial

Food Crops

- Ethanol
- Biodiesel
- Biomethane

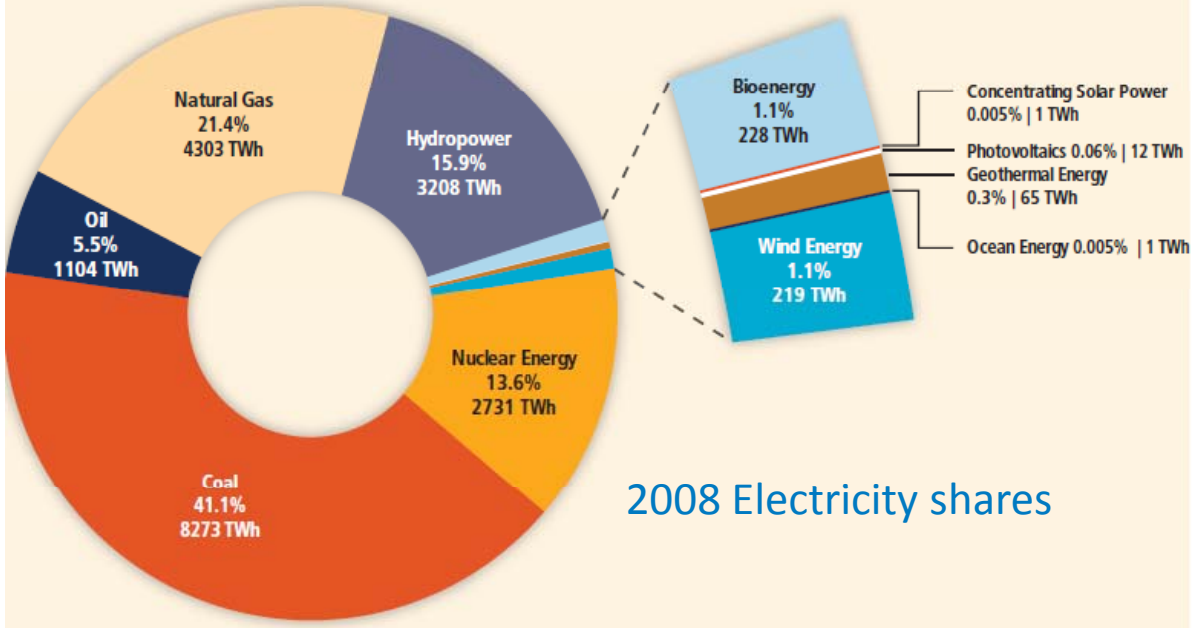
The current global energy system is dominated by fossil fuels



2008 Energy Sources Shares of Total Global Primary Energy Supply

Low Biomass Use Efficiency, 6.1%

Medium-High Biomass Use Efficiency , 4.1%



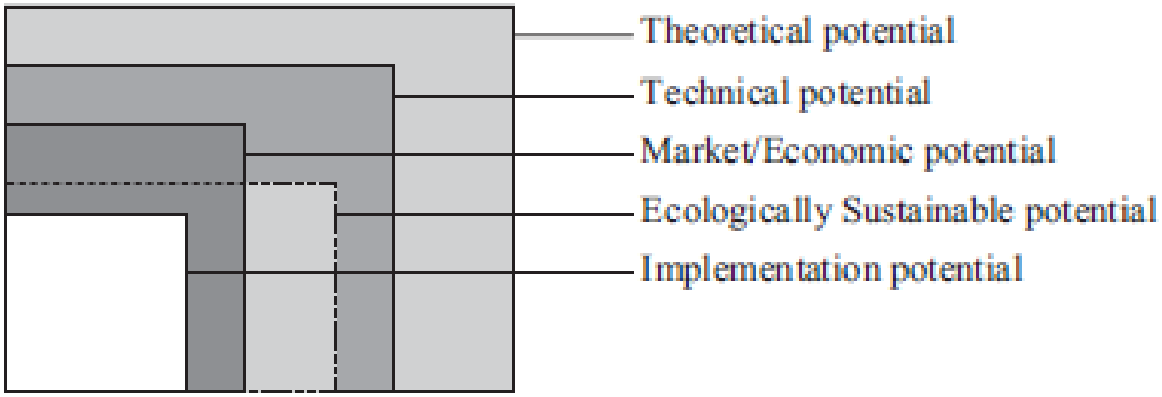
2008 Electricity shares

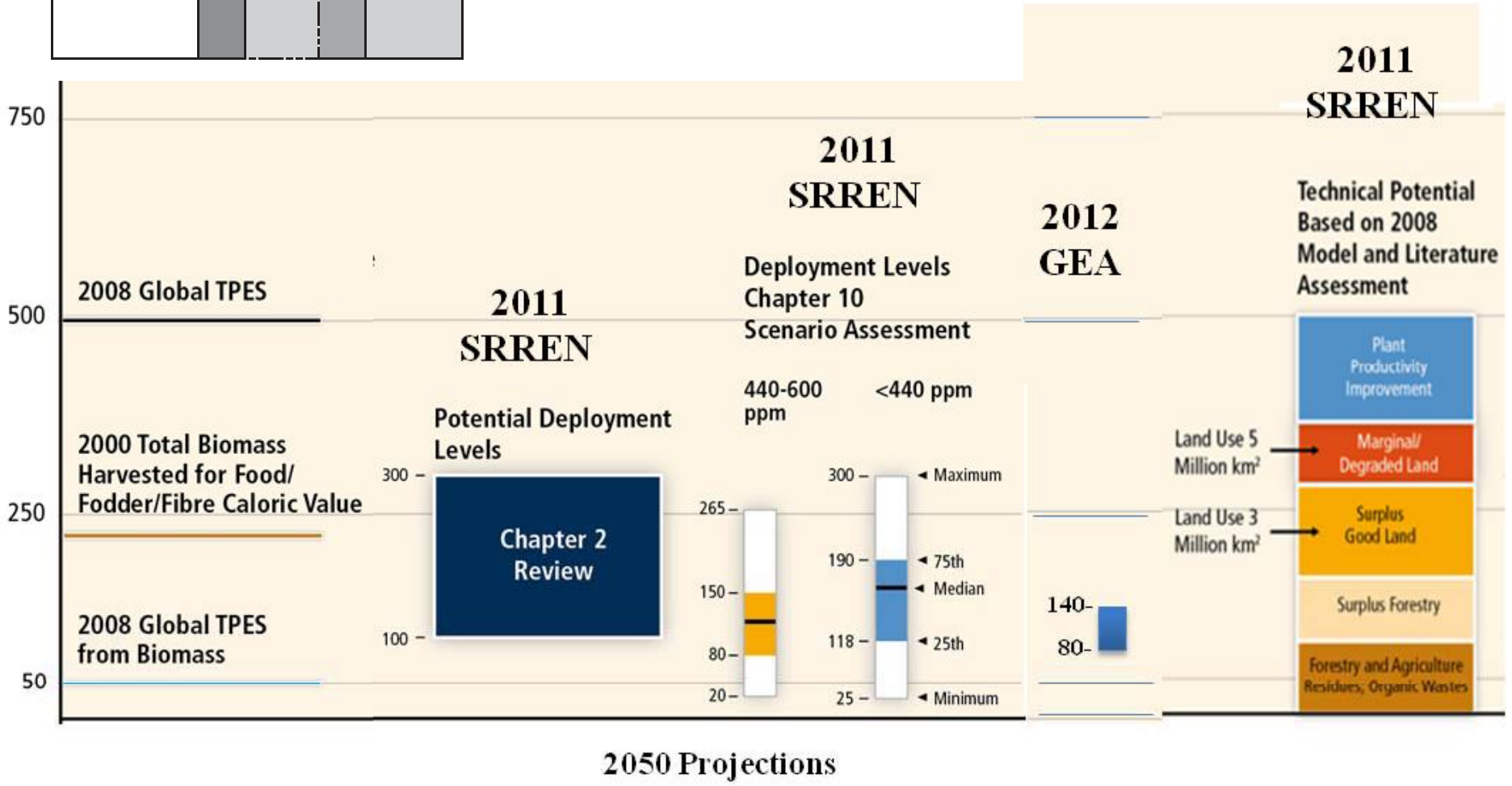
2008 Heat Demand:

All renewables share: 27%

- Traditional biomass 17%
  cooking stoves/heating
- Modern biomass 8%
  district heating
- Solar thermal/geothermal 2%

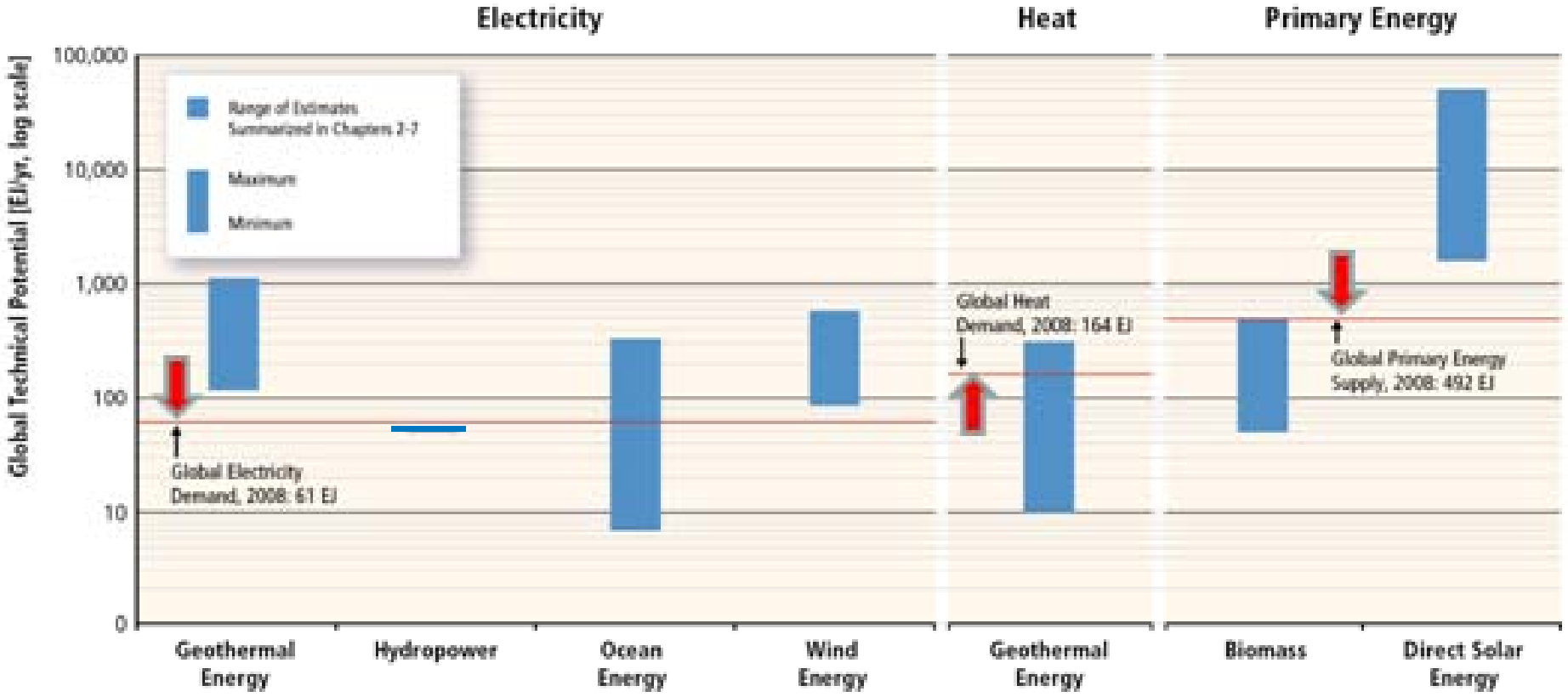
Resource Potentials





2011 SRREN = IPCC Special Report on Renewable Resources and Climate Mitigation
2012 GEA = Global Energy Assessment

The technical potential of renewable energy technologies to supply energy services exceeds current demands.



Range of Estimates of Global Technical Potentials

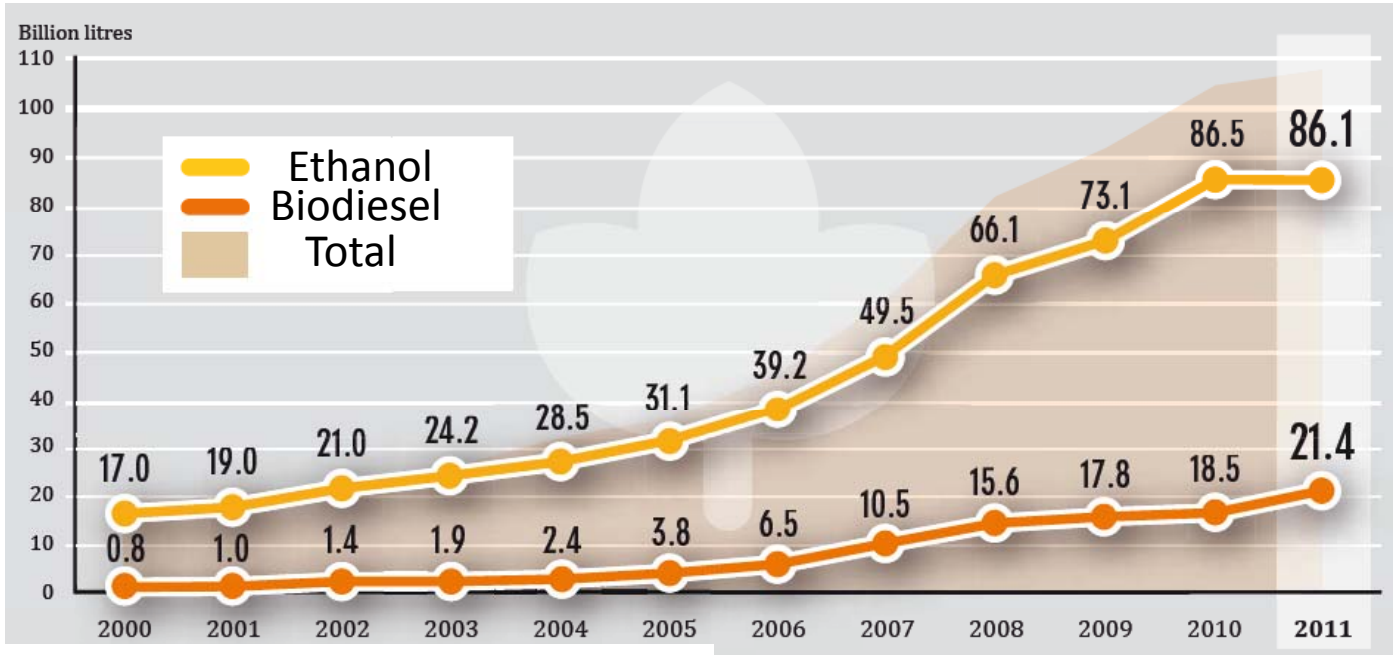
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

RESOURCE NOT LIMITING

ipcc INTERGOVERNMENTAL PANEL ON climate change

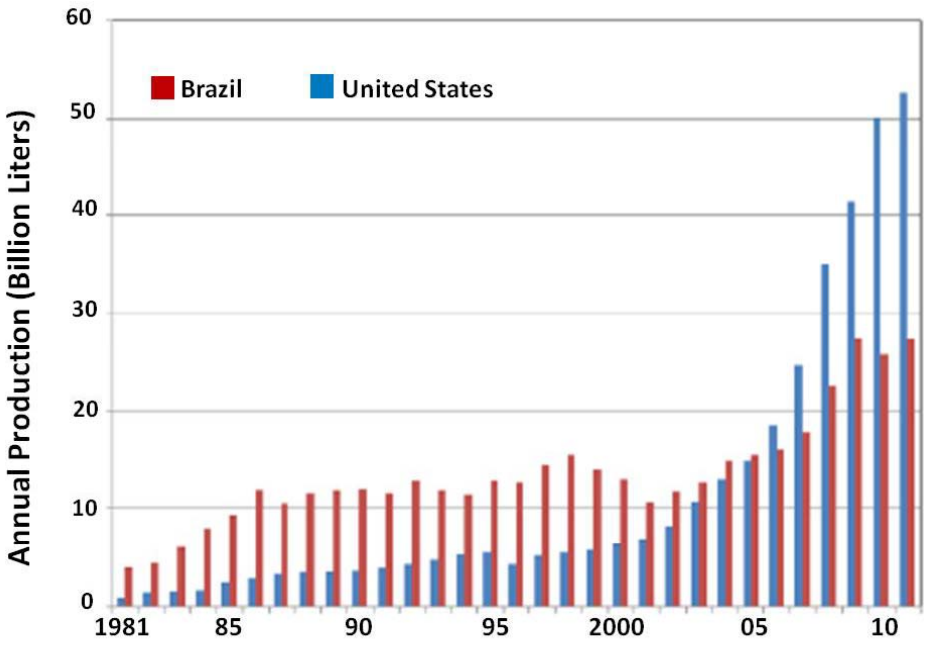
WHO UNEP

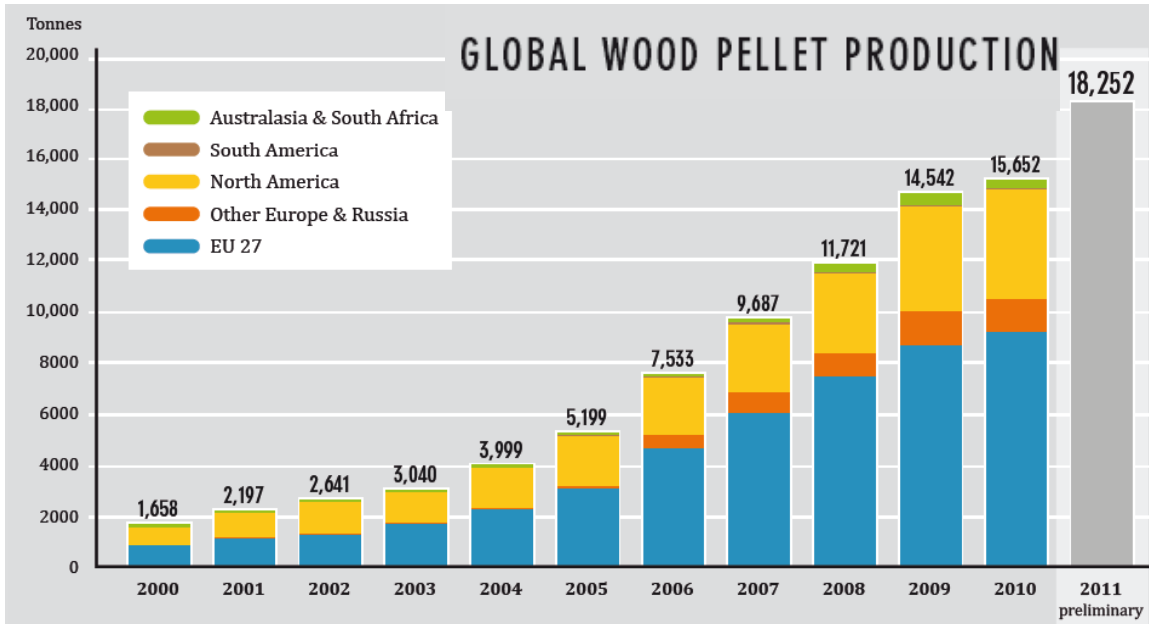
Bioenergy



REN21 Renewable Energy Policy Network for the 21st Century

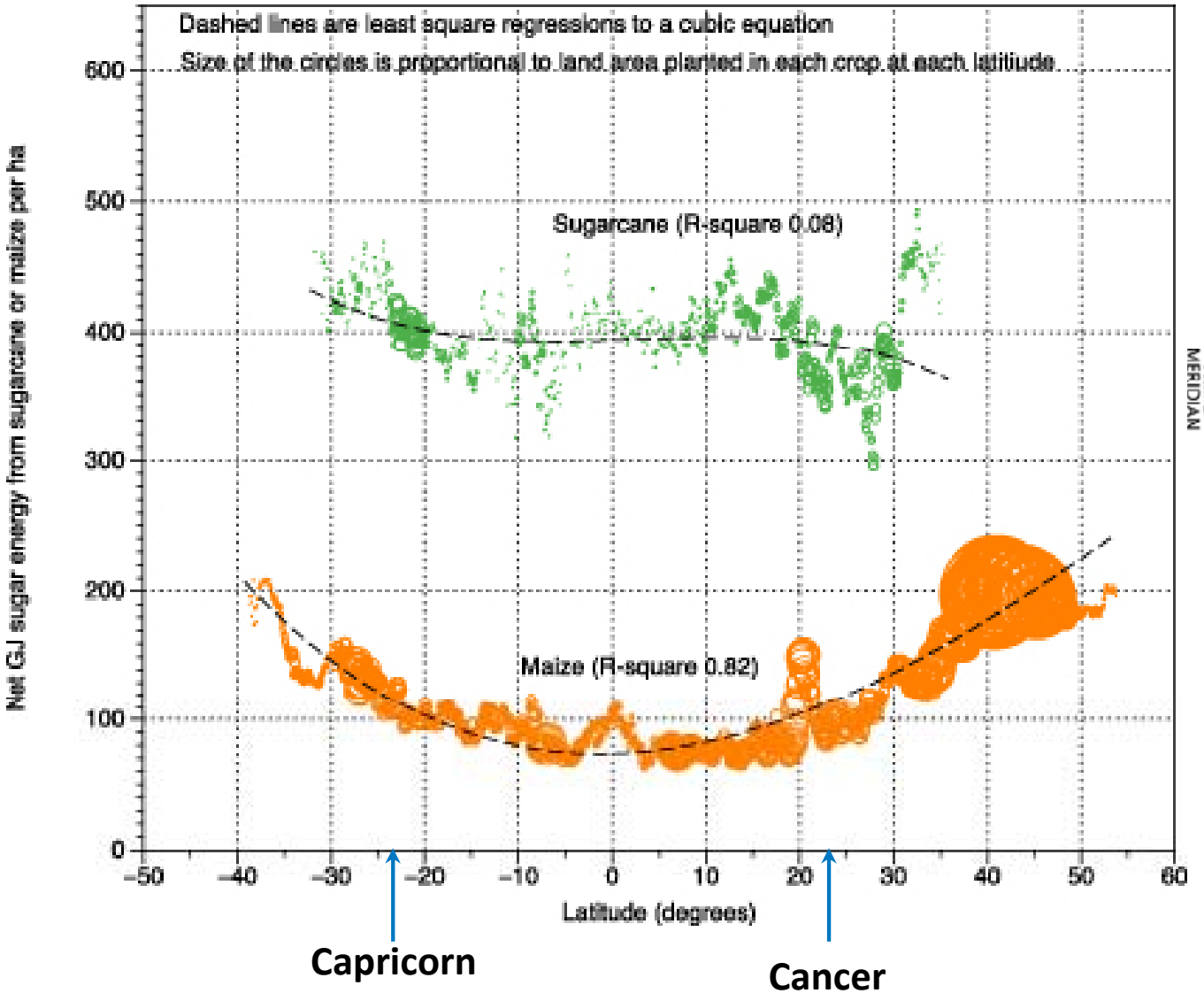
RENEWABLES 2012 GLOBAL STATUS REPORT

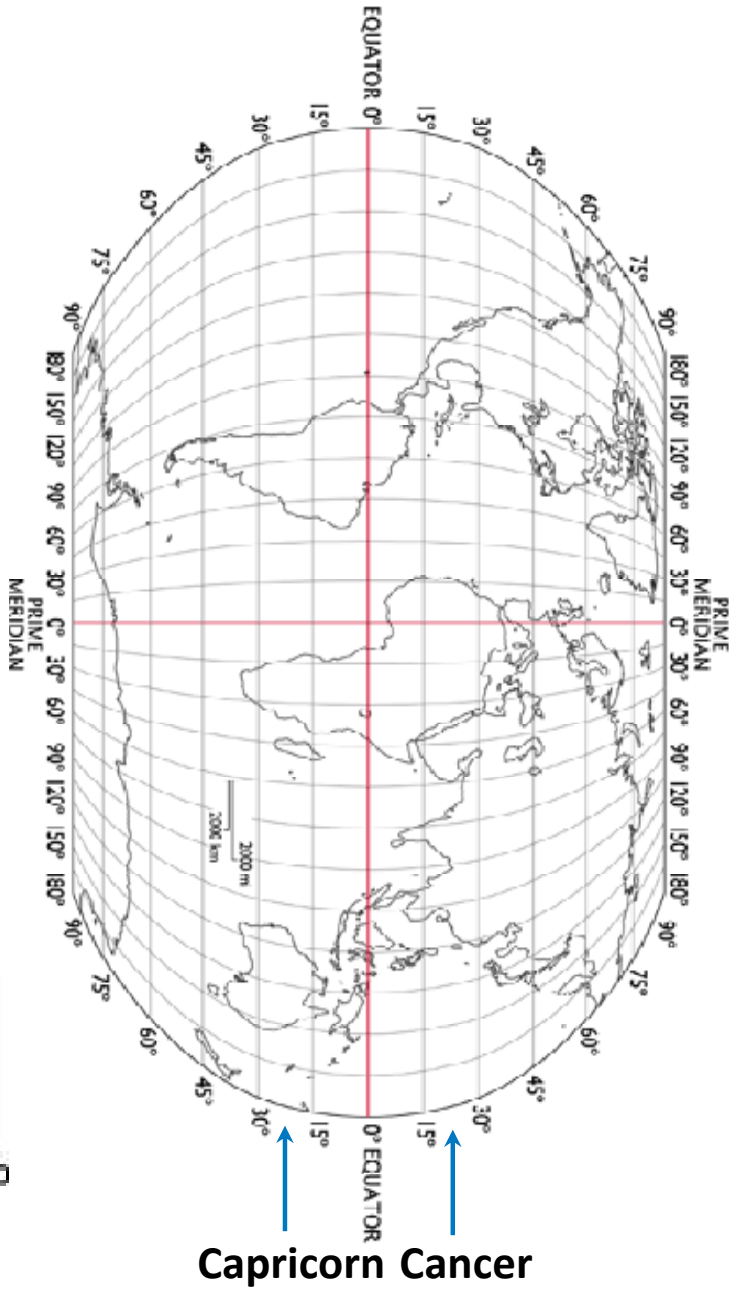




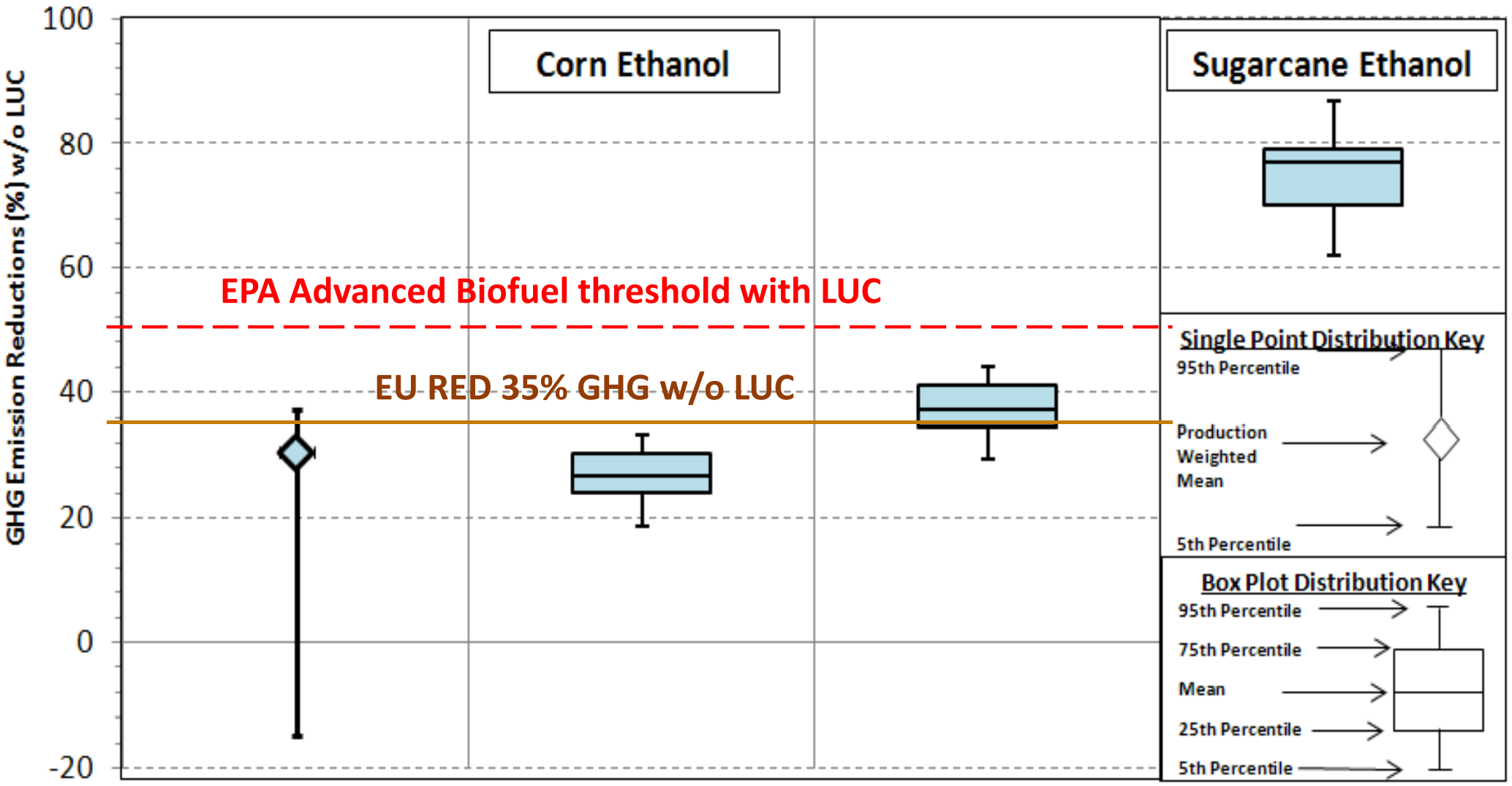
Latitude, soil conditions, biomass type matter

Figure 1 from Carlisle Ford Runge et al
2012 Environ. Res. Lett. 7 045906



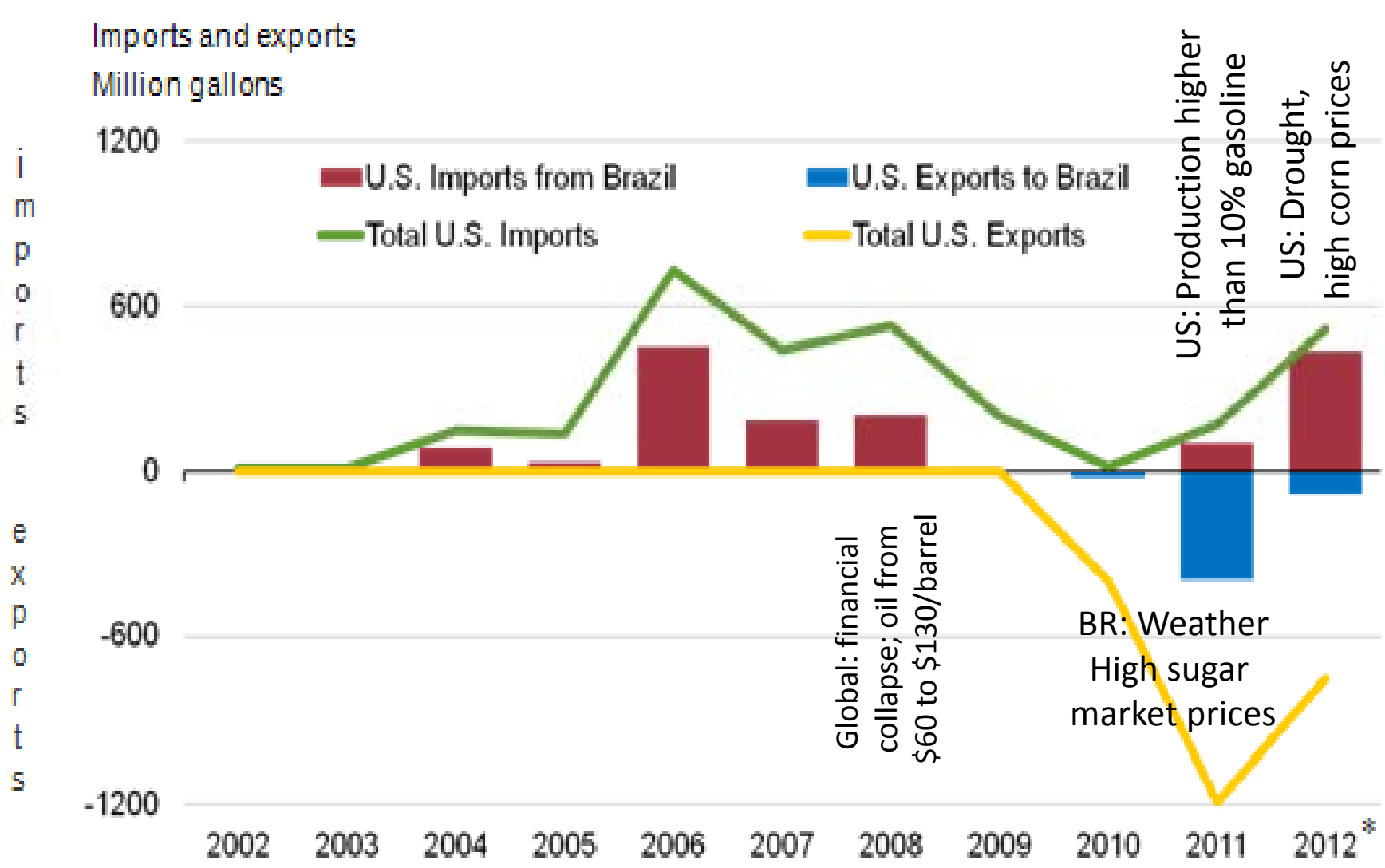


U.S. Brazil Bilateral Sustainability Benchmarks



Chum, Warner, Seabra, Macedo, Biofpr

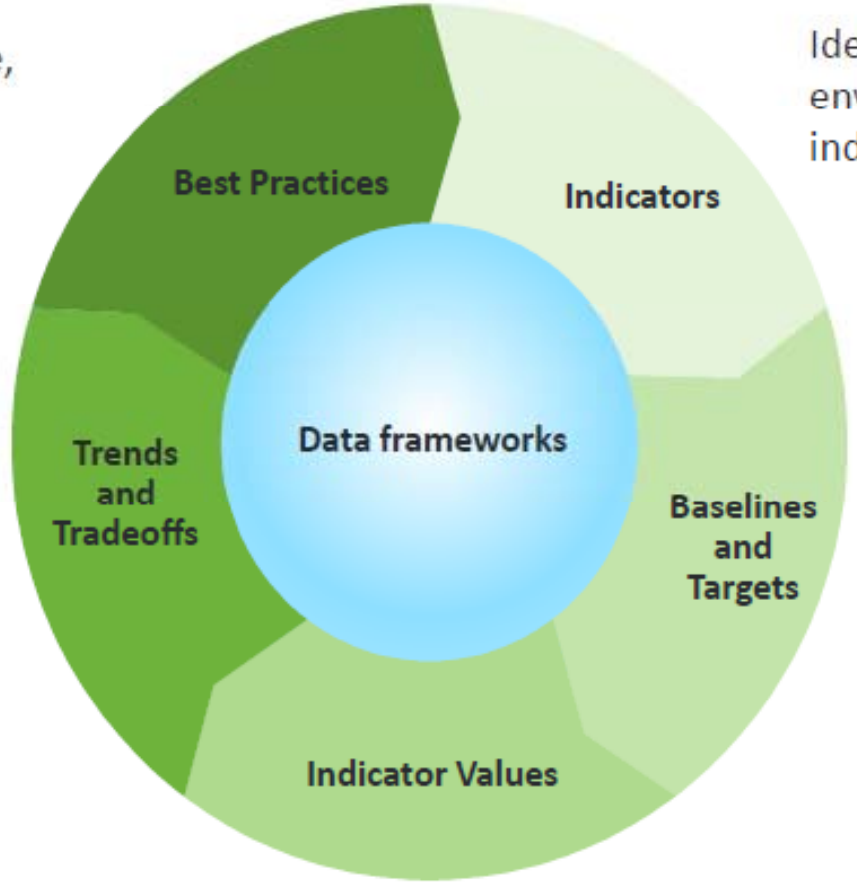
Commoditization of Biofuels



*2012 data includes actual data through October plus estimated data for November and December.

Source: EIA, U.S. Imports of Fuel Ethanol by Destination, http://www.eia.gov/dnav/pet/PET_MOVE_IMPCUS_A2_NUS_EPOOXE_IM0_MBBL_M.htm.

Framework to measure, evaluate, and improve sustainability



Develop, evaluate, and disseminate best practices

Identify relevant environmental/social indicators

Identify and balance tradeoffs and synergies

Establish baselines and set targets

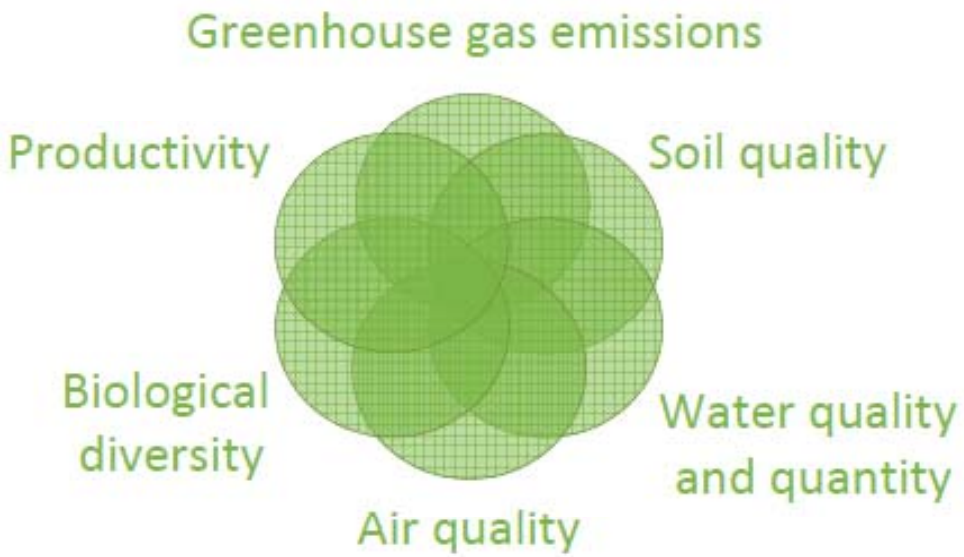
Assess progress by measuring environmental and social impacts

GBEP Global Bioenergy Partnership

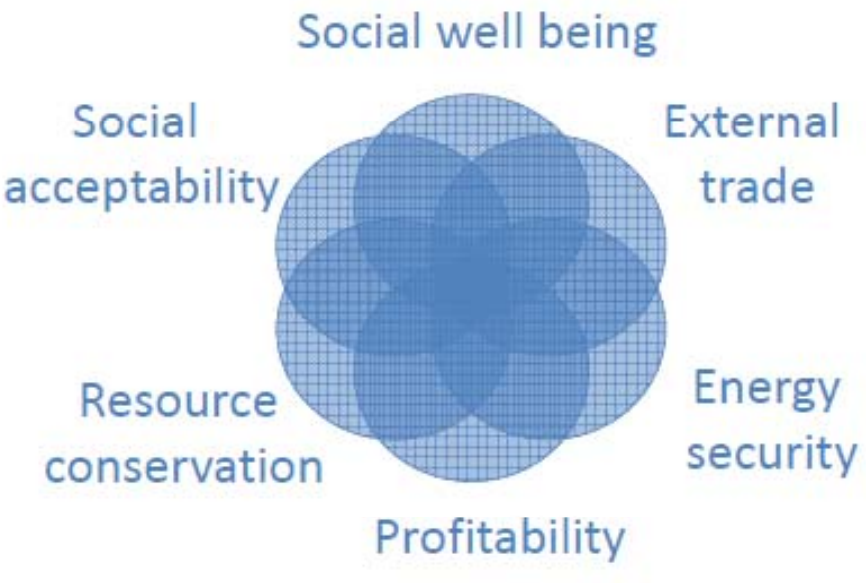
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

K. Johnson, http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2013_events/GBEP_Bioenergy_Week_Brasilia_18-23_March_2013/3.10_JOHNSON.pdf

Categories for sustainability indicators



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



Dale et al. (2013) *Ecological Indicators* 26:87-102.

Recognize that measures and interpretations are context specific

[Efroymson et al. (2013) *Environmental Management* 52:291-306]

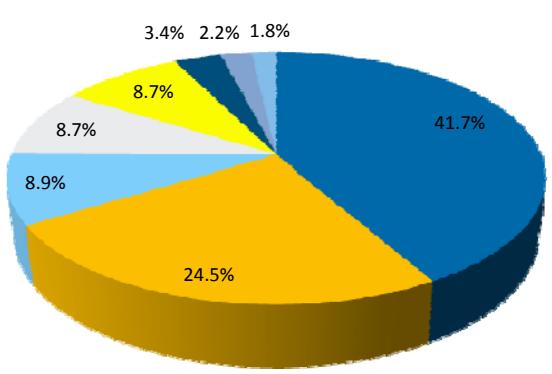
CBES
Center for BioEnergy Sustainability
http://www.ornl.gov/sci/ees/cbes/

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

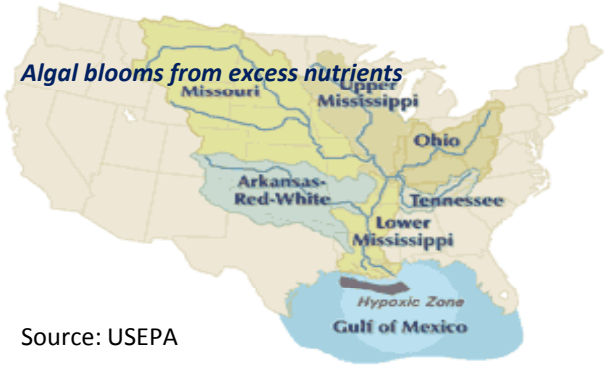
K. Johnson, http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2013_events/GBEP_Bioenergy_Week_Brasilia_18-23_March_2013/3.10_JOHNSON.pdf

Biomass production and nitrogen recovery

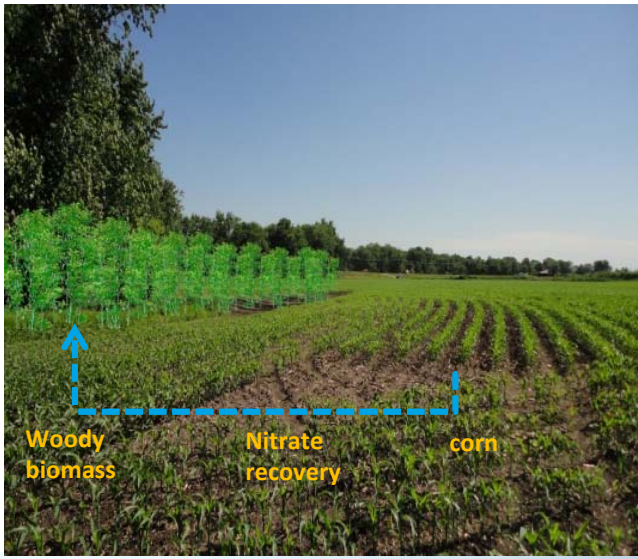
- Growing bioenergy crops on underproductive land to recover nitrogen in ground water from nearby corn fields
- Increasing overall productivity while mitigating non-point source pollution and GHG emissions from agriculture

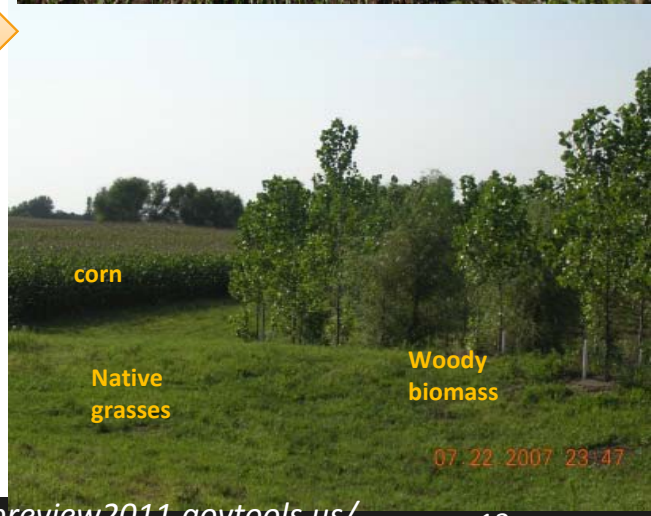


Source: GREET



Source: USEPA



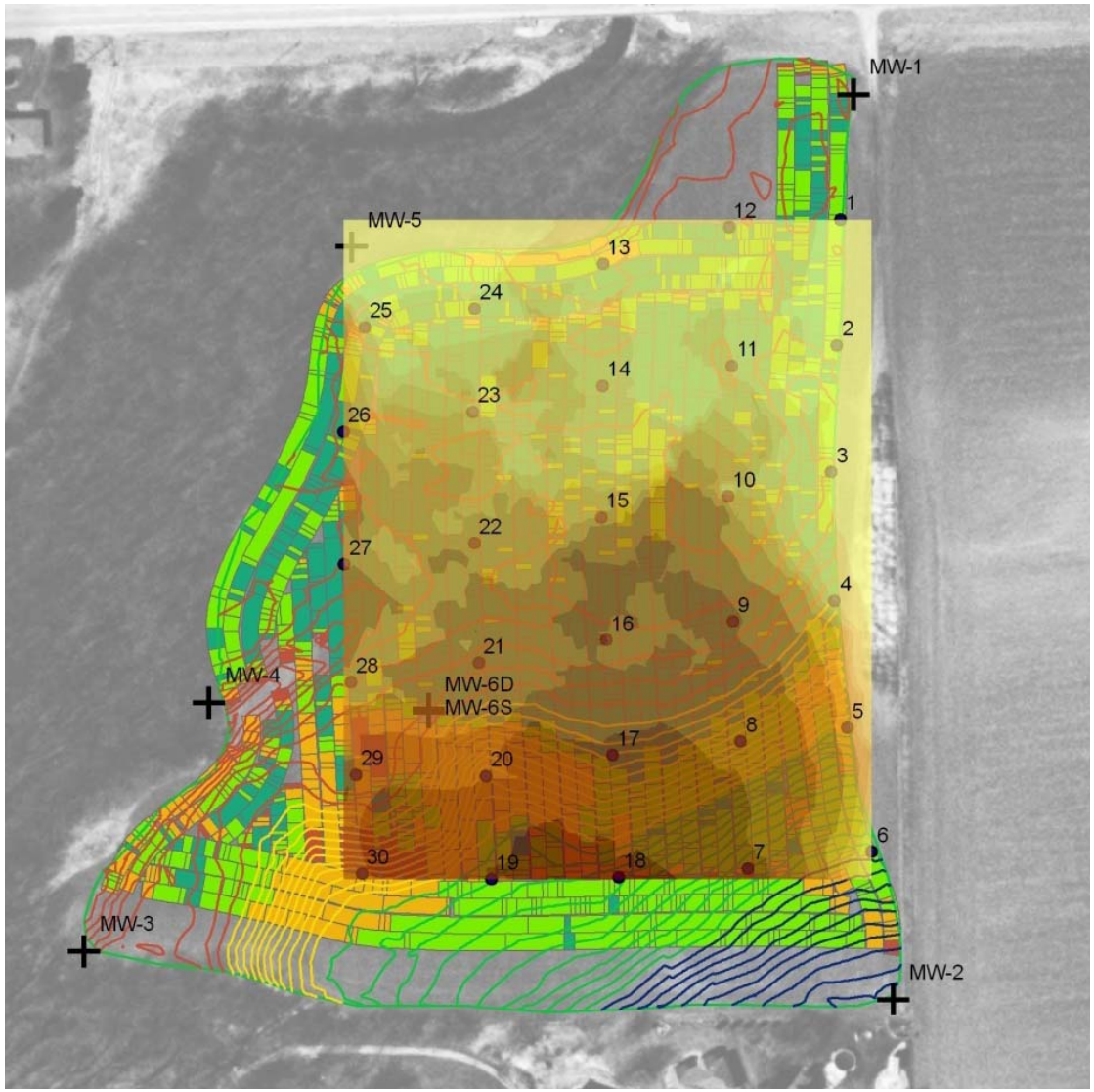


Negri et al., ANL, DOE OBP Program Review, obpreview2011.govtools.us/.

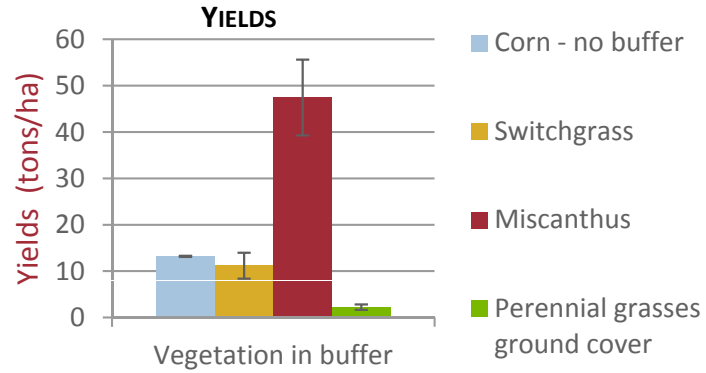
Biomass mitigating nitrate transport 4 ft under a corn field

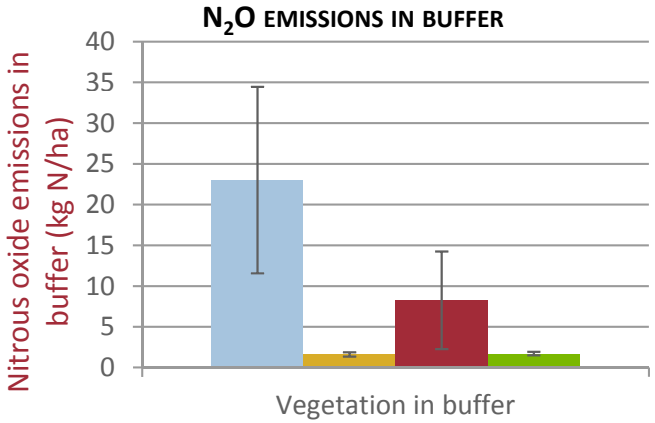
Landscape placement of biomass crop for by-design sustainability.

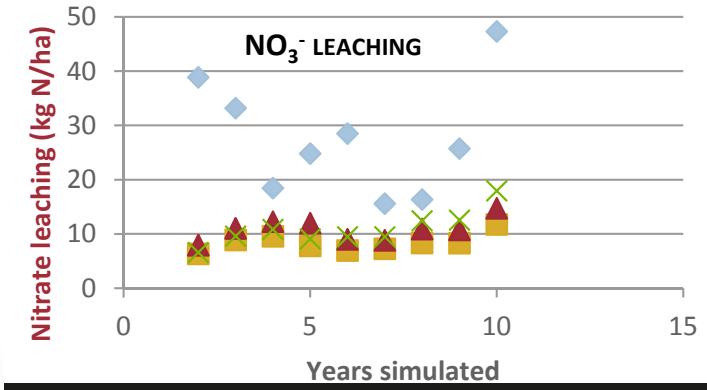
DeNitrification-DeComposition model results and field validation in Fairbury, IL



Negri et al., ANL, DOE OBP Program Review, obpreview2011.govtools.us/







Multiple

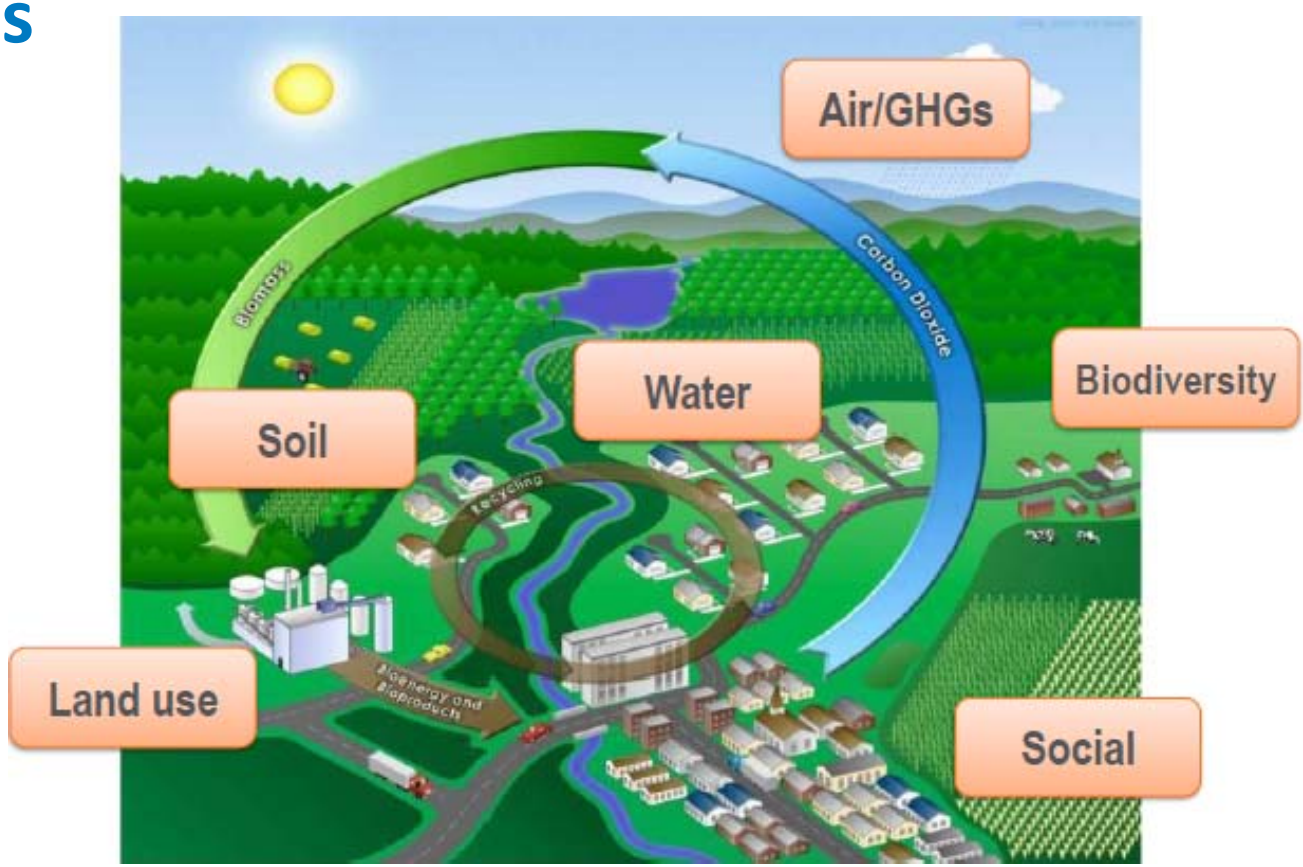
Supply Chains, Systems and Impacts

Feedstocks

- Agricultural Residues
- Energy Crops
- Forest Resources
- Waste
- Algae

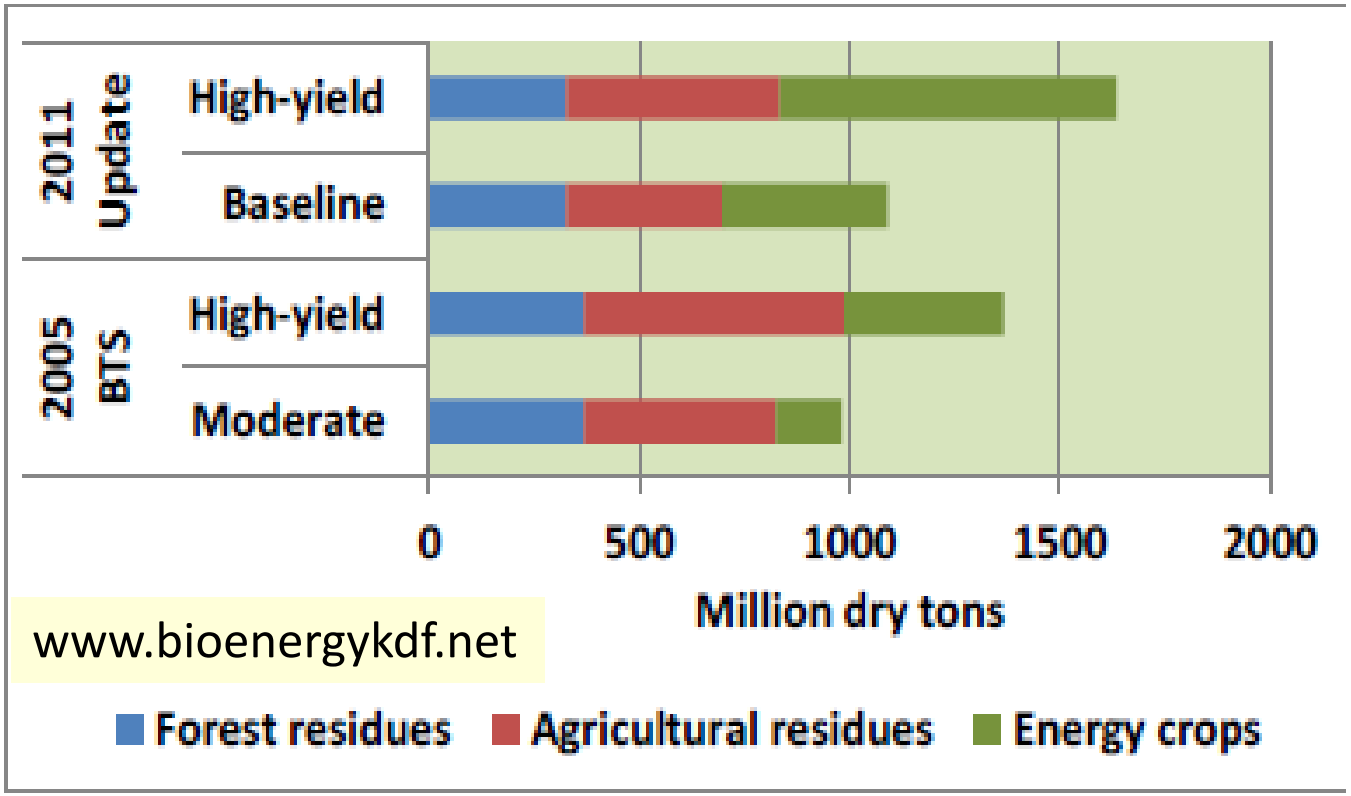
Products

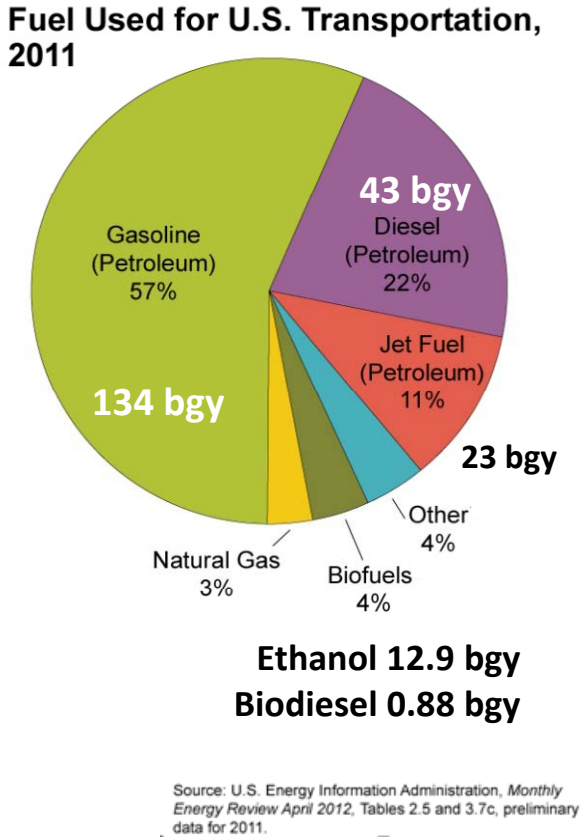
- ethanol
- diesel
- gasoline
- jet fuel
- biopower
- bioproducts



Increase Resiliency of Biofuels and Products Supply

How Much Lignocellulosic Biomass and at what cost?





2005: Potential to displace ~30% of petroleum-derived gasoline by 2022

2011 BTS (Billion Ton Study): 1 billion tons per year non-food lignocellulosic biomass could become available for $60/dry ton at the farm gate in the U.S.

- County level data and sustainability considerations included
- Supply logistics for more uniform feed under development , e.g., pre-processing depots link biomass producers with refiners for year round supply

Microalgae oils - preliminary estimate at ~5 billion gallons per year

Harvesting residue at sustainable rates

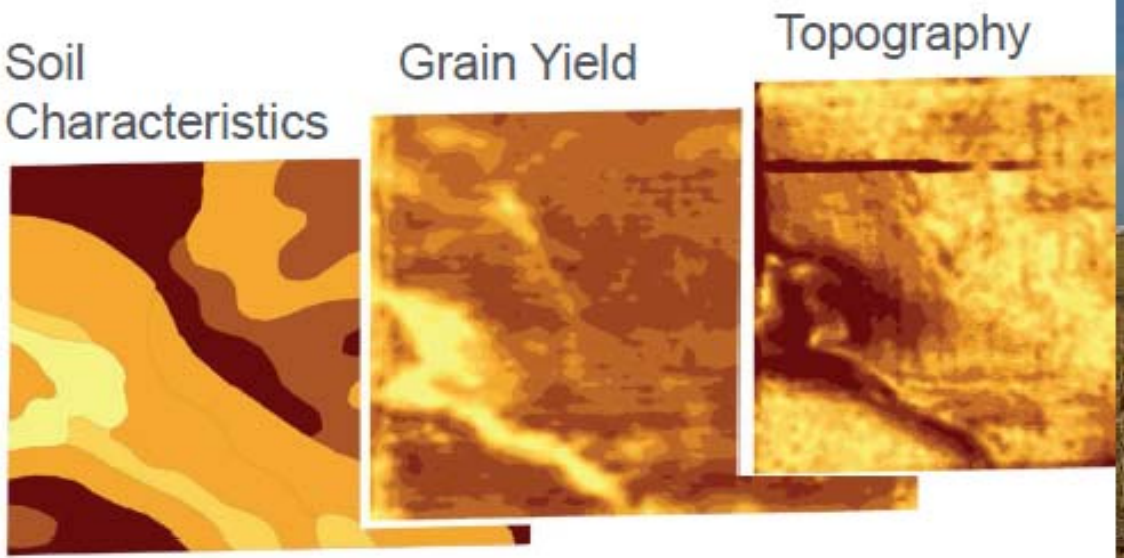
How much agricultural residue can be removed sustainably?

Limiting factors

- soil organic carbon
- soil erosion
- management of plant nutrients
- soil water and temperature dynamics
- soil compaction
- environmental degradation

Improved agronomic strategies

- reduced or no tillage
- integrated cropping systems
- removal rates based on specific field conditions



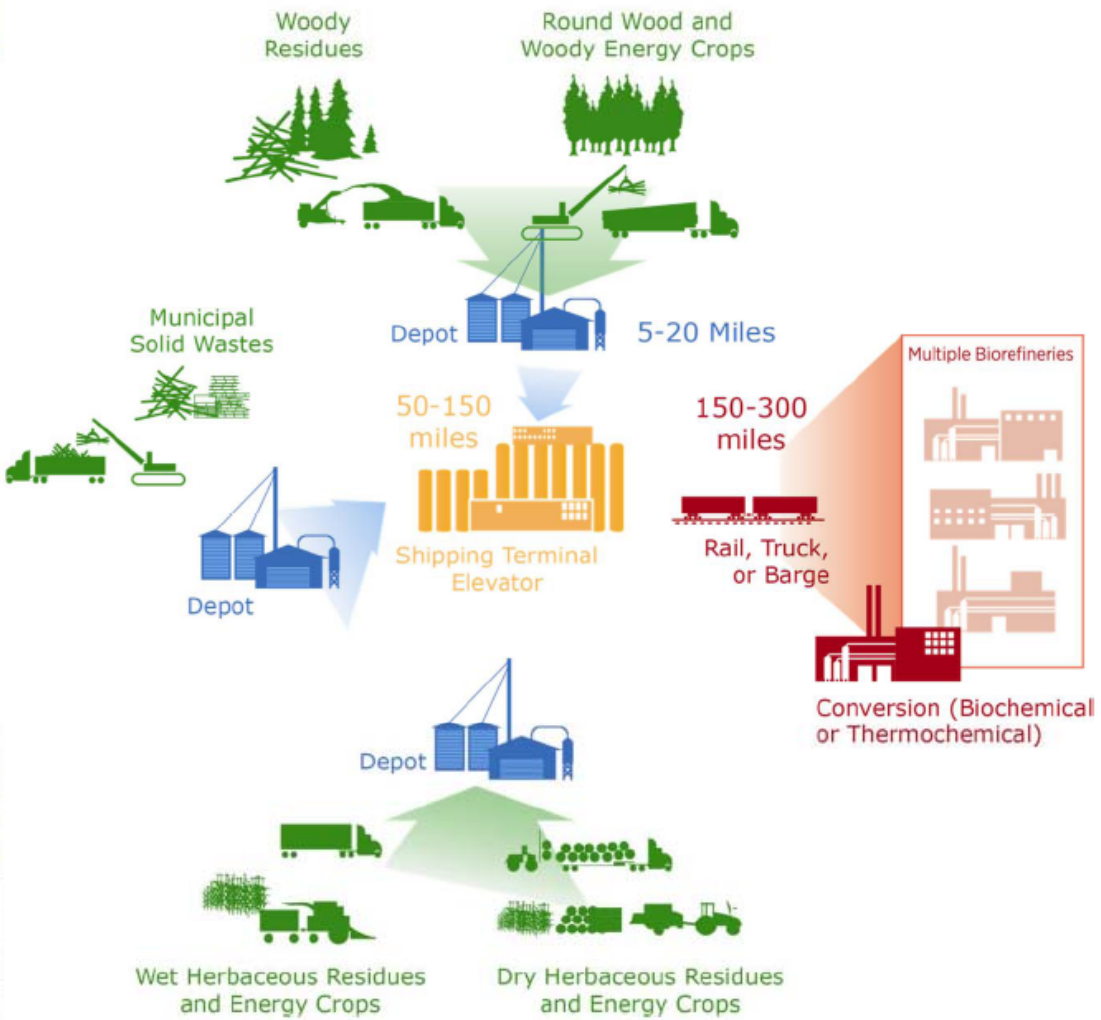
K. Johnson, http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2013_events/GBEP_Bioenergy_Week_Brasilia_18-23_March_2013/3.10_JOHNSON.pdf

Uniform-Format Feedstocks

Commodity Vision for Infrastructure Compatibility

Commodity Attributes
Standardized material formats are compatible with existing solid and liquid supply handling systems and infrastructures
Feedstock quality is assured through national and international standards
National market systems secure supply and demand in a sustainable way
Biomass feedstocks futures contracts are tradable on commodity exchanges.

Infrastructure Boundaries (Solid System Example)
Production to Preprocessing Depot (5 to 20-mile radius) Field trucks
Preprocessing Depot to Terminal (50 to 150-mile radius) Interstate trucks, short line railroad, internal waterway transport systems
Terminal to Biorefineries (150 to 300+-mile radius) Trans/intercontinental shipping systems (e.g., unit trains, ocean barges, and freightliners)



Adding Cellulosic Ethanol

Table 6. Energy balance and energy ratio of bioethanol.

	Corn	Sugarcane	Corn stover	Switchgrass	Miscanthus
Energy balance (MJ l^{-1})[a]	10.1	16.4	20.4	21.0	21.4
Energy ratio	1.61	4.32	4.77	5.44	6.01

[a] A liter of ethanol contains 21.3 MJ of energy (lower heating value).

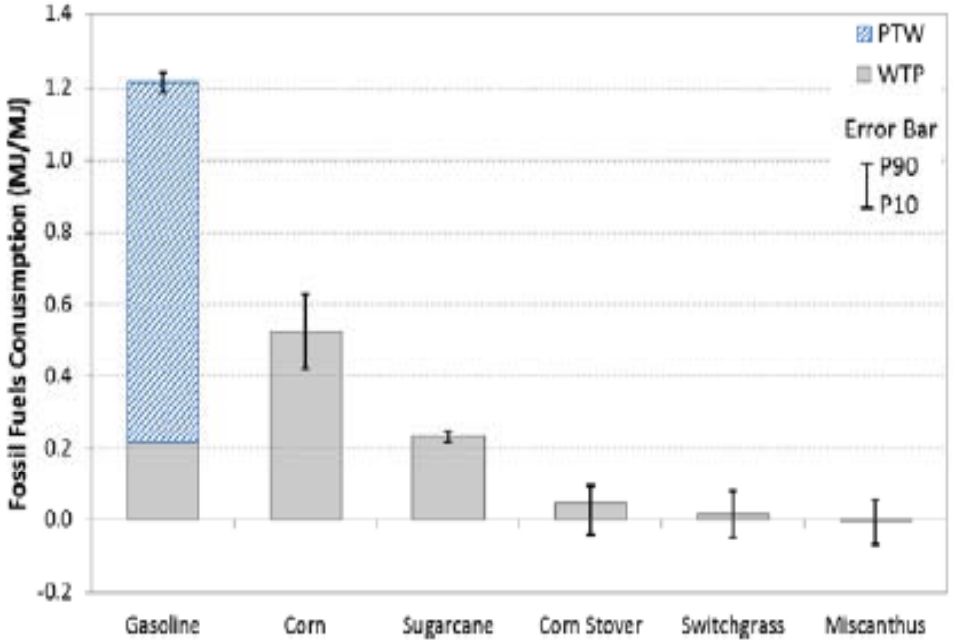


Figure 3. Well-to-wheels results for fossil energy use of gasoline and bioethanol.

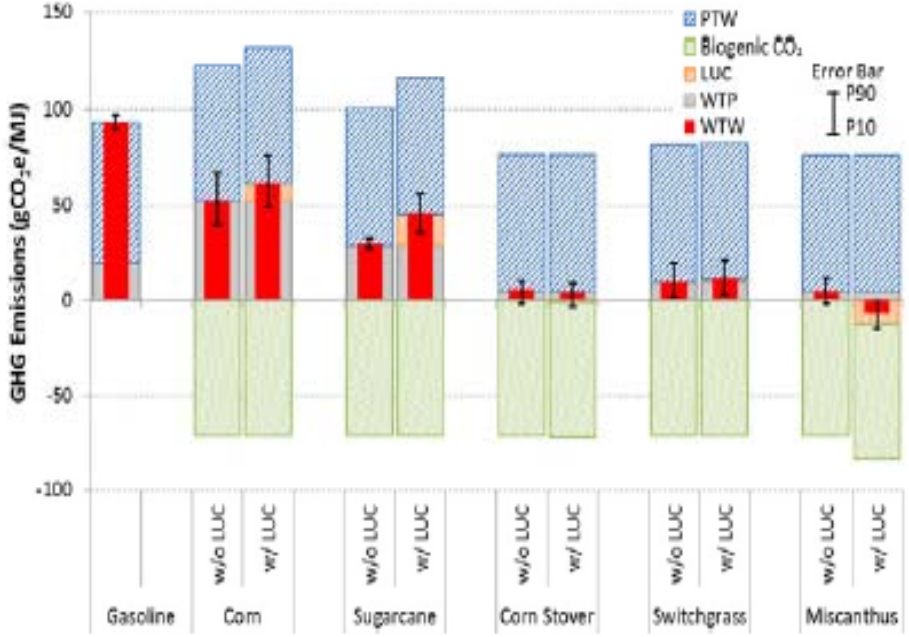
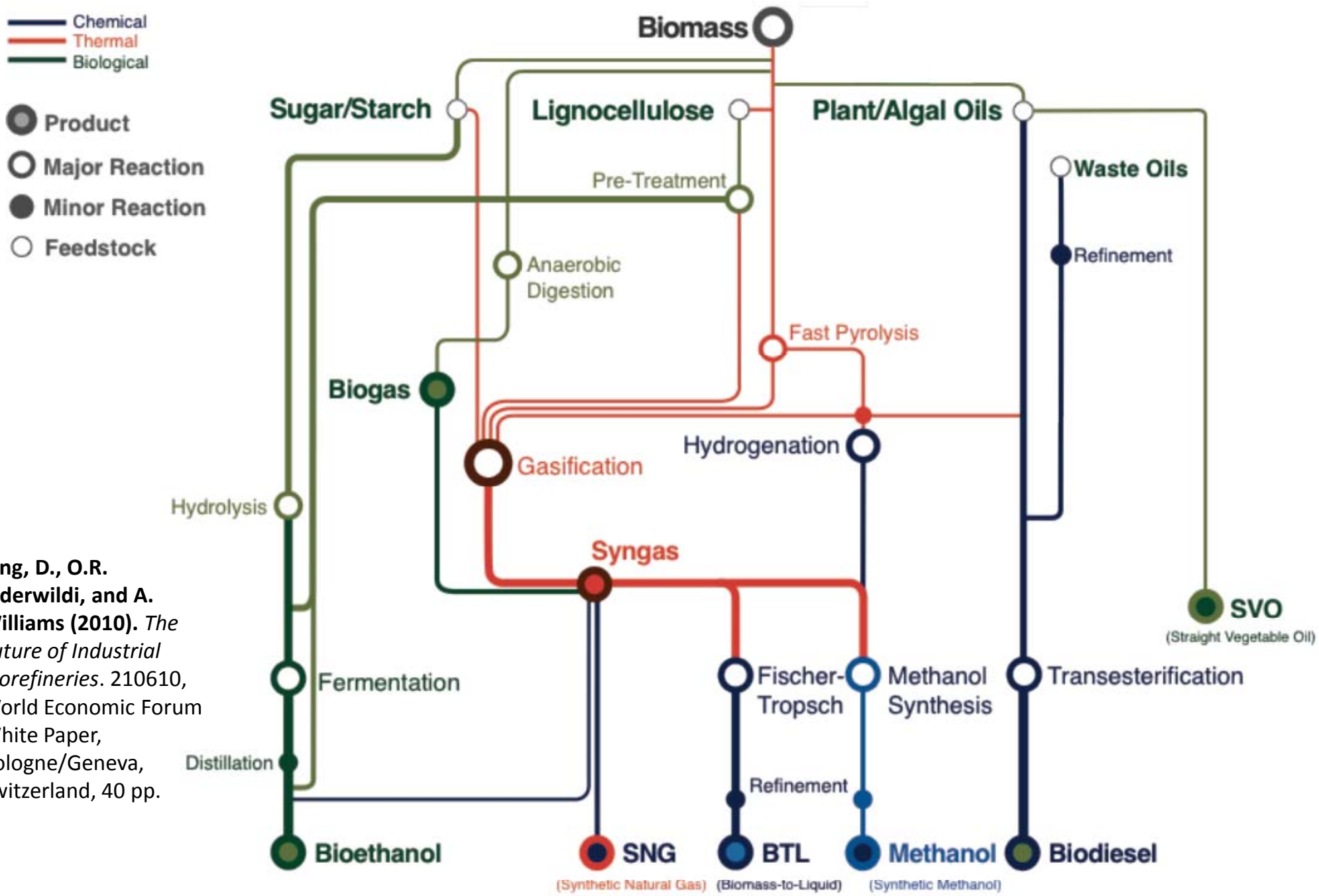


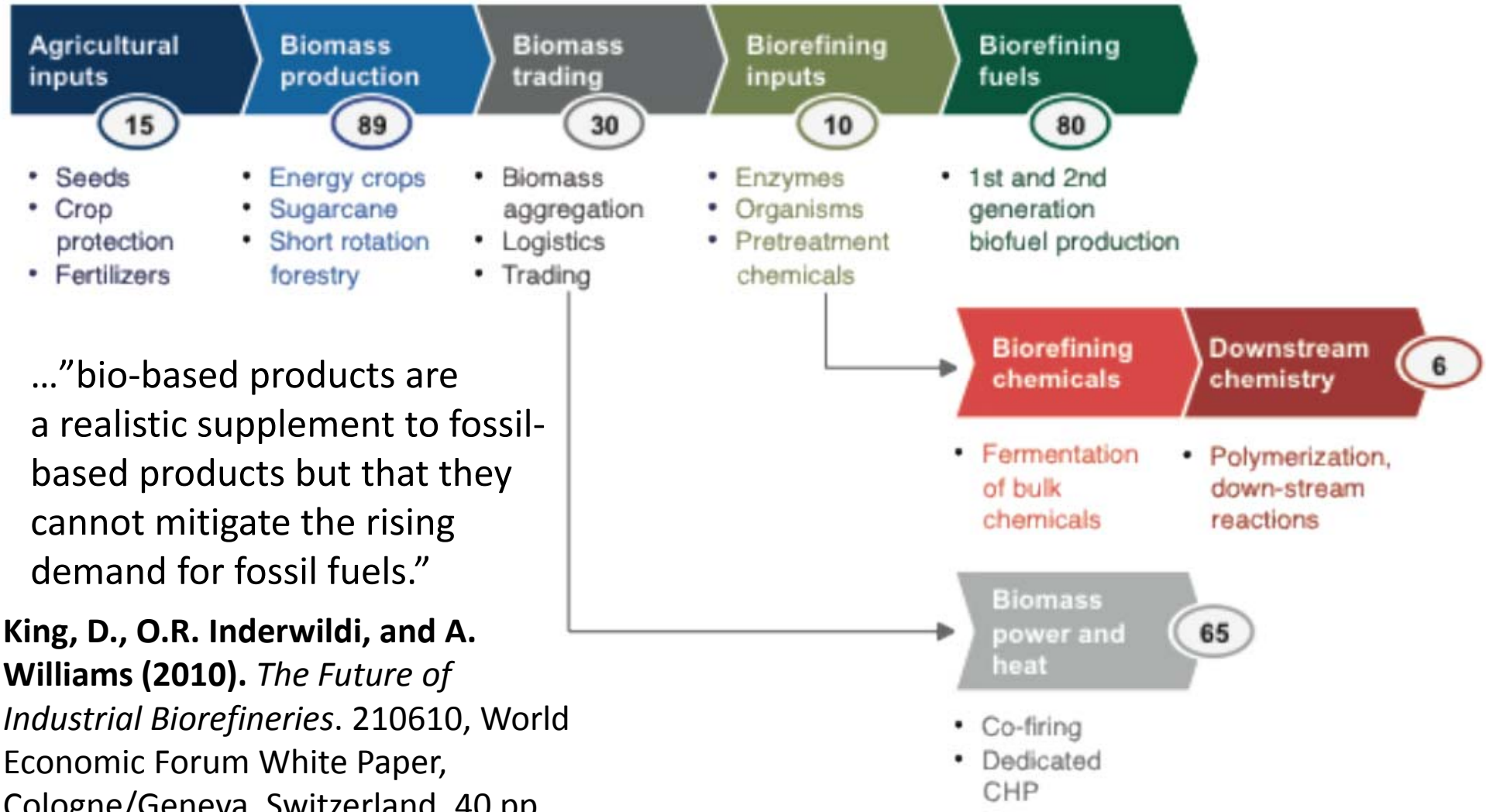
Figure 4. Well-to-wheels results for greenhouse gas emissions in CO_2e for six pathways.



King, D., O.R. Inderwildi, and A. Williams (2010). *The Future of Industrial Biorefineries*. 210610, World Economic Forum White Paper, Cologne/Geneva, Switzerland, 40 pp.

Figure 1: *Biofuel Flow.* The multiple synthetic conversion routes of major biofuels produced from first and second-generation biomass feedstock.

Biomass Value Chain Revenue Potentials



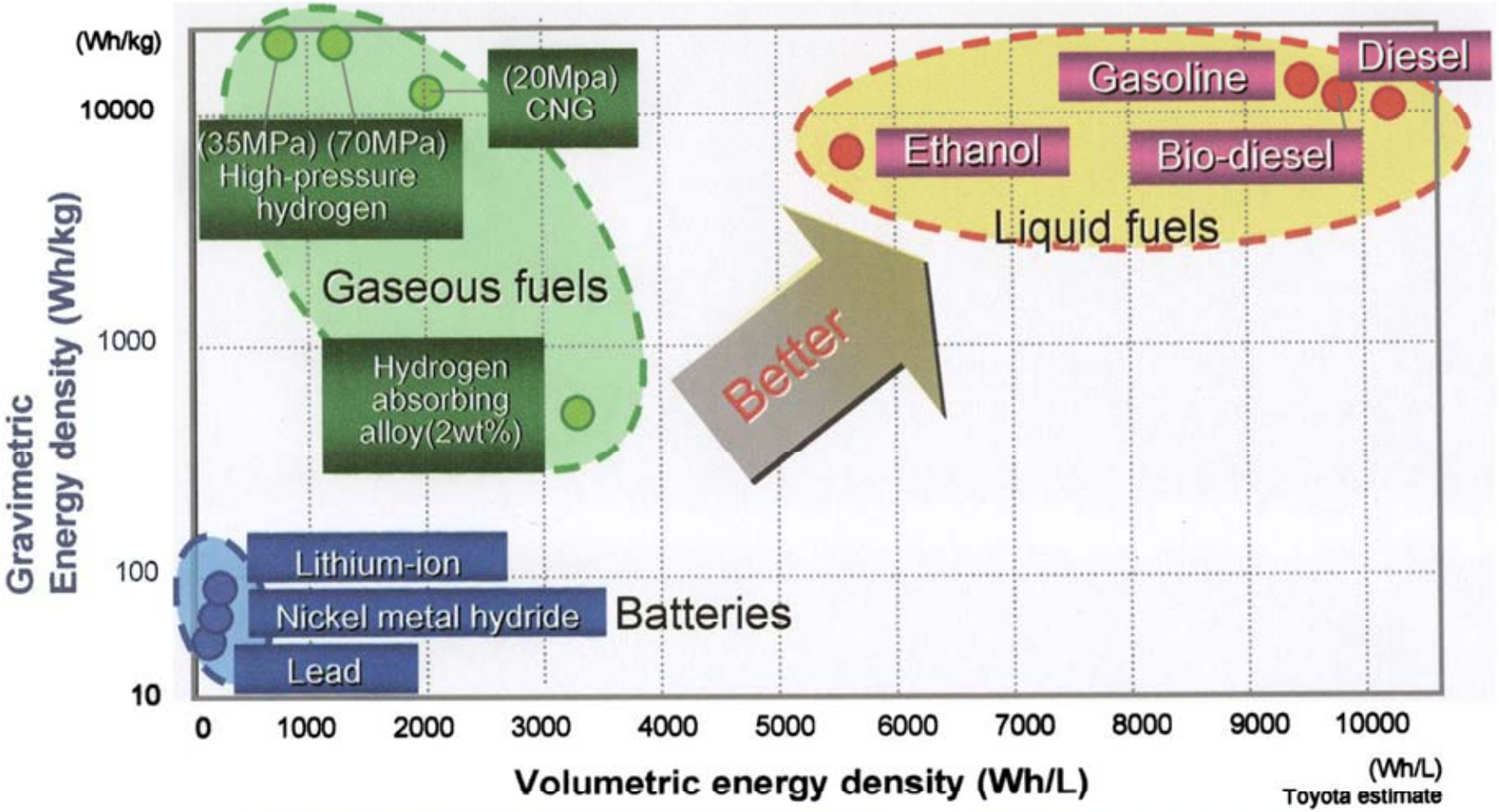
…"bio-based products are a realistic supplement to fossil-based products but that they cannot mitigate the rising demand for fossil fuels."

King, D., O.R. Inderwildi, and A. Williams (2010). *The Future of Industrial Biorefineries*. 210610, World Economic Forum White Paper, Cologne/Geneva, Switzerland, 40 pp.

Figure 4: *Revenue Potential*. There are significant revenue potentials along the entire biomass value chain. The values given are approximate business potential in US$ billions by 2020.

On-Board Energy Storage Challenges Remain

Alternative fuels and their density



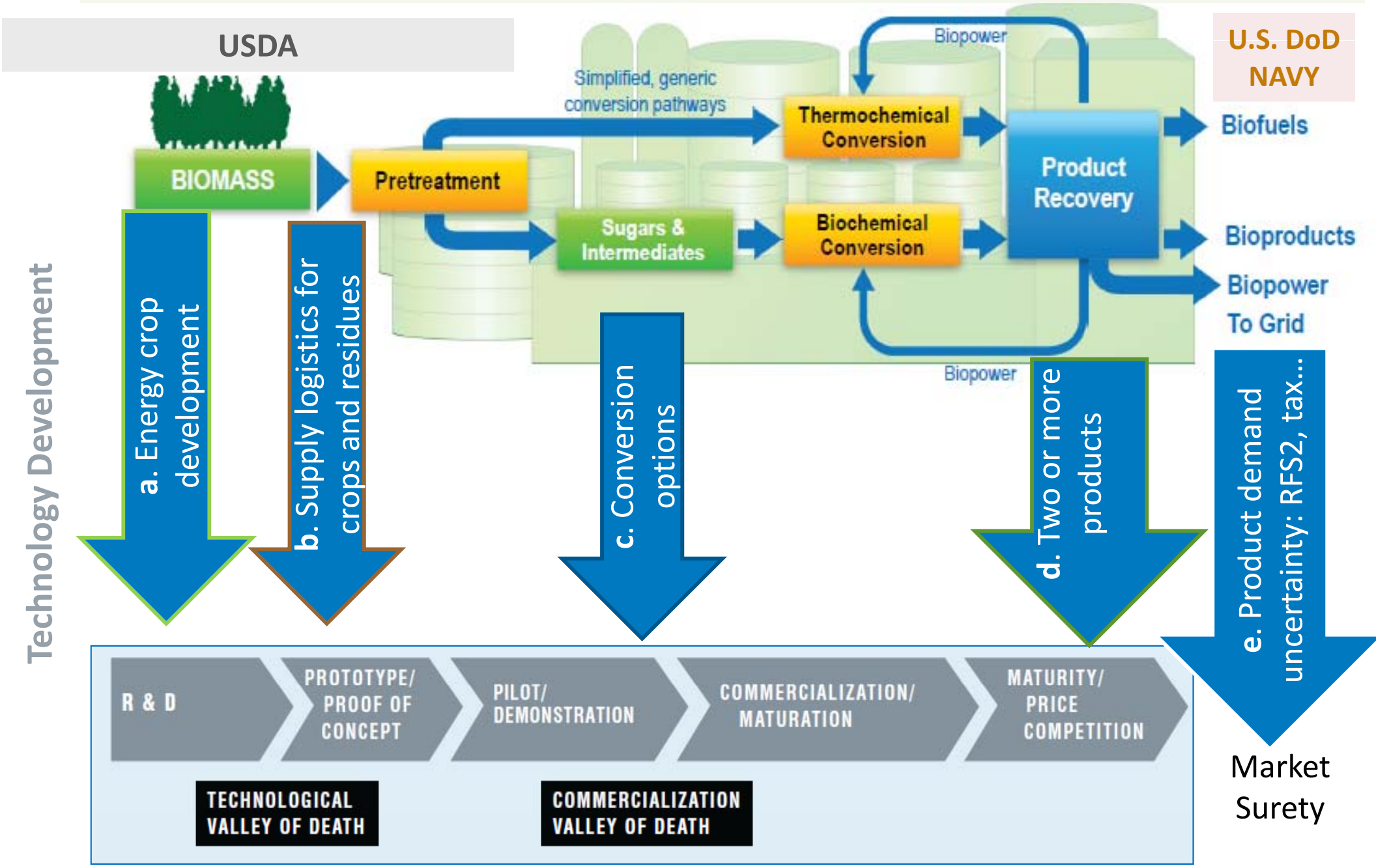
Hydrogen and Batteries have poor energy density compared to liquid fuels

17

17

Many options for road transport – hybrids, electric, etc.

U.S. DOE EERE Bioenergy Technologies Office Integrated Biomass Refineries Portfolio



Aviation and Military Fuels are areas of opportunity with few competing options

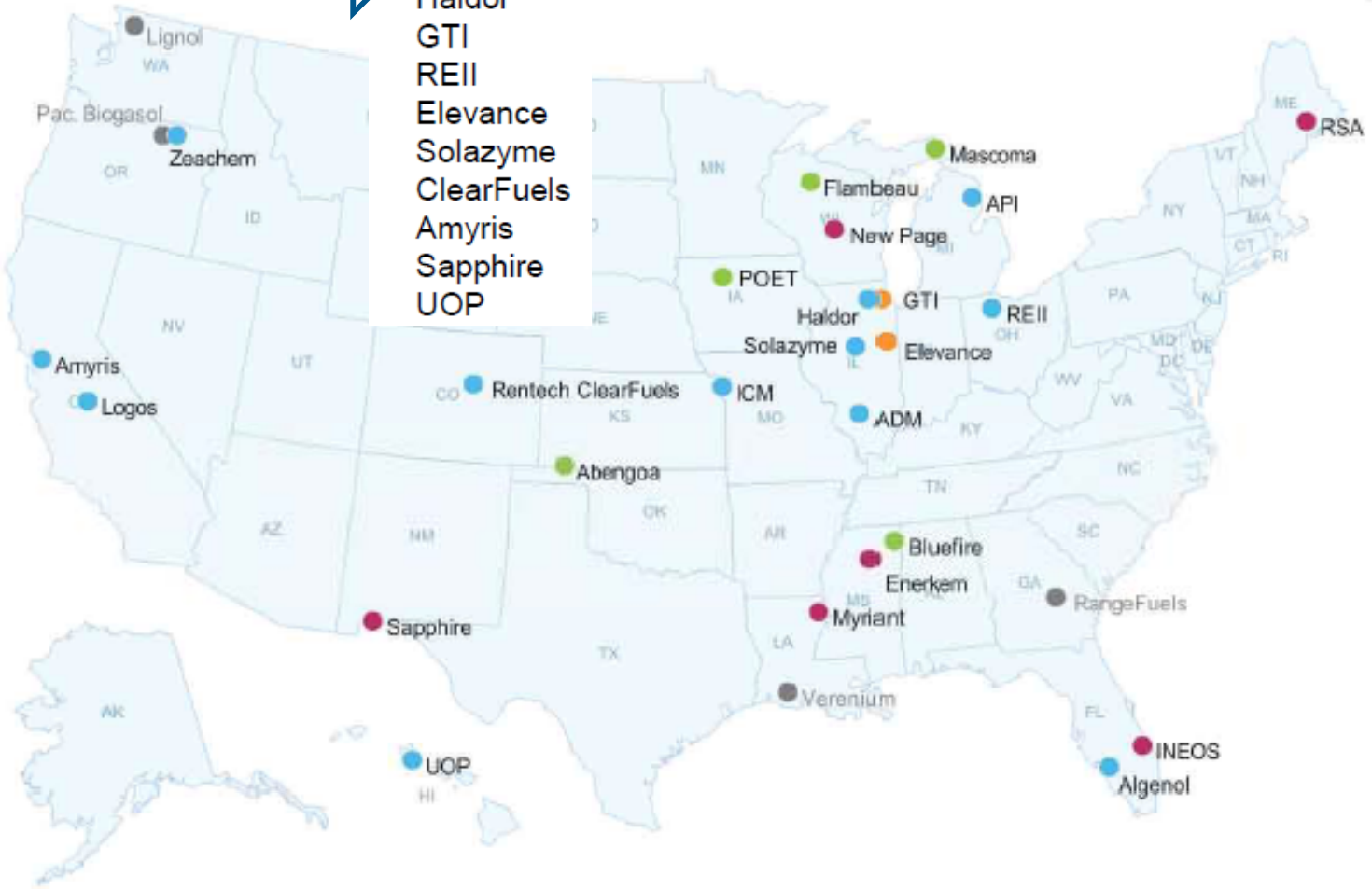
Integrated Biorefinery Projects

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 11 IBRs will produce hydrocarbons from biomass
- 12 IBRs will produce cellulosic ethanol from biomass

Hydrocarbons

Flambeau
New Page
Haldor
GTI
REII
Elevance
Solazyme
ClearFuels
Amyris
Sapphire
UOP

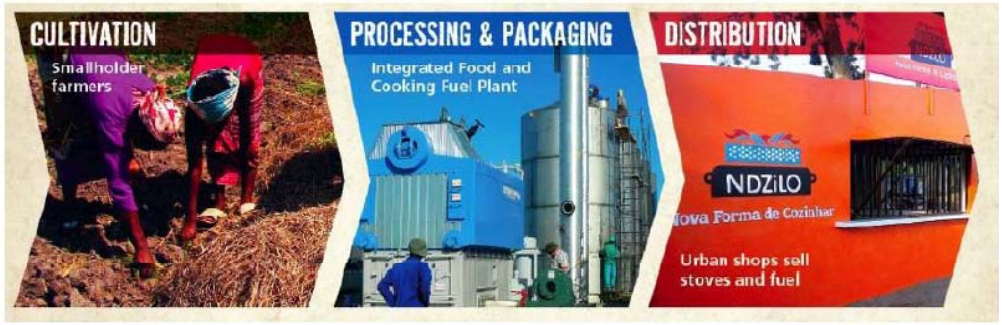


Project Scale Key

- Research and Development
- Pilot
- Demonstration
- Commercial
- Complete/Inactive

For more information visit:
http://www.eere.energy.gov/biomass/integrated_biorefineries.html

CleanStar's commercial strategy



Ethanol-based cooking fuel & Ethanol clean cookstove

NDZiLO

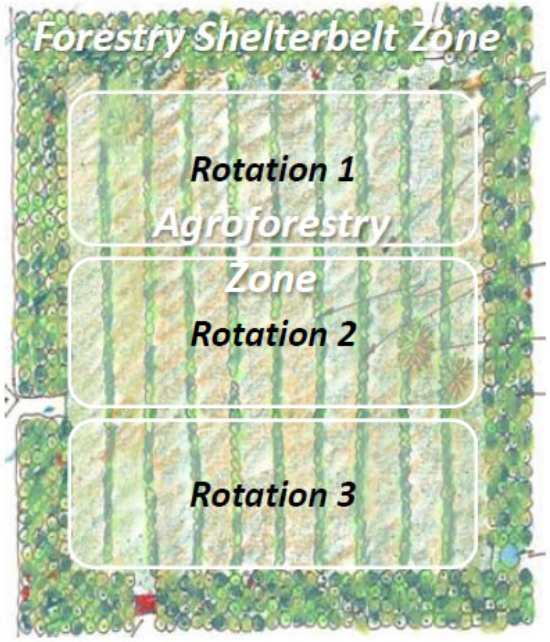
- Clean, safe and fast
- Cheaper than charcoal
- ~20L / month / family
- ~1 ton CO2 saved / month / family

Worlds First Sustainable Cooking Fuel Plant

Opened 17 May 2012

A low-input agroforestry cultivation system is at the core of our partnership with smallholders

- The system has a **1 ha agroforestry zone** with rows of fast-growing leguminous trees/shrubs and alleys planted with annual crop rotations
- This is surrounded by a **1 ha forestry shelterbelt zone** that contains indigenous trees and Pongamia oilseed trees
- The system involves a mix of multi-purpose crops & trees, incl. cassava, cowpea, soyabean, sorghum, ground nut, lucaena, pigeonpea, pongamia and native tree species



Company-owned retail network


Sales team undertakes in-home demonstrations and take orders


Customers visit shops to fulfil orders and collect stoves & fuel

NDZiLO shop network being rolled out in low-income neighbourhoods


Customers return every day / week to buy more fuel

Contributors

- Ethan Warner, Yimin Zhang, Rich Bain (NREL)
- Michael Wang, Christina Negri et al. (ANL)
- Virginia Dale, Keith Kline, et al. (ORNL)
- Kristen Johnson and Alison Goss Eng (DOE/EERE/BETO)
- Isaias Macedo and Joaquim Seabra (UNICAMP)
- CTBE and ICONE colleagues
- IPCC SRREN Chapter 2 and Annex II contributors
- IEA Bioenergy Agreement Strategic Project: Monitoring Sustainability Certification of Bioenergy Collaborators
- IEA Task 38 Climate Change Effects of Biomass and Bioenergy Systems
- IPCC 5th Assessment Report – WGIII Bioenergy Annex colleagues
- SCOPE Project Biofuels and Sustainability Colleagues

Web sites and Resources

- **DOE/EERE/Bioenergy Technologies Office** http://www1.eere.energy.gov/biomass/
  http://www1.eere.energy.gov/biomass/pdfs/replacing_barrel_overview.pdf
  http://www1.eere.energy.gov/biomass/technology_pathways.html
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  http://maps.nrel.gov/bioenergyatlas/
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Acknowledgments

- **The Bioenergy Technologies Office (BETO) of DOE/EERE sponsored the work described in the Sustainability Program; Valerie Sariski Reed Director and BETO's knowledgeable staff.**

Complex set of options - approximate development stages (I)

Table 2.5 | Examples of stages of development of bioenergy: thermochemical (orange), biochemical (blue), and chemical routes (red) for heat, power, and liquid and gaseous fuels from solid lignocellulosic and wet waste biomass streams, sugars from sugarcane or starch crops, and vegetable oils (IEA Bioenergy, 2009; Alper and Stephanopoulos, 2009; Regalbuto, 2009).

Type of Plant	Type of Product	Stage of Development of Process for Product(s) or System(s)			
		Basic and Applied R&D	Demonstration	Early Commercial	Commercial
Low Moisture Lignocellulosic	Densified Biomass	Torrefaction	Hydrothermal Oil (Hy Oil)	Pyrolysis Oil (Py Oil)	Pelletization
	Charcoal	Pyrolysis (Biochar)			Carbonization
	Heat			Small Scale Gasification	Combustion Stoves
		Combustion		Py/Hy Oil	Home/District/Industrial
	Power or CHP	Combustion Coupled with	Stirling Engine	ORC[1]	Steam Cycles
		Co-Combution or Co-Firing with Coal	Indirect	Parallel	Direct
		Gasification (G) or Integrated Gasification (IG)	IG-Fuel Cell IG-Gas Turbine		
			IG-Combined Cycle	G and Steam Cycle	

ORC = Organic Rankine Cycle

Complex set of options - approximate development stages (II)

Table 2.5 | Examples of stages of development of bioenergy: thermochemical (orange), biochemical (blue), and chemical routes (red) for heat, power, and liquid and gaseous fuels from solid lignocellulosic and wet waste biomass streams, sugars from sugarcane or starch crops, and vegetable oils (IEA Bioenergy, 2009; Alper and Stephanopoulos, 2009; Regalbuto, 2009).

Type of Plant	Type of Product	Stage of Development of Process for Product(s) or System(s)			
		Basic and Applied R&D	Demonstration	Early Commercial	Commercial
Wet Waste	Heat or Power or Fuel	Anaerobic Digestion to Biogas			
		Microbial Fuel Cell	2-Stage	Reforming to Hydrogen (H_2) / Biogas Upgrading to Methane	Landfills (1-Stage) / Small Manure Digesters
		Hydrothermal Processing to Oils or Gaseous Fuels			
Sugar or Starch Crops	Fuels	Sugar Fermentation		Butanol	Ethanol
		Microbial Processing[2]			
		H_2	Gasoline/ Diesel/ Jet Fuel	Biobutanol/Butanols[3]	
Oils Vegetable or Waste		Extraction and Esterification			Biodiesel
		Extraction and Hydrogenation		Renewable Diesel	
		Extraction and Refining	Jet Fuel		

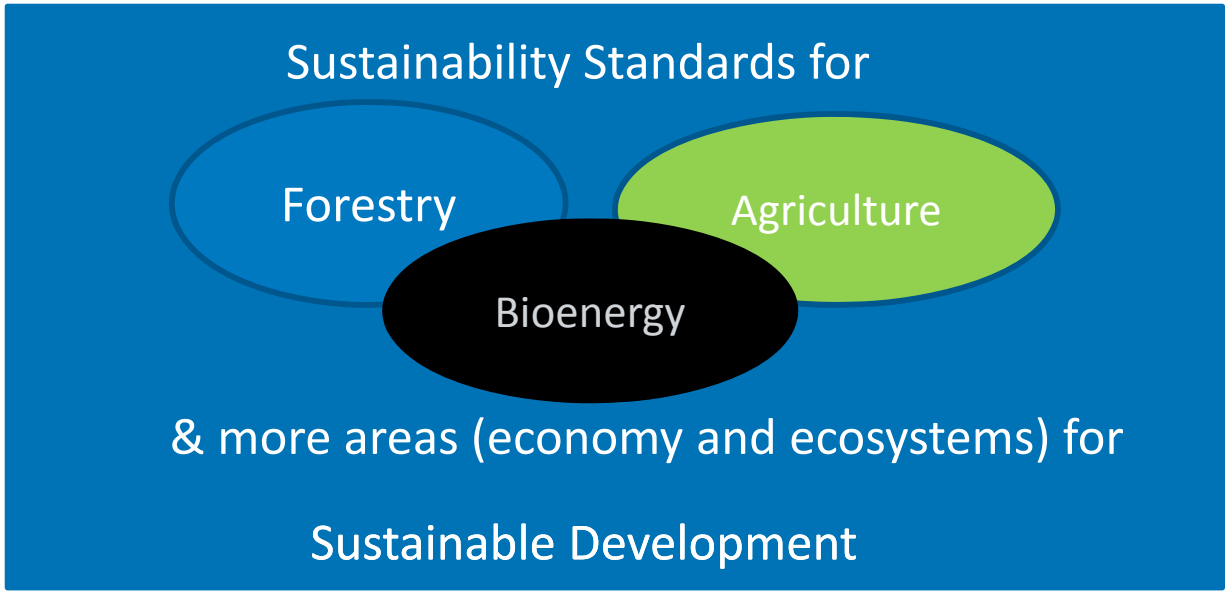
Notes: 1. ORC: Organic Rankine Cycle; 2. genetically engineered yeasts or bacteria to make, for instance, isobutanol (or hydrocarbons) developed either with tools of synthetic biology or through metabolic engineering. 3. Several four-carbon alcohols are possible and isobutanol is a key chemical building block for gasoline, diesel, kerosene and jet fuel and other products.

Global Level

Economy+
Environment+
Social Responsibility+
Millennium Development Goals

- **International Standards Organization (UN +)**
- **Rio 1992 – ISO Series of Environmental Standards (14000)**
- **2006– ISO Series on Social Responsibility (26000)**
- **Rio+20**

ISO to foster Sustainable Development



DNV sustainability services: Third party certification is a credible tool to show a company commitment to sustainable development.

DNV Business Assurance provides sustainable biofuels certification according the RSB and the ISCC certification schemes.

RSB certification requires compliance with 12 principles and criteria. The audit will address the following topics:

1. Legality
2. Impact assessment and stakeholder consultation
3. Planning, monitoring and continuous improvement
4. Greenhouse gas emissions
5. Human and Labour Rights
6. Local Development & Food Security
7. Conservation (Biodiversity and Ecosystem Services)

8-10. Soil, Water and Air protection

11. Use of technology, inputs and management of wastes
12. Land Rights.

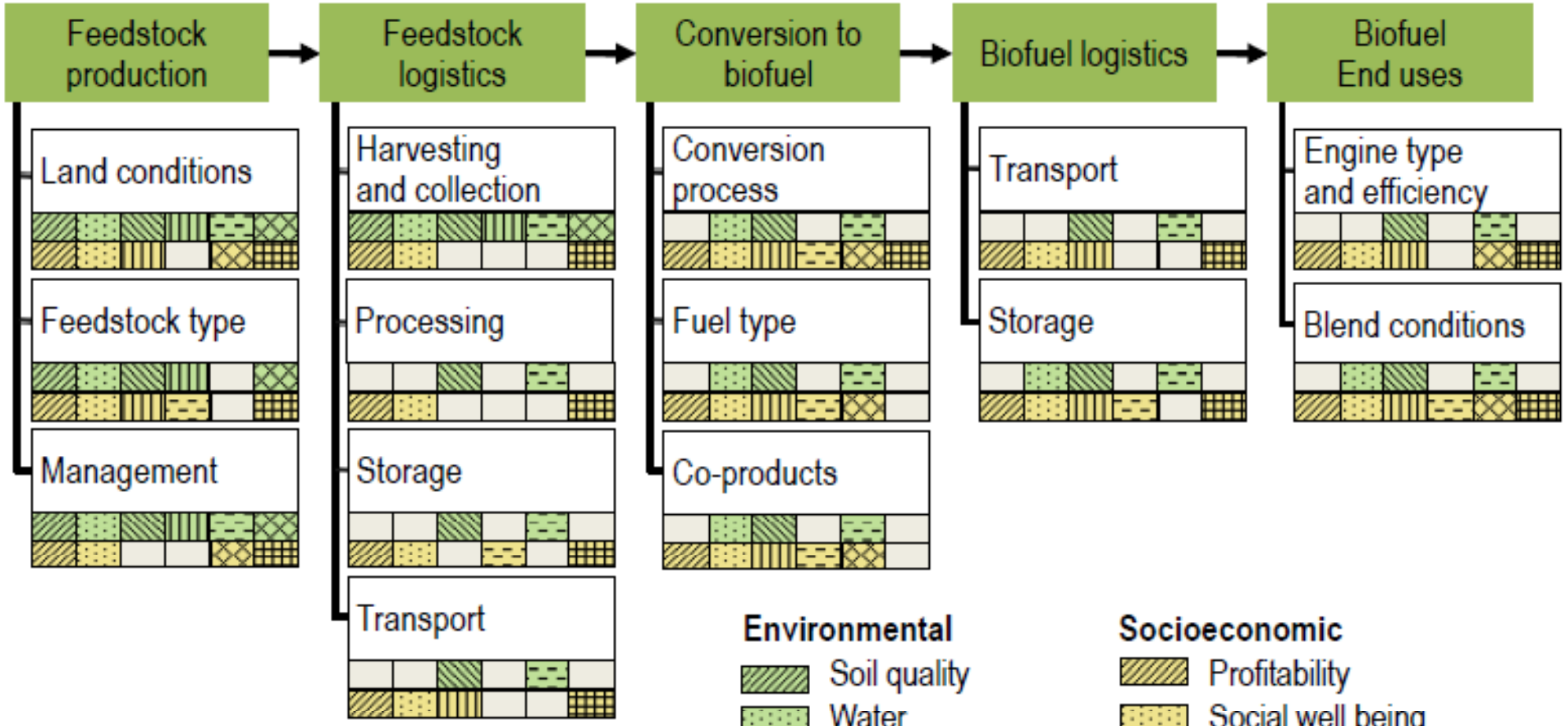
ISCC certification addresses the following topics:

- Conservation (Biodiversity & Ecosystem Services) and land with high carbon stock
- Soil, water & air and the application of Good Agricultural Practices
- Working conditions
- Human, labour and land use rights. Responsible community relations.
- Legality
- Good management practice
- Greenhouse gas emissions.

RSB and the ISCC standards comply to the EU RED Directive.

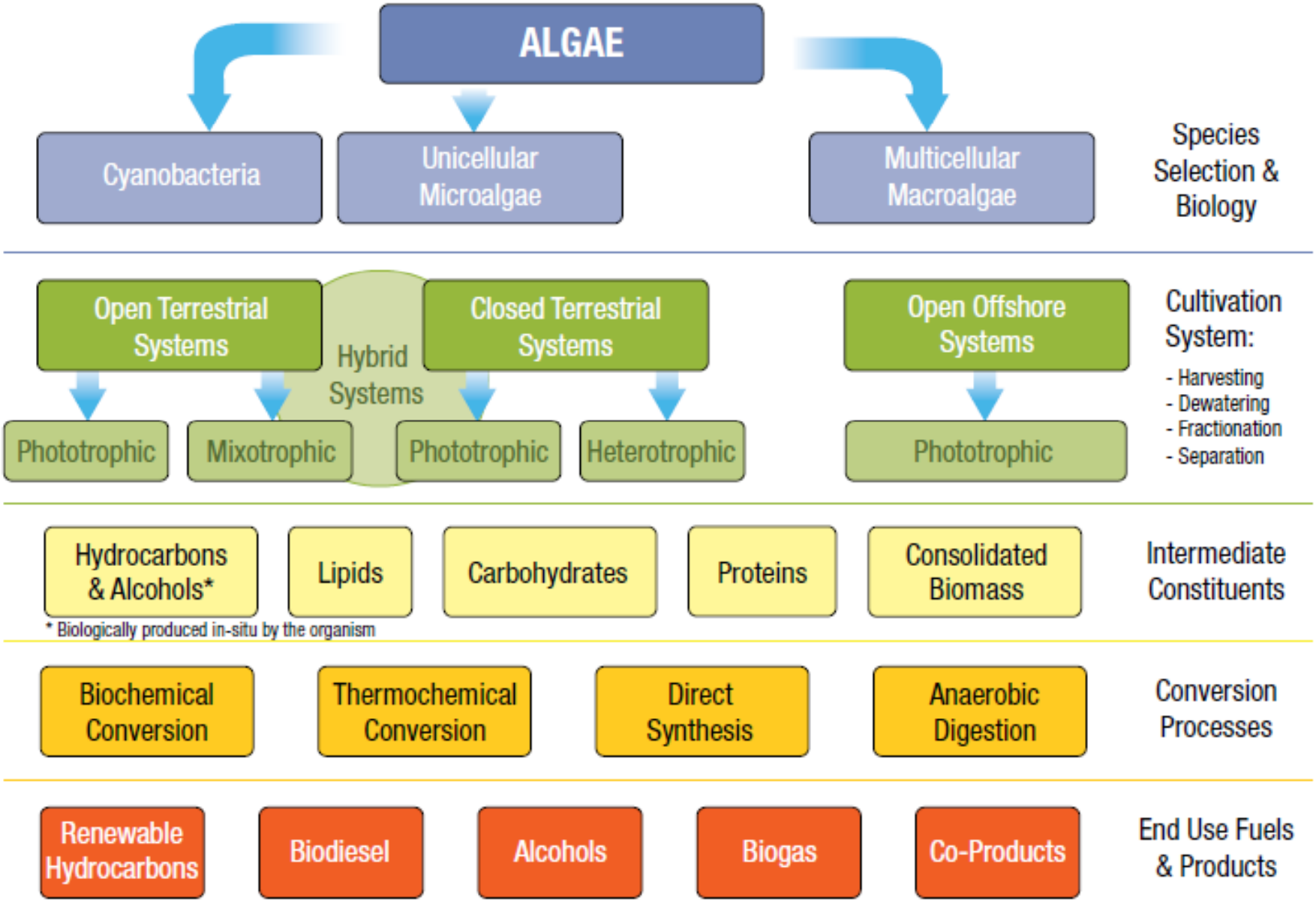
Looking at the biofuel supply chain in terms of sustainability indicators

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY



Efroymson et al. (2013)
Environmental Management 52:291-306.
Dale et al. (2013)
Ecological Indicators 26:87-102.

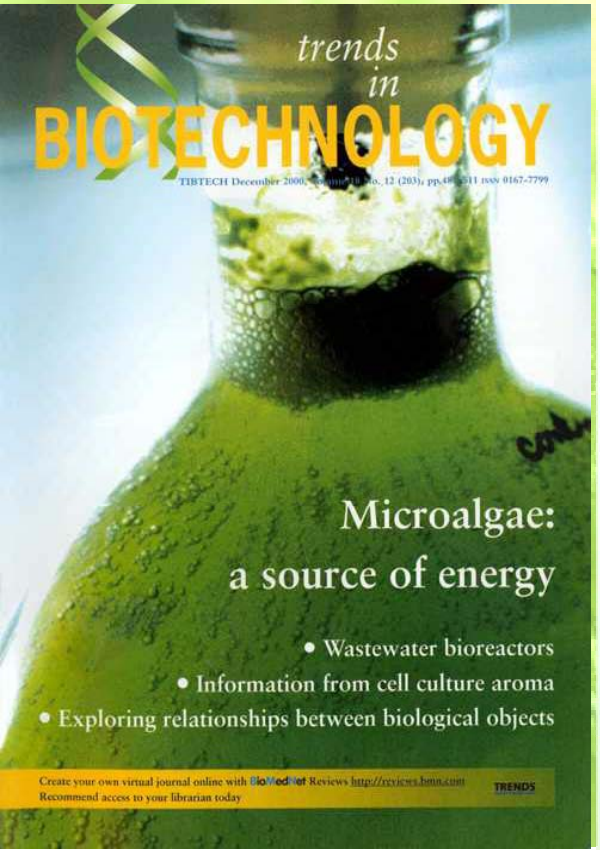
Photosynthetic Microorganisms



US DOE (2009). National Algal Biofuels Technology Roadmap. U.S. Department of Energy Biomass Program, Washington, DC, USA, 214 pp

Routes to Algal Biofuels

Defining a Biofuels Portfolio From Microalgae



Microalgae

Macroalgae

Intermediate

Hydrogen

Lipids or Hydrocarbons

Carbohydrates

Biomass

Syngas

Methane

Fuel

Hydrogen

Alkanes or "Green Diesel"

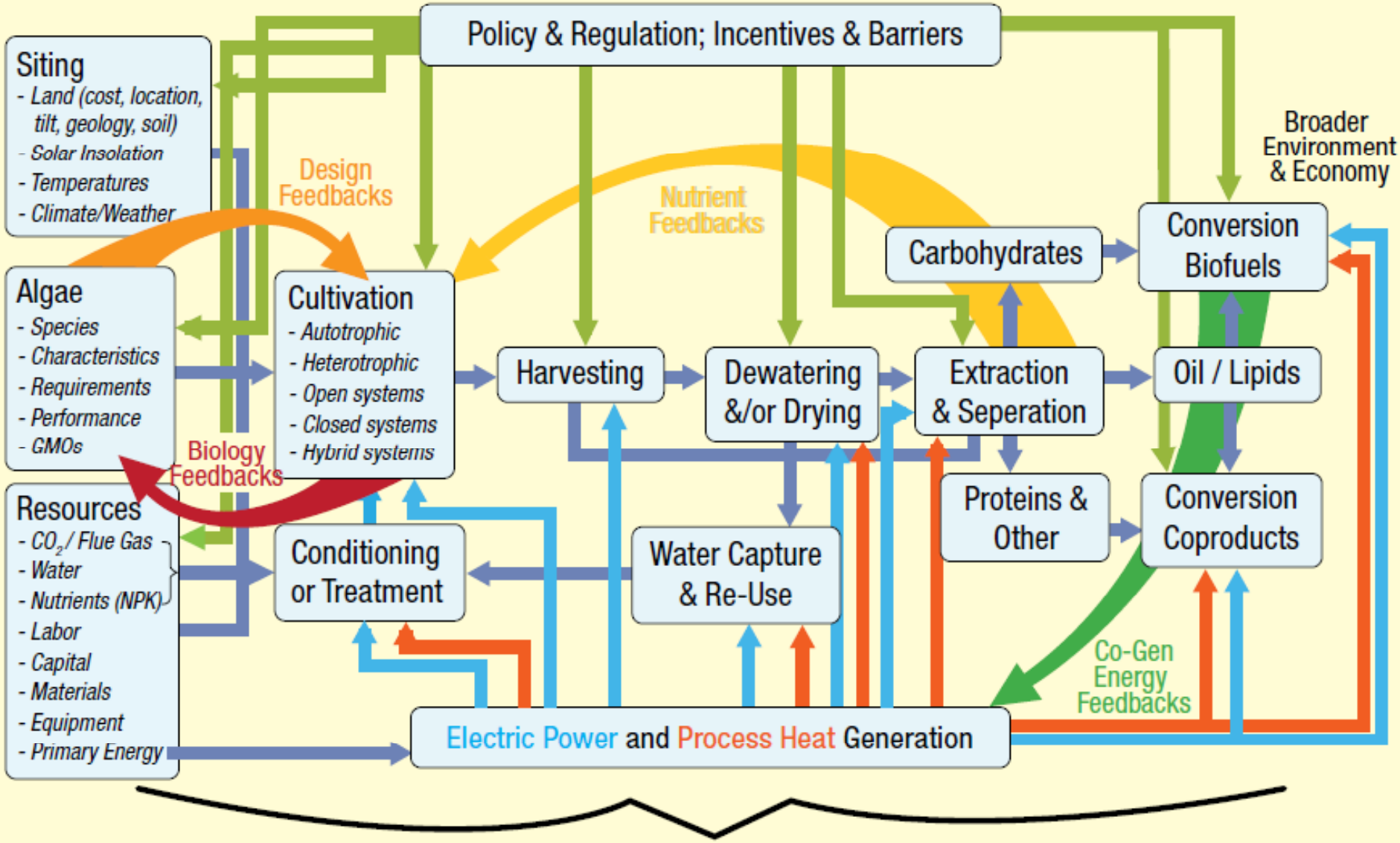
Biodiesel

Alcohols (Ethanol)

FT Liquids

Methane

Preliminary systems design and assessments guided by sustainability indicators



Biofuels Sustainability

Regional Initiatives

European Committee for Standardization (CEN TC383)

EU RED - Renewable Energy Directive

National Initiatives[1]

International Bodies' Initiatives

ISO TC248/13065 under development

Global Multi-stakeholder Voluntary Schemes[2]

FAO* GBEP* OECD* IDB IEA* IFC UNEP*

IDB Biofuels Sustainability Balanced Scorecard

2012 IFC Sustainability Framework

The Netherlands Renewable Energy Transport Regulation

U.K. Low Carbon Vehicle Partnership Fuels

Sweden-Brazil SEKAB Supply Chain Verifiable Sustainable Ethanol

U.S. Renewable Fuel Standard (RFS2)

U.S. Council on Sustainable Biomass Production (CSBP)

Greenergy (Brazilian Bioethanol verification programme)

U.K. Renewable Transport Fuel Obligation (RTFO)

German Biofuel Quota Law-Ordinance for Sustainability Requirements

California (U.S.) Low Carbon Fuel Standard (LCFS)

BonSucro (Better Sugarcane Initiative)

Roundtable on Sustainable Palm Oil (RSPO)

NTA 8080/ NTA 8081

International Sustainability and Carbon Certification System (ISCC)

Biomass Biofuels voluntary scheme (2BSvs)

Roundtable on Responsible Soy (RTRS)

Roundtable on Sustainable Biofuels (RSB)

KEYS:

National, sub- or supra-national governments , multilateral financing banks

Voluntary scheme holders from private sector, association, non-governmental organizations… Color indicates country originating scheme or country of application

[1]Australia Sub-national, NSW
[2]Some comply with ISEAL Alliance
*Facilitating multilateral organizations

Source: NREL (Chum, Warner), UNICA 2/18/13

GHG Emissions Reductions Targets

U.S. Volumetric Goal

- Energy Independence & Security Act 2007
  - 36 billion gallons renewable fuel by 2022
    - 21 billion gallons cellulosic + advanced biofuels (EPA is waiving volume based on projection of future production each year)

- Renewable Fuel Standard (RFS2) biofuels penetration goals are based on specific GHG reductions from the fossil fuel replaced considering a full consequential LCA model with LUC

	% reduction
– **Biomass-based diesel**	**50**
– **Advanced biofuels**	**50**
– **Corn grain-based ethanol**	**20**
– **Cellulosic Biofuels**	**60**

EU Volumetric Goal

- **Certified** reduction of 35% GHG emissions reduction relative to diesel or gasoline
  - 10% Biofuel target – proposed to be halved – concerns ILUC
  - About 70 producers and bundlers of U.S. corn ethanol meet the European standards
- Indirect Land Use change may be added to GHG
- Sugarcane or corn ethanol ILUC 4 times lower than biodiesel