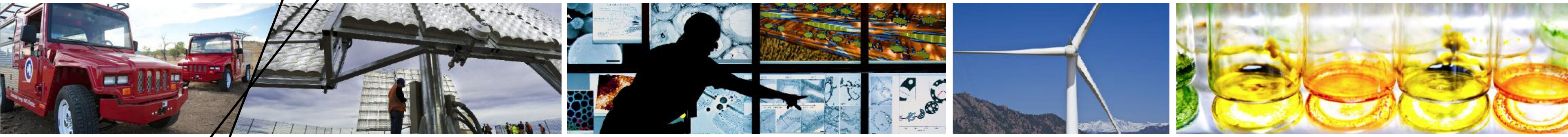
NATIONAL RENEWABLE ENERGY LABORATORY

FAPESP
BIOEN-BIOTA-PFPMCG-SCOPE Joint Workshop on Biofuels & Sustainability
26/02/2013 - FAPESP - São Paulo

Biofuels – Lessons Learned



Joint Workshop on Biofuels and Sustainability

BIOEN
BIOTA
PFPMCG
SCOPE

Helena L. Chum

São Paulo, February 26, 2013

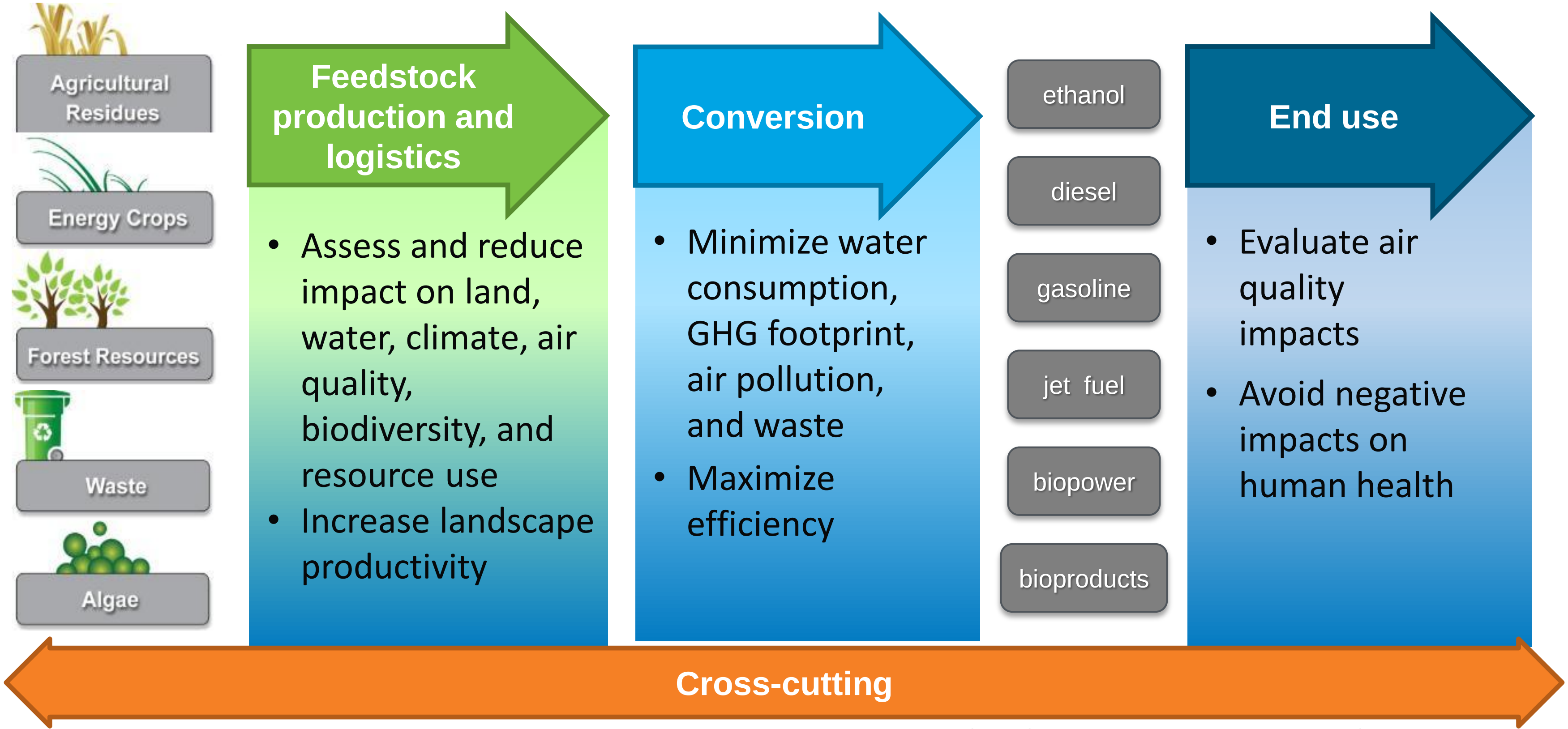
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- Context of Presentation
- Bioenergy Industry Characterization
- America's Leaders – Benchmarking and Improvements
- Design for sustainability
- Commoditization of Biofuels
- Technology Development: abundance of feedstocks, pathways, and energy products
- What does it take to get to market?
- Some key conclusions

DOE Bioenergy Technology Office's Sustainability Activities

Identifying and addressing the challenges for sustainable bioenergy production through field trials, applied research, capacity building, modeling, and analysis.



Agricultural Residues

Energy Crops

Forest Resources

Waste

Algae

Feedstock production and logistics

- Assess and reduce impact on land, water, climate, air quality, biodiversity, and resource use
- Increase landscape productivity

Conversion

- Minimize water consumption, GHG footprint, air pollution, and waste
- Maximize efficiency

ethanol

diesel

gasoline

jet fuel

biopower

bioproducts

End use

- Evaluate air quality impacts
- Avoid negative impacts on human health

Cross-cutting

- Life-cycle analysis of water consumption and GHG emissions
- Supply chain environmental, economic, and social factors

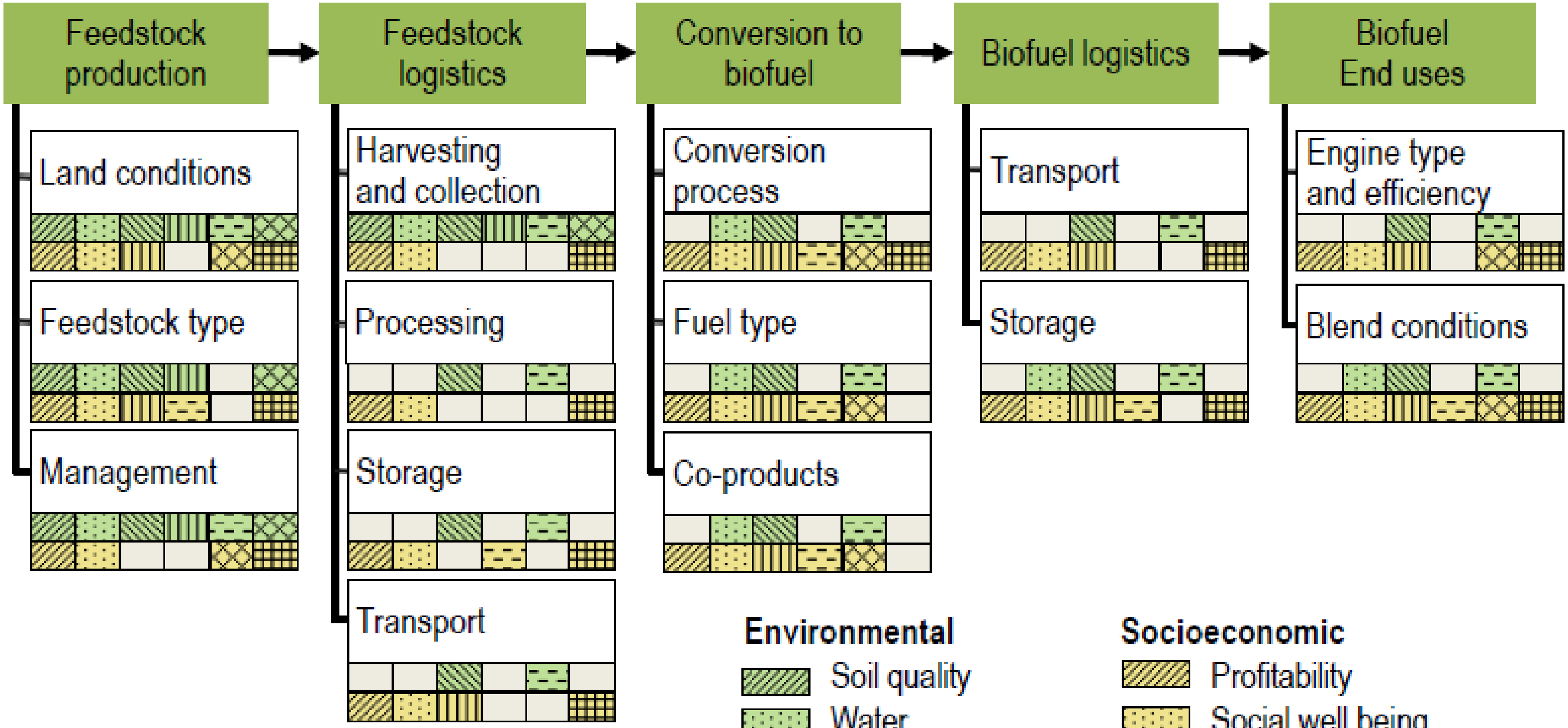
“Defining” Sustainability

- As defined in Executive Order 13514

> To create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations.

- **Bioenergy Technology Office’s sustainability efforts**
  - Maximize the benefits of bioenergy, domestically and globally
  - Enable long-term operations of feedstock and fuel production while protecting natural systems and human well-being
  - Enable the industry to take advantage of emerging environmental markets
  - Anticipate and mitigate showstoppers (e.g., resource constraints, regulations, conflicting social priorities)
  - Address a range of other environmental and socio-economic issues (e.g., water scarcity, climate change, human health)

Looking at the biofuel supply chain in terms of sustainability indicators



Environmental

- Soil quality
- Water
- Greenhouse gases
- Biodiversity
- Air quality
- Productivity

Socioeconomic

- Profitability
- Social well being
- External trade
- Energy security
- Resource conservation
- Social acceptability

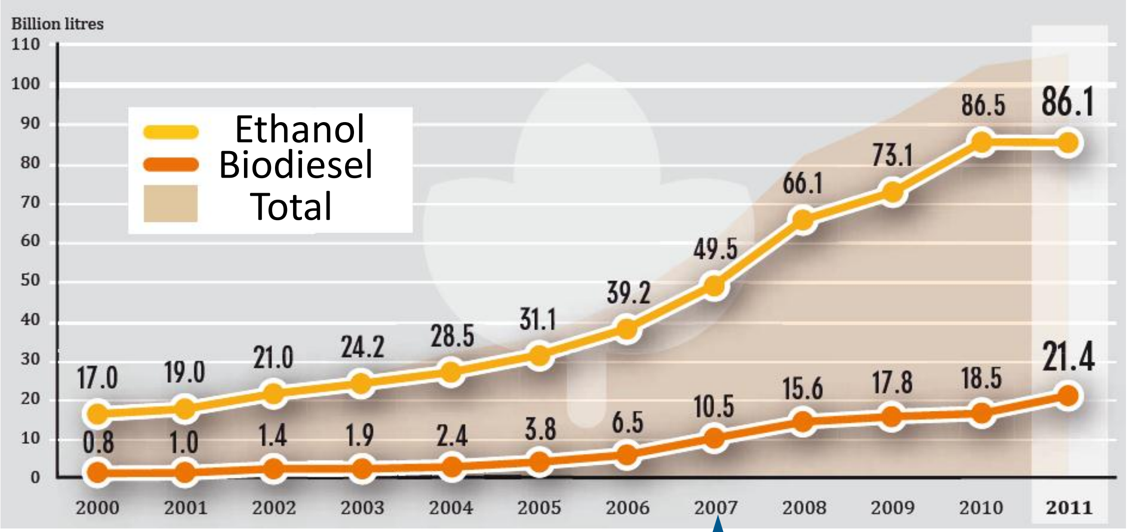
Categories without major effects

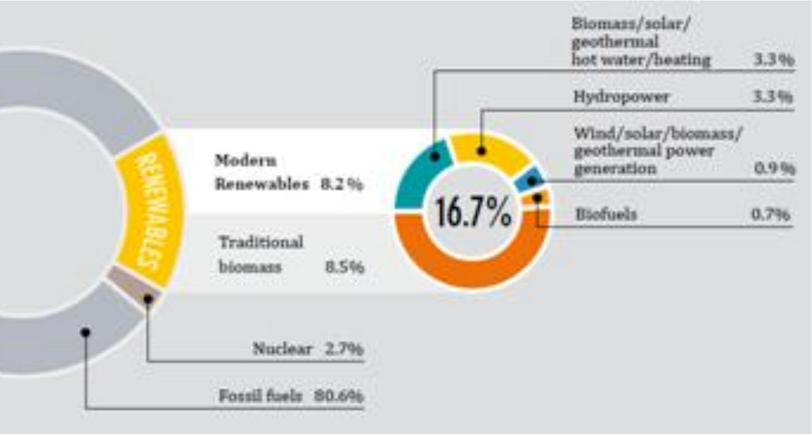
Efroymson et al. (2013)
Environmental Management 52:291-306.
Dale et al. (2013)
Ecological Indicators 26:87-102.

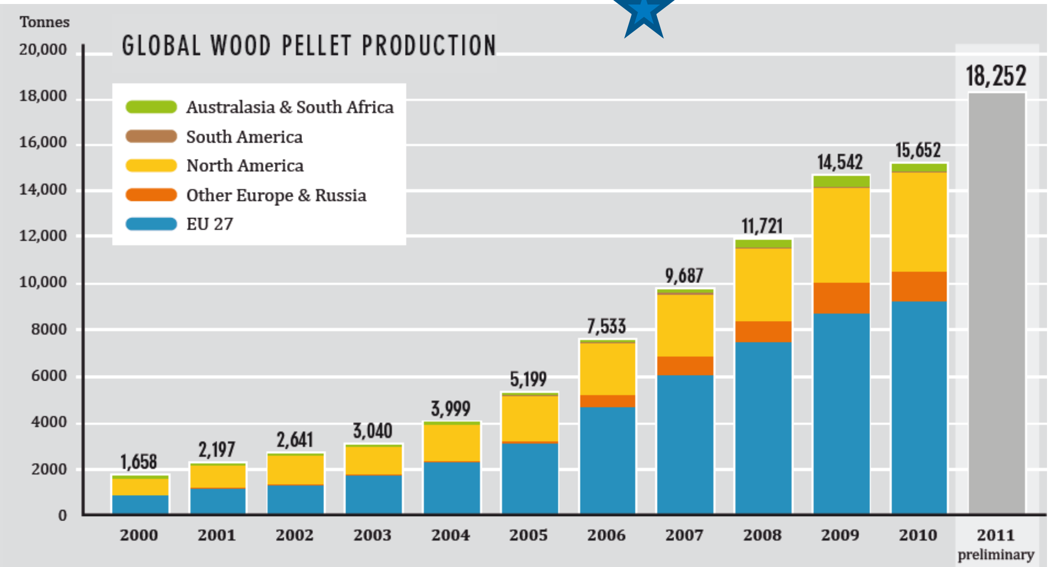
Biomass Energy – 53 EJ (2011) #4 Primary Source

REN21 Renewable Energy Policy Network for the 21st Century

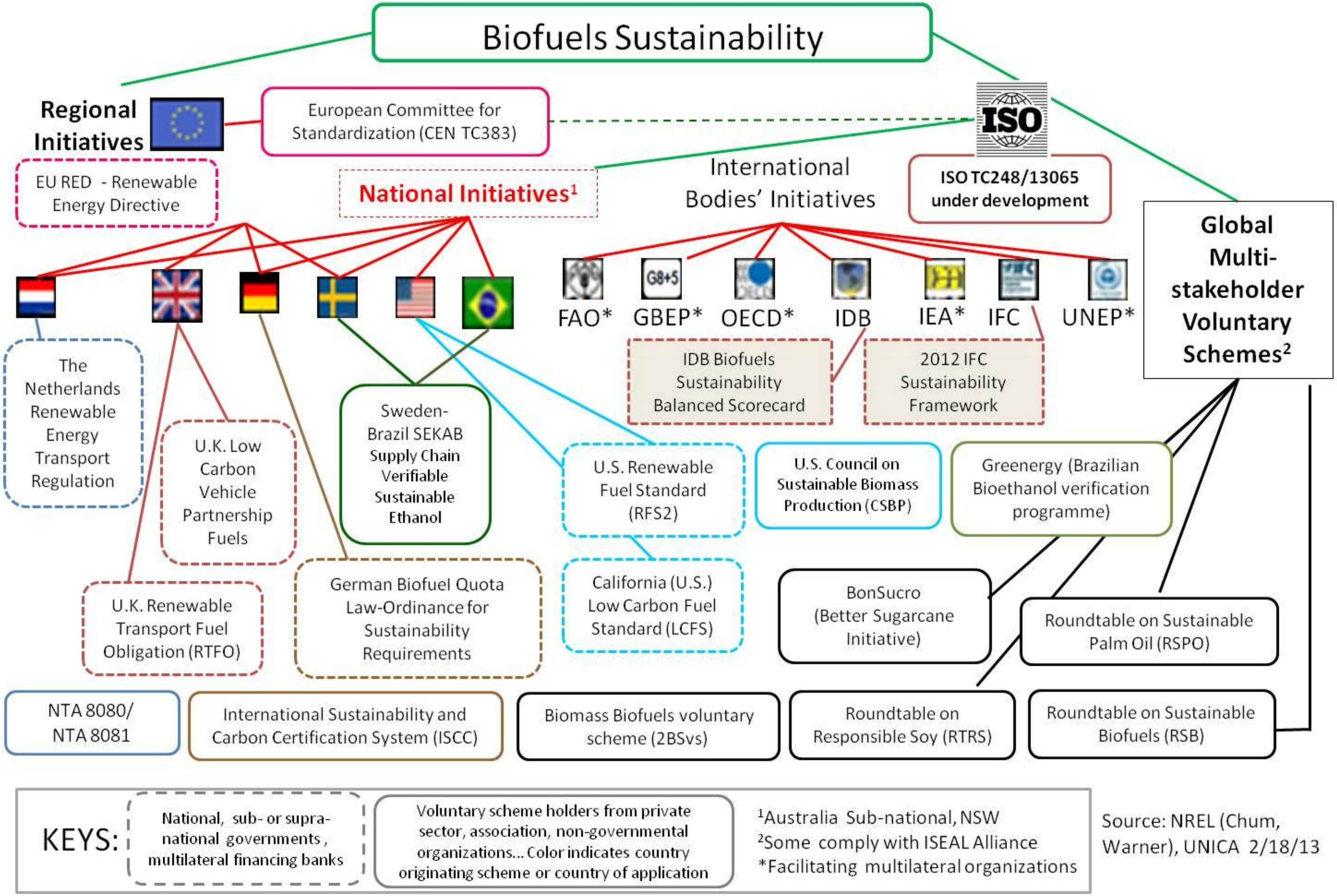
RENEWABLES 2012
GLOBAL STATUS REPORT







A maze of regulations, sustainability schemes, standards, and indicators, in addition to those of agriculture and forestry



Biofuels Sustainability

Regional Initiatives

EU RED - Renewable Energy Directive

European Committee for Standardization (CEN TC383)

National Initiatives[1]

International Bodies' Initiatives

ISO TC248/13065 under development

Global Multi-stakeholder Voluntary Schemes[2]

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

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)

IDB Biofuels Sustainability Balanced Scorecard

2012 IFC Sustainability Framework

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

See http://www.bioenergytrade.org/ongoing-work/monitoring-sust-certification-of-bioenergy.html

GBEP Consensus Indicators for government programs/policies

Environmental	Social	Economic
INDICATORS		
1. Life-cycle GHG emissions ★	9. Allocation and tenure of land for new bioenergy production	17. Productivity
2. Soil quality	10. Price and supply of a national food basket	18. Net energy balance ★
3. Harvest levels of wood resources	11. Change in income	19. Gross value added
4. Emissions of non-GHG air pollutants, including air toxics	12. Jobs in the bioenergy sector	20. Change in consumption of fossil fuels and traditional use of biomass
5. Water use and efficiency	13. Change in unpaid time spent by women and children collecting biomass	21. Training and re-qualification of the workforce
6. Water quality	14. Bioenergy used to expand access to modern energy services	22. Energy diversity ★
7. Biological diversity in the landscape	15. Change in mortality and burden of disease attributable to indoor smoke	23. Infrastructure and logistics for distribution of bioenergy
8. Land use and land-use change related to bioenergy feedstock production ★	16. Incidence of occupational injury, illness and fatalities	24. Capacity and flexibility of use of bioenergy

Americas' Leaders

Environ. Res. Lett. 7 (2012) 045905

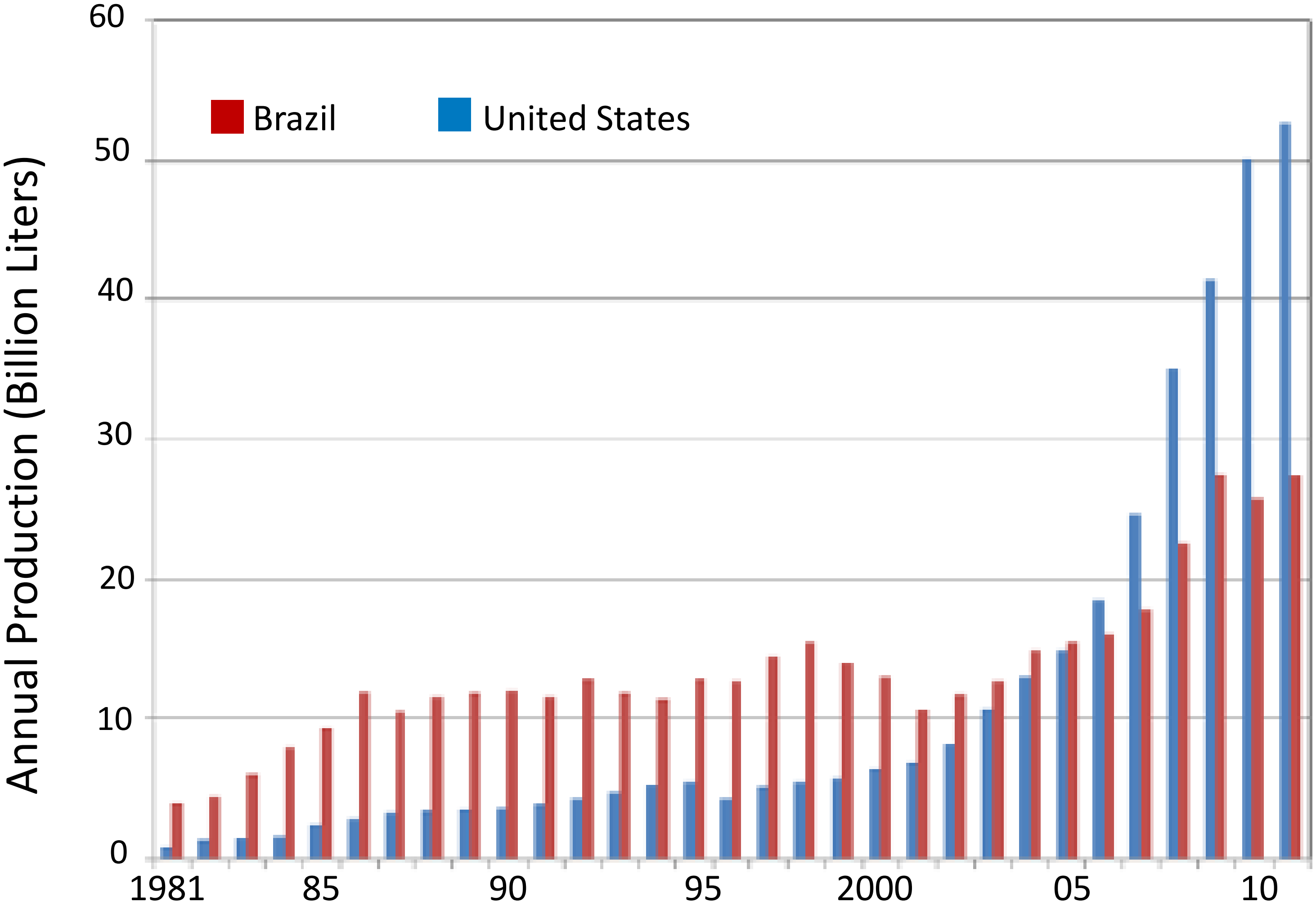
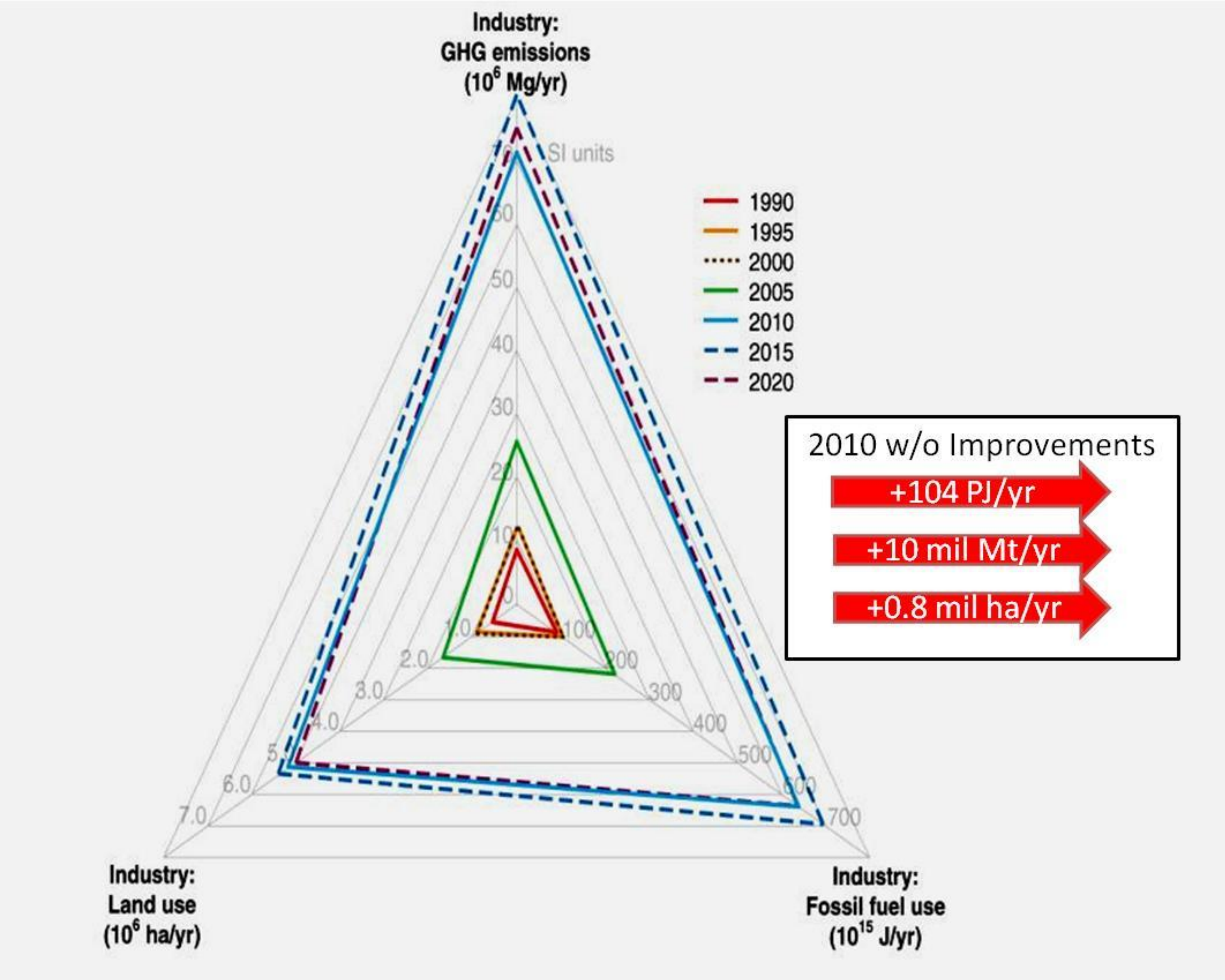


Figure 1. Annual ethanol production in the US and Brazil (based on data from the Renewable Fuels Association (RFA 2012) and Brazilian Sugarcane Association (UNICA 2012)).

M. Wang et al. (ANL)

Impact of corn and dry mill process improvements



2010 w/o Improvements

+104 PJ/yr

+10 mil Mt/yr

+0.8 mil ha/yr

Chum, Zhang et al., sub. Biofpr

Adding Cellulosic Ethanol

Environ. Res. Lett. **7** (2012) 045905 M Wang *et al*

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).

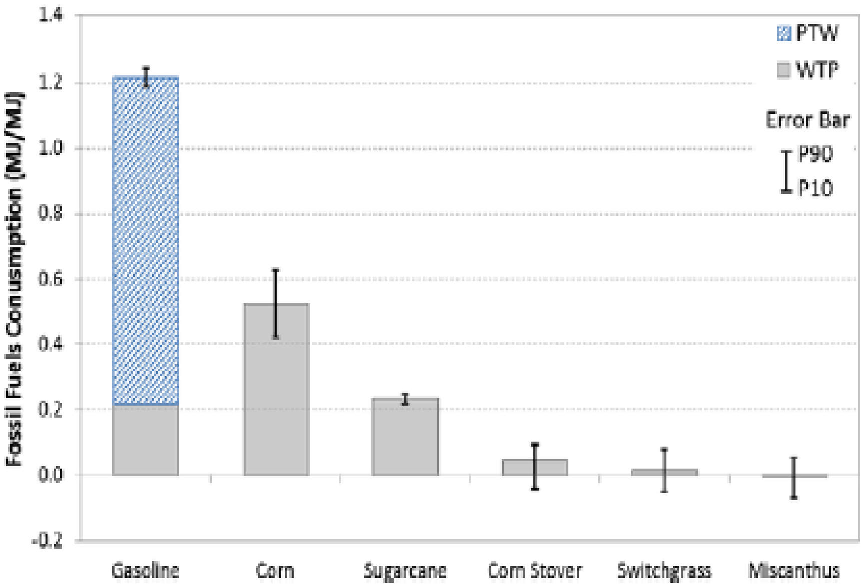


Figure 3. Well-to-wheels results for fossil energy use of gasoline and bioethanol.

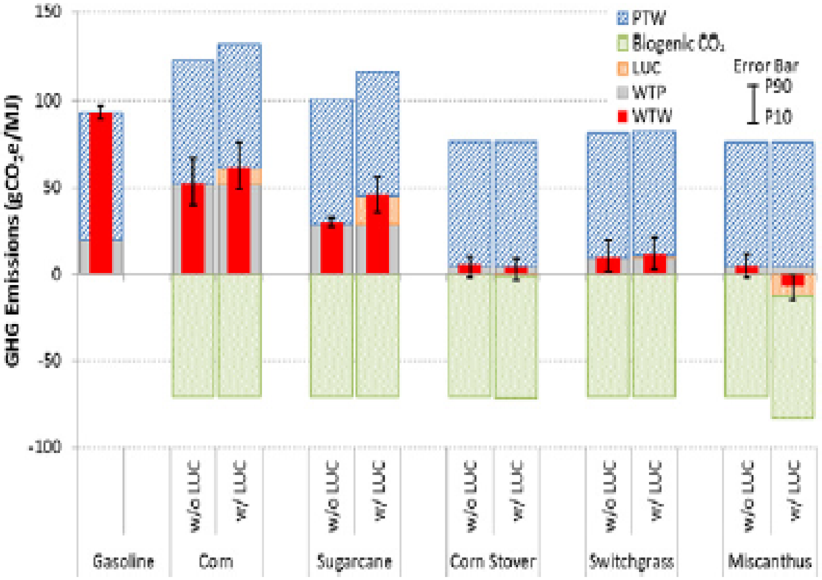
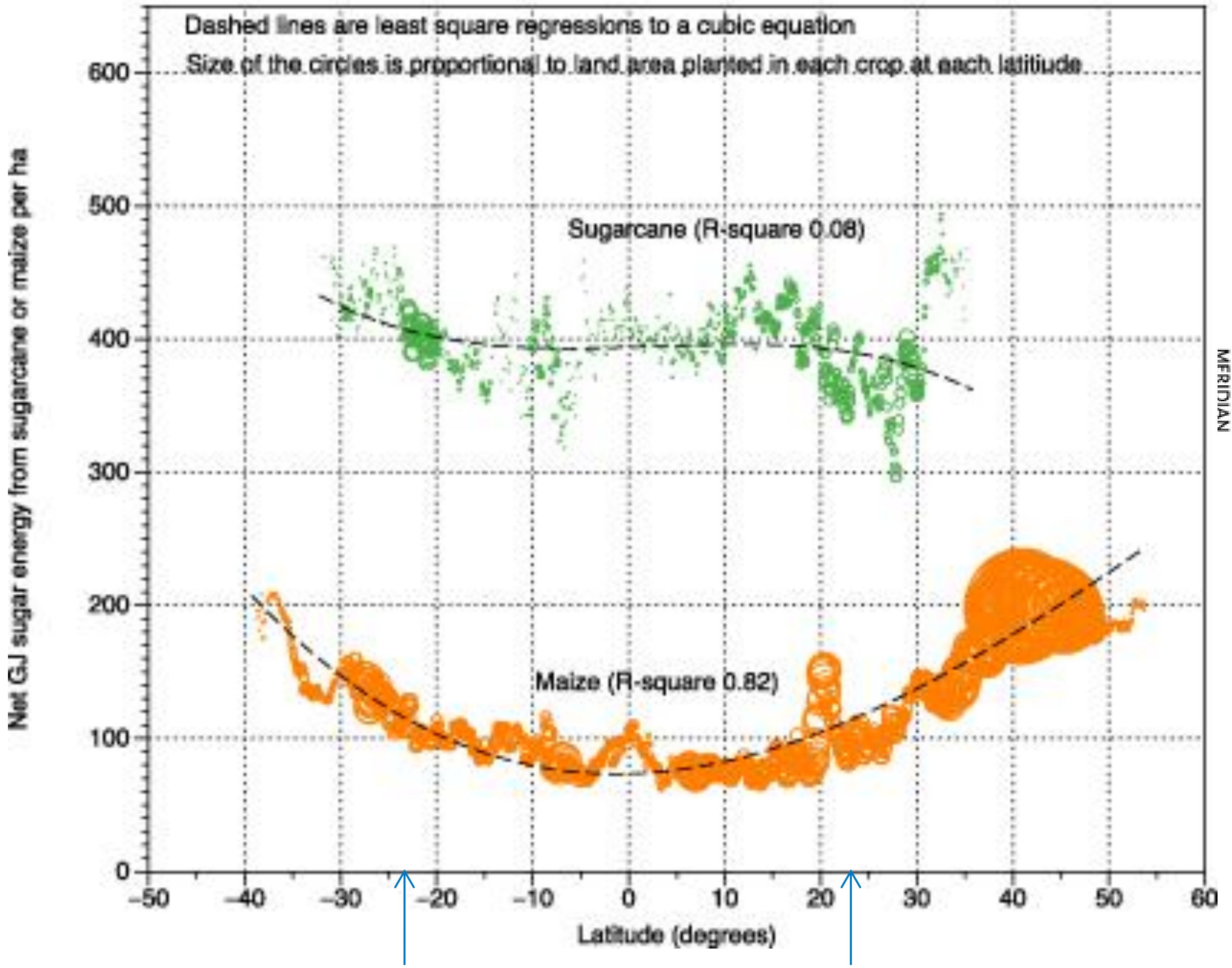


Figure 4. Well-to-wheels results for greenhouse gas emissions in CO$_2$e for six pathways.

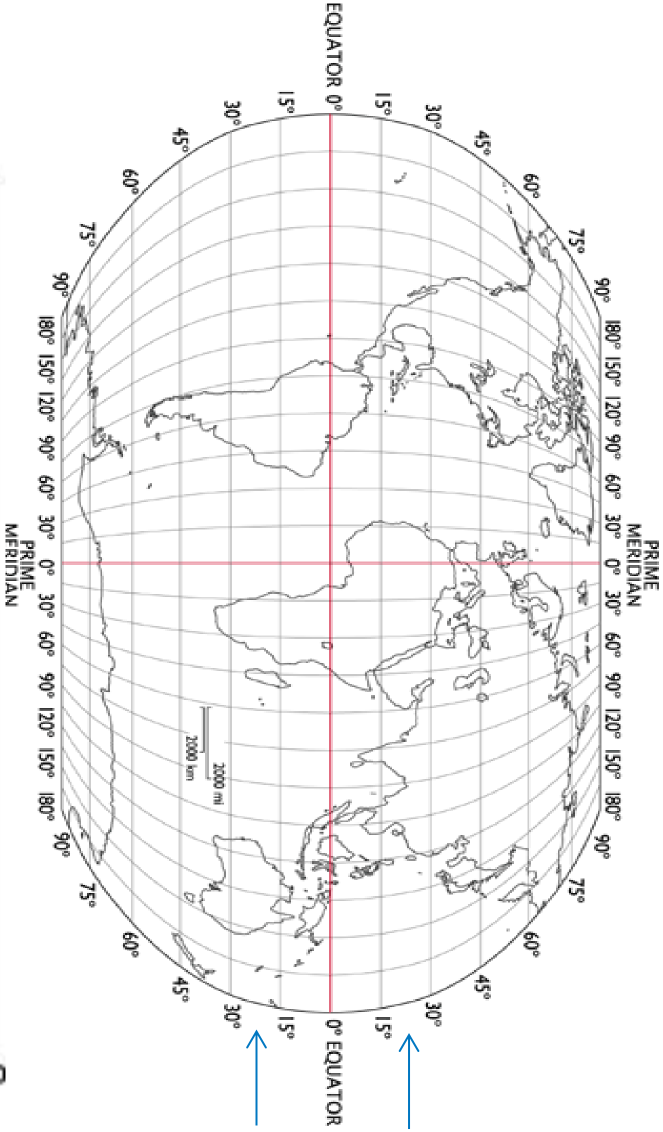
Latitude, soil conditions, biomass type matter

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



Capricorn

Cancer



Capricorn Cancer

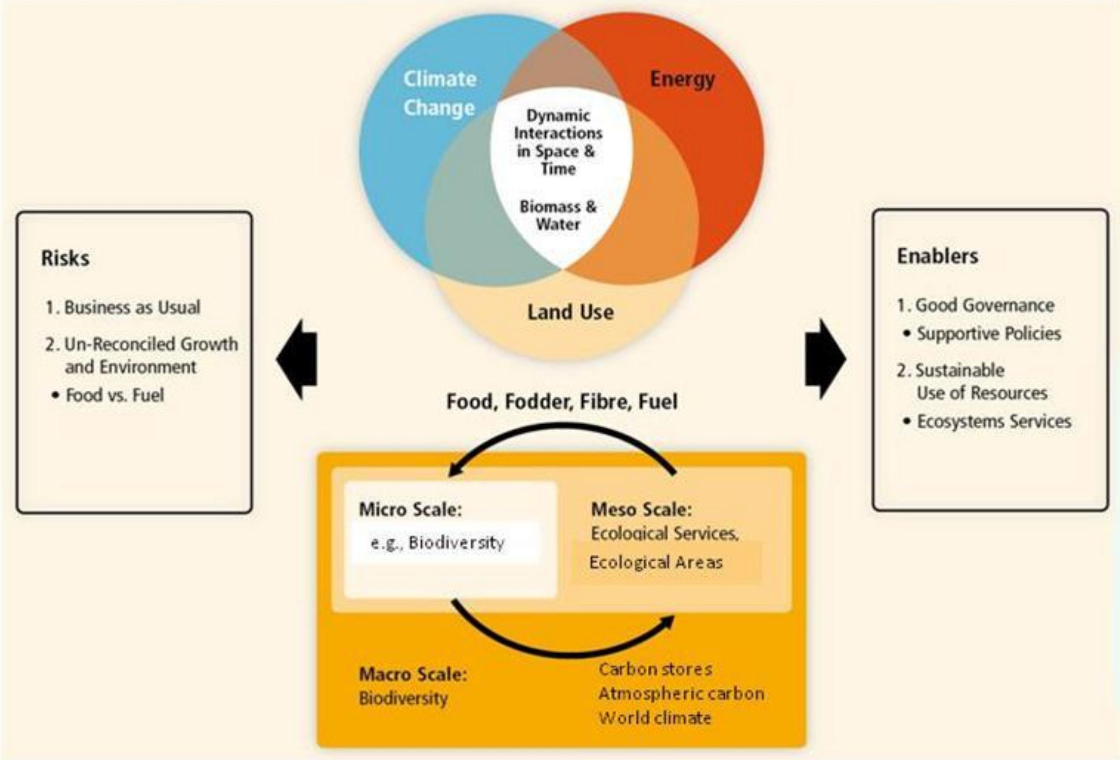
Uncertainties

- ***Biofuel sustainability standards driving the rise in the use of LCA as a tool in decision making***
- ***Methodological uncertainties – attributional LCA (ALCA) coproduct treatments, boundaries; incomplete accounting of global climate change forcings, latitude/longitude/geography dependent***
- ***Market-mediated changes in land use because of the expansion of biofuels (combining multiple models and data) is a consequential LCA with uncertainties. Assumes scenarios of fuel volumes.***
- ***Lack of cause (ethanol expansion) and effect (increased expansion of sugarcane plantations in the Amazonas region) demonstrated in several papers.***
- ***Science and data mining is still improving and direct measurements of land cover, land cover change, land use change is very important (e.g., Brazilian INPE and collaborators data)***
- ***Carbon Accounting for GHG inventories may be too simplistic***

Land-use change and bioenergy

- The positive greenhouse gas balance of biofuels can be affected by direct and indirect land-use changes.

- Proper governance of land use, zoning, and choice of biomass production systems are key challenges for policy makers.



Risks

1. Business as Usual
2. Un-Reconciled Growth and Environment
   - Food vs. Fuel

Enablers

1. Good Governance
   - Supportive Policies
2. Sustainable Use of Resources
   - Ecosystems Services

Doomsters vs. **Boomsters**

simplified scenarios can be replaced by win-win synergistic strategies such as:

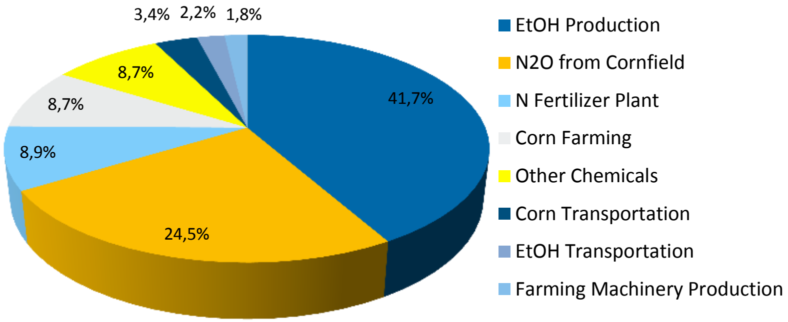
- Bioenergy uses (including cascading uses) improve post harvest biomass use efficiency

- Wise integration of bioenergy into agriculture and forestry landscapes can increase total biomass output from land and also mitigate several of the well documented consequences of present day agriculture and forestry (e.g., eutrophication, soil degradation, spread of resistant pests, "gene leakage" to outside croplands producing super weeds, shrinking lakes and falling groundwater tables, and others....)

Biomass production and nitrogen recovery

- Producing bioenergy crops without competing with food and feed crops
- Addressing pervasive non-point source pollution and GHG emissions from agriculture at the same time

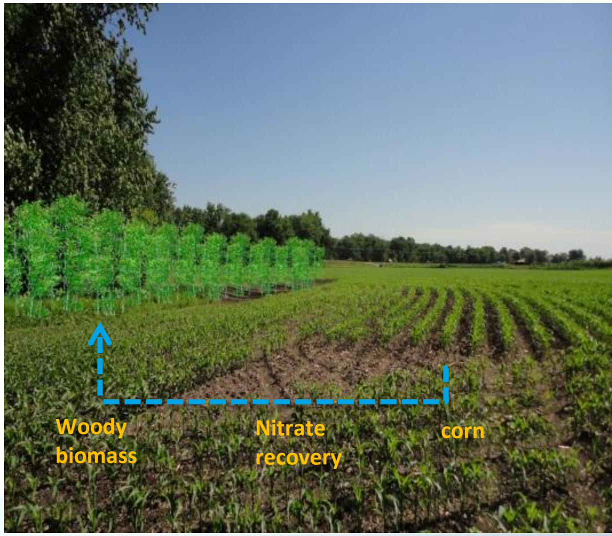
Share of GHG Emissions for Corn Ethanol
(total of 5,630 g/gal, with co-product credits)

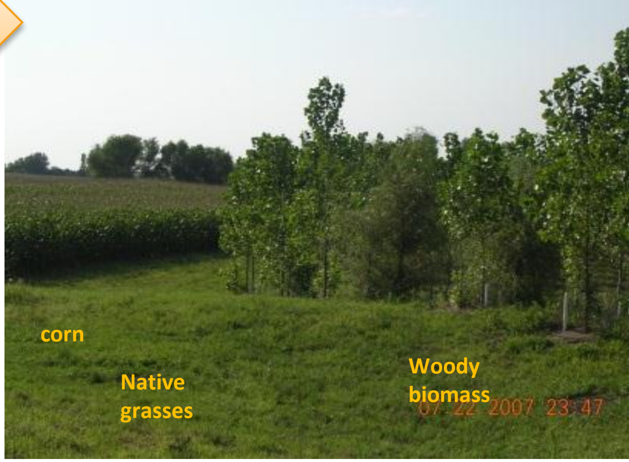


Source: GREET

Algal blooms from excess nutrients

Source: USEPA





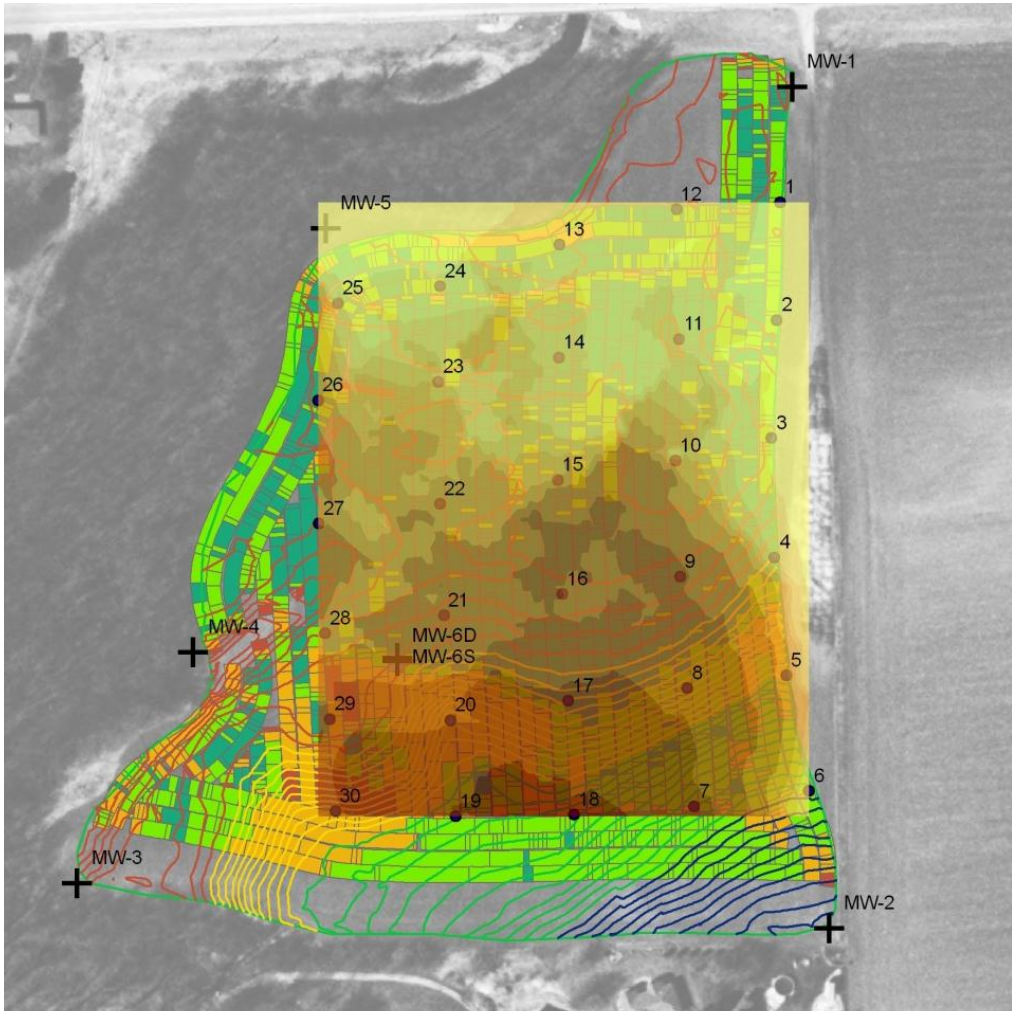
Potential production and feedstock intensification from “marginal”land

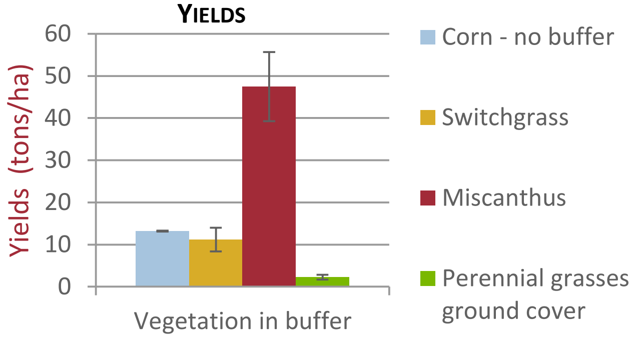
Negri et al., ANL, DOE OBP Program Review, obpreview2011.govtools.us/.

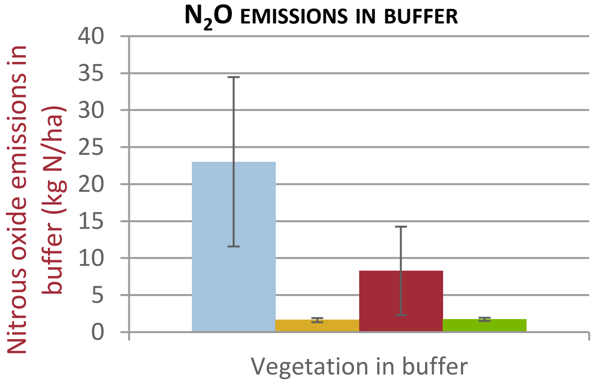
Biomass mitigating nitrate transport 4 ft under a corn field

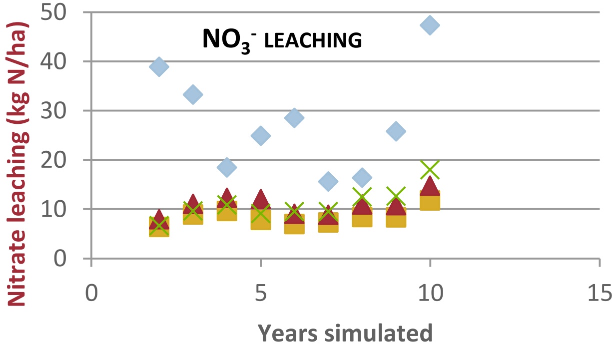
Landscape placement of biomass crop for by-design sustainability.

DNDC model results and field validation in Fairbury, IL









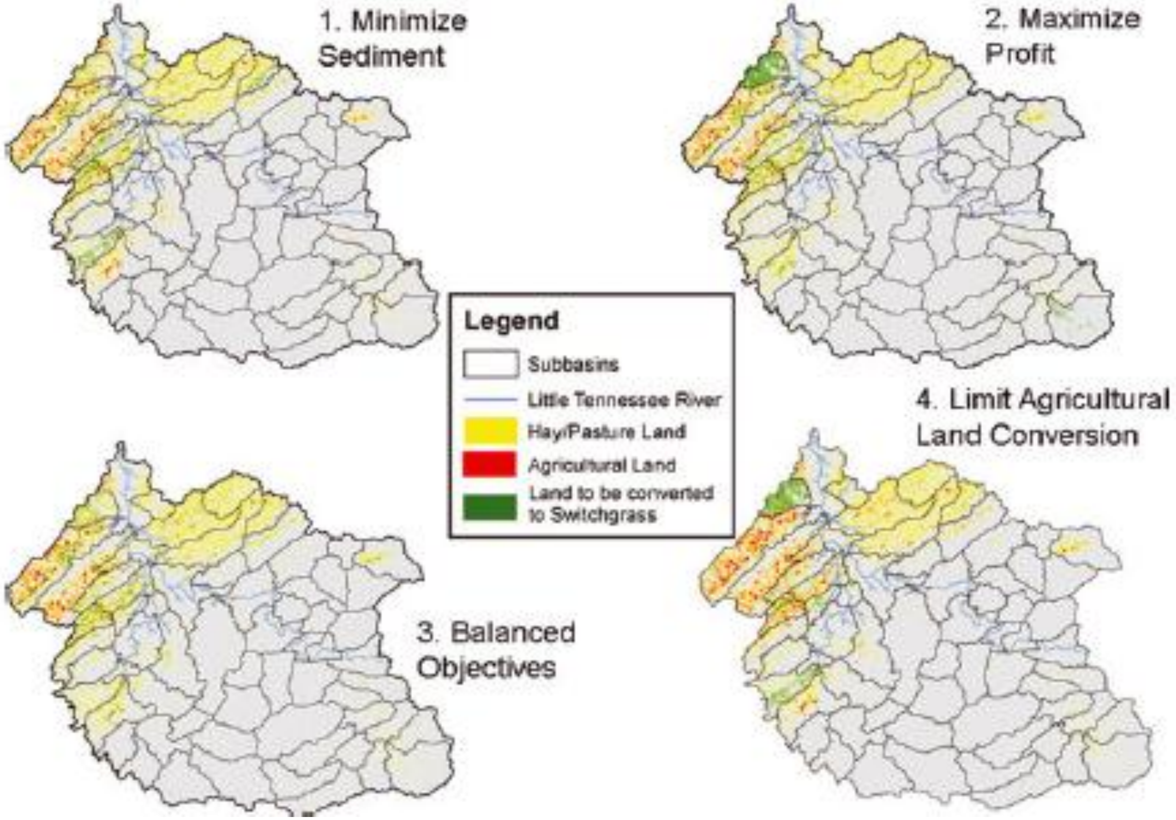
Negri et al., ANL, DOE OBP Program Review, obpreview2011.govtools.us/

An optimization model can identify “ideal” sustainability conditions for new feedstocks and conversion plants

Spatial optimization model

- Identifies where to locate plantings of bioenergy crops given feedstock needs for Vonore, TN cellulosic biofuel refinery

- Considering
  - –Farm profit
  - –Water quality constraints



Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Parish et al. Biofuels, Bioprod. Bioref. 6:58–72 (2012)



RE costs are still higher than existing energy prices, but in various settings RE is already competitive.

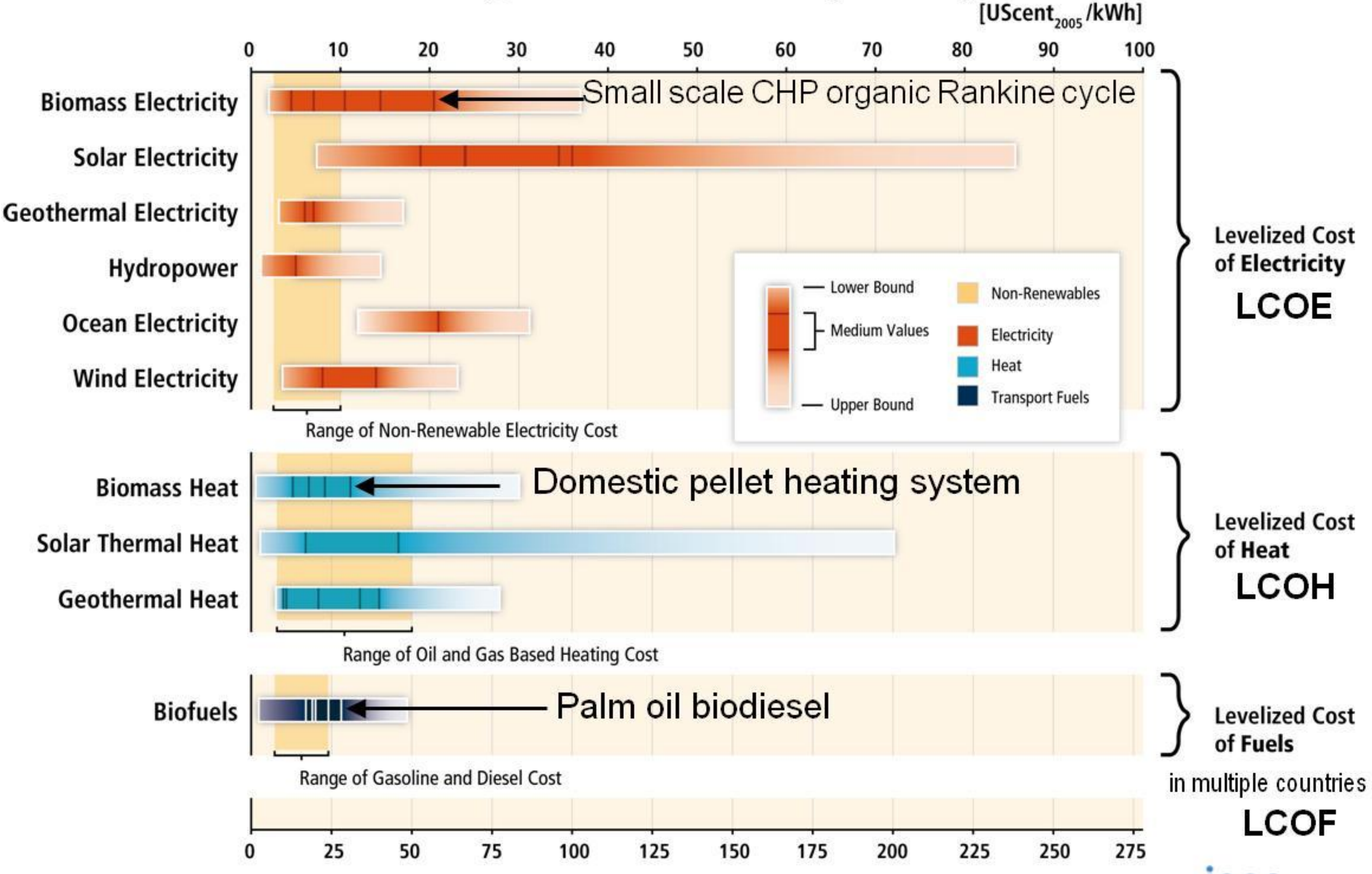
SRREN
Annex II

1st time that IPCC assembles comparative costs of all renewables and, in particular, with multiple biomass options to electricity, heat and electricity, biofuels and some biorefineries.

"The levelized cost of energy represents the cost of an energy generating system over its lifetime; it is calculated as the per-unit price at which energy must be generated from a specific source over its lifetime to break even. It usually includes all private costs that accrue upstream in the value chain, but does not include the downstream cost of delivery to the final customer; the cost of integration, or external environmental or other costs. Subsidies and tax credits are also not included."

Rich Bain, Helena Chum, NREL
Contributor at IPCC TSU: Steffen Schlömer
Contributor: Jose Moreira

RE costs are still higher than existing energy prices, but in various settings RE is already competitive.



Small scale CHP organic Rankine cycle

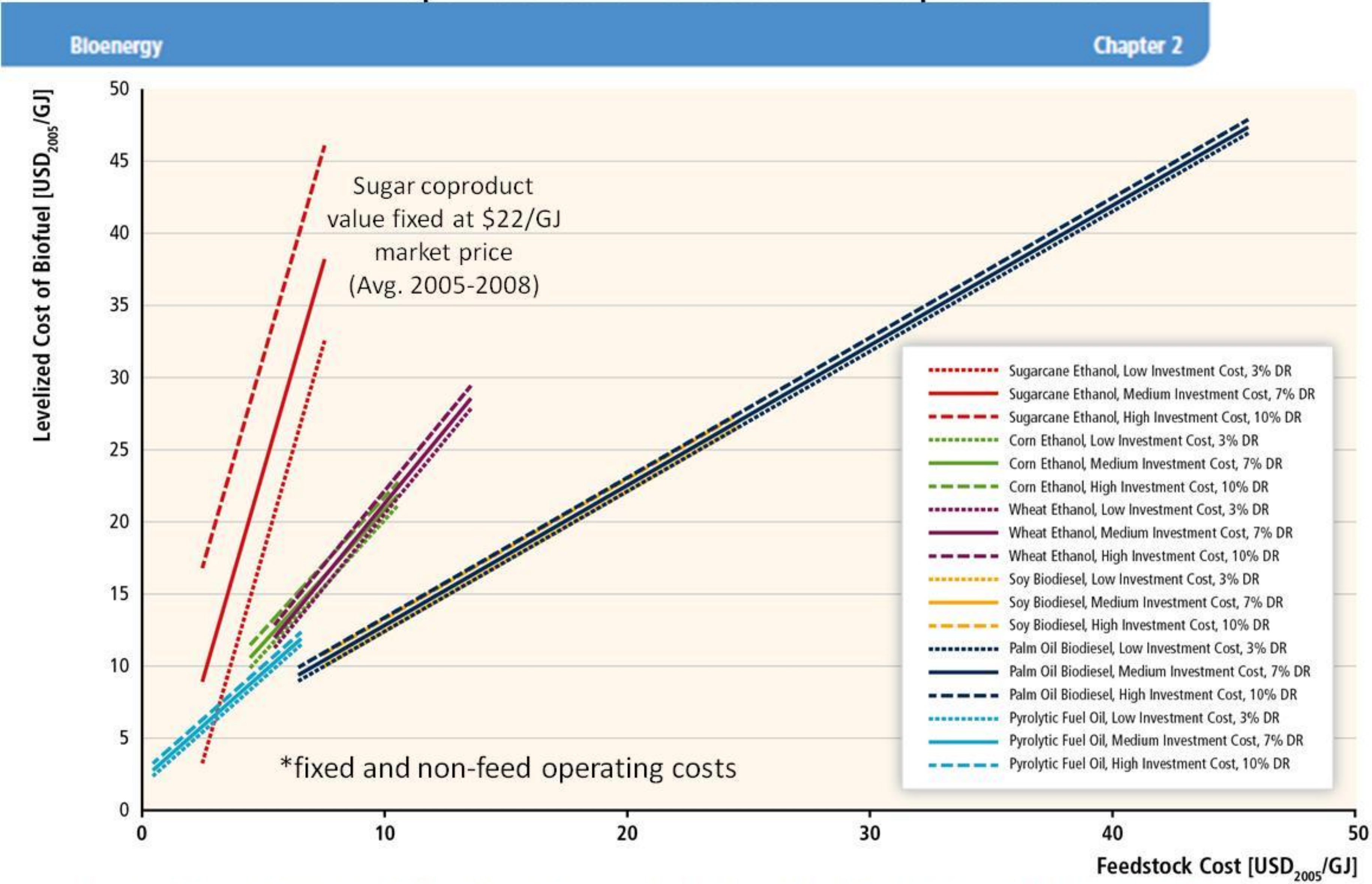
Domestic pellet heating system

Palm oil biodiesel

ipcc
INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

LCOF sensitivity to feedstock/investment costs and discount rate for midpoints of other variables* in multiple countries

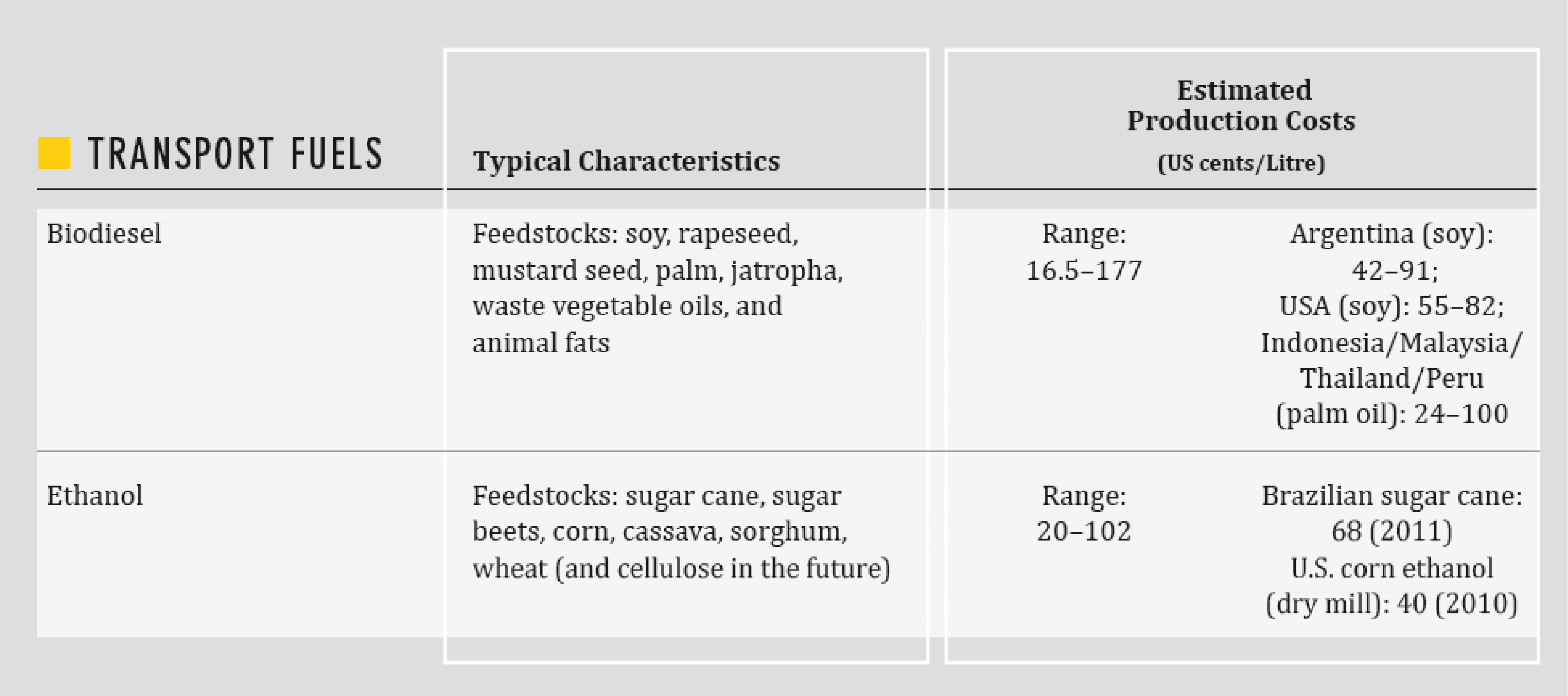


Sugar coproduct
value fixed at $22/GJ
market price
(Avg. 2005-2008)

*fixed and non-feed operating costs

References: Delta-T Corporation (1997); Sheehan et al. (1998b); McAloon et al. (2000); Rosillo-Calle et al. (2000); McDonald and Schrattenholzer (2001); Ibsen et al. (2005); Jechura (2005); Bohlmann (2006); CBOT (2006); Haas et al. (2006); Olverio (2006); Olverio and Ribeiro (2006); Ringer et al. (2006); Shapouri and Salassi (2006); USDA (2006); Bain (2007); Kline et al. (2007); USDA (2007); Alfstad (2008); RFA (2011); University of Illinois (2011).

2011 Biofuels estimated production costs



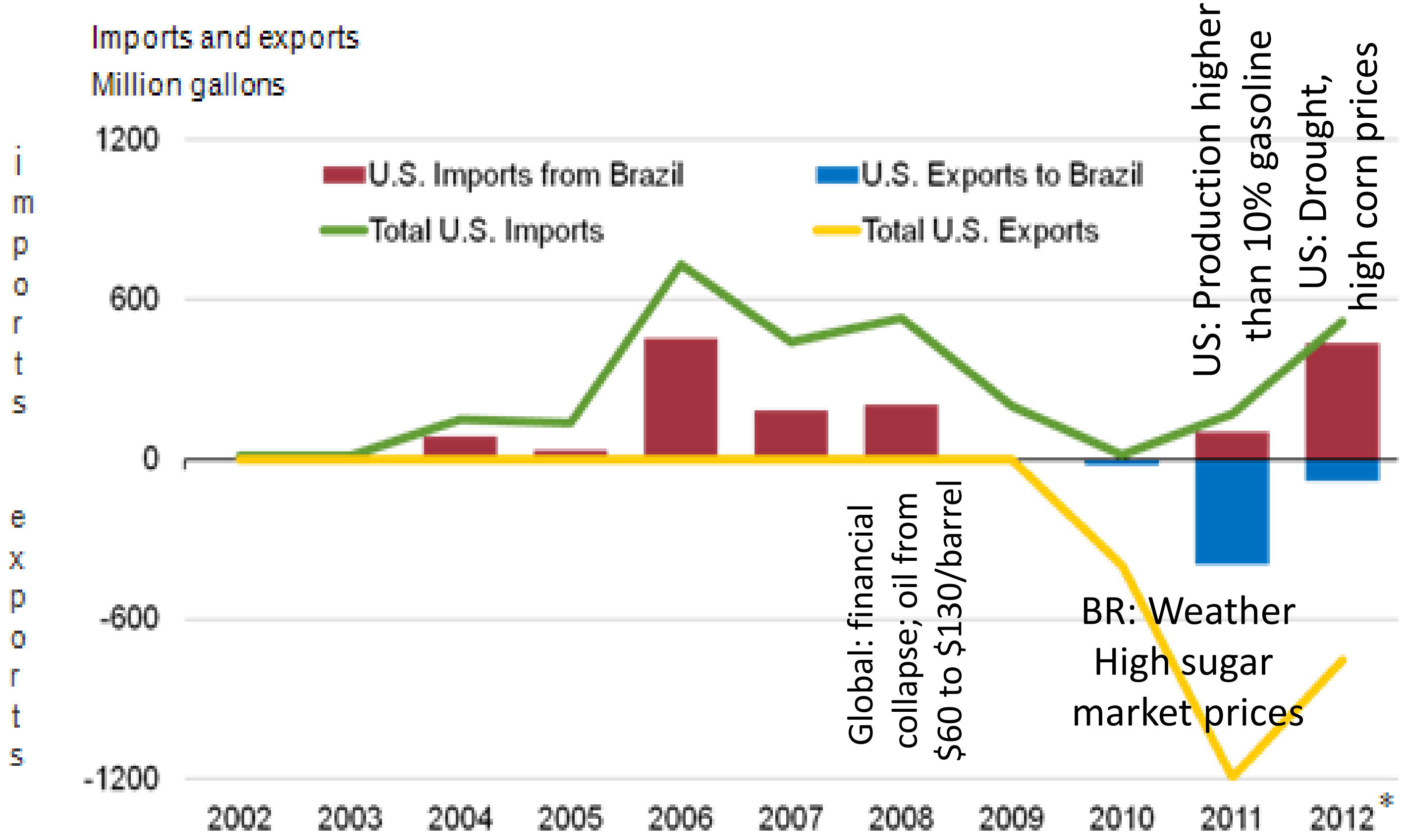
TRANSPORT FUELS	Typical Characteristics	Estimated Production Costs (US cents/Litre)	
Biodiesel	Feedstocks: soy, rapeseed, mustard seed, palm, jatropha, waste vegetable oils, and animal fats	Range: 16.5–177	Argentina (soy): 42–91; USA (soy): 55–82; Indonesia/Malaysia/ Thailand/Peru (palm oil): 24–100
Ethanol	Feedstocks: sugar cane, sugar beets, corn, cassava, sorghum, wheat (and cellulose in the future)	Range: 20–102	Brazilian sugar cane: 68 (2011) U.S. corn ethanol (dry mill): 40 (2010)

REN21 Renewable Energy Policy Network for the 21st Century

RENEWABLES 2012
GLOBAL STATUS REPORT

Commoditization of Biofuels

Biofuels reached some insurance of supplies through trade
Biofuels are 3% of global road transport fuels (energy basis)



Global: financial collapse; oil from $60 to $130/barrel

BR: Weather
High sugar
market prices

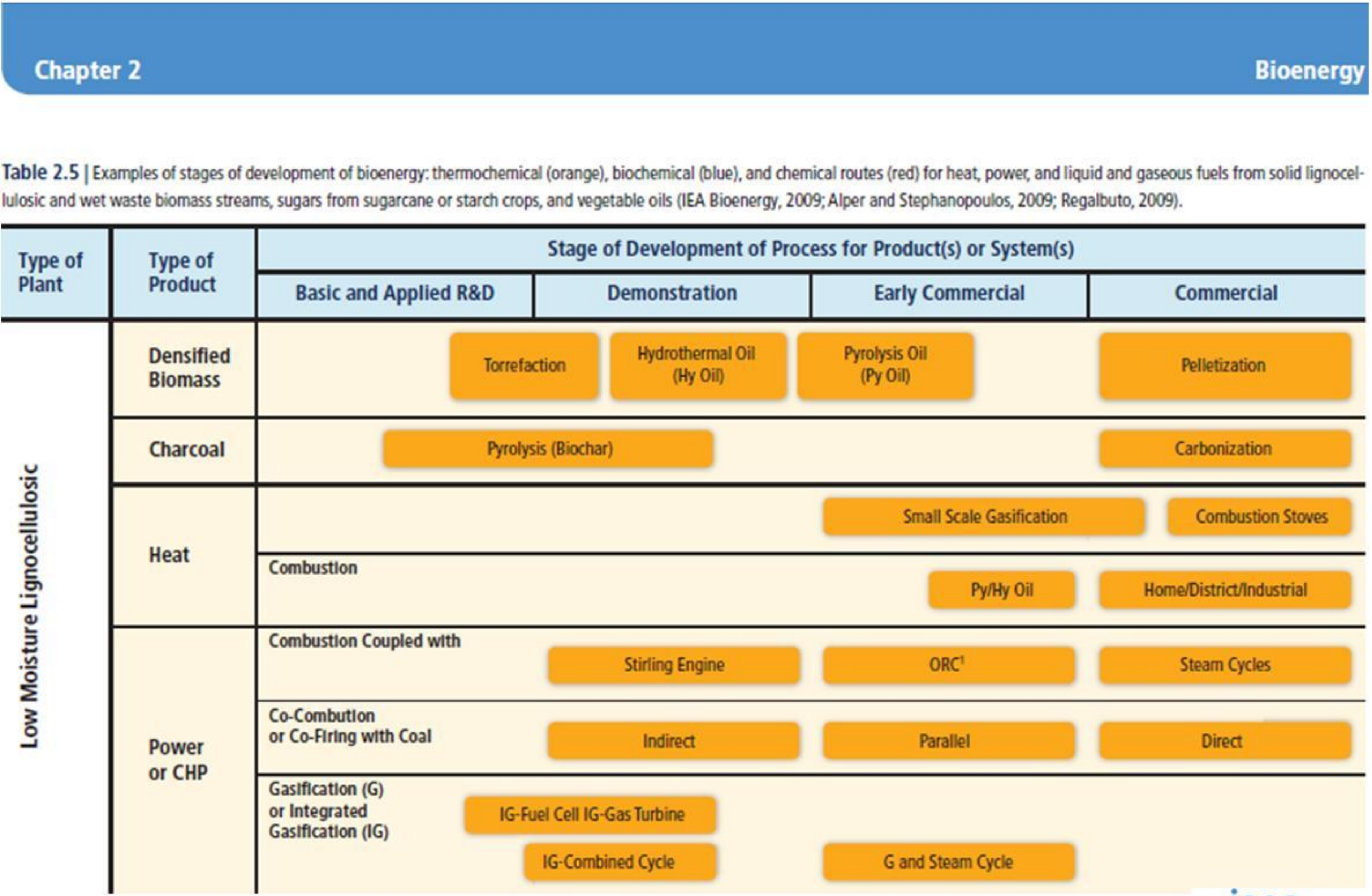
US: Production higher than 10% gasoline

US: Drought, high corn prices

*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.

Complex set of options - approximate development stages (I)



Chapter 2 **Bioenergy**

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)

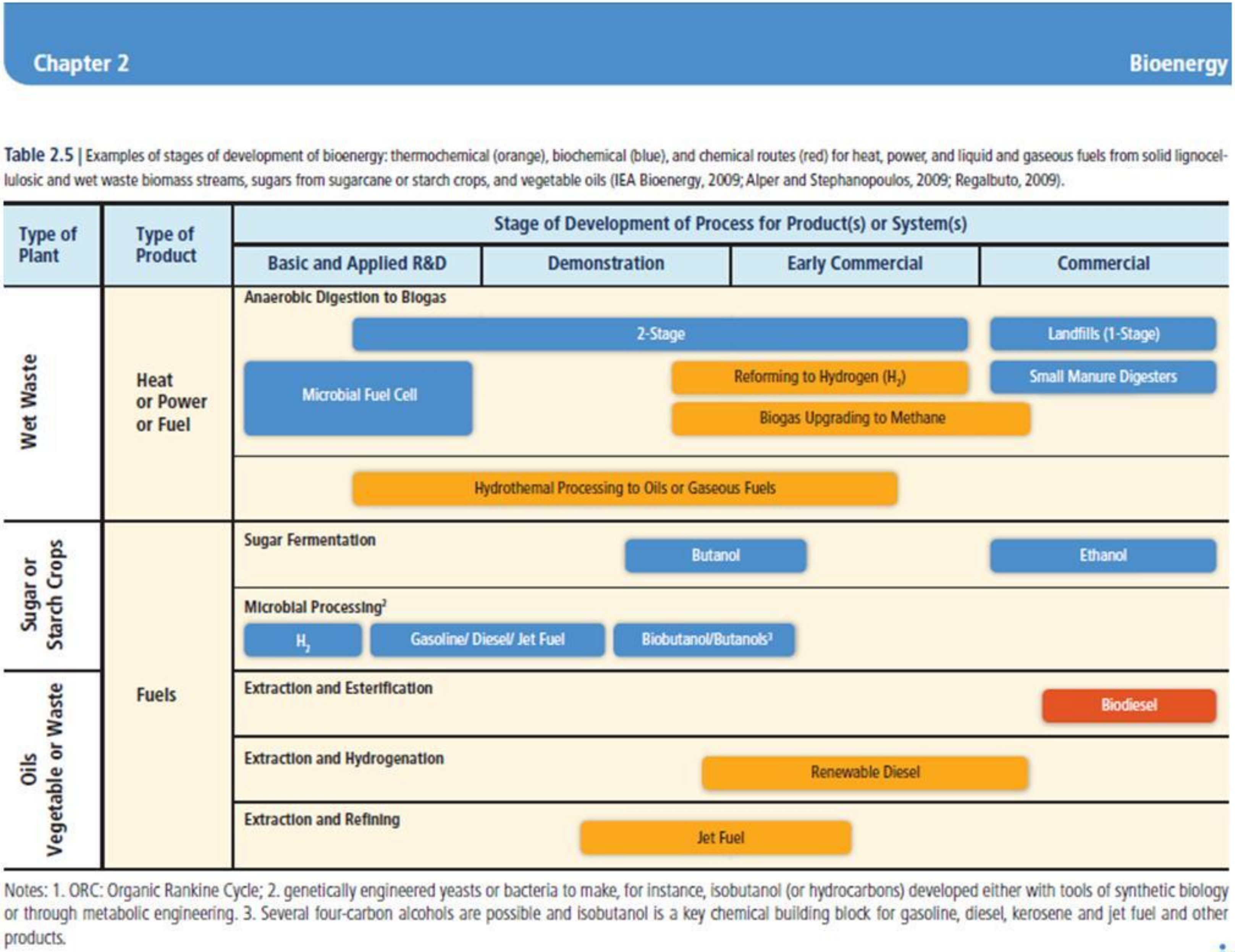


Table 2.5 | Examples of stages of development of bioenergy: thermochemical (orange), biochemical (blue), and chemical routes (red) for heat, power, and liquid and gaseous fuels from solid lignocellulosic and wet waste biomass streams, sugars from sugarcane or starch crops, and vegetable oils (IEA Bioenergy, 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**			
		2-Stage			Landfills (1-Stage)
		Microbial Fuel Cell	Reforming to Hydrogen (H_2)		Small Manure Digesters
			Biogas Upgrading to Methane		
		Hydrothemal 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]		
Vegetable or Waste Oils		**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.

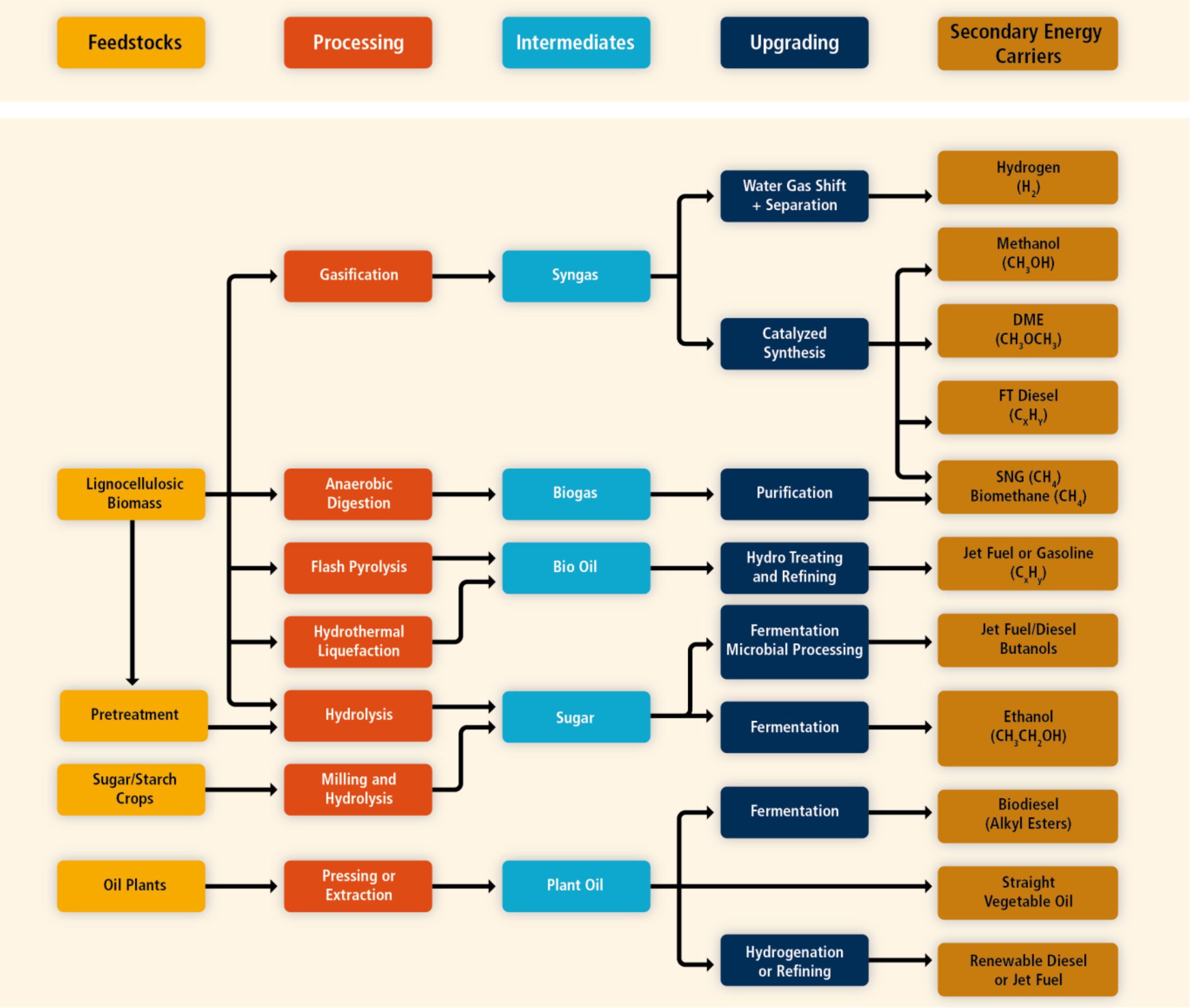
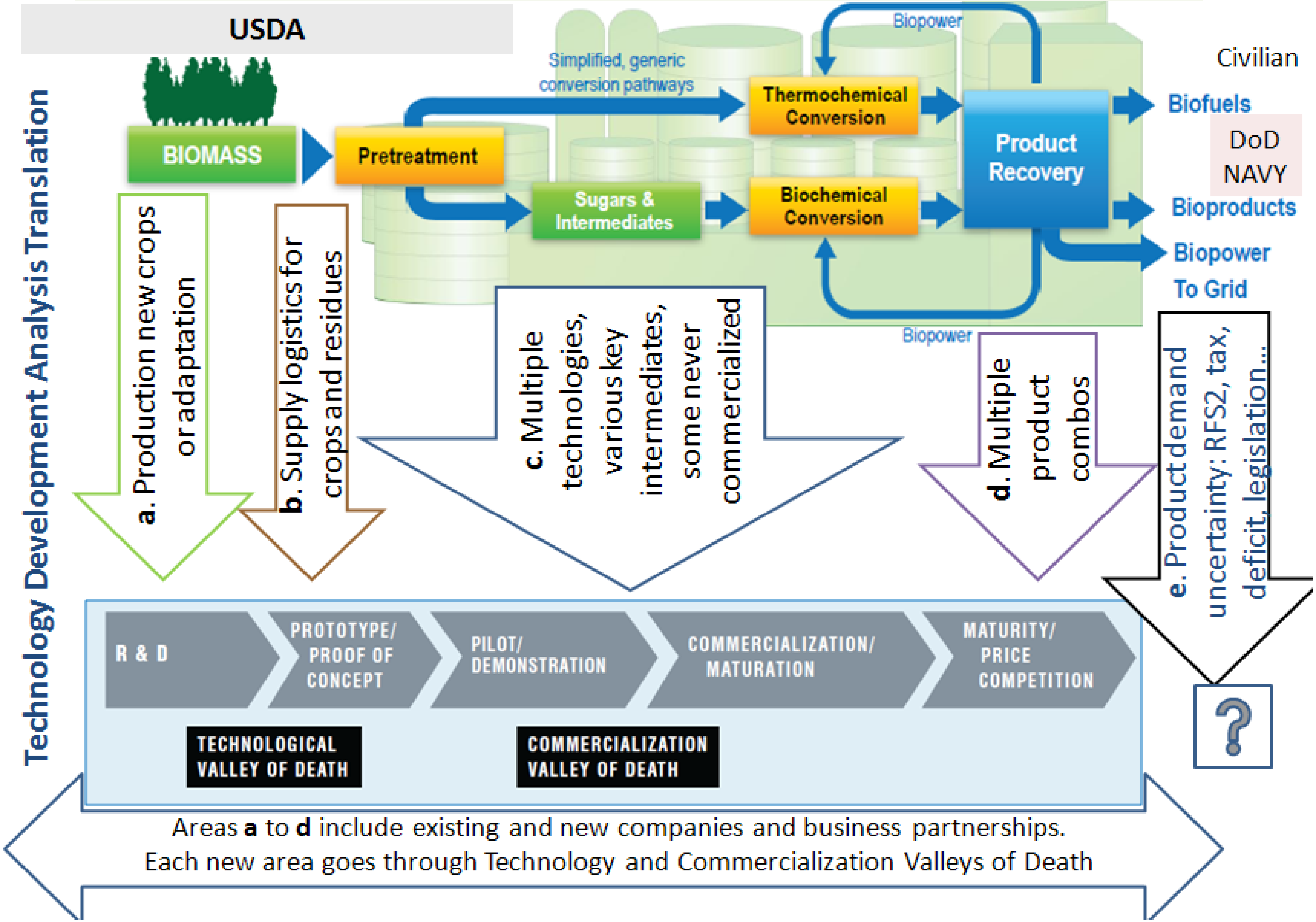


Figure 2.16 | Overview of lignocellulosic biomass, sugar/starch crops and oil plants (feedstocks) and the processing routes to key intermediates, which can be upgraded through various routes to secondary energy carriers, such as liquid and gaseous biofuels. Fuel product examples are (1) oxygenated biofuels to blend with current gasoline and diesel fuels or to use in pure form, such as ethanol, butanols, methanol, liquid ethers, biodiesel, and gaseous DME (dimethyl ether); (2) hydrocarbon biofuels such as Fischer Tropsch (FT) liquids, renewable diesel and some microbial fuels (which are compatible with the current infrastructure of liquid fuels because their chemical composition is similar to that of gasoline, diesel, and jet fuels (see Table 2.15.C)), or the simplest hydrocarbon methane for natural gas replacement (SNG) from gasification or biomethane from anaerobic digestion; and (3) H_2 for future transportation (adapted from Hamelinck and Faaij, 2006 and reproduced with permission from Elsevier B.V.).

Notes: Microbial fuels include hydrocarbons derived from isoprene, the component of natural rubber; a variety of non-fermentative alcohols with three to six carbon atoms including butanols (four carbons); and fatty acids which can be processed as plant oils to hydrocarbons (Rude and Schirmer, 2009).[1] For sugar and starch crops the sugar box indicates six-carbon sugars, while for lignocellulosic biomass this box is more complex and has mixtures of six- and five-carbon sugars, with proportions dependent on the feedstock type. Hardwoods and agricultural residues contain xylan and other polymers of five-carbon sugars in addition to cellulose that yield glucose, a six-carbon sugar.

1. Not shown are the aquatic plants (see Section 2.6.1.2) that can utilize the same types of processing shown for their vegetable oil and carbohydrate fractions.

US DOE EERE Porfolio Integrated Biorefineries



USDA

Technology Development Analysis Translation

BIOMASS

Pretreatment

Simplified, generic conversion pathways

Thermochemical Conversion

Sugars & Intermediates

Biochemical Conversion

Biopower

Product Recovery

Biopower

Civilian

Biofuels

DoD
NAVY

Bioproducts

Biopower To Grid

a. Production new crops or adaptation

b. Supply logistics for crops and residues

c. Multiple technologies, various key intermediates, some never commercialized

d. Multiple product combos

e. Product demand uncertainty: RFS2, tax, deficit, legislation…

R & D

PROTOTYPE/ PROOF OF CONCEPT

PILOT/ DEMONSTRATION

COMMERCIALIZATION/ MATURATION

MATURITY/ PRICE COMPETITION

?

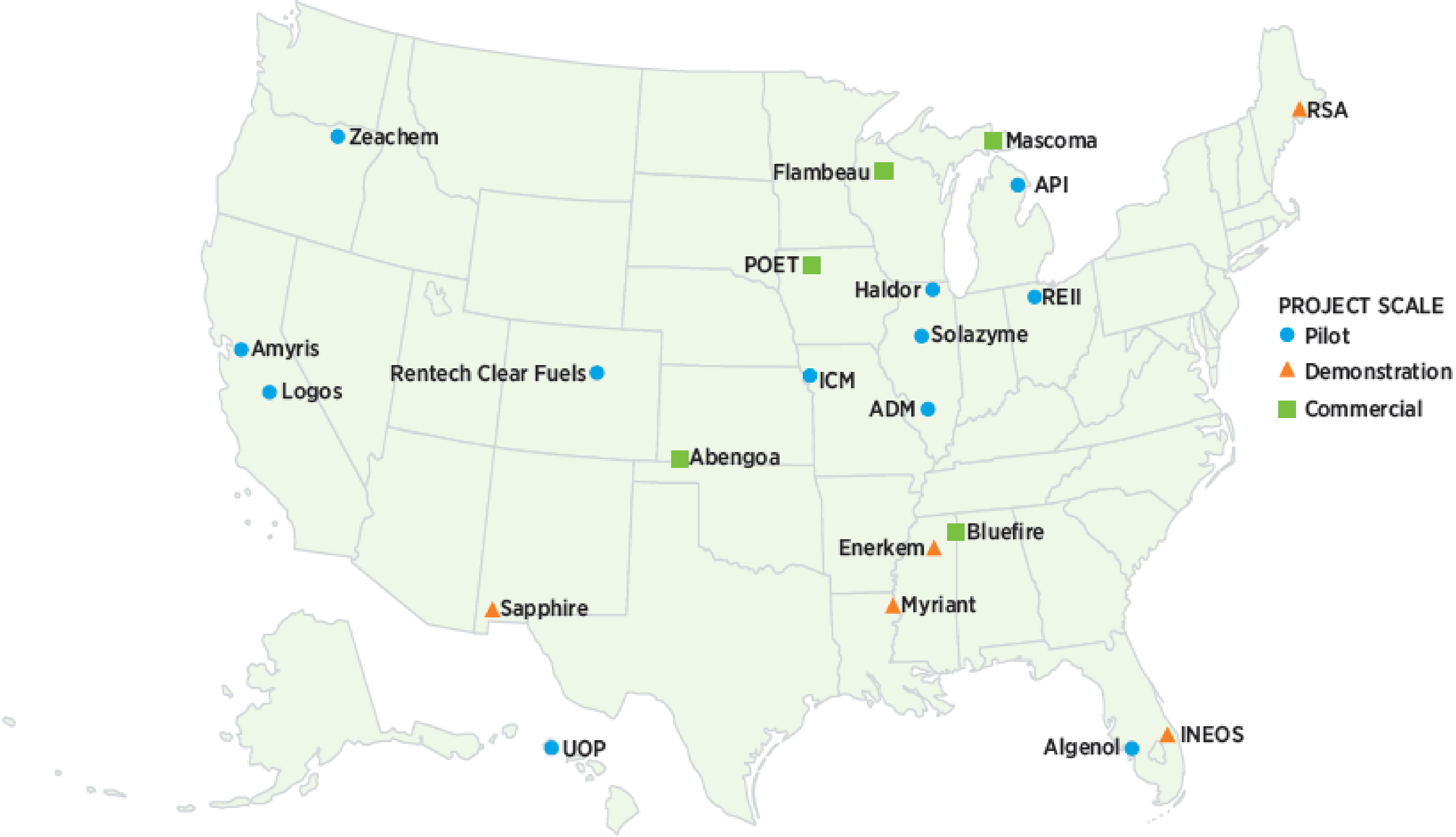
TECHNOLOGICAL VALLEY OF DEATH

COMMERCIALIZATION VALLEY OF DEATH

Areas **a** to **d** include existing and new companies and business partnerships.
Each new area goes through Technology and Commercialization Valleys of Death

Generic technology development pipeline, shown inside the light blue box, applies to multiple technology “pipelines” spanning the value chain exemplified by components (arrows) a, b, c, d. Components a through d generate, upon integration, a large number of possible development options. Coalitions or partnerships across the value chain(s) are evaluating options for continued investment. Interagency cooperation is enabling addressing technology and commercialization barriers. Supply chain component e is an area of concern.

Integrated Biorefinery Projects at Progressive Scales



Some Lessons Learned

- Technology development in conjunction with appropriate business models and financing mechanisms from government and private sector in partnership can lead to new and expand existing companies, economic growth, diversify fuels and energy sources, decrease fossil fuel reliance in transport, while caring for the environment.
- Supportive (and constant) policies have been and continue to be essential including for RD&D, support through the Valley of Death of technologies, first-of-a-kind commercialization of replicable projects, and still need to go through the commercialization Valley of Death.
- Sustainability needs to be addressed throughout the stages of development. Impacts across project, region, national and global level and at different times make analyses of impacts difficult. Multiple government organizations and stakeholders are involved.
- Integration of feedstock development, logistics, conversion to products and their use is essential. Many failures and delays resulted from underestimated difficulty of setting the whole supply chain.
- Balancing different markets/volumes/and quality requirements of feedstocks is a challenge and an opportunity for biorefineries.

Some SRREN Key conclusions (I)

- Bioenergy has significant potential to mitigate greenhouse gases if resources are sustainably developed and efficient technologies are applied.

- “For the increased and sustainable use of bioenergy, proper design, implementation and monitoring of sustainability frameworks can minimize negative impacts and maximize benefits with regard to social, economic and environmental issues.”

Some SRREN Key conclusions (II)

- **The impacts and performance of biomass production and use are region- and site-specific.**

Key options examples:

- Sugarcane ethanol production, waste to-energy systems, efficient cookstoves, biomass-based CHP are competitive
- Lignocellulosic based process heat and space heating in the near term partially substitute fossil fuels; biofuels and bioelectricity options, and biorefinery concepts can offer competitive deployment of bioenergy post 2020
- Bio-Carbon Dioxide Capture and Storage can offer negative carbon emissions when technologies are developed.
- New biomaterials are promising but less understood.
- Potential role aquatic biomass (algae) highly uncertain.

- **Rapidly changing policy contexts, recent market activity, increasing support for advanced biorefineries & lignocellulosic biofuel options, and in particular the development of sustainability criteria and frameworks, push bioenergy systems and their deployment in sustainable directions.**

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- IPCC SRREN Chapter 2 and Annex II contributors
- IEA Bioenergy Agreement Strategic Project: Monitoring Sustainability Certification of Bioenergy Collaborators

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
  http://www1.eere.energy.gov/biomass/pdfs/mypp_november_2012.pdf
  http://maps.nrel.gov/bioenergyatlas/
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