The IPCC Special Report on Renewable Energy Sources and Climate Change (CC) Mitigation

Bioenergy Chapter

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In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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★ Bioenergy CLAs

IPCC publishes Special Report on Renewable Energy Sources and Climate Change Mitigation

Potsdam, 11 May 2011 - By 2050, a maximum of 77 percent of the world's energy supply could be provided from renewable energy sources. The share of renewable energy in the future global energy mix differs substantially among scientific scenarios….A comprehensive review by the IPCC outlines the large potential of renewable energy sources to mitigate emissions of greenhouse gases and anthropogenic climate change. Special Report on Renewable Energy Sources and Climate Change Mitigation' (SRREN) has been approved by government representatives for IPCC member countries at the **11th Session of Working Group III** in Abu Dhabi, United Arab Emirates.

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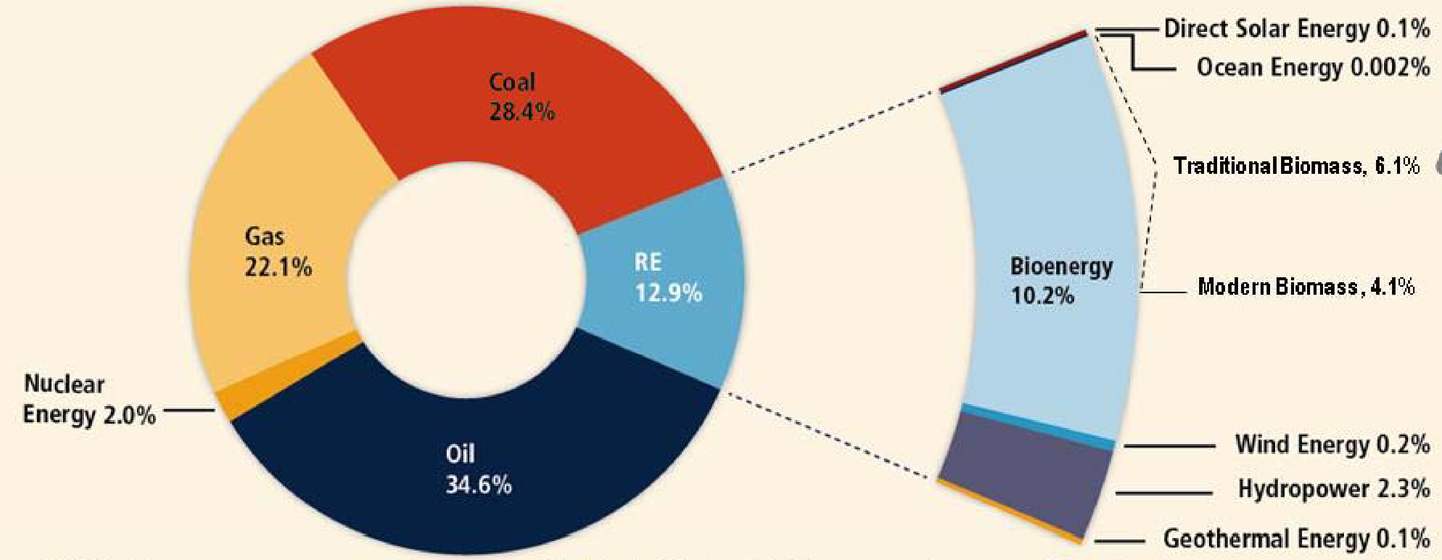
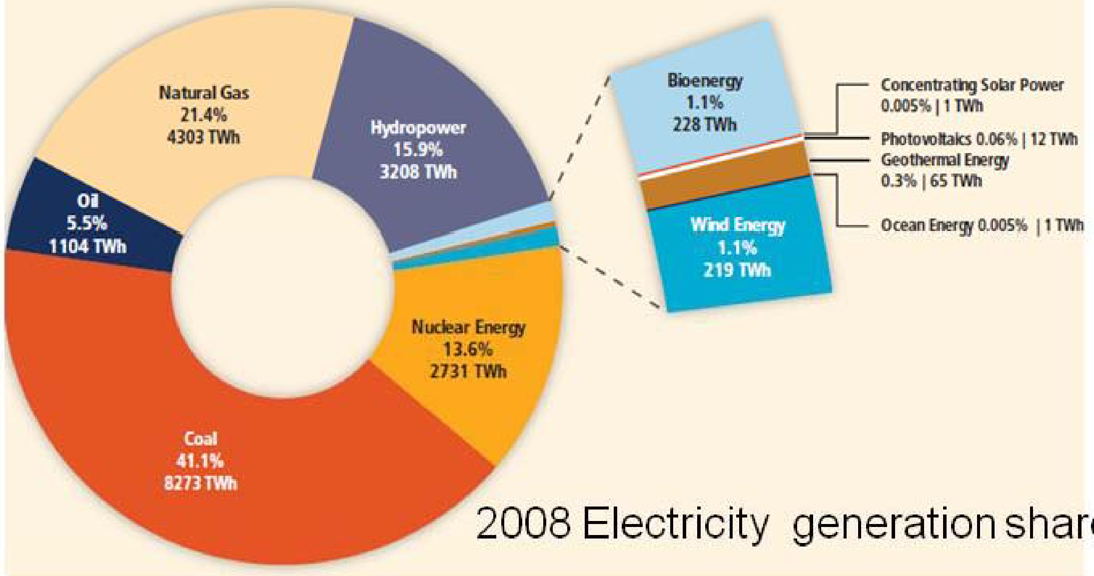
http://srren.ipcc-wg3.de/report

The current global energy system is dominated by fossil fuels

Biomass consumption in the residential sector in developing countries. Refers to the often unsustainable use for cooking and heating



2008 Energy sources shares of Total Global Primary Energy Supply



2008 Electricity generation shares

2008 Heat Demand:

All renewables share: 27%
- Traditional biomass 17%
- Modern biomass 8%
- Solar thermal/geothermal 2%

2008 Global Road Transport Fuel Demand:

- Biofuels share 2%

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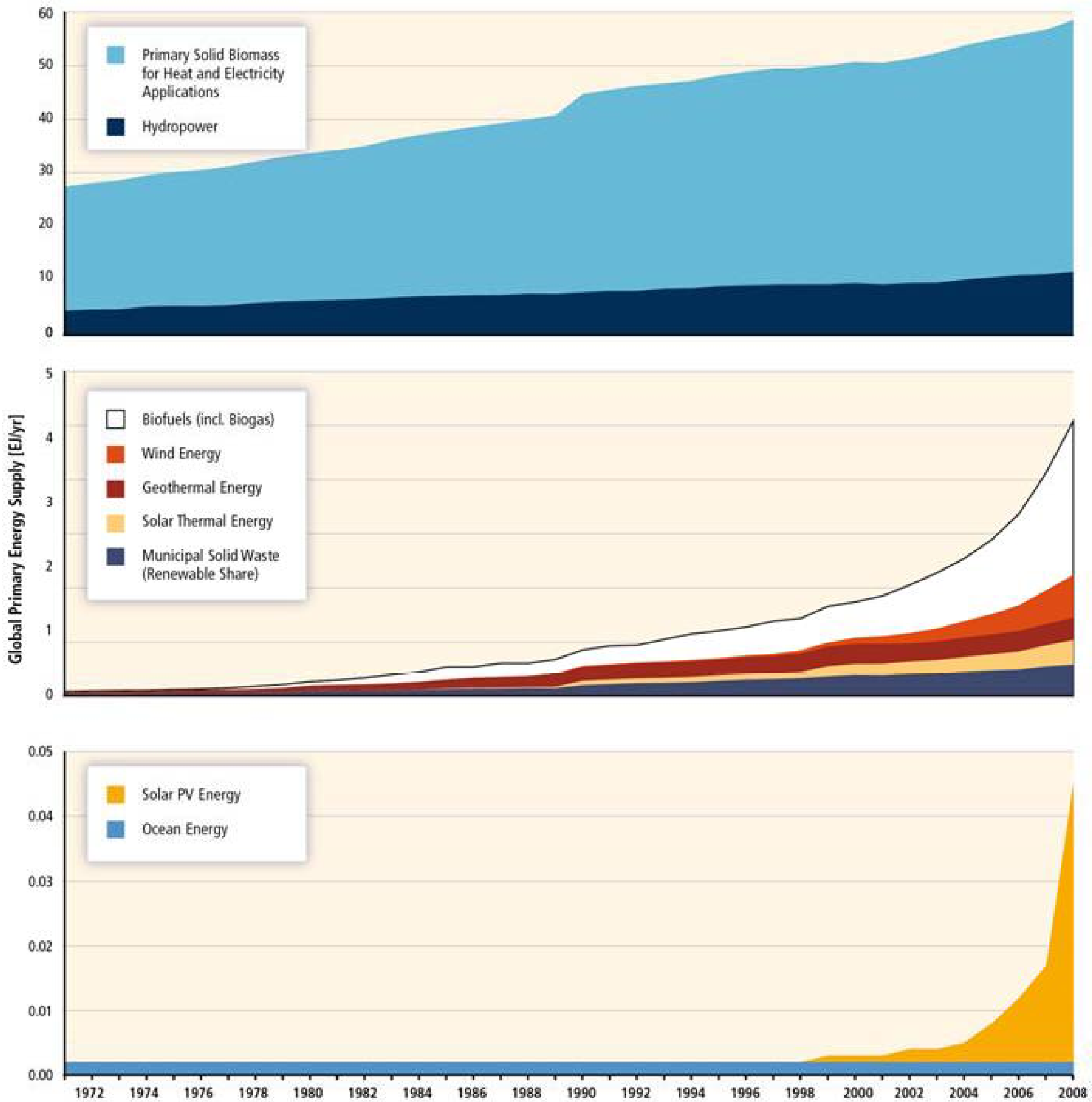
WMO UNEP

RE growth has been increasing rapidly in recent years.



140 GW of new RE power plant capacity was built in 2008-2009.

This equals 47% of all power plants built during that period.

- In 2009 RE capacity additions
- Wind power 32%, 38 GW
- Hydropower 3%, 31 GW
- Grid-connected PV 53%, 7 GW
- Geothermal power 4%, 0.4 GW

-Solar hot water/heating 21%, 31 GWth

- Biofuels – 2009 additions
- Ethanol 10%, 7 billion liters
-Biodiesel 9%, 2 billion liters

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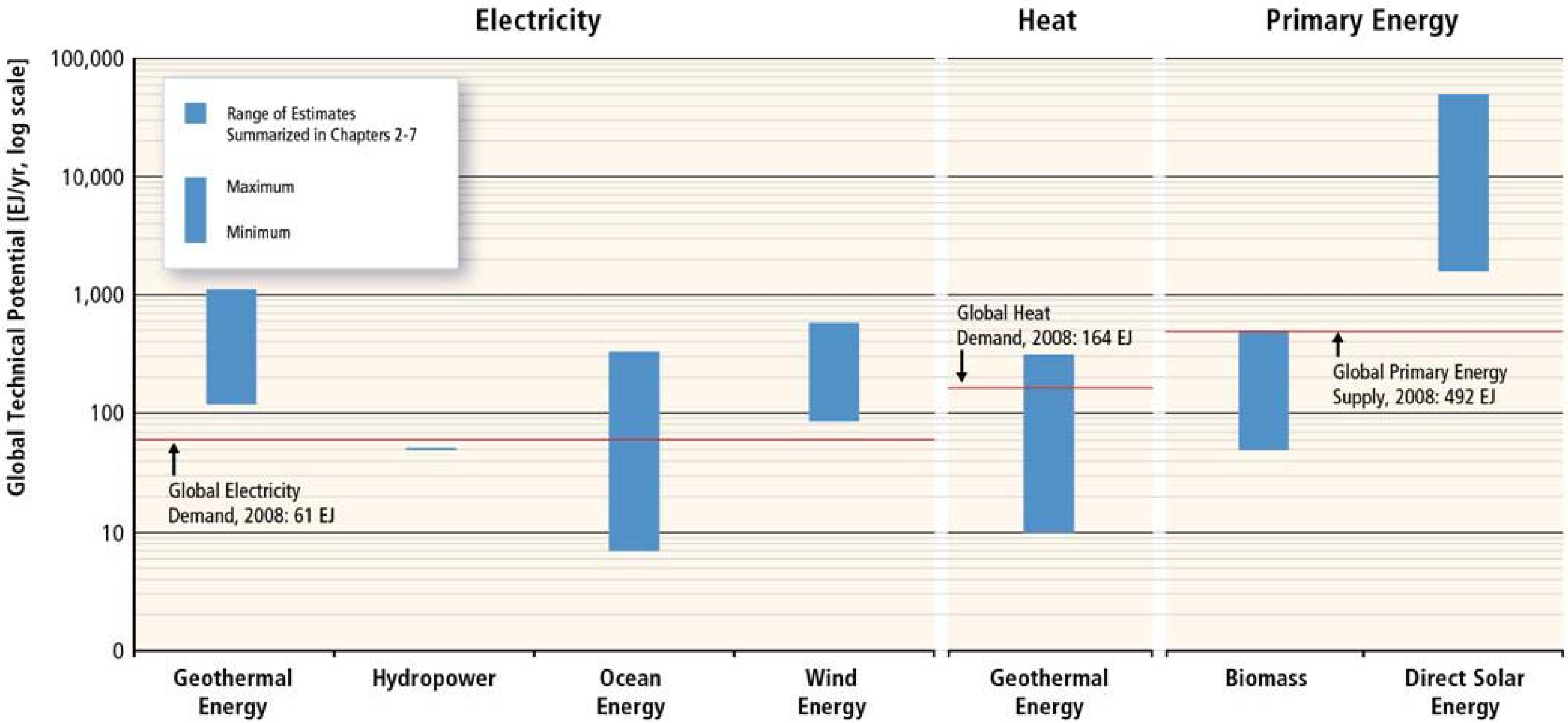
The technical potential of renewable energy technologies to supply energy services exceeds current demands.



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

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Key resource potential relationships

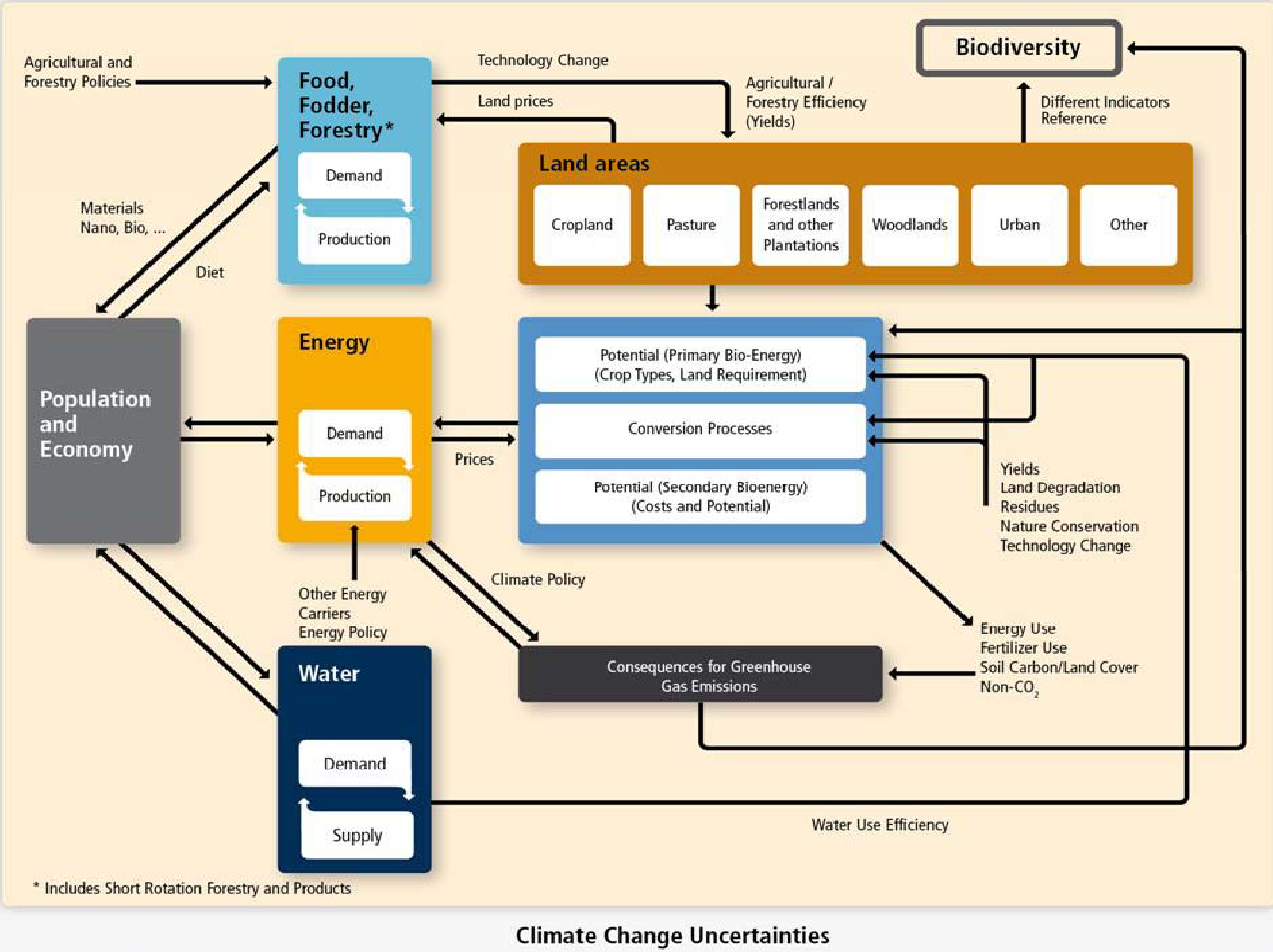
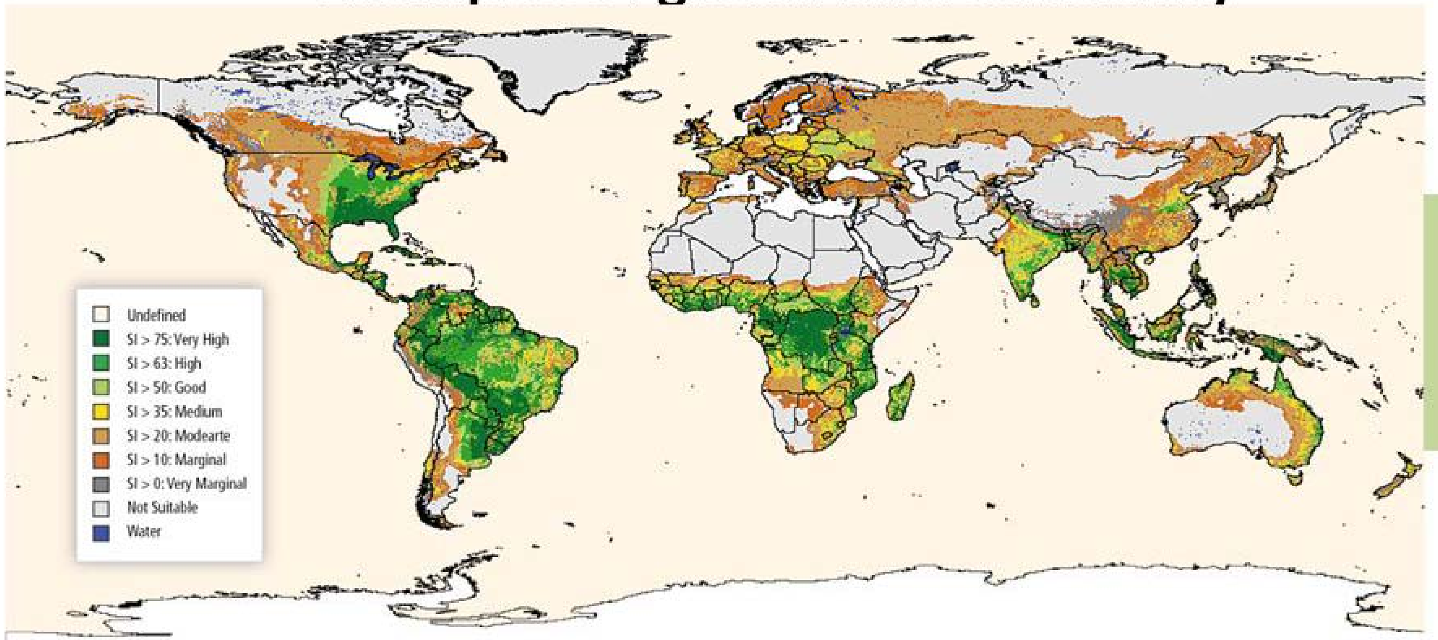
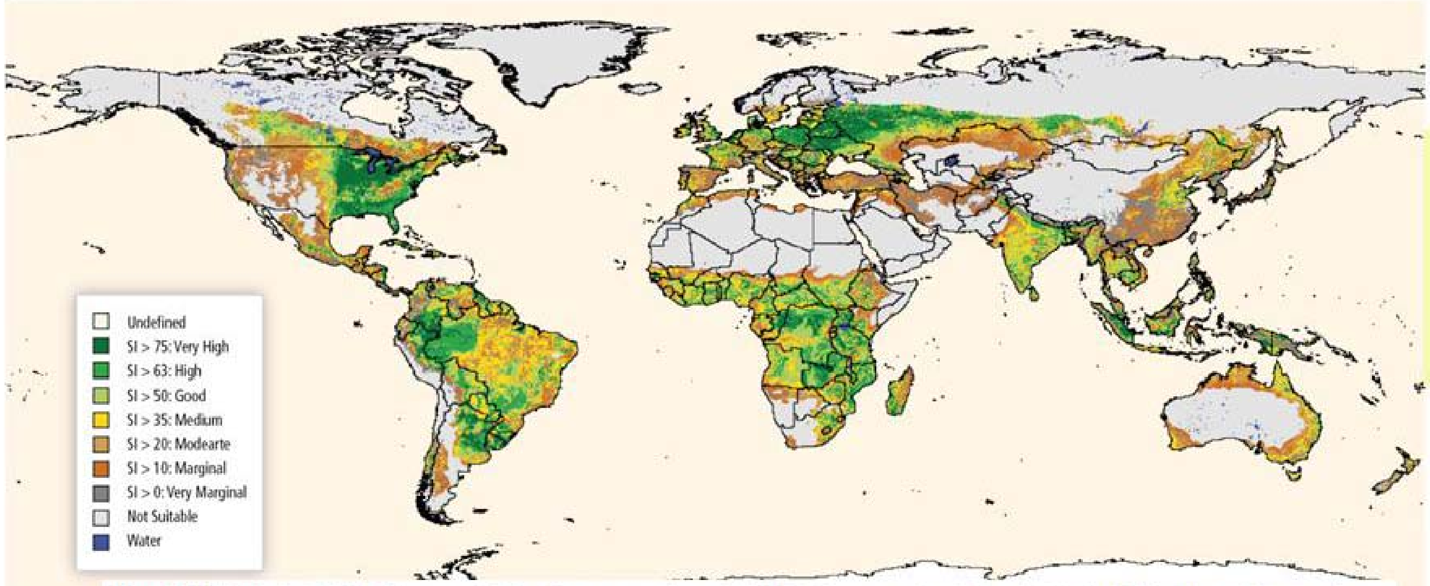


Figure 2.3 | Overview of key relationships relevant to assessment of biomass resource potentials (modified from Dornburg et al., 2010). Indirect land use and social issues are not displayed. Reproduced with permission from the Royal Society of Chemistry.

Examples of global land suitability



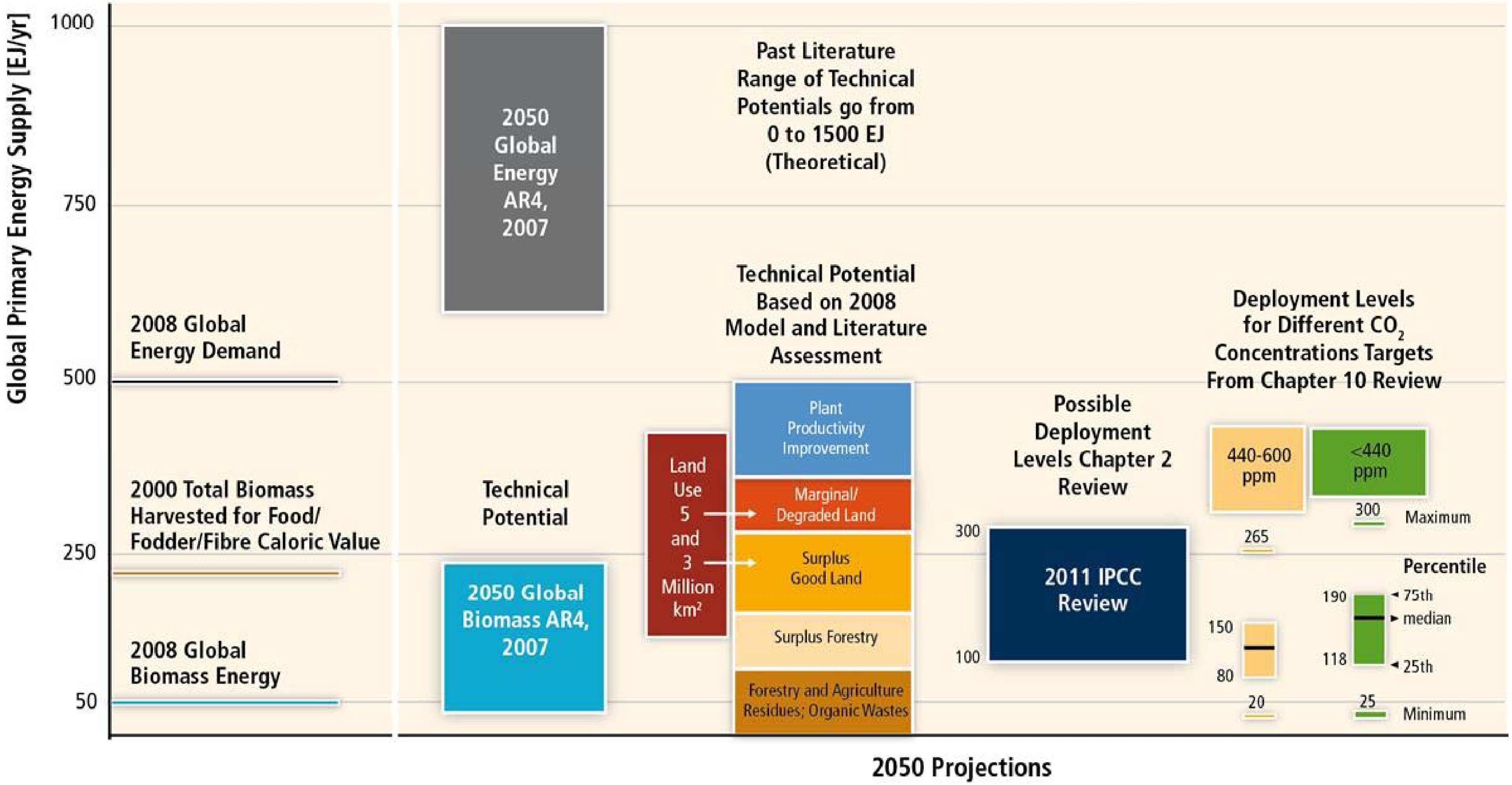
Herbaceous & woody lignocellulosic plants



Annual crops, perennial sugarcane, & jatropha

Figure 2.4 | Global land suitability for bioenergy plantations. The upper map shows suitability for herbaceous and woody lignocellulosic plants (*Miscanthus*, switchgrass, reed canary grass, poplar, willow, eucalyptus) and the lower map shows suitability for first-generation biofuel feedstocks (sugarcane, maize, cassava, rapeseed, soybean, palm oil, *Jatropha*). The suitability index (SI)[1] describes the spatial suitability of each pixel and reflects the match between crop requirements and prevailing climate, soil and terrain conditions. The map shows suitability under rain-fed cultivation and advanced management systems that assume availability of sufficient nutrients, adequate pest control and mechanization, and other practices. Results for irrigated conditions or low-input management systems would result in different pictures (Fischer et al., 2009; reproduced with permission from the International Institute for Applied Systems Analysis (IIASA)).

Terrestrial biomass for energy



- Intensification of agricultural practices and grazing for pasture use could release rain fed agricultural land (100 EJ)
- Significant penetration of bioenergy would require substantial (~x2) global agricultural yield increases
- Terrestrial resource potential assessments lack geo-hydrological modeling
- Aquatic biomass potential may be substantial compared conventional terrestrial energy crops but very uncertain. Yield potential of cultivated of microalgae production can be several fold that of palm oil.

Commercial Bioenergy Routes

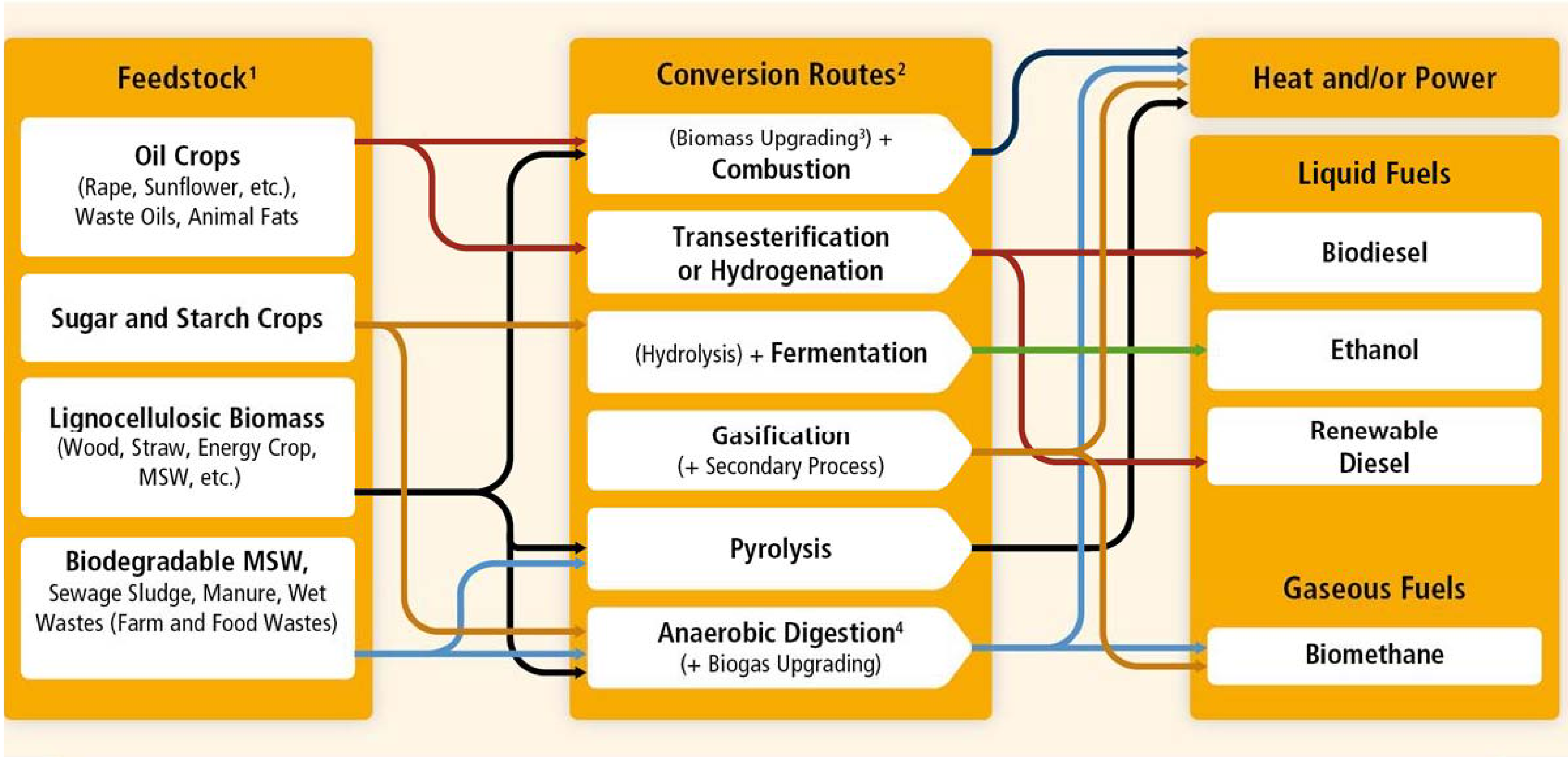
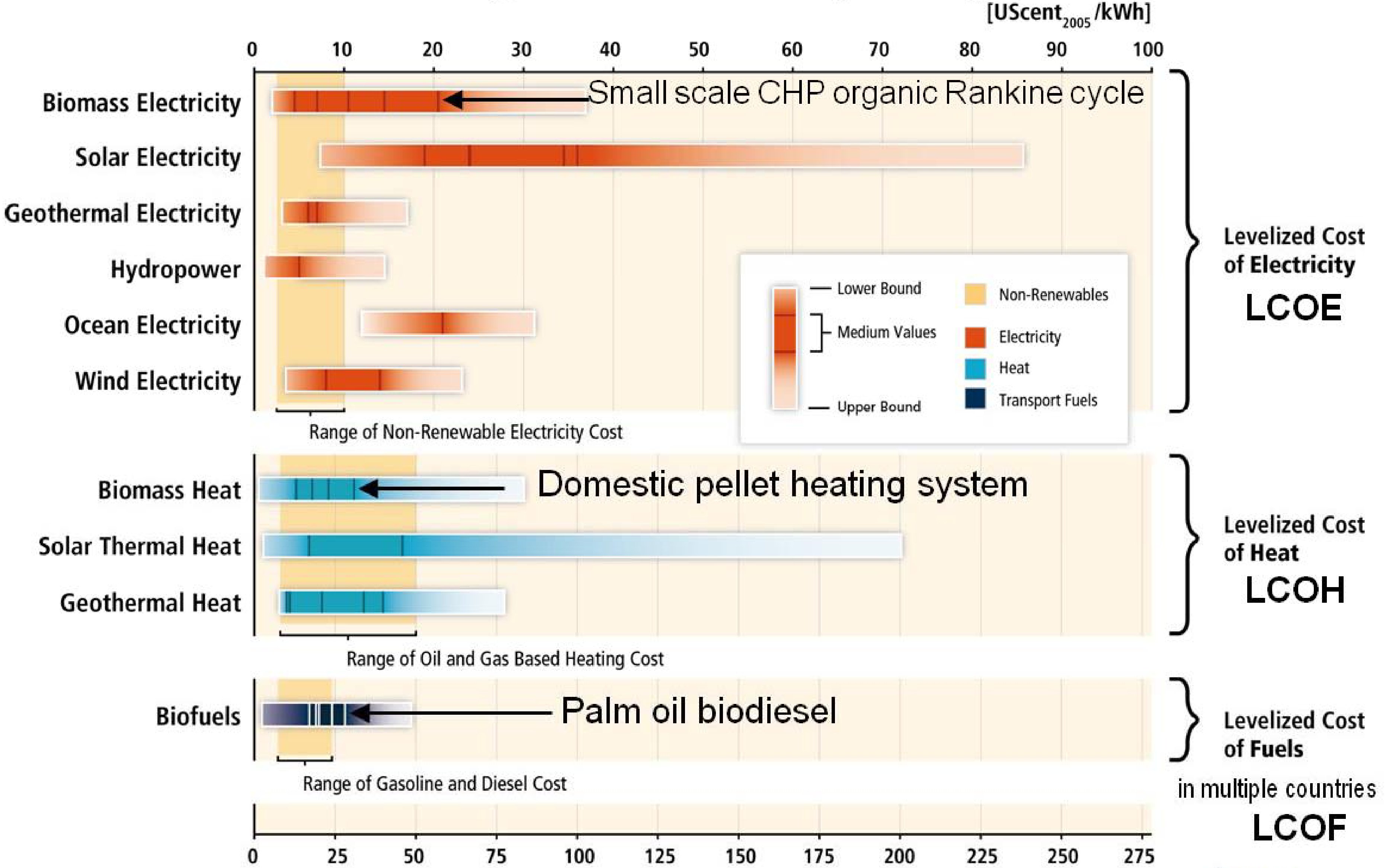


Figure 2.6 | Schematic view of commercial bioenergy routes (modified from IEA, Bioenergy, 2009).

Notes: 1. Parts of each feedstock, for example, crop residues, could also be used in other routes. 2. Each route also gives co-products. 3. Biomass upgrading includes any one of the densification processes (pelletization, pyrolysis, etc.). 4. Anaerobic digestion processes release methane and CO_2 and removal of CO_2 provides essentially methane, the main component of natural gas; the upgraded gas is called biomethane.

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



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

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

Typical levelized cost at 7% discount rate, feedstock cost region/application specific or for multiple countries for biofuels

Commercially Available Bioenergy

LCO Electricity

LCO Heat

LCO Intermediate Fuel

LCO Fuel from biomass at fixed coproduct revenue

Sugar at $22/GJ market price

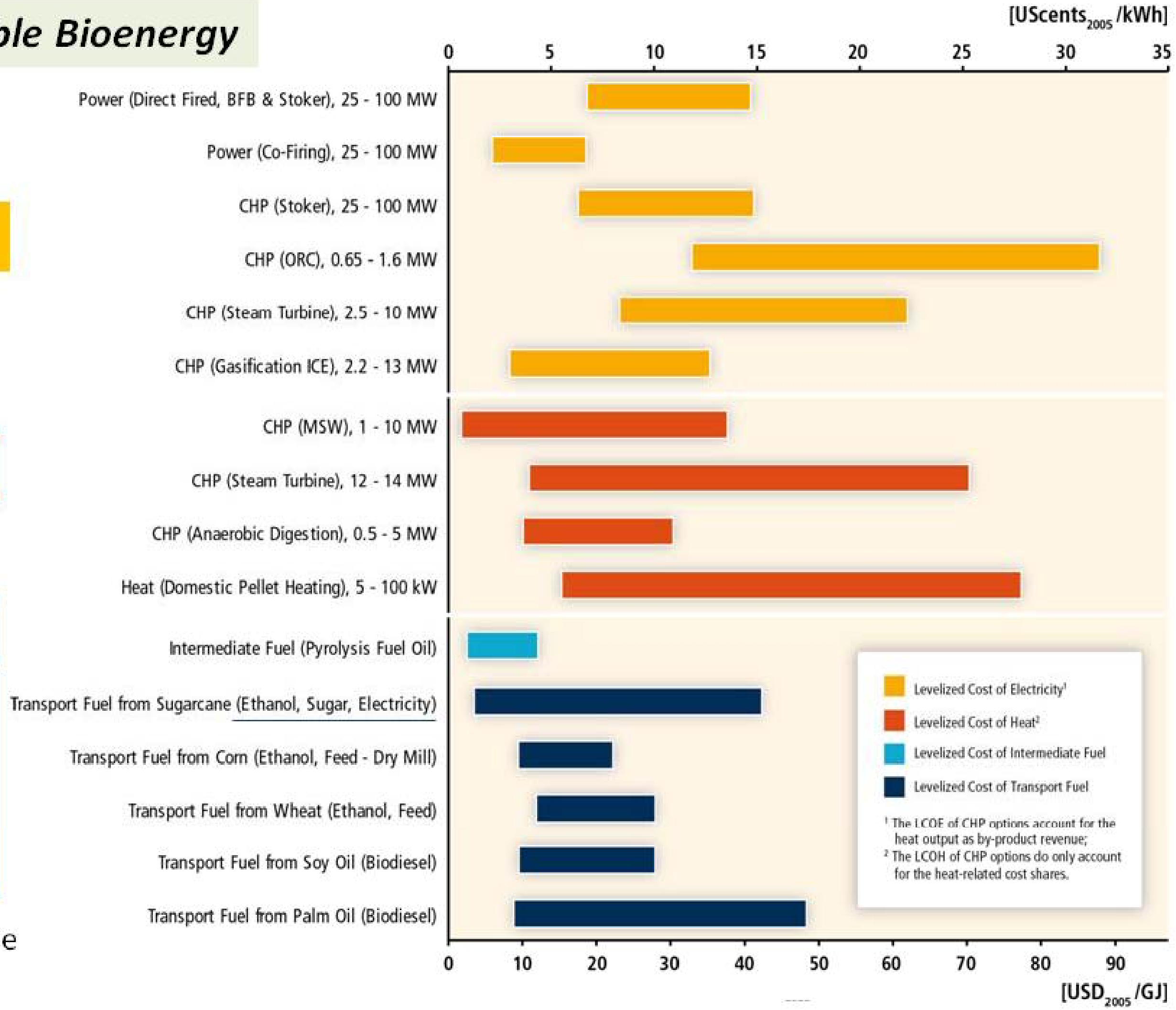

Figure 2.18 | Typical recent levelized cost of energy service from commercially available bioenergy systems at 7% discount rate. Feedstock cost ranges differ between technologies. For levelized cost at other discount rates (3 and 10%) see Annex III and Section 10.5. For biofuels, the range of LCOF represents production in a wide range of countries whereas LCOE and LCOH are given only for major user markets of the technologies for which data were available. The underlying cost and performance assumptions used in the calculations are summarized in Annex III. Calculations are based on HHV.

Abbreviations: BFB: Bubbling fluidized bed; ORC: Organic Rankine cycle; ICE: Internal combustion engine.

Table A.III.1 | Cost-performance parameters for RE power generation technologies.[i]

Resource	Technology	Input data: Typical size of the device (MW)[ii]	Input data: Investment cost (USD/kW)	Input data: O&M cost, fixed annual (USD/kW) and/or (non-feed) variable (US¢/kWh)	Input data: By-product revenue (US¢/kWh)[iii]	Input data: Feedstock cost (USD/GJ$_{feed, HHV}$[iv])	Input data: Feedstock conversion efficiency$_{el}$ (%)	Input data: Capacity factor (%)	Input data: Economic design lifetime (years)	Input data: References	Output data: LCOE[v] (US¢/kWh), Discount rate 3%	Output data: LCOE[v] (US¢/kWh), Discount rate 7%	Output data: LCOE[v] (US¢/kWh), Discount rate 10%
Bioenergy	Dedicated Biopower CFB[vi]	25–100	2,700–4,100[vii]	87 USD/kW and 0.40 US¢/kWh	n.a.[viii]	1.25–5.0[ix]	28	70–80	20	McGowin (2008)	6.1–13	6.9–15	7.9–16
	Dedicated Biopower Stoker[x]	See above	2,600–4,000[vii]	84 USD/kW and 0.34 US¢/kWh	n.a.[viii]	See above	27	See above	See above		5.6–13	6.7–15	7.7–16
	Dedicated Biopower (Stoker CHP[xi])	See above	2,800–4,200[vii]	86 USD/kW and 0.35 US¢/kWh	1.0[xii]	See above	24	See above	See above		5.1–13	6.3–15	7.3–17
	Co-firing: Co-feed	20–100	430–500[xiii]	12 USD/kW and 0.18 US¢/kWh	n.a.[viii]	See above	36	See above	See above	McGowin (2008)	2.0–5.9	2.2–6.2	2.3–6.4
	Co-firing: Separate Feed	See above	760–900[xiii]	18 USD/kW	n.a.[viii]	See above	36	See above	See above	Bain (2011)	2.3–6.3	2.6–6.7	2.9–7.1
	CHP (ORC[xiv])	0.65–1.6	6,500–9,800	59–80 USD/kW and 4.3–5.1 US¢/kWh	7.7[xv,xvi]	See above	14	55–68	See above	Obernberger et al. (2008)	8.6–26	12–32	15–37
	CHP (Steam Turbine)	2.5–10	4,100–6,200[xvii]	54 USD/kW and 3.5 US¢/kWh	5.4[xv, xviii]	See above	18	See above	See above		6.2–18	8.3–22	10–26
	CHP (Gasification ICE)[xix]	2.2–13	1,800–2,100	65–71 USD/kW and 1.1-1.9 US¢/kWh	1.0–4.5[xv, xx]	See above	28–30	See above	See above		2.1–11	3.0–13	3.8–14
Direct Solar Energy	PV (residential rooftop)	0.004–0.01	3,700–6,800[xxi]	19–110 USD/kW[xxii]	n.a.[viii]	n.a.[viii]	n.a.[viii]	12–20[xxiii]	20–30	see Section 3.8 and footnotes	12–53	18–71	23–86
	PV (commercial rooftop)	0.02–0.5	3,500–6,600[xxi]	18–100 USD/kW[xxii]	n.a.[viii]	n.a.[viii]	n.a.[viii]	See above	See above		11–52	17–69	22–83
	PV (utility scale, fixed tilt)	0.5–100[xxiv]	2,700–5,200[xxi]	14–69 USD/kW[xxii]	n.a.[viii]	n.a.[viii]	n.a.[viii]	15–21[xxiii]	See above		8.4–33	13–43	16–52
	PV (utility scale, one-axis)	0.5–100[xxiv]	3,100–6,200[xxi]	16–75 USD/kW[xxii]	n.a.[viii]	n.a.[viii]	n.a.[viii]	15–27[xxiii]	See above		7.4–39	11–52	15–62
	CSP	50–250[xxv]	6,000–7,300[xxvi]	60–82 USD/kW[xxvii]	n.a.[viii]	n.a.[viii]	n.a.[viii]	35–42[xxviii]	See above		11–19	16–25	20–31
Geothermal Energy	Geothermal energy (condensing-flash plants)	10–100	1,800–3,600[xxix]	150–190 USD/kW[xxx]	n.a.[viii]	n.a.[viii]	n.a.[viii]	60–90[xxxi]	25–30[xxxii]	see Section 4.7 and footnotes	3.1–8.4	3.8–11	4.5–13
	Geothermal energy (binary-cycle plants)	2–20	2,100–5,200[xxix]	See above	n.a.[viii]	n.a.[viii]	n.a.[viii]	See above	See above		3.3–11	4.1–14	4.9–17
Hydropower	All	<0.1 – >20,000[xxxiii]	1,000–3,000[xxxiv]	25–75 USD/kW[xxxv]	n.a.[viii]	n.a.[viii]	n.a.[viii]	30–60[xxxvi]	40–80[xxxvii]	see Chapter 5 and footnotes	1.1–7.8	1.8–11	2.4–15

able AIII.3 | Cost-performance parameters for biofuels.[i]

		Input data									Output data		
Feedstock	Fuel, Region	Typical size of the device (MW_{th})	Investment cost (USD/kW_{th}) [ii]	O&M cost, fixed annual (USD/kW_{th}) and non-feed variable (USD/GJ_{feed})	By-product Revenue (USD/GJ_{feed})	Feedstock cost (USD/GJ_{feed})	Feedstock conversion efficiency[iii] (%) Product only (product + by-product)	Capacity factor (%)	Economic design lifetime (years)	References	LCOF[iv] USD/GJ_{HHV}[v] Discount rate 3%	7%	10%
Sugarcane	**Ethanol**				Co-product: sugar[vi]								
	Overall	*170–1,000*	*83–360*	*16–35 USD/kW_{th} and 0.87 USD/GJ_{feed}*	*4.3*	*2.1–7.1*	*17 (39)*	*50%*	*20*	*Alfstad (2008), Bain (2007), Kline et al. (2007)*	*2.4–39*	*3.5–42*	*4.5–46*
	Brazil, Case A[vii]	See above	100–330	20–32 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	2.1–6.5[viii]	See above	See above	See above	Bohlmann and Cesar (2006), Oliverio (2006), van den Wall Bake et al. (2009)	2.4–38	3.5–41	4.5–44
	Argentina	See above	110–340	21–34 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	6.5[ix]	See above	See above	See above	Oliverio and Riberio (2006), see also row 'Overall' above	28–39	30–42	31–46
	Caribbean Basin[x, xi]	See above	110–360	22–35 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	2.6–6.2	See above	See above	See above	Rosillo-Calle et al. (2000) see also row 'Overall' above	6.4–38	7.7–42	8.8–46
	Colombia	See above	100–320	20–31 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	5.6	See above	See above	See above	McDonald and Schrattenholzer (2001), Goldemberg (1996), see also row 'Overall' above	23–32	24–36	25–39
	India	See above	110–340	21–33 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	2.6–6.2	See above	See above	See above	see row 'Overall' above	5.9–37	7.1–41	8.2–44
	Mexico	See above	83–260	16–25 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	5.2–7.1	See above	See above	See above	see row 'Overall' above	19–37	19–40	20–42
	USA	See above	100–320	20–31 USD/kW_{th} and 0.87 USD/GJ_{feed}	See above	6.2	See above	See above	See above	see row 'Overall' above	27–36	28–40	29–43

LCOE sensitivity to feedstock/investment costs and capacity factor at 7% discount rate

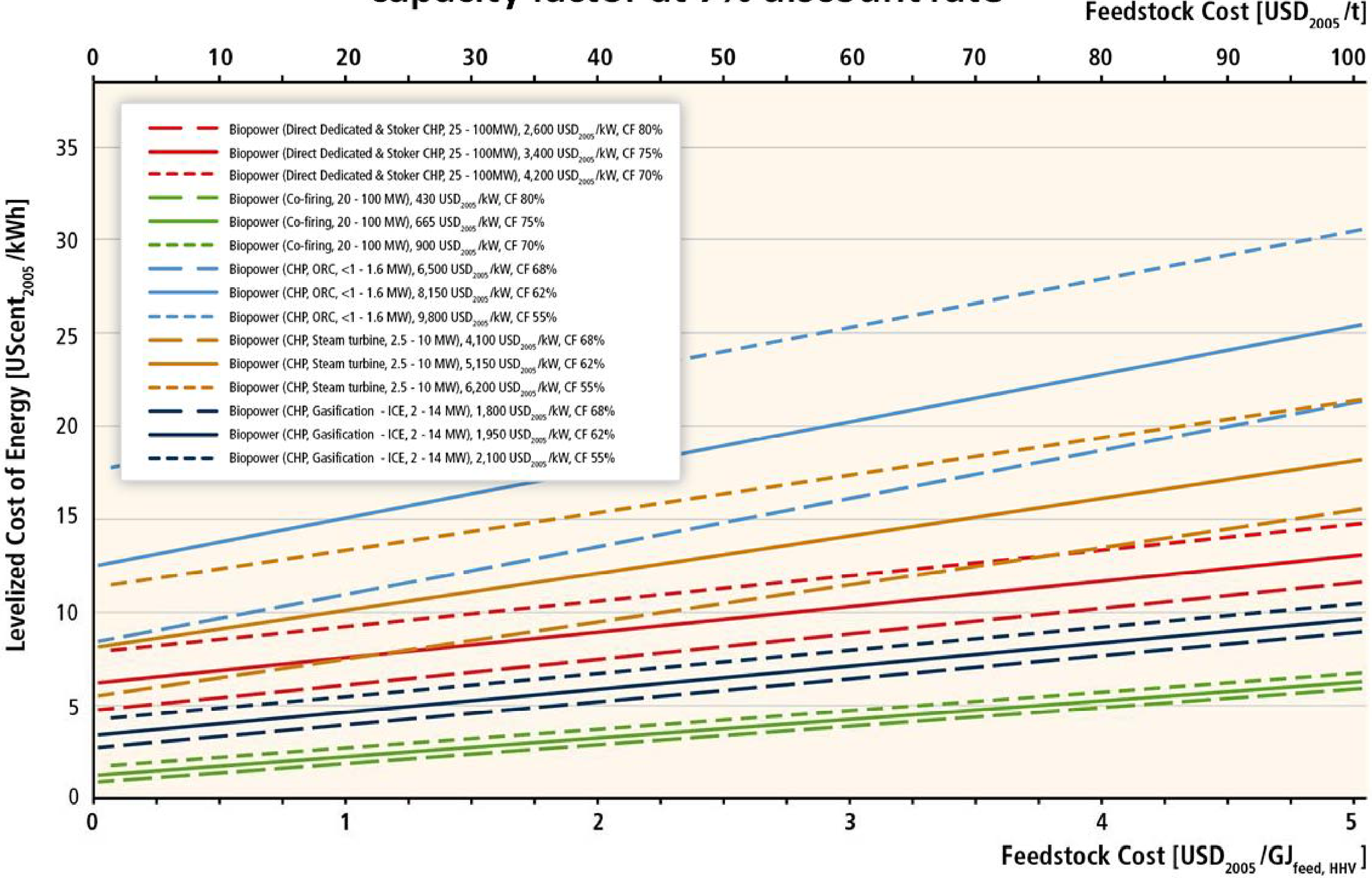

Figure 2.19 | Sensitivity of LCOE with respect to feedstock cost for a variety of investment costs and plant capacity factors (CF). LCOE is based on a 7% discount rate, the mid-value of the operations and maintenance (O&M) cost range, and the mid-value of the lifetime range (see Annex III). Calculations are based on HHV.

References: DeMeo and Galdo (1997); Bain et al. (2003); EIA (2009); Obernberger and Thek (2004); Sims (2007); McGowin (2008); Obernberger et al. (2008); EIA (2010b); Rauch (2010); Skjoldborn (2010); Bain (2011); QANDA (2011)

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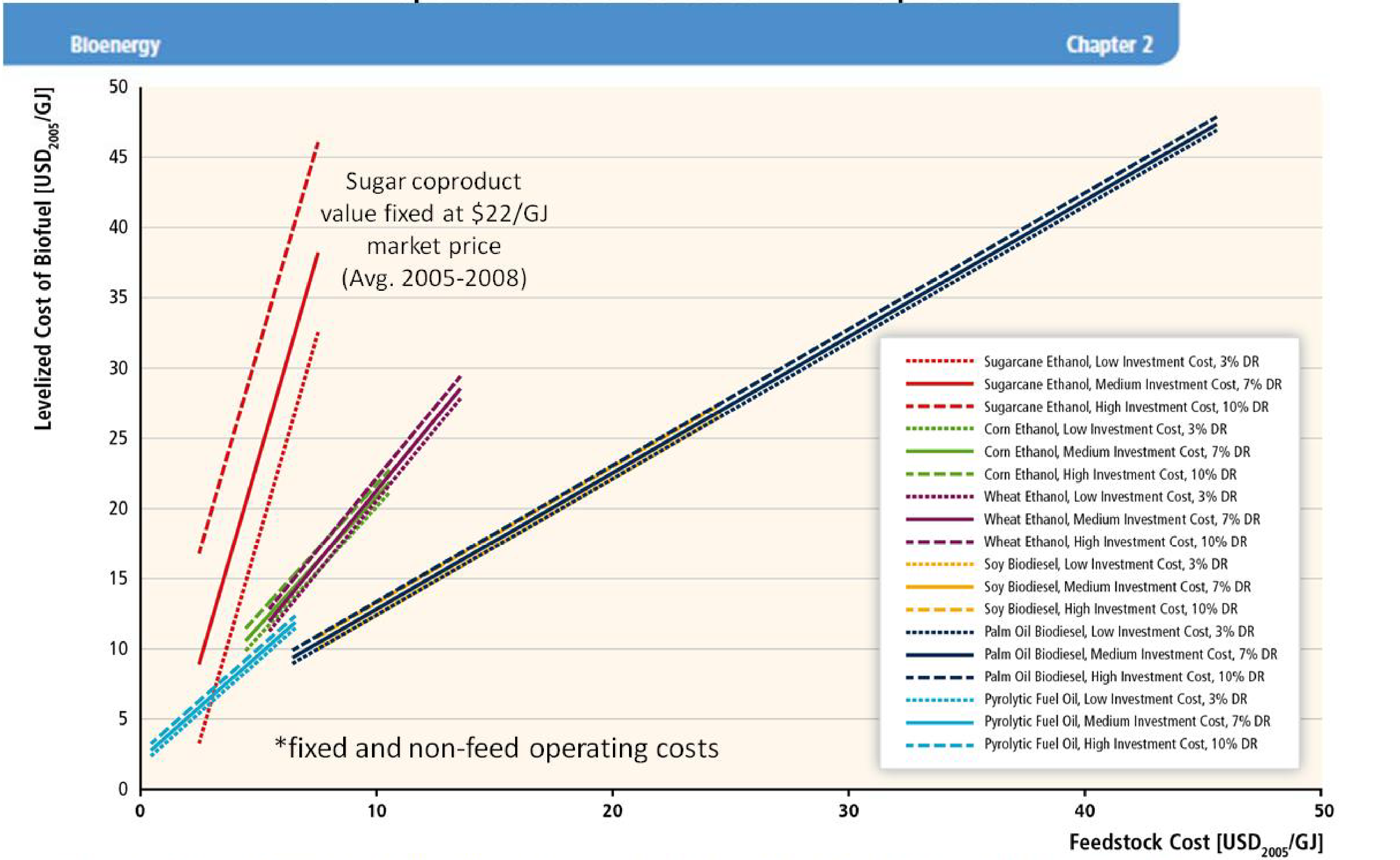
LCOF sensitivity to feedstock/investment costs and discount rate for midpoints of other variables* in multiple countries



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).

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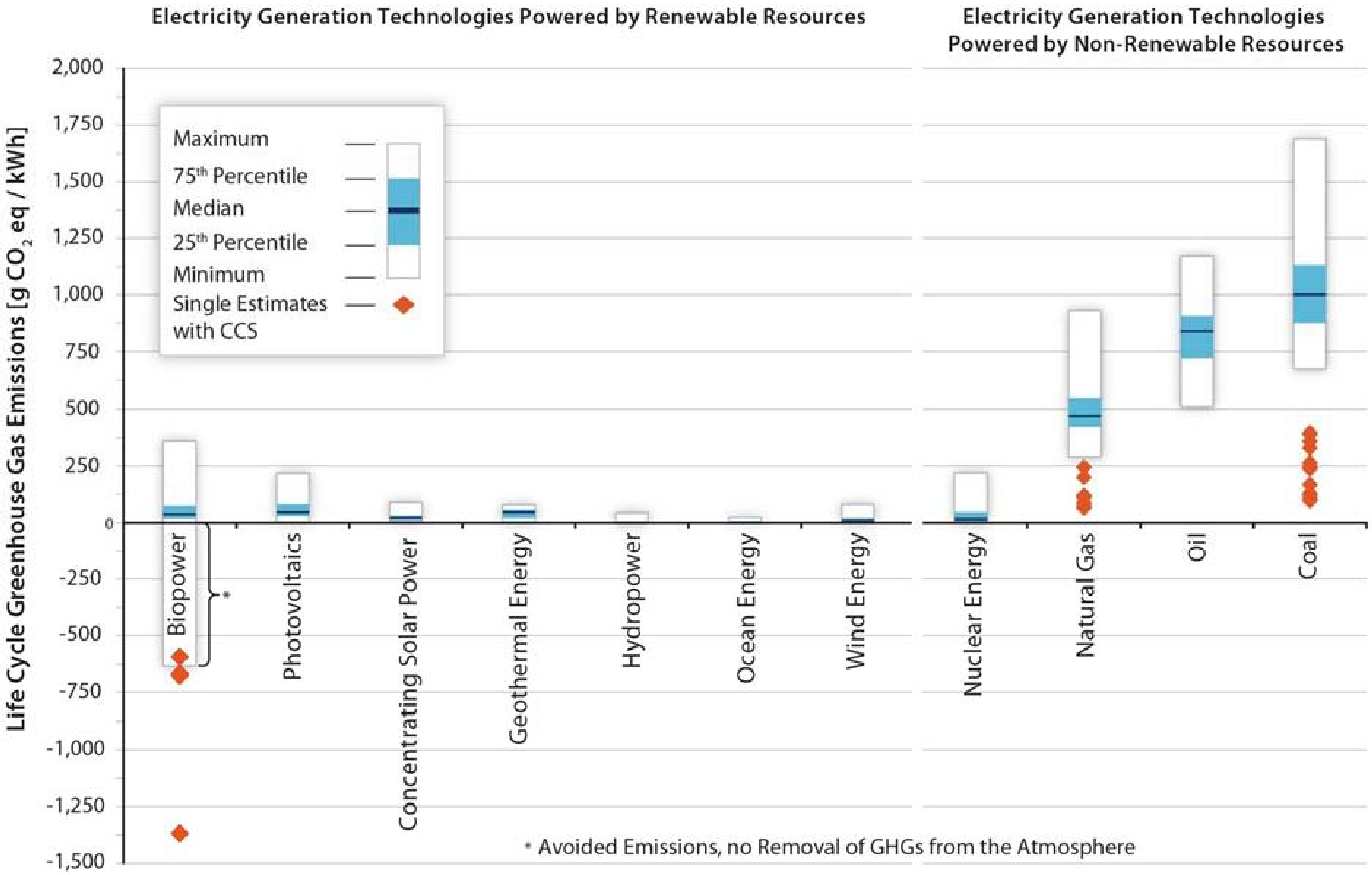
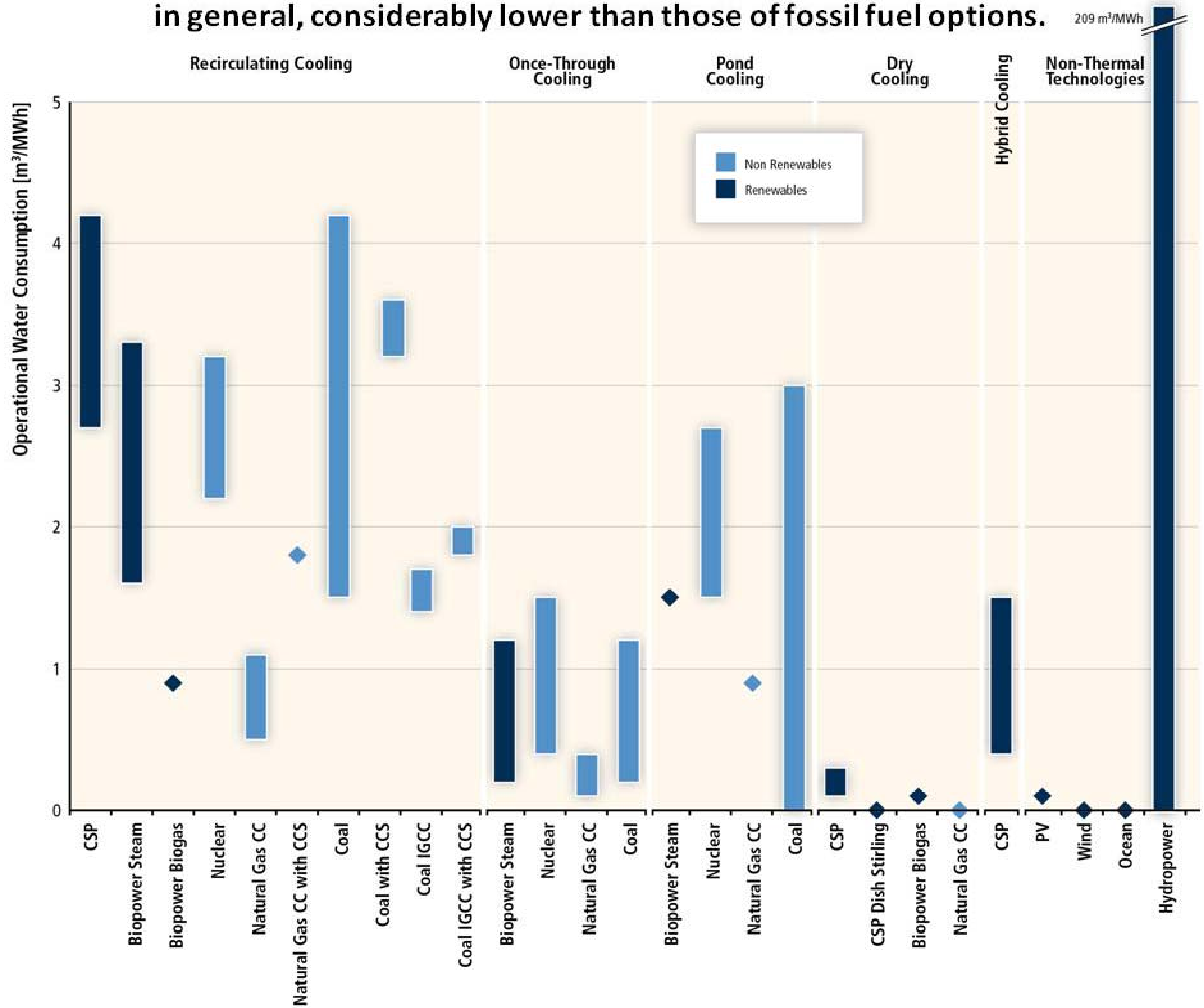
Attributional lifecycle GHG emissions of RE technologies are, in general, considerably lower than those of fossil fuel options.



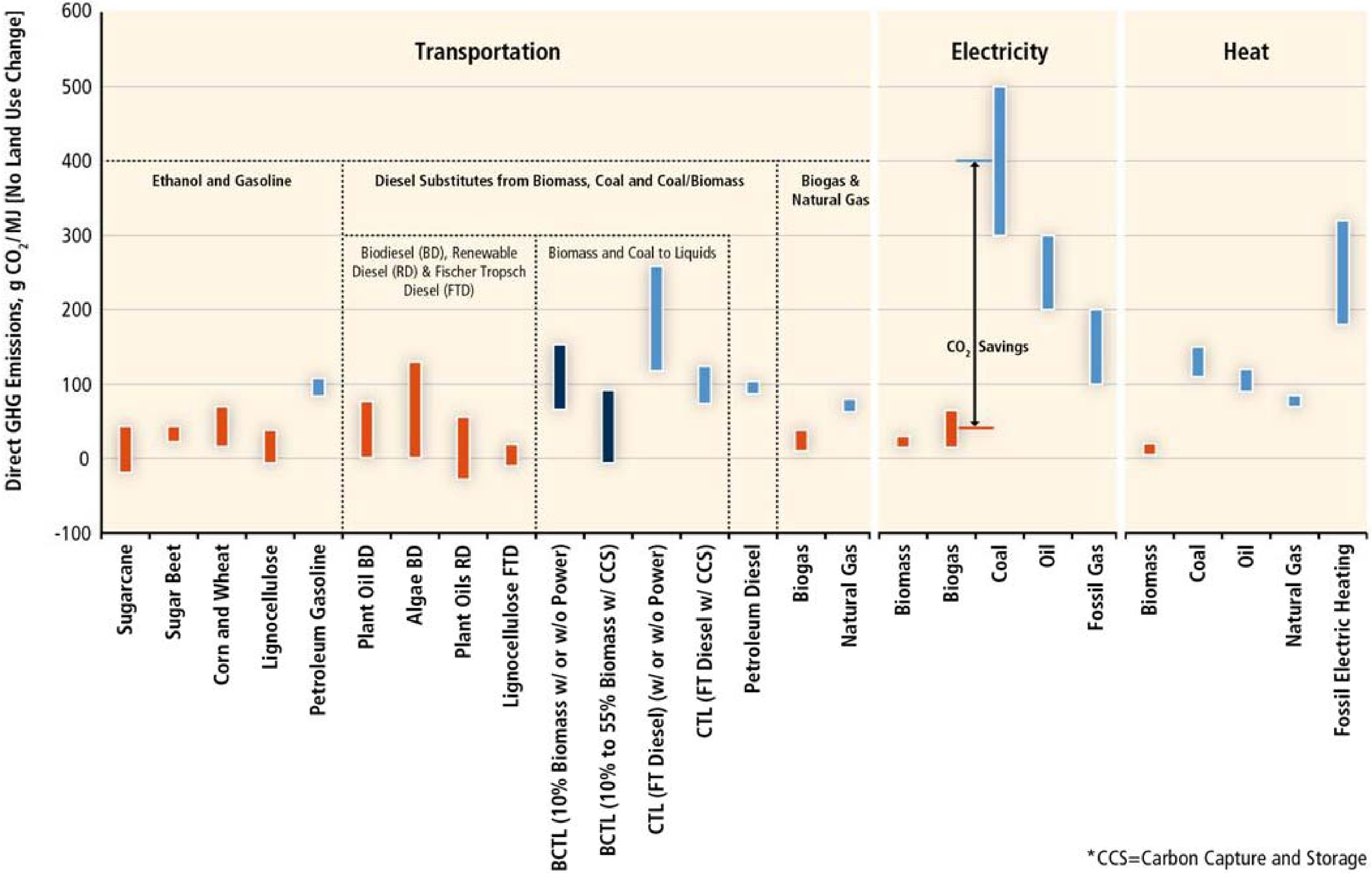
	Biopower	Photovoltaics	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

Except for hydropower, operational water consumption from RE technologies are, or can be, in general, considerably lower than those of fossil fuel options.



N:	18	4	1	5	4	1	16	2	7	3	1	3	3	9	1	1	1	7	11	2	1	2	4	2	2	1	4
Sources:	11	3	1	5	4	1	8	1	2	1	1	3	3	4	1	1	1	2	4	2	1	2	2	2	2	1	2

Attributional GHG emissions from modern bioenergy chains compared to fossil fuel energy systems, excluding land-use change effects.



*CCS=Carbon Capture and Storage

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Direct land use change GHG emissions examples

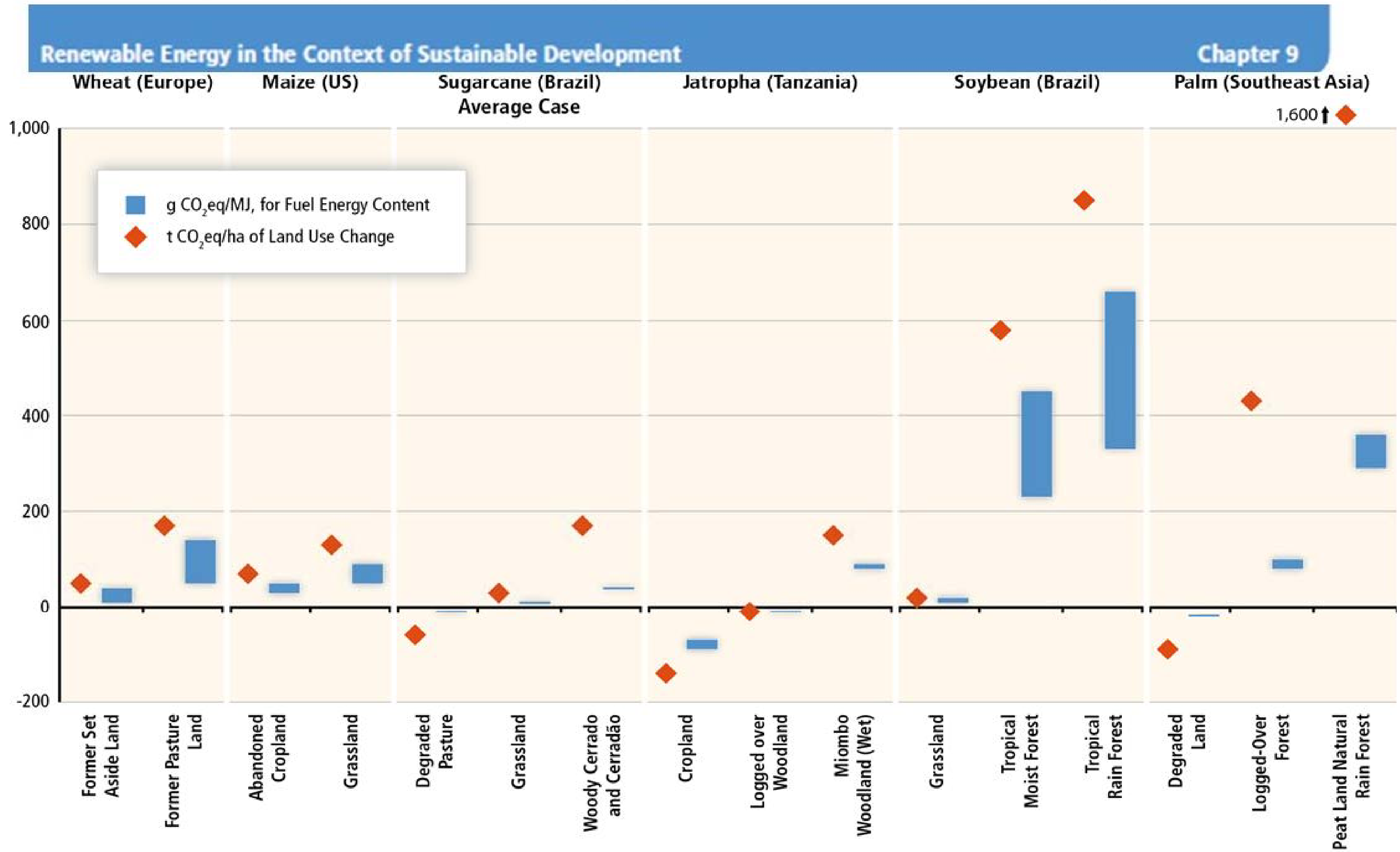

Figure 9.10 | Illustrative direct LUC-related GHG emission estimates from selected land use types and first-generation biofuel (ethanol and biodiesel) feedstocks. Results are taken from Hoefnagels et al. (2010) and Fargione et al. (2008) and, where necessary, converted (assuming a 30-year timeframe) to the functional units displayed using data from Hoefnagels et al. (2010) and EPA (2010b). Ranges are based on different co-product allocation methods (i.e., allocation by mass, energy and market value).

Site and prior use specific ....

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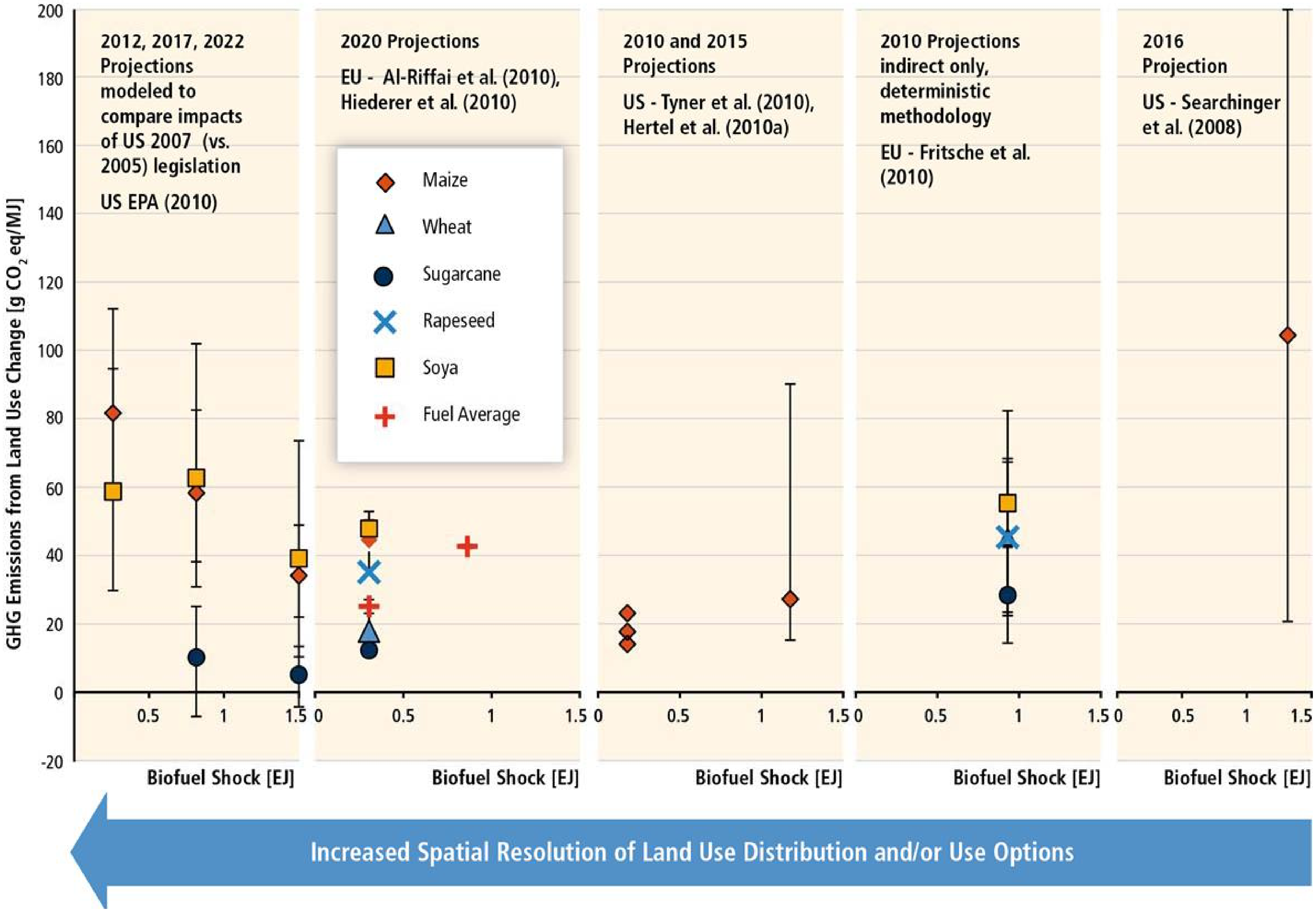
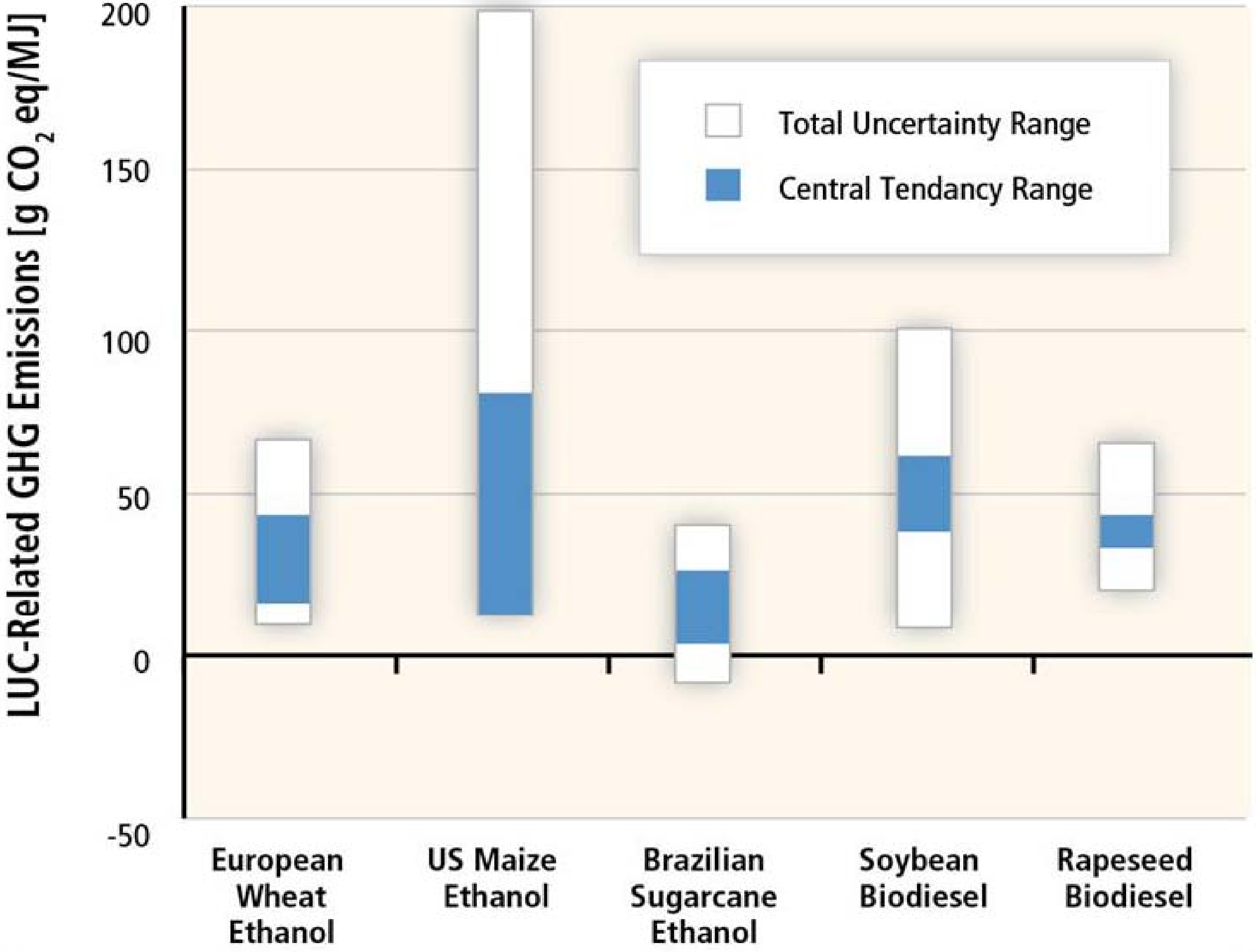
Land use change – Take I (Chapter 2)



Direct and indirect land use GHG emissions – Take II (Chapter 9)



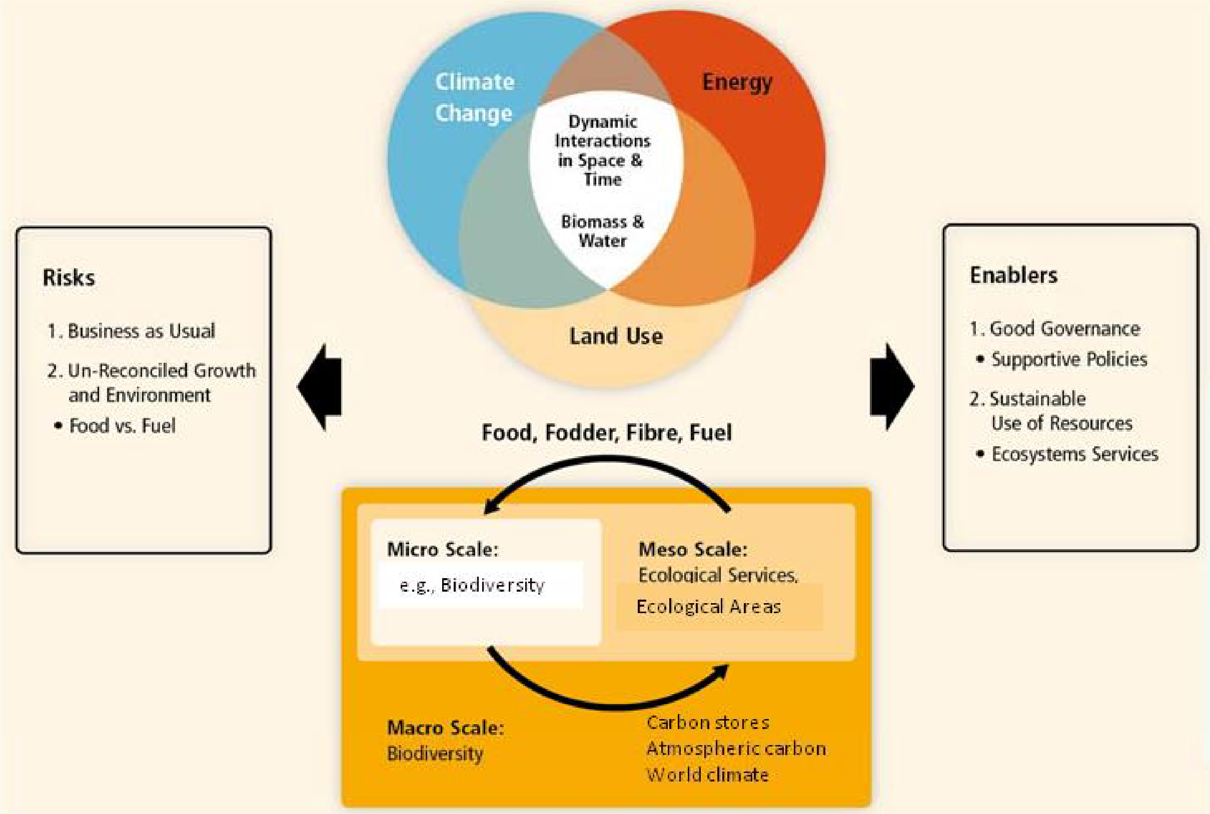
References:	3	5	2	3	2

Figure 9.11 | Illustrative estimates of direct and indirect LUC-related GHG emissions induced by several first-generation biofuel pathways, reported here as ranges in central tendency and total reported uncertainty. Estimates reported here combine several different uncertainty calculation methods and central tendency measures and assume a 30-year time frame. Reported under the x-axis is the number of references with results falling within these ranges (Sources: Searchinger et al., 2008; Al-Riffai et al., 2010; EPA, 2010b; Fritsche et al., 2010; Hertel et al., 2010; Tyner et al., 2010).

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.



Doomsters vs. **Boomsters**

-Not enough land/water for food/fodder/fiber/fuel…
-Destroy biodiversity…

-Intensify pasture and agriculture
- Increase global agricultural productivity
-Increase use of GMOs globally…

Can be done sustainably or not… it depends on location and <u>many other factors near and far</u> ..
Evolving sustainability metrics

One size does not fit all

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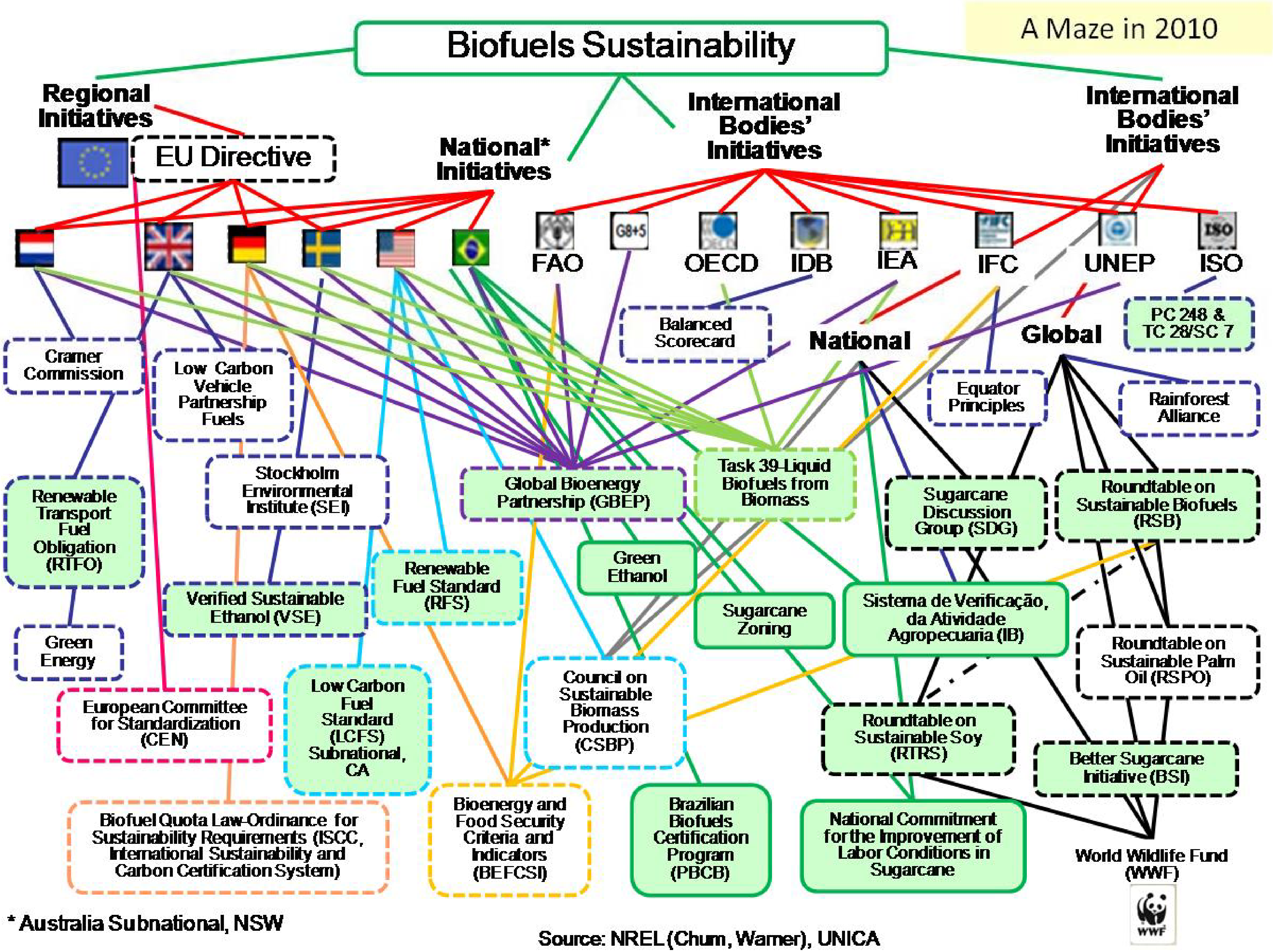
WMO UNEP


A Maze in 2010
Biofuels Sustainability
Regional Initiatives
EU Directive
National* Initiatives
International Bodies' Initiatives
International Bodies' Initiatives
FAO
G8+5
OECD
IDB
IEA
IFC
UNEP
ISO
Balanced Scorecard
National
Global
PC 248 & TC 28/SC 7
Cramer Commission
Low Carbon Vehicle Partnership Fuels
Equator Principles
Rainforest Alliance
Stockholm Environmental Institute (SEI)
Global Bioenergy Partnership (GBEP)
Task 39-Liquid Biofuels from Biomass
Sugarcane Discussion Group (SDG)
Roundtable on Sustainable Biofuels (RSB)
Renewable Transport Fuel Obligation (RTFO)
Green Ethanol
Verified Sustainable Ethanol (VSE)
Renewable Fuel Standard (RFS)
Sugarcane Zoning
Sistema de Verificação, da Atividade Agropecuaria (IB)
Green Energy
Roundtable on Sustainable Palm Oil (RSPO)
Low Carbon Fuel Standard (LCFS) Subnational, CA
Council on Sustainable Biomass Production (CSBP)
European Committee for Standardization (CEN)
Roundtable on Sustainable Soy (RTRS)
Better Sugarcane Initiative (BSI)
Biofuel Quota Law-Ordinance for Sustainability Requirements (ISCC, International Sustainability and Carbon Certification System)
Bioenergy and Food Security Criteria and Indicators (BEFCSI)
Brazilian Biofuels Certification Program (PBCB)
National Commitment for the Improvement of Labor Conditions in Sugarcane
World Wildlife Fund (WWF)
WWF
* Australia Subnational, NSW
Source: NREL (Chum, Warner), UNICA

Biofuel feedstock and fuel costs have declined for sugarcane and ethanol… and also for corn ethanol

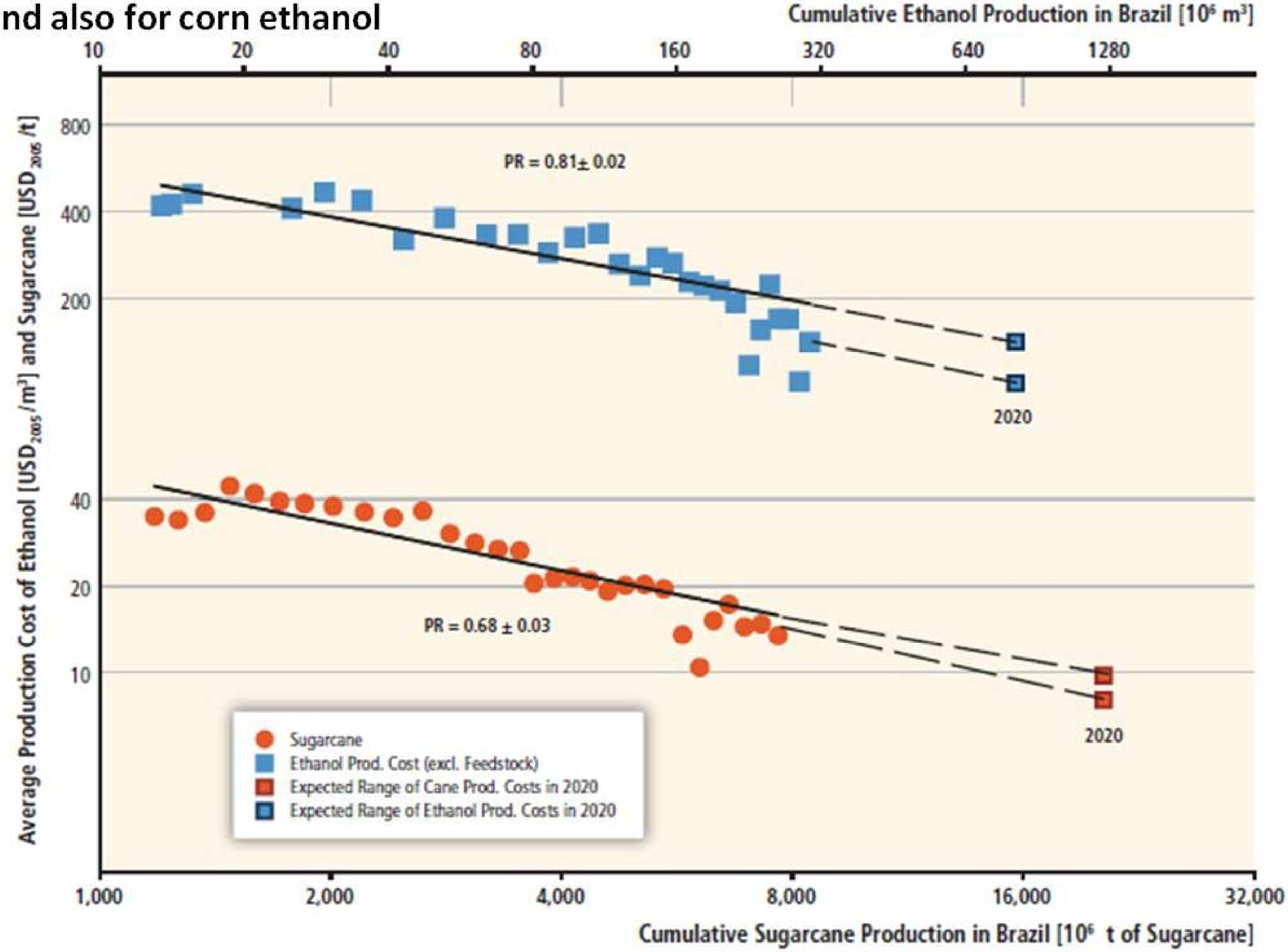


Figure 2.21 | Brazilian sugarcane and ethanol production cost learning curves for between 1975 and 2005 and extrapolated to 2020 (in USD_{2005}). Progress ratio (PR=1-LR) is obtained by best fit to data (van den Wall Bake et al., 2009; reproduced with permission from Elsevier B.V.).

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Technology costs continue to decrease for commercial and many developing technologies

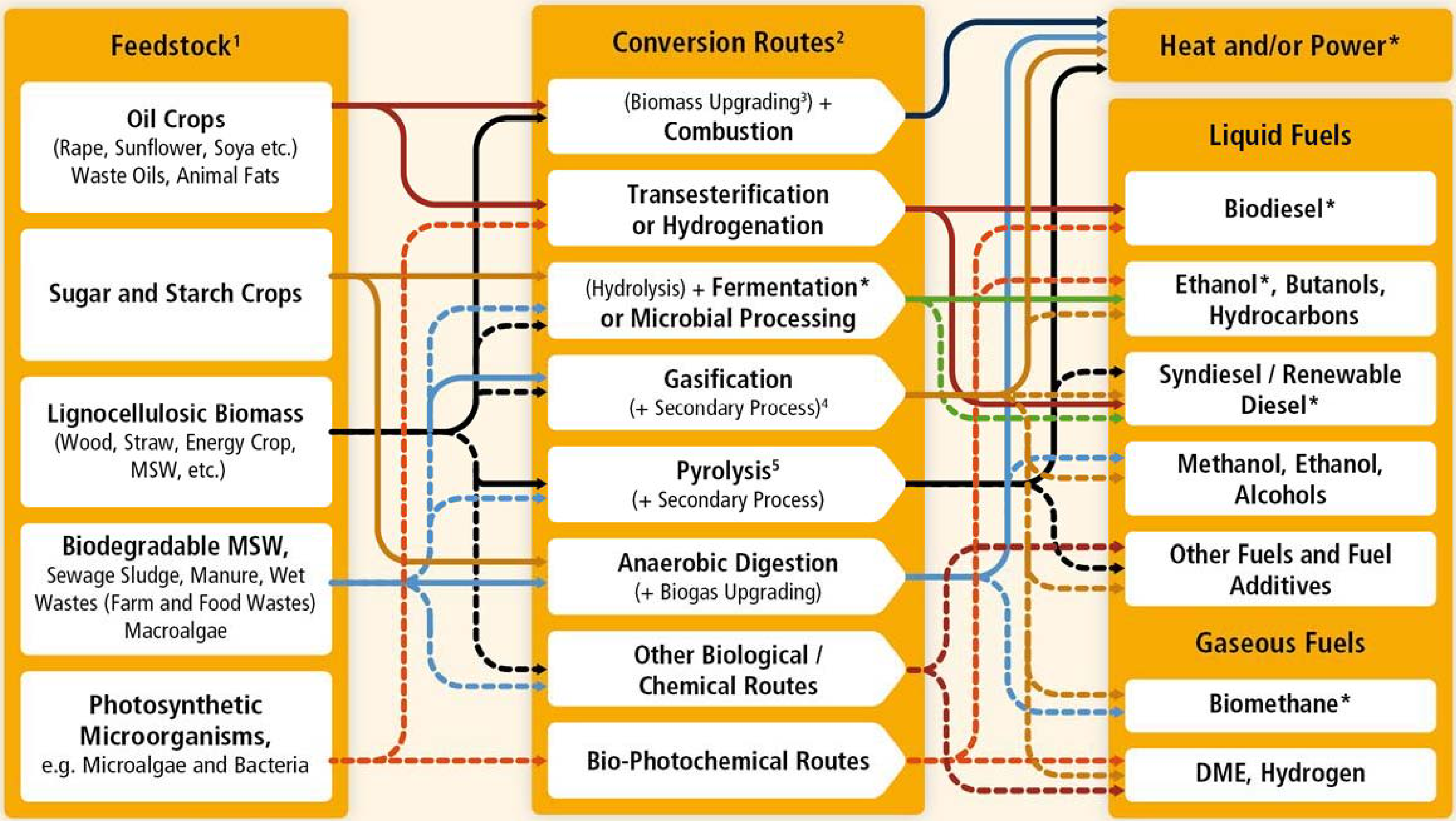


Figure 2.2 | Schematic view of the variety of commercial (solid lines, see Figure 2.6) and developing bioenergy routes (dotted lines) from biomass feedstocks through thermochemical chemical, biochemical and biological conversion routes to heat, power, CHP and liquid or gaseous fuels (modified from IEA Bioenergy, 2009). Commercial products are marked with an asterisk.

Notes: 1. Parts of each feedstock, for example, crop residues, could also be used in other routes. 2. Each route also gives coproducts. 3. Biomass upgrading includes any one of the densification processes (pelletization, pyrolysis, torrefaction, etc.). 4. Anaerobic digestion processes release methane and CO_2 and removal of CO_2 provides essentially methane, the major component of natural gas; the upgraded gas is called biomethane. 5. Could be other thermal processing routes such as hydrothermal, liquefaction, etc. DME=dimethyl ether.

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-Combustion 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).

<table>
<tr><th rowspan="2">Type of Plant</th><th rowspan="2">Type of Product</th><th rowspan="2"></th><th colspan="4">Stage of Development of Process for Product(s) or System(s)</th></tr>
<tr><th>Basic and Applied R&D</th><th>Demonstration</th><th>Early Commercial</th><th>Commercial</th></tr>
<tr><td rowspan="4">Wet Waste</td><td rowspan="4">Heat or Power or Fuel</td><td rowspan="3">Anaerobic Digestion to Biogas</td><td colspan="3">2-Stage</td><td>Landfills (1-Stage)</td></tr>
<tr><td rowspan="2">Microbial Fuel Cell</td><td colspan="2">Reforming to Hydrogen (H_2)</td><td>Small Manure Digesters</td></tr>
<tr><td colspan="3">Biogas Upgrading to Methane</td></tr>
<tr><td></td><td colspan="3">Hydrothermal Processing to Oils or Gaseous Fuels</td><td></td></tr>
<tr><td rowspan="2">Sugar or Starch Crops</td><td rowspan="5">Fuels</td><td>Sugar Fermentation</td><td></td><td colspan="2">Butanol</td><td>Ethanol</td></tr>
<tr><td>Microbial Processing[2]</td><td>H_2
Gasoline/ Diesel/ Jet Fuel</td><td colspan="2">Biobutanol/Butanols[3]</td><td></td></tr>
<tr><td rowspan="3">Oils Vegetable or Waste</td><td>Extraction and Esterification</td><td></td><td></td><td></td><td>Biodiesel</td></tr>
<tr><td>Extraction and Hydrogenation</td><td></td><td colspan="3">Renewable Diesel</td></tr>
<tr><td>Extraction and Refining</td><td></td><td colspan="2">Jet Fuel</td><td></td></tr>
</table>

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.

Projected production cost range estimated for groups of technologies

Table 2.18 | Projected production cost ranges estimated for developing technologies (see Section 2.6.3).

Selected Bioenergy Technologies	Energy Sector (Electricity, Thermal, Transport)*	2020-2030 Projected Production Costs (USD_{2005}/GJ)
IGCC[1]	Electricity and/or transport	12.8–19.1 (4.6–6.9 cents/kWh)
Oil plant-based renewable diesel and jet fuel	Transport and electricity	15–30
Lignocellulose sugar-based biofuels[2]	Transport	6–30
Lignocellulose syngas-based biofuels[3]		12–25
Lignocellulose pyrolysis-based biofuels[4]		14–24 (fuel blend components)
Gaseous biofuels[5]	Thermal and transport	6–12
Aquatic plant-derived fuels, chemicals	Transport	30–140

Notes: 1. Feed cost USD_{2005} 3.1/GJ, IGCC (future) 30 to 300 MW, 20-yr life, 10% discount rate; 2. ethanol, butanols, microbial hydrocarbons from sugar or starch crops or lignocellulose sugars; 3. syndiesel, methanol and gasoline, etc.; syngas fermentation routes to ethanol; 4. biomass pyrolysis (or other thermal treatment) and catalytic upgrading to gasoline and diesel fuel blend components or to jet fuels; 5. synfuel to SNG, methane, dimethyl ether, or H_2 from biomass thermochemical and anaerobic digestion (larger scale).
*Several applications could be coupled with CCS when these technologies, including CCS, are mature and thus could remove GHGs from the atmosphere.

See companion Table 2.15 with summary of ~ 25 developing technologies with estimated production costs projected for 2030 biofuel production and their 2010 industrial development level.
Difficulties: Most assessments reported under different financial assumptions and report on technologies at different stages of development. Many examples provide nth plant costs projected from bench or pilot, a few from demonstrations, and many reflect first-of-a-kind plant with company specific risk factors. Data comparability suffers.

Traditional biomass use decreases replaced, in part, by low emissions and more efficient advanced cookstoves and biogas systems, along with other modern fuels

Renewable Energy in the Context of Sustainable Development **Chapter 9**

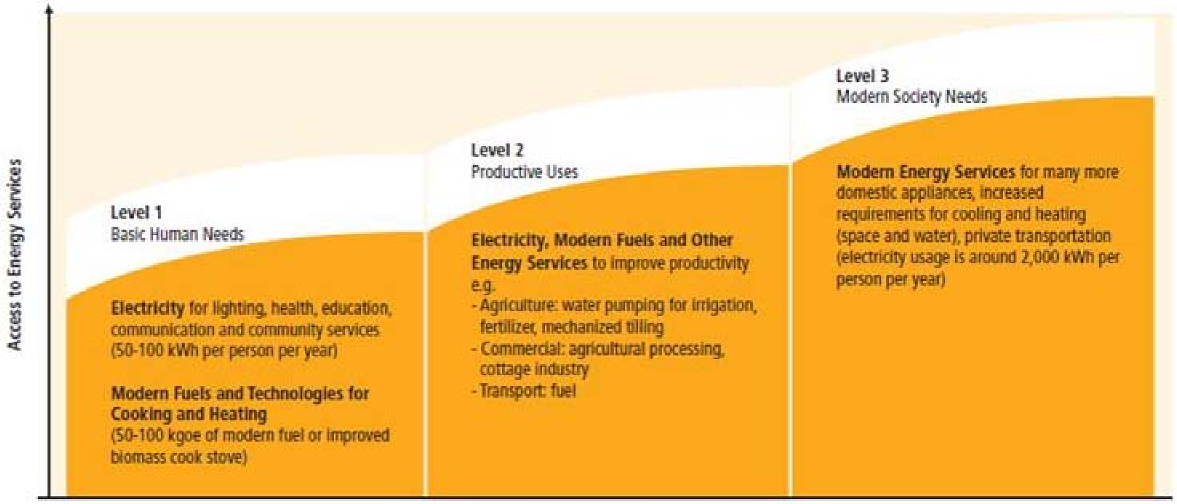
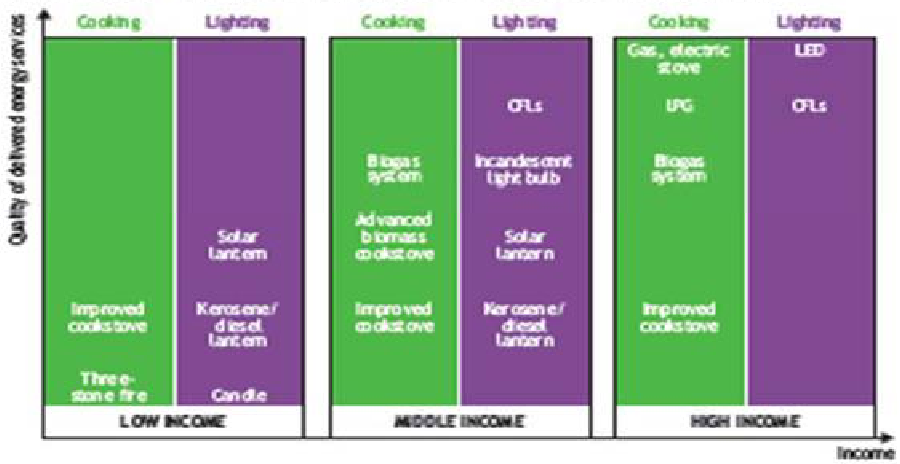


Figure 9.4 | Incremental level of access to energy services (AGECC, 2010; based on IEA data and analysis). Note: kgoe = kilo

2010 World Energy Outlook

Note: CFL=compact fluorescent light bulb, LPG= liquefied petroleum gas; and LED = light emitting diodes. Improved cookstoves have higher efficiency than cooking over a three-stone fire, but emissions are not reduced considerably, while advanced biomass cookstoves have equivalent efficiency and emissions reductions as liquid-fuel, gas and electric stoves.

Figure 8.20 • The quality of energy services and household income



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Chapter 10 Bioenergy Scenario Results

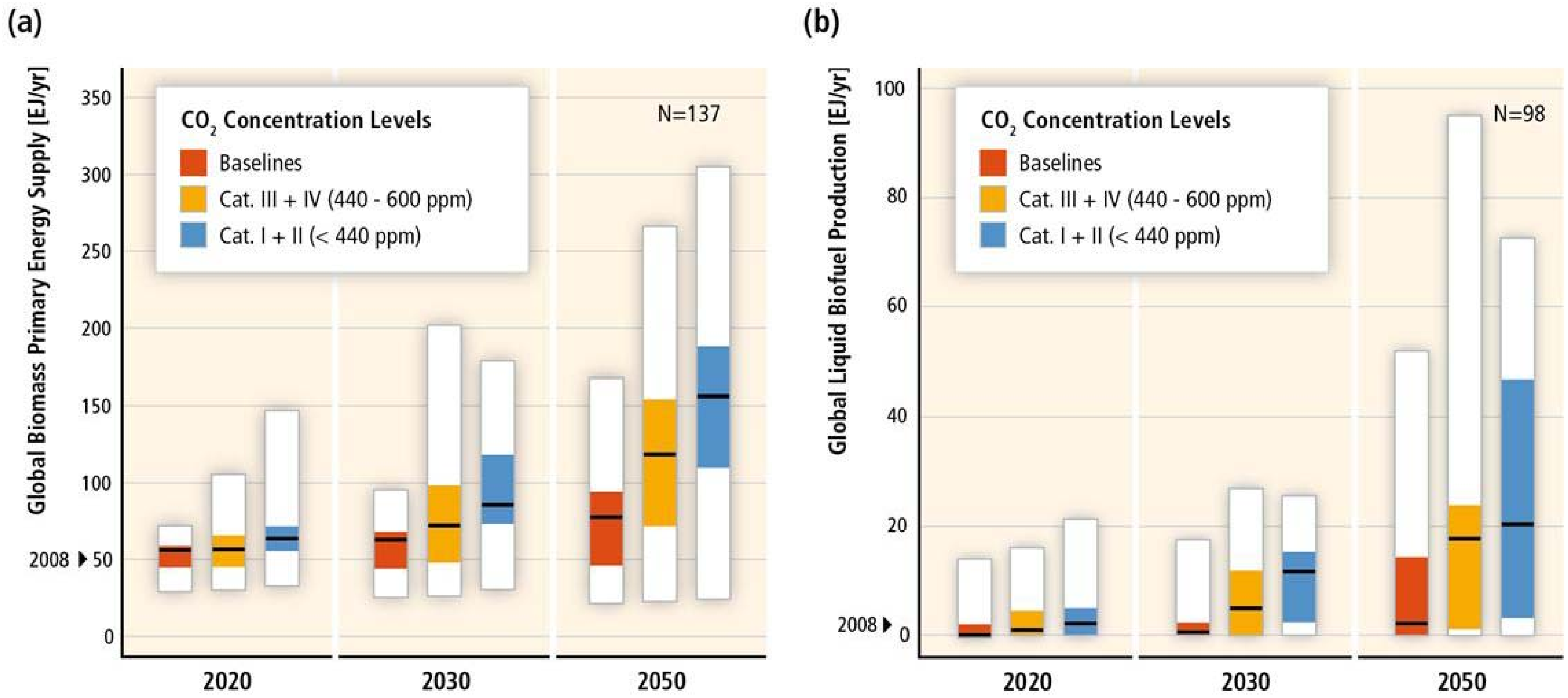

Figure 2.23 | (a) The global primary energy supply from biomass in long-term scenarios; (b) global biofuels production in long-term scenarios reported in secondary energy terms of the delivered product (median, 25th to 75th percentile range and full range of scenario results; colour coding is based on categories of atmospheric CO_2 concentration levels in 2100; the number of scenarios underlying the figure is indicated in the right upper corner) (adapted from Krey and Clarke, 2011). For comparison, the historic levels in 2008 are indicated by the small black arrows on the left axis.

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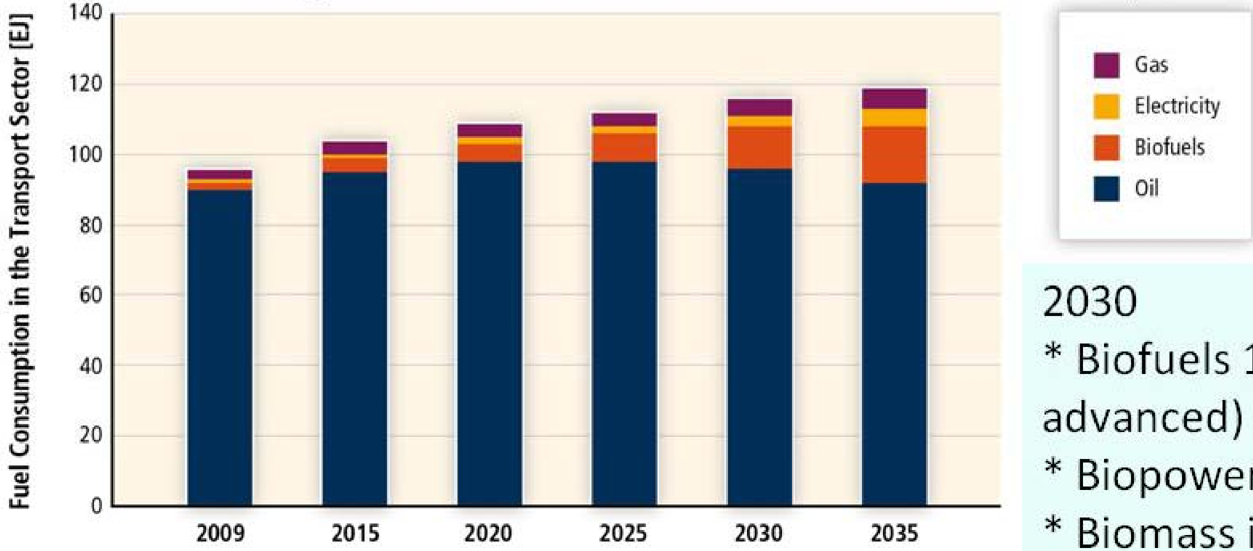
Higher resolution literature transport scenario results

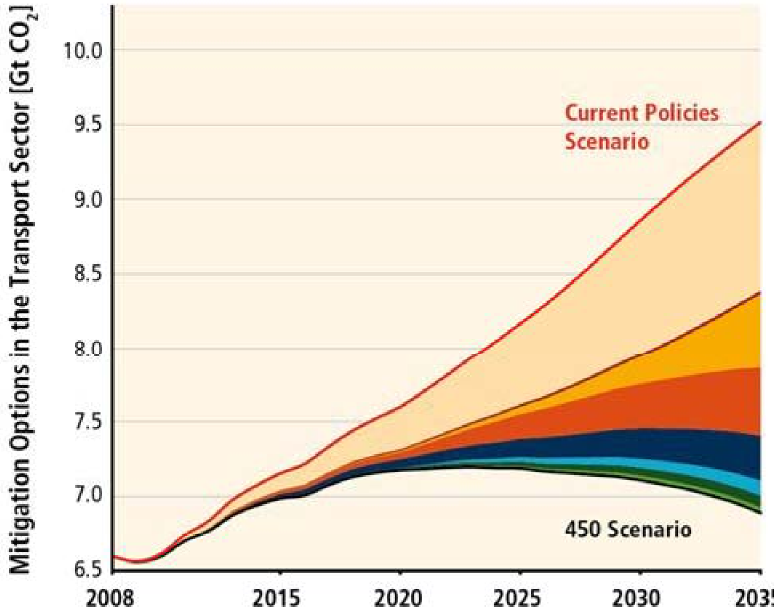
(a)



2010 IEA-WEO

2030
* Biofuels 11% global transport fuels (60% advanced) including aviation biofuels
* Biopower 5% global electricity
* Biomass industrial heating and modern building double each relative to 2008 levels

(b)



	Abatement 2020	2030	2035
Road	83%	80%	80%
Increased Efficiency	67%	51%	43%
Switch to Gas	3%	1%	1%
Switch to Electricity	2%	11%	19%
Switch to Biofuels	11%	17%	17%
Aviation	14%	15%	15%
Increase Efficiency	14%	12%	11%
Switch to Biofuels	0%	3%	4%
Navigation	2%	3%	3%
Other Transport	2%	2%	1%
Total [Gt CO_2]	0.4	1.7	2.6

Biofuels for Road

Aviation

Figure 2.24 | (a) Evolution of fuel consumption in the transport sector including biofuels (*World Energy Outlook 2010*, © OECD/IEA, figure 14.12, page 429 in IEA (2010b)) and (b) shares of carbon mitigation by various technologies including biofuels for road and aviation transport from current policies baseline (upper red line) to the 450 ppm bottom curve of the mitigation scenario. (*World Energy Outlook 2010*, © OECD/IEA, figure 14.14, page 432 in IEA (2010b))

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Key conclusions (I)

- Technical potential of up to 500 EJ/year by 2050, with large uncertainty around market and policy conditions that affect this potential.
- 100-300 EJ/year possible deployment levels by 2050.
- Major challenge but would contribute up to 1/3 to the world's primary energy demand in 2050.
- 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."

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 fuels, advanced bioelectricity options, and biorefinery concepts can offer competitive deployment of bioenergy in 2020 - 2030.
  - Bio-CCS can offer negative carbon emissions.
  - Advanced biomaterials 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.

Storylines below and **sketches** in the next figure help understand **high and low** bioenergy implementation scenarios that are equally possible **leading to** sustainable outcomes **or not** depending on **their development**.

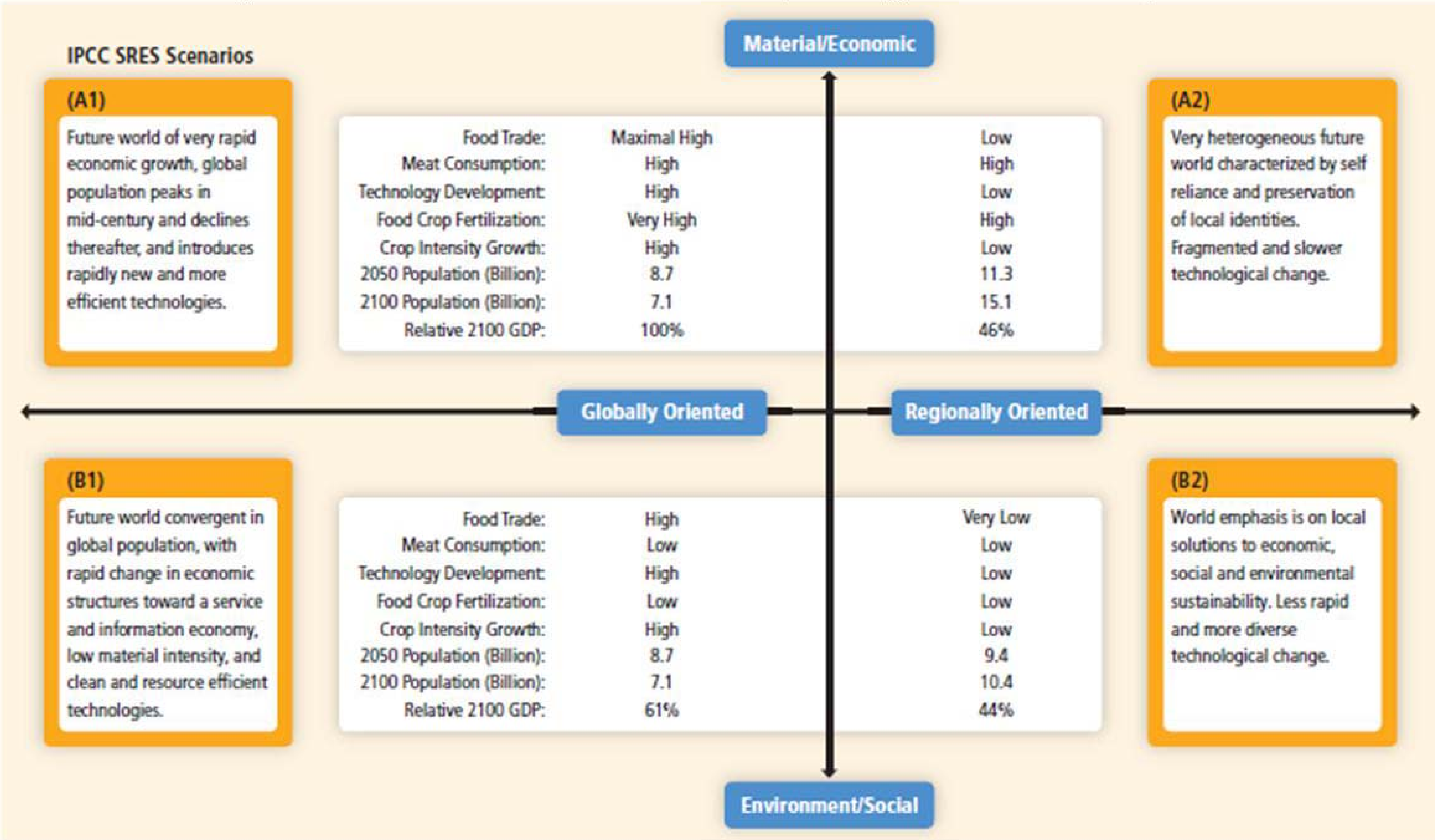

Figure 2.26 | Storylines for the key scenario variables of the IPCC SRES (IPCC, 2000) used to model biomass and bioenergy by Hoogwijk et al. (2005, reproduced with permission from Elsevier B.V.), the basis for the 2050 sketches adapted for this report and used to derive the stacked bar showing the upper bound of the biomass technical potential for energy in Figure 2.25.

2050 Bioenergy Storylines

Globally Oriented ← → Regionally Oriented

(A1) ~ 300 EJ/Poor Governance

Key Preconditions

- High energy demand results in high energy prices and drive strong biomass demand.
- Limited oversight on biomass production and use, largely driven by market demand.
- Fully liberalized markets for bioenergy as well as in agriculture as a whole.
- Strong technology development leading to increased demand for biochemicals and advanced transport fuels from biomass.

Key Impacts

- Production emphasis is on higher quality land, converted pastures, etc.
- Biomass produced and used in large scale operations, limiting small farmers' benefits.
- Large scale global trade and conversion capacity developed in major seaports.
- Competition with conventional agriculture for the better quality land, driving up food prices and increasing pressure on forest resources.
- GHG benefits overall but sub-optimal due to significant iLUC effects.

(A2) ~ 100 EJ/Poor Governance

Key Preconditions

- High fossil fuel prices expected due to high demand and limited innovation, which pushes demand for biofuels use from an energy security perspective.
- Increased biomass demand directly affects food markets.

Key Impacts

- Increased biomass demand partly covered by residues and wastes, partly by annual crops.
- Additional crop demand leads to significant iLUC effects and biodiversity impacts.
- Overall increased food prices linked to high oil prices.
- Limited net GHG benefits.
- Sub-optimal socio-economic benefits.

(B1) ~ 300 EJ/Good Governance

Key Preconditions

- Well working sustainability frameworks and strong policies are implemented.
- Well developed bioenergy markets.
- Progressive technology development, e.g. biorefineries, new generation biofuels and multiple products, successful use of degraded lands.
- Developing countries succeed in transitioning to higher efficiency technologies and implement biorefineries at scales compatible with available resources.
- Satellite processing emerges.

Key Impacts

- 35% biomass from residues and wastes, 25% from marginal/degraded lands and 40% from arable and pasture lands (~3 and ~1 million km², respectively).
- Moderate energy price (notably oil) due to strong increase of biomass and biofuels supply.
- Food and fuel conflicts largely avoided due to strong land-use planning and alignment of bioenergy production capacity with efficiency increases in agriculture and livestock management.
- Soil quality and soil carbon improve and negative biodiversity impacts are minimised using diverse and mixed cropping systems.

(B2) ~ 100 EJ/Good Governance

Key Preconditions

- Focus on smaller scale technologies, utilization of residues, waste streams and smaller scale cropping schemes (e.g. Jathropha) and a large array of specific cropping schemes.
- International trade is constrained and trade barriers remain.
- Effective national policy frameworks control bioenergy deployment, put priority on food and optimize biomass production and use for specific regional conditions.

Key Impacts

- Biomass comes from residues, organic wastes and cultivation on more marginal lands.
- Smaller scale bioenergy applications developed specially and used locally.
- Substantial benefits provided for rural economies in terms of employment and diversified energy sources providing services.
- Food, land-use and nature conservation conflicts are largely avoided.
- Significant GHG mitigation benefits are constrained by limited bioenergy deployment.
- Transport sector still uses a high share of petroleum to cover energy needs.