Biofuel Pathways Energy Comparisons

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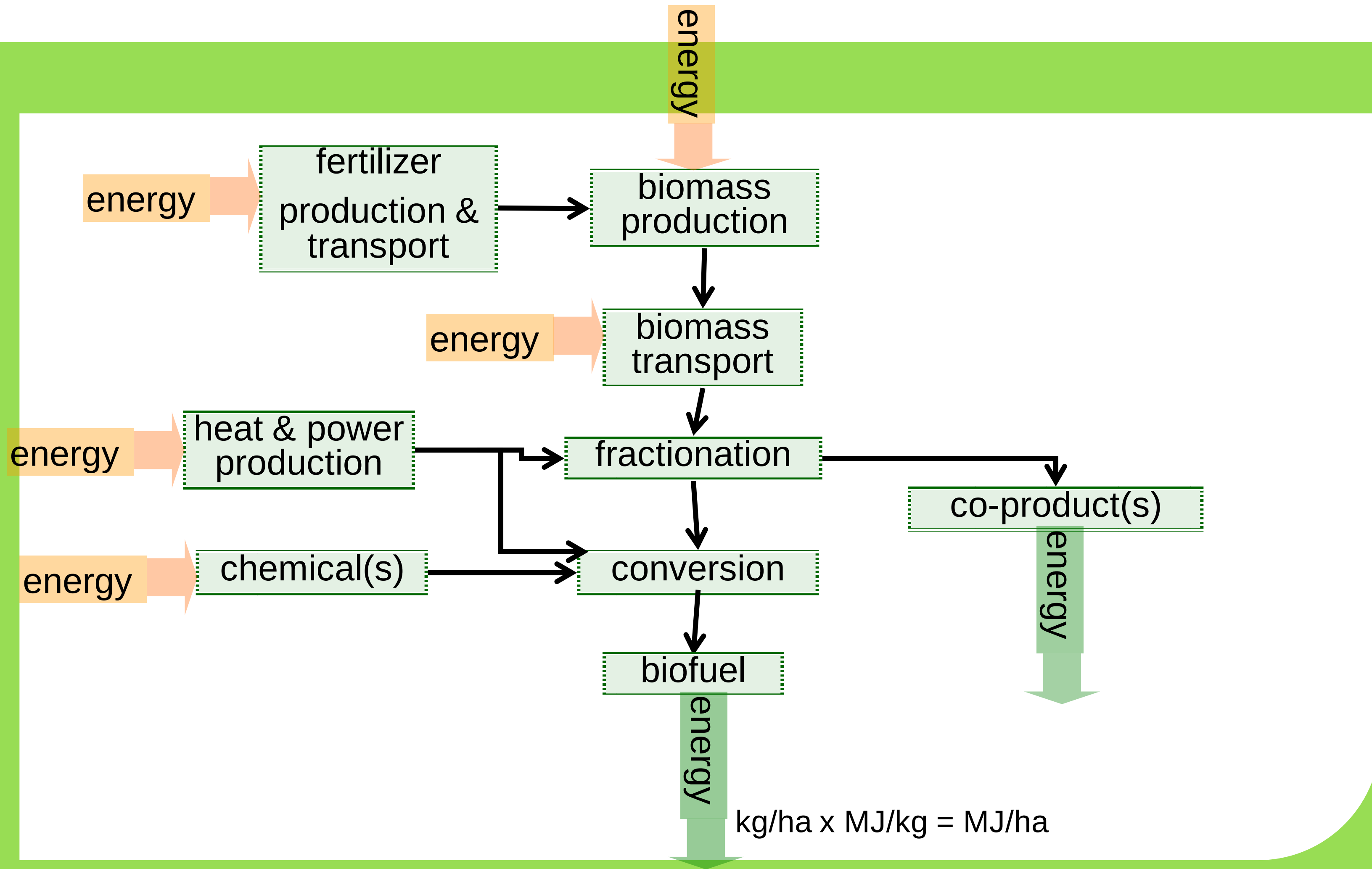
NESTE OIL

Energy Flows in Agricultural Systems



Why Net Energy Yields?

- Increasing population and economic development in Asian countries will place ever growing pressure on land for food, fibre, fuel and chemicals production

- Wise use of land means that feedstocks with maximum yields are supported and encourage

Data

The main data source for energy consumption was:

WELL-TO-WHEELS ANALYSIS OF

FUTURE AUTOMOTIVE FUELS AND POWERTRAINS

IN THE EUROPEAN CONTEXT

WELL-to-TANK Report - Appendix 1

Version 3c, July 2011

http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/22590/2/eur%2024952%20en%20n.pdf

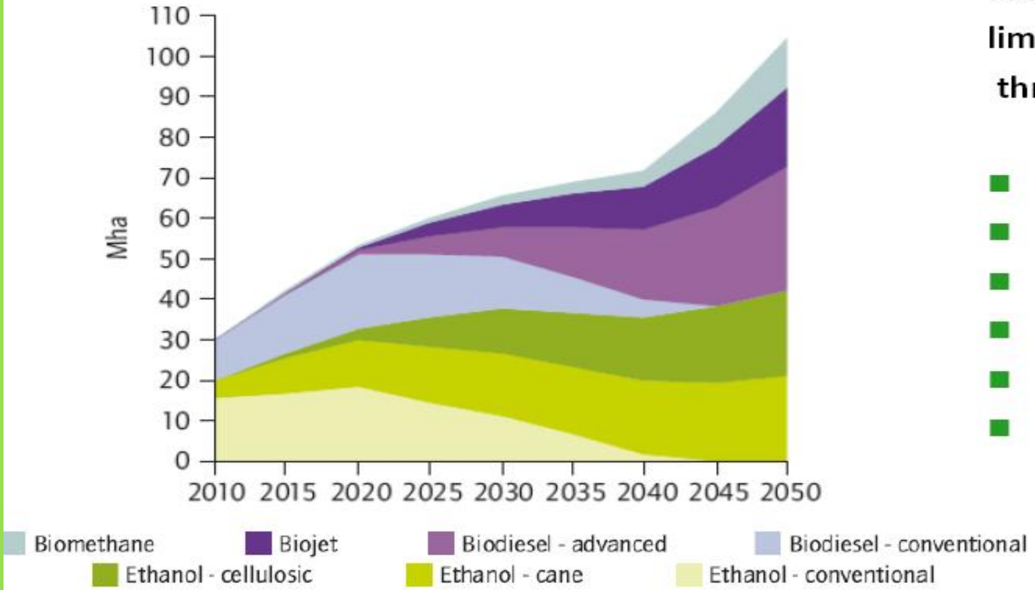
This same data was used in BioGrace and has been used in the EU RED.

Data on crop yields was taken from FAOSTAT

Biofuel Land Requirements to 2050

International Energy Agency

Land Requirements



Note: This is gross land demand, excluding land-use reduction potential of co-products

Pressure on agricultural land can be limited and risk of ILUC can be mitigated through:

- Productivity improvements
- Use of residues and wastes
- Use of pasture/ unused land
- Potential for wood biomass
- Biomass cascading & biorefineries
- Land-use zoning and sustainable land-use management schemes

- Land required to produce biofuels increases from **30 Mha** today to **100 Mha** in 2050, in addition to **1 billion tons of residues**
  - Sustainable land expansion will be challenging given increasing demand for food and biomaterial

Introduction to Energy Calculations

- Various methodologies are used such as net energy gain and net energy ratio
    - net energy ratio (NER)
    - energy return on investment (EROI)
- These indicators illustrate how much energy is expended to achieve a unit of energy
- These indicators however do not address the land required to achieve this energy
- This study looks at energy ratio on the basis of primary energy as well as fossil energy gain per hectare

BioFuel Pathways

Ethanol from

- sugar cane
- corn
- wheat

Biodiesel = FAME & Renewable Diesel

- crude palm oil (CPO)
- soyabean / soya oil
- rapesseed / rapeseed oil

Biofuels Heating Values

Ethanol with a lower heating value (LHV) of 26.81 MJ/kg and a density of 0.794 kg/l has a LHV of 21 MJ/l which is 21/32 x 100 = 66% of gasoline

Biodiesel = FAME produced by reacting vegetable oils with methanol has a LHV of 37.2 MJ/kg and density of 0.89 kg/l giving 33.1 MJ/l which is 33/36 x 100 = 92% that of diesel

Renewable Diesel (RD) produced by reaction of vegetable oils with hydrogen has a LHV of 44 MJ/kg and density of 0.79 kg/l giving 34.8 MJ/l which is 97% that of diesel.

Ethanol Pathways

In ethanol production, the feedstock must first be converted into sugars. When the feedstock is starch, enzymes hydrolyze the starch into simple sugars.

Co-products from corn / wheat processes are animal feeds such as DDGS (distiller dried grains). These must be dried before storage.

Sugars are fermented to ethanol using yeast. Fermentors are aerated. The products are ethanol and carbon dioxide. Ethanol is removed from water by distillation (heating) followed by drying using molecular sieves or membranes.

BioDiesel / Renewable Diesel Pathways

Vegetable oils are first extracted from rapeseeds or soyabeans by crushing, screw pressing and solvent extraction using hexane. Vegetable oils are extracted from palm fresh fruit bunchs by sterilization, stripping, digestion, screw pressing and centrifugation.

In the biodiesel process 10 kg of methanol produced from methane is reacted with 100 kg of vegetable oil producing 100 kg of biodiesel and 10 kg of glycerol. Glycerol has a number of possible uses.

In the Renewable Diesel process 3-4 kg of hydrogen reacts with vegetable oils producing hydrocarbons, water, carbon dioxide and propane. Propane is used within the process for energy or to produce hydrogen.

BioDiesel / Renewable Diesel Pathways

- Biodiesel and Renewable Diesel have similar process energy requirements, both processes use natural gas to produce either methanol or hydrogen
- Renewable diesel produced in a hydrotreating process uses 0.15 MJ_x/MJ_f compared to 0.19 MJ_x/MJ_f for biodiesel
- Renewable diesel releases the carbon dioxide from hydrogen production in the process step whereas biodiesel releases the fossil carbon dioxide during the combustion step

Electricity & Heat Efficiencies

- Electrcity produced in central thermal plants in a steam turbine has efficiency of ~ 2.7 $MJ_{fuel\ input}$ /$MJ_{electr.}$

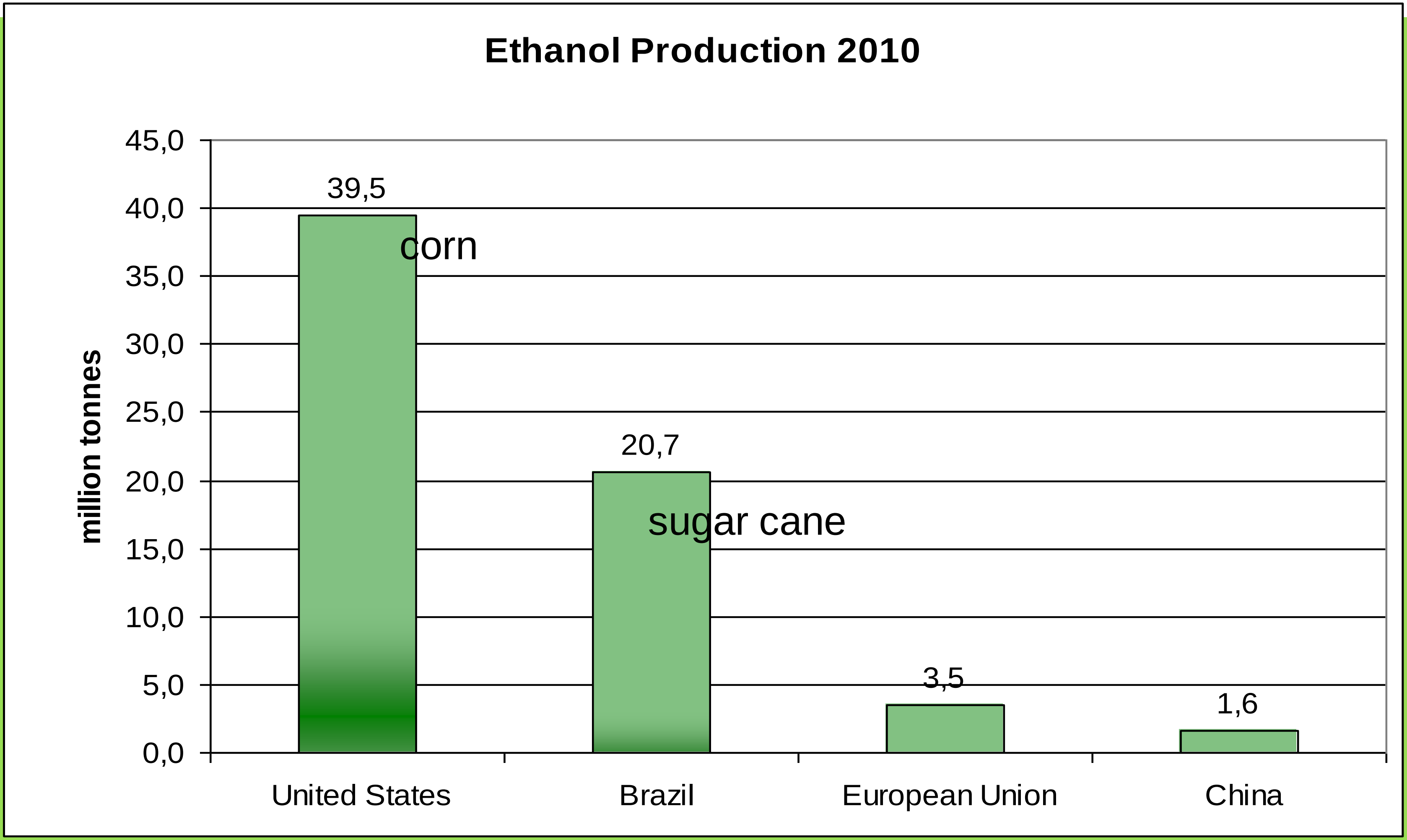
- Cogeneration plants also known as CHP plants (combined heat and power) typically have thermal efficiencies of ~ 75 %; with electrical power at 35% of fuel input and steam at 65%; this gives 1.3 $MJ_{fuel\ input}$ /$MJ_{electr.}$ and 1.3 $MJ_{fuel\ input}$ /$MJ_{steam.}$

Chemicals, Fuels

The following values from BioGrace www.biograce.net are used

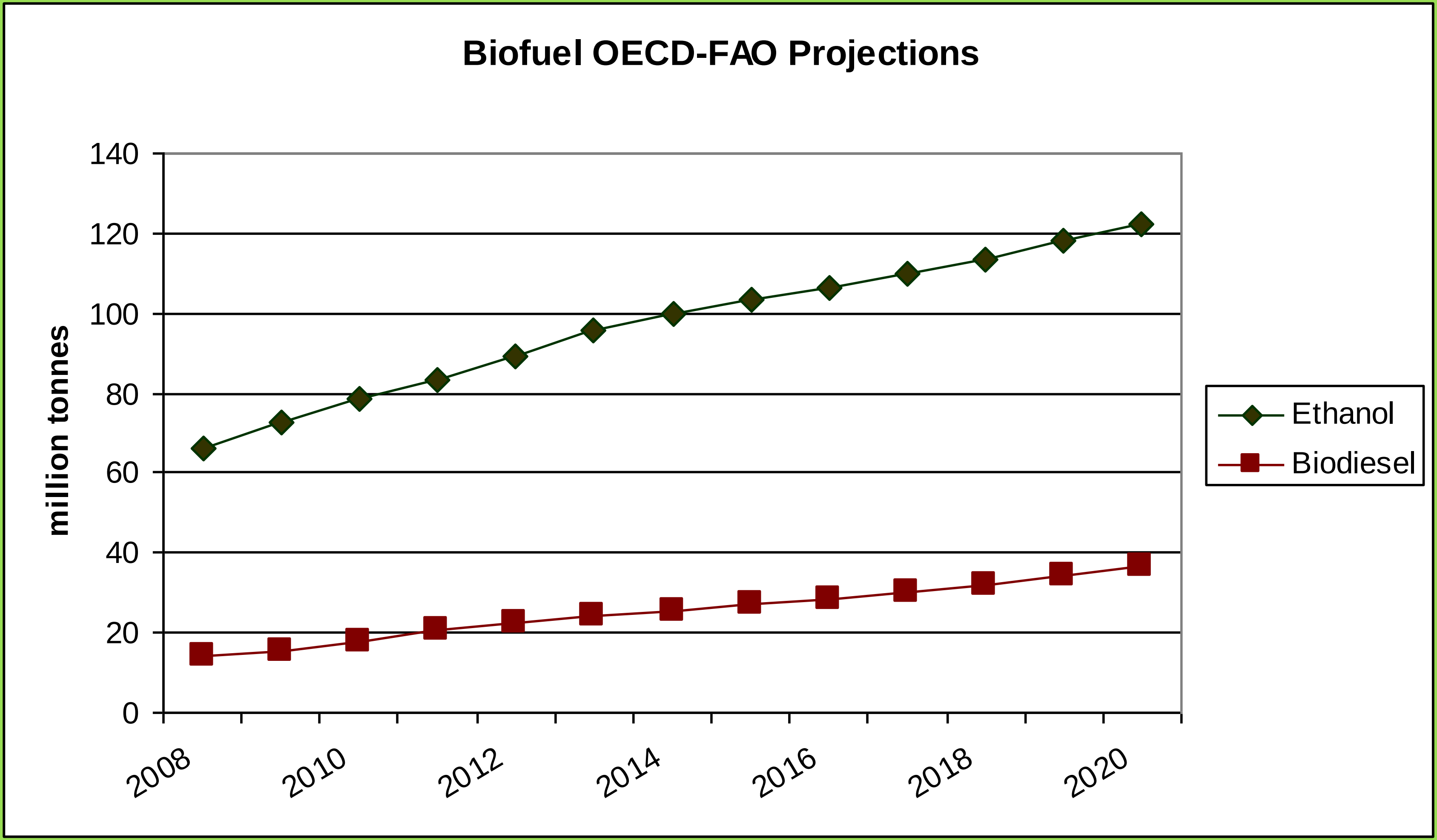
- N-fertiliser (kg N) 49 MJ_{fossil}/kg
- P2O5-fertiliser (kg P2O5) 15.2 MJ_{fossil}/kg
- K2O-fertiliser (kg K2O) 9.7 MJ_{fossil}/kg
- CaO-fertiliser (kg CaO) 2 MJ_{fossil}/kg
- Diesel 1.16 MJ_{fossil}/MJ
- Methanol 1.66 MJ_{fossil}/MJ
- Hydrogen 1.48 MJ_{fossil}/MJ

Ethanol Consumption 2010



Source: F.O. Lichts. "Industry Statistics: 2010 World Fuel Ethanol Production". Renewable Fuels Association

Defining the Demand



Feedstock Yield Variations

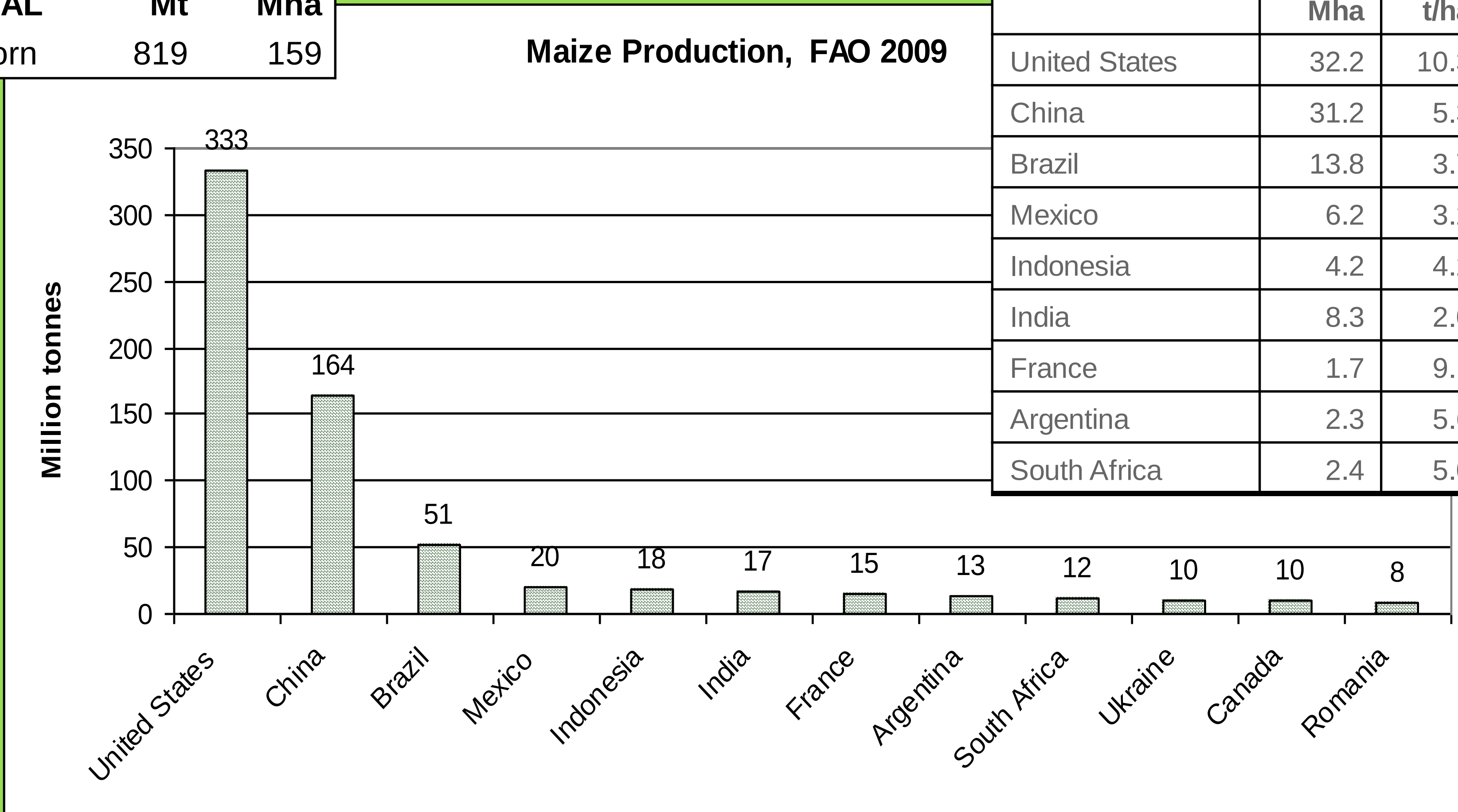
		BIOFUEL	CROP YIELD (Tonnes/ha)	CONVERSION EFFICIENCY (Litres/tonne)	BIOFUEL YIELD (Litres/ha)
Sugar beet	Global	Ethanol	46.0	110	5 060
Sugar cane	Global	Ethanol	65.0	70	4 550
Cassava	Global	Ethanol	12.0	180	2 070
Maize	Global	Ethanol	4.9	400	1 960
Wheat	Global	Ethanol	2.8	340	952
Sugar cane	Brazil	Ethanol	73.5	74.5	5 476
Sugar cane	India	Ethanol	60.7	74.5	4 522
Oil palm	Malaysia	Biodiesel	20.6	230	4 736
Oil palm	Indonesia	Biodiesel	17.8	230	4 092
Maize	USA	Ethanol	9.4	399	3 751
Maize	China	Ethanol	5.0	399	1 995
Soybean	USA	Biodiesel	2.7	205	552
Soybean	Brazil	Biodiesel	2.4	205	491

} double cropping (Soybean USA / Soybean Brazil)

Source: Rajagopal et al., 2007, for global data; Naylor et al., 2007, for national data.
http://www.greenfacts.org/en/biofuels/figtableboxes/biofuel-yields-countries.htm

Corn Production Statistics

TOTAL	Mt	Mha
corn	819	159

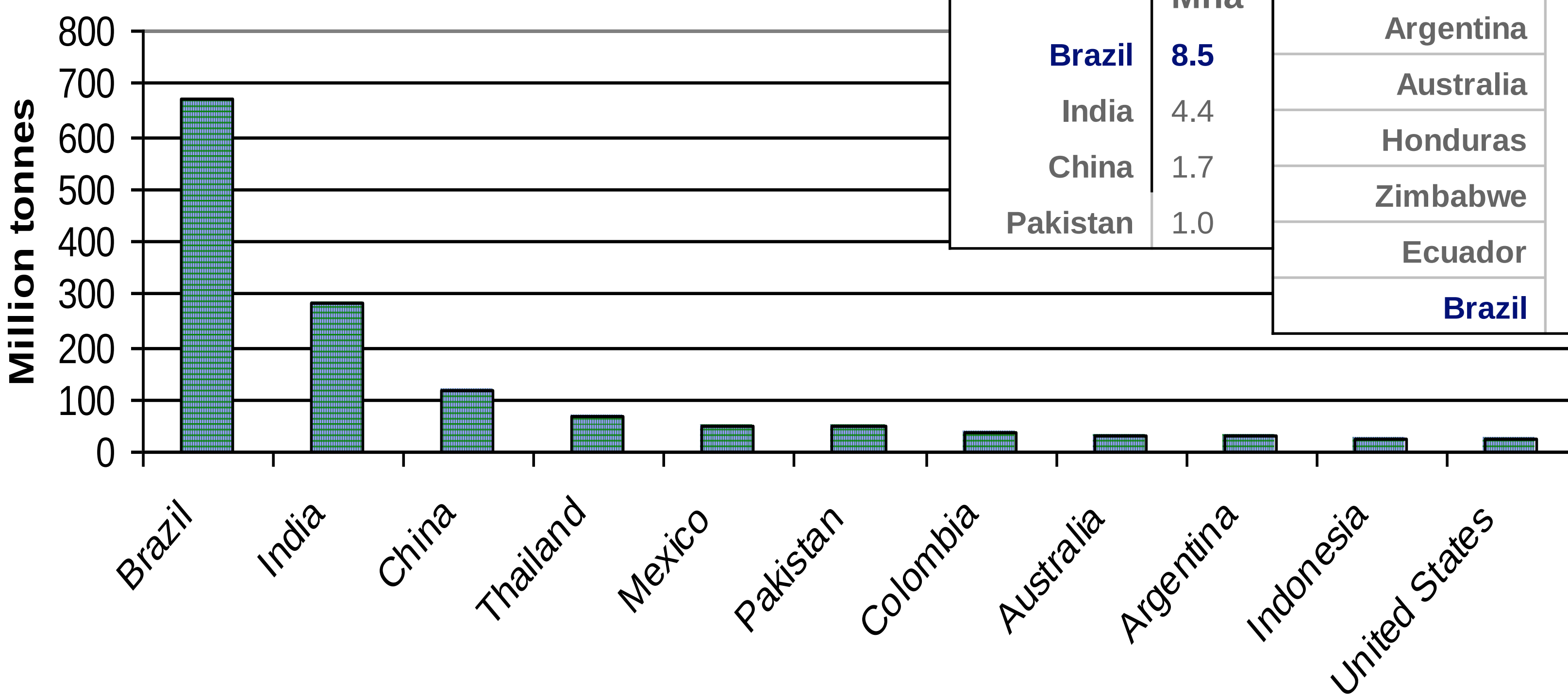


	Mha	t/ha	Mt
United States	32.2	10.3	333
China	31.2	5.3	164
Brazil	13.8	3.7	51
Mexico	6.2	3.2	20
Indonesia	4.2	4.2	17.6
India	8.3	2.0	16.7
France	1.7	9.1	15.3
Argentina	2.3	5.6	13.1
South Africa	2.4	5.0	12.1

Sugar Cane Statistics (sugar @ 12-14% of cane)

TOTAL	Mt	Mha
cane (wet)	1530	23.8
sugar	216	

Sugar Cane Production, FAO 2009

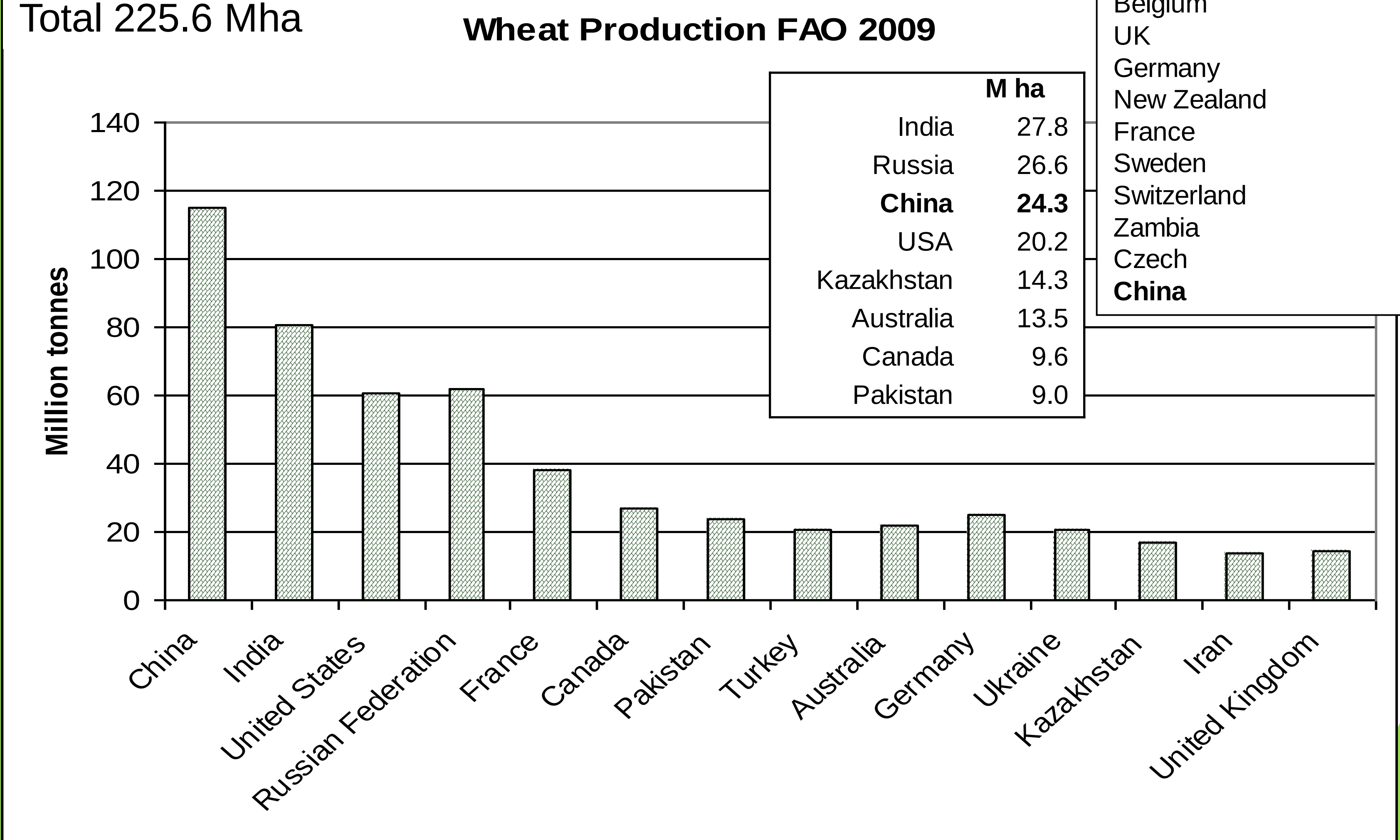


	Mha
Brazil	**8.5**
India	4.4
China	1.7
Pakistan	1.0

	t/ha
Colombia	101.4
Chad	100.0
Nicaragua	85.6
Argentina	84.4
Australia	80.4
Honduras	80.1
Zimbabwe	79.5
Ecuador	79.3
Brazil	**78.9**

Wheat Statistics (starch @ 70% of grain)

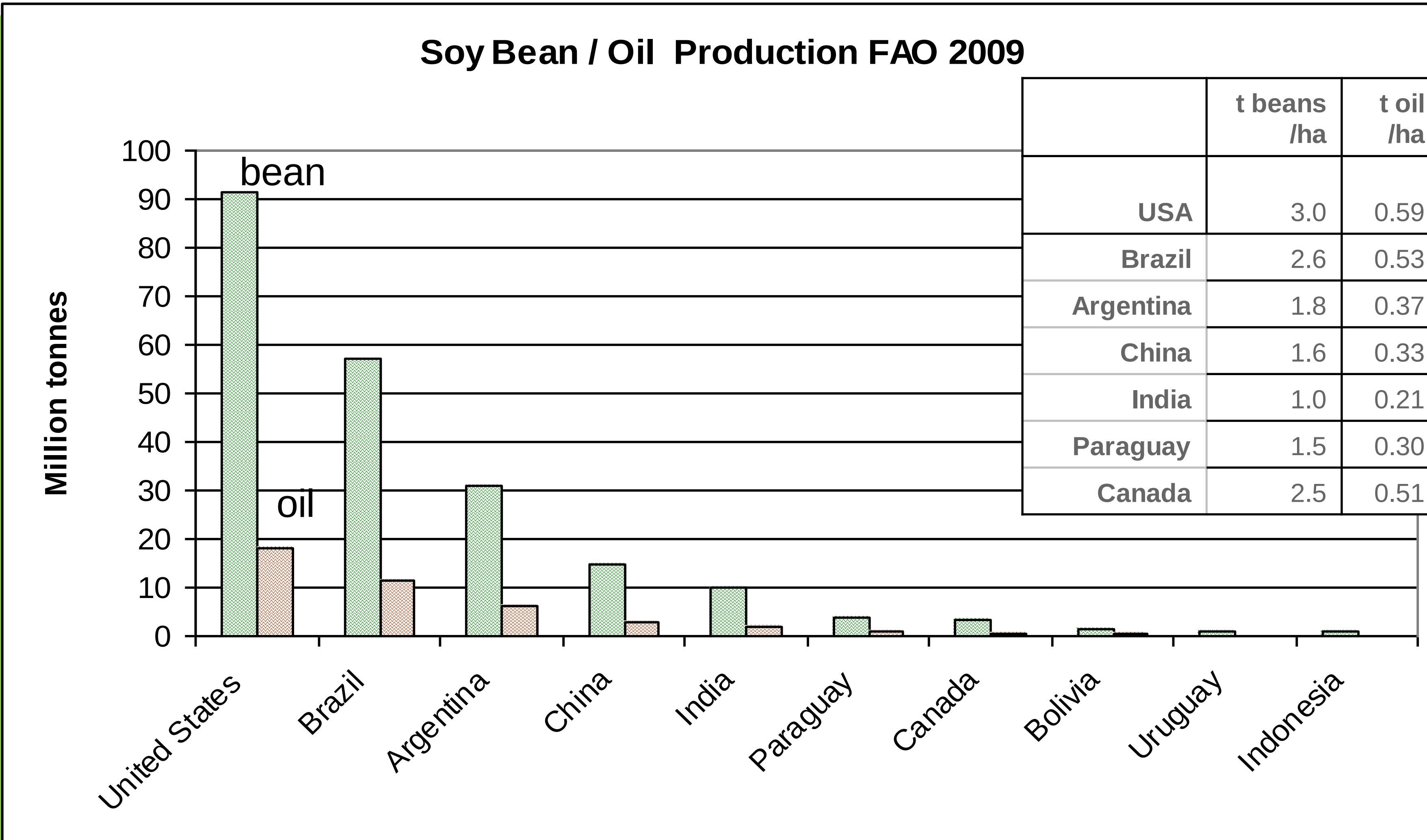
Total 225.6 Mha



	M ha
India	27.8
Russia	26.6
China	**24.3**
USA	20.2
Kazakhstan	14.3
Australia	13.5
Canada	9.6
Pakistan	9.0

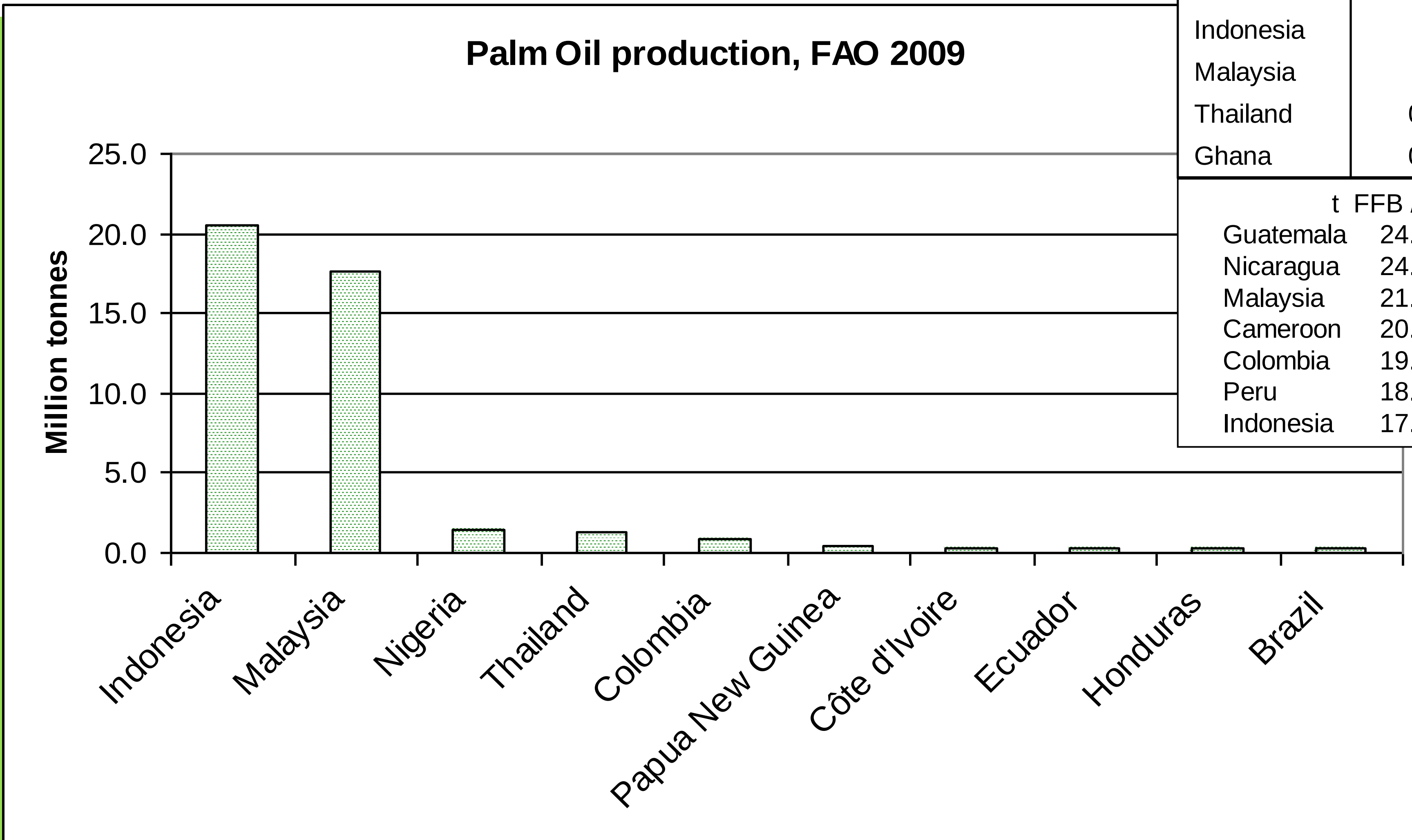
	t / ha
Belgium	9.5
UK	7.9
Germany	7.8
New Zealand	7.5
France	7.4
Sweden	6.1
Switzerland	6.0
Zambia	5.7
Czech	5.2
China	**4.7**

Soya bean Statistics (oil @ 20 wt% of bean)



	t beans /ha	t oil /ha
USA	3.0	0.59
Brazil	2.6	0.53
Argentina	1.8	0.37
China	1.6	0.33
India	1.0	0.21
Paraguay	1.5	0.30
Canada	2.5	0.51

Palm Statistics (CPO @ 19-21 wt% of FFB)

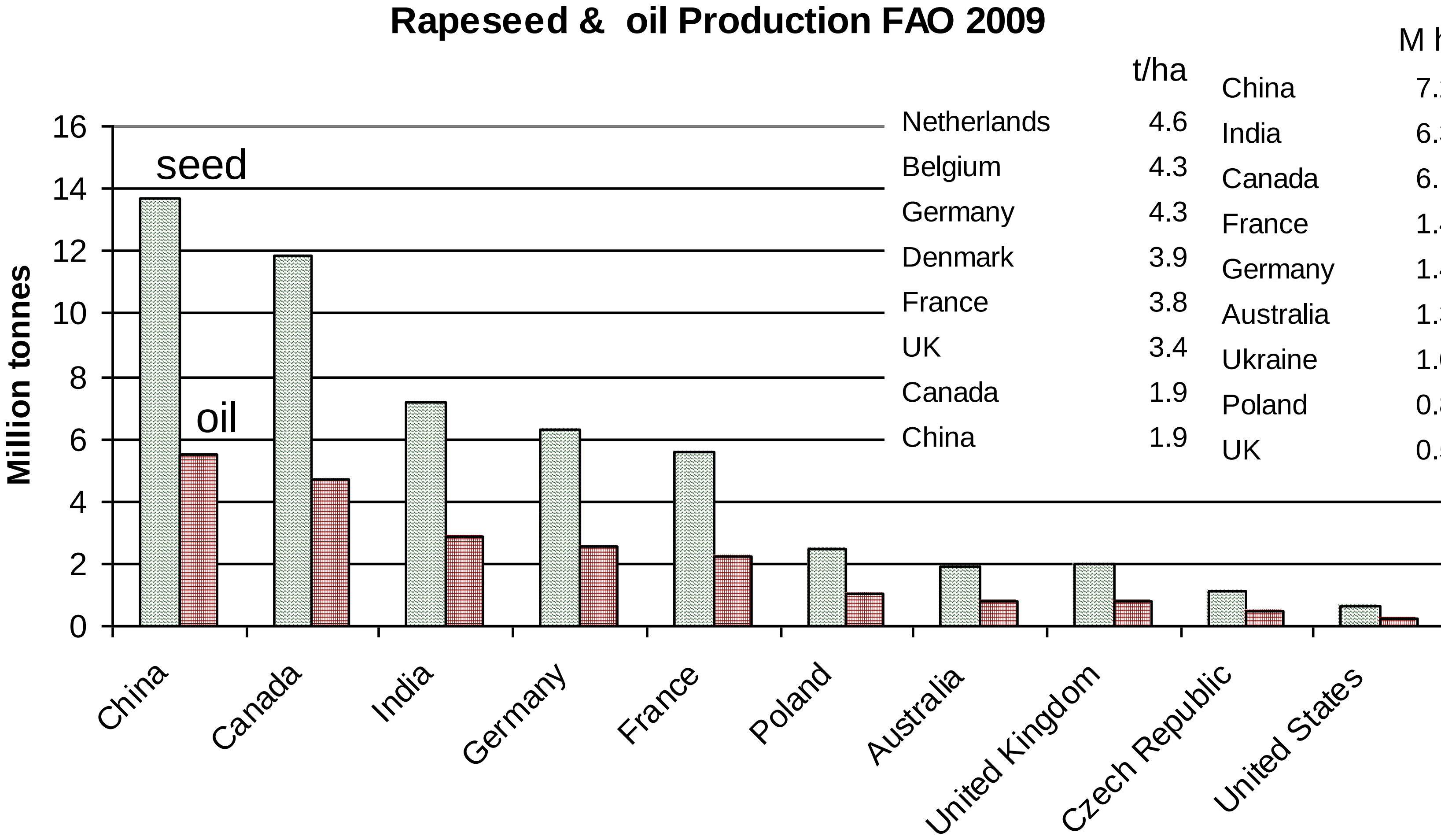


	Mha
Indonesia	5
Malaysia	4.0
Thailand	0.51
Ghana	0.35

	t FFB /ha
Guatemala	24.7
Nicaragua	24.3
Malaysia	21.2
Cameroon	20.8
Colombia	19.4
Peru	18.9
Indonesia	17.2

Note: FAO statistics for mature ha only.

Rape seed Statistics (oil @ 40-42 wt% of seed)



	t/ha
Netherlands	4.6
Belgium	4.3
Germany	4.3
Denmark	3.9
France	3.8
UK	3.4
Canada	1.9
China	1.9

	M ha
China	7.28
India	6.30
Canada	6.10
France	1.48
Germany	1.47
Australia	1.39
Ukraine	1.01
Poland	0.81
UK	0.58

Rapeseed oil @ 40 wt% of seed

Farming Energy (fossil part)

	Yields	Expended energy Fertilizers, pesticides + diesel
	t/ha/a	Primary MJ_x / MJ $_{prod.(seed, bean,etc.)}$
Wheat (grain)	5.2 t@ 13.5% moisture	0.146
Sugar cane (Brazil)	68.7 t@ 72% moisture	0.021
Maize (corn, EU) kernel	3.8 t @ 15% moisture	0.12
Rapeseed (seeds)	2.4 t @ 10% moisture	0.16
Soyabean	2.8 t @ 15% moisture	0.093
Oil palm FFB	19 t @ 34% moisture	0.05

BioGrace Values (typical values)

http://re.jrc.ec.europa.eu/biof/xls/Biofuels pathways RED method 14Nov2008.xls

	Crop yield	Crop yield	N fert.	N ferti.	Final Fuel	
	Fresh (t / ha)	dt/ha	kg N / ha	MJ/ha	MJ/ha	MJ_N/MJ_f
Corn (EU)	3,9	3,3	51,7	2533,3	31181	8,1 %
Wheat (EU)	5,2	4,5	109,3	5355,7	40688	13,2 %
Sugarbeet (EU)	68,9	17,2	120,0	5880	152544	3,9 %
Sugarcane	68,7	18,9	62,5	3062,5	133574	2,3 %
Rapeseed (NW Europe)	3,1	2,8	137	6713	43067	15,6 %
Soybean	2,8	2,4	8	392	18299	2,1 %
Palm fruit bunch	19,0	12,5	128	6272	150066	4,2 %

Credits for By-Products

		Expended energy Fertilizers, pesticides + diesel
	Type	Primary MJ_x / $MJ_{prod.(seed, bean, etc.)}$
Wheat (grain)	DDGS exported as animal feed	-0.14
Sugar cane (Brazil)	bagasse used for process heat	0.0 (receives credit when energy is exported)
Rapeseed (seeds)	meal for animal feed	-0.11
Soyabean	Meal for animal feed	-0.32
Oil palm FFB	Palm kernel meal	-0.09

Process Energy Consumption (fossil part)

		Expended energy crushing, ethanol production
	Type	Primary $MJ_{foss.}$ / MJ $_{prod.(seed, bean,etc.)}$
Wheat (grain)	fermentation, distillation	0.46 using NG for heat; 0.15 electr.; higher using coal,
Sugar cane (Brazil)	fermentation, distillation	0.003 (bagasse in CHP) -0.14 for excess bagasse
Rapeseed Soyabean	Oil extraction	0.08
Oil palm FFB	Oil extraction	0.0 uses shell & fibre

Note: Processes typically use a combination of fossil energy as well as process wastes and side streams with low economic value for energy purposes

Sugar cane ethanol

EtOH from sugar cane (Brazil), no credit for excess bagasse	
	Expended energy primary MJ_x / $MJ_{prod.}$
Cultivation	0.06
Road transport	0.01
Ethanol plant	0.004
Shipping & Distribution	0.11
	0.184

Wheat ethanol

Ethanol from wheat, Conv. NG boiler, DDGS as animal feed	
	Expended energy primary MJ_x / $MJ_{prod.}$
Cultivation	0.27
Road transport	0.03
Ethanol plant	0.61
Shipping & Distribution	0.03
	0.94

Rapeseed oil biodiesel

Rapeseed methyl ester, meal as animal feed, glycerine as animal feed	
	Expended energy primary MJ_x / $MJ_{prod.}$
Cultivation, drying	0.27 + 0.02
Road transport + distribution & retail	0.02 + 0.02
Oil mill	0.08
Esterfication	0.17
	0.58

Soya oil biodiesel

Imported soya beans, glycerine as chemical, soya meal replaces EU wheat	
	Expended energy primary MJ_x / $MJ_{prod.}$
Cultivation	0.28
Road transport + distribution & retail	0.49 (beans shipped from Brazil to Europe)
Oil mill	0.08
Esterfication	0.17
	1.02

Palm oil biodiesel

Imported palm oil, glycerine as chemical	
	Expended energy primary MJ_x / MJ $_{prod.}$
Cultivation	0.10
FFB transport	0.06
Oil mill	0.0
shipping+ distribution	0.05 + 0.02
Esterfication	0.17
	0.4

Total energy vs. Fossil Energy ratios

	Expended energy MJ_{foss} / $MJ_{prod.}$	FER MJ_{prod} / MJ_{foss}
Wheat ethanol	0.94 – 0.14= 0.8	1.3
Sugar cane ethanol	0.18	5.6
Soya biodiesel	1.02 – 0.32 = 0.7 /1/	1.4
Rape oil biodiesel	0.58	1.7
Palm oil biodiesel	0.4 – 0.09=0.31	3.2

Notes: 1. due to shipping of beans to EU

Energy outputs per hectare

	Energy / ha / a		
	GJ biomass	GJ fuel gross	GJ fuel net (gross- fossil)
Wheat to ethanol (no straw)	77	40.7	8
Sugar cane to ethanol	370	133	109
Soyabean to biodiesel	56	18	6
Rapeseed to biodiesel	74	43	18
Palm oil to biodiesel	300	150	103

Net Energy Conclusions

- Crop yields vary considerably due to amounts of fertilizers, climatic conditions, soil conditions and plant varieties
- Inorganic fertilizers produced using fossil fuels, nitrogen fertilizers being the most intensive
- Both palm oil extraction and sugar cane ethanol production use high amounts of crop residues during processing which reduce their fossil requirements

Net Energy Conclusions

- On an energy basis, both sugar cane ethanol and palm oil biodiesel / renewable diesel produce significantly more energy than comparative pathways on the order of 3-6 times more per unit area
- In a land limited future where biofuel production is due to increase, biofuel production should be concentrated in those areas and on those biofuel pathways that maximize energy outputs provided these can meet the sustainable production criterae

Extra slide

	Density kg/m³	LHV MJ/kg
Diesel	832	43,1
Gasoline	745	43,2
HFO	970	40,5
Ethanol	794	26,81
Methanol	793	19,9
FAME	890	37,2
Syn diesel (BtL)	780	44,0
HVO	780	44,0

Lower Heating Value LHV MJ/kg (at 0% water)

Corn	18,5
FFB	24,0
Rapeseed	26,4
Soybeans	23,5
Sugar beet	16,3
Sugar cane	19,6
Sunflower seed	26,4
Wheat	17,0
Waste vegetable / animal oil	37,1
Crude vegetable oil	36,0
DDGS (10 wt% moisture)	16,0

Glycerol	16,0
Palm kernel meal	17,0
Palm oil	37,0
Rapeseed meal	18,7
Soybean oil	36,6
Soy bean meal	-
Sugar beet pulp	15,6
Sugar beet slops	15,6
Wheat straw	17,2