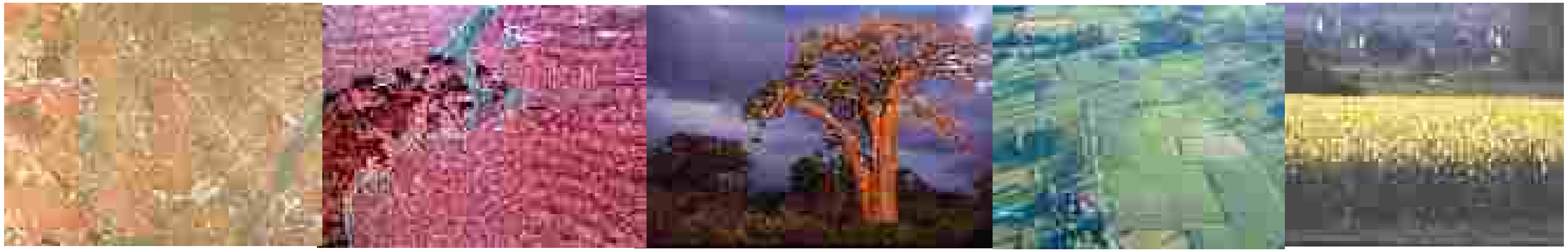

Life Cycle Inventory of Biodiesel Production from Jatropha

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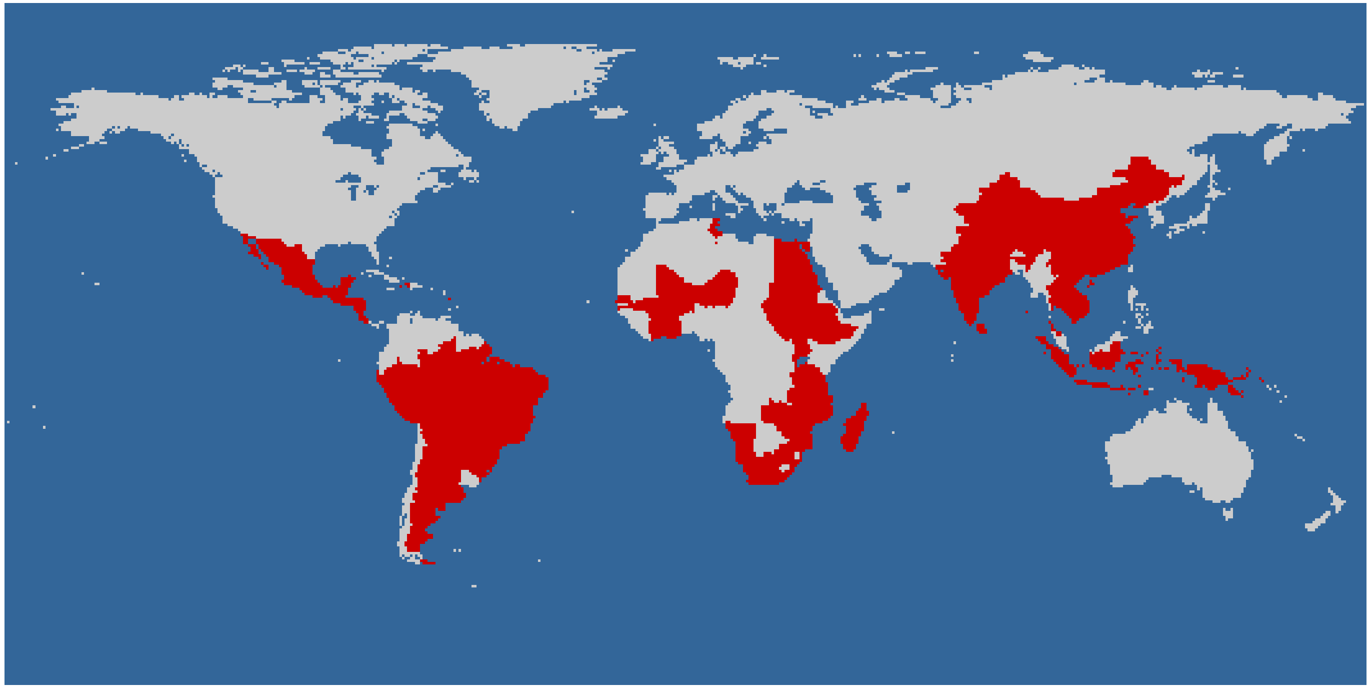
w.biw.kuleuven.be/lbh/lbnl/forecoman/english/index.asp

Jatropha's multiple promises

- drought resistent (minimum 200mm rainfall)
- high production of quality oil (up to 8 t seeds/ha/yr)
- poverty reduction
- combatting desertification
- multipurpose

The Jatropha hype



Jatropha projects reported on the Internet

Why is there a hype for tropical biofuels?

in Europe:

- EU policies on renewables
- Kyoto obligations
- but lack of space in Europe
- and higher NPP in tropics
- cheaper production in tropics (e.g. palm oil, soybean)
- tax exemptions and subsidies also valid for imported bioenergy

Why is there a hype for tropical biofuels?

in developing countries:

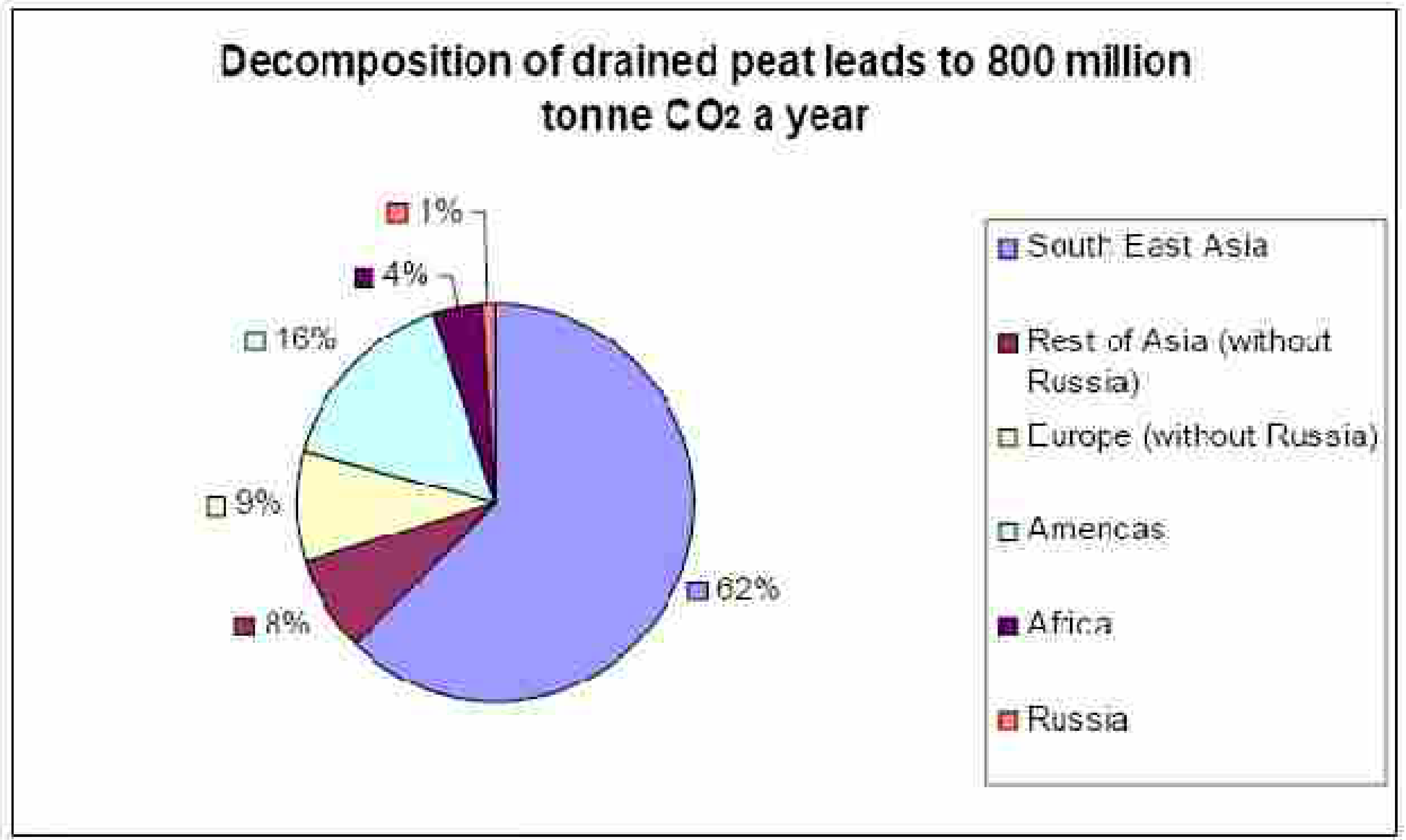
- become OPEC
- produce cash crop with stable high prices (unlike coffee, cocoa)
- become independent from oil import (e.g. 300,000 ha of oil palm would suffice for Tanzania)
- realize a positive import/export balance

Is their use sustainable?

Let's take oil palm as an example:

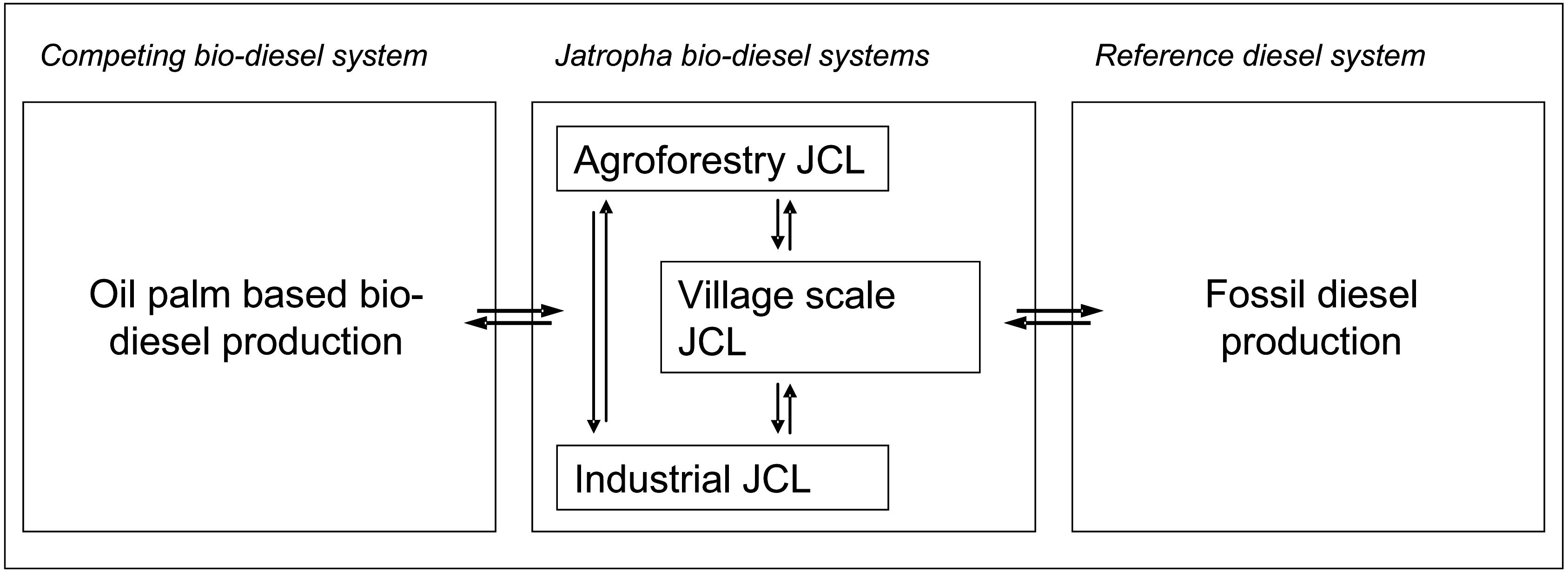
- highly positive energy and GHG balances thanks to high production if locally used
- important loss of this balance through shipping and transformation to diesel
- strong negative GHG balance if resulting from conversion of natural forest (extremely negative if conversion from peatland forest, cfr. SE Asia)
- in this case also high land use impact as a consequence of biodiversity loss

Tropical deforestation and peatland drainage for oil palm development

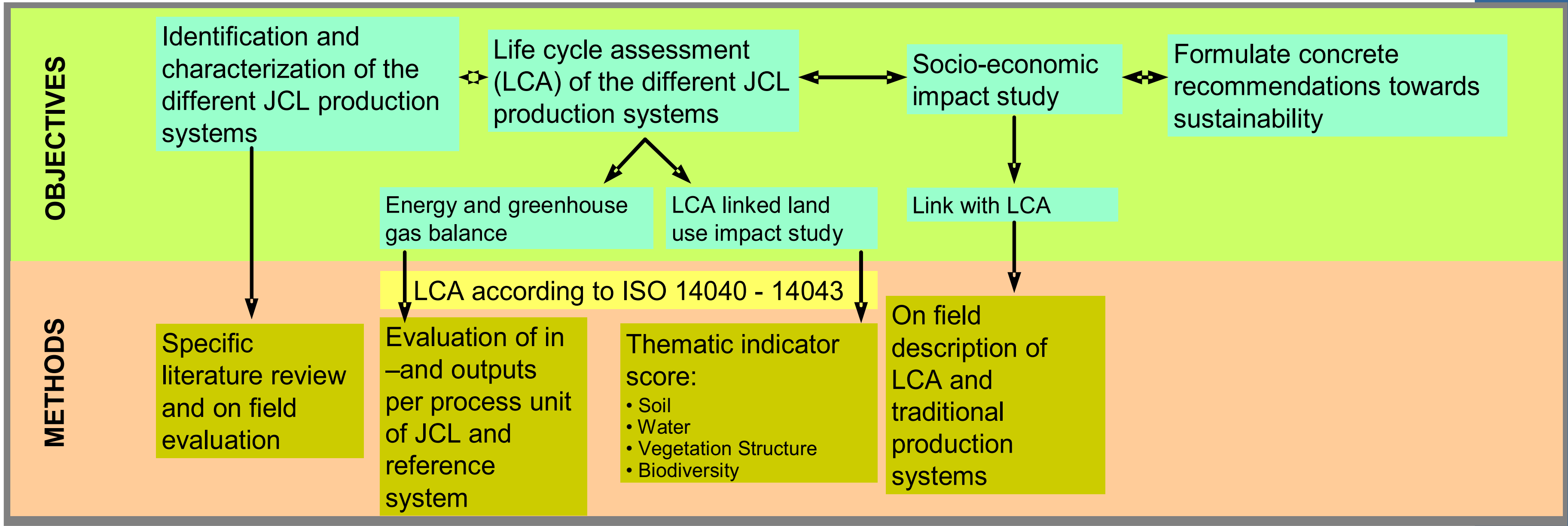


Source: Wetlands International and Delft Hydraulics

Objective of our study: Comparison of biodiesel from Jatropha and Oil palm with fossil diesel



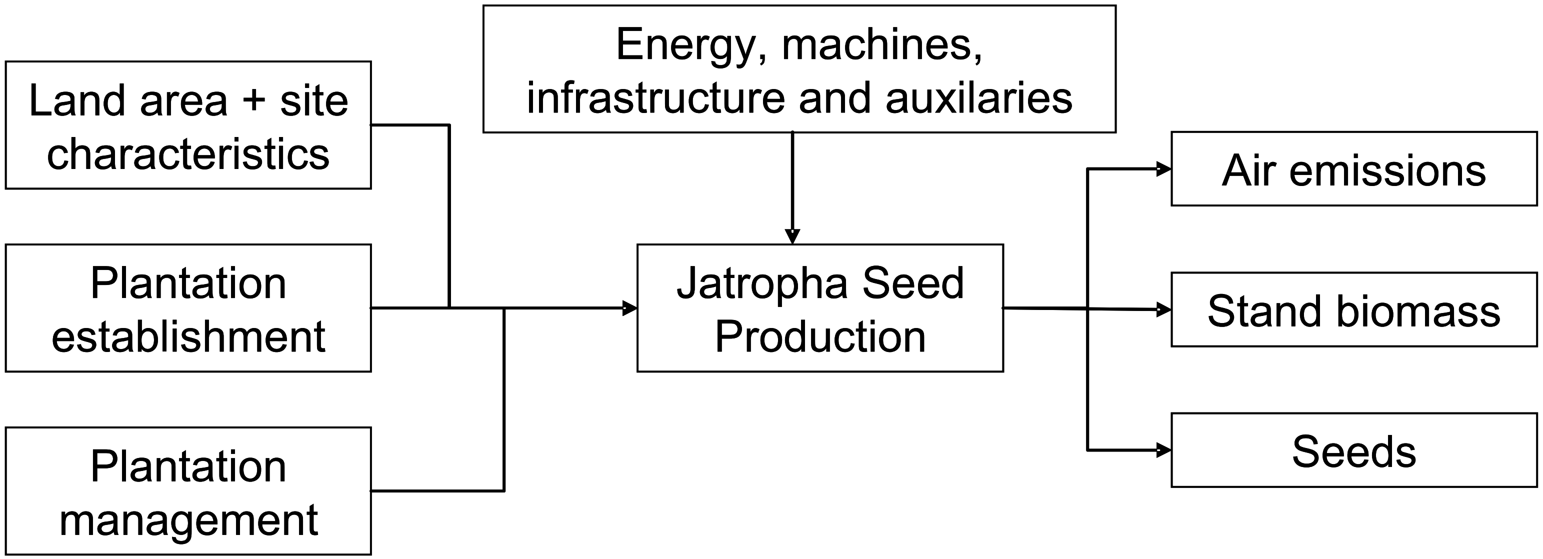
Research strategy



Preliminary results: unit processes and their life cycle inventory

1. Plantation unit process
2. Oil extraction unit process
3. Biodiesel production unit process
4. By-products unit process

1. Plantation unit process



Propagation

Generative (seeds)

- 2 seeds at 2 cm depth

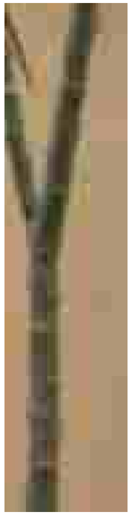
Direct seeding

- Sowing according to plant geometry
- Rainfall or life saving irrigation

Precultivating seedlings

- Nursery polybags 12,5×22,5 cm
- Nursery seedbeds: 2×25-30 cm

Vegetative (cuttings)



- 30 – 200 cm long
- 2,5 – 4,5 cm diameter
- lower part of branch

Direct Planting

- Rainfall or life saving irrigation

Precultivating plants

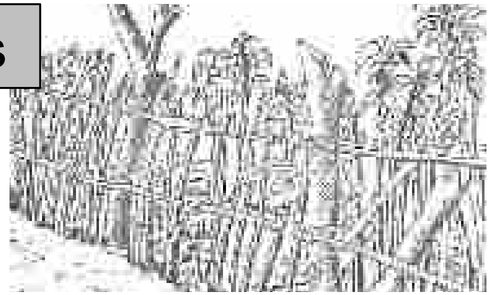
- Nursery beds: 30×30 cm

Plantation design

Block Plantation

- Planting pits: 45×45×45 cm^3
- spacing: 2×2; 2,5×2,5 or 3×3 m

Living fences



Also erosion control and prevention

- 15-25 cm within and between rows

Plantation management

Weeding — Field should be free of weeds at all times

Pruning — Canopy management

Around 6 month age

30-45 cm

Cut back at 30-45 cm

End of 1st year

Pinch or prune the secondary and tertiary branches

During 2nd and ongoing years

Prune branches at ⅓ - ⅔

- Pruning during dry winter period
- Every 10 years cut back plant till 45 cm stump

Living fence:

Pinch terminals

Fertilizing, Irrigating — Depending on site and agro-climatic situation

Drawings from Henning R. – The Jatropha Booklet - http://www.jatropha.de/ - visited 30/01/2006

Potential environmental benefits of Jatropha cultivation

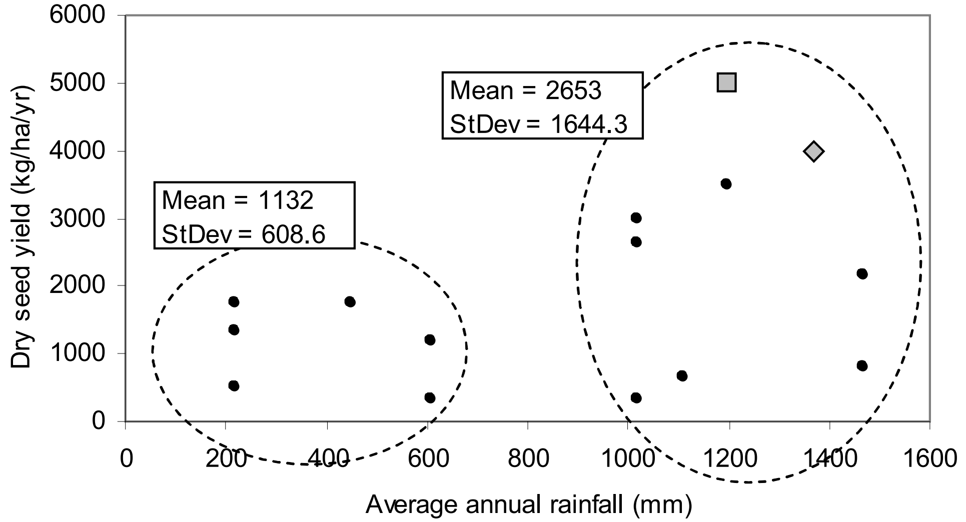
- Combatting desertification by restoration of vegetative cover in degraded areas
- Prevention and control of soil erosion through its unique root architecture (taproot + 4 laterals)



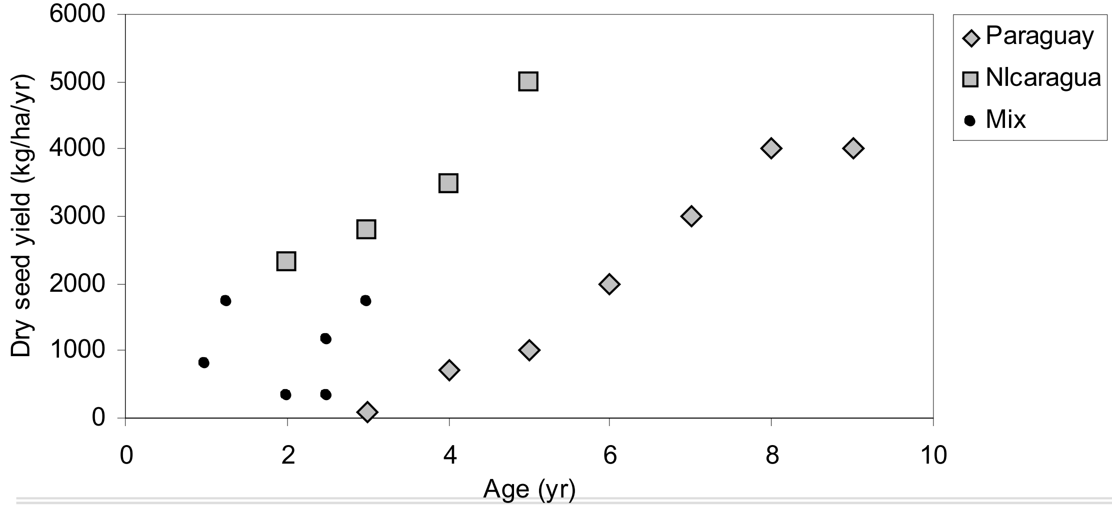
Meta-analysis of dry seed yield against (a) rainfall and (b) age

Achten et al., *in prep. for Biomass & Bioenergy*

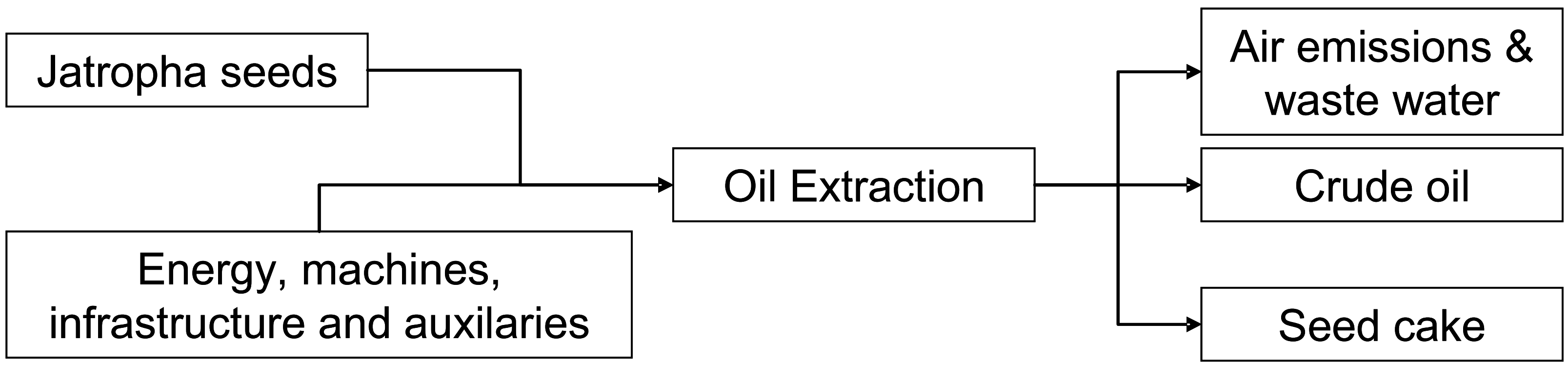
a.



b.

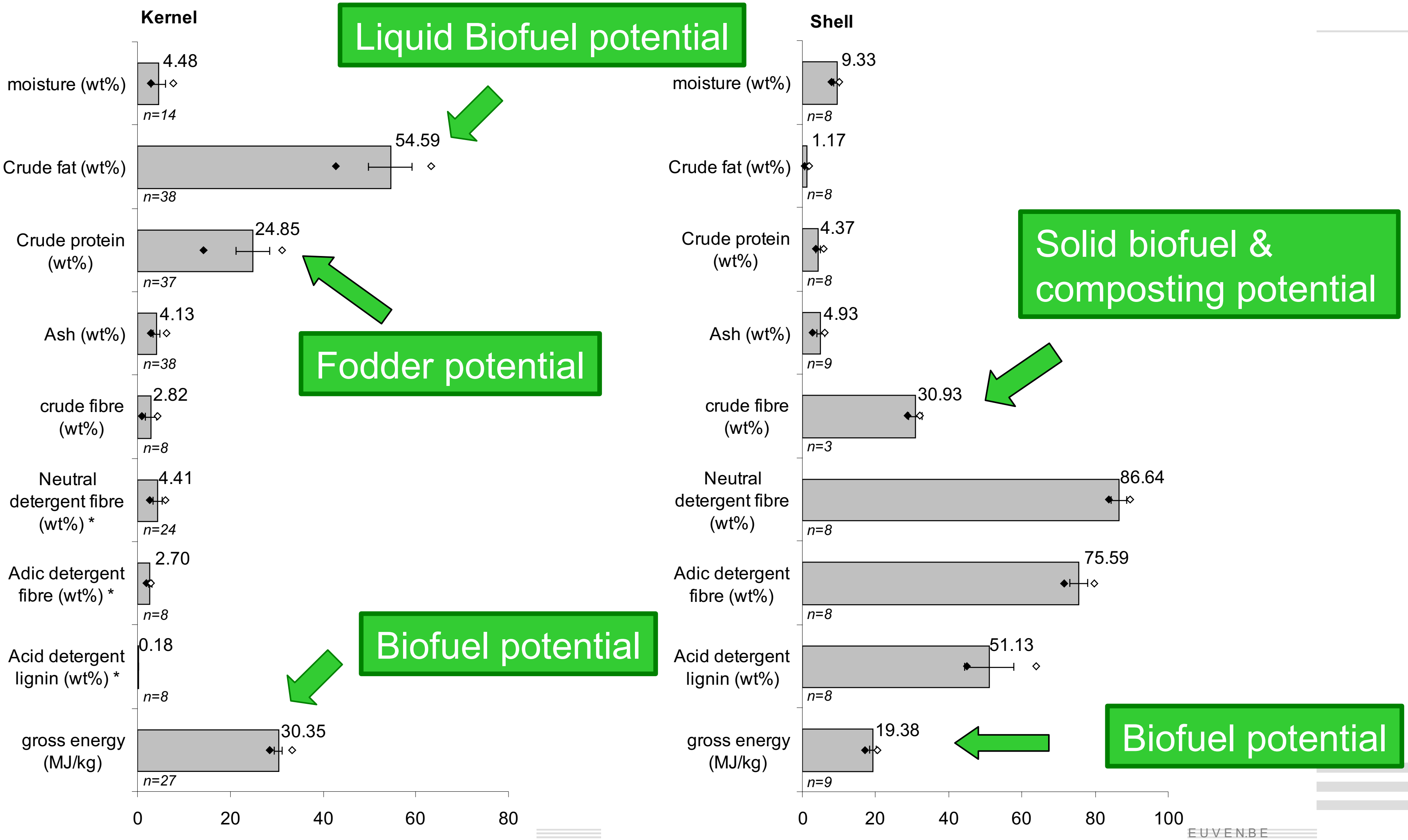


Oil extraction unit process



Kernel and shell composition

Achten et al., *in prep. for Biomass & Bioenergy*



Crude oil composition and characteristics

Achten et al., *in prep. for Biomass & Bioenergy*

	Range			Mean	StDev	*n*
Specific gravity / density (g/cm^3)	0.860	-	0.933	0.914	0.018	*13*
Calorific value (MJ/kg)	37.83	-	42.05	39.63	1.52	*9*
pour point (°C)		-3				*2*
cloud point (°C)		2				*1*
Flash point	210	-	240	235	11	*7*
Cetane value	38.0	-	51.0	46.3	6.2	*4*
saponification number (mg/g)	102.9	-	209.0	182.8	34.3	*8*
viscosity at 30°C (cSt)	37.00	-	54.80	46.82	7.24	*7*
Free fatty acids (wt%)	0.18	-	3.40	2.18	1.46	*4*
Unsaponifiable (wt%)	0.79	-	3.80	2.03	1.57	*5*
Iodine number (mg iodine/g)	92	-	112	101	7	*8*
Neutralization number (mg KOH/g)	0.92	-	6.16	3.71	2.17	*4*
monoglycerides (wt%)	nd	-	1.7			*1*
diglycerides (wt%)	2.50	-	2.70			*2*
triglycerides (wt%)	88.20	-	97.30			*2*
Carbon residue (wt%)	0.07	-	0.64	0.38	0.29	*3*
Sulfur content (wt%)	0	-	0.13			*2*

Better than palm oil, less good than fossil diesel

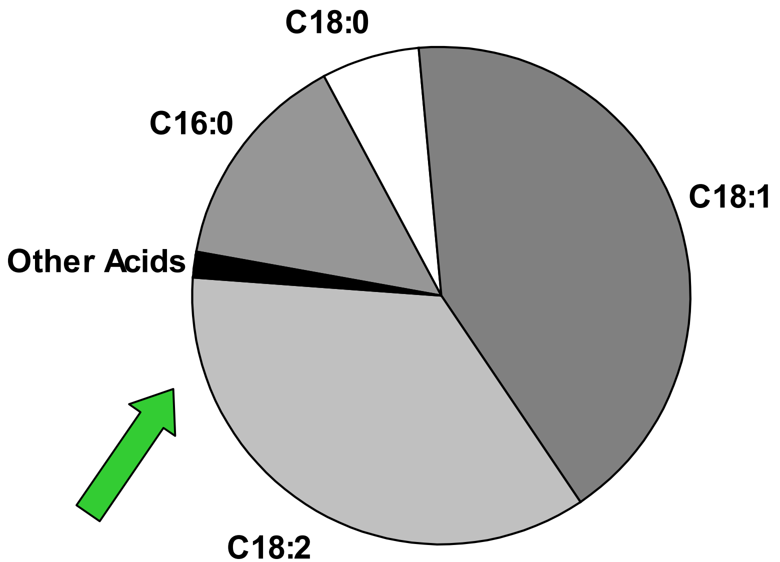
Too high for direct combustion

Degumming before transesterification if >2%

Potential for high diesel yield

Fatty acid composition of crude oil

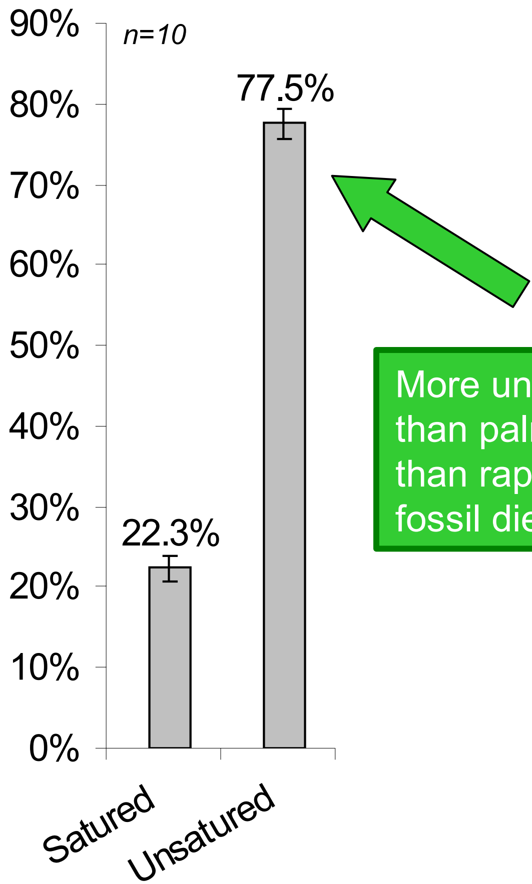
Achten et al., *in prep. for Biomass & Bioenergy*



Fatty acids with C-16-18 will yield methyl esters comparable to petrodiesel

n=22

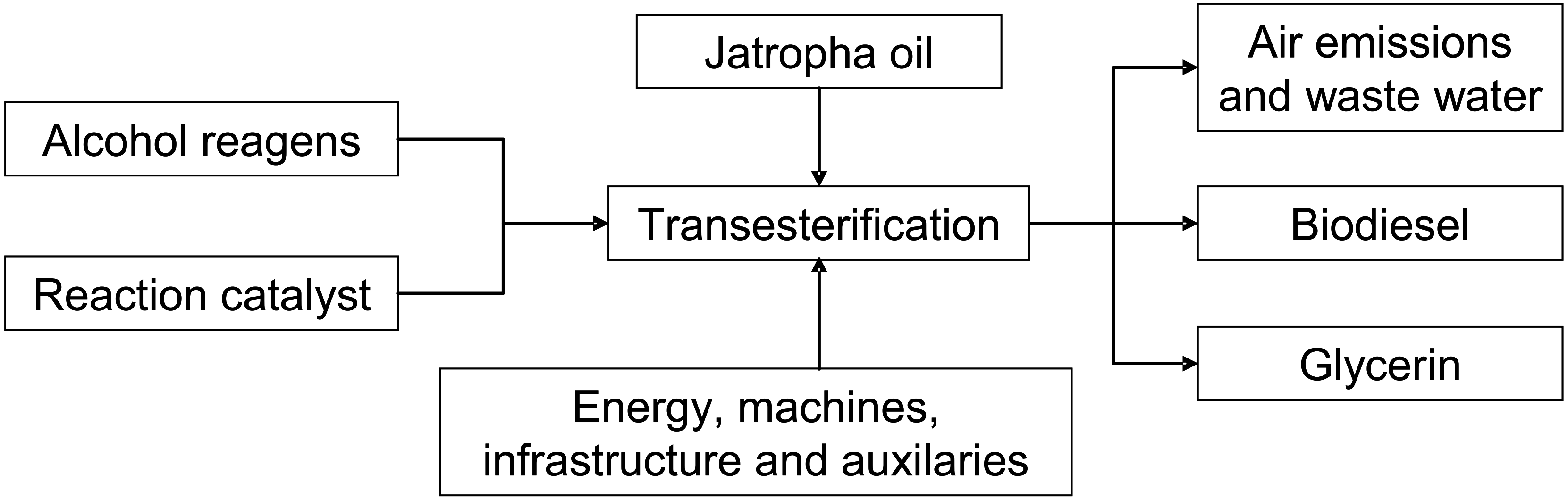
	C16:0	C18:0	C18:1	C18:2
Mean	14.54	6.30	42.02	35.38
StDev	2.37	3.41	8.07	6.26



More unsaturated than palm oil but less than rapeseed oil and fossil diesel

C16:0 = Palmitic Acid; C18:0 = Strearic Acid; C18:1 Oleic Acid; C18:2 = Linoleic Acid. Other Acids containing Capric Acid, Myristic Acid (C14:0), Palmitoleic Acid (C16:1), Linolenic Acid (C18:3), Arachidic Acid (C20:0), Behenic Acid (C22:0), cis-11-Eicosenoic Acid (C20:1) and cis-11,14-Eicosadienoic Acid (C20:2).

Biodiesel production unit process



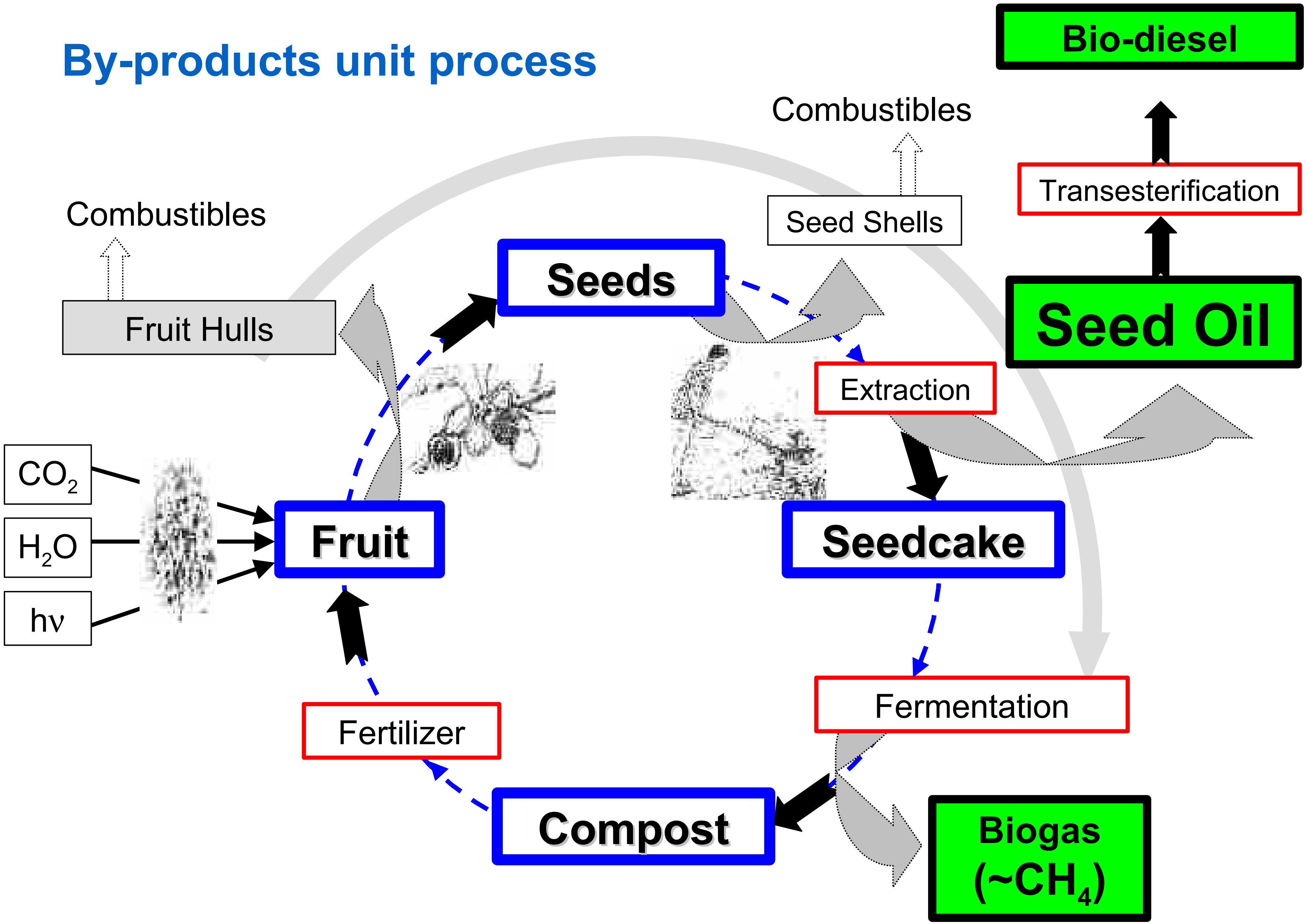
JCL (m)ethyl ester characteristics compared with the EU and USA Standards

Achten et al., *in prep. for Biomass & Bioenergy*

	JME range			JME mean	JME sd	JME *n*	JEE *n=1*	EN 14214:2003	ASTM D6751
Density (g/cm³)	0.864	-	0.880	0.875	0.007	6	0.89	0.86 - 0.90	
Calorific value (MJ/kg)	38.45	-	41.00	39.65	1.28	3			
Flash point	170	-	192	186	11	4	190	120	130
Cetane value	50.0	-	56.1	52.3	2.3	5	59	min 51	min 47
saponification number (mg/g)	202.6					1			
viscosity at 30°C (cSt)	4.84	-	5.65	5.11	0.47	3	5.54	3.5-5.0*	1.9-6.0*
Iodine number (mg iodine/g)	93	-	106					max 120	max 115
Neutralization number (mg KOH/g)	0.06	-	0.50	0.27	0.22	3	0.08		
monoglycerides (wt%)	0.24					1	0.55	max 0.8	
diglycerides (wt%)	0.07					1	0.19	max 0.2	
triglycerides (wt%)	nd					0	nd	max 0.2	
Carbon residue (wt%)	0.02	-	0.50	0.18	0.27	3		max 0.3	
Sulfur content (wt%)	0.0036	-	0.5			2		max 0.01	max 0.015
Sulfated ash (wt%)	0.005	-	0.014	0.013	0.002	4			
Methyl ester content (wt%)				99.6		1	99.3	min. 96.5	
methanol (wt%)	0.06	-	0.09			2	0.05	max 0.2	
water (wt%)	0.07	-	0.1			1	0.16	max 0.5	max 0.2
free glycerol (wt%)	0.015	-	0.03			2	nd	max 0.25	max 0.24
total glycerol (wt%)	0.088	-	0.1			2	0.17		

JME = *Jatropha* methyl ester. JEE = *Jatropha* ethyl ester.

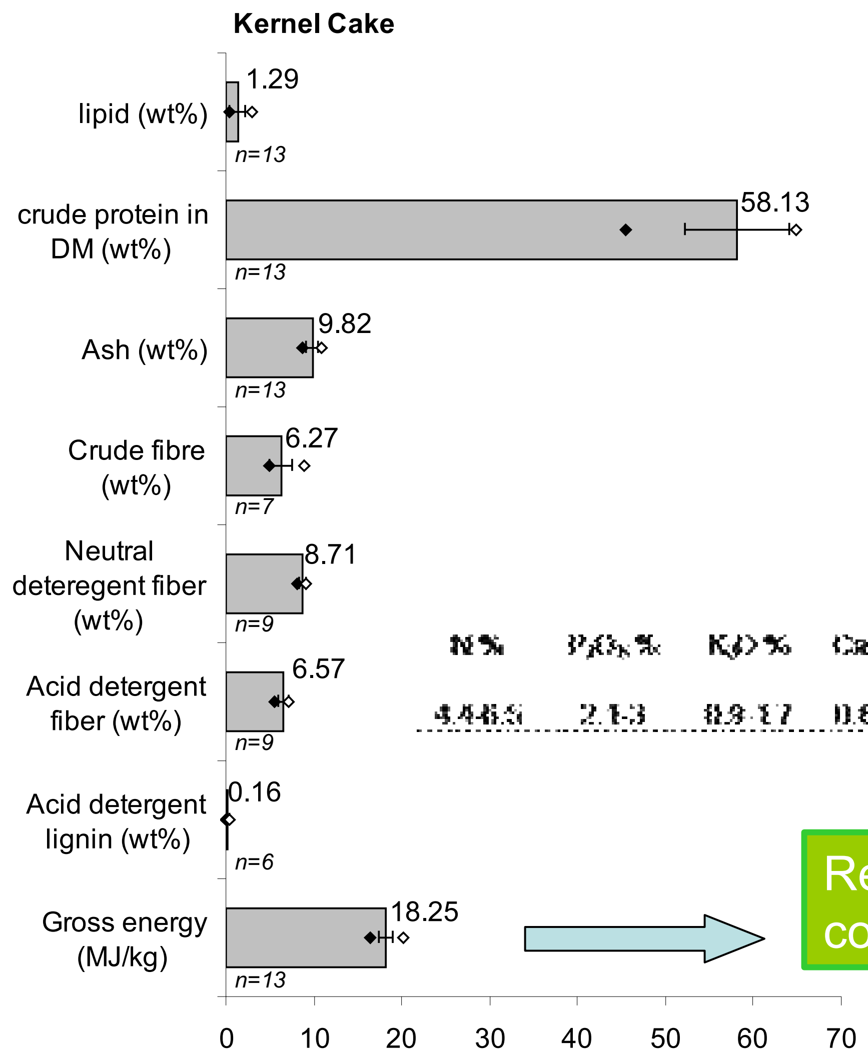
By-products unit process



Drawings from Henning R. – The Jatropha Booklet - http://www.jatropha.de/ - visited

Kernel cake composition

Achten et al., *in prep. for Biomass & Bioenergy*



Potential fodder after detoxification

N %	P_2O_5 %	K_2O %	CaO %	MgO %
4.4-6.5	2.1-3	0.9-1.7	0.6-0.7	1.3-1.4

Higher nutrient concentration than chicken or cattle manure

Relatively high energy content: briqetting

Some outlooks per impact category

1. Land use impact

3. GHG balance

5. Energy balance

How to measure the land use impact?

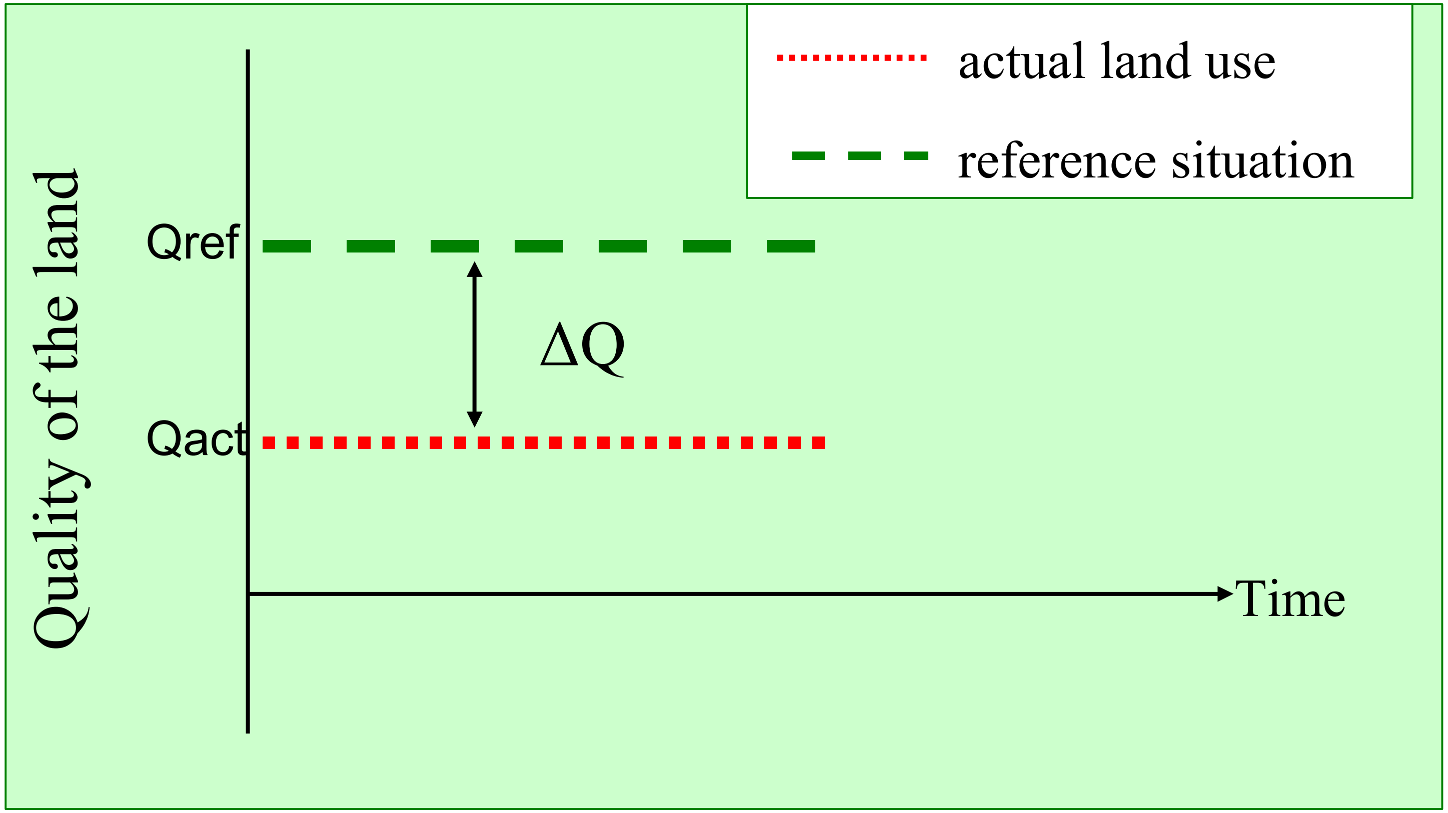
The most simple way is to measure **how much land** is used during **how much time** to produce **1 functional unit** of the product (e.g. 100km transport with JCL biodiesel):

$$S = A^* \, t$$

Where S is the impact score, A and t the area and time needed to produce 1 functional unit.

How to make land use impact assessment more realistic?

Using indicators comparing the ecological quality of the land (Q) between the actual land use and a reference situation (the PNV - potential natural vegetation of the site)



Which indicators?

Using 17 quantitative indicators covering 4 themes:

Ecosystem Structure

- Vegetation (biomass & structure)
- Biodiversity (genetic information)

Ecosystem Function

- Soil (buffering of sediment- and nutrient flows)
- Water (buffering of water flows)

Vegetation indicators

Code	Indicator	Calculation	Reference state	Alternatives
V1	Total living Biomass (TB)	$\left(1-\frac{TB_{act}}{TB_{ref}}\right)*100$	TB_{ref}	Total above-ground living biomass
V2	Canopy fractal dimension (FD)	$\left(1-\frac{FD_{act}}{FD_{ref}}\right)*100$	FD_{ref}	Leaf area index, canopy height, root FD
V3	Free Net Primary Production (fNPP)	$\left[1-\left(\frac{NPP_{act}-harvest}{NPP_{ref}}\right)\right]*100$	No harvest	Crop biomass

Biodiversity indicators

Code	Indicator	Calculation	Reference state	Alternatives
B1	Shannon Diversity index (SI)	$\left(1-\frac{SI_{act}}{SI_{ref}}\right)*100$	SI_{ref}	Number of species compared to regional species pool
B2	Exotic species cover (EX)	$EX_{act}*100$	No exotics	
B3	Fertilization	$\left(\frac{A_{aff}}{A_{tot}}*N*I\right)$ A=area; N=number of applications; I=intensity factor	No application	
B4	Use of biocides	$\left(\frac{A_{aff}}{A_{tot}}*N*I\right)$ N=number of applications per decade; A=area	No biocides	

Soil indicators

Code	Indicator	Calculation	Reference state
S1	Loss of permeability (PE)	$\left(\frac{A_{aff} * (PE_{ref} - PE_{act})}{A_{tot} * PE_{ref}}\right) * 100$	PE_{ref}
S2	Disturbance of structure	$\left(\frac{A_{aff} * D}{A_{tot}} * N\right)$ A=area; D= depth in m; N=number of applications	No disturbance
S3	Soil erosion	$\left(1 - \frac{USLE_{ref}}{USLE_{act}}\right) * 100$	$USLE_{ref}$

Soil indicators

Code	Indicator	Calculation	Reference state
S4	Cation Exchange Capacity (CEC)	$\left(1-\frac{CEC_{act}}{CEC_{ref}}\right)*100$	CEC_{ref}
S5	Base saturation (BS)	$\left(1-\frac{BS_{act}}{BS_{ref}}\right)*100$	No disturbance

Water indicators

Code	Indicator	Calculation	Reference state
W1	Evapotranspiration (ET)	$\left(1-\frac{ET_{act}}{ET_{ref}}\right)*100$	ET_{ref}
W2	Surface runoff (RO)	$\left(1-\frac{RO_{ref}}{RO_{act}}\right)*100$	RO_{ref}
W3	Drainage, irrigation	$\left(\frac{A_{aff}}{A_{tot}}\right)*100$ A=area	No artificial change of water balance

Example

Jatropha production in semi-arid area in Ethiopia. Production 1500 kg of seeds/year yielding 640 l of biodiesel per hectare. With a consumption of 8l/100km the area*time requirement is 1.25 m^2*year/km

Jatropha replaces traditional cereal production yielding 1000 l of bio-ethanol per hectare. With a consumption of 10l/100km the area*time requirement is 1 m^2*year/km

Example

Indicator	Reference system (dryland forest)	Biodiesel from Jatropha	Bioethanol from cereals
Avg. living biomass (ton)	50	20	2* *6t during 4 months
Leaf Area Index	4	2	1* *3 during 4 months
fNPP	1	0.2	0.1
Shannon diversity	1	0.3	0.2
Exotic species cover (% of total cover)	0	0.6	0.3* *0.9 during 4 months
Use of fertilizers	0	25%*1*0.3	100%*1*0.3
Use of biocides	0	0	0

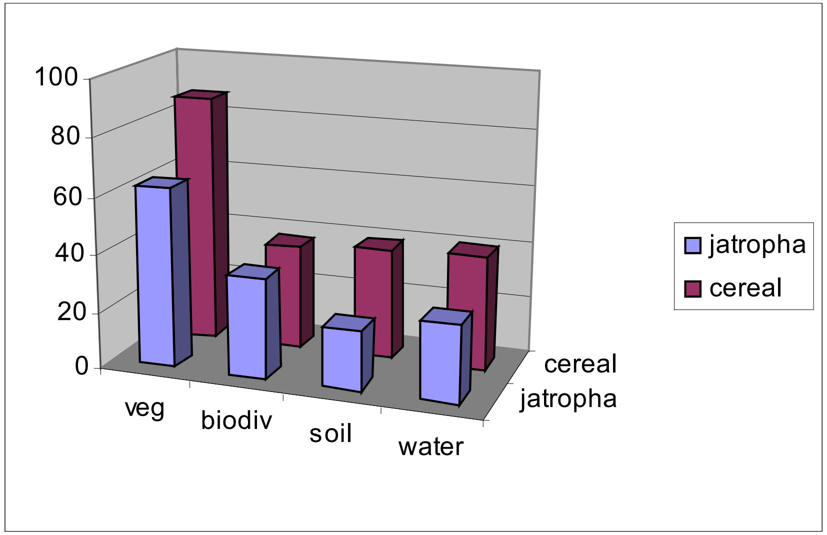
Example

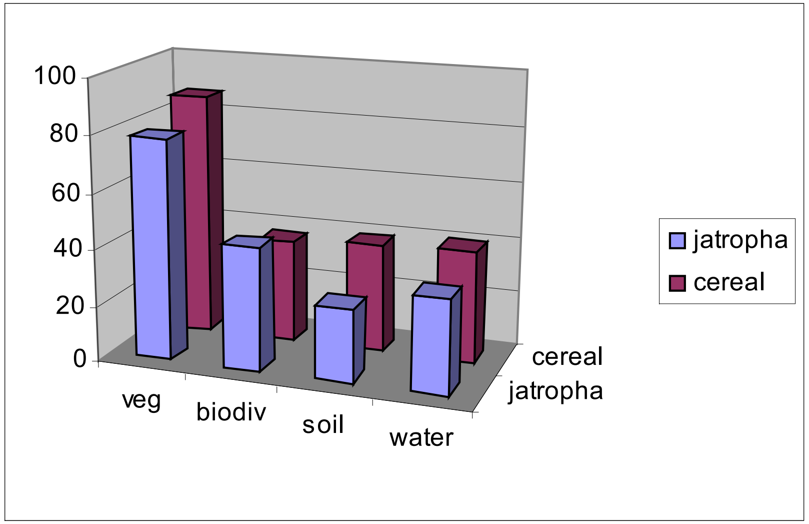
Indicator	Reference system (dryland forest)	Biodiesel from Jatropha	Bioethanol from cereals
Soil compaction	0	0	100%*0.1
Soil disturbance	0	10%*0.25*0.02 = 0.05	100%*0.25*2 = 50
Soil erosion (t/ha/yr)	0	1	10
CEC (Organic matter content in %)	10	6	4
Base Saturation (%)	30	40	50

Example

Indicator	Reference system (dryland forest)	Biodiesel from Jatropha	Bioethanol from cereals
Evapotranspiration (mm)	400	400	300
Surface runoff (mm)	10	50	150
Drainage/irrigation (mm)	0	0	0

Example





Result on a hectare basis

Result per functional unit (m^2*yr/km)

Expected Land use impact

1. Impact on vegetation structure
   - Positive if reclamation of wasteland; negative if destruction of (semi-)natural vegetation

3. Impact on biodiversity
   - Monoculture: improved by intercropping, agroforestry, and set aside part of the land
   - Some unchecked reports on invasiveness
   - Positive: low use of biocides

4. Impact on soil
   1. Mostly positive impact (erosion control, carbon seqestration)
   2. Negative impact if intensively grown with high input of fertilizers and machinery

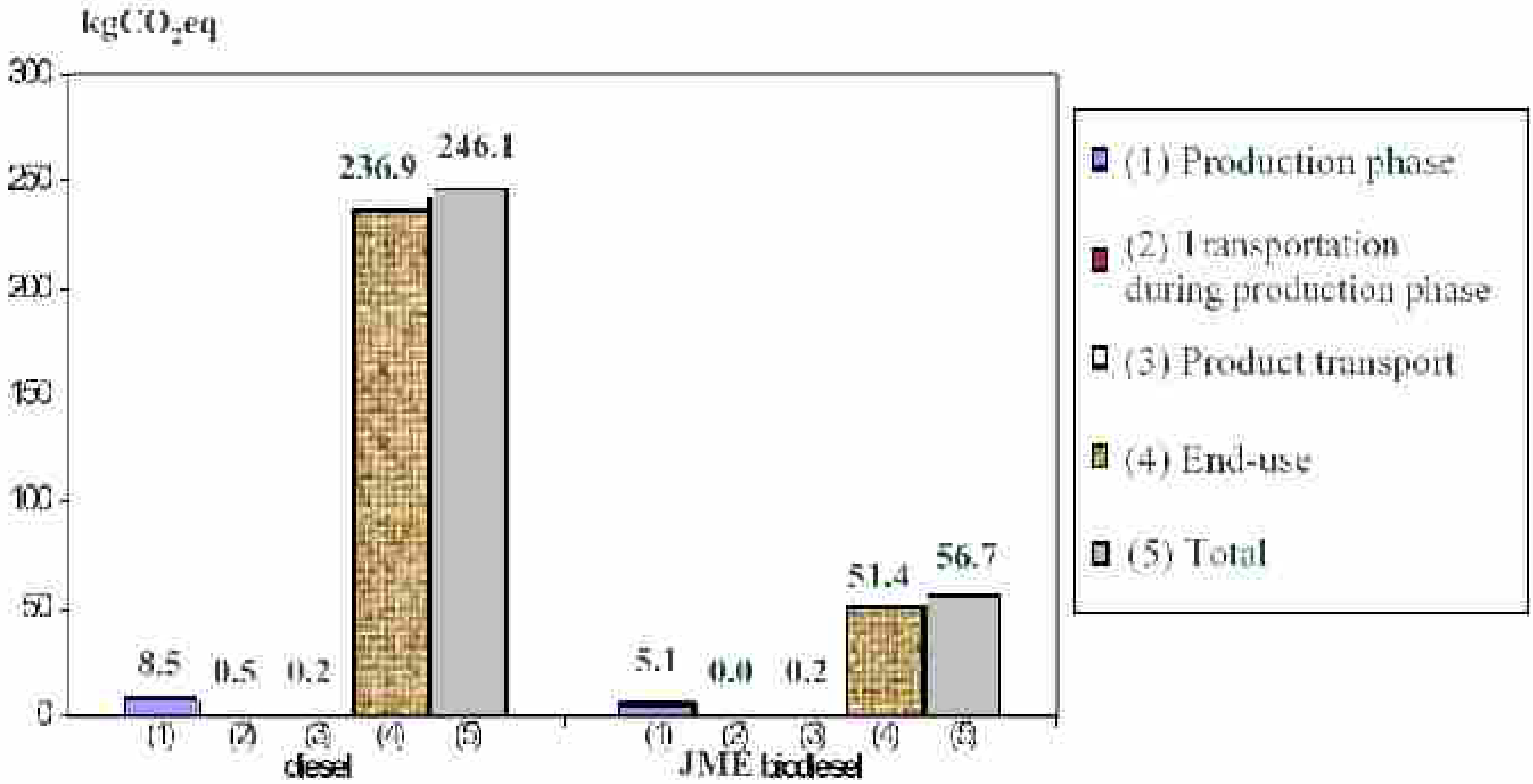
6. Impact on water
   - Positive on-site, negative off-site (cfr. Heuvelmans et al. 2005, J. of LCA); more research needed

Expected GHG balance

Positive GHG balance. But may become less positive

- After transesterification
- without energetic use of the byproducts
- with increasing N-fertilisation
- if shipped to remote markets such as Europe

Expected GHG balance



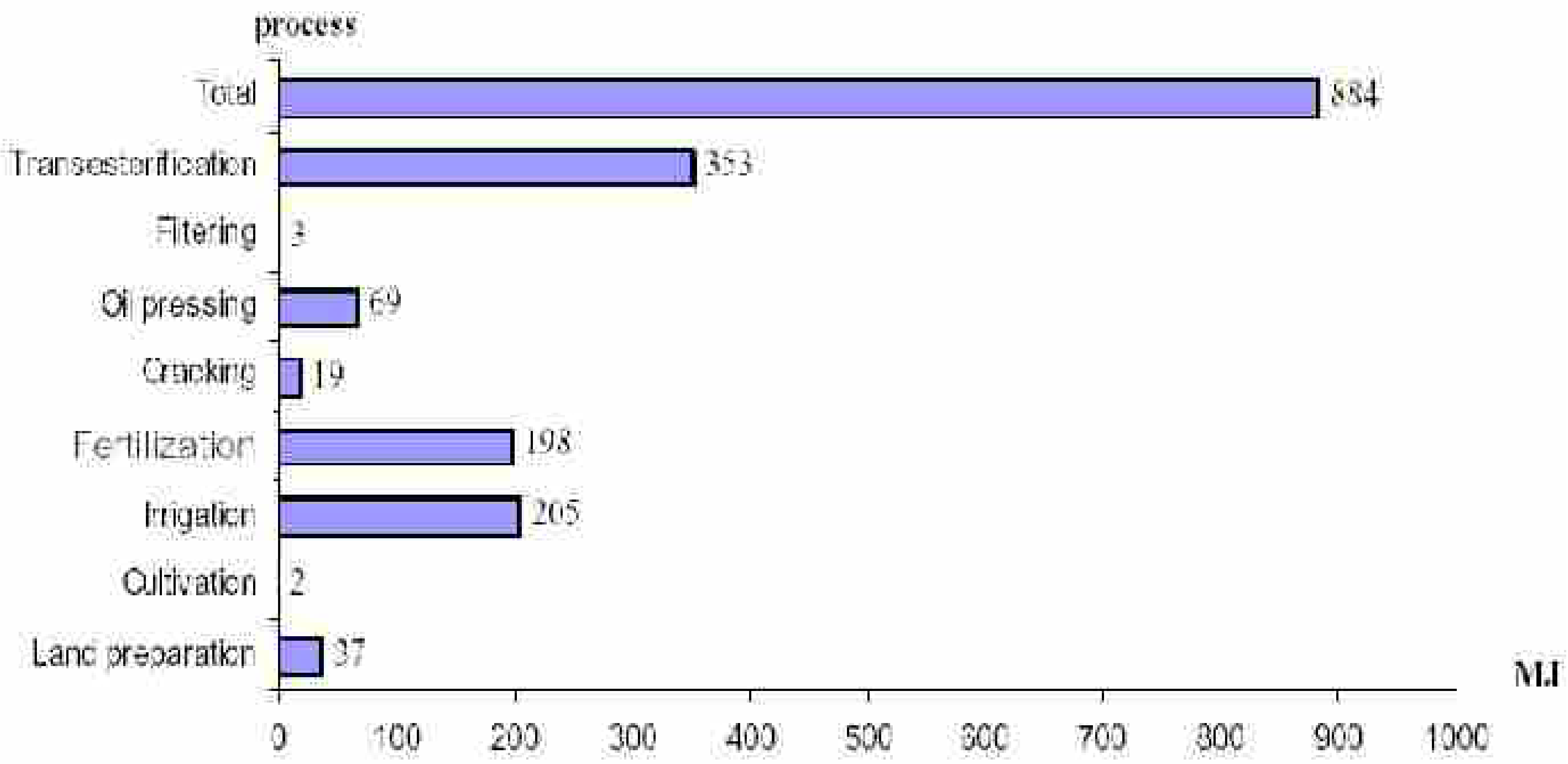
Source: K. Prueksakorn & S.H. Gheewala, 2006. Energy and Greenhouse Gas Implications of Biodiesel Production from Jatropha curcas L.

Expected Energy balance

Positive energy balance. But may become less positive:

• After transesterification
• without energetic use of the byproducts
• with increasing intensification and mechanisation of the production cycle
• if shipped to remote markets such as Europe

Energy consumption when producing 1 GJ of Jatropha methyl ester and co-products



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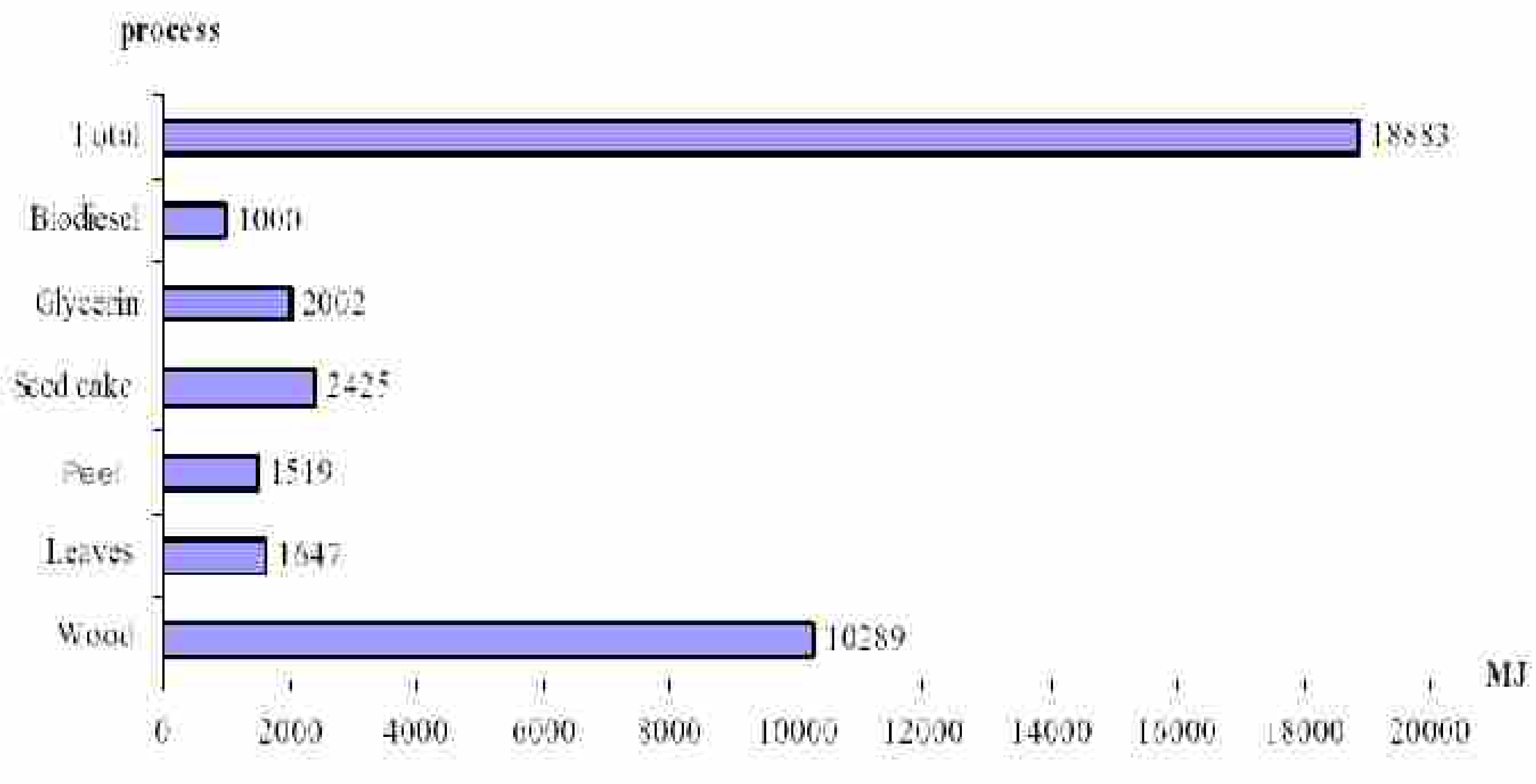
Energy production when producing 1 GJ of Jatropha methyl ester and co-products



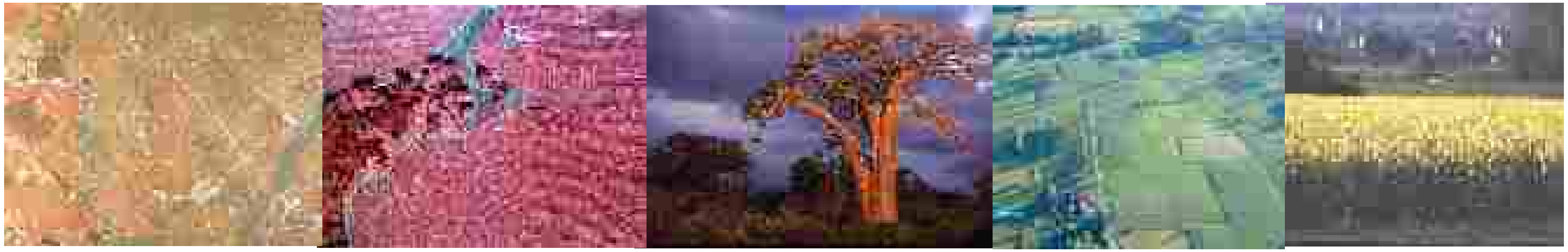
Source: K. Prueksakorn & S.H. Gheewala, 2006. Energy and Greenhouse Gas Implications of Biodiesel Production from Jatropha curcas L.

Final conclusion

The Jatropha hype is not sufficiently supported by hard data on crop production, production optimization, and environmental impact

Urgent need for:

- Reliable inventory data for the complete life cycle
- Special focus on land use impact (including benefits)
- Research on water relationships



Thank you for your attention!

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Ackowledgements: VLIR (Flemish Interuniversity Council)