Lecture 21A & 21B

Energy Resources, Economics and Environment

Net Energy Analysis

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1997-06-15

Environmental management — Life cycle assessment — Principles and framework

Management environnemental — Analyse du cycle de vie — Principes et cadre

https://web.stanford.edu/class/cee214/Readings/ISOLCA.pdf

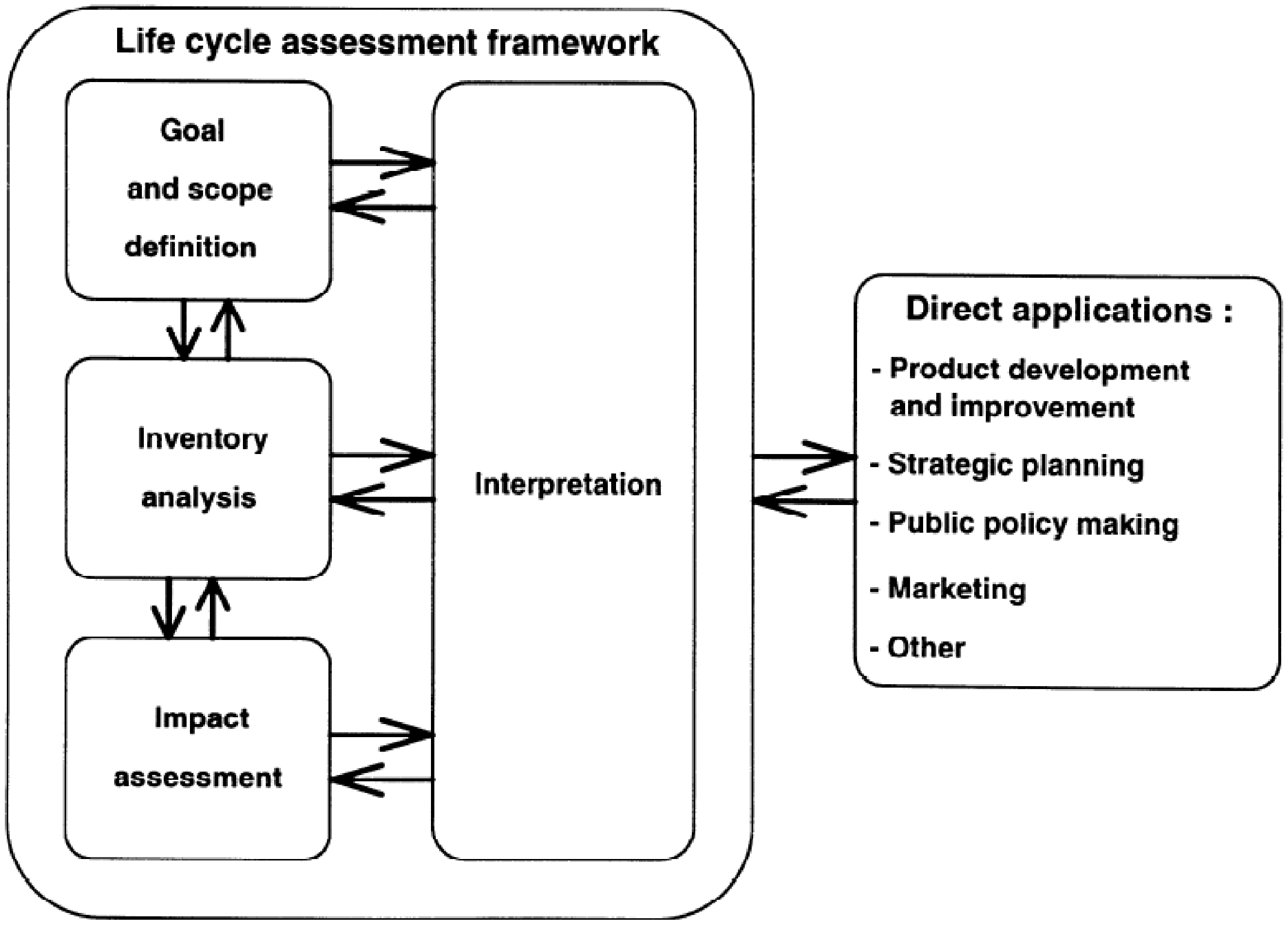


Figure 1 : Phases of an LCA

https://web.stanford.edu/class/cee214/Readings/ISOLCA.pdf

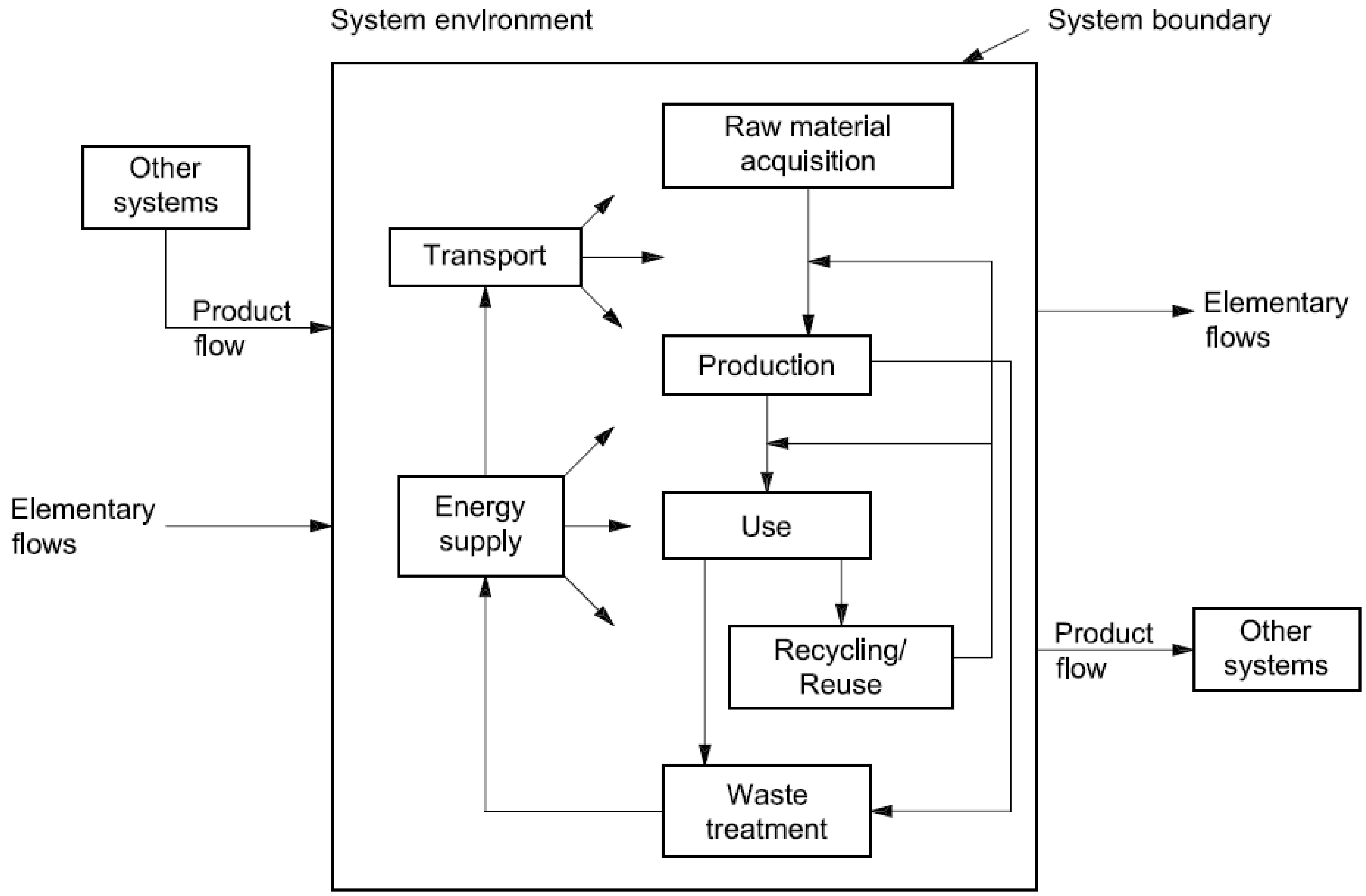


Figure 2 — Example of a product system for LCA

http://www.cscses.com/uploads/2016328/20160328110518251825.pdf

Goals and Scope

- Goal- intended application, reason for study, audience, comparative assessment
- Scope – product system, functions, functional unit, system boundary, allocation procedures

Functional unit

- Functional unit related to the purpose of the process or system
- Should be consistent across options being assessed
- Quantified performance of a product system for use as a reference unit

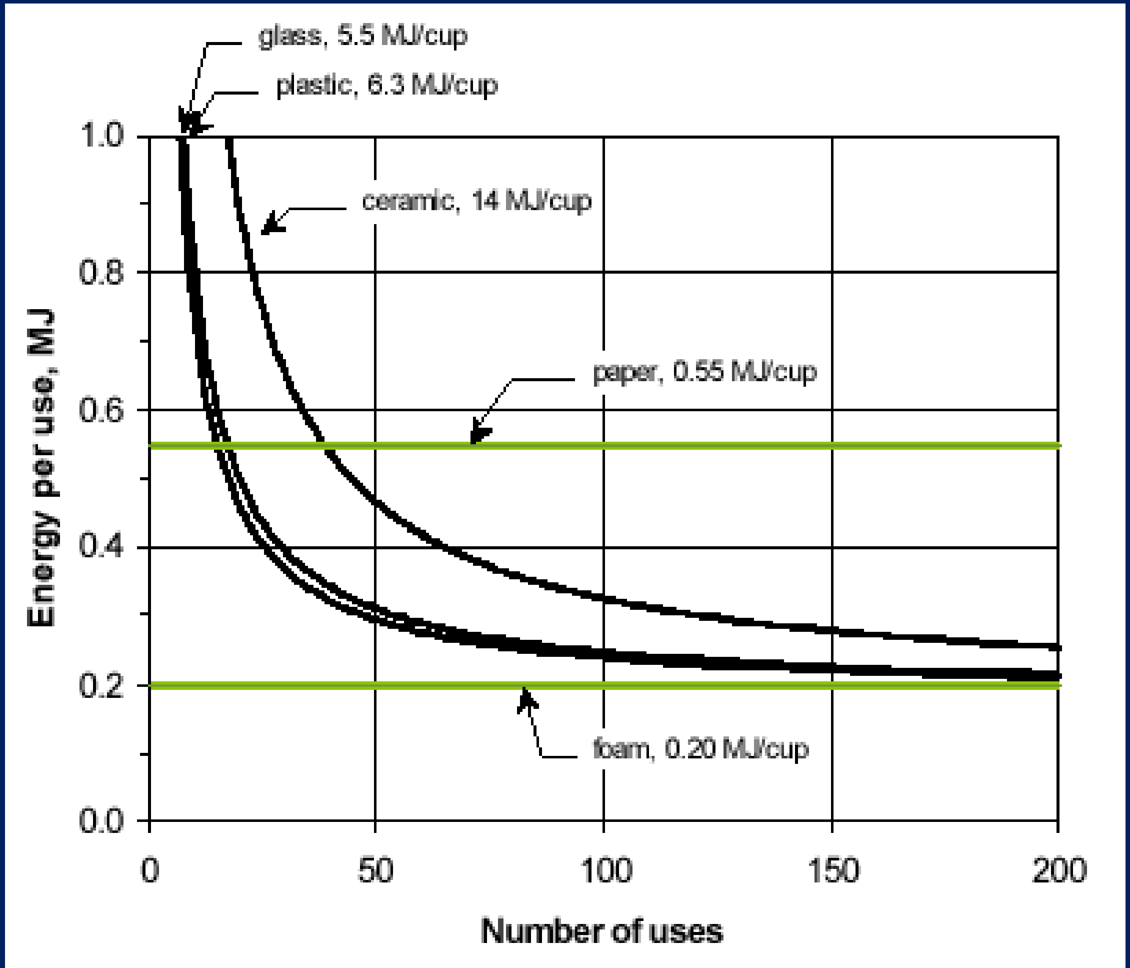
Paper vs Polystyrene Cups

Cup type	Cup Mass g/cup	Material Specific Energy MJ/kg	Embodied Energy MJ/cup
Ceramic	292	48	14
Plastic	59	107	6.3
Glass	199	28	5.5
Paper	8.3	66	0.55
Foam	1.9	104	0.20

www.ilea.org/lcas/**hocking**1994.html

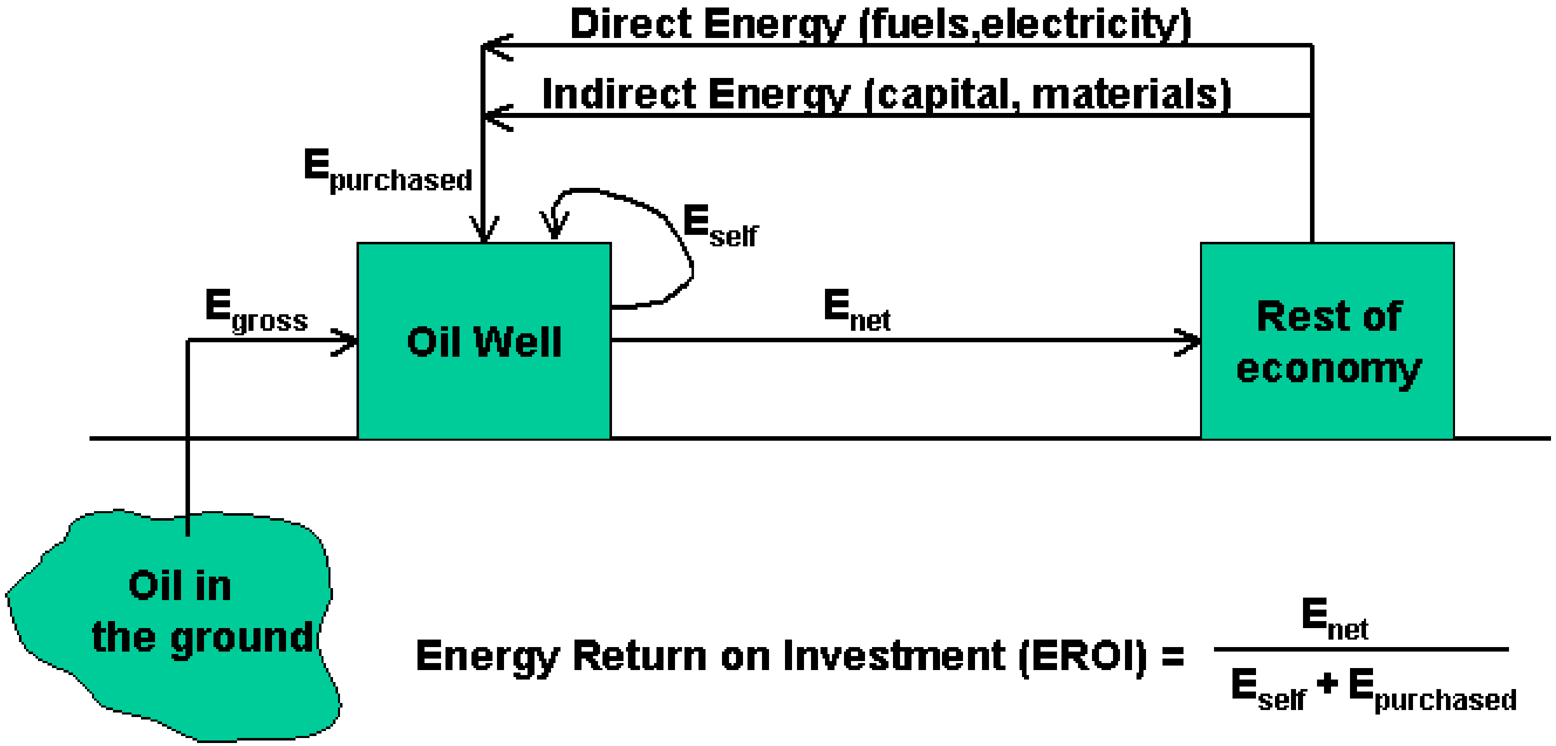
Hocking, Martin B. "**Reusable and Disposable Cups: An Energy-Based Evaluation**." Environmental Management 18(6) pp. 889-899

Re-usable vs Disposable Cups



www.ilea.org/lcas/**hocking**1994.html

Net Energy Analysis

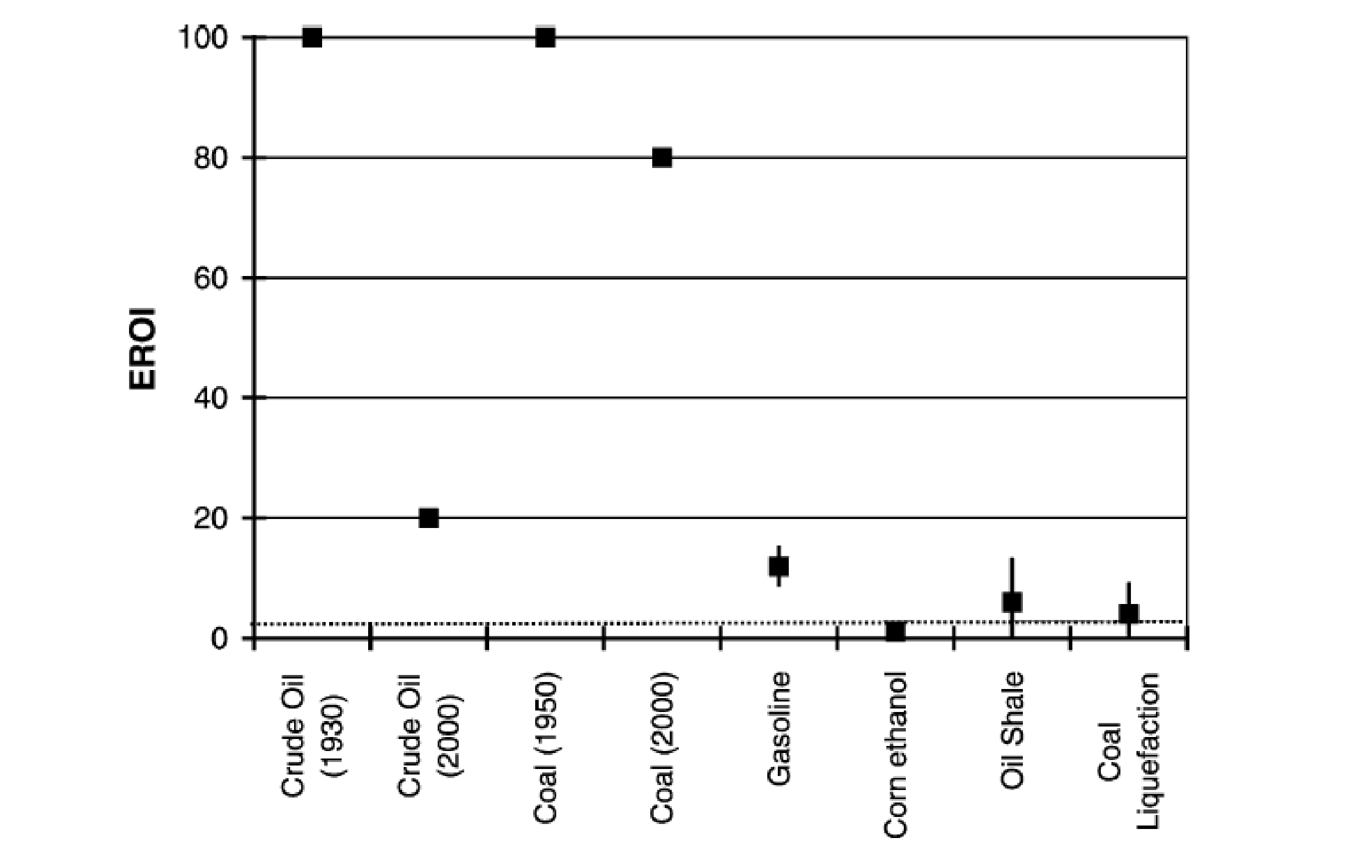


Energy Return on Investment (EROI) = $\dfrac{E_{net}}{E_{self} + E_{purchased}}$

Energy Surplus = $E_{net} - [E_{self} + E_{purchased}]$

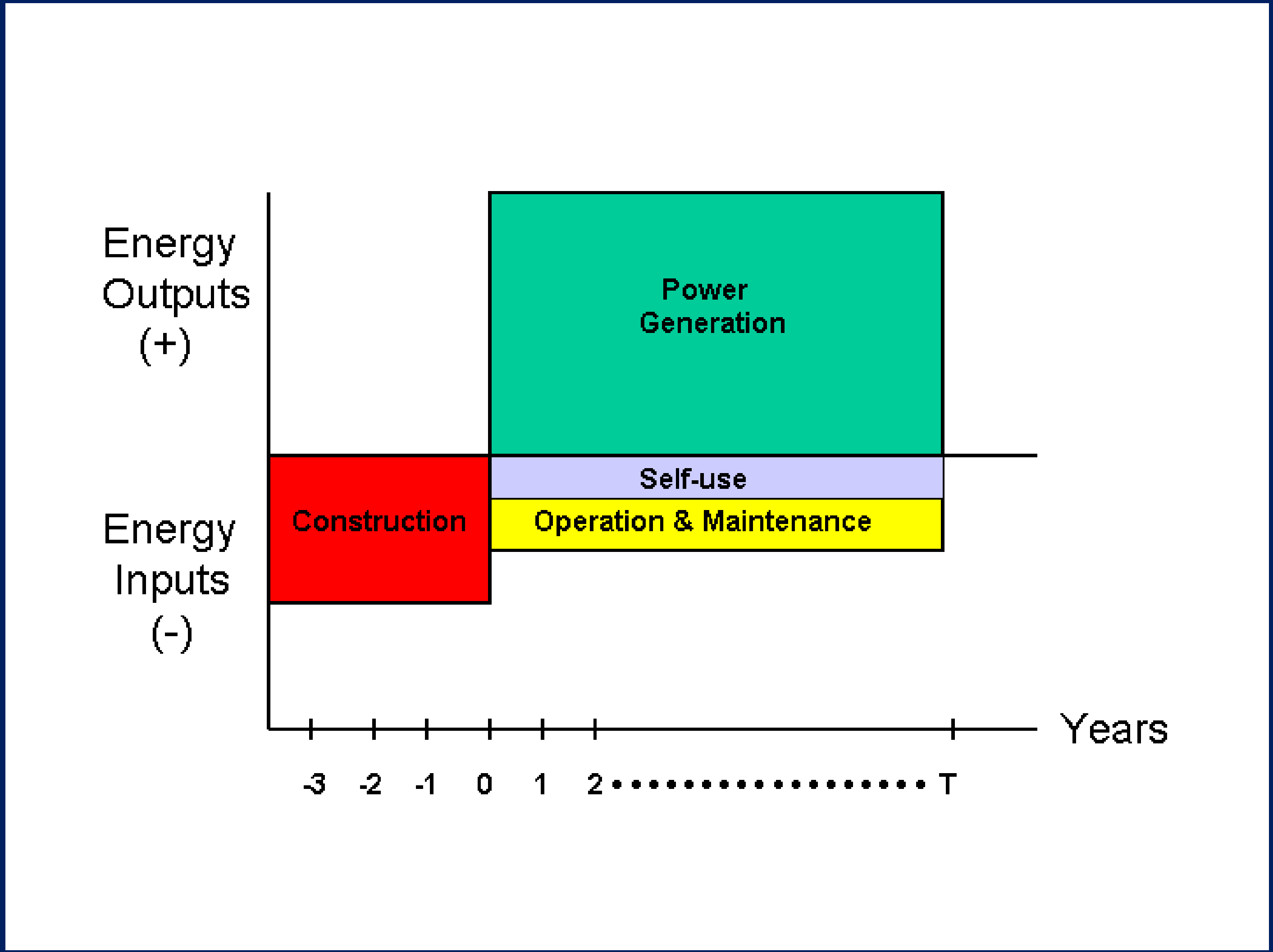
Source : www.oilanalytics.org/neteng/neteng.htm

Energy Return on Investment



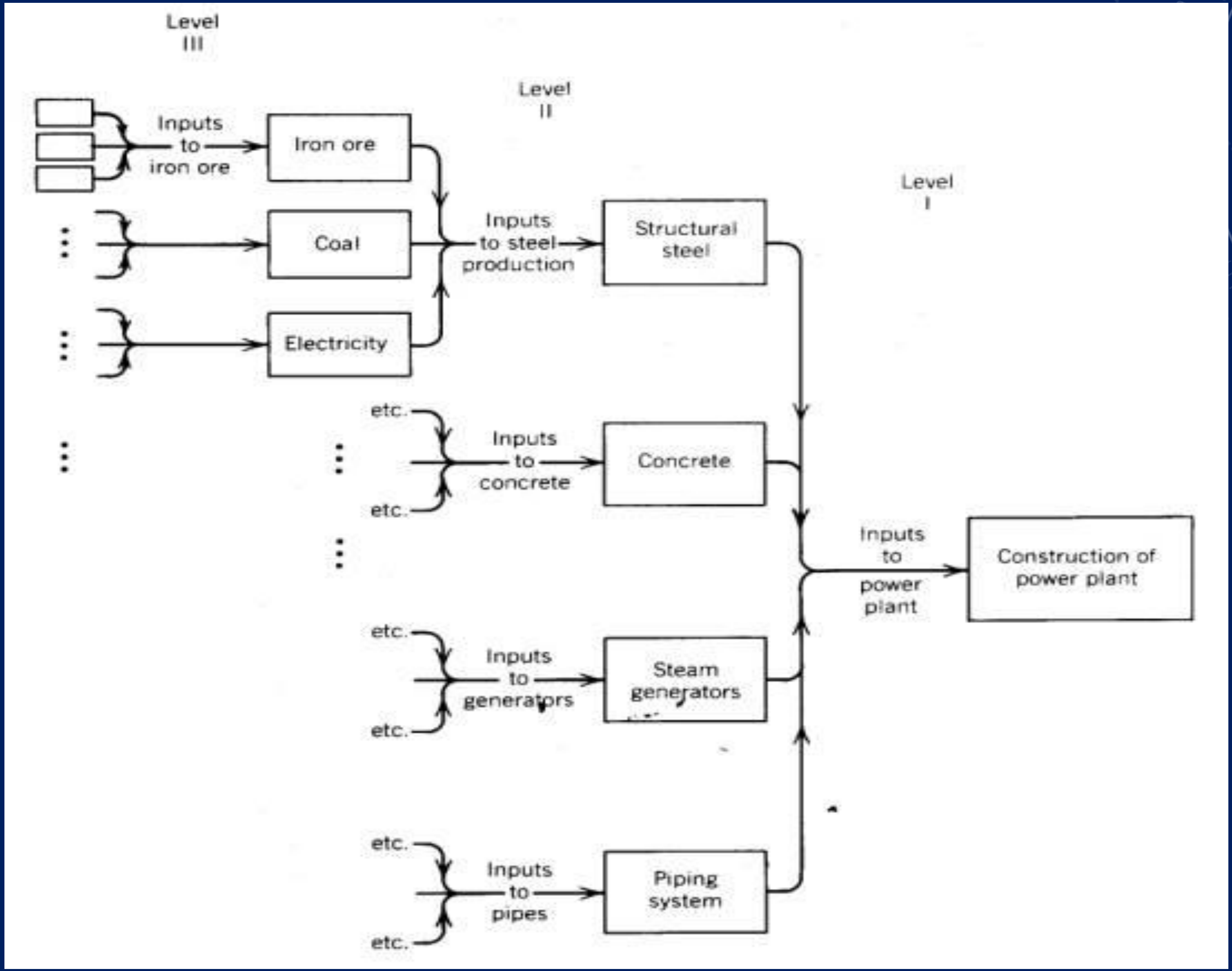
Source: Cleveland,Energy (2005)

Energy Inputs and Outputs-Power Plant



Source : www.oilanalytics.org/neteng/neteng.htm

Levels of Net Energy analysis



Source : www.oilanalytics.org/neteng/neteng.htm

CO_2 emissions of Coal Based Power

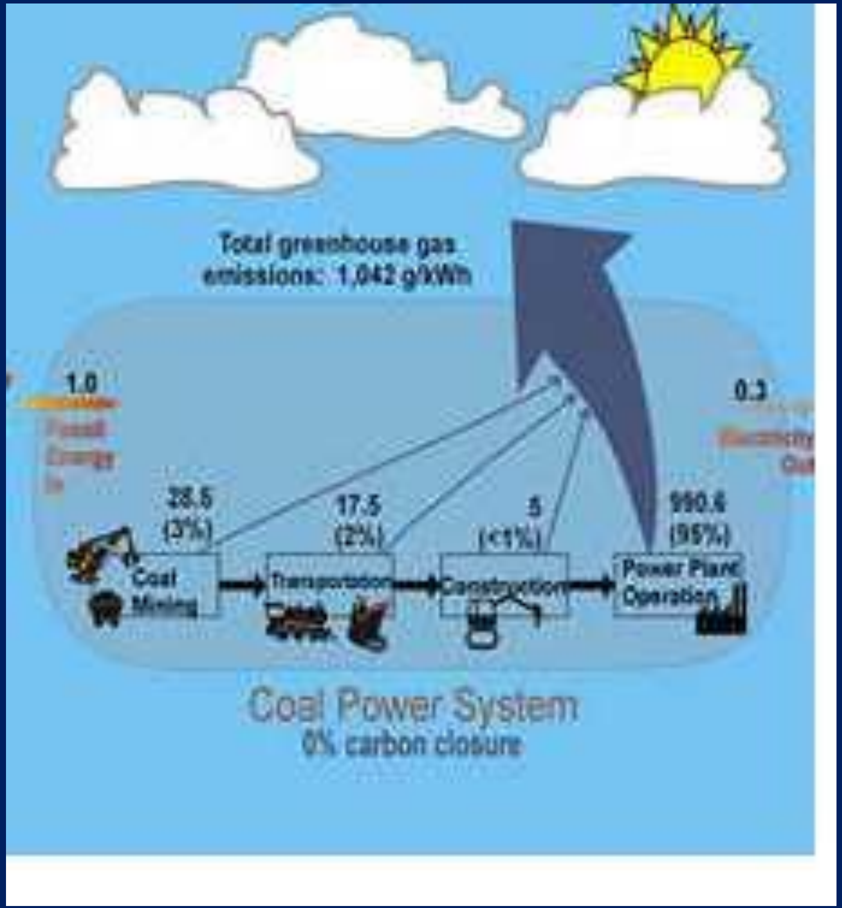
Mining 28.5(3%)

Transport17.5(2%)

Construction 5

Operation 990.8(95%)

Total 1042g/kWh



Source: NREL LCA Study

CO_2 emissions of Biomass Based Power

Feedstock 28 production(62%)

Transport 6 (12%)

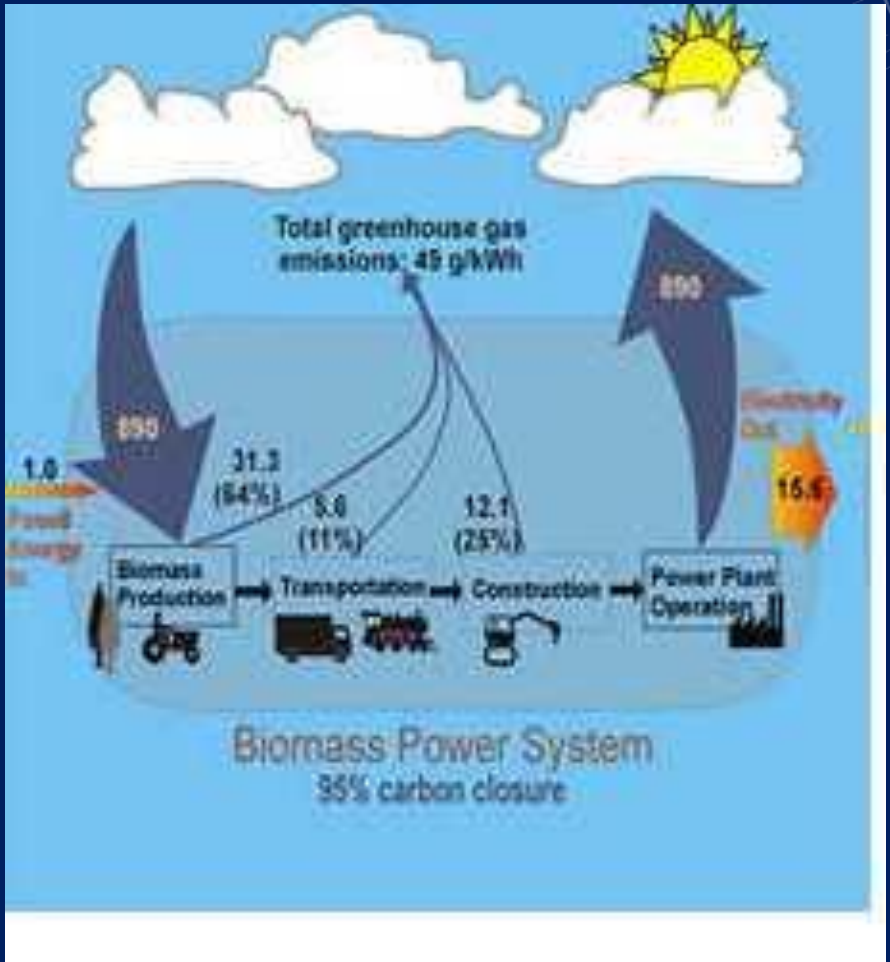
Construction 12 (26%)

CO_2 recycled:890g/kWh

Net CO2 emissions:

46 g/kWh

Source: Mann& Spath (1997)



Environmental Science & Technology

Article

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pubs.acs.org/est

Life Cycle Greenhouse Gas Impacts of Coal and Imported Gas-Based Power Generation in the Indian Context

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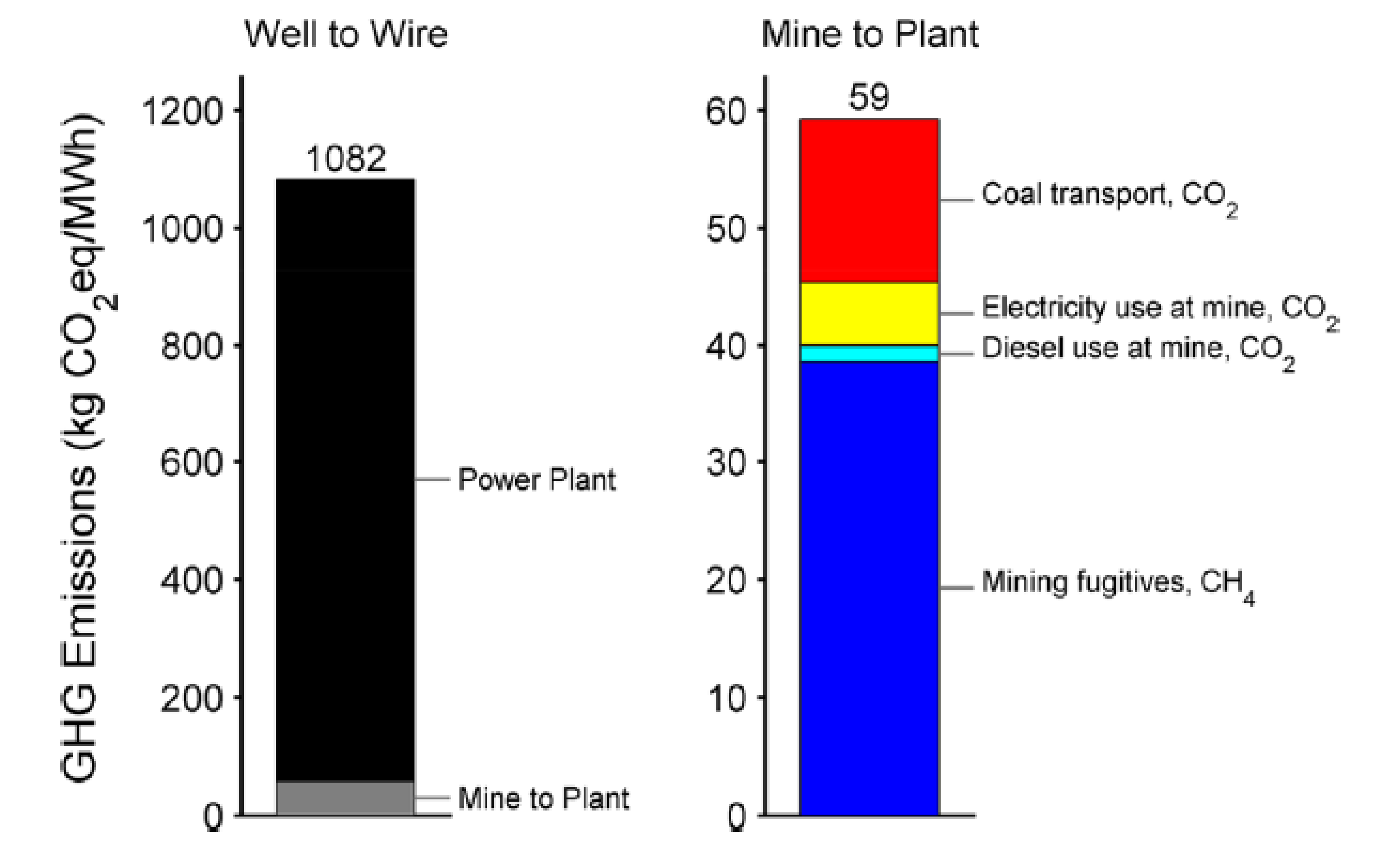
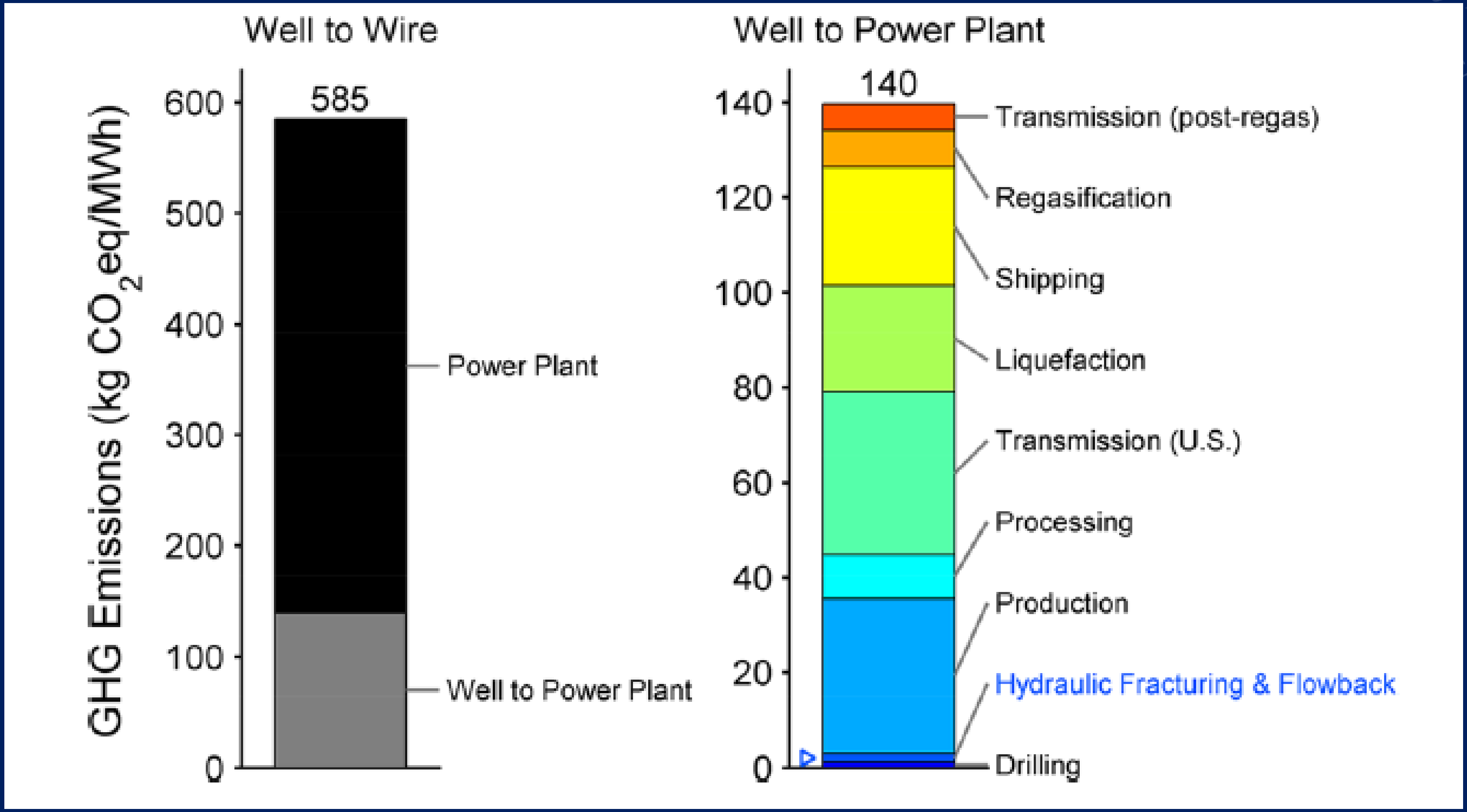
Supporting Information

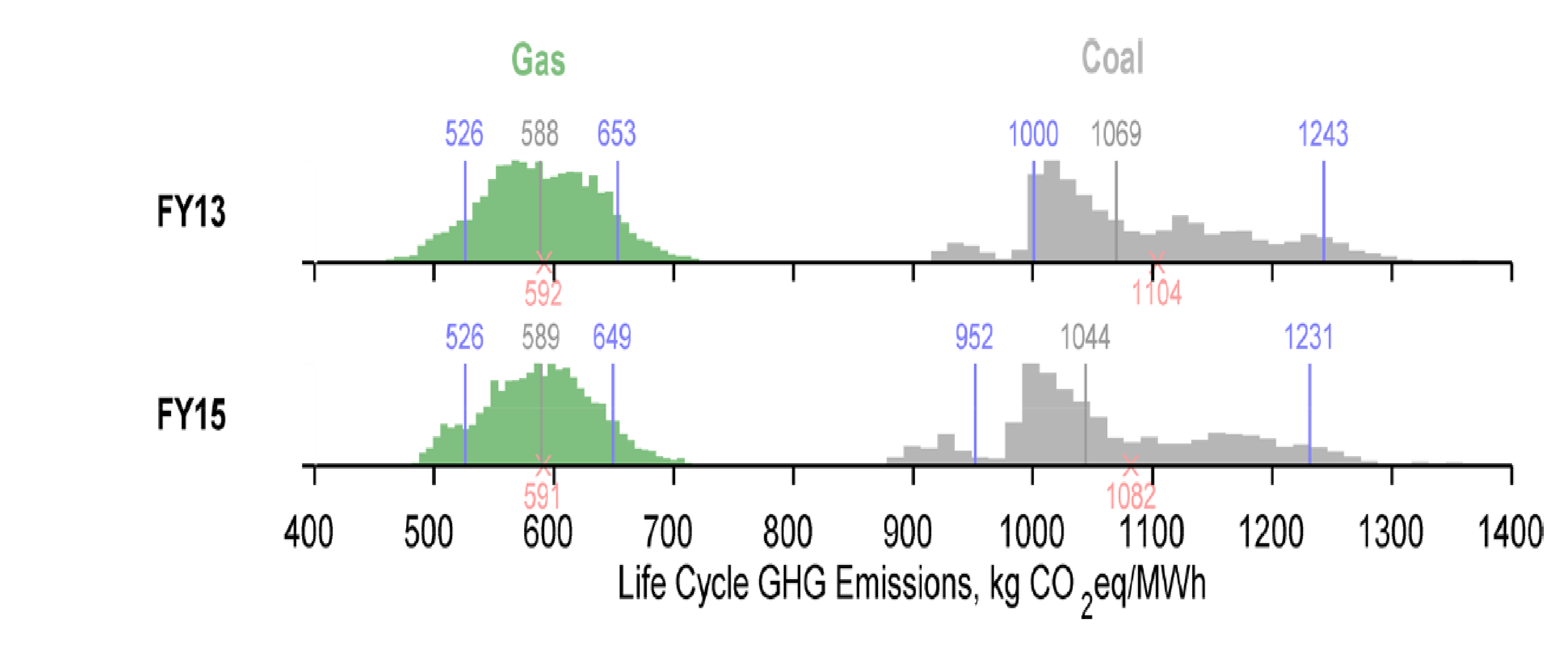
Life Cycle GHG Emissions – Indian Coal plants



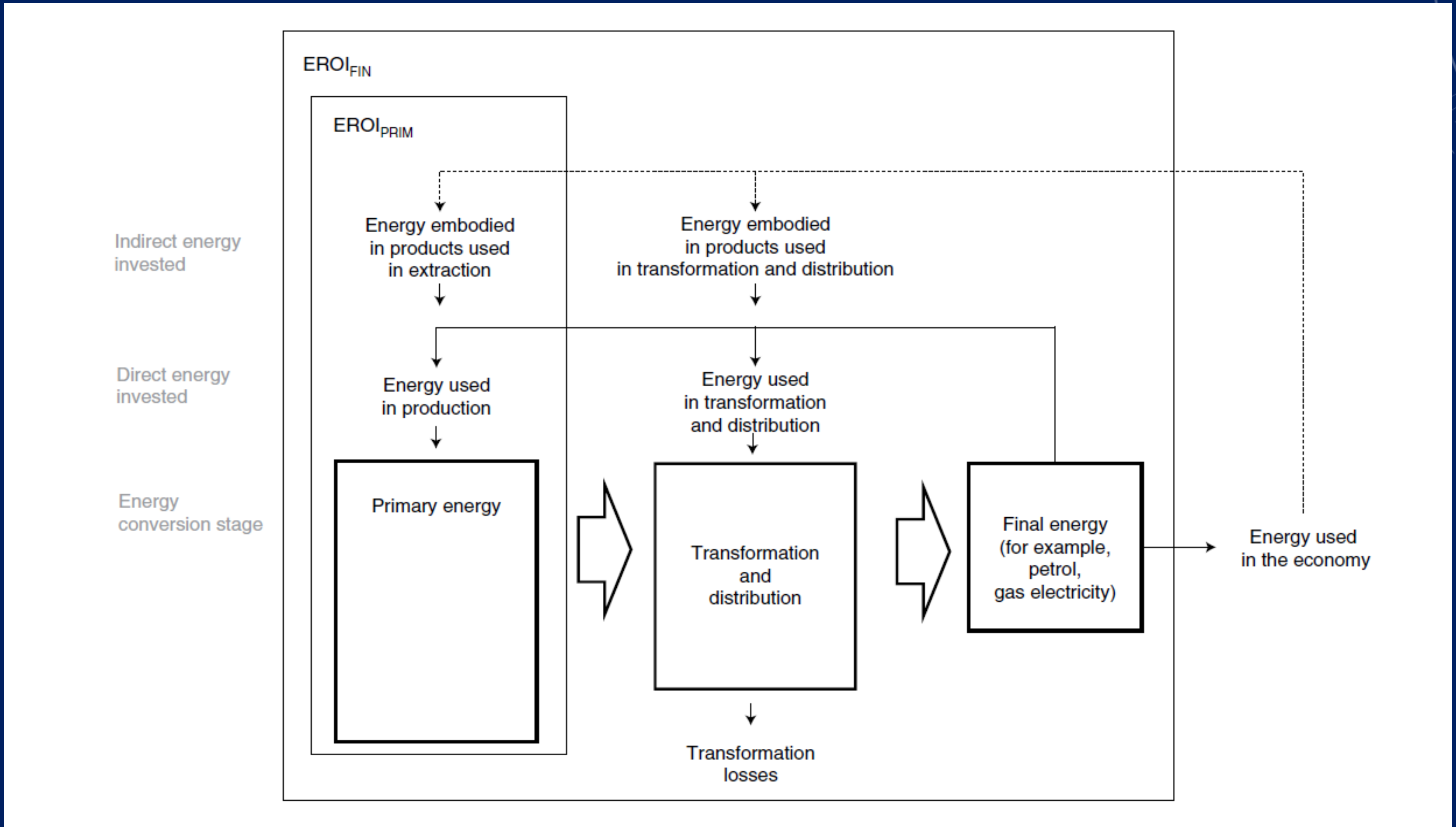
LNG based GHG emissions for Indian power sector



GHG emissions distribution Indian power sector

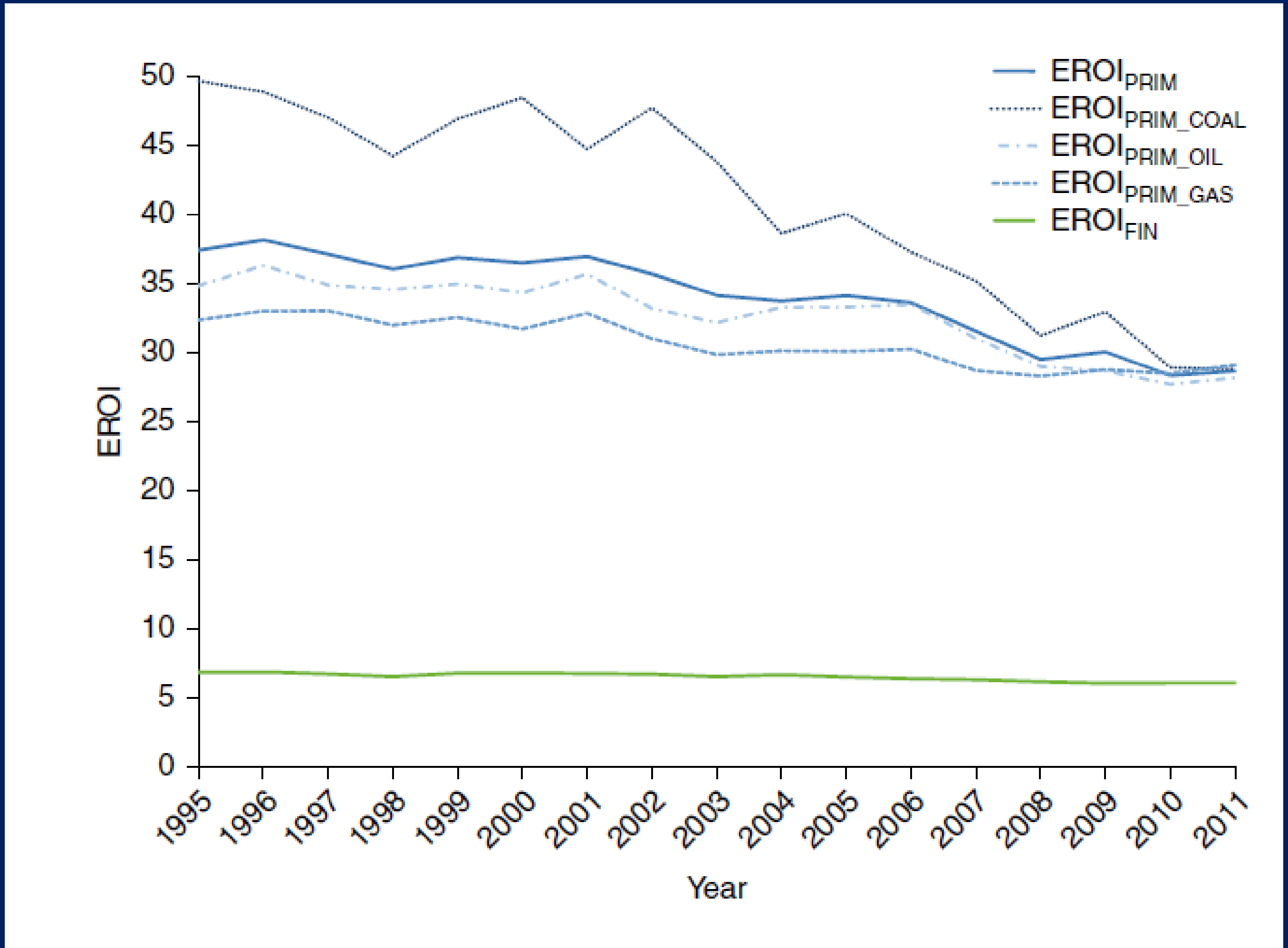


EROI- Calculation



Brockway et al Nature Energy, 2019

EROI – Time series trends



Brockway et al Nature Energy, 2019

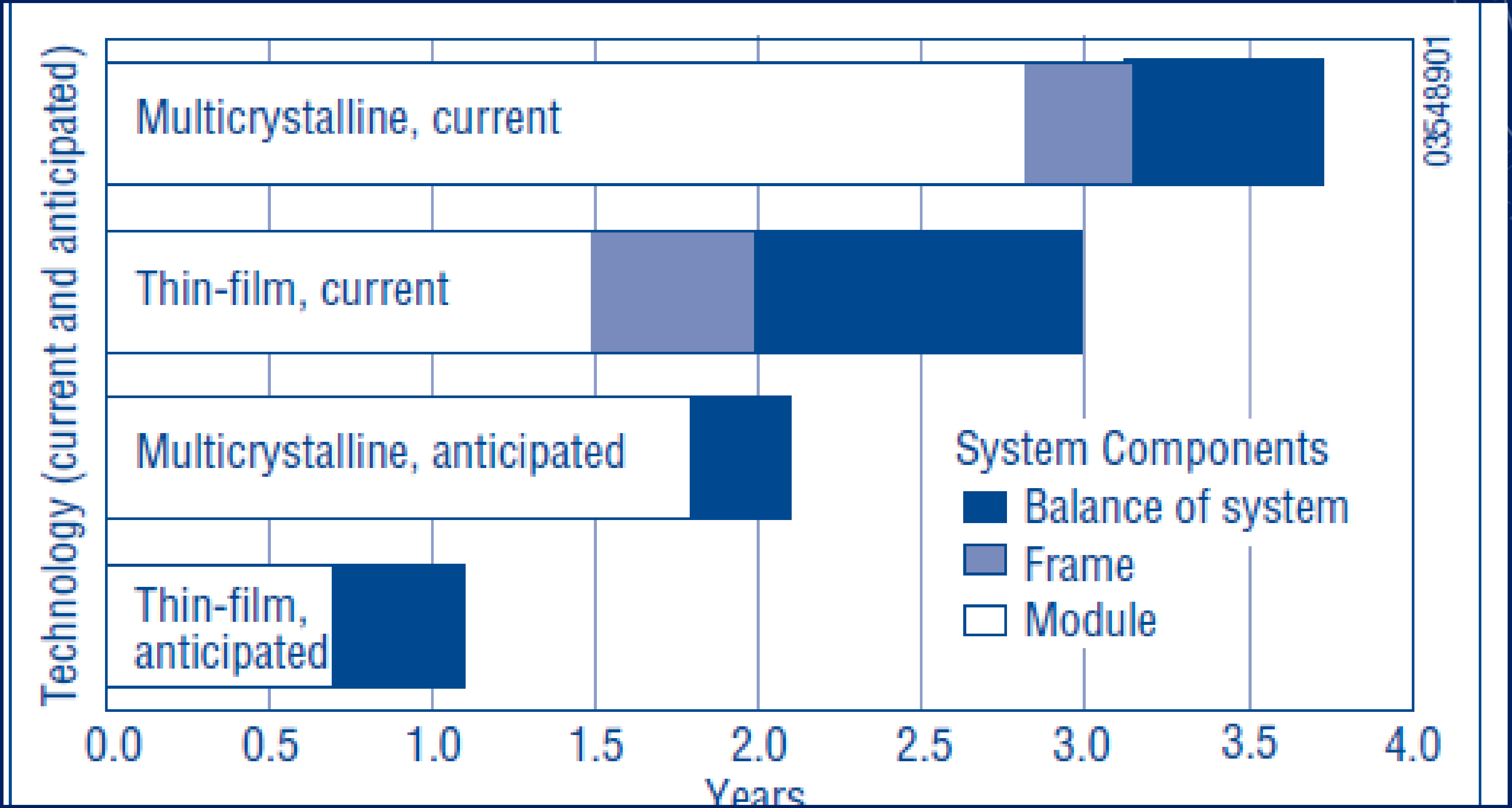
EROI- Summary comparison

Energy source/carrier	Published EROI ratio (X:1) estimate		
	$EROI_{PRIM}$	$EROI_{FIN}$	Reference
Coal	40–55 (mine mouth)		Hall et al.[15]
	80 (mine mouth)		Court and Fizaine[25]
Oil	15 (well head)		Court and Fizaine[25]
	18 (well head)		Gagnon et al.[7]
	20 (well head)		Hall et al.[15]
		4–5 (refined oil fuels)	Brandt[54]
Gas	18 (well head)		Gagnon et al.[7]
	20 (well head)		Hall et al.[15]
	75 (well head)		Court and Fizaine[25]
Electricity (gas)		6[a]	Hall et al.[15]
		8[a]	King and Van Den Bergh[10]
		11[b]–14[b]	Raugei and Leccisi[18]
Electricity (coal)		4[b]	Raugei and Leccisi[18]
		13[a]–18[a]	Hall et al.[15]
		17[a]	King and Van Den Bergh[10]
Electricity (photovoltaics)	19[c]–38[c]	6[b]–12[b]	Raugei et al.[55]
		10[a]	Hall et al.[15]
		4[b]–20[b]	Leccisi et al.[56]
Electricity (wind)		14[b]–26[b]	Kubiszewski et al.[57]
		15[b]–30[b]	Raugei and Leccisi[18]

[a]Includes power plant/transformational conversion efficiencies only. [b]Includes power plant/transformational conversion efficiencies and supply chain energy investments. [c]Primary energy equivalent value by Raugei et al.[55], estimated by dividing the $EROI_{FIN}$ value for photovoltaics (6–12) by the EU-27 electric grid efficiency, η_{grid} = 0.31.

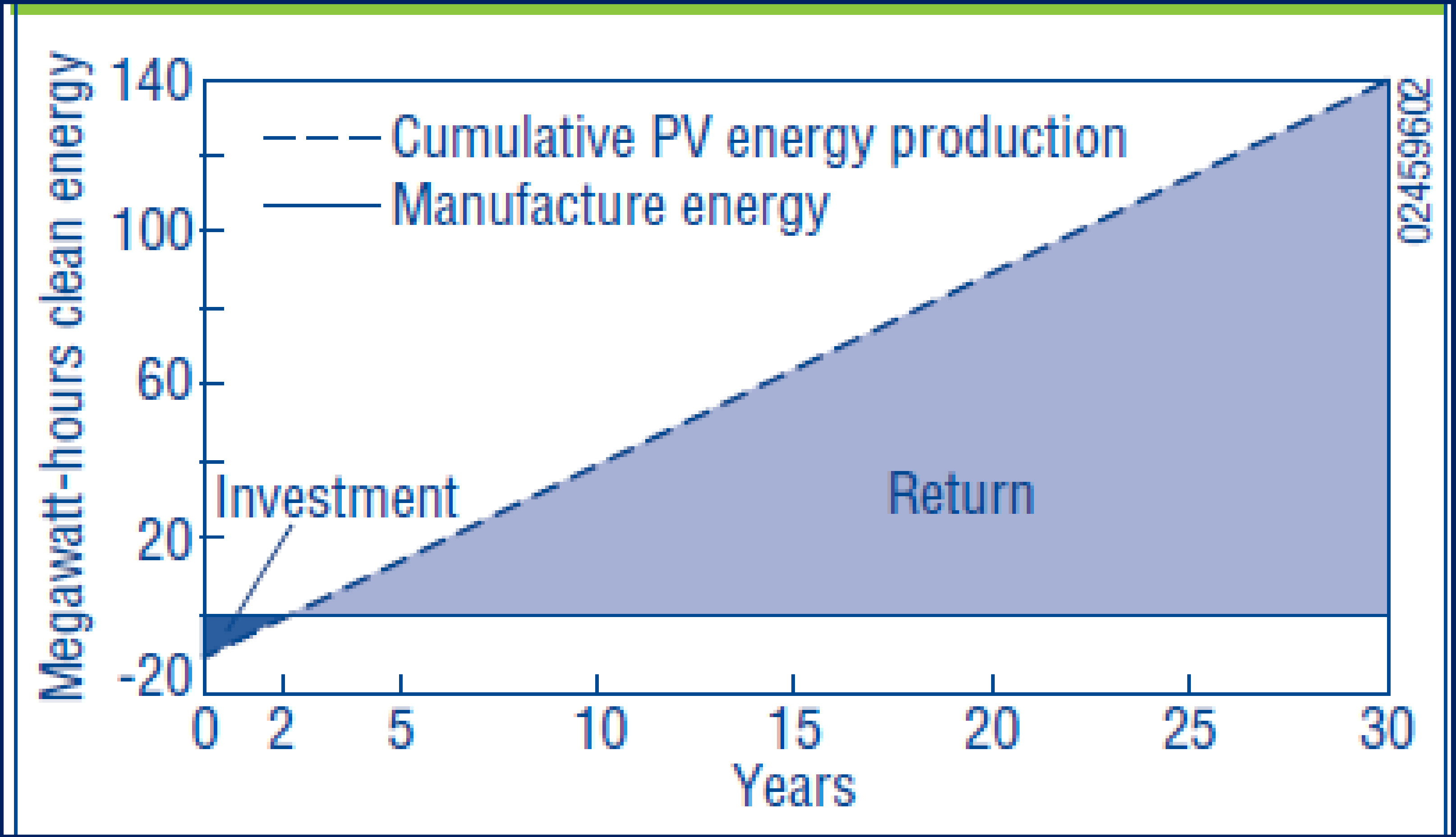
Brockway et al Nature Energy, 2019

Energy Payback Period - PV



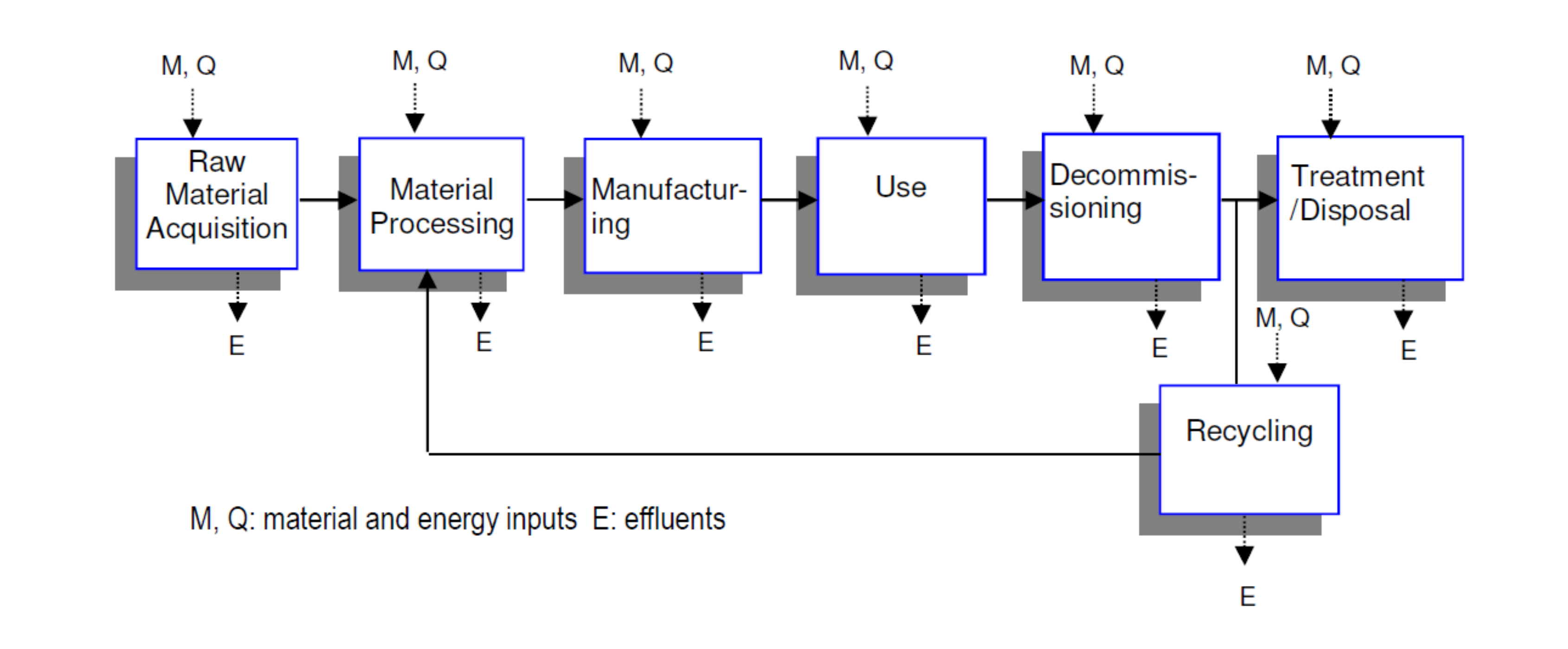
https://www.nrel.gov/docs/fy04osti/35489.pdf

Energy Payback Period - PV

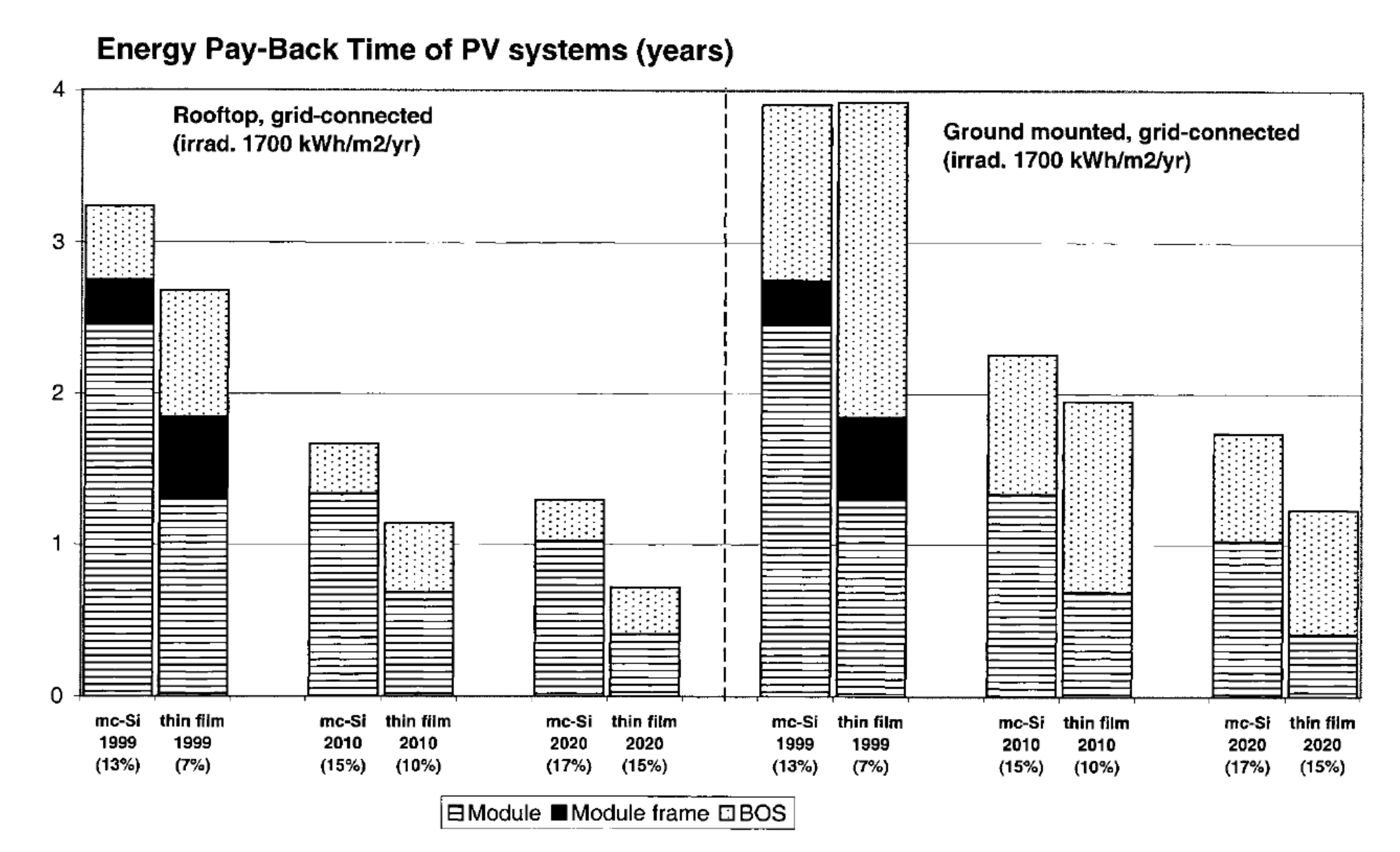


https://www.nrel.gov/docs/fy04osti/35489.pdf

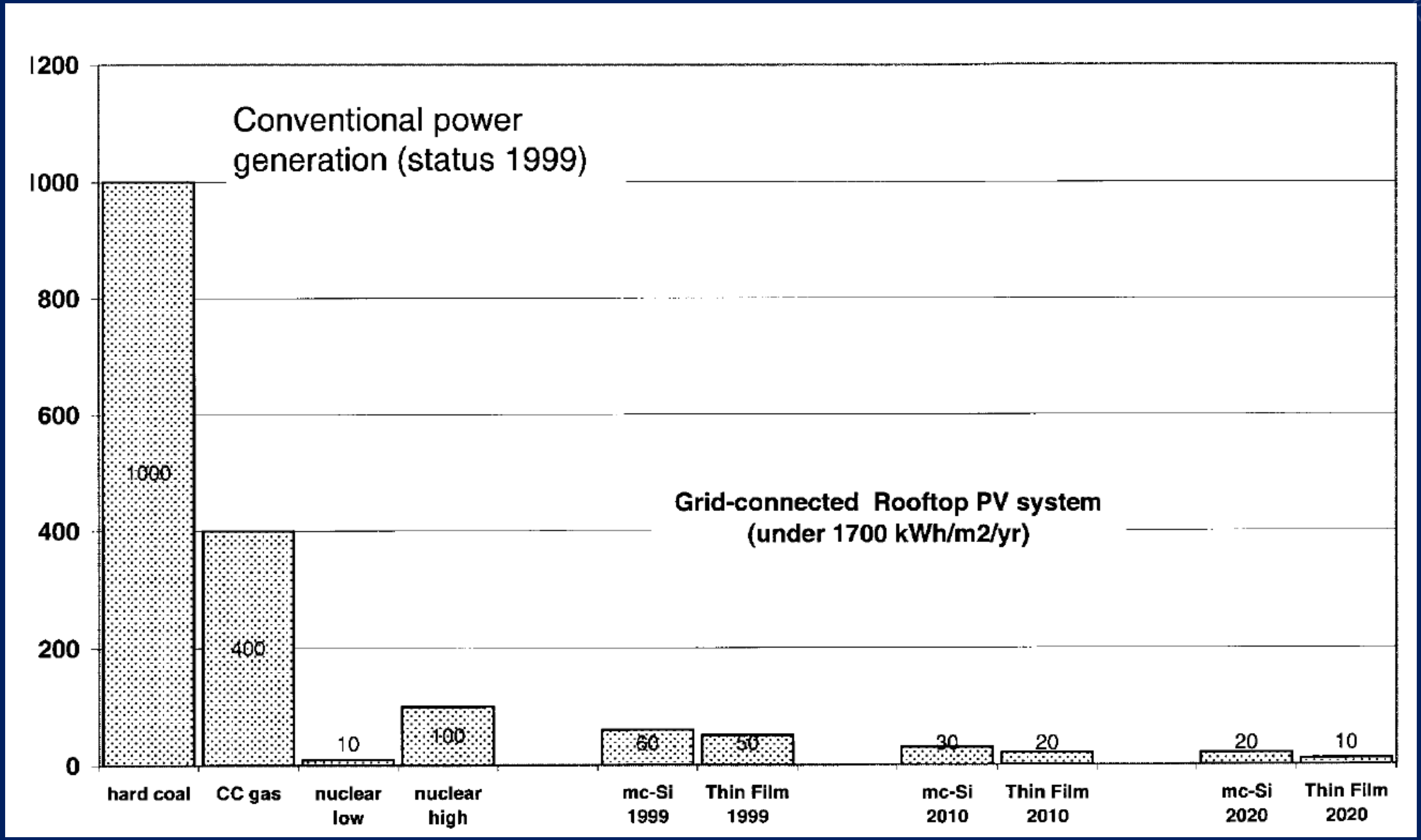
LCA-PV Steps


M, Q
Raw Material Acquisition
E
M, Q
Material Processing
E
M, Q
Manufacturing
E
M, Q
Use
E
M, Q
Decommissioning
E
M, Q
Treatment /Disposal
E
M, Q
Recycling
E
M, Q: material and energy inputs E: effluents

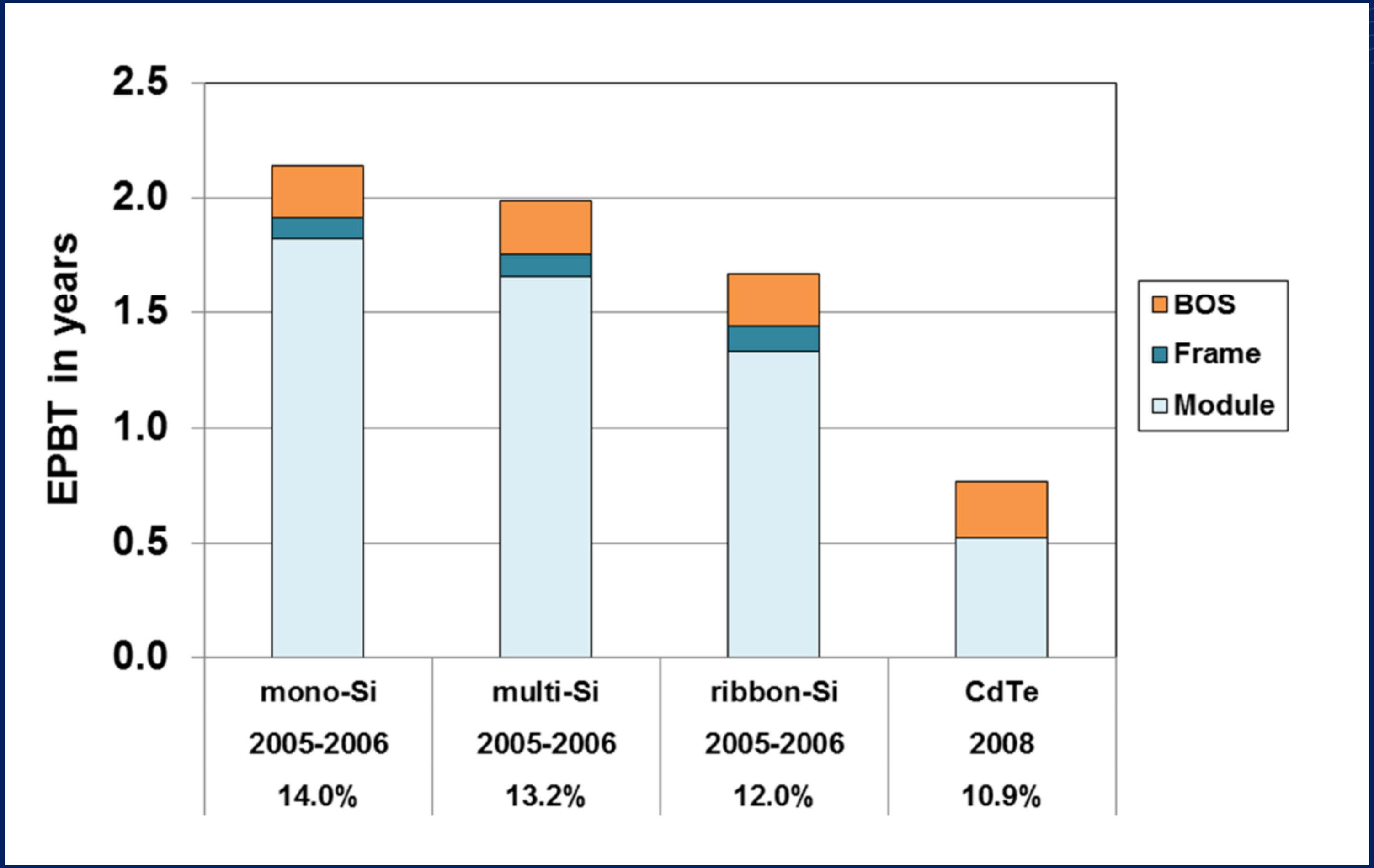
Alsema analysis

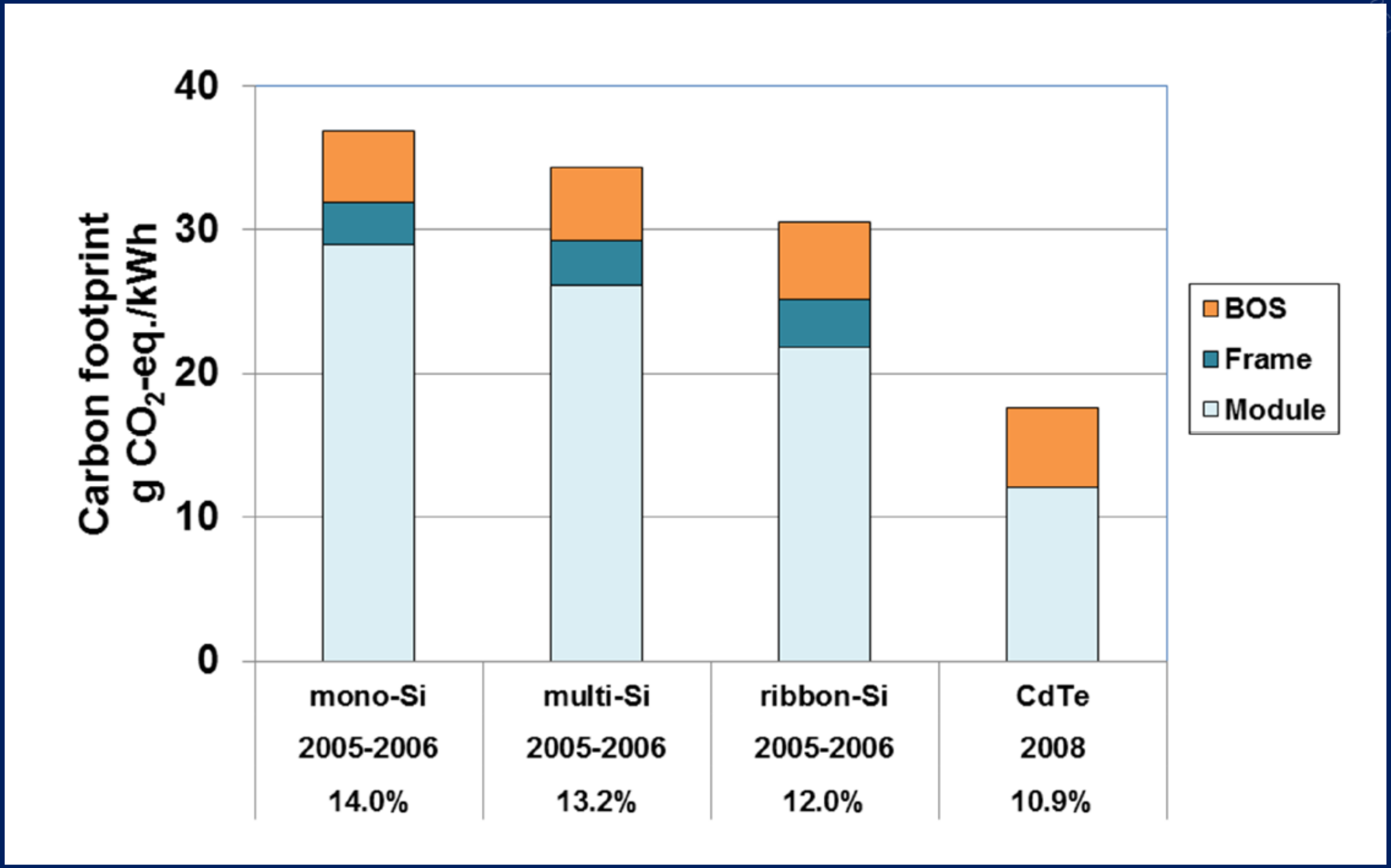


GHG Emissions per kWh



EPBT – EU report

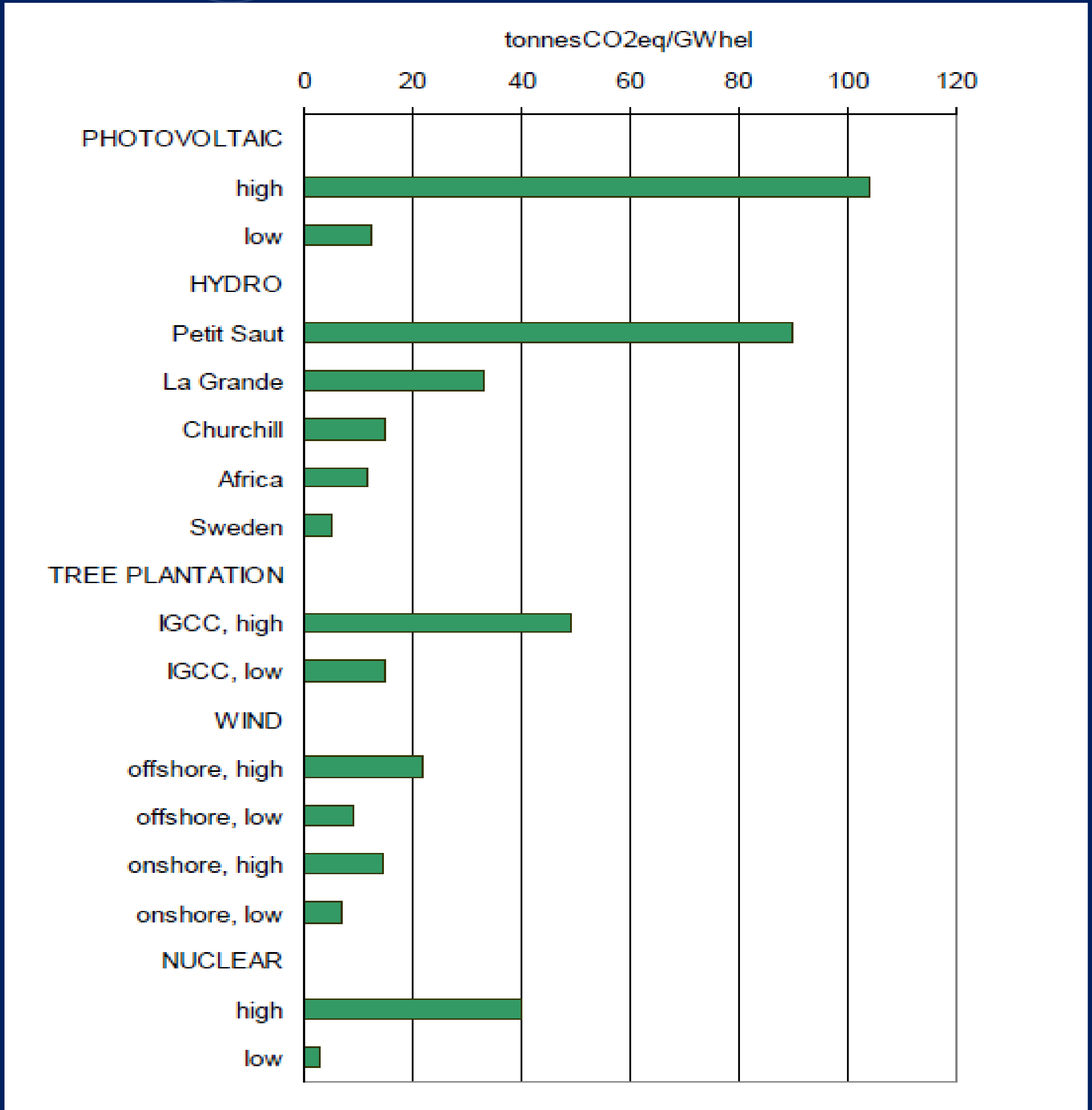




40
30
20
10
0
Carbon footprint
g CO_2-eq./kWh
BOS
Frame
Module
mono-Si
2005-2006
14.0%
multi-Si
2005-2006
13.2%
ribbon-Si
2005-2006
12.0%
CdTe
2008
10.9%

Impact Category	Scale	Relevant LCI Data	Common Characterisation Factor	Description of Characterisation Factor
Global Warming	Global	Carbon Dioxide (CO_2)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents
		Nitrous Oxide (N_2O)		Note: Global warming potentials can be 50, 100 or 500-year potentials
		Methane (CH_4)		
		Chlorofluorocarbons (CFCs)		
		Hydrochlorofluorocarbons (HCFCs)		
		Methyl Bromide (CH_3Br)		
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents
		Hydrochlorofluorocarbons (HCFCs)		
		Halons		
		Methyl Bromide (CH_3Br)		
Acidification	Regional	Sulphur Oxides (SOx)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents
	Local	Nitrogen Oxides (NOx)		
		Hydrochloric Acid (HCL)		
		Hydrofluoric Acid (HF)		
		Ammonia (NH_4)		
Eutrophication	Local	Phosphate (PO_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents
		Nitrogen Oxide (NO)		
		Nitrogen Dioxide (NO_2)		
		Nitrates		
		Ammonia (NH_4)		
Photochemical Smog	Local	Non-methane volatile organic compounds (NMVOC)	Photochemical Oxidant Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents
Human Health	Global	Total releases to air, water and soil.	LC_{50}	Converts LC_{50} data to equivalents
	Regional			
	Local			
Resource Depletion	Global	Quantity of minerals used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve
	Regional	Quantity of fossil fuels used		
	Local			
Land Use	Global	Quantity disposed of in a landfill	Solid Waste	Converts mass of solid waste into volume using an estimated density

Type of impact	Combustion based				Nuclear	Hydro	Wind	Solar
	Coal	Oil	Gas	Biomass				
Resource depletion	X	X	X		X			
Land use, visual impact	(X)			X		X	X	X
Watercourse regulation						X		
Thermal releases	X	X	X	X	X			
Noise							X	
Radiation					X			
Air quality	X	X	X	X				
Acidification	X	X	X	X				
Eutrophication	X	X	X	X				
Greenhouse effect	X	X	X	X				

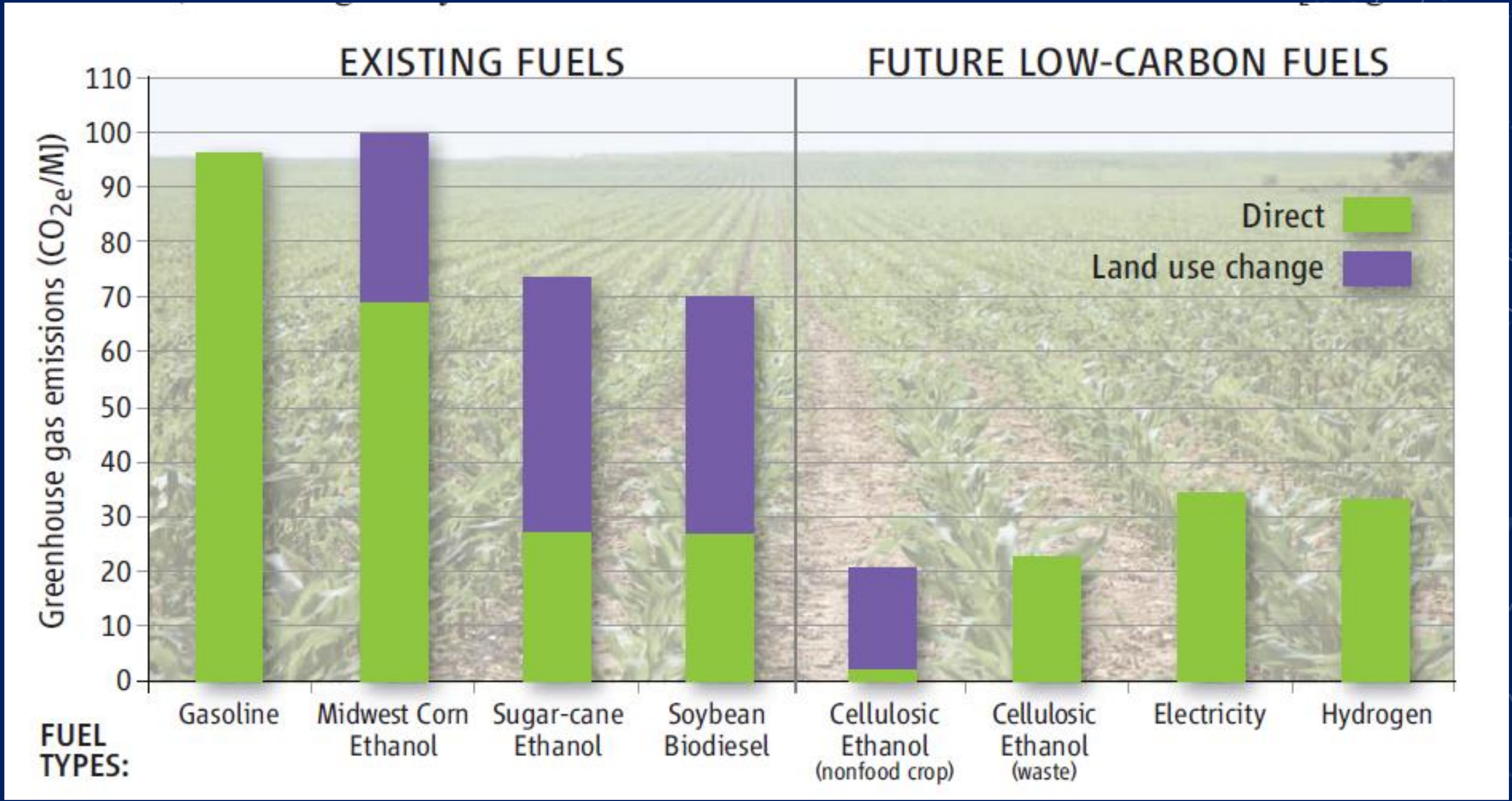

tonnesCO2eq/GWhel
0
20
40
60
80
100
120
PHOTOVOLTAIC
high
low
HYDRO
Petit Saut
La Grande
Churchill
Africa
Sweden
TREE PLANTATION
IGCC, high
IGCC, low
WIND
offshore, high
offshore, low
onshore, high
onshore, low
NUCLEAR
high
low

BIOFUELS

Corn-Based Ethanol Flunks Key Test

In setting state rules for low-carbon fuels, California officials have calculated that corn ethanol is worse than gasoline

https://science.sciencemag.org/content/sci/324/5927/587.full.pdf



https://science.sciencemag.org/content/sci/324/5927/587.full.pdf

Primary energy analysis of RME

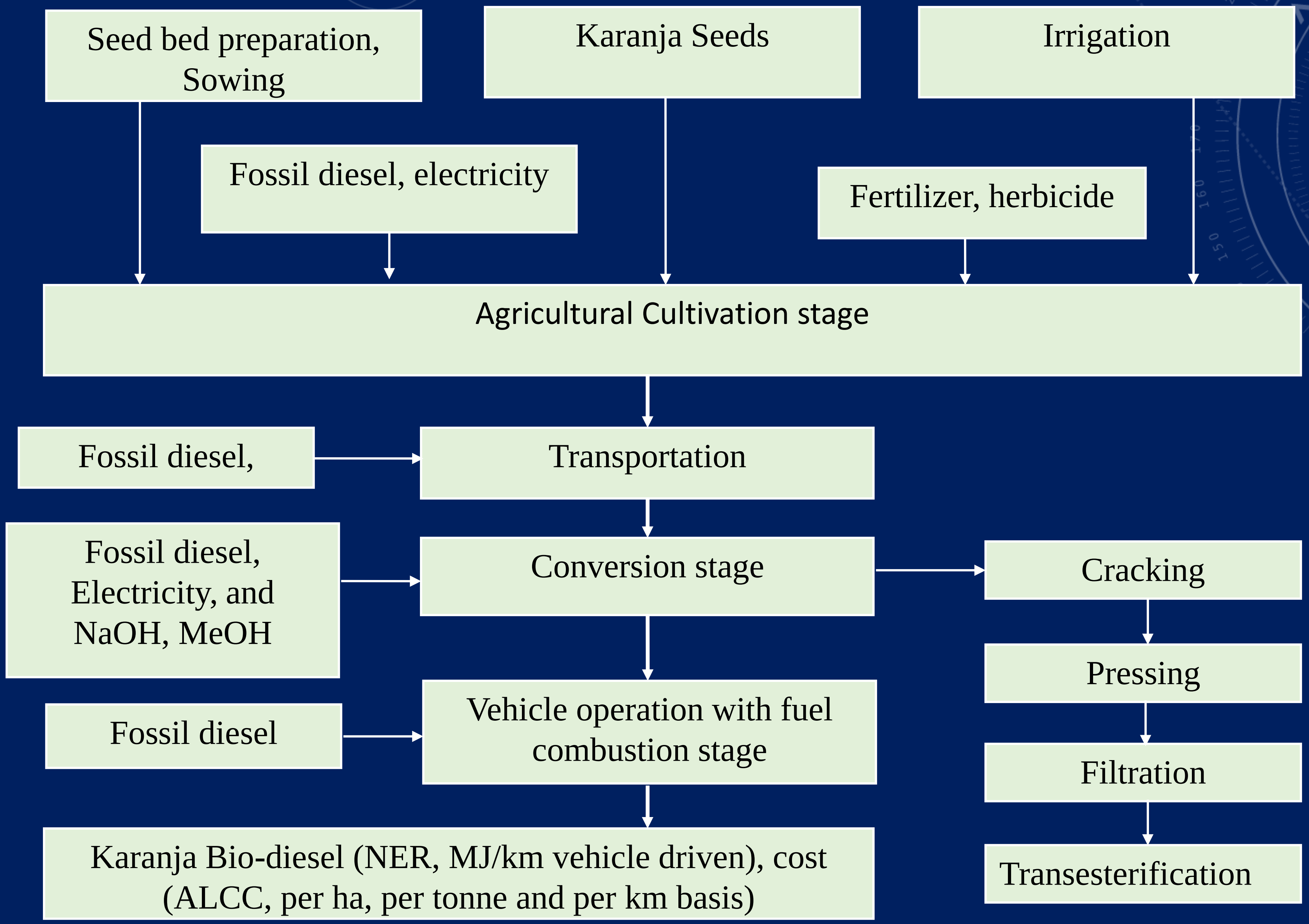
- Rapeseed Methyl Ester (RME)-Transport
- Plant Production(incl fertilisers) 9000 MJ/ha
- Harvesting, transport & oil extraction 5600 MJ/ha
- 60% to rapeseed oil (meal 40%) 8800 MJ/ha
- Refining & Esterification 7900 MJ/ha
- 96% to RME (glycerine 4%) 16000 MJ/ha
- Final transport 200 MJ/ha
- Total annual 16,200 MJ/ha (Kaltschmitt et al,1997)
- Diesel 4600 MJ (pre-chain) + 42500 (fuel) 47,100 MJ

Comparison of RME & Diesel

Parameter	RME	Diesel
PE (GJ)	16.2	47.1
CO_2 equiv kg	1594	3752
CO_2 kg	1037	3523
SO_2 equiv g	12487	11813
SO_2 g	1670	2857
No_x g	14274	12691
CO g	11689	11160

Annual values/ha from Kaltschmitt et al,1997 - Germany

Life cycle inventory



Methodology for analysis

- Life cycle Approach
- NER = **E***out*/**E***in*

If NER > 1, Replacement viable

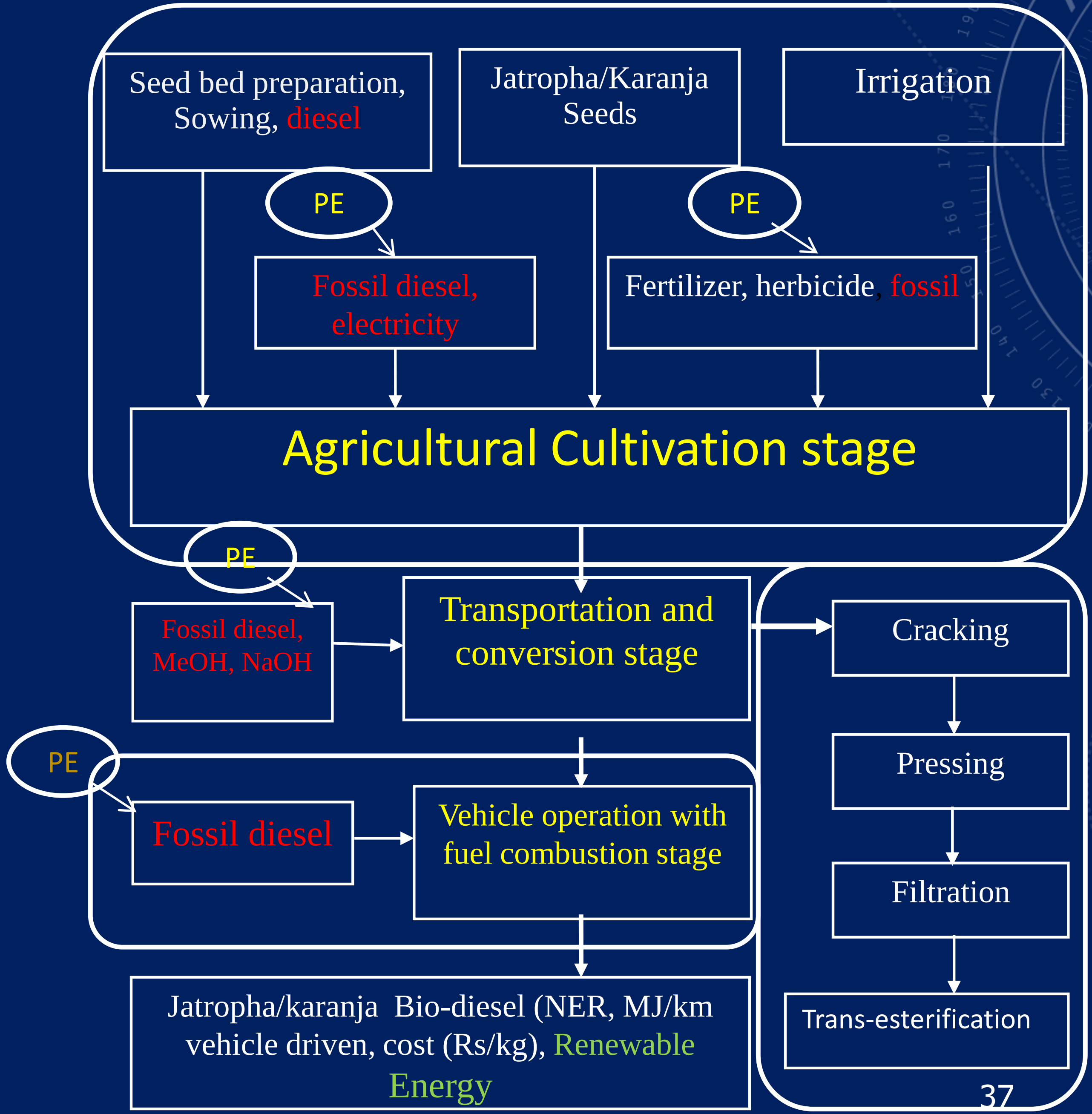
NER < 1, Replacement not viable

- CRF (d, n)=[d *(1+d)^n]/[(1+d)^n-1]
- ALCC = AC + C_0*CRF (d, n)
- NER (Net Energy Ratio)
- ALCC (Annualized cost)
- CRF (Cash recovery factor)

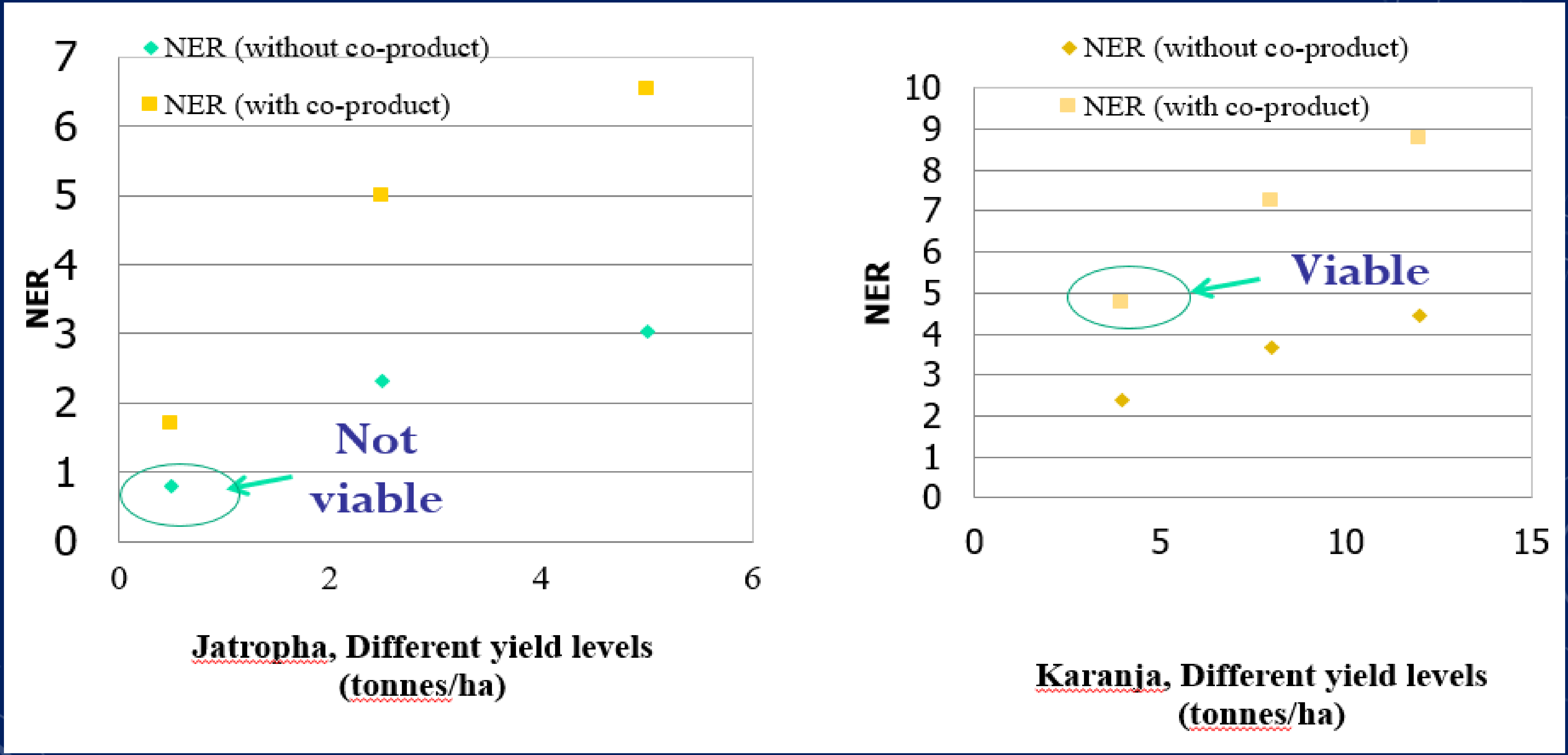
Secondary Energy

Primary Energy

Renewable Energy



Jatropha and Karanja Analysis results



Rs. 33-36/kg 2007 values

Rs. 21-25/kg

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- Varadharajan, A., Venkateshwaran W. S., Banerjee, R., "Energy analysis of biodiesel from Jatropha." In *Proceedings of 10th World Renewable Energy Congress (WRECX)*, Glasgow, Scotland, United Kingdom, July 19-25, 2008.
- Sarkar, A., Banerjee, R., "Net energy analysis of hydrogen storage options," *International Journal of Hydrogen Energy*, (30)8, 867-877, July 2005.
- Allwood et al, 2011