OSU~EmEA - 18

Emergy Evaluation of Energy Alternatives

Net Emergy, Emergy Yield Ratio, Energy Return on Energy Invested (EROEI)

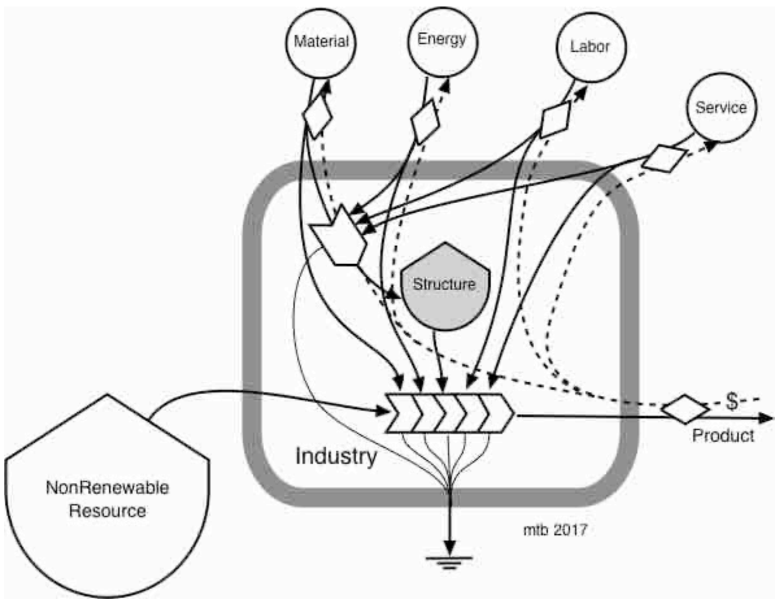
Net Energy…

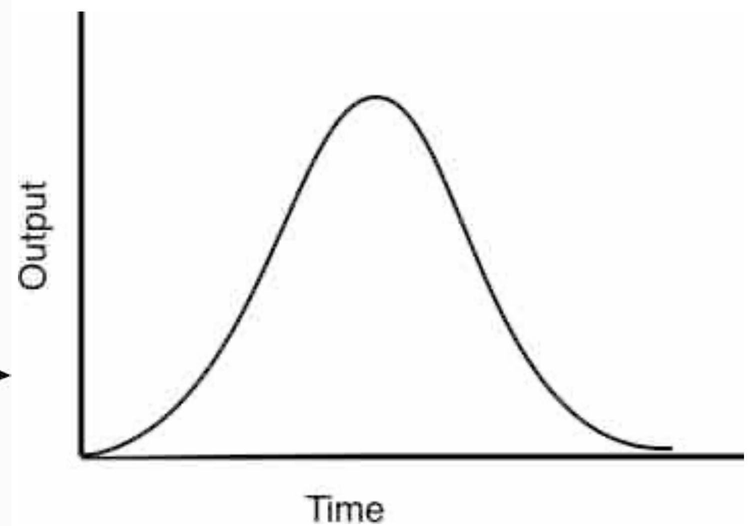
A reminder…

SI multiples for joule (J)

Submultiples			Multiples		
Value	**Symbol**	**Name**	**Value**	**Symbol**	**Name**
10^{-1} J	dJ	decijoule	10^{1} J	daJ	decajoule
10^{-2} J	cJ	centijoule	10^{2} J	hJ	hectojoule
10^{-3} J	**mJ**	**millijoule**	10^{3} J	**kJ**	**kilojoule**
10^{-6} J	**µJ**	**microjoule**	10^{6} J	**MJ**	**megajoule**
10^{-9} J	**nJ**	**nanojoule**	10^{9} J	**GJ**	**gigajoule**
10^{-12} J	**pJ**	**picojoule**	10^{12} J	**TJ**	**terajoule**
10^{-15} J	fJ	femtojoule	10^{15} J	PJ	petajoule
10^{-18} J	aJ	attojoule	10^{18} J	EJ	exajoule
10^{-21} J	zJ	zeptojoule	10^{21} J	ZJ	zettajoule
10^{-24} J	yJ	yoctojoule	10^{24} J	YJ	yottajoule
Common multiples are in bold face					

Characteristic yield from nonrenewable resources

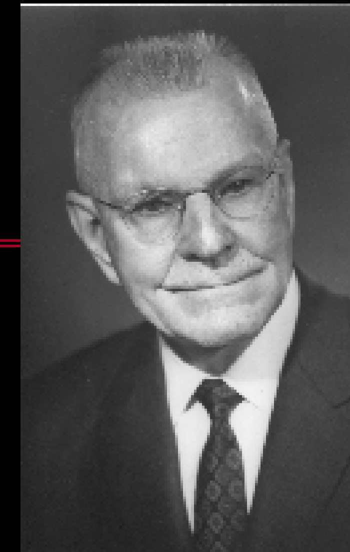




M.King Hubbert's Blip

"Reality is merely an illusion, albeit a very persistent one." ***Albert Einstein***

Peak Oil…

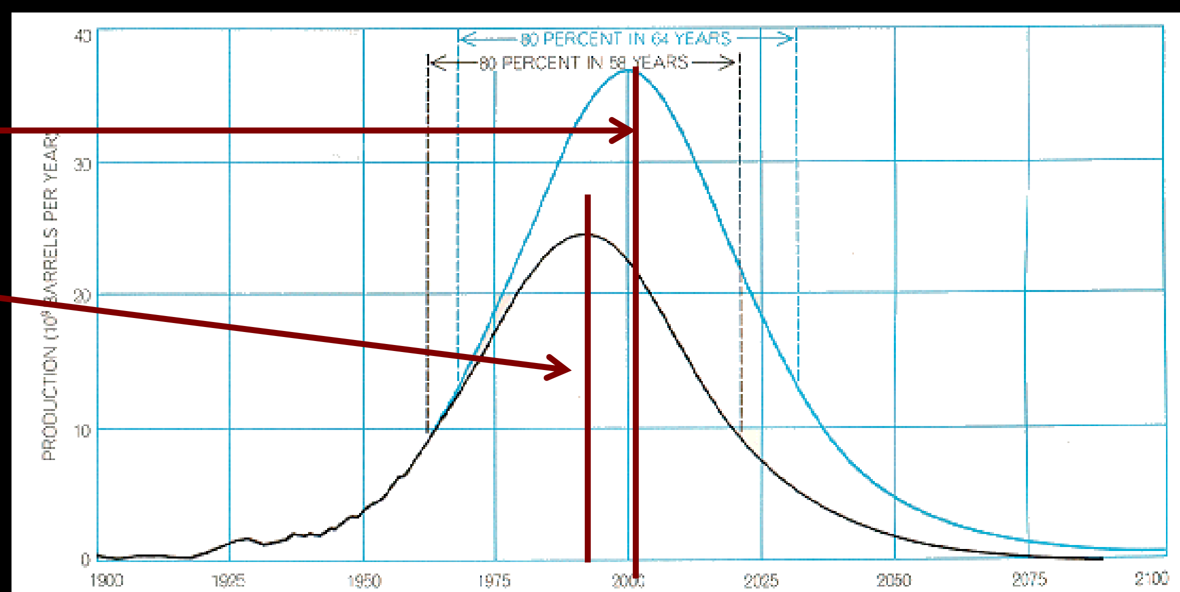


"My analyses are based upon the simple fundamental geologic fact that initially there was only a fixed and finite amount of oil in the ground, and that, as exploitation proceeds, the amount of oil remaining diminishes monotonically."

M.King Hubbert

Peak oil 2000

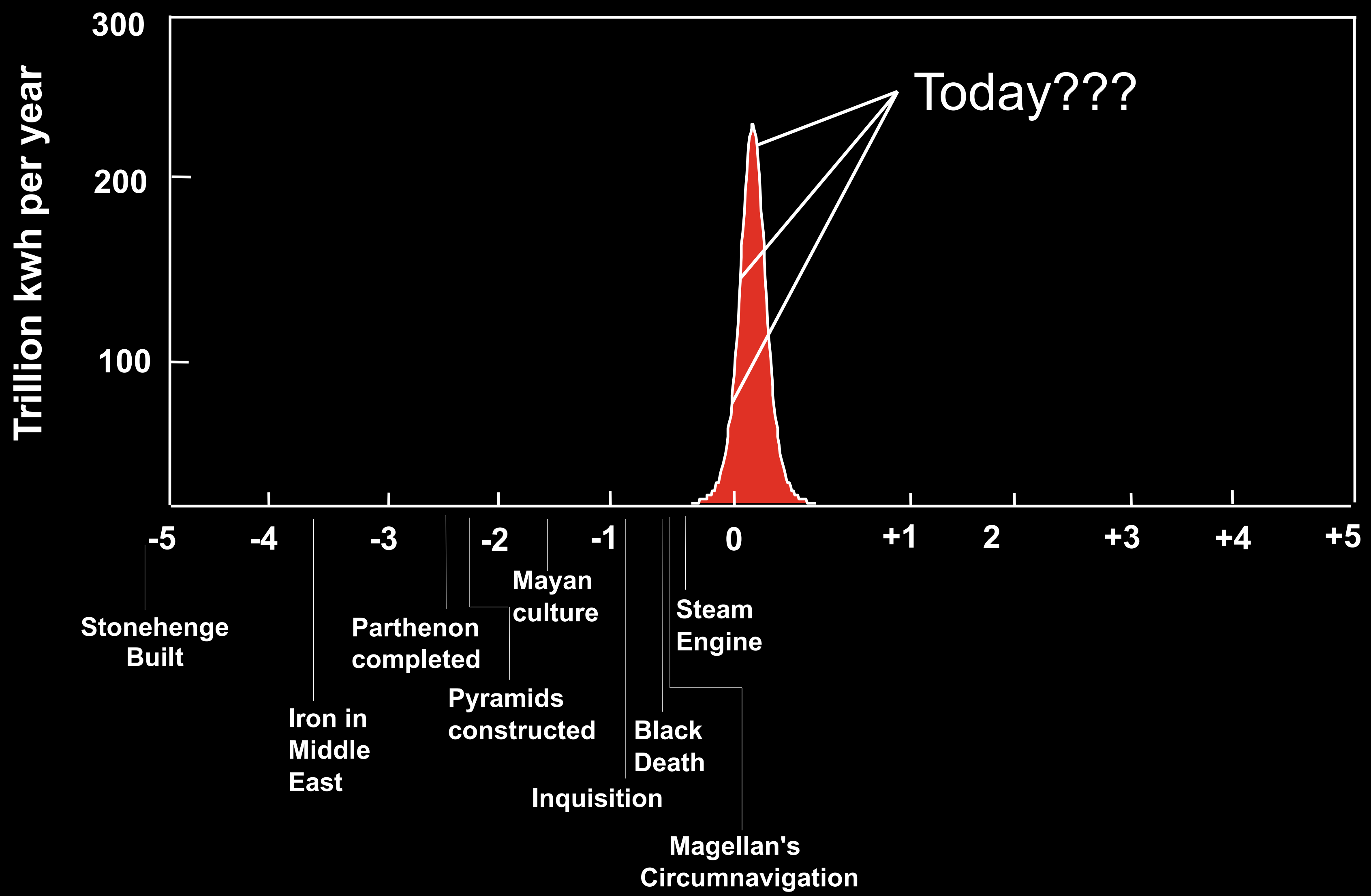
Peak oil 1991 or 92



CYCLE OF WORLD OIL PRODUCTION is plotted on the basis of two estimates of the amount of oil that will ultimately be produced. The colored curve reflects Ryman's estimate of $2,100 \times 10^9$ barrels and the black curve represents an estimate of $1,350 \times 10^9$ barrels.

The Epoch of Fossil Fuel Exploitation

(after Hubbert, 1969)



Peak Oil…

The End of Oil and the Inevitable Road to Sustainability
by Bob Banner

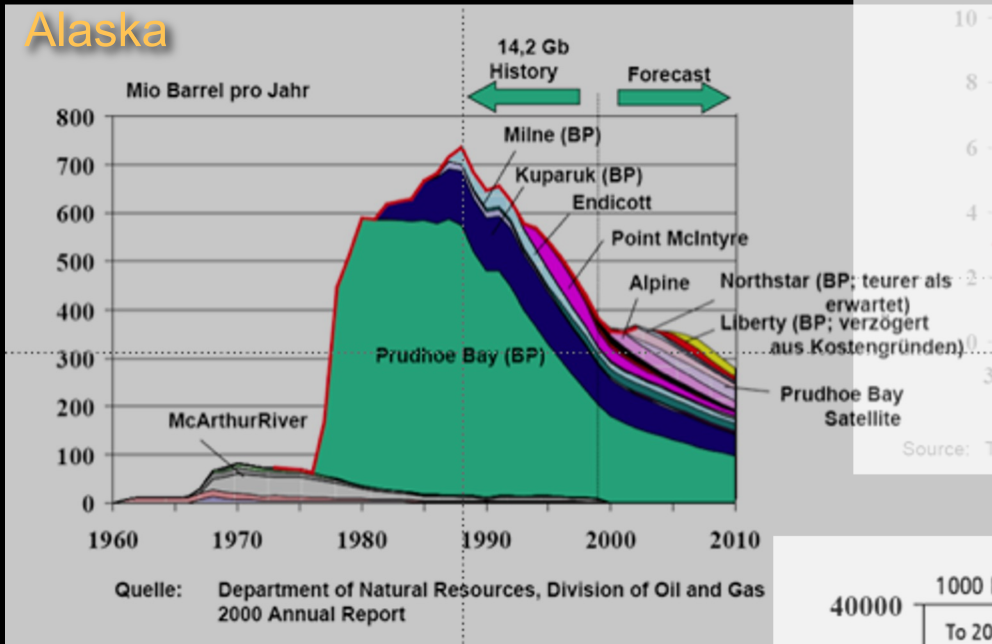
Peaking World Oil Production Could Cause Severe Disruptions

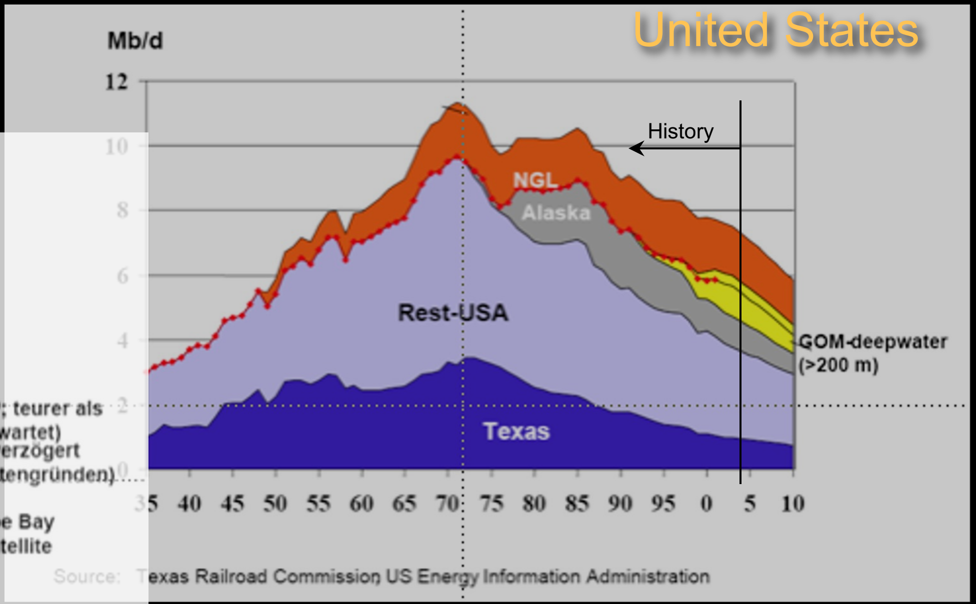
IEA to call for an emergency oil plan
by Javier Blas and Kevin Morrison

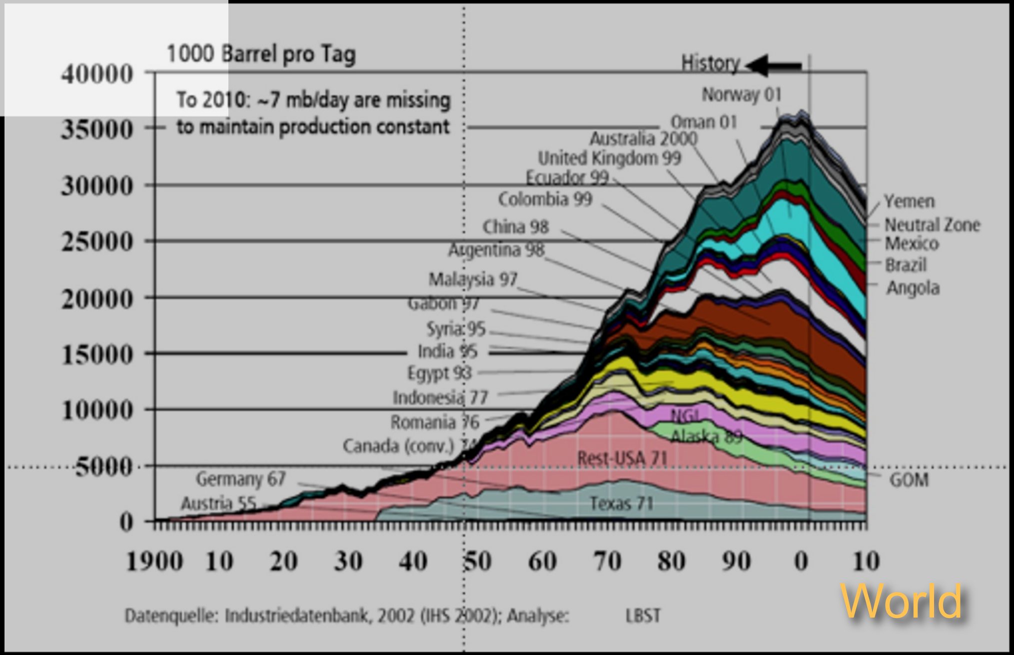
ASPO
www.peakoil.net
Association for the Study of Peak Oil&Gas

Running on empty
by Christopher Kremmer

Back to the post-oil future
by Richard Heinberg

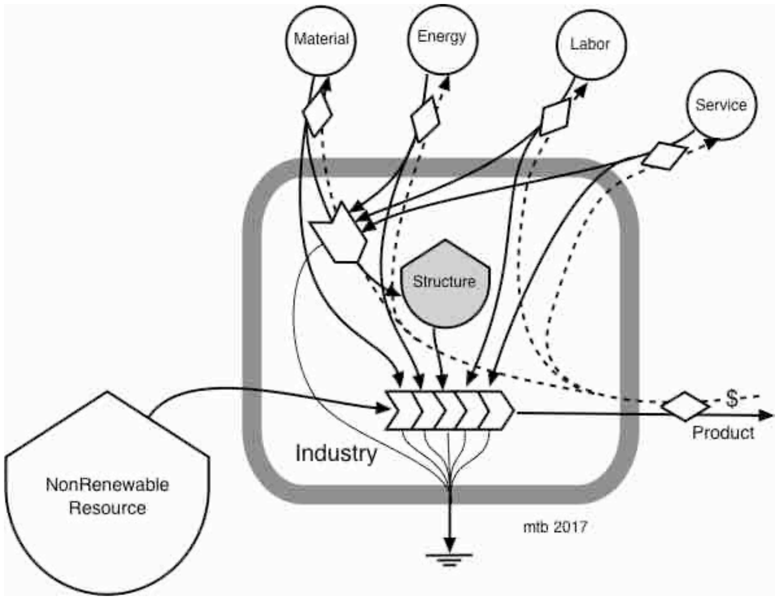


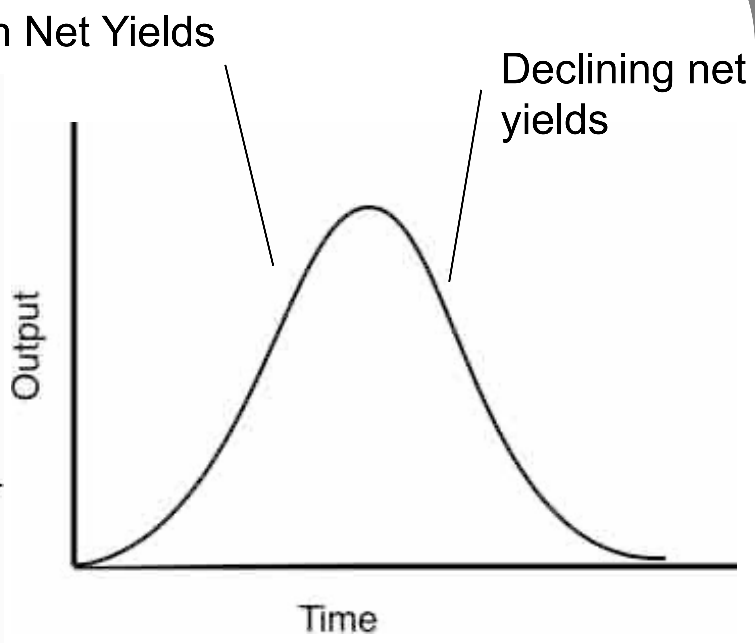




the hydrocarbon age is about over.

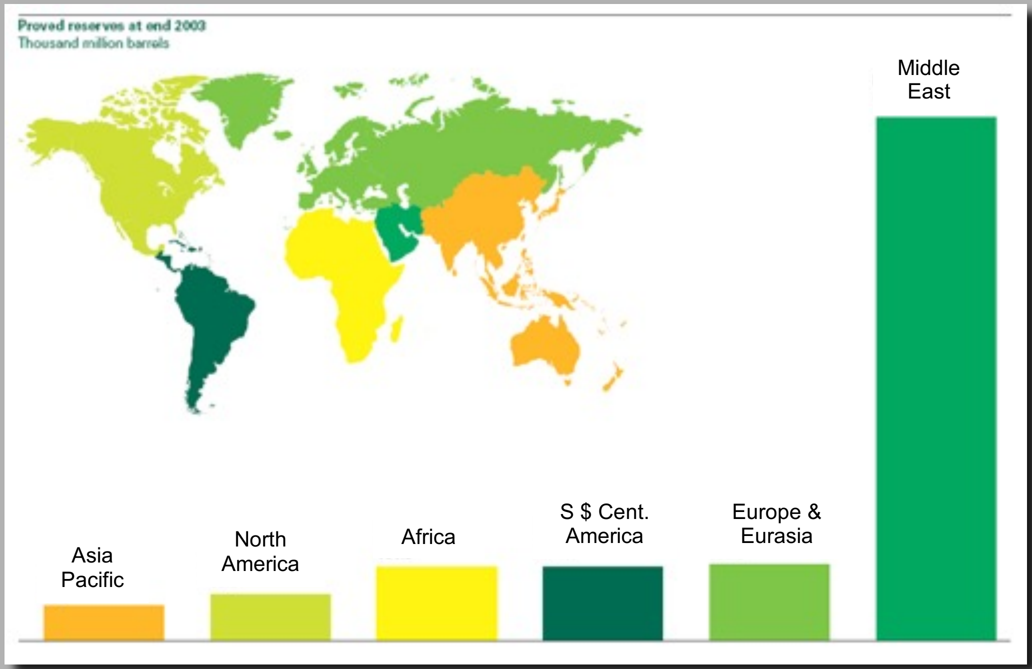
Characteristic yield from nonrenewable resources

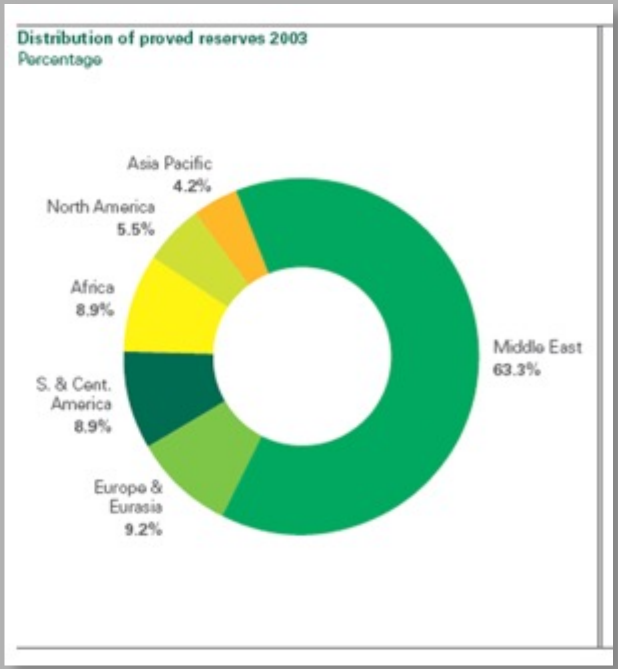




Peak Oil…

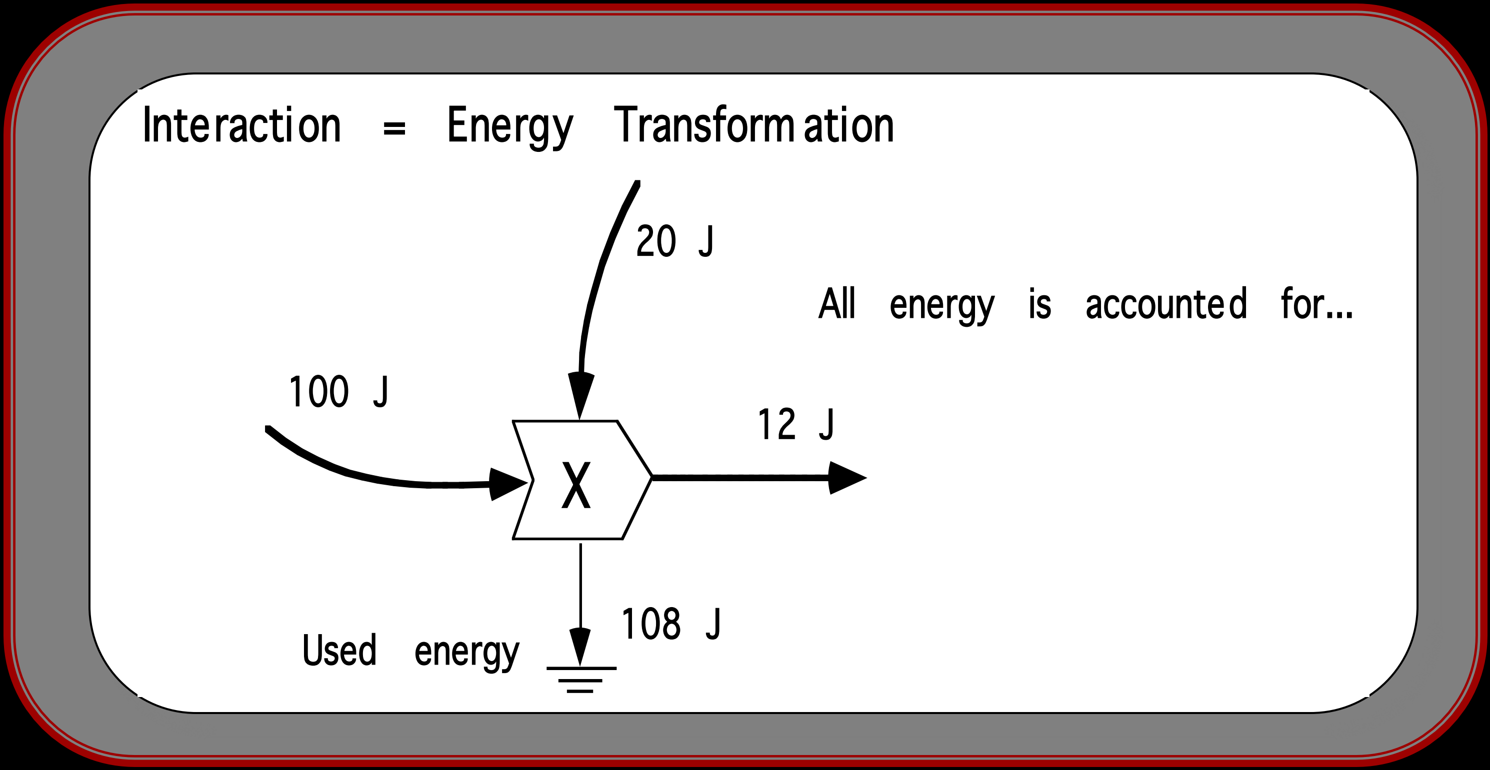
Global politics for the next two decades…





1st Law of Thermodynamics

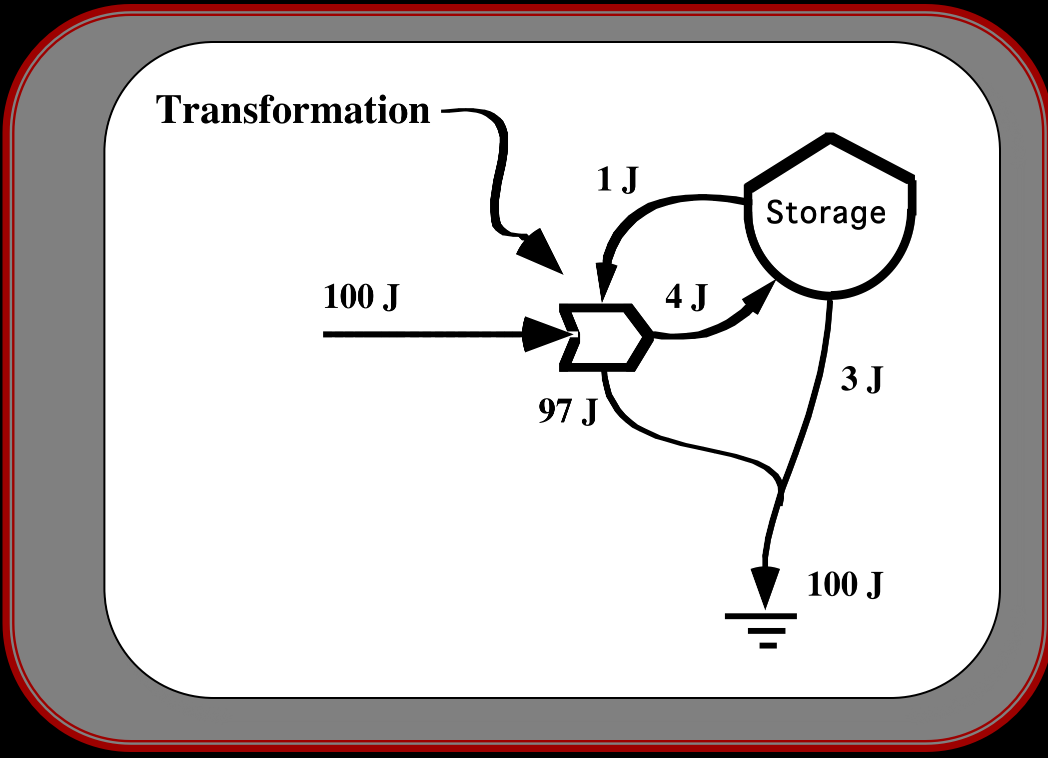
Energy cannot be created or destroyed



2nd Law of Thermodynamics

In all real process (transformations), some energy loses its ability to do work

We sometimes speak loosely of energy being “used up” whereas what is really meant is that the potential for driving work is consumed, while the calories of energy inflows and outflows are the same.



Net Emergy…emergy costs of obtaining energy

When the energy cost of recovering a barrel of oil becomes greater than the energy content of the oil, production will cease, no matter what the monetary price may be.

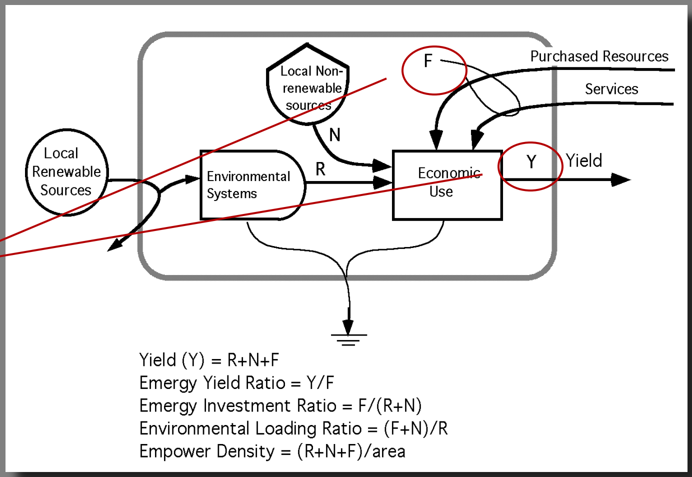
M. K. Hubbert

EYR Defined…

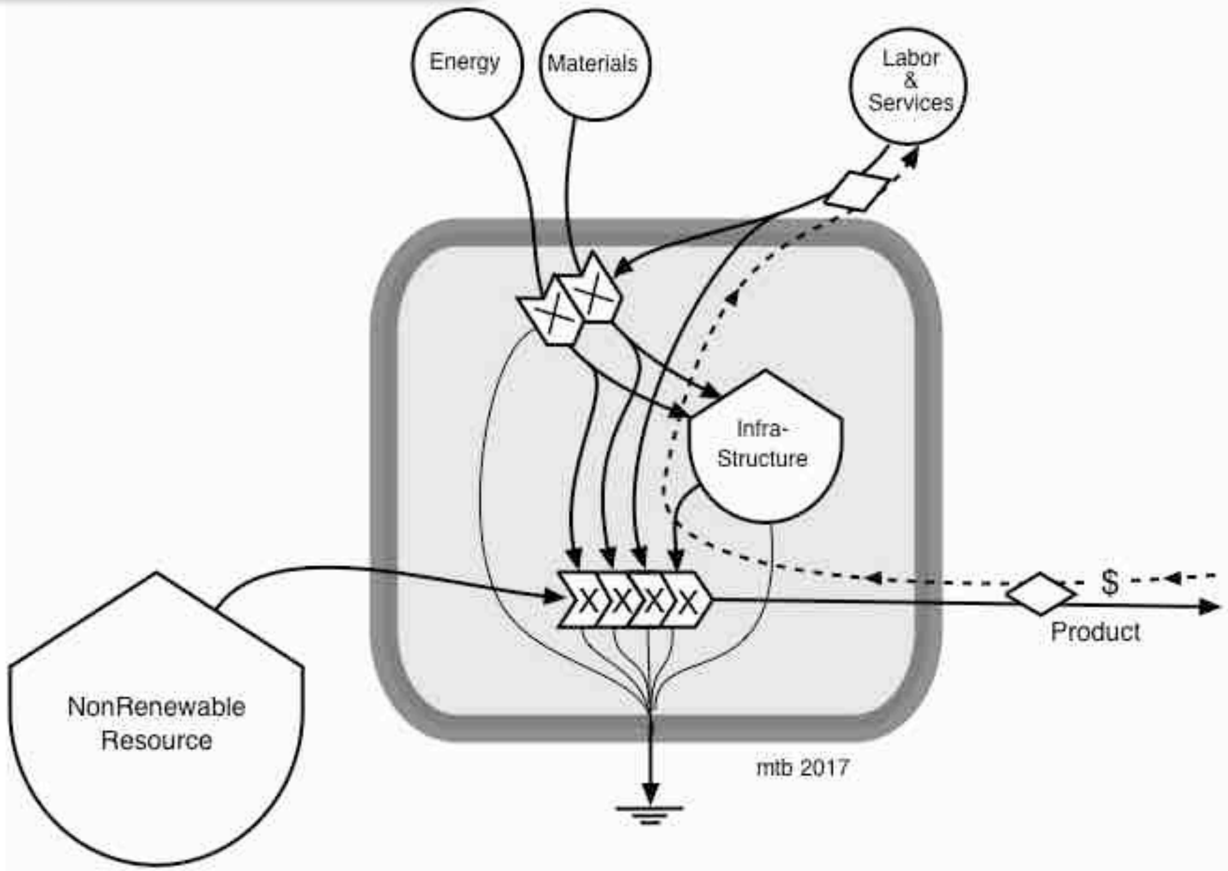
Emergy yield ratio. The ratio of the emergy yield from a process to the emergy costs. The ratio is a measure of how much a process will contribute to the economy.

Yield (Y) =R+N+F

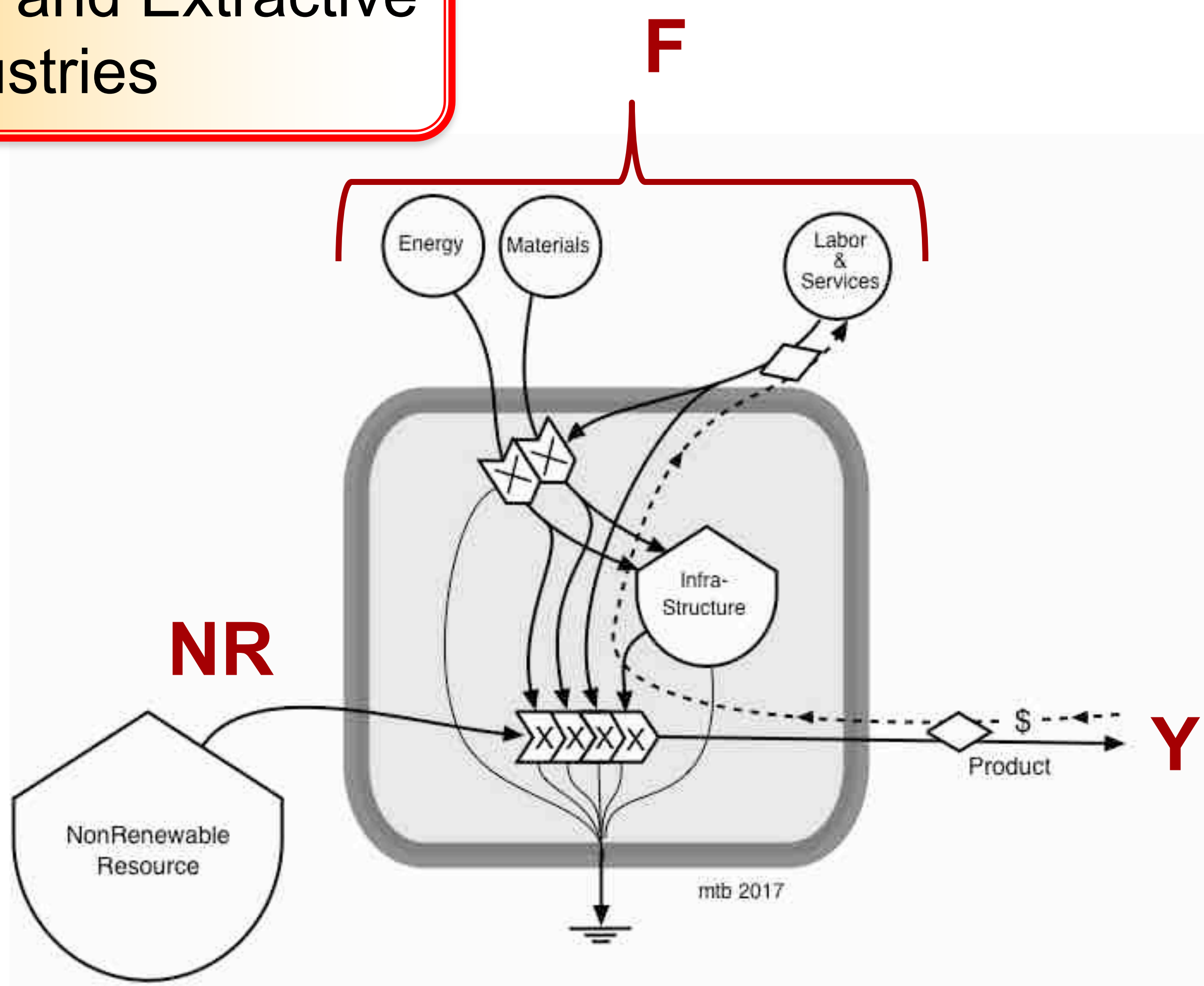
$$EYR = \frac{Y}{F}$$



Emergy Yield and Extractive Industries



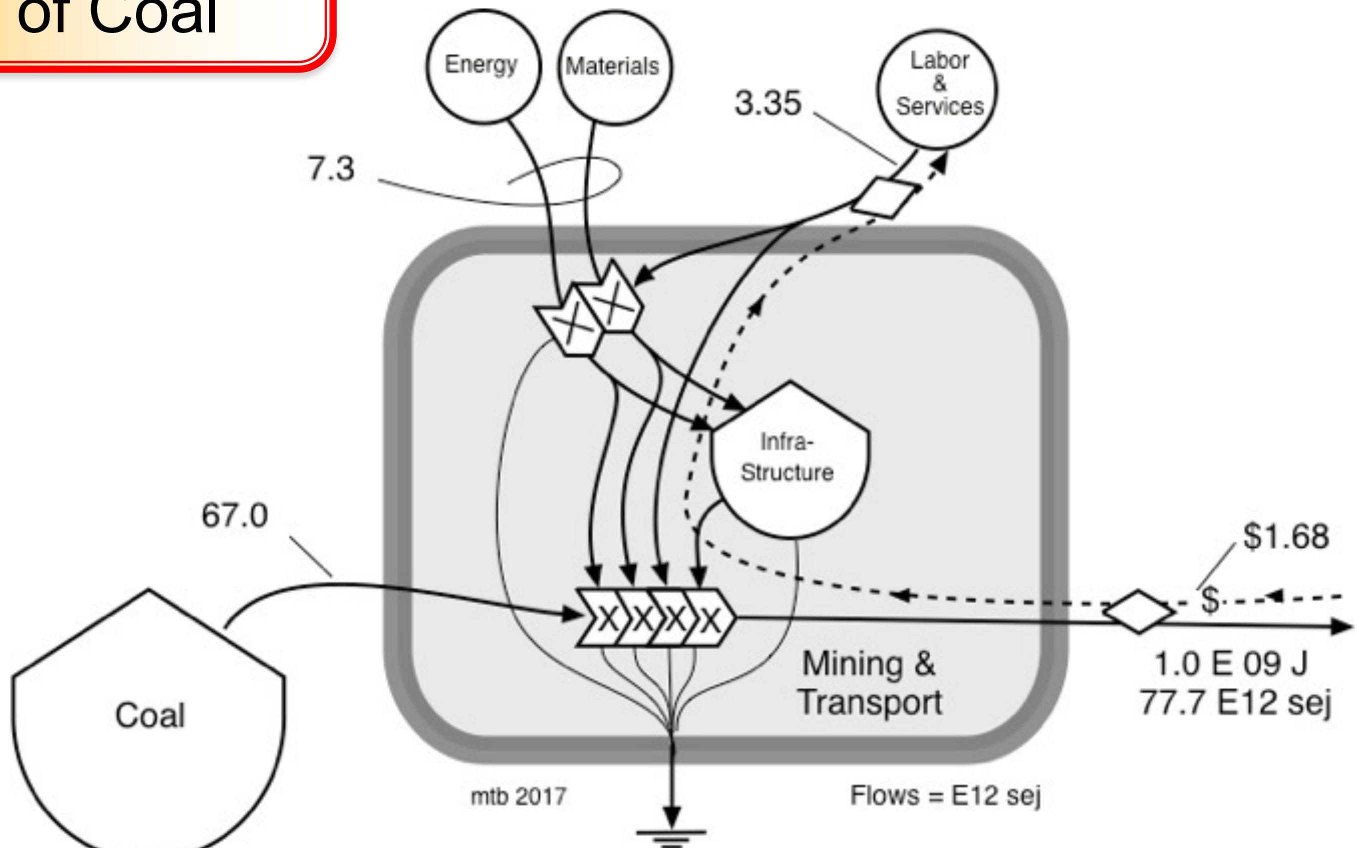
Emergy Yield and Extractive Industries



Emergy Yield, Y = NR + F

Emergy Yield Ratio, EYR = Y / F

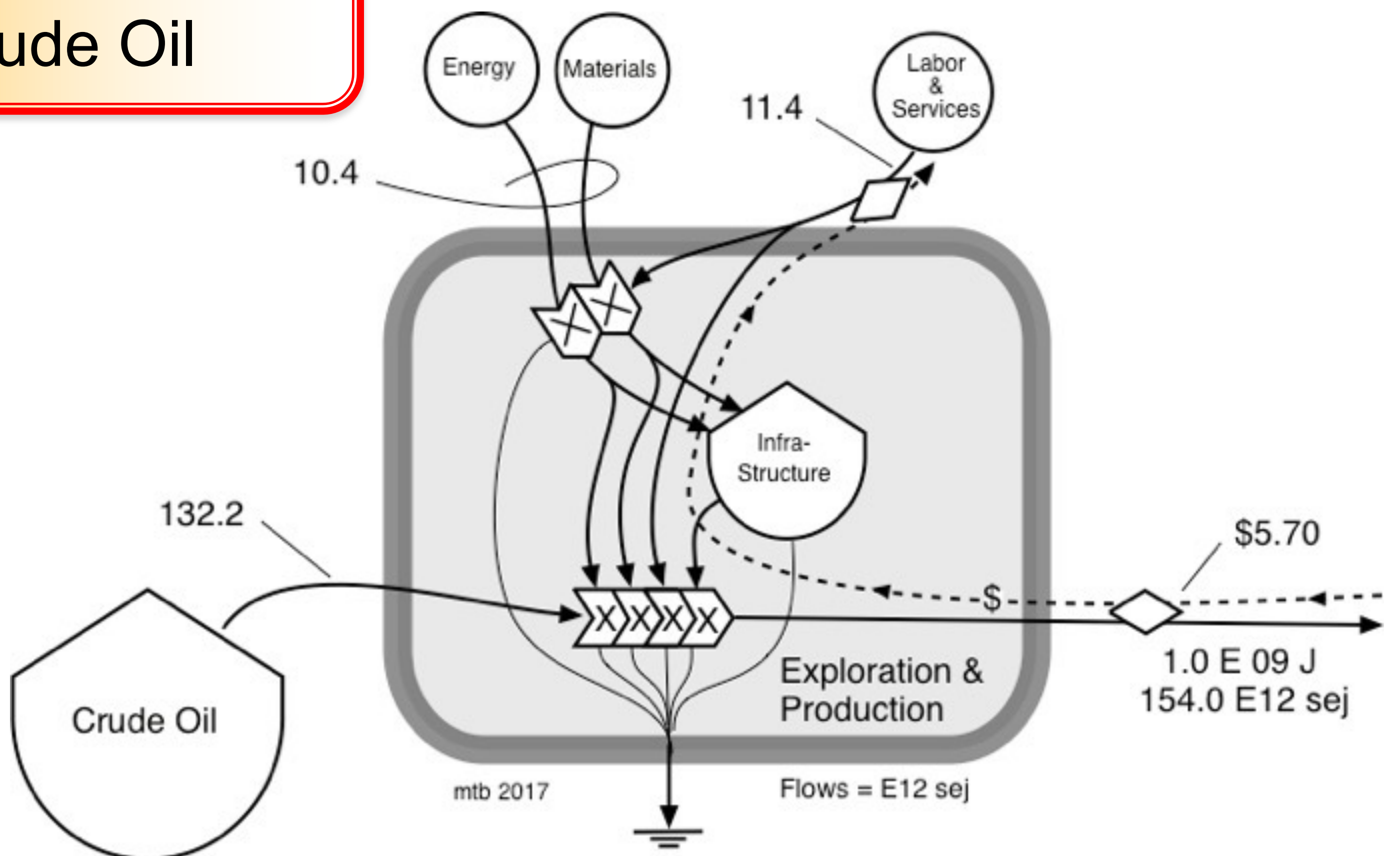
Emergy Yield Ratio of Coal



$$\text{EYR w/out L \& S} = \frac{74.3 \text{ E12 sej}}{17.3 \text{ E12 sej}} = 10.2 / 1$$

$$\text{EYR w/ L \& S} = \frac{77.7 \text{ E12 sej}}{10.7 \text{ E12 sej}} = 7.0 / 1$$

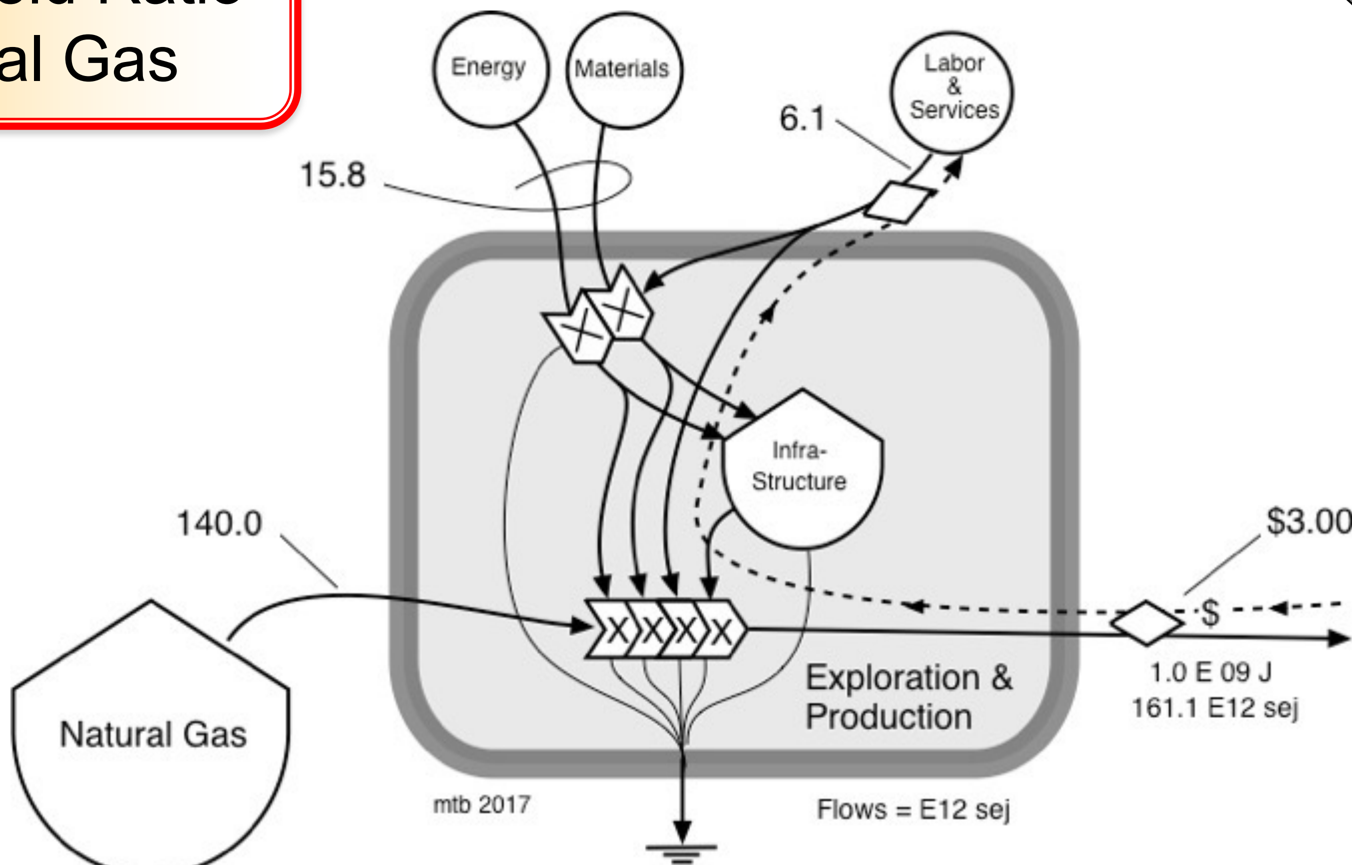
Emergy Yield Ratio of Crude Oil



EYR w/out L & S = $\frac{142.6 \text{ E12 sej}}{10.4 \text{ E12 sej}}$ = 13.7 / 1

EYR w/ L & S = $\frac{154.0 \text{ E12 sej}}{21.8 \text{ E12 sej}}$ = 7.0 / 1

Emergy Yield Ratio of Natural Gas



EYR w/out L & S = $\frac{155.8 \text{ E12 sej}}{15.8 \text{ E12 sej}}$ = 9.9 / 1

EYR w/ L & S = $\frac{161.1 \text{ E12 sej}}{21.8 \text{ E12 sej}}$ = 7.4 / 1

Summary of Emergy Yield Ratios of Fuels

Without Labor & Services

Fuel at "WellHead"

Fuel Type	EYR (w/out L & S)
Soft Coal	6.2/1
Hard Coal	10.2/1
Crude Oil	13.7/1
Natural Gas	9.9/1

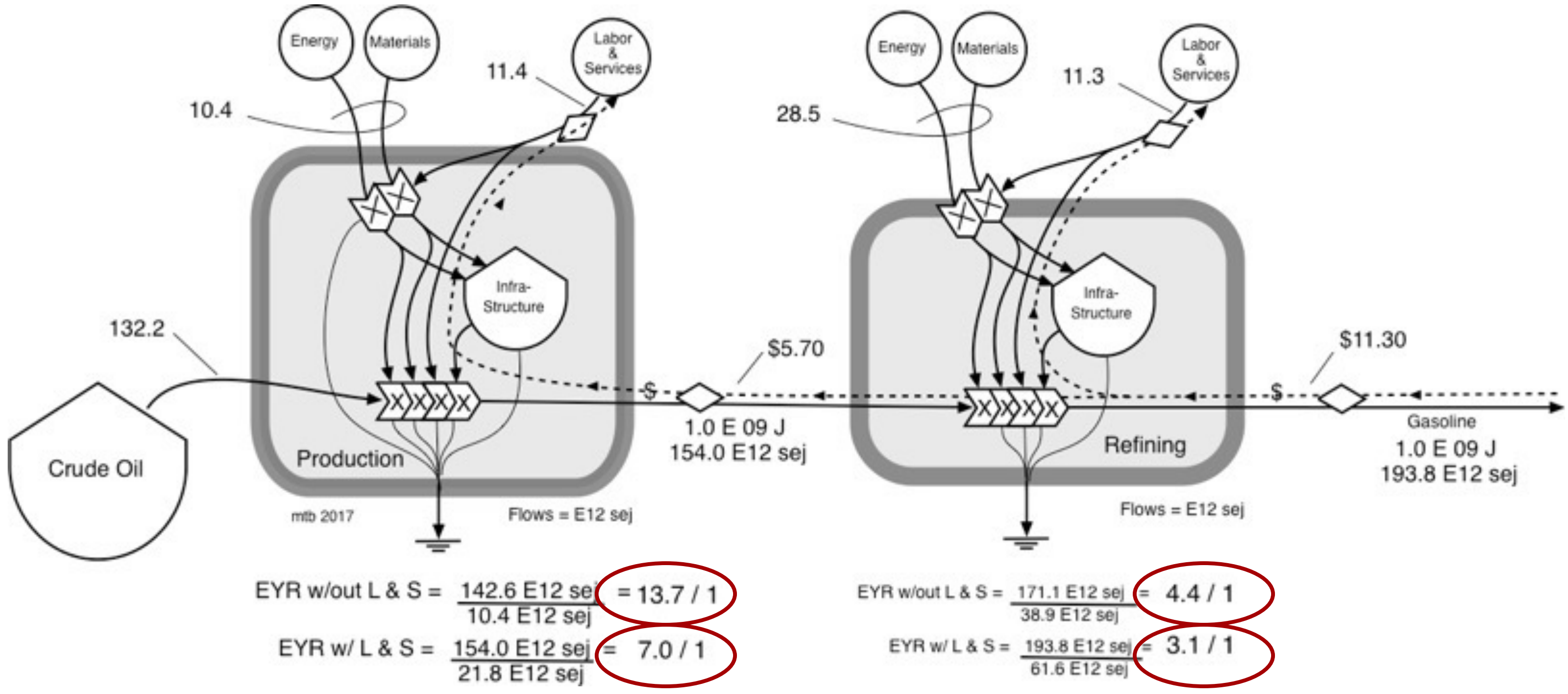
Summary of Emergy Yield Ratios of Fuels

With Labor & Services

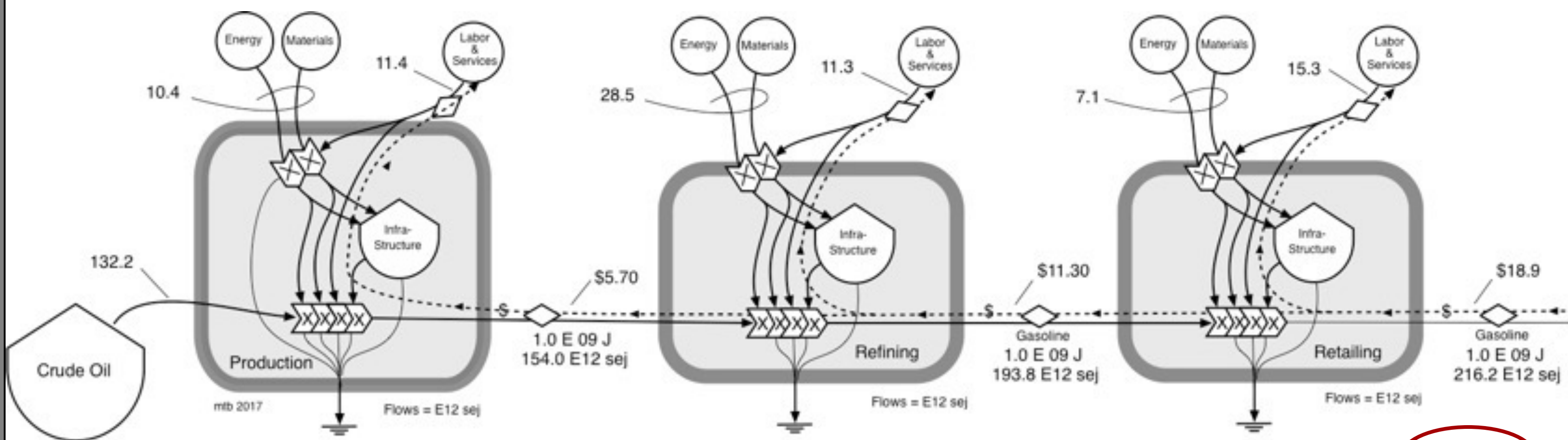
Fuel at "WellHead"

Fuel Type	EYR (w/ L & S)	Cost/ E9 J
Soft Coal	4.8/1	$1.50
Hard Coal	7.0/1	$1.68
Crude Oil	7.0/1	$5.72
Natural Gas	7.4/1	$3.00

EYR of Refined Crude Oil into Gasoline



EYR of Refined Crude Oil into Gasoline and after Retail Sale



EYR w/out L & S = $\frac{142.6 \text{ E12 sej}}{10.4 \text{ E12 sej}}$ = 13.7 / 1

EYR w/ L & S = $\frac{154.0 \text{ E12 sej}}{21.8 \text{ E12 sej}}$ = 7.0 / 1

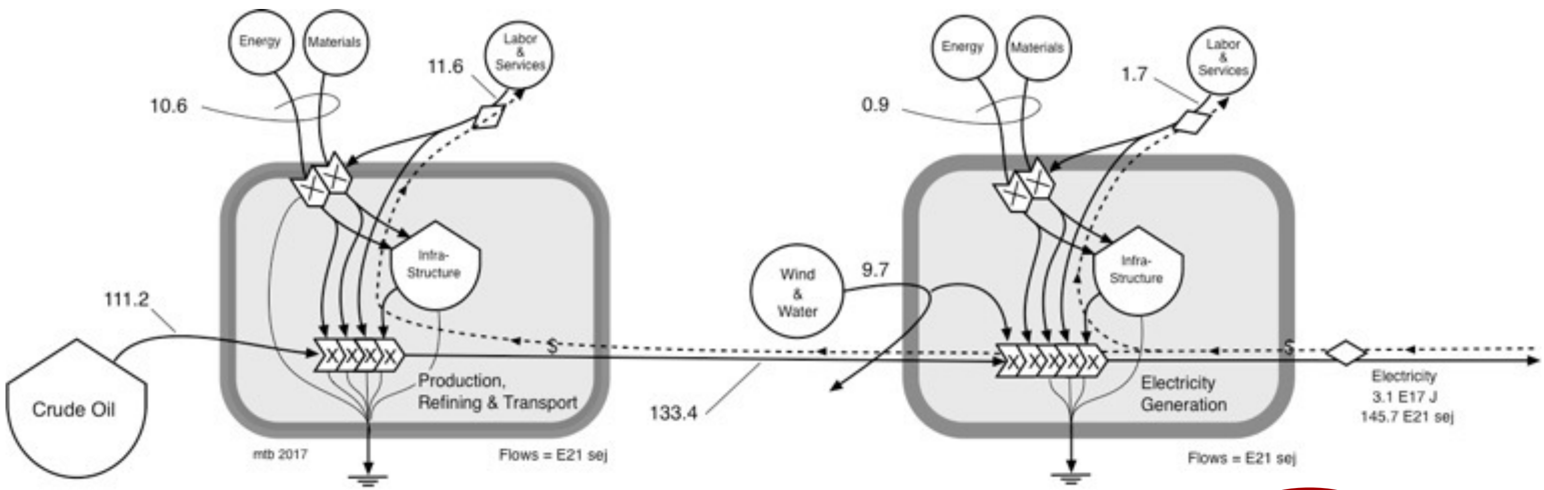
EYR w/out L & S = $\frac{171.1 \text{ E12 sej}}{38.9 \text{ E12 sej}}$ = 4.4 / 1

EYR w/ L & S = $\frac{193.8 \text{ E12 sej}}{61.6 \text{ E12 sej}}$ = 3.1 / 1

EYR w/out L & S = $\frac{178.2 \text{ E12 sej}}{46.0 \text{ E12 sej}}$ = 3.9 / 1

EYR w/ L & S = $\frac{216.2 \text{ E12 sej}}{76.9 \text{ E12 sej}}$ = 2.8 / 1

EYR of Thermal Electricity Generation



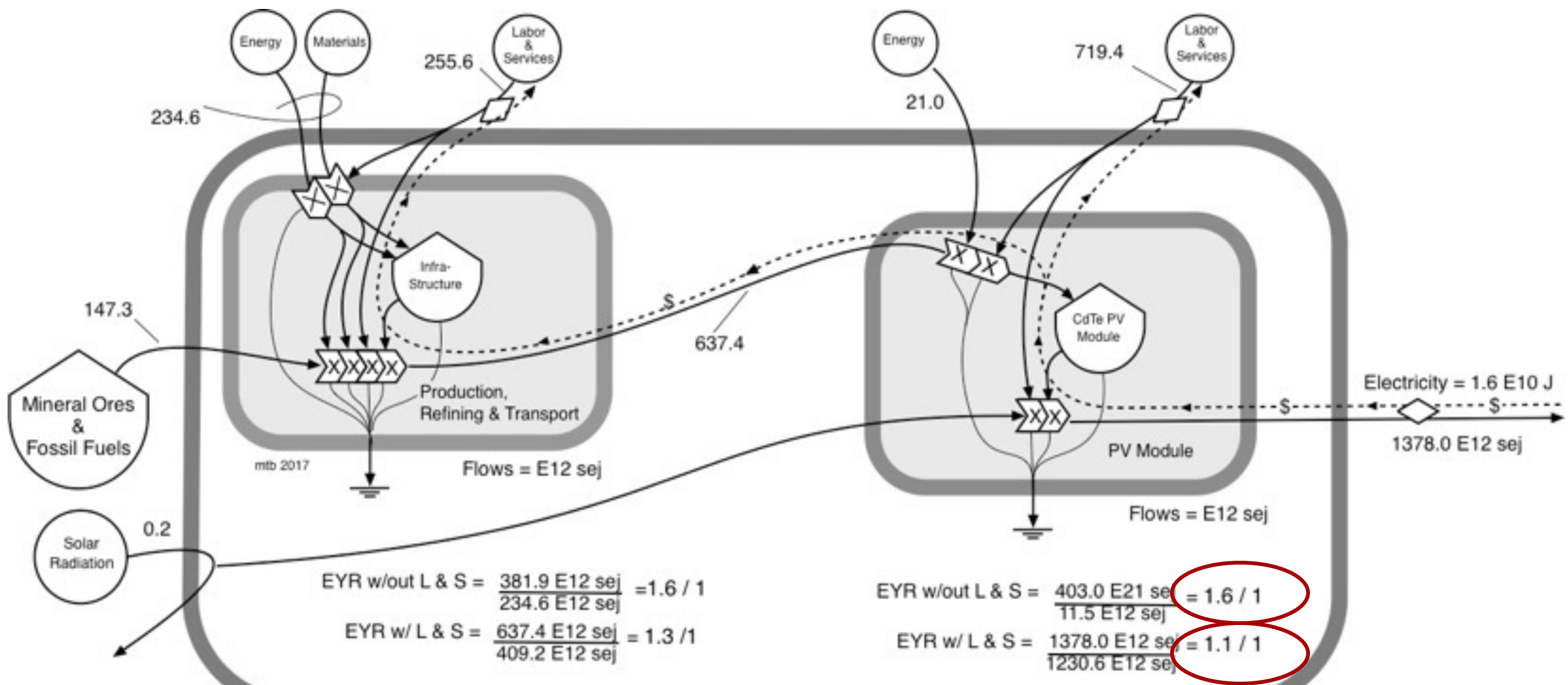
EYR w/out L & S = $\frac{121.8\ E21\ sej}{10.6\ E21\ sej}$ = 11.5 / 1

EYR w/ L & S = $\frac{133.4\ E21\ sej}{22.2\ E12\ sej}$ = 6.0 / 1

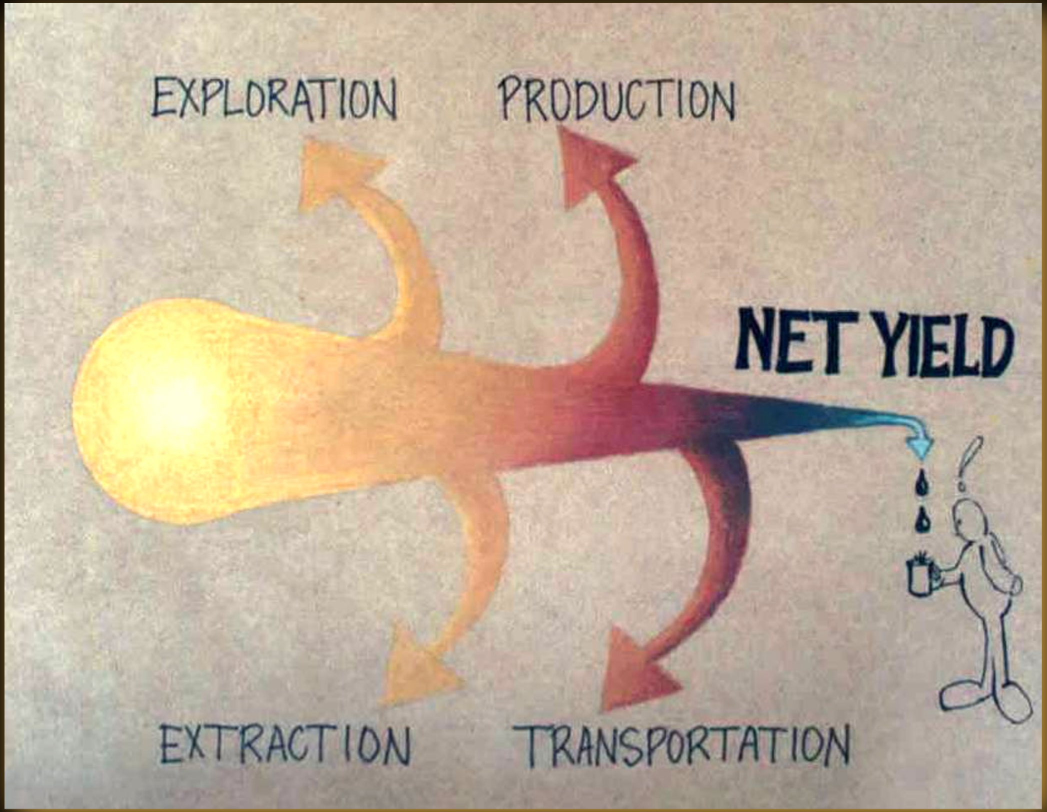
EYR w/out L & S = $\frac{132.4\ E21\ sej}{11.5\ E12\ sej}$ = 11.5 / 1

EYR w/ L & S = $\frac{145.7\ E12\ sej}{24.8\ E12\ sej}$ = 5.9 / 1

EYR of CdTe Photo Voltaic System

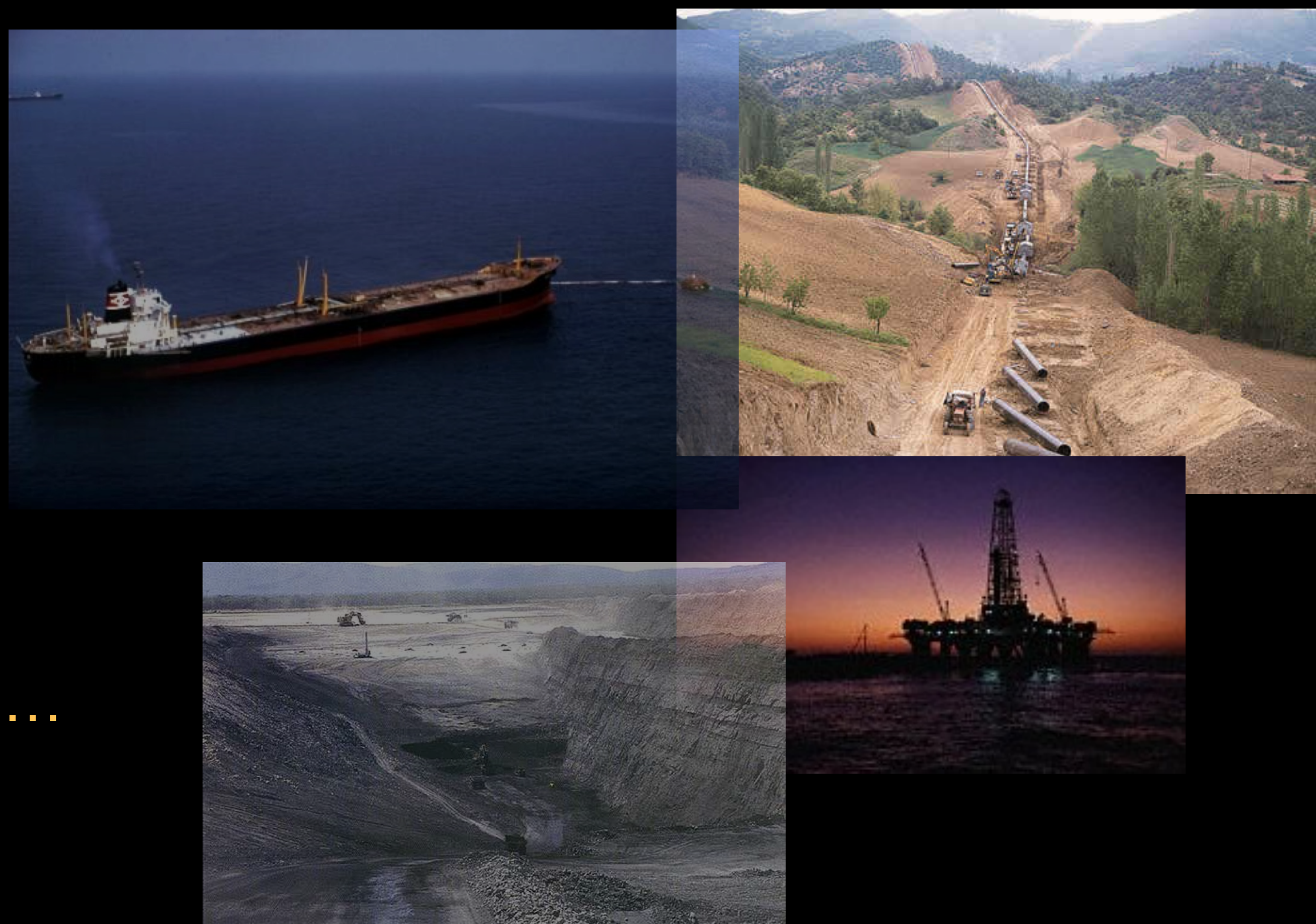


Net Emergy…



We believe that to maintain society's current level of infrastructure and information processing, a minimum net emergy of about 4/1 is required.

Net Emergy…*conventional sources*



All declining…

Net Emergy…*so called renewable sources*

Corn…

James Duncan
Mark Kalivoda
Andres G. Mirabal
Brad Walker
Christopher Zeier

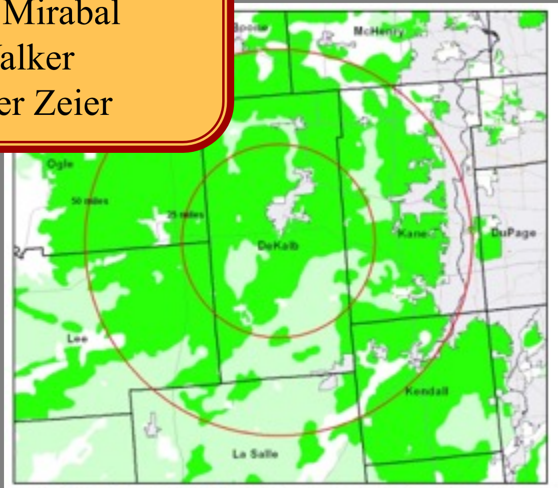
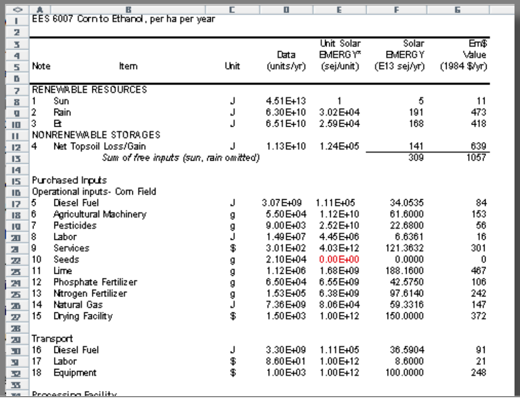


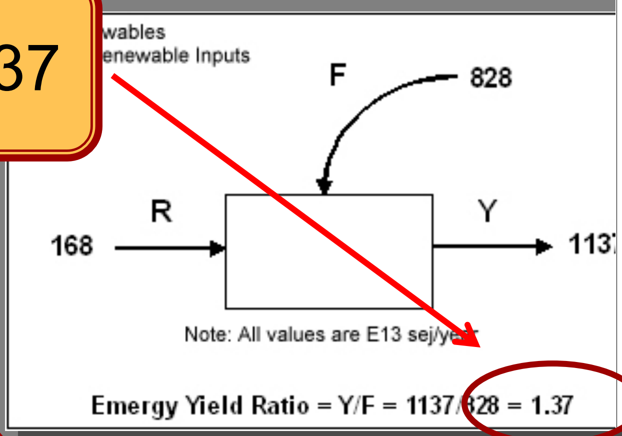
Figure 1: Map of northern Illinois showing typical area agricultural lands used for corn or soybean production. Dark and light green areas are Prime Farmland Types 1 and 2 respectively per USDA - STATSGO.

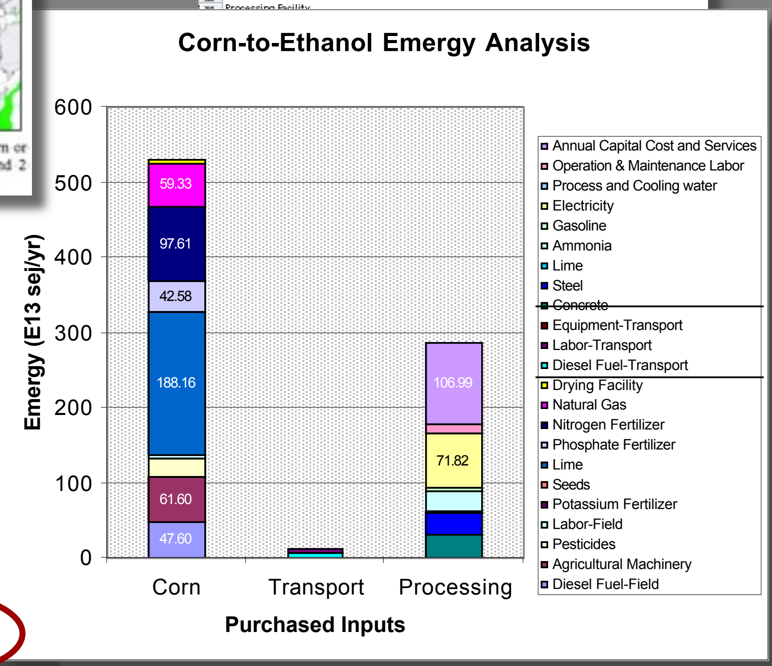


EES 6007 Corn to Ethanol, per ha per year

Note	Item	Unit	Data (units/yr)	Unit Solar EMERGY* (sej/unit)	Solar EMERGY (E13 sej/yr)	Em$ Value (1984 $/yr)
RENEWABLE RESOURCES						
1	Sun	J	4.51E+13	1	5	11
2	Rain	J	6.30E+10	3.02E+04	191	473
3	Et	J	6.51E+10	2.59E+04	168	418
NONRENEWABLE STORAGES						
4	Net Topsoil Loss/Gain	J	1.13E+10	1.24E+05	141	639
	Sum of free inputs (sun, rain omitted)				309	1057
Purchased Inputs						
Operational inputs- Corn Field						
5	Diesel Fuel	J	3.07E+09	1.11E+05	34.0535	84
6	Agricultural Machinery	g	5.50E+04	1.12E+10	61.6000	153
7	Pesticides	g	9.00E+03	2.52E+10	22.6800	56
8	Labor	J	1.49E+07	4.45E+06	6.6361	16
9	Services	$	3.01E+02	4.03E+12	121.3632	301
10	Seeds	g	2.10E+04	0.00E+00	0.0000	0
11	Lime	g	1.12E+06	1.68E+09	188.1600	467
12	Phosphate Fertilizer	g	6.50E+04	6.55E+09	42.5750	106
13	Nitrogen Fertilizer	g	1.53E+05	6.38E+09	97.6140	242
14	Natural Gas	J	7.36E+09	8.06E+04	59.3316	147
15	Drying Facility	$	1.50E+03	1.00E+12	150.0000	372
Transport						
16	Diesel Fuel	J	3.30E+09	1.11E+05	36.5904	91
17	Labor	$	8.60E+01	1.00E+12	8.6000	21
18	Equipment	$	1.00E+03	1.00E+12	100.0000	248

EYR = 1.37





BioDiesel…

Sean King
Thiago Romanelli
Rogerio Amoeda
Tom Sentner
Ryan Brady
Tyler Nesbit

…uation for soybean production.

Note	Item	Units	Data	Emergy/Unit	Emergy (E12 sej/yr)
	…nspiration	J	1.17E+10	3.06E+04	357.10
	…soil loss	J	3.60E+10	1.24E+05	4464.00
3	Irrigation water	J	9.39E+09	6.89E+04	646.70
4	Nitrogen	g	1.11E+04	6.80E+10	755.24
5	Phosphorus	g	3.48E+04	6.22E+10	2164.56
6	Potash	g	5.93E+04	3.11E+09	184.42
7	Fossil Fuels	J	1.16E+09	1.11E+05	128.76
8	Herbicides	g	4.56E+03	2.49E+10	113.54
9	Seeds	g	7.04E+04	5.35E+09	376.64
10	Machinery	g	2.00E+04	1.13E+10	226.00
11	Electricity	J	4.09E+07	2.92E+05	11.94
12	Labor	J	9.29E+06	7.48E+06	69.49
Agriculture Outputs					
13	Soybeans	g	2.31E+06	4.11E+09	9498.40

Table 3 – Emergy evaluation of crude soybean oil extraction process.

Note	Item	Units	Data	Emergy/Unit	Emergy (E12 sej/yr)
Crushing Inputs					
17	Soybeans	g	2.31E+06	4.23E+09	9760.84
18	Electricity	J	6.69E+08	2.92E+05	195.35
19	Fossil Fuels	J	2.97E+09	1.11E+05	329.67
20	Steam	J	2.46E+09	4.57E+04	112.42
21	Hexane	g	5.39E+03	5.70E+09	30.72
22	Labor	J	2.31E+05	7.48E+06	1.73
23	Machinery	g	4.41E+04	1.13E+10	498.33
24	Water	J	4.32E+04	3.06E+04	0.00
Crushing Outputs					
25	Crude soybean oil	g	3.92E+05	2.79E+10	10929.06

…biod…

Note	Item	Un…	Data	Emergy/Unit	Emergy (E12 sej/yr)
		g			
		J			
		J			
		J			
	Labor	J			
34	Sodium hydroxide	g	9.07E+03	5.70E+09	51.70
				5.70E+09	51.81
				5.70E+09	162.45
				5.70E+09	192.66
				1.13E+10	47.01
				1.13E+10	89.72
				7.94E+09	168.33
Processing Outputs					
41	Biodiesel oil	g	3.78E+05	3.17E+10	11992.12
42	Crude glycerin	g	8.04E+04	1.49E+11	11992.12

Table 2 – Emergy evaluation for transported soybeans.

Note	Item	Units	Data	Emergy/Unit	Emergy (E12 sej/yr)
Bean Transport Inputs					
14	Soybeans	g	2.31E+06	4.11E+09	9498.40
15	Truck transport 1	mton-mile	1.62E+02	1.62E+12	262.44
Bean Transport Outputs					
16	Soybeans	g	2.31E+06	4.23E+09	9760.84

Table 4 – Emergy evaluation for transported crude soybean oil.

Note	Item	Units	Data	Emergy/Unit	Emergy (E12 sej/yr)
Oil Transport Inputs					
26	Crude soybean oil	g			10929.06
27	Truck tran…				262.44
Oil Transport Ou…					
28					

…on system

	Value	Unit
…uts (R+N) =	4821.10	E12 sej/ha/yr
…inputs (F) =	7171.02	E12 sej/ha/yr
…put emergy (Y) =	11992.12	E12 sej/ha/yr
…stment ratio (F/(R+N)) =	1.49	
…nvironmental loading ratio ((F+N)/R) =	32.58	
Emergy sustainability index ((Y/F)/(F+N)/R) =	0.05	
Net yield (Y/F) =	**1.67**	

EYR = 1.67/1

Biomass to Electricity…

E. Campbell,
J. Fleischman,
M. Maascione,
B. Becker,
K. Smith

Table 2: Summary table of emergy accounting for hypothetical co-firing and biomass-fired power plants in North Central Florida. For complete table see appendix 1, table 5.

	Renewable Emergy	Invest. Emergy	Transformity	Yield Ratio
Co-fired Plant (30 MW from biomass)				
Wood Production Stage	9.3E+19	7.74E+19	2.27E+04	7.30
Chipping/Transportation	0	4.38E+19	3.20E+04	2.59
Power Plant	0	1.99E+19	1.81E+05	2.19
Biomass Plant (220 MW from biomass)				
Wood Production Stage	5.46E+20	4.54E+20	2.27E+04	7.30
Chipping/Transportation	0	5.54E+20	4.27E+04	1.85
Power Plant	0	1.99E+19	1.74E+05	1.83

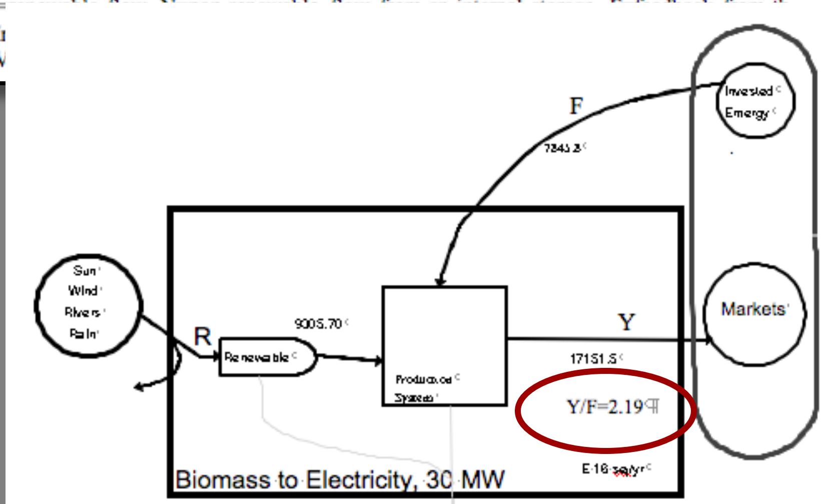
Table 3: Emergy indices[a] for three combustion electricity pl

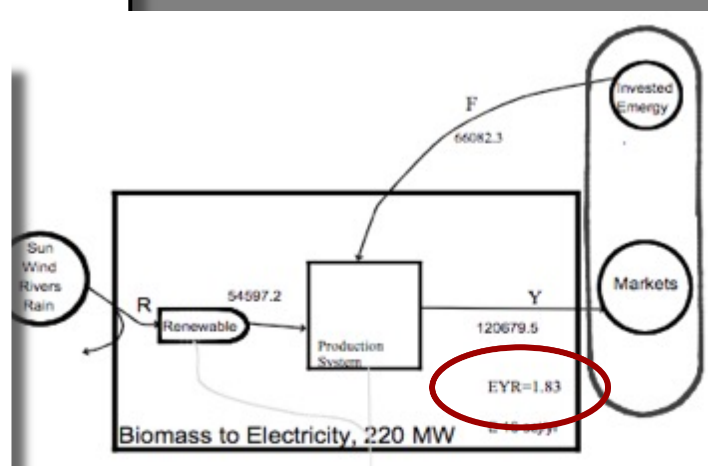
Plant Type:	% renew R/(R+N+F)	NRR (N+F)/R	EYR Y/F	(F+N)/R	EYR/ELR
30 MW Biomass	0.54	0.84	2.19	0.84	2.59
220 MW Biomass	0.45	1.21	1.83	1.21	1.51
1280 MW Coal[b]	0.09	10.36	5.46	10.36	0.53

R=

[a] I

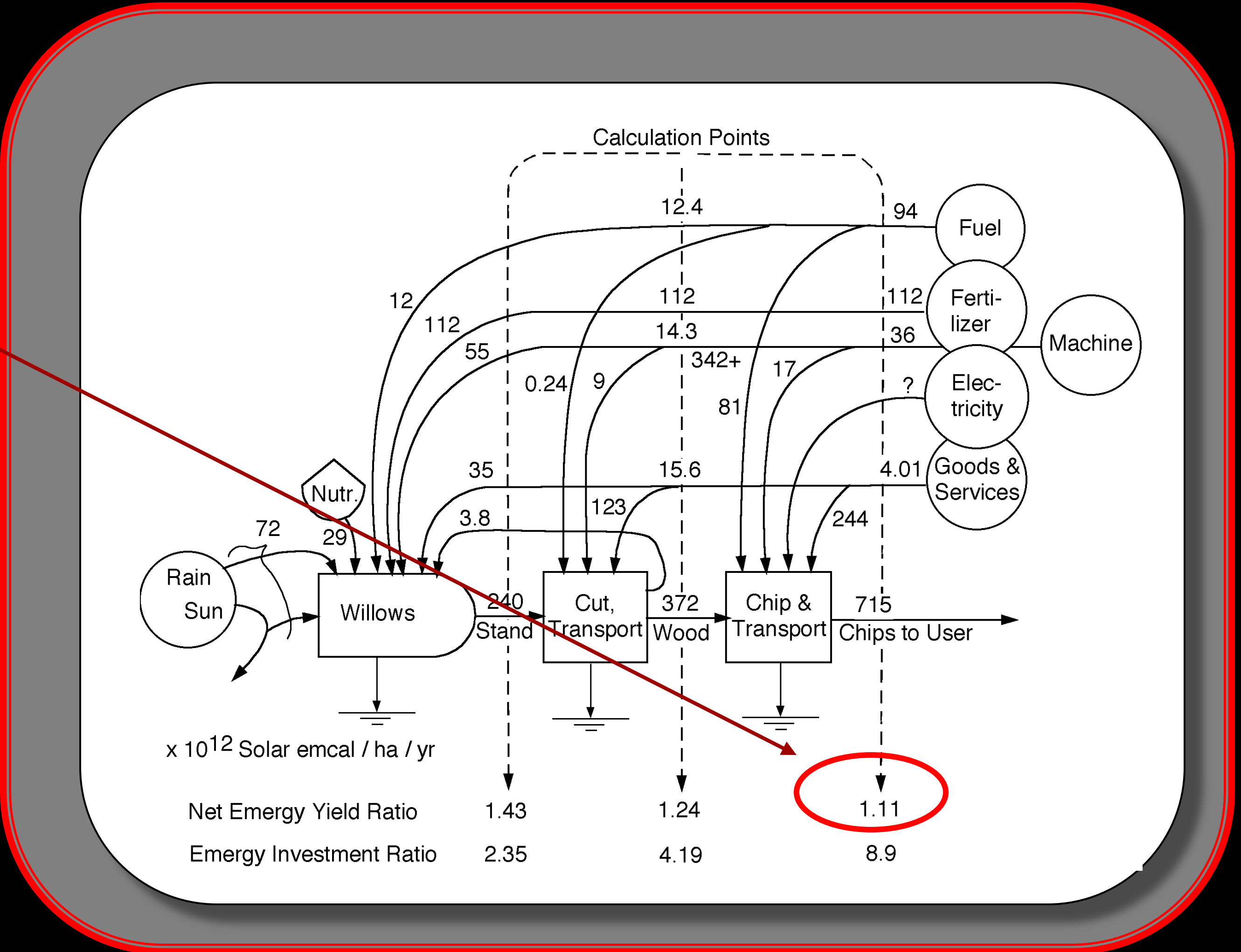
[b] V





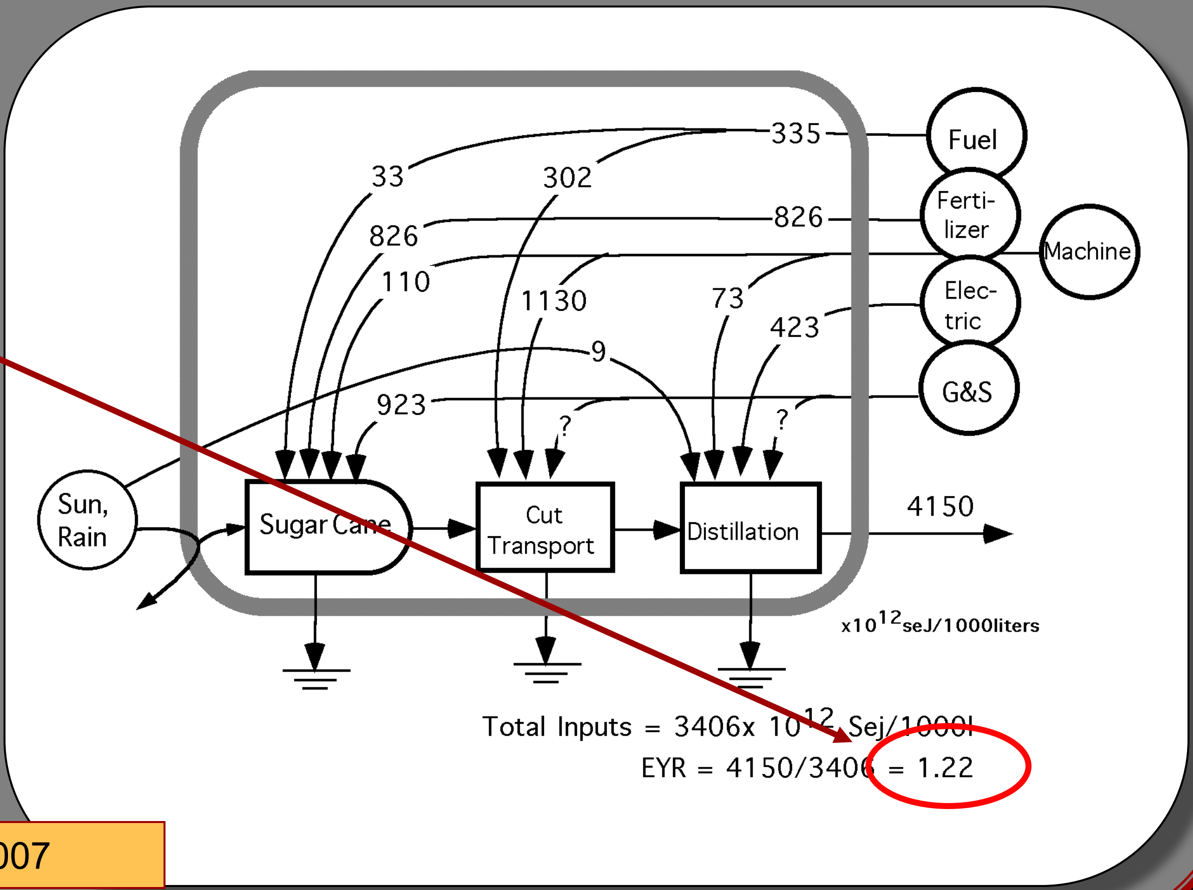
Net Emergy…

Emergy Yield Ratio of willow biomass is barely 1/1



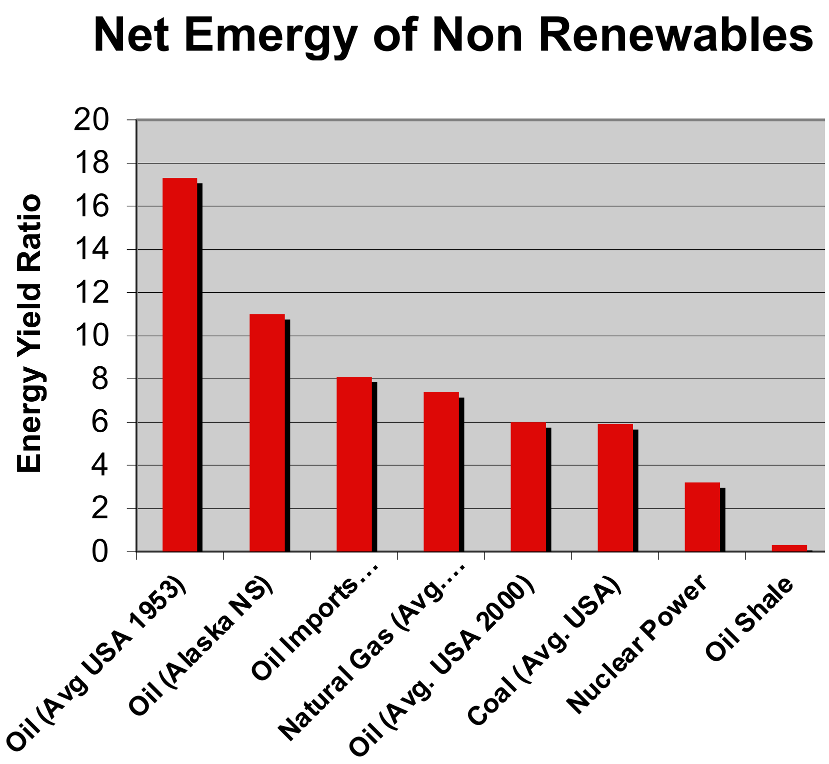
Net Emergy…

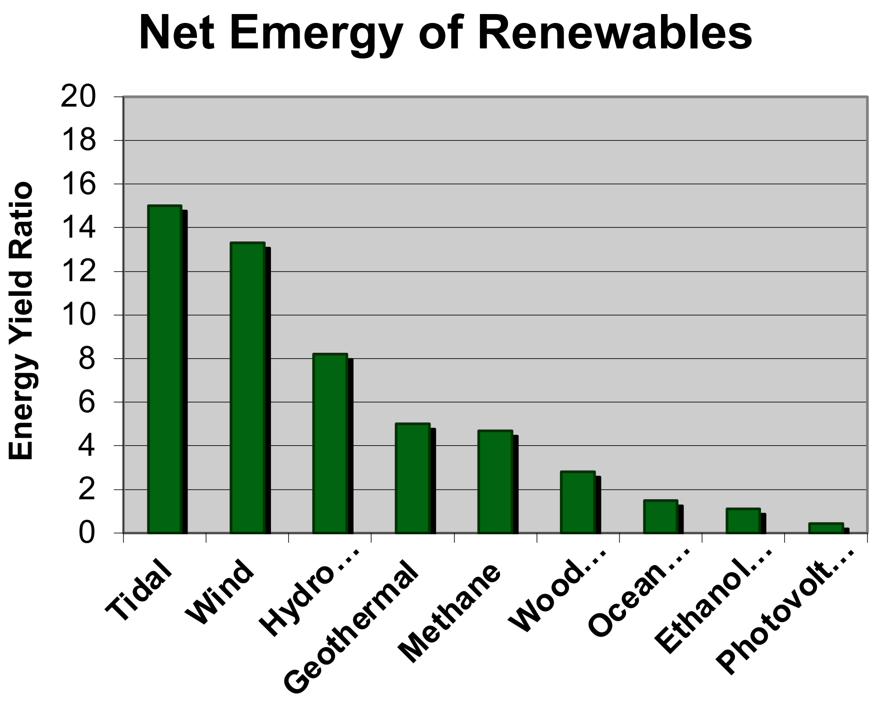
Emergy Yield Ratio of Sugarcane to Ethanol



Data from Pimentel & Patzek 2007

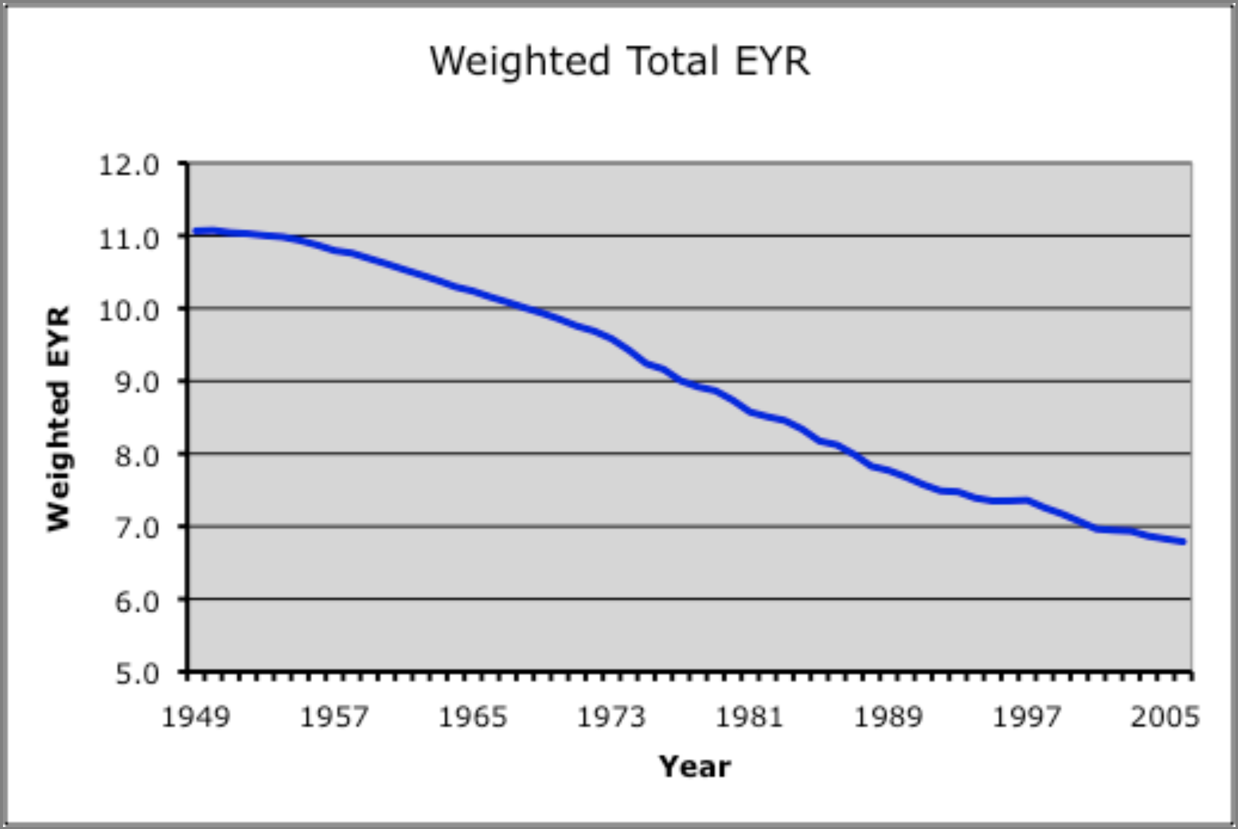
Net Emergy…


Net Emergy of Non Renewables
Energy Yield Ratio
20
18
16
14
12
10
8
6
4
2
0
Oil (Avg USA 1953)
Oil (Alaska NS)
Oil Imports…
Natural Gas (Avg.…
Oil (Avg. USA 2000)
Coal (Avg. USA)
Nuclear Power
Oil Shale

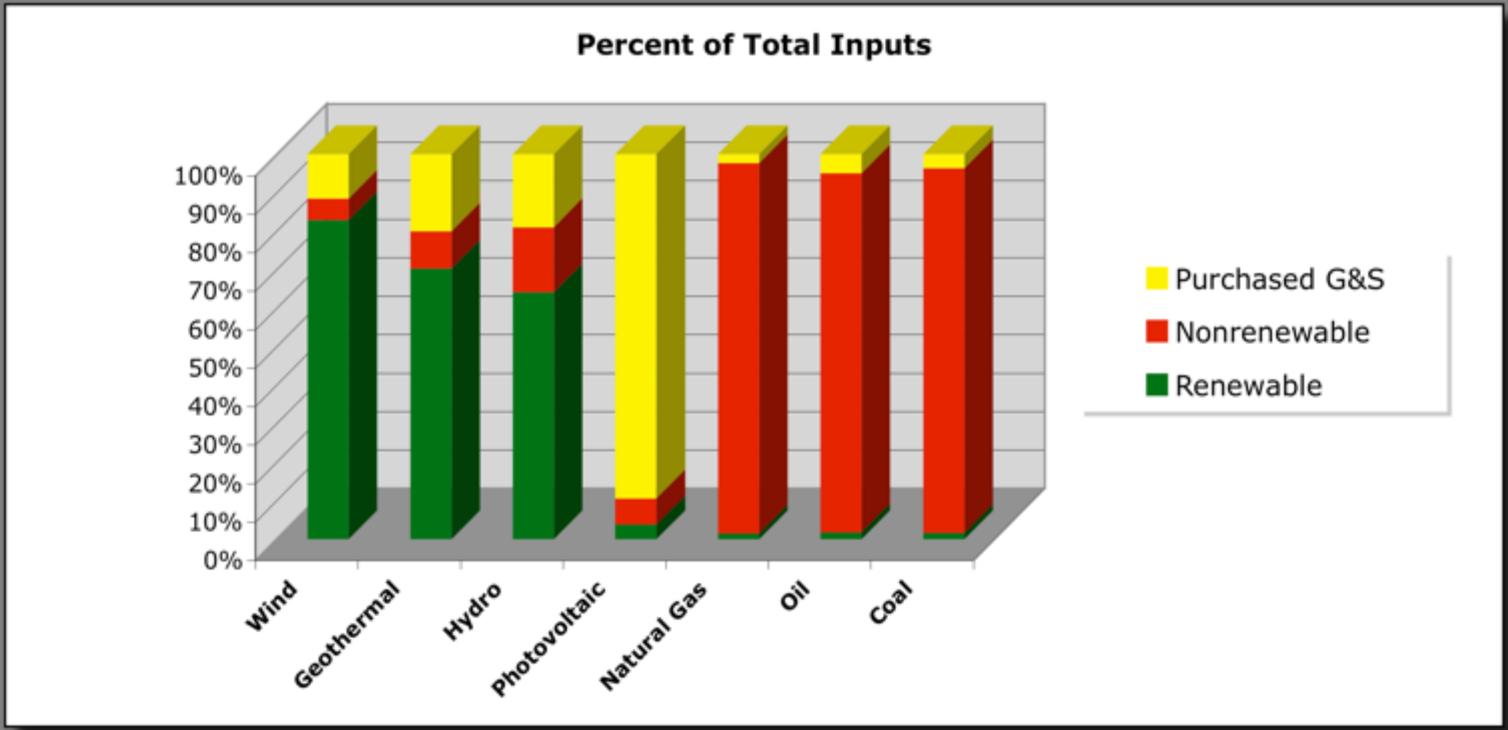

Net Emergy of Renewables
Energy Yield Ratio
20
18
16
14
12
10
8
6
4
2
0
Tidal
Wind
Hydro…
Geothermal
Methane
Wood…
Ocean…
Ethanol…
Photovolt…

Decreasing Emergy Yield Ratio of energy resources (USA)

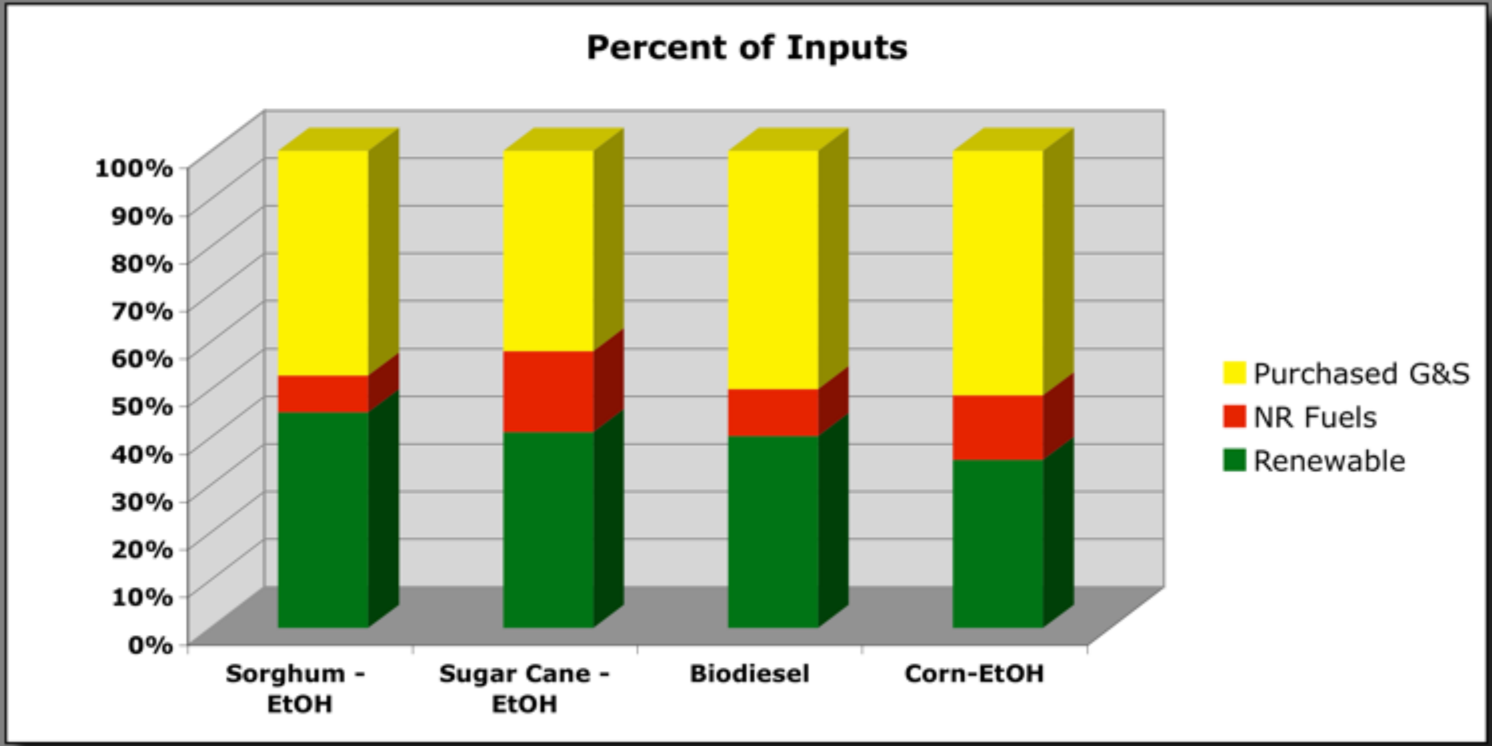
…EYR of both renewable and non-renewable sources



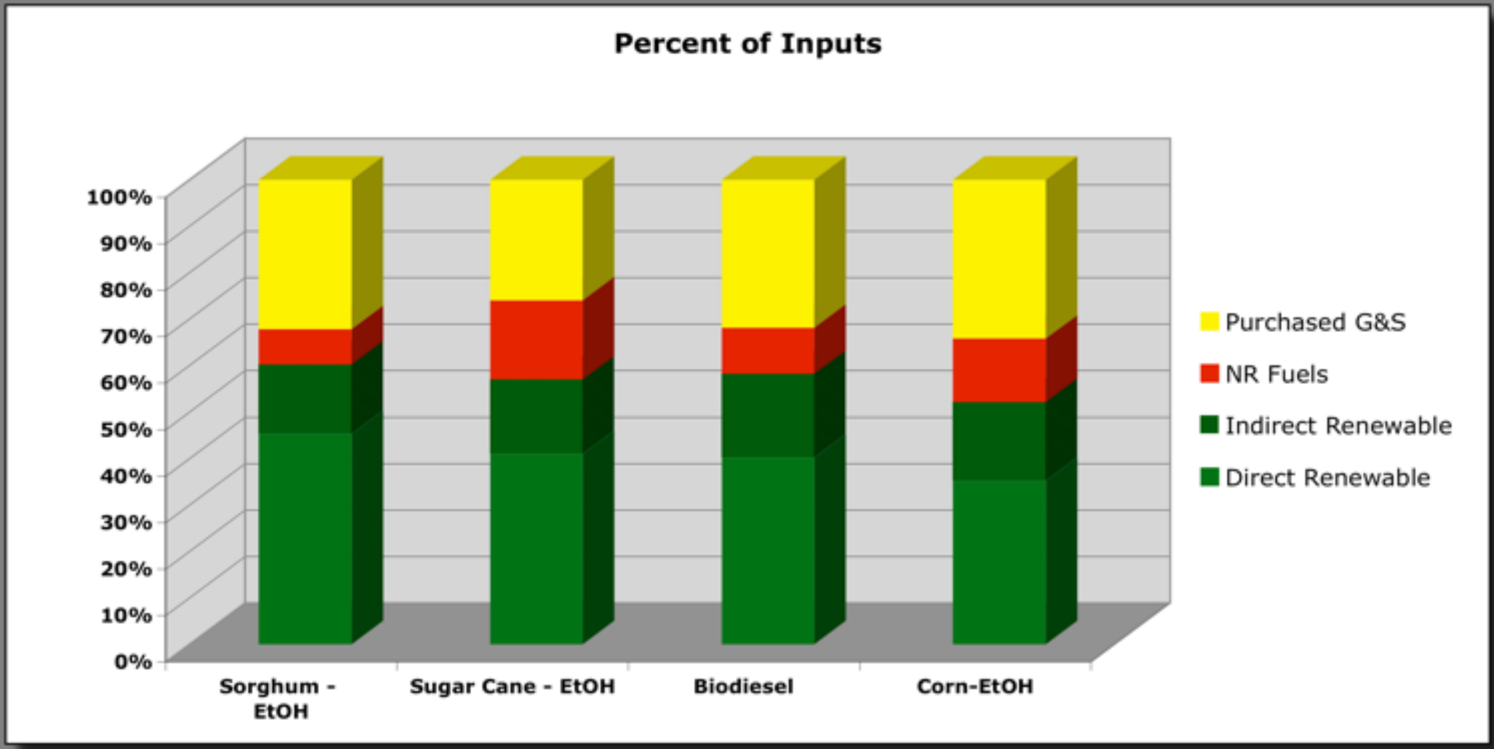
Environmental contributions to electric generation systems



Direct environmental contributions to Bioenergy systems



Direct & Indirect environmental contributions to Bioenergy systems



Net Emergy…

An important fact of life….

As the Net Emergy declines, the amount of energy used to accomplish the same amount of end use (eg miles driven) increases…

At 5/1 compared to 10/1

You can drive half as far for the same emergy investment

Feasibility of Large-Scale Biofuel Production

Does an enlargement of scale change the picture?

Mario Giampietro, Sergio Ulgiati, and David Pimentel

Biofuels are widely seen as a feasible alternative to oil. Indeed, in 1995 the Clinton Administration proposed amendments to the Clean Air Act that would require gasoline sold in the nine most polluted US cities to contain additives from renewable sources, such as grain alcohol. This move, even if blocked by a three-judge panel of the US Court of Appeals in Washington, DC (Southerland 1995), has helped to focus attention on the question of whether research and development in biofuel production from agricul-

Large-scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it

for fossil fuels. Common examples are ethanol, methanol, and biodiesel. Ethanol alcohol can be obtained by yeast- or bacteria-mediated fermentation of sugar crops, such as sugarcane, sugarbeet, and sweet sorghum, or of starchy crops, such as corn and cassava. It can also be obtained, albeit at lower yields, from cellulose, a sugar polymer from woody crops, through acid or enzymatic hydrolysis followed by fermentation. Methanol can be obtained from wood or woody crops by means of a wood gasification process followed by com-

Giampietro, et.al 2003 …

Table 1. Typical biofuel production systems from agricultural crops.

Indicators of performance	Biodiesel[a]	Ethanol in temperate areas	Ethanol in (sub)tropical areas
Gross energy yield (GJ · ha^{-1} · yr^{-1})	20–40	40–80	80[b]–130[c]
Net energy yield (GJ · ha^{-1} · yr^{-1})	<0–10	<0–30	50[b]–70[c]
Output–input energy ratio	0.6–1.3	0.5–1.7	3.0[b]–2.5[c]
Net to gross ratio (F*/F1)	<0–0.2	<0–0.4	0.66[b]–0.60[c]
Water requirement (t · ha^{-1} · yr^{-1})	4000–7000	4000–8000	10,000[b]–15,000[c]
Energy throughput (net MJ/h)	<0–250	<0–1000	250[b]–1600[c]
Best-performing system	oilseed rape	corn–sorghum	sugarcane
Land requirement (ha/net GJ)	0.100	0.033	0.020[b]–0.014[c]
Water requirement (t/net GJ)	500	170	200[b]–200[c]
Labor requirement (h/net GJ)	4	1	4[b]–0.6[c]

[a]Trans-methylester from oil seeds (sunflower, rapeseed, or soybeans). Sunflower and soybean systems have net energies close to or less than zero.
[b]Low-input production, as in the Brazilian ProAlcohol Project (Giampietro et al. 1997a).
[c]High-input production, as reported in Pimentel et al. (1988).

Giampietro, et.al 2003 …

Water…

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Water…

Using the numbers in the previous table…

- FL Transportation energy = 9.5 E17 J/yr
- FL water consumption = 11.3 E 12 l/yr
- Water required for ethanol from sugarcane = 200t/net GJ = 2 E5 l/1 E9 J

$$\frac{9.5\ E\ 17\ J/yr}{1.0\ E9\ J/ha} * 2E5\ l = $$ **1.9 E 14 liters of water**

This is almost 17 times current total water consumption in the State!!!

Water…

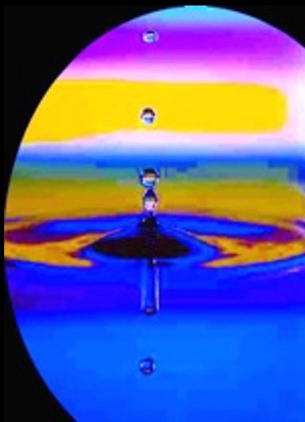
Lower estimate…(process water only)

Using current estimates of water requirements for ethanol from sugarcane…

- FL Transportation energy = 9.5 E17 J/yr
- FL water consumption = 11.3 E 12 l/yr
- Water required for ethanol from sugarcane = 30t/net GJ = 3 E4 l/1 E9 J

$$\frac{9.5\text{ E }17\text{ J/yr}}{1.0\text{ E9 J/ha}} * 3\text{E4 l} = \textbf{2.9 E 13 liters of water}$$

…almost 2.5 times current total water consumption in Florida!!



Land…

Renewable Ethanol…? LAND

Using current Florida sugarcane production per hectare (70 GJ/ha)

FL gasoline consumption = 9.49 E 17 J/yr

$$\frac{9.49 \text{ E } 17 \text{ J/yr}}{70 \text{ E}9 \text{ J/ha}} = 1.35 \text{ E } 7 \text{ ha of land}$$

Florida LAND Area = 1.4 E7 ha

Questions ?

Comments ?

Concerns?