1st South East European Conference on Sustainable Development of Energy, Water and Environment Systems

System Approach to Sustainable Biofuel Production

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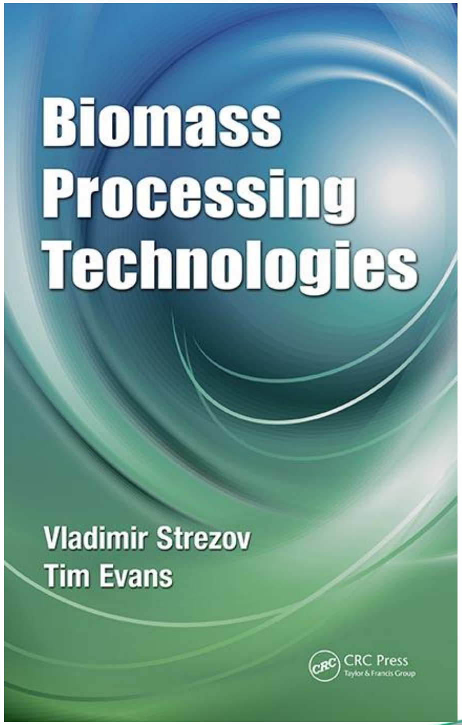
MACQUARIE UNIVERSITY FACULTY OF SCIENCE

Outline

- Energy and sustainability
- Biomass properties
- Biomass processing technologies
- Production of biofuels
- System engineering of biomass applications

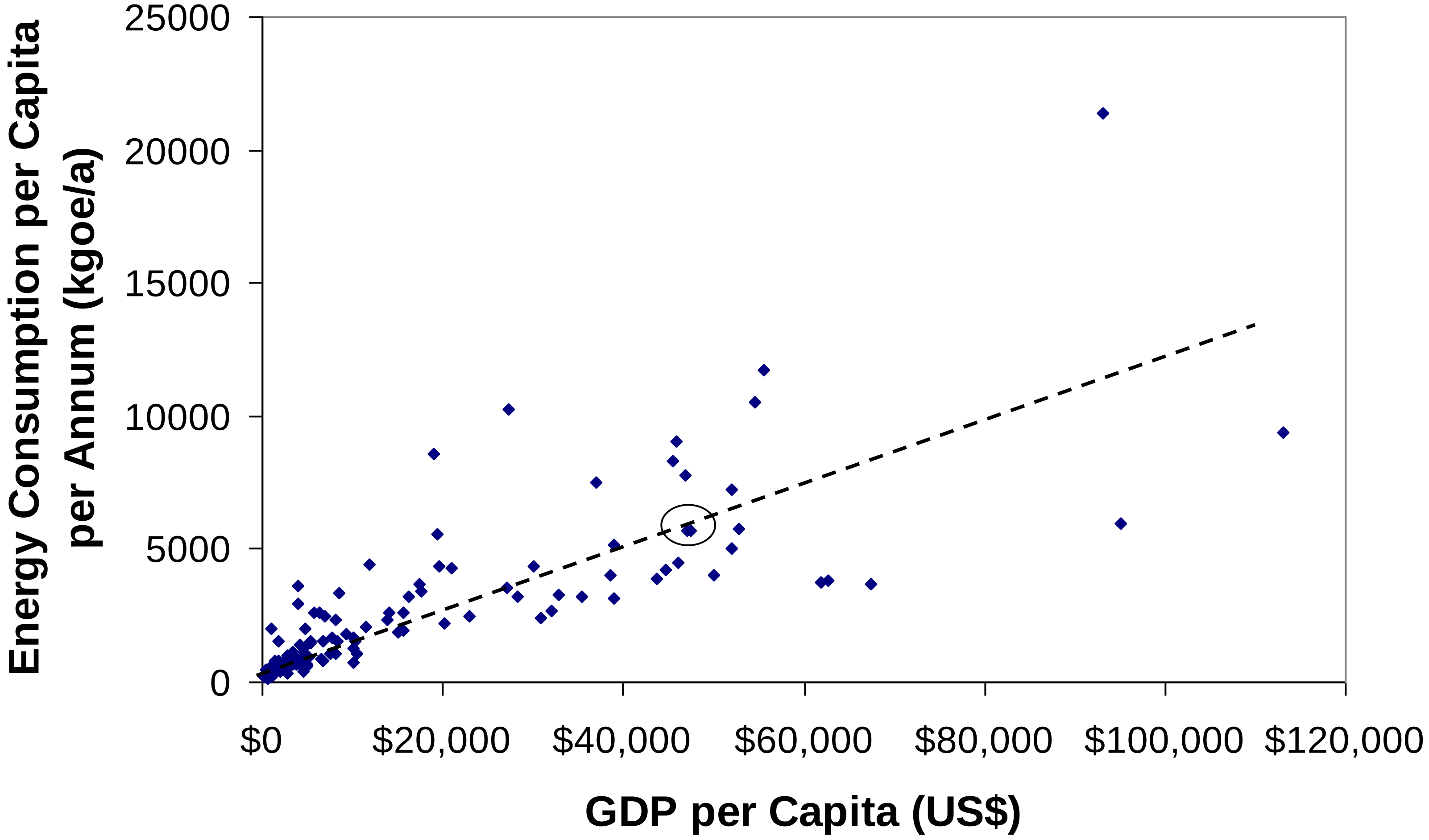


Biomass Processing Technologies

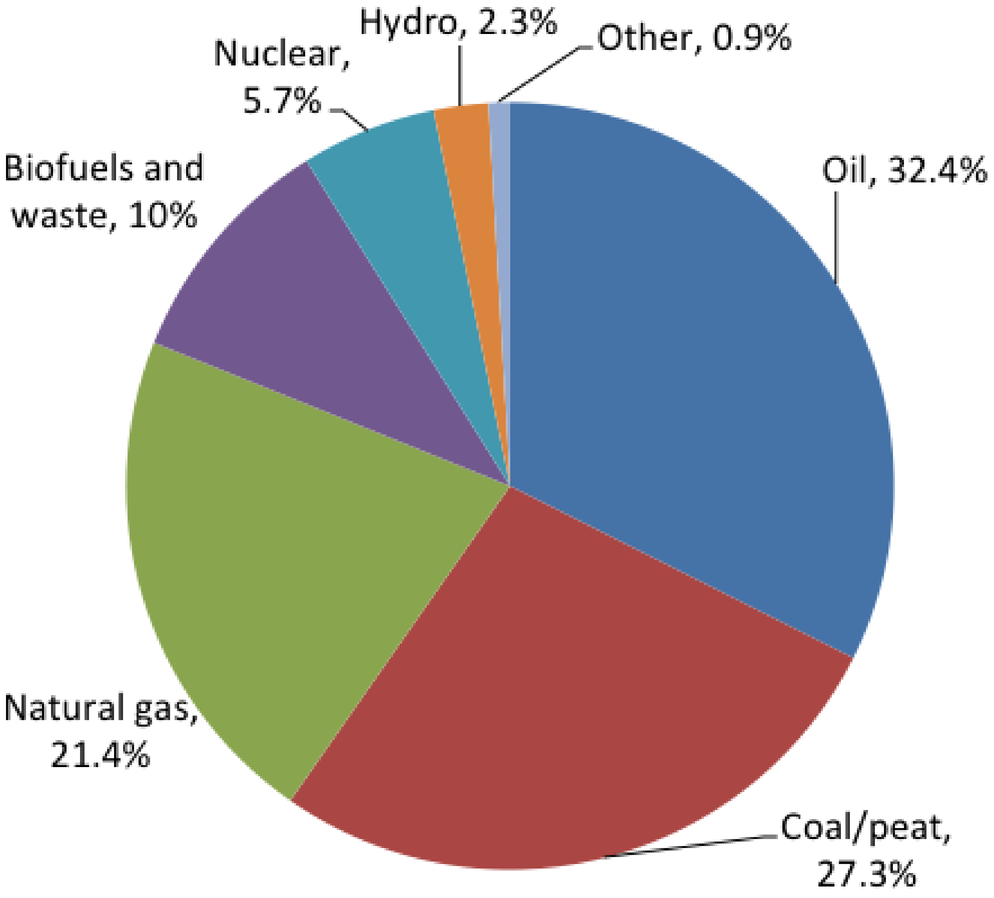
Vladimir Strezov
Tim Evans

CRC Press
Taylor & Francis Group

Energy Use and Economy



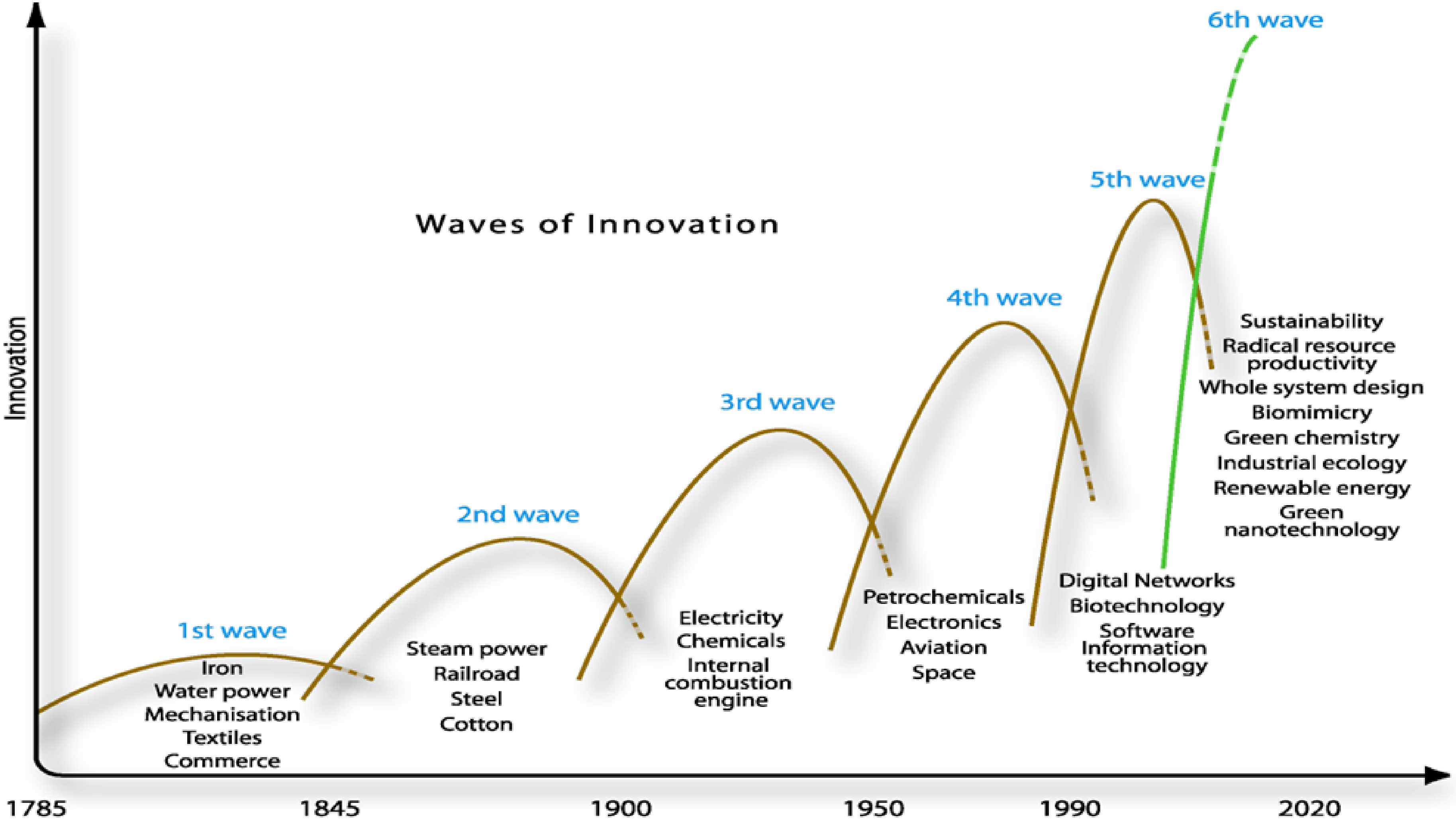
Total world primary energy production



Source: IEA, International Energy Agency, Biofuels and Waste, 2013

Innovation is the central issue in economic prosperity.

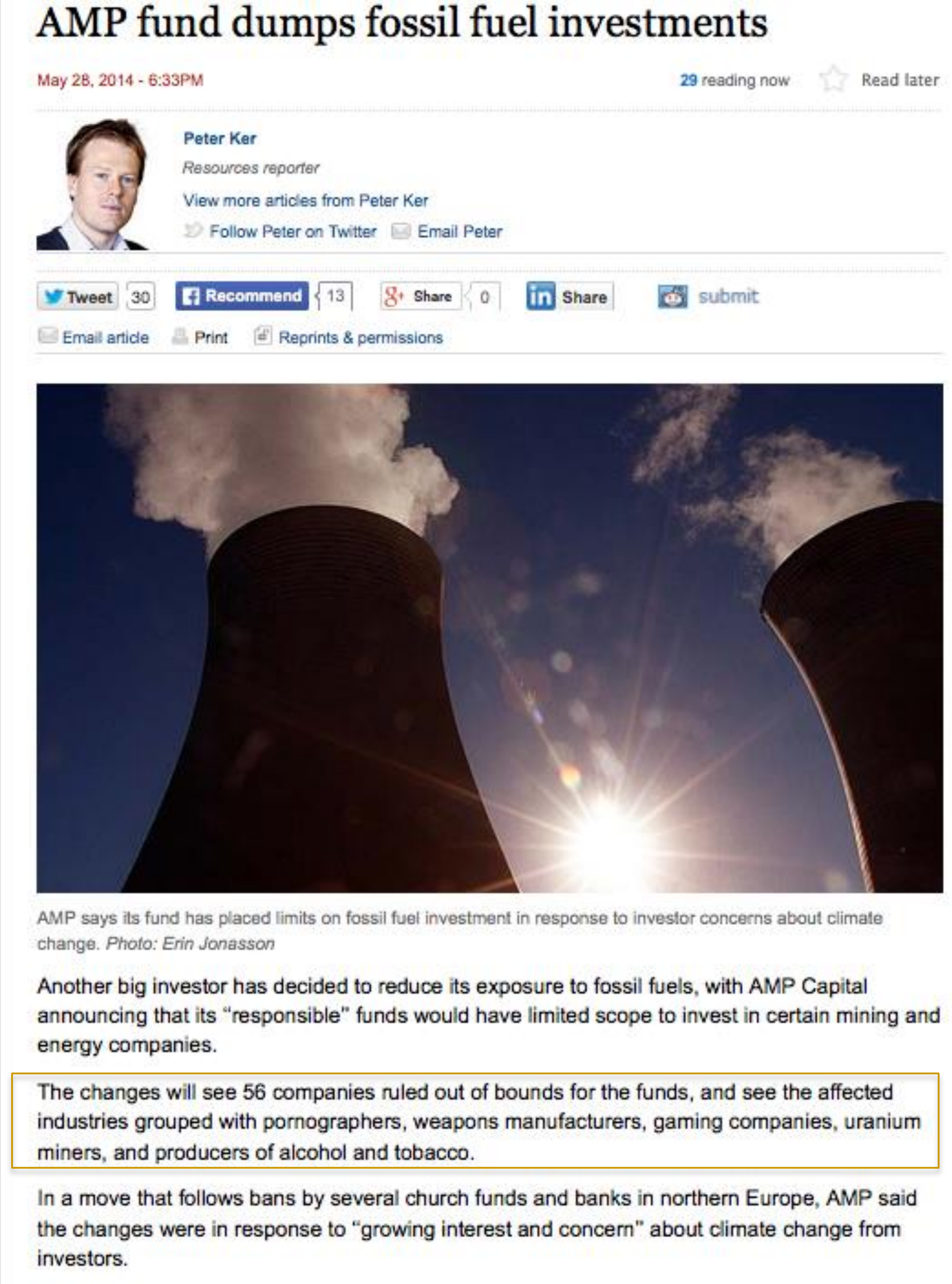
Michael Porter, Harvard Business School



Source: The Natural Edge Project

The Natural Advantage of Nations (Vol.I): Business Opportunities, Innovation and Governance in the 21st Century

http://www.naturaledgeproject.net/



AMP fund dumps fossil fuel investments

May 28, 2014 - 6:33PM

Peter Ker

Resources reporter

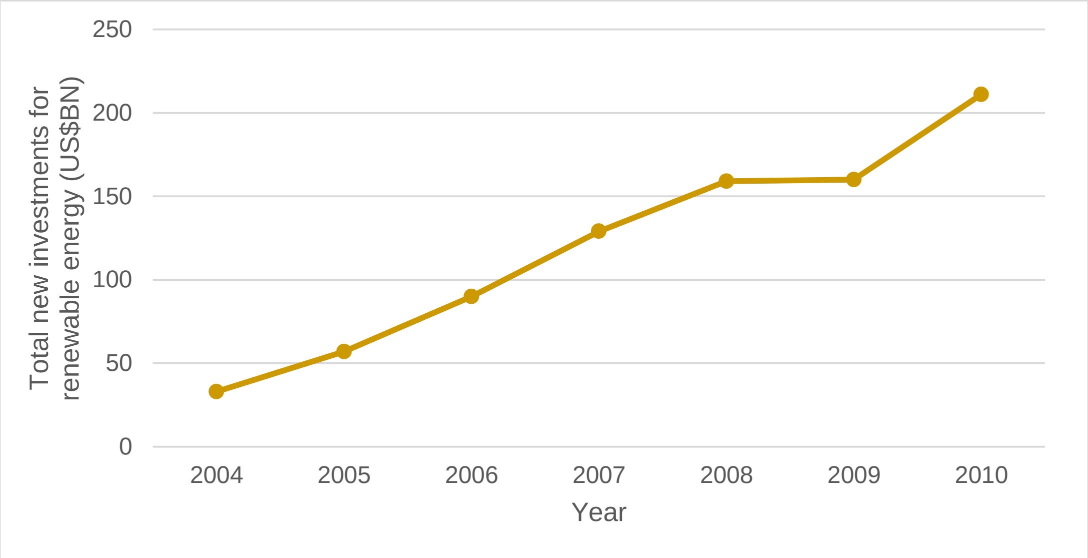
AMP says its fund has placed limits on fossil fuel investment in response to investor concerns about climate change. *Photo: Erin Jonasson*

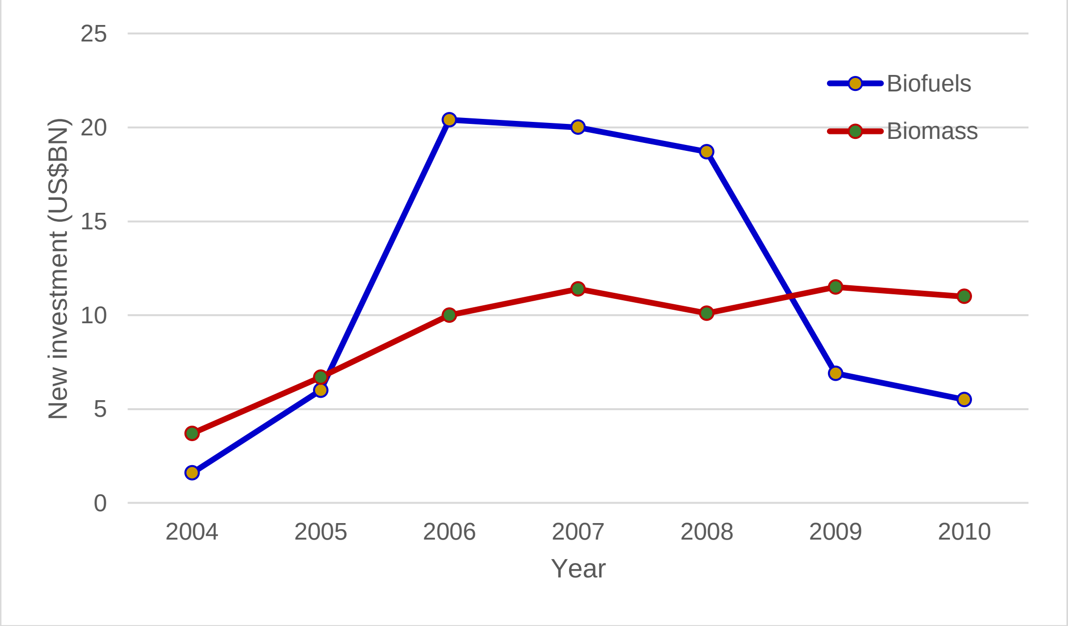
Another big investor has decided to reduce its exposure to fossil fuels, with AMP Capital announcing that its "responsible" funds would have limited scope to invest in certain mining and energy companies.

The changes will see 56 companies ruled out of bounds for the funds, and see the affected industries grouped with pornographers, weapons manufacturers, gaming companies, uranium miners, and producers of alcohol and tobacco.

In a move that follows bans by several church funds and banks in northern Europe, AMP said the changes were in response to "growing interest and concern" about climate change from investors.

Investments in renewable and biomass energy





Source: *McCrone, et al., 2011*

Definition of biomass

- any renewable material sourced from a biological origin and includes anthropogenic-modified material including products, by-products, residues and waste from agriculture, industry and the municipality

$CO_2 + H_2O + hv \rightarrow \{CH_2O\} + O_2$

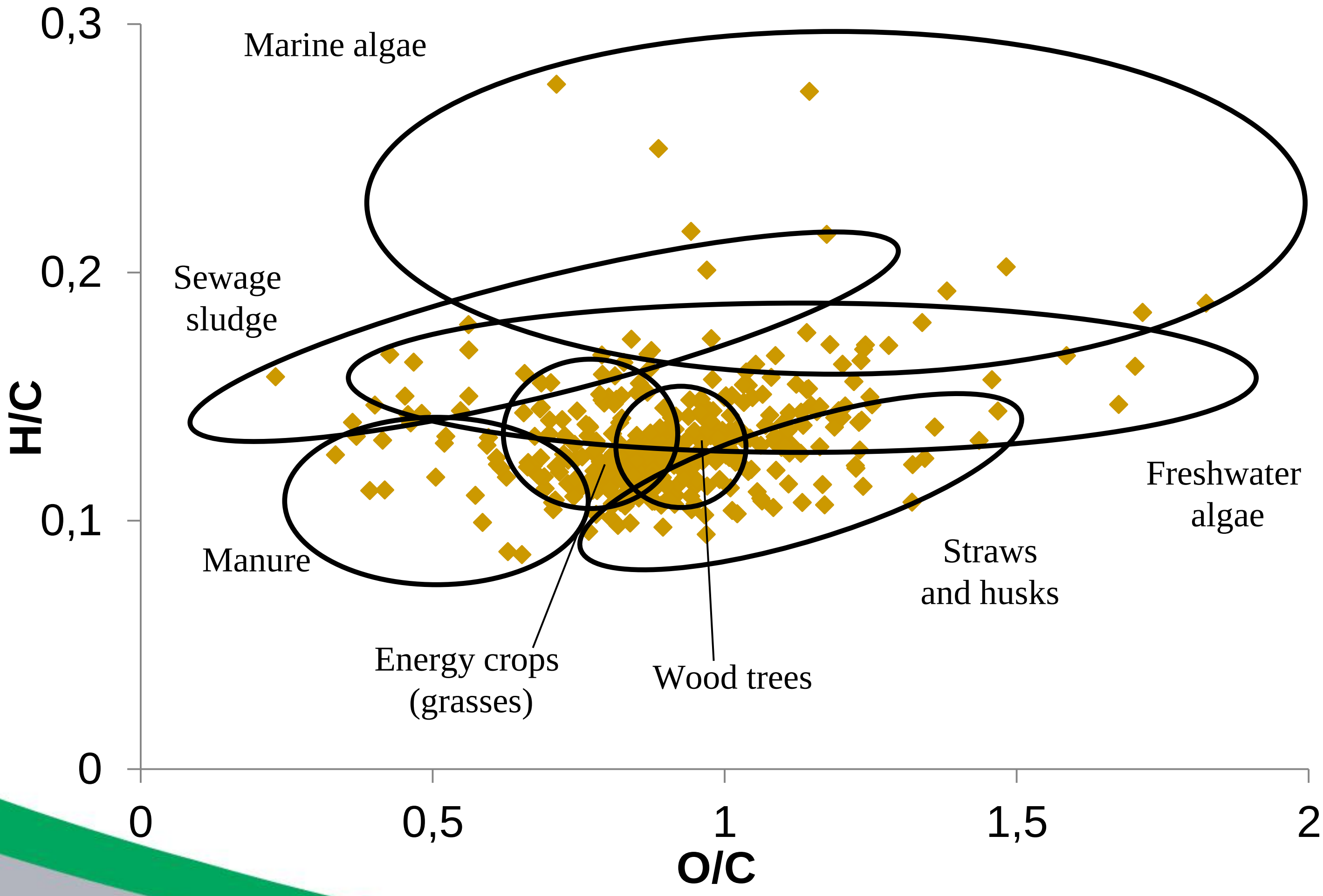
Where *hv* is the energy from the sun and

$\{CH_2O\}$ is the organic plant material with the basic form accepted to be that of glucose $C_6H_{12}O_6$

Source: McKendry, *Bioresource Technology*, 83, 37-46, 2002

Biological origin	Plants	Terrestrial	Wood	Roots		
				Trunk		
				Leaves		
			Non-wood	Herbaceous plants		
				Grasses		
			Fruit	Soft fruit		
				Seeds		
				Hard shells		
		Aquatic	Freshwater algae			
			Saltwater	Microalgae		
				Macroalgae		
	Animals	Tallow				
		Manure				
	Human	Sewage				
Biomass production route	Accidental (wastes and residues)	Weeds				
		Agricultural wastes				
		Forest wastes				
		Industrial and commercial wastes				
	Deliberately cultivated (energy crops)	Cultivation conditions	Soil	Biomass cultivated on agricultural soils		
				Biomass cultivated on marginal soils and degraded land		
			Water	Freshwater	Natural (creeks, rivers, lakes, sea, ocean)	Photobi reactor
				Saltwater		
		Edible properties	Edible (food crops)			
			Non-edible			
	Natural biomass	Biomass replanted after harvesting	Short regrowth rates			
			Long regrowth rates			
		Biomass not replaced after harvesting	Biomass regenerated naturally			
			Biomass regeneration suppressed by other plants and weeds			

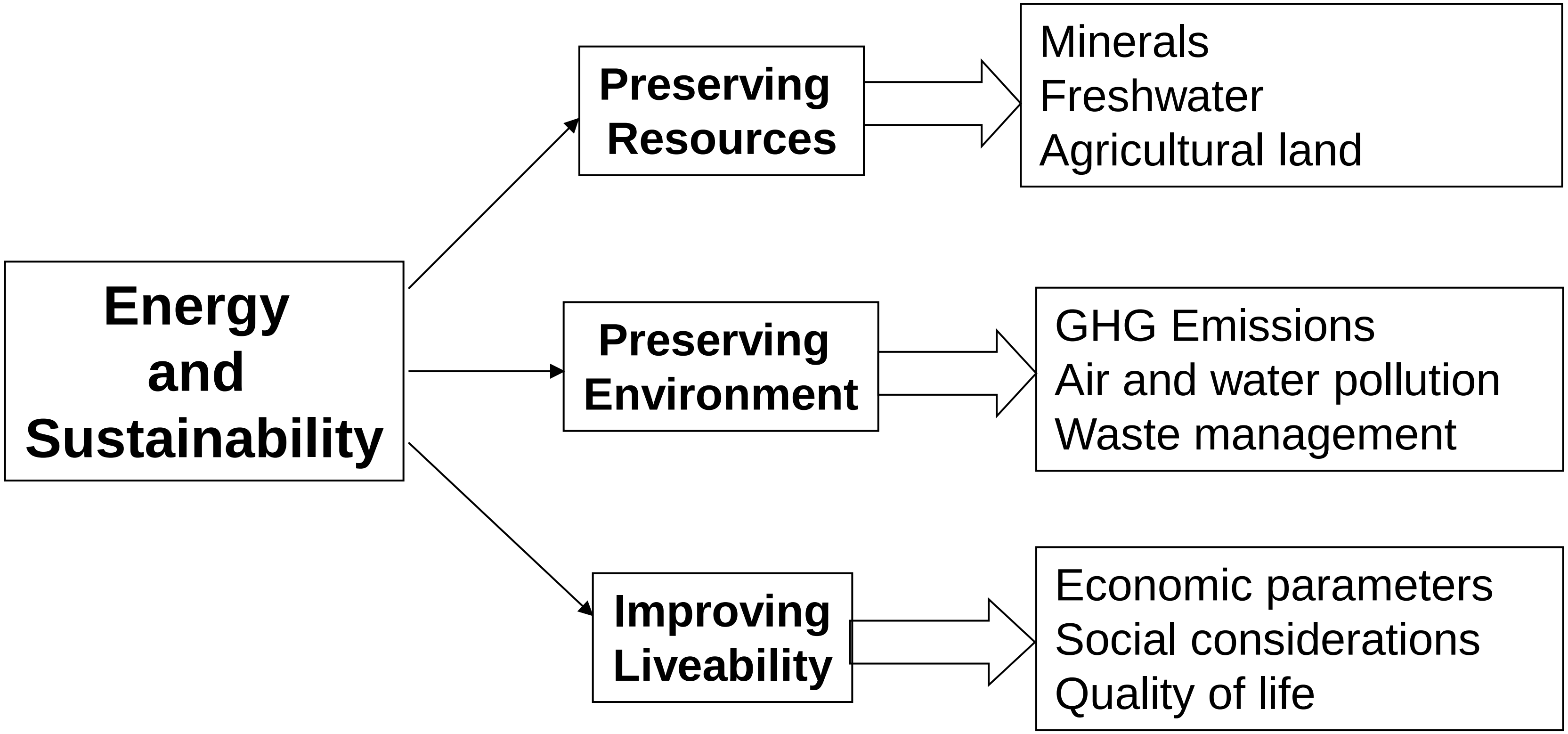
H:C to O:C diagram



Biomass fuel quality

- Lipid to carbohydrate ratio (L/C)
  - L/C >0.5 suitable for biodiesel production
  - African oil palm L/C = 4.7
- Carbohydrate to fibre ratio (C/F)
  - C/F>5 indicates suitability for fermentation
- Moisture to Fixed Carbon ratio (moist/FC)
- Ash to Fixed Carbon ratio (ash/FC)
- Mineral matter properties
- Grindability

Energy and Sustainability



Energy and Sustainability

Preserving Resources

Minerals
Freshwater
Agricultural land

Preserving Environment

GHG Emissions
Air and water pollution
Waste management

Improving Liveability

Economic parameters
Social considerations
Quality of life

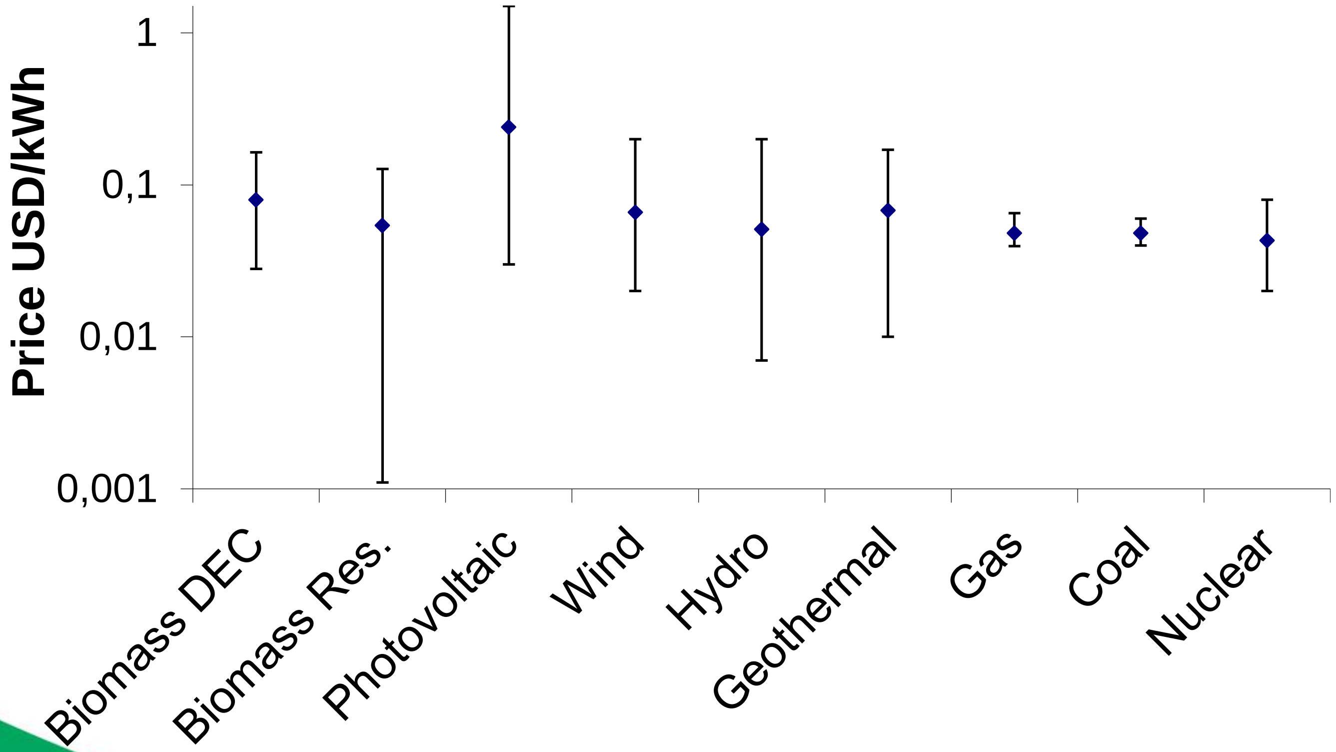
Sustainability Indicators for Power Generation Technologies

- Sustainability = Benefits / Risks

  Risk = Hazard + Outrage (P. Sandman, 1993)

- Parameters:
  - ☐ Cost of electricity
  - ☐ Greenhouse gas emissions
  - ☐ Availability of resources and technological limitations
  - ☐ Efficiency of energy generation
  - ☐ Land use
  - ☐ Water consumption
  - ☐ Social impacts

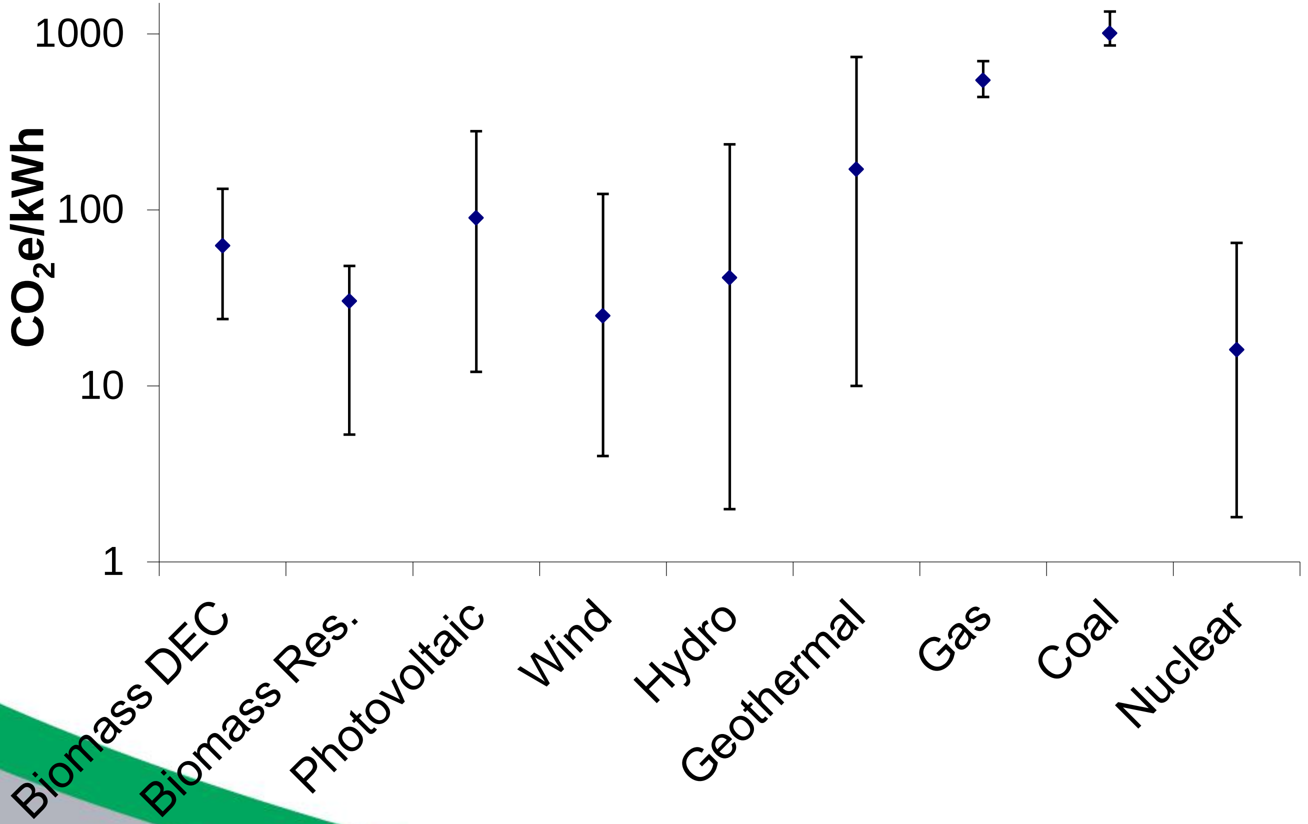
Typical Costs for Electricity Generation



Mean Price USD/kWh:

Biomass	
DEC	$0.054
Res	$0.08
PV	$0.24
Wind	$0.07
Hydro	$0.05
Geoth	$0.07
Coal	$0.042
Gas	$0.048
Nucle	$0.043

Greenhouse Gas Emissions for Electricity Generation



GHG emissions gCO_{2-e}/kWh:

Biomass	
DEC	62
Res	30
PV	90
Wind	25
Hydro	40
Geoth	170
Bioma	60
Coal	1000
Gas	543
Nucle	16

Fossil Fuel Reserves

- Under current consumption rates fossil fuel reserves are estimated at:

  Black Coal → 173 years

  Brown Coal → 225 years

  Oil → 45 years

  Gas → 66 years

  (Uranium → 49 years)

From: Fossil Fuels Reserves and Alternatives, Royal Netherlands Academy of Arts & Sciences, 2005

Land Use and Water Consumption

Technology	Footprint m^2/kWh	Water use kg/kWh
Biomass DEC	0.553	90
Biomass Res.	0.001	78
Photovoltaic	0.045	0.01
Wind	0.072	0.001
Hydro	0.152	36
Geothermal	0.05	12
Gas	0.003	78
Coal	0.004	78
Nuclear	0.0005	107

Survey

- Solar is the most popular technology by a significant margin with 50% of support
- Wind has high public support at 13%
- Geothermal and biomass are not well understood in Australia
- Hydro is favoured when existing dams are used, new dams are highly controversial
- 70% of Australians want to move away from coal and >75% do not want nuclear introduced

Sustainability Ranking

Ranking	Technology	Scaled Value
1	Wind	0.55
2	Hydro	0.57
3	Geothermal	0.70
4	PV	0.77
5	Biomass Residues	0.78
6	Gas	0.79
7	Nuclear	0.79
8	Coal	0.82
9	Biomass Crops	1

Sources:
Evans et al., *Renewable and Sustainable Energy Reviews*, 13, 1082-1088, 2009
Evans et al., *Renewable and Sustainable Energy Reviews,* 14, 1419-1427, 2010

Source: N. Myers, 2006

Processing of biomass fuels

Thermochemical Processing	Combustion	Heat
		Steam
		Electricity
	Gasification	Steam
		Heat
		Electricity
		Methane
		Hydrogen
	Pyrolysis	Charcoal/biochar
		Biogas
		Bio-oil
	Hydrothermal processing	Charcoal
		Biogas
		Bio-oil
Biochemical Processing	Anaerobic digestion	Biogas
		Digestate
	Fermentation	Ethanol Fermentate
Physicochemical Processing	Esterification	Biodiesel

Biomass combustion

Cofiring with coal:

1) direct co-firing where biomass is pre-mixed with coal and then fed into the combustor along with coal;

2) parallel co-firing, where biomass and coal are combusted in separate combustors and the steam streams produced from different combustors then converge;

3) indirect co-firing, when the biomass fuel is firstly gasified separately and the produced gas is then combusted in the downstream coal boiler.

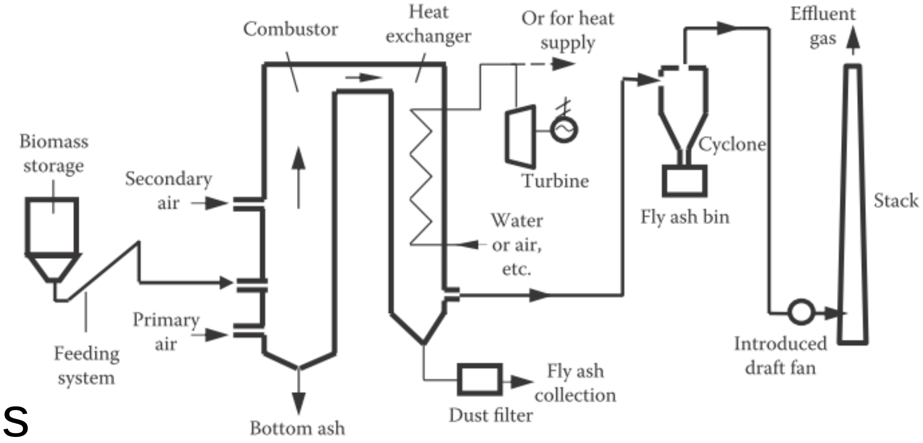


FIGURE 3.1
Basic components of an integrated boiler system for biomass combustion.

Source: Strezov and Evans, Biomass Processing Technologies, CRC Press, 2014

Generations of Liquid Biofuel Sources

G1	G2	G3	G4
Soya Oil Rape Oil Palm Oil Tallow Sugarcane Corn Sugarbeet Wheat	Switchgrass Waste Biomass Wheat Stalks Corn Husks	Algae Genetically Modified Crops	Carbon Negative Biomass Integrated geo-engineering

Biodiesel production

Five steps:

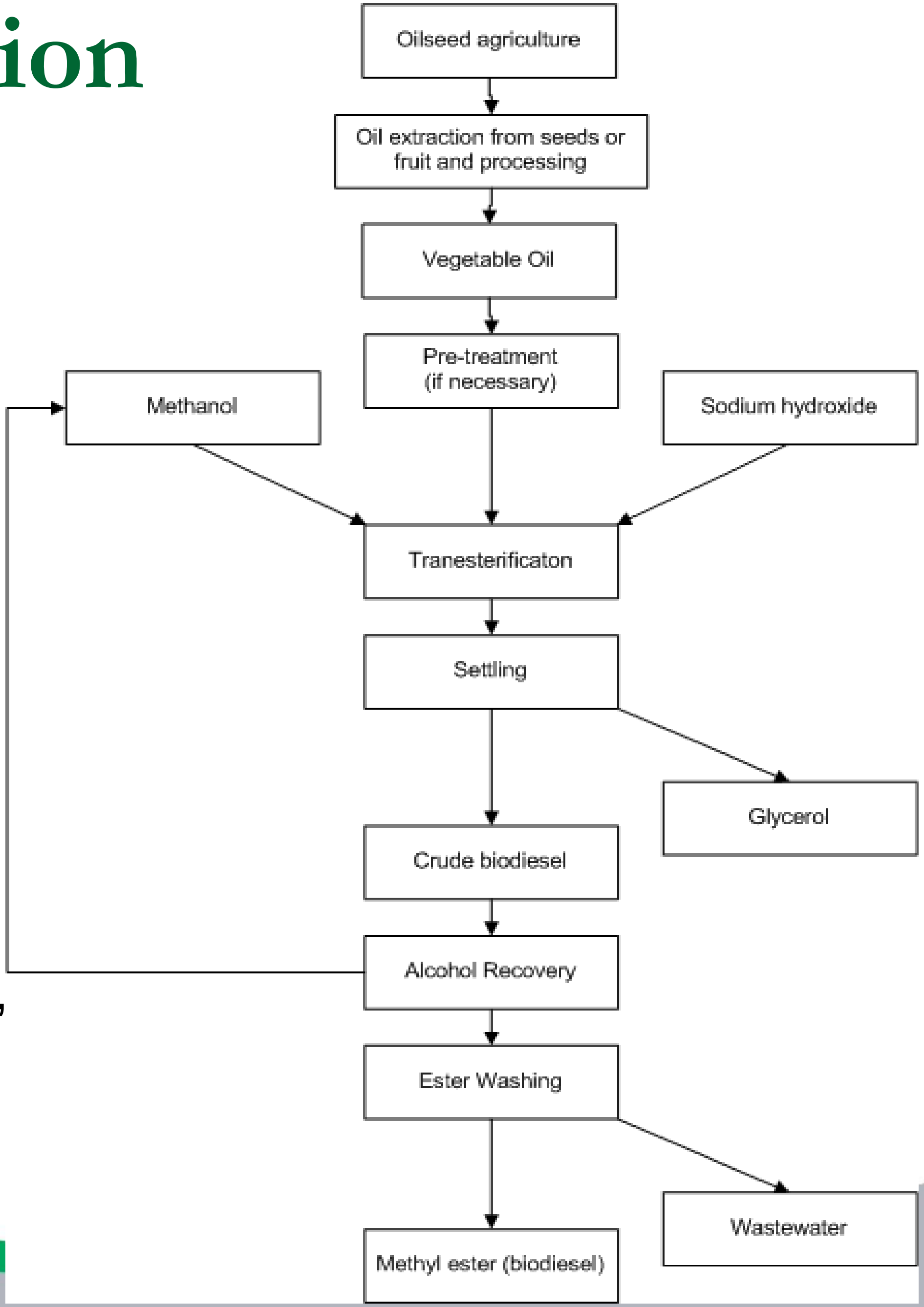
(1) oil production,

(2) pretreatment of oils to remove components that would be detrimental to subsequent processing steps,

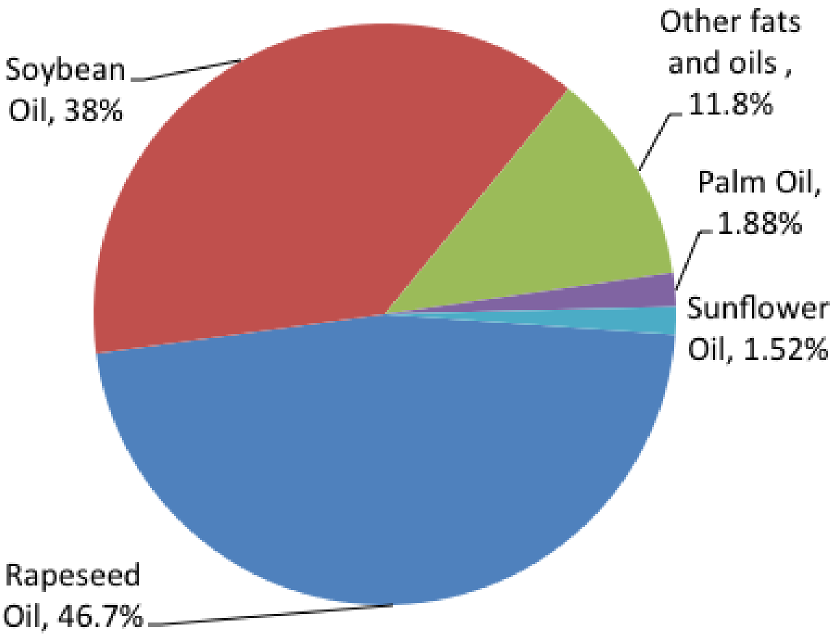
(3) esterification whereby the pretreated oils are reacted with alcohol to form alkyl esters (biodiesel) and glycerol,

(4) separation of the glycerol from the alkyl ester, and

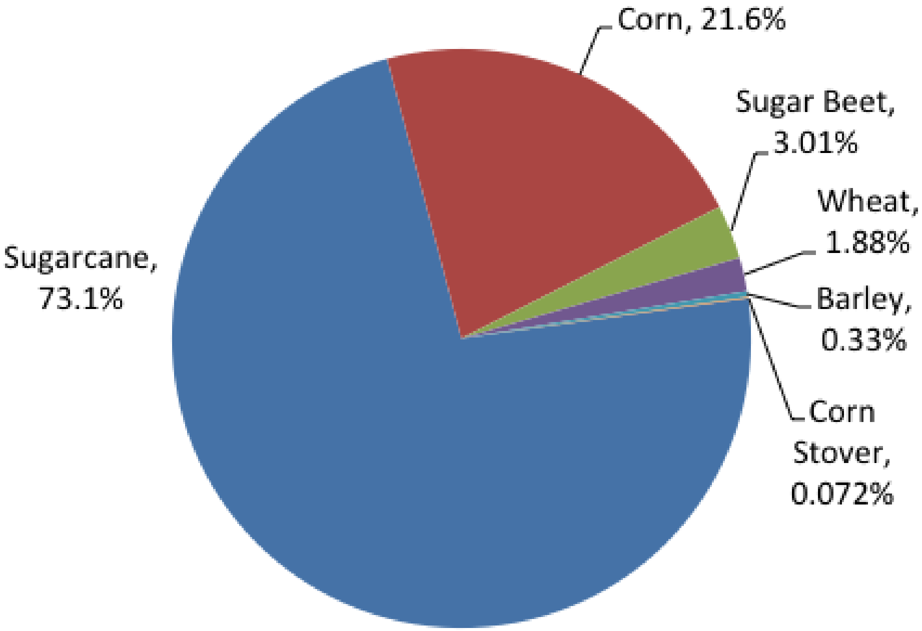
(5) alkyl ester purification to remove any soaps and remaining methanol, catalyst and glycerol



Biofuel production in 2012



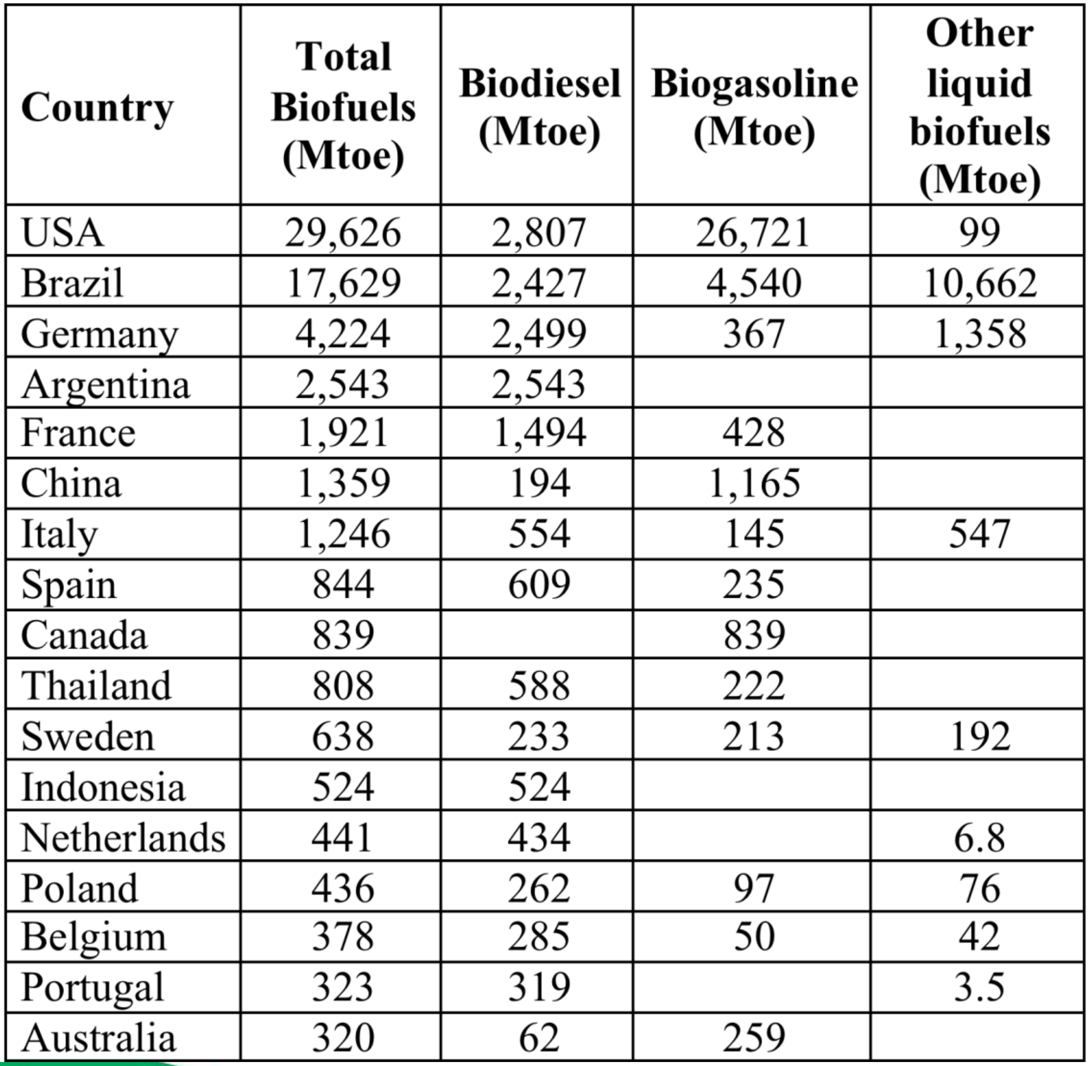
Biodiesel production



Ethanol production

Source: FAPRI (Food and agricultural policy research Institute), 2013

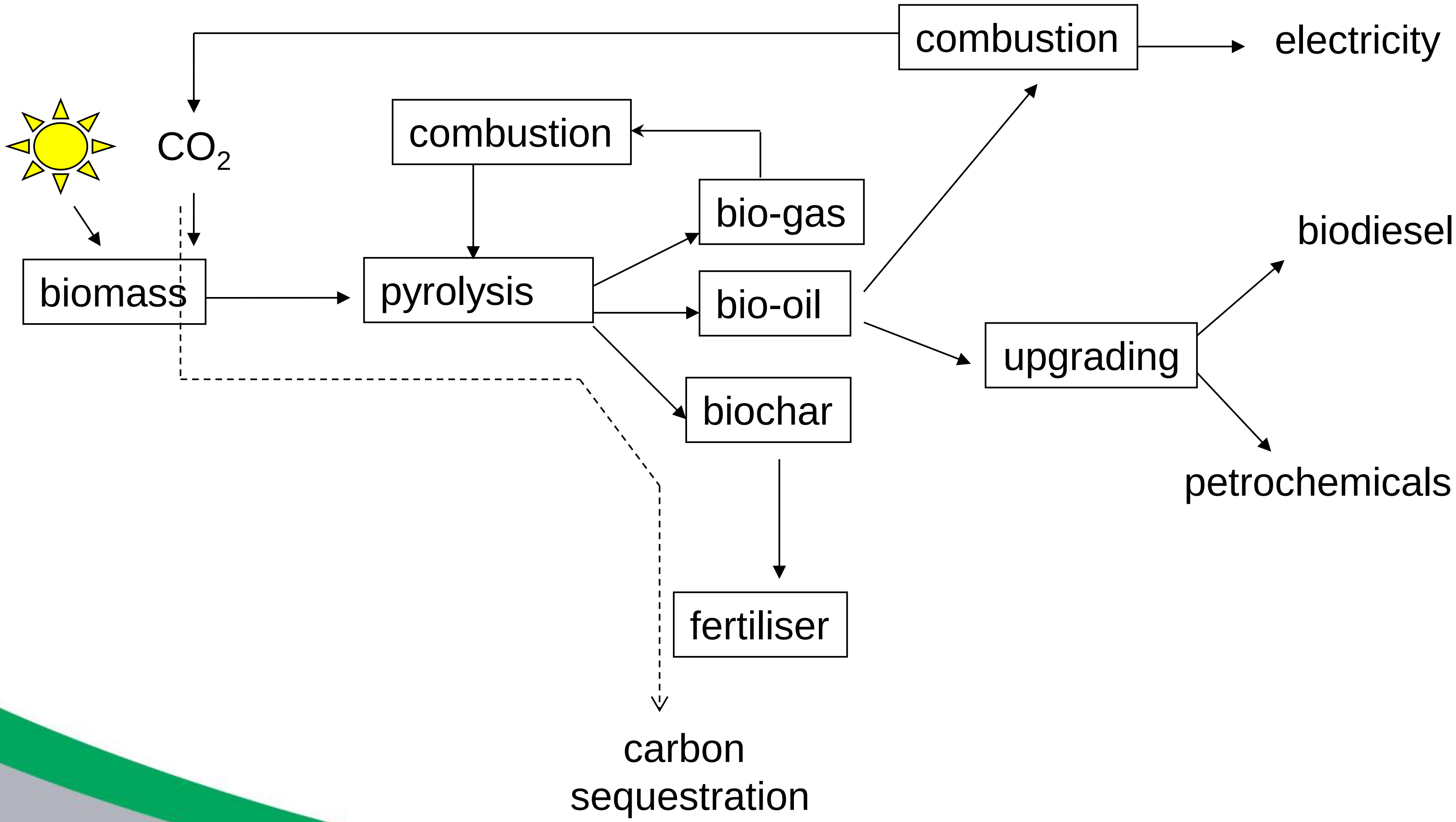
Biofuel production in 2011



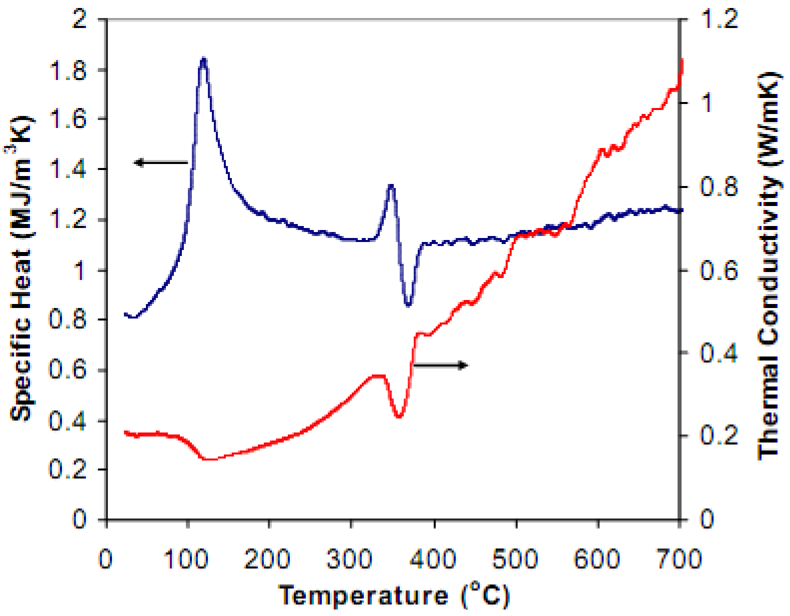
Country	Total Biofuels (Mtoe)	Biodiesel (Mtoe)	Biogasoline (Mtoe)	Other liquid biofuels (Mtoe)
USA	29,626	2,807	26,721	99
Brazil	17,629	2,427	4,540	10,662
Germany	4,224	2,499	367	1,358
Argentina	2,543	2,543		
France	1,921	1,494	428	
China	1,359	194	1,165	
Italy	1,246	554	145	547
Spain	844	609	235	
Canada	839		839	
Thailand	808	588	222	
Sweden	638	233	213	192
Indonesia	524	524		
Netherlands	441	434		6.8
Poland	436	262	97	76
Belgium	378	285	50	42
Portugal	323	319		3.5
Australia	320	62	259	

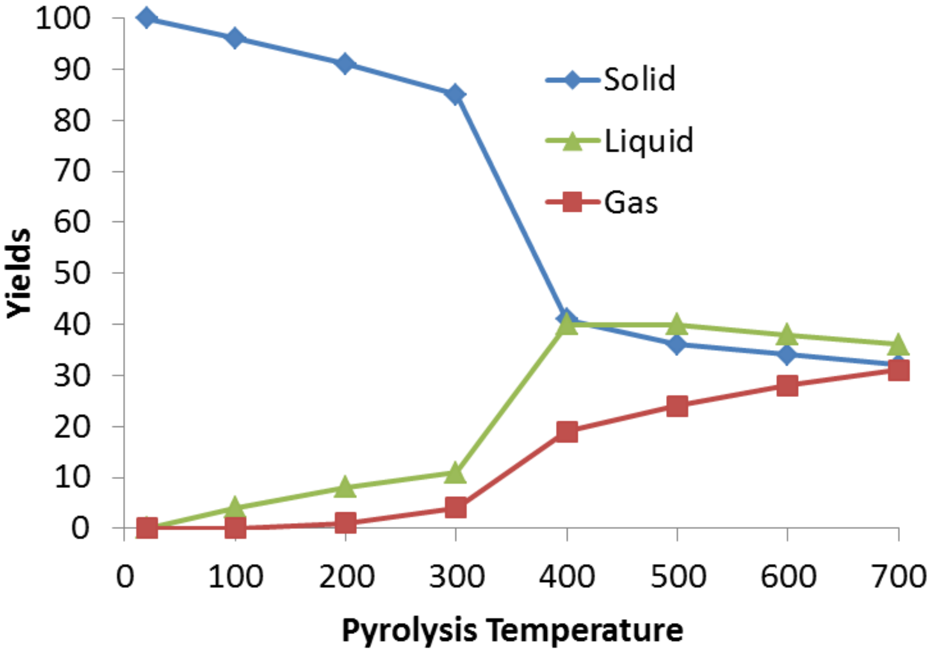
Source: Euromonitor International (2012)

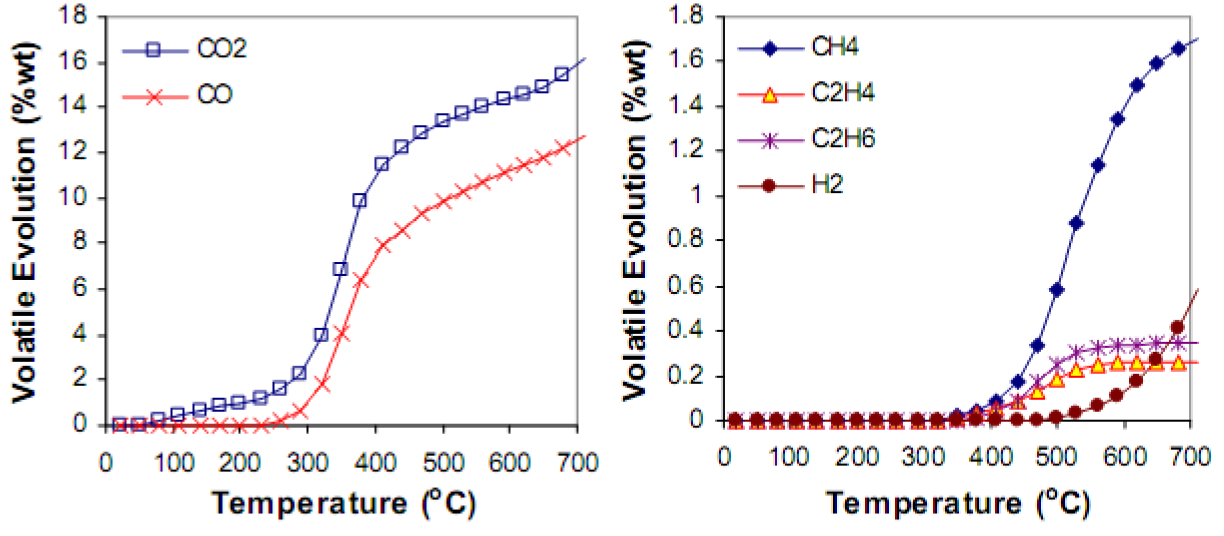
Biomass pyrolysis



Paper Sludge Pyrolysis

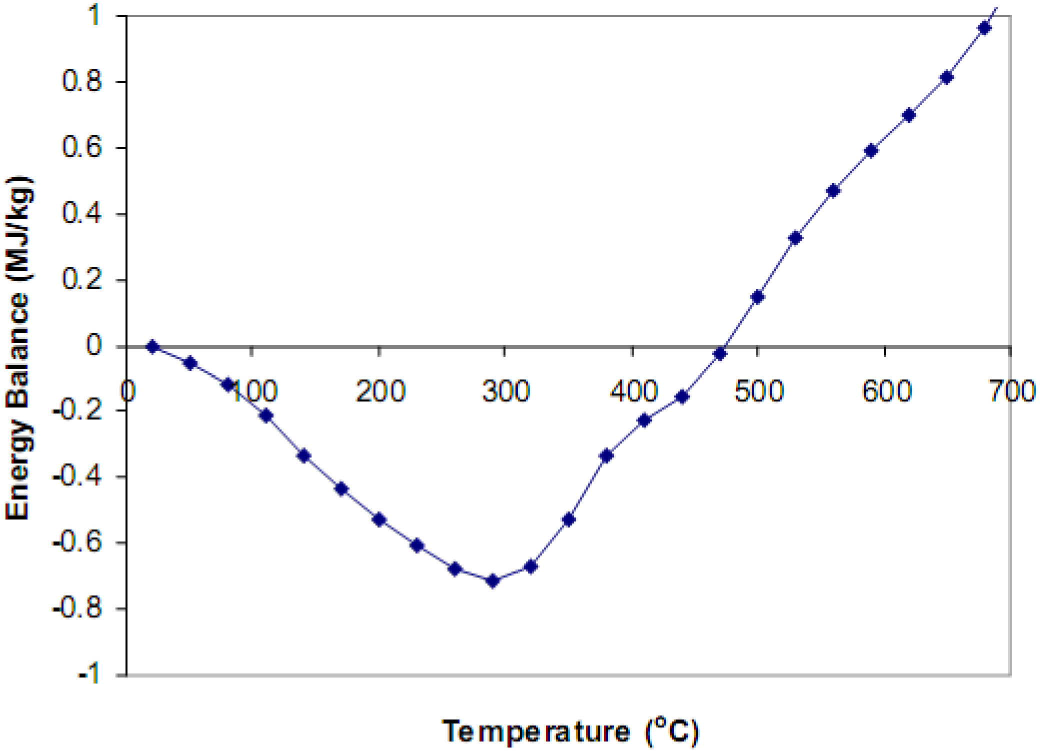






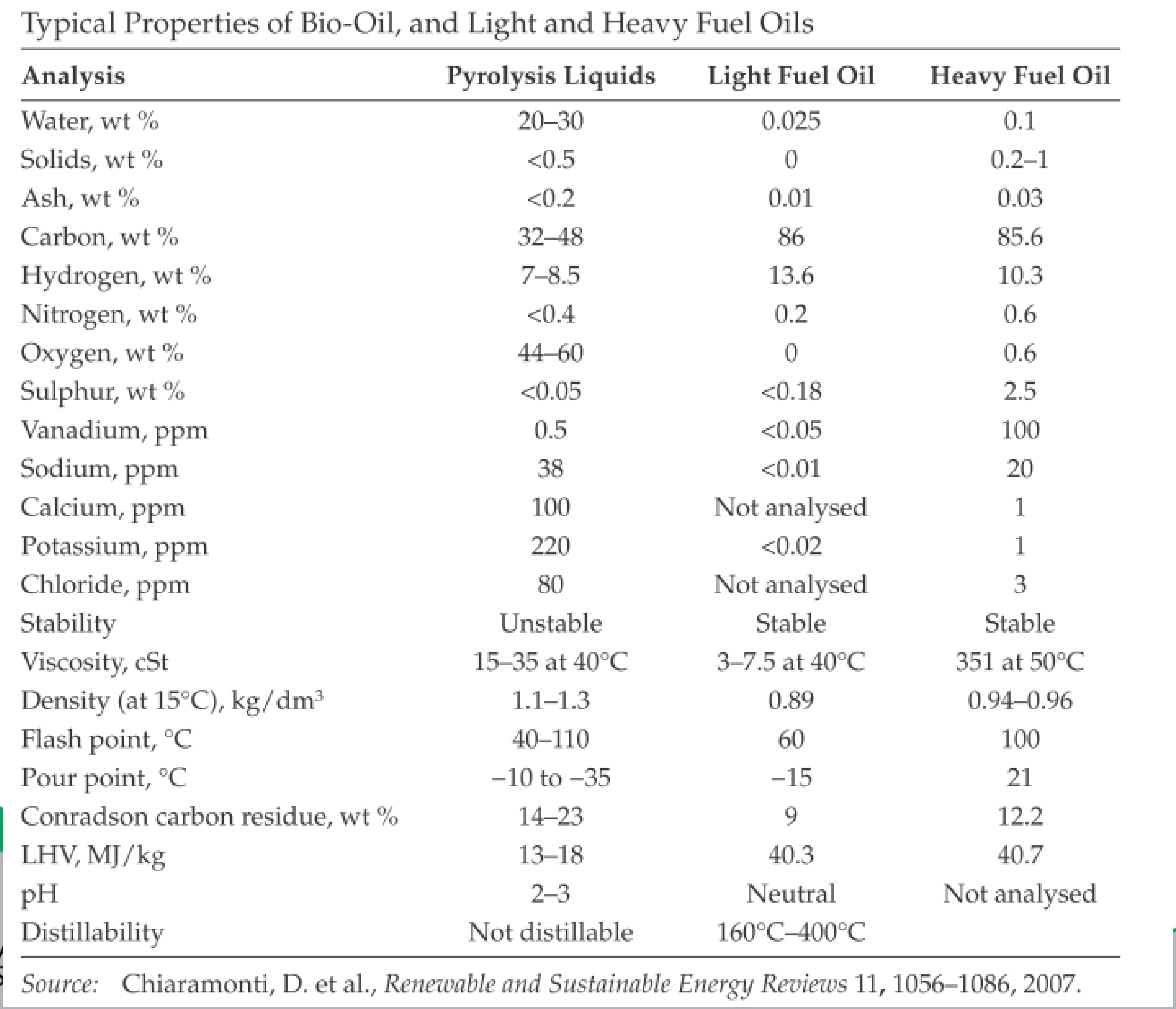
Strezov & Evans, *Waste Management*, 29, 1644-1648, 2009

Energy Balance for Paper Sludge Pyrolysis



For a dried paper sludge sample, the energy balance, becomes positive under stoichiometric and no-heat loss conditions at temperatures above 500 °C.

Strezov & Evans, *Waste Management*, 29, 1644-1648, 2009



Typical Properties of Bio-Oil, and Light and Heavy Fuel Oils

Analysis	Pyrolysis Liquids	Light Fuel Oil	Heavy Fuel Oil
Water, wt %	20–30	0.025	0.1
Solids, wt %	<0.5	0	0.2–1
Ash, wt %	<0.2	0.01	0.03
Carbon, wt %	32–48	86	85.6
Hydrogen, wt %	7–8.5	13.6	10.3
Nitrogen, wt %	<0.4	0.2	0.6
Oxygen, wt %	44–60	0	0.6
Sulphur, wt %	<0.05	<0.18	2.5
Vanadium, ppm	0.5	<0.05	100
Sodium, ppm	38	<0.01	20
Calcium, ppm	100	Not analysed	1
Potassium, ppm	220	<0.02	1
Chloride, ppm	80	Not analysed	3
Stability	Unstable	Stable	Stable
Viscosity, cSt	15–35 at 40°C	3–7.5 at 40°C	351 at 50°C
Density (at 15°C), kg/dm^3	1.1–1.3	0.89	0.94–0.96
Flash point, °C	40–110	60	100
Pour point, °C	−10 to −35	−15	21
Conradson carbon residue, wt %	14–23	9	12.2
LHV, MJ/kg	13–18	40.3	40.7
pH	2–3	Neutral	Not analysed
Distillability	Not distillable	160°C–400°C	

Source: Chiaramonti, D. et al., *Renewable and Sustainable Energy Reviews* 11, 1056–1086, 2007.

Agricultural use of the biochar – Terra Preta Soils

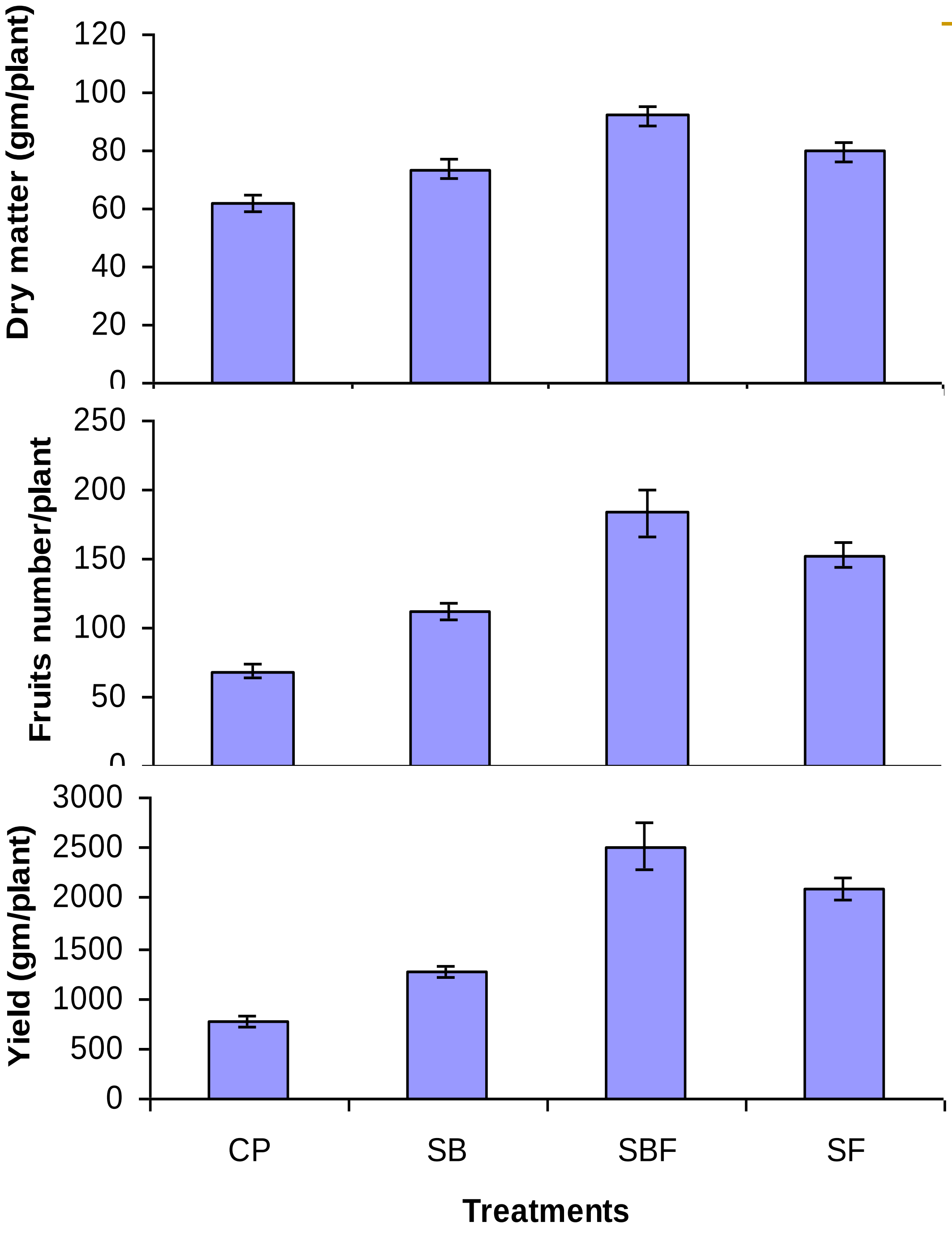
Source: Glacer, http://www.carbon-terra.eu/en/biochar/application/Terra_Preta

Terra Preta or “dark earth” are carbon-rich soils discovered in the Amazon region

Biochar is now used to produce Terra Preta type of fertile soils as it improves:

- Water holding capacity
- Soil aeration
- Improves microbial activity
- Stimulates nutrient dynamics
- Stops nutrient leaching
- Carbon mitigation

Tomato cultivation with sewage sludge biochar



Tomatoes grown in:

CP = soil only

SB = soil + 10% biochar

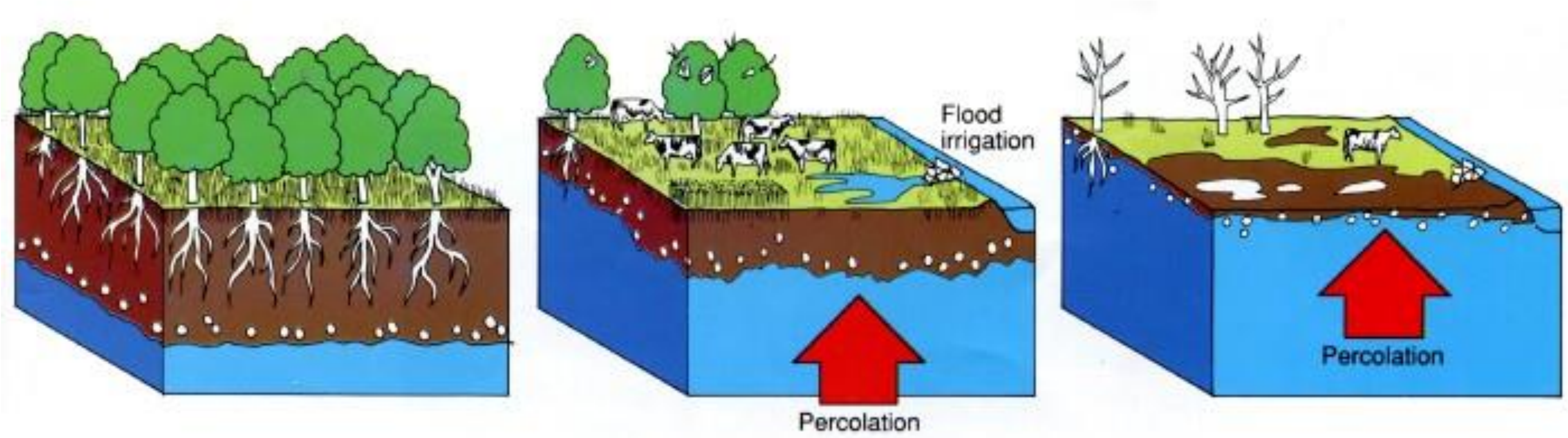
SBF = soil + biochar + fertiliser

SF = fertiliser

Hossain et al, *Chemosphere*, 78, 1167-1171, 2010

Western Australia Mallee Tree Project

Soil salinity



Before clearing
The system is in balance.
Most water is used where it falls.

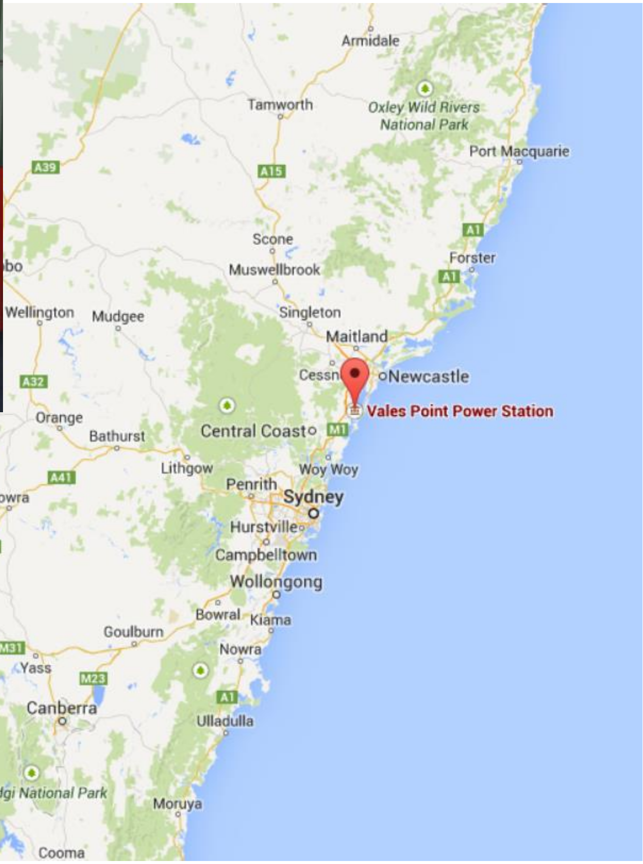
After clearing and irrigating
Evaporation and irrigation seepage concentrates saline groundwater at the surface.

Later
Protective plant cover is killed by the accumulation of salt at the surface.
The land is open to erosion.

Sources:
http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_salinity_management_irrigation

Continuous Biomass Converter at Vales Point Power Station

Source: The Crucible Group Pty Ltd



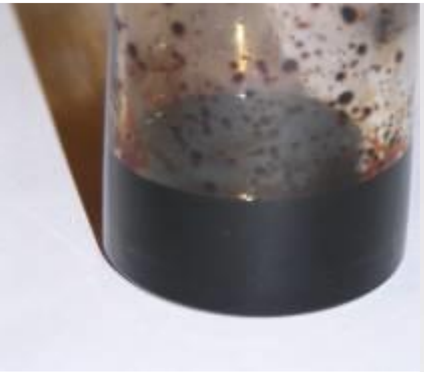
Algal biomass

From: A. Ben-Amotz, Bio-Fuel and CO2 Capture by Algae, 2008

Bio-oil Extraction from Algae

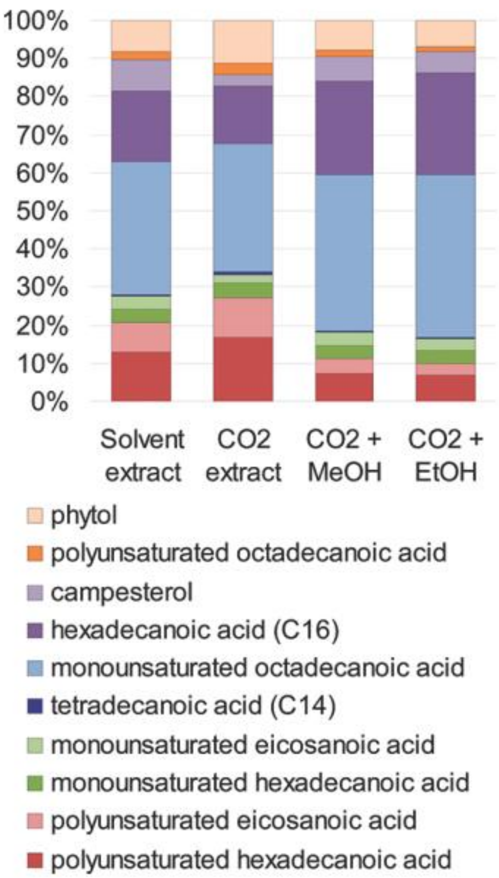
Algae Biomass

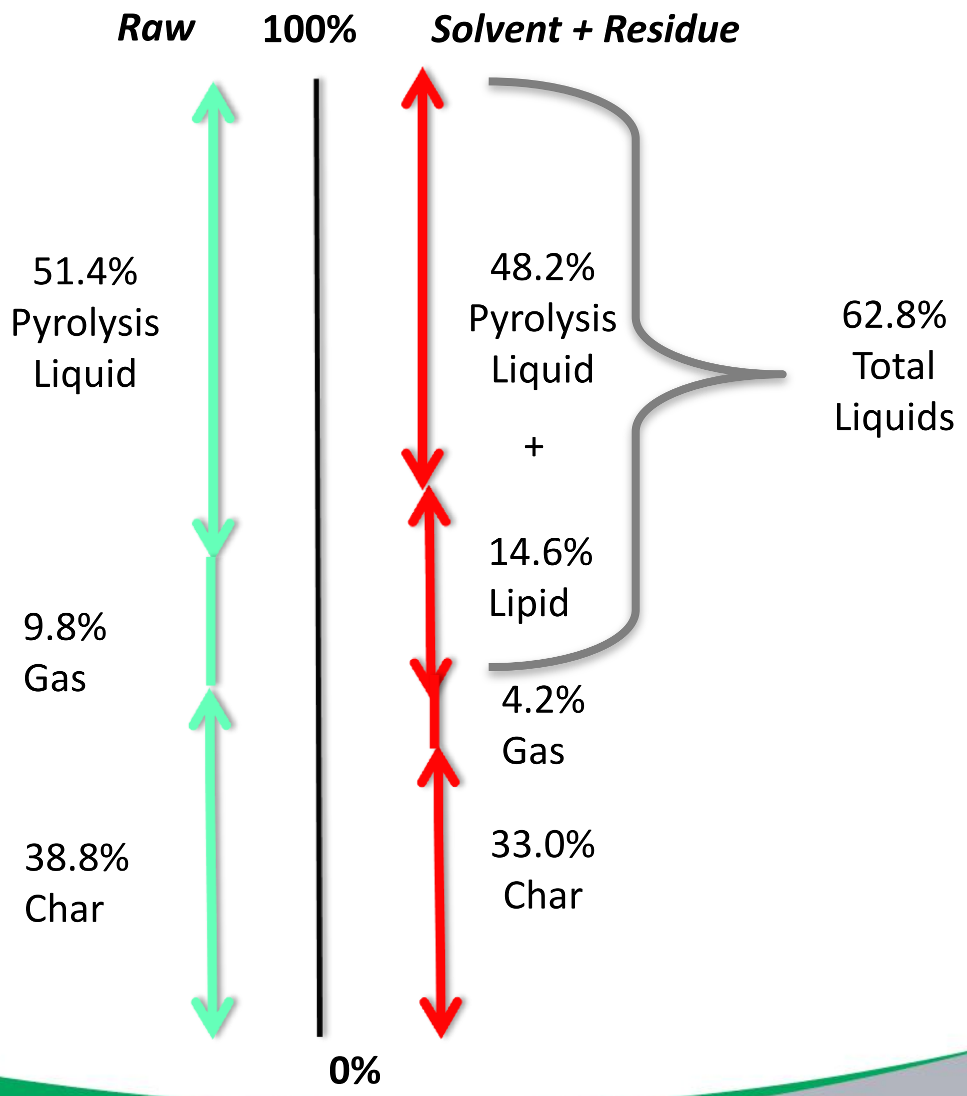
Algae Bio-oil



Algae Bio-char

Processing of microalgae





Raw **100%** ***Solvent + Residue***

51.4% Pyrolysis Liquid

9.8% Gas

38.8% Char

48.2% Pyrolysis Liquid

\+

14.6% Lipid

4.2% Gas

33.0% Char

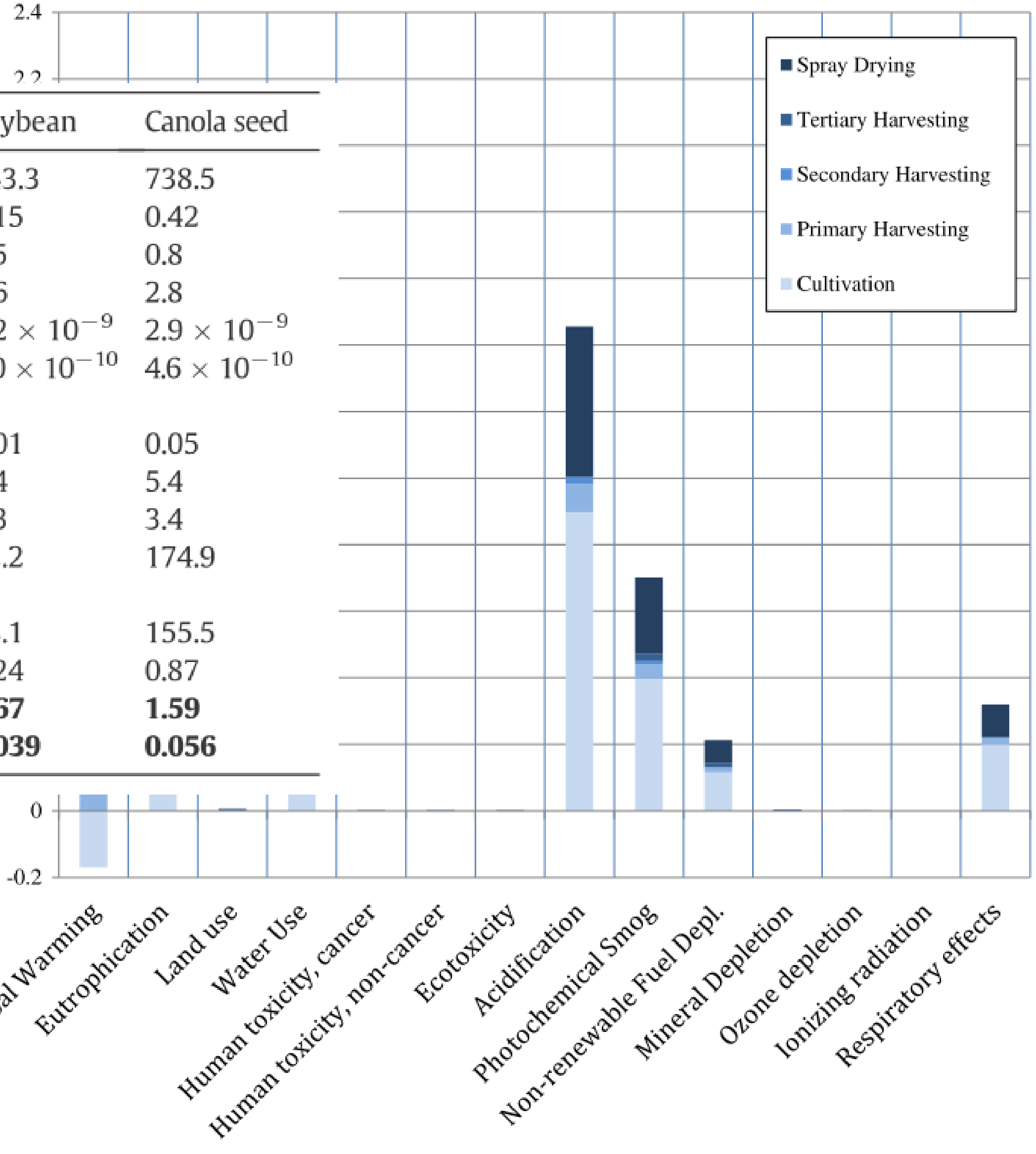
62.8% Total Liquids

0%

Grierson et al, *Energy & Fuels*, 248-255, 2012

Environmental Impact Contribution per tonne of algae

Impact category	Unit	Microalgae	Soybean	Canola seed
Global warming	kg CO_2 eq	−222	243.3	738.5
Eutrophication	kg PO_4 eq	1.1	0.15	0.42
Land use	ha a	0.001	0.5	0.8
Water use	kL H_2O	96.2	0.6	2.8
Human toxicity, cancer	CTUh	2.0×10^{-9}	1.2×10^{-9}	2.9×10^{-9}
Human toxicity, non-cancer	CTUh	2.0×10^{-10}	2.0×10^{-10}	4.6×10^{-10}
Ecotoxicity	CTUe	0.07	0.01	0.05
Acidification	kg SO_2 eq	24.9	1.4	5.4
Photochemical smog	kg NMVOC eq	9.8	1.3	3.4
Non-renewable fuel depl.	kg oil eq	605.4	62.2	174.9
Mineral depletion	kg Fe eq	827.3	28.1	155.5
Respiratory effects	kg PM2.5 eq	3.1	0.24	0.87
Ecopoints (total)	**p**	**2.23**	**0.67**	**1.59**
Equivalence in Ecopoints	**p/GJ**	**0.138**	**0.039**	**0.056**



Grierson et al, *Algal Research*, 299-311, 2013

Conclusions

- Biomass will play one of the key roles in sustainable energy future
  - but, this is subject to how biomass is produced
- Standard classification of biomass properties and quality are needed
  - that will include physico-chemical properties, but also the biomass production route
- Some biomass technologies are already available, but the engineering systems needed for energy sustainability require further research

Acknowledgements

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- Dr Tao Kan, Macquarie University
- Mr Gary Leung, Macquarie University
- Dr Katrin Thommes, Macquarie University
- Ms Cara Mulligan, University of Newcastle

Thank you!

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