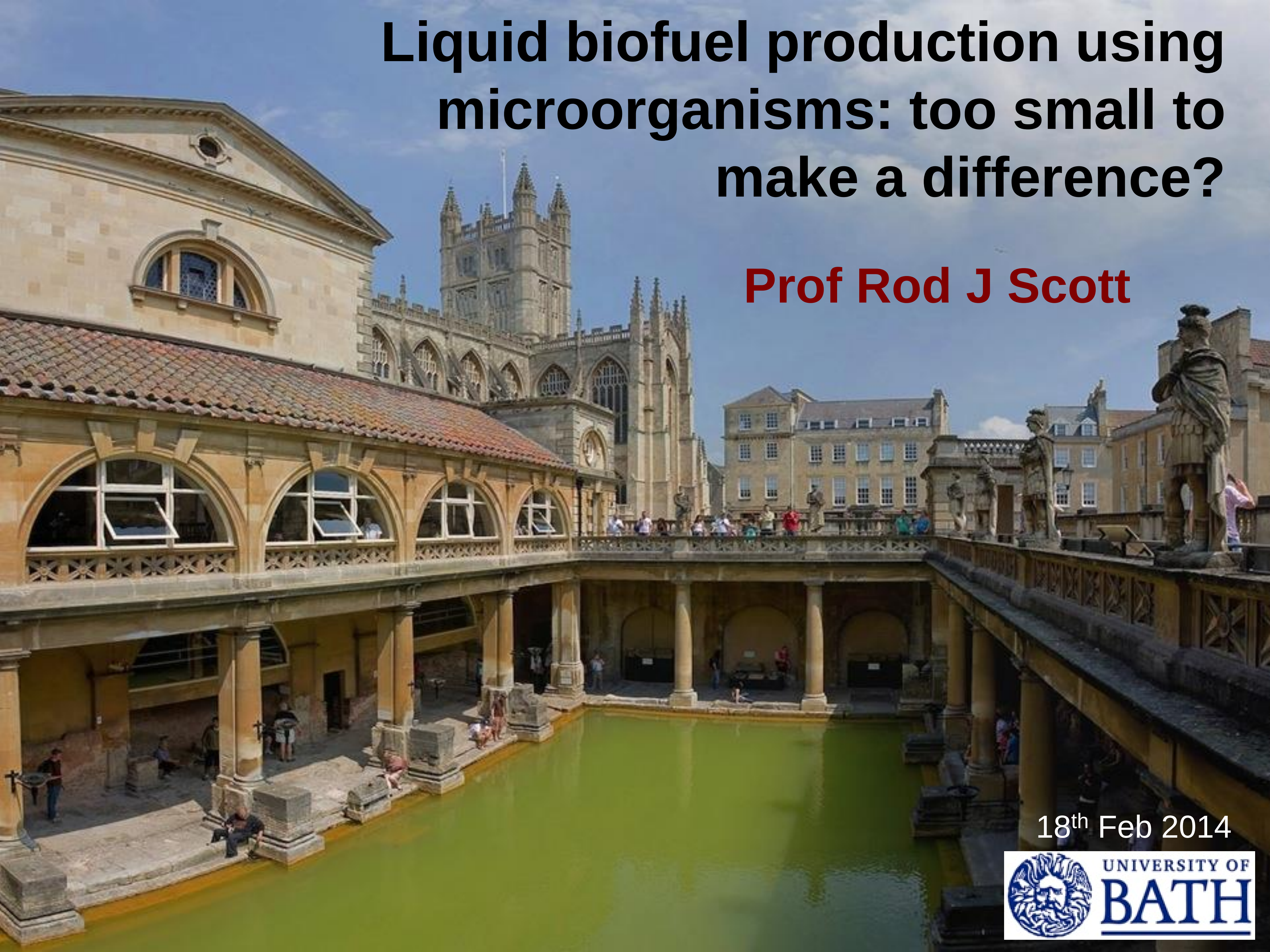
Liquid biofuel production using microorganisms: too small to make a difference?

Prof Rod J Scott



18th Feb 2014

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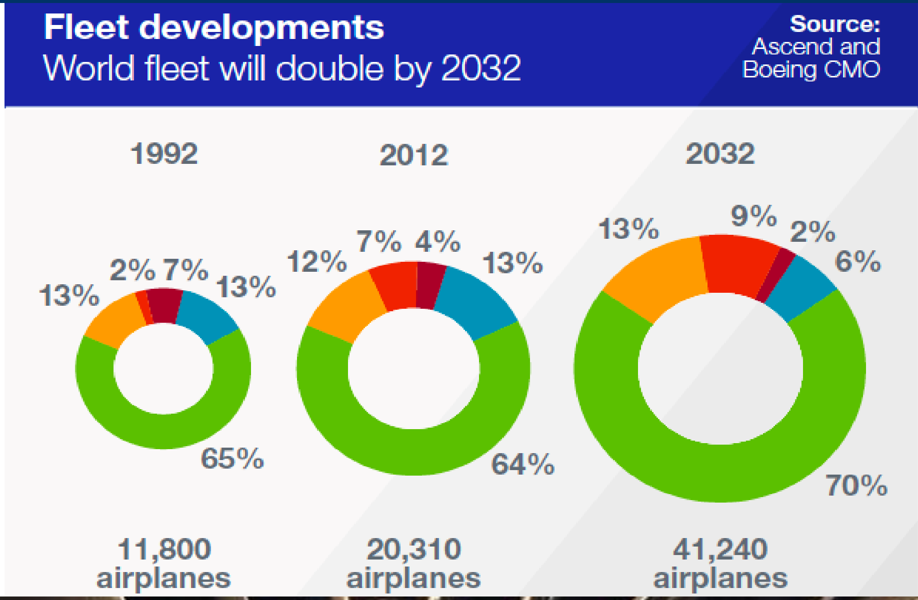
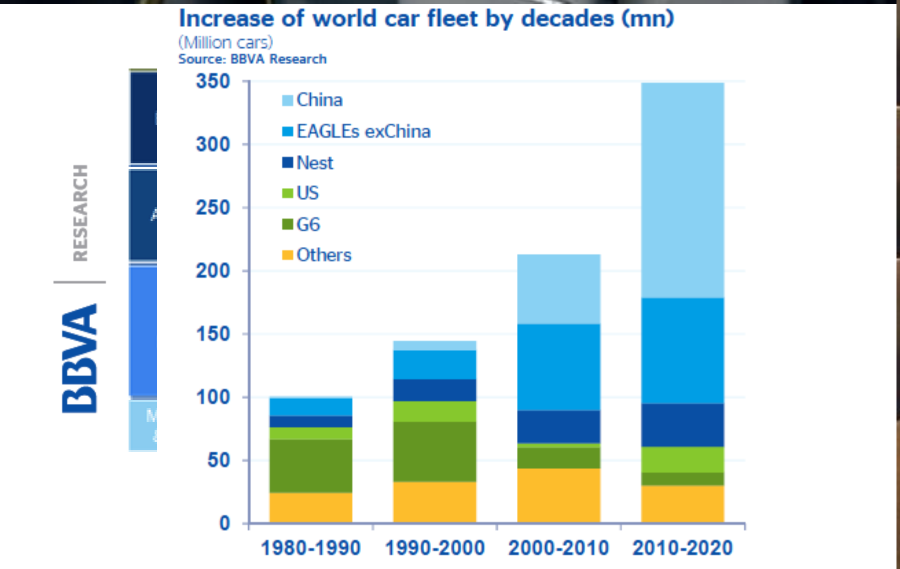
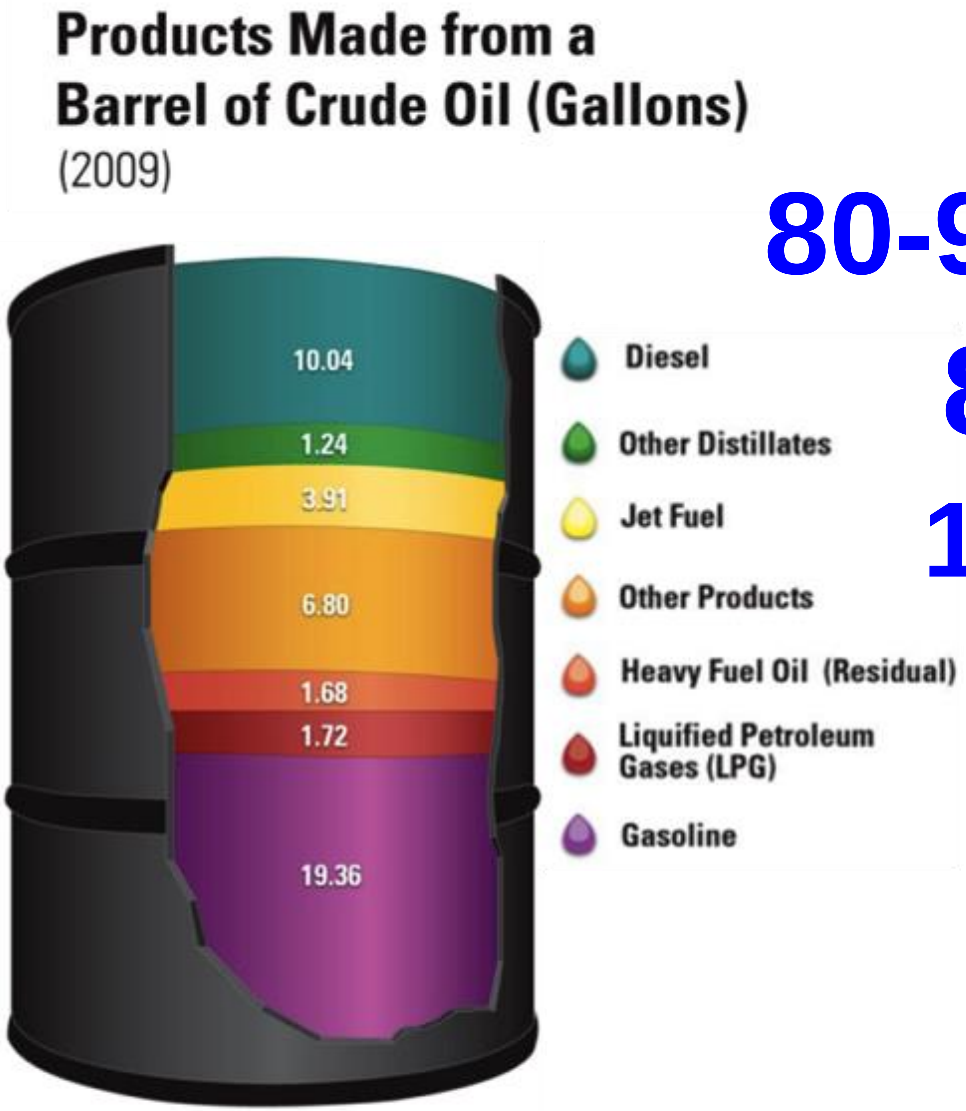
Thirst for fuel: car and air transport





Global, per day, oil consumption



80-90 million barrels/day

80% liquid fuels

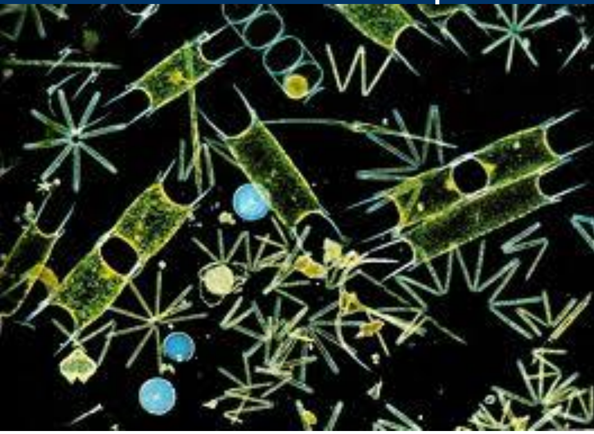
14,310,000,000 L/day

Units above are gallons

1 barrel of oil = 159 litres

5,724 Olympic swimming pools

How is oil made and how long does it take?



NATURALLY: **10-30 million years**

buried to depth sufficient to achieve high temperature & pressure

30 barrels/day for

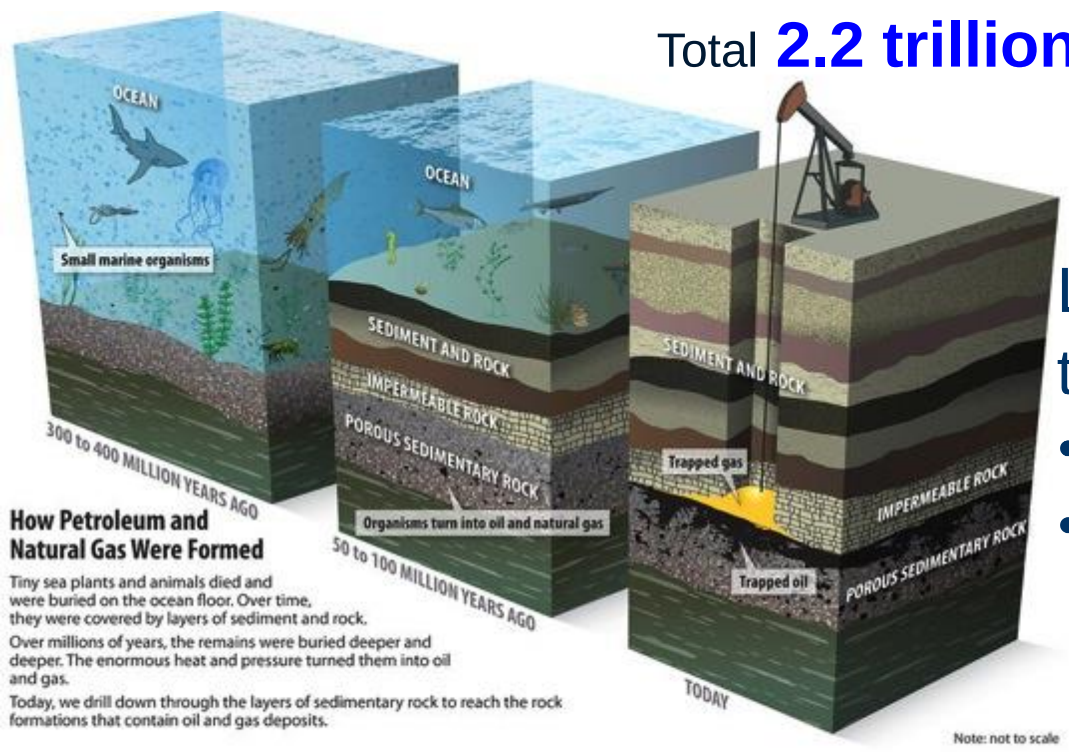
200 million years

Total **2.2 trillion** barrels

Current consumption is

2-3 million times

faster than formation



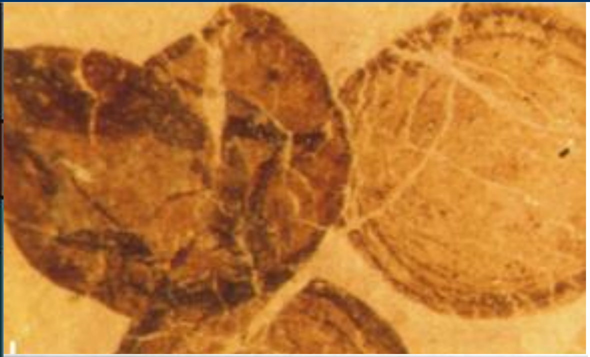
LAB: **hours-days** @ high temperature and pressure

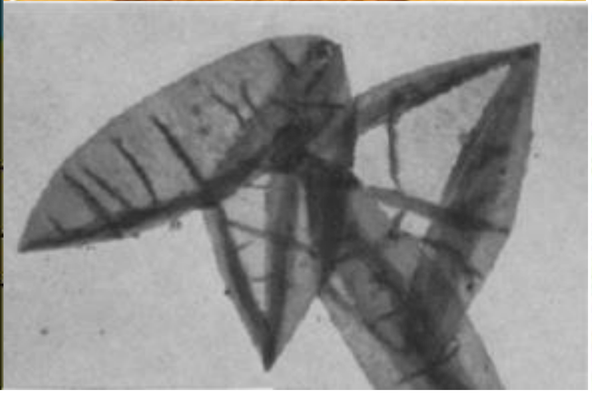
- pyrolysis
- **hydrothermal liquifaction**

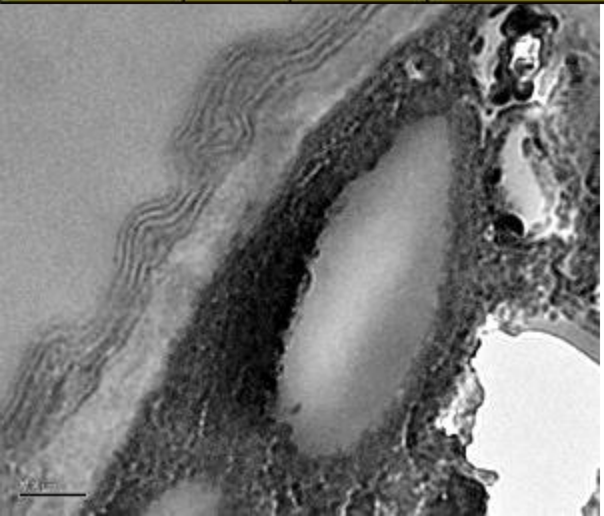
Oil is derived from a tough algal cell wall biopolymer, algaenan

Types of Kerogen
and Their Hydrocarbon Potential

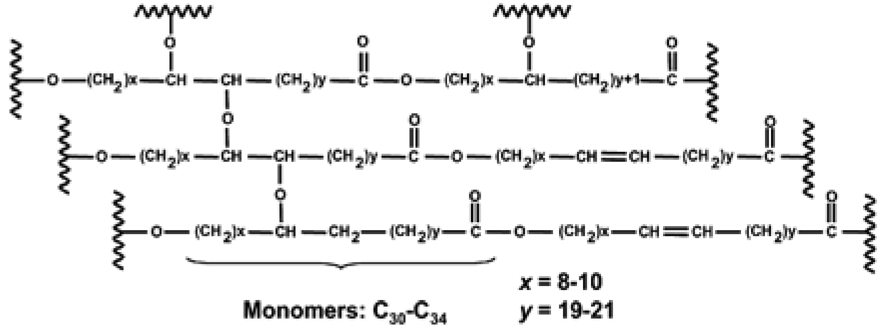
Environment	Kerogen Type	Kerogen Form	Origin	HC Potential
Aquatic	I	Alginite	Algal bodies	
		Amorphous Kerogen	Structureless debris of algal origin	Oil
	II		Structureless planktonic material, primairly of marine origin	
Terrestrial		Exinite	Skins of spores and pollen, cuticle of leaves and herbaceous plants	
	III	Vitrinite	Fibrous and woody plant fragments and structureless, colloidal humic matter	Gas, some oil
				Mainly gas
	IV	Inertinite	Oxidized, recycled woody debris	None



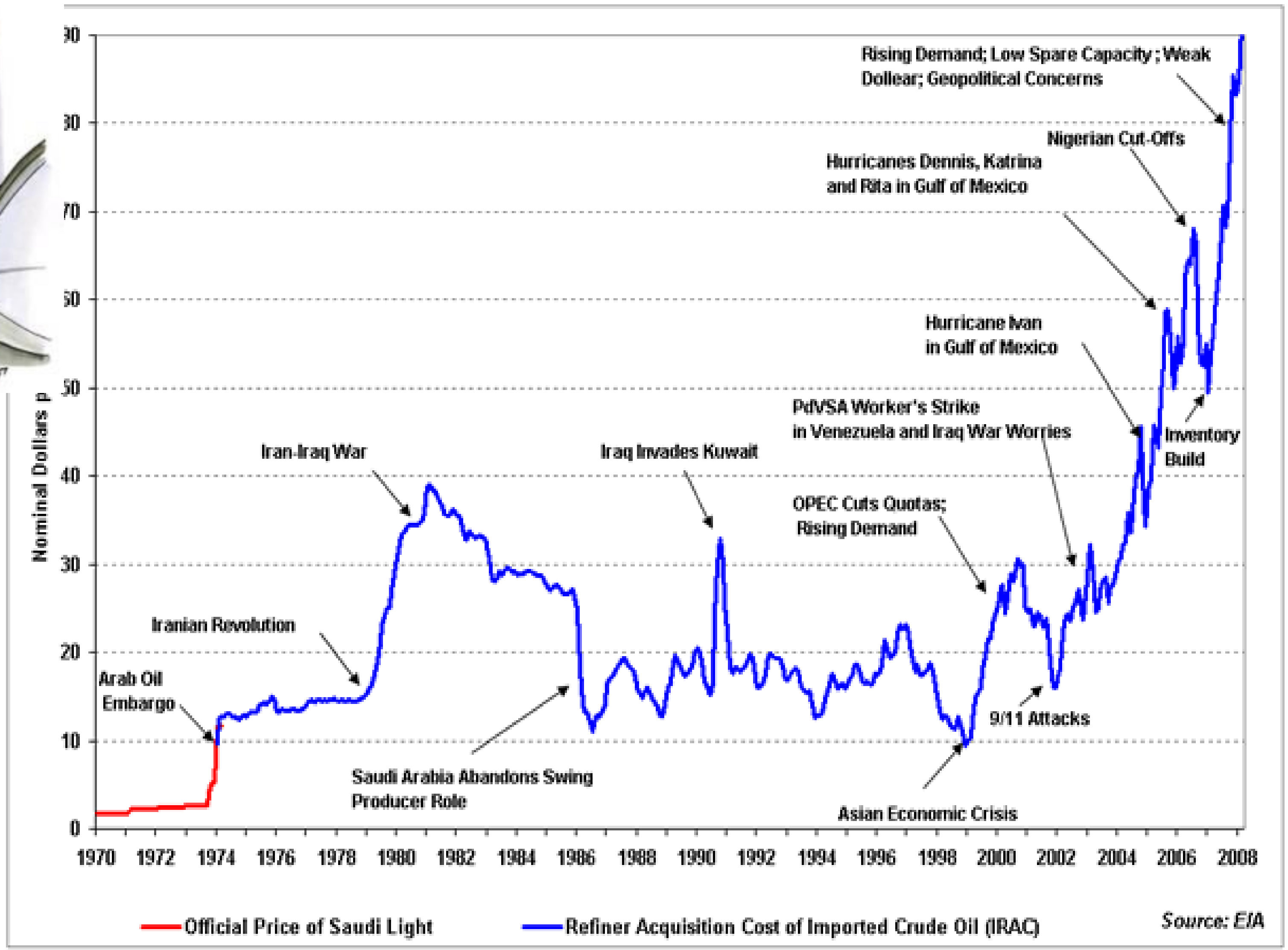




VLCFA (C_{18}-C_{36}) polyester heteropolymer



Fuel: rising demand for a finite resource



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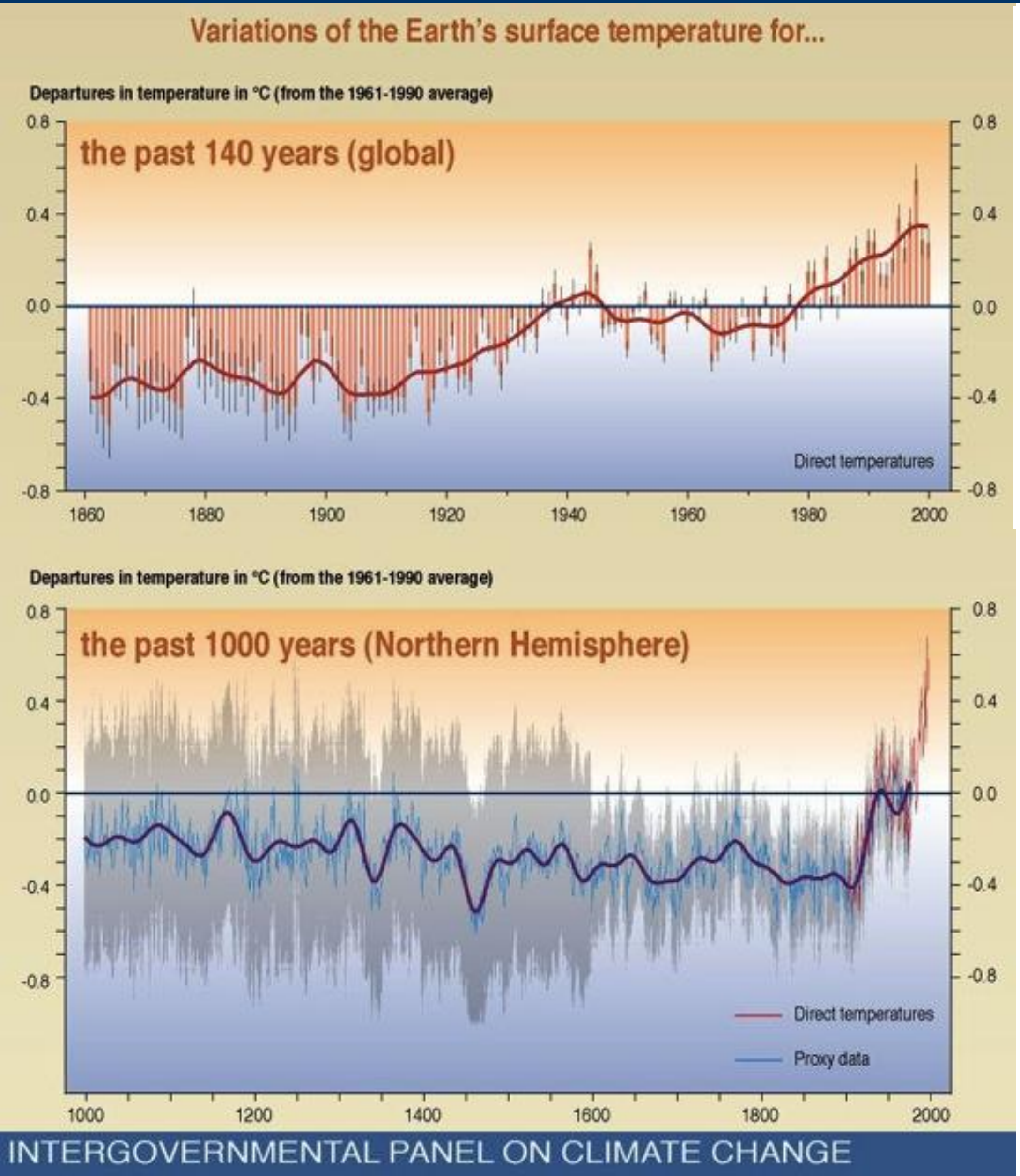
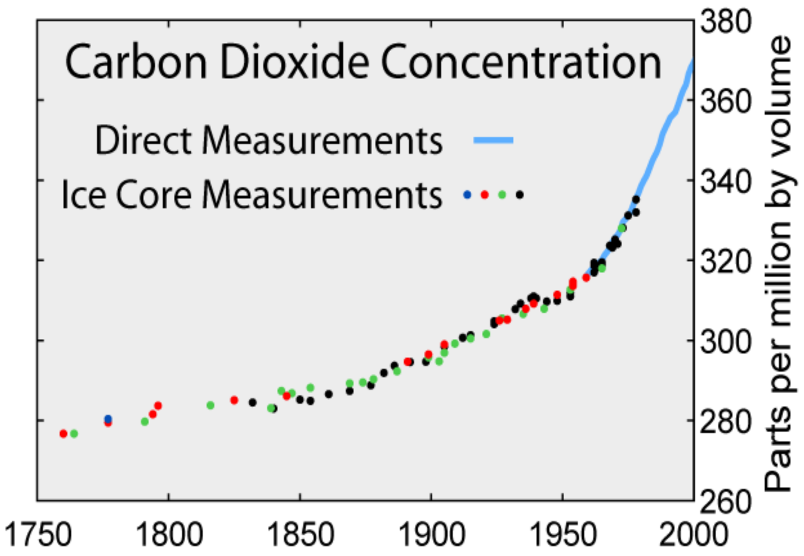
Rising temperature and atmospheric CO_2 levels





< 2ºC rise limit

2020 20-40% reduction

2050 80-90% reduction

Copenhagen 2009

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I-SEE seminar 18th MARCH 2014
A cool look at Global Warming

Liquid renewables

33%

Photovoltaic
Solar thermal
Geothermal
Wind and wave

66%

Ethanol
Biodiesel
Methane
Butanol
Hydrogen

Need renewable source of **liquid fuel**

Solar powered liquid renewable fuels

3,400,000

EJ/year @ surface

(1 EJ=10^{18} joules)

10x

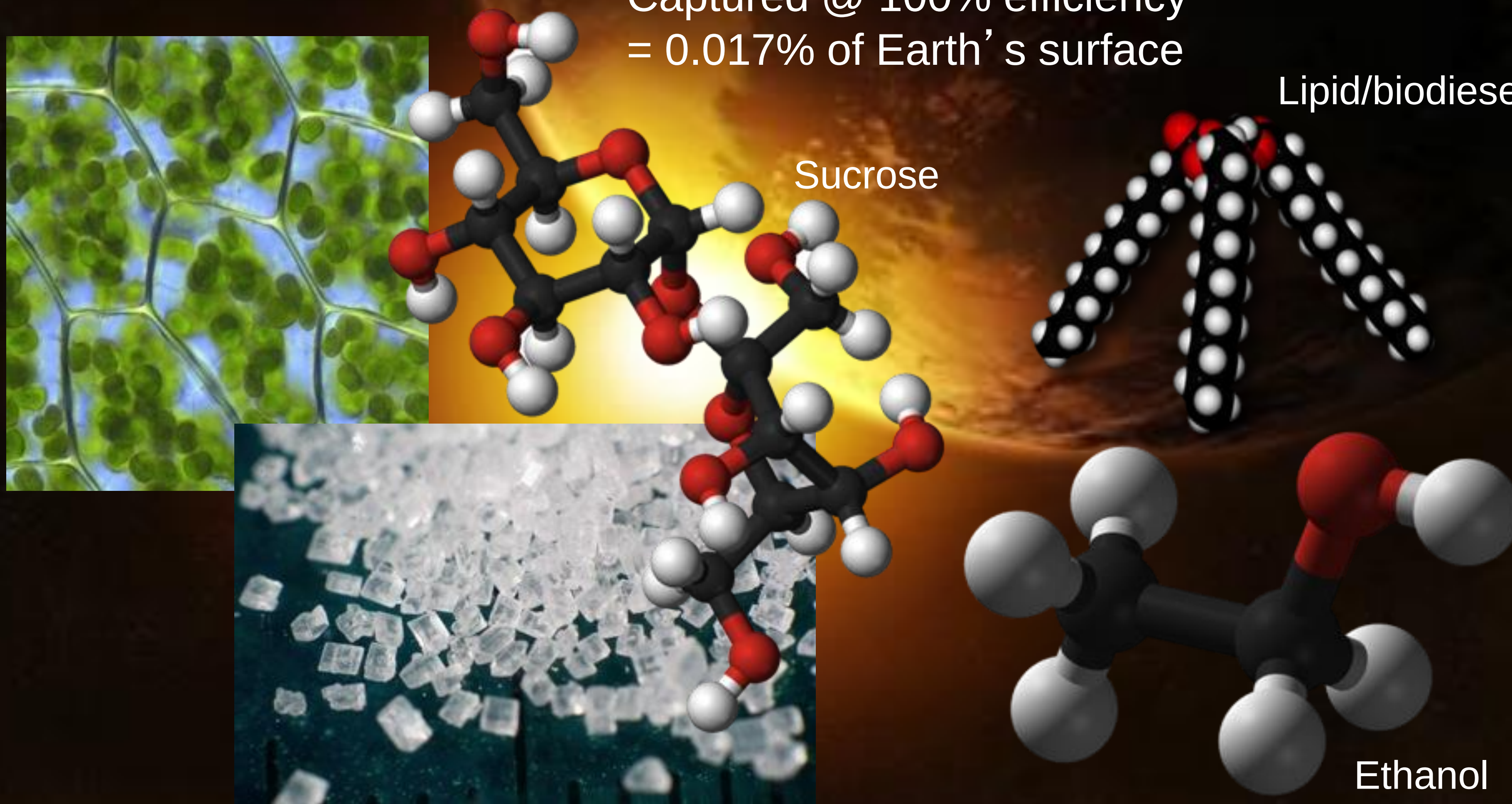
all the estimated
(discovered and undiscovered)
non-renewable energy resources,
inc. fossil fuels and nuclear

Biofuels: solar to chemical energy

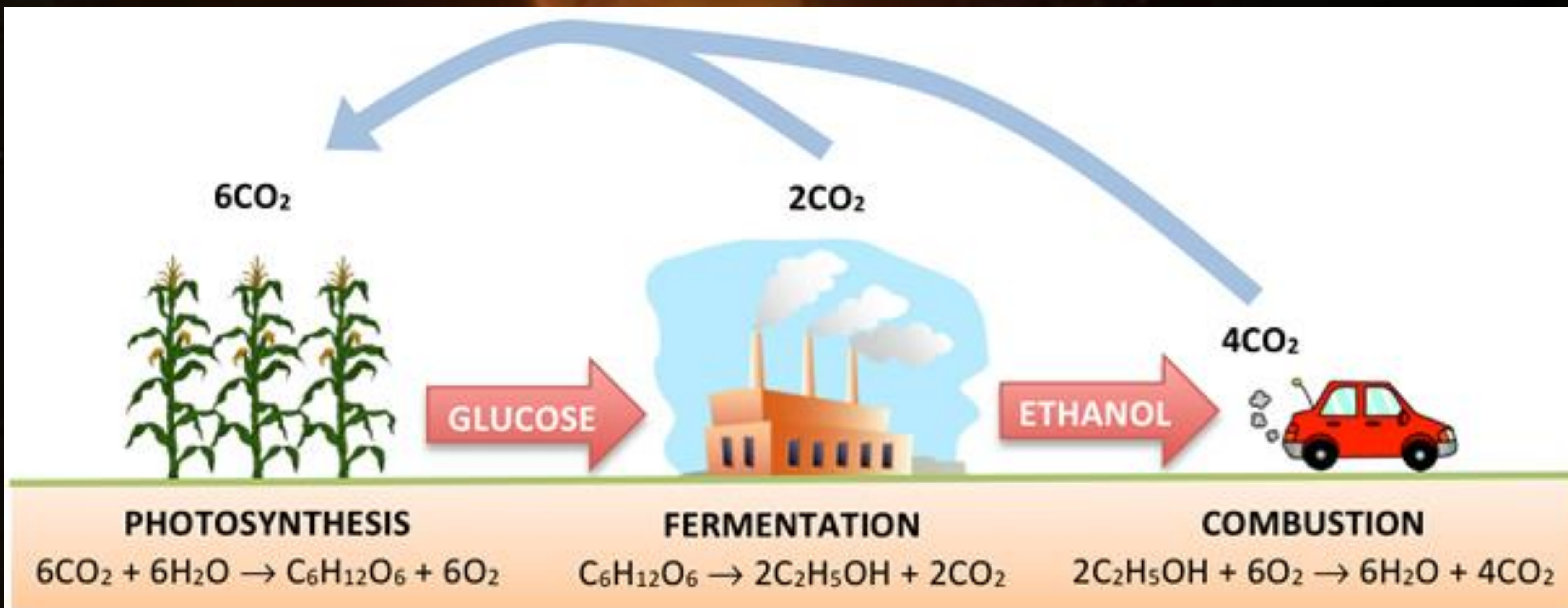
Use photosynthesis to capture solar energy in combustible molecules – ethanol, hydrocarbons

5,700 X global energy demand/day

Captured @ 100% efficiency
= 0.017% of Earth's surface



With benefits: CO_2 mitigation



Drop-in

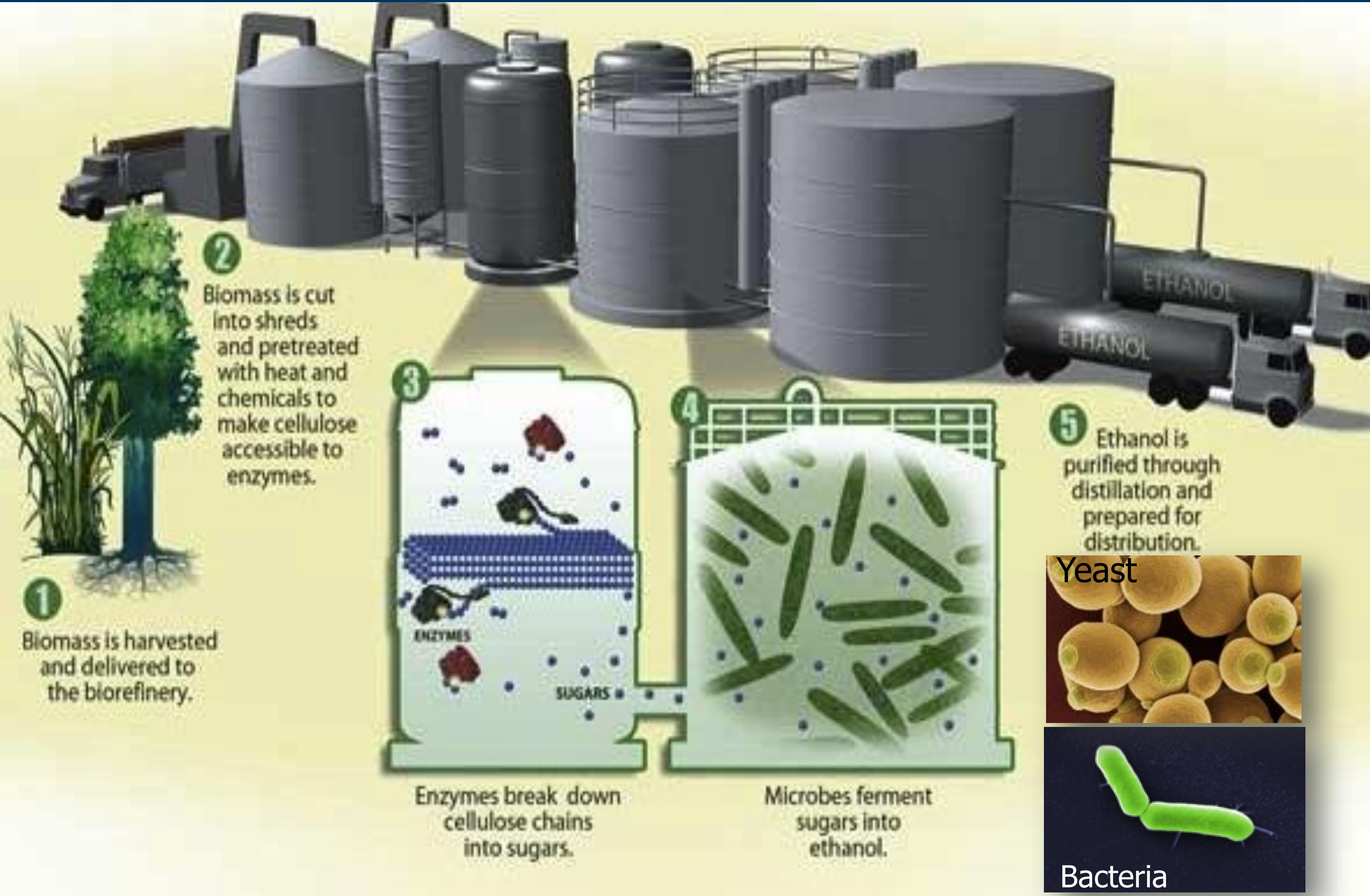

A Comum
G Supra Aditivada
G Supra Aditivada
A Comum
Imperdível
R$ 7,90
litro
BR


FLEXPOWER

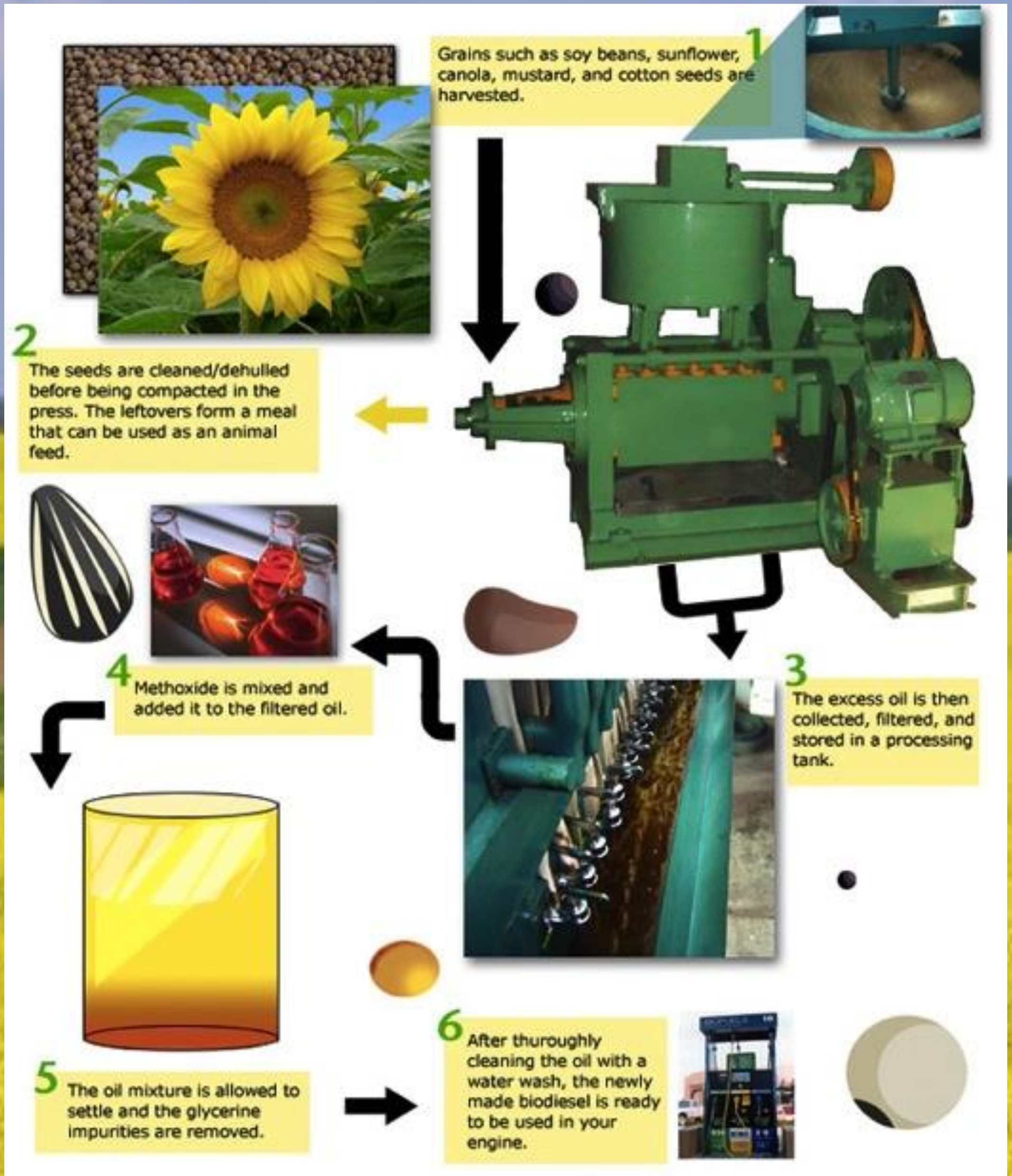

Flex


ATTENTION
E15
Up to 15% ethanol
Use only in
• 2001 and newer passenger vehicles
• Flex-fuel vehicles
Don't use in other vehicles, boats, or gasoline-powered equipment. It may cause damage and is prohibited by federal law.

Making drop-in biofuels: bioethanol



Making drop-in biofuels: biodiesel



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Brazilian sugarcane bioethanol

8% solar conversion efficiency
(3.6-6.4% of arable land)

50% domestic transport fuel

1% of Brazil's arable land

7,534,247 L/day
(global gasoline = 6,153,300,000 L/day)

45% more ethanol per unit area than corn ethanol

$0.29/L US corn ethanol
$0.22/L Brazil sugarcane ethanol
OECD (2006) 2004 prices.

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Biofuels: challenges to development

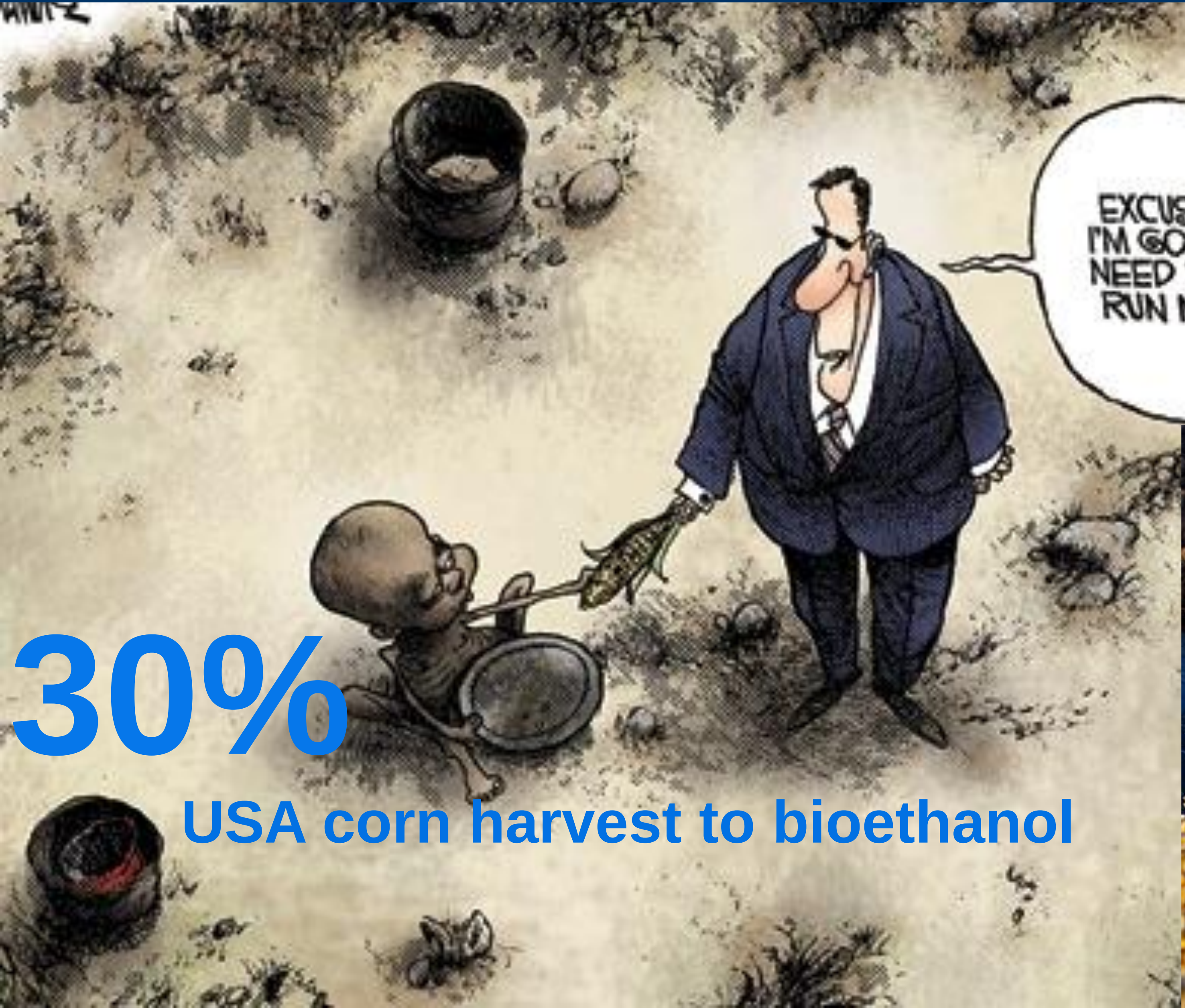
Food for Fuel

Cheap competition

Lack of incentive

Cost

Conflict for resources: Food vs Fuel



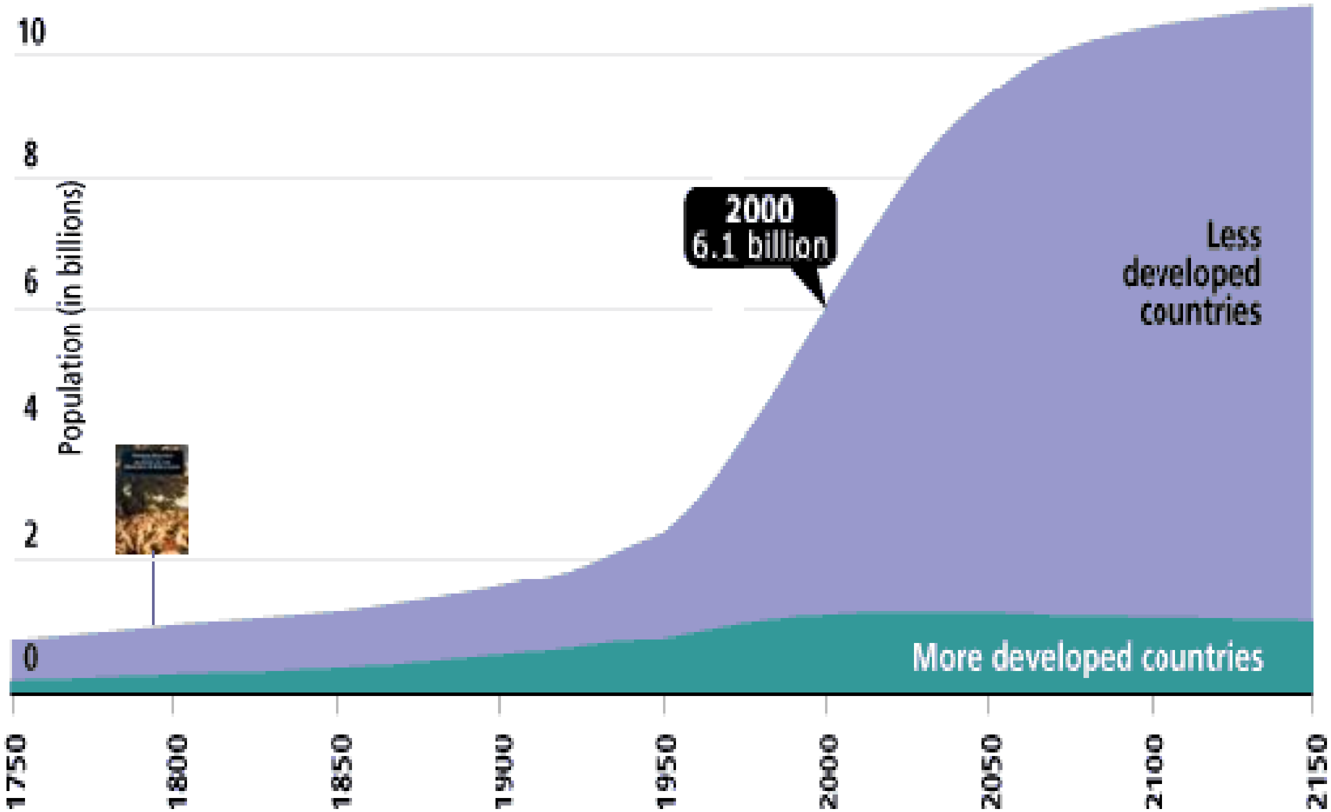
30%

USA corn harvest to bioethanol

54%

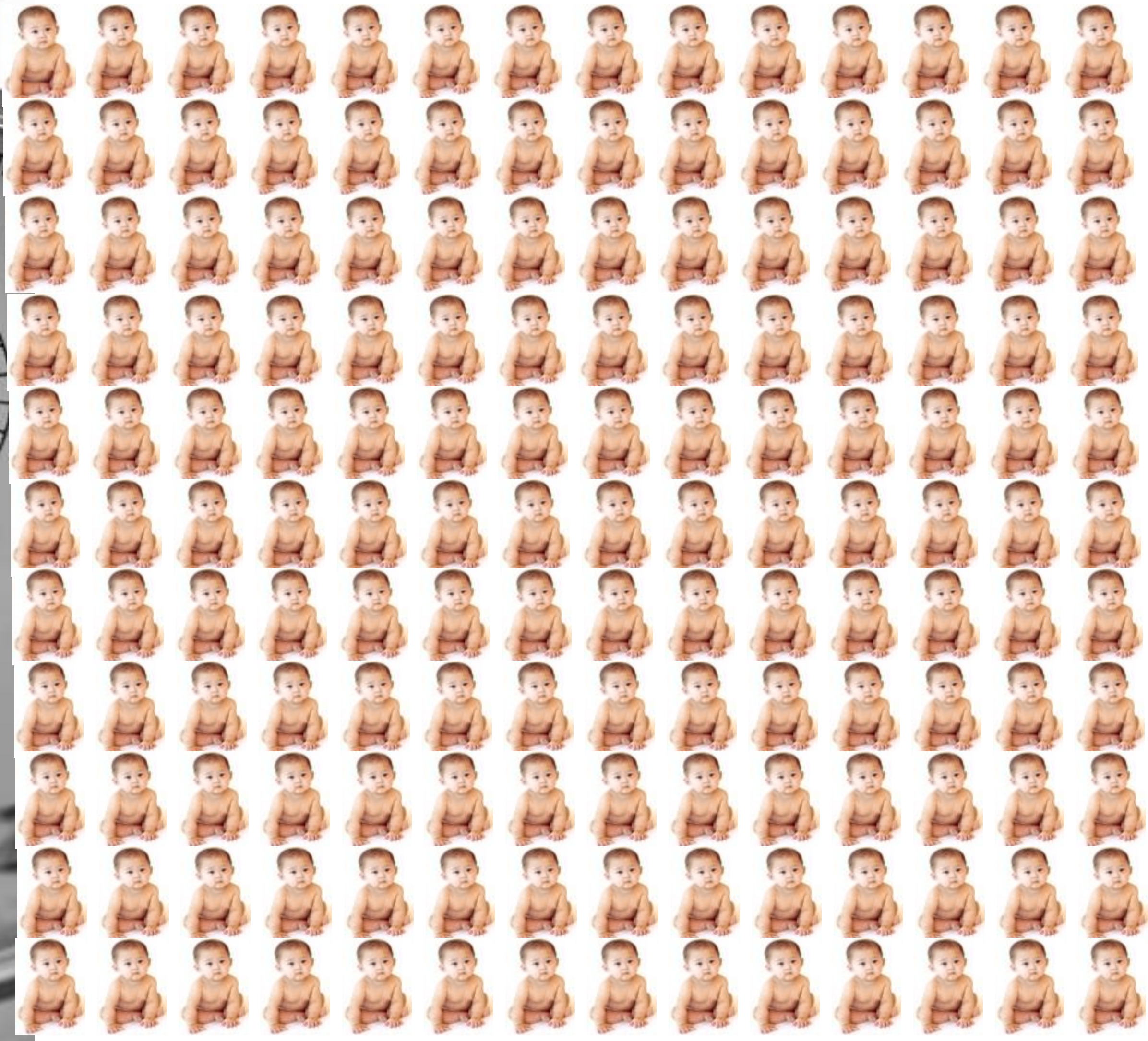
Population - competition for resources

2013 = 7,200,000,000



http://www.worldometers.info/world-population/

Wait a minute -149 new people



Agriculture must be protected

2050 = 9.3 billion people

Global **grain** production must **DOUBLE**

Land is limited or in the wrong place

8.6	18.4	25.0	24.0	8.7	11.0	3.8

% of total world population @ 2050

Land is limited or in the wrong place

Perfect storm

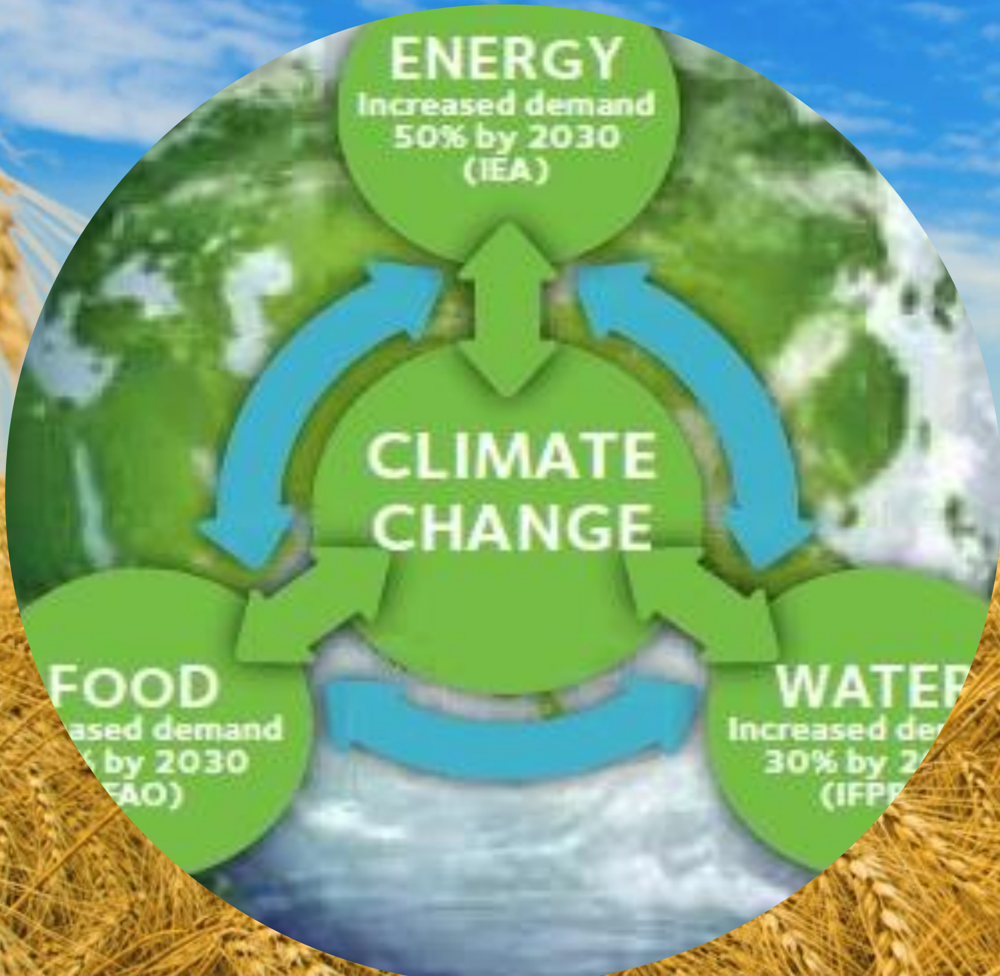
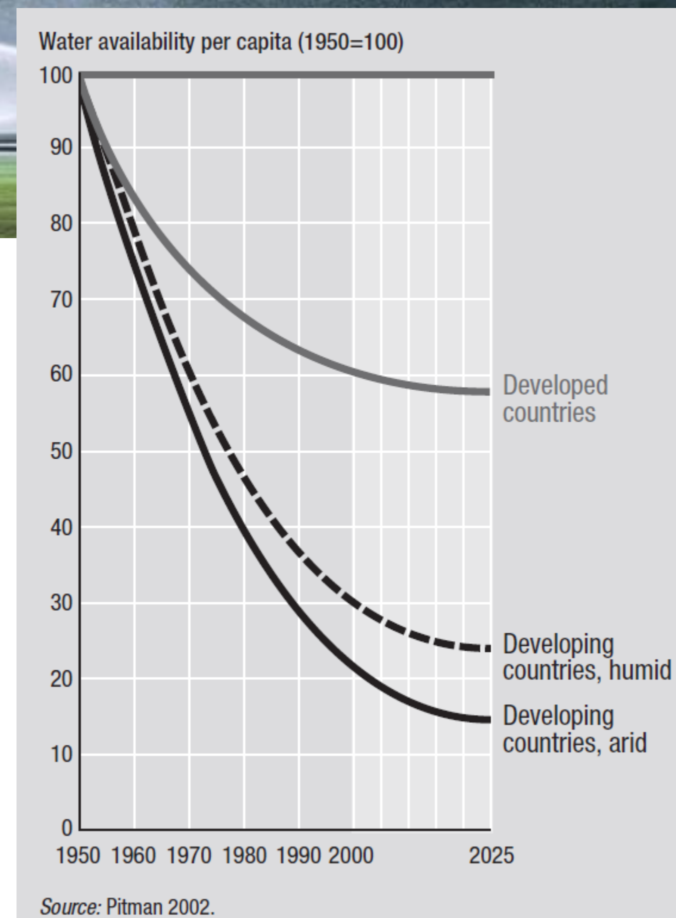


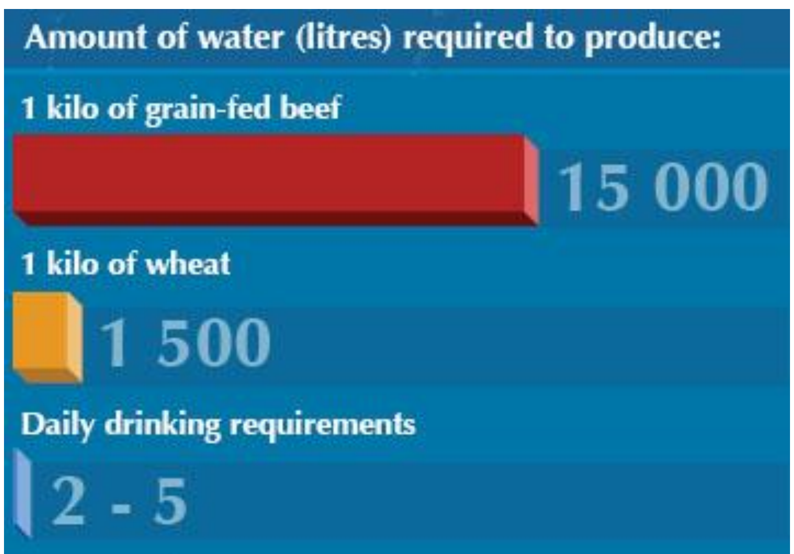
Table 3—Expected impacts of climate change on global cereal production

	1990-2080 (% change)
World	-0.6 to -0.9
Developed countries	2.7 to 9.0
Developing countries	-3.3 to -7.2
Southeast Asia	-2.5 to -7.8
South Asia	-18.2 to -22.1
Sub-Saharan Africa	-3.9 to -7.5
Latin America	5.2 to 12.5

Conflict for resources: Drink or Drive

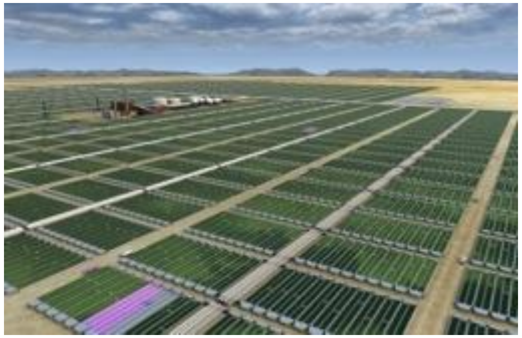


Agriculture –
70% global water consumption



Microbes – small, but big in biomass

Microalgae offer efficient land-use and less competition with agriculture



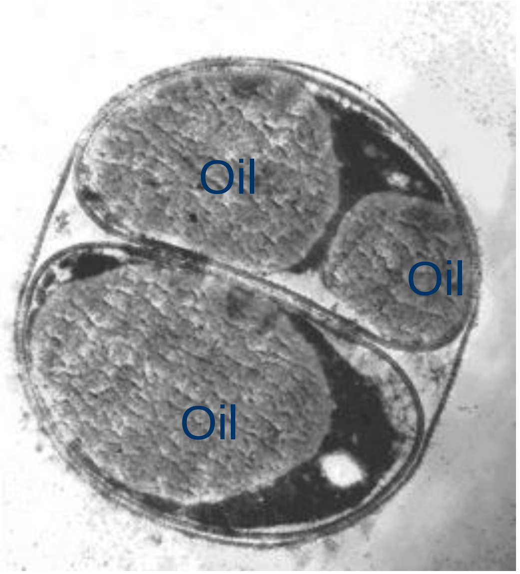
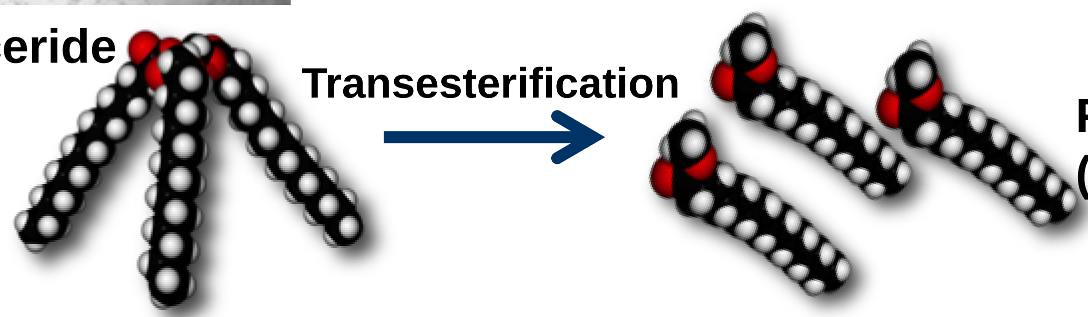


Table 1
Comparison of some sources of biodiesel

Crop	Oil yield (L/ha)	Land area needed (M ha)[a]	Percent of existing US cropping area[a]
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil palm	5950	45	24
Microalgae[b]	136,900	2	1.1
Microalgae[c]	58,700	4.5	2.5

[a] For meeting 50% of all transport fuel needs of the United States.
[b] 70% oil (by wt) in biomass.
[c] 30% oil (by wt) in biomass.

Chisti 2007



Biofuels: challenges to development

Food for Fuel

Cheap competition

Lack of incentive

Cost

Challenges: cheap competition

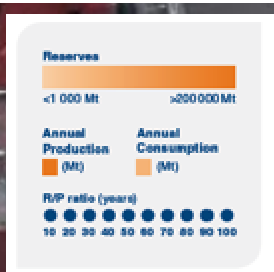
WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE
For sustainable energy.

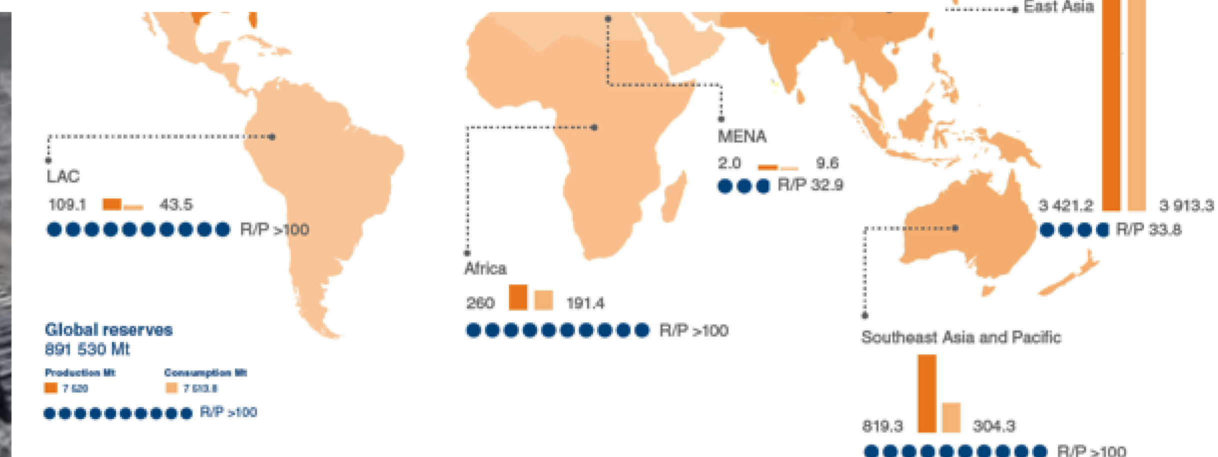
World Energy Resources

2013 Survey

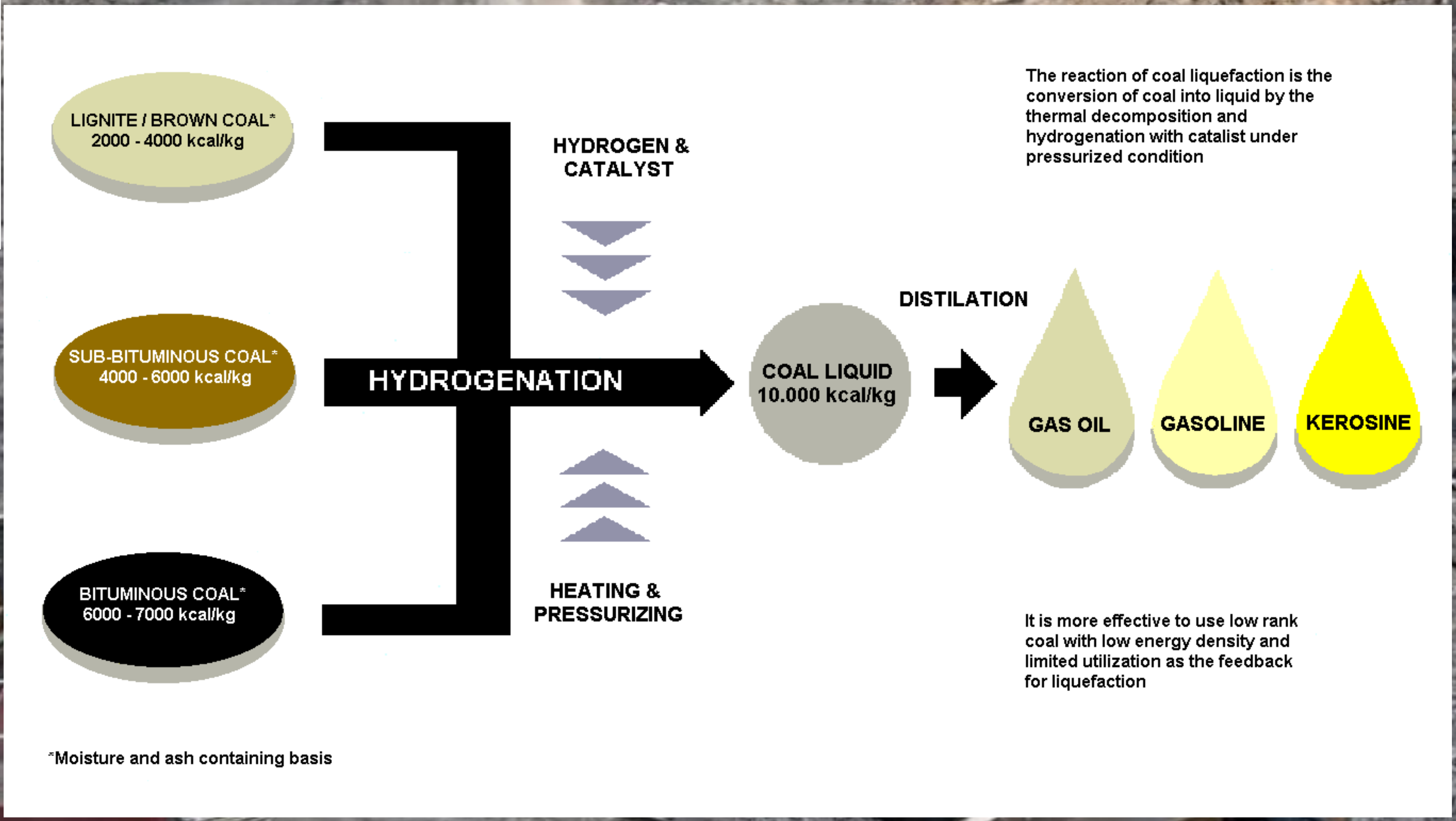
Coal: plentiful supply

	Reserves (Mt)		Production (Mt)		2011 R/P
Country	**2011**	**1993**	**2011**	**1993**	**years**
United States of America	237 295	168 391	1 092	858	> 100
Russian Federation	157 010	168 700	327	304	> 100
China	114 500	80 150	3 384	1 150	34
Australia	76 400	63 658	398	224	> 100
India	60 600	48 963	516	263	> 100
Rest of World	245 725	501 748	1 805	1 675	> 100
Global total	**891 530**	**1 031 610**	**7 520**	**4 474**	**> 100**



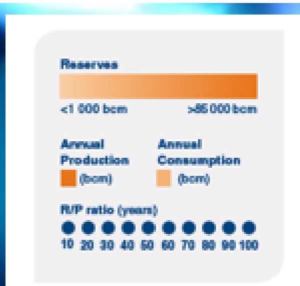


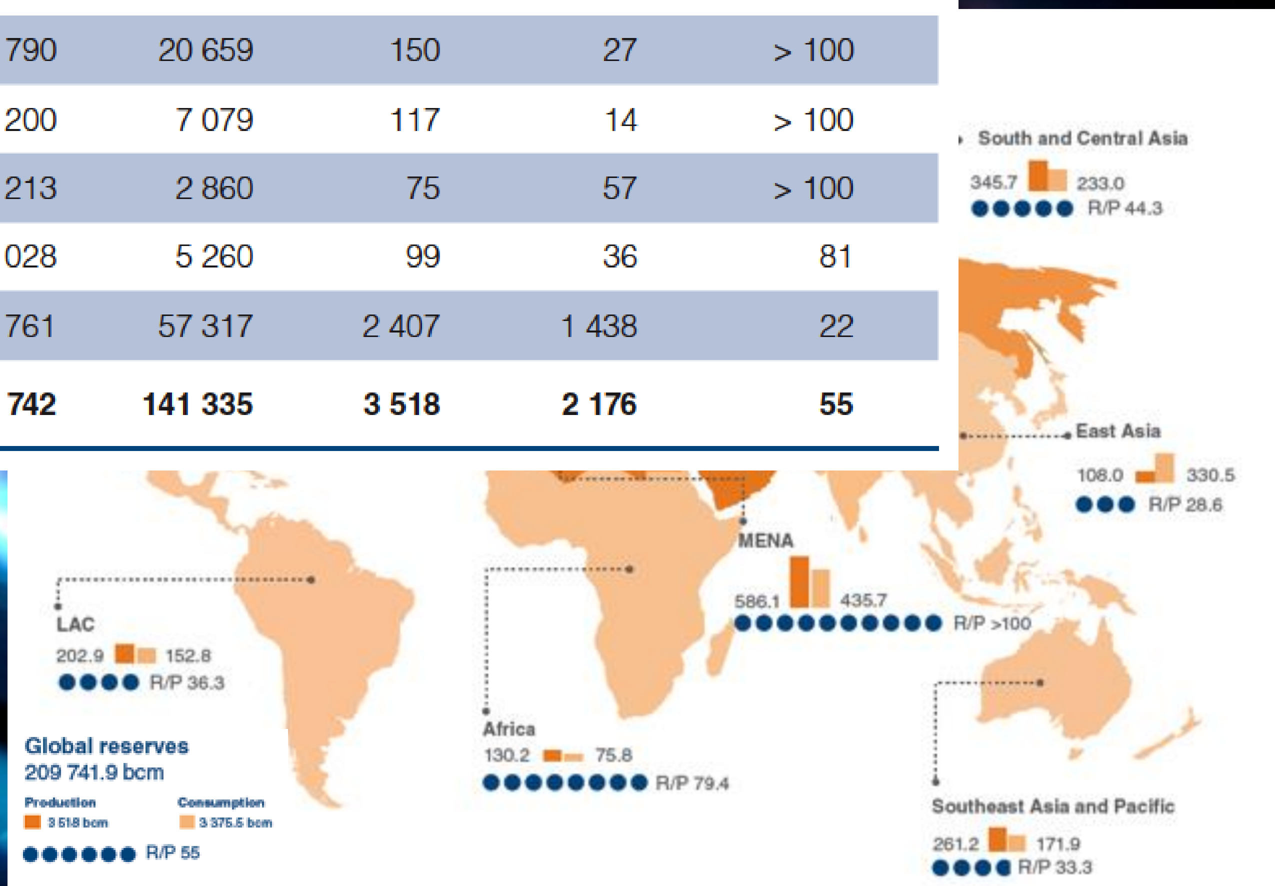
Coal to liquid



Natural gas

Country	Reserves (bcm) 2011	Reserves (bcm) 1993	Production (bcm) 2011	Production (bcm) 1993	R/P years
Russian Federation	47 750	48 160	670	604	71
Iran	33 790	20 659	150	27	> 100
Qatar	25 200	7 079	117	14	> 100
Turkmenistan	25 213	2 860	75	57	> 100
Saudi Arabia	8 028	5 260	99	36	81
Rest of World	69 761	57 317	2 407	1 438	22
Global Totals	**209 742**	**141 335**	**3 518**	**2 176**	**55**





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Gas to liquid: Fischer–Tropsch process

sasol
reaching new frontiers


Franz Fischer 1934


Hans Tropsch1930

Biofuels: challenges to development

Food for Fuel

Cheap competition

Lack of incentive

Cost

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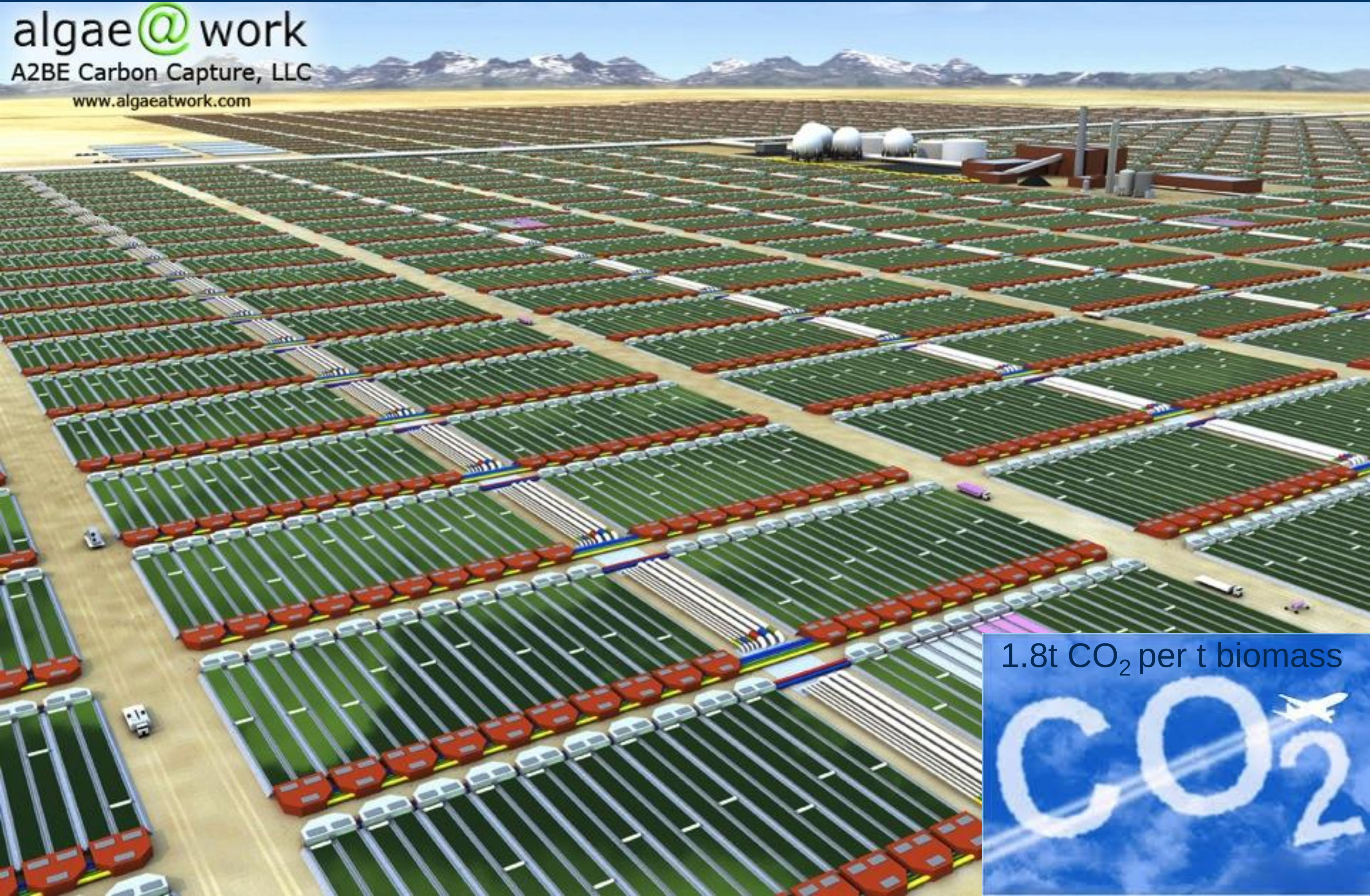
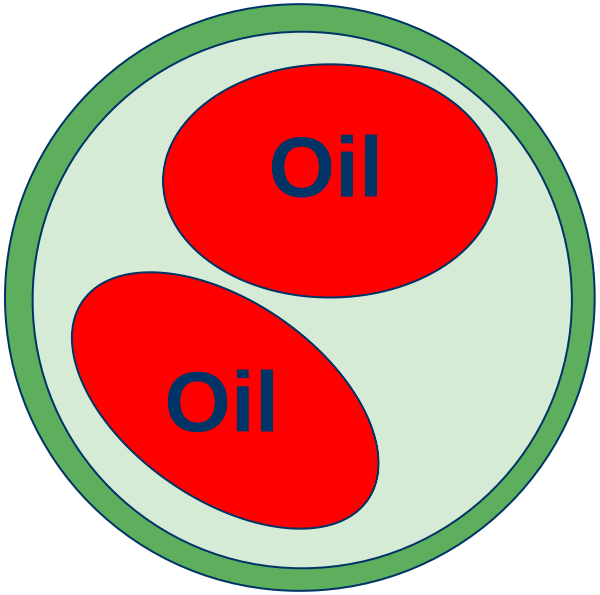
Algaloil



1.8t CO_2 per t biomass

Challenges: cost

1 barrel of oil (159 L) @ $110.88 (Brent Crude) $0.69/L



CapEx

- Open ponds
- Closed photobioreactor

OpEx

- Electricity for cultivation
- CO_2
- Nitrogen fertilizer
- Phosphate fertilizer
- Electricity for harvesting/dewatering
- Electricity for cell cracking
- Oil extraction
- Transesterification

Challenges: cost

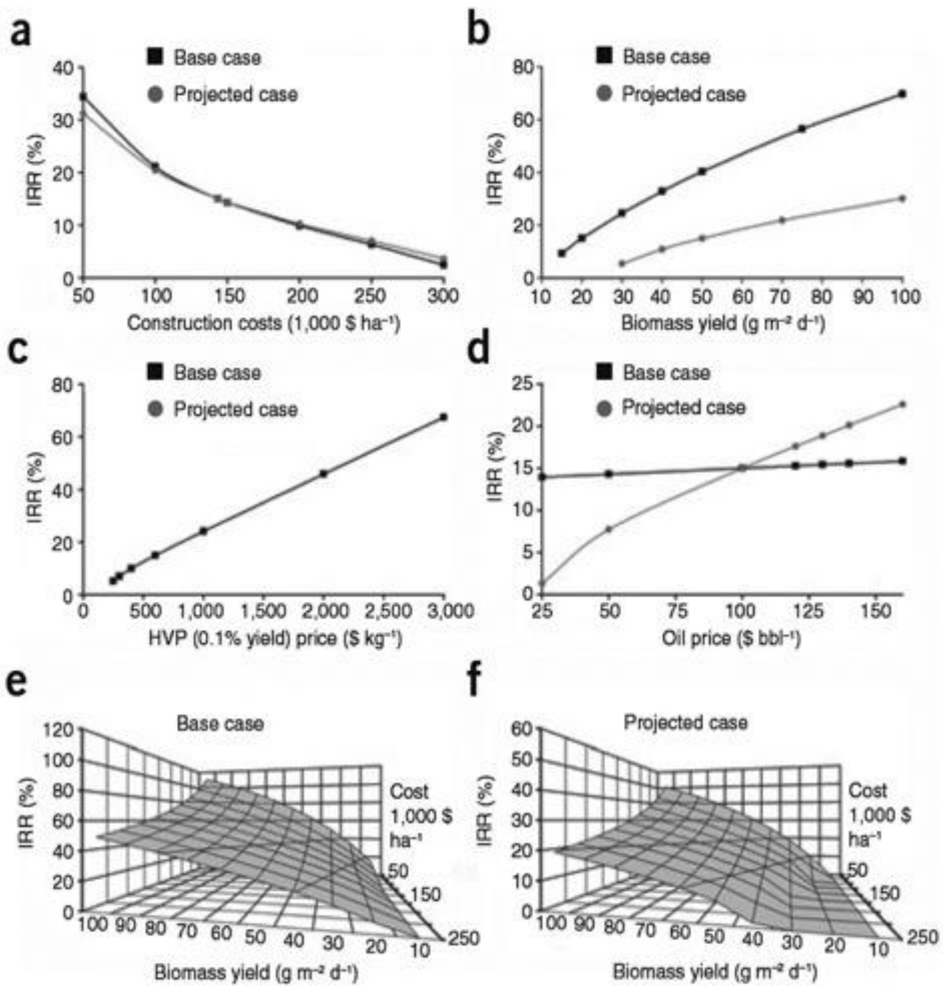


Figure 1 Sensitivity analysis. Using the parameters described in the text, an industrial feasibility study was constructed to model the effect of varying specific interconnected parameters on the internal rate of return (IRR). (**a**–**d**) The effect of these variables on the base case and projected case scenarios. (**e**,**f**) Potential gains from simultaneous advancement in the key factors of construction cost and biomass productivity.

Reduce capital costs of production facilities (open pond/PBR)

Increase productivity (biomass yield g/m^2/d)

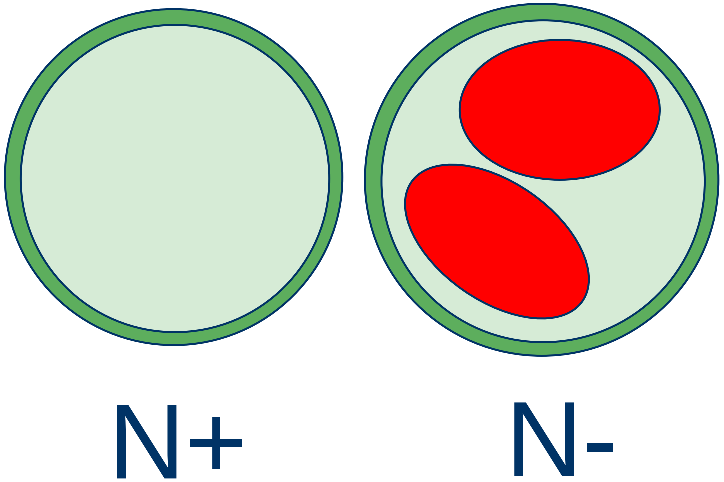
Stephens et al 2010

Constraints that add significantly to cost

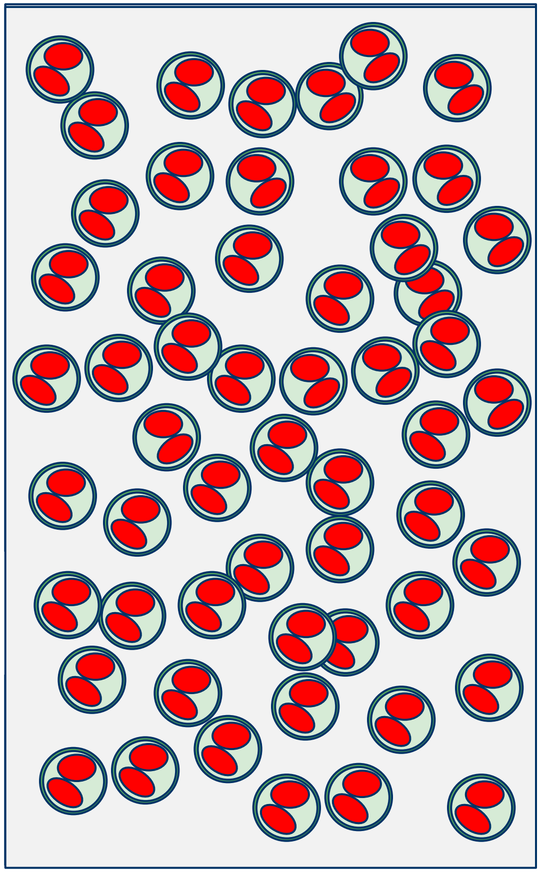
Oil is synthesized in nutrient poor stationary phase cells

Results in 2 phase production process

Fed-batch challenging

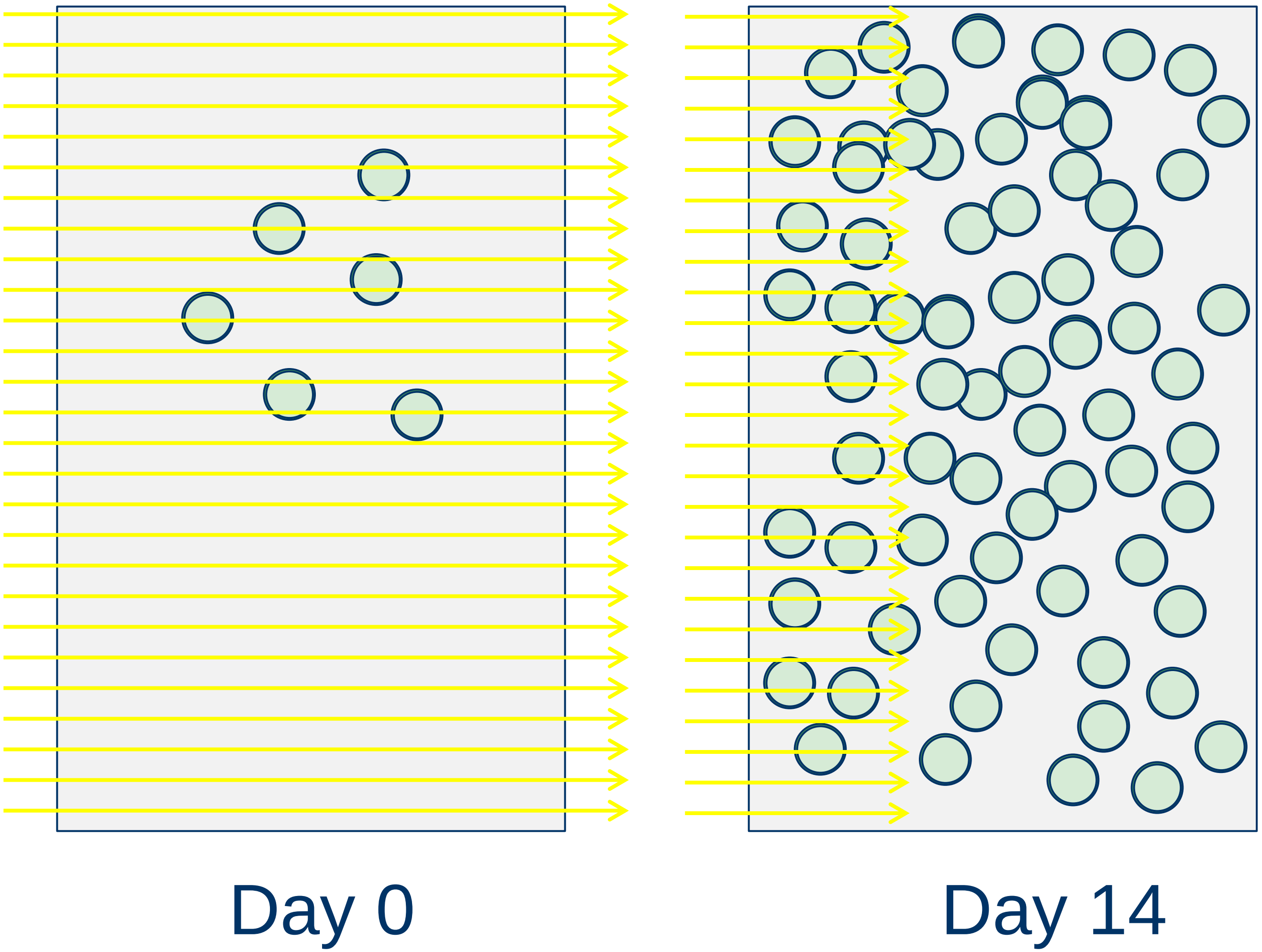


Day 21



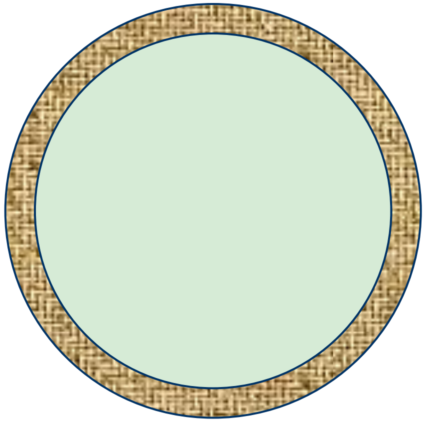
Constraints that add significantly to cost

There is a trade-off between light penetration and culture density
Resulting in high harvesting & dewatering costs



Low cell density
at harvest
< 3 g/L
WET, WET, WET

Better algal strains



Features

- High growth rates
- Resist contamination
- High cell wall algaenan content
- Low protein (NOX)

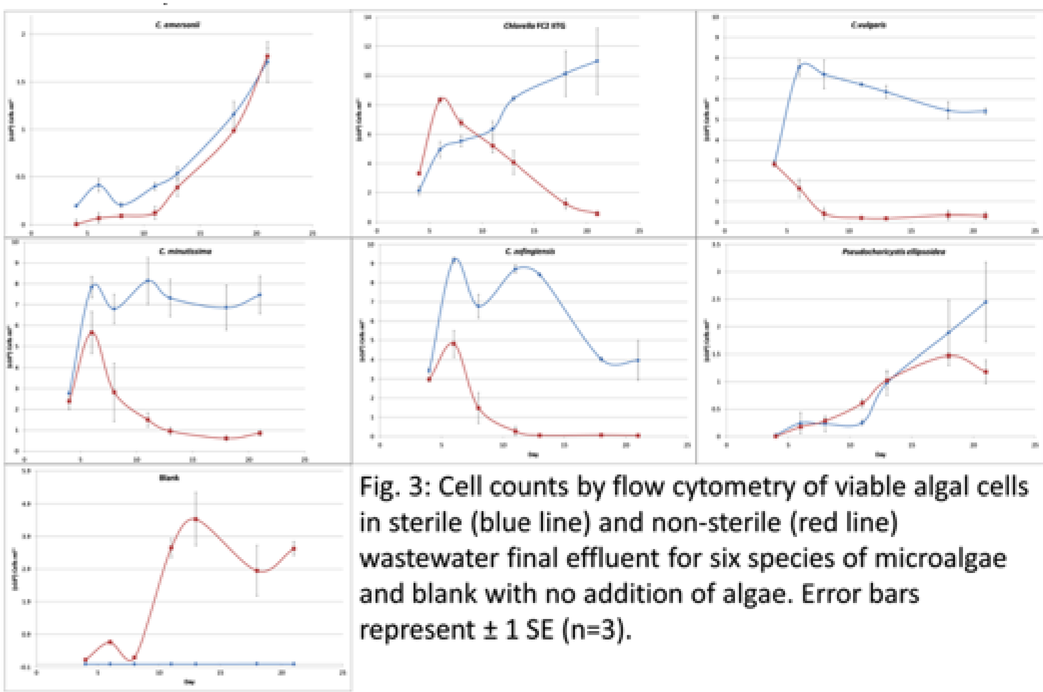
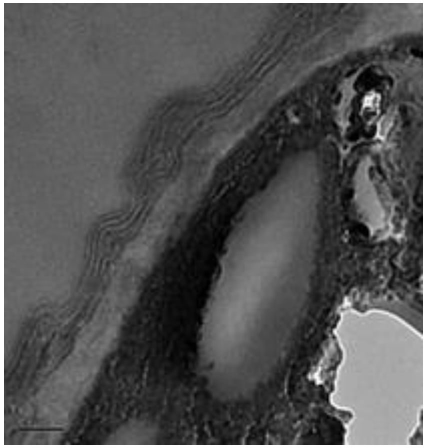
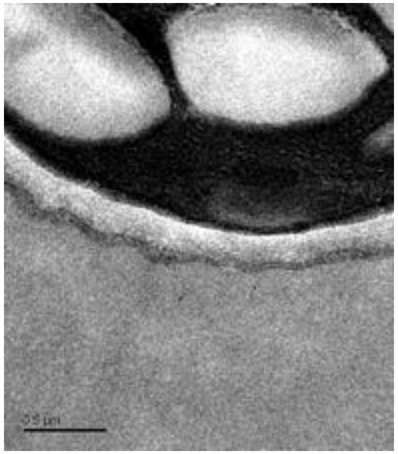


Fig. 3: Cell counts by flow cytometry of viable algal cells in sterile (blue line) and non-sterile (red line) wastewater final effluent for six species of microalgae and blank with no addition of algae. Error bars represent ± 1 SE (n=3).

C.emersonii



S.vacuolatus



(H. D. Smith-Baedorf, 2012)

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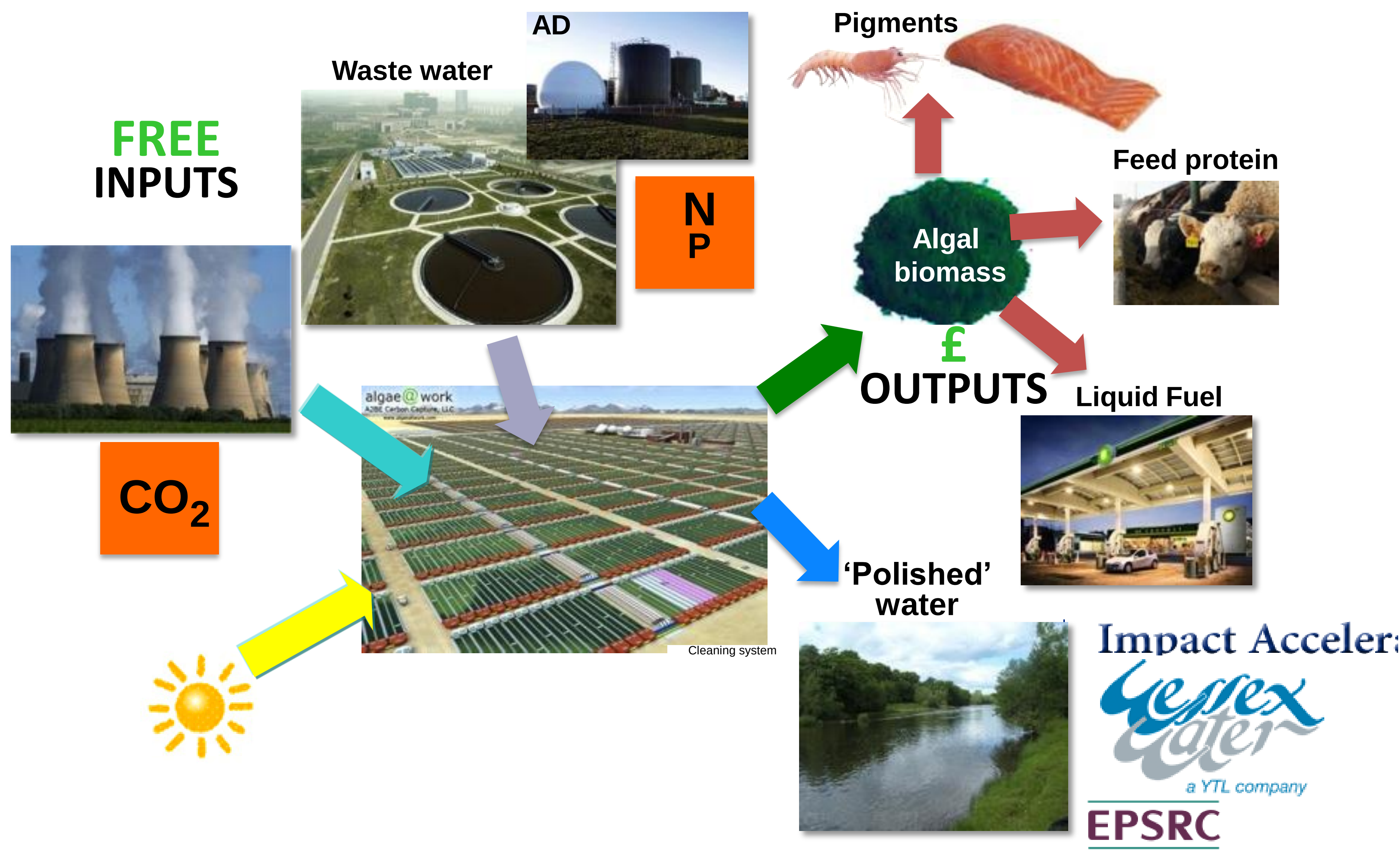
Waste feedstocks and co-products reduce production costs



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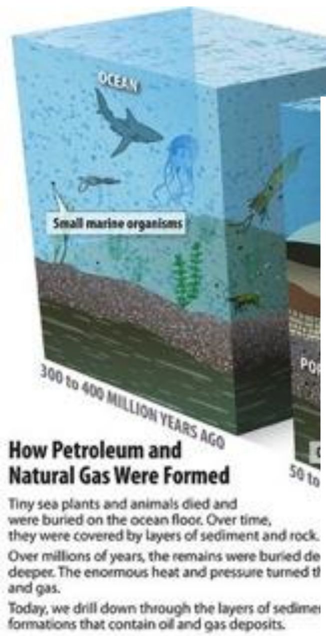
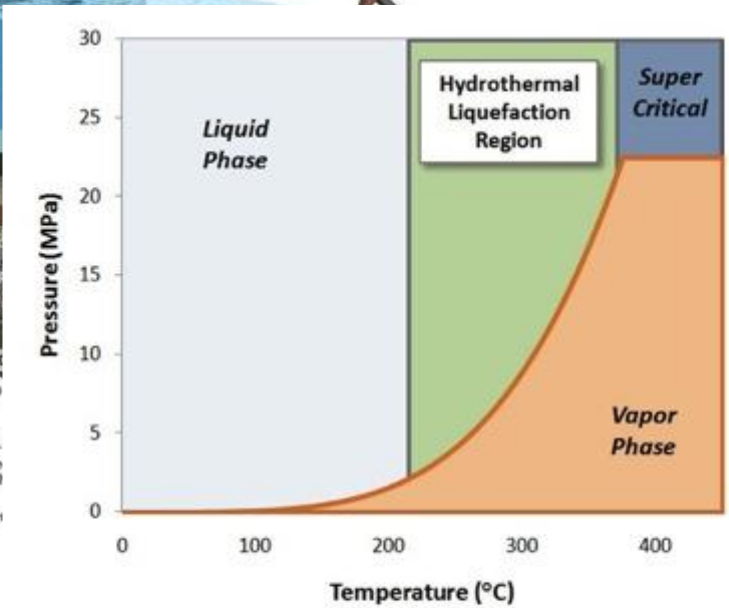
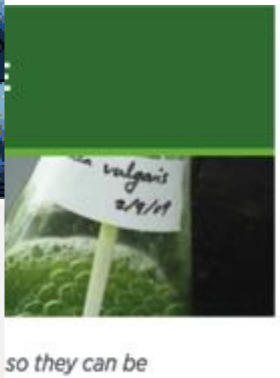
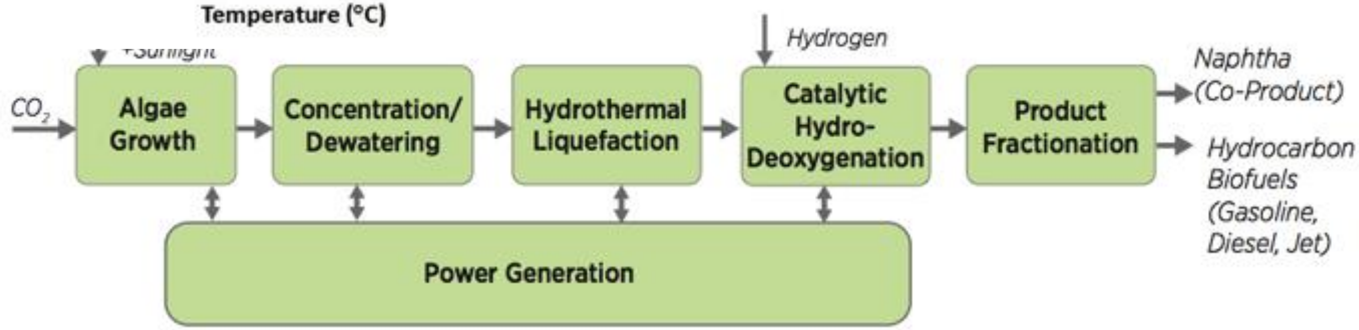
Hydrothermal liquifaction

Mitigate constraints by mimicking natural oil forming process to produce bio-crude (for direct blending with petroleum crude)









Cost comparisons

Algae-derived gasoline produced using HTL

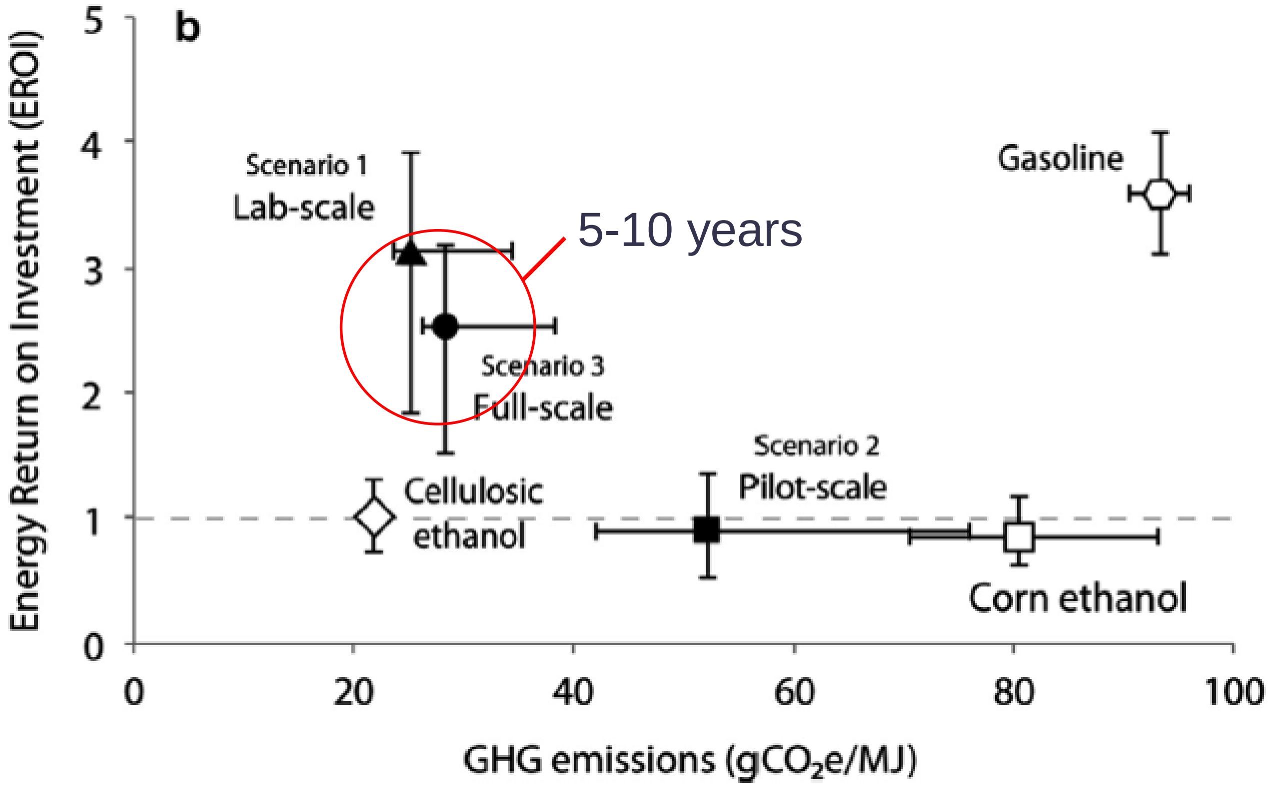


Table 1
Three scenarios were defined to capture the emergent nature of the algae-to-energy sector.

#	Name	Description
1	Lab scale	Modeling inputs were obtained from a variety of published sources from small scales under idealized conditions. These types of data have been used in many LCA studies (Frank et al., 2013; Stephenson et al., 2010; Clarens et al., 2010; Liu et al., 2012)
2	Pilot scale	Parameters were based on values collected between 2012 and 2013 in pilot scale operations at the Sapphire facility in Las Cruces, NM.
3	Full scale	Input parameters are based on industry forecasts with respect to energy efficiencies and yields for the coming 5 years. This scenario does not include advances that would be made possible by genetic engineering of algae strains.

Liu et al 2013 Bioresource Technology **148**

Liquid biofuel production using microorganisms: too small to make a difference?

Thank you