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Can We Make Lignocellulosic Biofuels Sustainable?

Richard Templer

São Paulo, Brazil
February 24th – March 1st 2009

The alliance

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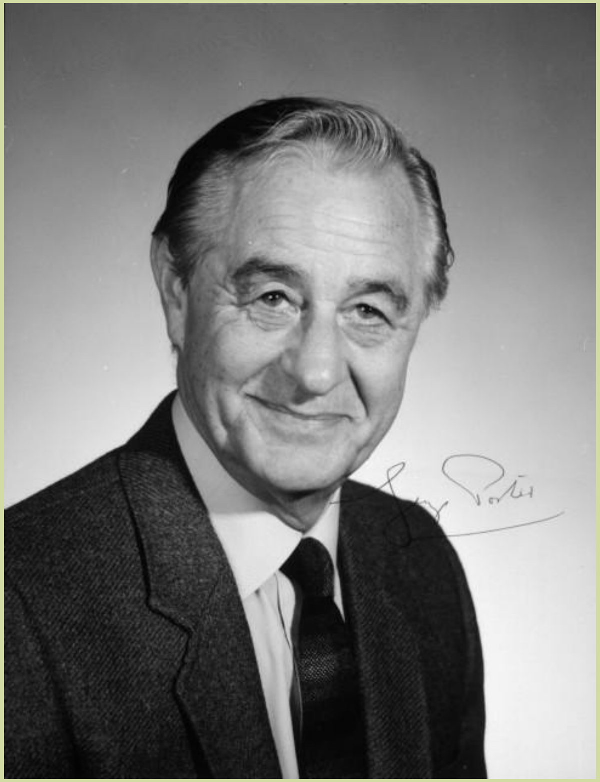


ROTHAMSTED RESEARCH

Imperial College London

John Innes Centre

IGER

Over 130 scientists, engineers, economists and policy experts.

Plants that fuel the future

- Transport fuel
- Chemicals
- Materials
- Heat and power
- Land remediation

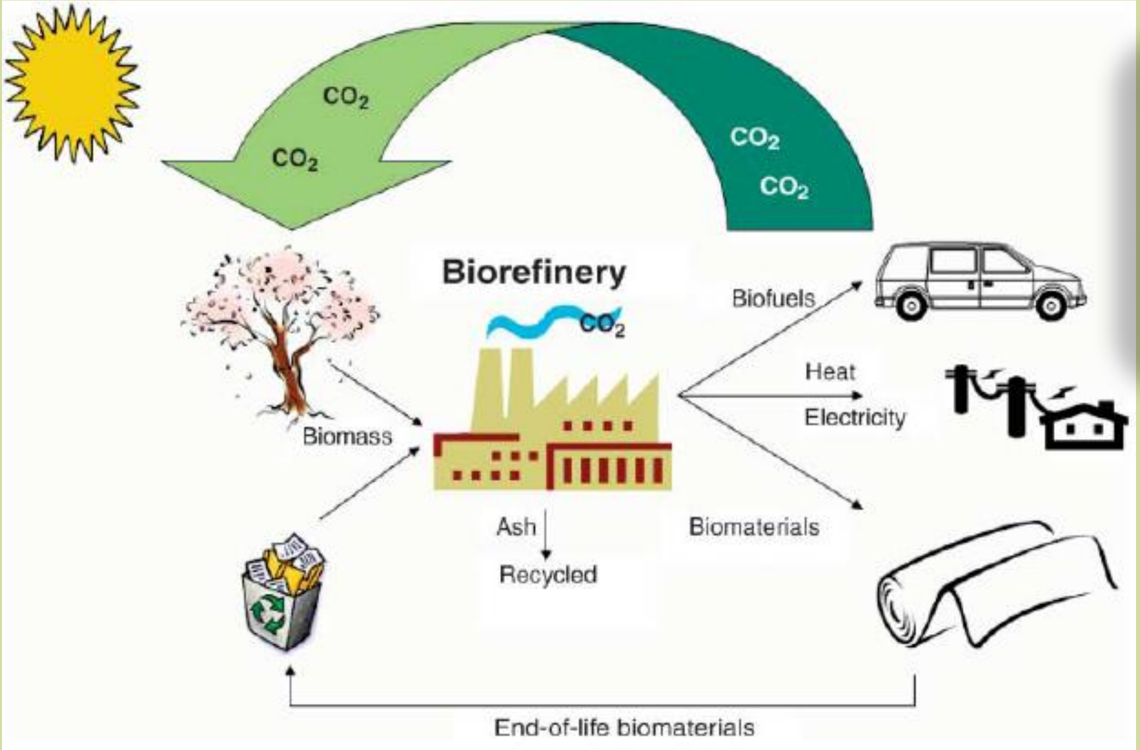
Mission

Devise economically, socially and environmentally sustainable routes to the production of energy and materials from plants with a positive impact on climate change and energy security.

A focus on perennial biomass

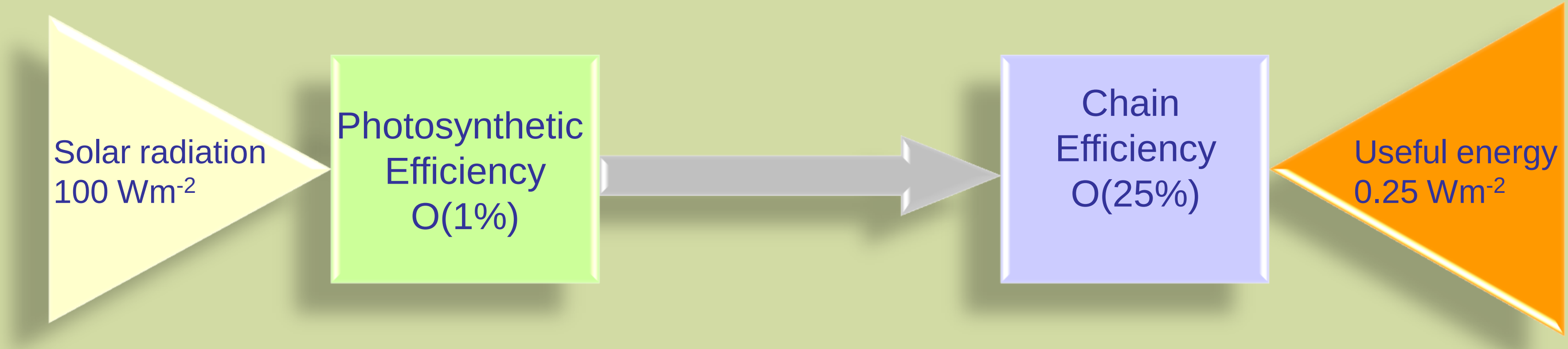
- Highest potential energy savings and GHG reductions (for temperate zones)
- Recycle their nutrients (lower inputs required)
- Lower environmental footprint
- Non-food crop
- 80% of the plant mass is used as feedstock
- Longer growing season (more carbon fixed)
- No annual cultivation

A manifesto, of sorts….



Ragauskas et al. Science 311 (2006)

A focus on the system



Solar radiation
$100\ \mathrm{Wm}^{-2}$

Photosynthetic Efficiency O(1%)

Chain Efficiency O(25%)

Useful energy
$0.25\ \mathrm{Wm}^{-2}$

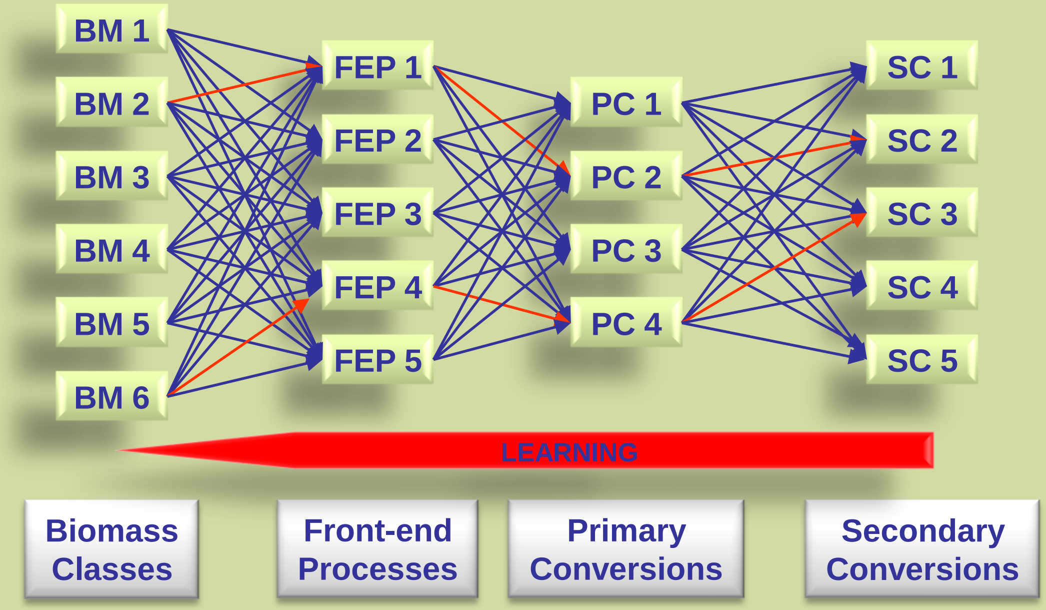
Scope for 2-fold improvement

Scope for 3-fold improvement

Dunnett and Shah J Biobased Mater Bio 1 (2007)

Overall: realistic scope for 6-fold improvement!

Finding the best system



Science and technology challenges

- Increase biomass yields
- Reduce threats to and from biomass
- Increase processable biomass
- Create optimised processing
- Create flexible, modular biorefining
- Create integrated delivery pipelines
- Develop platforms of understanding
- Develop disruptive technology

Yield improvement

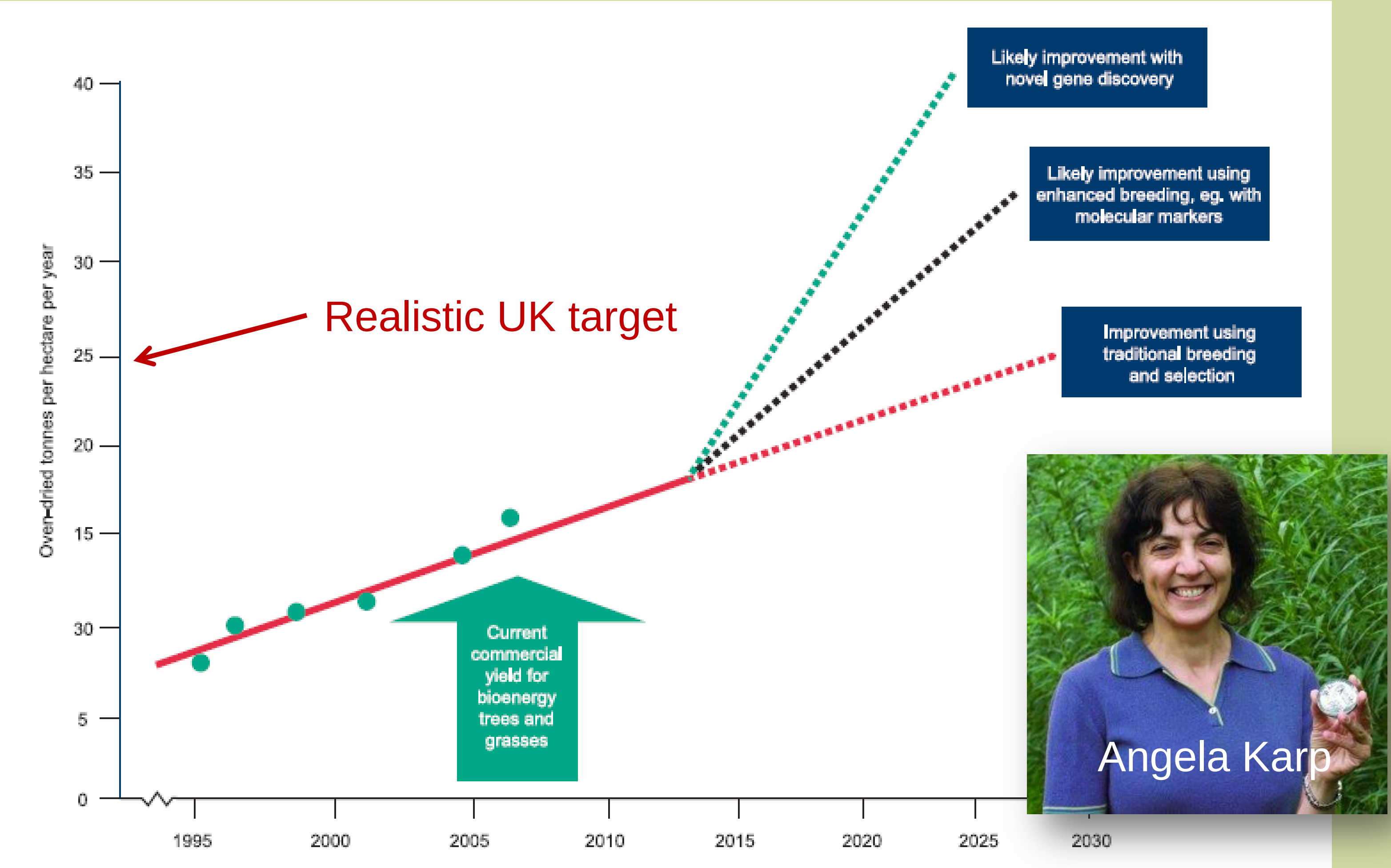
Yield improvement – germplasm collections

1,300 accessions of willow (incl. 100 pure species) at Rothamsted Research

Extensive perennial grass collections including 800 accessions of Miscanthus @ Rothamsted and IBERS

500 diverse poplars capturing wide natural diversity

Yield improvement – Willow



Likely improvement with novel gene discovery

Likely improvement using enhanced breeding, eg. with molecular markers

Improvement using traditional breeding and selection

Realistic UK target

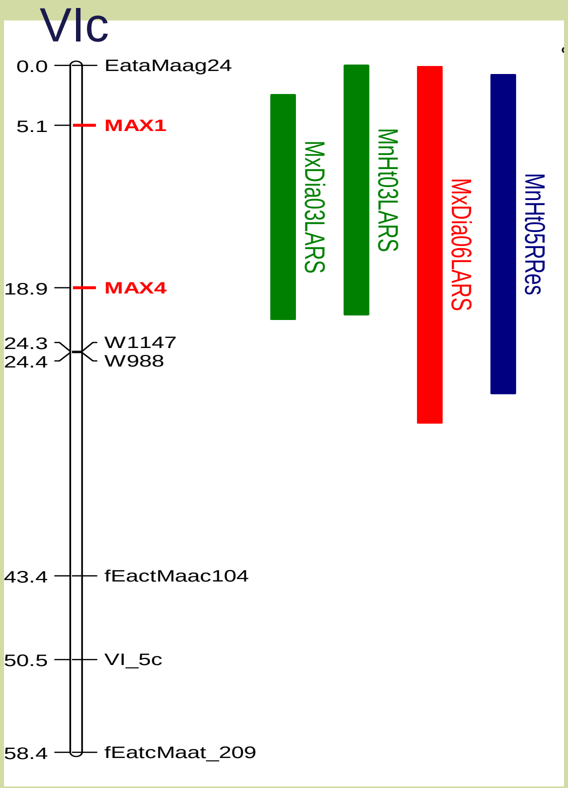
Current commercial yield for bioenergy trees and grasses

Angela Karp

Yield improvement – accelerated breeding

Many thin stems

Fewer thick stems



The more axillary branching (*max*) mutants in Arabidopsis have altered branching. Corresponding genes map to yield QTL in willow.

Yield improvement – new genetic leads

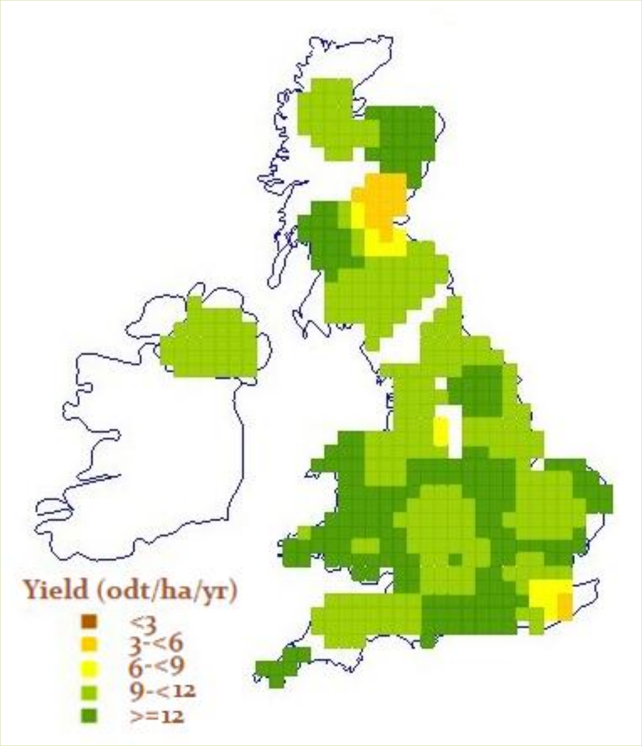
The mutated gene is implicated
in response to pathogen infection

The mutated gene
encodes a UDP
glycosyl transferase

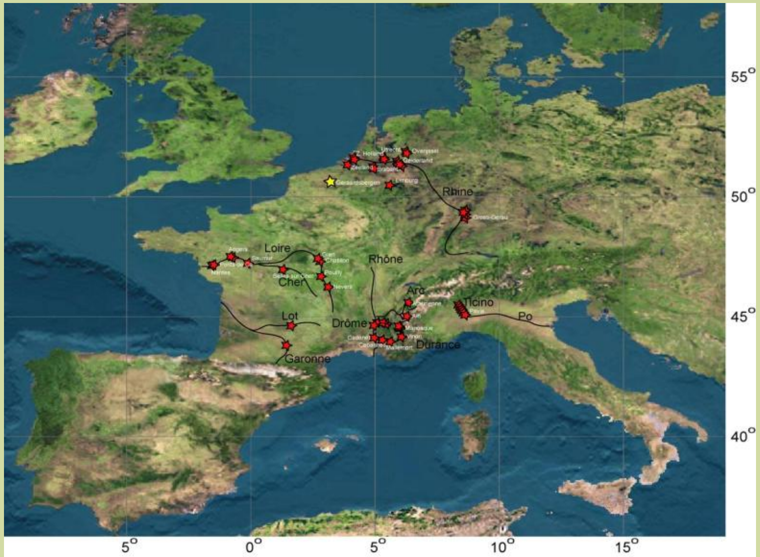
Yield improvement – agronomic models

Example data on poplar locations/yield - TSEC-Biosys Project

from:- Matt Ayott, Gail Taylor
Southampton University



Productivity map of *Populus trichocarpa* genotype ‘trichobel’, second rotation

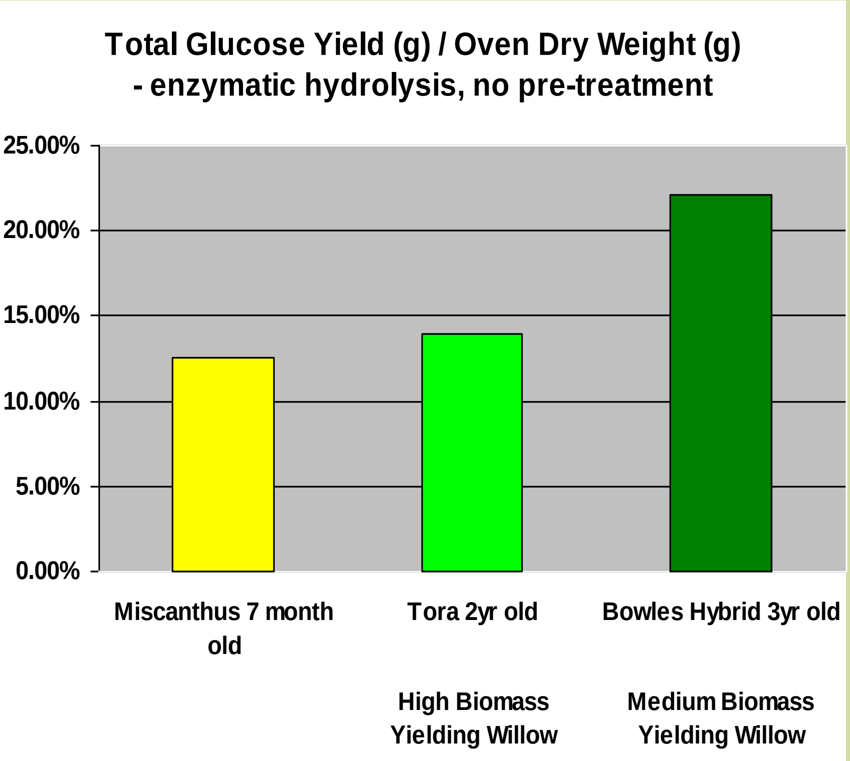


energypoplar EC FP7 Project

Processability

Processability – not big but sweet

Nick Brereton, PhD student



An example in Willows

Bowles hybrid releases its glucan much more readily than other varieties, even though it does not produce the greatest mass

Processability – variable alcohol yields with genotype

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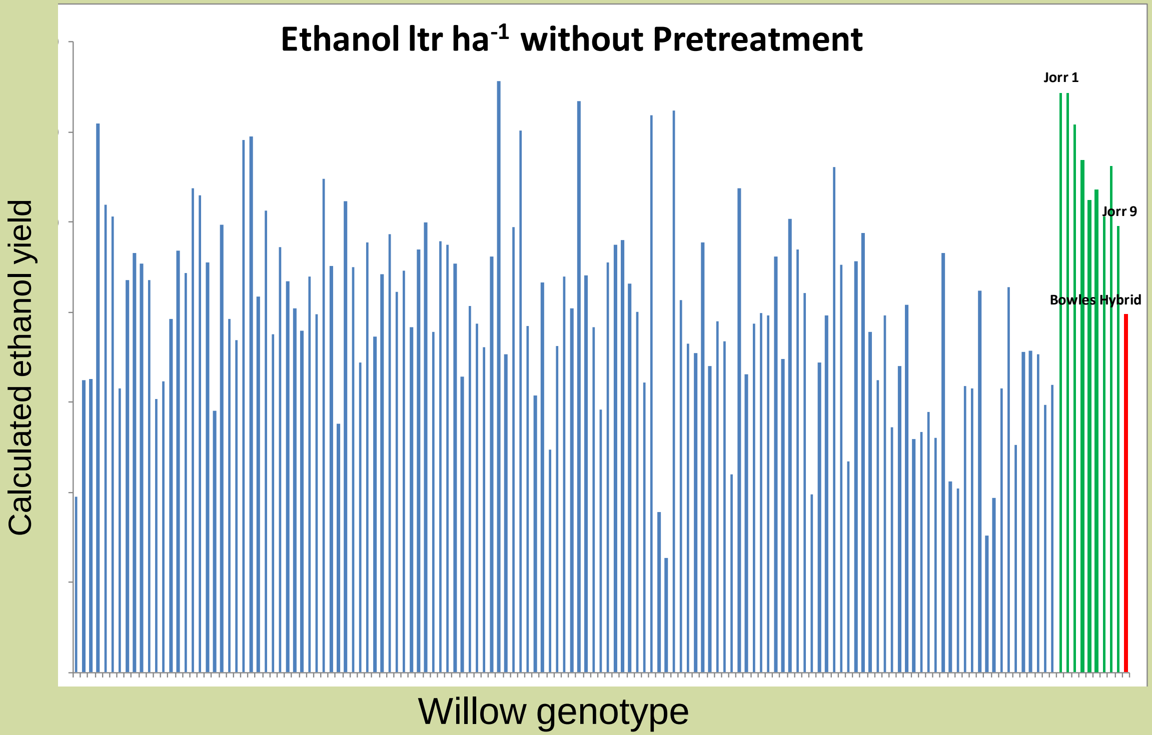
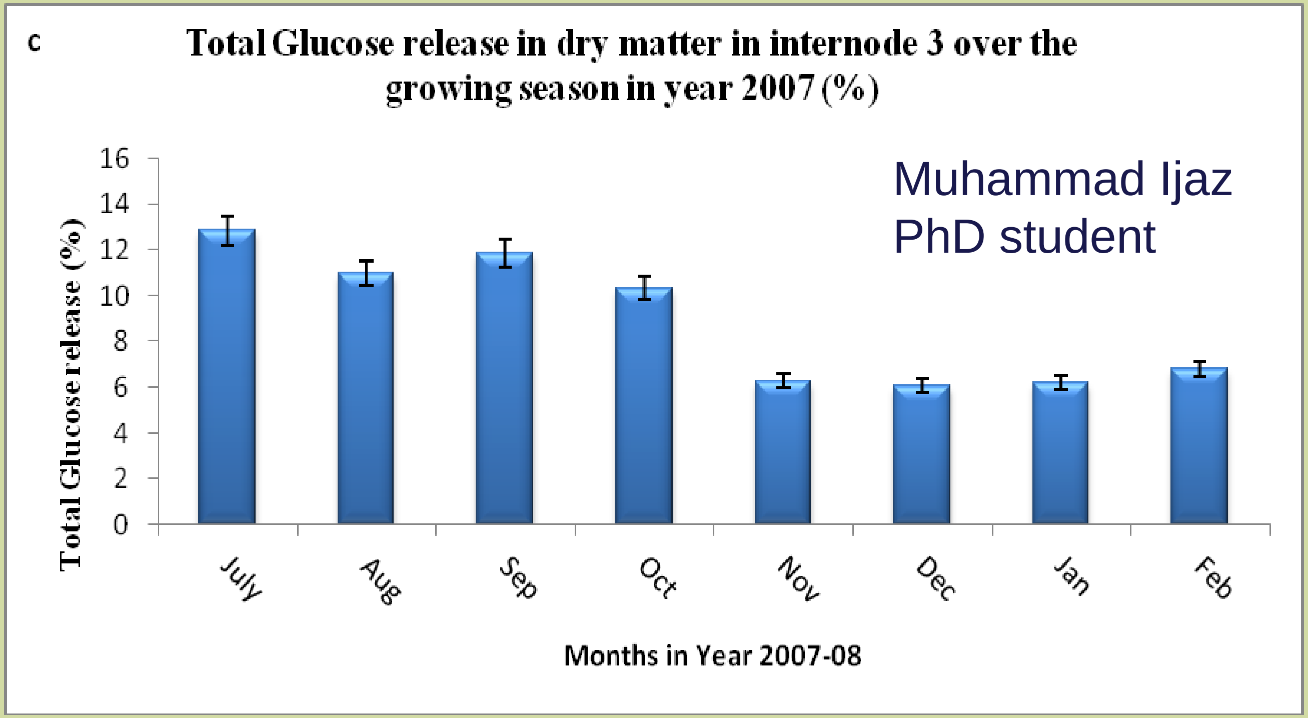
*Natural variation is **large** in saccharification and ethanol potential yield.*



NOTE:
No pre-treatment, the 'inherent' enzymatic sugar release is being investigated here

Processability – variable alcohol yields with season



Muhammad Ijaz
PhD student

Saccharification potential (no pre-treatment) changes substantially over the development cycle

Harvesting time influences ease of enzymatic hydrolysis

Optimised processing

Optimised processing – brown rot fungi

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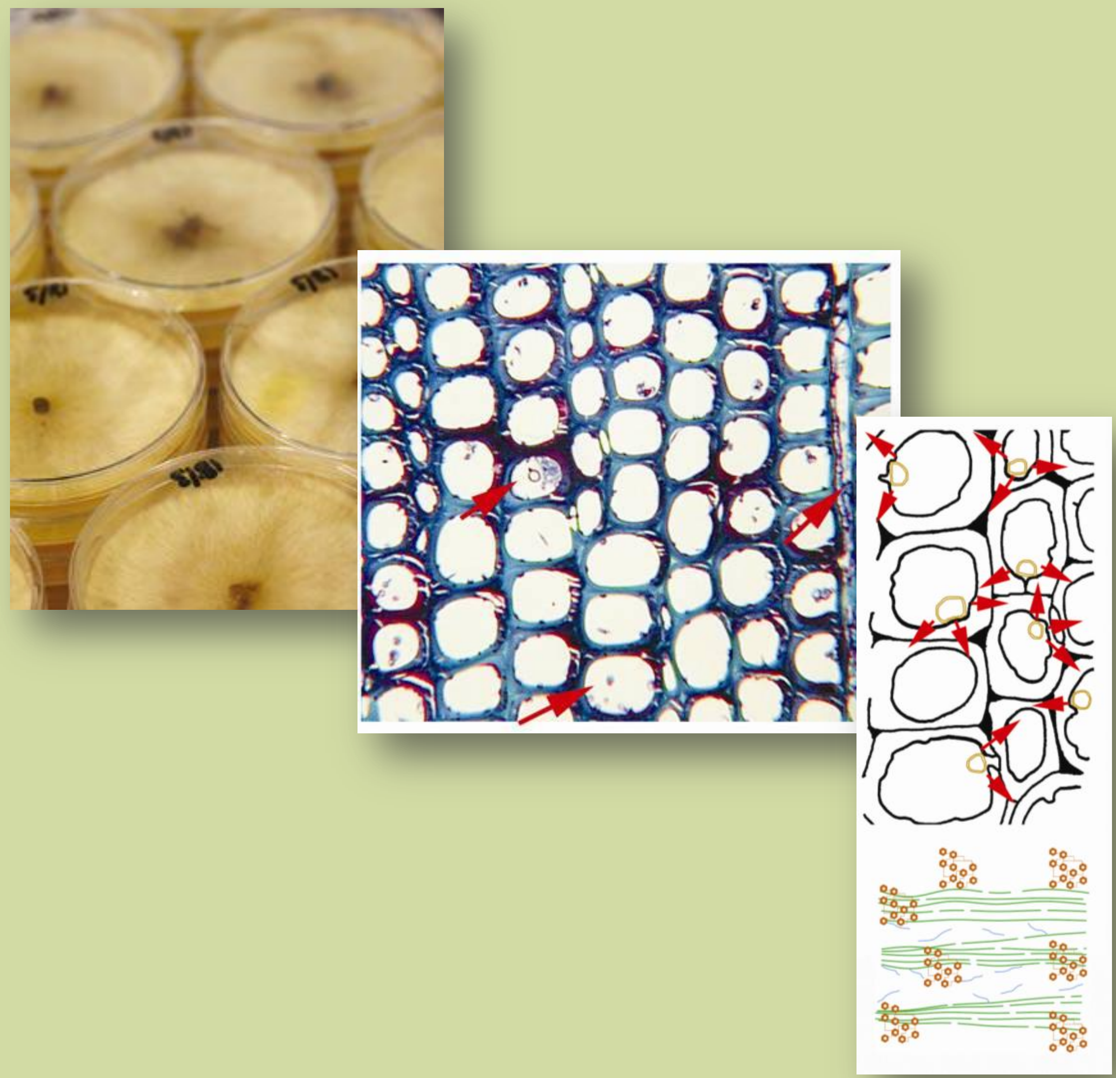
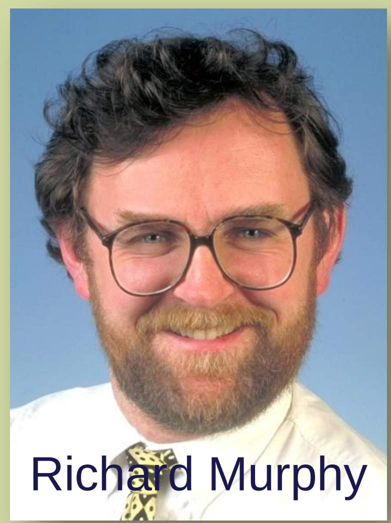




Richard Murphy

with
Mike Ray- Research Fellow,
David Leak
and Pietro Spanu

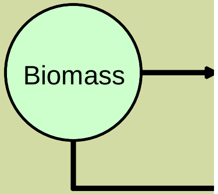
Optimised processing – brown rot fungi

from pine sapwood

- Up to 70% of glucan becomes available for enzymatic hydrolysis
- Ferments to ethanol without inhibition
- No harmful waste streams
- Low energy inputs
- Little GHG emission

Process integration

Process integration



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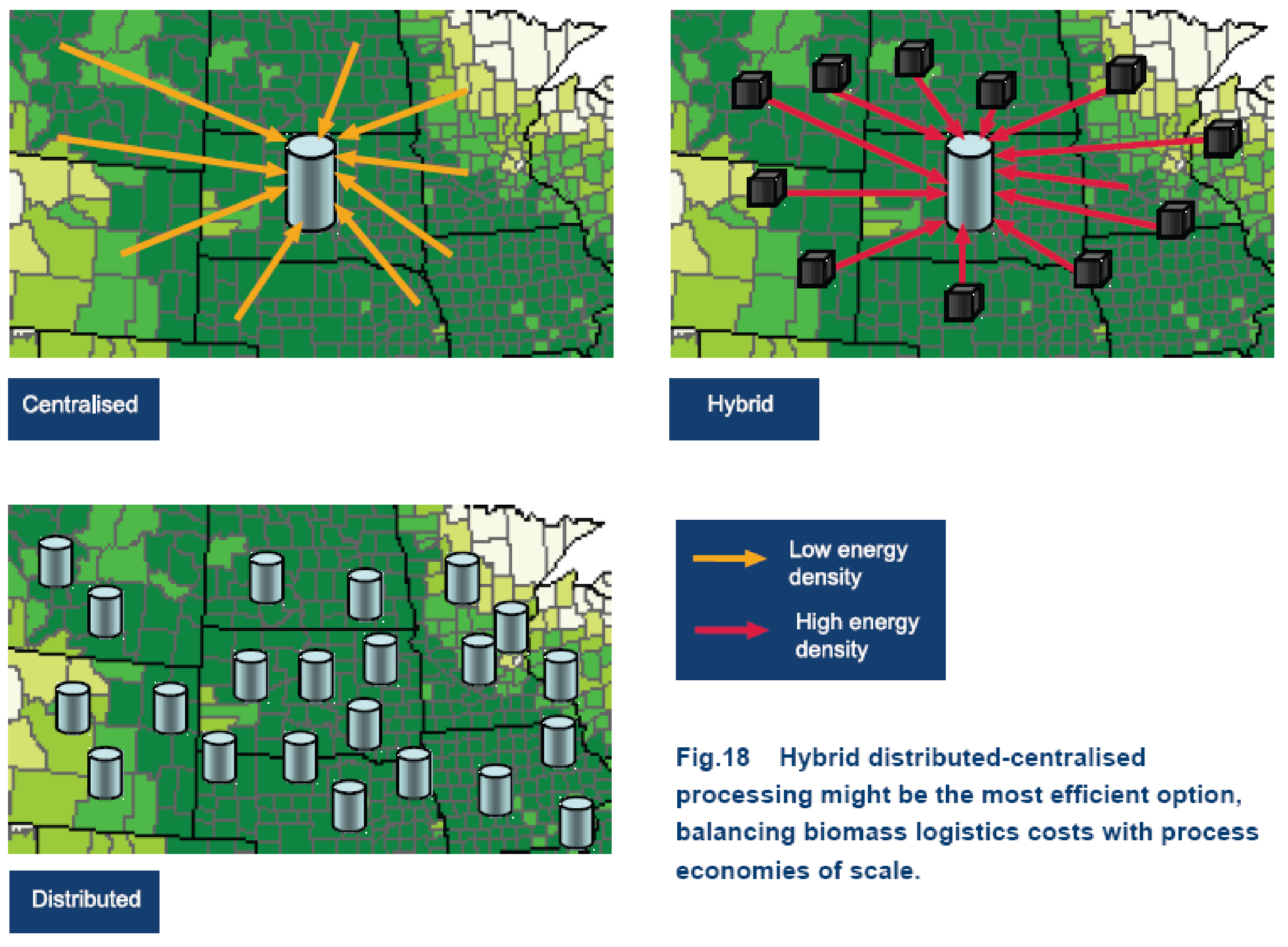


Fig.18 Hybrid distributed-centralised processing might be the most efficient option, balancing biomass logistics costs with process economies of scale.

The essential messages

- There is a lot of headroom to make truly sustainable lignocellulosic biofuel
- You must look at integrated processes to achieve this
- The world is only now generating the knowledge that can guide us in choosing the best processes
- But.....

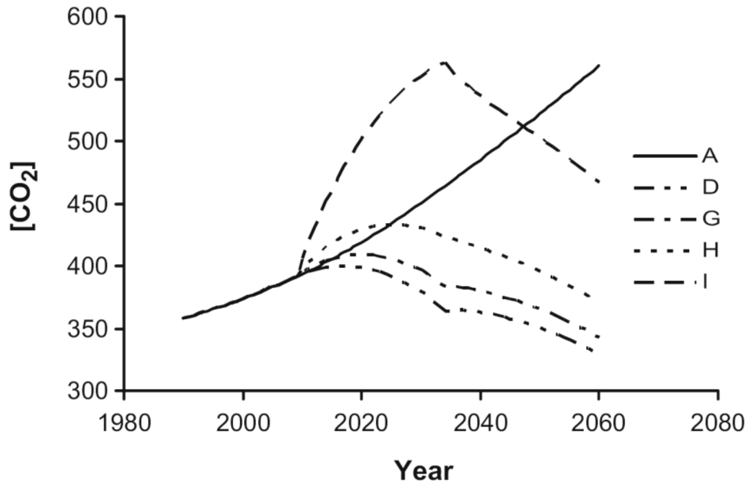
Land use, policy and economics

Land use change - GHG and soil carbon balances

‘Direct’ & ‘Indirect Effects’

- Read (2007)
- Searchinger et al + Fargione et al (2008)
- Galbraith (2005)

Not all land use change has to be ‘negative’

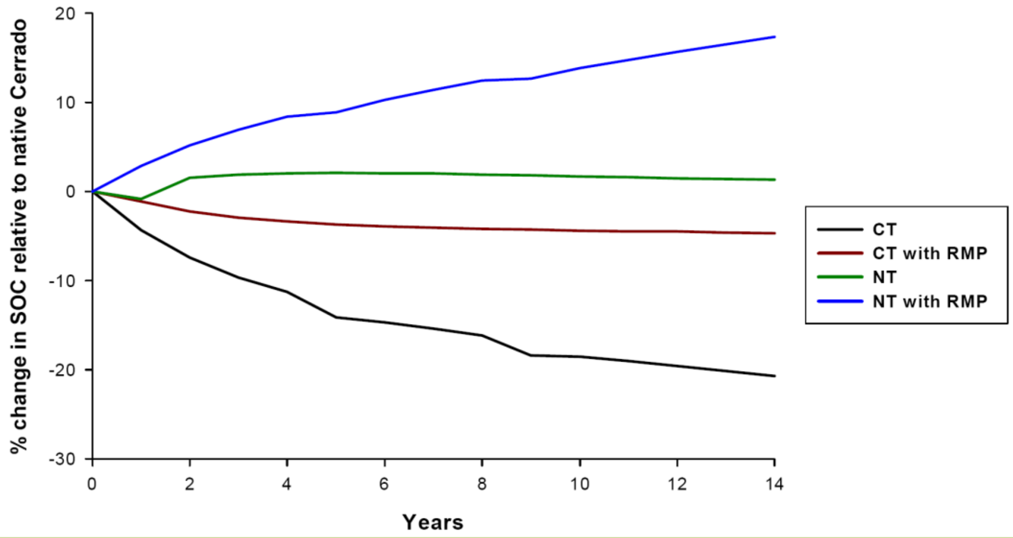


Legend

A	SRES-A2
D	SRES-A2 with sugar cane, switch-grass and forestry land use change activities but no CCS
G	SRES-A2 with three land use change activities and 30 tC per ha released through land use change
H	SRES-A2 with three land use change activities and 90 tC per ha released through land use change
I	SRES-A2 with three land use change activities and 300 tC per ha released through land use change

Fig. 2 CO2 in atmosphere (ppm) with CO2 release at time of land use change

Figure 4.3: Mean modelled change in SOC for each management scenario (0-20 cm) for the first 14 years following conversion from Cerrado.



Dr Jem Woods

Land availability

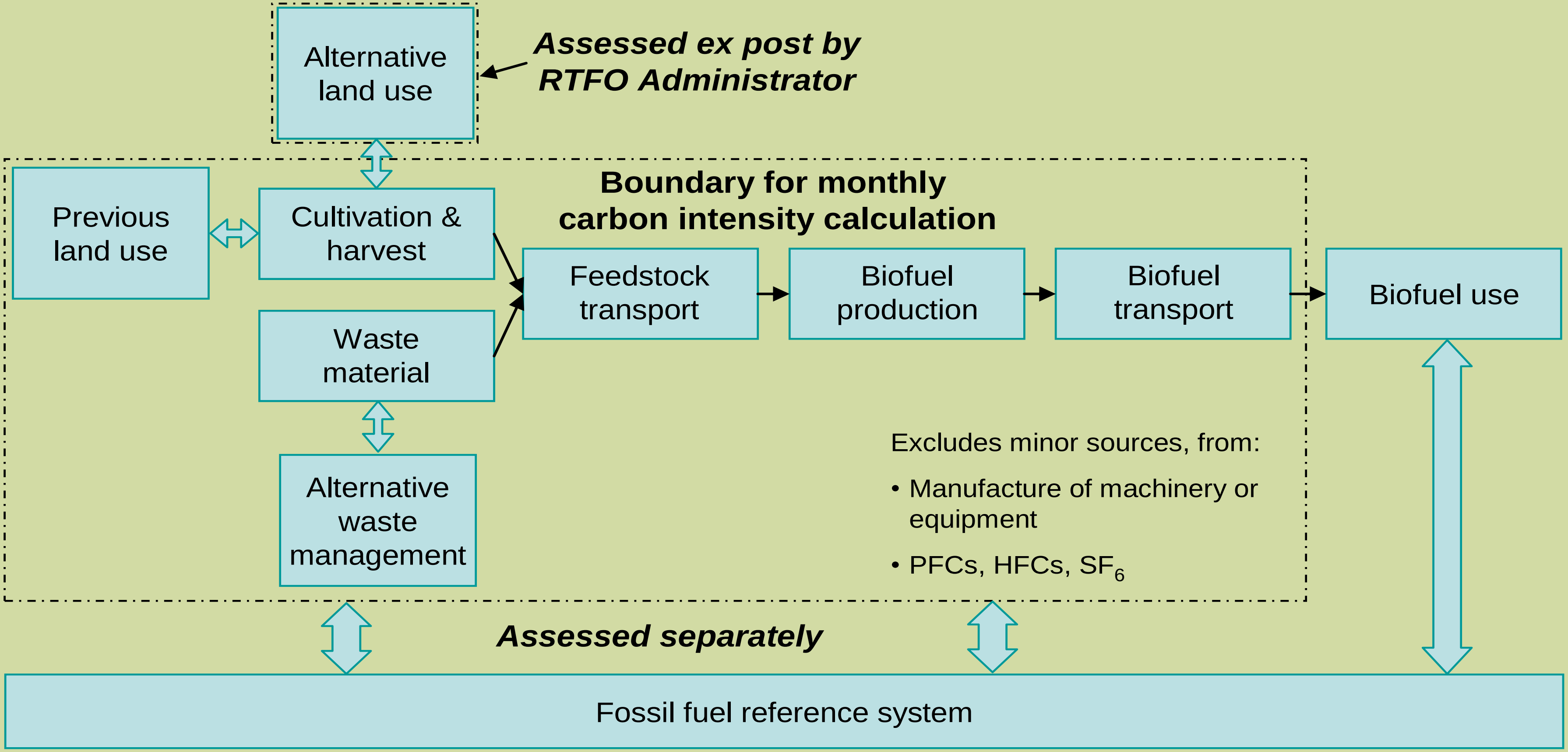
Country	Population	Total Land	Arable land	Land Considered Suitable for Crop Growth		% Suitable	% of suitable used
	2005 (people)	(1000 ha)	(2001-2005) (1000 ha)	- no constraints - (1000 ha)	- with constraints - (1000 ha)	(%)	(%)
Brazil	186,831	853,363	58969	239,573	614,064	28%	25%
China	1,312,979	934,949	142265	178,228	756,722	19%	80%
India	1,134,403	306,140	159712	139,357	166,783	46%	115%
Southern Africa							
Tanzania	38,478	93,819	9118	35,964	57,855	38%	25%
South Africa	47,939	122,300	14753	31,154	91,075	25%	47%
Mozambique	20,533	79,854	4270	48,043	31,811	60%	9%
Zambia	11,478	74,837	5260	22,304	52,533	30%	24%
Angola	16,095	123,776	3200	40,383	83,313	33%	8%
UK	60,245	24,418	5728	9,888	14,530	40%	58%
South East Asia							
Indonesia	226,063	189,220	22600	79,444	109,776	42%	28%
Malaysia	25,653	33,300	1800	16,495	16,805	50%	11%
Total	3,080,697	2,835,976	427,675	840,833	1,995,267	30%	51%
World	6,515,000	12,976,000		3,500,000			

Policy is crucial – UK RTFO

- The UK Renewable Transport Fuels Obligation (RTFO) provides a mechanism to support the use of sustainable biofuels in the UK market
- It assesses greenhouse gas emissions and other sustainability-linked criteria in an LCA context
- The first Quarterly Report on this by the Renewable Fuels Agency was published in October 2008

see http://www.renewablefuelsagency.org/

Supply chains and boundaries in the UK RTFO process



Assessed ex post by RTFO Administrator

Alternative land use

Boundary for monthly carbon intensity calculation

Previous land use

Cultivation & harvest

Waste material

Alternative waste management

Feedstock transport

Biofuel production

Biofuel transport

Biofuel use

Excludes minor sources, from:

- Manufacture of machinery or equipment
- PFCs, HFCs, SF_6

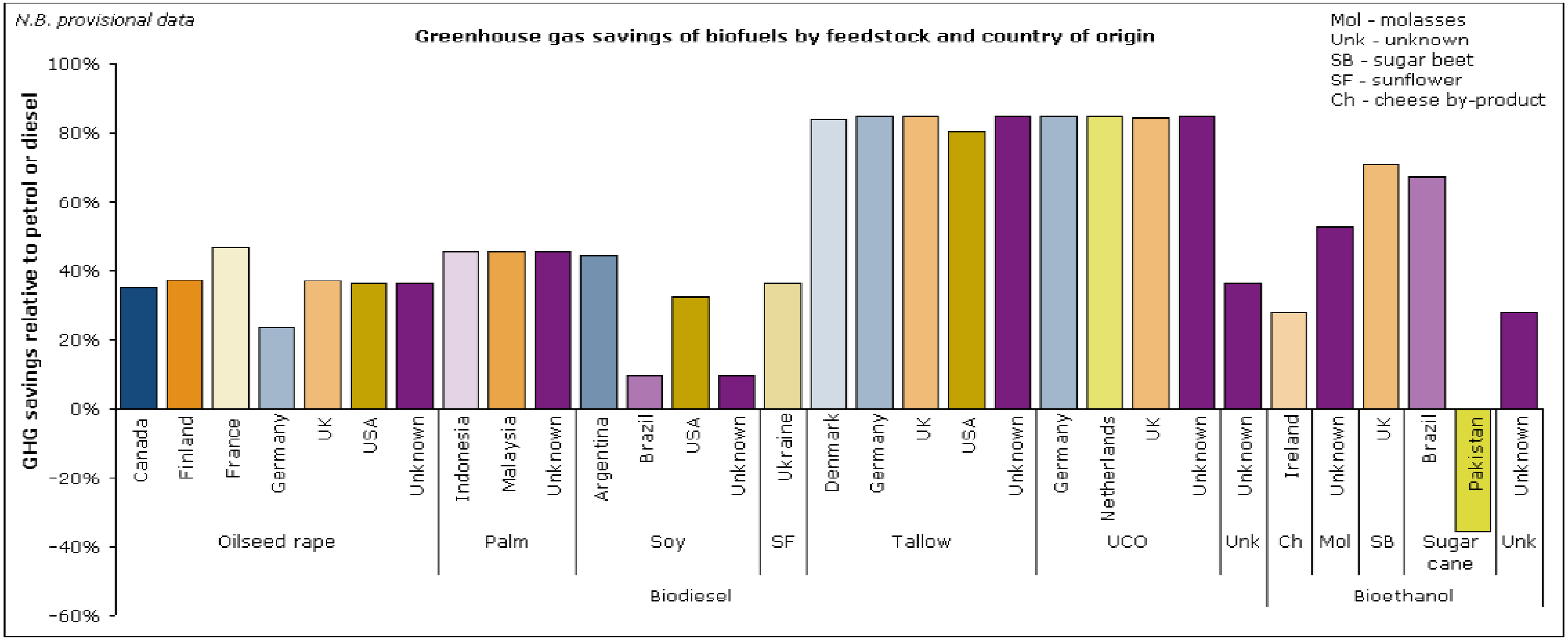
Assessed separately

Fossil fuel reference system

E4TECH, 2007

UK RTFO 1st quarterly report

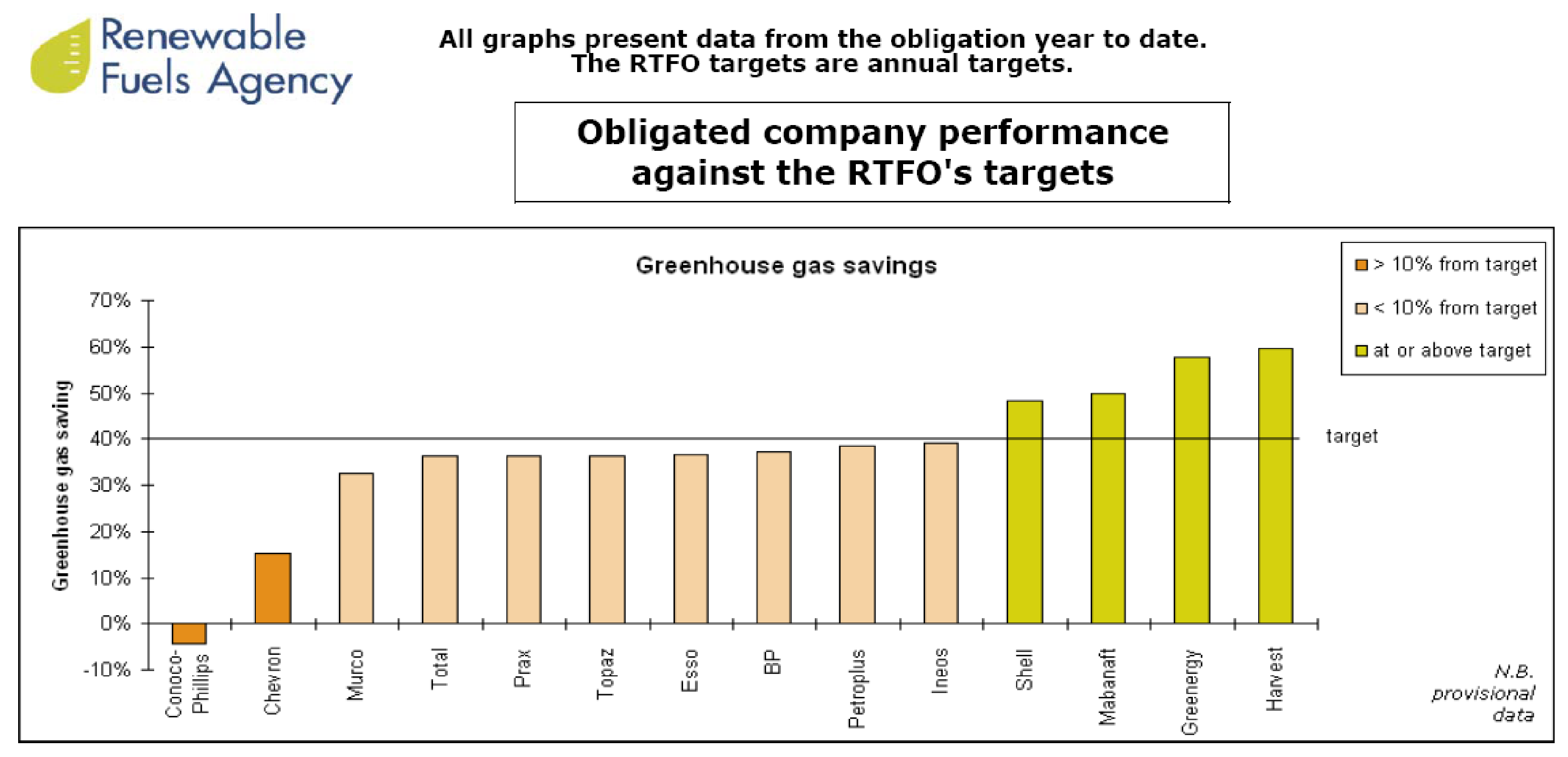
The methodology is indicating differential savings in GHGs – this is expected on the basis of LCA studies



Note: data is for obligation year to date based on submitted monthly returns to the RFA. Final audit of this data occurs annually and revisions to the data may occur at any point up to that time. RFA will publish a comprehensive end of year dataset

UK RTFO 1st quarterly report

Overall GHG savings were 44% vs a target of 40%



Renewable Fuels Agency

All graphs present data from the obligation year to date.
The RTFO targets are annual targets.

Obligated company performance against the RTFO's targets

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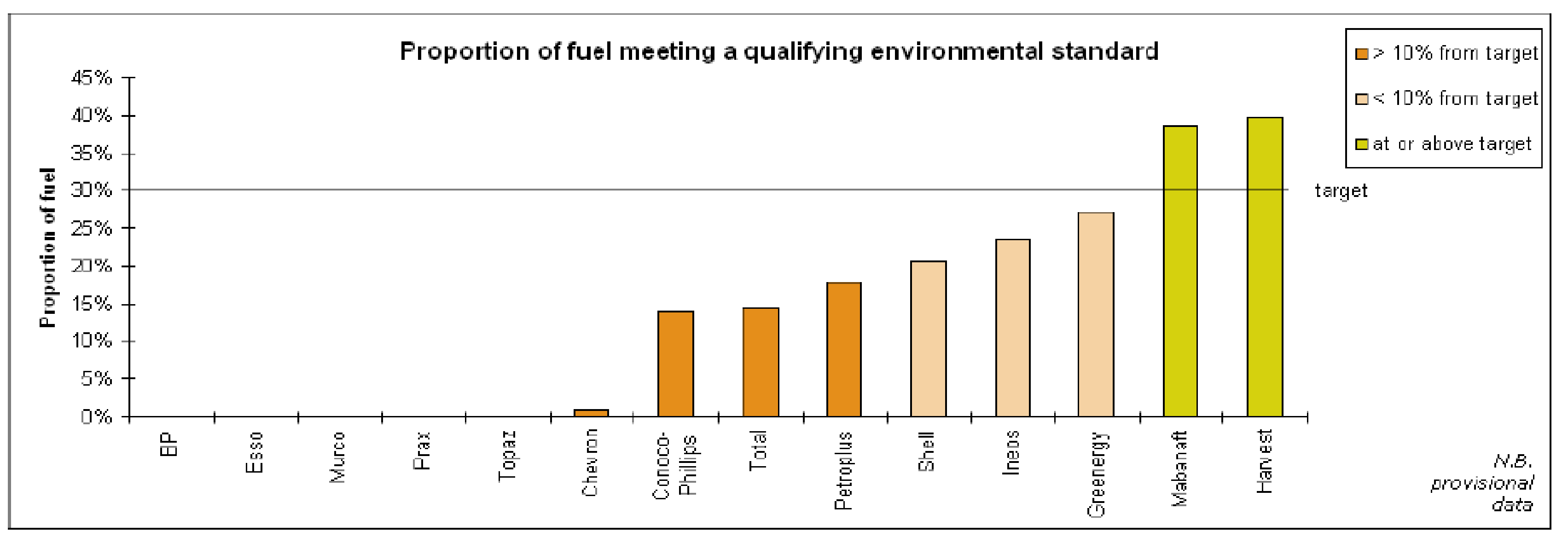
UK RTFO 1st quarterly report

A ‘qualifying environmental standard’ is an existing certification scheme that meets an acceptable number of the seven RTFO sustainability principles (fuels from ‘wastes’ automatically comply)



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Costs will come down

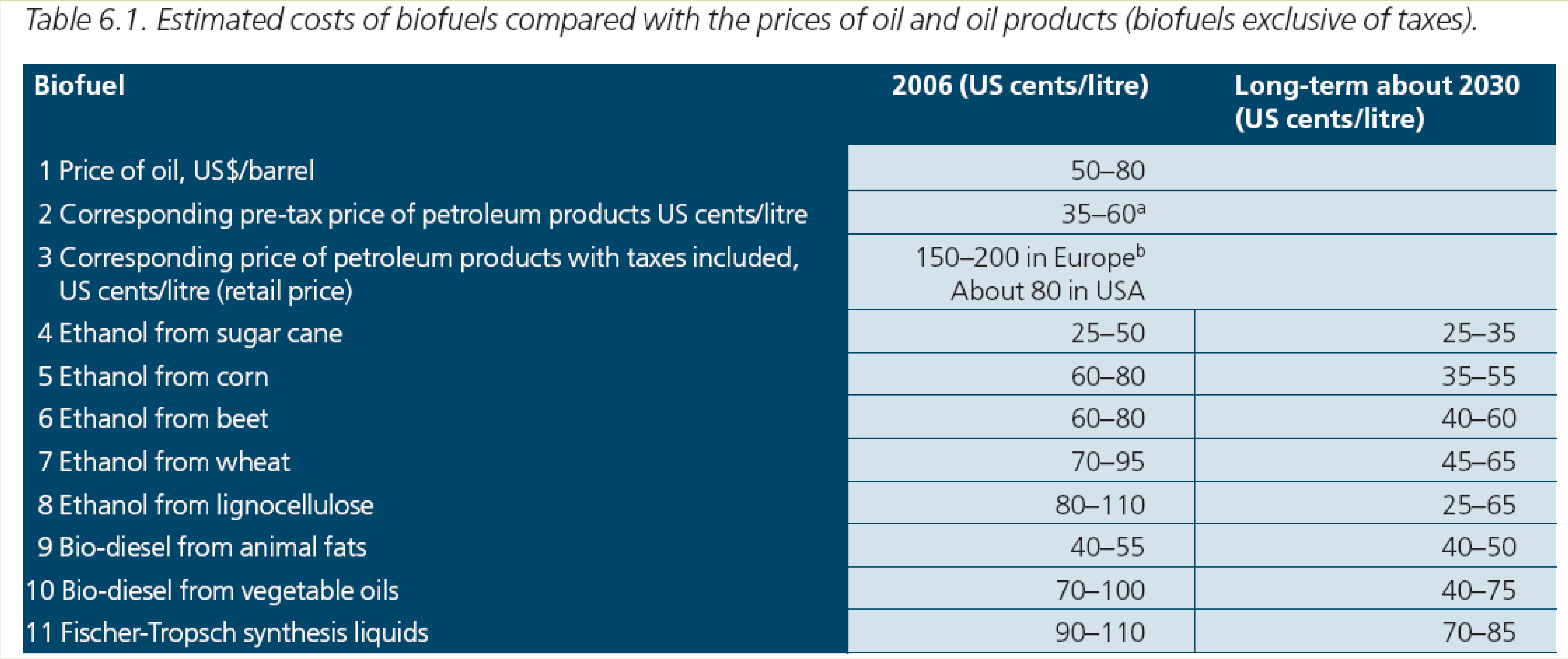

Table 6.1. Estimated costs of biofuels compared with the prices of oil and oil products (biofuels exclusive of taxes).

Biofuel	2006 (US cents/litre)	Long-term about 2030 (US cents/litre)
1 Price of oil, US$/barrel	50–80	
2 Corresponding pre-tax price of petroleum products US cents/litre	35–60[a]	
3 Corresponding price of petroleum products with taxes included, US cents/litre (retail price)	150–200 in Europe[b] About 80 in USA	
4 Ethanol from sugar cane	25–50	25–35
5 Ethanol from corn	60–80	35–55
6 Ethanol from beet	60–80	40–60
7 Ethanol from wheat	70–95	45–65
8 Ethanol from lignocellulose	80–110	25–65
9 Bio-diesel from animal fats	40–55	40–50
10 Bio-diesel from vegetable oils	70–100	40–75
11 Fischer-Tropsch synthesis liquids	90–110	70–85

From: The Royal Society report - Sustainable Biofuels (2008)

Embedding sustainability

Embedding sustainability in R&D

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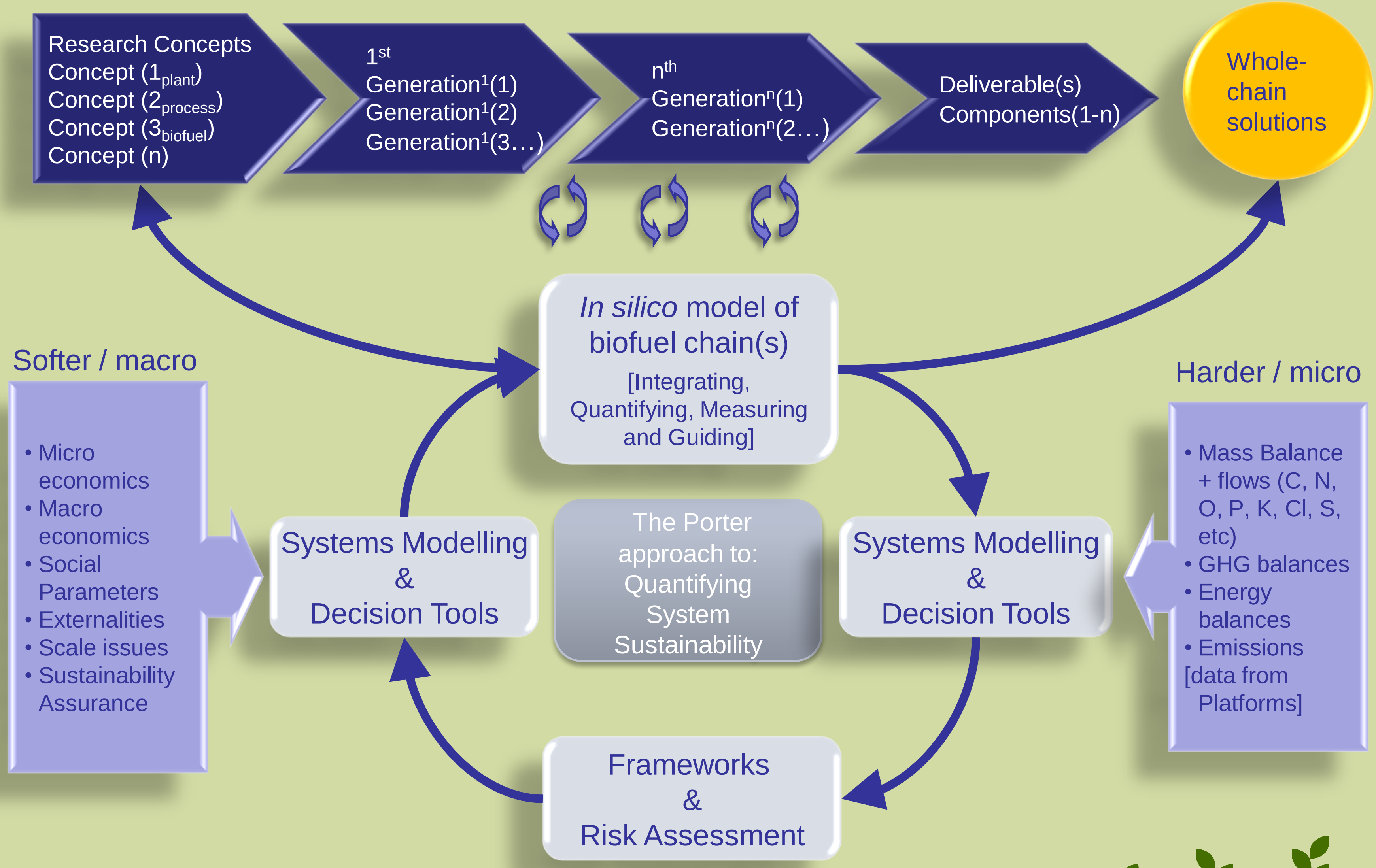


Research Concepts
Concept (1_{plant})
Concept ($2_{process}$)
Concept ($3_{biofuel}$)
Concept (n)

1st
Generation^1(1)
Generation^1(2)
Generation^1(3…)

nth
Generation^n(1)
Generation^n(2…)

Deliverable(s)
Components(1-n)

Whole-chain solutions

In silico model of biofuel chain(s)
[Integrating, Quantifying, Measuring and Guiding]

Softer / macro

- Micro economics
- Macro economics
- Social Parameters
- Externalities
- Scale issues
- Sustainability Assurance

Systems Modelling & Decision Tools

The Porter approach to: Quantifying System Sustainability

Systems Modelling & Decision Tools

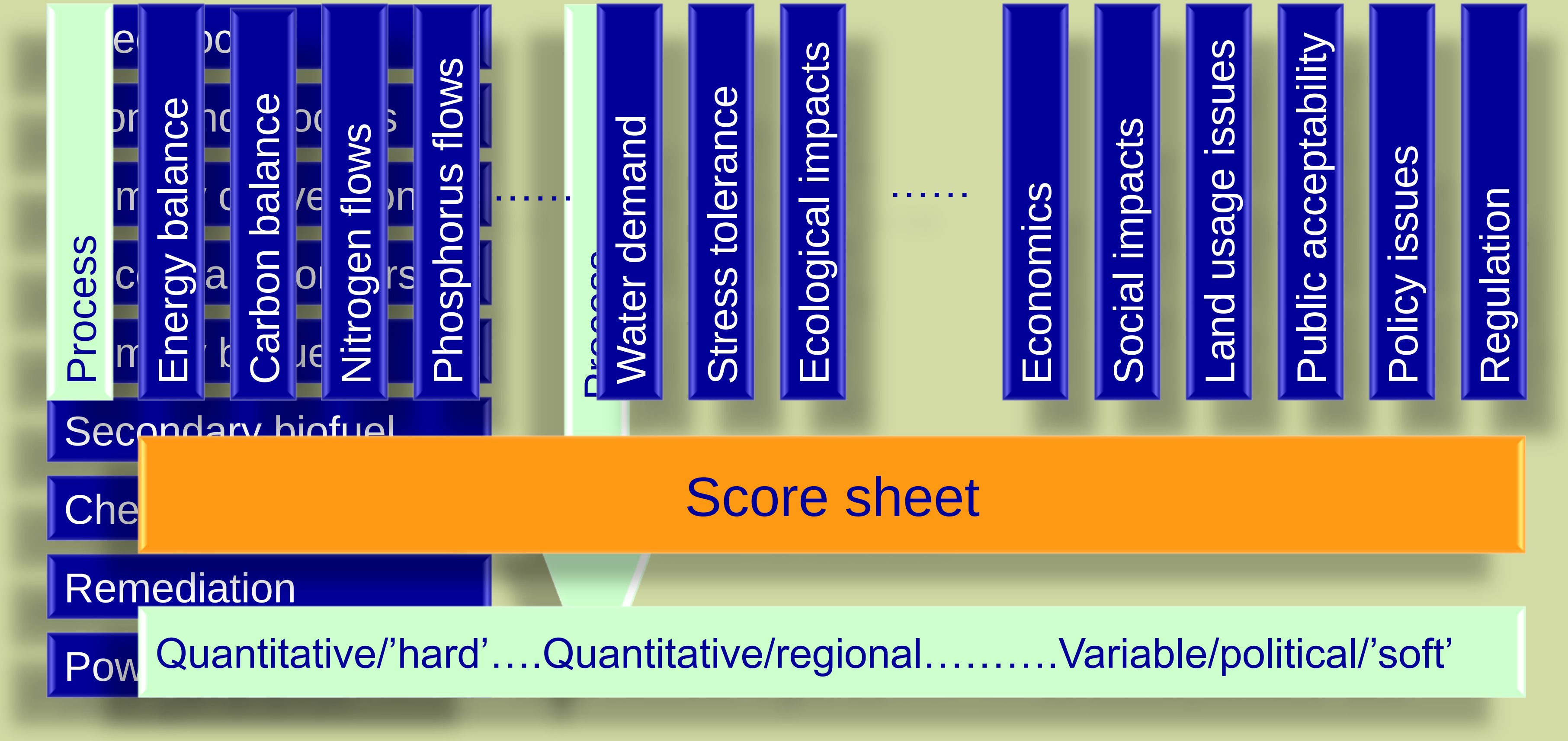
Harder / micro

- Mass Balance + flows (C, N, O, P, K, Cl, S, etc)
- GHG balances
- Energy balances
- Emissions

[data from Platforms]

Frameworks & Risk Assessment

The sustainability matrix



Process

Energy balance

Carbon balance

Nitrogen flows

Phosphorus flows

……

Water demand

Stress tolerance

Ecological impacts

……

Economics

Social impacts

Land usage issues

Public acceptability

Policy issues

Regulation

Secondary biofuel

Che

Remediation

Pow

Score sheet

Quantitative/’hard’….Quantitative/regional……….Variable/political/’soft’

See more of us at

- www.porteralliance.org.uk