Research and Strategy in Energy

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BP Chief Scientist

Follow on to Steve Koonin's initiatives at BP

Rigorous technical information to inform decisions

Well to Wheels vs. Tank to Wheels

The Energy Biosciences Institute

Tailored yeast for lignocellulosic sugar mixtures

The Big Problem

Energy production in a resource-constrained world

Energy scales

2010 World Energy Use
~ 16 TW-year
~140000 TWh
~12 Gtoe
~ 88 Gboe
~ 480 x10^9 MBTU
~ 500 x10^9 GJ

Thermodynamic Limits		
Fuel	**Heat of Combustion MJ/kg**	**Combustion CO_2 kg CO_2/MJ**
Coal	15-27	0.07 - 0.19
Oil	~42	~0.074
Methane	55	0.050
Butanol	36	0.065
Ethanol	30.5	0.063
Sucrose	16.5	0.093
Glucose	14.2	0.10

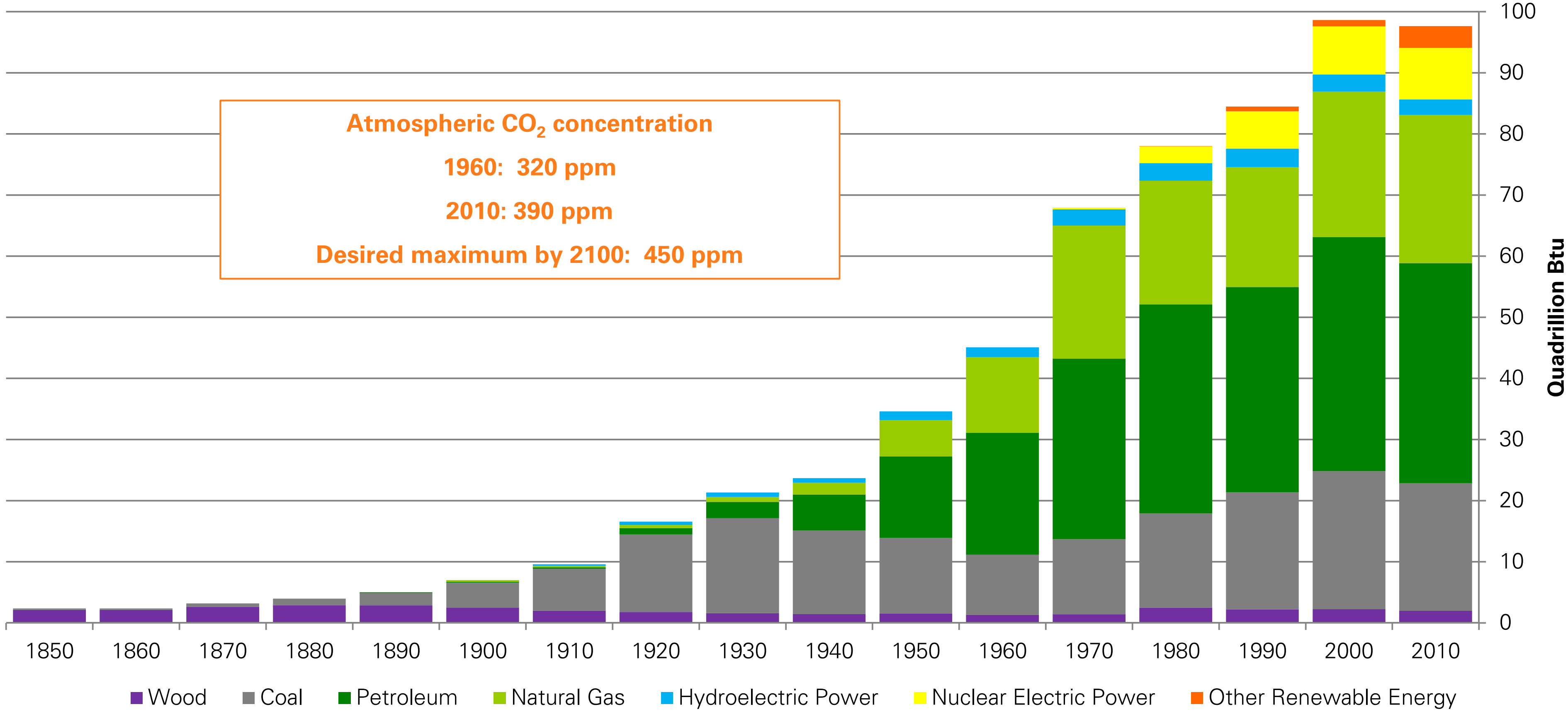
Caution:

In the energy literature the prefixes m, mm, M, or MM are somewhat randomly used to mean a thousand or a million. Bn or bn is often also used to indicate a billion.

Here M means million and k, G and T also have standard meaning.

Transition in the energy supply

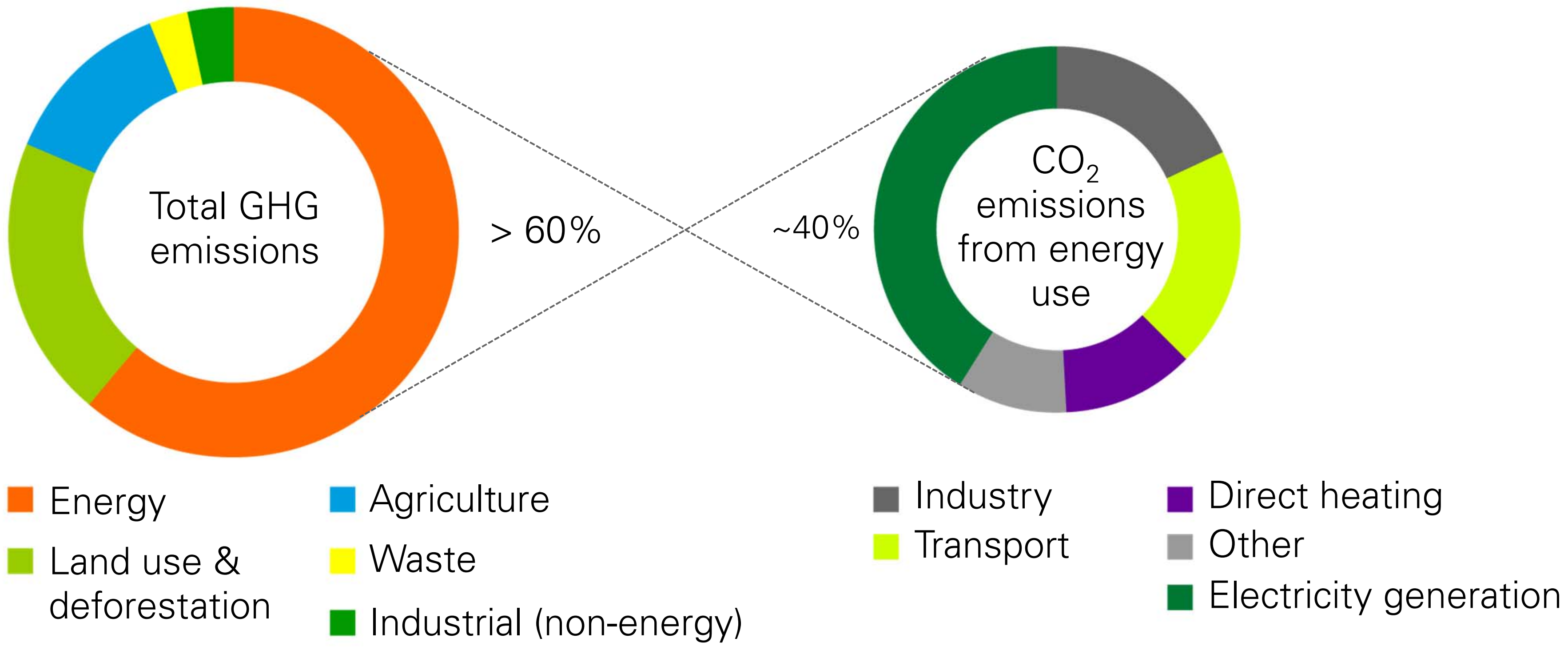
U.S. Primary Energy Consumption Estimates by Source, 1850-2010



Source: U.S. Energy Information Administration Annual Energy Review, Tables 1.3, 10.1, and E1

Greenhouse gas emissions and energy

Total GHG emissions: 44 Gtonne CO_2e/year in 2005:



Source: World Resource Institute, 2006

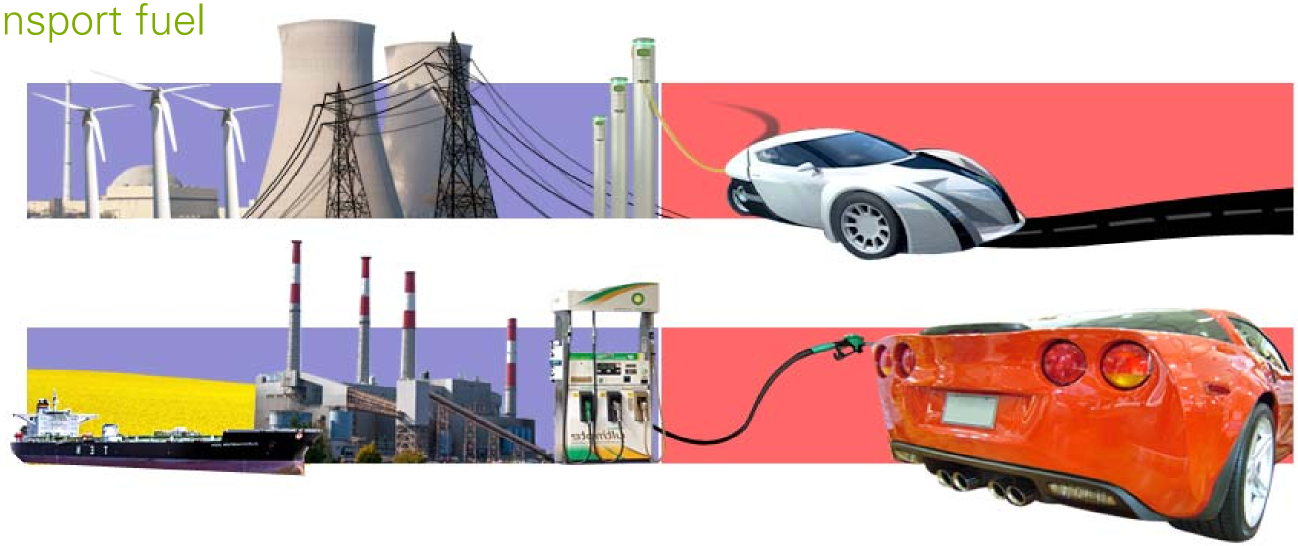
Fuel standards and the Tank to Wheels Fallacy

WELL TO TANK

(WTT) Extract the raw material and make the transport fuel

TANK TO WHEELS

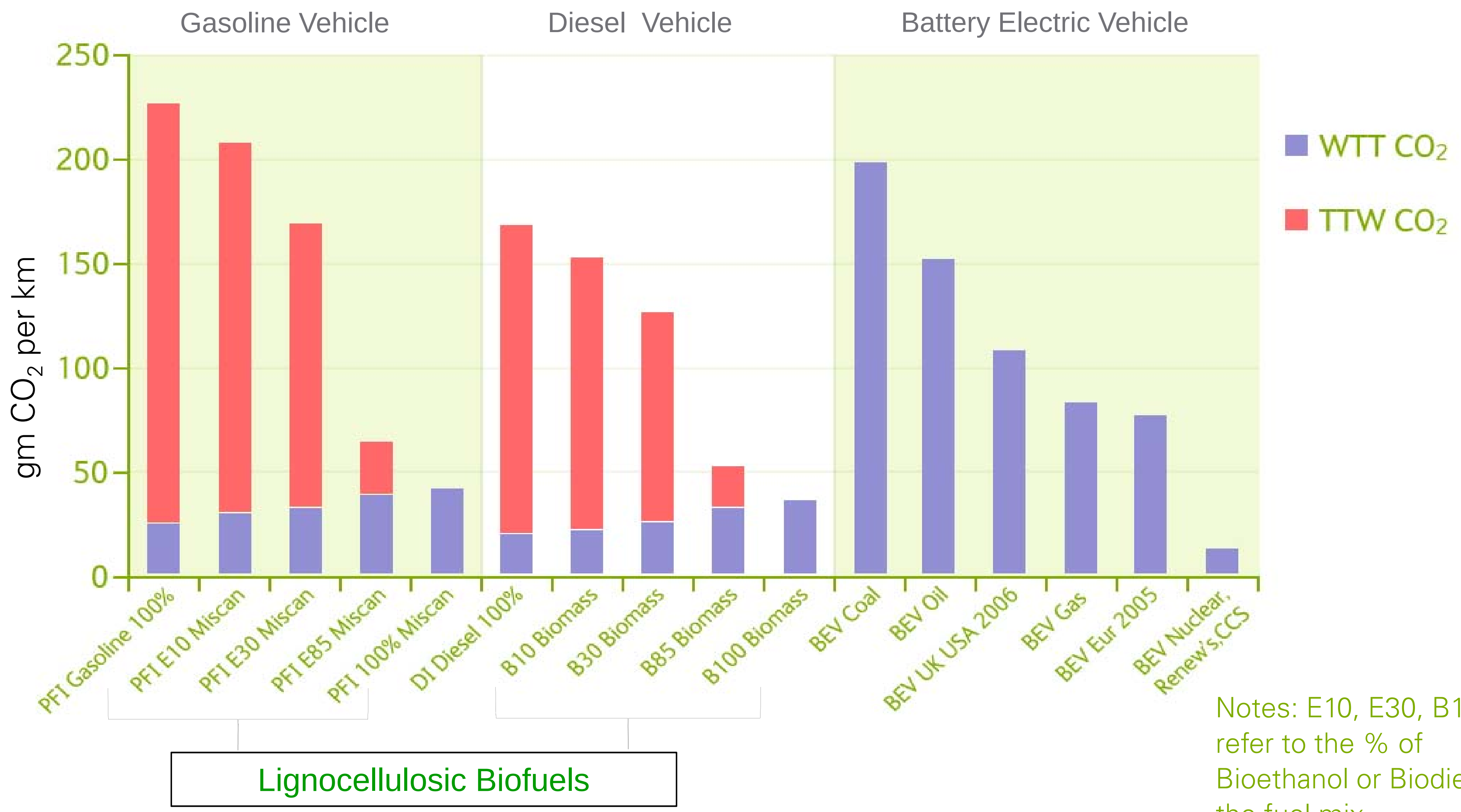
(TTW) Use the fuel to move the vehicle



Battery Electric vehicle **(BEV)** using grid electricity

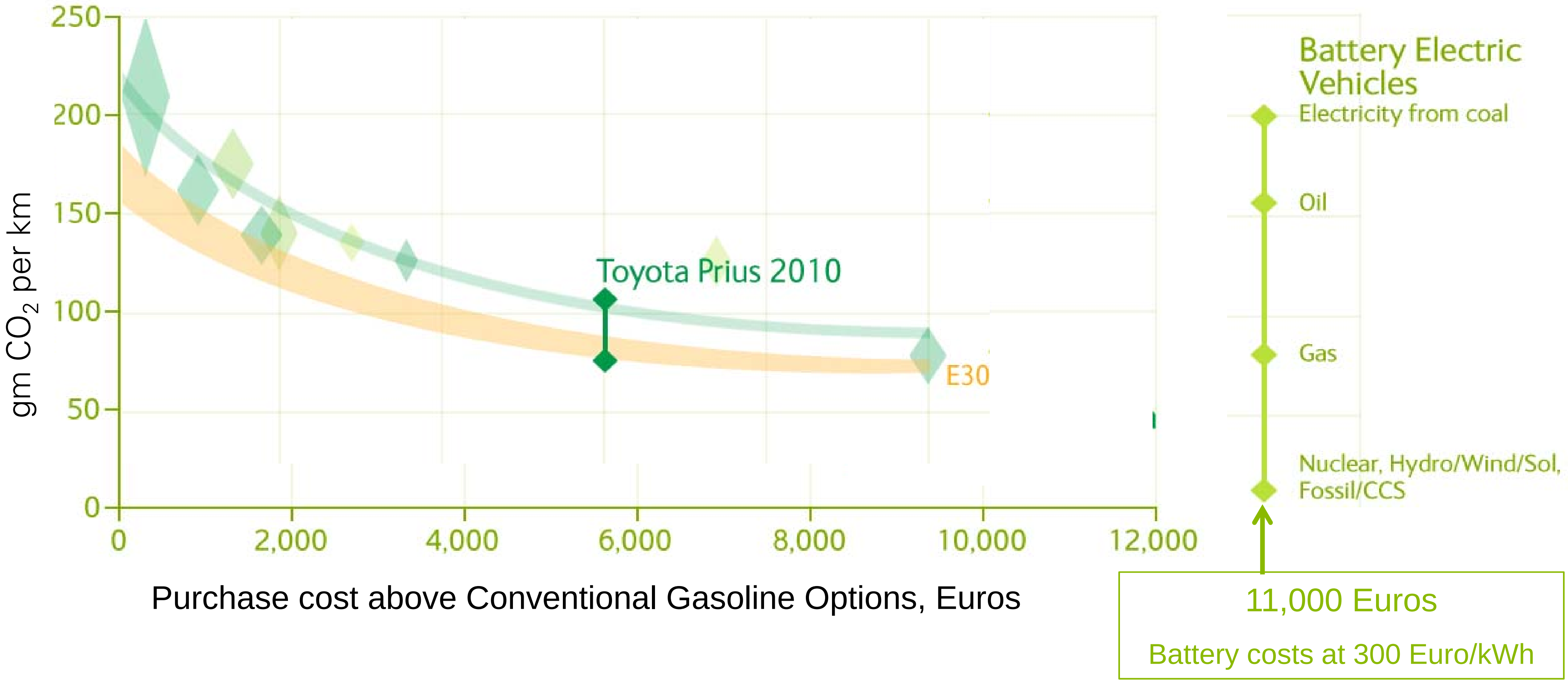
Conventional gasoline vehicle (PFI)

Well-to-Wheels CO2 emissions and LC Biofuels

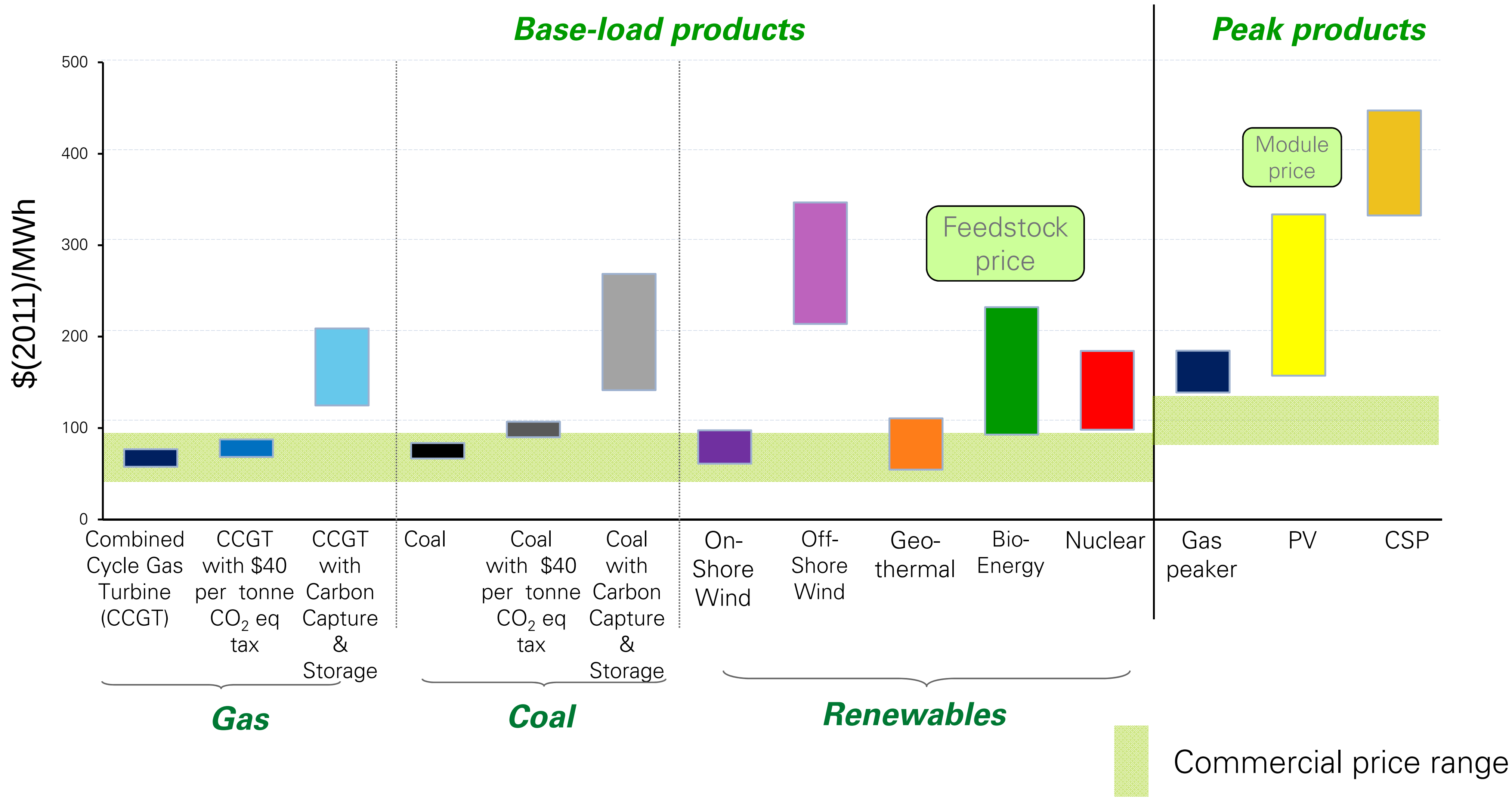


Notes: E10, E30, B10, B30 refer to the % of Bioethanol or Biodiesel in the fuel mix

Well-to-Wheels CO_2 emissions and vehicle effficiency

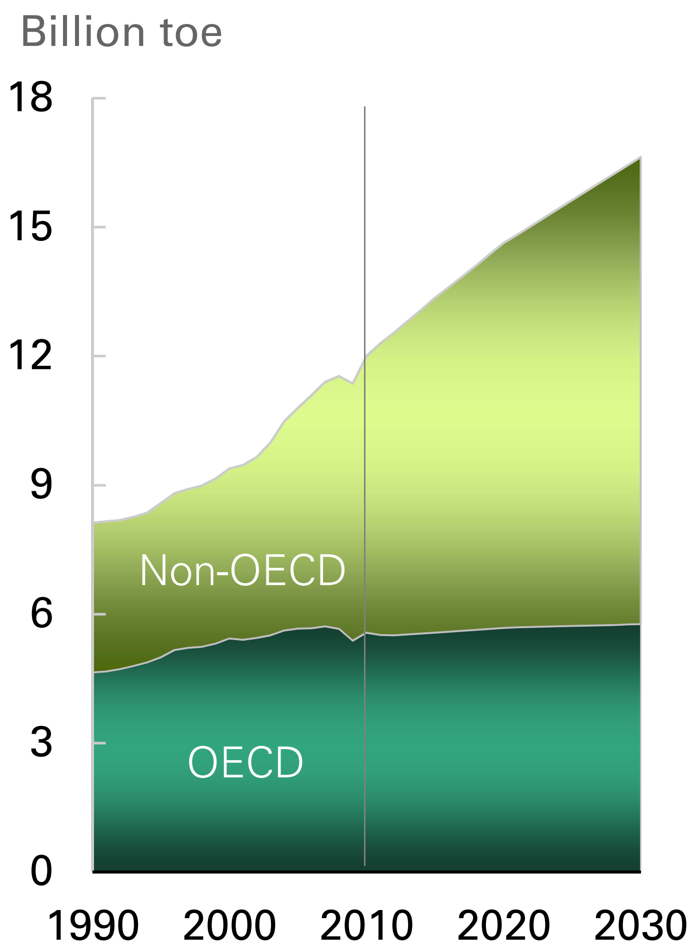


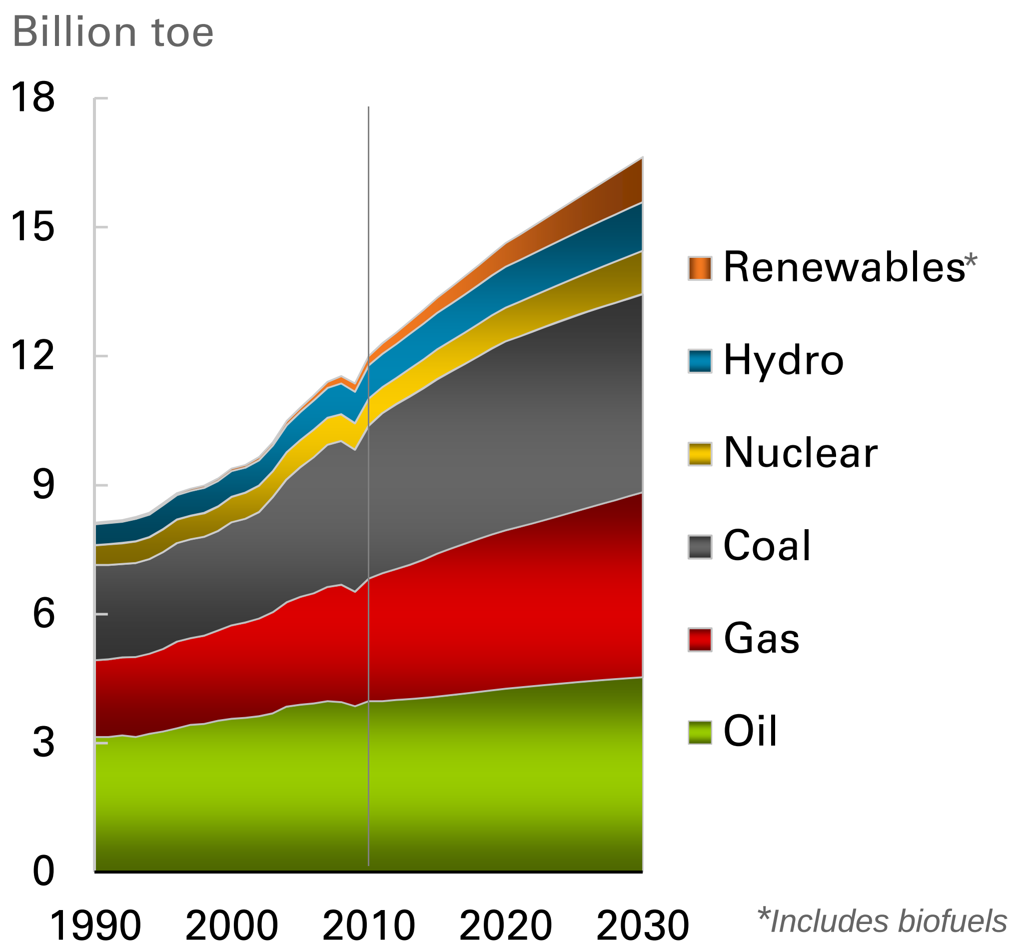
Levelized Cost of Electricy



Source: AE Strategy

Global context – energy demand is rising

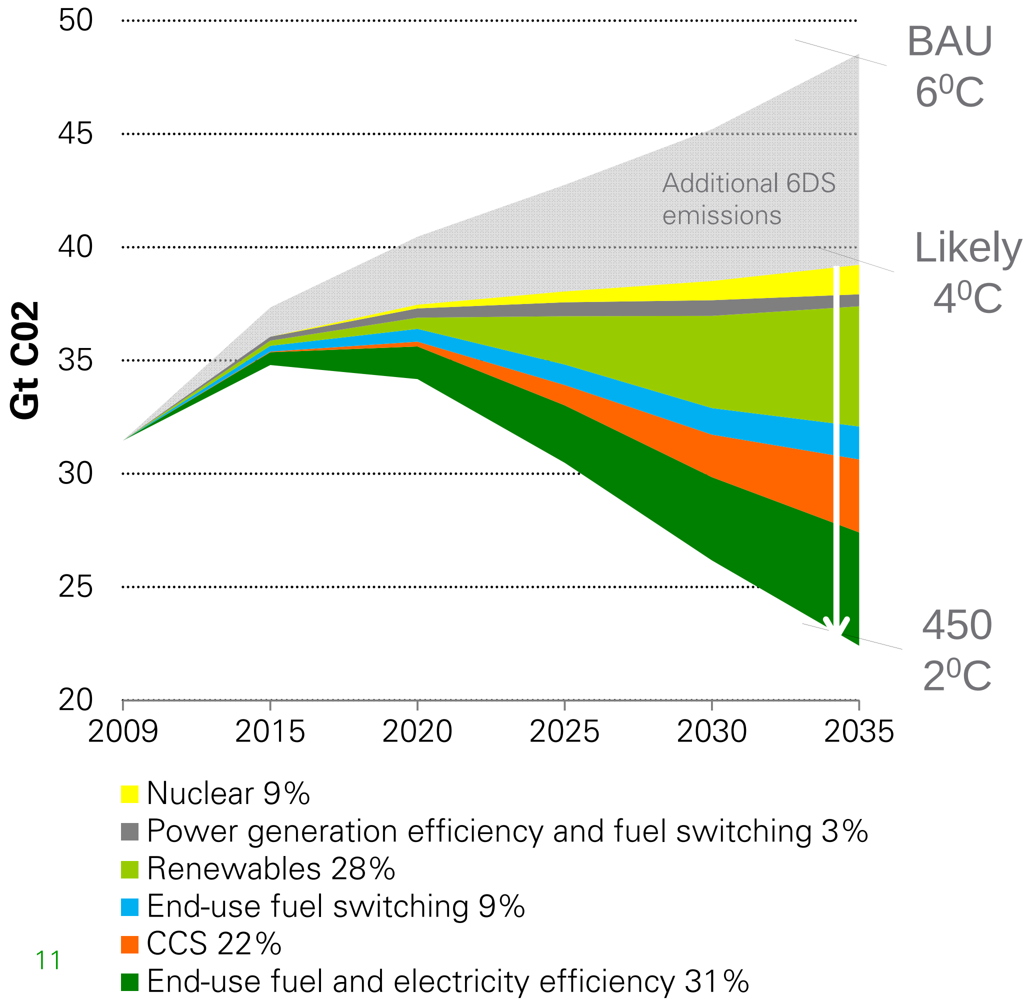




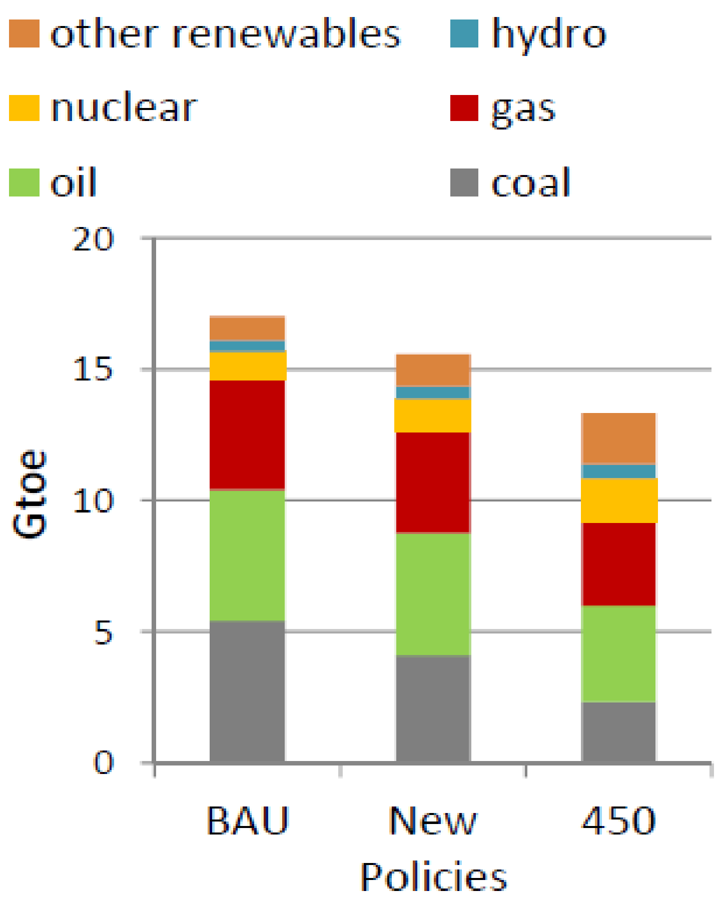
Source: BP Energy Outlook 2030, Jan 2012

Changes required for sustainability

Contributions to reductions in the IEA 2DS:



Scenarios: energy mix in 2035



Source: IEA
World Energy Outlook 2011

BP energy production 2011

Oil and Gas


Oil ~ 107 Mtonne

~ 2.7% of world oil

Gas ~ 69 Mtoe

~ 2.3% of world gas

Low carbon

BP Biofuels

~ 7 million tonne
total crush capacity

~ 500 M liters

~ 0.7 % of world biofuels

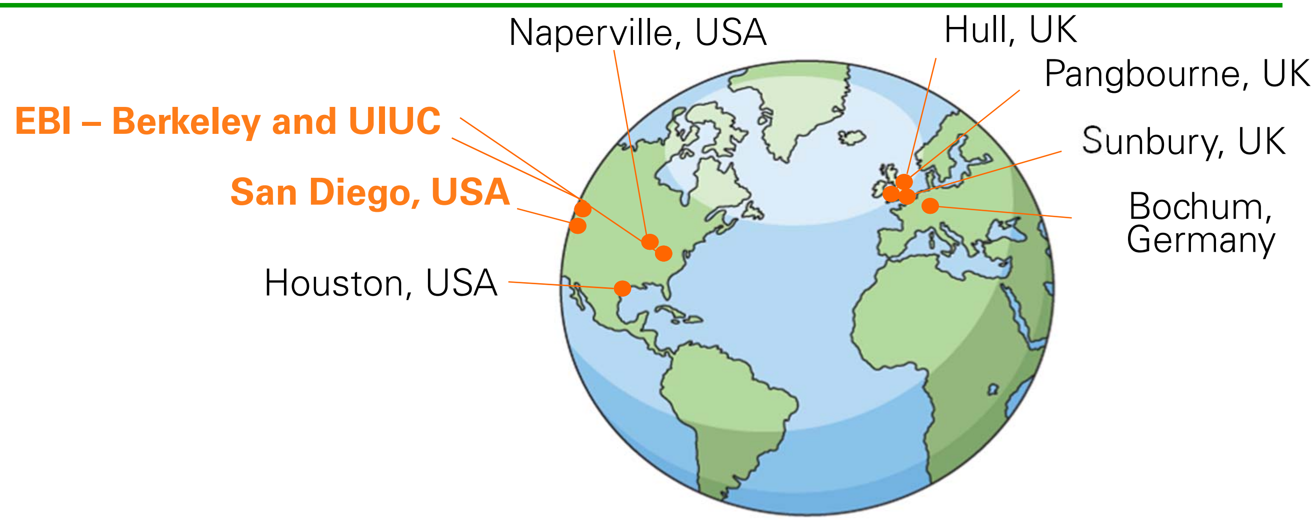
BP Wind Energy

~ 2 GW
gross rated capacity

~ 0.8 % of world wind

For world energy use statistics see: bp.com/statisticalreview

Science and Biofuels



The Energy Biosciences Institute

Founded in 2007 as a joint program among BP, UC Berkeley, UIUC and LBNL

$35M/year open research + $15M/year commercial

http://www.energybiosciencesinstitute.org/

Low Carbon Energy– biofuels

Process energy – ΔE (MJ/kg biofuel

Process GHG – ΔC (kg CO_2e/kg biofuel)

Photosynthesis → **Agriculture** → **Biofuel**

Transport

Processing

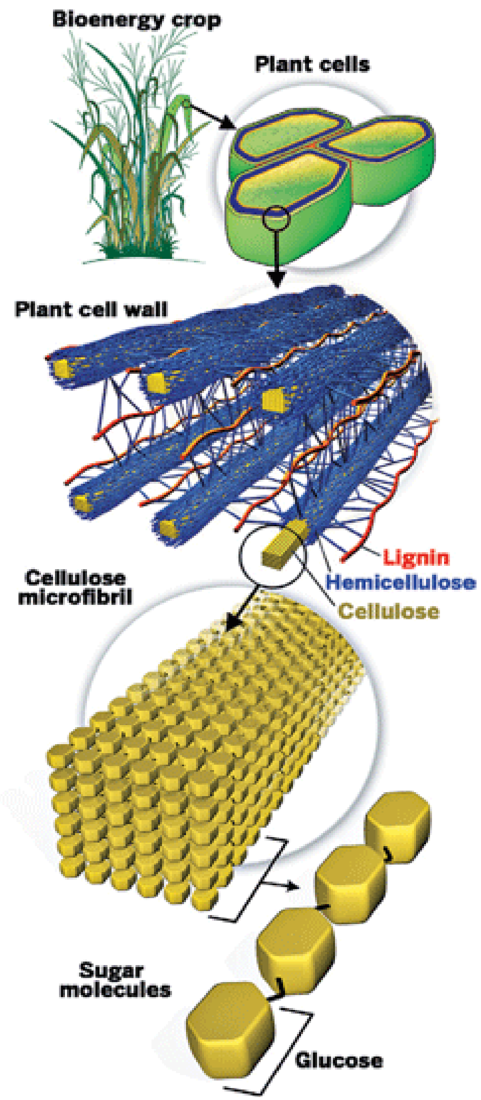
$$nCO_2 + nH_2O \xrightarrow{h\nu} (CH_2O)_n + nO_2$$

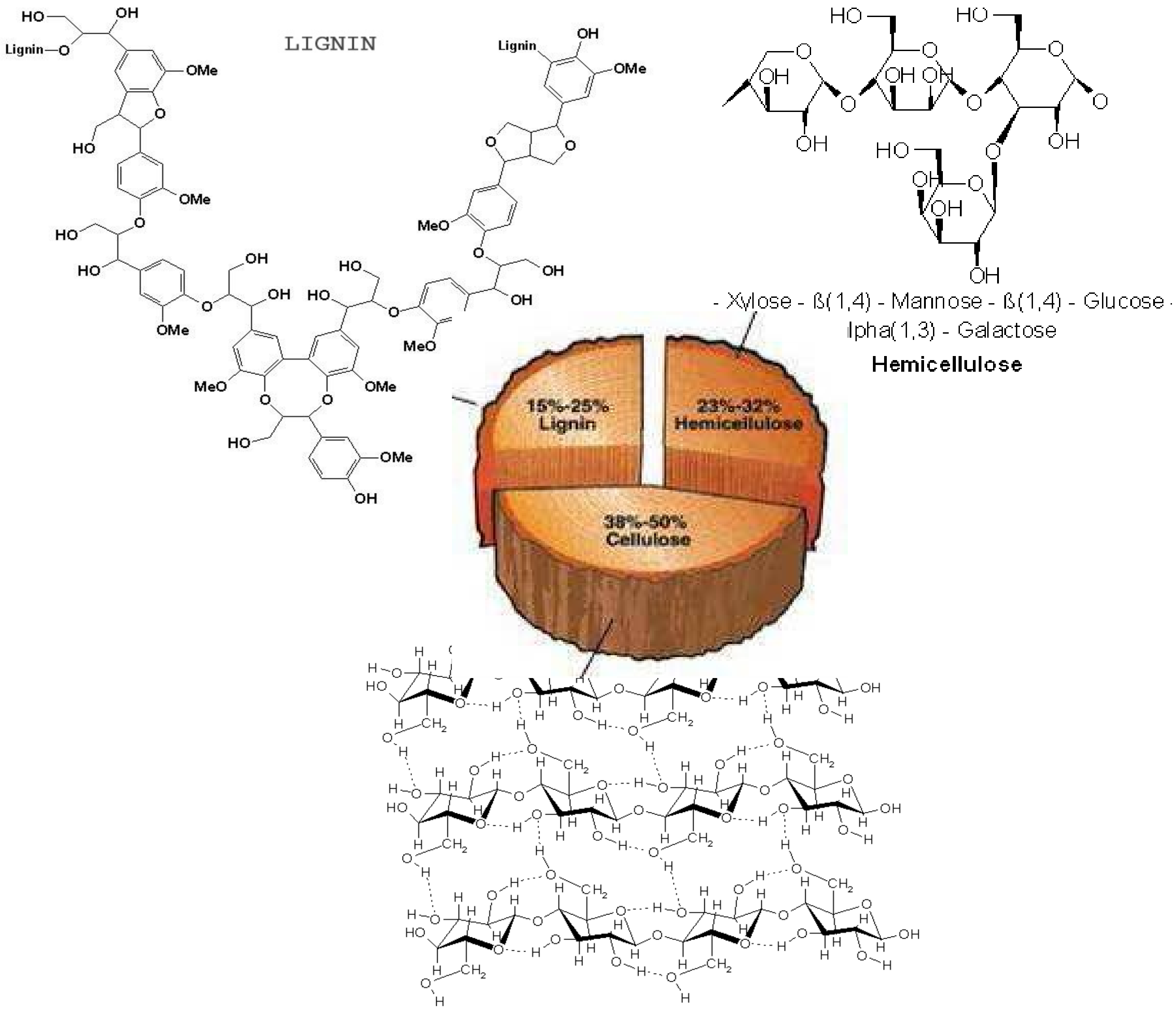
Combustion energy E(MJ/kg)

All carbon in the biofuel derived from atmospheric CO_2

Biofuel Net Combustion CO_2 $\Delta C/(E-\Delta E)$

Lignocellulosic Biofuels



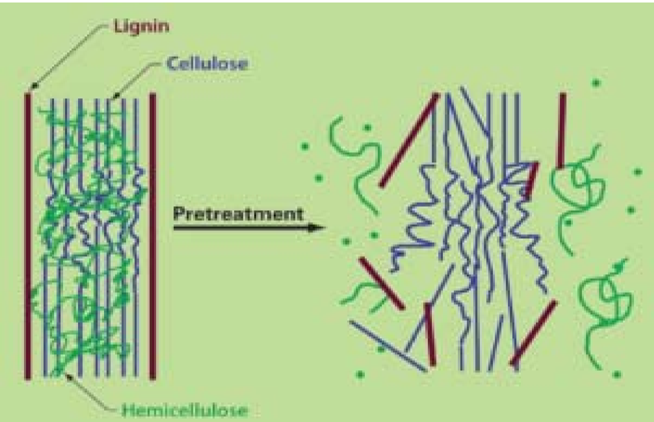


Base case LC to Ethanol Production Flowchart

Cellulose Process

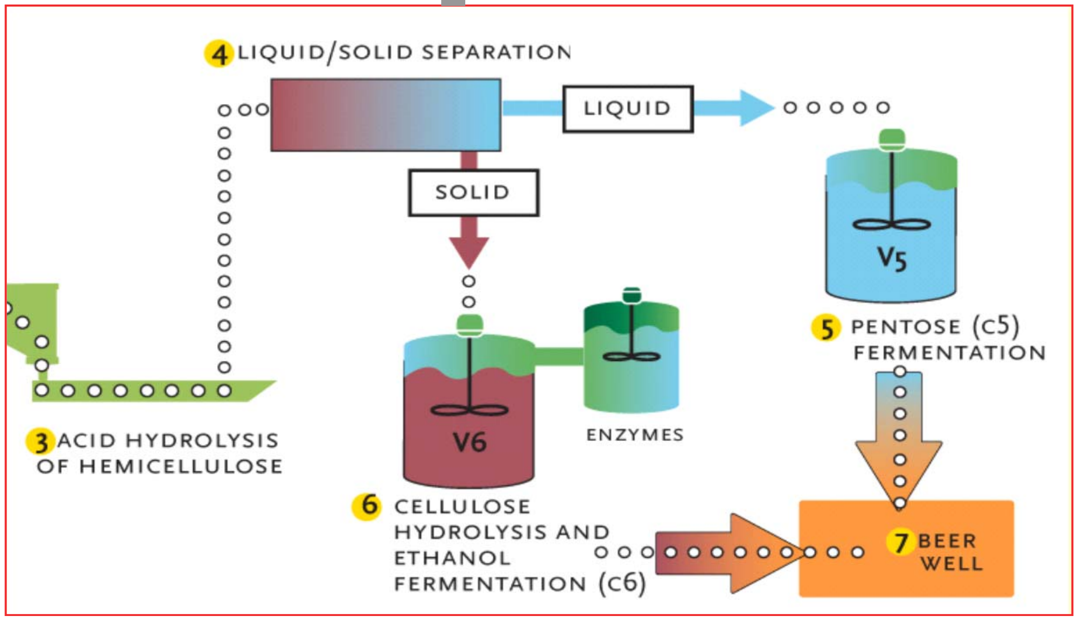
Co-Product Recovery
Animal Feed
Chemicals

Sugar → Ferment-ation → Distillation → Drying → Ethanol



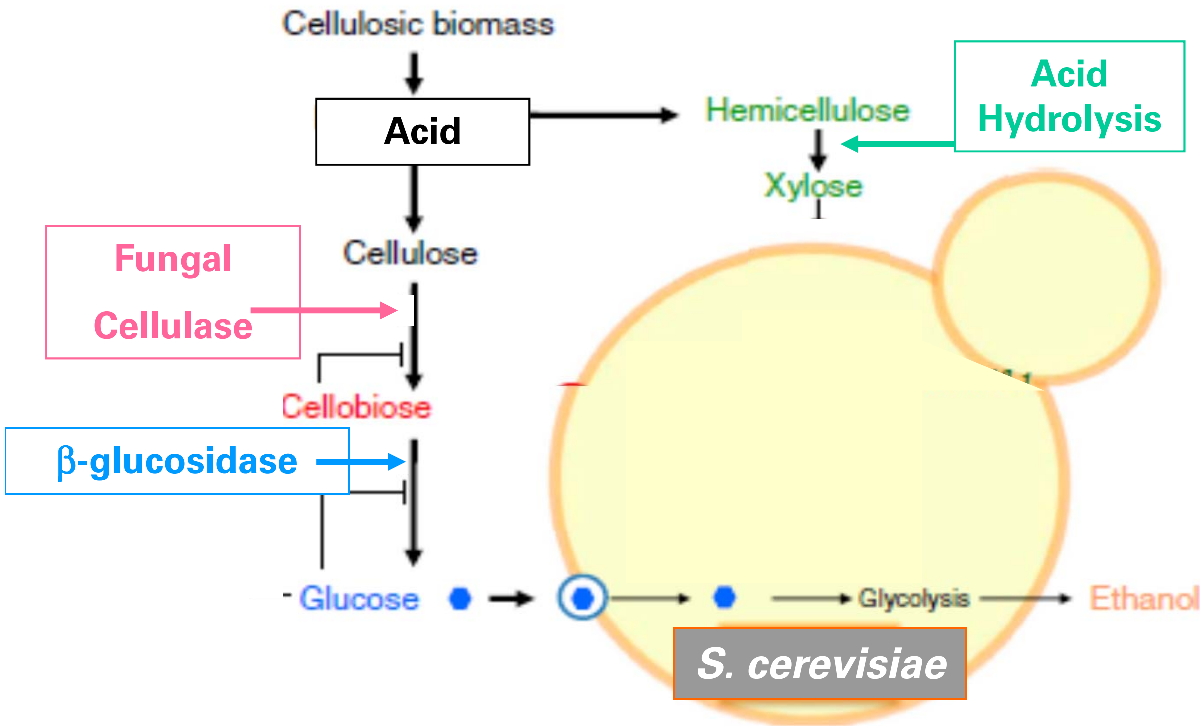
Biomass → Biomass Pretreatment → Cellulose & Hemicellulose Conversion Hydrolysis

- Heat and Power
- Fuels and Chemicals



Slide Adapted from Bruce Dale

Fermentation of LC sugars



Problem: Standard fermentation yeast cannot import and metabolize xylose.

Pretreatment:

Acid pretreatment of biomass yields cellulose and hemicelluose

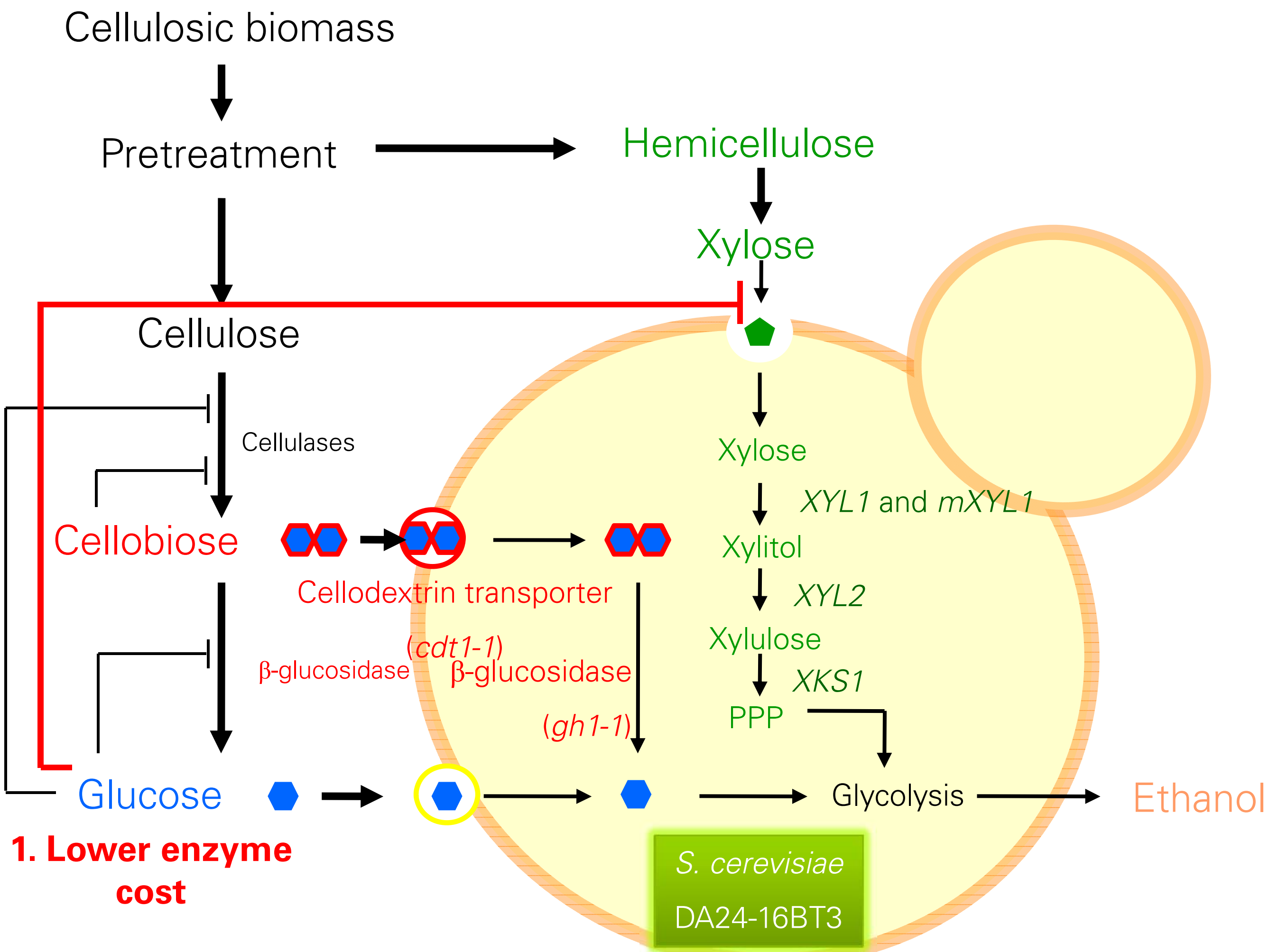
Saccharification

Hydrolysis breaks hemi-cellulose to sugar xylose and cellulose (in a two-step process) to glucose

Fermentation

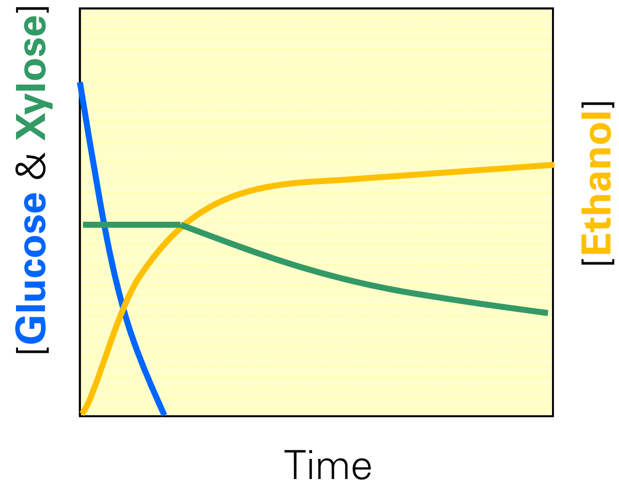
Yeast imports glucose, converts via glycolysis and exports ethanol

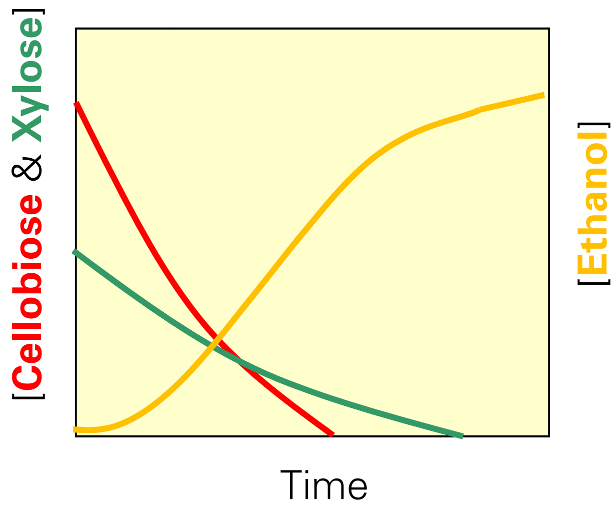
Co-fermentation of cellobiose and xylose



1. Lower enzyme cost

3. Enable a continuous process



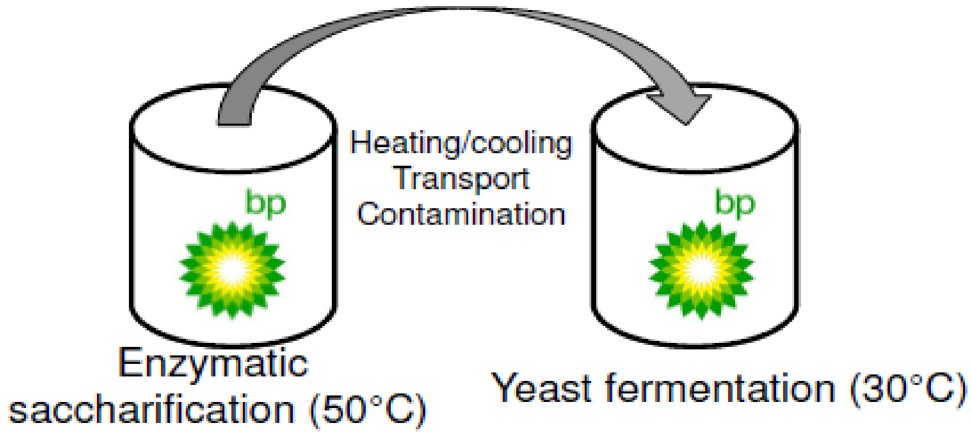


2. Higher productivity

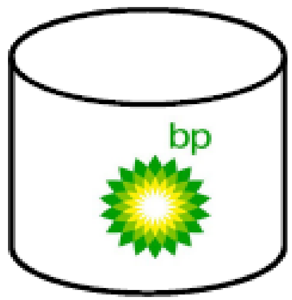
Ha et al. *PNAS*, **108**:504-509

Research Goal– Bioengineering

Present: Success in developing a commercially viable process with enzymatic digestion of cellulose and single-yeast fermentation, but ... batch process with multiple "pots"



Desired: One pot, continuous flow process, recycling of yeast and enzymes, continuous removal of fuel



SSCF (45°C-50°C)

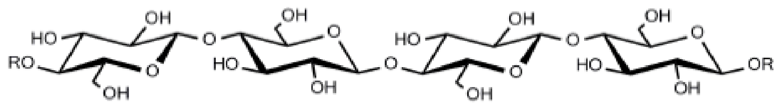
Modification of Saccharification Enzyme

Energy Biosciences Institute

bp

Neurospora crassa

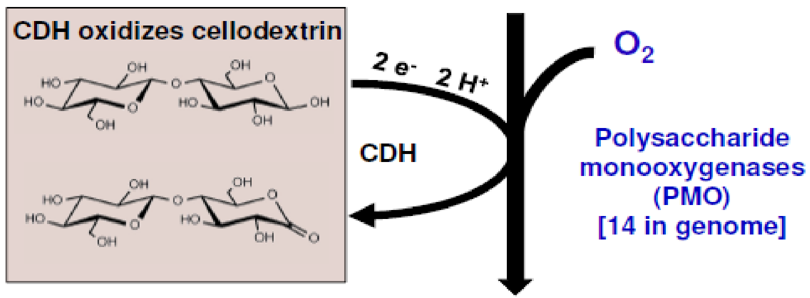
- Saprophyte: grows on dead plant material (burned grasses)
- Used as a model system for molecular biology since the 1940s
  - Large compendium of strains maintained by the Fungal Genetics Stock Center
    - Full genome deletion collection



GH-61 Cellulases (now called PMO)

Thermostable proteins

Regulation of enzyme expression



Oxidative cellulose cleavage

+

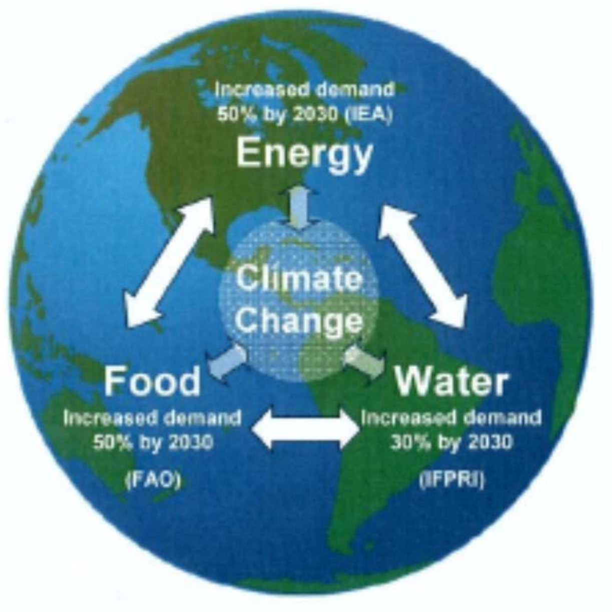
Enhanced cellulose degradation

Energy Sustainability ?

FOOD, ENERGY, WATER AND THE CLIMATE: A PERFECT STORM OF GLOBAL EVENTS?

By John Beddington CMG FRS

Chief Scientific Adviser to HM Government



The Big Problem

Energy production in a resource-constrained world

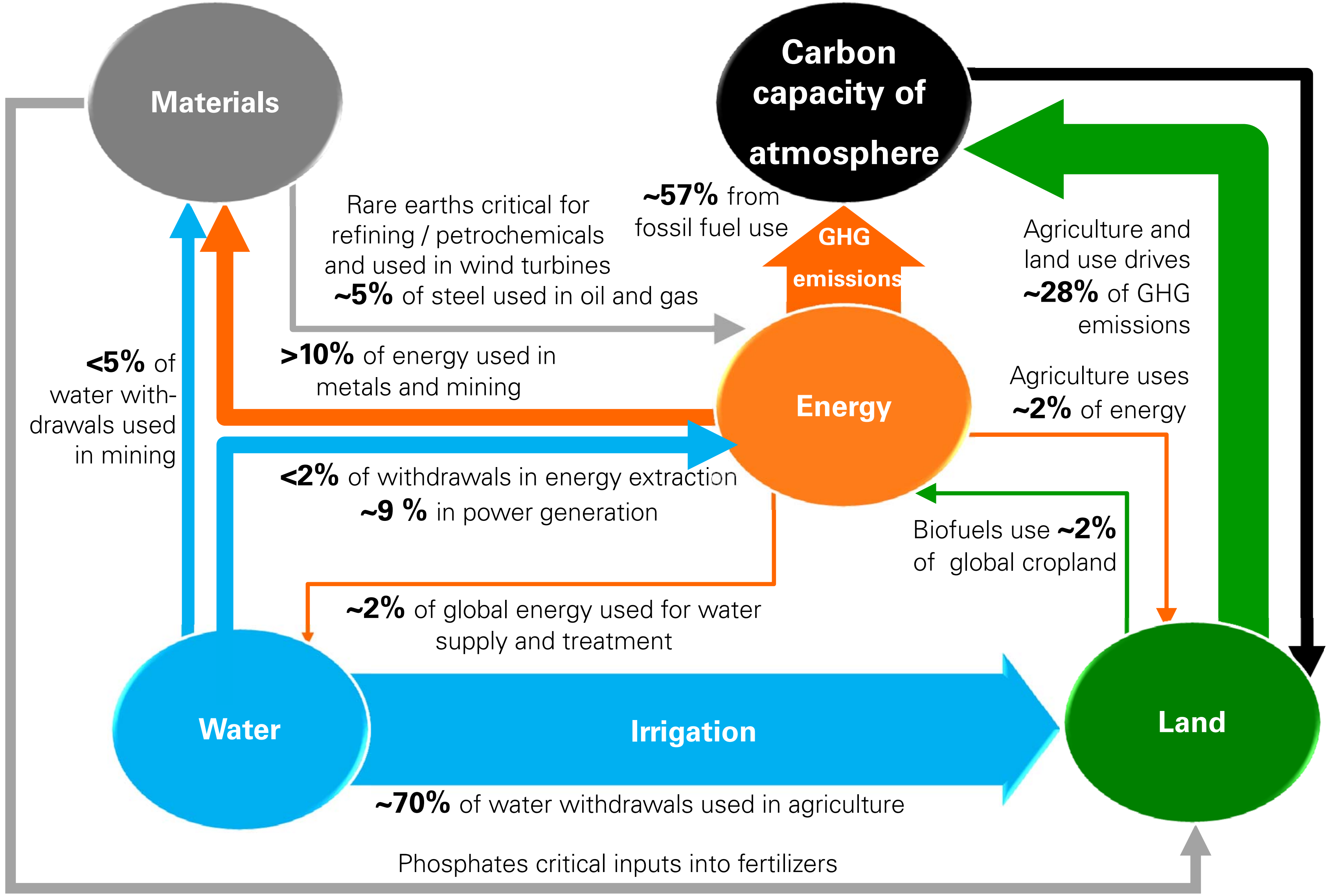
LoSal is a registered trademark of BP plc

The Energy Sustainability Challenge

What are the implications of natural resource (water, land and minerals) constraints on energy production and supply in the context of a growing world population, greenhouse gas emissions and climate change?

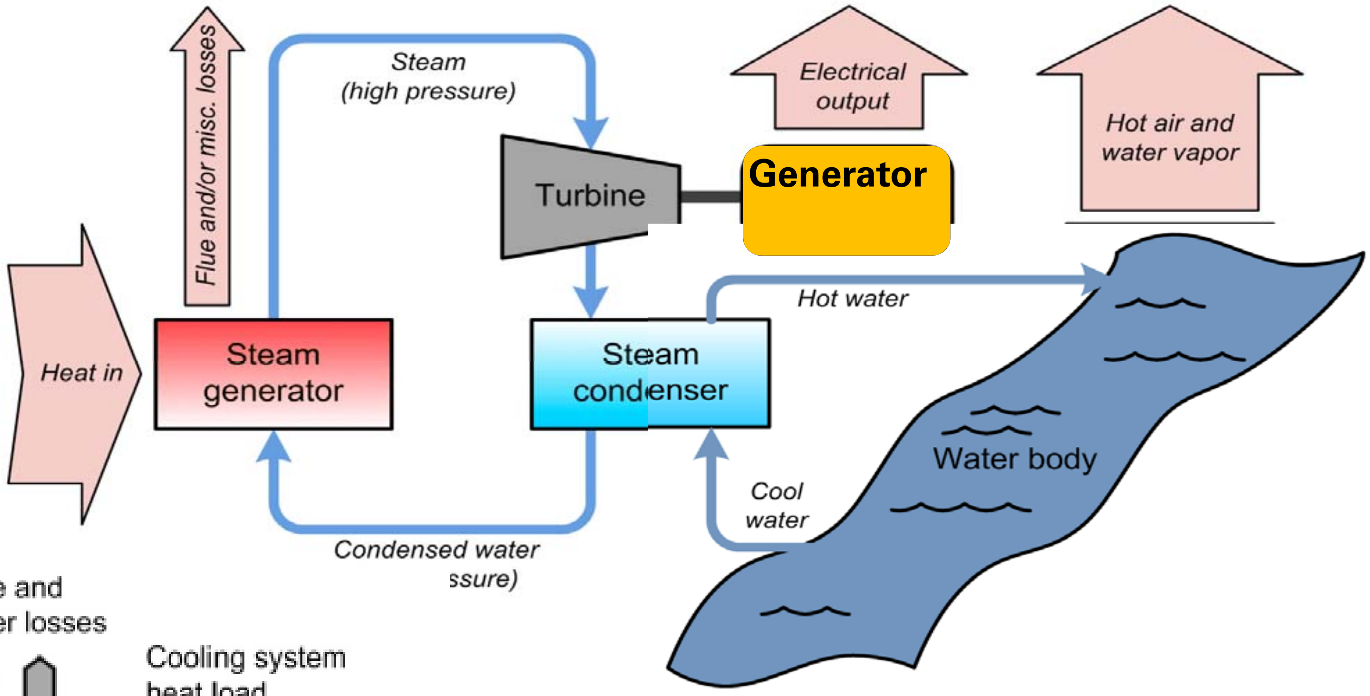
Complexity, connectivity and scale

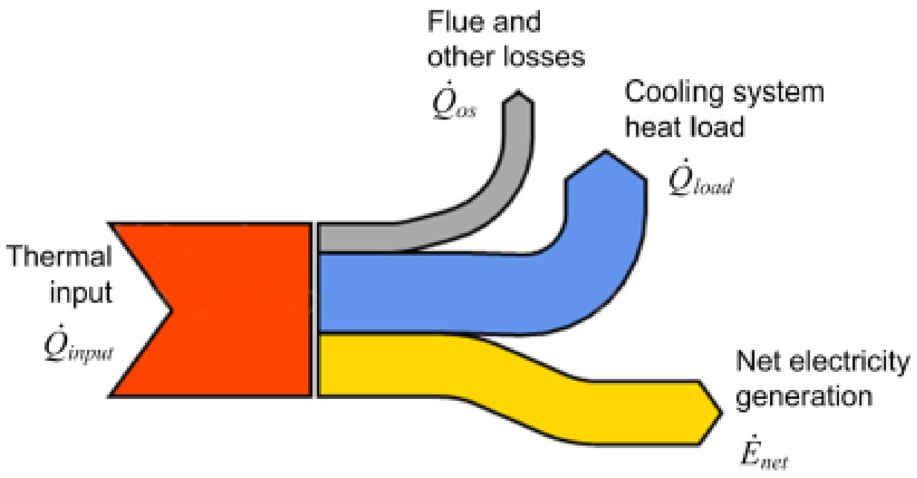
Sound information is essential for policy and planning



Source: McKinsey analysis with ESC updates

Water Use in Power Production



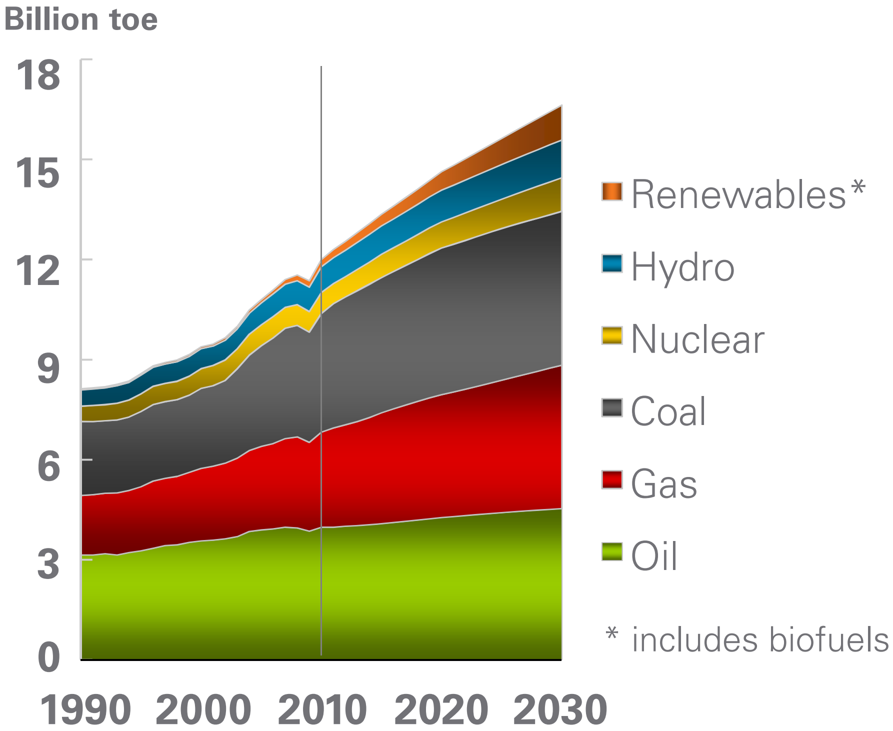


Power plant energy balance: Three ultimate destinations for thermal input, one of which (cooling system) needs water

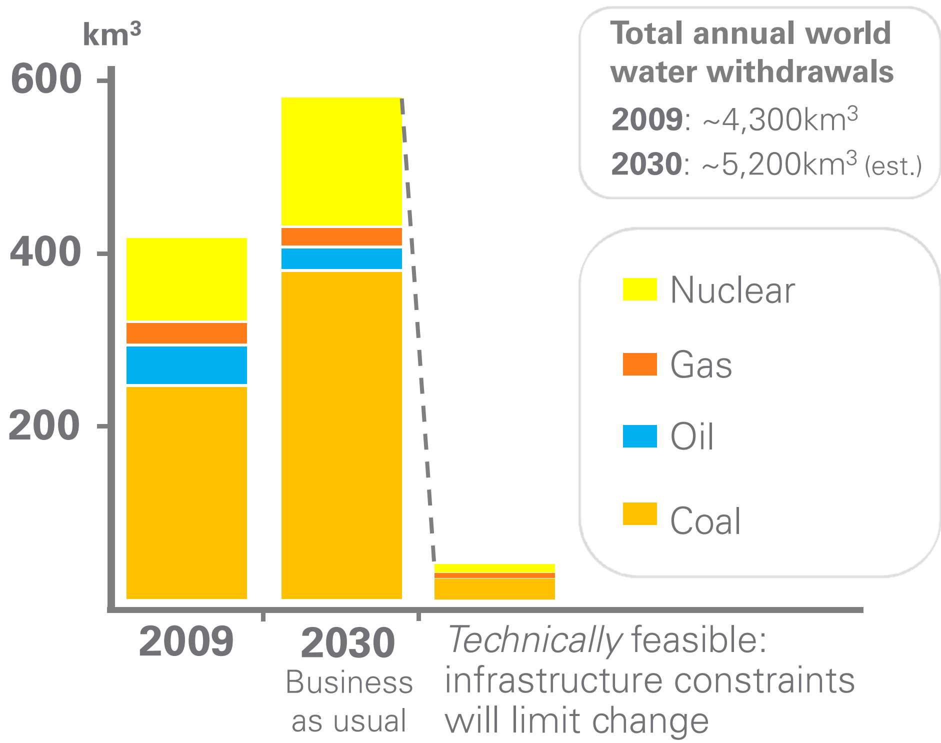
Energy and water use projections

Technical choices can significantly reduce the impact on natural resources

Projected energy growth



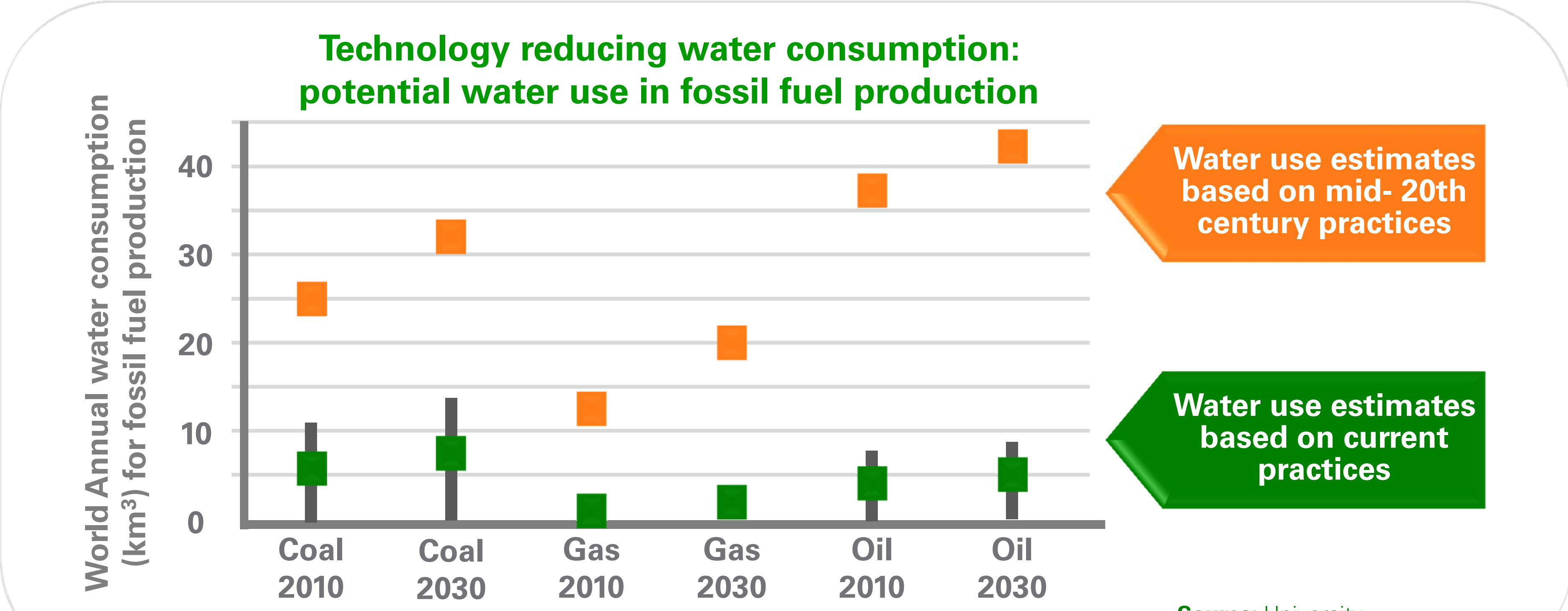
Water withdrawals for thermoelectric power



Source: BP 2030 Energy Outlook (2012)

Water for fossil fuel extraction

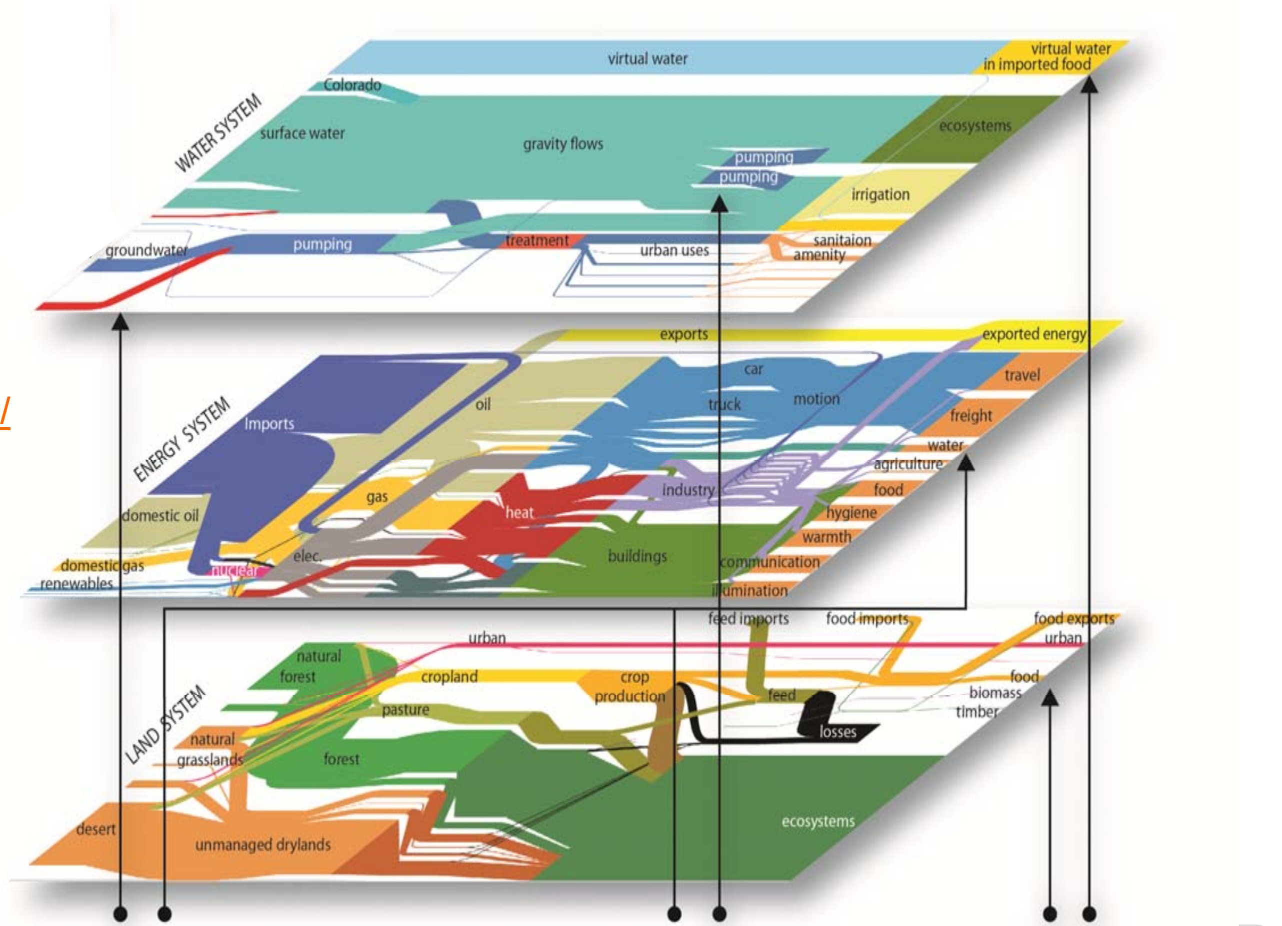
In energy extraction, advances in the past 50 years have dramatically improved water management



Source: University of Texas at Austin

Linked Resources – energy-water-land

http://foreseer.org/



Foreseer tool

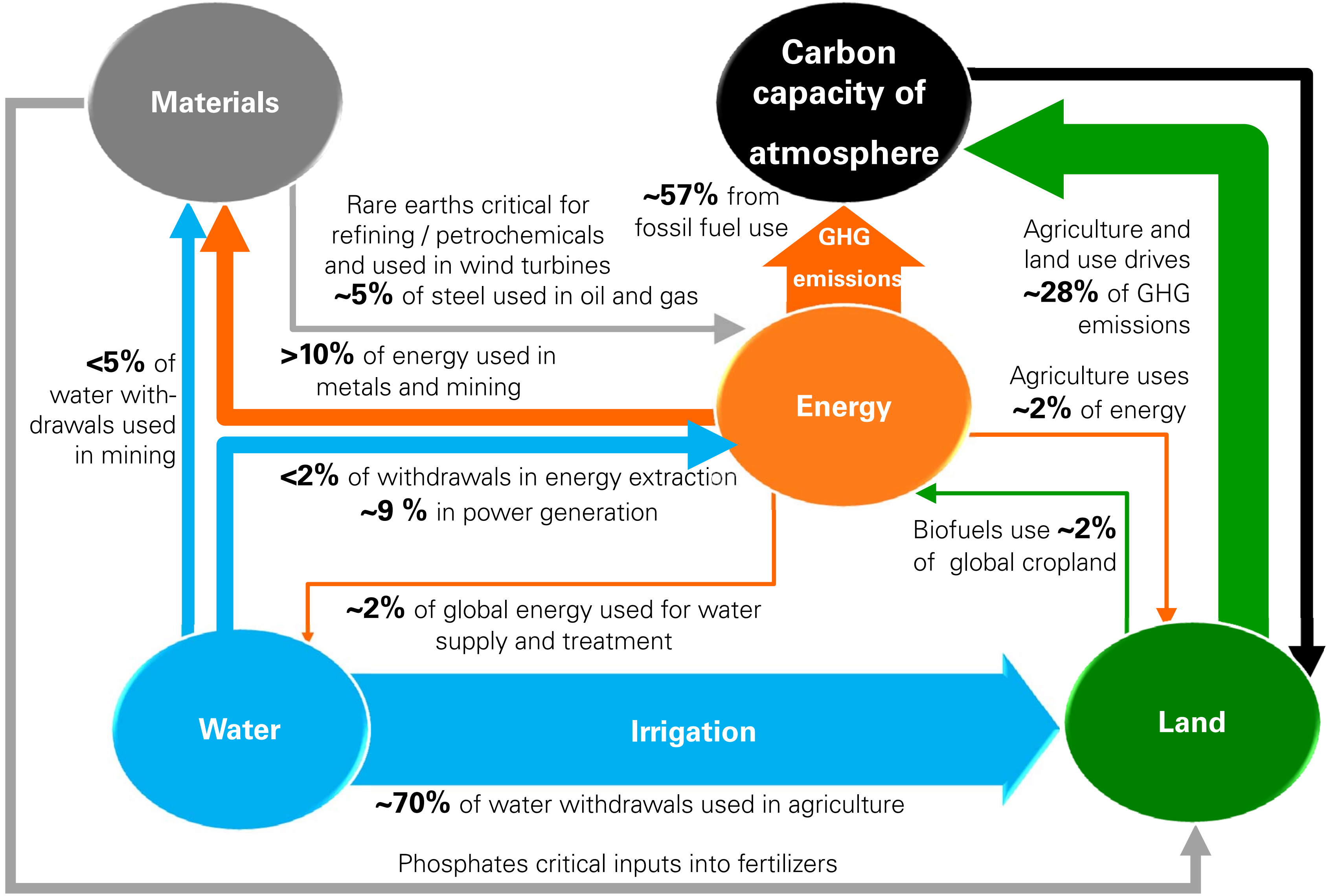
Julian Allwood, University of Cambridge, 2012

Increase supply of water

Increase in irrigation efficiency

Reduce food crops

Complexity, connectivity and scale
Sound information is essential for policy and planning



Source: McKinsey analysis with ESC updates

Happy Birthday Steve!

- Rigorous technical analysis: Improving engine efficiency is the most effective *near term* opportunity to reduce total greenhouse gas emissions due to transport.
- EBI: Fundamental advances based on genetic manipulation of yeasts and enzyme-producing fungi are essential to reducing the capital and operating costs for lignocellulosic crops
- The Big Problem: Energy-related water, land and minerals constraints can be managed sustainably…

…however doing so will require technically sound governance decisions

Back up Material

Land and Water Scales

Land Areas
Total: 148.9 million km² = 14,890 Mha
Crop land: 1553 M ha
Pasture: 3326 M ha
Secondary forest: 1093 M ha
Primary forest: 2574 M ha

Renewable Fresh Water Resources (in 2000)	World Water withdrawals per year (in 2000)
*44,000 km^3	*3800 km^3
44 Tm^3	3.8 Tm^3
12 Pgal (US)	1.0 Pgal (US)
9.7 Pgal (Impl.)	0.84 Pgal (Impl.)
44 PLiter	3.8 PLiter
36 Gacre-foot	3.1 Gacre-foot
44 Ttonne	3.8 Ttonne

*Land values from G.C. Hurtt,

Global Change Biology 12, 1208 (2006)

*Water values from the 3d UN World Water Development Report, 2009,

Table 7.1