The Energy Challenge

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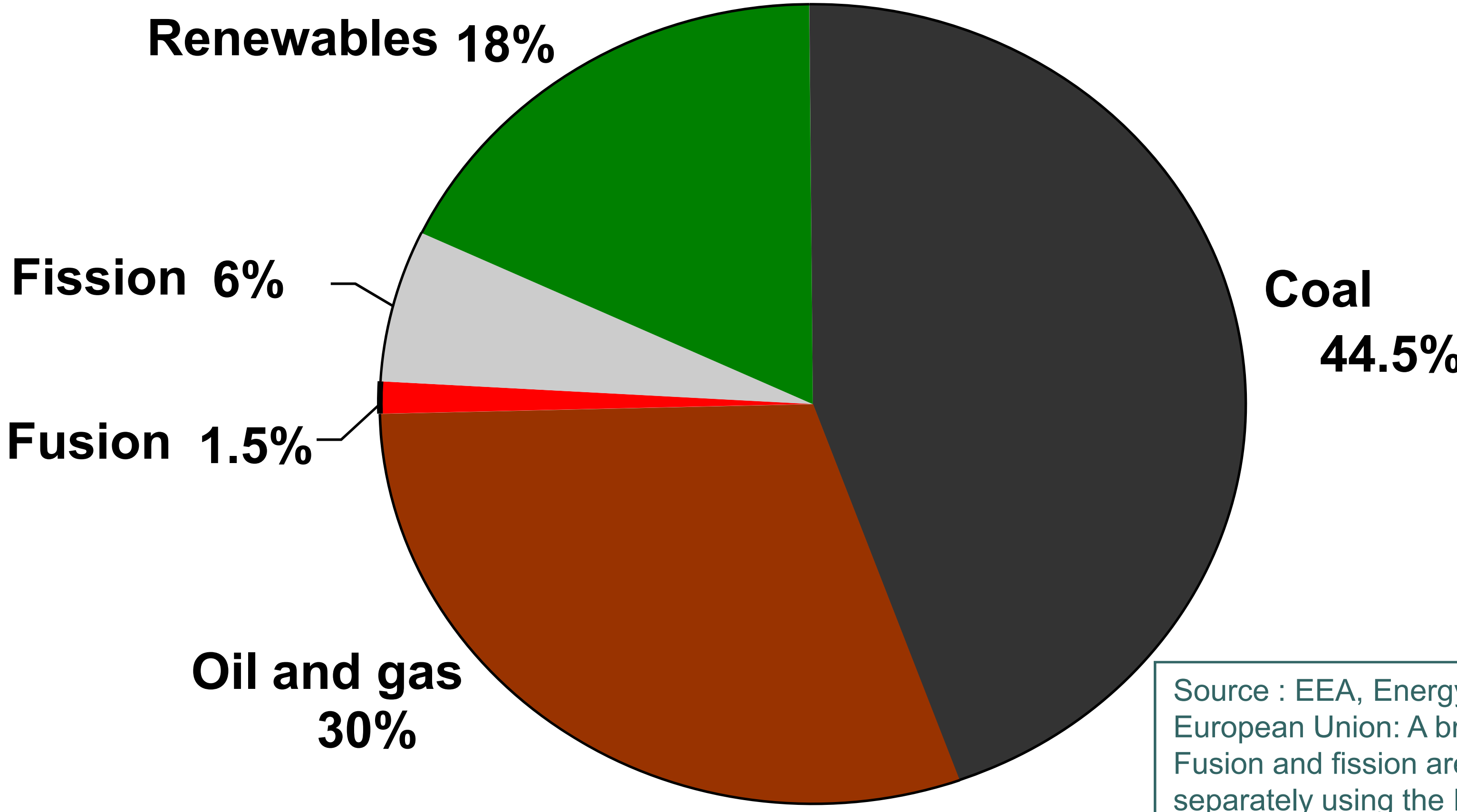
Energy and Well Being

Energy Challenge: A Summary

- Large increases in energy use is expected (50% increase by 2030, 400% increase by the end of the century)
- IEA world Energy Outlook indicate that this will require increased use of fossil fuels
  - Air pollution & Climate Change
  - Will run out sooner or later
- Limiting CO_2 to 550ppm by 2050 is an ambitious goal.
  - USDOE: “The technology to generate this amount of emission-free power does not exist.”
  - IEA report: “Achieving a truly sustainable energy system will call for radical breakthroughs that alter how we produce and use energy.”
- Public funding of energy research is down 50% since 1980 (in real term). World energy R&D expenditure is 0.25% of energy market of $4.5 trillion.

Most of public energy expenditures is in the form of subsidies

Energy Subsides (€28B) and R&D (€2B) in the EU



Source : EEA, Energy subsidies in the European Union: A brief overview, 2004. Fusion and fission are displayed separately using the IEA government-R&D data base and EURATOM 6th framework programme data

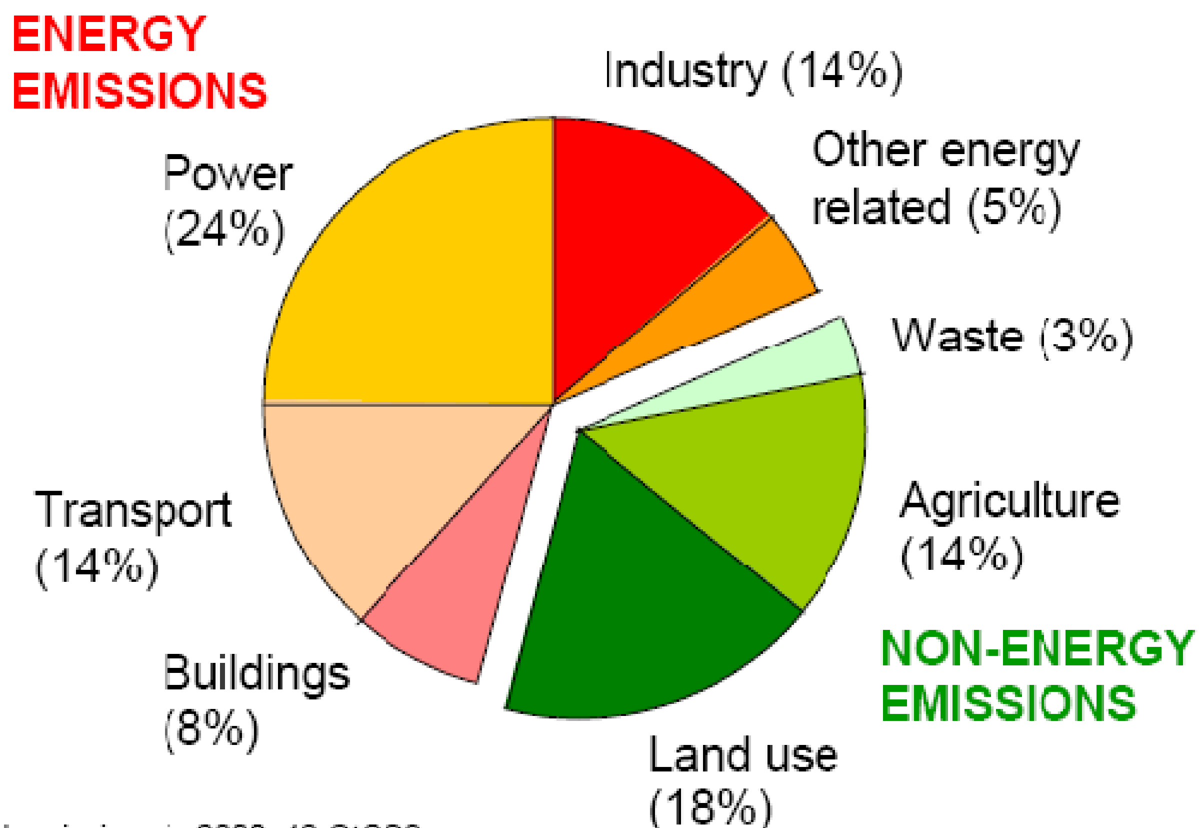
Slide from C. Llewellyn Smith, UKAEA

Technologies to meet the energy challenge do not exist

- Improved efficiency and Conservation
  - Huge scope but demand has always risen faster due to long turn-over time.
- Renewables (will be discussed in follow-up lectures)
  - Intermittency, cost, environmental impact.
- Carbon sequestration
  - Requires handling large amounts of C (Emissions to 2050 =2000Gt CO_2)
- Fission (will be discussed in follow-up lectures)
  - fuel cycle and waste disposal
- Fusion (will be discussed in follow-up lectures)
  - Probably a large contributor in the 2^{nd} half of the century

- **No Silver Bullet. Solution probably will be a cocktail!**

Many sources contribute to the emission of greenhouse gases



Total emissions in 2000: 42 GtCO2e.

Energy emissions are mostly CO_2 (some non-CO_2 in industry and other energy related).
Non-energy emissions are CO_2 (land use) and non-CO_2 (agriculture and waste).

It is more important to consider Emissions instead of Energy end-use.

Energy Efficiency and Transportation Fuels

Energy Efficiency

- **Production: e.g.** world average power plant efficiency ~ 30% → 45% (state of the art) would save 4% of anthropic carbon dioxide
  - ✓ use of flared gas in Africa could produce 20 GW (= half Africa's current electricity)
- **Distribution:** typically 10% of electricity lost (→ 50% due to 'non-technical losses' in some countries: need better metering)
- **Use:** e.g., better insulated homes, more efficient transport
- Huge scope but demand is rising faster due to long turn-over time.

- **Energy Efficiency and Conservation should not be confused**

Buildings

- Consumes ~ 50% of energy (Constructing, maintaining, occupying buildings)
- Improvements in design could have a big impact (e.g. could cut energy used to heat homes by up to factor of three)
- **Issue:** turn over of housing stock ~ 100 years
- **Tools**: better information, regulation, financial instruments

Source: Foster and Partners. Swiss Re Tower uses 50% less energy than a conventional office building (natural ventilation & lighting…)

Transportation

- Road transport is growing rapidly e.g. IEA estimates 700 million light vehicles today → 1,400 million in 2030 (China: 9M → 100M)
  - For the world's per capita petrol consumption to equal that in the USA, total gas consumption would have to increase almost ten fold!
- Huge scope for more efficient (lighter) cars
- There have been huge improvements in efficiency – but it has been used to provide heavier cars and (more powerful cars?)
- **After the end of oil? Syn-fuels coal & gas, bio material → oil, hydrogen, electric…**

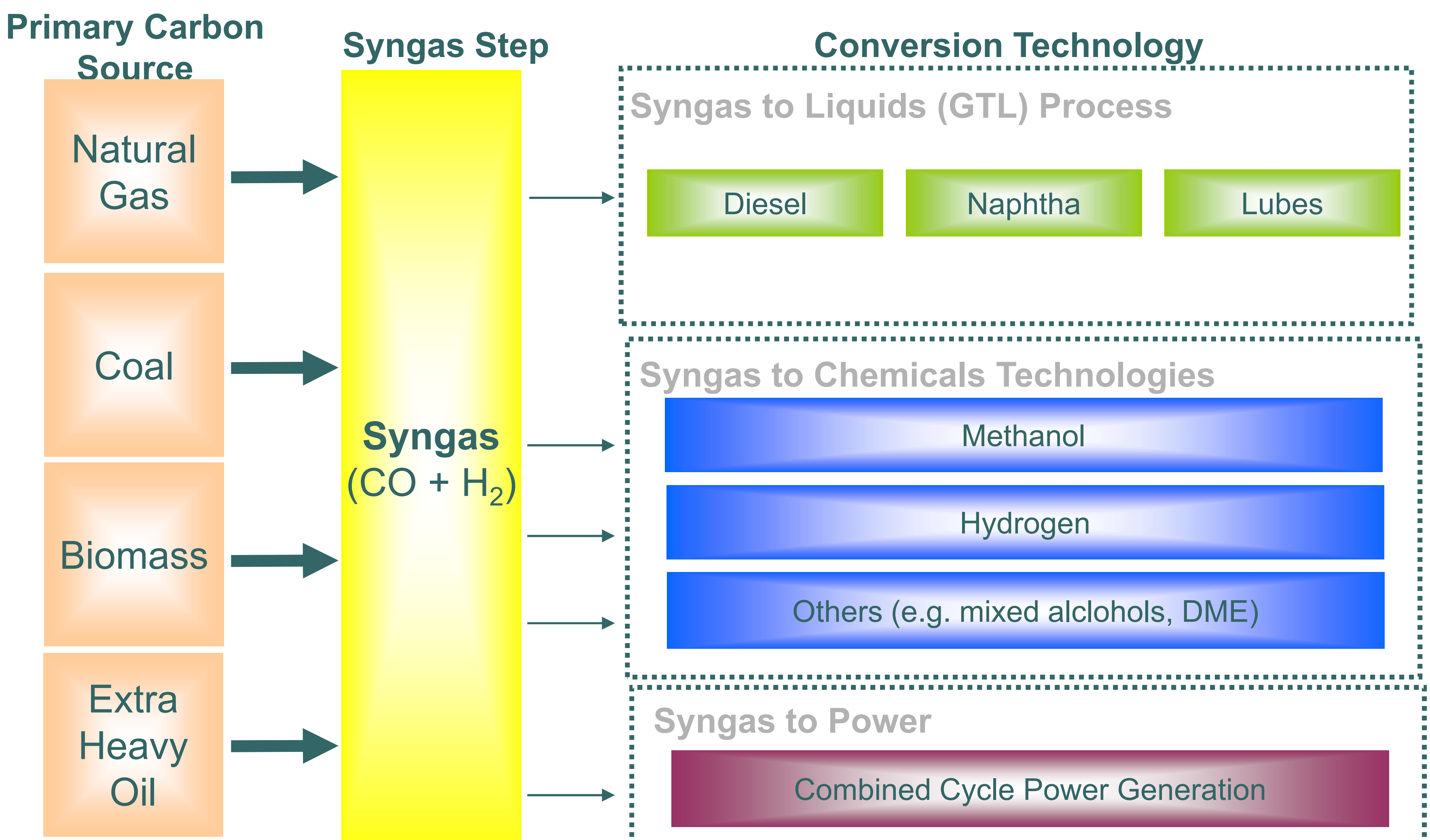
US Autos (1990-2001)

Net Miles per Gallon:	**+4.6%**
- *engine efficiency:*	***+23.0%***
- *weight/performance:*	***-18.4%***
Annual Miles Driven:	**+16%**
Annual Fuel Consumption:	**+11%**

Hydrogen

- Excites public and politicians (no CO_2 at point of use)
- Has to be produces (e.g., by electrolysis, or ‘thermo [high temperature] - chemical cracking’ of water)
- Hydrogen would helpful only if no CO_2 at point of production, e.g.
  - capture and store carbon at point of production
  - produced from renewables (reduces problem of intermittency)
  - produced from fission or fusion
- Excellent energy/mass ratio but energy/volume terrible
- Need to compress or liquefy (uses ~ 30% of energy, and adds to weight), or absorb in light metals (big chemical challenge)

Bio-fuels are Synthetic Fuels from Biomass



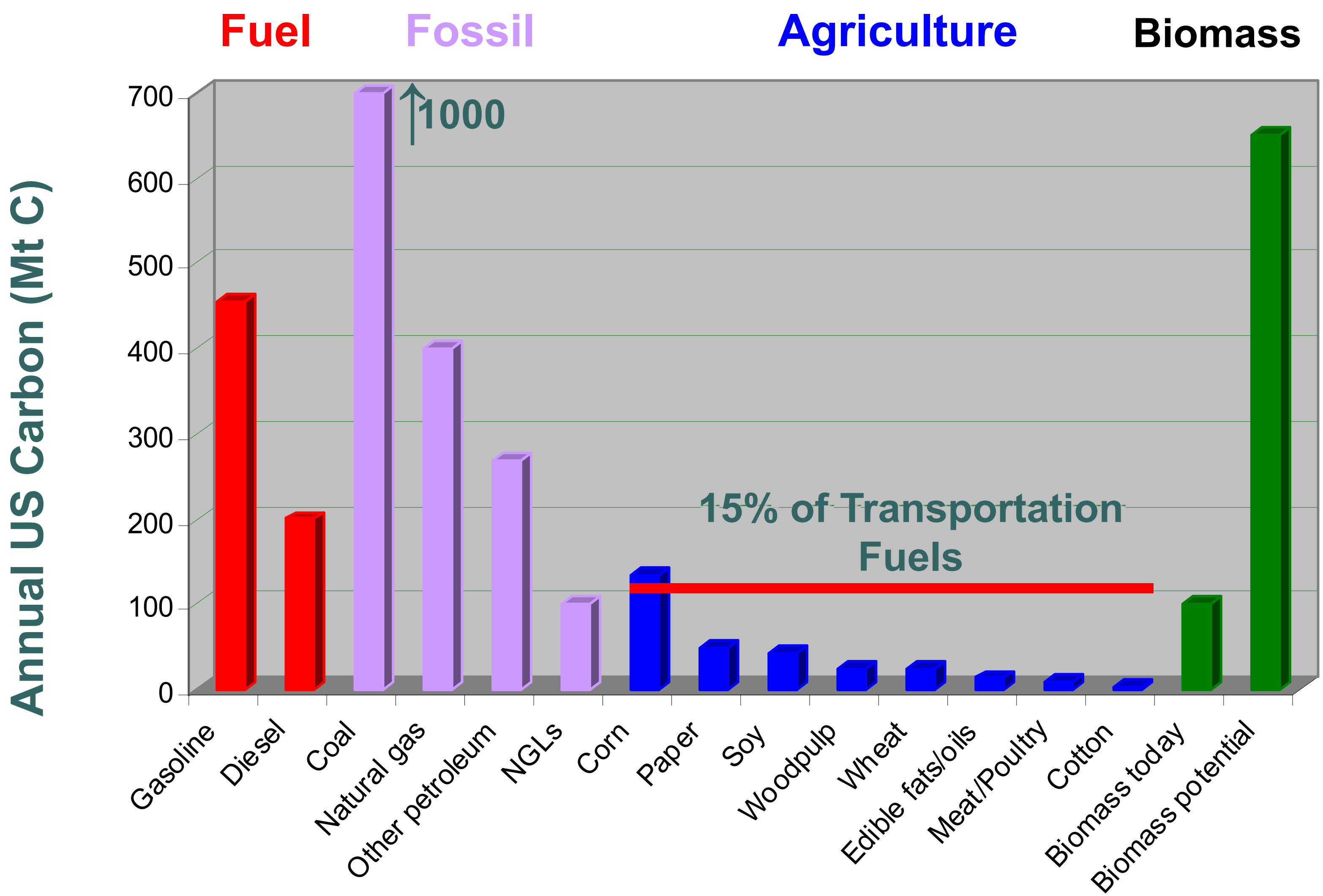
Biofuels today

- 2% of transportation pool
- (Mostly) Use with existing infrastructure & vehicles
- Growing support worldwide
- Conversion of food crops into ethanol or biodiesel
  - US Corn ethanol economic for oil > $45 /bbl
  - Brazilian sugarcane economic for oil > $22/bbl

Food Crops for Energy

Flex Fuel Offers in Brazil

what carbon “beyond petroleum”?



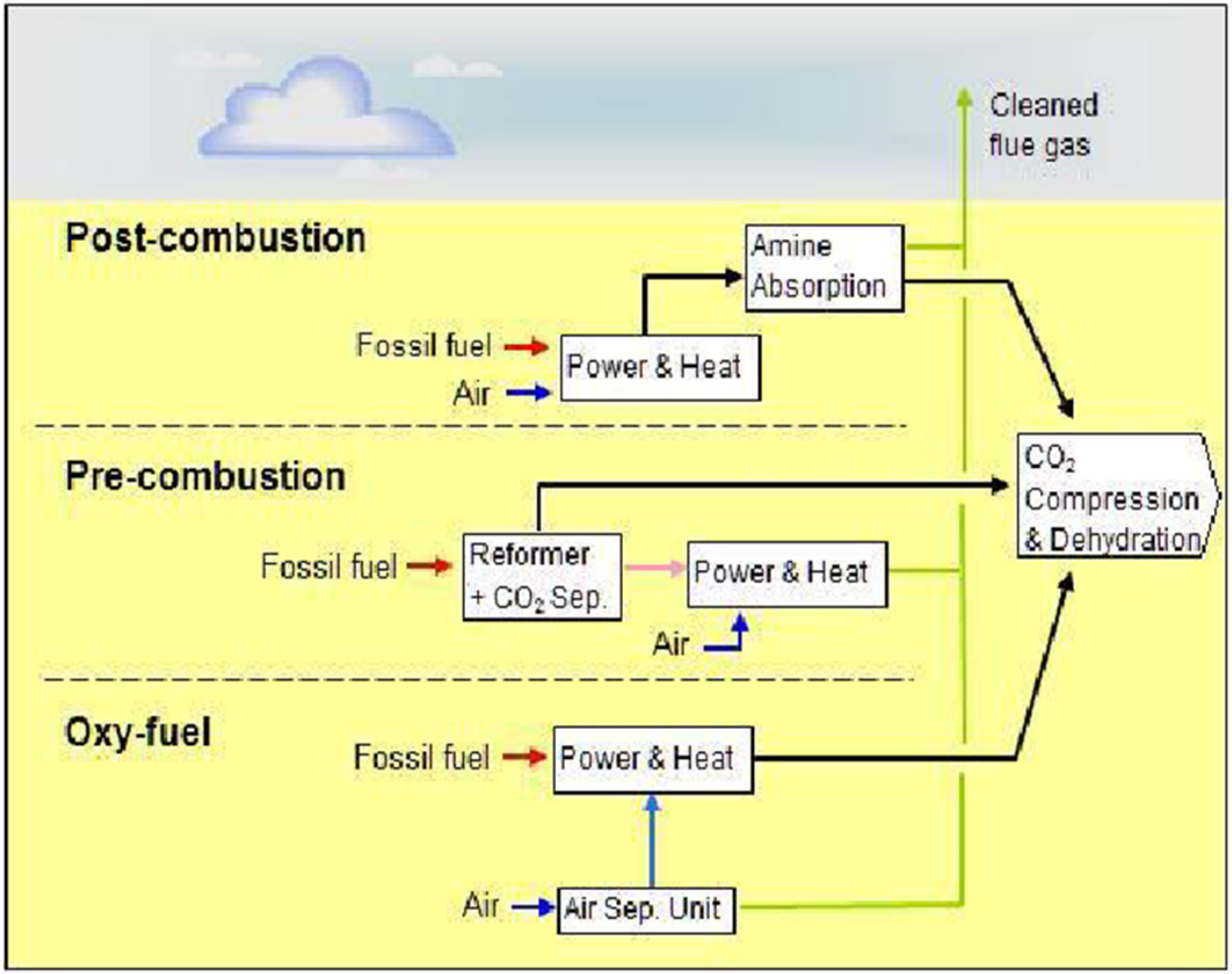
key questions about biofuels

- **Costs**
  - Biofuel production costs
  - Infrastructure & vehicle costs
- **Materiality**
  - Is there sufficient land after food needs?
  - Are plant yields sufficiently high?
- **Environmental sustainability**
  - Field-to-tank CO_2 emissions relative to business as usual?
  - Agricultural practice – water, nitrogen, ecosystem diversity and robustness, sustainability, food impact
- **Energy balance**
  - More energy out than in?
  - Does it matter?

Corn ethanol is sub-optimal

- **Production does not scale to material impact**
  - 20% of US corn production in 2006 (vs. 6% in 2000) was used to make ethanol displacing ~2.5% of petrol use
  - 17% of US corn production was exported in 2006
- **The energy and environmental benefits are limited**
  - To make 1 MJ of corn ethanol requires 0.9 MJ of other energy (0.4 MJ coal, 0.3 MJ gas, 0.04 MJ of nuclear/hydro, 0.05 MJ crude)
  - Net CO_2 emission of corn ethanol ~18% less than petrol
- **Ethanol is not an optimal fuel molecule**
  - Energy density, water, low vapour pressure, corrosive,…
- **There is tremendous scope to improve (energy, economics, emissions)**

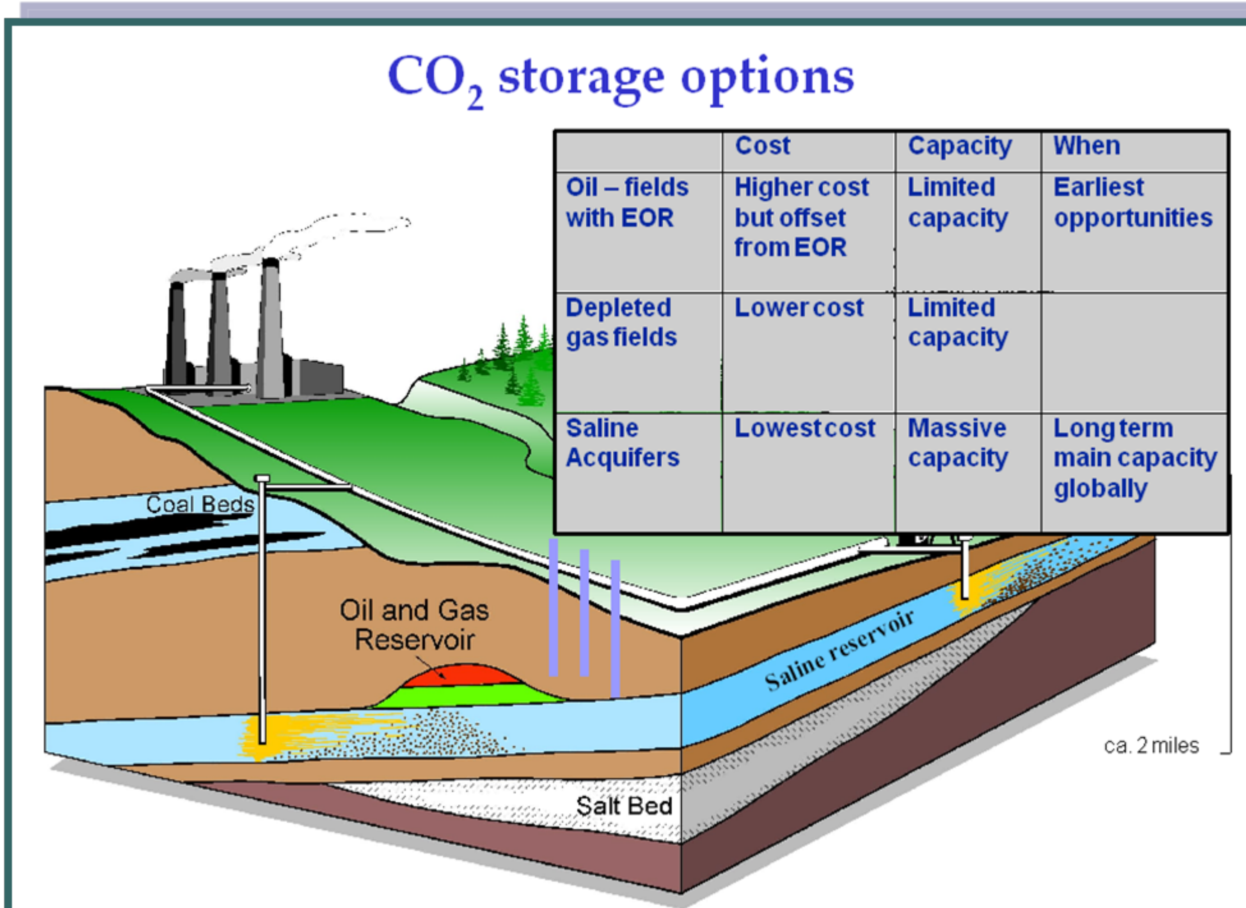
Carbon Dioxide Capture Technologies



Carbon/CO_2 capture and storage ('sequestration')

- Possible in principle from coal or gas power stations (35% of total of CO_2 from fossil fuels) and from some industrial plants (not from cars, domestic) – needs to last well beyond end of fossil fuel era (and not leak too much)
- **Downsides**
  - not proven on large scale (from coal: 3Mt captured in 2003 vs. 9,593 Mt produced), *but can build 'capture ready' plants now*
  - would increase cost by (1-2)p/kWhr; needs CO_2 cost above $25/tonne to be viable
  - decrease efficiency by ~10% (i.e. 45% → 35%)

Storage Options:

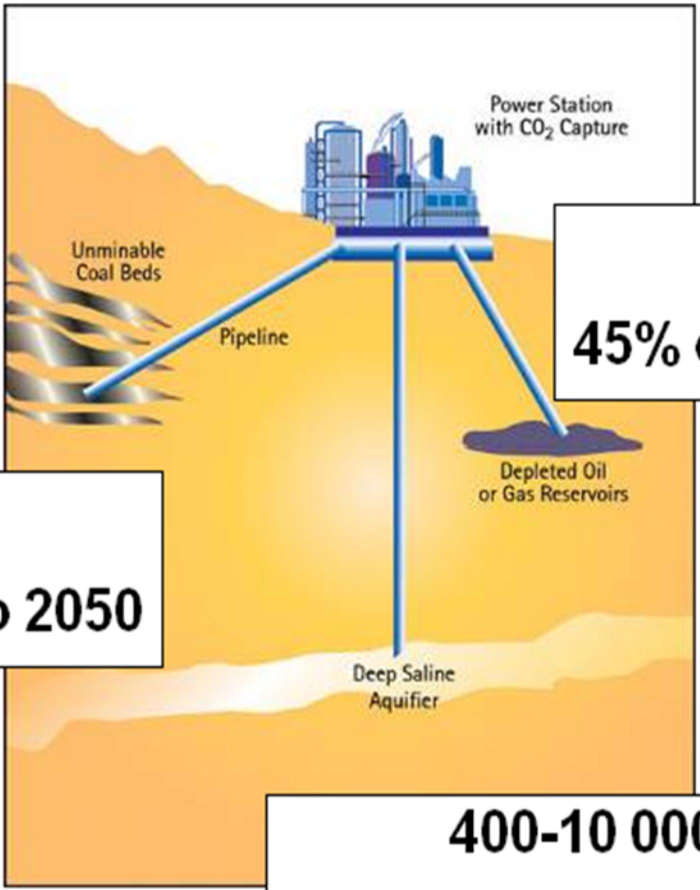


	Cost	Capacity	When
Oil – fields with EOR	Higher cost but offset from EOR	Limited capacity	Earliest opportunities
Depleted gas fields	Lower cost	Limited capacity	
Saline Acquifers	Lowest cost	Massive capacity	Long term main capacity globally

After capture, compress (>70 atmos. → liquid) transmit and store (>700m):

Geological Storage Potential

Courtesy of IEA GHG R&D Programme



920 Gt CO_2

45% of Emissionsto 2050

40 Gt CO_2

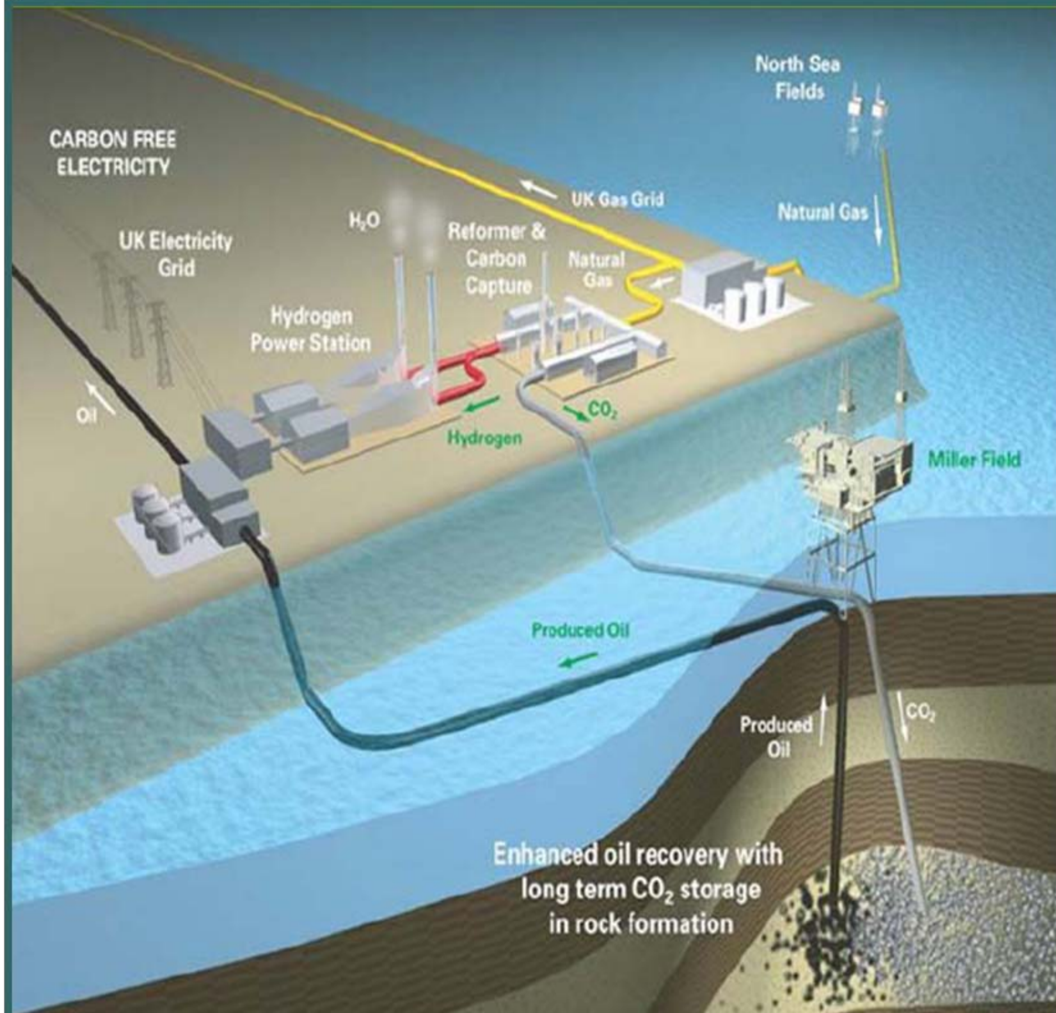
<2% of Emissionsto 2050

400-10 000 Gt CO_2

20-500 % of Emissionsto 2050

substantial storage potential

BP Hydrogen Power Plant



- CCS is a material CO_2 mitigation option for power
- Technologies largely proven
- 1MtCO_2 p.a. pilot plant operating in Algeria
- First large scale hydrogen power plant announced in Scotland
- Single 350MW plant in UK generates more carbon free electricity than entire UK wind park
- But need right policy framework to be viable

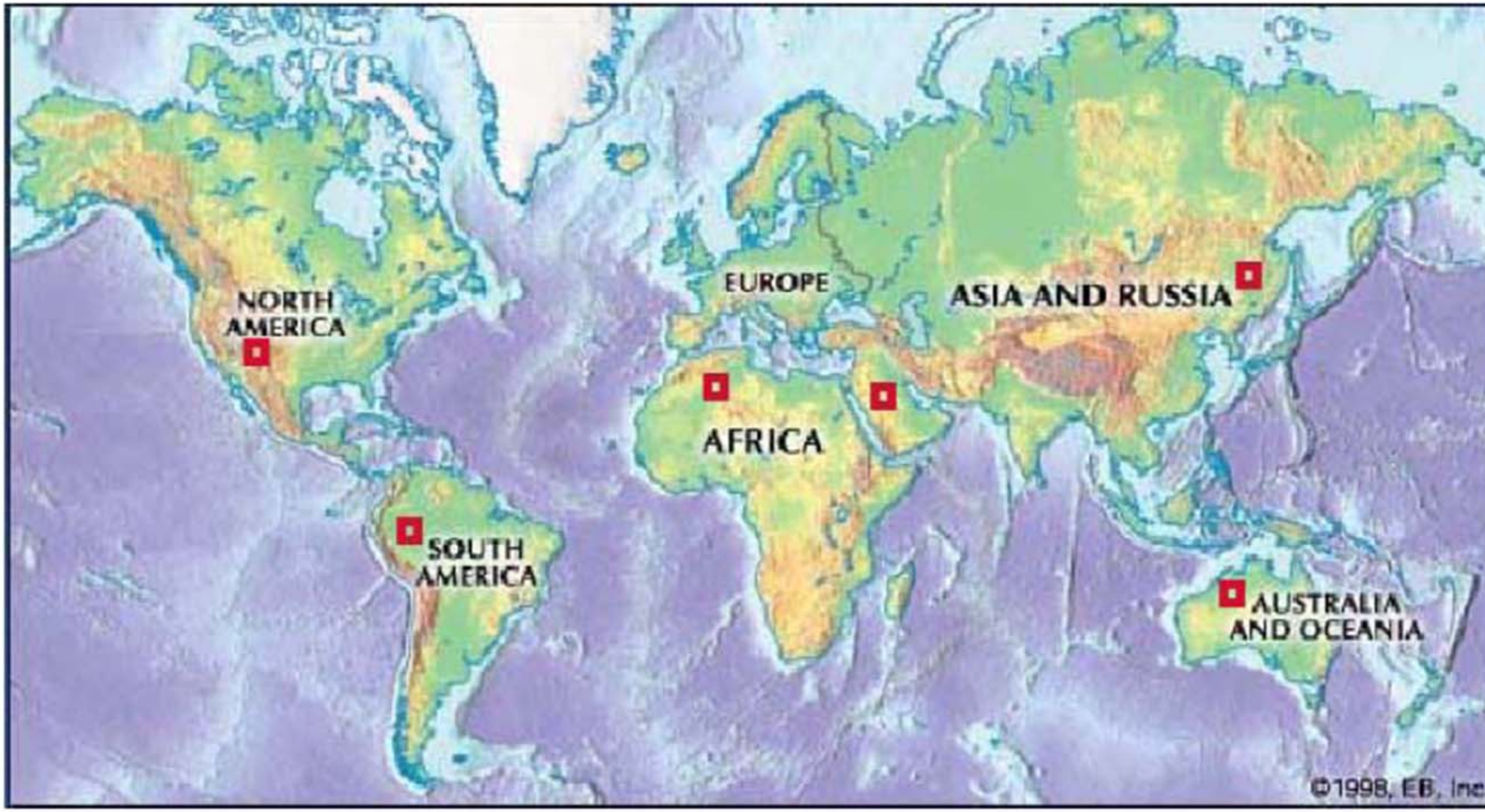
Renewables

(Seek significant fraction of world's 14 TW consumption)

Potential of Renewables

- **Solar** - 85,000 TW reaches earth's surface $\rightarrow$ 25,000 TW on land, if capture [PV] 0.5% at 15% efficiency $\Rightarrow$ **19 TW** ~ 1.35x current total use
  - **but:** cost, location, timing $\rightarrow$ storage? [note – lose (conversion efficiency)^2]
- **Tidal** - input 3 TW; at reasonable sites - 0.2 TW peak/0.06 TW average (for barrages: underwater tidal streams could do better)
- **Waves** - 1 TW available in principle on continental shelves, 0.1 TW in shallow water

Size of PV stations to generate 20TW



6 boxes sized to produce 3.3TW of power each (20TW total – 630EJ)

Source: Lewis et al 2003c

Potential of Renewables II

- **Wind** - 200 TW input ⇒ no more than a few TW available (bottom of atmosphere)
- **<u>Biomass</u>** - 40 TW from *all* current growth (farms + forests etc) ⇒ absorbing CO_2 [average solar → biomass efficiency ~ 0.2%; sugar cane ~ 1.5%], conversion to useable form inefficient
- **Hydro –** 1.5 TW_e max, 1 TW_e useful, 0.3 TW_e already in use
- **Geothermal** - total flux out of earth* ~ 10 TW → maximum useful 0.1 TW (well exploited where sensible: 10 GW installed) ; more available by 'mining' up to 100 GW?

Any Questions?