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 CO₂ 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 Subsidies (€28B) and R&D (€2B) in the EU

- Coal: 44.5%
- Oil and gas: 30%
- Renewables: 18%
- Fission: 6%
- Fusion: 1.5%


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 CO₂)

- 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 2nd half of the century

- No Silver Bullet. Solution probably will be a cocktail!
Many sources contribute to the emission of greenhouse gases

<table>
<thead>
<tr>
<th>Source</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>24%</td>
</tr>
<tr>
<td>Transport</td>
<td>14%</td>
</tr>
<tr>
<td>Buildings</td>
<td>8%</td>
</tr>
<tr>
<td>Industry</td>
<td>14%</td>
</tr>
<tr>
<td>Other energy related</td>
<td>5%</td>
</tr>
<tr>
<td>Waste</td>
<td>3%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>14%</td>
</tr>
<tr>
<td>Land use</td>
<td>18%</td>
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</tbody>
</table>

Total emissions in 2000: 42 GtCO2e.
Energy emissions are mostly CO2 (some non-CO2 in industry and other energy related).
Non-energy emissions are CO2 (land use) and non-CO2 (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…)
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

Primary Carbon Source
- Natural Gas
- Coal
- Biomass
- Extra Heavy Oil

Syngas Step: Syngas (CO + H₂)

Conversion Technology
- Syngas to Liquids (GTL) Process
  - Diesel
  - Naphtha
  - Lubes
- Syngas to Chemicals Technologies
  - Methanol
  - Hydrogen
  - Others (e.g. mixed alcohols, DME)
- Syngas to Power
  - Combined Cycle Power Generation
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
what carbon “beyond petroleum”? 

Annual US Carbon (Mt C)

Fuel
- Gasoline
- Diesel
- Coal
- Natural gas
- Other petroleum
- NGLs
- Corn
- Paper
- Soy
- Woodpulp
- Wheat
- Edible fats/oils
- Meat/Poultry
- Cotton
- Biomass today
- Biomass potential

Agriculture

Fossil

Biomass

15% of Transportation Fuels

↑ 1000
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 CO₂ 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

Post-combustion
- Fossil fuel → Amine Absorption → Power & Heat
- Air → Power & Heat

Pre-combustion
- Fossil fuel → Reforming + CO₂ Sep. → Power & Heat
- Air → Power & Heat

Oxy-fuel
- Fossil fuel → Power & Heat
- Air → Air Sep. Unit

CO₂ Compression & Dehydration → Cleaned flue gas
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% $\rightarrow$ 35%)
Storage Options:

CO$_2$ storage options

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Capacity</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil – fields with EOR</td>
<td>Higher cost but offset from EOR</td>
<td>Limited capacity</td>
<td>Earliest opportunities</td>
</tr>
<tr>
<td>Depleted gas fields</td>
<td>Lower cost</td>
<td>Limited capacity</td>
<td></td>
</tr>
<tr>
<td>Saline Aquifers</td>
<td>Lowest cost</td>
<td>Massive capacity</td>
<td>Long term main capacity globally</td>
</tr>
</tbody>
</table>

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

- 40 Gt CO₂ < 2% of Emissions to 2050
- 920 Gt CO₂ = 45% of Emissions to 2050
- 400-10 000 Gt CO₂ = 20-500% of Emissions to 2050

substantial storage potential

Courtesy of IEA GHG R&D Programme
BP Hydrogen Power Plant

- CCS is a material CO₂ mitigation option for power
- Technologies largely proven
- 1MtCO₂ 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 → 25,000 TW on land, if capture [PV] 0.5% at 15% efficiency ⇒ 19 TW ~ 1.35x current total use

  - but: cost, location, timing → 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)

- **Biomass** - 40 TW from *all* current growth (farms + forests etc) ⇒ absorbing CO₂ [average solar → biomass efficiency ~ 0.2%; sugar cane ~ 1.5%], conversion to useable form inefficient

- **Hydro** – 1.5 TWₑ max, 1 TWₑ useful, 0.3 TWₑ 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?