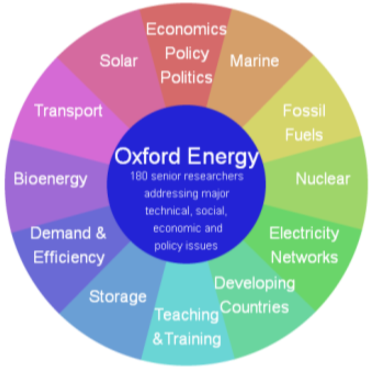

Can Future Energy Needs be Met Sustainably?

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Whether future energy needs can be met sustainably depends on

- scale of future needs
- what is meant by sustainability
- the price society will be prepared to pay
- future technological developments

Two simpler questions have clearer answers:

Can future energy needs be met with fossil fuels?

Yes for at least 50 years

Can future energy needs be met without fossil fuels?

With existing technology - incredibly difficult: impossible at a price society would be prepared to pay

Drivers of Energy Policy

1. Security

Is there enough to meet needs? Will the lights stay on? Are there queues at petrol pumps?

2. Cost

Is energy affordable? Do energy prices foster industrial competiveness and development?

3. Clean Environment

Does the system minimise pollution, health and climate impacts?

Trade-offs are required → highly political, economic, and social as well as technical issue. In practice security and costs are mainly driving what's happening.

Outline

- Crucial facts
- Future needs
- Sustainability
- Fossil fuels
- Electricity
- Low carbon energy
- Conclusions

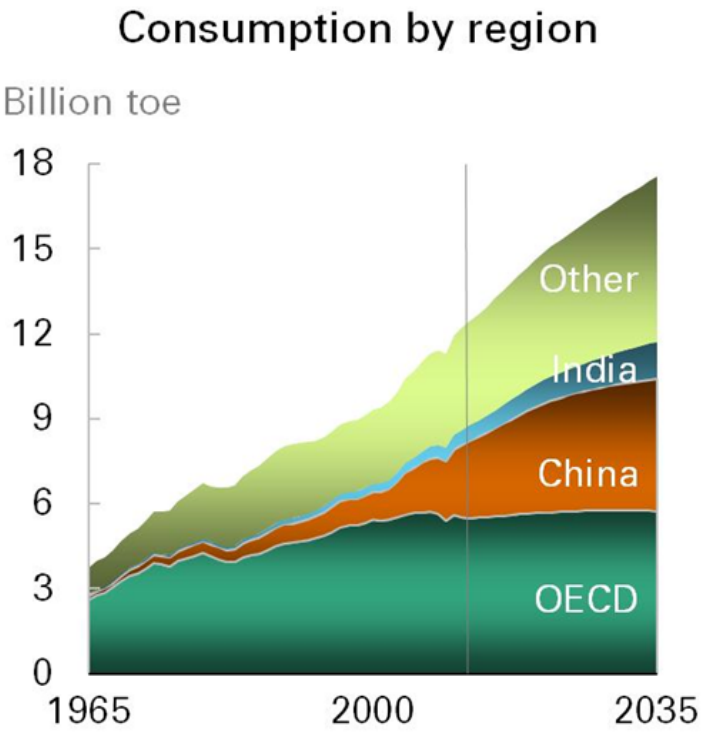
Crucial fact 1

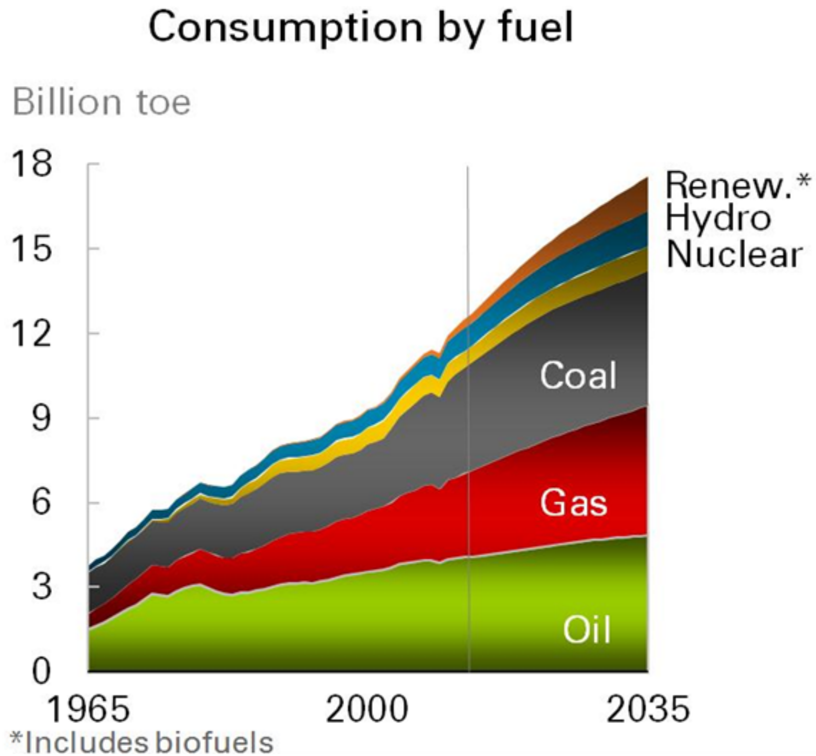
The world is using a lot of energy at an average rate equivalent to burning 1.9 tonnes of oil (toe) a year for every man, woman and child on the planet, in a very uneven manner, e.g. per person

USA 7.2 toe, UK 3.2 toe, China 2.2 toe, Bangladesh 0.23 toe

Estimates of the differences of the energy embodied in manufactured imports and exports suggest that the annual per capita energy needed to support current lifestyles is around

USA 7.8 toe, UK 3.7 toe, China 1.7 toe





BP Past data + Projections

Based on "most likely" assessment of future policy trends. Not included: 10% from biomass *(apart from biofuels which contribute ~ 0.5%)* and waste. Includes ~ 6% oil & gas → non-energy uses.

Fact 2 Energy use is growing rapidly: the growth is from Non-OECD countries and is expected to continue

Fact 3 Fossil fuels are set to continue to dominate

Fact 4 The contribution of renewables is expected to remain relatively small, despite rapid growth in percentage terms

Fact 5 **'Final Energy*' is used**

* in the form it is bought by consumers (oil, electricity, …), excluding non-energy use

-**by user:** industry - 31%, transport - 31%, residential - 25%, commerce and public services - 9%, agriculture, forestry, fishing - 2.4%, ….

-**by purpose/form** (approx.): heat - 50%, transport – 30%, electricity – 20%

Allowing for losses* in transforming primary → final energy

*mainly in electricity generation

the calls on primary energy are *very approximately*:

Heat ≈ Electricity ≈ 40%, Transport ≈ 20%

Future Energy Needs

Energy and Development

- **1.2 billion still lack electricity, 2.6 billion lack clean cooking facilities**

  - more energy needed to lift billions out of poverty

- **Energy use in developing countries is increasing:**

2035 (BP projection)	**Population**	**Energy**	**CO_2**
Non-OECD	+ 28%	+ 69%	+ 54%
OECD	+ 11%	+ 5%	- 9%

But: big gap - energy per capita in USA = 3.3*x China = 31 x Bangladesh

* **4.5** allowing for energy in imports/exports

- to reach US level with population of 9 billion (2050), **need fivefold increase in energy**

- **Want – less energy intensive ways to meet goals + greater efficiency**

  – developing countries unencumbered by existing infrastructure: new approaches?

Demand for energy can be lowered by

- **Changing life-styles,** e.g. bicycle to work, ….

- **Better planning and design**

e.g. designing buildings to make good use of natural light, planning cities to encourage walking, bicycling or use of public transport: major opportunities in rapidly developing countries

Demand management is vital but is unlikely to mitigate rising demand very significantly

- **Using it more efficiently**

Efficiency - “Low Hanging Fruit”?

- **World energy intensity = consumption/GDP: - 1% p.a. for last 20 years**
- **Nevertheless world energy consumption: + 1.9% p.a.**
- **International Energy Agency expects intensity to fall by over 2% p.a. in coming decades, but energy use will still rise by almost 1.5% p.a.**
- **Technically could do *much* better**

IEA claims *energy use in 2035 could be reduced by 14 % relative to New Policy Scenario solely by adopting measures that save both energy and money*

If this is true, why’s it not happening?

Energy Efficiency

Technically, large improvements (40% or more?) look possible, **but** they are not happening

-Appraisal optimism and neglect of transaction costs

-Direct and (more importantly) indirect rebound effect

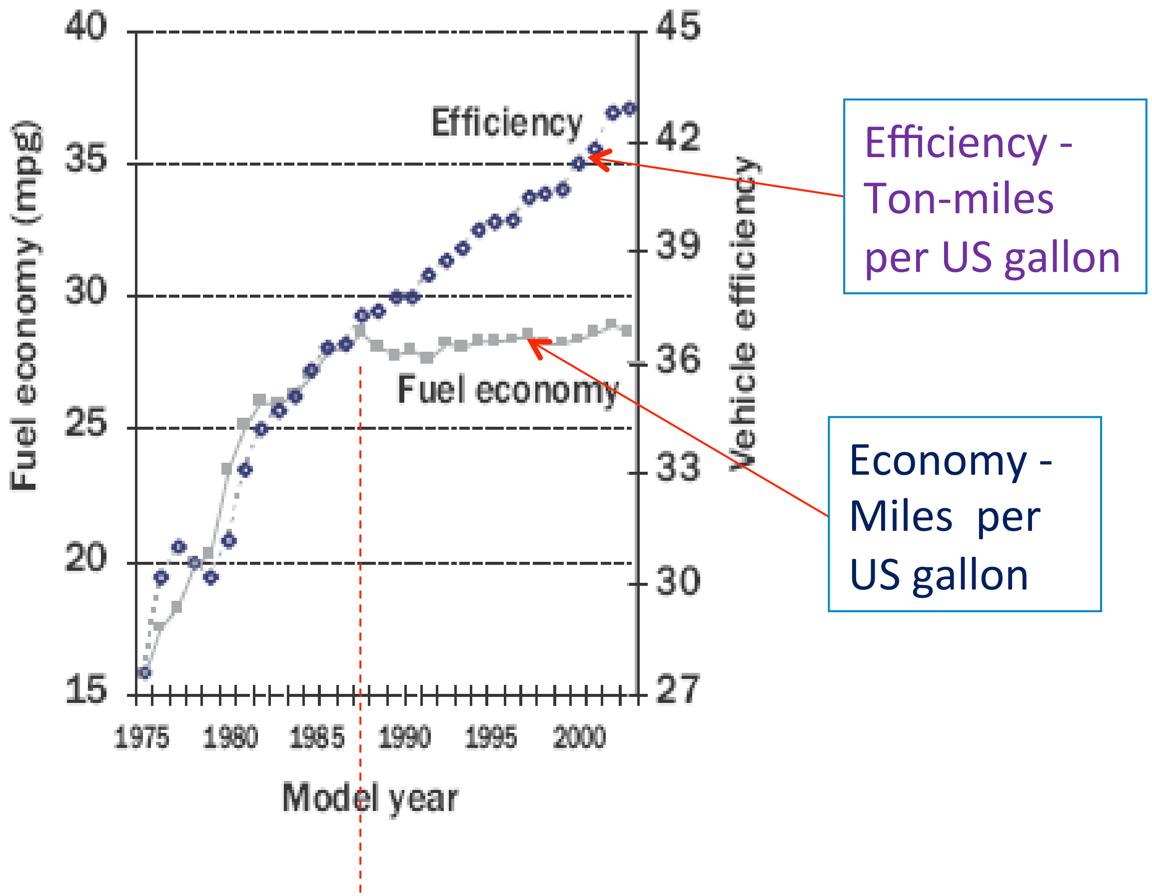
-No incentives for the affluent to make small savings, which collectively can be large, e.g. electric lighting – uses 20% of electricity

-Poor lack capital

Need regulation - cars, buildings, light-bulbs, appliances…

Effect of Regulation

US Passenger Vehicles



End of mandatory **C**orporate **A**verage **F**uel **E**conomy standards

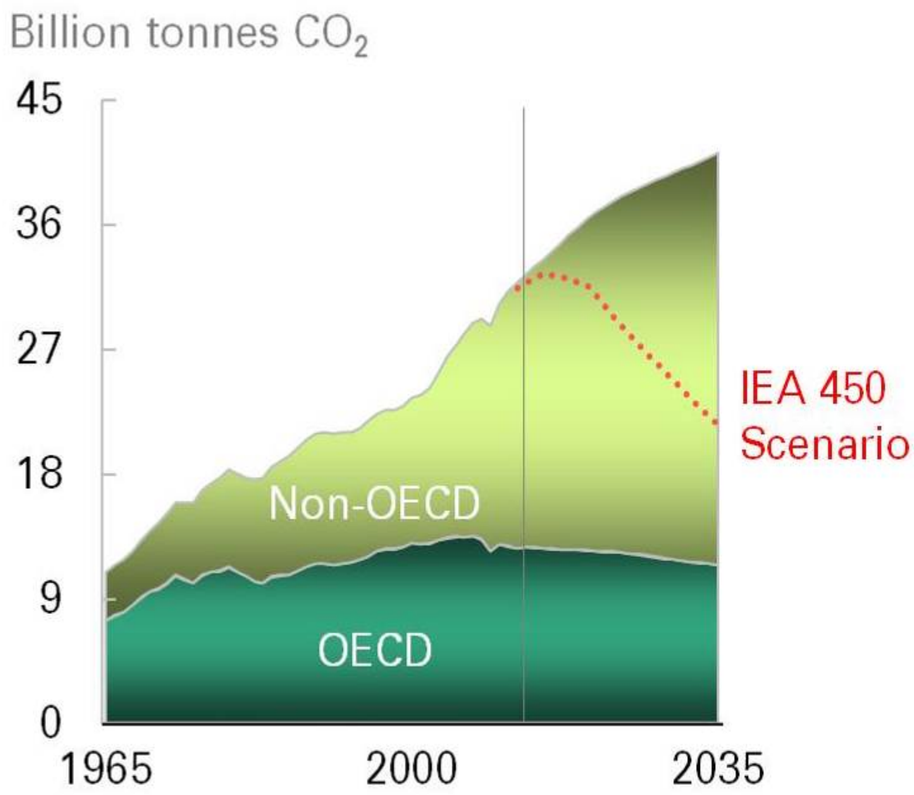
Current standards for new vehicles:

35.5 mpg by 2016

54.5 mpg by 2025

Sustainability

BP Projection of CO_2 Emissions



2035 projection unlikely to be badly wrong
– infrastructure mostly in place

Air Pollution

Premature (typically 10 years loss of useful life) **deaths:**

Globally (WHO 2014): **7 million p.a.** out of 56 million p.a.

3.7 m from outdoor pollution
4.3 m from indoor pollution
} Some double counting

Compare: cardiovascular (heart disease + stoke) 14.1 m………road accidents 1.3 m

Not just in developing countries:

US (2013 MIT study): **210 k p.a. from burning fossil fuels** out of 2.5 million

200 k from particulates: 58 k road transport
54 k power generation
43 k industry
} coal the big culprit
42 k commercial & residential
13 k marine & rail transport

Big uncertainties in numbers but undoubtedly

→ A large coal power station is far more lethal than Chernobyl

Fossil Fuels

Saudi saying: "My father rode a camel. I drive a car. My son flies a plane. His son will ride a camel"

True? I think not

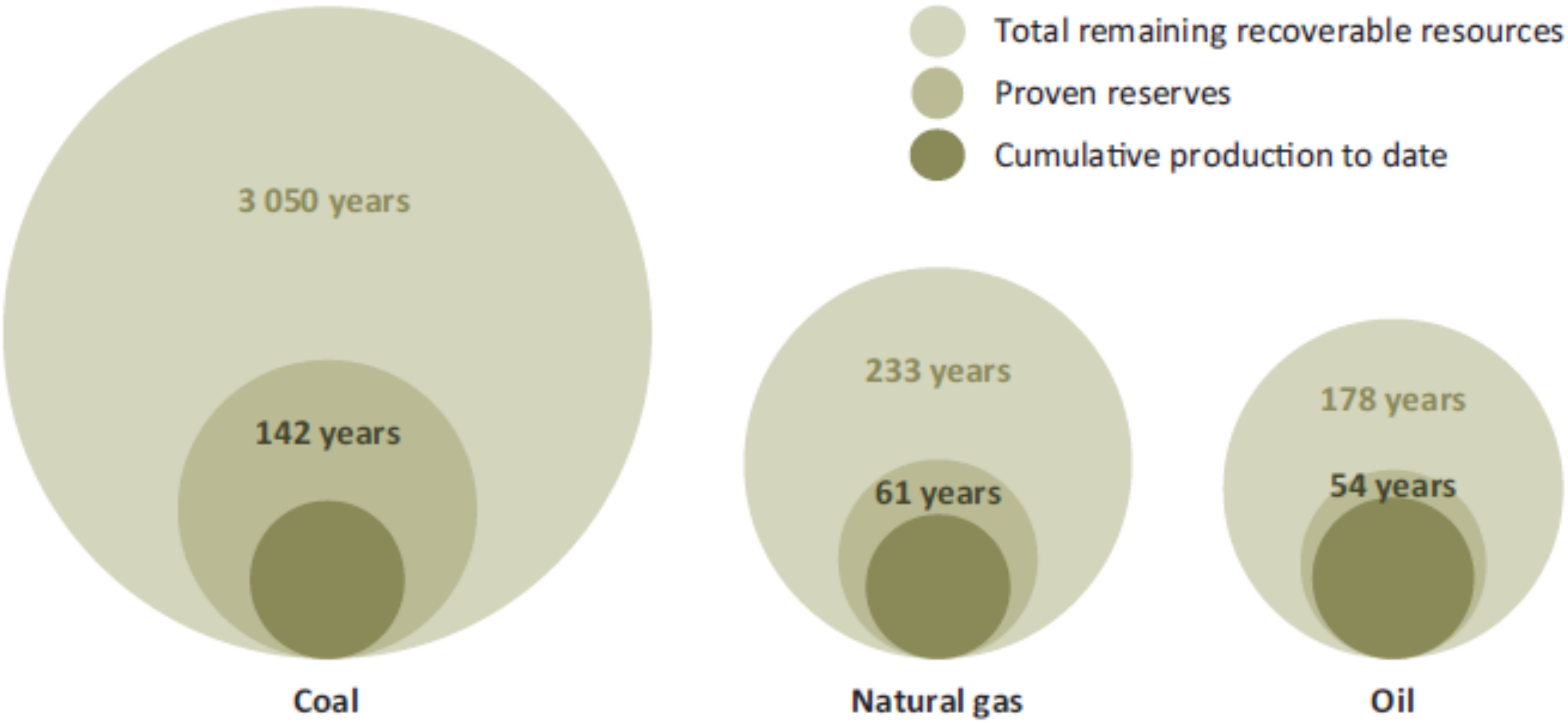
The sun may be setting on production of conventional oil in conventional places, **but** world awash with fossil fuels, much in forms (shale gas, tar sands,…) or places (under 2 km of water and 5 km of rock and sand off Brazil, the arctic,..) thought economically or technically out of reach until recently

As the world becomes increasingly reliant on these sources, will costs rise steeply?

…..don't bet on it. Technology will advance and other sources (methane hydrates, oil shale..) may become economically accessible

But in the (very) long run fossil fuels will become increasingly scare and expensive

Fossil Fuel Resources (IEA WEO 2013)
- remaining years at current rate of use

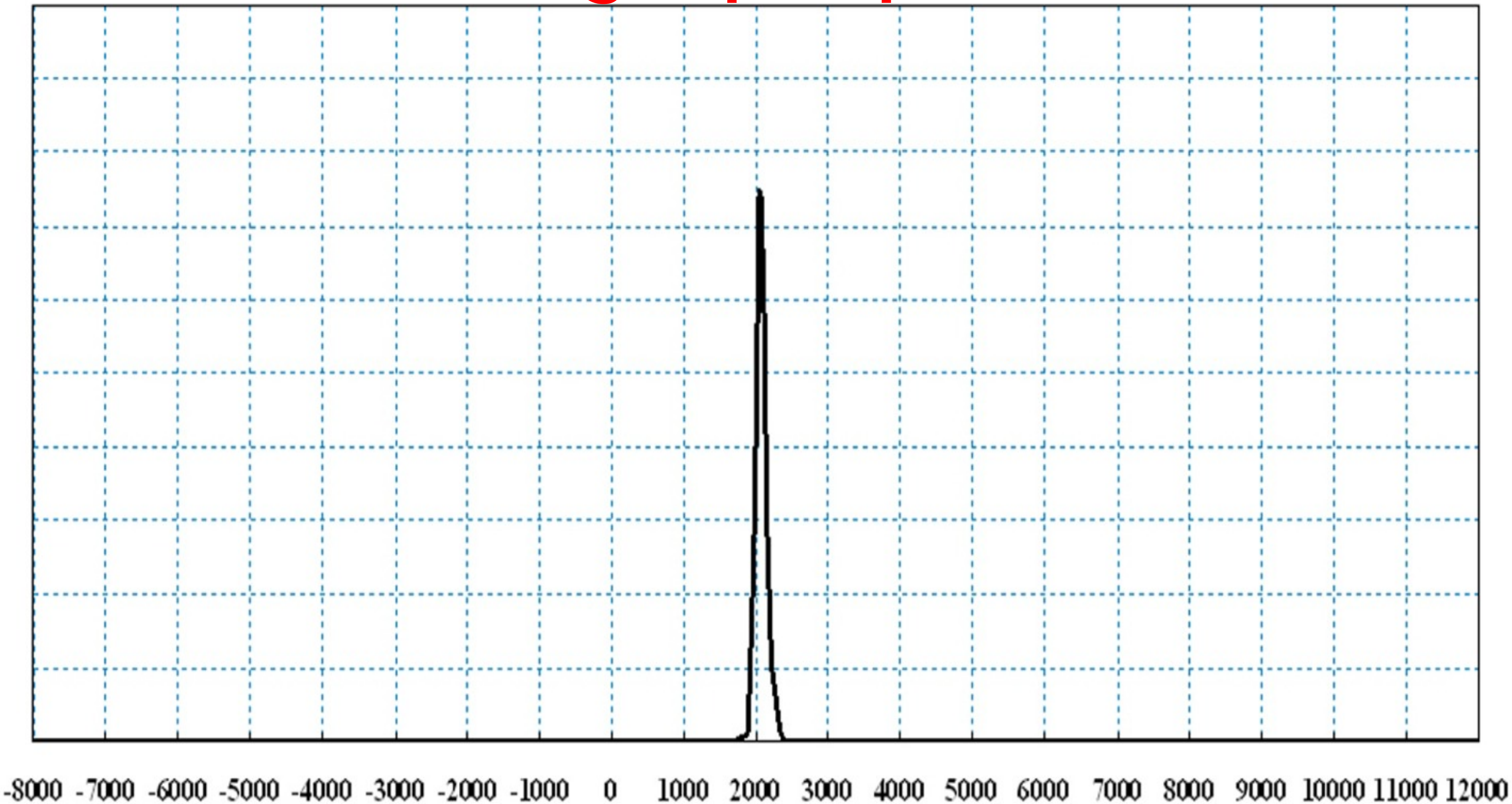


Oil and gas expected to be revised upwards as technology improves

Oil resources: 45% conventional, 32% extra-heavy + bitumen, 18% kerogen, 6% tight oil.   37% of-shore (> 1/3 deep water)

Gas resources : 25% shale

From a longer perspective



Fossil Fuel Use

- a brief episode in the world's history

Questions about Fossil Fuels

- **Will US-shale experience** (oil & gas) **be replicated?**
- **Could there be another US shale-type revolution** (methane hydrates,..)**?**
- **Is there enough affordable gas to allow a rapid move from coal?**
- **How much can efficiency of coal power stations improve?**

  China: burns 26% of world's coal in generating power @ 32% average efficiency

  2035, IEA NPS: power from coal + 47%, average efficiency→ 37% , coal + 29%

  With 48% efficiency = state of the art → would not need any more coal

  Moving from 37% to 48% would save more coal than the anticipated contribution of wind + solar > 3 x current total UK electricity consumption
- **What will C**arbon **C**apture and **S**torage (major role in many green scenarios) **cost, and how far/fast can the cost fall?**

Electricty

Electricity Generation

Source

	IEA 2012
Total TWh	22752
Fossil	67.7% Coal 40.3% Gas 22.4% Oil 5.0%
Hydro	16.5%
Nuclear	10.8%
Wind	2.3%
Biomass	1.5%
Solar	0.45%
Waste	0.42%
Geo	0.31%
Marine	0.0022%
Σ Renewables	21.5%

Cost

Generation costs of renewables (in good conditions) and conventional sources becoming comparable, e.g. US EIA projections for plants coming on line in 2019, in cents/kWh:

On-shore wind 8, PV 13,…

Coal 10, Nuclear 10,…

But dispatchable sources (coal, gas, nuclear, bio,…) *more valuable than* **non-dispatchable sources** (wind, solar) *even if generation costs the same,* e.g. wind blows in night in California, when electricity demand and price are low

which need back-up (if substantial, also improved grid and/or storage). Folklore: does not add much to cost if renewables below 20%, but Germany at 13% wind + solar in trouble….

Problems with Renewables 1

- **Germany** – *on a sunny + windy day, solar + wind can provide more than needed*

Producers paid to switch off (UK and elsewhere also)

But sometimes no sun or wind – need 100% back-up

as more solar and wind installed, back-up used less, cost goes up: who will invest?

- **Study** (F Wagner) imagines that solar + wind increase six fold (to 500 TWh output ~ 80% of total use)

Optimising on/off-shore wind /solar mix, using 2012 data, to minimise surplus **but**

Still surplus of 131 TWh + need 73 GW back-up (vs. max demand of 83 GW)

Huge Cost!! Solutions?

- Import/export more? Swings much too big in this case (although super-grid would help)
- Storage? Amounts orders of magnitude too big for hydro
- Manage demand? Would help, but could not fix this case
- Add some load following nuclear – anathema in Germany, expensive

Need all of the above + economic/policy instruments to make it happen

Problems with Renewables 2

Need better studies of whole system, assuming different levels of renewables:

•Possible expansion of the European grid → super-grid

•Storage – expect for hydro, other options* years away from being available on a grid-scale

*CAES; hot pebbles; batteries; gas – hydrogen, ammonia; liquid air; tidal lagoons;…

•Demand management

•Variety of back-ups

•……

•Economics/policies, including incentives to make things happen

Low Carbon Energy

The Potentially Major Renewables

Geothermal and marine can be important locally but not globally

Current order of importance

1. Biomass
2. Hydro
3. Wind
4. Solar

Ordered by theoretical potential

1. Solar
2. Wind

need storage/backup, better/bigger grid

3. Biomass
4. Hydro

can provide storage/backup

Without solar, could at best only provide half the energy *currently* supplied by fossil fuels

The Potentially Major Renewables

Sun → 170 Wm^{-2} at earth's surface:

	Figure of merit – average round clock	**On 250,000 km^2 ***	**2013 – global contribution****
Solar **PV or CSP**	**@15% efficiency: 25 $W_e m^{-2}$**	**6,000 GW_e**	**14 GW_e**
Wind	**North sea: 3.5 $W_e m^{-2}$**	**850 GW_e**	**60 GW_e**
Biomass	**1 $W_{th} m^{-2}$**	**250 GW_{th}**	**1,700 GW_{th}**

* ≈ area of UK = 0.18% of (all land – Antarctica)
= 0.55% of all agricultural land (crops + pasture ≈ 33% of total)

** Total global - electricity consumption = 2,640 GW_e
- energy consumption = 18,500 GW_{th}

Hydro - **Technically feasible maximum of order 1500 GW_e**
- **Current contribution 432 GW_e**

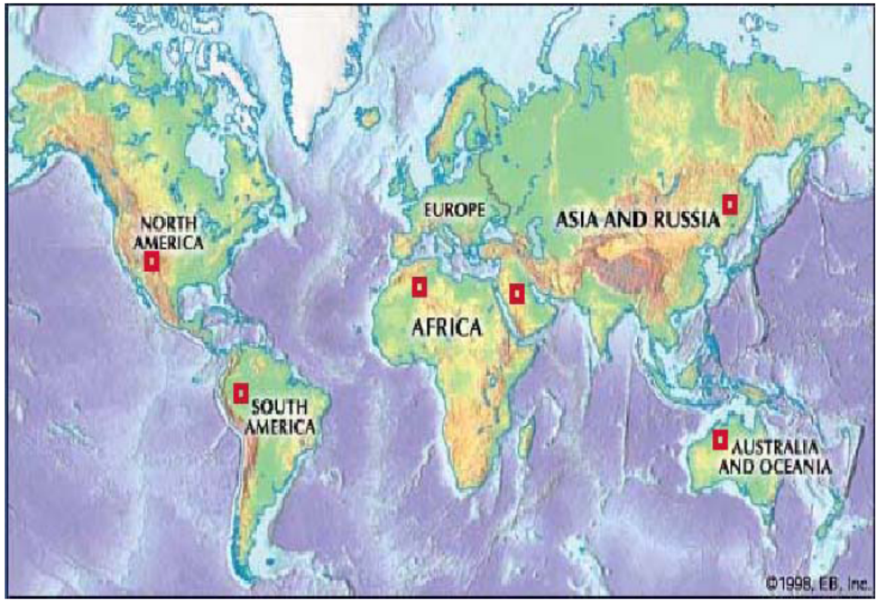
Solar

Solar could in principle power the world:

but

- in 2013 provided only 0.54% of electricity

- not yet competitive with gas or coal, even without cost of back-up, or storage and better transmission. However

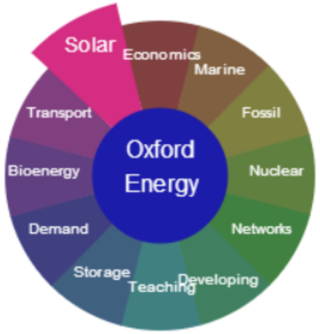


6 boxes sized to produce 3.3TW of power each (20TW total – 630EJ)

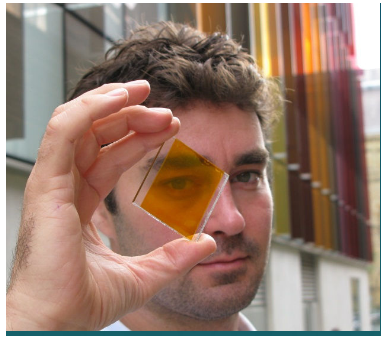
Source: Lewis et al 2003c

Photovoltaics – cost falling and promise of further reductions (perovskites?) but cost of solar cells is now only half the total

Solar Cells Based on Perovskites



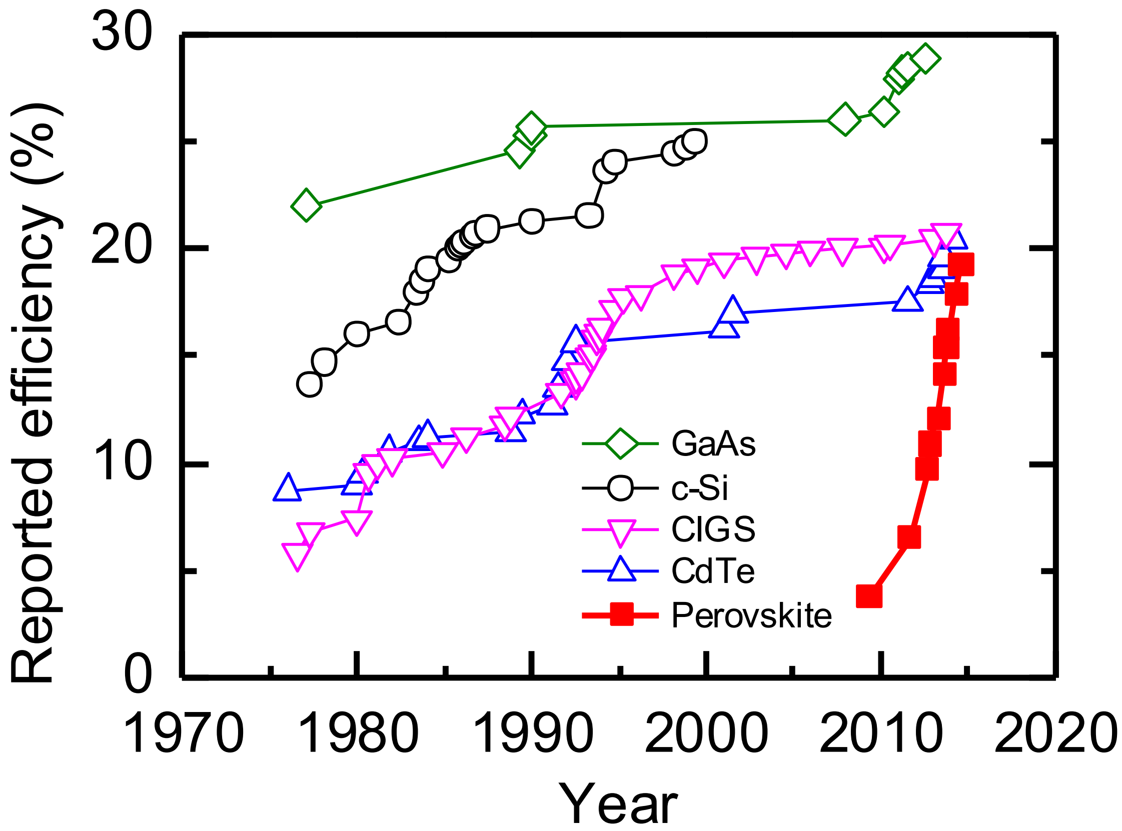
Pioneered by Henry Snaith
One of '10 people who mattered' in 2013 according to Nature

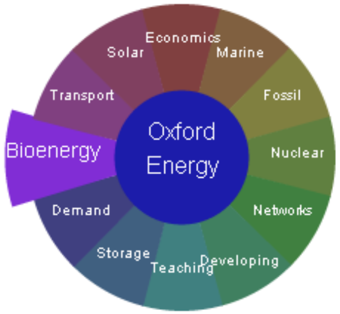


Meteoric rise in efficiency:

Over 30% by 2016?

Looks as if it will be much cheaper than Silicon – but the target is moving





Large Scale Anaerobic Digestion?

Electricity as cheap as coal?

By learning from cows, hope to reduce biogas plant sizes by a factor of 20 → big cost savings

A huge resource

Crop waste + dry-land CAM plants that you could add a vast amount

Better than batteries

Biogas (easy to store)+ solar perfect for mini-grids

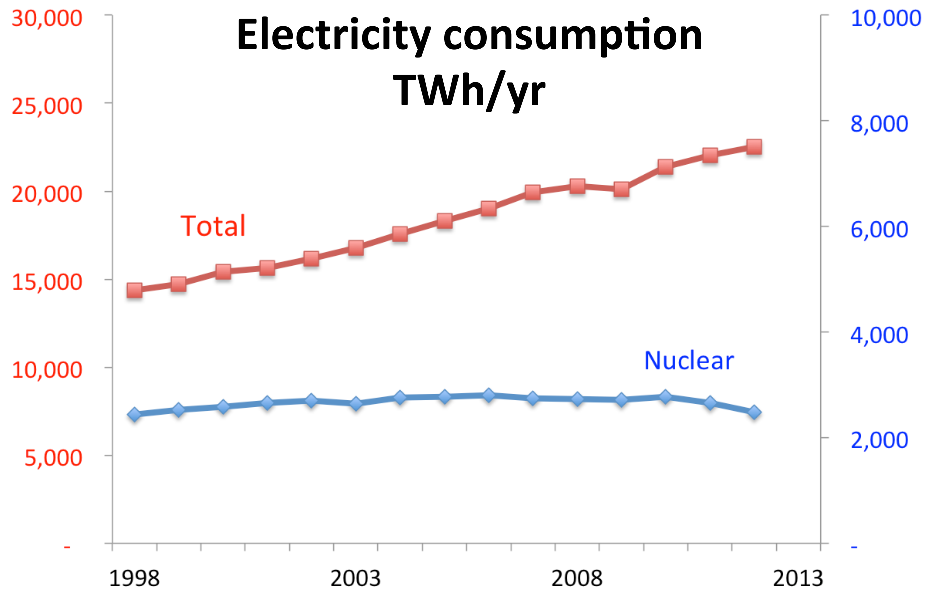
Valuable co-products

Biogas plant waste can supply charcoal, fish and fertiliser

Nuclear

Fission

- Falling absolutely (Fukushima) and relatively (increased use of fossil fuels in China & elsewhere)
- Could be a much bigger player
  Barriers:
- Perceptions about safety: the record is excellent
- **Cost**



Fusion

- It works (sun & stars, the Joint Europeans Torus has produced 16 MW of fusion power albeit briefly) and has many attractions
- **Question: when/whether can it be made to work reliably and competitively** (with what?) **on the scale of a power station?**

Nuclear Priorities

Light Water Reactors are likely to provide most nuclear energy for the next 50 years + some from Advanced Boling Water Reactors. The priorities should be to

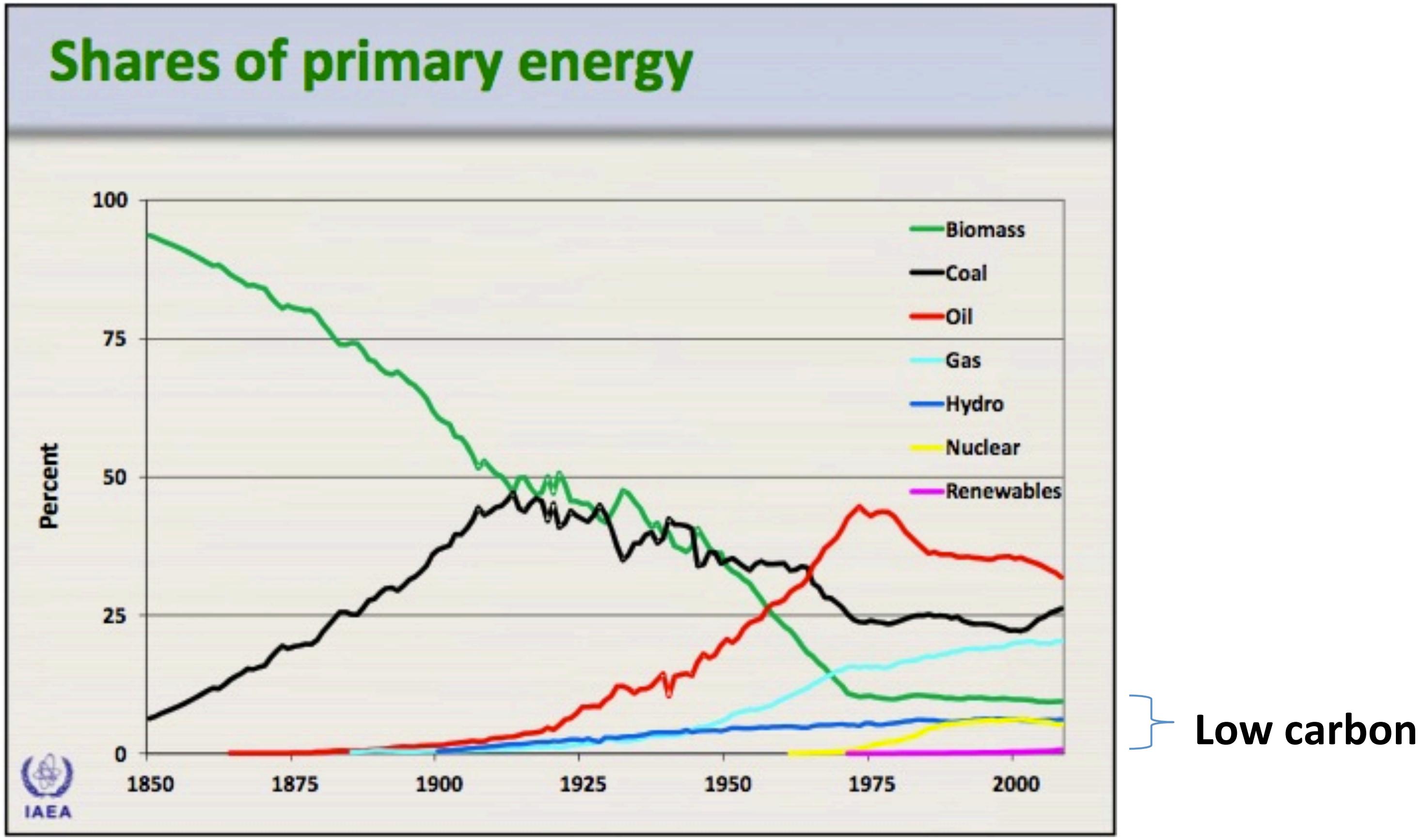
- Build on success of LWRs & drive down cost (standardisation, build many, build fast,…) → quadruple by 2040?
- Select one or two Generation IV reactors → development and demonstration → commercialisation by 2050
- Continue developing fusion for the long-term

Towards Conclusions

- Before the world's energy needs can be met sustainably at a cost society is willing to pay, transformative changes* will be needed
- What can we learn from past transformations?
- What actions should we be taking?

* slides from an Oxford energy meeting on transformative change on 17 June can be found at www.energy.ox.ac.uk

Past Transformations



Inertia: past decisions on infrastructure

Drivers of change: cumulative deployment, passage of time, cumulative spend on R&D

Often unexpected and long in gestation, e.g. US shale revolution

Necessary Actions - Technical

- Face the fact that for foreseeable future the world will depend heavily on fossil fuels, and:
  - **Replace coal with gas** as far as possible (pollution, CO_2)
  - **Develop CCS** – and roll out on large scale *(if feasible, safe, competitive with low carbon sources)*
  - **Improve efficiency of use of fossil fuels**
- **Reduce energy use** (planning)/**improve efficiency** – potential gains not happening (even if save money). Need incentives/regulation
- **Drive down costs** and expand use of low carbon energy sources
- **Expand nuclear**
- **Develop energy storage**
- **Develop smart grid**

Challenge: devise economic tools and ensure the political will to make this happen

Policy (effects risks, costs, investment, fuel & carbon price, consumer behaviour…. and innovation) **can**

- **prevent innovation and risk taking**

  Political and industrial systems often intertwined, incumbents able to use existing policy structures to stifle innovation and new entrants

  Regulatory hurdles (heath and safety) protect incumbents

  Market regulations can add costs for players wishing to introduce new business models and technologies

- **encourage innovation, change behaviour, oil the wheels**

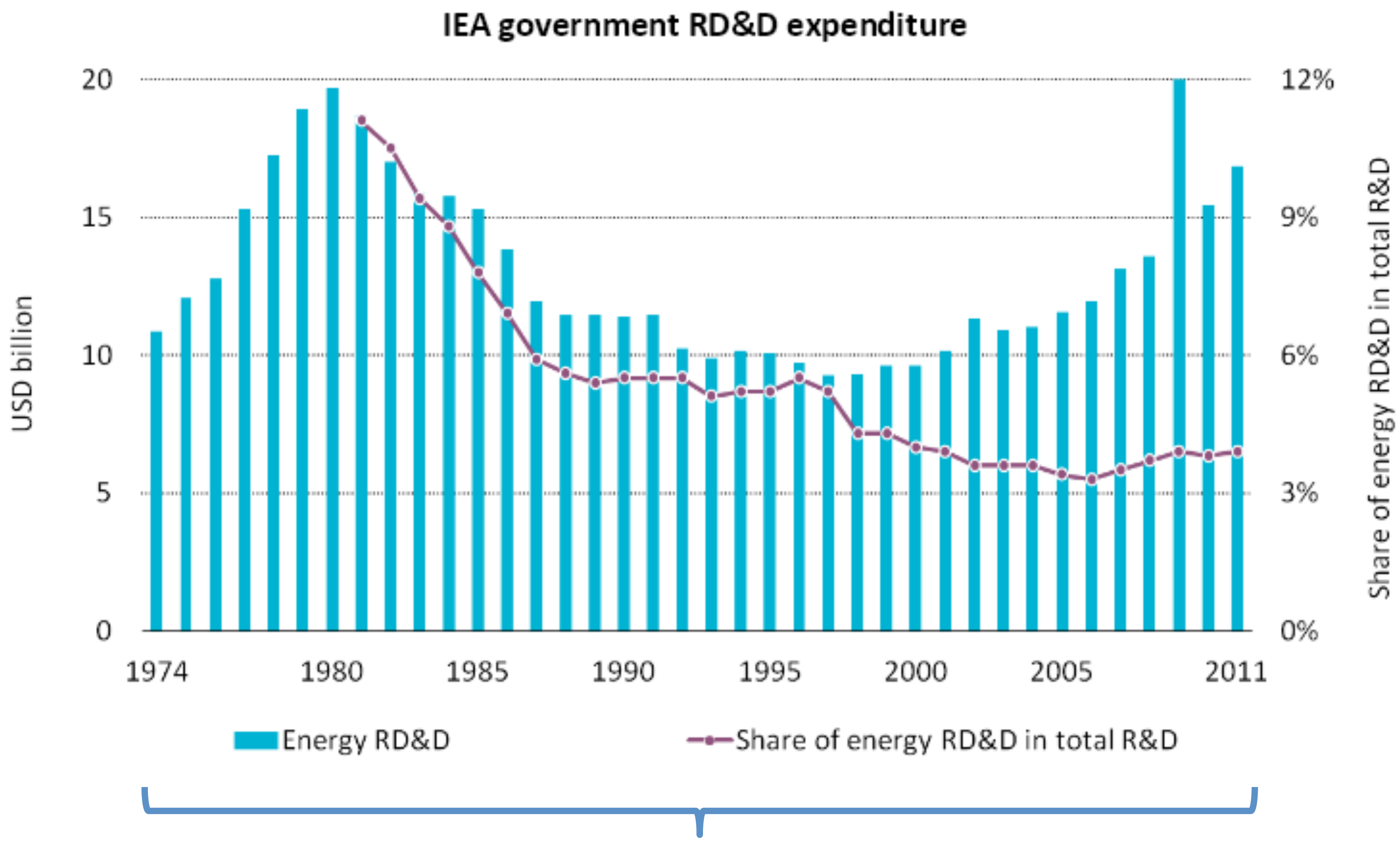
  e.g. of wholesale power markets do a reasonable job dispatching the lowest short-run cost power, but are not stimulating new build - hard to find an EU government without a capacity market under consideration

Necessary Actions - Policy

- **Better planning to reduce demand –** *especially in growing cites/ developing countries*
- **Stronger regulations,** vehicles, performance of appliances, buildings…
- **Phase out $550 billion/year of subsidies for consumption of fossil fuels** (only 8% benefits world's 20% poorest people)
- **Carbon tax** (provides more certainty than cap and trade) + in the absence of global agreement: **B**order **C**arbon **A**djustments

\- direct regulation of power plants

- **Increase the $100 billion/year subsidies to launch* new not yet cost-effective energy sources and efficiency measures** *then phase out
- **Increase long-term publicly funded R&D**



In this period world energy use increased 113%

Concluding Remarks

- To allow everyone on the planet to lead decent lives, much more energy will be needed
- We can meet the need with fossil fuels for (at least) 50 years - but we should be decarbonising
- No real progress with decarbonisation – need to drive down cost of low carbon technologies, manage demand, improve efficiency (regulation)
- Need to put a price on carbon (or pollution?), more R&D

Without secure fossil fuel supply the world's poor will remain poor for the foreseeable future

Without vigorous development of non-fossil sources, serious decarbonisation will not be possible