An economic perspective on technological transitions related to energy and climate change

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Structure of presentation

- Technological transitions
  - What are they?
  - How do they come about?
- Technological transitions, energy and climate change
  - Why do we need one?
  - What sorts of technologies/changes will be involved?
  - What might a 2050 energy system look like (after a technological transition)?
- How might a low-carbon technological transition be brought about?

What is a technological transition?

- A technological transition is a process whereby a *pervasive* technological *system* in a society undergoes *fundamental* change
  - Pervasive: is important for basic societal functioning
  - System: involves more than one technology, usually with elements of infrastructure
  - Fundamental: the functioning of society is greatly altered
  - Examples
    - Sailing ships to steam ships
    - Horse-drawn to horse-less carriages (i.e. Cars)
    - Advent of disruptive technologies
      - Electricity
      - Information and communication technologies
  - Low-carbon energy system?

How does a technological transition come about?

Two examples of theories:

- Multi-level system change involving niches, regimes, landscapes (Geels)
- Alignment/co-evolution of social sub-systems (Freeman & Louca)

Technological regimes

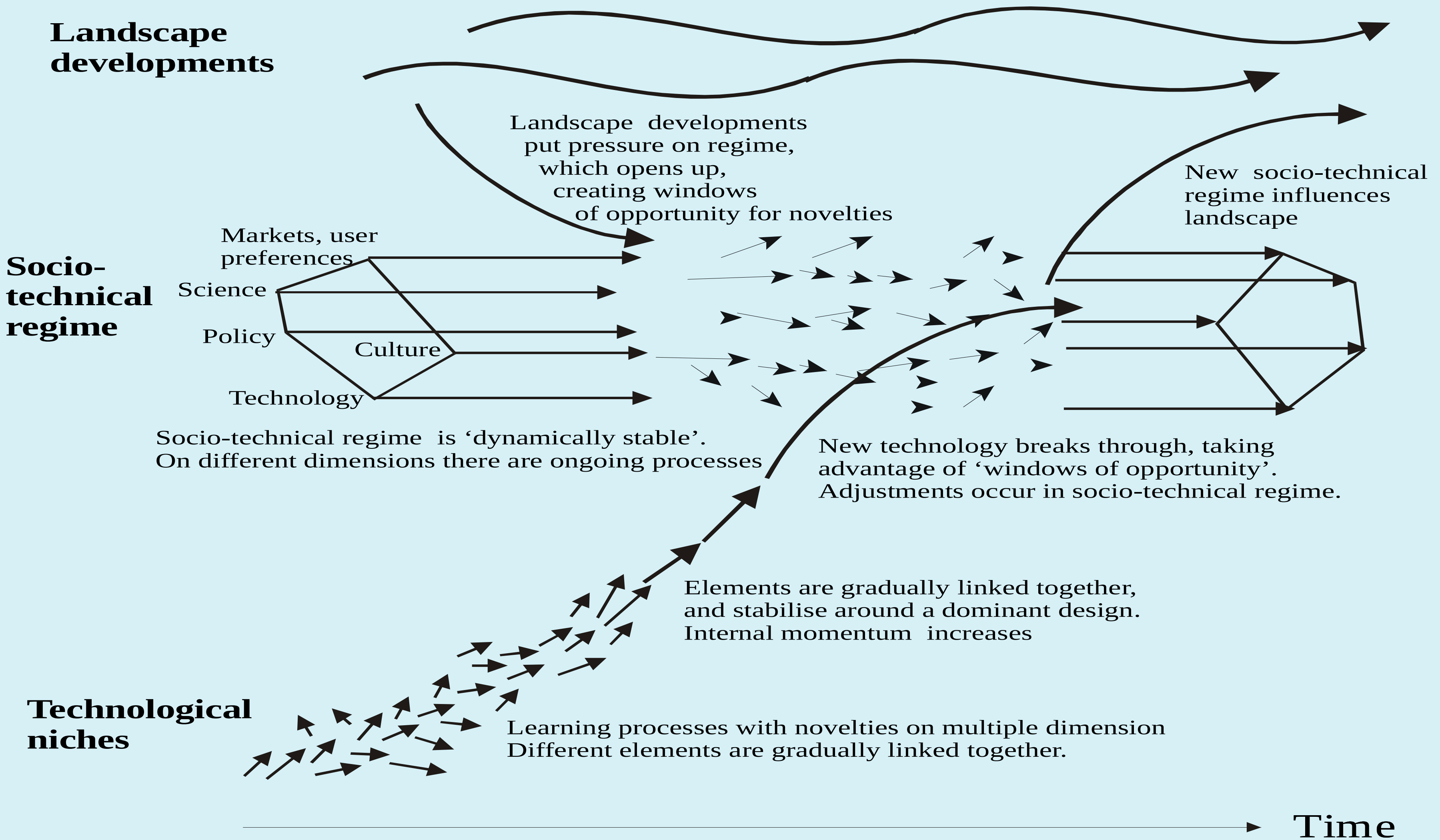
- Regime stability/’lock-in’: learning by using; network externalities; economies of scale; increasing informational returns; deployment of complementary technologies (Arthur 1988, p.591)
- Change in socio-technical configuration (Geels 2002, pp.94-5)
  - Economics: price, performance, user preferences
  - Sociology: actors, interactions, institutions, context (also related to existing technology/socio-technical configuration)
  - Socio-technical: large technical systems, networks

Technological transitions - Geels

- Interactions between three levels
  - Landscapes: strong, underlying features of ideology, culture, value systems and policy (e.g. role of state market, ideas of justice/fairness; change slowly
  - Socio-technical regimes: interlocking structures of technologies, infrastructures, social practices and behaviours; stable, because of ‘lock-in’
  - Niches: small markets or protected spaces in which new technologies develop – or not; most niches remain just that, and ultimately disappear
- Under certain conditions niches can destabilise and ultimately displace a socio-technical regime

The development of niches

(Geels 2002a, Figure 3.6, p.110, 2005)



Co-evolution of social sub-systems – Freeman and Louca

- Need for co-evolutionary alignment between different interacting sub-systems (Freeman & Louca 2001)
  - Science, technology, economy, politics, culture: application to Kondratiev cycles

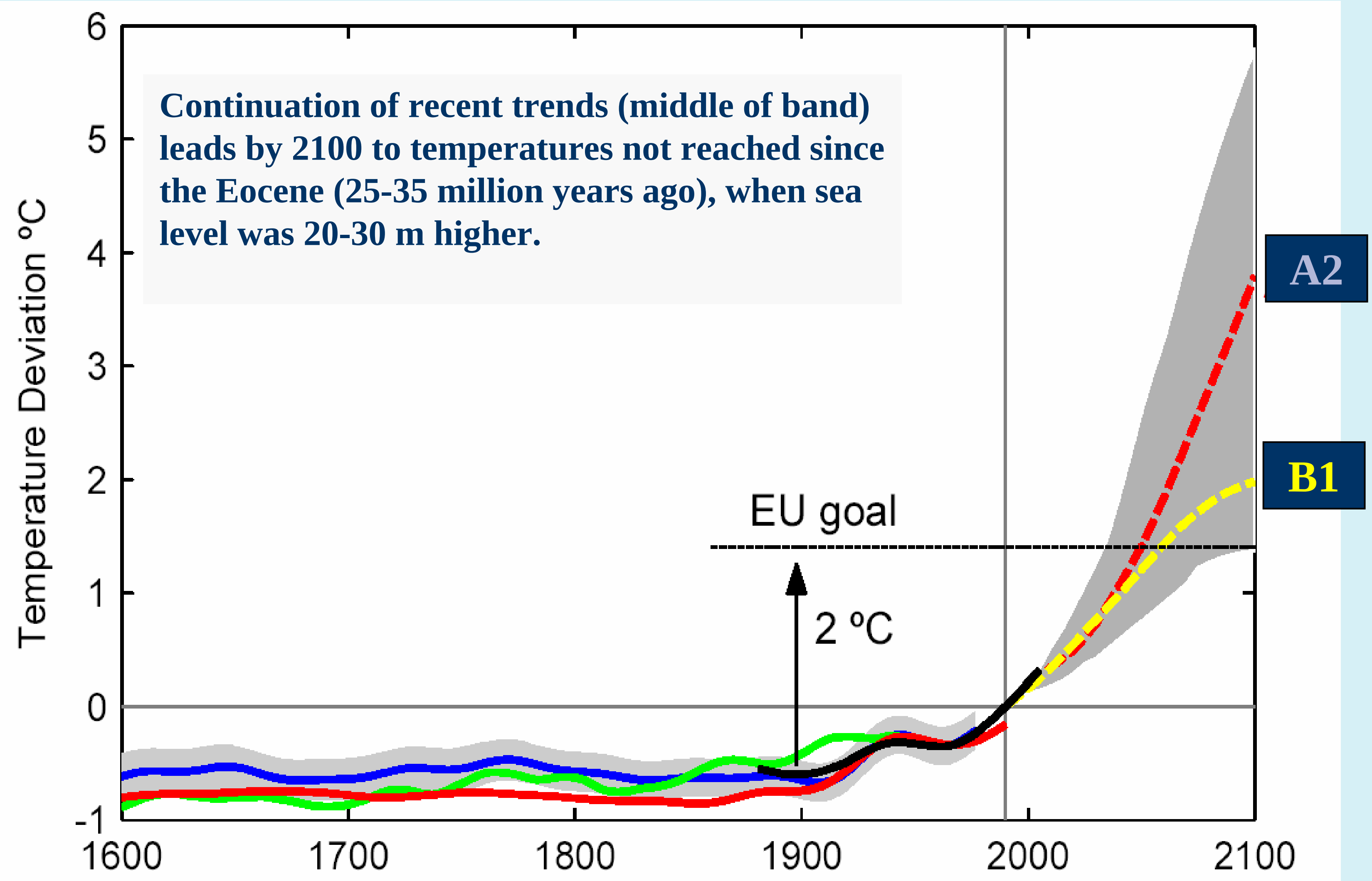
- **The Physical Dimension**, which deals with the physical issues involved in the production/storage/distribution/end use of the good or service under consideration, and has the following components:
  - *Science* the physically possible
  - *Technology* physical realisation of the physically possible
  - *Infrastructure* physical (including technical) support and diffusion of the physical realisation

- **The Socio-Economic Dimension**, which deals with the interests and drivers that push technical change along: *entrepreneurs* (and profits), *consumers* (and preferences), and *public policy* pressures, and has the following components:
  - *Economics* issues of allocation, distribution, competition
  - *Institutions* legal, financial, regulatory, planning frameworks
  - *Political Drivers* social perceptions driving political priority (security of supply, environmental issues) and the planning system, and the policy instruments through which these perceptions are implemented
  - *Culture* social perceptions driving social acceptability, consumer demand

Technological transitions, energy and climate change - why do we need one?

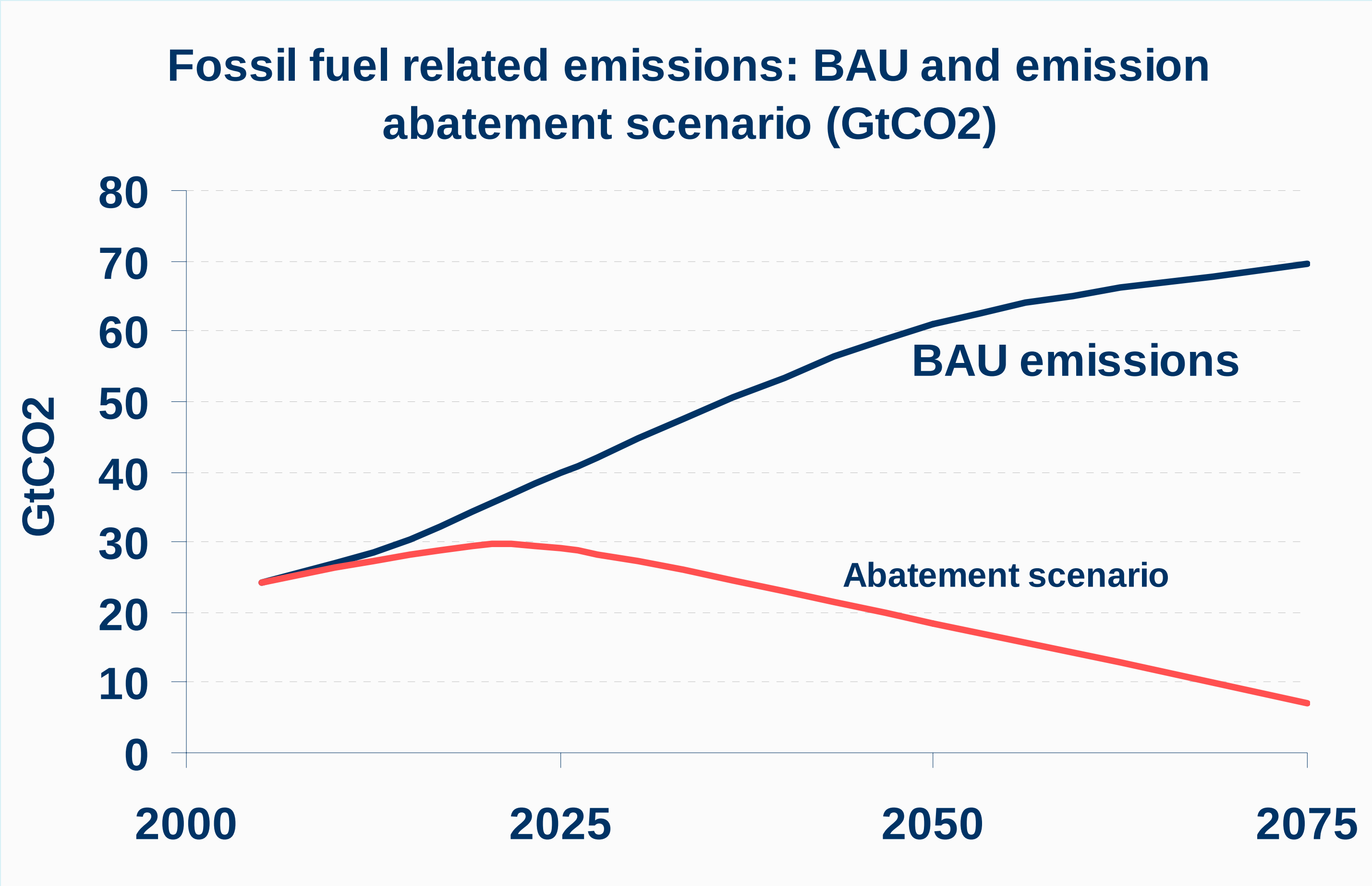
- Avoiding 'dangerous anthropogenic climate change'
  - Pre-industrial CO_2 concentrations : 280 ppm
  - Current CO_2 concentrations: 380 ppm
  - Current GHG (CO_2e) concentrations: 430 ppm
  - Rate of GHG concentration increase: 2.5 ppm p.a.
  - Current global average temperature increase since 1900: 0.7^{o}C
  - Target temperature increase for 'acceptable' climate change: 2^{o}C
  - Probability that this will be exceeded at 450ppm: 80%

The climate implications of where we're headed: The next 100 years compared to the last 400



Source: Professor John Holdren, Harvard University

Emissions scenario to limit temperature change

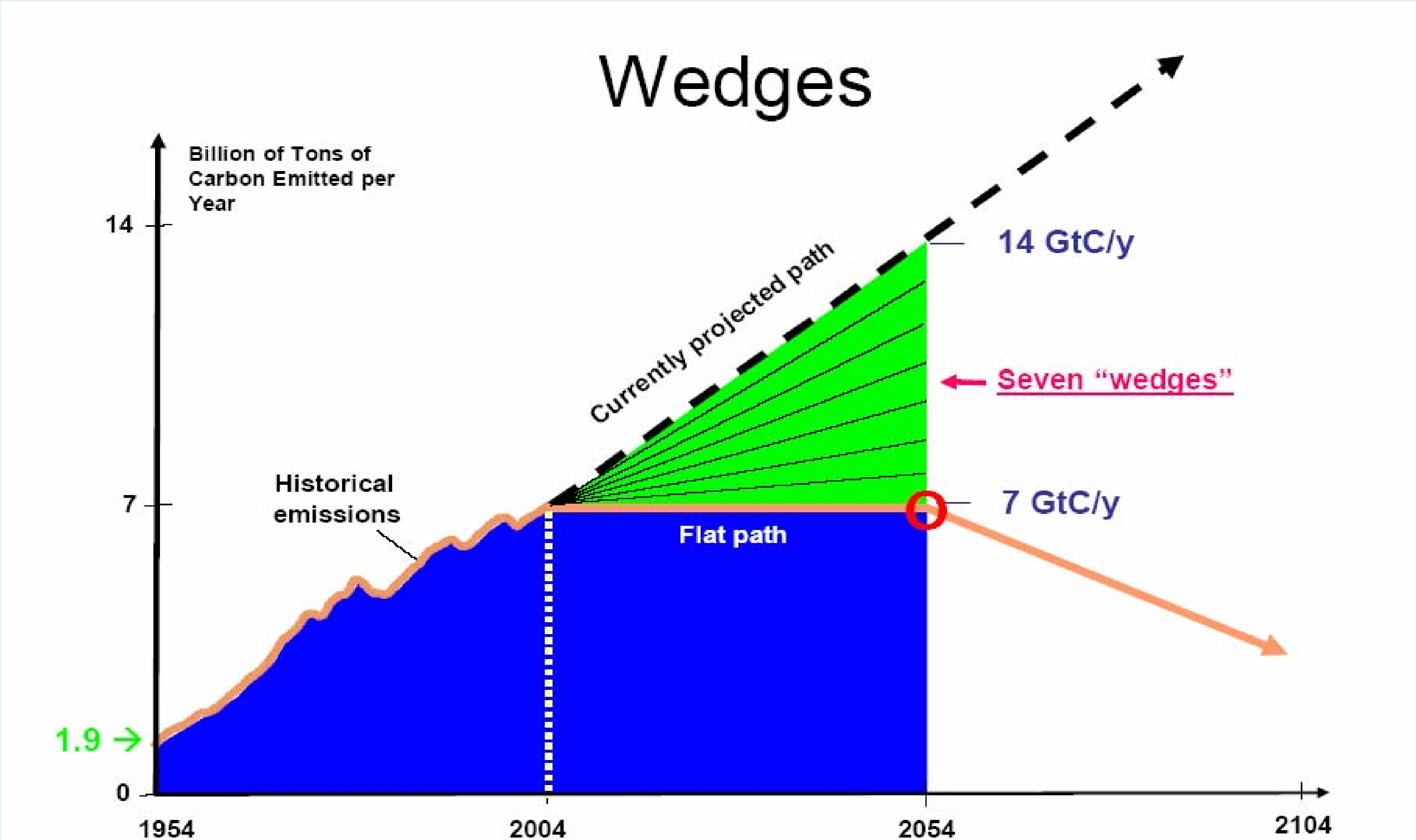


Source: Stern Review, Part III, Chapter 9

The necessary improvements in carbon productivity

- Carbon productivity = GDP/carbon; carbon intensity = carbon/GDP
- Carbon intensity of energy = carbon/energy
- Carbon emissions = Population * GDP/capita * carbon/GDP
- To reduce carbon emissions, reduce either carbon intensity of energy or energy intensity of GDP or both
- To achieve 450ppmv atmospheric concentration of CO_2, assuming ongoing economic and population growth (3.1% p.a. real), need to increase carbon productivity by a factor of 10-15 by 2050, or approx. 6% p.a.
- Compare current increase in carbon productivity of 0% p.a. over 2000-2006, i.e. global carbon emissions rose at 3.1% p.a.; also
- Compare 10-fold improvement in labour productivity in US over 1830-1955, must achieve the same factor increase in carbon in 42 years

What sorts of technologies/changes will be involved – the Socolow 'wedges'



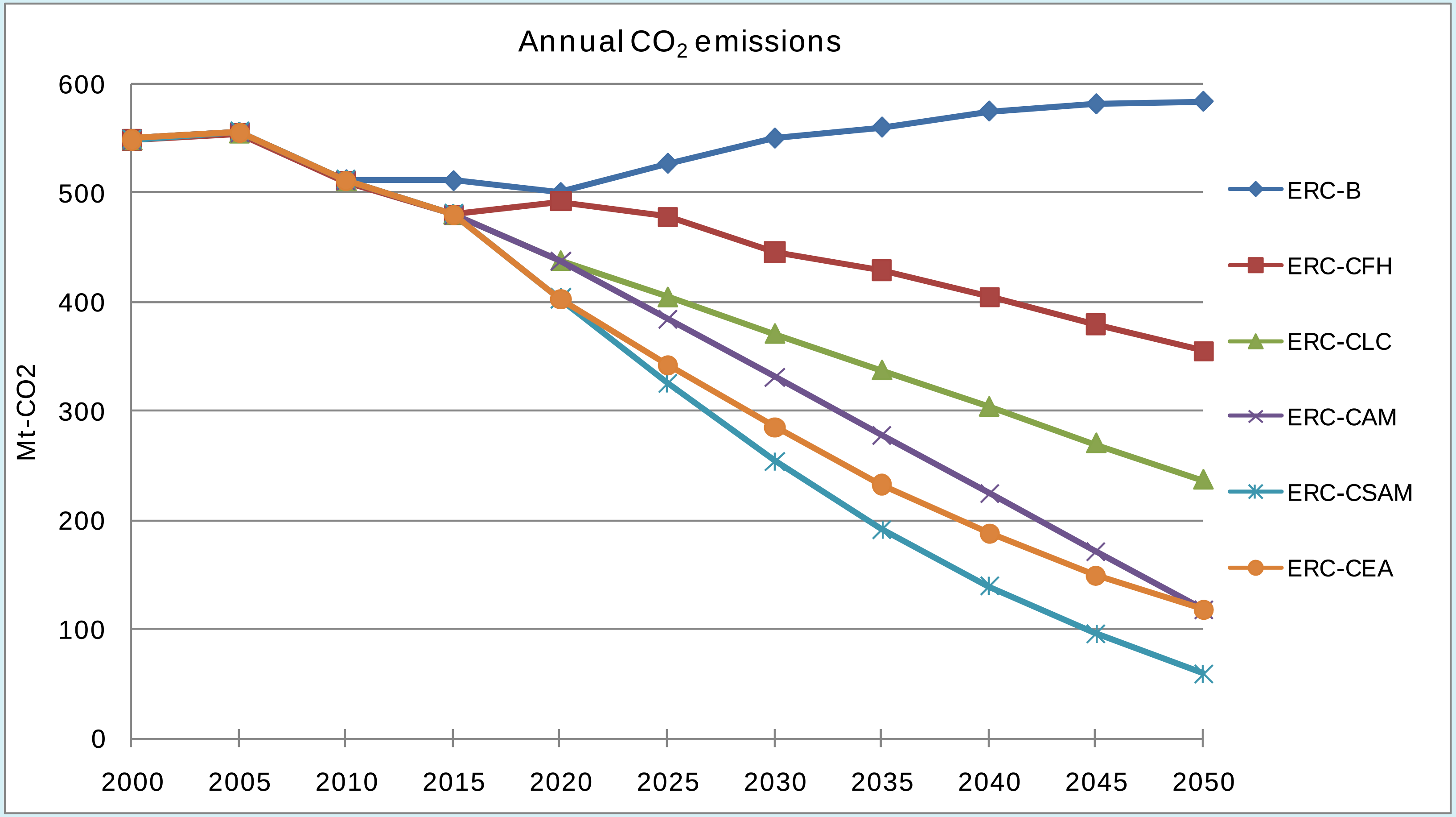
Potential “wedges”: cuts of 1Gt of carbon per year in 2054

- **Efficient vehicles:** *Increase fuel economy for 2 billion autos from 30 to 60 mpg.*
- **Nuclear:** *Tripling of capacity to 1050 Gwatts.*
- **Gas for coal substitution:** *1400 Gwatts of electricity generation switched from coal to gas.*
- **Carbon capture and storage:** *Introduce CCS at 800 Gwatt coal stations*
- **Wind power:** *50 times as much wind power as at present.*
- **Solar PV:** *700 times 2004 capacity*
- **Hydrogen:** *Additional 4000 Gwatts of wind capacity or additional CCS capacity*
- **Biomass fuel:** *100 times the current Brazilian ethanol production*

Source: Professor Robert Socolow “Stabilisation Wedges”

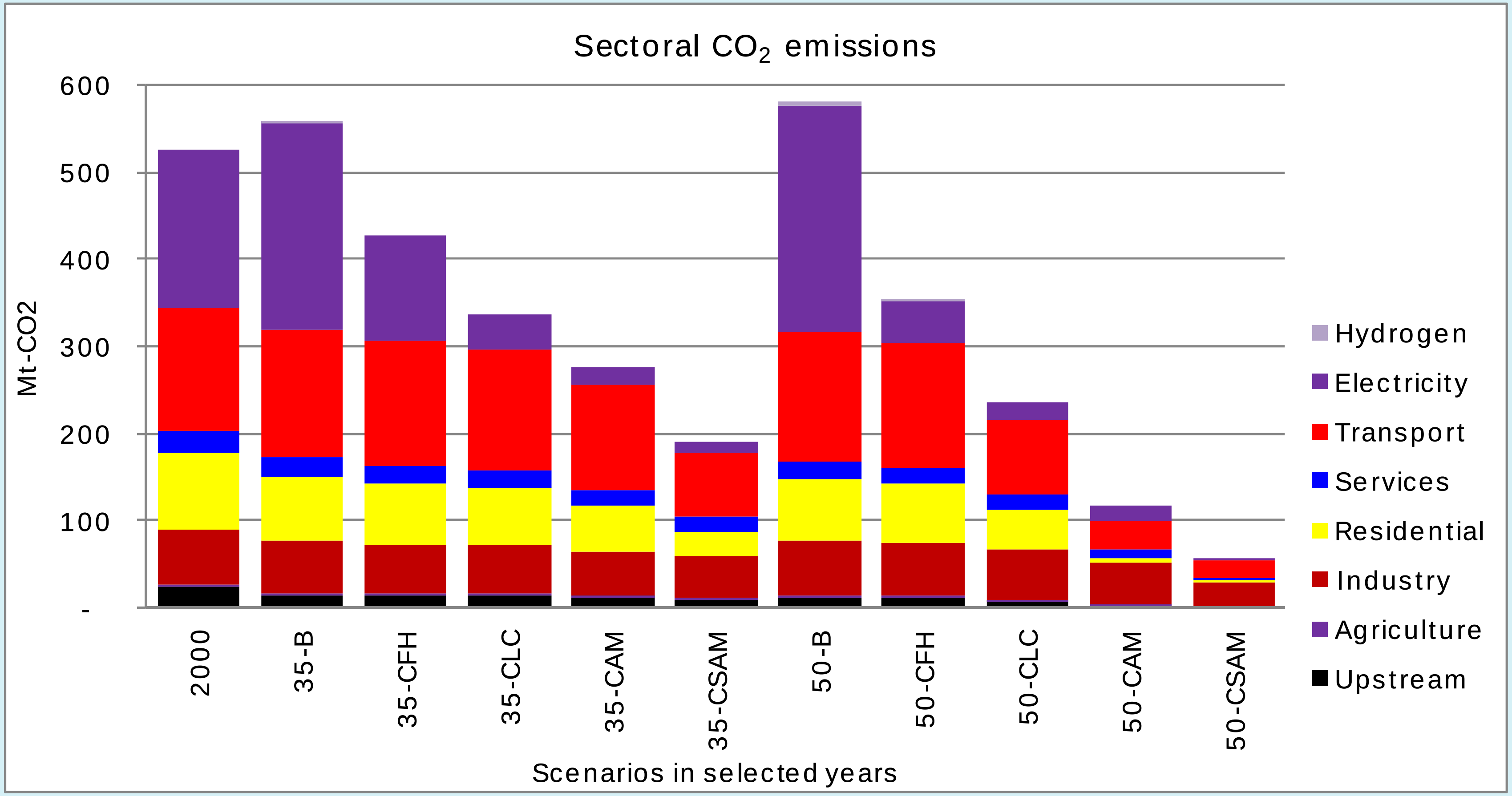
What might a 2050 energy system look like (after a technological transition)?

UK CO_2 emissions under scenarios with different carbon constraints



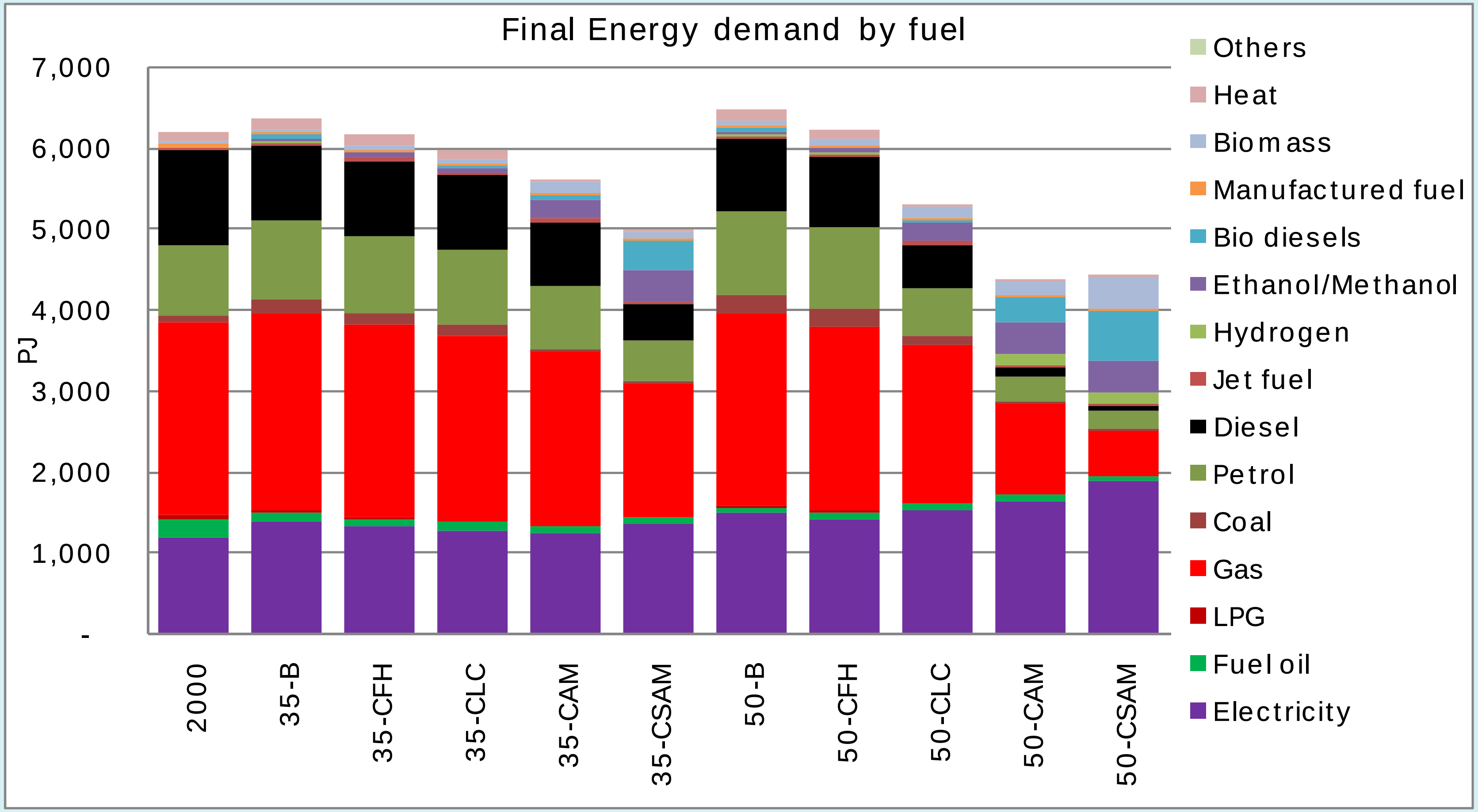
What might a 2050 energy system look like (after a technological transition)?

Sectoral CO_2 emissions in years 2000, 2035, 2050 in different scenarios



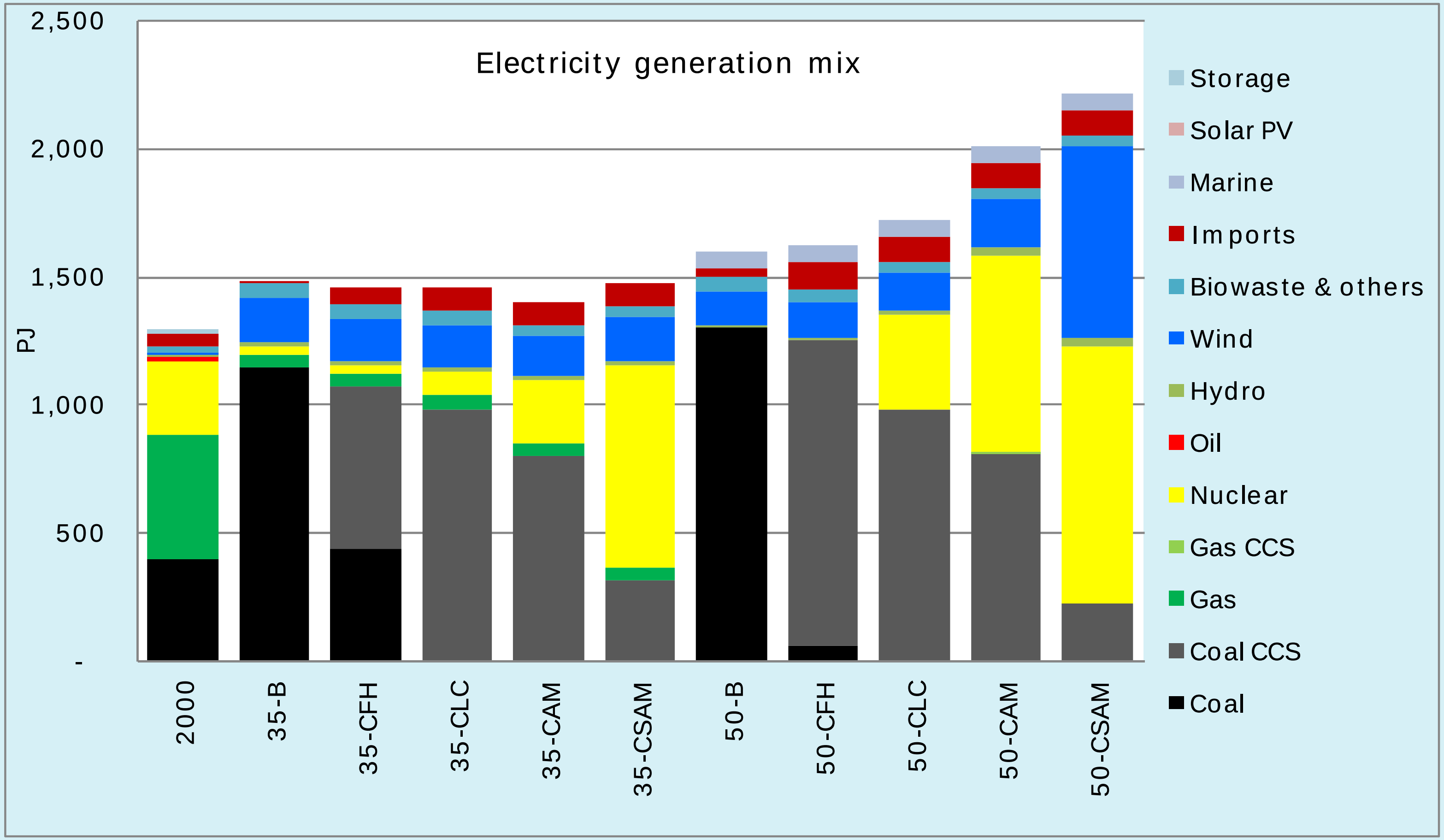
What might a 2050 energy system look like (after a technological transition)?

Final energy demand under different carbon constraints



What might a 2050 energy system look like (after a technological transition)?

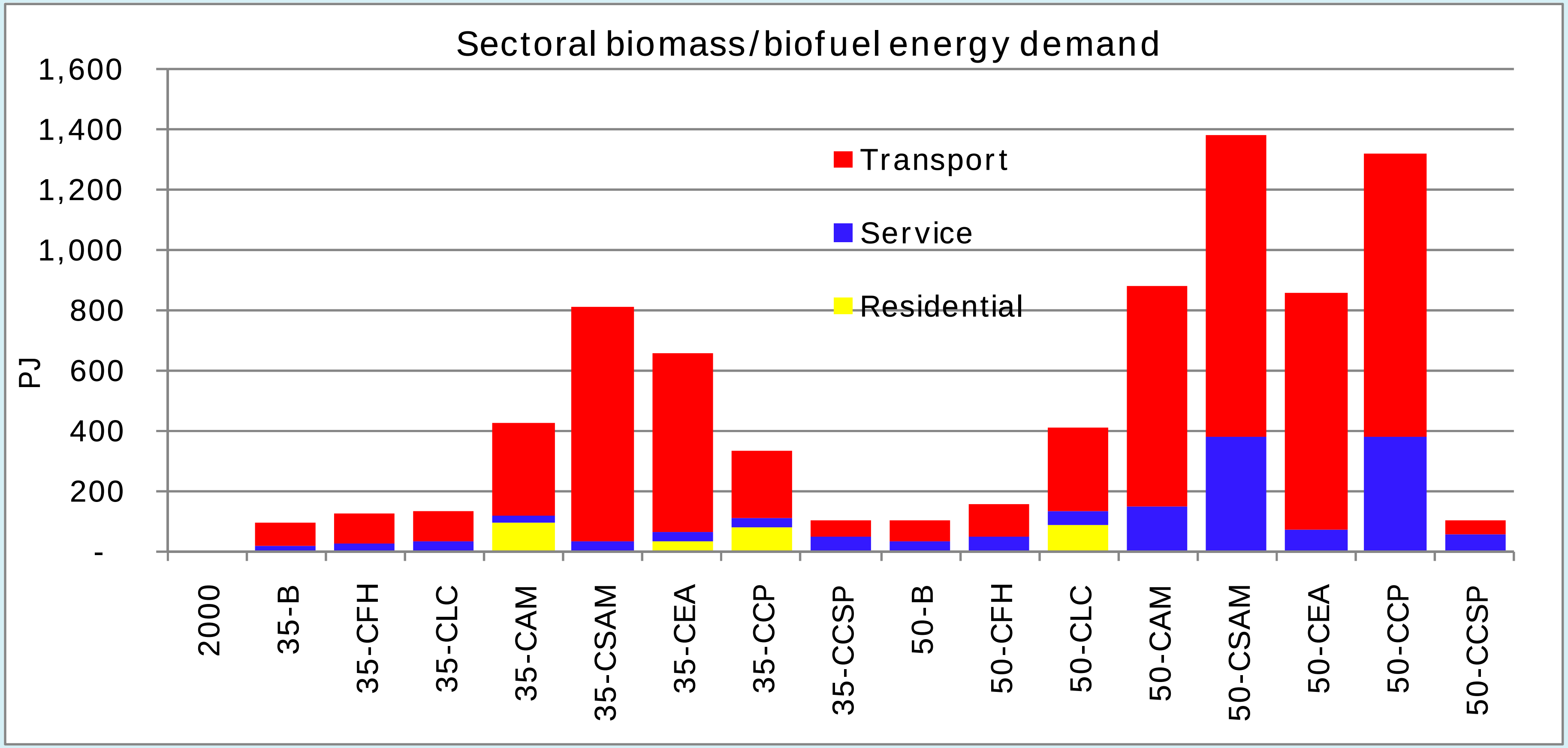
Electricity generation mix under different carbon constraints



What might a 2050 energy system look like (after a technological transition)?

Sectoral biomass under different carbon constraints

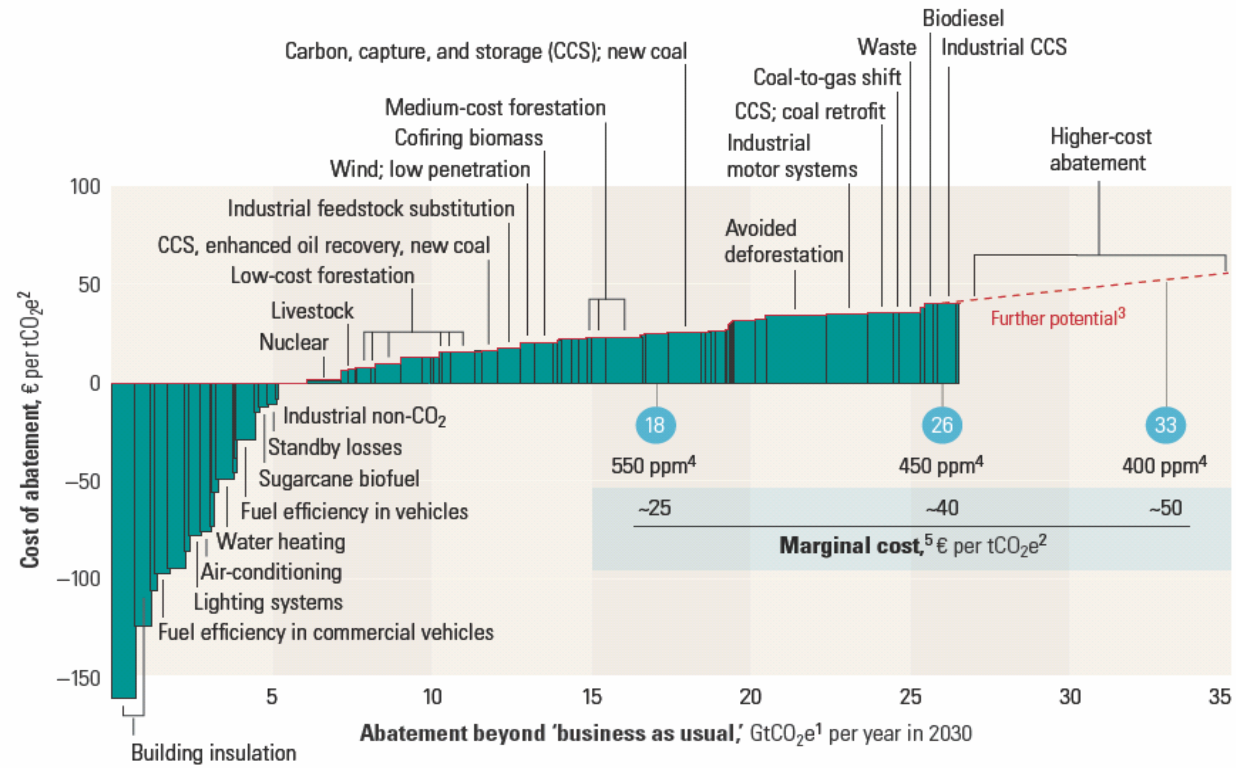
Energy 2050 – www.ukerc.ac.uk



How might a low-carbon technological transition be brought about?

- An unprecedented policy challenge: the Stern Review Policy Prescription
  - Carbon pricing: carbon taxes; emission trading
  - Technology policy: low-carbon energy sources; high-efficiency end-use appliances/buildings; incentivisation of a huge investment programme
  - Remove barriers to and promote behaviour change: take-up of new technologies and high-efficiency end-use options; low-energy (carbon) behaviours (i.e. less driving/flying/meat-eating/lower building temperatures in winter, higher in summer)

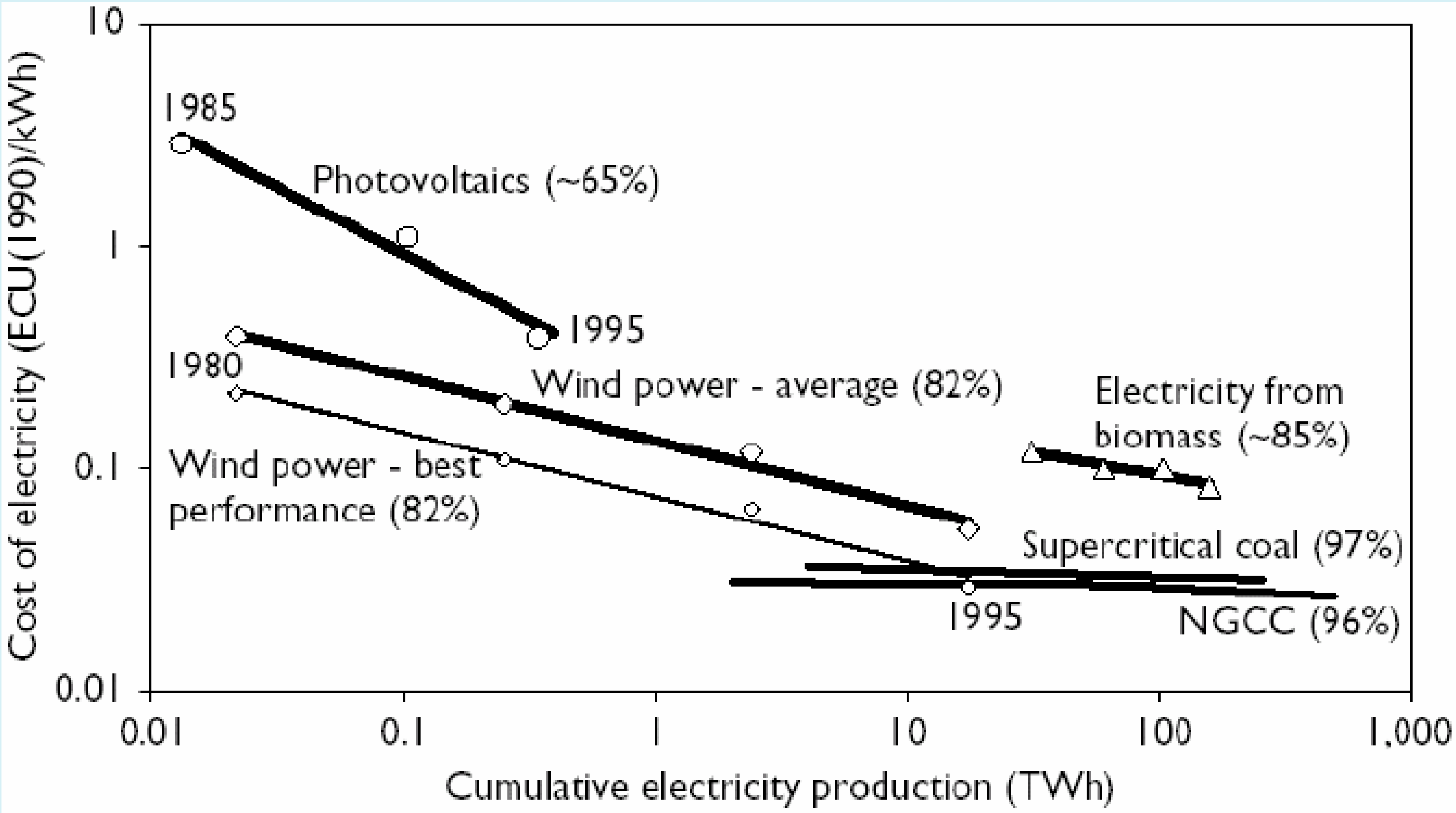
The (micro)economic cost: global cost curve for greenhouse gas abatement



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly, by increasing demand for energy and transport around the world, and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

Source: A cost curve for greenhouse gas reductions, The Mckinsey Quarterly, February 2007

Cost evolution and learning rates for selected technologies



Source: IEA, 2000, Stern Review, Chapter 9

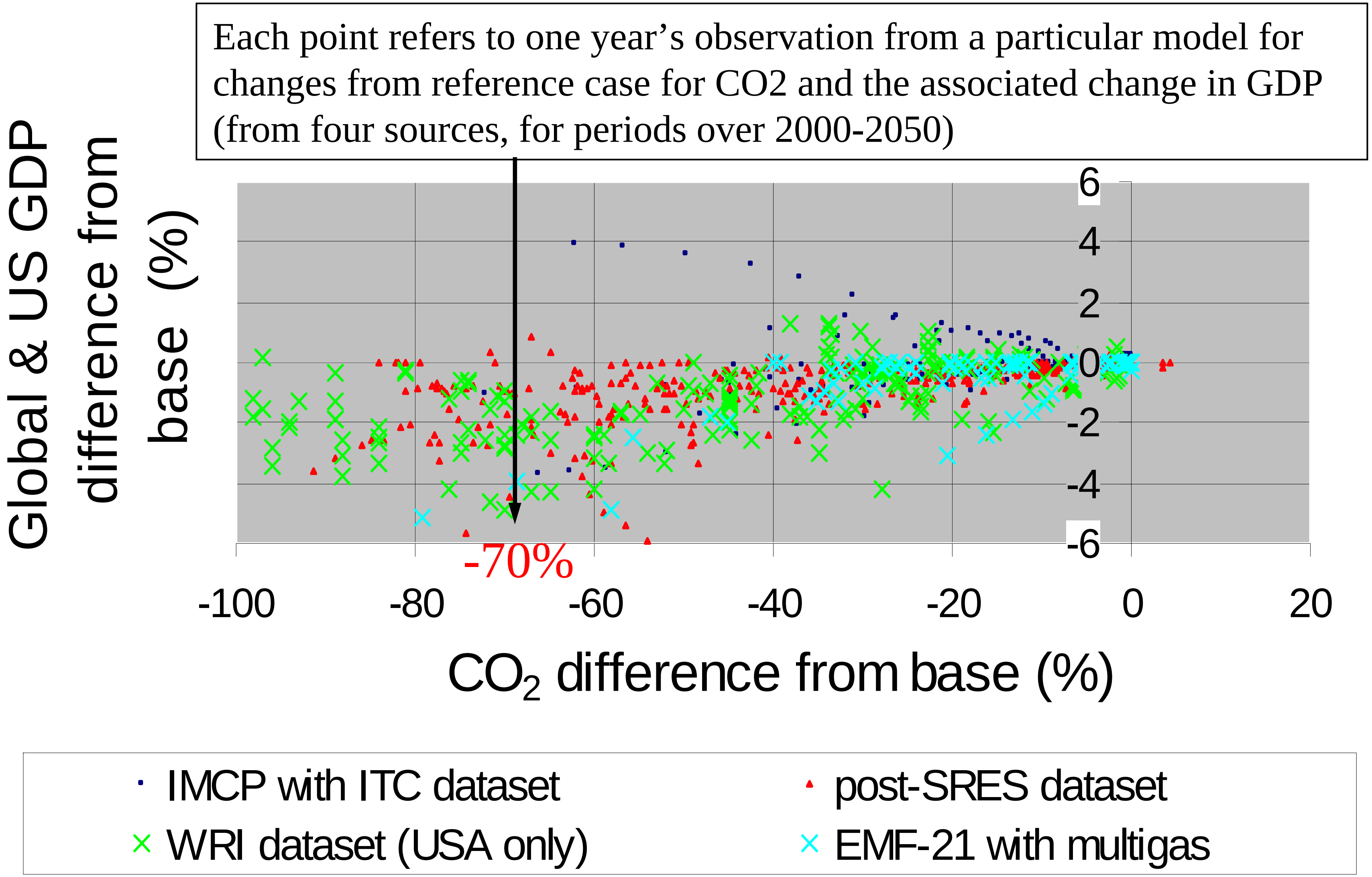
Policies for carbon reduction

- Huge policy innovation over the last ten years; we know what to do
- Limited results from these policies; we don't apply the policies hard enough
- Carbon emissions still rising in most industrial (let alone developing) countries
- Many policies need local implementation/enforcement
- (Much) More stringent application of policy instruments (especially price-based to avoid rebound effects)
- Political feasibility
- Implications for economic growth

The macro-economic costs of climate change mitigation

- Optimists:
  - ‘Costs’ are really investments, can contribute to GDP growth
  - Considerable opportunity for zero-cost mitigation
  - A number of low-carbon technologies are (nearly) available at low incremental cost over the huge investments in the energy system that need to be made anyway
  - ‘Learning curve’ experience suggests that the costs of new technologies will fall dramatically
  - Climate change policies can spur innovation, new industries, exports and growth
- Pessimists:
  - Alternative energy sources are more expensive, are bound to constrain growth
  - Cheap, concentrated energy sources are fundamental to industrial development

Scatter plot of model cost projections, 2000-2050



Policy conclusions

- Attaining the 2°C target or anything near it will require huge investments in low-carbon technologies right along the innovation chain (research, development, demonstration, diffusion).
- IEA ETP estimates of *additional* investment needs in energy sector: USD 45 trillion (1.1% global GDP from now until 2050)
  - Buildings and appliances: USD 7.4 trillion; Power sector: USD 3.6 trillion
  - Transport sector: USD 33 trillion; Industry: USD 2.5 trillion
- Government funding of R,D&D must increase dramatically, but demonstration and diffusion can only be driven at scale by markets
- This will require high (now) and rising carbon prices over the next half century, to choke off investment in high-carbon technologies (e.g. runways) and incentivise low-carbon investments
- These high carbon prices will also greatly change lifestyles and consumption patterns
- Provided that the world goes cooperatively in this direction, there are enormous profits to be made from these high carbon prices and changing consumptions patterns
- Technological and policy uncertainty mean that the risks are also high

Overall conclusions

- The innovation potential exists for a transition to a low-carbon energy system to be technologically feasible, economically feasible

BUT

- It requires sustained, wide-ranging, radical policy interventions to bring about technological revolution and change lifestyles.
- These interventions are resisted by affected economic sectors (e.g. energy) and households who want to keep current lifestyles (e.g. transport), or attain Western lifestyles
- Politicians may not be able to bring about a low-carbon technological transition before runaway climate change