Future Uncertain: Big tent *vs* winner takes most

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Big tent *vs* Winner take all

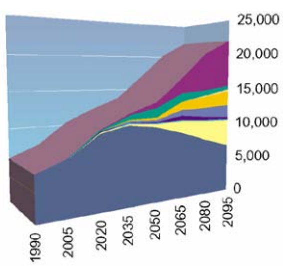
We are often told that that the climate problem is so hard we will need (almost) everything on the menu: wind, carbon capture, nuclear, solar, biomass….

Maximum capacity or maximum feasible contribution of a technology.

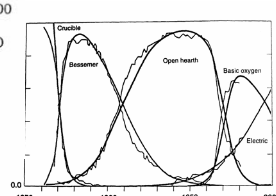
The strong non-linearity's in the evolution of technological systems suggest that the results often approach winner-take-all

- Economies of scale
- Induced technological change
- Network externalities

Sharp transitions are the norm…

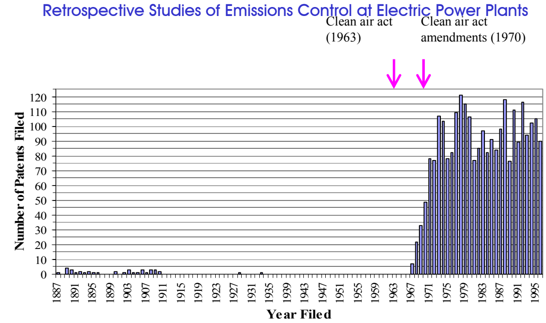


Source: Edmonds et al, 2003



Source: Grubler, Nakicenovik and Victor, 1999

Technology does respond to policy: Retrospective Studies of Emissions Control at Electric Power Plants



U.S. patents relevant to SO_2 control technology. (Source: Taylor, Rubin, & Hounshell, *Environmental Science & Technology*, 2003)

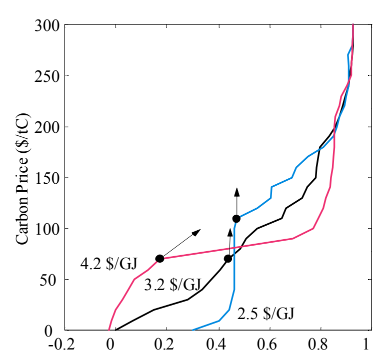
Fossil fuels without CO_2 emissions

15 years ago
A handful of papers
No RD&D budget
No serious assessments of economics or risks

Current
RD&D budget ~ $ 100 m/yr
Major projects starting up.
Total C mitigation flux > solar
Risk assessments
IPCC special report
Biomass with capture

Current Projects
~40 Acid gas projects
Weyburn (Prairie Canada)
Sleipner (North sea Norway)
Snøhvit (Northern Norway)
In Salah (Southern Algeria)
Gorgon (Northwest Australia)

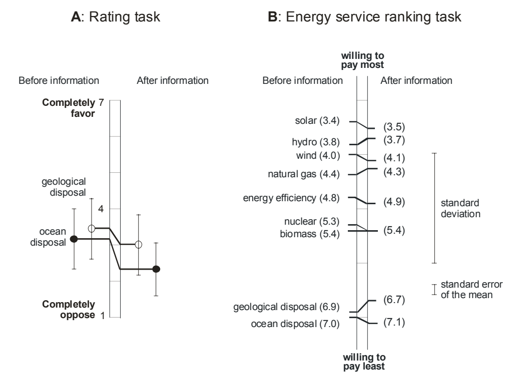
Squeezing carbon out of the electric sector



Risks: A taxonomy

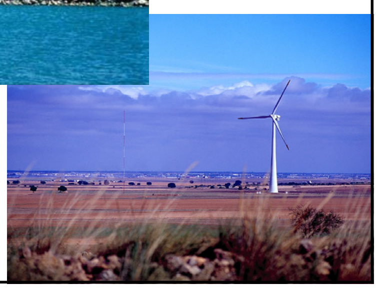
Risks of Geologic Storage

- Local
  - Surface Release
    - Suffocation
    - Ecosystem impacts (tree roots, ground animals)
  - CO_2 in Subsurface
    - Metals mobilization
    - Other contaminant mobilization
    - Effects on potable water
  - Quantity-based
    - Ground heave
    - Induced seismicity
    - Displacement of groundwater resources
    - Damage to hydrocarbon production
    - Damage to other mineral resources (mining)
- Global
  - Surface Release
    - CO_2 back to atmosphere



More than 1000 55 kW NEG Micon turbines at Palm Springs

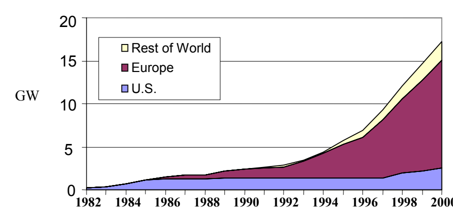
Picture: Danish Wind Industry Association



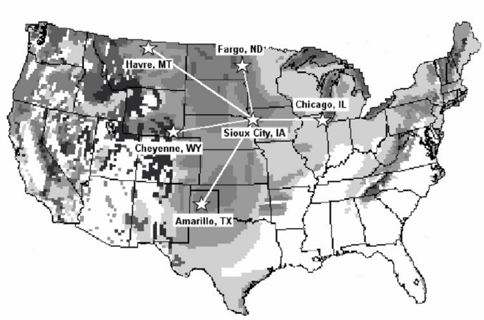
GE 3.6 MW turbine in Spain
Rotor diameter: 104 m
Hub height: ~100 m

Picture: GE

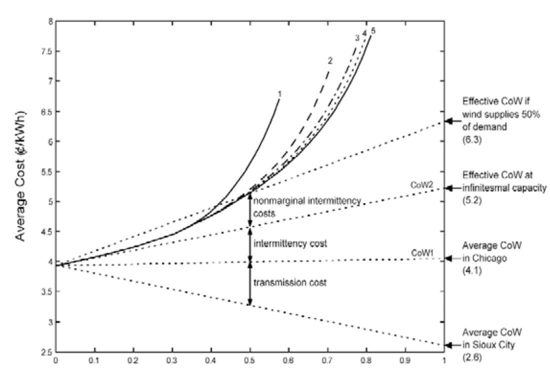
Global Wind Capacity



Top Wind Energy Markets (by installed capacity, in MW)	2001 Additions	2001 Year End Total	Fraction of Electricity Demand Served
Germany	2,659	8,750	3%
United States	1,695	4,261	0.2%
Denmark	853	3,337	15%
Spain	117	2,417	3%
India	240	1,407	1%

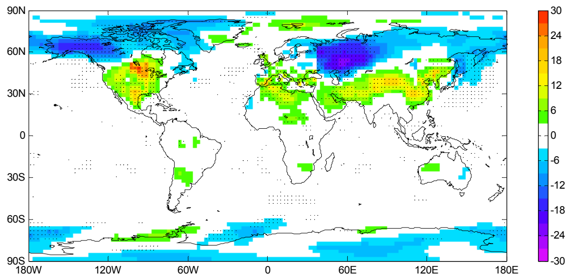


Is there a threshold?



NCAR: Pattern of annual temperature response

Annual temperature response as a function of power dissipation based on point-by-point regression of temp change against dissipation across ensemble of model runs.



Units: mK TW^{-1}

It's hard to make **predictions**, especially about the **future**

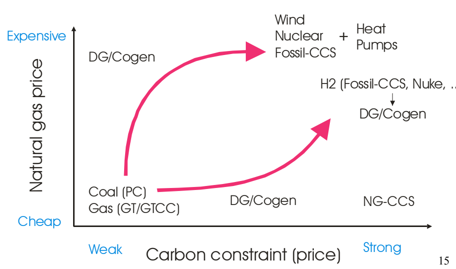
-Yogi Bera

Consider the co-evolution of the buildings and electricity sectors

Ignoring security, the two largest uncertainties in the energy future for electricity and buildings are the cost of NG and the importance of carbon constraints.

We will some eventually arrive at a high-gas high-carbon price world.

How we get there determines what that world looks like.



To elaborate just these two futures:

Electron world. The share of primary energy going to electricity continues to increase. Diverse electric supply: Wind, solar, nuclear, fossil, fossil-CCS.

- Diverse electric supply: Wind, solar, Nuclear, Fossil, Fossil-CCS.
- Electric only buildings with heat pumps.
- Personal transport with grid-chargeable hybrids or small scale electrolytic H_2.

Gas world. Share of primary to central station electricity decreases. At first gas-DG-cogen triumphs, then as natural gas gets expensive gas distribution gradually switches to H_2.

- Diverse H_2 supply: biomass, solar, nuclear, fossil, fossil-CCS.
- gas only buildings with cogen and fuel cells.
- most transport uses H_2 produced distantly

Towards better assessment

Improving technology assessment

Players and the game

Assessment should be a contact sport: It must not be divorced from innovation. Consider TEAP *vs* IPCC.

Timescale

The Kyoto time scale is too short for technological change to act, and too short for sensible decisions about capital allocation.

The century time scale is too long for meaningful forecasts energy system evolution or its response to carbon constraints.

Sound policy requires an intermediate time scale. One that is appropriate to capital investment decisions, and one that permits some skill in technological forecasting.

Question formulation

Mitigation cost *vs* technology cost & performance.

Getting the best players

Select carefully. Use network techniques to select individuals for stature among their technical peers.

Use consultants. As firms have outsourced what were formally key technical competencies, the role of independent technology consultants has grown.

Make the game interesting and short. The most useful players will typically be those who have the least time to play the game.

Use companies that see the take the climate problem seriously.

Non-attribution.

Choose the right convener. The ideal convener is politically independent and disinterested, yet be able command the attention of important policymakers when disseminating results because participants motivation to play will be influenced by their confidence in the former and expectations of the later. These attributes are often mutually exclusive.

Compose groups with both overlapping and mixed expertise. Avoid the one-expert-per-domain formula

Think very hard about motivation to participate.

Structuring the game

Avoid direct estimates of costs wherever possible. Use comparative measures. For example, compare the costs of reducing CO_2 emissions across technologies at a certain date, or compare the costs of reducing emissions across time. Such comparative measures are (arguably) both more robust and more relevant to public policy.

Chose the right timescale for analysis. Too much climate policy analysis has focused on the decadal scale of Kyoto or the century timescale of 'optimal climate policy'. Both are inappropriate for building sound policy.

Specify assumptions clearly. Spend as much (or more) time on the background scenarios as on elicitation of judgments about costs under these scenarios. Disagreement about cost is often a proxy for disagreement about exogenous assumptions.

Disaggregate were appropriate.

Provide explicit judgments about uncertainty. Use the tools of expert elicitation, then iterate while facilitating structured (e.g., Delphi-style) debate about divergent experts judgments.

Some closing thoughts…

There is no BAU. The issue is predicting the economies responsiveness to carbon constraints.

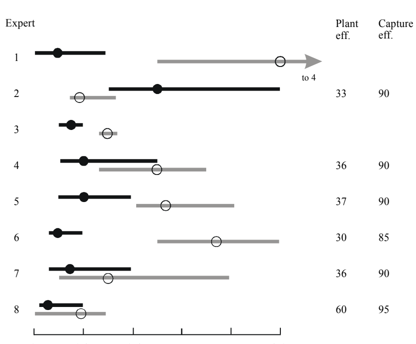
Estimates of mitigation cost must make subjective probabilities explicit.

We need assessment tools that take path dependency seriously. We need to understand the consequences of 'winner-take-most' for cost assessment and technology policy.

- How would probabilistic estimates of control costs look if you ensemble average over uncertain winner-take-all futures.
- Can we produce estimates of control costs in which uncertainty does not → ∞.

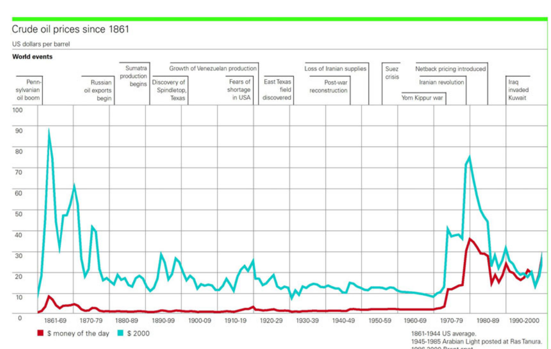
Technology is different from science & impacts. Assessment tools must reflect this. The failures of WGIII are not simply organizational.

Expert elicitation of costs of CO_2 capture technologies



Ratio of cost with capture to cost without capture
(cost of electricity in 2030 [above, black] or capital cost of plant in 2015 [below, gray])

Predict this!



BP Review of World Energy, 2001

Selected Publications on CO_2 Capture and Storage

See www.andrew.cmu.edu/user/dk3p

Ha-Duong, M. and D. W. Keith (2003). "Carbon storage: the economic efficiency of storing CO2 in leaky reservoirs." *Clean Technology and Environmental Policy* **5**: 181-189.

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Keith, D. W. and E. A. Parson (2000). "A Breakthrough in Climate Change Policy?" *Scientific American* Febuary: 78-79.

Parson, E.A. and D.W. Keith (1998). Fossil fuels without CO_2 emissions. *Science* **282**: 1053-1054.

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