Coal, Wind & Nuclear: Tradeoffs And Options In Ontario

The Future of Coal in Ontario?

Old Mill, Toronto

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How Industry May Change Climate

The amount of carbon dioxide in the air will double by the year 2080 and raise the temperature an average of at least 4 per cent. The burning of about two billion tons of coal and oil a year keeps the average ground temperature somewhat higher than it would otherwise be. If industrial growth extended over several thousand years instead of over a century only, the oceans would have absorbed most of the excess carbon dioxide. Seas circulate so slowly that they have had little effect in reducing the amount of the gas as man's smoke-making abilities multiplied during a hundred years.

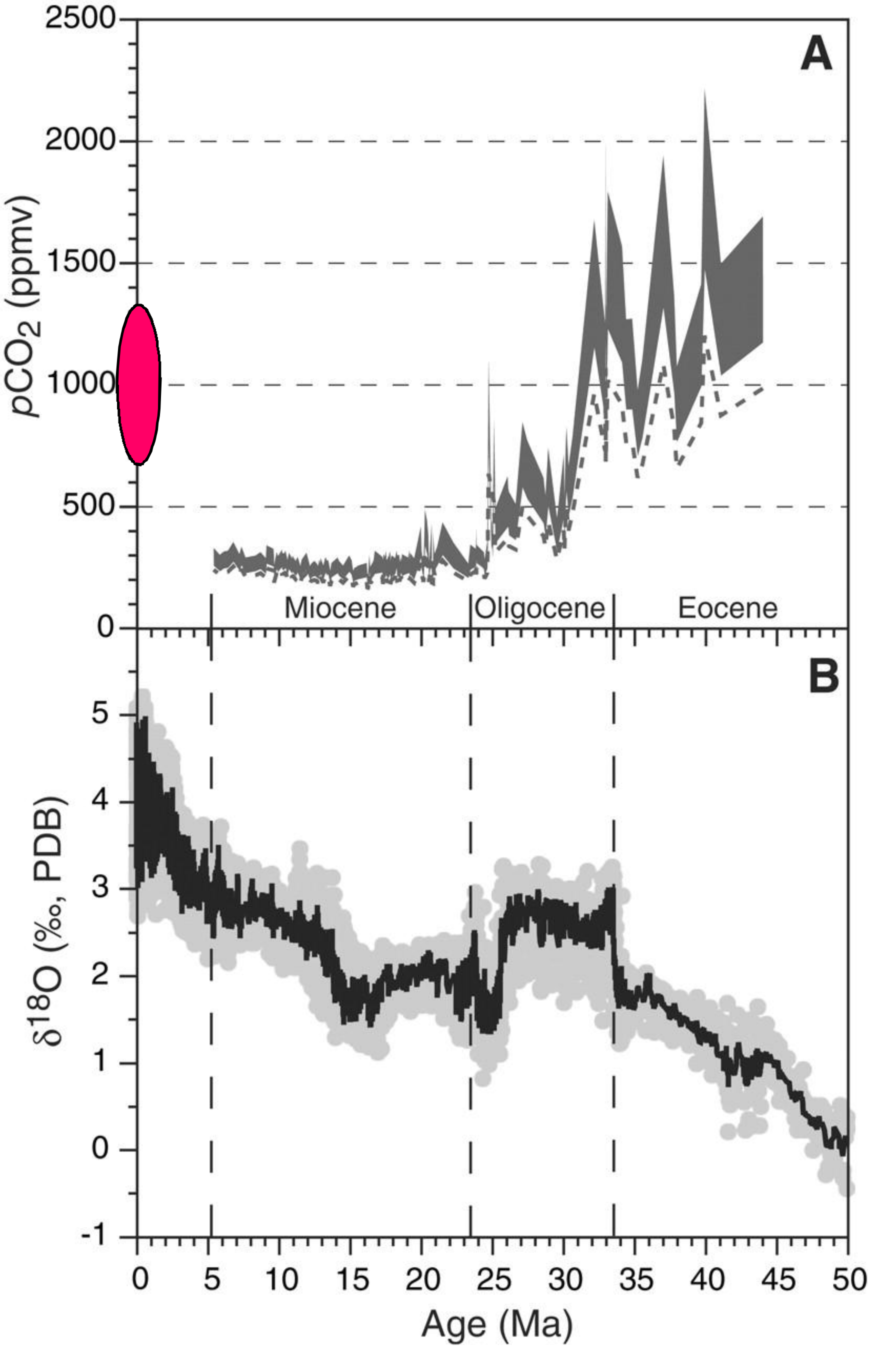
All this and more came out in the course of a paper that Dr. Gilbert N. Plass of Johns Hopkins presented before the American Geophysical Union. He found that man's industries add six billion tons of carbon dioxide to the atmosphere.

rents necessary for the onset of precipitation. This may mean less rainfall and cloud cover, so that still more sunlight can reach the earth's surface. Thus man tends to make his climate warmer and drier; should there be a decrease in carbon dioxide, a cooler and wetter climate would result.

Theory Applied to Glaciers

All this reinforces a theory advanced in 1861 that decreases in carbon dioxide explain the growth and advance of glaciers at various intervals in the earth's history. Dr. Plass finds the theory plausible. If the theory is correct, millions of years of mountain-building preceded each glacial period. During these long periods large quantities of exposed fire-made rock weathered during the uplift of the land, with the result that the amount of free carbon dioxide in the air was greatly reduced. If reduction amounted to only

New York Times, May 24th **1953**

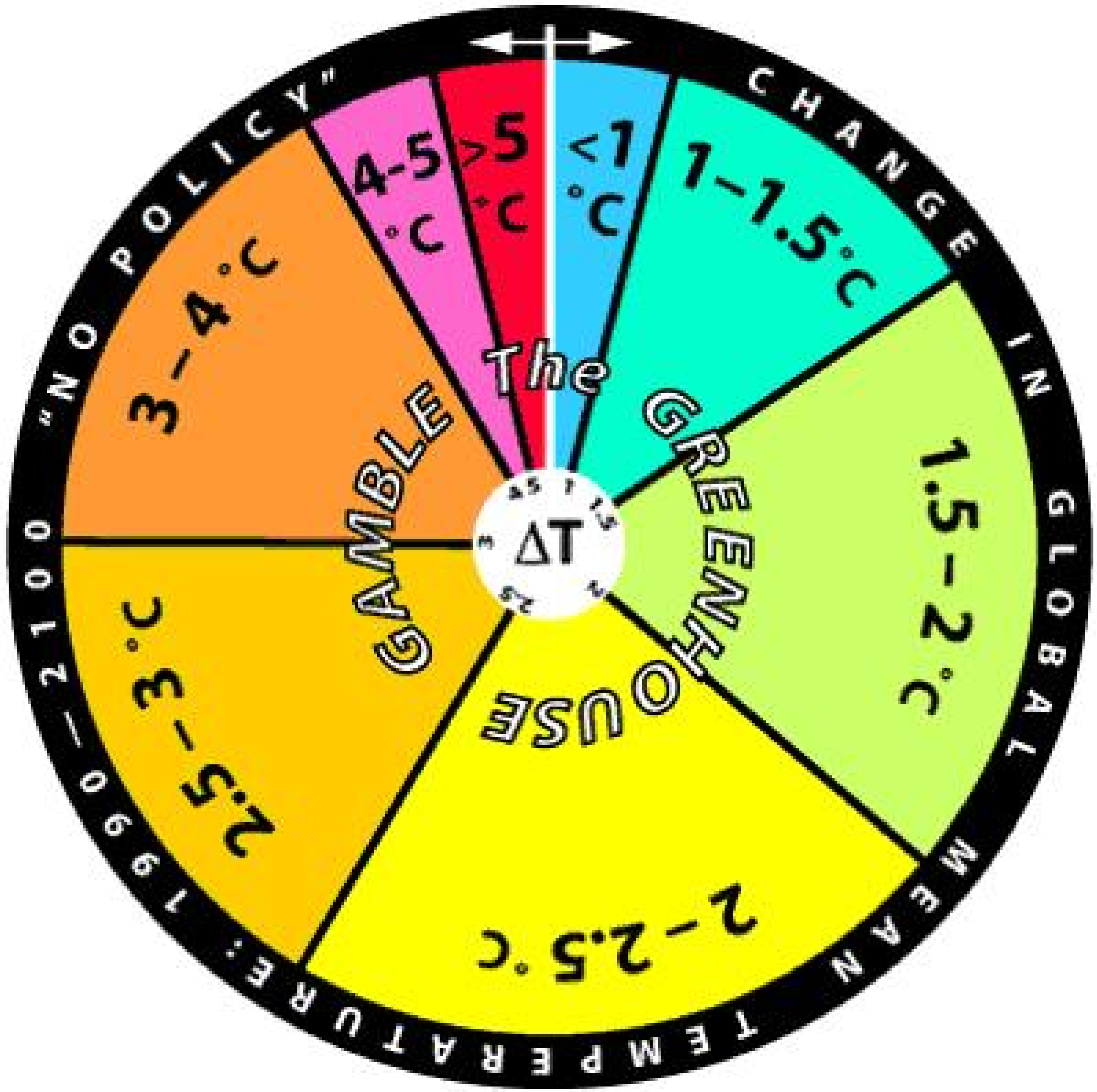


"The vertebrate fauna provides strong evidence for a mild, equable Arctic climate during the Eocene."

"…on the east coast of Axel Heiberg Island, we recovered fossils of crocodilians, gar, and at least three families of turtle"

Eberle & Storer, Northernmost record of brontotheres, Axel Heiberg Island, Canada--implications for age of the Buchanan Lake formation and brontothere paleobiology, *Journal of Paleontology*, 1999.

Pagani et al, Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleogene
Science **309**, 600 - 603 (2005).



Credit: MIT Joint Program on the Science & Policy of Global Change

CO_2 Capture and Storage

Status of CO_2 Capture and Storage

15 years ago

- A handful of papers, negligible research budget, and no serious assessments of economics or risks

Now

- RD&D budget greater than 200 $m/yr
- Many serious research projects.
- Lots of attention: IPCC special report, G8 communiqués …
- A host of major projects in the serious talk stage e.g., Gorgon, SaskPower…
  …and a few large projects that are moving beyond it, e.g. BP's Carson
- But still only two operational megaton per-year scale projects which are beyond business-as-usual
  - Sleipner: gas processing, North sea Norway.
  - In Salah: gas processing, Algeria.
  - Snøhvit: LNG, Northern Norway.

The tool box

Coal gasification

- Now over 60 GW_{th} syngas capacity worldwide.

Hydrogen production from natural gas

- H_2 used for hydro-cracking & desulphurization and ammonia synthesis
- H_2 is ~1.5% primary energy in US.

Capture of CO_2 in aqueous amines

- Capture from exhaust gas in >20 facilities.
- 100's of facilities for high-partial pressure gas streams (e.g., sour gas)

CO_2 transport over 1000 km distances

Injection into deep geological formations

- ~0.5% CO_2 emissions in US.
- Hazardous waste, natural gas storage, Florida sewage treatment water.

Risks of Geologic Storage

Local

Surface Release
- Suffocation
- Ecosystem impacts (tree roots, ground animals)

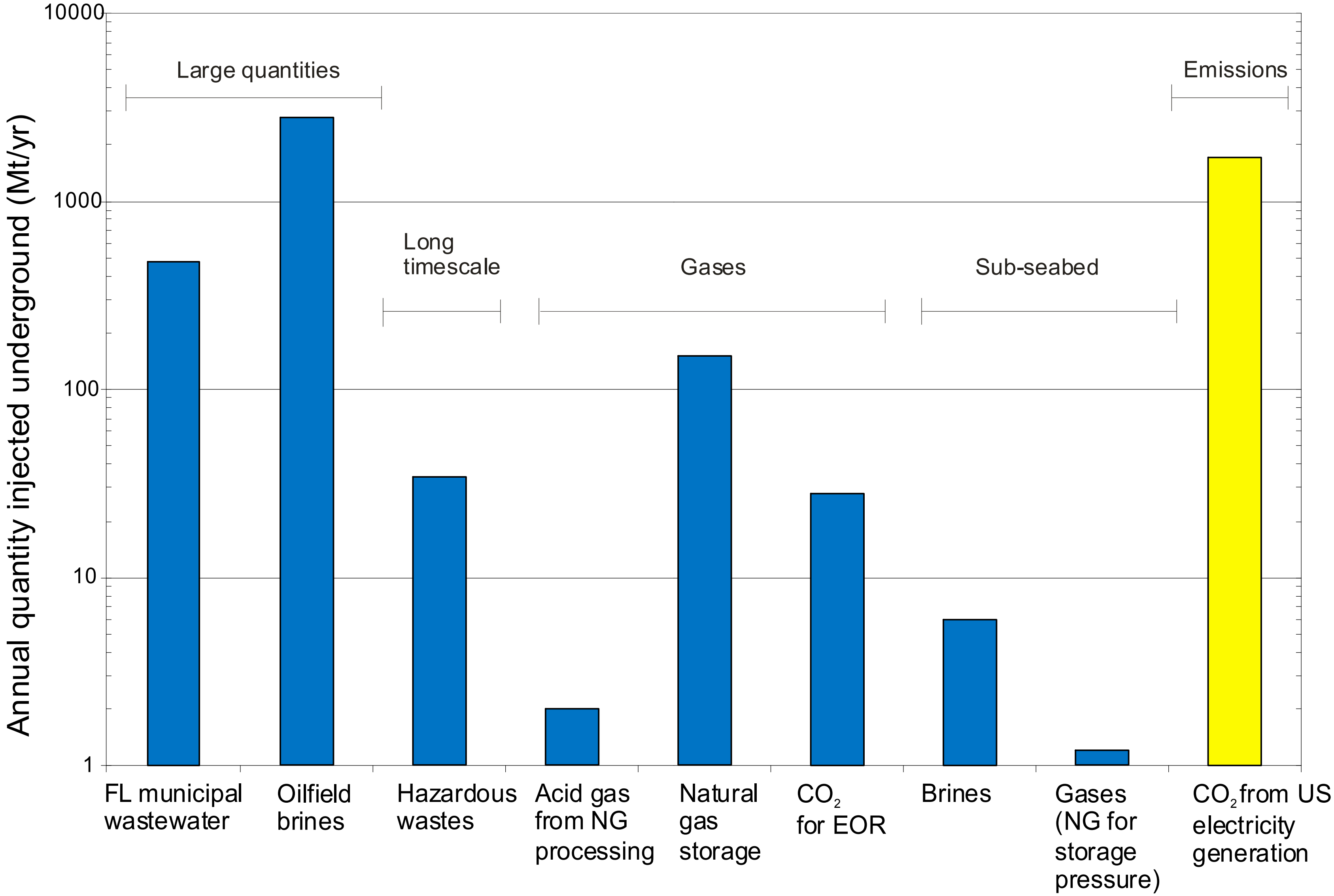
CO_2 in Subsurface
- Metals mobilization
- Other contaminant mobilization
- Effects on potable water

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

U.S. experience with underground injection



Scientific Basis For Estimates of Leakage Risk

Kind of evidence	Average annual fraction released	Representative references
CO_2 in natural formations	The lifetime of CO_2 in natural formations (>10 million yr in some cases) suggests an average release fraction $<10^{-7}$ yr^{-1} for CO_2 trapped in sedimentary basins. In highly fractured volcanic systems, rate of release can be many orders of magnitude faster.	Stevens *et al.*, 2001a; Baines and Worden, 2001
Oil and gas	The presence of buoyant fluids trapped for geological timescales demonstrates the widespread presence of geological systems (seals and caprock) that are capable of confining gasses with release rates $<10^{-7}$ yr^{-1}.	Bradshaw *et al.*, 2005
Natural gas storage	The cumulative experience of natural gas storage systems exceeds 10,000 facility-years and demonstrates that operational engineered storage systems can contain methane with release rates of 10^{-4} to 10^{-6} yr^{-1}.	Lippmann and Benson, 2003; Perry, 2005
Enhanced oil recovery (EOR)	More than 100 $MtCO_2$ has been injected for EOR. Data from the few sites where surface fluxes have been measured suggest that fractional release rates are near zero.	Moritis, 2002; Klusman, 2003
Models of flow through the undisturbed subsurface	Numerical models show that release of CO_2 by subsurface flow through undisturbed geological media (excluding wells) may be near zero at appropriately selected storage sites and is very likely $<10^{-6}$ in the few studies that attempted probabilistic estimates.	Walton *et al.*, 2005; Zhou *et al.*, 2005; Lindeberg and Bergmo, 2003; Cawley *et al.*, 2005
Models of flow through wells	Evidence from a small number of risk assessment studies suggests that average release of CO_2 can be 10^{-5} to 10^{-7} yr^{-1} even in existing oil fields with many abandoned wells, such as Weyburn. Simulations with idealized systems with 'open' wells show that release rates can exceed 10^{-2}, though in practice such wells would presumably be closed as soon as CO_2 was detected.	Walton *et al.*, 2005; Zhou et al., 2005; Nordbotten *et al.*, 2005b
Current CO_2 storage projects	Data from current CO_2 storage projects demonstrate that monitoring techniques are able to detect movement of CO_2 in the storage reservoirs. Although no release to the surface has been detected, little can be concluded given the short history and few sites.	Wilson and Monea, 2005; Arts *et al.*, 2005; Chadwick, *et al.*, 2005

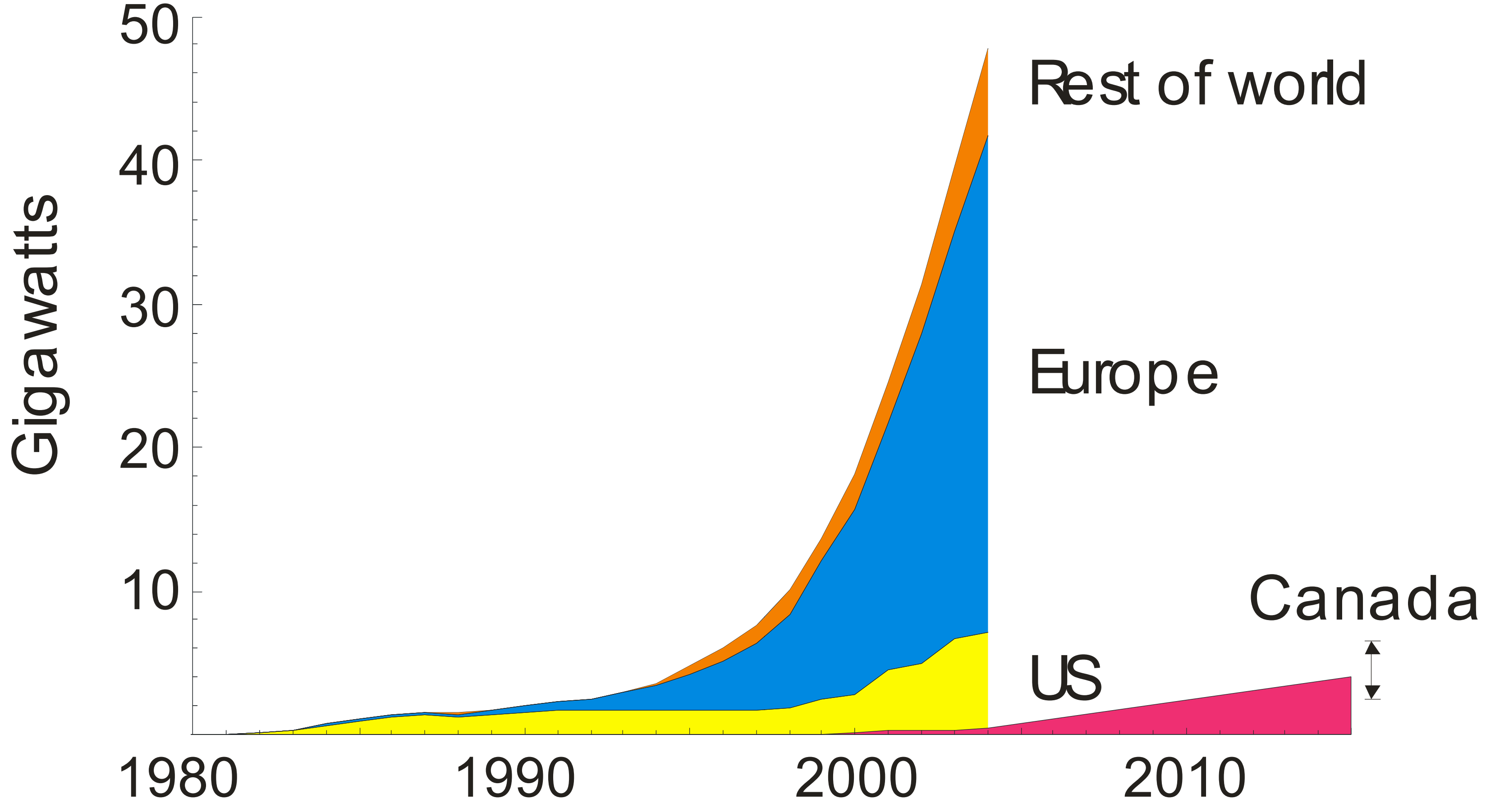
Table 5.5, IPCC Special Report on CO_2 Capture and Storage

Wind

A field of 55 kW turbines from the 1980's

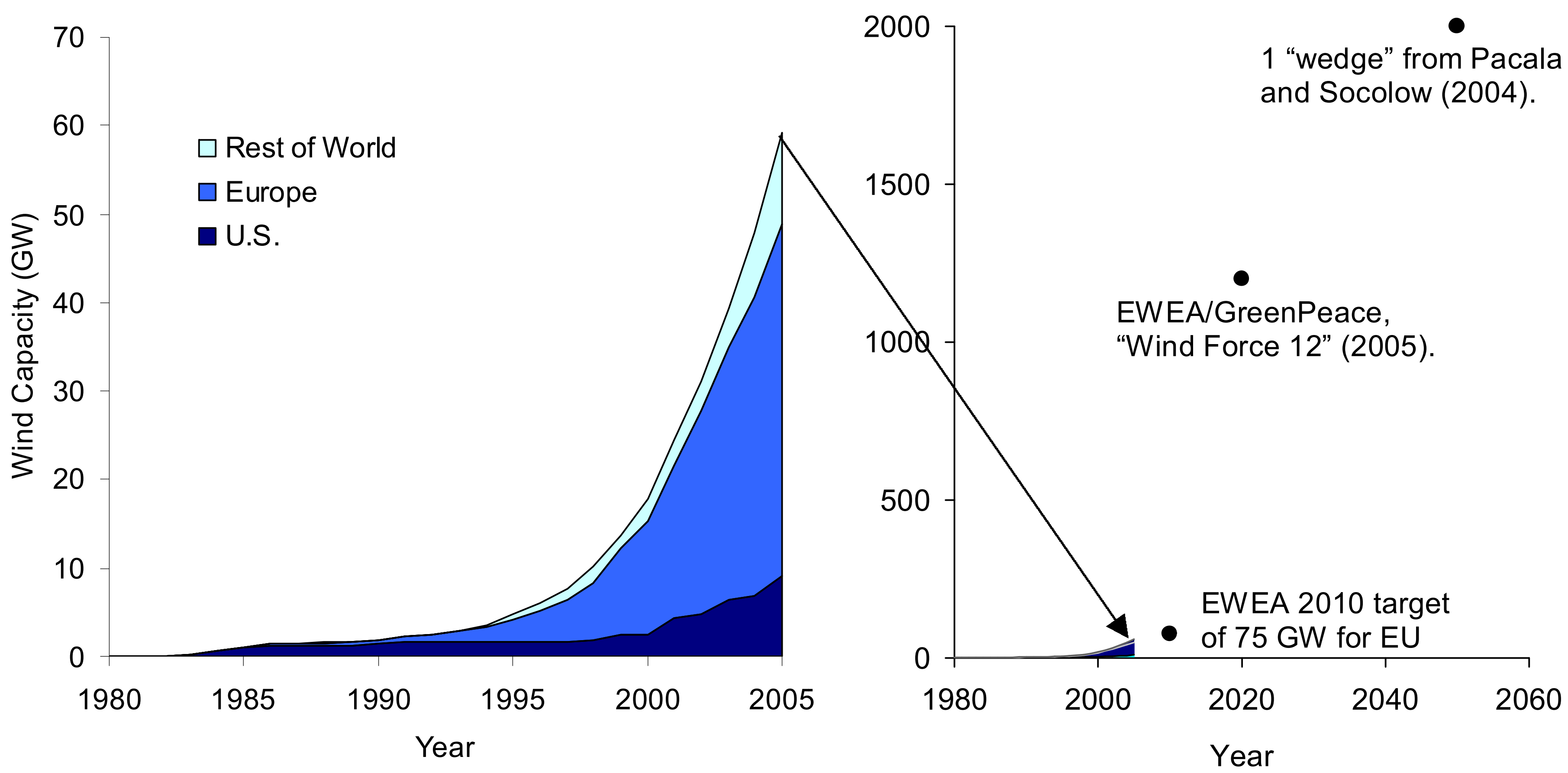
GE 3.6 MW turbine in Spain
Rotor diameter: 104 m
Hub height: ~100 m
Cost: about 5 million $CDN

Growth of Wind Generating Capacity



- A 10$ billion year industry.
- Much larger than solar, much smaller than hydro or nuclear.

Global Wind Capacity



Wind Power Economics

At the turbine, the current cost of wind power is about 7-12 c/kWhr.

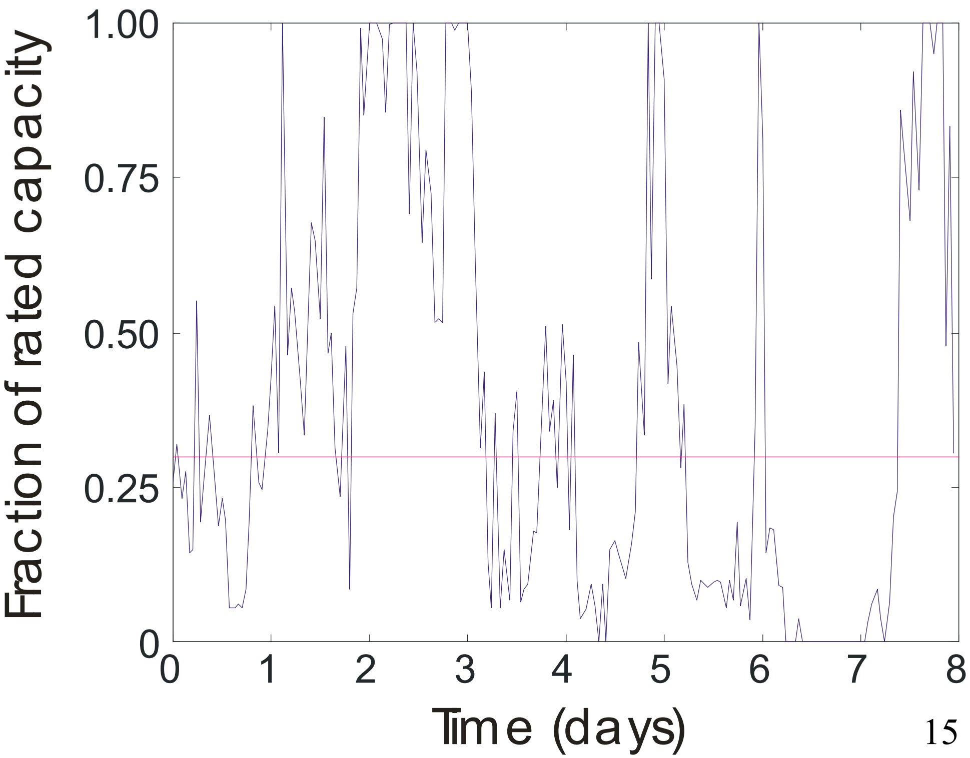
But wind does not blow where or when we want it to.

➔ Location and intermittency add to the cost of wind power

Many studies assert that there is a threshold at about 10% in wind's fractional contribution to the electricity supply:

Below the threshold these limitations can be ignored.

Above it they make wind prohibitively expensive.



Wind Power Economics: Some Conclusions

If the electric power system coevolves with growth of wind power

→ there is no threshold.

→ the additional costs of Location and intermittency can be as low as a few cents per kWhr.

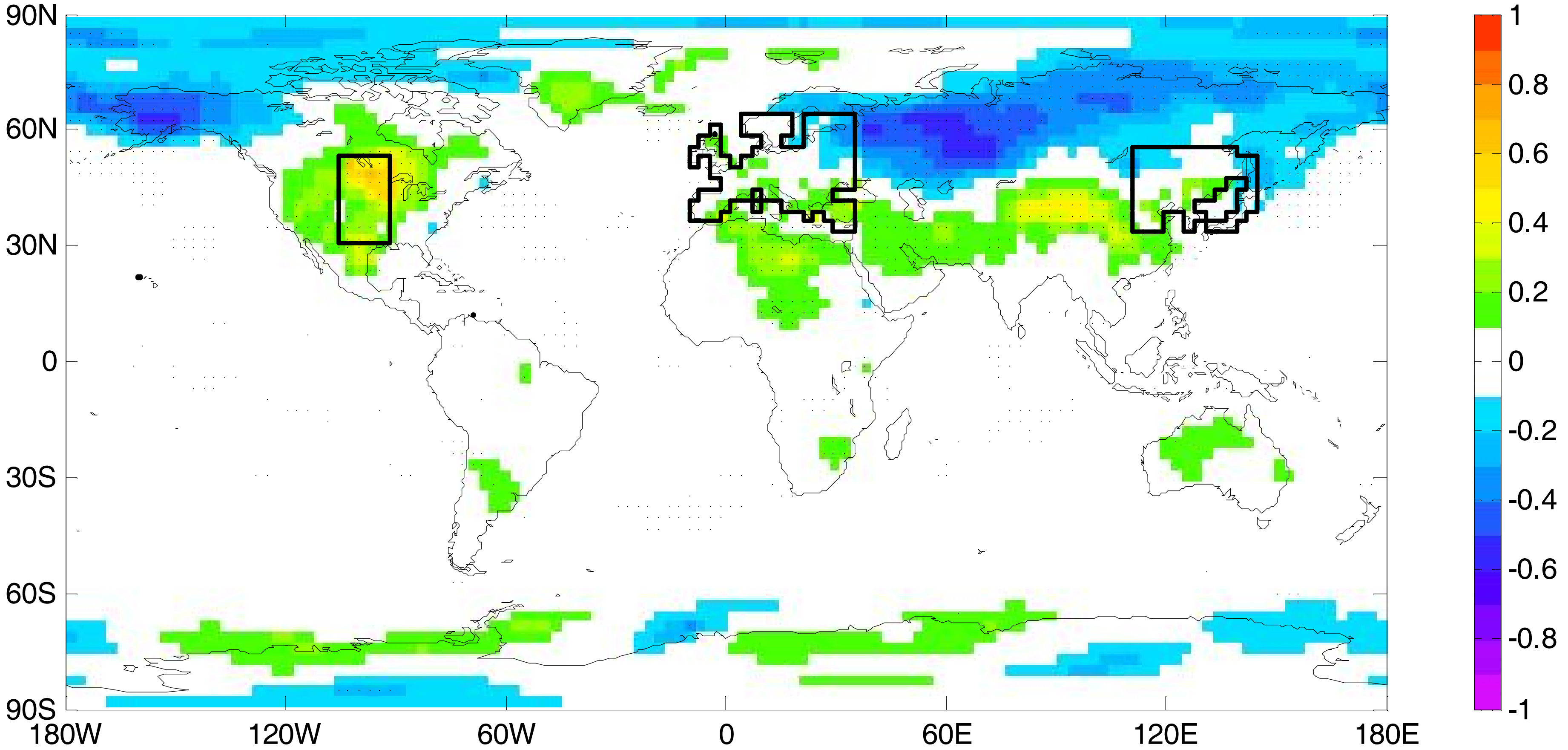
→ wind power might supply as much half of the total electricity at costs competitive with other large scale low-carbon technologies such as nuclear power and coal with CO_2 capture and storage.

Assumptions

- Wind power ~4 c/kWhr at the turbine.
- An efficient electricity market.
- Wind projects large enough to take advantage of economies of scale in electric transmission.
- Wind matched by gas or hydro not nuclear or coal.

Climate Change Due to Very Large-Scale Wind Power

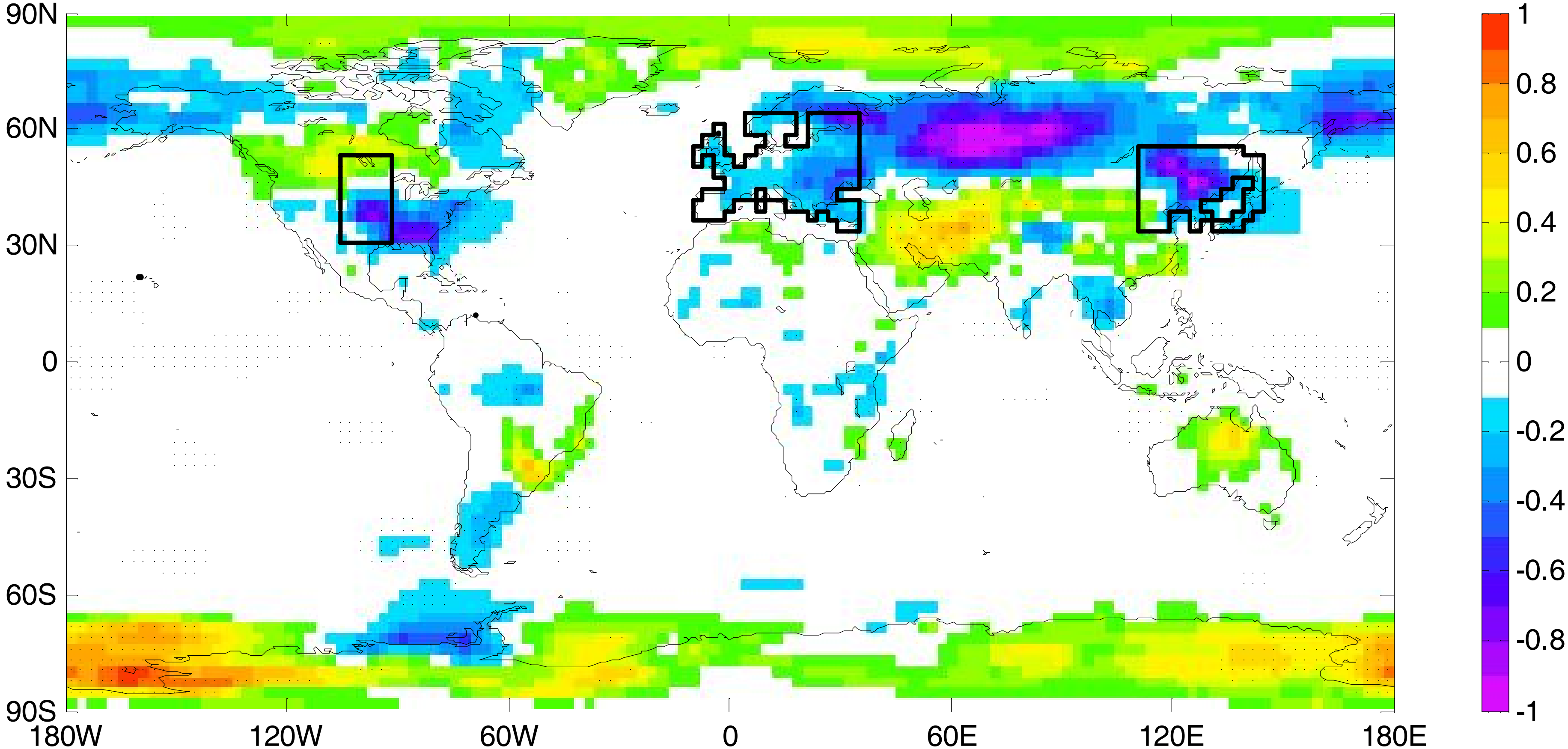
Annual average surface air temperature change due to generating about 10,000 gigawatts of wind power in the areas outlined in black. Simulated at the National Center for Atmospheric Research (NCAR).



Units: centigrade degrees

Climate Change Due to Very Large-Scale Wind Power

Annual average surface air temperature change due to generating about 10,000 gigawatts of wind power in the areas outlined in black. Simulated at the Geophysical Fluid Dynamics Laboratory (GFDL).



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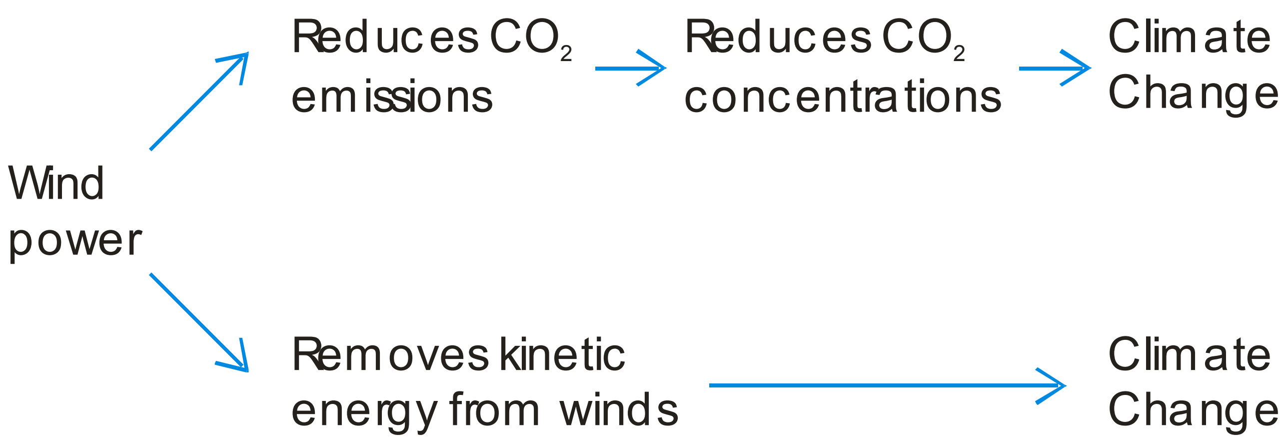
Climatic Impact of Wind Power

First interpretation: who cares? The amount of wind power used in the climate models is absurdly large.



What is the ratio of unintended climate impact to indented climate benefit?

This question matters for any amount of wind power.

Nuclear Power

Nukes

Why?

- The only current large-scale near-zero-emissions electricity technology that could be widely deployed in current electric power systems.
- Canadian.

Why not?

- Mining
- Cost
- Operating risk
- Waste disposal
- Weapons

Mining

Rabbit Lake mine pit leaves an ugly scar prominently featured in Pembina's recent report on nuclear power

But, the energy extracted at the Rabbit Lake pit equivalent to

- 10,000 km^2 of intensively harvested biomass for 100 years.
- A coal mine with an area of order 100-1000 km^2

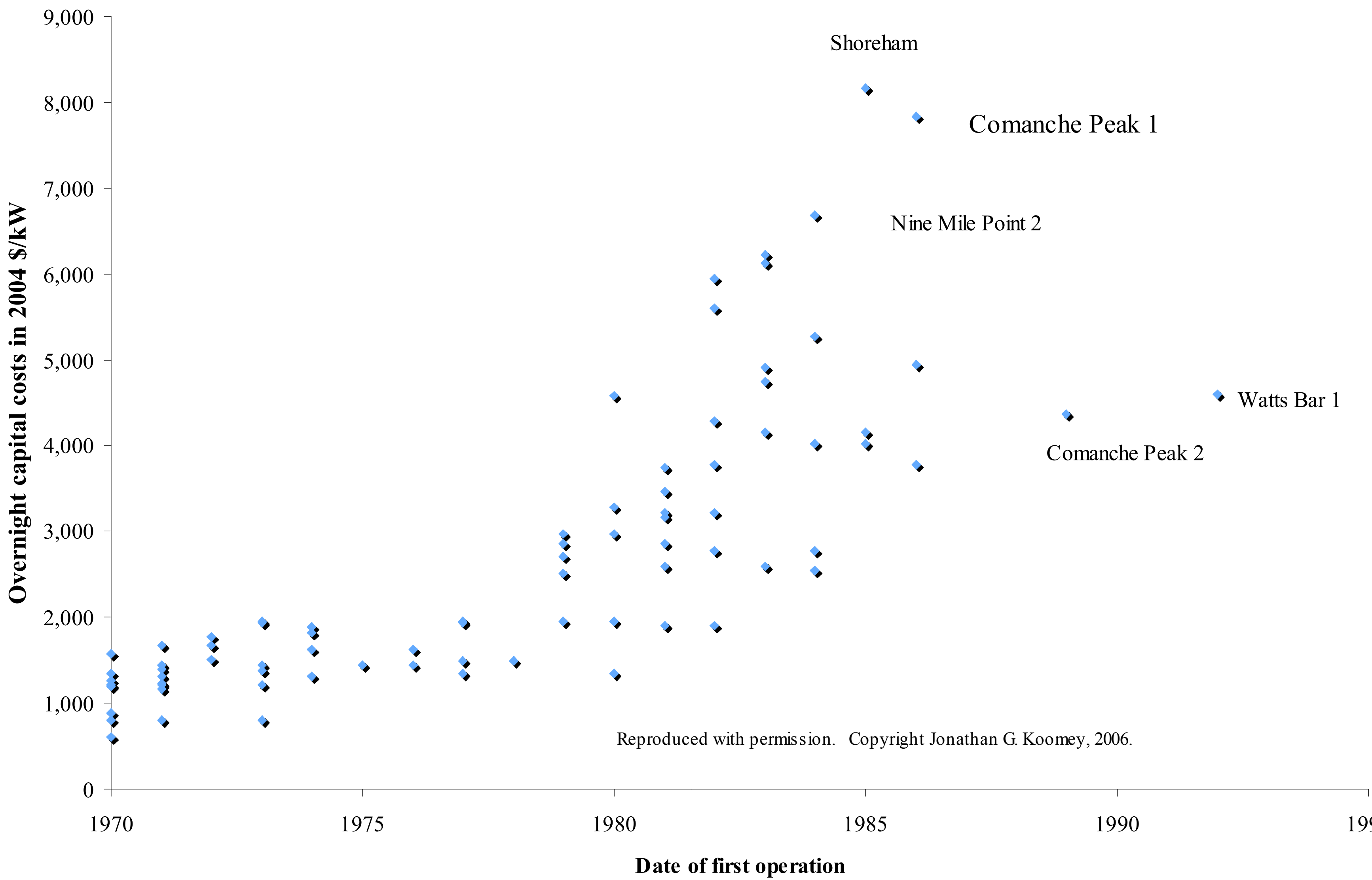
The report mentions the 18 Mt of waste rock the industry moves per year.

- Bad, but the North American coal mining moves that much in a day

➔ Uranium mining is ugly but not in terms of land use per unit energy.

If impact on natural landscapes is the concern natural gas, coal, wind, hydro and biomass are all arguably worse than nuclear.

Historic Nuclear Capital Costs



Proliferation

Two facts

- New nukes in Canada has no direct implications for weapons proliferation.
- No state has build weapons by diversion from civilian reactors.

But…

A rebirth of civilian nuclear power as serious response to climate change

↓

Widespread deployment of nuclear technology around the world

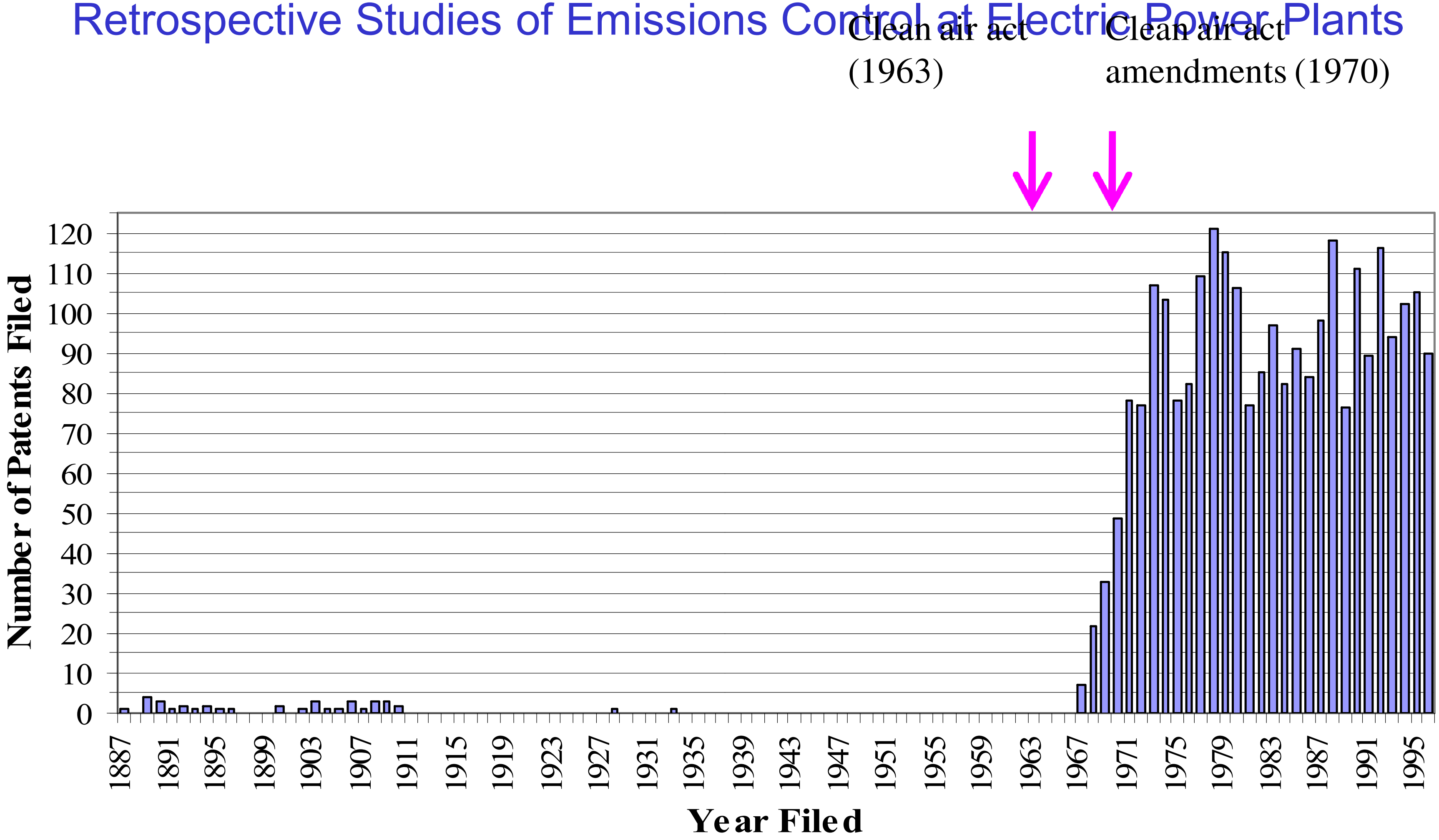
↓

Adoption of advanced fuel cycles

↓

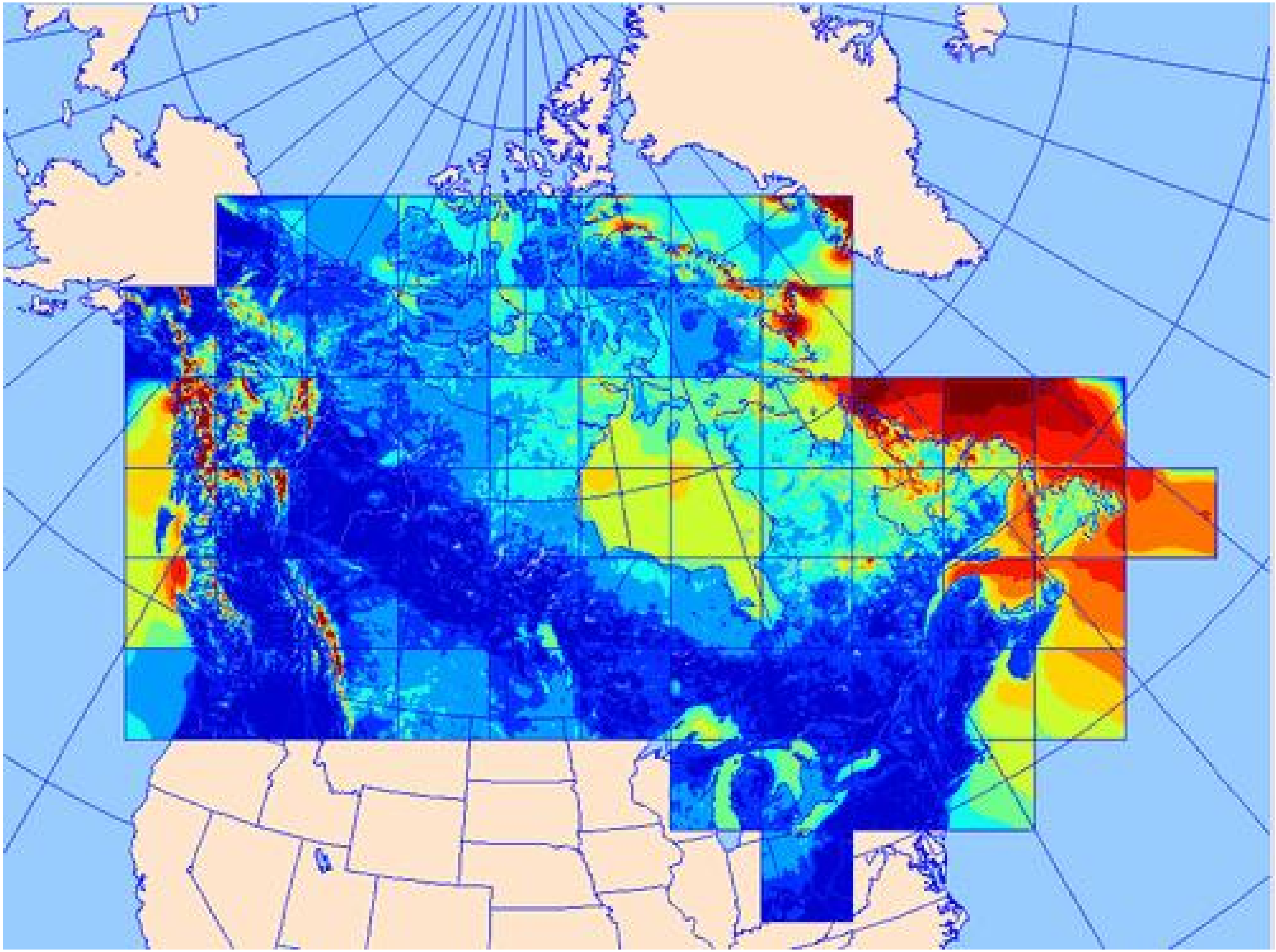
Accelerated diffusion technologies and materials for weapons

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

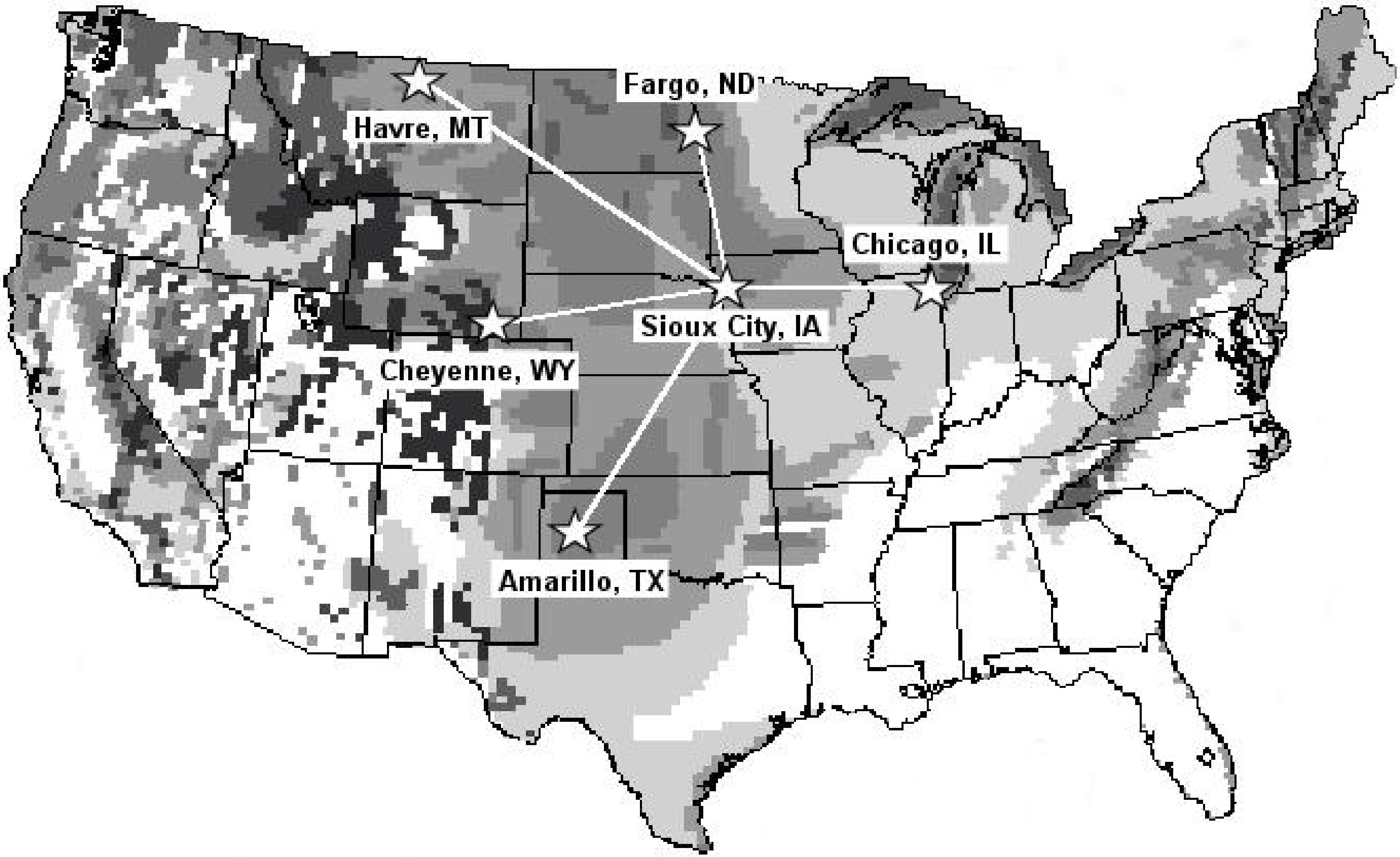


U.S. patents relevant to SO_2 control technology. (Source: Taylor, Rubin, & Hounshell, *Environmental Science & Technology*, 2003)

Location: The best wind sites are far from population centers



Wind Site Configuration



Model Results: Average Cost of Electricity