Technology and Climate Change

APEGGA, 17 February 2005

David Keith
(keith@ucalgary.ca)

Department of Chemical and Petroleum Engineering
Department of Economics
University of Calgary

Thanks to: Carnegie Mellon, Sloan, National Science Foundation, USDOE, Electric Power Research Institute, NOAA, USEPA, Exxon, API, NSERC-Canada, CFI-Canada.

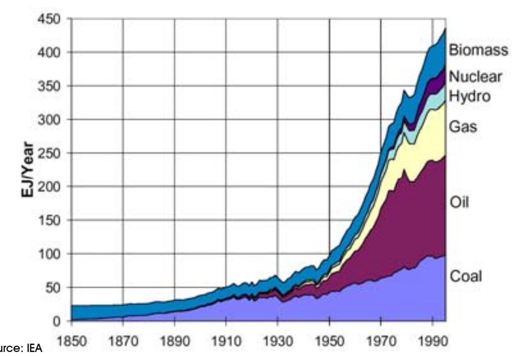
Climate Decision Making Center
Carnegie Mellon

UNIVERSITY OF CALGARY

Energy and Climate Change: Why worry?

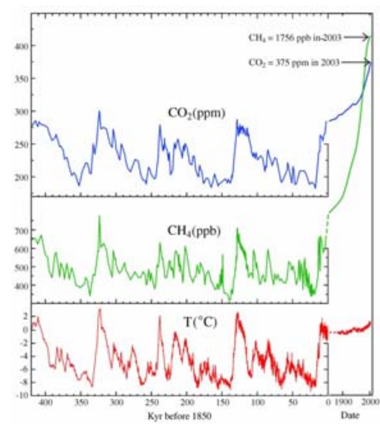
2

World primary energy mix 1850-1995



Source: IEA

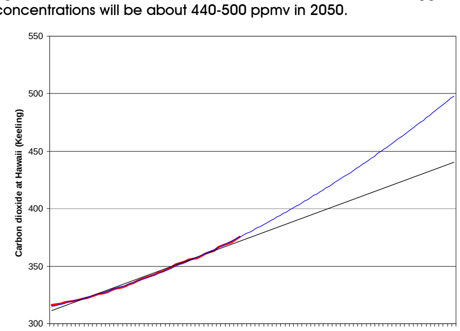
3



4

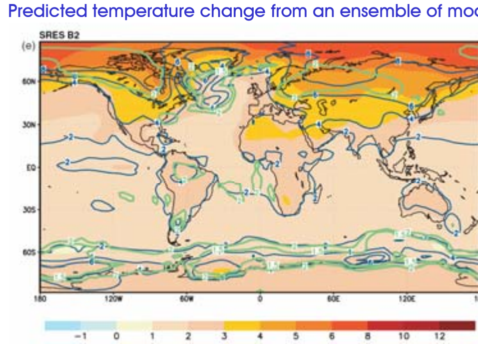
Concentrations of CO_2 are rising due to fossil fuel emissions

CO_2 growth rates have steadily increased. Naïve extrapolations suggest concentrations will be about 440-500 ppmv in 2050.



5

Predicted temperature change from an ensemble of models



IPCC TAR, WGI, Fig 9.10 The multi-model ensemble annual mean change of the temperature (colour shading), its range (thin blue isolines) (Unit: °C) and the multi-model mean change divided by the multi-model standard deviation (solid green isolines, absolute values) for the SRES scenario B2 showing the period 2071 to 2100 relative to the period 1961 to 1990.

6

Do these changes matter?

1. A third to a half as big as the glacial-to-interglacial transitions.
2. Temperatures around here would change by about 4C under a low-emissions growth scenario. Compare this to the difference between the climate in Calgary and some other cities you know:
   – Fort McMurray: -3.4
   – Edmonton: -0.2
   – Vancouver: +6
3. Arctic ocean will likely be nearly ice free in summer.

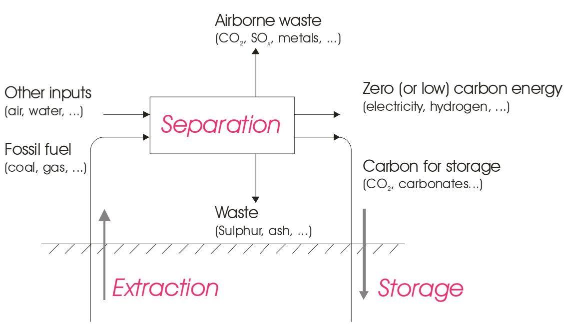
If the climate changes are smooth and slow then the net economic impacts may be near zero, but….
- Some regions/industries will benefit strongly and others will suffer serious impacts. Net impacts are not all that maters.
- Natural ecosystems will change, some dramatically.
- There are real risks that the slow changes will trigger something more sudden.

7

Fossil Fuels Without CO_2 Emissions

8

Fossil fuels without CO_2 emissions



9

Parts already in the tool box

Enabling technologies
- Coal gasification (~60 GWth syngas worldwide).
- Hydrogen production from natural gas (~1.5% primary energy in US).
- Capture of CO_2 in aqueous amines (Capture from exhaust gas in >20 facilities).
- CO_2 transport and injection into deep geological formations (~0.5% CO_2 emissions in US).

10

Status of CO_2 Capture and Storage

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

Now
RD&D budget greater than $ 100 m/yr
Major projects starting up.
Total CO_2 mitigation > solar
Risk assessments
IPCC special report
Biomass with capture

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

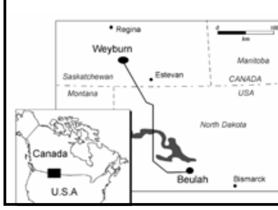
11

Weyburn

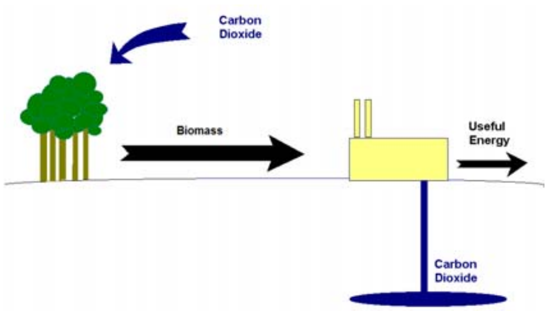
Enhanced Oil Recovery at Weyburn using CO_2 from coal → synthetic NG.

- 320 km pipeline
  ≈1.8 $MtCO_2$/yr
  >1% H_2S

- Large international monitoring effort examining fate of injected CO_2



Biomass with Capture



Source: James Rhodes.

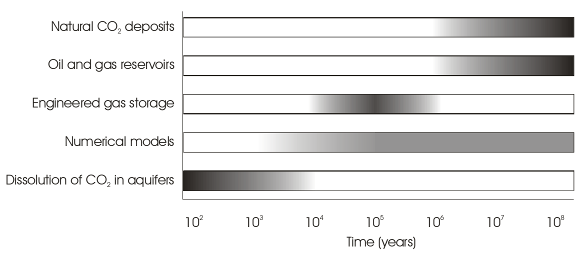
13

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

14

Time scales for geologic storage



15

Opportunities and barriers

Alberta has perhaps the best opportunities in the world to execute capture and storage projects an industrial scale. Why?

1. A mature basin with a well-developed infrastructure;
2. a large and rapidly growing sources of non-combustion/high-partial-pressure CO_2 from which capture is comparatively inexpensive such as CO_2 associated with natural gas production and Oil Sands upgrading; and,
3. some, albeit confused and contentious, commitment to reduce greenhouse gas emissions.

New technologies depend on niche markets: Even if goal is CCS for fossil-electric power plants, use of low-cost niches can play a vital enabling role.

Barriers

- Federal-provincial politics.
- Complexity.
- How to decouple CCS from oncoming Kyoto train wreck?

16

Implications of our growing ability to manage carbon

Fundamental change in our thinking about the future of fossil fuels.

Potential make the fossil fuel industry the engine of abatement rather than the break.

Wedge issue for the environmental community.

Expected cost ←→ politically acceptable commitment to CO_2 control

17

Other Options

18

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

Wind power today

40 GW (gigawatt) global capacity, growing by over 6 GW per year.

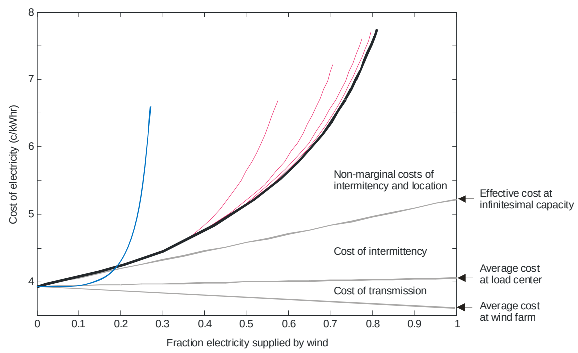
A 10$ billion a year industry.

But, still just over 0.5% of global electricity supply.

Average costs of electricity at the turbine is about 4-6 c/kWhr in good sites, and there are real prospects to get costs below 3 c/kWhr in less than two decades.

20

Is there a threshold in the cost of wind power?



Source: Decarolis & Keith, *Energy Policy.*

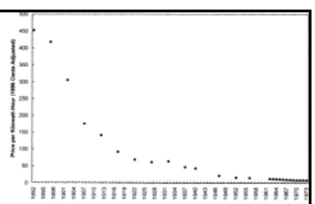
21

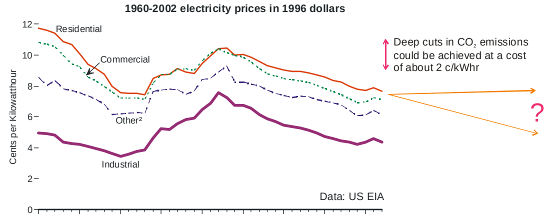
What Will it Cost to Manage the CO_2-Climate Problem?

How should we do it?

22

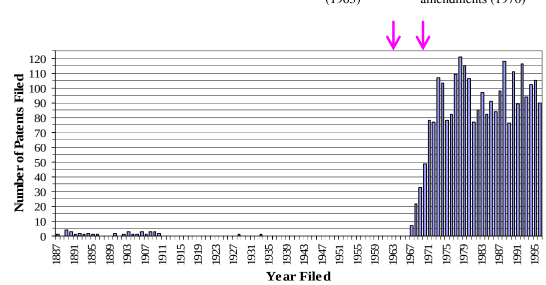
How much is 2 cents?





23

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)

24

Elements of a Sound Climate Policy

Slow and steady.

Use instruments that unleash private sector innovation and bring the least-cost alternatives to the top.

- Cap-and-trade or taxes rather than targeted incentives and technology-specific regulations.
- Reduce friction in housing and consumer markets. Novel financing schemes, performance standards and measures, etc.
- Government support of long-range RD&D.

Allow for business cycle variability.

Enable learning-by-doing in both technology and policy instruments.

25

Selected Publications on CO_2 Capture and Storage

Full text PDF's at www.ucalgary.ca/~keith

Claire Palmgren, Wändi Bruine de Bruin, David W. Keith and M. Granger Morgan (submitted). Initial Public Perceptions of Deep Geological and Oceanic Disposal of Carbon Dioxide. *Environmental Science and Technology*.

Joshuah K. Stolaroff, Gregory V. Lowry and David W. Keith (submitted). Using CaO- and MgO-rich Industrial Waste Streams for Carbon Sequestration. *Energy Conversion and Management*.

James S. Rhodes and David W. Keith (submitted). Engineering-economic analysis of biomass IGCC with carbon capture and storage. *Biomass & Bioenergy*.

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.

Wilson, E. J., T. L. Johnson, and D.W. Keith. (2003) Regulating the Ultimate Sink: Managing the risks of geologic CO_2 sequestration. *Environmental Science and Technology*, **37**: 3476-3483.

Keith, D.W. (2002). *Towards a Strategy for Implementing CO_2 Capture and Storage in Canada.* Oil, Gas and Energy Branch, Environment Canada, Ottawa, Ontario. ISBN: 0-662-31755-6.

Keith, D. and M. Wilson (2002). *Developing Recommendations for the Management of Geologic Storage of CO_2 in Canada.* Regina, SK, University of Regina: 39.

Keith, D. W. (2001). Industrial Carbon Management: An Overview. *Carbon Management: Implications for R&D in the Chemical Sciences and Technology*. A. T. Bell and T. J. Marks. Washington, DC, National Academies Press: 127-146.

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

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

Keith, D. W. and H. Dowlatabadi (1992). "A Serious Look at Geoengineering." *Eos, Transactions American Geophysical Union* **73**: 289-293.

27