Environmental Technology
Innovation and Its Implications for Carbon Management

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Research Team

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  - USDOE/OBER  
  - NSF
Motivation

• Assumptions about technology innovation and diffusion are among the most important uncertainties in integrated assessment models used to study global climate change

• Most models use simple (exogenous) assumptions, or ignore technological change altogether

• Innovations in environmental technology have not been well studied in the past, but are critical for climate policy analysis
Focus on Carbon Capture and Sequestration Technologies

- CO₂ capture and sequestration (CCS) is a relatively new carbon management option that could allow continued use of fossil fuels with no/low atmospheric emissions of CO₂
- Most attractive applications are for large-scale power generation and synfuels production
- CO₂ capture technology now used in small-scale industrial processes and oil/gas production
- Geologic sequestration now being demonstrated in the North Sea and Canada
CO₂ Capture at a Coal-Fired Power Plant
(Shady Point, Oklahoma)

Source: ABB Lummus
IA Modeling Needs

• Integrated assessment models must be capable of representing the CSS option, and the potential for technology innovations to improve performance and reduce costs in the future
The Role of Government Actions

- Because environmental quality is a public good, markets for environmental technologies (such as CCS) depend primarily on government actions in the form of requirements and/or incentives to reduce pollutant emissions.
Project Goals and Approach

- Elucidate government role in environmental technology innovation and diffusion
- Focus on major environmental technologies already in use at electric power plants with relevance to CO$_2$ capture technology:
  - SO$_2$ control
  - NO$_x$ control
- Quantify rates of technical change for these systems based on historical experience
- Use these empirical results to study potential role of carbon capture and sequestration (in collaboration with IIASA and others)
Key Actors and Processes in Environmental Technology Innovation

Invention

Learning by Doing

Adoption & Diffusion

Other R&D Performers

Affected Sources & Industries

Environmental Equipment Suppliers

GOVERNMENT

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Research Methods

- Analysis of Patents Filed in the U.S.
- Analysis of Technological “Learning”
- Analysis of Major Conference Activities
- Detailed Interviews with Key Experts

… this talk will focus on the first two methods
Results for SO$_2$ Control Technology
U.S. Government Actions Affecting SO₂ Control Technology

- **Legislation / Regulation**
  - New Source Performance Standards of 1971, 1979
  - Stringent SO₂ reductions for new and existing sources
  - SO₂ capture technology required for new plants since 1979

- **R&D Funding / Financial Incentives**
  - EPA multi-million $ research budget in 1970s
  - DOE Clean Coal Technology Program (since 1985)

- **Facilitating Technology Transfer**
  - SO₂ Control Symposia (since 1969)
  - Other conferences, workshops, etc
Emission Reduction Options

- Reduce (or shut down) production
- Switch to a cleaner fuel
- Switch to a cleaner production process
- Trade emission allowances
- Install emission control technology
Technologies for SO$_2$ Control

- **Low to Moderate Removal Efficiency**
  - Coal cleaning processes
  - Sorbent injection systems

- **High Removal Efficiency**
  - Flue gas desulfurization (FGD) systems
  - Combined pollutant removal systems
Insights from Patent Analysis

• Historical trends in inventive activity and their relation to key government actions

• Identify categories and types of environmental technology innovations

• Identify sources of inventive activity
  ▪ By performer (e.g., industry, gov’t, etc.)
  ▪ By nation of origin
Identifying Relevant Patents

• **Class-based filter**
  - Relevant classes identified from patent examiner interviews
  - Patent records available for > 100 years
  - 2,681 SO$_2$-relevant patents identified

• **Abstract-based filter**
  - Relevant patents identified by reading patent abstracts (after keyword search)
  - Available electronically only since 1974
  - 1,237 SO$_2$-relevant patents identified
  - Best representation of commercial successes
Inventive Activity in SO$_2$ Control
(U.S. Patents, Class-based dataset)

Year Filed

Number of Patents Filed

No Federal R&D

Some Federal R&D

CAA Regs + R&D

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Adoption of FGD Technology
(Coal-Fired Power Plants)

Cumulative Capacity of Wet Scrubbers (GW)

Year Scrubber in Service

US
Japan
Germany
Other
Historical Trend in FGD Costs
(500 MW plant, 3.5%S coal, 90% SO$_2$ removal, 65% CF)

![Graph showing historical trend in FGD costs]

- **Capital Cost**
- **O&M Cost**

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Learning (Experience) Curves

General equation:

\[ y_i = ax_i^{-b} \]

where,

- \( y_i \) = time or cost to produce \( i^{th} \) unit
- \( x_i \) = cumulative production thru period \( i \)
- \( b \) = learning rate exponent
- \( a \) = coefficient (constant)

Percent cost reduction for a doubling of cumulative output is often used as a measure of learning rate.
Experience Curves for Electric Power Technologies

Source: IIASA
This curve used by IIASA to represent technical change for CO₂ capture systems

Cost reduction ~ 15% per doubling of capacity

y = 1.635x^{-0.205}

R² = 0.79

Cumulative FGD Capacity (GWe) in U.S., Germany, Japan

Normalized Experience Curve for FGD Capital Cost
Results for $NO_x$ Control Technology
U.S. Government Actions Affecting NO\textsubscript{x} Control Technology

- **CAA Legislation / Regulation**
  - Ozone Transport Commission and EPA SIP-Call, 1990s

- Low to moderate reductions for *new sources* since 1971; stringent standards since 1997

- Some reductions at existing *gas-fired* plants since 1970s; no significant reductions for existing *coal-fired* plants until mid-1990s
Technologies for NO\textsubscript{x} Control

- **Low to Moderate Removal Efficiency**
  - Low-NO\textsubscript{x} burners
  - Other combustion modifications
  - Non-selective catalytic reduction (SNCR)

- **High Removal Efficiency**
  - Selective catalytic reduction (SCR)
  - Combined pollutant removal systems
Inventive Activity in NO\textsubscript{x} Control
(U.S. Patents, Class-based dataset)

Year Patent Filed

Number of Patents Filed

CAA
Inventive Activity in Post-Combustion NO_x Control
NO$_x$ Invention by Nation of Origin

Note: Data from 1974-84 represents a 10-year average
Adoption of SCR Technology
(Coal-Fired Power Plants)

Year SCR Online

Cumulative GWe

Japan
Germany
Others
US
World

Experience Curve for SCR Capital Cost
(500 MW coal plant, 80% NOx removal)

World fossil-fueled installed SCR capacity (GWe)

SCR Capital cost (% of base value)

\[ y = 1.38 x^{-0.24} \]
\[ y = 1.29 x^{-0.18} \]

Coal plant capacity
Total plant capacity (est.)
Experience Curve for SCR O&M Cost
(500 MW coal plant, 80% NO$_x$ removal, 65% CF)

\[
y = 2.44 x^{-0.73}
\]

\[
y = 1.83 x^{-0.49}
\]

- SCR O&M (% of base value)
- World fossil-fueled installed SCR capacity (GWe)

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Key Findings & Conclusions

- The cost of new generations of environmental technology has declined significantly with increased deployment and use worldwide.

- Environmental technology innovation has occurred in a global marketplace.

- Government regulations appear to have stimulated inventive activity more than R&D support alone.

- The stringency of emission reduction requirements appears a major factor in *stimulating* and *directing* inventive activity in environmental technology.
**Relevance for Integrated Assessments of Climate Change**

- Does consideration of technological change significantly affect the role of CO$_2$ capture and sequestration as a strategy for climate change mitigation?

  Yes! ...as you will see in Leo Schrattenholzer’s presentation of IIASA modeling results