Effect of Government Actions on Environmental Technology Innovation: Applications to the Integrated Assessment of Carbon Sequestration Technologies

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July 25, 2000
Assumptions about technology innovation and diffusion are among the most important uncertainties in current IA models.

Most models use simple metrics/assumptions; a few treat technological change endogenously.

Results are highly dependent on these (and other) assumptions.
Carbon Sequestration Technologies for Electric Power Plants

- CO$_2$ separation, capture, and storage could become viable carbon management options, allowing continued use of fossil fuels with no/low atmospheric emissions.

- IA models must be capable of representing these options, *and the potential for technology innovations to improve performance and reduce costs in the future*. 
Role of Government Actions

- As with other environmental technologies, future markets for CO$_2$ sequestration technologies will be driven mainly by government requirements and incentives to control greenhouse gas emissions.
- Models of technology innovation and diffusion in this domain can benefit from the study of other environmental technologies now in use.
Study Scope and Objectives

- Develop new tools and techniques to elucidate the role of government actions on future innovations in carbon sequestration technology.
- Draw upon and extend results of recent work by M. Taylor, et al. focused on innovations in SO$_2$ control technology over the past 30 years.
- Incorporate study findings and models into IA frameworks at IIASA and elsewhere to examine the role of carbon sequestration technologies over a range of scenarios.
Case Study Nearing Completion: SO₂ Control Industry

- Primary Source of SO₂: Coal-fired power plants
- Legislation/Regulation
  - New Source Performance Standards 1971, 1979
- R&D Funding / Financial Incentives
  - EPA multi-million $ research budget in 1970s
  - DOE Clean Coal Technology Program starts 1985
    - $2.5 billion government cost-sharing for advanced technology demonstrations (over 14 years)
- Facilitating Technology Transfer
  - The SO₂ Control Symposia start in 1969
  - EPA is initial sponsor; later EPRI and DOE co-sponsor
## Characteristics of Legislation/Regulation

<table>
<thead>
<tr>
<th>LEGISLATION/REGULATION</th>
<th>SO₂ REDUCTION REQUIRED AND TIMETABLE</th>
<th>IMPLEMENTING MECHANISM</th>
<th>AFFECTED SOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970 CAAA</td>
<td>As needed to achieve NAAQS within 5 years</td>
<td>SIPs</td>
<td>Existing</td>
</tr>
<tr>
<td>1971 NSPS</td>
<td>1.2 lbs/MBtu heat input (0-70% removal, depending on fuel sulfur content)</td>
<td>Performance standards</td>
<td>New &amp; Modified</td>
</tr>
<tr>
<td>1977 CAAA 1979 NSPS</td>
<td>70-90% Independent of fuel sulfur content</td>
<td>Technology-based standard</td>
<td>New &amp; Modified</td>
</tr>
<tr>
<td>1990 CAAA</td>
<td>40% over 10 years, 2 phases (On top of any previous reductions)</td>
<td>Emission cap w/trading of emission credits</td>
<td>Existing</td>
</tr>
</tbody>
</table>
Potential Industry Actions

- Plant shut-down
- Reduce generation
- Switch to low-sulfur fuels
- Install control technology
- Trade SO$_2$ allowances (since 1990)
Technology Responses

- **Pre-combustion:** Coal cleaning (<30% removal)
- **During combustion:** Sorbent injection (<50%)
- **Post-combustion:** Flue gas desulfurization (FGD)
  - Wet Systems: Lime/limestone scrubbers (90-98%)
  - Dry Systems: Lime spray dryer scrubbers (70-90%)
    Sorbent injection processes (<50%)
Schematic of a Power Plant
SO\textsubscript{2} Removal System
Evaluating Technology Innovation

- **Approach:** Integrate several complementary evaluation methods and apply to an environmental industry or technological system defined by a single pollutant: sulfur dioxide (SO$_2$)

- **Rationale:** The interaction between government, industry, and technological change is complex. By evaluating this interaction from different perspectives, a more realistic understanding can be developed while weaknesses in individual measures can be counteracted.
Research Methods to Evaluate Technology Innovation

- Analysis of Patents Filed in the U.S. and Europe
  - Inventive activity, linkages to adoption and diffusion
  - Identify key agents
- Analysis of Technological “Learning”
  - Technological change attributed to experience
  - Technological change attributed to generational improvements
- Analysis of Technical Conferences
  - Inventive activity, linkages to adoption and diffusion
  - Identify key agents, industry structure, alliances, knowledge flows
- Retrospective Analyses by Key Agents
  - Innovative inputs
  - Organizational context and constraints
  - Importance of patents, conferences to industry and technology
  - Elicitation of learning curves, expert opinion of patenting trends
Technology Actors

- Equipment vendors
- Architect & engineering firms
- Individual utilities
- Research Sponsors
  - Government (DOE, EPA)
  - Utilities (EPRI)
- Universities
Technological Innovation

Inventive Activity
- R&D
  - Goal-setting
  - Funding priorities
  - IP protection
  - Alliances

Marketing
- Product introduction
- Advertising
- Customer relations

Adoption & Diffusion

Learning by Doing

The Black Box of Technological Change
Role of Government?

Knowledge Gained from Operating Experience
Measuring Innovation

R&D
- Goal-setting
- Funding priorities
- IP protection
- Alliances

Marketing
- Product introduction
- Advertising
- Customer relations

Patents and Activity in Technical Conferences

The Black Box of Technological Change
Role of Government?

Learning by Doing

Learning Curves

Expert Interviews
Data Contained in a Patent

United States Patent
Felsvang et al. 4,279,873

PROCESS FOR FLUE GAS DESULFURIZATION

Inventors: Karsten S. Felsvang, Allerød; Ove E. Hansen, Værløse; Elisabeth L. Rasmussen, Holte, all of Denmark

Assignee: A/S Nira Atumizer, Soborg, Denmark

Appl. No.: 39,892
Filed: May 17, 1979

FOREIGN PATENT DOCUMENTS
96138 10/1958 Czechoslovakia
1333635 10/1973 United Kingdom

Primary Examiner—O. H. Vertiz
Assistant Examiner—Gregory A. Heller
Attorney, Agent, or Firm—Schuyler, Banner, Birch, McKe & Beckett

ABSTRACT
SO₂ is absorbed from hot flue gas by spray drying a Ca(OH)₂-containing suspension in the flue gas. Fly ash is left in the flue gas which is to be treated in the spray absorption process, and the powder which is produced by the spray absorption process and which consequently contains the fly ash and partly reacted Ca(OH)₂ is partially recycled. Operation is controlled to obtain a temperature of the flue gas after the treatment which is 8°-20° C above the saturation temperature of the flue gas at this stage. The process leads to optimum use of the Ca(OH)₂ used as absorbent and of the neutralization power inherent in the fly ash. Problems due to sedimentation of the absorbent before its atomization are avoided.

13 Claims, 4 Drawing Figures
Total U.S. Inventive Activity: Patents by Examiner-Based Method

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Obtained patent lists from companies occupying a significant portion of the U.S. scrubbing market in 1973-93

<table>
<thead>
<tr>
<th>Patent Examiner Class-Based Filter</th>
<th>Company A Commercially Successful Patents (16)</th>
<th>Company B Commercially Successful Patents (69)</th>
<th>Company C Commercially Successful Patents (15)</th>
<th>Total Patents from the 3 Portfolios</th>
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<tr>
<td>56%</td>
<td>46%</td>
<td>87%</td>
<td>54%</td>
<td></td>
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## Linking Patents to Commercial Success: Abstract-based Method

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<td>100%</td>
<td>75%</td>
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<tr>
<td>Patent Examiner Class-Based Filter Set Finds:</td>
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Patent Activity by Technology Type: Pre-Combustion Control

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Social Networks and Tech Transfer: Conference Presentations

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Realized Improvements in FGD Technology Performance

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Realized Improvements in FGD Technology Cost

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Extension to IA of Carbon Management: Research Tasks

**Phase I:** Refine current models of technology innovation in the SO$_2$ domain

**Phase II:** Apply study methods to innovations in power plant NOx controls

**Phase III:** Extend methods and models to carbon sequestration technology

**Phase IV:** Implement findings in large-scale IA models (IIASA, others) to assess role of alternative carbon management options