The Ingredients of a Realistic Path Forward to Reduce the Release of Anthropogenic CO$_2$ to the Atmosphere While Allowing the Long-Term Utilization of Global Fossil Resources

Edward S. Rubin
Department of Engineering and Public Policy
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania

Presentation to the
13$^{th}$ Annual CCUS Conference
Pittsburgh, Pennsylvania
May 1, 2014
Or ...

Can We Have Our Cake and Eat it Too?

Edward S. Rubin
Department of Engineering and Public Policy
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania

Presentation to the
13th Annual CCUS Conference
Pittsburgh, Pennsylvania
May 1, 2014
Or ...

Is There a Future for CCS? Is There a Future for CCS? If so, How do We Get There? (Realistically)

Edward S. Rubin
Department of Engineering and Public Policy
Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania

Presentation to the
13th Annual CCUS Conference
Pittsburgh, Pennsylvania
May 1, 2014
Outline of Talk

• A brief retrospective on CCS
• The good news
• The not-so-good news
• A path forward
A brief retrospective on CCS
(1990 – present)
Early-Mid 1990s

CCS: A technical curiosity

1990

No mention of CCS

1992

Description of CO₂ collection and disposal

1995

One sentence on CO₂ capture and disposal
Mid-Late 1990s

Deserves a closer look

- Growing concerns about climate change (Kyoto Protocol)
- New studies of CCS for coal-fired power plants show greater potential than before (especially for IGCC)
- Growing consensus among analysts that CCS could improve the cost-effectiveness of mitigation strategies
- USDOE announces new initiative on CCS

E.S. Rubin, Carnegie Mellon
Early-Mid 2000s

Let’s see what it can do

- DOE’s Carbon Sequestration Program grows
- Original FutureGen project announced (2003); CSLF formed to promote CCS worldwide
- 3rd IPCC assessment found that: “Physical removal and storage of CO₂ is potentially a more viable option than at the time of the SAR.”
- IPCC commissions a “Special Report on Carbon dioxide Capture and Storage” (completed in 2005)
Mid-Late 2000s

Gotta have it!

- Bullish coal outlook in wake of NG price hikes
- Planned demonstrations of CCS at coal plants throughout Europe, North America, Australia
- Carbon pricing in EU; widespread expectation of climate change legislation in the U.S.
- IPCC 4th AR (2007) says CCS is a key component of cost-effective strategies for climate stabilization
Early-Mid 2010s

Retrenchment

- No U.S. climate legislation
- Financial crisis, economic downturn
- Shale gas euphoria
- Cutbacks in CCS demos and budgets; greater emphasis on utilization

E.S. Rubin, Carnegie Mellon
Looking toward 2020

A critical period for CCS

- Need successes and growth to preserve and regain global momentum
The Good News
First large-scale power plant demonstrations coming this year

- Sask Power Boundary Dam project (Canada)
  - 110 MW coal-fired unit
  - Post-combustion capture +EOR
  - ~ 1 Mt CO₂/yr

- Southern Co. Kemper County IGCC project (Mississippi)
  - 582 MW coal-fired unit
  - Pre-combustion capture +EOR
  - ~ 3.5 Mt CO₂/yr
Other Projects Moving Ahead
(Planned projects in the U.S. as of December 2013)

Major CCS Demonstration Projects
Project Locations & Cost Share

- **FutureGen 2.0**
  - Large-scale Testing of Oxy-Combustion w/ CO₂ Capture and Sequestration in Saline Formation
  - Project: ~$1.65B – Total; ~$1.0B – DOE
  - SALINE – 1 MM TPY 2017 start

- **Summit TX Clean Energy**
  - Commercial Demo of Advanced IGCC w/ Full Carbon Capture
  - ~$1.7B – Total
  - $450M – DOE
  - EOR – ~2.2 MM TPY 2017 start

- **HECA**
  - Commercial Demo of Advanced IGCC w/ Full Carbon Capture
  - ~$4B – Total, $408M – DOE
  - EOR – ~2.55 MM TPY 2019 start

- **NRG**
  - W.A. Parish Generating Station
  - Post Combustion CO₂ Capture
  - $775 M – Total
  - $167M – DOE
  - EOR – ~1.4 MM TPY 2016 start

- **Air Products and Chemicals, Inc.**
  - CO₂ Capture from Steam Methane Reformers
  - EOR in Eastern TX Oilfields
  - $431M – Total, $284M – DOE
  - EOR – ~0.925 MM TPY 2012 start

- **Archer Daniels Midland**
  - CO₂ Capture from Ethanol Plant
  - CO₂ Stored in Saline Reservoir
  - $208M – Total, $141M – DOE
  - SALINE – ~0.9 MM TPY 2014 start

- **Southern Company**
  - Kemper County IGCC Project
  - Transport Gasifier w/ Carbon Capture
  - ~$2.01B – Total, $270M – DOE
  - EOR – ~3.0 MM TPY 2014 start

- **Kemper County IGCC Project**
  - Transport Gasifier w/ Carbon Capture
  - ~$4B – Total, $408M – DOE
  - EOR – ~2.55 MM TPY 2019 start

- **Leucadia Energy**
  - CO₂ Capture from Methanol Plant
  - EOR in Eastern TX Oilfields
  - $436M – Total, $261M – DOE
  - EOR – ~4.5 MM TPY 2017 start

Source: USDOE, 2013
Two new demonstration projects in the UK recently announced

- Peterhead project
  - 385 MW gas-fired unit
  - Post-combustion capture + offshore storage
  - \(~ 1 \text{ Mt CO}_2/\text{yr}\)
  - (FEED studies)

- White Rose project
  - 426 MW coal-fired unit
  - Oxy-combustion capture + offshore storage
  - \(~ 2 \text{ Mt CO}_2/\text{yr}\)
R&D Programs Actively Pursing Lower-Cost Technologies

Source: USDOE, 2010

E.S. Rubin, Carnegie Mellon
New Studies Show Importance of CCS for Climate Change Mitigation
IPCC affirms CCS as a key component of cost-effective strategies to meet goals.
Without CCS...

- The cost of mitigating climate change is substantially higher; and ...

- Climate stabilization levels needed may not be achievable

Source: IPCC, AR5 WG III, 2014
Scenarios for U.S. GHG Reductions

Results from EMF-24

Source: Clarke et al. (in press), 2014
California electricity generation mix and carbon intensity for 2050 scenarios

Source: UC Davis, ITS, 2014
Cost-effectiveness of NGCC-CCS vs. Intermittent Renewables for Europe

Results for four stylized electric power systems serving demands under 450 ppm scenarios:

- NGCC-CCS
- IRES+ NGCC
- IRES+ NGCC-CCS
- IRES+ Storage

NGCC-CCS has lowest LCOE and lowest cost of CO₂ avoided thru 2040

Source: van der Broek et al., 2014
The Not-So-Good News
Drawbacks of CCS Technology

• Not yet proven at full-scale power plants
• Legal and regulatory issues remain in some areas (esp. regarding storage sites)
• Varied levels of public acceptance
• It is relatively expensive
  – Utilization for EOR can offset some, but not all, of current CCS costs for power plant projects

E.S. Rubin, Carnegie Mellon
A New CCUS Option 😊

E.S. Rubin, Carnegie Mellon
Key Barriers to CCS Deployment

- Policy
- Policy
- Policy

Without a policy requirement or strong incentive there is no reason to deploy CCS widely

E.S. Rubin, Carnegie Mellon
Strong Interactions Between Policy and Other Key Factors

These interactions depend strongly on local and national settings.
The Climate Problem Hasn’t Gone Away

“GHG emissions accelerate despite reduction efforts” - IPCC

Source: IPCC, WG3, 2014
Without mitigation, atmospheric concentrations may more than double before end of century.

"Without more mitigation, global mean surface temperature might increase by 3.7° to 4.8°C over the 21st century." - IPCC

Source: IPCC, WG3, 2014
Impacts grow more severe as global temperature increases

**WATER**
- Increased water availability in moist tropics and high latitudes
- Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes
- Hundreds of millions of people exposed to increased water stress

**ECOSYSTEMS**
- Up to 30% of species at increasing risk of extinction
- Increased coral bleaching
  - Most corals bleached
  - Widespread coral mortality
- Terrestrial biosphere tends towards a net carbon source as:
  - ~15%
  - ~40% of ecosystems affected
- Ecosystem changes due to weakening of the meridional overturning circulation

**FOOD**
- Complex, localised negative impacts on small holders, subsistence farmers and fishers
  - Tendencies for cereal productivity to decrease in low latitudes
  - Tendencies for some cereal productivity to increase at mid- to high latitudes
- Productivity of all cereals decreases in low latitudes
- Cereal productivity to decrease in some regions

**COASTS**
- Increased damage from floods and storms
  - About 30% of global coastal wetlands lost
  - Millions more people could experience coastal flooding each year

**HEALTH**
- Increasing burden from malnutrition, diarrhoeal, cardio-respiratory, and infectious diseases
- Increased morbidity and mortality from heat waves, floods, and droughts
- Changed distribution of some disease vectors
- Substantial burden on health services

Source: IPCC, 2007

E.S. Rubin, Carnegie Mellon
More extreme events are expected as atmospheric concentration rises.
Political realities slow U.S. effort to enact climate change laws

By Coral Davenport
The New York Times

WASHINGTON — The United States needs to enact a major climate change law, such as a tax on carbon pollution, by the end of this decade to stave off the most catastrophic impacts of global warming, according to the authors of a report released earlier this month by the U.N. Intergovernmental Panel on Climate Change.

But aggressive efforts to tackle climate change have repeatedly collided with political reality in Washington, where some Republicans question the underlying science of global warming and lawmakers’ ties to the fossil fuel industry have made them resistant to change. The rise of the Tea Party in recent years has also made a tax increase — one by President Bill Clinton in 1993 and one by President Barack Obama in 2010 — ultimately failed, contributing to heavy Democratic losses in midterm elections.

Lawmakers who back such efforts, which represent a threat to the bottom lines of the fossil fuel industry, particularly coal, the nation’s top source of carbon pollution, have been criticized by campaigns from Republicans, Tea Party-affiliated “super PACs” like Americans for Prosperity, and the coal and oil industries.

Many members of the Republican Party question the established science that carbon pollution contributes to climate change — and hundreds have also signed on to a pledge promising never to raise taxes.

But there has not been a huge push through even more stringent pollution-cutting policies, according to the report’s authors.

“We need to increase the slope and the pace of the change,” said David Victor, one of the report’s authors and an expert on climate and energy policy at the University of California, San Diego. “Accelerating what we’re doing in the U.S. will be very important for the next administration.”

Despite the history of roadblocks to enacting climate change policy, some experts say they do see some potential for a legislative path to cut U.S. carbon pollution.

One window could open if Congress takes up a comprehensive effort to overhaul the nation’s corporate tax code, which could happen after the 2016 presidential election.

E.S. Rubin, Carnegie Mellon
A Path Forward
Ingredients of a Realistic Path Forward for CCS

- Successful startup and completion of planned demonstration projects
- Launching of new projects for “next generation” processes
- Sustained R&D programs worldwide
- Strong policy drivers for CCS
  - Carrots
  - Sticks

E.S. Rubin, Carnegie Mellon
Policy options that can foster CCS and technology innovation

<table>
<thead>
<tr>
<th>“Technology Policy” Options</th>
<th>Regulatory Policy Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Gov’t Funding of Knowledge Generation</td>
<td>Direct or Indirect Support for Commercialization and Production</td>
</tr>
<tr>
<td>- R&amp;D contracts with private firms (fully funded or cost-shared)</td>
<td>- R&amp;D tax credits</td>
</tr>
<tr>
<td>- Intramural R&amp;D in government laboratories</td>
<td>- Patents</td>
</tr>
<tr>
<td>- R&amp;D contracts with consortia or collaborations</td>
<td>- Production subsidies or tax credit for firms bringing new technologies to market</td>
</tr>
<tr>
<td></td>
<td>- Tax credits, rebates, or payments for purchasers/users of new technologies</td>
</tr>
<tr>
<td></td>
<td>- Gov’t procurement of new or advanced technologies</td>
</tr>
<tr>
<td></td>
<td>- R&amp;D tax credits</td>
</tr>
</tbody>
</table>
Inventive activity in SO\textsubscript{2} control soared after CAA requirements

U.S. patenting activity in SO\textsubscript{2} control technology, 1880–2000

Source: Rubin et al. 2007

E.S. Rubin, Carnegie Mellon
Trends in FGD Deployment and Cost (1972 –2000)

Technology innovations reduced SO₂ capture costs dramatically as global markets grew in response to new policy requirements.

Could CCS follow a similar path?

Source: Rubin et al. 2007
Some Recent Developments

**EPA Unveils Retooled Carbon Standards for New Plants**

Sets Separate Rules for Coal and Gas; Lists CCS as ‘Best System of Emission Reduction’

Tamar Hallerman

*GHG Monitor*

8/2013

The Environmental Protection Agency unveiled a retooled carbon pollution rule for new power plants today that targets both coal and gas units and provides incentives for plant developers to install carbon capture and storage technology. New limits for power plants depending on the type of unit:

- Coal-fired units — 1,100 lbs CO₂/MWh over a 12-month operating period;
- Coal-fired units that choose to average their emissions over a seven-year period — 1,000 to 1,050 lbs CO₂/MWh;
- Gas-fired turbines larger than 850 MWe — 1,000 lbs CO₂/MWh; and
- Gas-fired turbines smaller than 850 MWe — 1,100 lbs/MWh.

EPA retrofitted the standards after receiving more than 2.5 million public comments on its proposed performance standard of 1,300 lbs CO₂/MWh. EPA noted that old proposal today in light of the new action plan. "We are very confident that the carbon pollution standards that we are proposing today for new coal-fired units will be further developed for the next generation of power plants in this country," EPA Administrator Gina McCarthy told reporters.

‘Best System of Emission Reduction’

EPA lists CCS as the "best system of emission reduction" in the text of the proposed rule, citing four power plants (Kemper County, Boundary Dam, Texas Clean Energy Project and Carbon Energy California) as evidence. This development shows that power plant operators would only need to install "partial" carbon capture in order to capture provides meaningful emission reductions. It has been adequately demonstrated to be technically feasible, deployment and further development of the technology," the rule states. EPA officials said that most coal plants..."In order to incentivize developers to install CCS technology, EPA said it would allow plant operators the option is that CCS may present a challenge, and if it is not financially feasible, it may be technically feasible, but it is not ready to be deployed. "The seven-year time frame is not the original April 2012 proposal. The agency will be accepting public comments on the new proposal for 60 days after it is published in the Federal Register. Also plans on holding a public meeting on the rule in the near future.

**BBC News**

**Science & Environment**

17 April 2014 Last updated at 12:12 ET

EU green light for UK carbon capture and storage project

By Matt McGrath
Environmen Correspondent, BBC News

A UK project to capture CO₂ and bury it under the North Sea looks set to receive a 300 million euro boost from the EU.

The European Commission has confirmed that the White Rose carbon capture and storage (CCS) project is in line to win the cash (equivalent to about £250m).
What is the Future of CCS?

- Will soon see first large-scale power plant demonstrations, with

- Continued support for R&D; but …

- Growth will depend on the outlook for strong policy drivers that create markets for CCS

- WATCH THIS SPACE FOR FUTURE UPDATES

E.S. Rubin, Carnegie Mellon
Thank You

rubin@cmu.edu