The Outlook for Improved Carbon Capture Technology

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Outline of Today's Talk

- Defining "improved technology"
- A look at some past trends
- The potential for future improvements
- What it takes to achieve them

Two Principal Measures of Improved Capture Technology

Improvements in performance

- Higher CO_2 capture efficiency
- Lower energy penalty
- Increased reliability
- Reduced life cycle impacts

Reductions in cost

- Capital cost
- Cost of electricity
- Cost of CO_2 avoided
- Cost of CO_2 captured

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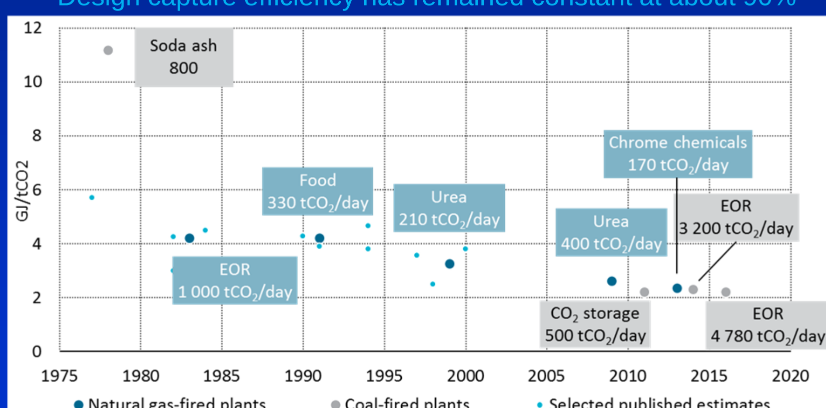
Thermal energy required for solvent-based CO_2 capture has fallen by half since 1990

Design capture efficiency has remained constant at about 90%



Source: IEA, 2015, based on data from Rochelle (2014) and Yeh & Rubin (2012)

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Most improvement goals focus on cost reductions for CO_2 capture

The specific form and magnitude of cost goals may change over time;
here are recent goals of the U.S. Department of Energy

Table 3-1. **Market-Based R&D Goals for Advanced Coal Power Systems**

	Goals (for nth-of-a-kind plants)		Performance Combinations that Meet Goals	
R&D Portfolio Pathway	*Cost of Captured CO_2, \$/tonne*[1]	*COE Reduction*[2]	*Efficiency (HHV)*	*Capital/O&M Reduction*[3]
2nd-Geneneration R&D Goals for Commercial Deployment of Coal Power in 2025[4]				
In 2025, EOR revenues will be required for 2nd-Generation coal power to compete with natural gas combined cycle and nuclear in absence of a regulation-based cost for carbon emissions.				
Greenfield Advanced Ultra-Supercritical PC with CCS	40	20%	37%	13%
Greenfield Oxy-Combustion PC with CCS	40	20%	35%	18%
Greenfield Advanced IGCC with CCS	≤40	≥20%	40%	18%
Retrofit of Existing PC with CCS	45	n/a		
Transformational R&D Goals for Commercial Deployment of Coal Power in 2035[4]				
Beyond 2035, Transformational R&D and a regulation-based cost for carbon emissions will enable coal power to compete with natural gas combined cycle and nuclear without EOR revenues.				
New Plant with CCS—Higher Efficiency Path	<10[5]	40%	56%	0%
New Plant with CCS—Lower Cost Path	<10[5]	40%	43%	27%
Retrofit of Existing PC with CCS	30	≥40%	n/a	

Source: USDOE/NETL, Carbon Capture Technology Program Plan (2012)

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Ten Ways to Reduce CCS Cost

(inspired by D. Letterman)

10. Assume high power plant efficiency
9. Assume high-quality fuel properties
8. Assume low fuel price
7. Assume EOR credits for CO_2 storage
6. Omit certain capital costs
5. Report \$/ton CO_2 based on short tons
4. Assume long plant lifetime
3. Assume low interest rate (discount rate)
2. Assume high plant utilization (capacity factor)
1. Assume **all of the above !**

***. . .** and we have not yet considered the CCS technology!*

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Past trends in CCS cost estimates

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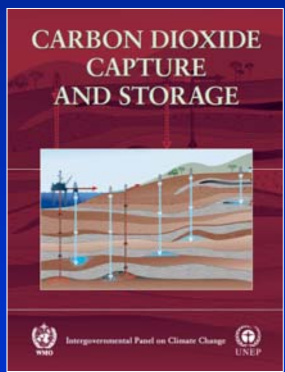
The IPCC Special Report on CCS

- Commissioned by IPCC in 2003; completed in December 2005
- First comprehensive look at CCS as a climate change mitigation option (9 chapters; ~100 authors)
- Included a detailed review of cost estimates for CO_2 capture, transport and storage options



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2015 Cost Update

(with J. Davison and H. Herzog, IJGGC, *in press*)

- Compiled data from recent CCS cost studies in the U.S. and Europe for new power plants with:
  - Post-combustion CO_2 capture (SCPC and NGCC)
  - Pre-combustion CO_2 capture (IGCC)
  - Oxy-combustion CO_2 capture (SCPC)
- Adjusted all costs to constant 2013 US dollars
- Adjusted SRCCS costs from 2002 to 2013 USD using:
  - Capital /O&M cost escalation factors +
  - Fuel cost escalation factors (for COE)
- Compared current cost estimates to SRCCS values

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Key Assumptions: Then and Now

- Basic power plant design parameters such as net plant efficiency, CO_2 emission rates, and CO_2 capture rates have not changed appreciably since the SRCCS
- Some assumptions affecting CCS costs have changed:
  - Average power plant sizes without CCS are about 10% to 25% larger than in SRCCS studies
  - Assumed capacity factors are higher (by 10 %-pts for PC, plants, 2 %-pts for IGCC plants, and 8 %-pts for NGCC)
  - Fixed charge factor are lower (by about 10% for NGCC, 20% for IGCC and 30% for SCPC)
  - Different parameter values for plants with and w/o capture
  - Increased focus on potential for utilization via CO_2–EOR

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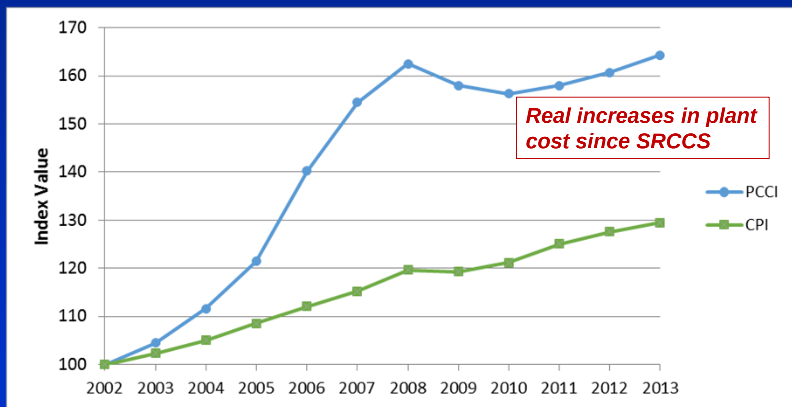
Capital Cost Trends



CPI = U.S. Consumer Price Index (BLS, 2014)
PCCI = Power Capital Costs Index (excluding nuclear) (IHS-CERA, 2014)

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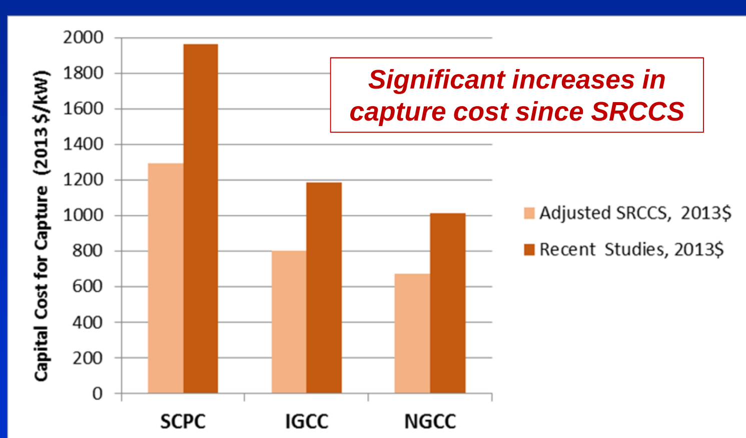
Added Capital Cost for CO_2 Capture

(over and above the reference plant cost without capture)



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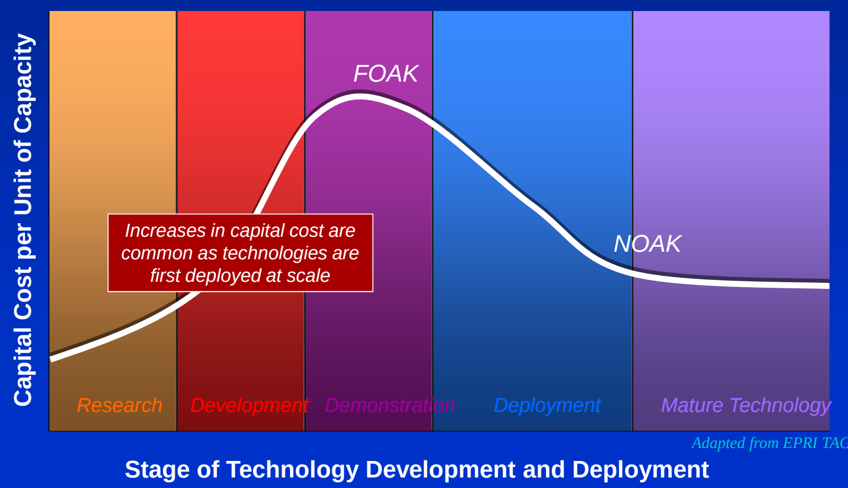
Typical Cost Trend of a New Technology



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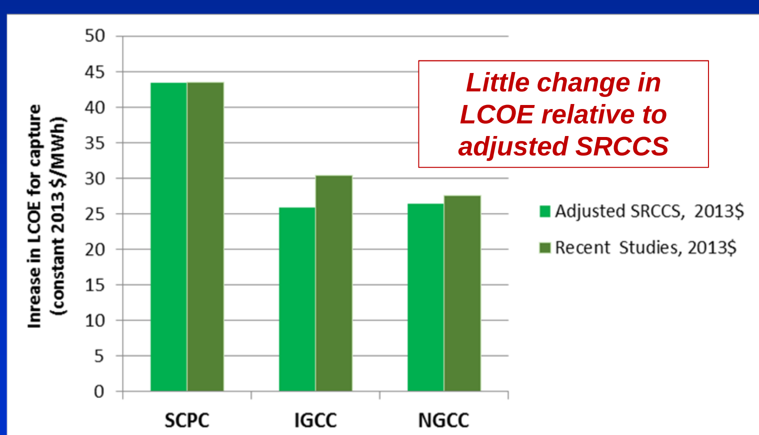
Added LCOE for CO_2 Capture

(excluding transport & storage costs)



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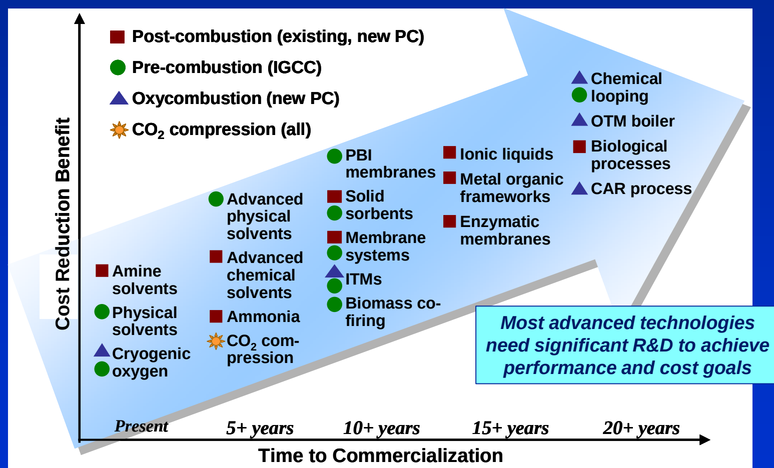
Other Conclusions from the Study

- For new SCPC plants oxy-combustion shows potential to be cost competitive with post-combustion capture
- Based on current cost estimates for the four CCS pathways analyzed, there are no obvious winners or losers
- For all options, CCS cost can be reduced significantly if CO_2 can be sold for enhanced oil recovery in conjunction with geological storage over the life of the project

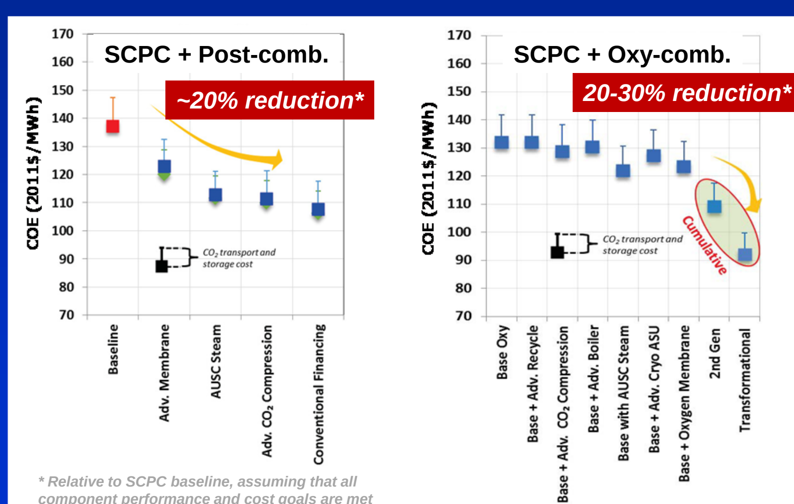
The potential for future cost reductions

Examples of Advanced CO_2 Capture Technologies Under Development



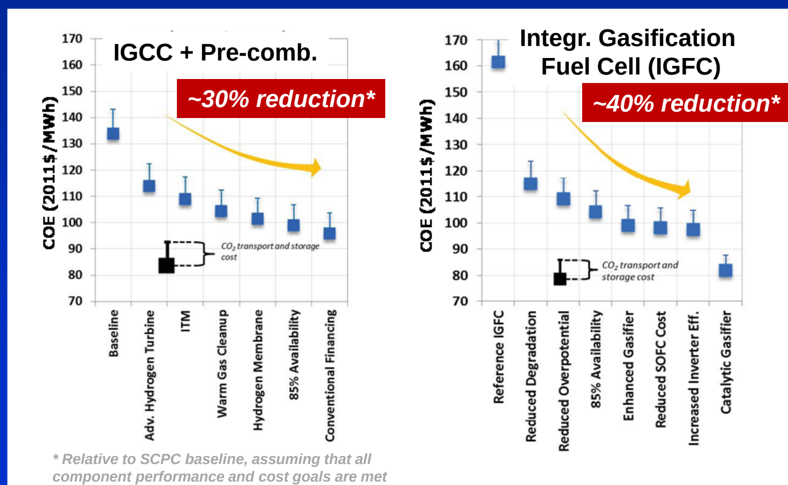
Source: USDOE, 2010

Projected cost reductions from "bottom-up" analyses of advanced plant designs *(1)*



Source: Gerdes et al, NETL, 2014

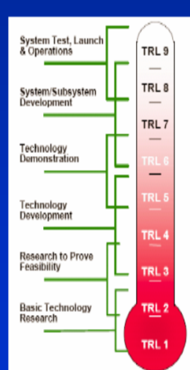
Projected cost reductions from "bottom-up" analyses of advanced plant designs *(2)*



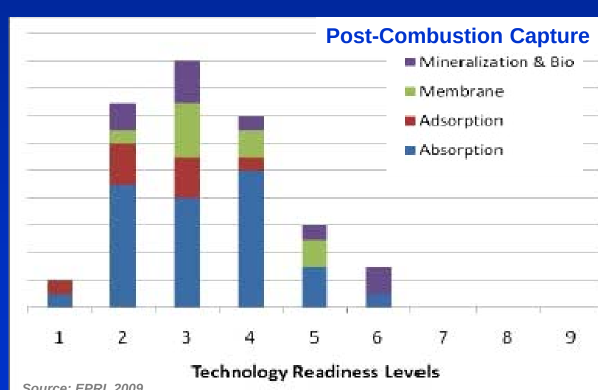
Source: Gerdes et al, NETL, 2014

Most New Capture Concepts Are Still Far from Commercial

Technology Readiness Levels



Source: NASA, 2009



Source: EPRI, 2009

Technology Scale-Up Takes Time and Money

TRL	Scale	Cost to achieve	Time to achieve
6 Process Development Unit	Up to ~5% full scale	$ millions to $10s of millions	24-48 months
7 Pilot Plant	At least 5% full scale	$10s of millions to $100s of missions	24-60 months
8 Commercial Pilot Plant	At least 25% full scale	$100s of millions	4-7 years
9 1st Commercial Deployment	Full scale	$100s of millions to $ billions	4-7 years

Source: EPRI, 2014

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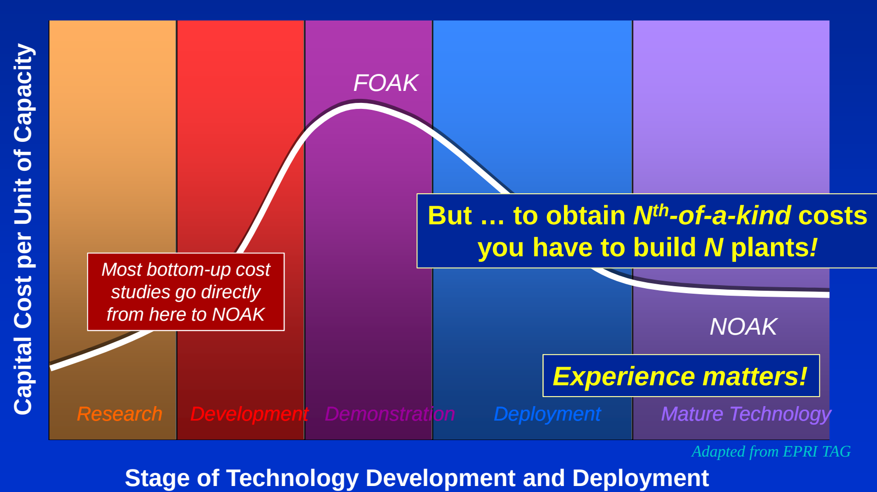
Most studies seek NOAK cost estimates while still at at early stages of development



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An Alternative Approach to Estimating NOAK Costs

- Use traditional "bottom-up" methods to estimate FOAK cost for an advanced technology based on its current state of development*
- Then use a "top-down" model based on learning curves to estimate future (NOAK) costs as a function of installed capacity (and other factors, if applicable)
- From this, estimate level of deployment needed to achieve an NOAK cost goal (e.g., an X% lower LCOE)

This approach explicitly links cost reductions to commercial experience

*as specified in current AACE/EPRI/NETL guidelines

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Projected Cost Reductions from a "Top-Down" Analysis

Learning curves applied to capacity projections from energy-economic modeling, 2001–2050*

Power Plant System	**Reduction in Cost of Electricity* ($/MWh)**	Reduction in Mitigation Cost* ($/t$CO_2$ avoided)
SCPC –CCS	**14% – 44%**	19% – 62%
NGCC –CCS	**12% – 40%**	13% – 60%
IGCC –CCS	**22% – 52%**	19% – 58%

* Ranges based on low and high global carbon price scenarios.

Source: van der Brock et al, 2010

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What does it take to achieve these cost reductions ?

Ingredients of Technology Innovations that Reduce Costs

- Sustained R&D
- Markets for the technology
- Learning from experience

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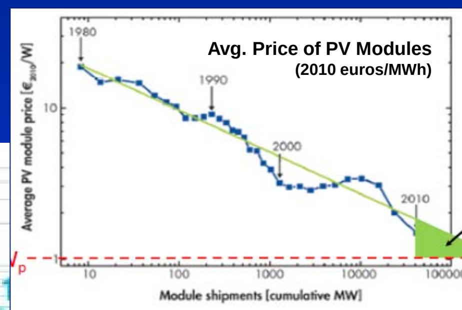
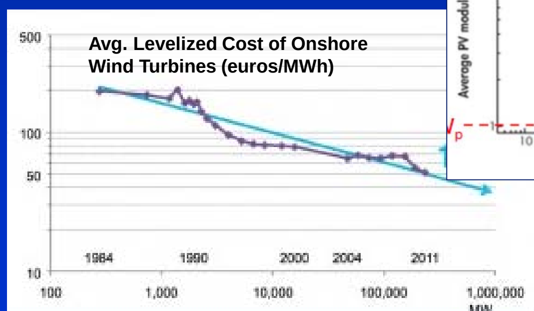
We've seen this work for other low-carbon energy technologies …

Deployment and cost reductions driven by government incentives and regulatory policies to promote renewable energy technologies



Source: Kleiburg, ECN, 2011



Source: Bloomberg New Energy Finance

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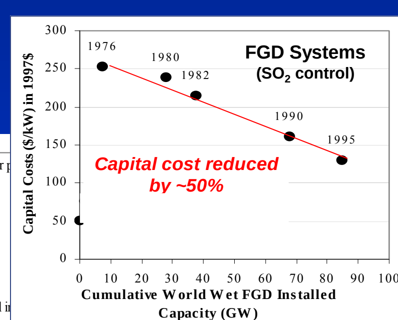
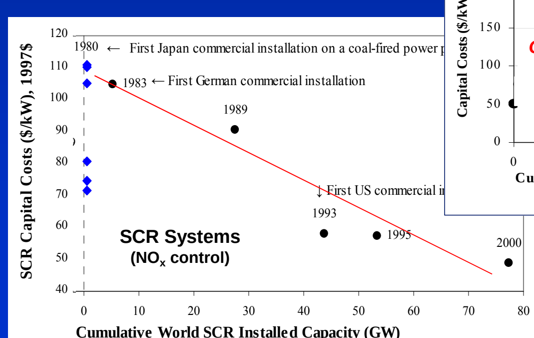
… and for post-combustion capture of power plant air pollutants

Deployment and cost reductions driven by government regulatory policies to reduce emissions of major air pollutants



Source: Rubin, et al. 2007



Could CCS follow a similar path?

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Key Barriers to CCS Deployment

- Policy
- Policy
- Policy

Without a policy requirement or strong incentive to reduce CO_2 emissions significantly there is no reason to deploy CCS widely

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Policy options that can foster CCS and technology innovation

"Technology Policy" Options			Regulatory Policy Options
Direct Gov't Funding of Knowledge Generation	**Direct or Indirect Support for Commercialization and Production**	**Knowledge Diffusion and Learning**	**Economy-wide, Sector-wide, or Technology- Specific Regs and Standards**
• R&D contracts with private firms (fully funded or cost-shared) • Intramural R&D in government laboratories • R&D contracts with consortia or collaborations	• R&D tax credits • Patents • Production subsidies or tax credit for firms bringing new technologies to market • Tax credits, rebates, or payments for purchasers/users of new technologies • Gov't procurement of new or advanced technologies • Demonstration projects • Loan guarantees • Monetary prizes	• Education and training • Codification and diffusion of technical knowledge (e.g., via interpretation and validation of R&D results; screening; support for databases) • Technical standards • Technology/Industry extension program • Publicity, persuasion and consumer information	• Emissions tax • Cap-and-trade program • Performance standards (for emission rates, efficiency, or other measures of performance) • Fuels tax • Portfolio standards

Source: NRC, 2010

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What is the Outlook for Improved Capture Technology?

- Sustained R&D is essential to achieve lower costs; but …
- Learning from experience with full-scale projects is especially critical.
- Strong policy drivers that <u>create</u> <u>markets</u> for CCS are needed to spur innovations that significantly reduce the cost of capture
- **WATCH THIS SPACE FOR UPDATES ON PROGRESS**

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Thank You

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