Evaluating the Cost of Emerging Technologies

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Presentation to the
CLIMIT Workshop on Emerging CO_2 Capture Technologies
Olso, Norway

January 26, 2016

Outline

- Defining “emerging technologies”
- Current cost evaluations for CO_2 capture
- Limitations of current costing methods
- A suggested path forward

Defining Emerging Technologies

- The technology is not yet deployed or available for purchase at a commercial scale
  - Current stage of development may range from concept to large pilot or demonstration project
- Process design details still preliminary or incomplete
- Process performance not yet validated at scale, or under a broad range of conditions
- May require new components and/or materials that are not yet manufactured or used at a commercial scale

Many terms are used to describe new technologies sought for CO_2 capture

- Advanced
- Breakthrough
- Emerging
- Game-changing
- Improved
- Leap-frog
- Next-generation
- Novel
- Radical
- Step-out
- Transformational

Two Principal Goals of Emerging Capture Technology

- Improvements in performance
  - Lower energy penalty
  - Higher capture efficiency
  - Increased reliability
  - Reduced life cycle impacts
- Reductions in cost
  - Capital cost
  - Cost of electricity
  - Cost of CO_2 avoided
  - Cost of CO_2 captured

Most goals focus on reducing cost

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, 2012

Ten Ways to Reduce CCS Cost

(inspired by D. Letterman)

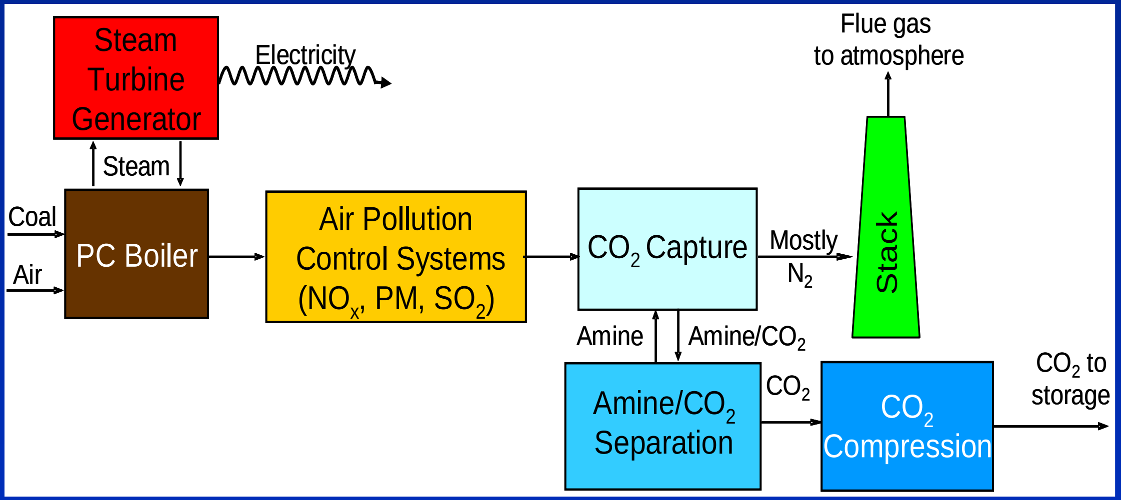
10. Assume high power plant efficiency
9. Assume high-quality fuel properties
8. Assume low fuel price
7. Assume EOR credits for CO_2 storage
6. Omit certain capital costs
5. Report $/ton CO_2 based on short tons
4. Assume long plant lifetime
3. Assume low interest rate (discount rate)
2. Assume high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

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

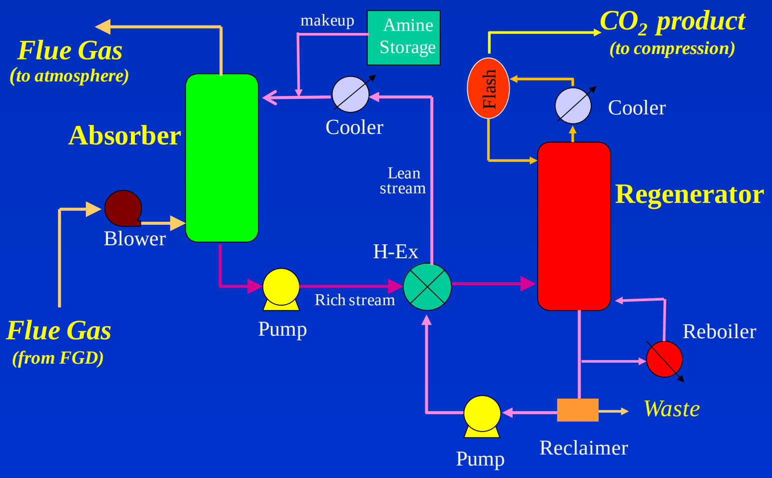
Current methods of cost evaluation

Specify a "baseline" system using current capture technology

Post-Combustion Capture at a Coal-Fired Power Plant



Details of amine capture system



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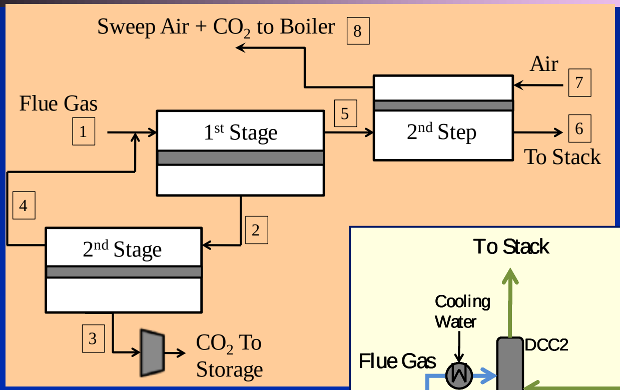
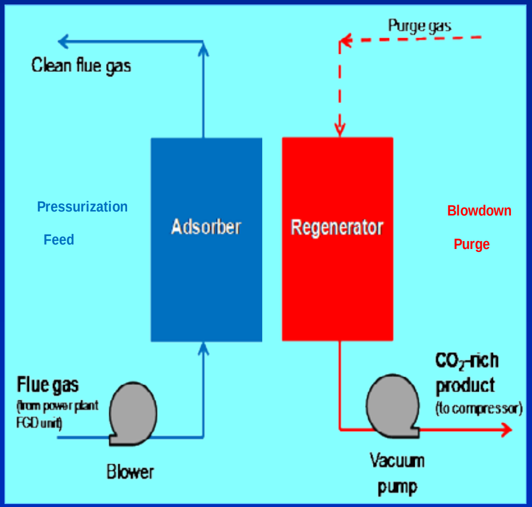
Specify design and performance of the emerging capture technology

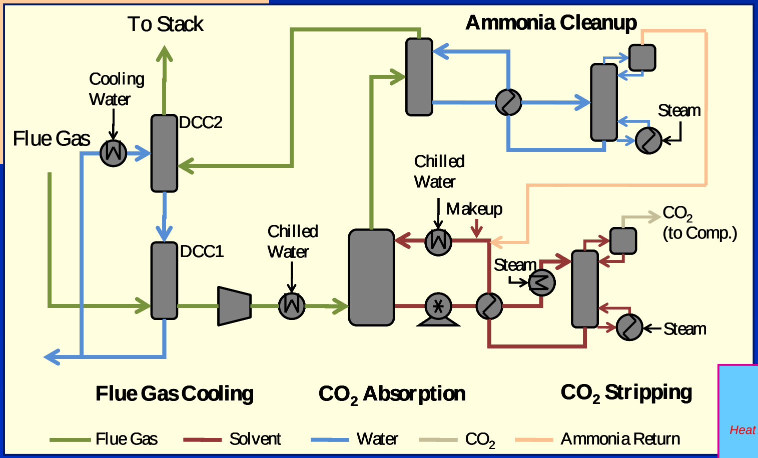


Polymer membranes

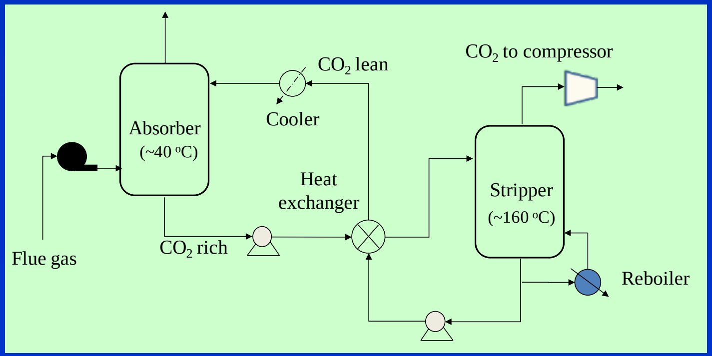
MOFs & other solid sorbents



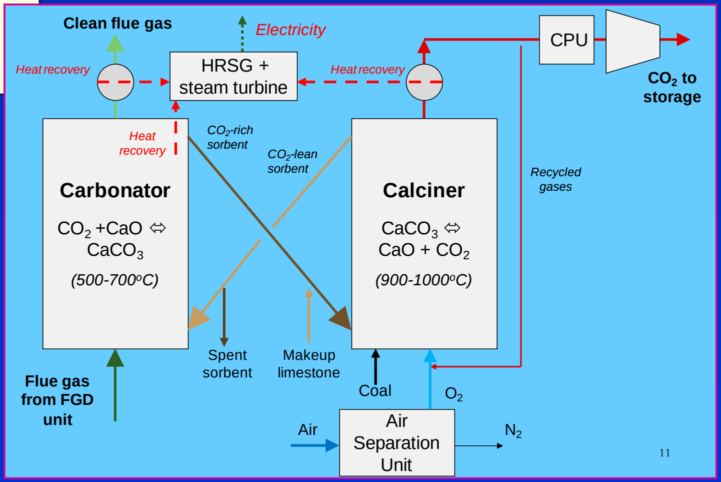
Chilled ammonia



Ionic liquids



Calcium looping



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Compare systems using a "bottom-up" costing method

Different organizations employ slightly different costing methods

A standardized costing method is now available

Items to be included in a power plant or capture technology cost estimate

Recommended nomenclature for power plant capital cost estimates.

Capital cost element to be quantified	Sum of all preceding items is called:
Process equipment Supporting facilities Labor (direct and indirect)	
	Bare Erected Cost (BEC)
Engineering services	
	Engineering, Procurement & Construction (EPC) Cost
Contingencies: Process Project	
	Total Plant Cost (TPC)
Owner's costs: Feasibility studies Surveys Land Insurance Permitting Finance transaction costs Pre-paid royalties Initial catalyst and chemicals Inventory capital Pre-production (startup) Other site-specific items unique to the project (such as unusual site improvements, transmission interconnects beyond busbar, economic development incentives, etc.)	
	Total Overnight Cost (TOC)
Interest during construction (IDC) Cost escalations during construction	
	Total Capital Requirement (TCR)

Recommended nomenclature for power plant O&M costs.

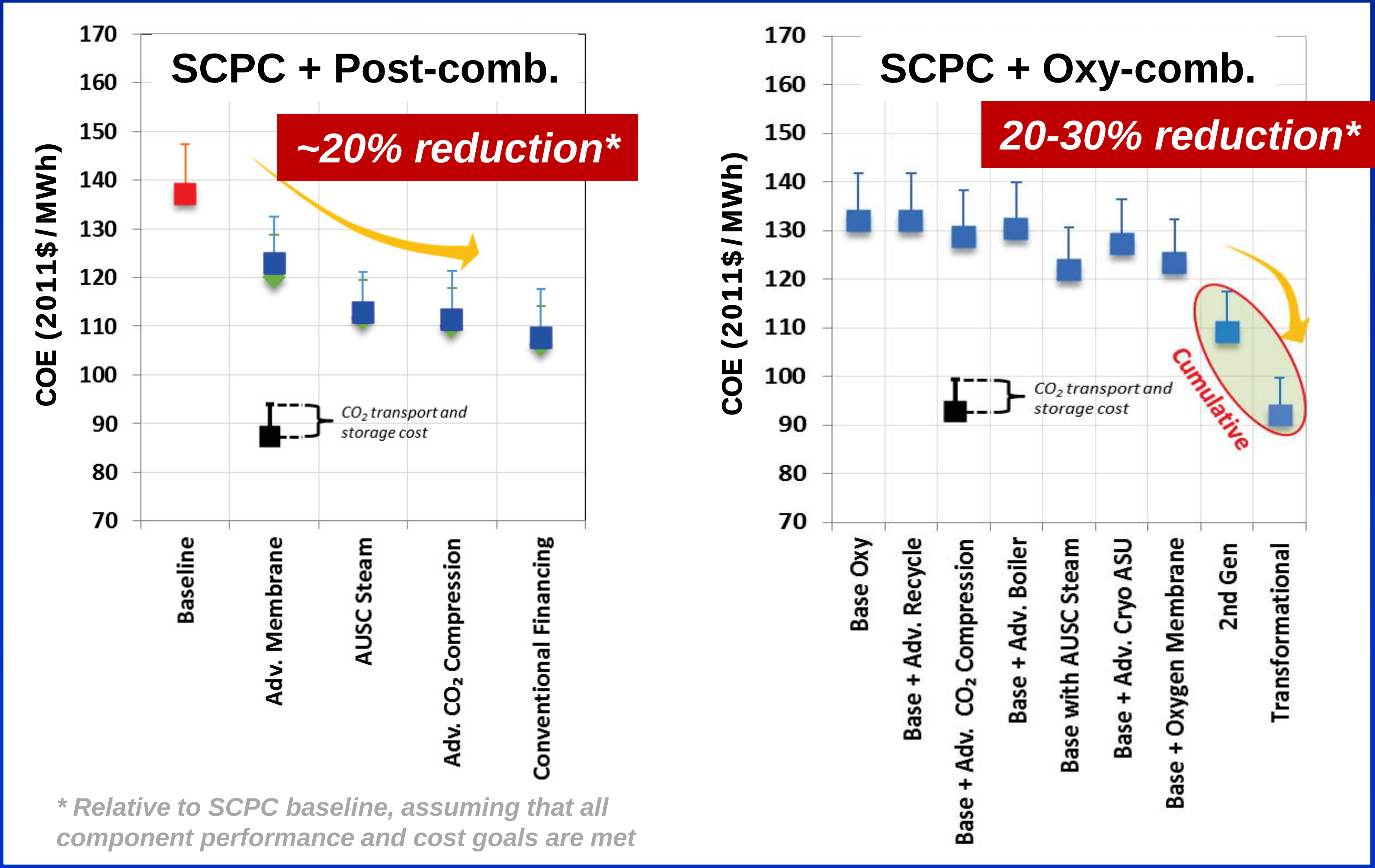
Operating and maintenance cost item to be quantified	Sum of preceding ite
Operating labor Maintenance labor Administrative and support labor Maintenance materials Property taxes Insurance	
	Fixed O&M Costs
Fuel Other consumables, e.g.: Catalysts Chemicals Auxiliary fuels Water Waste disposal (excl. CO_2) CO_2 transport CO_2 storage Byproduct sales (credit) Emissions tax (or credit)	
	Variable O&M Costs

Source: Rubin et al., IJGGC, 2013

Studies of emerging technologies typically seek "Nth-of-a-kind" (NOAK) costs

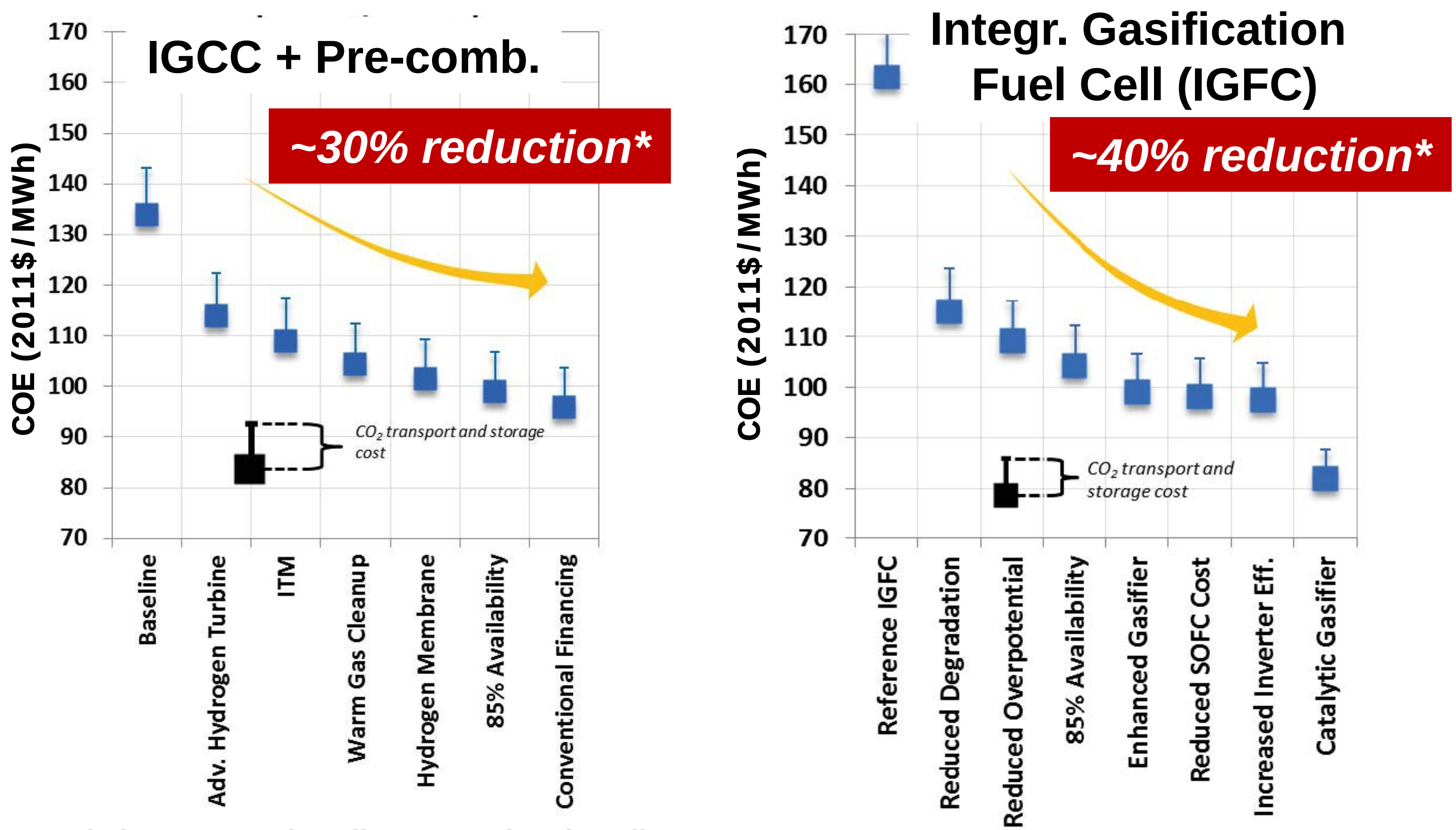
- Capital cost items are estimated assuming a mature technology
- Operating and maintenance costs assume reliable process operation at design conditions
- Plant financing may or may not include a risk premium for a new technology

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)*



** Relative to SCPC baseline, assuming that all component performance and cost goals are met*

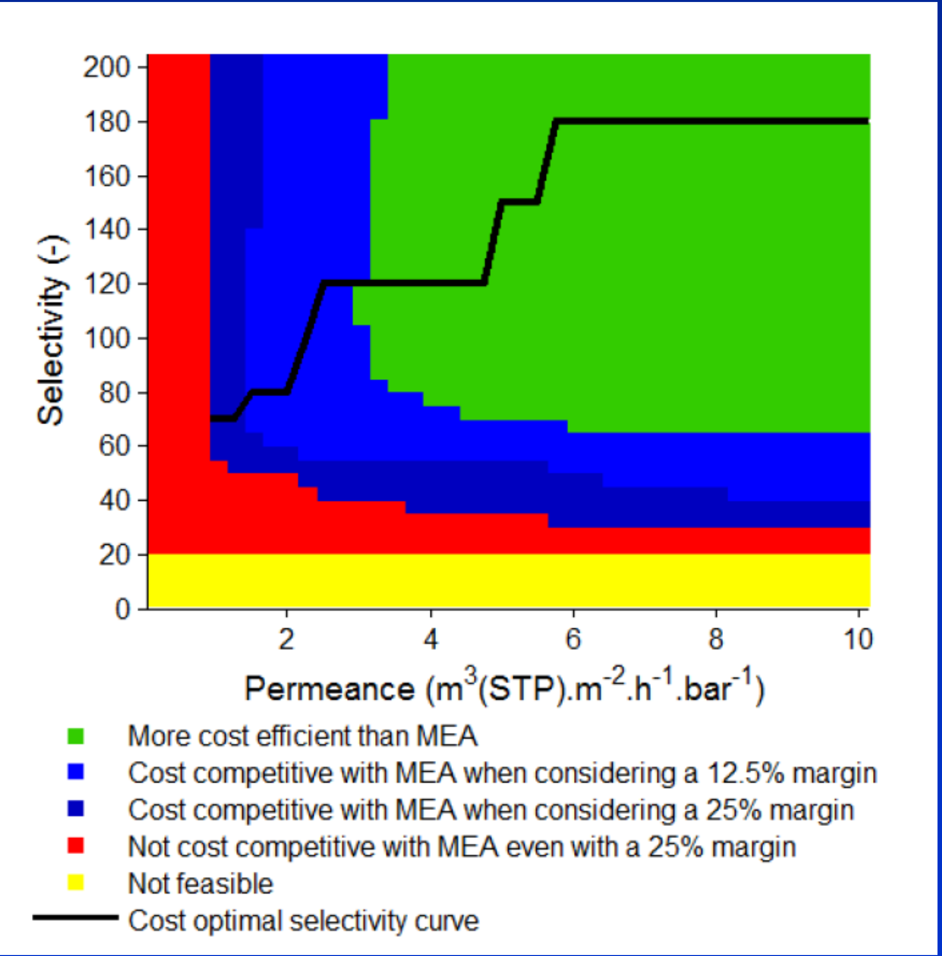
Source: Gerdes et al, NETL, 2014

What do we learn from this type of analysis?

- Quantify potential cost reductions if R&D goals are met for each technology component
- Contribution of each component to total cost
- Cost implications of various “what if” specifications of process performance and/or cost parameters
- R&D goals needed to achieve a desired cost for the overall system (or plant component)

Example of a “What If” Analysis

Impact of membrane properties required for competitive membrane-based capture assuming mature technology and membrane cost of $50/m^2$



Source: Roussanaly et al,, 2015

What we do *not* learn from bottom-up cost studies

- Likelihood of achieving performance and/or cost goals
- Time or experience needed to achieve cost reductions of different magnitude
- Expected N^{th}-of-a-kind cost of a full-scale system

These factors weigh heavily in the selection and support of new or proposed technologies

Limitations of Current Costing Method

- Bottom-up costing methods are not well-suited for estimating the future cost of emerging technologies that are still far from commercialization
- Bottom-up methods serve mainly to estimate the current cost of a commercial installation based on current information
- Applications to emerging technologies typically ignore established guidelines, especially for process and project contingency costs (which constitute a significant portion of the total capital requirement)

DOE/EPRI Guidelines for Process Contingency Cost

- "Factor applied to new technology … to quantify the uncertainty in the technical performance and cost of the commercial-scale equipment" based on the current state of technology. *- EPRI TAG*

Current Technology Status	Process Contingency Cost (% of associated process capital)
New concept with limited data	40+
Concept with bench-scale data	30-70
Small pilot plant data	20-35
Full-sized modules have been operated	5-20
Process is used commercially	0-10

Source: EPRI, 1993; AACE, 2011; NETL, 2011

Cost estimates for emerging technologies typically assume process contingency values for mature commercial technology

This is an incorrect specification of process contingency

DOE/EPRI Guidelines for Project Contingency Cost

- "Factor covering the cost of additional equipment or other costs that would result from a more detailed design of a definitive project at an actual site." *- EPRI TAG*

EPRI Cost Classification	Design Effort	Project Contingency (% of total process capital, eng'g. &home office fees, and process contingency)
Class I (~AACE Class 5/4)	Simplified	30–50
Class II (~AACE Class 3)	Preliminary	15–30
Class III (~ AACE Class 3/2)	Detailed	10–20
Class IV (~AACE Class 1)	Finalized	5–10

Source: EPRI, 1993

Many Class I-III studies assume ≤10%

Contingency Costs Assumptions for Emerging Capture Technologies

Parameter	Typical Assumption	Guideline Value*	Capital Cost Increase
Process Contingency (%TPC)	10%	~40%	***30%***
Project Contingency (%TPC)	10%	~30%	***20%***
TOTAL Contingency (%TPC)	**20%**	**~70%**	***50%***

*Based on proposed designs for membrane, solid sorbents, and other post-combustion processes with limited data.

Total contingency costs are significantly under-estimated in most capture technology cost studies.

For emerging technologies, cost guidelines applied to full-scale plants effectively represent FOAK cost estimates.

Illustrative Case Study Cost Results:
NOAK vs. FOAK assumptions for an emerging process

New coal-fired plant with net capacity of ~1000 MW

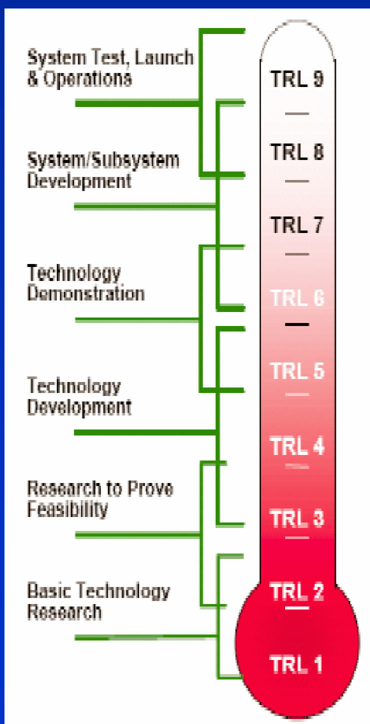
Parameter	Typical assumptions	Revised assumptions (FOAK)
Capture system capital reqm't. ($/$kW_{net}$)	3,089	4,088
Total plant capital cost ($/$kW_{net}$)	4,231	5,374
Levelized cost of electricity ($/MWh)	103	141
Cost of CO_2 avoided ($/tonne)	56	105
Cost of CO_2 captured ($/tonne)	44	83

*All costs in constant 2012 US dollars; FOAK costs include higher contingency and financing costs.

How can we do better ?

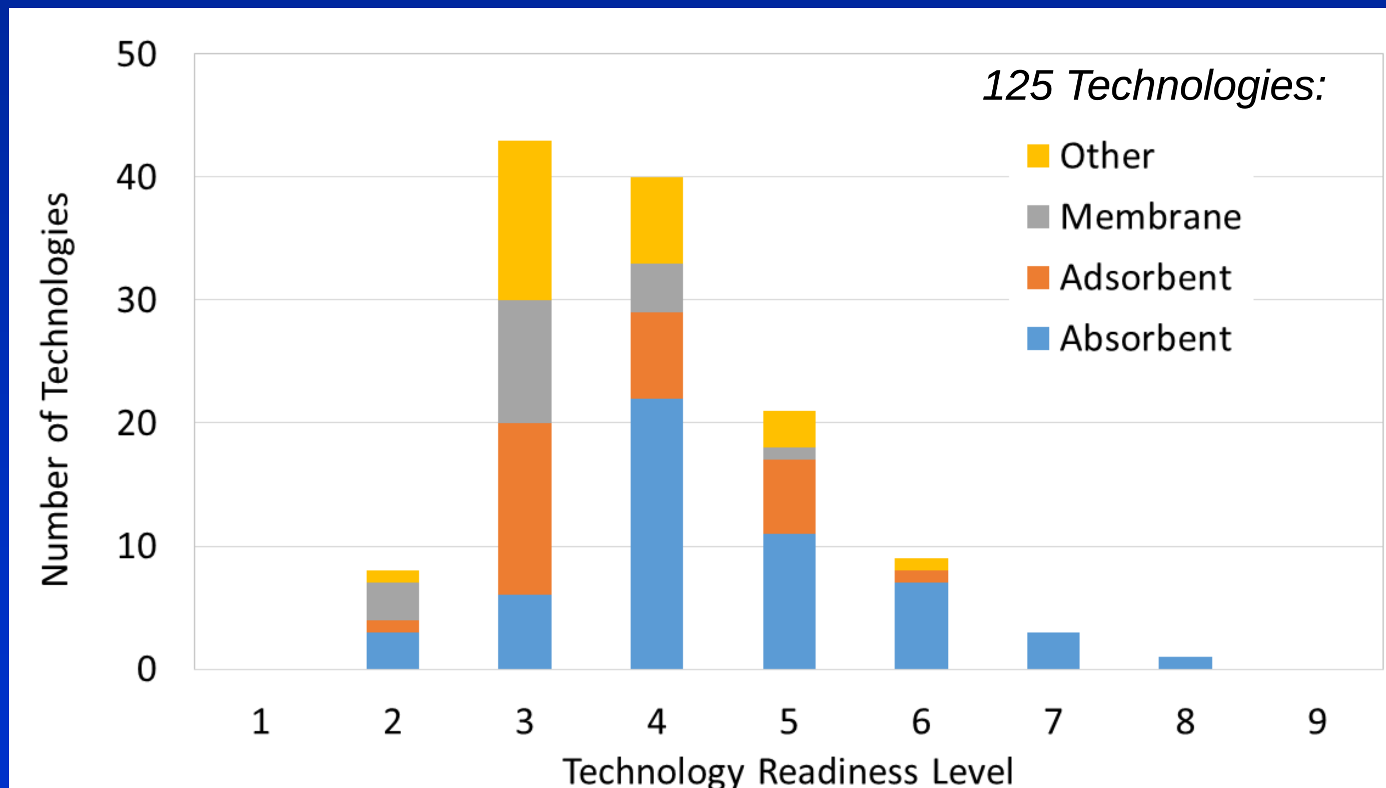
Most New Capture Concepts Are Still Far from Commercial

Technology Readiness Levels



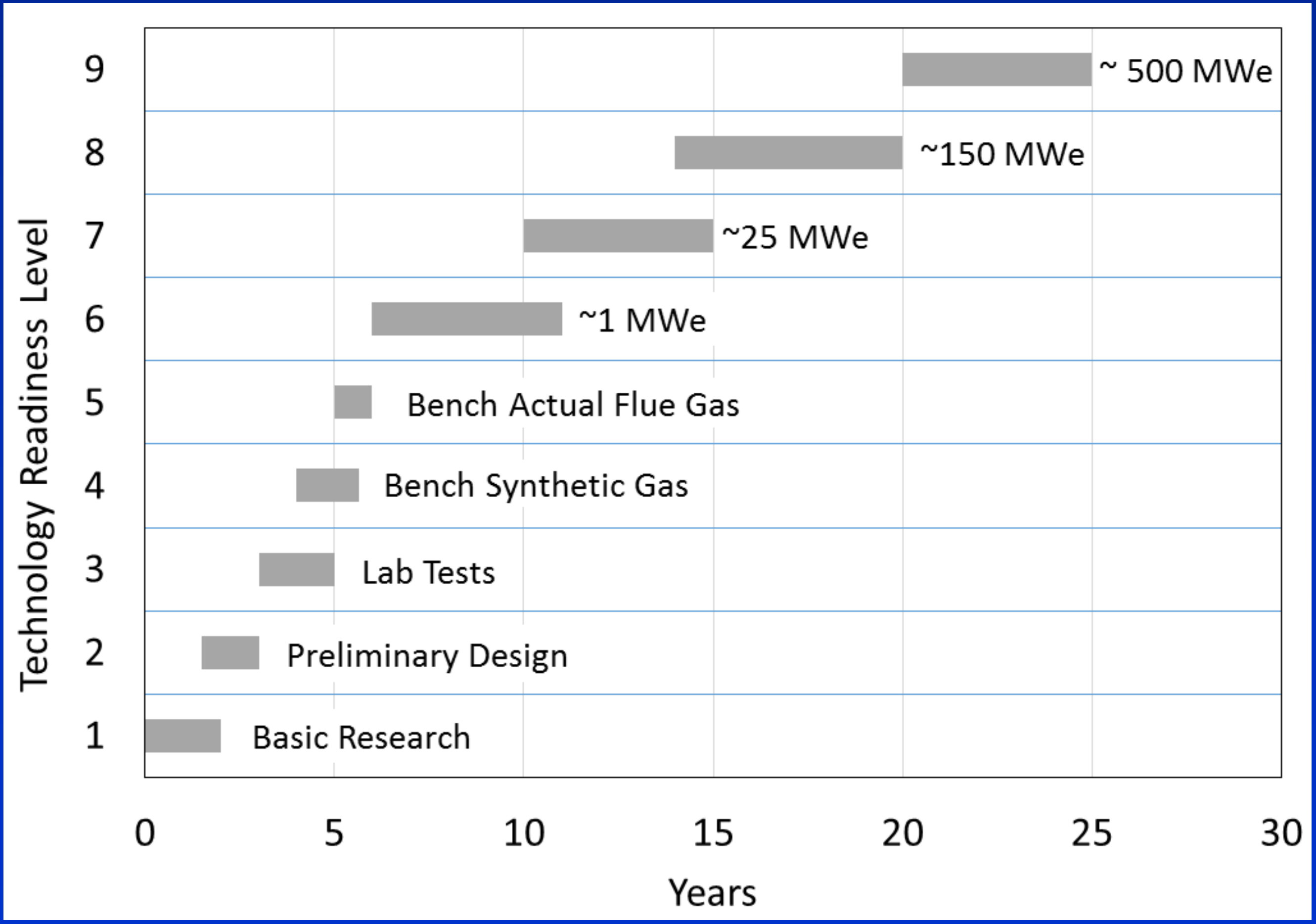
Source: NASA, 2009

Post-Combustion Capture



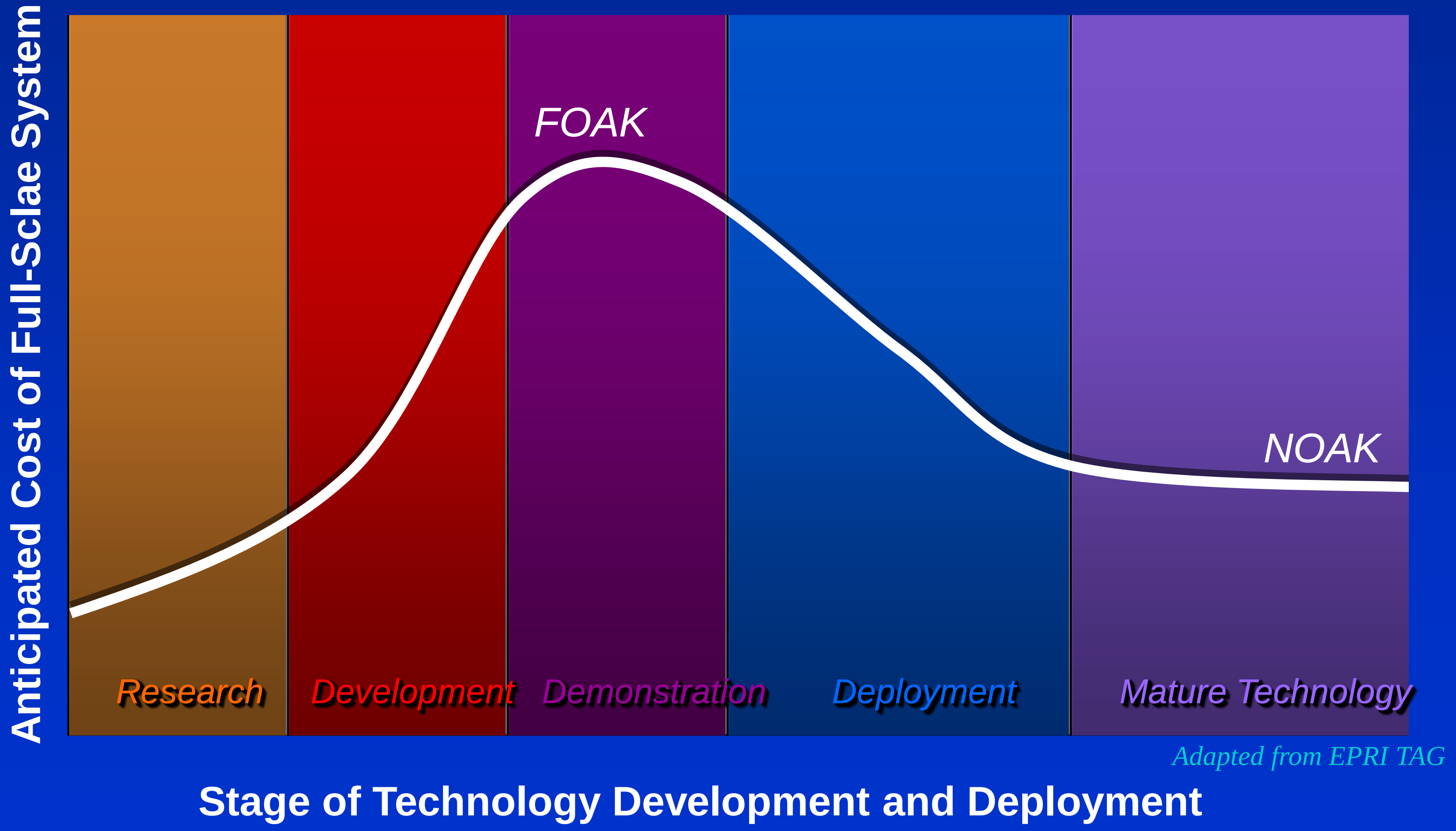
Source: Bhown, EPRI, 2014

Technology Scale-Up Takes Time (and Money)



Source: Bhown, EPRI, 2014

Typical Trend of Cost Estimates for a New Technology



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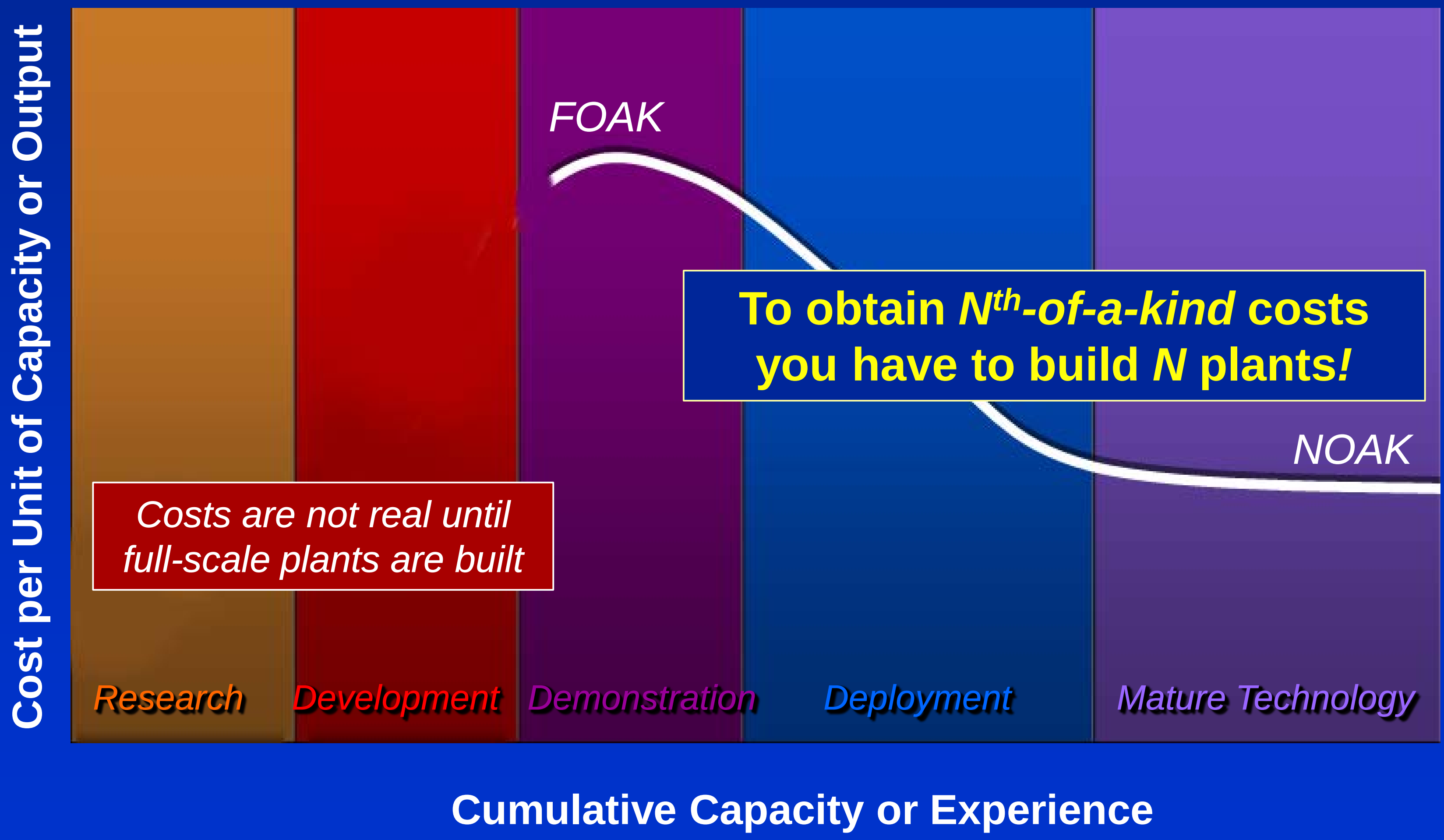
Typical Trend of Actual Cost for a New Technology



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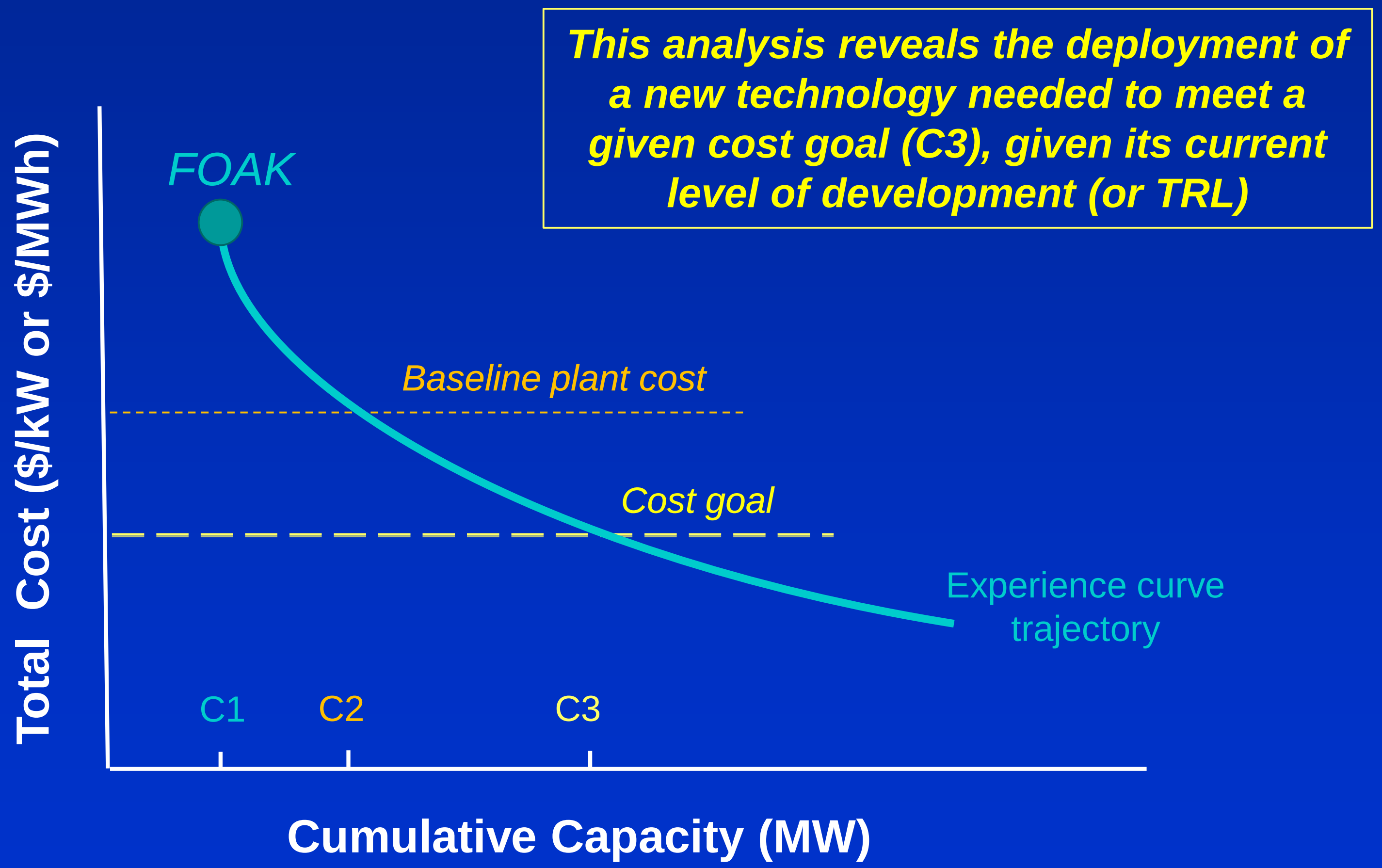
A Suggested Approach to Estimating NOAK Costs

- Use traditional "bottom-up" methods to estimate FOAK cost of an emerging 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)

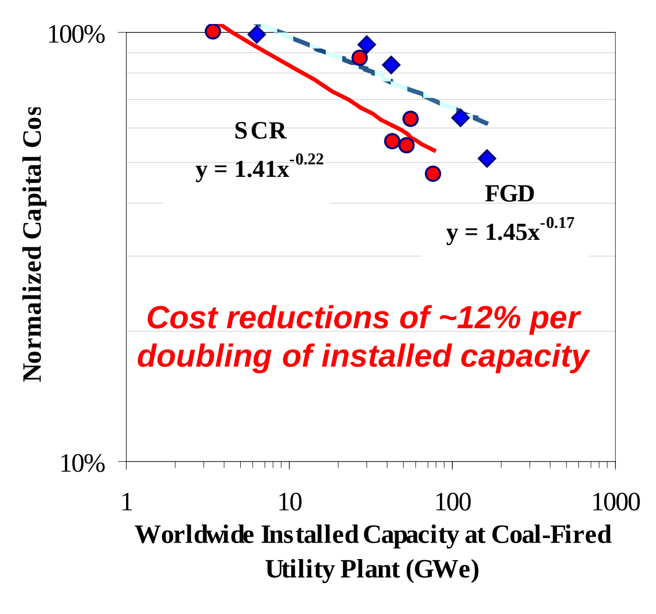
This approach explicitly links cost reductions to commercial experience

*as specified in current AACE/EPRI/NETL guidelines

Illustrative Example



Historical learning rates are available for a variety of relevant technologies



Source: Rubin, et al., 2007

One-factor learning (experience) curves are the most prevalent, of the form: $C_i = a\,x_i^{-b}$

Technology and energy source	No. of studies with one factor[a]	No. of studies with two factors	One-factor models[b] Range of learning rates	Mean LR
Coal				
PC	4	0	5.6% to 12%	8.3%
PC+CCS[d]	*2*	*0*	*1.1% to 9.9%*[d]	
IGCC[d]	*2*	*0*	*2.5% to 16%*[d]	
IGCC+CCS[d]	*2*	*0*	*2.5% to 20%*[d]	
Natural Gas				
NGCC	5	1	–11% to 34%	14%
Gas Turbine	11	0	10% to 22%	15%
NGCC+CCS[d]	*1*	*0*	*2% to 7%*[d]	
Nuclear	4	0	negative to 6%	-
Wind				
Onshore	12	6	–11% to 32%	12%
Offshore	2	1	5% to 19%	12%
Solar PV	14	3	10% to 47%	22%
Biomass				
Power generation[e]	2	0	0% to 24%	11%
Biomass production	3	0	20% to 45%	32%
Geothermal[f]	0	0	-	-
Hydroelectric	1	1	1.4%	1.4%

Source: Rubin, et al., 2015

Additional Ways to Improve Cost Estimates
(for discussion another day)

Seven steps to improve cost estimates for emerging CO_2 capture technologies:

1. Use non-economic metrics for earliest-stage technologies
2. When costing a technology define the full system
3. Use standard costing methods
4. Quantify cost elements appropriately
5. Use learning curves when estimating NOAK costs
6. Characterize and quantify uncertainties
7. Report cost metrics that are useful and unambiguous

What is the Outlook for Lower-Cost 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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