# Seven Simple Steps to Improve Cost Estimates for Advanced Carbon Capture Technologies

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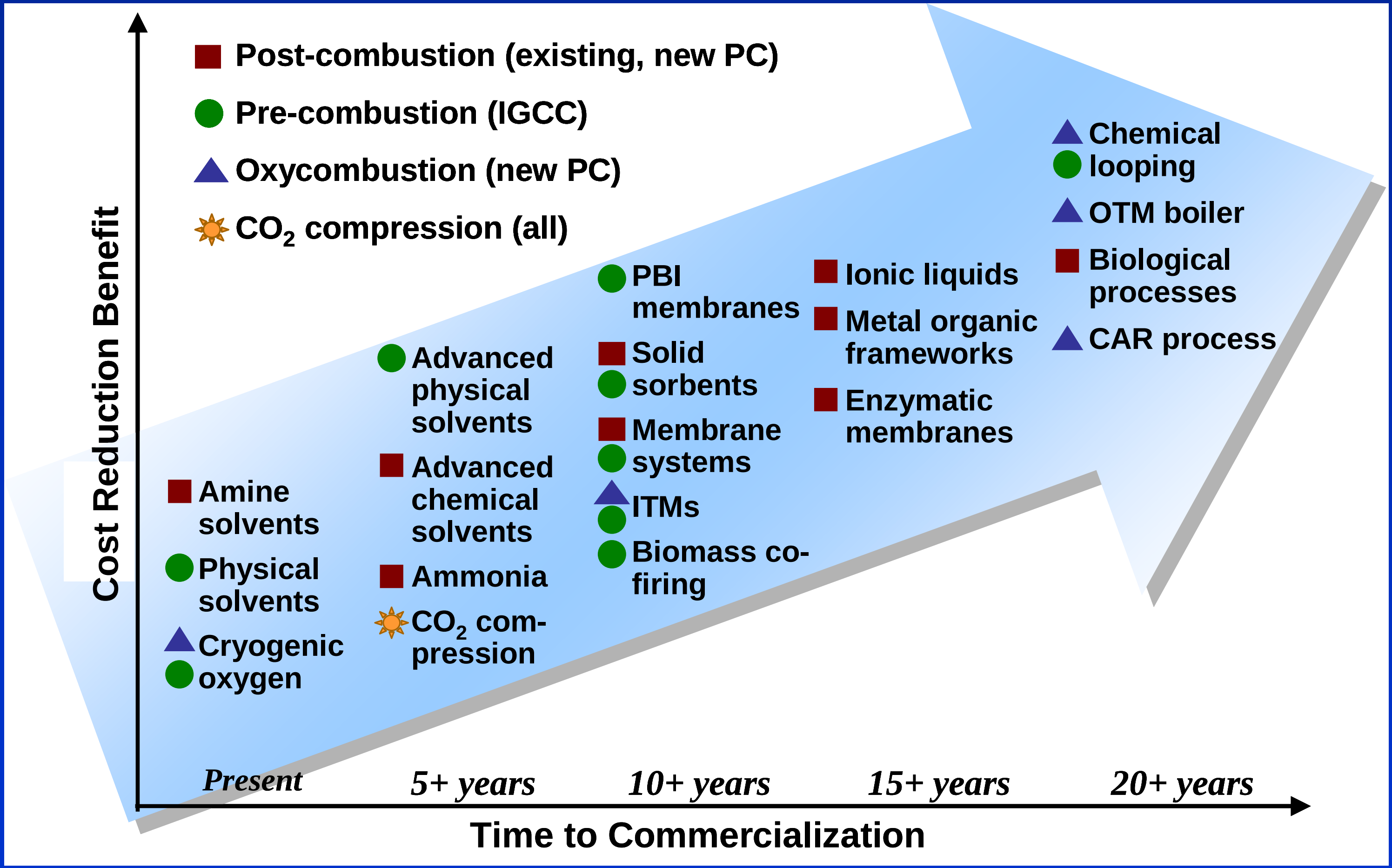
# Here, “Advanced Carbon Capture Technology” Means …

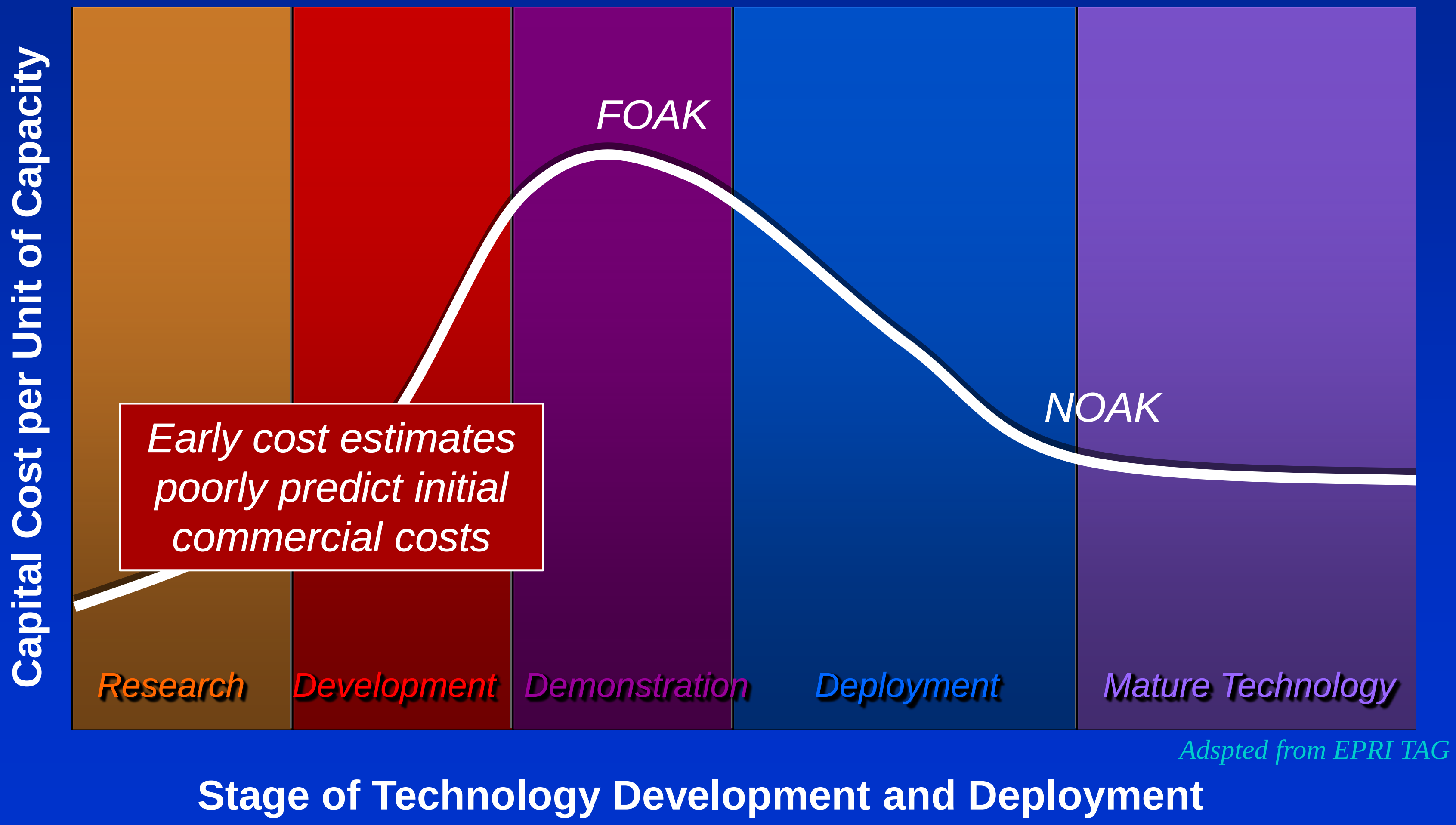
- Any technology that is not yet deployed or available for purchase at a commercial scale
  - Current stage of development may range from concept to large pilot or demonstration project
- Process design details still preliminary or incomplete
- Process performance not yet validated at scale, or under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

# Examples of Advanced Technologies: Everything beyond *Present*




Source: USDOE, 2010

# Typical Cost Trend of a New Technology

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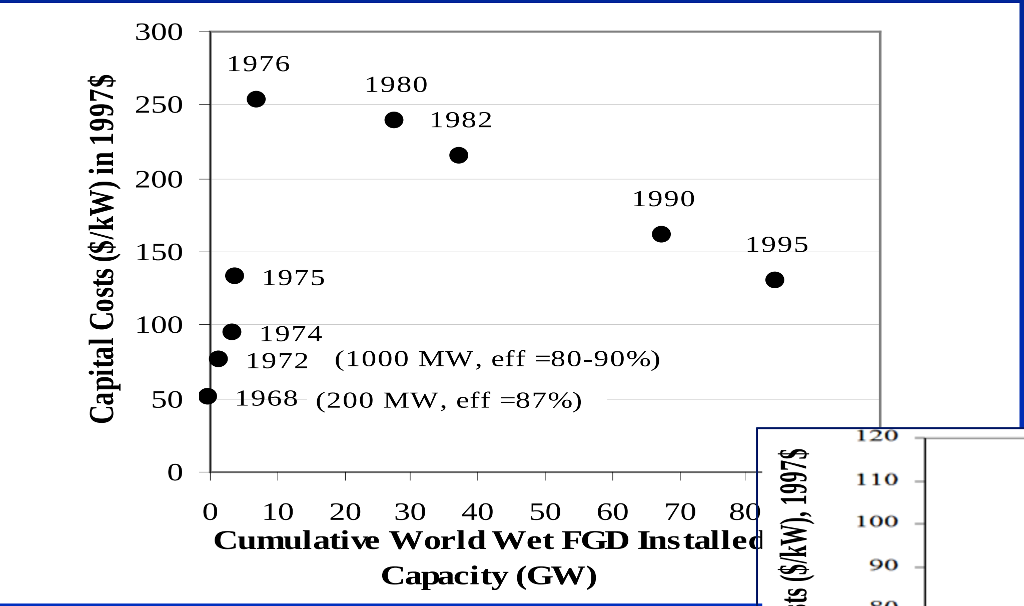
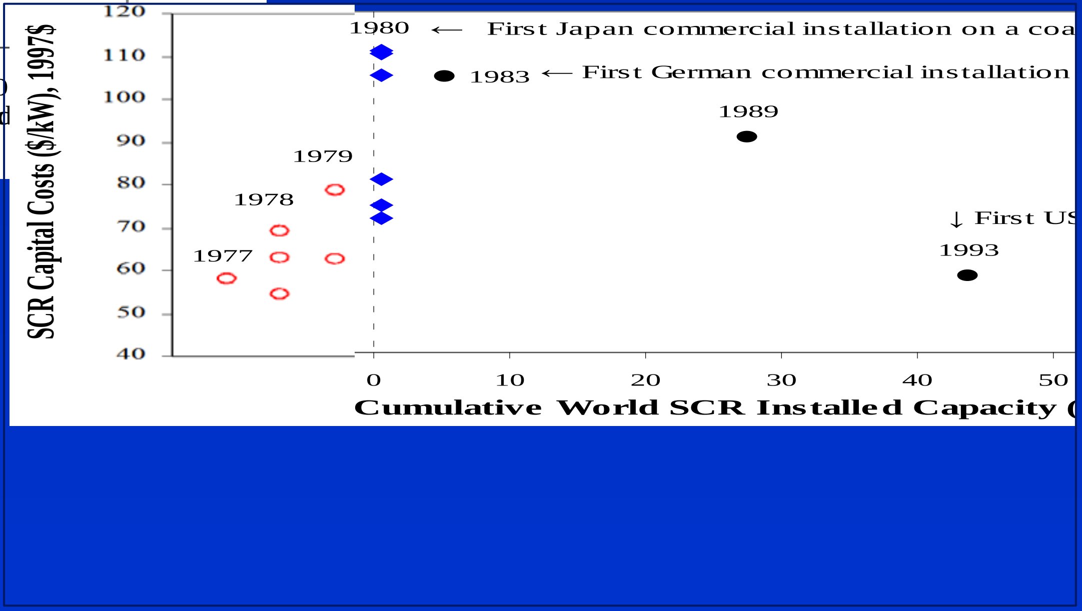
# Historical cost of $SO_2$ and $NO_x$ controls follow trend shown in previous slide




*Source: Rubin et al. 2007*

Capital Cost of Power Plant Flue Gas Desulfurization (FGD) and Selective Catalytic Reduction (SCR) Technologies



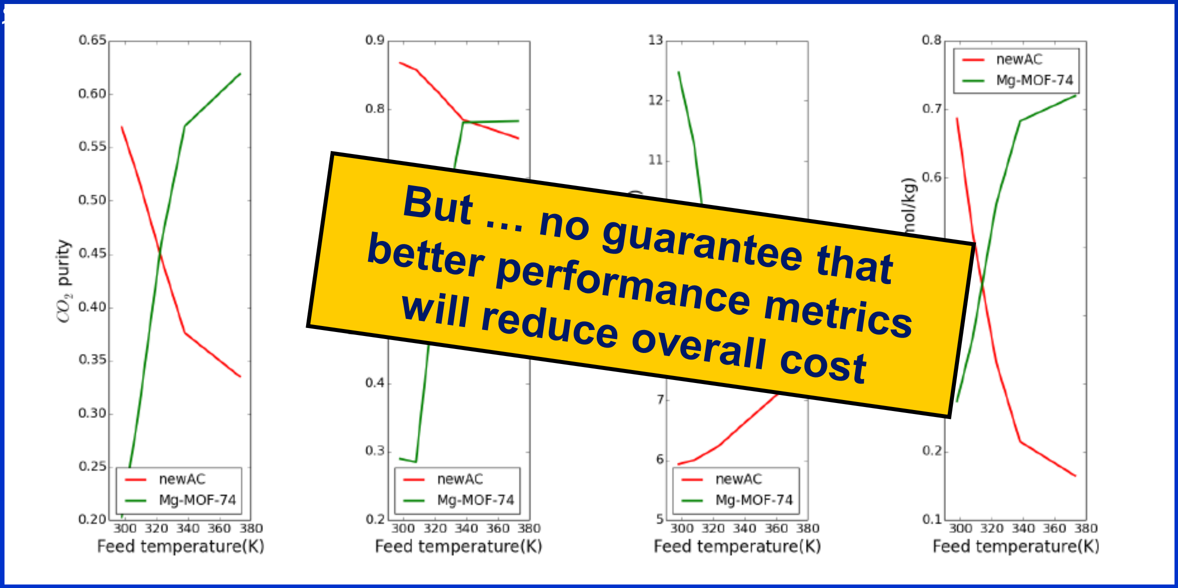

All costs based on a standardized 500 MW coal-fired power plant (except where noted)

*How can we do a better job of costing advanced technologies ?*

# *Step 1*

# Avoid Cost Estimates at the Earliest Stages of Development

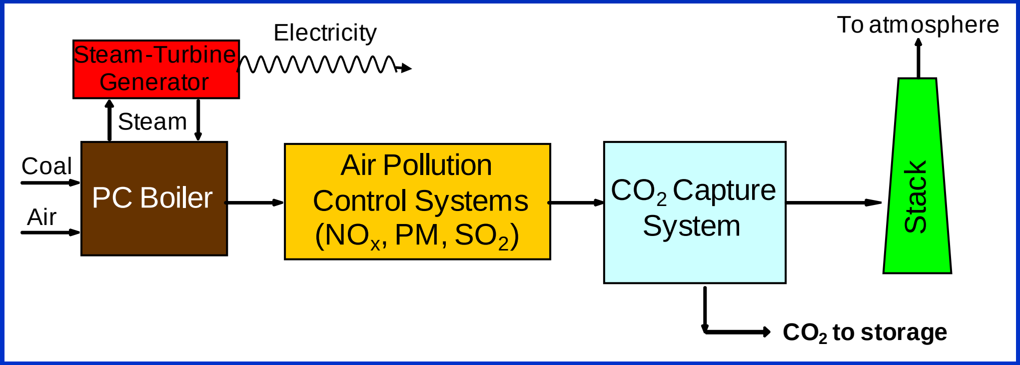
- Don't ask about cost for new capture technologies or process concepts.  Instead ….
- Use performance metrics and other non-economic criteria to evaluate and screen novel materials, components and early-stage concepts (low TRLs), e.g.,



# *Step 2*

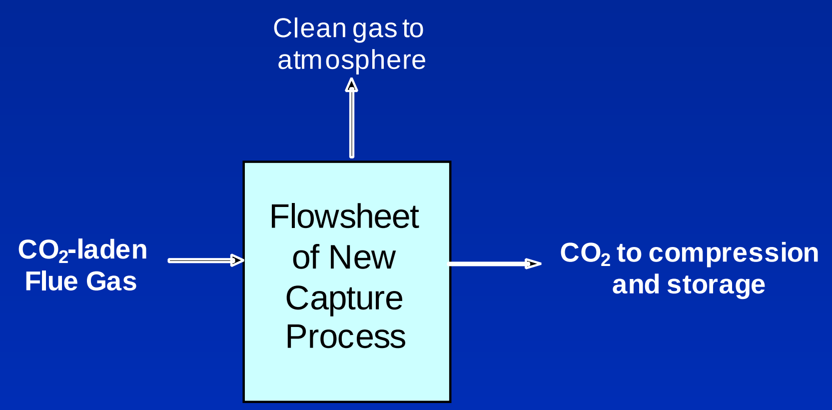
# When a cost estimate is needed, define the full system involved

- The cost of power plant carbon capture is correctly calculated as the difference in cost between similar plants with and without the capture technology
- Care must be taken to include all relevant plant components within the system boundary (battery limits) analyzed

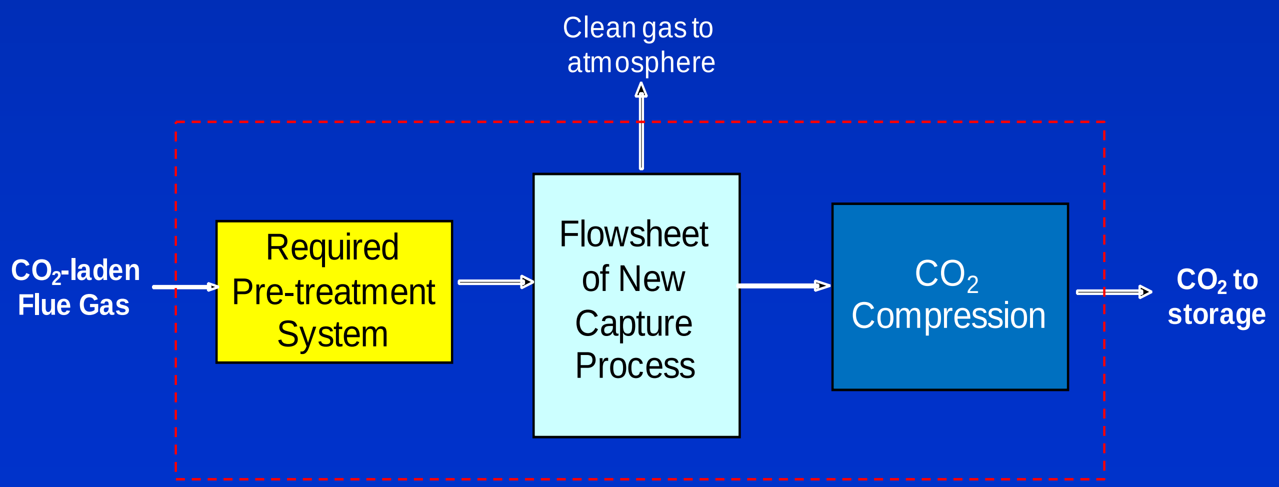


# Capture system boundaries should include all components needed

*For example, some studies report cost for only the “bare” capture process*




*… ignoring other components that are also needed*



# *Step 3*

# Use Proper Costing Method

Different organizations have used different costing methods, but …


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 items |
|---|---|
| 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*

# *Step 4*

# Use Appropriate Values of Cost Elements to Estimate Full-Scale Cost

- The value of many cost elements in the preceding lists depends upon the technical maturity of the process; thus, use of an appropriate value is especially important for processes at early stages of development
- This is particularly true for Process and Project Contingency Costs, which constitute a significant fraction of the total capital requirement of a project
- Currently, most cost estimates for advanced carbon capture processes ignore established guidelines for process and project contingency costs

# EPRI/DOE/AACE 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 <u>current</u> 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*

Most advanced capture system cost estimates assume ***much smaller*** process contingencies than guidelines require (e.g., zero to <20%)

# EPRI/DOE/AACE 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/DOE Class 5/4) | Simplified | 30–50 |
| Class II (~AACE/DOE Class 3) | Preliminary | 15–30 |
| Class III (~ AACE/DOE Class 3/2) | Detailed | 10–20 |
| Class IV (~AACE/DOE Class 1) | Finalized | 5–10 |

*Source: EPRI, 1993*

Many Class I-III studies assume ≤10%

# Contingency Costs Assumptions for Advanced Capture Technology

| 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.

***The total contingency cost for advanced capture processes is significantly under-estimated in most cost studies, leading to systematically low capital cost estimates relative to guidelines***

# *Step 5*

# Use Learning Curves to get NOAK Costs
## (Supplemented by Conventional Bottom-Up Analysis)

- Cost studies of advanced technologies often assume cost parameters for a mature ($N^{th}$-of-a-kind) plant in a bottom-up analysis to show potential benefits of a new technology
- But research on technology innovation shows that “learning by doing” is needed to achieving cost reductions
- So to realize $N^{th}$-of-a-kind costs you have to build *N* plants
- Historical learning (experience) curves can provide an empirical estimate of expected cost reductions relative to FOAK costs as a function of technology deployment
- They can be used together with bottom-up analyses to estimate the deployment needed to achieve $N^{th}$-plant costs

# One-Factor Learning (Experience) Curves are the Most Prevalent

<u>Model equation</u>: $C_i = a\, x_i^{-b}$

where,

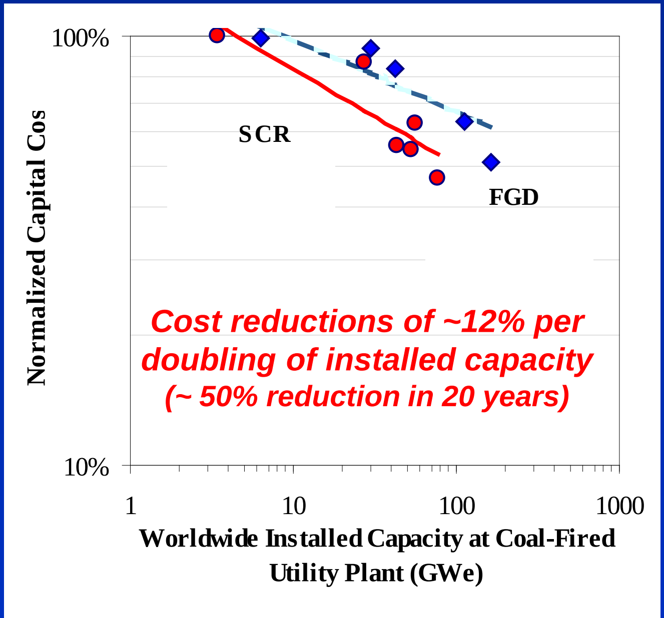
$C_i$ = cost to produce the *i* th unit

$x_i$ = cumulative capacity thru period *i*

b = learning rate exponent

a = coefficient (constant)

*Fractional cost reduction for a doubling of cumulative capacity (or production) is defined as the learning rate: $LR = 1 - 2^b$*




- Most appropriate for projecting future cost of a technology that is already commercially deployed
- Application to advanced (pre-commercial) processes requires careful consideration of the "starting point" (cost and experience base) for future cost reductions

## *Step 6*

# Characterize and Quantify Uncertainty in Key Performance and Cost Metrics

A variety of methods are available for characterizing and quantifying uncertainty, including:

- Overall accuracy estimates
- Sensitivity analysis
- Probabilistic estimates ( based on models, data and/or expert elicitations)

***Quantification of uncertainties can improve cost estimates by identifying risks as well as opportunities***

# Overall Accuracy for Conventional Costing Methods

Cost Accuracy (as a %of nominal cost)

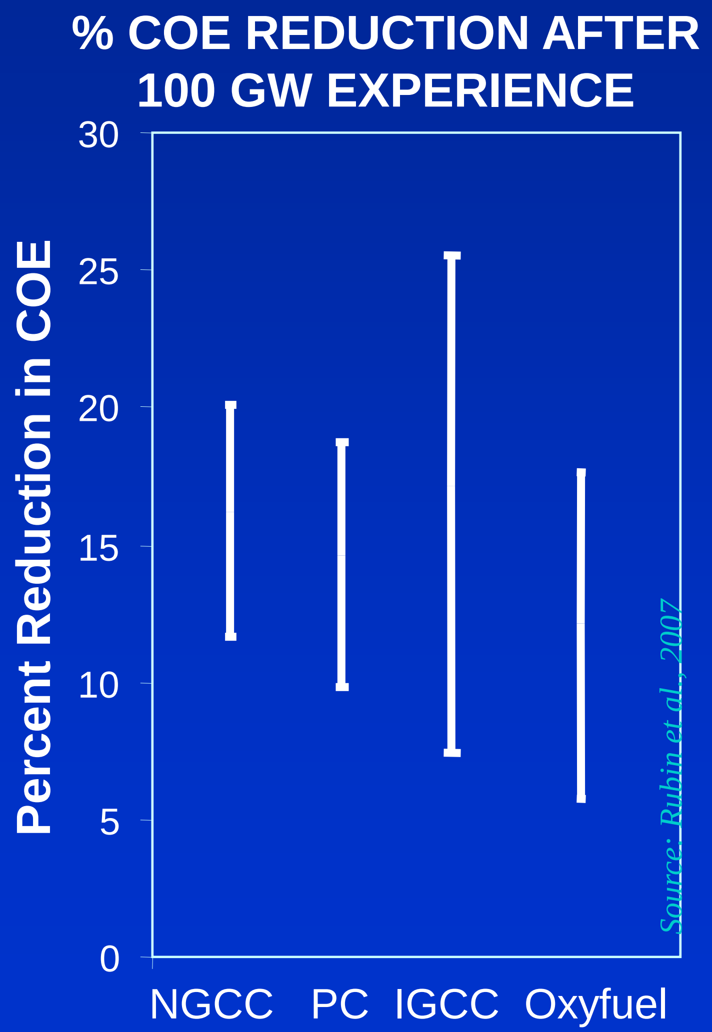
| Estimate Rating[b] | | Technology Development Rating[b] | | | | |
|---|---|---|---|---|---|---|
| | | A | B | C | D | E and F |
| | | Mature | Commercial | Demo | Pilot | Lab and Idea |
| A. | Actual | 0 | – | – | | – |
| B. | Detailed | -5 to +8 | -10 to +15 | -15 to +25 | – | – |
| C. | Preliminary | -10 to +15 | -15 to +20 | -20 to +25 | -25 to +40 | -30 to +60 |
| D. | Simplified | -15 to +20 | -20 to +30 | -25 to +40 | -30 to +50 | -30 to +200 |

*Source: AACE and EPRI*

*Costs for advanced processes are more likely to exceed the nominal costs*

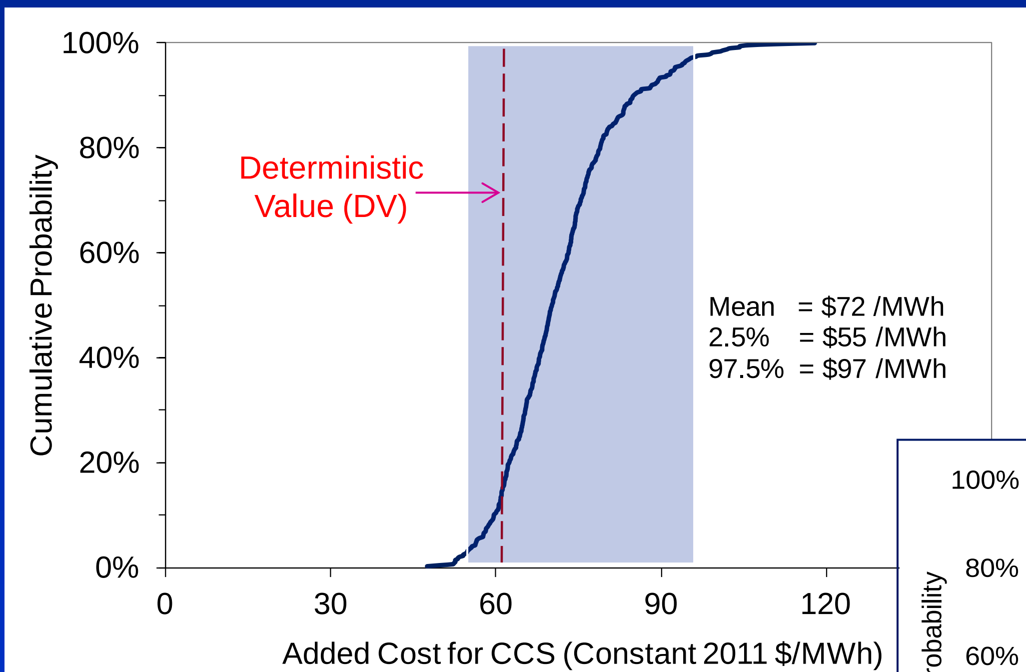
# Uncertainty in Learning Curve Estimates of Future Cost Reduction for Plants w/ CCS

- Experience curves used to project pathway from FOAK to NOAK costs for advanced technologies
- Error bars show range of projected cost reduction based on uncertainty in key model parameters for each technology



# Probabilistic Case Study Results:

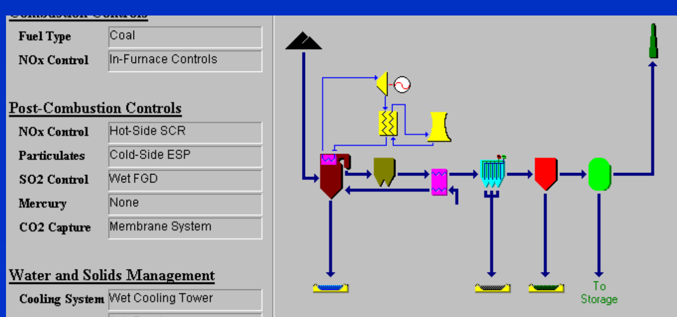
## SCPC-CCS (550 $MW_{net}$) w/ 2-Stage Membrane Capture System

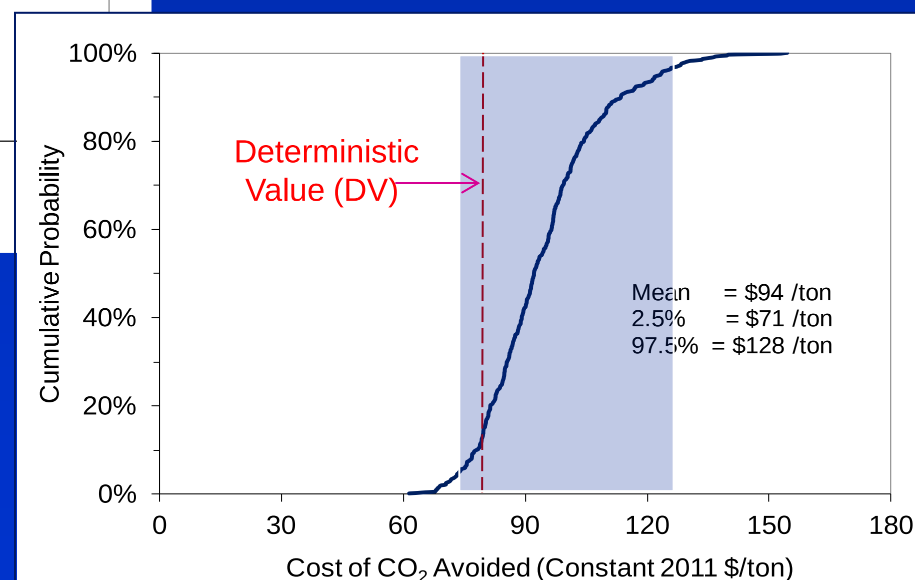



**95% CONFIDENCE INTERVALS=**

Added COE:
DV +31/-6 $/MWh **(+51%/ -10%)**

$CO_2$ Avoidance Cost:
DV +49/-8 $/ton= **(+62%/ -10%)**

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# *Step 7*

# Report Cost Metrics that are Useful and Unambiguous

- Always report the cost year, and whether values are in constant or current dollars *(the difference can be sizeable!)*
- Useful cost metrics for $CO_2$ capture systems include (but are not limited to):
  - Added cost of electricity generation
  - Added capital cost
  - Cost of $CO_2$ avoided (for a clearly-defined ref plant)

# *In Summary:* Seven Simple Steps to Improve Cost Estimates for $CO_2$ Capture

1. Use non-cost metrics for earliest-stage technologies
2. When costing a technology define the full system
3. Use proper 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

# A Final Word of Wisdom

"It's tough to make predictions, especially about the future"

- *Yogi Berra*

# *Thank You*

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