Toward a Common Method of Cost Estimation for Power Plants with CCS

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The Problem

- Despite many recent studies on the cost of CO_2 capture and storage (CCS) there remain significant differences in the costing methods (as well as key assumptions) employed by different organizations that are not readily apparent.
- Such differences contribute to confusion, misunderstanding and (in some cases) the mis-representation of CO_2 abatement costs, especially among audiences unfamiliar with details of CCS costing.

Who Cares?

Audiences for CCS Cost Estimates

Government
- Policymakers
- Analysts
- Regulators
- R&D agencies

Industry
- Operators
- Vendors
- A&E firms
- Venture capital
- Tech developers
- R&D orgs

NGOs
- Environmental
- Media
- Academia
- Foundations

Some of these groups are also sources of cost estimates

Common Uses of CCS Costs

Cost Estimates for CCS
(and other technologies)

Technology Assessments
- R&D priorities
- Capital investments
- Marketing

Policy Assessments
- Legislation
- Regulation
- Advocacy

Source: Based on Herzog, 2011

Outline of Talk

- Comparison of costing methods and assumptions used by major organizations
- Needs for improving the quantification and reporting of CCS cost estimates
- A proposed path forward

A Hierarchy of Methods to Estimate CCS Costs

- Ask an expert
- Use published values
- Modify published values
- Derive new results from a model
- Commission a detailed engineering study

Recent CCS Cost Studies

- 2005: IPCC Special Report on CCS
- 2007: Rubin, et al., *Energy Policy*
- 2007: EPRI Report No. 1014223
- 2007: DOE/NETL Report 2007/1281
- 2007: MIT *Future of Coal* Report
- 2008: EPRI Report No. 1018329
- 2009: Chen & Rubin, *Energy Policy*
- 2009: ENCAP Report D.1.2.6
- 2009: IEAGHG Report 2009/TR-3
- 2009: EPRI Report No. 1017495
- 2010: Carnegie Mellon IECM v. 6.4
- 2010: UK DECC, Mott MacDonald Report
- 2010: Kheshgi, et al., SPE 139716-PP
- 2010: DOE/NETL Report 2010/1397
- 2010: DOE EIA Cost Update Report
- 2011: OECD/IEA Working Paper
- 2011: Global CCS Institute Update

Common Measures of CCS Cost

- Cost of CO_2 avoided ($/ton CO_2)
- Cost of CO_2 captured ($/ton CO_2)
- Increased capital cost ($/kW)
- Increased cost of electricity ($/MWh)

All measures are relative to a reference plant without CCS, whose performance and cost must be specified

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How consistent are underlying costing methods ?

Capital Cost Elements (Recent Studies)

EPRI (2009)	USDOE/NETL (2007)	USDOE/NETL (2010)	USDOE/EIA (2010)
Process facilities capital	Bare erected cost (BEC)	Bare erected cost (BEC)	Civil Structural Material & Installation
General facilities capital	Eng. & Home Office Fees	Eng. & Home Office Fees	Mechanical Equip. Supply & Installation
Eng'g, home office, overhead & fees	Project Contingency Cost	Project Contingency Cost	Electrical/I&C Supply and Installation
Contingencies—project and process	Process Contingency Cost	Process Contingency Cost	Project Indirects
Total plant cost (TPC)	**Total plant cost (TPC)**	**Total plant cost (TPC)**	EPC Cost before Contingency and Fee
AFUDC (interest & escalation)		Pre-Production Costs	Fee and Contingency
Total plant investment (TPI)		Inventory Capital	**Total Project EPC**
Owner's costs: royalties, preproduction costs, Inventory capital, Initial catalyst and chemicals, Land		Financing costs	Owner's Costs (excl. project finance)
		Other owner's costs	**Total Project Cost (excl. finance)**
Total Capital Requirement (TCR)		**Total overnight cost (TOC)**	

No consistent set of cost categories or nomenclature across studies

IEA GHG (2009)	ENCAP (2009)	UK DECC (2010)
Direct materials	EPC costs	Pre-licencing costs, Technical and design
Labour and other site costs	Owner's costs	Regulatory + licencing + public enquiry
Engineering fees	**Total Investment**	Eng'g, procurement & construction (EPC)
Contingencies		Infrastructure / connection costs
Total plant cost (TPC)		**Total Capital Cost (excluded IDC)**
Construction interest		
Owner's costs		
Working capital		
Start-up costs		
Total Capital Requirement (TCR)		

O&M Cost Elements in Recent Studies

Category	USDOE/NETL (2007)	USDOE/NETL (2010)	EPRI (2009)
Fixed O&M	Operating labor	Operating labor	Operating labor
	Maintenance –labor	Maintenance –labor	Maintenance costs
	Admin. & support labor	Admin. & support labor	Overhead charges (admin & support labor)
		Property taxes and insurance	
Variable O&M (excl. fuel)	Maintenance – material	Maintenance – material	Maintenance costs
	Consumables (water, chemicals, etc.)	Consumables (water, chemicals, etc.)	Consumables (water, chemicals, etc.)
	Waste disposal	Waste disposal	Waste disposal
	Co- or by-product credit	Co- or by-product credit	Co- or by-product credit
	CO2 transport and storage	CO2 transport and storage	CO2 transport and storage

Category	IEA GHG (2009)	UK DECC (2010)
Fixed O&M	Operating labour	Operating labour
	Indicative cost	Planned and unplanned maintenance (additional labour, spares and consumables)
	Administrative and support labour	
	Insurance and local property taxes	Through life capital maintenance
	Maintenance cost	
Variable O&M (excl. fuel)	Consumables (water, chemicals, etc.)	Repair and maintenance costs
	By-products and wastes disposal	Residue disposal and treatment
	CO2 transport and storage	Connection & transmission charges
		Insurance
		CO2 transport and storage
		Carbon price

No consistent set of cost categories or nomenclature across studies

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Elements of "Owner's Costs" in Several Recent Studies

USDOE/NETL (2007)	USDOE/NETL (2010)	EPRI (2009)	IEA GHG (2009)	UK DECC (2010)
(None)	Preproduction (Start-Up) costs	Preproduction (Start-Up) costs	Feasibility studies	(None)
	Working capital	Prepaid royalties	Obtaining permits	
	Inventory capital	Inventory capital	Arranging financing	
	Financing cost	Initial catalyst/chem.	Other misc. costs	
	Land	Land	Land purchase	
	Other			

No consistent set of cost categories or nomenclature across studies

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How consistent are key assumptions ?

Key Assumptions Also Vary Across Studies

Parameter	USDOE/NETL 2007	USDOE/NETL 2010	EPRI 2009	IEA GHG 2009	UK DECC 2010
Plant Size (PC case)	550 MW (net)	550 MW (net)	750 MW (net)	800 MW (net)	1600 MW (gross)
Capacity Factor	85%	85%	85%	85% (yr 1= 60%)	varies yearly
Constant/Current $	Current	Current	Constant	Constant	Constant
Discount Rate	10%	10%	7.09%	8%	10%
Plant Book Life (yrs)	20	30	30	25	32-40 (FOAK) 35-45 (NOAK)
Capital Charge Factor					
no CCS	0.164	0.116	0.121	N/A	N/A
w/ CCS	0.175	0.124	0.121	N/A	N/A
Variable Cost Levelization Factor					
no CCS	1.2089 (coal) 1.1618 (other)	1.2676	1.00	1.00	N/A
- w/ CCS	1.2022 (coal) 1.1568 (other)	1.2676	1.00	1.00	N/A

N/A: not available

Transparency is critical for understanding

Many Factors Affect CCS Cost

- Choice of Power Plant and CCS Technology
- Process Design and Operating Variables
- Economic and Financial Parameters
- Choice of System Boundaries
- Time Frame of Interest

Ten Ways to Reduce CCS Costs

(Inspired by D. Letterman)

10. Assume high power plant efficiency
9. Assume high-quality fuel properties
8. Assume low fuel cost
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 haven't yet considered the CCS technology!

What about uncertainty, variability and bias ?

Uncertainty, Variability & Bias

- Variability and uncertainty can (in principle) be accounted for in costing methods, e.g., via parametric (sensitivity) analysis, choice of parameter values, and/or probabilistic analysis
- Bias can arise in project design specifications and choice of parameters and values for cost estimates
  - Can be difficult to detect or prove
  - Independent (3rd party) evaluations can be helpful

Especially important for evaluating new or emerging technologies, but often ignored or not treated rigorously

The Need

- Need to improve the consistency, reporting, and transparency of costing methods and assumptions to enhance the understanding and rigor of CCS cost estimates

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A Path Forward

- Need for improved costing methods was affirmed at a 2011 international workshop on CCS costs:
  <https://kminside.globalccsinstitute.com/community/extranet/ccs_costs_network>
- An *ad hoc* Task Force formed in October 2011 to work on ways to:
  - Harmonize methods of estimating and reporting CCS costs
  - Improve methods of characterizing the variability and uncertainty in CCS costs (especially for new and emerging technologies)
  - Improve methods for comparing costs of CCS to other GHG mitigation options

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CCS Cost Methods Task Force

- George Booras (EPRI)
- John Davison (IEAGHG)
- Clas Ekström (Vattenfall)
- Mike Matuszewski (USDOE)
- Sean McCoy (IEA)
- Ed Rubin (CMU) *(Chair)*
- Chris Short (GCCSI)

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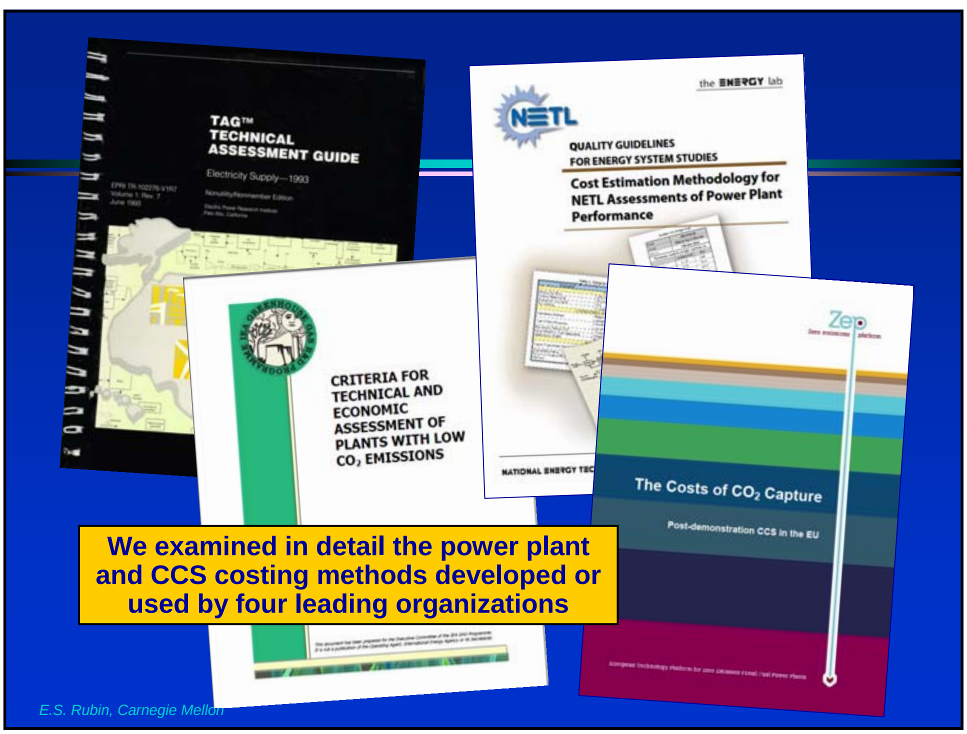

A draft white paper addresses six major topics relevant to CCS costs

- Defining Project Scope and Design
- Defining Nomenclature and Cost Categories for CCS Cost Estimates
- Quantifying Elements of CCS Cost
- Defining Financial Structure and Economic Assumptions
- Calculating the Costs of Electricity and CO_2 Avoided
- Guidelines for CCS Cost Reporting

Toward a Common Method of Cost Estimation for CO_2 Capture and Storage at Fossil Fuel Power Plants

A White Paper Prepared by
the
Task Force on CCS Costing Methods

Ed Rubin (CMU) (Chair)
George Booras (EPRI)
John Davison (IEAGHG)
Clas Ekstrom (Vattenfall)
Mike Matuszewski (USDOE/NETL)
Sean McCoy (IEA)
Chris Short (GCCSI)

April 22, 2012

Vetted at a followup workshop in May 2012

Task Force Recommendation

- We found that with a few changes in each of the four costing methods studied, a “common language” and costing methodology could indeed be achieved!
- Here is what it would look like for capital costs …

Capital Cost Element to be Quantified	Sum of All Preceding Items is Called:
Process equipment	
Supporting facilities	
Labor (direct & 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	
- Permitting	
- Finance transaction costs	
- Pre-paid royalties	
- Initial catalyst & 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	
Cost escalations during construction	
	Total Capital Requirement (TCR)

Task Force Recommendation (con't.)

- … and here's what it would look like for plant operating and maintenance (O&M) cost items

At the May workshop the leading organizations agreed to adopt this common nomenclature

Operating & Maintenance Cost Item to be Quantified	Sum of All Preceding Items is Called:
Operating labor	
Maintenance labor	
Administrative & support labor	
Maintenance materials	
Property taxes	
Insurance	
	Fixed O&M Costs
Fuel	
Other consumables, e.g.: - 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

The Devil is in the Details

- Even with a common nomenclature and set of cost elements, different methods of quantifying each item will still result in different costs.

- We found many similarities, as well as some differences, in the methods used by the four organizations studied
- Some cost items are amenable to guidelines (e.g., process contingency cost adders); others are far more difficult (e.g., items whose cost is "specified by the contractor").

Here we emphasize the importance of full reporting to reveal sources of cost differences

Task Force Guidelines

- The Task Force developed a series of “checklists” of data and information that should be reported in:
  - Technical reports
  - Journal/conf. papers
  - Presentations

Information Needed	Presentations
Power plants without CO_2 capture (reference/baseline plants)	
Fuel type (class of hard coal, lignite, gas)	X
Power plant type (e.g. PF, BFB, CFB or NGCC)	X
Plant capacity (MW electric)	
- Gross (to define boiler or gas turbine size class)	X
- Net	X
Net electric efficiency and/or heat rate (state if based on LHV or HHV)	X
CO_2 emissions (per MWh net electricity or per MWh fuel; state if LHV or HHV)	X
In addition for power plants with CCS	
Type of power plant CO_2 capture; e.g. post-combustion, oxy-combustion, IGCC with pre-combustion	X
Capture technology (e.g. MEA, advanced amine, chilled ammonia, Selexol, solid absorption/desorption process, etc.	X
Captured CO_2 per MWh net electricity or per MWh fuel (state if LHV or HHV) or “capture rate” (% of produced CO_2)	X
Capital costs	
Type of plant, e.g. first-of-a-kind, N^{th}-of-a-kind	X
Year, currency (to enable later updates and comparisons between studies from different years, using suitable plant/equipment cost indices)	X
Contingencies (sum of process and project contingencies)	X
Resulting ”Total Overnight Cost”	X
- Construction cost escalation rate (if applied)	X
O&M costs (excluding CO_2 transport & storage)	
CO_2 emissions cost per tonne (if included)	X
CO_2 transport & storage costs	
Overall net cost per tonne of CO_2 stored, with breakdown into transport and storage (if available).	X
Levelized cost of electricity	
Method/approach used; also state if calculation uses real (constant money values) or nominal (current money values)	X
Interest rate/discount rate/WACC; also state if real or nominal	X
Inflation and other price escalation rates (if applied).	X
Economic lifetime	X
Load factor/equivalent full load operation hours	X
- Fuel prices per GJ or MWh fuel (state HHV or LHV)	X
CO_2 avoidance cost	
State and define reference plant case	X

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Task Force Guidelines

- The complete checklists are in the draft white paper

Information Needed	Reports	Papers	Presentations
Power plants without CO_2 capture (reference/base line plants)			
Battery limits	X		
Fuel type (class of hard coal, lignite, gas)	X	X	X
- Moisture and ash contents	X	X	
- LHV and HHV. (state “as received”, dry matter, dry and ash free).	X	X	
- Definition of LHV	X		
Power plant type (e.g. PF, BFB, CFB or NGCC)	X	X	X
- Steam parameters (pressures/temperatures)	X	X	
- GT-class (e.g. F-class, H-class)	X	X	
- Gasifier type (for IGCC)	X	X	
Plant location type (immediate to port, inland)	X	X	
- Ambient conditions (ISO, other conditions)	X	X	
Cooling water (cooling tower or once through sea/lake/river water)	X	X	
Plant capacity (MW electric)			
- Gross (to define boiler/GT size class)	X	X	X
- Net	X	X	X
Net electric efficiency and/or heat rate (state if based on LHV or HHV)	X	X	X
CO_2 emissions (per MWh net electricity or per MWh fuel; state if LHV or HHV)	X	X	X
Environmental requirements anticipated.	X		
In addition for power plants with CO_2 capture			
Plant capacity (is the boiler/GT capacity or the gross or net output the same as the reference plant)	X	X	
Type of concept for power plant with CO_2 capture; e.g. post-combustion, oxy-fuel, IGCC with pre-combustion	X	X	X
Capture technology (e.g. MEA, advanced amine, chilled ammonia, Selexol etc or solid absorption/desorption process	X	X	X
Delivered captured CO_2:			
- Pressure, temperature	X	X	
- Purity requirements anticipated (at least state if sufficient for transport in carbon steel pipelines or ships)	X		
Captured CO_2 per MWh net electricity or per MWh fuel (state if LHV or HHV), or “capture rate” (% of produced CO_2)	X	X	X

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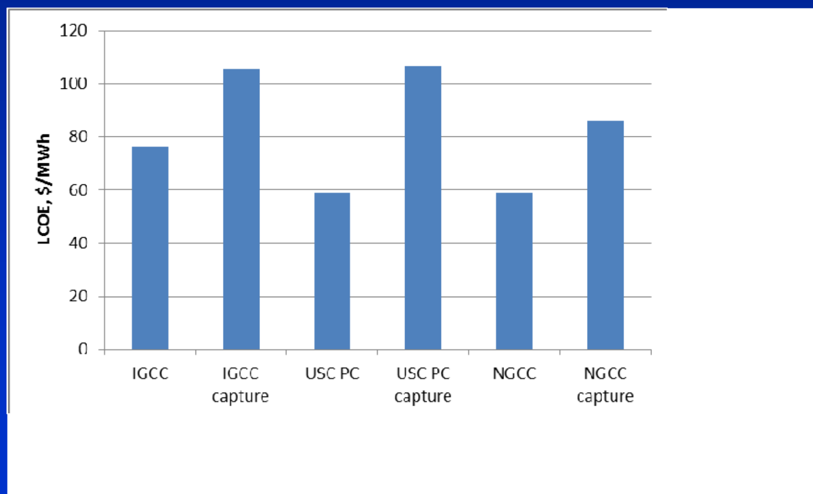
We also have some examples of "Bad" Practice …



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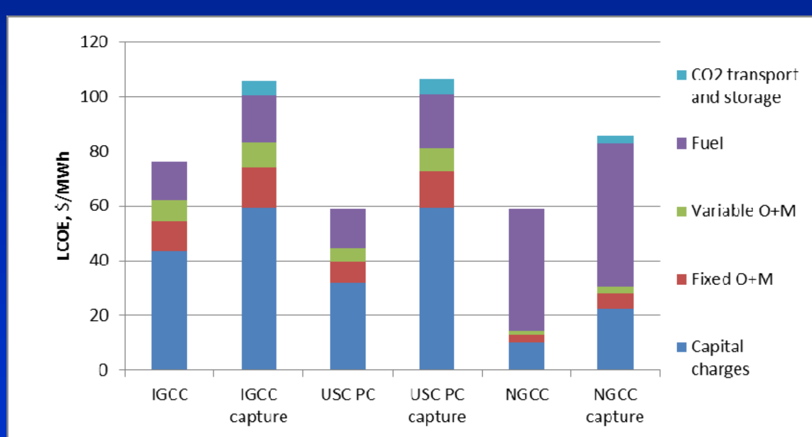
… and "Good" Practice for information in graphs and tables



Bituminous coal: $1.6/GJ (LHV), Gas: $7/GJ (LHV), Annual capital charge factor: 0.11
CO2 transport + storage: $6/t, 90% load factor, Constant $, 2007

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Next Steps

- Finalize the White Paper based on comments and feedback from reviewers
- Complete a companion paper for the International Journal of Greenhouse Gas Control (IJGGC)
- Disseminate recommendations broadly and pursue followup with leading U.S. and international organizations involved in CCS cost estimation
- Extend Task Force activities to consider issues related to costing of new technologies and other GHG mitigation options

Thank You

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