

Report of a Recent CCS Cost Workshop: Part I

Audiences, Measures and Methods for CCS Costs

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Background

- In recent years, reported costs of CCS have increased. There's been growing interest—*and growing confusion*—over the cost of CCS in different applications.
- This led to an ad hoc meeting of ~20 people last fall during GHGT-10 (organized by J. Davison and H. Herzog) to discuss interest in a network or workshop focused on CCS cost issues.
- The response was extremely positive. Seven people agreed to form a steering committee to plan a workshop in the March 2011 time frame, focused on CCS at power plants.
- The workshop was held on March 22-23 at the IEA offices in Paris. 40 invited participants attended.

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Steering Committee

- John Davison, IEA GHG
- Clas Ekström, Vattenfall
- Matthias Finkenrath, IEA
- Howard Herzog, MIT
- Richard Rhudy, EPRI
- Ed Rubin, Carnegie Mellon
- Chris Short, GCCSI

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CCS Cost
Workshop
participants
and plenary
session



Workshop Participants

- **Experts from industry, government, academia, NGOs**
 - Alstom Power, Amec, BG Group, Carnegie Mellon University, Clean Air Task Force, CSIRO, DOE/NETL, E.On gas storage, ENEL, EPRI, ExxonMobil, Foster Wheeler, gasNatural fenosa, GCCSI, IEA, IEAGHG, MIT, Panaware ab, RWE Power, Schlumberger, SFA Pacific, Shell, Southern Company, Statoil, Suncor, Teekay Shipping, Tel-Tek, Tsinghua University, University of Ulster, Vattenfall
- **Experts from Europe, the Pacific, and North America**
 - Australia, Canada, China, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, UK, USA

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Workshop Agenda – Day 1

Keynote 1: Audiences and Uses for CCS Cost Estimates (Herzog)

- Government, Industry, NGO respondents
- Open discussion

Keynote 2: CCS Costing Methods and Measures (Rubin)

- Vendor, Utility, R&D organization respondents
- Open discussion

Keynote 3: Status of CO₂ Capture Costs (Finkenrath)

- Europe, North America, Asia/Pacific respondents
- Open discussion

Keynote 4: Status of CO₂ Transport Costs (Nilsson)

Keynote 5: Status of Geologic Storage Costs (Tombari)

- Transport, Storage, Policy Expert respondents
- Open discussion

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Workshop Agenda – Day 2

Breakout Session 1a: Capture Costs

Breakout Session 1b: Capture Costs

Breakout Session 2: Transport Costs

Breakout Session 3: Storage Costs

- Further discussion of topics presented on Day 1
- Need, role and agenda for a CCS cost network

Reports from Breakout Sessions

General Discussion:

- Major conclusions/insights from the workshop
- Recommendations/plans for follow-up action

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Today's Agenda

- I will summarize the keynote sessions on audiences, measures, and methods of CCS costing
- Howard Herzog will summarize sessions on the status of CCS costs, and the outcomes of the workshop
- Barry Jones and Stu Dalton will offer brief comments, followed by audience Q&A
- This afternoon in session 3-G we (plus John Tombari) will continue the discussion of CCS cost issues

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Audiences for CCS Costs

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Users (and Generators) of CCS Cost Estimates

Many people use cost estimates in many ways

Government

- Policymakers
- Analysts
- Regulators
- R&D Agencies

Industry

- Operators
- Vendors
- A&E Firms
- Venture Cap.
- Tech Developers
- R&D Orgs

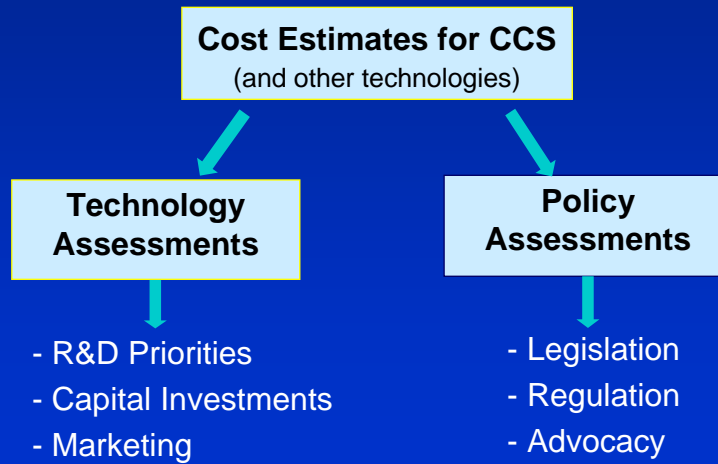
NGOs

- Environmental
- Media
- Academia
- Foundations

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Source: Howard Herzog / MIT Energy Initiative

Simplified View of the Uses of CCS Cost Estimates



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Source: Howard Herzog / MIT Energy Initiative

CCS in a Mitigation Portfolio

- Many users of CCS costs are also interested in how CCS compares to the cost of other CO₂ mitigation technologies or options
 - A desire for consistency across cost estimates for different technologies, but very difficult to achieve
- Different audiences also typically require (or get) different types and quality of cost information
 - Limited number of comprehensive independent studies vs. “derivative” studies
 - “Top down” vs. “bottom up” estimates

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Source: Howard Herzog / MIT Energy Initiative

Measures of CCS cost

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Common Measures of CCS Cost

- Cost of CO₂ avoided
- Cost of CO₂ captured
- Added cost of electricity
- Capital cost

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Dollars per Ton

- This is the metric most commonly used in technical and policy forums to quantify the cost of CCS (as well as other methods of reducing carbon emissions)
- Also the measure that is most easily misunderstood and misapplied

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Same Units, Different Meanings

- Cost of CO₂ Avoided (\$/t CO₂)

$$= \frac{(\$ / \text{MWh})_{\text{CCS}} - (\$ / \text{MWh})_{\text{reference}}}{(\text{t CO}_2 / \text{MWh})_{\text{ref}} - (\text{t CO}_2 / \text{MWh})_{\text{CCS}}}$$

- Cost of CO₂ Produced (\$/t CO₂)

$$= \frac{(\$ / \text{MWh})_{\text{reference}} - (\$ / \text{MWh})_{\text{CCS, produced}}}{(\text{t CO}_2 / \text{MWh})_{\text{CCS}} - (\text{t CO}_2 / \text{MWh})_{\text{reference}}}$$

- Cost of CO₂ Abated (Reduced) (\$/t CO₂)

$$= \frac{(\$ \text{ NPV})_{\text{CCS}} - (\$ \text{ NPV})_{\text{reference}}}{(\text{t CO}_2)_{\text{ref}} - (\text{t CO}_2)_{\text{CCS}}}$$

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Use with caution!

Methods for CCS cost estimates

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A Hierarchy of Methods

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

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Current Status

- Individual organizations have developed detailed procedures and guidelines for calculating power plant costs (capital, O&M, COE) in a consistent fashion
- However, there are significant differences in the costing methods used by different organizations concerned with CO₂ capture and storage

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Capital Cost Elements in Recent Studies

| EPRI TAG (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 | Mech. 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) |
| Total Capital Requirement (TCR) | | Other owner's costs | Total Project Cost (excl. finance) |
| | | 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) | | |

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O&M Cost Elements in Recent Studies

| Category | USDOE/NETL (2007) | USDOE/NETL (2010) | EPRI TAG (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 |

No consistent set of cost categories or nomenclature across studies

| 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 | |

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Many Factors Affect CCS Costs

- Choice of Power Plant and CCS Technology
- Process Design and Operating Variables
- Economic and Financial Parameters
- Choice of System Boundaries; *e.g.*,
 - One facility vs. multi-plant system (regional, national, global)
 - GHG gases considered (CO₂ only vs. all GHGs)
 - Power plant only vs. partial or complete fuel cycle
- Time Frame of Interest
 - First-of-a-kind plant vs. n^{th} plant
 - Current technology vs. future systems
 - Consideration of technological “learning”

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Uncertainty, Variability and Bias

- Cost methods can (in principle) account for variability and uncertainty, e.g., via parametric (sensitivity) analysis 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

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The Devil is in the Details

- Need to improve the reporting and transparency of costing methods and assumptions to improve the understanding of CCS costs



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Thank You

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*Howard Herzog now will present Part II:
Workshop reports on status of cost estimates
for capture, transport and storage,
with plans for follow-on activities*

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