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International Energy Agency

Understanding costs for CO_2 capture, transport, and storage

IEA-SENER Joint Workshop
CCS in Mexico: Policy Strategy Options for CCS
Mexico City, 7-8 March 2012

Sean McCoy
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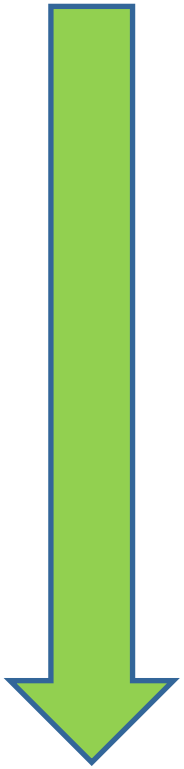
Outline

1. Why undertake cost & performance analysis
2. Key factors in cost estimation
3. Capture: cost estimates by technology stage
4. Transport: cost for mature technologies
5. Storage: the most difficult part of the chain to cost
6. Conclusions

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Multiple different reasons exist that motivate analysis of CCS cost

Less Specific



More Specific

- Modeling global energy policy
- Development of national (or regional) energy policy
- Evaluating government or private investment into CCS as a technology
- Developing government incentive policy for CCS
- Project scoping and screening studies
- Project pre-feasibility & conceptual design studies
- R&D portfolio technology assessment
- 3rd party financial and insurance assessments
- Front-end engineering and design studies
- Detailed engineering design studies

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Many factors impact estimated costs for CCS

- The choice of power plant (in power generation) and CCS technologies
- Process design and operating variables (e.g. capacity factor)
- Economic and financial parameters (e.g. cost of capital)
- Choice of system boundaries, for example:
  - One facility vs. multi-plant system (regional, national, global)
  - GHG gases considered (CO_2 only vs. all GHGs)
  - Power plant only vs. partial or complete life cycle
- Time frame of interest
  - Current technology vs. future (improved) systems
  - Consideration of technological “learning”

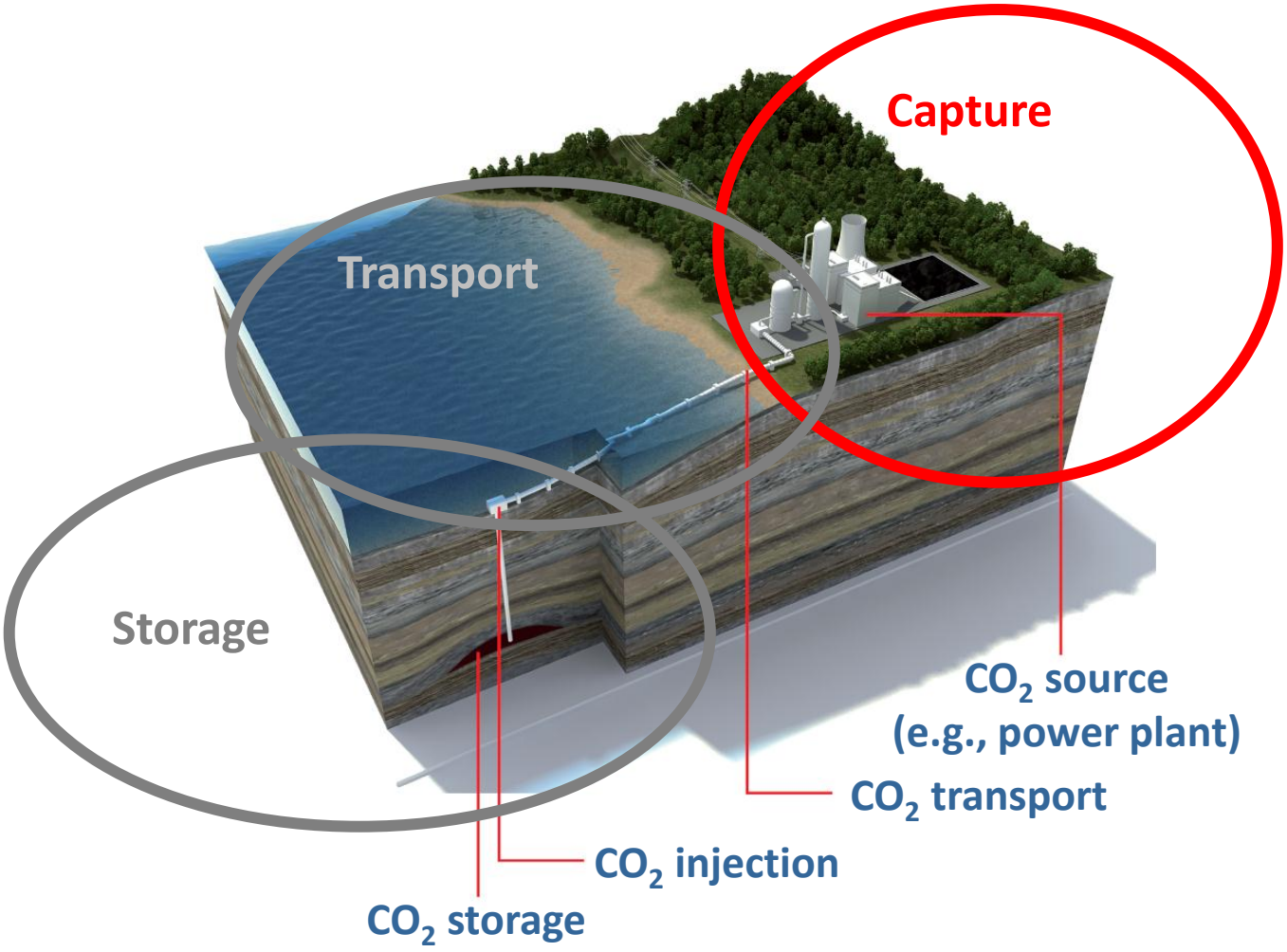
Rubin, 2008

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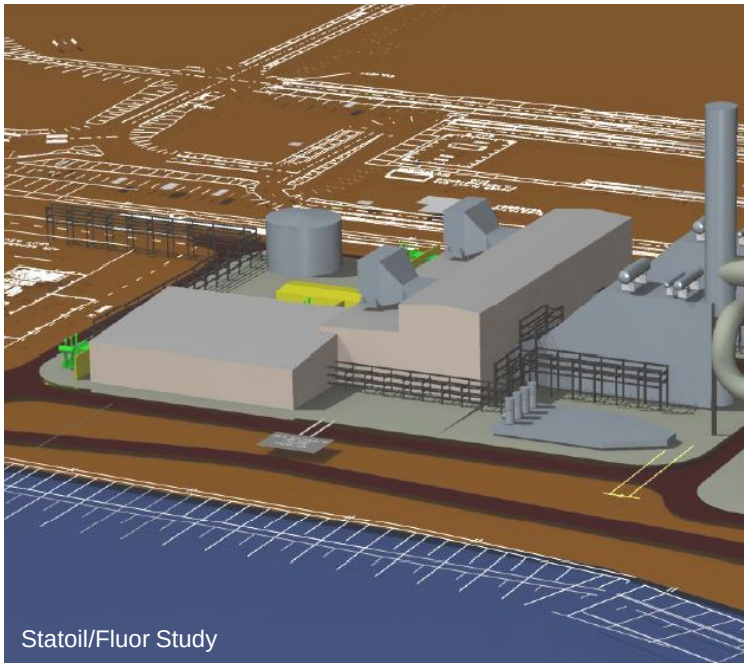
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Power plant cost and performance analysis



Example:
800 MW Natural Gas Combined Cycle

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Assessing the cost: early commercial plants

Re-evaluated engineering study data of various institutions:

- Carnegie Mellon University – CMU
- China-UK Near Zero Emissions Coal Initiative – NZEC
- CO_2 Capture Project – CCP
- Electric Power Research Institute – EPRI
- Global CCS Institute – GCCSI
- Greenhouse Gas Implementing Agreement – GHG IA
- National Energy Technology Laboratory – NETL
- Massachusetts Institute of Technology – MIT

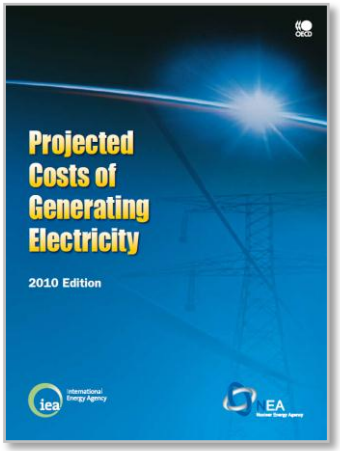
Cost and performance estimates for **more than 50 capture installations across all capture routes**

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Assessing the cost: Scope of cost estimates and method

- **Recalibrated scope** of published cost data
- **Updated** of costs to 2010 USD (CEPCI)
- Focus on **new-built** power plants on a brown-field site
- **Cost terminology** and **Levelized Cost of Electricity (LCOE):** Methodology based on **2010 OECD Study** with input from international expert group:
  - **Overnight costs** key metric for capital costs
  - Higher **contingency** for CCS vs. non-CCS plants
  - **Same financial boundary conditions**; **fuel prices differ** across regions
  - However, in contrast to OECD 2010 study, **no CO_2 price** is included



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Summary of results for early commerical plants in OECD Countries

Fuel	Coal *(similar for all capture routes; relative to a pulverized coal baseline)*	Natural gas *(post-combustion)*
Efficiency penalty	10 %-points	8 %-points
Capital costs	3 800 USD/kW (74% increase)	1 700 USD/kW (82% increase)
Cost of CO_2 avoided	55 USD/tCO_2	80 USD/tCO_2

Notes: Averages figures for OECD countries shown (costs in China estimated to be about half), capital costs are overnight costs

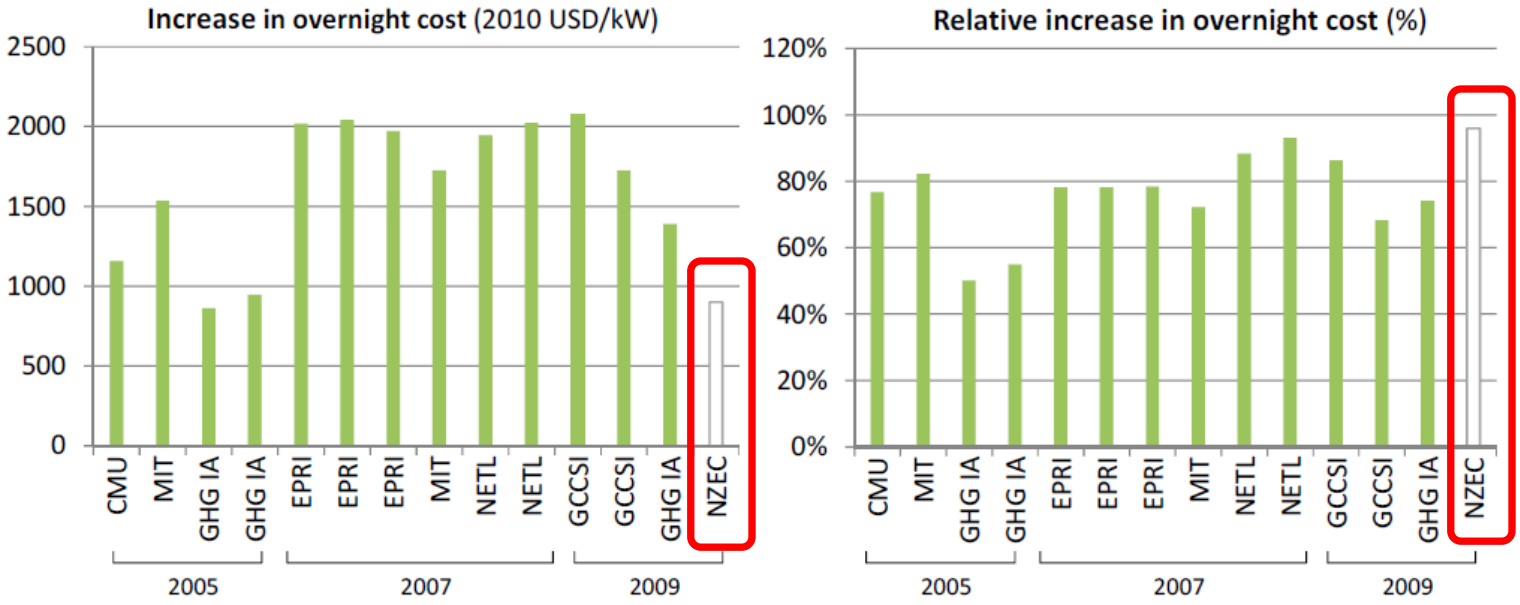
Note that the **CO_2 transport & storage cost and performance impact is not included, as these are** highly site-specific

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Early commerical plant cost is highly variable across studies

Example: Post-combustion capture from coal (with amines)



- **Substantial variation** of costs across studies and over time
- **Relative cost increase** appears slightly **more stable**
- Absolute **costs in China estimated half** of average OECD costs

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Early commerical plant cost is highly variable across studies

Example: Oxy-combustion capture from coal (2010 USD, OECD countries)

Specific fuel type	Bit coal		Sub-bit & Lignite		*Overall Average*
Power plant type	**USCPC**	**SCPC**	**SCPC**	**CFB**	
Number of cases included	2	3	3	2	
Net power output w/ capture (MW)	541	533	550	549	*543*
Net efficiency w/ capture, LHV (%)	35.0	31.2	31.2	31.2	*31.9*
Overnight cost w/ capture (USD/kW)	3 419	3 500	4 161	4 885	*3 959*
Relative increase in overnight cost	**62%**	**67%**	**75%**	**96%**	***74%***
Cost of CO_2 avoided (USD/tCO_2)	**50**	**45**	**49**	**69**	***52***

Notes: Data cover only CO_2 capture and compression but not transportation and storage. Overnight costs include owner's, EPC and contingency costs, but not IDC. A 15% contingency based on EPC cost is added for unforeseen technical or regulatory difficulties for CCS cases, compared to a 5% contingency applied for non-CCS cases. IDC is included in LCOE calculations. Fuel price assumptions differ between regions.

- Influence of fuel and power plant type can be significant
- Other factors include e.g. ambient conditions & cooling options
- Variability across studies depending on exact scope, different location or boundary conditions

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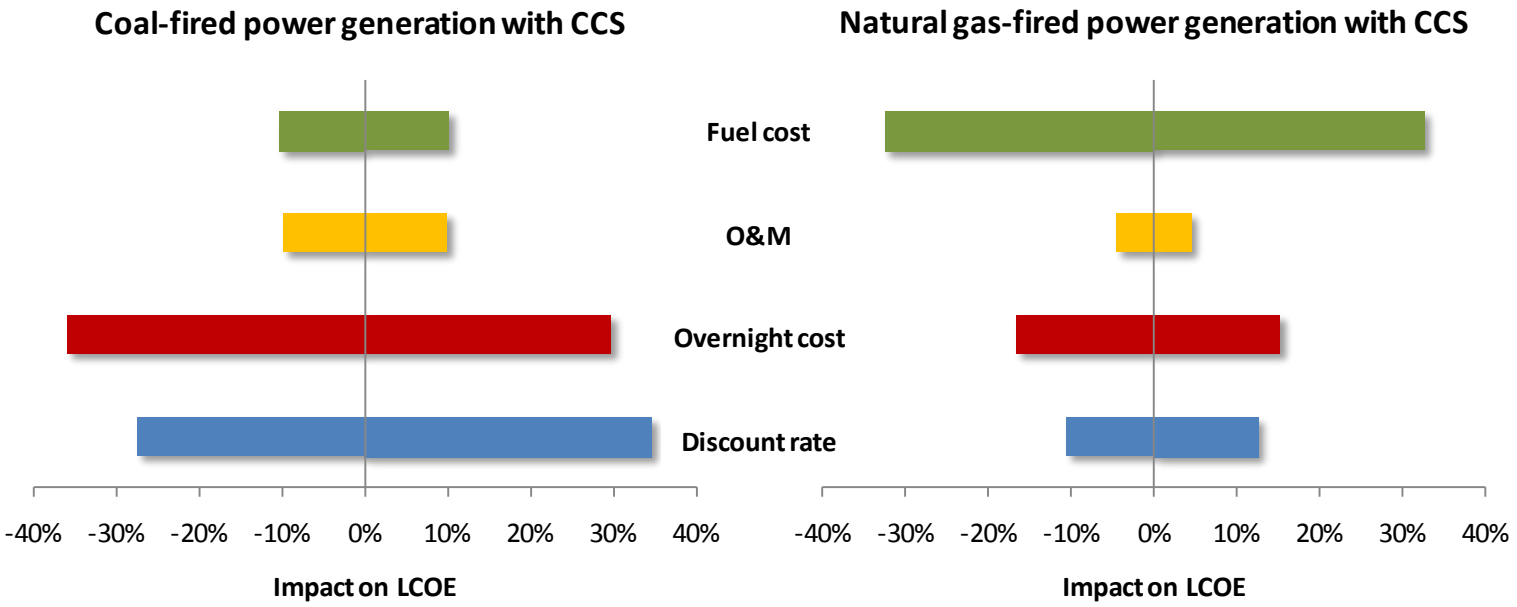
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Accuracy of data and sensitivity of results for early commerical plant analysis

- Typical **accuracy** ranges of **feasibility study** cost estimates estimated **-15% to -30% on the low side**, and **+20% to +50% on the high side**
- **Significant sensitivity** of results to parameter assumptions

Impact of a ±50% variation in baseline assumptions on LCOE



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From generic to site-specific costs for early plants*

- Gassnova estimated costs for a **retrofit of post-combustion capture** to a natural gas power plant in a **rural area in Norway**
- **Project- and site- specific costs added 30% to EPC** (Engineering, Procurement and Construction) contract costs for the CO_2 capture plant
- The project- and site-specific costs included:
  - site preparation;
  - connections for flue gas and other utilities;
  - sea water cooling system;
  - power supply;
  - fire water supply;
  - training of personnel;
  - and, miscellaneous other costs in the construction phase

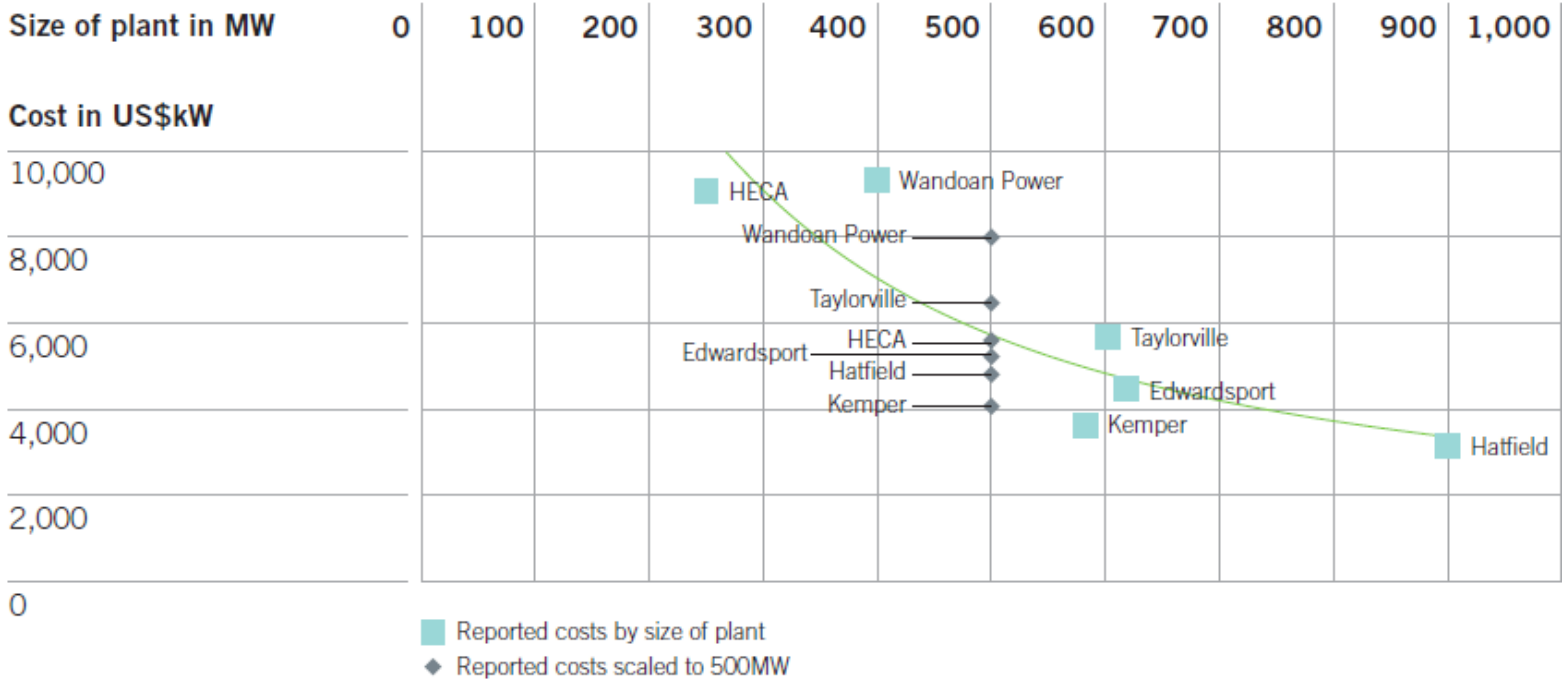
** Personal communication with Tore Hatlen, Gassnova, 2011*

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Project investment cost for Demo Plants

Example: Project investment costs for emerging IGCC projects



- Original cost data spread between 3 800 and 9 500 USD/kW
- Costs between 4 200 and 8 100 USD/kW after normalization
- Investment requirements higher than for early commercial units

Figure: GCCSI, 2011

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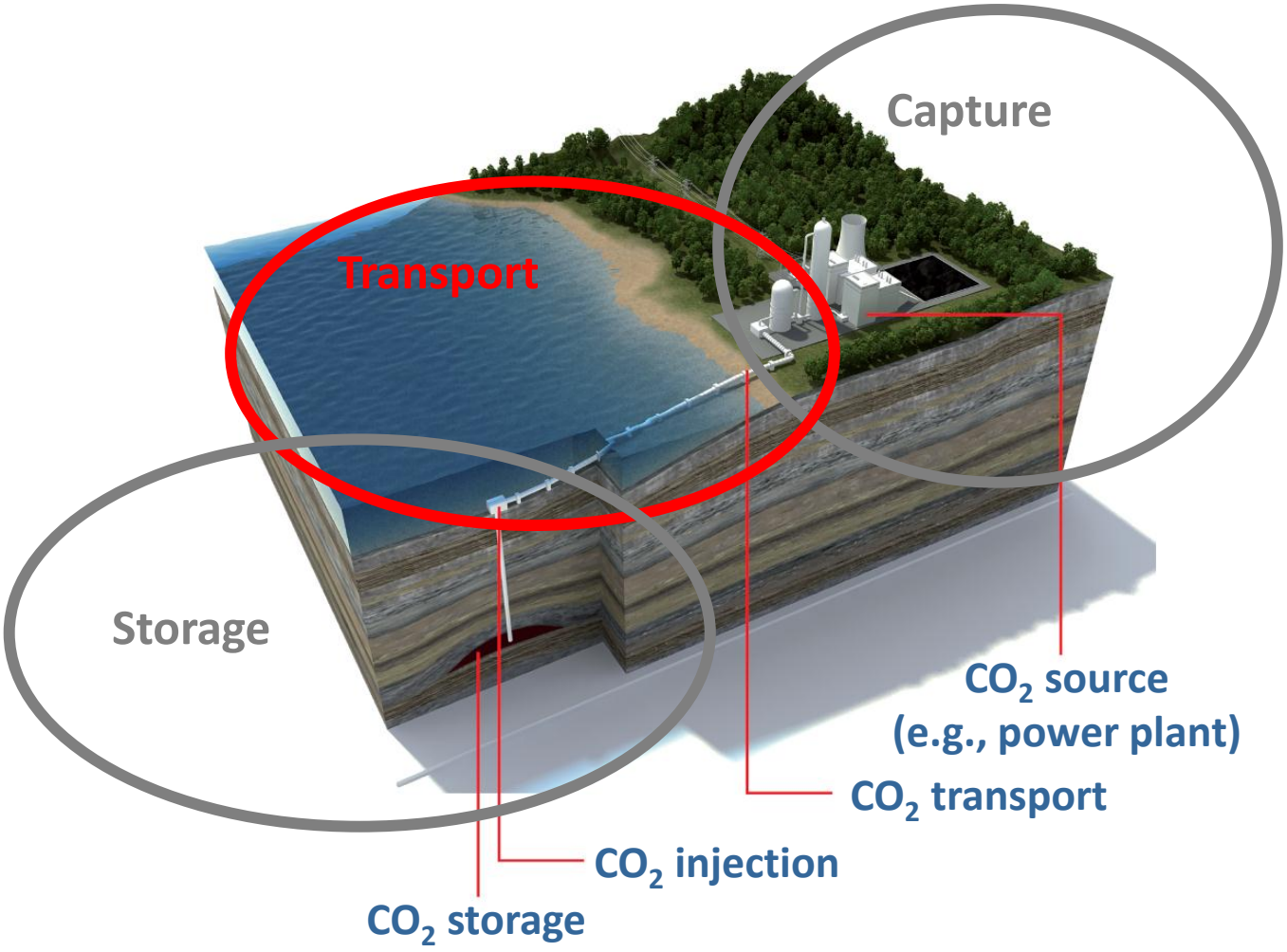
Retrofit applications in power generation

- Feasibility and cost of CCS retrofit are **highly site-specific**
- Often **incremental LCOE** is higher than for a new-built
- **Cost per ton of CO_2 avoided increases** as a result of these higher costs
- Studies indicate:
  - Most cost-effective to combine retrofit with a major plant repowering for older subcritical plants
  - Apply retrofit only to newer supercritical coal units
- Some argument can be made for retrofitting older, less efficient plants if **they are fully depreciated**

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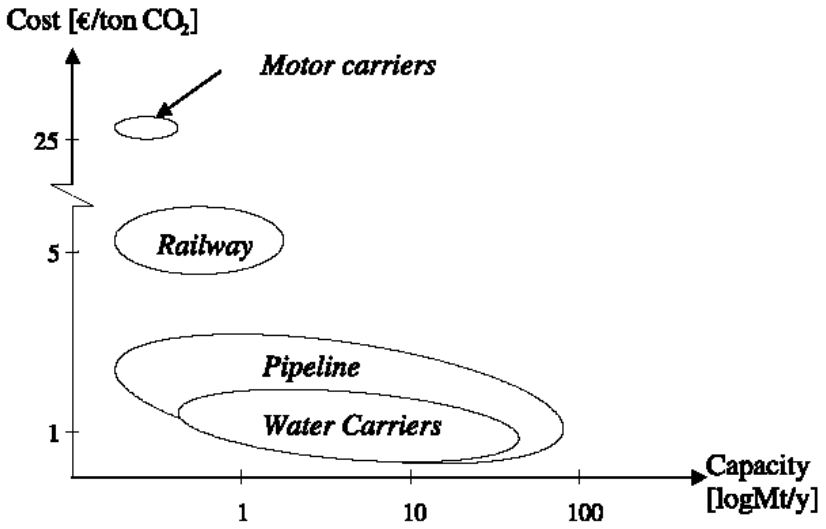
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There are four possible modes for CO_2 transport

- Depending on distance, volume, and location options are by motor carrier (truck), rail, pipeline, and ship
- Motor carrier & rail have limitations due to rates of loading & unloading
- Over long distance & large capacity, pipeline and ship are most viable



Svensson et al., 2004

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We have experience in transporting CO_2 by pipeline

- In 2010, the US had 6,600 km of CO_2 pipelines that moved over 60 Mt of CO_2
- Most of the US CO_2 pipeline mileage was built in the 1970's and 80's for enhanced oil recovery (EOR)
- On a per tonne-km basis they are safer than natural gas pipelines
- CO_2 is also moved in offshore pipelines as part of the Snøhvit project



Map: Oil & Gas Journal, 2001

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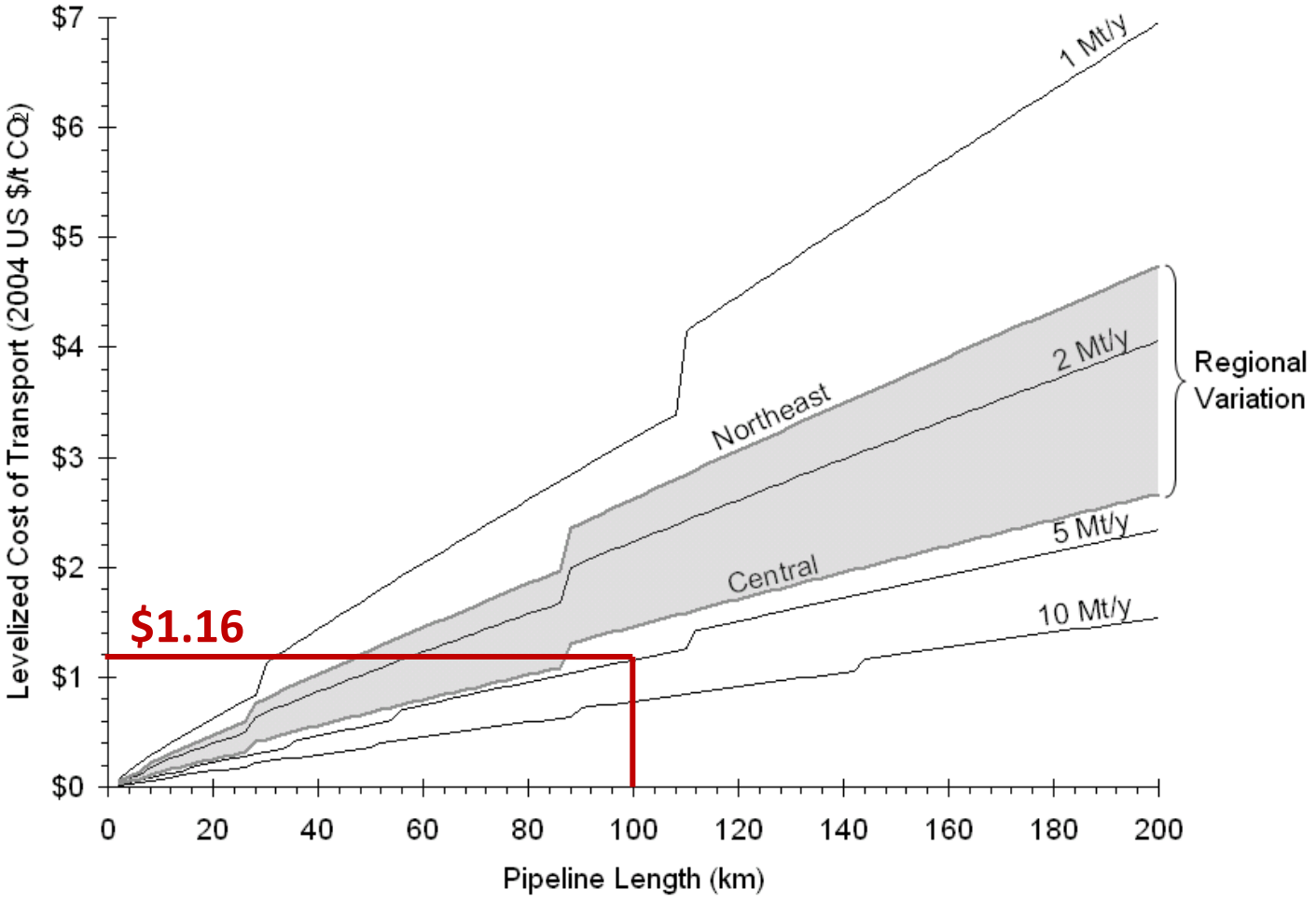
Numerous factors affect the cost of CO_2 pipeline transport

- The cost of pipeline transport varies with:
  - Design capacity of the pipeline (e.g. tons of CO2 per year)
  - length of the pipeline,
  - terrain which the pipeline crosses; and,
  - for onshore cases, land use along the route.
- In general, the cost of transport shows economies of scale with capacity and increases linearly with distance (McCoy, 2008)
- The strong economies of scale point to development of a network infrastructure (Chandel et al., 2010)

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The cost of transporting CO_2 is relatively small



Source: McCoy & Rubin, 2008

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We know how to move CO_2 and like fluids by ship



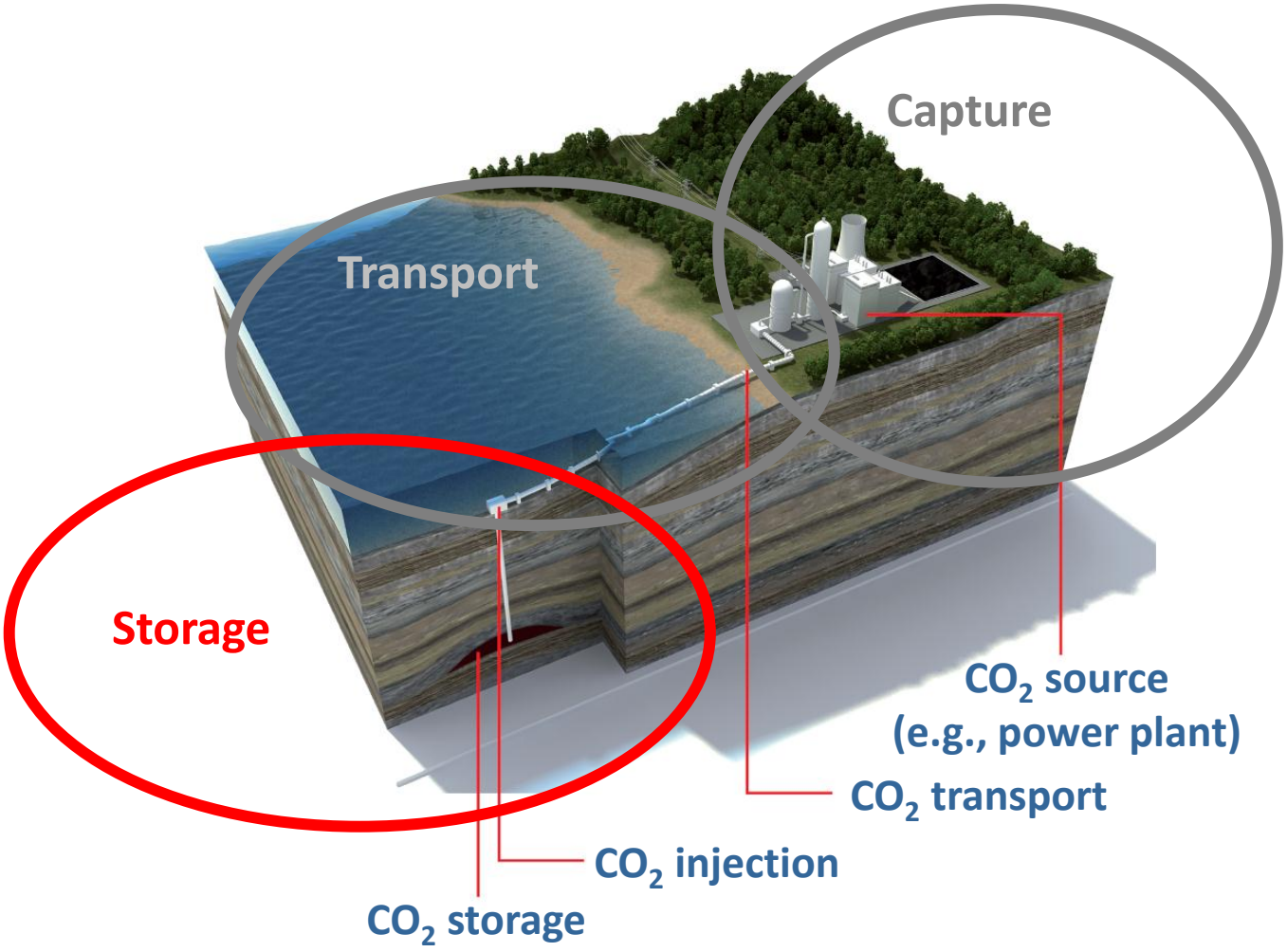
Photo: StatoilHydro

- Transporting CO_2 by ship has been demonstrated at small scale
- However, ship transport requires a full infrastructure: liquefaction, temporary storage, loading and unloading facilities, etc.
- A recent study estimates a North Sea point-to-point system to cost 20-30 USD/t CO_2

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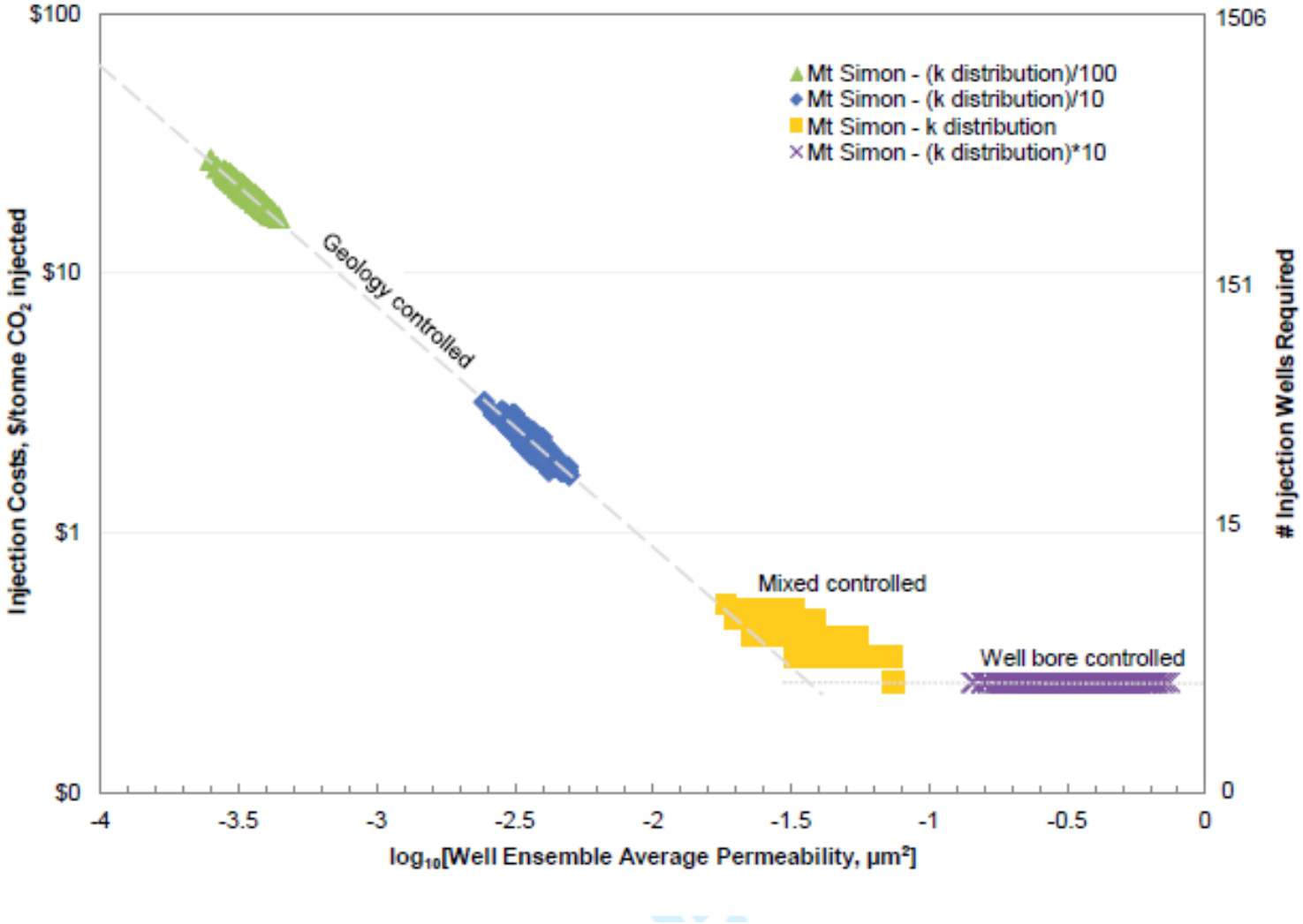
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Numerous factors affect the cost of storage

- What type of storage: saline aquifers or CO_2-flood enhanced oil recovery (CO_2-EOR)
- Where: onshore or offshore?
- Subsurface geological parameters:
  - Porosity, depth, (net) thickness, permeability
  - Reservoir structure and hydraulic connectivity
  - Not just scalar parameters (i.e., single values) but **distributions over space**
  - In general, **not parameters that can be changed through engineering design**
- Well design (e.g., vertical vs. horizontal)
- Monitoring, measurement, and verification packages
- Economic and financial parameters (e.g. cost of capital)
- Time frame of interest: for how many years at what rate?

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Example: Permeability distribution has a strong impact on cost

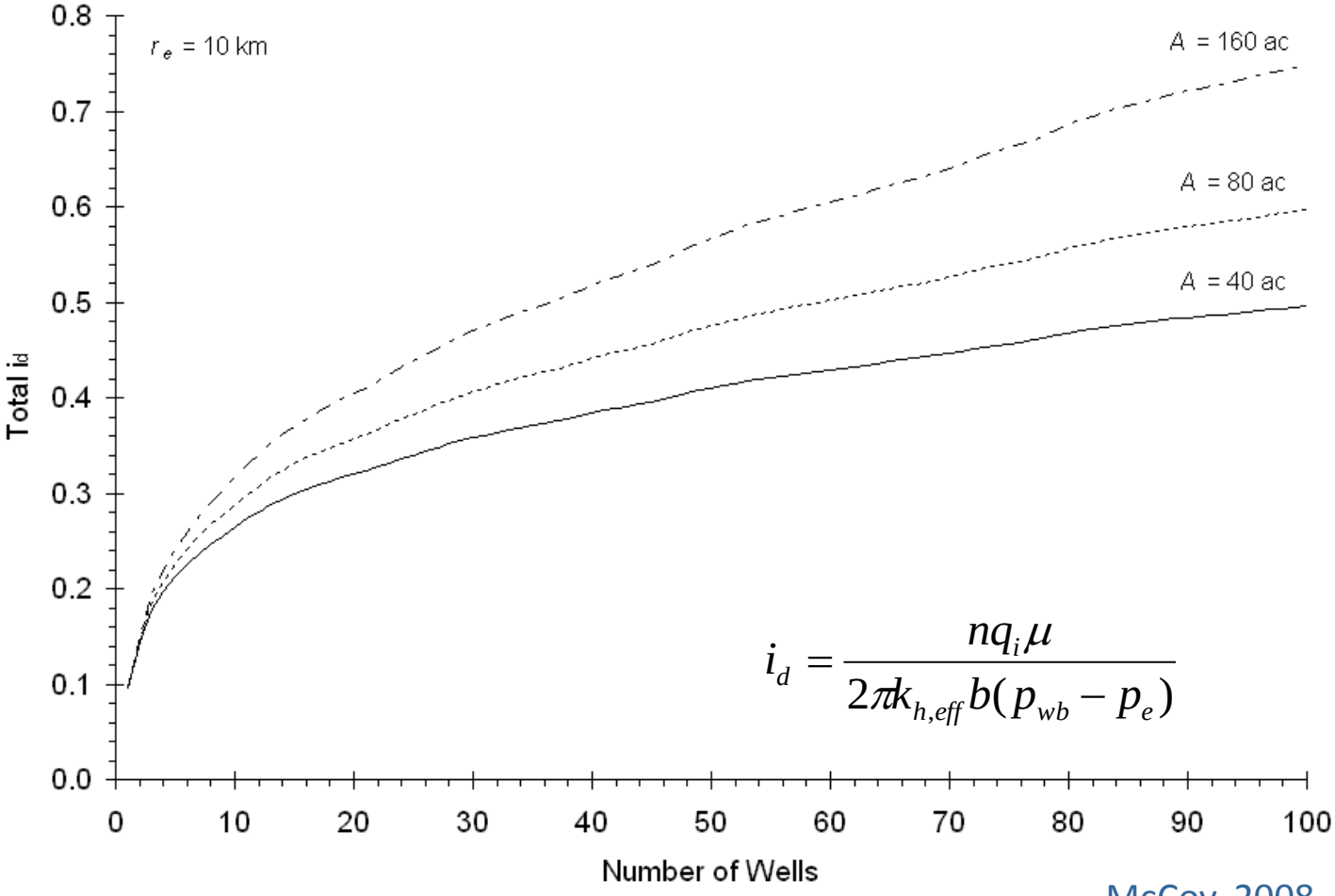


(Heath et al., 2012)

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Example: Diminishing returns to additional wells



McCoy, 2008

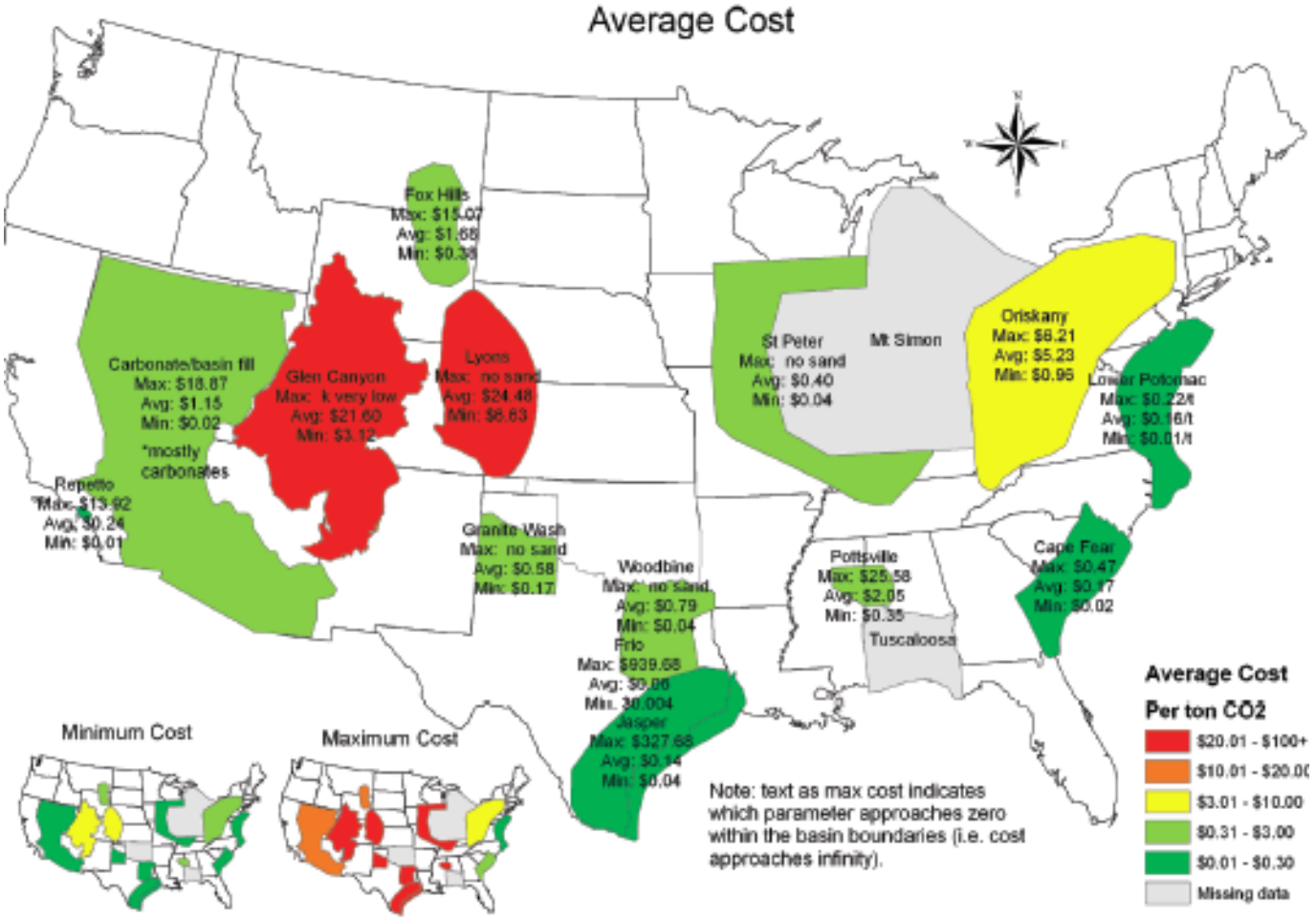
The bottom line: **you can't drill your way out of a poor site!**

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Example: Storage cost is widely varied in the US



Cost ranges from **less than a dollar per ton CO_2 stored to just over USD 20 per ton CO_2 stored**—not including MMV or management of long-term liability

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Conclusions

- **Variability between** and **uncertainty** of costs remains significant
- Capture:
  - No **single technology outperforms** others for coal-fired power generation
  - For near-term CO_2 capture from natural gas-fired power plants, **post-combustion CO_2 capture appears most attractive**
  - The **relative increase of cost** compared to a plant without CO_2 capture often **comparably stable across studies**
- Transport:
  - Pipeline transport **is mature technology** and **onshore costs are low**, and generally well understood
  - offshore costs are higher, but there are fewer examples of projects
- Storage: Numerous, **inherently site-specific factors**, affect the cost of storage. General estimates imply that low-cost sites exist, but they must be discovered.
- **Harmonization** of costing methodologies and formats of reporting data is desirable in order to increase transparency

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Thank-you!

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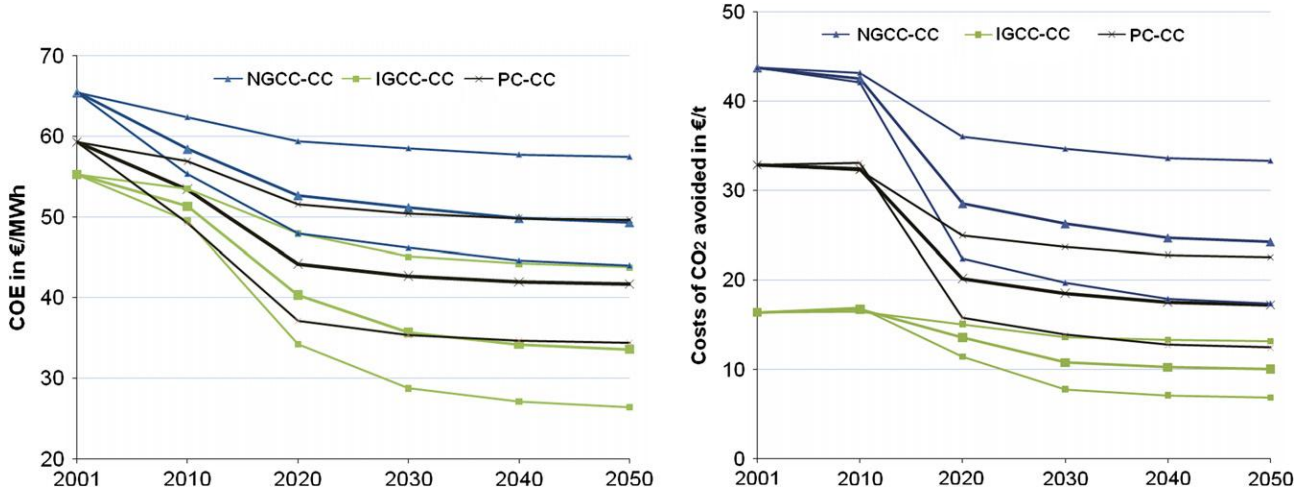
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Estimates of Future Cost of Capture

Significant reduction in the cost of CO_2 capture after 100 GW of capacity (Rubin et al., 2007)

Technology	Capital cost	Total cost
NGCC, post-combustion	20	40
PC, post-combustion	15	26
IGCC, pre-combustion	15	20
Oxyfuel combustion	13	13

Projections of COE and CO_2 mitigation costs (Van den Broek et al., 2010; CCC scenario)

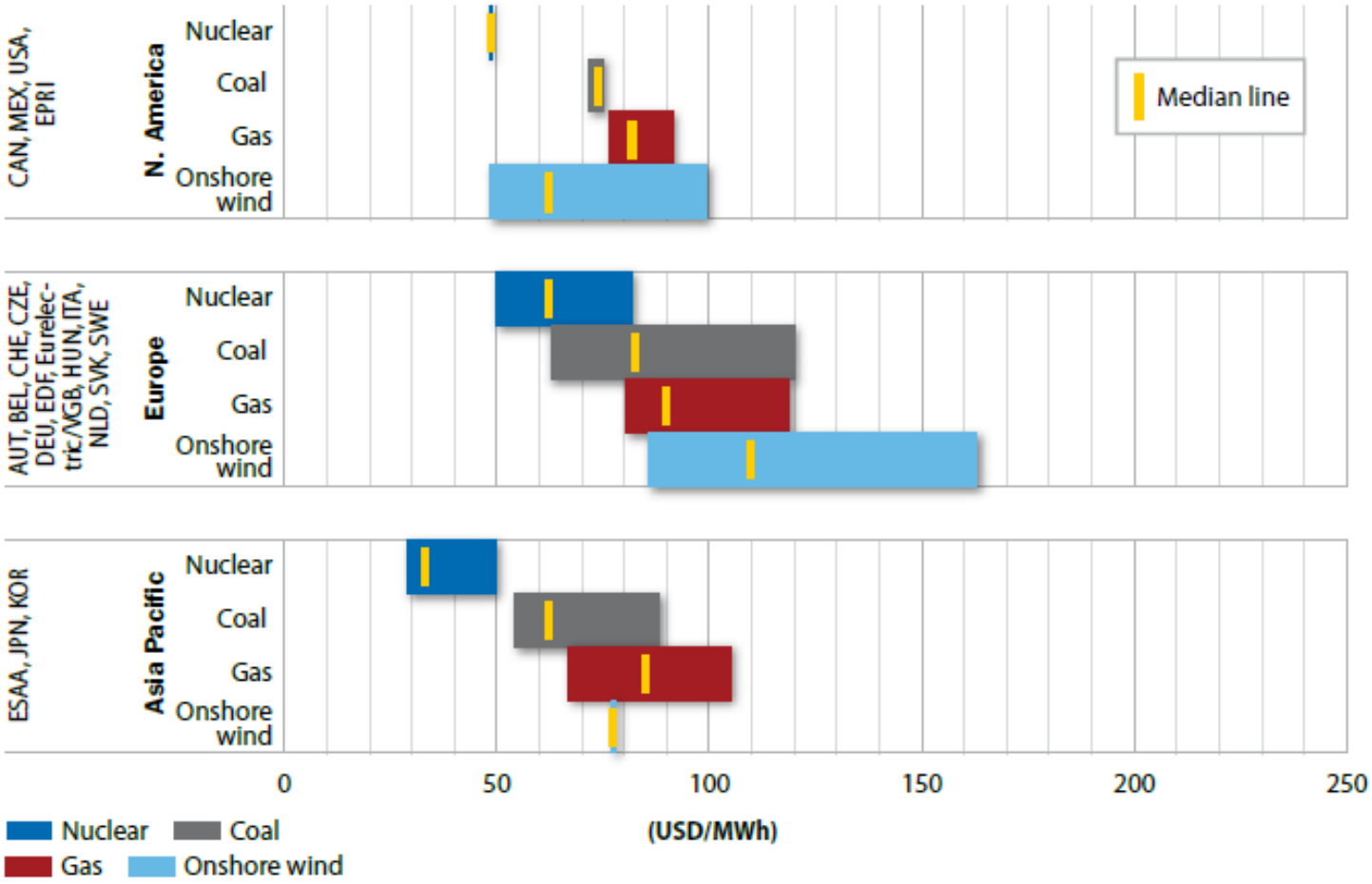


Engineering-economic analysis and historical experience curves **suggests significant cost reduction potential** with deployment

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Figure ES.1: Regional ranges of LCOE for nuclear, coal, gas and onshore wind power plants
(at 5% discount rate)



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Table 6.1: Median case							
Median case specifications		Nuclear	CCGT	US/USC coal	Coal w/90%CC(S)	Onshore wind	Solar PV
Capacity (MW)		1 400.0	480.0	750.0	474.4	45.0	1.0
Owner's and construction		3 681.07	1 018.07	1 915.65	3 336.96	2 236.80	5 759.35
Overnight cost ($/kW)*		4 101.51	1 068.97	2 133.49	3 837.51	2 348.64	6 005.79
O&M ($/MWh)		14.74	4.48	6.02	13.61	21.92	29.95
Fuel cost ($/MWh)		9.33	61.12	18.21	13.04	0.00	0.00
CO_2 cost ($/MWh)		0.00	10.54	23.96	3.22	0.00	0.00
Efficiency (net, LHV)		33%	57%	41.1%	34.8%	-	-
Load factor (%)		85%	85%	85%	85%	26%	13%
Lead time (years)		7	2	4	4	1	1
Expected lifetime (years)		60	30	40	40	25	25
LCOE ($/MWh)	5%	58.53	85.77	65.18	62.07	96.74	410.81
	10%	98.75	92.11	80.05	89.95	137.16	616.55
*Overnight costs include owner's, construction and contingency costs but exclude IDC.							

Notes:

- Years refer to the duration of plant construction.
- All costs are expressed in USD (2008 average values: 1 USD = 0.684 EUR).
- Construction costs include owner's and EPC costs but exclude contingency and IDC.
- Thermal plant efficiencies are net. Fuel price calculations are based on the lower heating value (LHV) of fossil fuels.

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Early commercial plants

Average cost estimates across studies (2010 USD, OECD countries)

Fuel type	COAL			NG
Capture route	**Post-combustion**	**Pre-combustion**	**Oxy-combustion**	**Post-combustion**
Reference plant w/o capture	PC	IGCC (PC)	PC	NGCC
Net efficiency penalty (LHV, %-pts)	10.5	7.5	9.6	8.3
Overnight cost w/ capture (USD/kW)	3 808	3 714	3 959	1 715
Relative overnight cost increase	75%	44% (71%)	74%	82%
LCOE w/ capture (USD/MWh)	107	104	102	102
Relative LCOE increase	63%	39% (55%)	64%	33%
Cost of CO_2 avoided (USD/tCO_2)	58	43 (55)	52	80

Notes: Data cover only CO_2 capture and compression but not transportation and storage. The accuracy of feasibility study capital cost estimates is on average ±30%, hence for coal the variation in average overnight costs, LCOE and cost of CO_2 avoided between capture routes is within the uncertainty of the study. Underlying oxy-combustion data include some cases with CO_2 purities <97%. Overnight costs include owner's, EPC and contingency costs, but not IDC. A 15% contingency based on EPC cost is added for unforeseen technical or regulatory difficulties for CCS cases, compared to a 5% contingency applied for non-CCS cases. IDC is included in LCOE calculations. Fuel price assumptions differ between regions.

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