Economic assessment of CCS

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China Australia Geological Storage of CO_2

Summer School

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Aims of presentation

- To show:
  - how CCS costs are calculated
  - some of the factors that affect CCS costs
  - how to read the CCS research literature and economic reports
  - how to use economics to compare different CCS projects
  - how economics can be used to make business and investment decisions for CCS

Outline

Part I – Economic methodology

- Fundamentals of cash flow analysis
- Net and incremental cash flow for a project
- Economic indicators – present value

Part II – Calculating the effectiveness of CO_2 mitigation

- CO_2 avoided
- $ per tonne CO_2 avoided
- Cost of electricity

Outline

Part III – Evaluating CCS projects

- Main factors affecting CCS costs
- Factors affecting capture costs
- Factors affecting transport and injection costs

Part IV – Variability and uncertainty

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Aims of doing economics

1. Assess whether the project is economically viable
2. Compare CCS with alternatives
3. Comparison within CCS projects (trade-offs)

Why use cash flow?

- Most of the literature has analyses that show economics without projecting cash flow.
- This is simplistic.
- Projecting cash flow allows revenues and costs to change over time.
- The effect of tax, inflation and other costs can be changed over time.

Cash Flow

- Cash flow is the cash received less the cash spent over a defined period of time

Net cash flow = cash received

less

cash spent

Simple Cash Flow ($ million)

Year	1	2	3	4	….	27	28
Cash received			400	400	….	400	
Cash spent	500	1,000	150	150	….	150	350
Net cash flow	-500	-1,000	250	250	….	250	-350

Cash in = Revenue

- Examples of CCS revenue
  - Enhanced oil recovery
  - Enhanced coal bed methane recovery
  - Enhanced gas recovery
  - Revenue from a carbon price

Cash spent = Project costs

- Project costs consist of
  - Capital costs
  - Operating costs
  - Abandonment costs

Capital costs (Capex) = One-off costs

- Examples of CCS capital costs
  - CO_2 separation plant
  - Compressors
  - Pipelines
  - Platforms
  - Wells

Operating costs (Opex) = On-going costs

- Example operating costs
  - Maintenance
  - Office overheads
  - Transport tariffs
  - Energy
  - Labour

Abandonment costs = End-of-life costs

- Abandonment includes
  - Plugging and abandoning wells
  - Dismantling and removing platforms
  - Decommissioning process equipment
  - Salvaging equipment (where possible)
  - Site restoration
  - On-going monitoring

Example of a project cash flow

- A coal bed methane project produces 100 Bcf of methane annually. It sells it a price of $4 per Mcf.
- The plant cost $1,500 million and has an operating costs of $150 million annually. Abandonment costs are $350 million.

Q – What is the simple cash flow of the project over a 28 year period (2 yr build, 25 yr operate, 1 yr abandon)?

A – Revenue = 100 Bcf x $4 per Mcf

= $400 million annually

Bcf = billion cubic feet

Mcf = thousand cubic feet

Project Cash Flow ($ million)

Year	1	2	3	4	….	27	28
Revenue			400	400	….	400	
Capex	500	1,000					
Opex			150	150	….	150	
Abandex							350
Net cash flow	-500	-1,000	250	250	….	250	-350

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Example of incremental cash flow

- A similar coal bed methane project employs CO_2 injection. The CCS project has a capital cost of \$600 million, operating costs of \$90 million annually and an abandoning cost of \$140 million.

Q – What is the project cash flow and incremental CCS cash flow if CO_2 injection increases the annual production to 120 billion cubic feet (Bcf) of methane.

A – Revenue = 120 Bcf x \$4 per Mcf

= \$480 million

Incremental increase in revenue = \$480 - 400 million

= \$80 million

Project Cash Flow ($ million)

Year	1	2	3	4	….	27	28
Revenue			400 +80	400 +80	….	400 +80	
Capex	500 +200	1,000 +400					
Opex			150 +90	150 +90	….	150 +90	
Abandex							350 +140
Net cash flow	-700	-1,400	240	240	….	240	-490

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Incremental net cash flow (NCF)

Net cash flow for original project + CCS project

less

Net cash flow for original project

equals

Incremental Net cash flow for CCS project

Incremental CCS Cash Flow ($ million)

Year	1	2	3	4	….	27	28
Revenue			80	80	….	80	
Capex	200	400					
Opex			90	90	….	90	
Abandex							140
Net cash flow	-200	-400	-10	-10	….	-10	-140

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Present value

- One way to present project costs as a single number is the present value (PV)

- PV is the equivalent value of the costs today

- It is the money we would invest today in a bank to enable us to meet the costs of the project as they fall due

Present Value Example ($ million)

Year	0	1	2	3	....	27	28
Cash flow		-200	-400	-10	....	-10	-140
Bank interest							
Balance at start							
Balance at end							

Using bank interest rate = 7%

Discount rate

- The bank rate in the previous example is the discount rate

- In general, the discount rate is the return we would get on an alternative investment

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Calculating Present Value

$$DiscountRate = d\%$$

$$DiscountFactor_n = \frac{1}{(1+d\%)^n}$$

$$PV = \sum_n \frac{dollars_n}{(1+d\%)^n}$$

Simplified NPV calculation ($ million)

Year	Present Value	1	2	3	….	27	28
Revenue				80	….	80	
Capex		200	400				
Opex				90	….	90	
Abandex							140
Net Cash flow		-200	-400	-10	….	-10	-140

Using d% = 7%

$$PV_{factor} = \sum_{n} \frac{factor_n}{(1+d\,\%)^n}$$

Net Present Value (NPV)

- **It is the present value of the NET cash flow**
- **It is the money you have to put in the bank today to match the NET cash flow from the project**

$$
\begin{aligned}
NPV &= \sum PV \\
&= PV_{Revenue} - PV_{Capital} - PV_{Operating} \\
&\quad - PV_{Abandonment}
\end{aligned}
$$

Simplified NPV calculation ($ million)

Year	Present Value	1	2	3	….	27	28
Revenue	814			80	….	80	
Capex	536	200	400				
Opex	916			90	….	90	
Abandex	21						140
Net Cash flow	-659	-500	-400	-10	….	-10	-140
NPV							

$$NPV = \sum PV$$

$$PV_{NCF} = \sum_{n} \frac{NCF_n}{(1+d\,\%)^n}$$

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Other ways of calculating total project costs

- The economics team of the CO2CRC always use NPV
- Other researchers use annualised cost with amortization or annuities
- Annuities and NPV methods should give the same value when annual cash flows are constant

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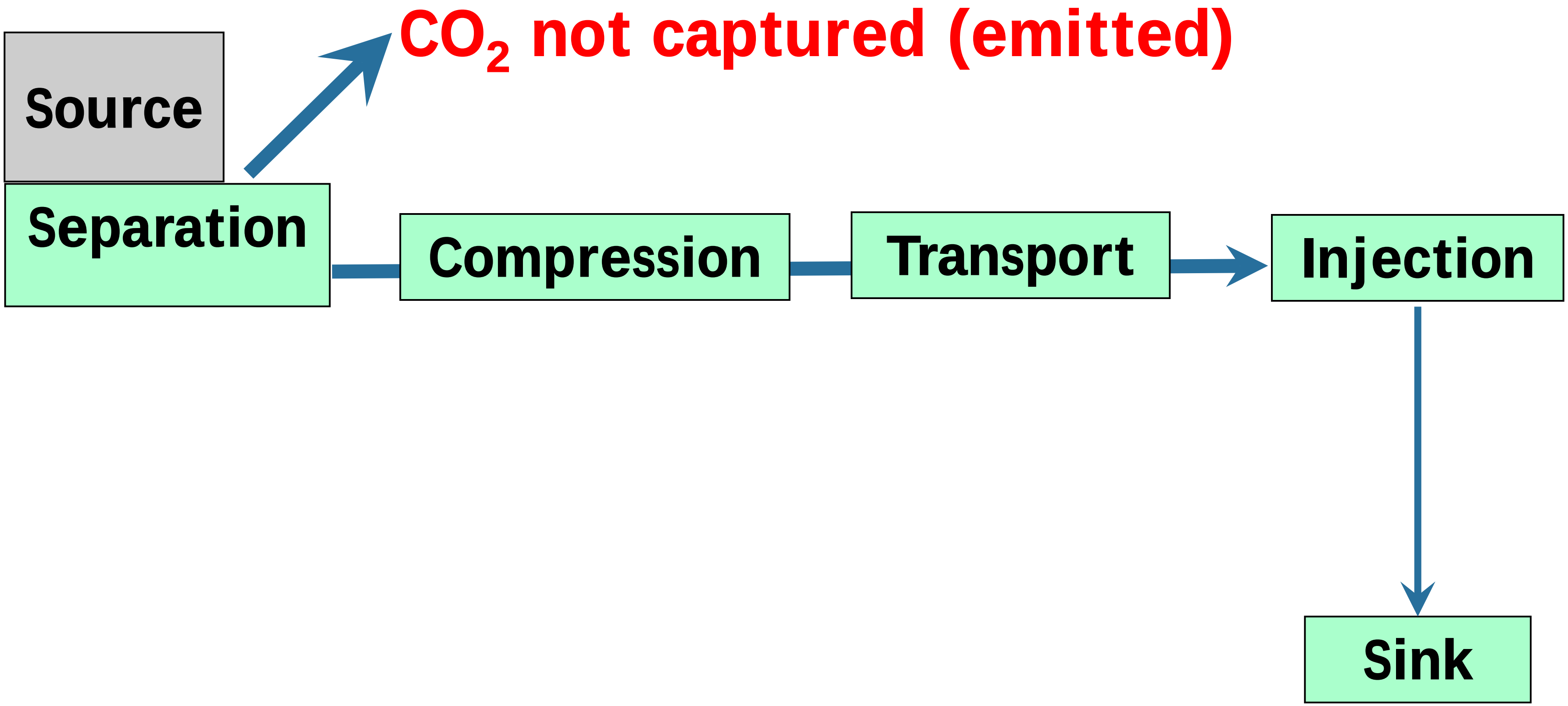
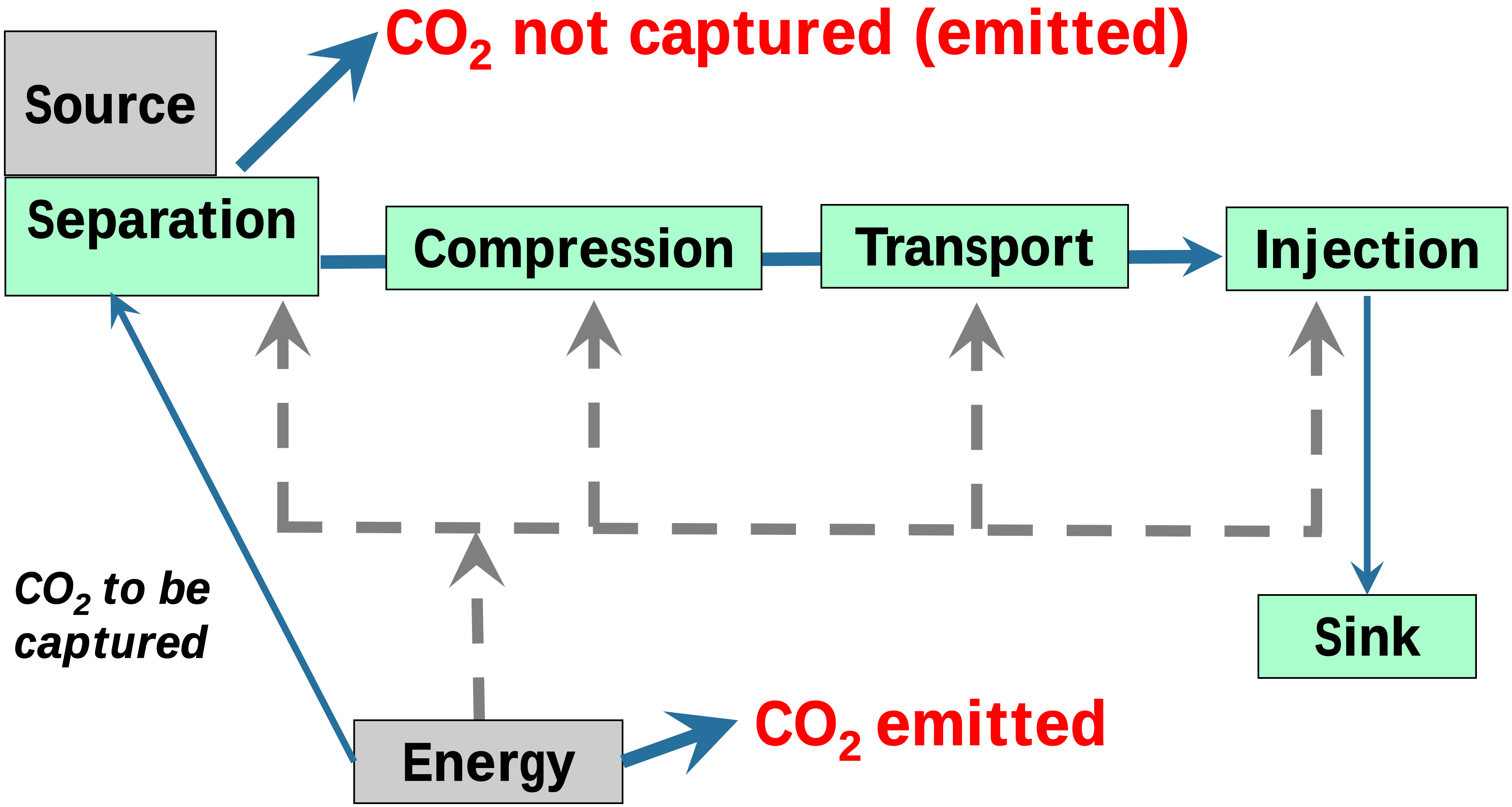
Generic CCS process including energy



Generic CCS process including energy



Energy

- The energy for CCS can come from –
  - Coal
  - Oil
  - Gas
  - Biomass
  - Solar
  - Wind
  - etc.
- The energy may come from the same source as the emissions, or a different source

CO_2 avoided

CO_2 avoided = $\boxed{CO_2 \text{ emitted without CCS}}$

less

$\boxed{CO_2 \text{ emitted with CCS}}$

CO_2 avoided in CCS in tonnes

Before CCS

- 100 generated by source
- 100 emitted by source

After CCS

- 100 generated by original source
- 30 generated by CCS facilities
- Capture and store 90% of total CO_2 generated
- 13 emitted
- 87 avoided

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- **\$ per tonne CO_2 avoided**
- Cost of electricity

$ per tonne CO_2 avoided

- Represents the revenue per tonne you need to make CCS viable

- Using PV method –

$$\frac{\$}{tonne\ \ CO_2\ \ avoided} = \frac{PV_{AllCosts}}{PV_{CO_2\ \ avoided}}$$

Incremental cash flow for CCS (in millions)

Year	Present Value	1	2	3	….	27	28
Revenue ($)	814			80	….	80	
Expenses ($)	1473	200	400	90	….	90	140
CO_2 avoided (tonnes)	25			2.5	….	2.5	
Revenue from carbon price ($)							
Net Cash flow ($)							

Cost of CO_2 avoided = $659 million / 25 million tonnes avoided

= $26 per tonne avoided

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Cost of Electricity (COE)

$$PV_{AllCosts} = PV_{Power\ \ Plant} + PV_{CCS\ \ Plant}$$

$$COE_{Sent\ \ Out} = \frac{PV_{AllCosts}}{PV_{Electricity\ \ Sent\ \ Out}}$$

Δ cost of electricity sent out

- Represents the increase in cost of electricity sent out from a power plant
- Important variable in assessing the impact of CCS to the business/home

Change in Cost of Electricity ($/MWh)	=	Cost of Electricity with CCS ($/MWh)	—	Cost of Electricity without CCS ($/MWh)

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Part III – Evaluating CCS projects

- **Main factors affecting CCS costs**
- Factors affecting capture costs
- Factors affecting transport and injection costs

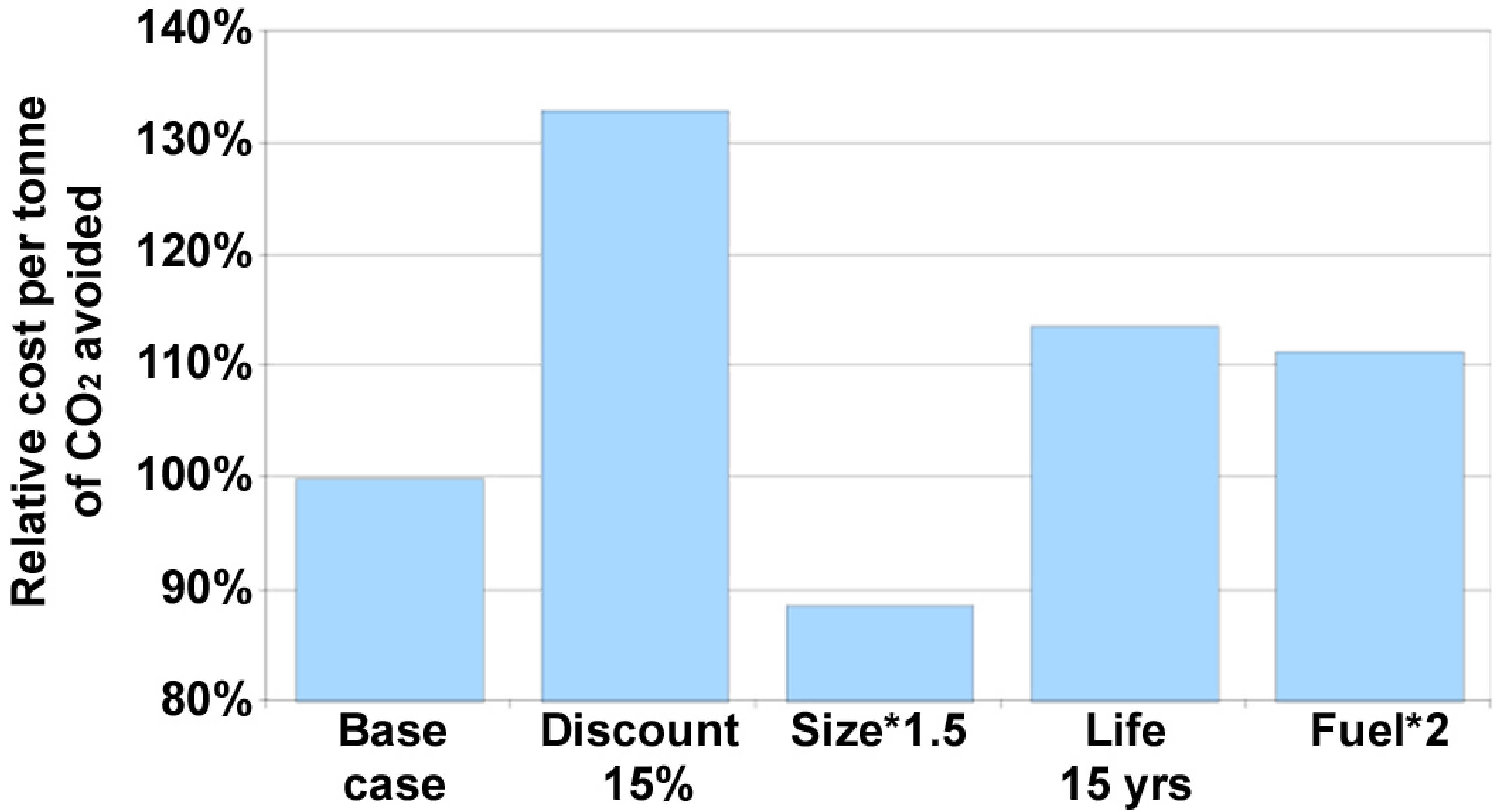
Part IV – Variability and uncertainty

Major factors affecting CCS costs

- Economic factors
  - Discount rate
  - Project life
  - Capex, Opex and Abandex

- Project specific factors
  - CO_2 avoided
  - Energy used
  - Load factor

Effect of assumptions



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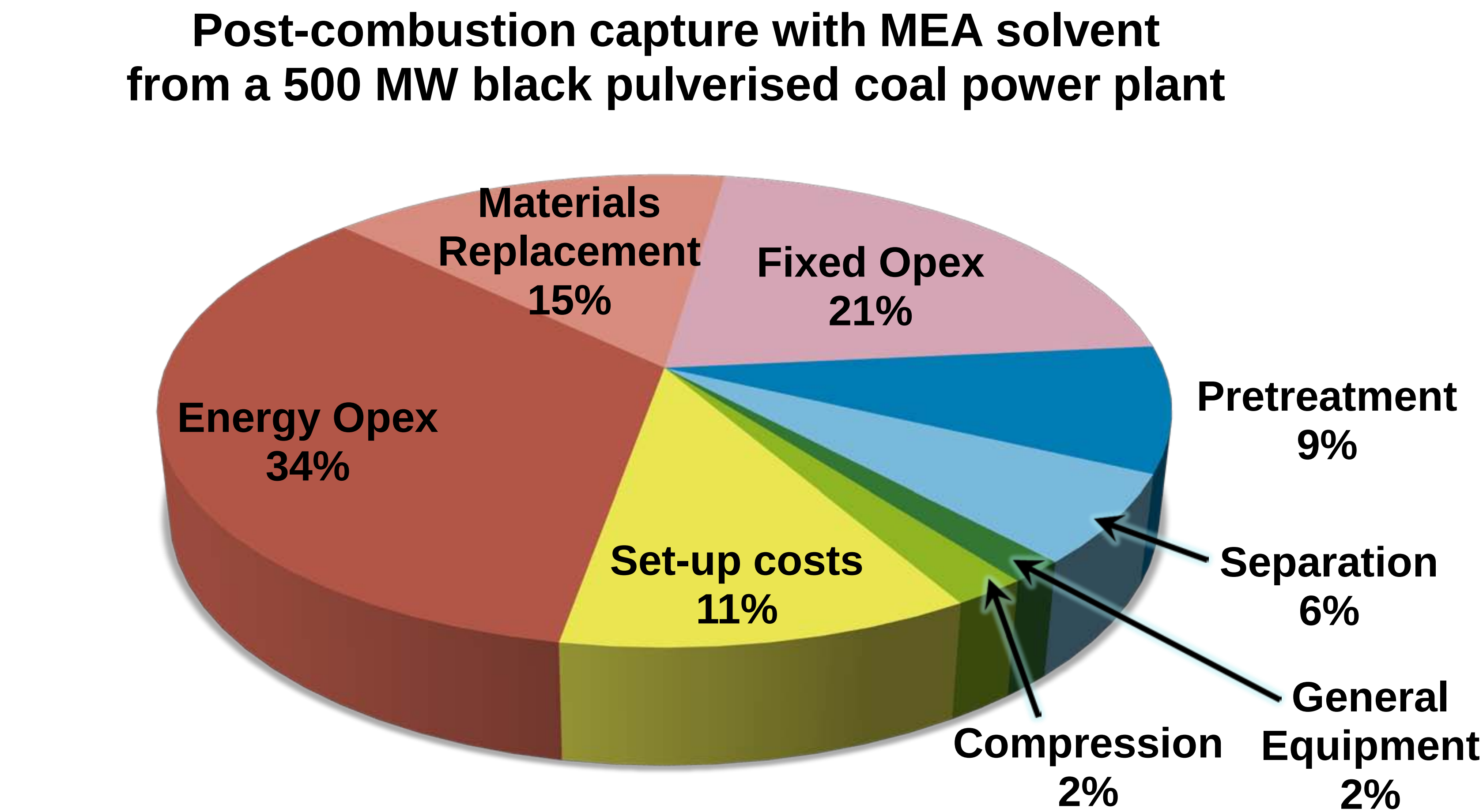
Cost of solvent absorption



Adapted from: Wiley, Ho & Allinson 'Capture of CO_2 from low concentration industrial emission sources in Australia', CO2CRC Symposium, Coolum, 2009

Reducing capture costs

Reduce!

$$\frac{\$}{tonne\ \ CO_2\ \ avoided} = \frac{PV_{AllCosts}}{PV_{CO_2\ \ avoided}}$$

Reduce!

Increase!

- **Reduce Capex** – cheaper, more efficient equipment
- **Reduce Opex** – more efficient equipment, less energy demand
- **Reduce energy penalty** – use improved solvent, heat and process integration

- **Increase CO_2 captured** – improve capture efficiency
- **Reduce CO_2 emitted** – improve process efficiency, change fuel
- **Increase energy efficiency** – heat and process integration

Example: Effect of solvent regeneration energy

- Compare the capture costs and energy demand using MEA or KS1 solvent absorption

Solvent	Solvent loss (kg solvent / tonne CO_2 captured)	Steam used (kg steam / kg CO_2 captured)	CO_2 avoided (tonne / MWh)	Capture Cost ($ / tonne CO_2 avoided)*
MEA	1.6	1.8	0.500	65
KS1	0.35	1.5	0.542	53

78% reduction

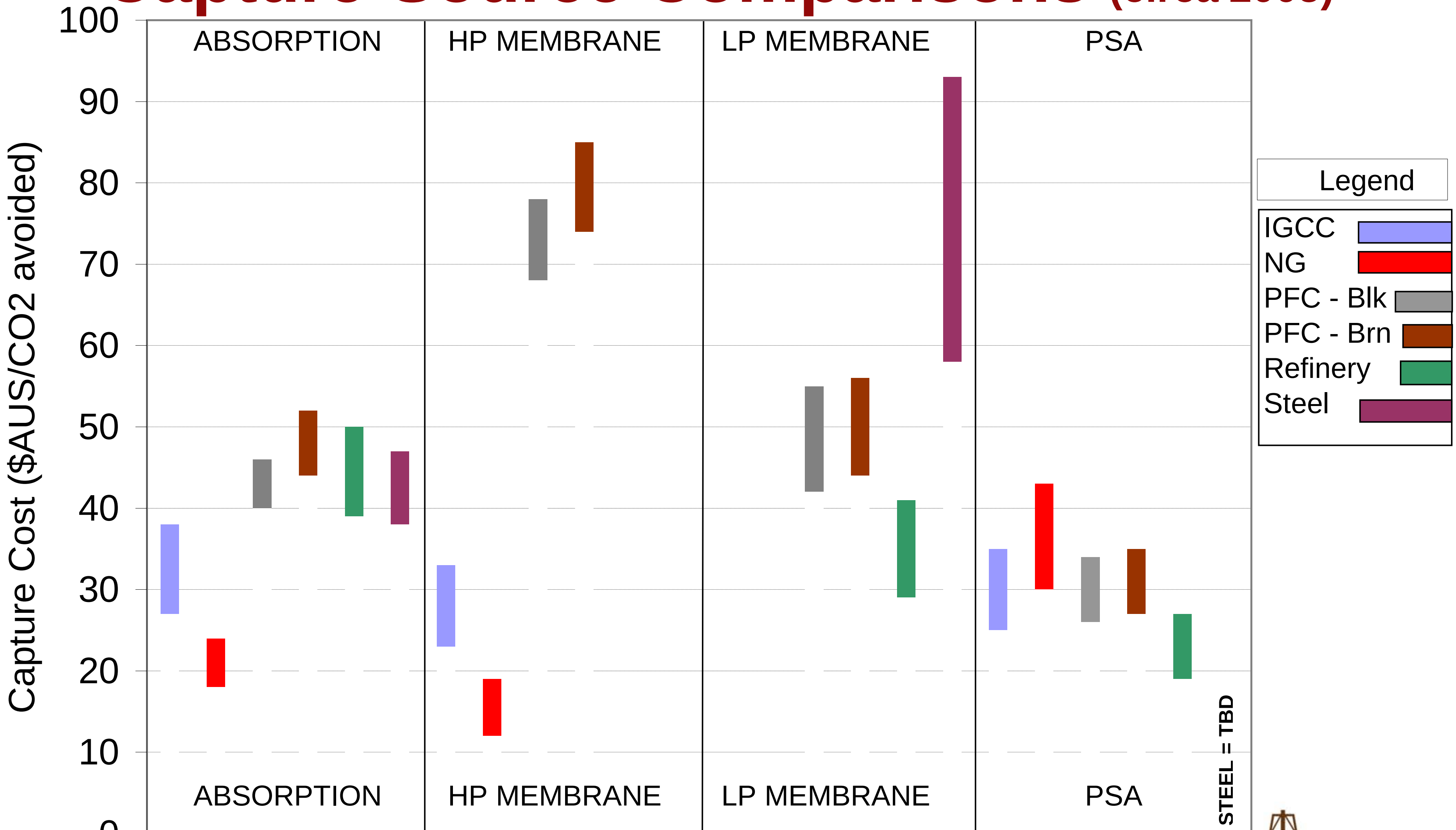
15% reduction

8% increase

18% reduction

*Costs in 2008 Australian dollars

Capture-Source Comparisons (circa 2005)



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- **Factors affecting transport and injection costs**

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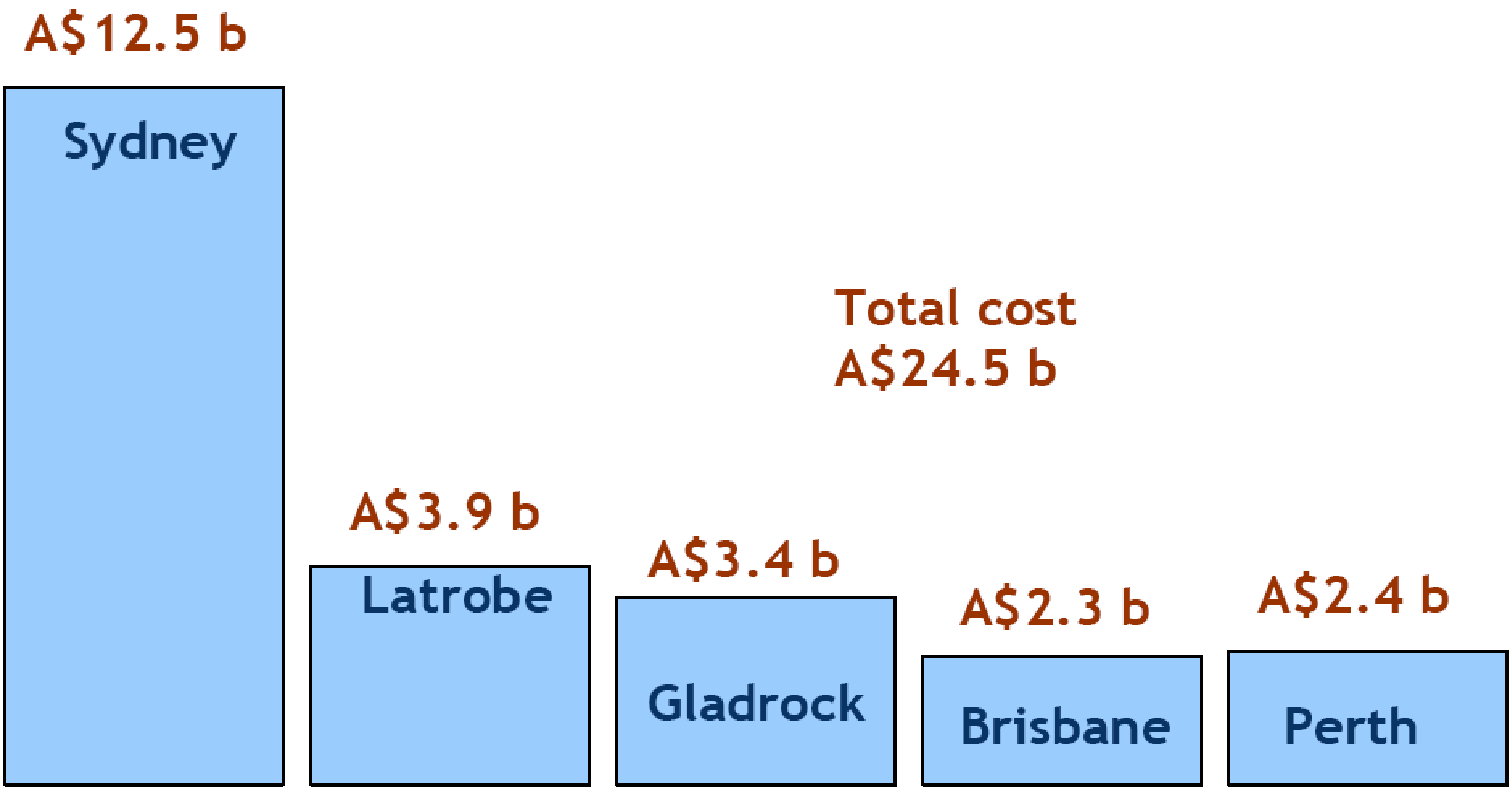
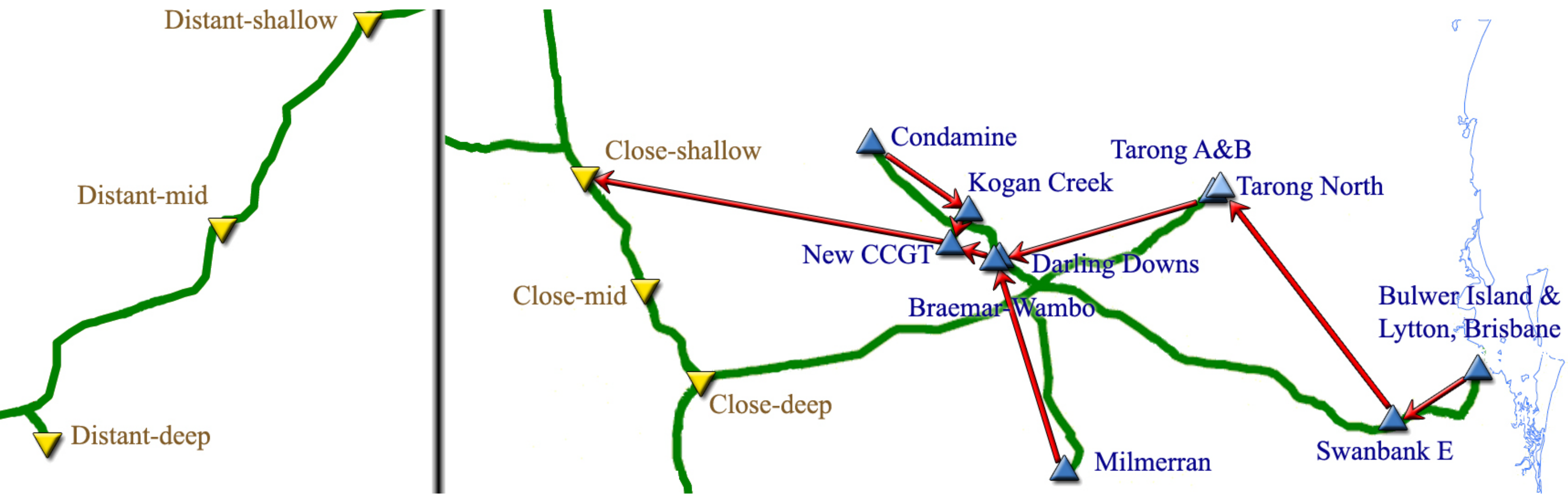
Capital costs for CO_2 transport & injection*

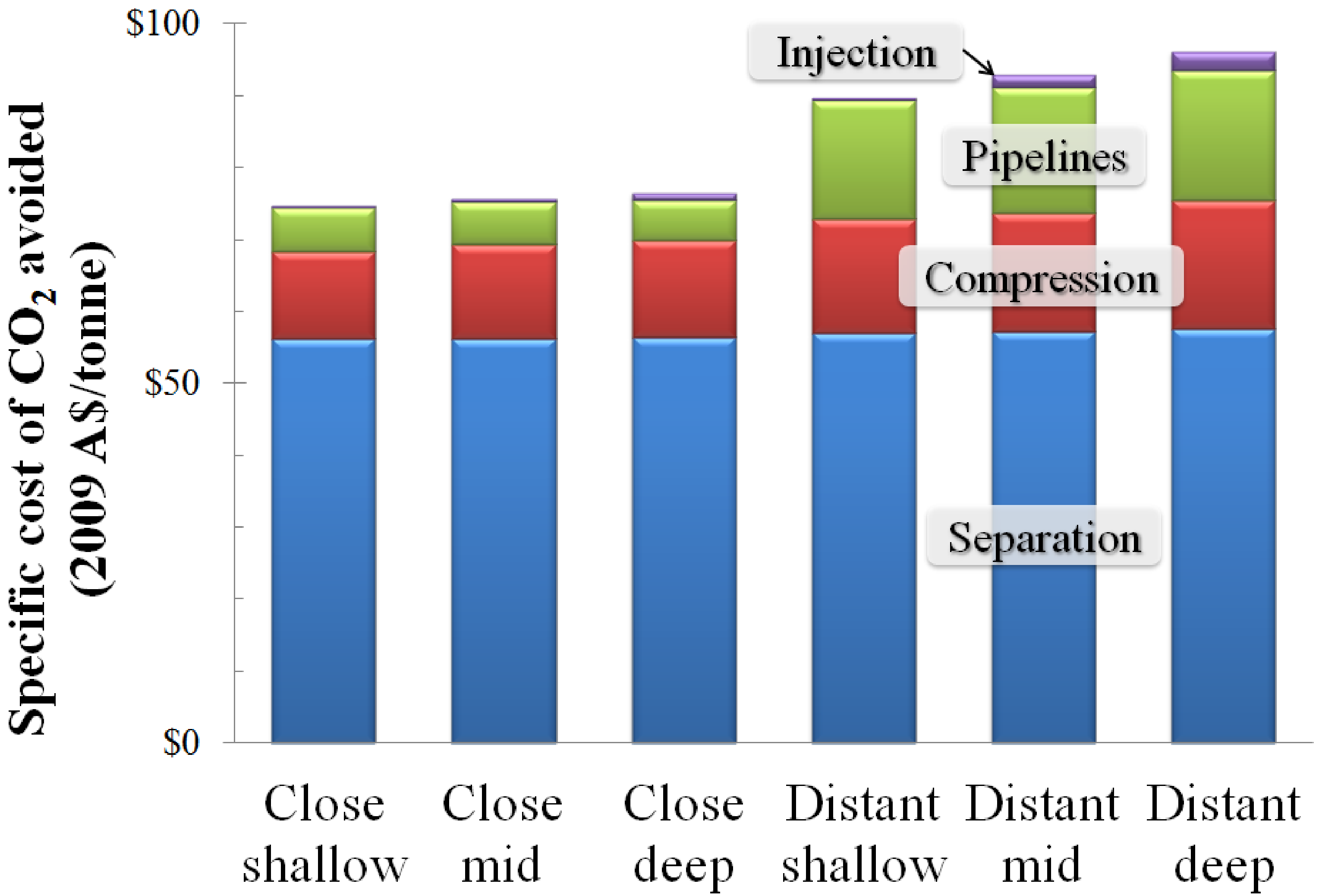


***Costs in billions – 10^9 – of Australian dollars in 2006**

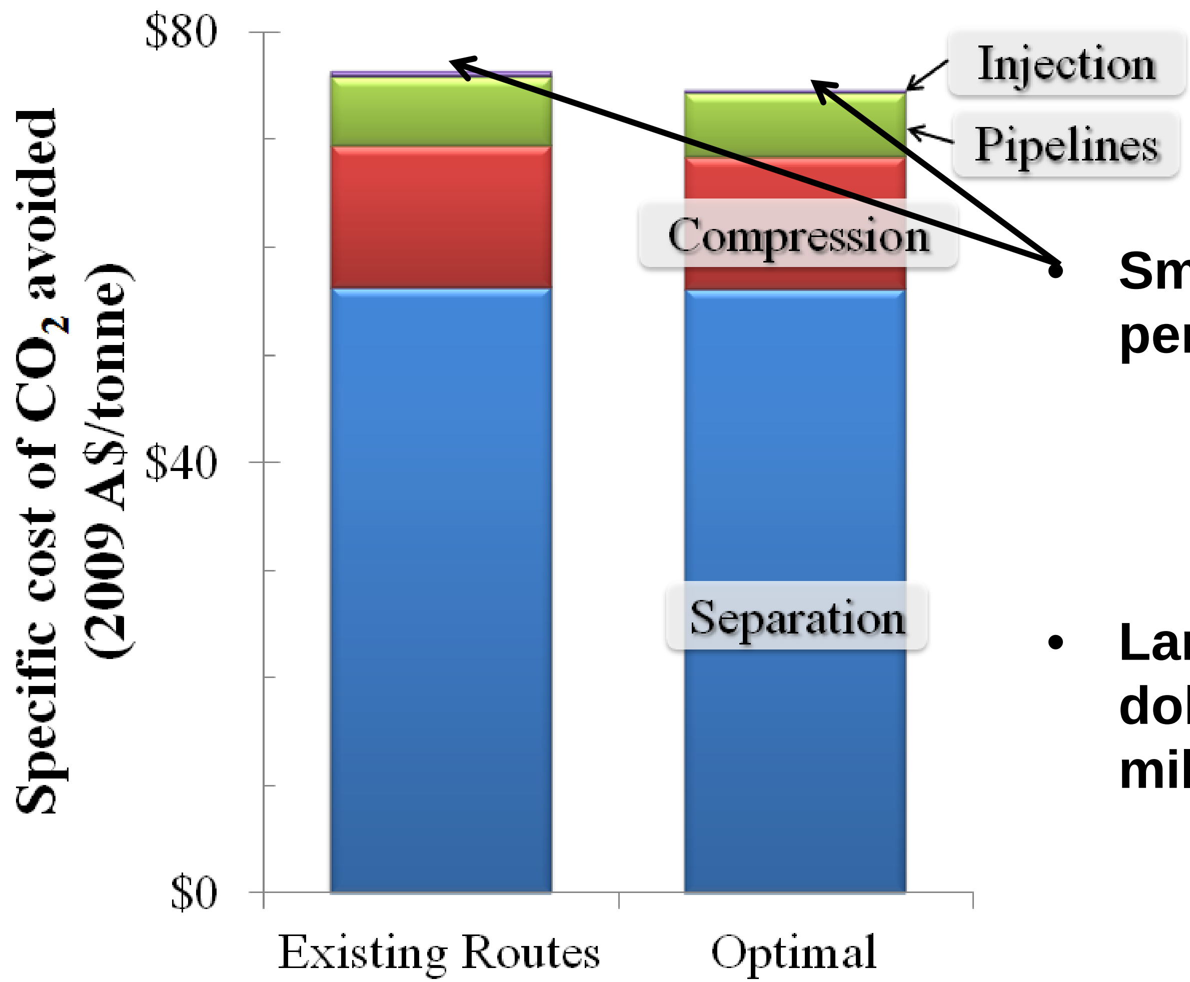
Example: CCS in South-East Queensland



Choosing injection location



Choosing pipeline routes

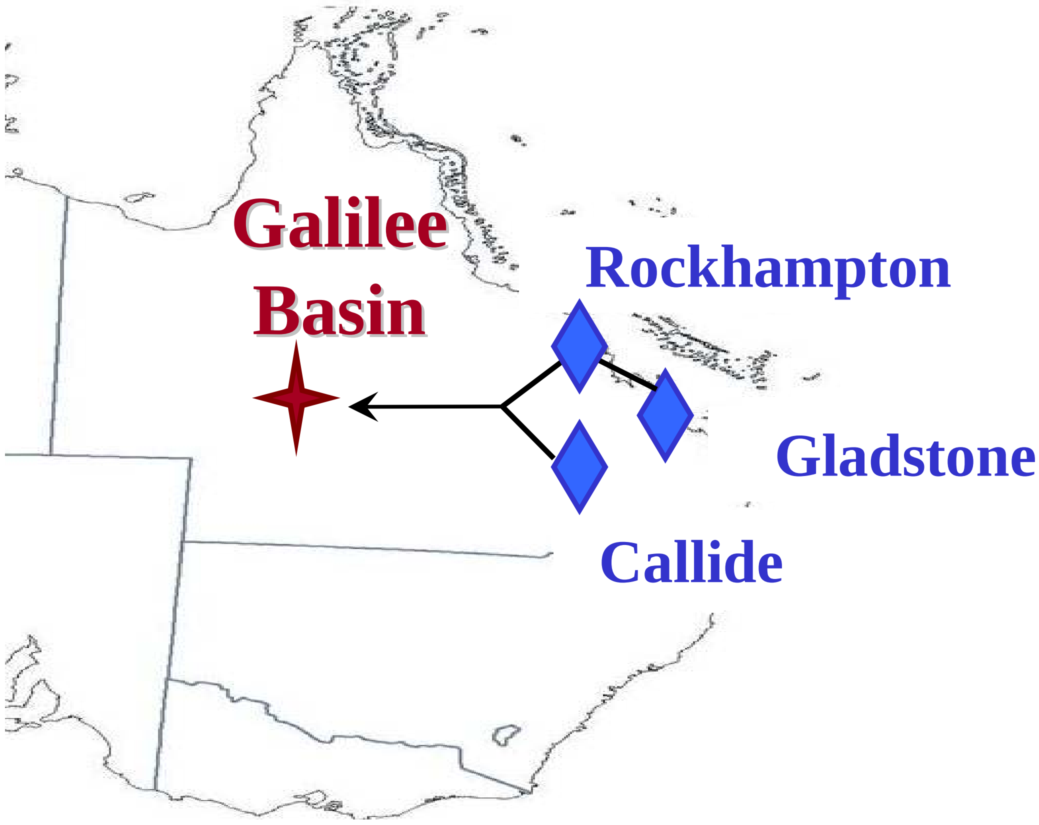


- Small differences in cost per tonne avoided

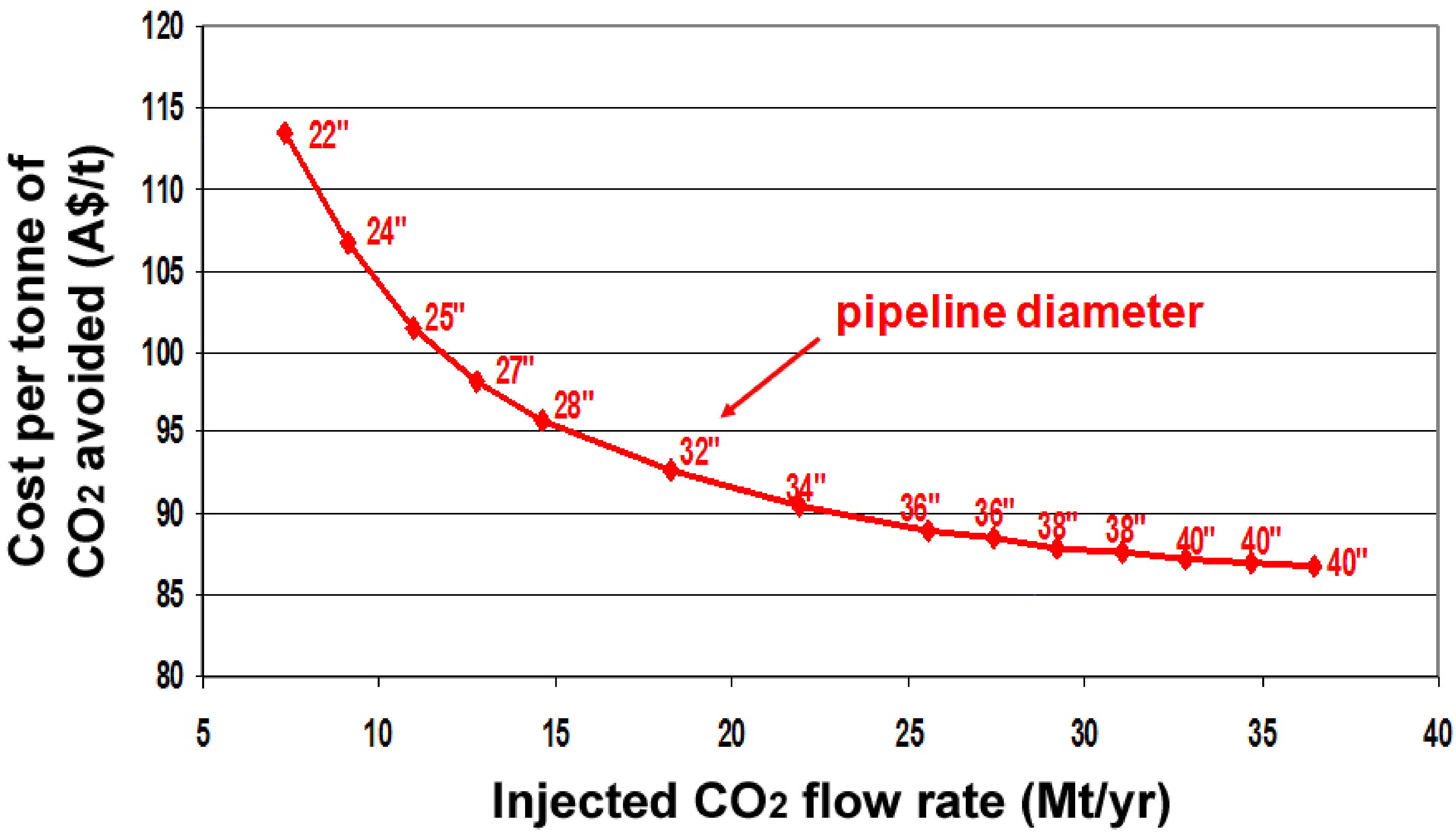
BUT

- Large differences in total dollar values (A$360 million)

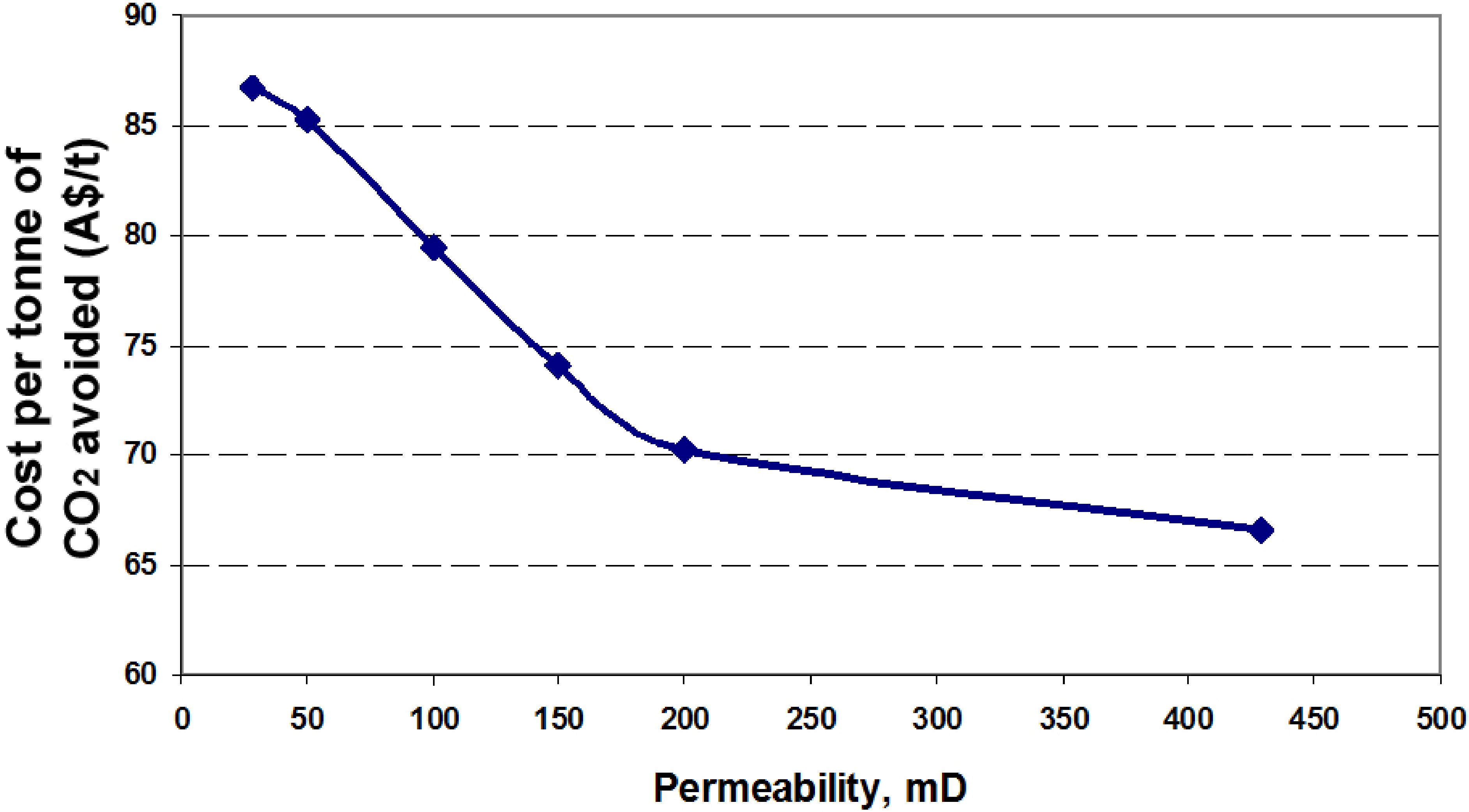
Example: CCS in central Queensland



Effect of flow rate



Effect of sink permeability



Effect of well type

- Horizontal wells compared to vertical wells
- Trade-offs –
  - Horizontal wells = high costs, better injectivity
  - Vertical wells = low costs, less injectivity

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Variability and uncertainty

- Variability
  - Shows the effect of known differences between projects
  - Examples – distance, location, size
- Uncertainty
  - Lack of knowledge about data and future events
  - Examples – energy prices, costs of equipment, reservoir parameters

Uncertainties at each stage

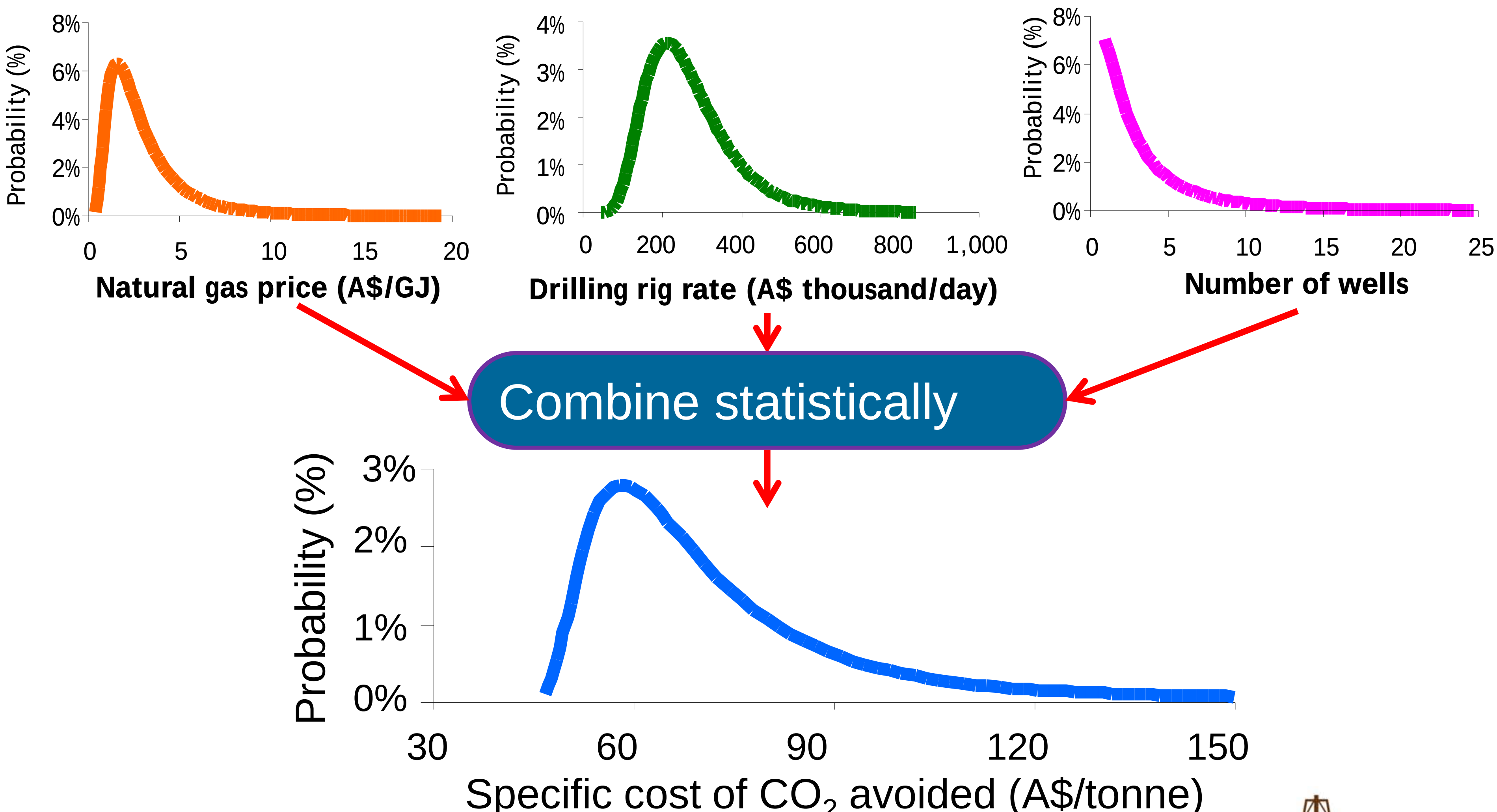
Separation	Transport	Injection	Storage
Capital cost	Capital cost	Rig rate	Seal integrity
Fuel cost	Fuel cost	Fuel cost	Fault reactivation
Feed gas composition	Transport route	Permeability	Monitoring cost
Performance	Booster locations	Thickness	Capacity
Consumable cost	Permitting	Fracture pressure	Reservoir conditions

Single point cost estimates

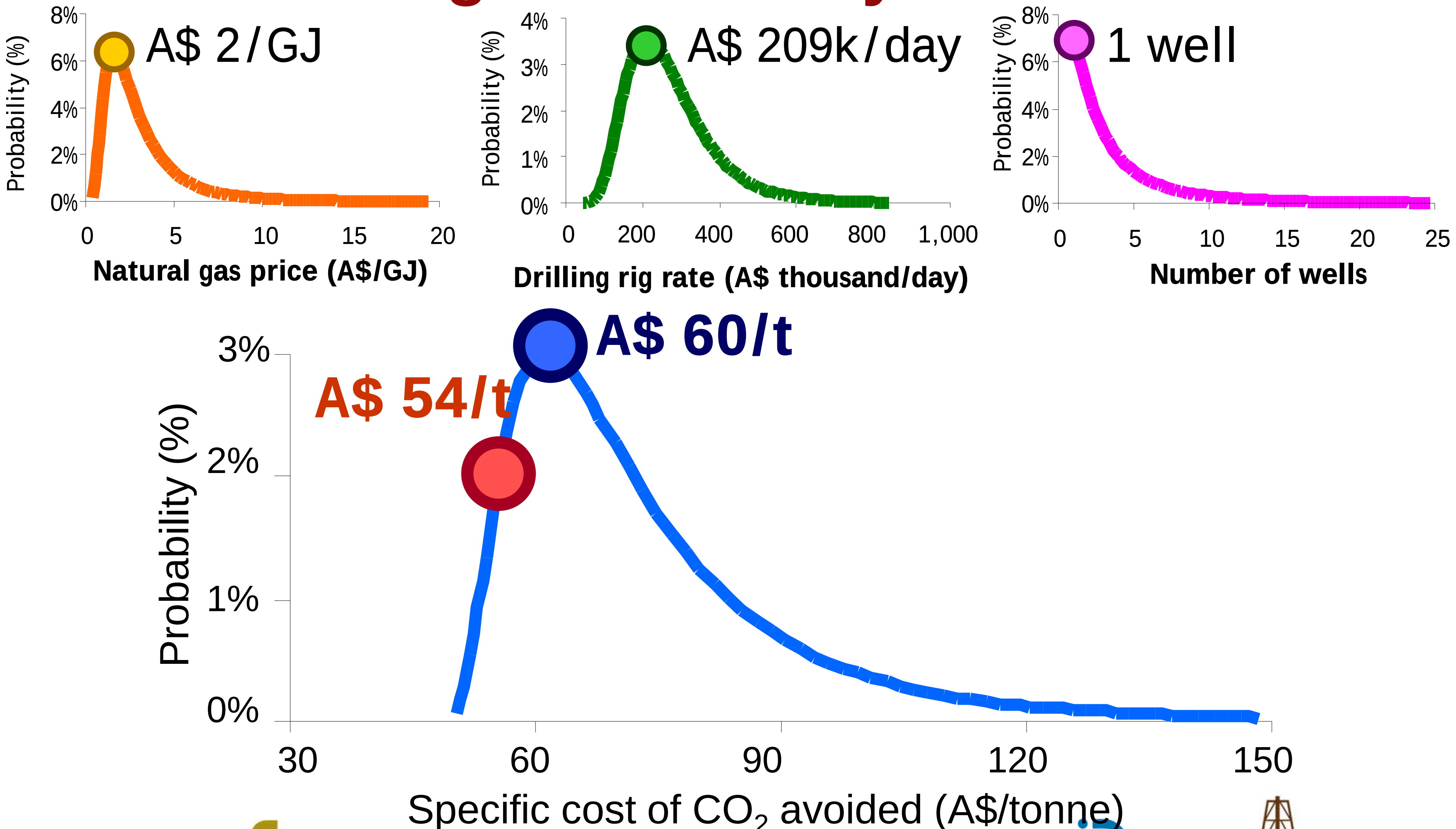
Present values		
Capital cost	1,800	A$
Operating cost	1,1	on
Abandonment		$ million
Total cost	,000	A$ million
CO	55	Million tonnes
Co CCS	54	A$ per tonne

Misleading

Combining uncertain inputs



Combining “most likely” values



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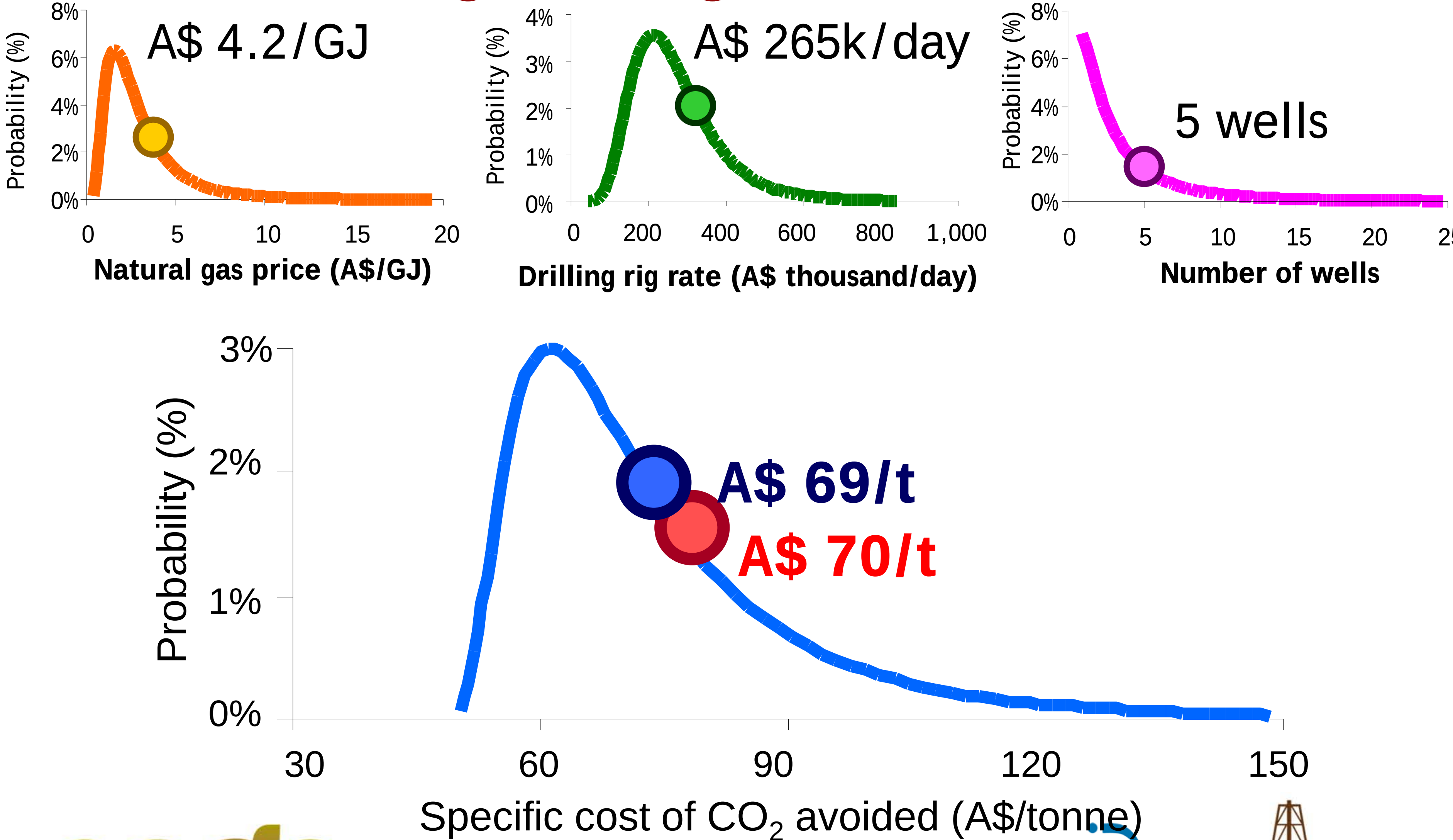
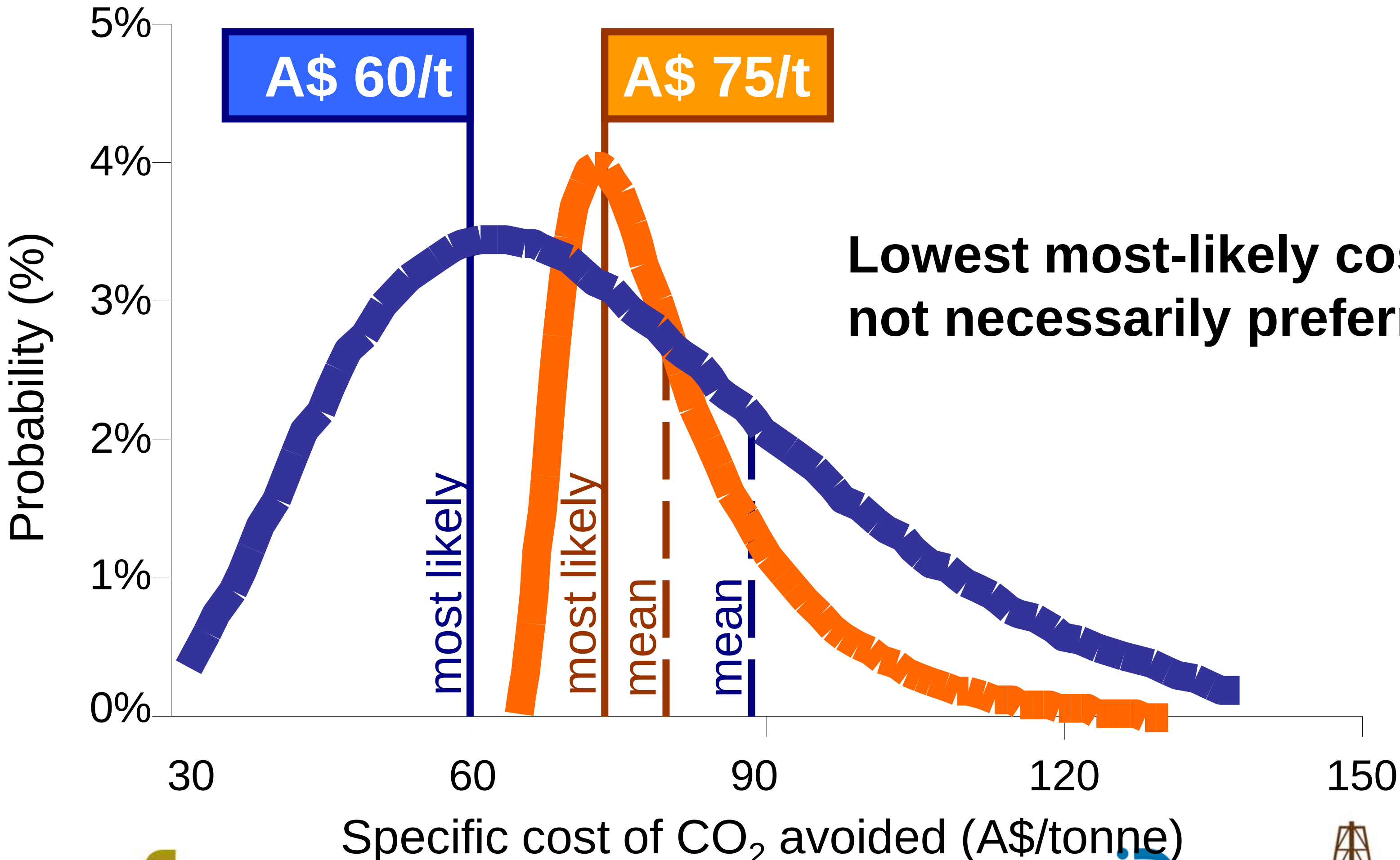
Combining average values



A choice between two projects



Lowest most-likely cost is not necessarily preferred

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Summary

- CCS costs are project specific
- CCS projects require large expenditure
- There is variability and uncertainty in estimating costs

CO2CRC Participants

Australian Government Geoscience Australia

CSIRO

Curtin University of Technology

MONASH University

The University of Adelaide Australia

The University of Melbourne

UNSW The University of New South Wales Sydney • Australia

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Brown Coal Innovation Australia

bp

Chevron

Foundation for Research Science & Technology

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GNS Science

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QER

Queensland Government

RioTinto

sasol *reaching new frontiers*

Shell

Solid Energy Coals of New Zealand

Stanwell Corporation Limited

Schlumberger

Total

State Government Victoria Department of Primary Industries

Government of Western Australia Department of Mines and Petroleum

xstrata coal

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