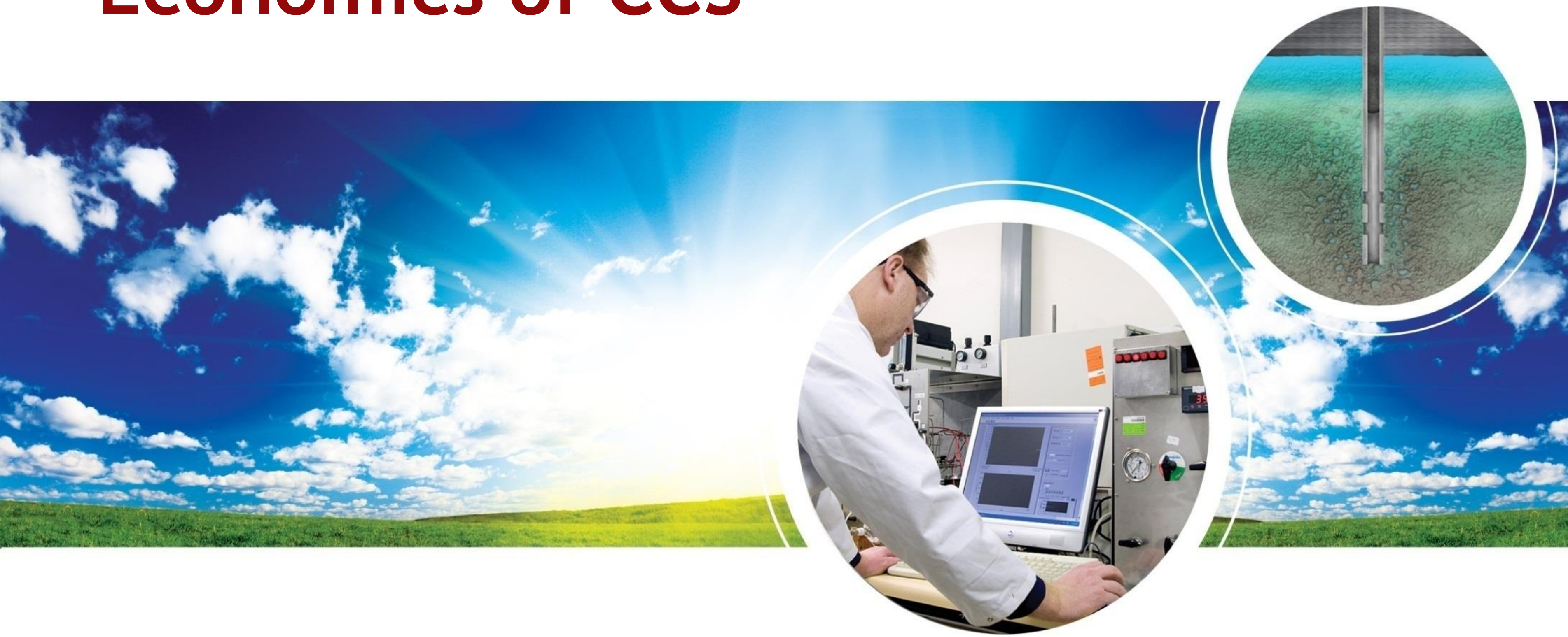
# Economics of CCS

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# Aims of doing economics

- **Assess whether the project is economically viable**
  评估项目的经济可行性
- **Compare CCS with alternatives**
  对比CCS和其他减排技术
- **Design of CCS projects (trade-offs)**
  对比不同的CCS项目方案（权衡取舍）

# Aims of presentation

- To show:
  - how to calculate CCS costs
  - some of the factors that affect CCS costs
  - 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

- Cash flow analysis（现金流分析法）
- Present value（现值）

## Part II - Measures of CCS economics

- $CO_2$ avoided（清除的$CO_2$）
- $ per tonne $CO_2$ avoided（清除每吨$CO_2$的单位成本）

## Part III - Evaluating CCS projects

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

# Cash flow analysis

# Cash Flow

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

Net cash flow = cash received

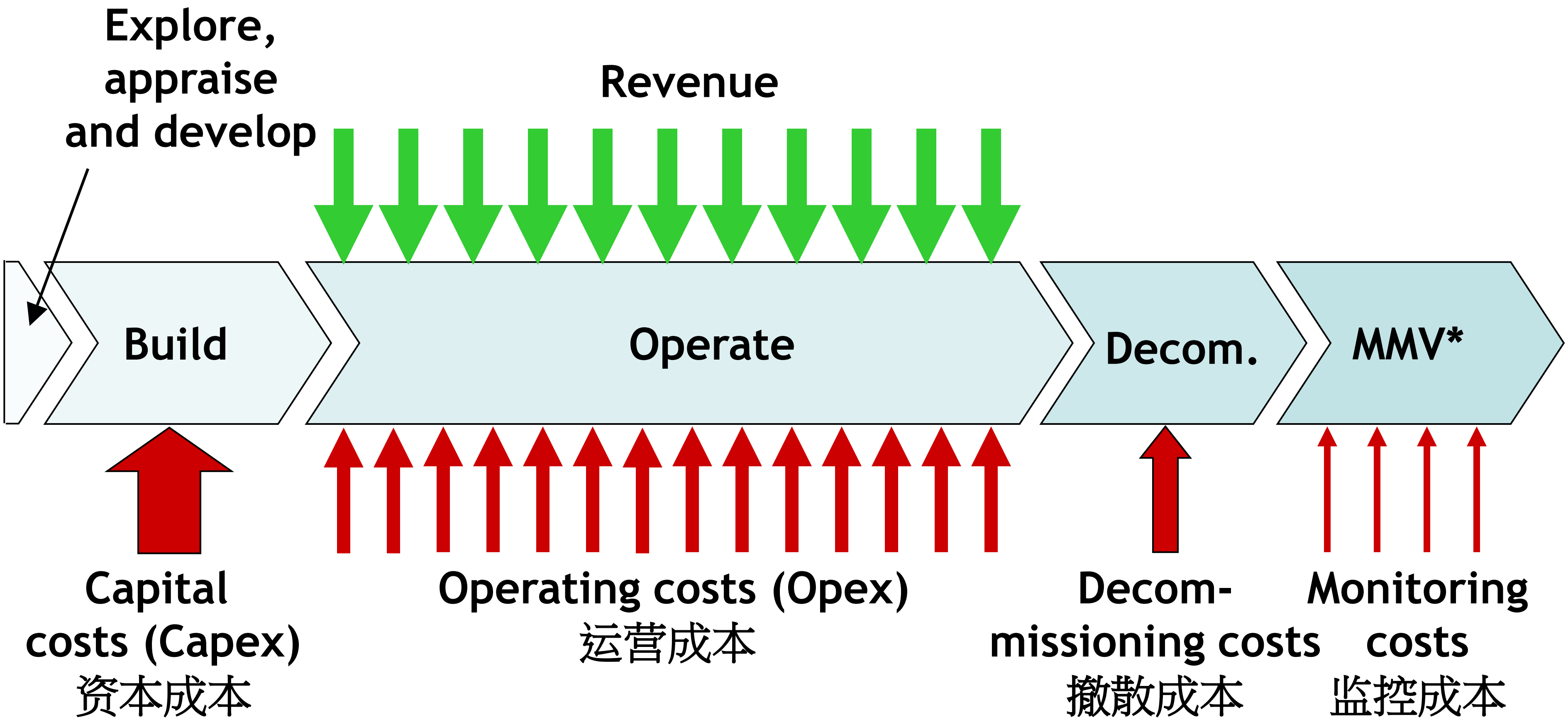
less

cash spent

# Why use cash flow?

- It is simple.
- Projecting cash flow allows revenues and costs to change over time.
- The effect of tax, inflation and other costs can be added or changed over time.

# Components of CCS cash flow




*MMV = Measurement, Monitoring & Verification

# Typical CCS project cash flow

| Build (2-3 yrs) | Operate (20-40 yrs) | Decom. (1+ yrs) |
|---|---|---|
| | Revenue (sales, carbon price) | |
| Capex | Opex | Decom. costs |
| Purchase and install capture plant, compressors, pipelines, platforms, drill and complete wells | Energy, material costs, cooling water, maintenance, office overheads, insurance, labour, etc. | Plugging and abandoning wells, site remediation, platform removal, etc. |
| Net Cash Flow | | |

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# Example of a CCS project cash flow

- A CCS project has -
  - a capital cost of $600 million
  - an operating cost of $90 million per year
  - a decommissioning cost of $140 million

- Project life is 28 years (2 yr build, 25 yr operate, 1 yr decommissioning).

# CCS project Cash Flow ($ million)

| Year | 1 | 2 | 3 | 4 | …. | 27 | 28 |
|---|---|---|---|---|---|---|---|
| Capex | 200 | 400 | | | | | |
| Opex | | | 90 | 90 | …. | 90 | |
| Decom. costs | | | | | | | 140 |
| Project cash flow | -200 | -400 | -90 | -90 | …. | -90 | -140 |

# Present Value

# Present value of project costs

- We use present value to represent future costs on the same basis
- PV is the equivalent value of the costs today
- It is the amount of money we would need to invest today in a bank to enable us to meet the costs of the project when they are due

# Discount rate （贴现率）

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

  Bank

  Shares on the stock market

  Company's own shares

# Calculating Present Value

$$\text{Discount rate} = d\%$$

$$\text{Present value} = \frac{\$ \text{ in year } n}{(1+d\%)^n}$$

- Discount rate = 7%
- What is the present value of $100 received after one year?
- PV = $\$100 / (1+7\%)^1$
  $= \$93.5$

# Calculating Present Value ($ million)

| Year | 1 | 2 | 3 | .... | 27 | 28 |
|---|---|---|---|---|---|---|
| Project cash flow | -200 | -400 | -90 | .... | -90 | -140 |

Present values (7%)

-187

-349

-73

⋮

-14

-21

Present Value of project costs = sum PVs = -1,473

# Net Present Value (PV)

- It is the present value of project net cash flow.
- It represents the project by a single number and takes time into account.
- It is the amount of money we would need to invest today in a bank to enable us to meet the costs of the project over the entire project life.

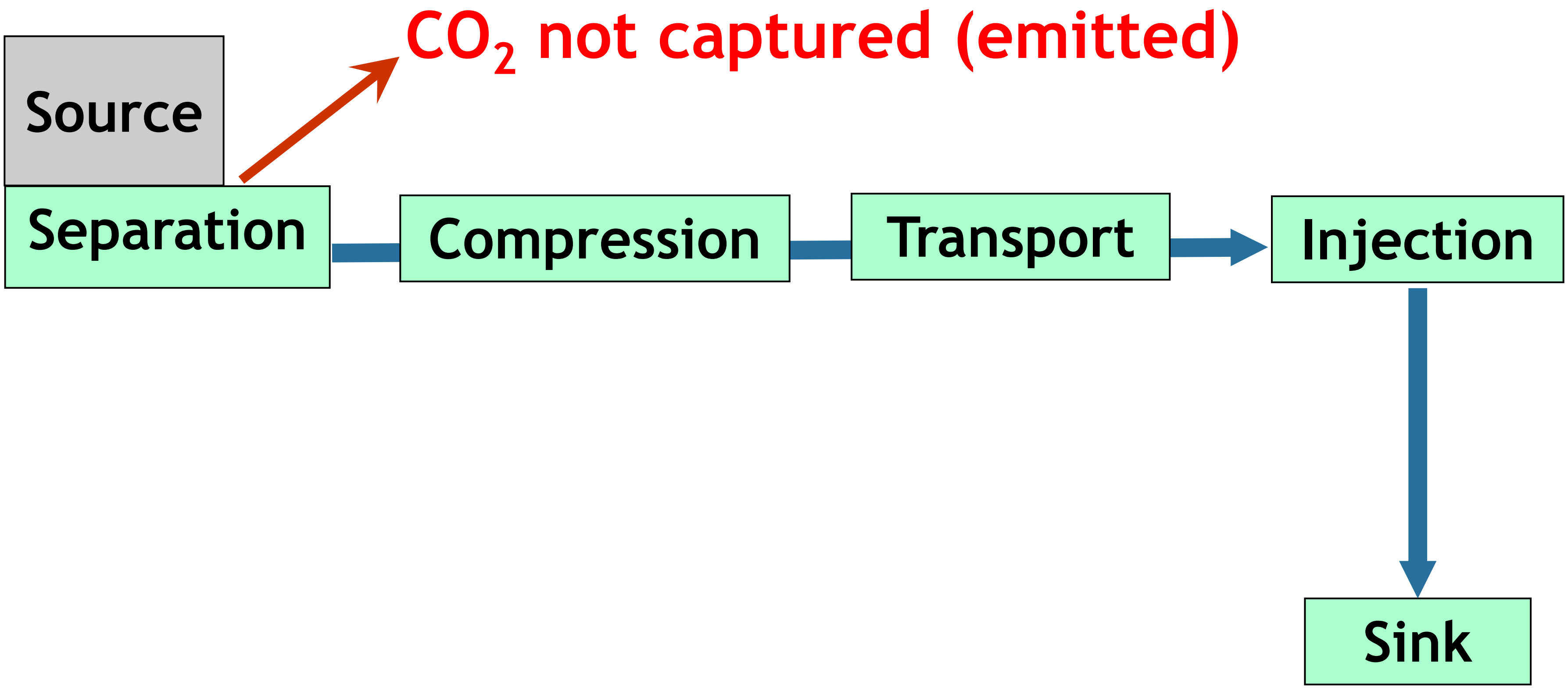
# CO2CRC methodology

- Uses PV method and cash flow analysis over the project life because it is flexible.
  - Allows us to spread capital costs over several years
  - Allows costs to change over time
  - Allows us to change or add variables over time

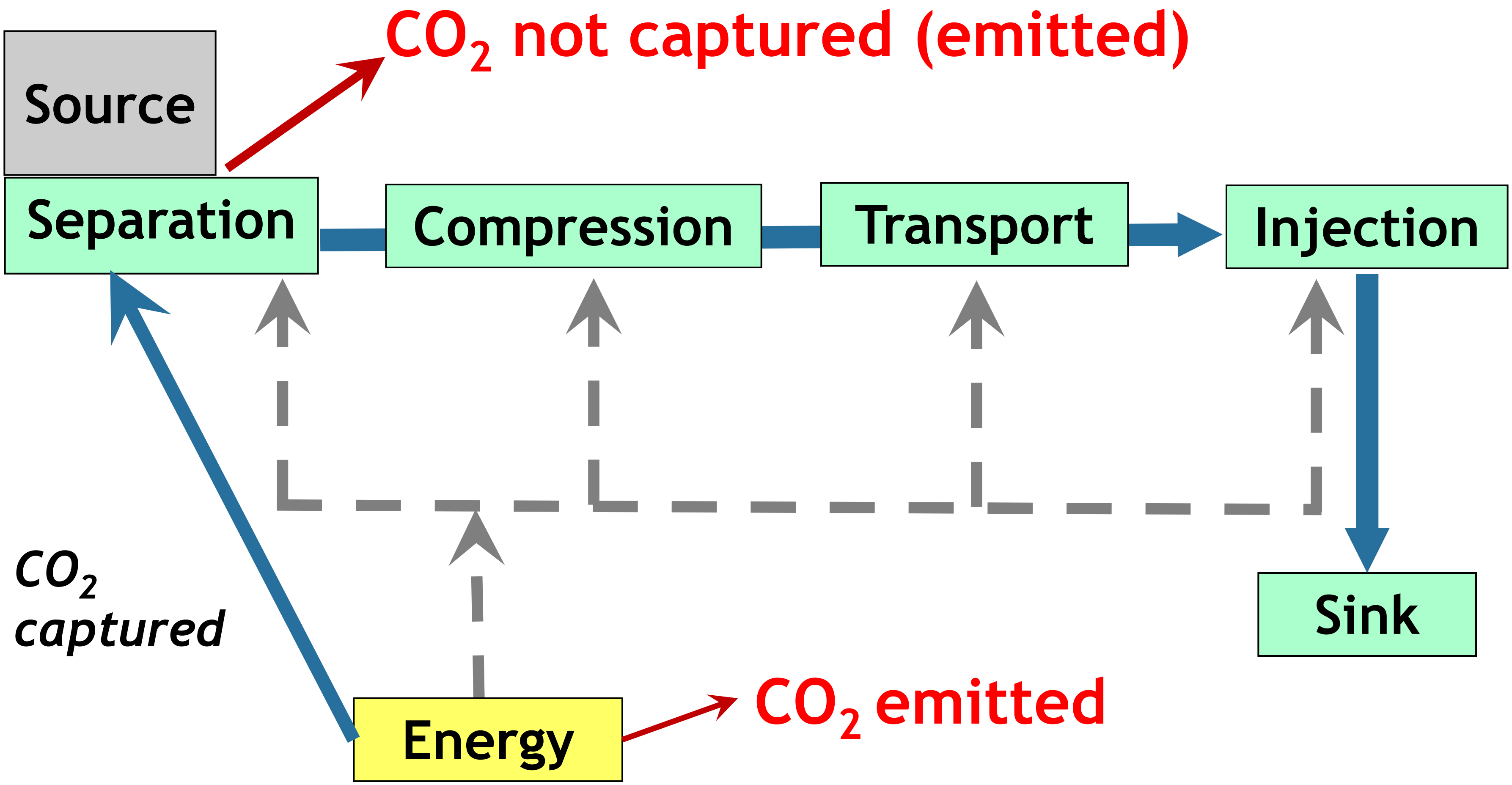
## Measures of CCS economics

# $CO_2$ avoided

# Generic CCS process



# Generic CCS process including energy



# $CO_2$ avoided

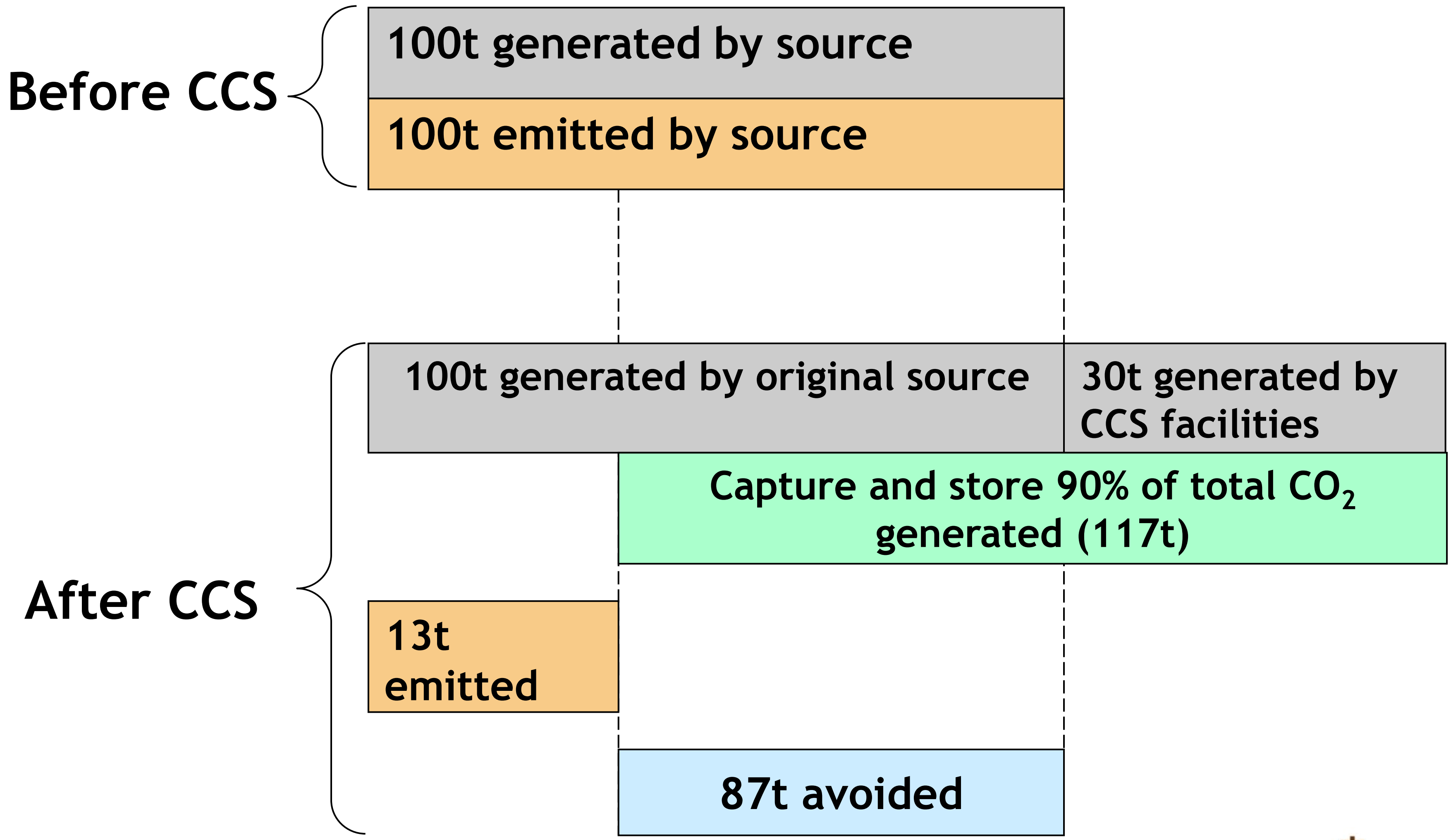
$CO_2$ avoided = $CO_2$ emitted without CCS

less

$CO_2$ emitted with CCS

The amount of $CO_2$ avoided is different from the amount of $CO_2$ captured and stored!

# $CO_2$ avoided by CCS



## Measures of CCS economics

# \$ per tonne $CO_2$ avoided

# $ per tonne $CO_2$ avoided

- Specific cost of $CO_2$ avoided
- Describes overall CCS project costs

- Using PV -

$ per tonne $CO_2$ avoided =

PV of all costs for CCS

divided by

PV of $CO_2$ avoided

# Cash flow for CCS

| Year | Present Value | 1 | 2 | 3 | .... | 27 | 28 |
|---|---|---|---|---|---|---|---|
| Project costs ($ million) | 1,473 | 200 | 400 | 90 | .... | 90 | 140 |
| $CO_2$ avoided (million tonnes) | 31 | | | 3 | .... | 3 | |

$ per tonne $CO_2$ avoided = 1,473 / 31

= $48 per tonne avoided

# Warning

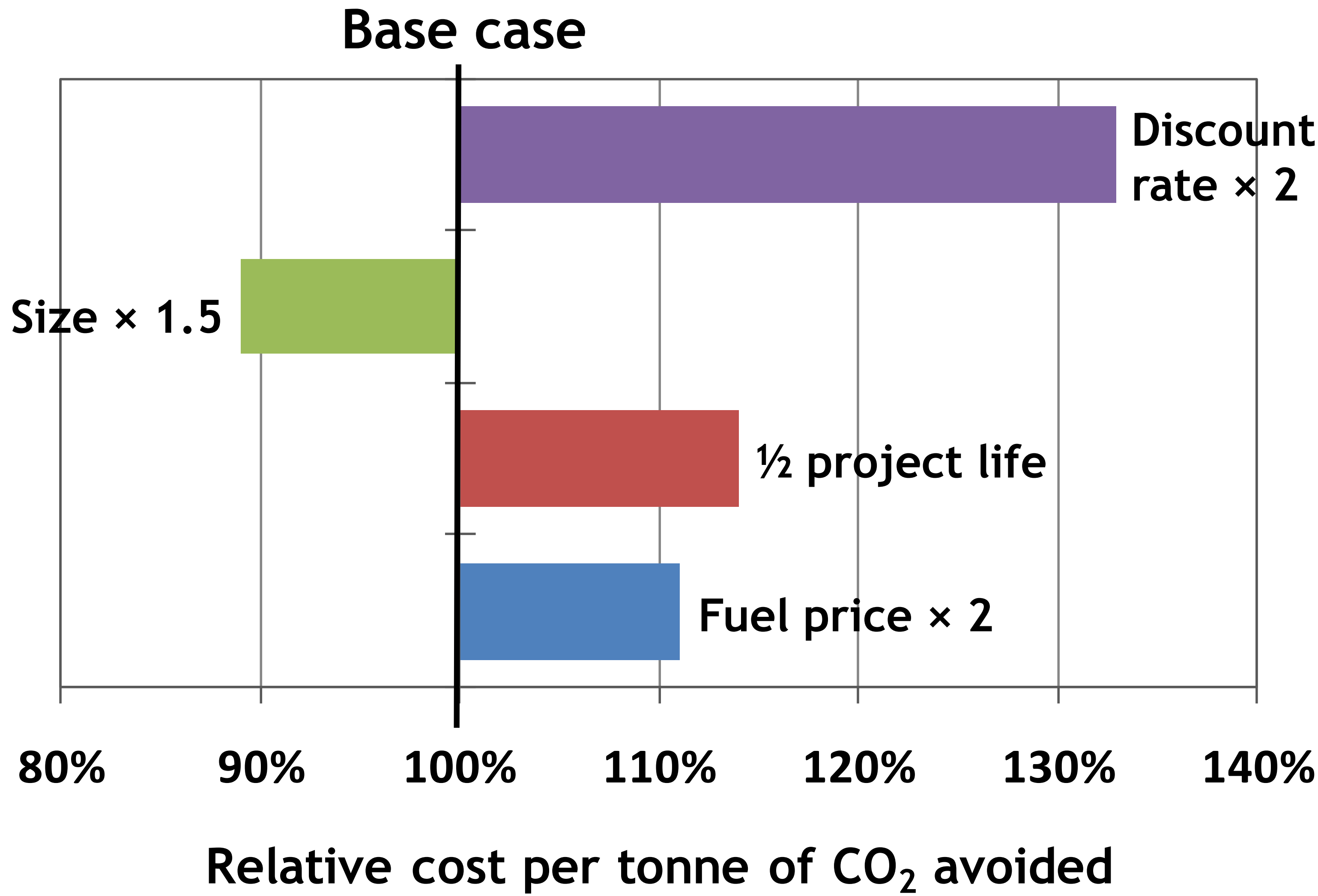
- $CO_2$ avoided is different for CCS, capture alone and storage alone
- Therefore can't add capture $/t avoided to storage $/t avoided
- Do calculation on whole process

# Factors affecting CCS costs

# Economic factors

- Discount rate
- Project life
- Fuel costs
- Exchange rate
- Capex, Opex and Decom. costs

# Effect of assumptions

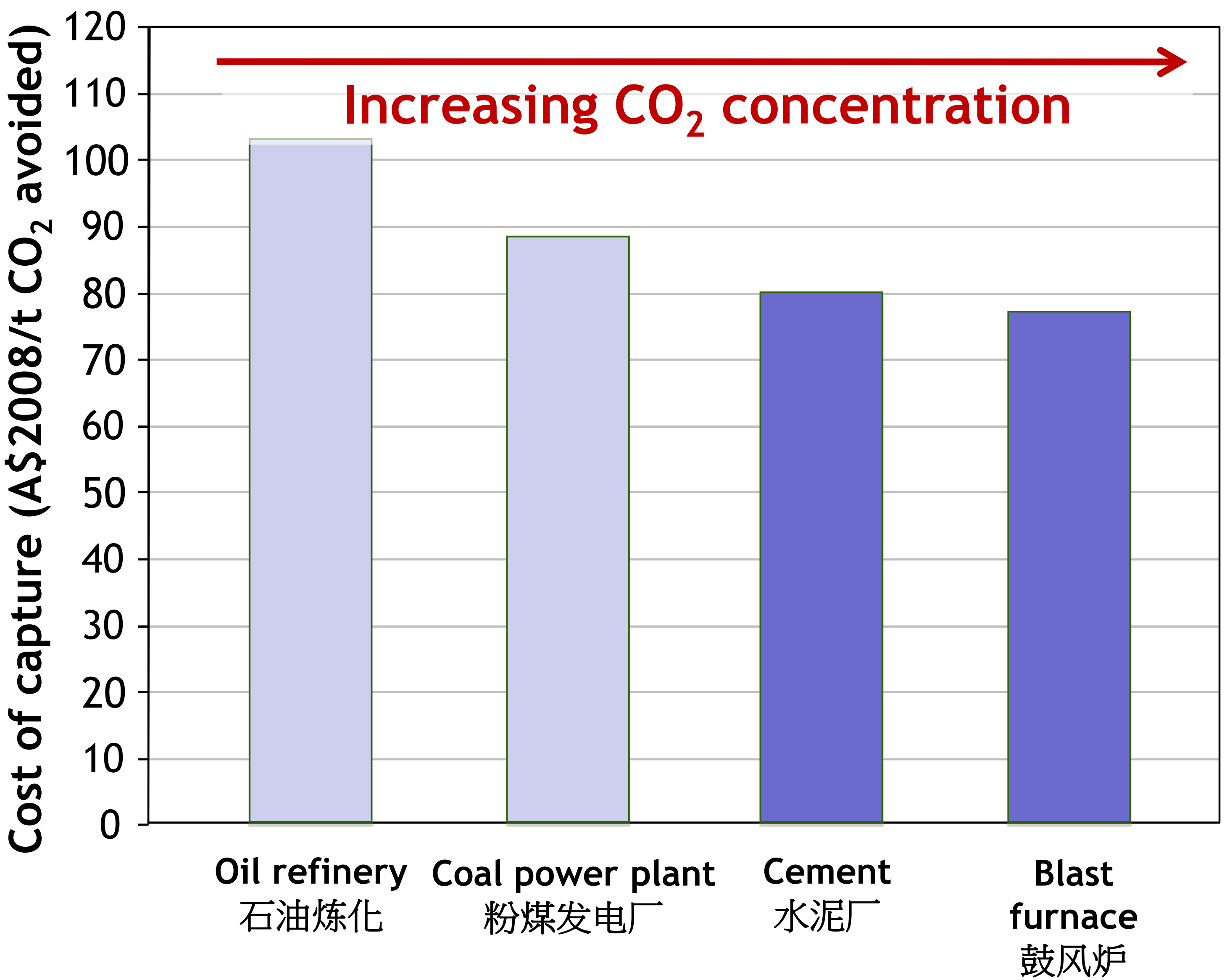


# Project specific factors

| Capture | Transport | Injection |
|---|---|---|
| $CO_2$ concentration | $CO_2$ concentration | $CO_2$ concentration |
| Flow-rate | Flow-rate | Flow-rate |
| Source type | Distances | Areal extent |
| Capture method | Onshore or offshore | Formation properties |
| Source temperature | Land use | Injection well type |
| Source pressure | Topography | Exploration |
| … | … | … |

# Factors affecting capture costs

# Effect of $CO_2$ concentration




Ho et al., International Journal of Greenhouse Gas control, 2011. 5(1):p.46-60.

# Reducing capture costs

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

Reduce! (→ $ per tonne CO2 avoided)

Reduce! (→ $PV_{Costs}$)

Increase! (→ $PV_{CO_2\ avoided}$)

- **Reduce Capex** –
  cheaper equipment
- **Reduce Opex** -
  more efficient equipment, less energy demand
- **Reduce energy required by capture** –
  use improved technologies, heat and process integration
- **Increase $CO_2$ captured** –
  improve capture rate
- **Reduce $CO_2$ emitted** –
  improve process efficiency, change fuel
- **Increase energy efficiency** –
  heat and process integration

# Example: Effect of improving capture technology

- Compare the energy requirement and costs 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 (A$2008 / 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 |

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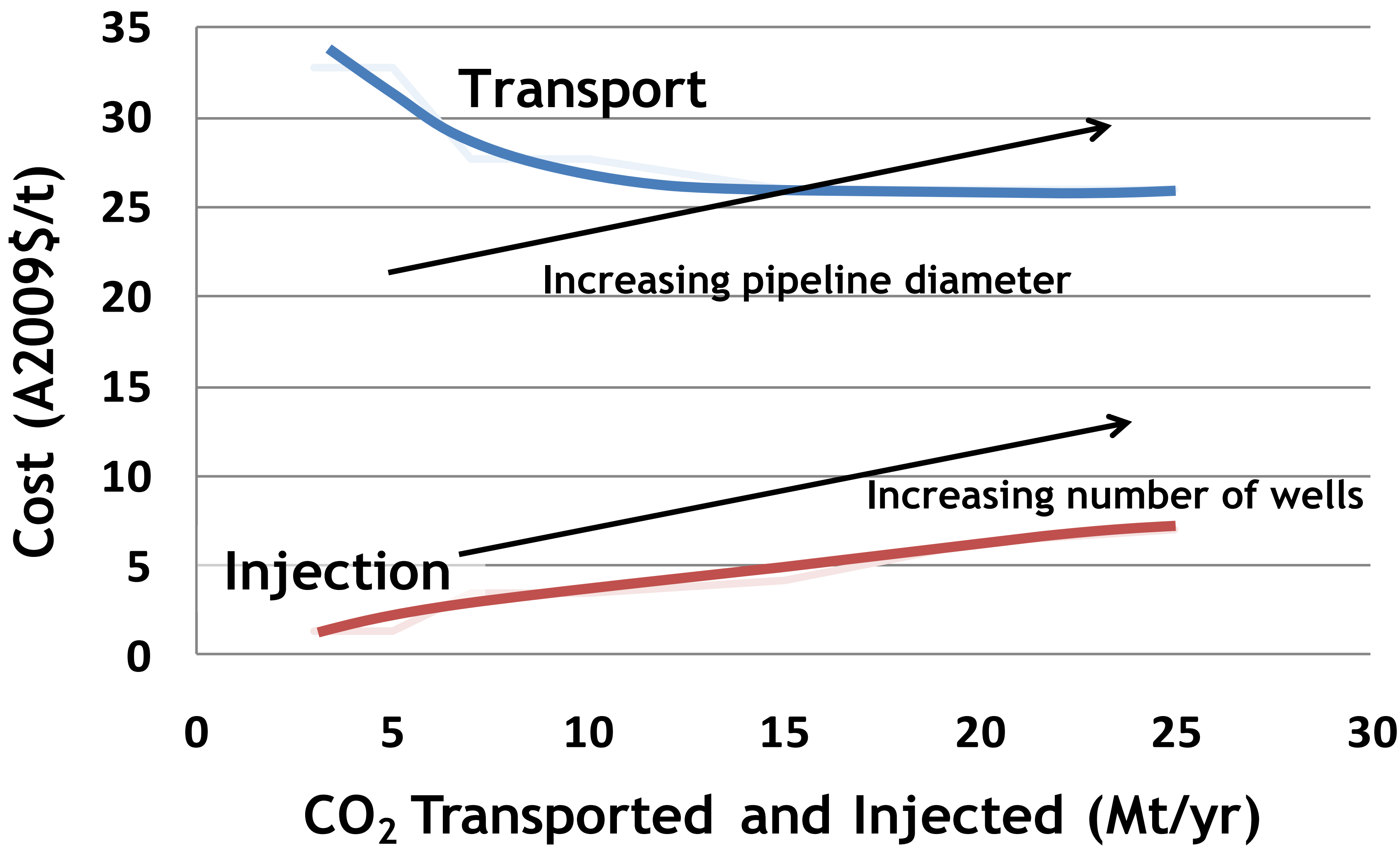
# Factors affecting transport and injection costs

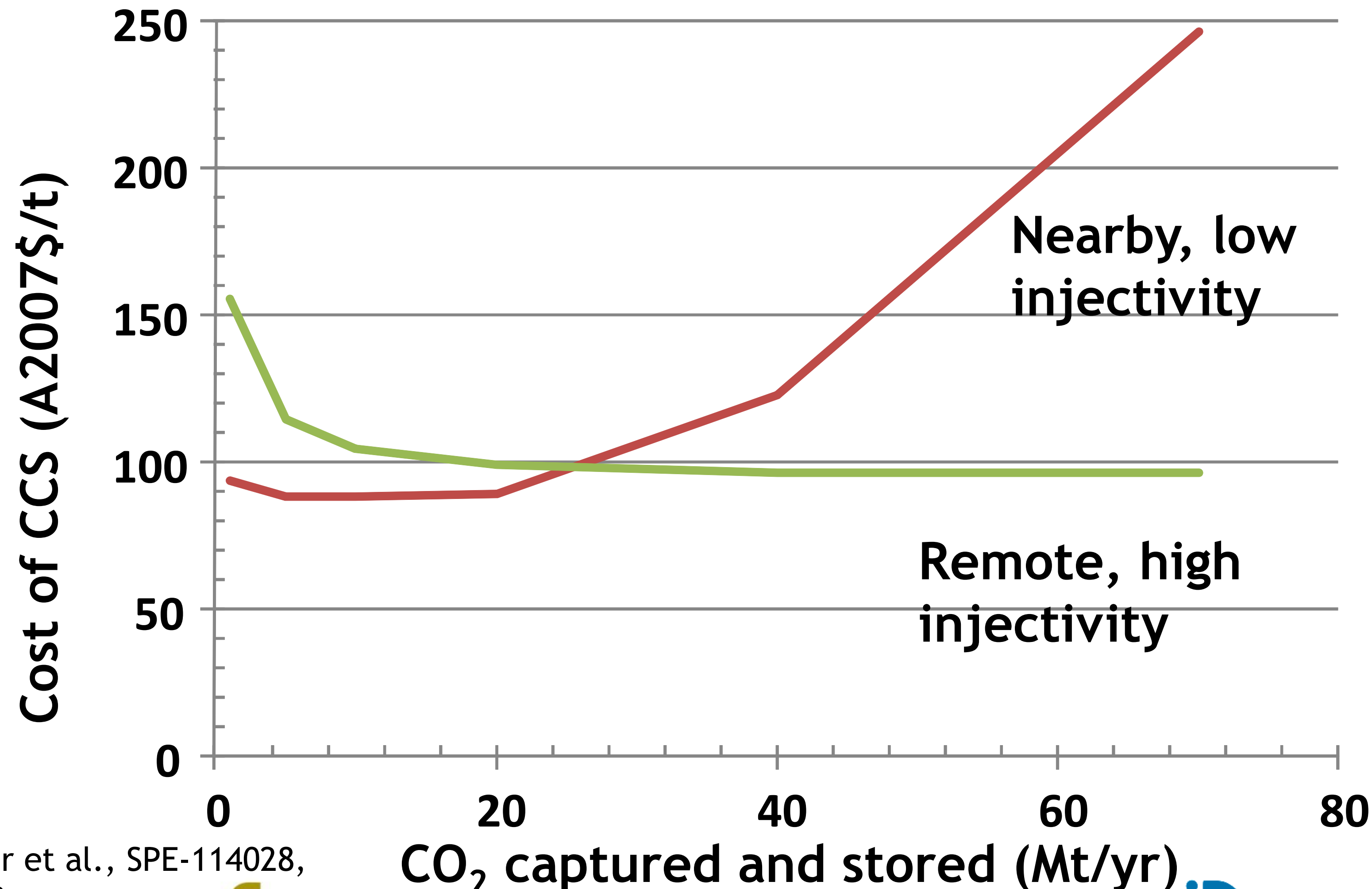
# Effect of flow rate – economies of scale




Allinson et al., CO2CRC Report #09-1536, 2009.

# Trade-offs in CCS costs

## Choosing between two sinks




Cinar et al., SPE-114028, 2008.

# Summary

- Represent costs over time using cash flow and present value

  用现金流和现值表示一段时间的成本

- $ per tonne $CO_2$ avoided gives the cost of avoiding emissions (breakeven)

  每吨$CO_2$的清除成本代表了清除二氧化碳排放的成本（盈亏平衡所需碳价）

- CCS costs are project specific

  CCS的成本由项目特定因素决定

# CO2CRC Participants

Australian Government Geoscience Australia | CSIRO | Curtin University | MONASH University | The University of Adelaide Australia

The University of Melbourne | UNSW Australia | The University of Western Australia | anlecr&d | BG GROUP

bhpbilliton | bp | Brown Coal Innovation Australia | Chevron | GNS Science | INPEX

KIGAM Korea Institute of Geoscience and Mineral Resources | NSW Government Trade & Investment | RioTinto | sasol reaching new frontiers | Shell

TOTAL | Department of State Development Business and Innovation, State Government Victoria | Government of Western Australia Department of Mines and Petroleum | GLENCORE

**Supporting Partners:** The Global CCS Institute | The University of Queensland | Process Group | Lawrence Berkeley National Laboratory
CANSYD Australia | Government of South Australia | Charles Darwin University | Simon Fraser University