



Costs, Profitability and Potential Gains of the CarbFix Program

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Background

- BSc Business Administration
 - ❖ Reykjavík University
- MSc Sustainable Systems
 - ❖ Reykjavík Energy Graduate School of Sustainable Systems
- Thesis in connection with CarbFix
 - ❖ Completion December, 2009
 - ❖ Defense January, 2010

CarbFix & CCS

- ❑ Carbon Capture & Storage
 - ❖ Capture ↓ Transport ↓ Storage
- ❑ CO₂ source from H₂S abatement pilot plant
 - ❑ 98% CO₂
 - ❑ 2% H₂S
- ❑ Pilot program *in-situ* mineralization using basalt.
 - ❑ Long term storage



Storage Capacity:
12 million tonnes
CO₂

or ~200 years of
storage from
Hellisheiði

Source: Google Maps



Source: Gíslason et al., 2009

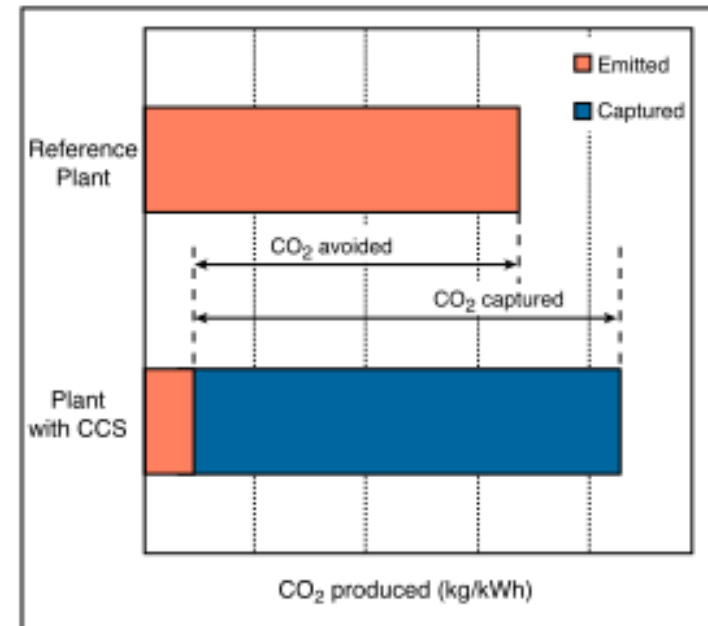
Thesis Goals

- Cost Analysis
- Profitability Assessment
- Sensitivity Analysis
 - ❖ CarbFix Pilot Program
 - ❖ Hellisheiði Full Scale Program
 - ❖ Pulverized Coal plant with CarbFix
- Market Analysis

Costs of CCS

□ Capture from combustion

- ❖ Large energy penalty
 - ❖ Regeneration of solvent
 - ❖ Compression
- ❖ Makes up 83% - 93% of total CCS costs
- ❖ \$25 - \$38/tCO₂ captured
 - ❖ 2020: \$10 - \$25/tCO₂ captured



Source: IPCC, 2005

CCS Costs

□ Transport

- ❖ Mature technology
- ❖ \$1 - \$6/tCO₂

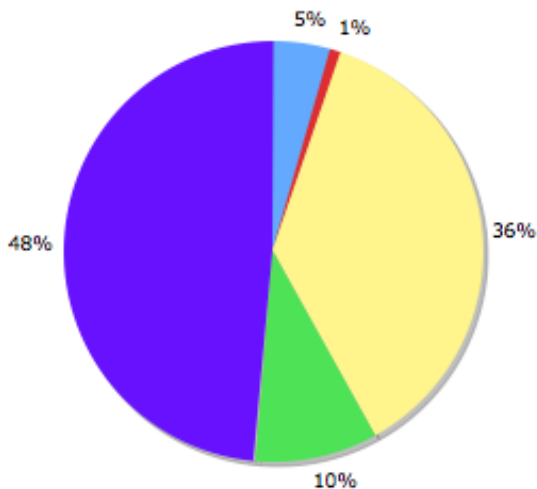
□ Storage

- ❖ \$0,5 - \$9/tCO₂
 - Drilling
 - Site screening
 - Monitoring
- ❖ Limited data on *in-situ* mineralization

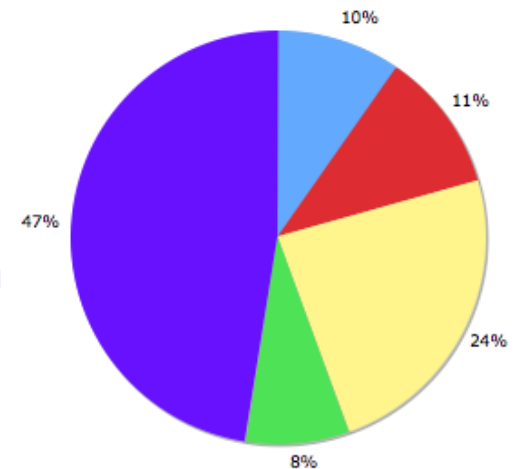
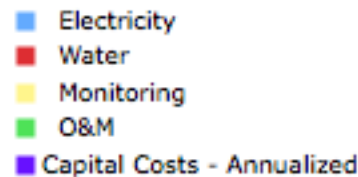
□ Total costs in the range of \$26,5 - \$53/tCO₂

Pilot vs. Full-Scale

	CarbFix Pilot	Hellisheiði FS
Water flow (l/s)	1,81	49,1
Energy Demand, kW	200	650
Energy Penalty	0,09%	0,31%
CO ₂ Flow Rate, kg/s	0,067	1,8
Injection well(s)	1	1
Monitoring wells	9	9



CarbFix Pilot



Hellisheiði Full-Scale

Pilot vs. Full-Scale

- Pilot - \$840/tCO₂
- Hellisheiði FS - \$47/tCO₂

Injection wells increase the levelized cost.
Hellisheiði scenario increases to \$95 when the
injection wells are 10.

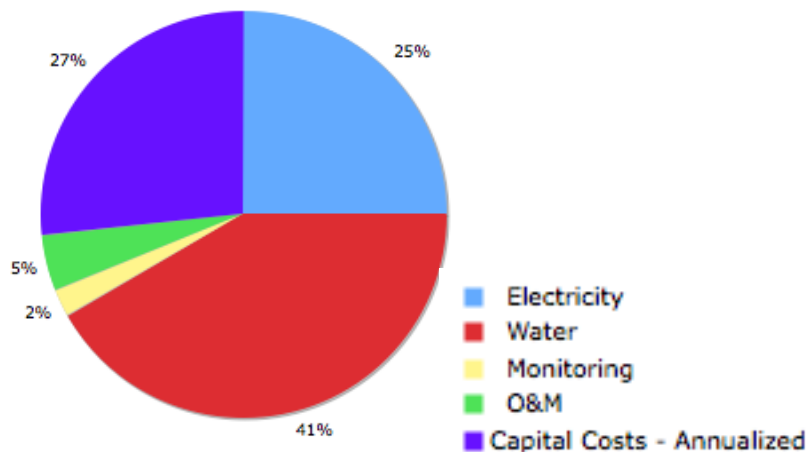
- Hellisheiði in 10 years
 - ❖ Emissions increase from 60 to 90 th. tCO₂/yr
 - ❖ Costs are then \$37/tCO₂ with 1 well
 - ❖ \$69/tCO₂ with 10 wells

Pulverized Coal Plant

Reference Plant	
Gross output (MW _e)	308,6
Net output (MW _e)	291,5
Capacity Factor (%)	85
Emission Rate (tCO ₂ MWh ⁻¹)	0,971
Total Emissions (tCO ₂ /yr)	2.108.000
Capture Plant	
Net output (MW _e)	291,5
Emission Rate (tCO ₂ MWh ⁻¹)	0,121
Emissions captured (tCO ₂ /yr)	2.360.000
Emissions avoided (tCO ₂ /yr)	1.846.000
\$/tCO ₂ captured	25

Pulverized Coal Plant

Water Flow (l/s)	2.019
Energy Demand, MW	18
Energy Penalty	8%
CO ₂ Flow Rate, kg/s	74,8
Injection well(s)	17
Monitoring wells	9



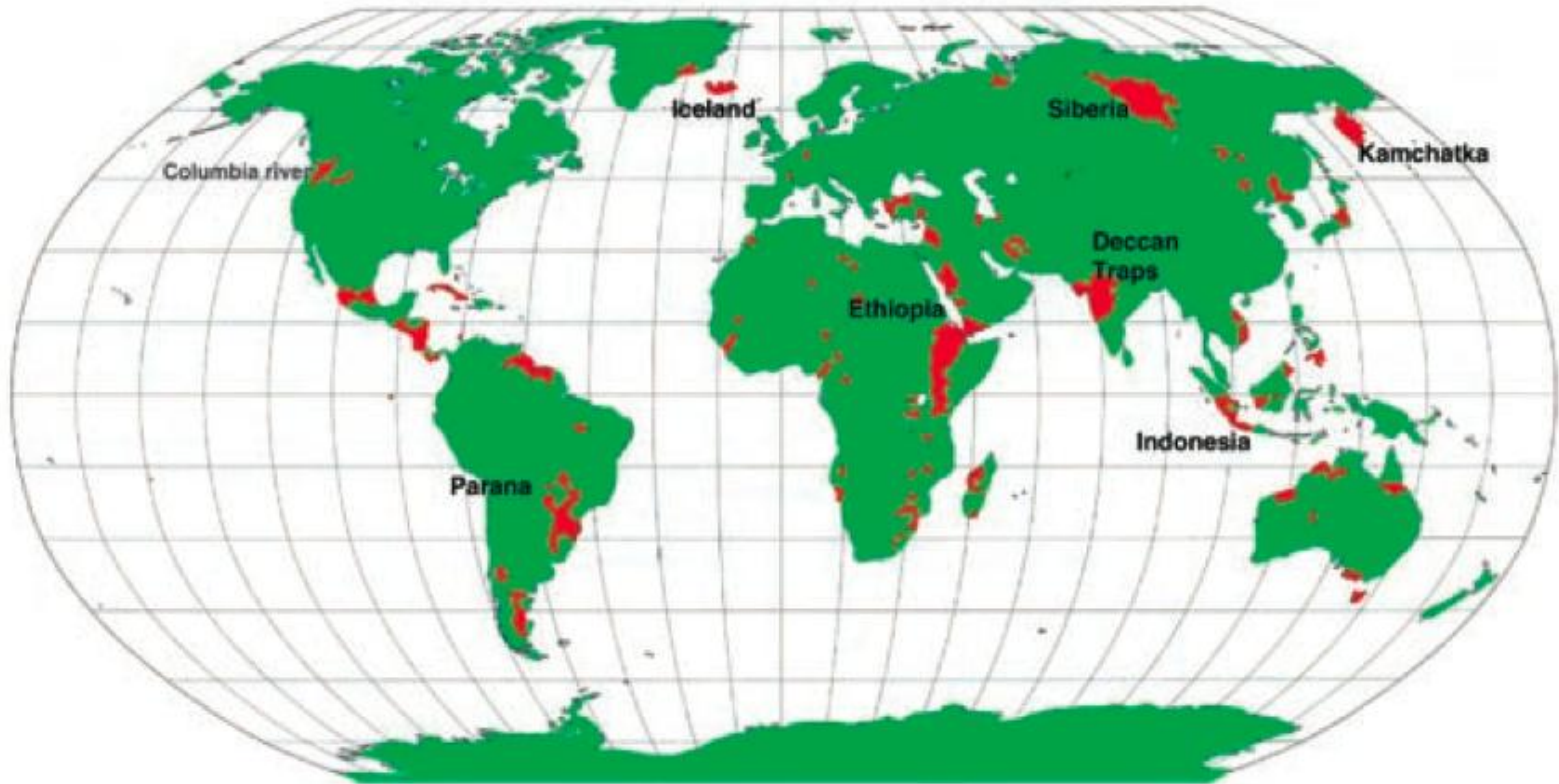
□ \$13/tCO₂ captured

□ with base costs this is \$38/tCO₂ captured

Sensitivity Analysis

- ❑ CarbFix Pilot & Hellisheiði FS
 - ❖ Capital Costs
 - ❖ Monitoring Costs
- ❑ Pulverized Coal
 - ❖ Capital Costs
 - ❖ Water Costs
 - ❖ Electricity Costs
- ❑ Monte Carlo Simulation (Capital Costs)
 - ❖ CarbFix Pilot \Rightarrow \$773 - \$864
 - ❖ Hellisheiði FS \Rightarrow \$44 - \$48
 - ❖ Pulverized Coal \Rightarrow \$12,5 - \$13,2
- ❑ Monte Carlo Simulation (Water/Electricity Costs)
 - ❖ Pulverized Coal \Rightarrow \$9,8 - \$12

Market Analysis

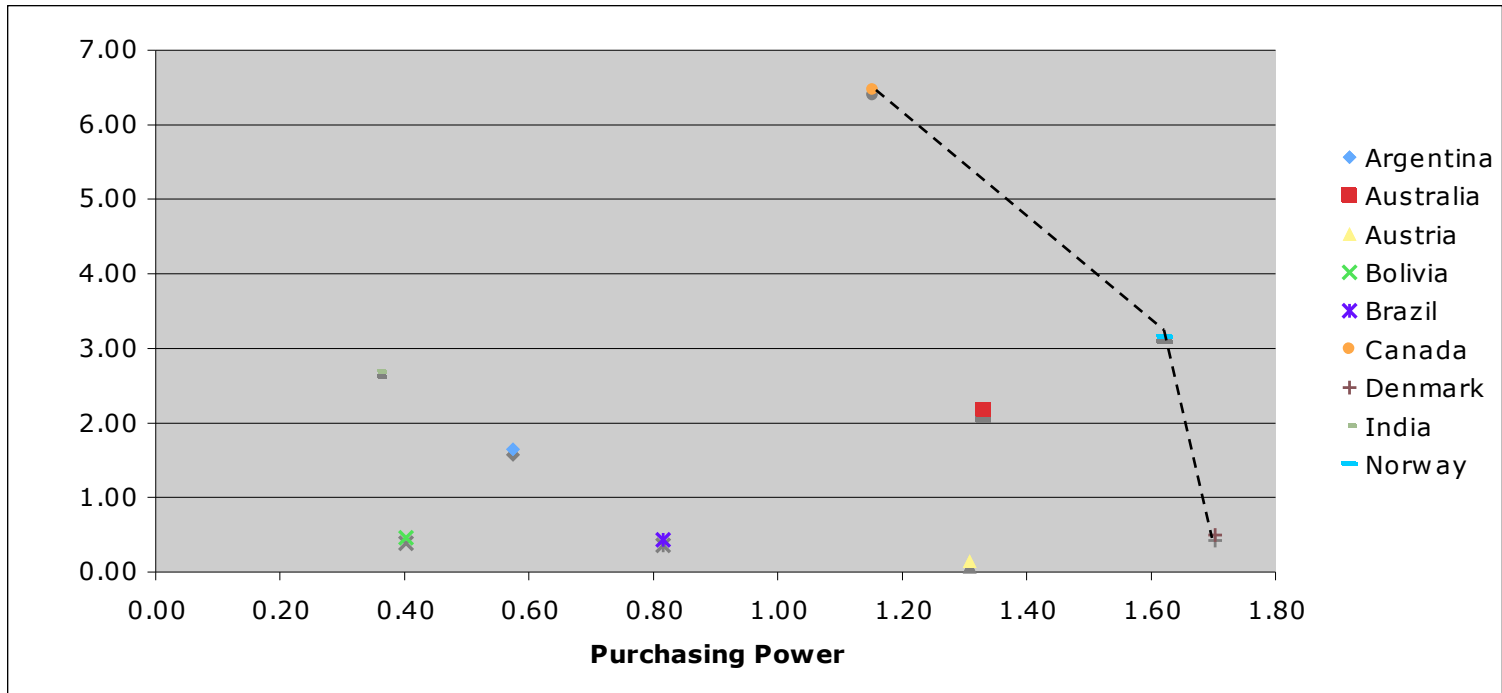


Source: Oelkers et al., 2008

Market Analysis

- ❑ Simple Multiattribute Rating Technique (SMART)
- ❑ PESTLE Analysis
 - ❖ 26 attributes identified
 - ❖ Political (3)
 - ❖ Economical (3)
 - ❖ Social (12)
 - ❖ Technical (3)
 - ❖ Legal (1)
 - ❖ Environmental (4)
- ❑ 56 countries
- ❑ Attribute scores paired against purchasing power of the currency

SMART Example



Factors affecting deployment

□ Liability

- ❖ Short-term & Long-term
- ❖ Insurance vs. Indemnities
- ❖ Multiparty Liability

□ Regulations

- ❖ Classification of CO₂
- ❖ Pore Space Ownership
- ❖ Licensing & Permits

□ Incentives

- ❖ Taxes vs. Trading

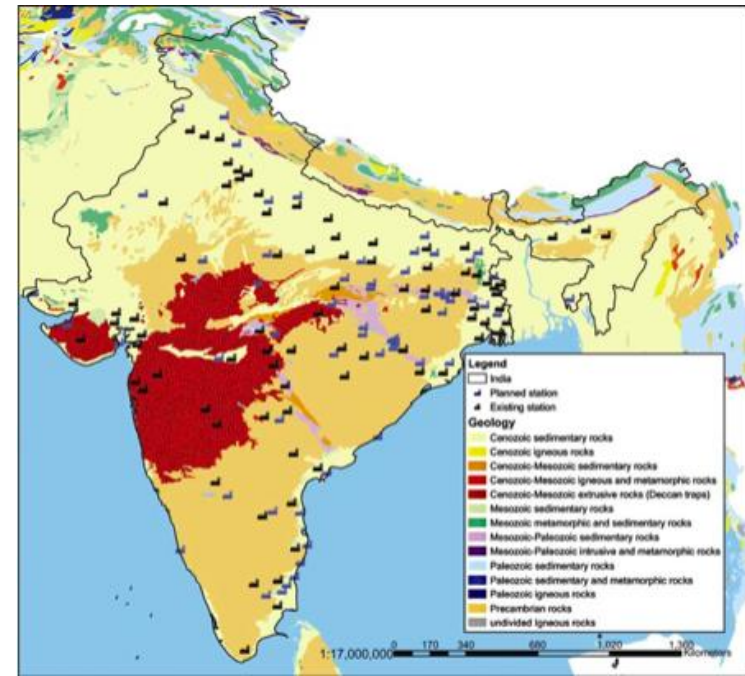


Q&A Session

Thank you!

Basalt

- ❑ Igneous rock
 - ❖ Glassy or crystalline
- ❑ 90% of Iceland
- ❑ Basalt shields worldwide
 - ❖ Columbia River >200.000 km³
 - 100 GT of CO₂
 - ❖ Deccan Volcanic Province ~512.000 km³
 - ❖ Siberia
 - ❖ Ethiopia
 - ❖ Indonesia
 - ❖ Australia
 - ❖ Multiple off-shore shields



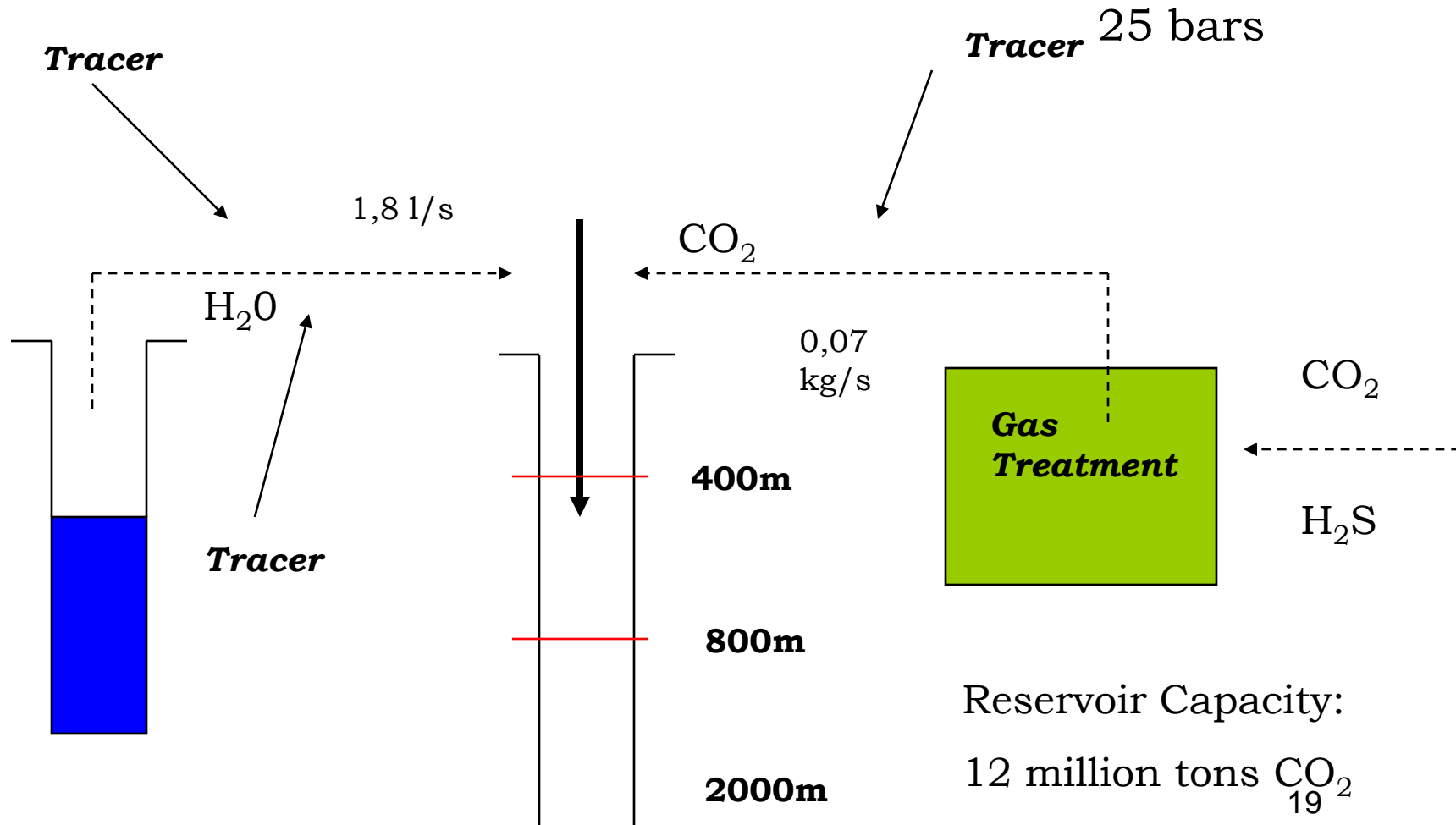
McGrail et al., 2006

Schematic

Variables:

19° C

25 bars



CCS Costs

Assumptions	IEA	Parsons
Reference plant (without capture)		
Reference plant net output (MW)	758	462
Plant capacity factor (%)	85	65
Net plant efficiency, LHV (%)	44	42
Reference plant emission rate (tCO ₂ MWh ⁻¹)	0.743	0.774
Capture plant		
CO ₂ capture technology	MEA	MEA
Net plant output with capture (MW)	666	329
Net plant efficiency, LHV (%)	35	30
CO ₂ capture system efficiency (%)	88	90
CO ₂ emission rate after capture (tCO ₂ MWh ⁻¹)	0.117	0.108
CO ₂ captured (Mt yr ⁻¹)	4,061	1,830
CCS energy requirement (% more input MWh ⁻¹)	26	40
Cost Results		
Cost year basis	2004	2000
% increase in capital cost	44	73
% increase in cost of electricity	42	66
Cost of CO ₂ captured (US\$/tCO ₂)	23	35
Adjusted to 2008	26	43