Injection Strategies for Large-Scale CO_2 Storage

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IEAGHG Study Programme

Recent and Ongoing CO_2 Storage Studies

- Storage Capacity Coefficients
- Global Storage Potential for CO2-EOR
- Injection Strategies
- Brine Displacement and Pressurisation
- Potential Impacts on Groundwater Resources
- Effects of Impurities
- Storage Resource Gap Analysis
- Caprock Systems for Storage

Injection Strategies Study

- Study completed in 2010 by CO2CRC, project team led by Karsten Michael
- Assessed parameters that can influence injection,
- Consider methods of design of injection strategies,
  - Case studies to demonstrate different strategies,
- Assess technical aspects of well design,
- Cost estimation tool:
  - Comparative rather than predictive.

Moving up in scale

Injection rates on the order of 10 MtCO_2/year for many sites;

CCS infrastructure will need to be of the same scale as that of the current petroleum industry;

- **Management of reservoir pressures (water production) to avoid fracturing, seismic events and impact on resources (groundwater, petroleum).**

Need to optimise storage process by:

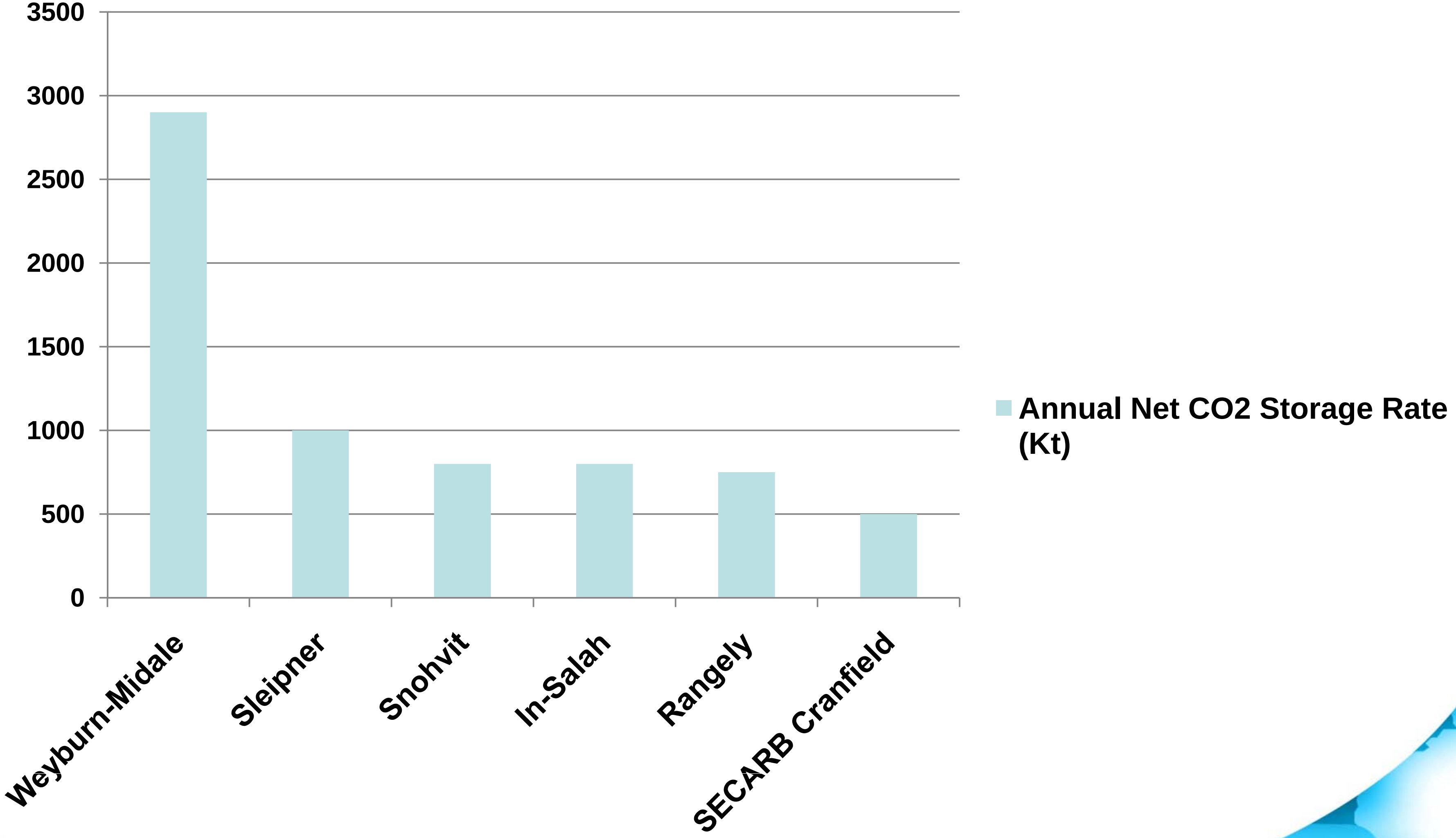
- **Multi-well injection schemes;**
- **Enhancement of dissolution and residual trapping mechanisms to maximise effective storage capacity (co-injection of brine/CO_2).**

Active projects, early 2009

Bellingham Cogeneration Facility	IFFCO CO2 Recovery Plant – Aonla
CASTOR Project	Prosint Methanol Plant
Great Plains Synfuel Plant	Rangely CO2 Project
IMC Global Soda Plant	Schwarze Pumpe
In Salah	SECARB - Cranfield II
K12-B	Shady Point Power Plant
Ketzin Project	Sleipner
MRCSP - Michigan Basin	Snohvit LNG Project
Nagaoka	SRCSP - Aneth EOR-Paradox Basin
Otway Basin Project	SRCSP - San Juan Basin
Pembina Cardium Project	Sumitomo Chemicals Plant
Petronas Fertilizer Plant	Warrior Run Power Plant
IFFCO CO2 Recovery Plant - Phul	Weyburn
Chemical Co. "A" CO2 Recovery Plant	Zama EOR Project

- Capture over 100ktCO_2
- Injection over 10ktCO_2 for storage
- Monitored EOR over 10ktCO_2
- Capture over 10ktCO_2 from flue gas
- Coal bed storage over 10ktCO_2

Net CO_2 Storage per Year



Industrial Analogues

Characteristics	CO_2 Storage	EOR	Acid-gas injection	Natural gas storage	Liquid waste disposal (deep)	Geothermal*
Purpose						
Time scale						
Injection depth						
Injection volume						
Injection rate						
Injection fluid						
Reservoir geometry						
Number of wells						
Well types						
Well completion						
Monitoring						

Predictive Modelling

- Can vary from simple analytical equations to complex numerical models
- Based on knowledge from oil and gas industry, hydrogeology, theory
- Knowledge gained from recent experimentation and early demonstration projects
- Required by Regulators

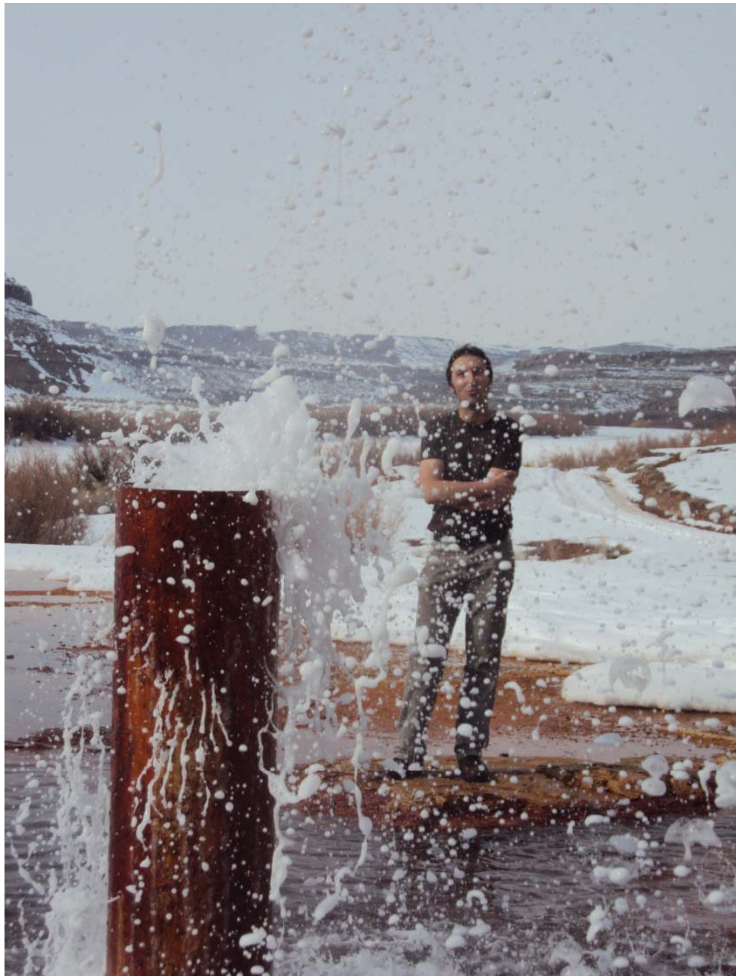
IEAGHG Modelling Network

First meeting in Orleans, Feb 2009

Second meeting in Utah, Feb 2010

2011: offer to host by Shell and University of W Australia

Network details at www.ieaghg.org



Injection Strategy – Parameters 1

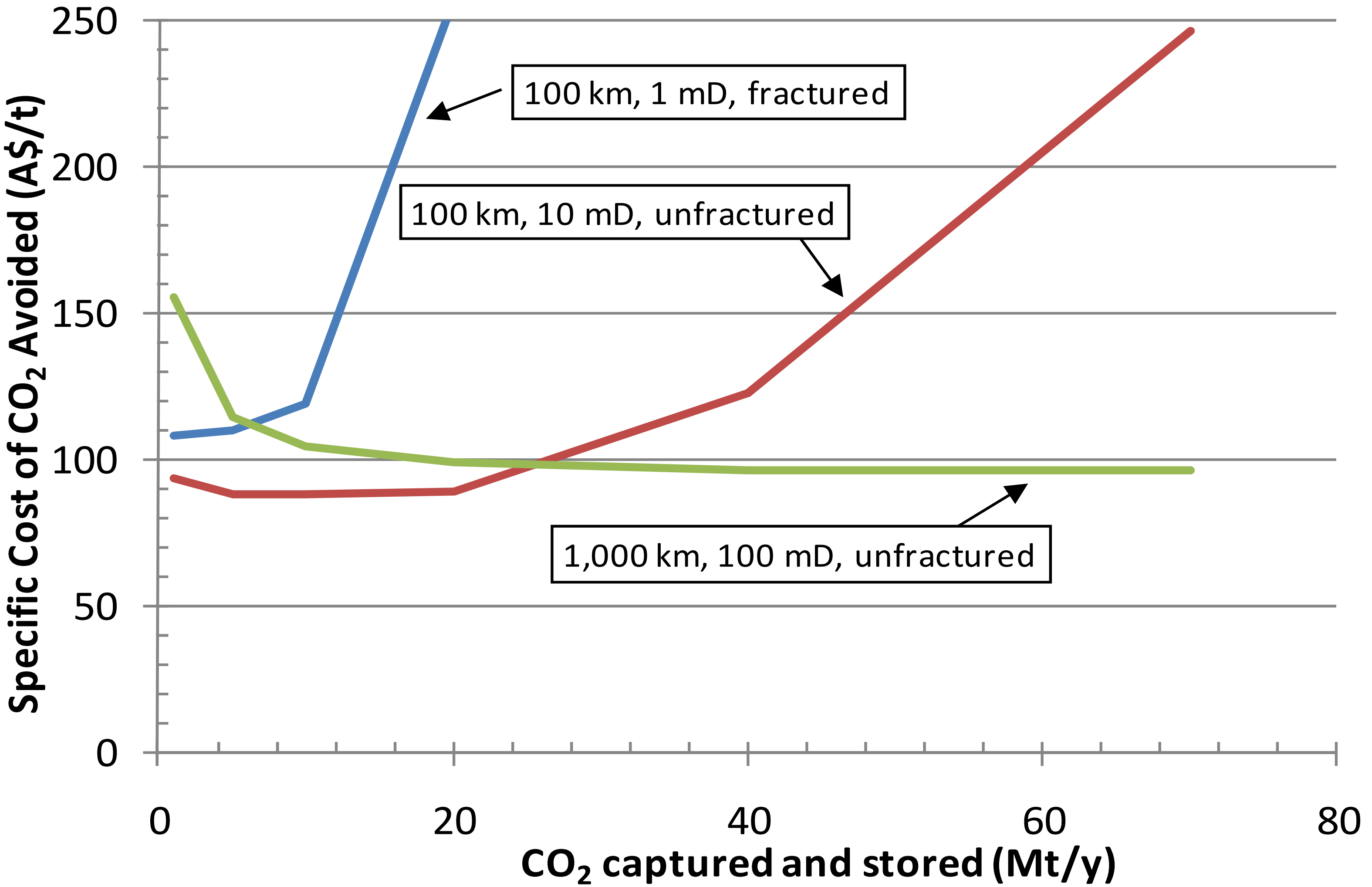
- Definition of Injectivity:
  - The ability of a geological formation to accept fluids by injection through a well or series of wells.

- Many factors effecting injectivity, but primary is bottom-hole pressure, surpassing this pressure limit is likely to lead to migration and leakage.
  - Bottom-hole pressure influenced by:
    - Injection rate,
    - Permeability,
    - Formation thickness,
    - CO_2 / brine viscosity,
    - Compressibility.

Injection Strategy – Parameters 2

- Greater storage efficiency = Greater Injectivity
  - o Heterogeneity:
    - » Increased heterogeneity : increased storage efficiency
  - o Pressure Maintenance:
    - » Water production wells reduce formation pressures, maintain injectivity
  - o Co-Injection:
    - » Improves level of residual gas trapping, reduces mobile CO_2
  - o Dissolution in Brine:
    - » Alternative to co-injection, similar effects, but increase in initial costs
  - o Injection below oil-water contact:
    - » Reduces potential for buoyancy driven migration

Trade-off between Transport Distance & Permeability



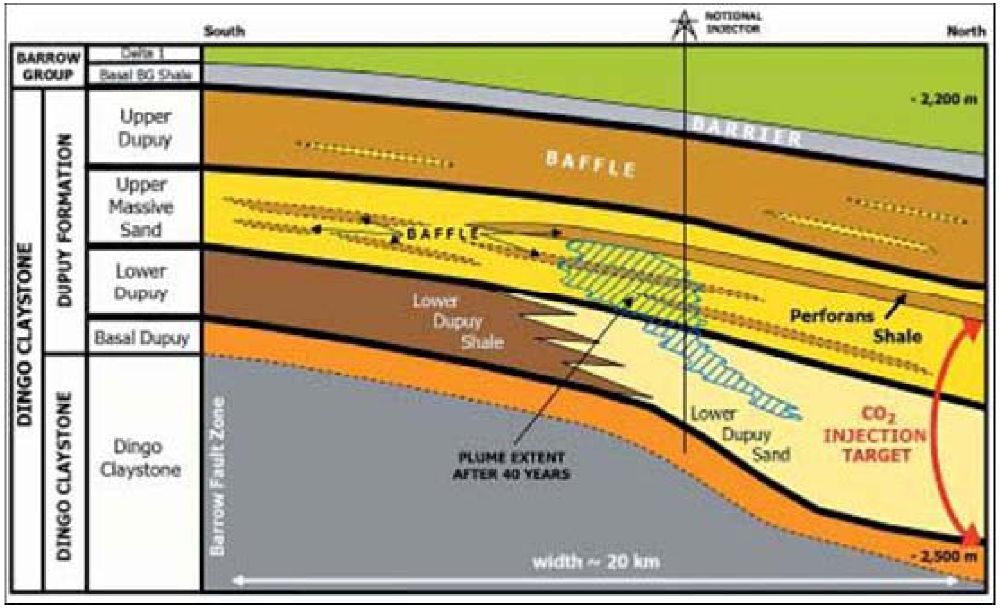
Cinar et al., 2009

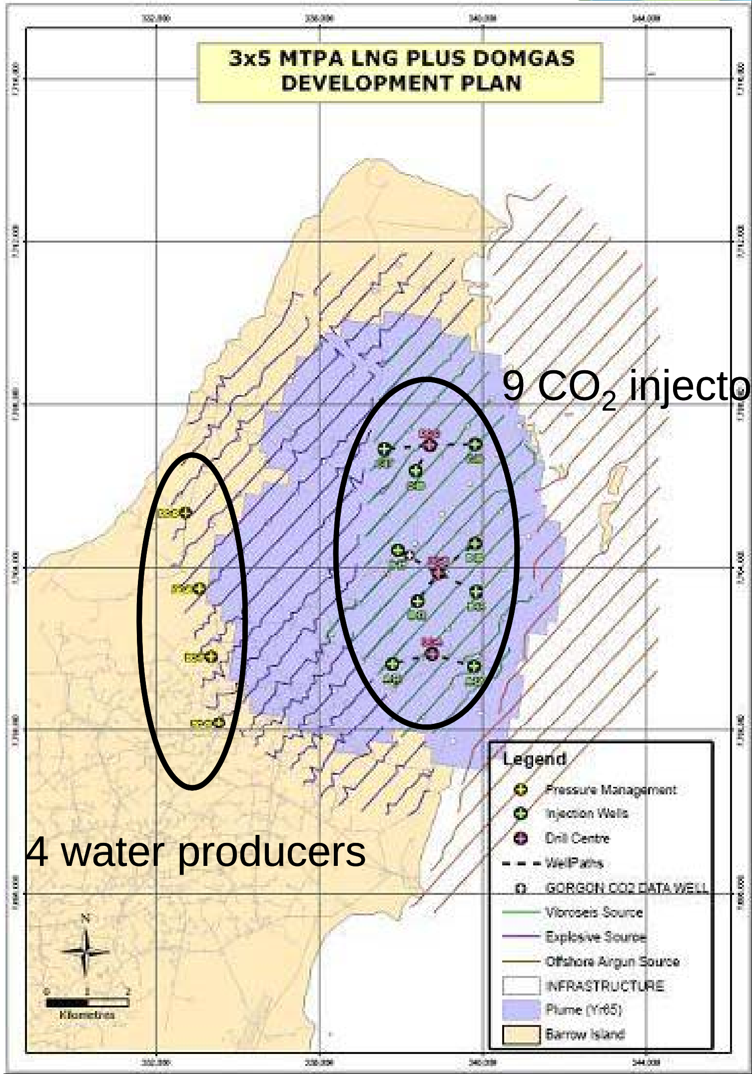
Existing Injection Strategies

- Snøhvit, Norway, LNG Project.
  - 0.75 Mt/yr CO2 injected through single well into DSF below Jurassic gas reservoir
  - Single well injection, considerable upscale necessary to analogise with commercial CCS projects of the future

- Gorgon, Australia, Offshore Natural Gas Production,
  - Produced gas approx. 14% CO_2, removed from gas stream, compressed and transported via 12km pipeline to storage site.
  - Anticipated 9 injector wells, in 3 groups
  - Budget contingency allows for additional wells if necessary.
  - 4.9 Mt/yr CO_2 injected, with total projected storage of 125 Mt CO_2
  - Water production wells also planned to maximise control of plume, and manage reservoir pressures

Pressure Maintenance - Gorgon Proposal





Economics of Injection Strategies

- **Costs of links explained:**
  - Costs of CCS = capture, transport and storage costs
  - Costs of Transport = Compression, boosting and pipeline costs
  - Costs of Storage = Injection and transport costs
  - Costs of Injection = Wells, wellhead boosting and treatment costs
- **Factors affecting Injection Costs:**
  - Permeability
  - Fracture Gradient
  - Formation Thickness
  - Formation Depth
  - Well Deviation
  - Hydraulic Fracturing

Cost Tool Data Fields

INPUTS

Select currency for economic results		EUR	
Storage flowrate	Mt/yr	8.0	
Onshore / offshore	-	Onshore	
Storage formation properties			Classification
Depth calculated based on formation pressure (d)	m	2,000	M
Formation thickness (h)	m	100	H
Permeability (k)	mD	1000	XXH
Formation pressure	Mpa	21	
Fracture pressure	Mpa	34	
Selected storage formation	[case code]		kXXH_hH_dM

Select method for well costs calculation		Method 1
Method 1		
Mob/demob costs	US$ million	0.5
Unit well cost	US$ million	2.5
Method 2		
Mob/demob costs	US$ million	0.5
Rig-rate	US$/day	32,000
Ratio of day-rate to rig-rate *	-	2.5
Drilling time on well-site	days/well	31
Method 3		
Mob/demob costs	US$ million	0.5
Rig-rate	US$/day	32,000
Ratio of day-rate to rig-rate *	-	2.5
Pre-spud time	days/well	1.0
Time-to-depth curve - slope	days/well	3.3
Time-to-depth curve - exponent	1/km	0.8
Ratio of completion-time to drilling time	-	0.25
Method 4		
Mob/demob costs	US$ million	0.5
Rig-rate	US$/day	32,000
Ratio of day-rate to rig-rate *	-	2.5
Pre-spud time	days/well	1.0
Ratio of completion-time to drilling time	-	0.25
	Depth, m	Time, days
Enter the first depth and drilling time here -->	2,100	19
Enter the second depth and drilling time here -->	3,000	40
	Depth, km	LN(Time)
	2.1	2.9
	3.0	3.7
Time-to-depth curve - slope	days/well	3.34
Time-to-depth curve - exponent	1/km	0.83

OUTPUTS

Capital costs break down

	Number	Size	Unit cost	Total cost
	-	MW,MW,km	€ million	€ million
Extra Power	-	10.0	1.2	16
Injection Booster	1	10.0	7.8	8
Injection Distribution	-	188.6	-	22
Injection Wells	9	-	2.5	17
Injection Platforms	0	-	-	0
Owners' costs	-	-	-	4
Contingency	-	-	-	7
Total capital costs	-	-	-	73

Total CO_2 avoided	Mt	318.9
Annual operating costs	€ mill/yr	4.1
Total decommissioning costs	€ million	14
Present value of all costs	€ million	420
Specific costs of CO_2 avoided	€ /t	3.9

Study Summary

- ***Bottom hole injection pressure is a major limiting factor for storage capacity***
- ***Analytical models can provide simple screening tool for assessment of CO_2 storage feasibility***
- ***Numerical models are needed to better account for complexity of natural systems***
- ***Experience from other types of injection/disposal operations provides examples for optimising storage efficiency***
- ***Most of the storage technology is in place, but the pure size of future CCS projects might provide unexpected new challenges.***

Concluding Remarks

- **Pressure build-up is most influential factor on injectivity and storage potential,**

- **Pressure management will therefore prove a vital element of injection strategies,**

- **Large scale demonstrations will enhance knowledge and understanding.**

Thank you for your attention