



What have we learnt to date from large-scale CCS projects ?

IEA Greenhouse Gas R&D Programme

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Climate Change Congress, Copenhagen 10-12 March 2009



What have we learnt to date - projects?

- Review current operational large-scale CCS projects
 - Assess learning from projects
 - Identify gaps in the global CCS project portfolio
- Focus on projects relevant to full-commercial scale operation
 - Includes:
 - Large-scale pilot
 - Demonstration
 - Commercial
 - Excludes
 - Small and medium pilot
 - Lab scale
- Define criteria – Identify projects – Collect information - Analyse



Criteria for large-scale operational projects

- Indicative criteria defined for 'large-scale operational projects'
- Was, or had been, operational by the end of 2008, and either:-
 - Captures over 10,000 tCO₂ per year from a flue gas
 - Injects over 10,000 tCO₂ per year with the purpose of geological storage with monitoring
 - Captures over 100,000 tCO₂ per year from any source
 - Coal-bed storage of over 10,000 tCO₂ per year
- *Commercial CO₂ EOR is excluded unless there is a monitoring programme to provide learning.*
- *Does not need to be fully integrated*
- Added term '*large-scale operational*' to IEA GHG Projects database









Projects identified

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 - Phulpur	Weyburn
Chemical Co. “A” CO2 Recovery Plant	Zama EOR Project



Projects identified

Bellingham Cogeneration Facility	IFFCO CO2 Recovery Plant – Aonla	
CASTOR Project	Prosint Methanol Plant	
Great Plains Synfuel Plant	Rangely CO2 Project	 Capture over 100ktCO ₂
IMC Global Soda Plant	Schwarze Pumpe	
In Salah	SECARB - Cranfield II	 Injection over 10ktCO ₂ for storage
K12-B	Shady Point Power Plant	
Ketzin Project	Sleipner	
MRCSP - Michigan Basin	Snohvit LNG Project	
Nagaoka	SRCSP - Aneth EOR-Paradox Basin	 Monitored EOR over 10ktCO ₂
Otway Basin Project	SRCSP - San Juan Basin	
Pembina Cardium Project	Sumitomo Chemicals Plant	 Capture over 10ktCO ₂ from flue gas
Petronas Fertilizer Plant	Warrior Run Power Plant	
IFFCO CO2 Recovery Plant - Phulpur	Weyburn	
Chemical Co. "A" CO2 Recovery Plant	Zama EOR Project	 Coal bed storage over 10ktCO ₂



Project Locations





Information Gathering

- 28 large scale operational projects identified
- Each project has been asked to provide information using a questionnaire
- 18 Responses so far (6th March 2009)

- Analysis of projects in 2 parts:
 - Extent of project coverage
 - Key learning from projects



Extent of coverage - Capture

- 13 plants capturing from combustion processes
 - 11 post-combustion
 - 1 pre-combustion
 - 1 oxyfuel
- 9 projects source CO₂ from industrial processing (Natural gas separation, ammonia, LNG, hydrogen production)
- Multiple fuels represented
 - Hard coal
 - Lignite
 - Natural Gas
 - Industrial processes
- Over 10Mt of CO₂ captured per year



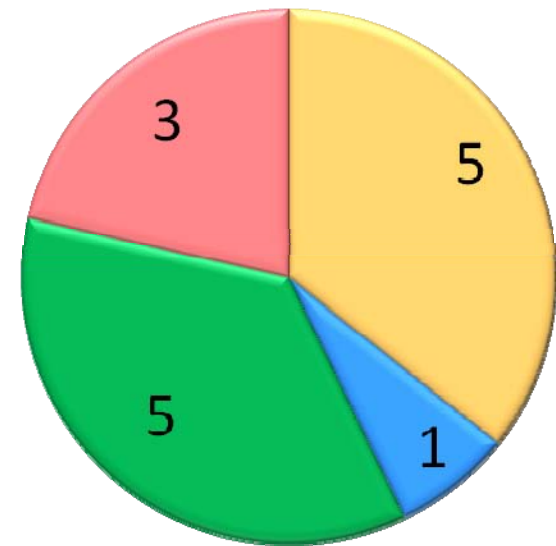
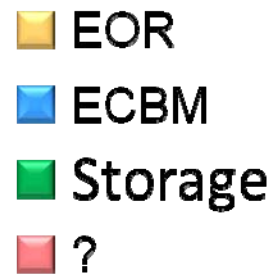
Extent of coverage - Transport

- Pipeline
 - Single sink source pipelines
 - Multiple source-multiple sink pipeline networks
- Truck
- Cross-border transport
- Transport over 860km



Extent of coverage – Injection

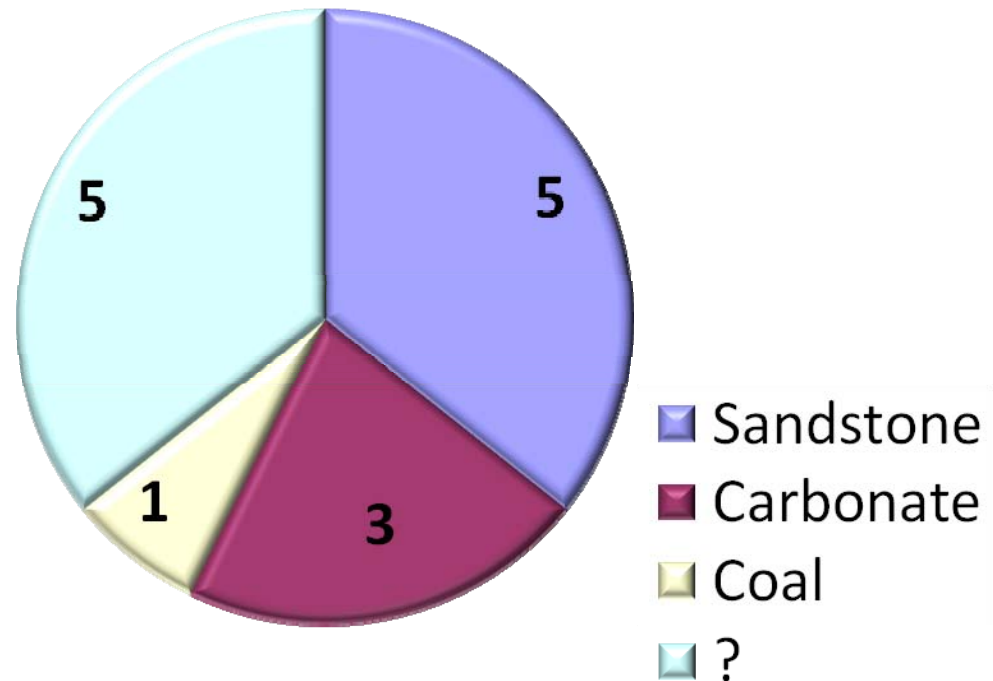
- Over 10Mt injected per year
- Multiple purposes for injection
 - Storage
 - EOR
 - ECBM





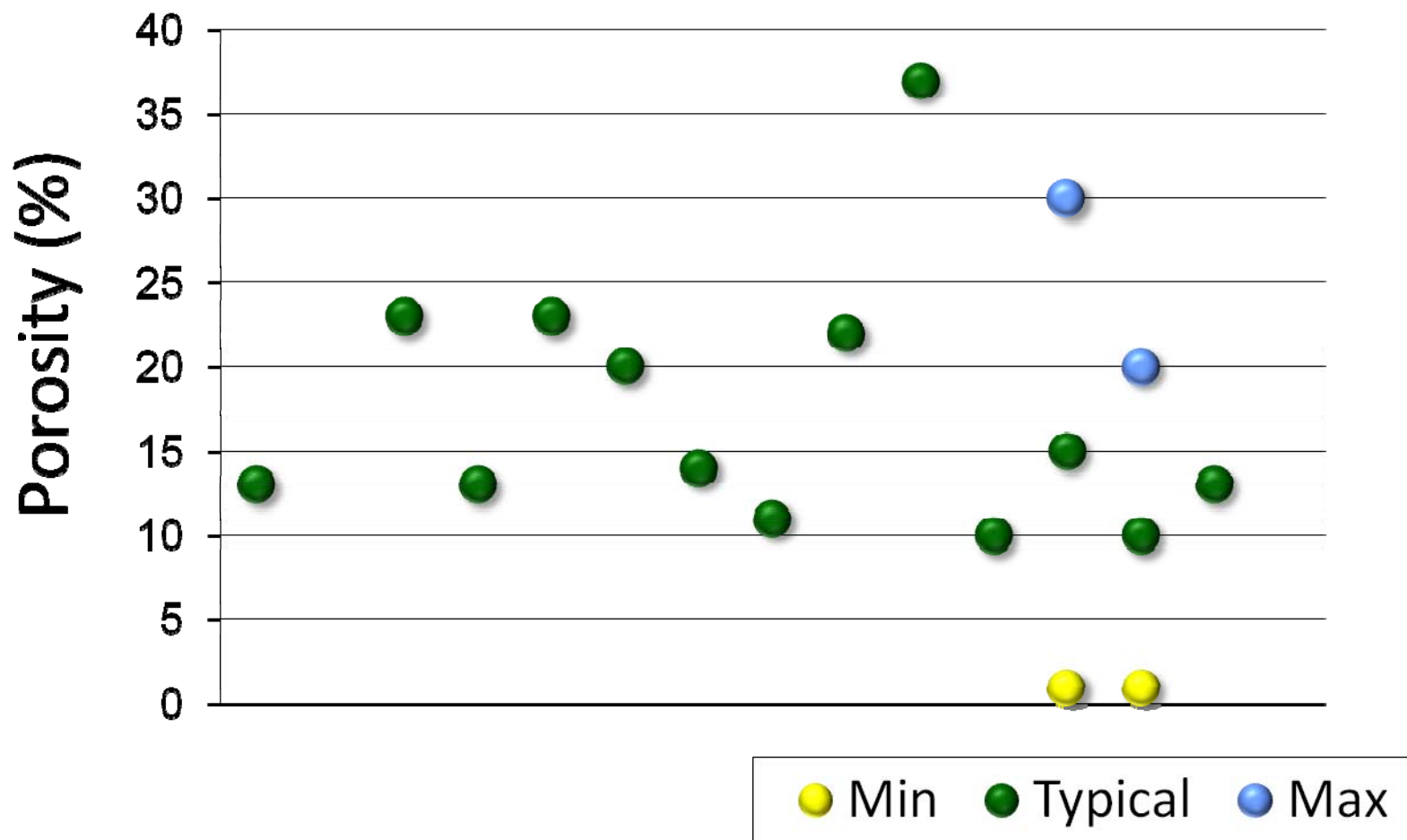
Extent of coverage – Storage Formations

- A variety of storage formations
 - Sandstone
 - Carbonate
 - Coal



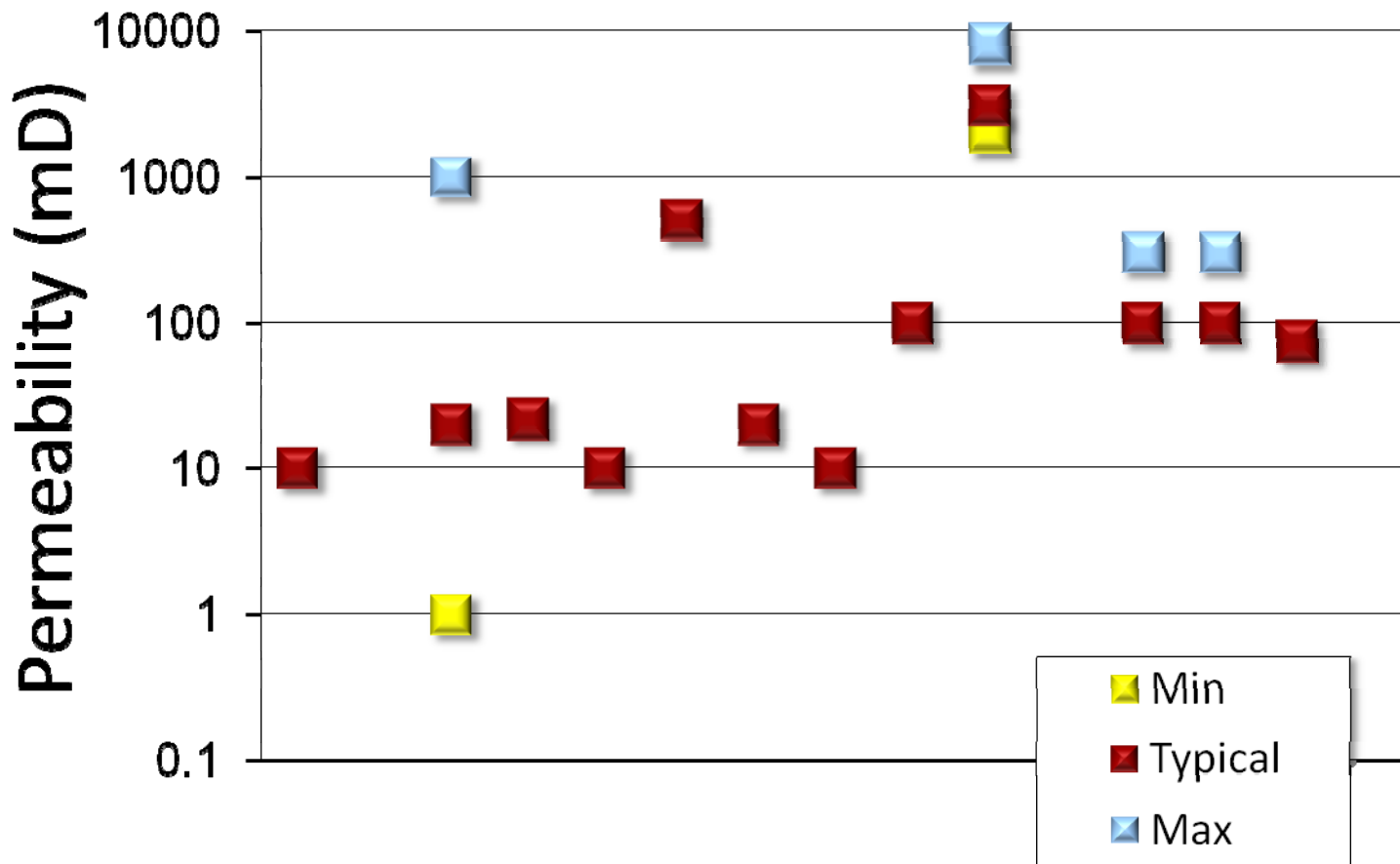


Porosity



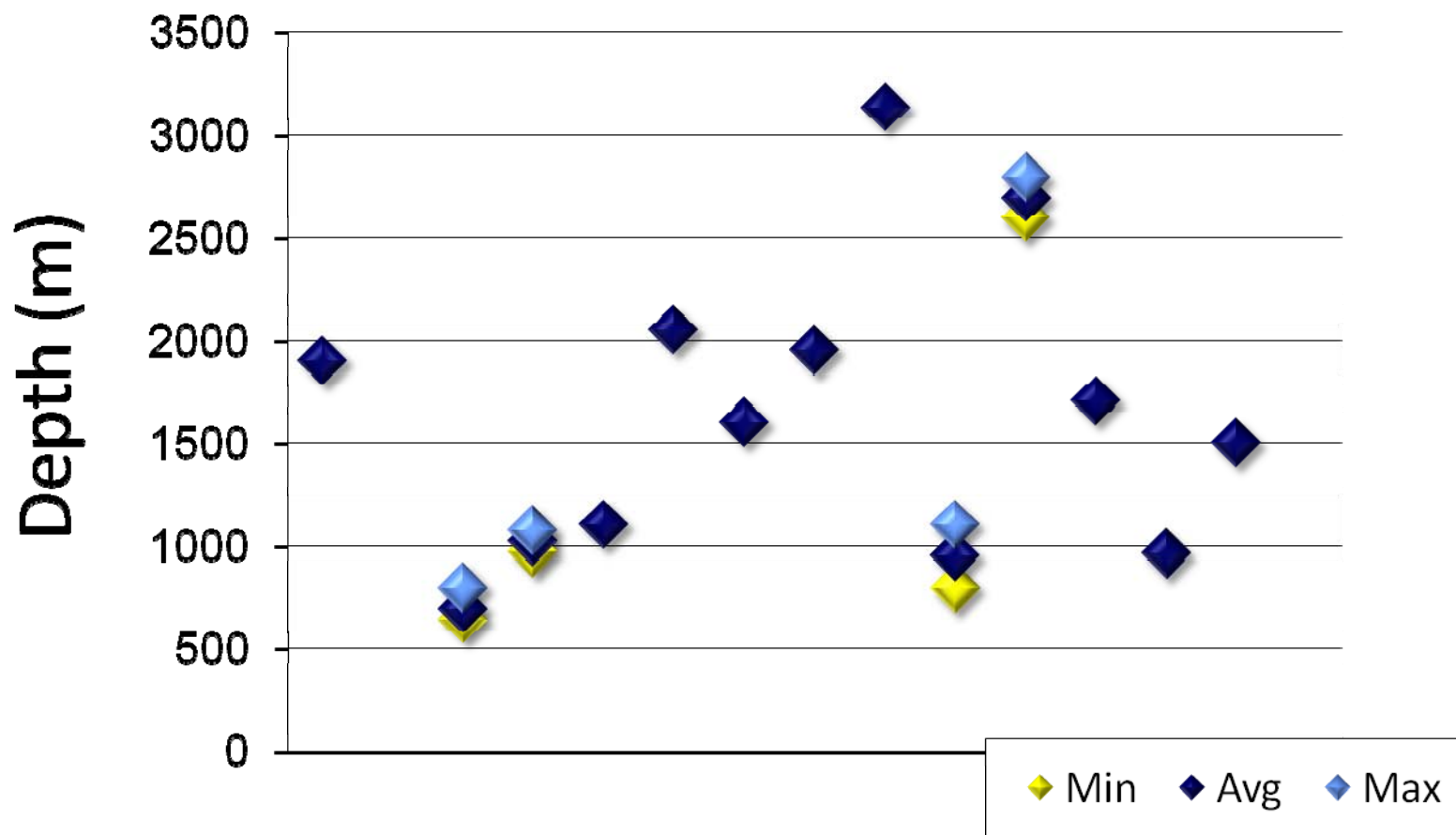


Permeability





Reservoir Depth



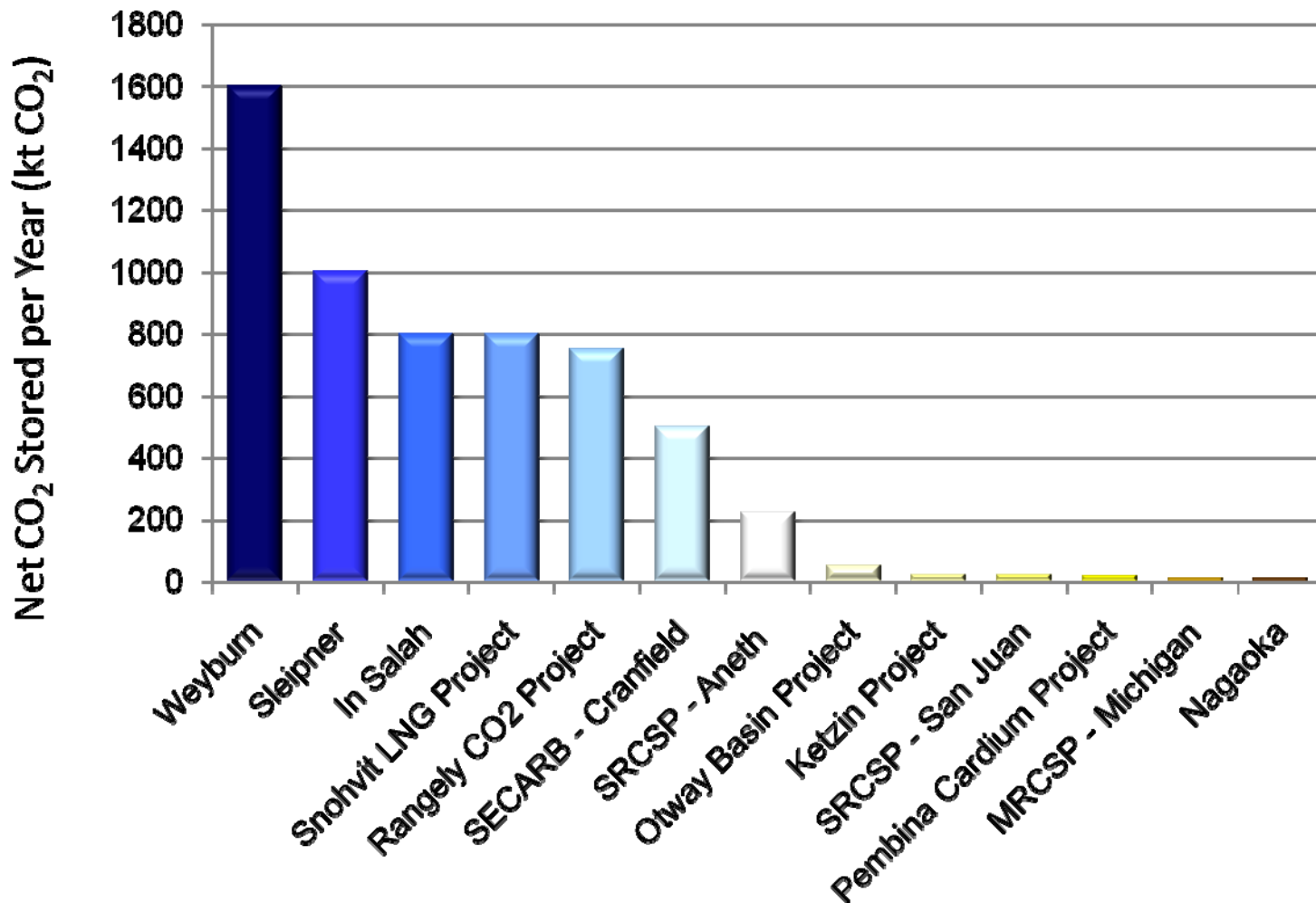


Extent of coverage – Storage amounts

- There are six projects that store over 40,000t CO₂ per year
- All projects combine store almost 6Mt per year
- Total of 57 project years of CO₂ storage experience
- Over 40Mt of CO₂ stored



Net CO₂ Storage per Year





Extent of coverage – Monitoring

- 2D seismic
- 3D seismic
- 4D seismic
- Vertical seismic profiling
- Cross-well seismic
- Electrical conductivity
- Microseismic
- Passive seismic
- Soil gas sampling
- Detector arrays
- Eddy covariance
- Observation wells
- Time lapse microgravity
- Well temperature and pressure
- Well logs
- Tracers
- Ground water geochemistry
- Interferometry
- Satellite imaging
- Tilt meters



Extent of coverage vs ZEP project matrix

Archetype 1	• Lignite/co-firing with Biomass	• Pre-combustion, variant A	• Cross-border pipeline	• Offshore depleted oil & gas field
Archetype 2	• Gas	• Post-combustion, variant A	• Pipeline	• Onshore structural deep saline aquifer
Archetype 3	• Hard Coal	• Oxy-fuel, variant A	• Ship	• Offshore open deep saline aquifer
Archetype 4	• Hard Coal	• Post-combustion, variant A	• Pipeline	• Onshore depleted oil & gas field
Archetype 5	• Lignite	• Oxy-fuel, variant B	• Pipeline	• Onshore structural deep saline aquifer
Archetype 6	• Hard Coal	• Pre-combustion, variant B	• Pipeline	• Offshore depleted oil & gas field
Archetype 7	• Hard Coal	• Post-combustion, variant B	• Pipeline	• Onshore open deep saline aquifer

Demonstrated in operational large projects

Not demonstrated in operational large projects

Project matrix courtesy of EU Technology Platform for Zero Emission Fossil Fuel Power Plants - ZEP (2008)



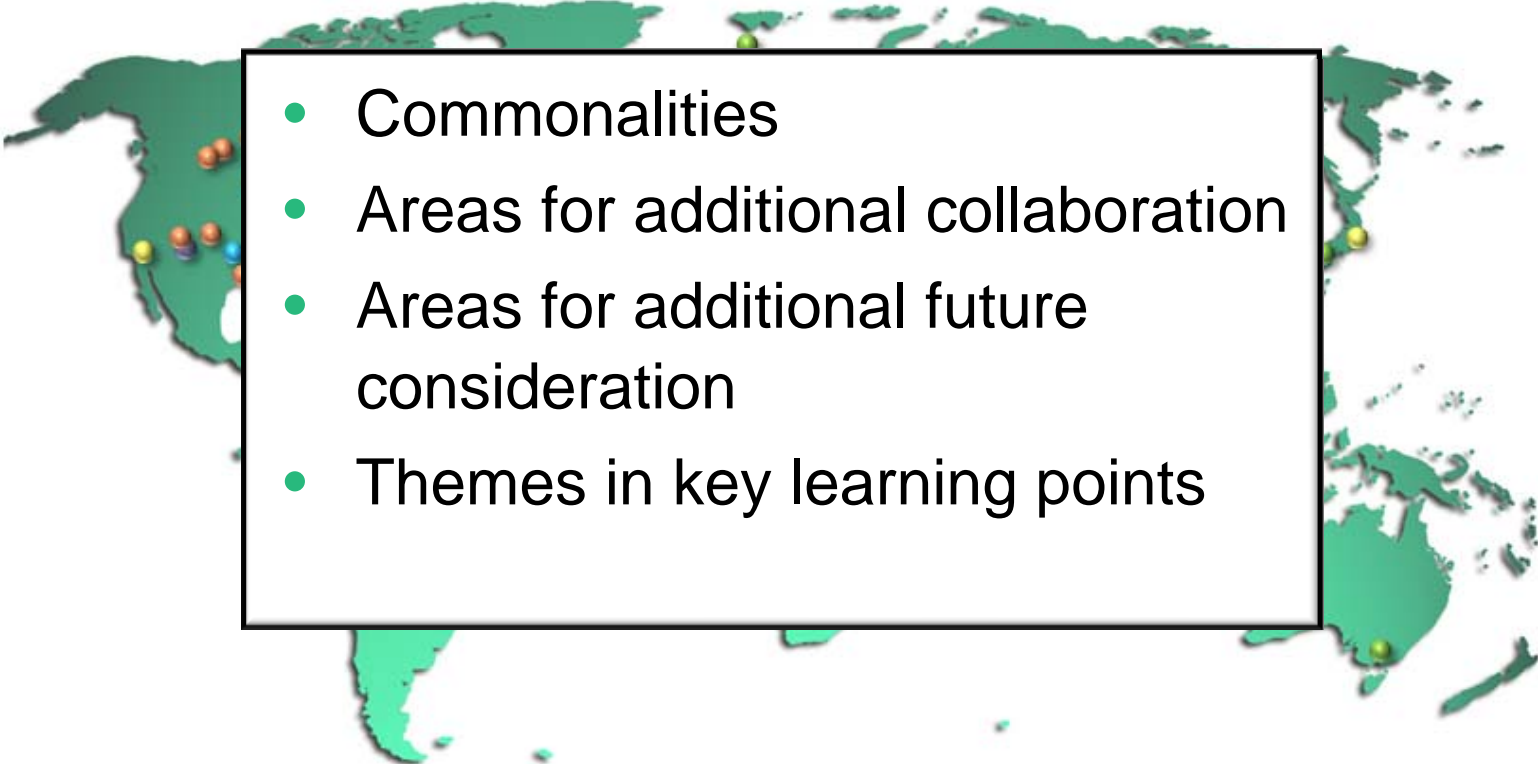
Extent of Coverage

- If integrated CCS from electricity production is a 4 link chain:
 - Electricity production
 - Capture
 - Transport
 - Storage
- 2 and 3 link chains have been demonstrated over 1Mt CO₂ per year





Learning From Projects - preliminary and not yet complete

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- A world map with several colored pins (red, orange, yellow, green, blue) indicating project locations across North America, Europe, and Asia.
- Commonalities
 - Areas for additional collaboration
 - Areas for additional future consideration
 - Themes in key learning points



Commonalities

- Injectivity
 - Very important
 - Multiple examples of issues and solutions
- Material corrosion
 - Less problems than expected
- Seismic
 - Effective for monitoring the CO₂ plume - where it can be used
 - Not quantitative beyond a certain resolution
 - Expensive



Commonalities cont.

- Electrical conductivity
 - Seen as promising, not yet used commercially
- Microseismic
 - Doesn't add a lot to monitoring portfolio
- Monitoring overlying layers
 - Very good way of demonstrating seal integrity (Especially to non-experts)
- Downhole sampling
 - Better sampling at reservoir conditions valuable
 - Not yet practiced by many projects



Areas for Additional Collaboration

- Design of a monitoring programme
 - Proving integrity
 - Enough experience to move on from expansive research programmes to start designing commercial monitoring programmes
- Comparison of hydrate experience



Areas for Additional Collaboration cont.

- Injection performance
 - Different issues of impairment
 - Varied experience of injecting into depressurised formations
- Material corrosion
 - Successful management of material selection and corrosion - could reduce costs for future projects



Themes in Key Learning Points

- Effectiveness of monitoring techniques – what to drop and what to develop
- Injectivity – prediction, restoration and enhancement
- Dealing with hydrates
- Performance of materials in CO₂ environments
- Well designing, placing, monitoring



What has not been covered

- More on capture and on regulatory issues
- Commercial gasification processes
 - Have not been reviewed here but offer considerable learning for pre-combustion capture
- CO₂ transport by ship



Preliminary Conclusions

- Elements of CCS are operating at large scale
- Integrated CCS is operating at large scale, just not from power plant
- **There is a lot that has been learnt from existing projects, but more can be done to share the learning**
- CCS industry can build on existing projects' experience
- Increasing IPR issues will affect sharing learning



IEA Greenhouse Gas R&D Programme

- General - www.ieagreen.org.uk
- CCS - www.co2captureandstorage.info

