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

IEA Greenhouse Gas R&D Programme

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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 tCO_2 per year from a flue gas
  - Injects over 10,000 tCO_2 per year with the purpose of geological storage with monitoring
  - Captures over 100,000 tCO_2 per year from any source
  - Coal-bed storage of over 10,000 tCO_2 per year
- *Commercial CO_2 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

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- 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

Project Locations

- 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

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

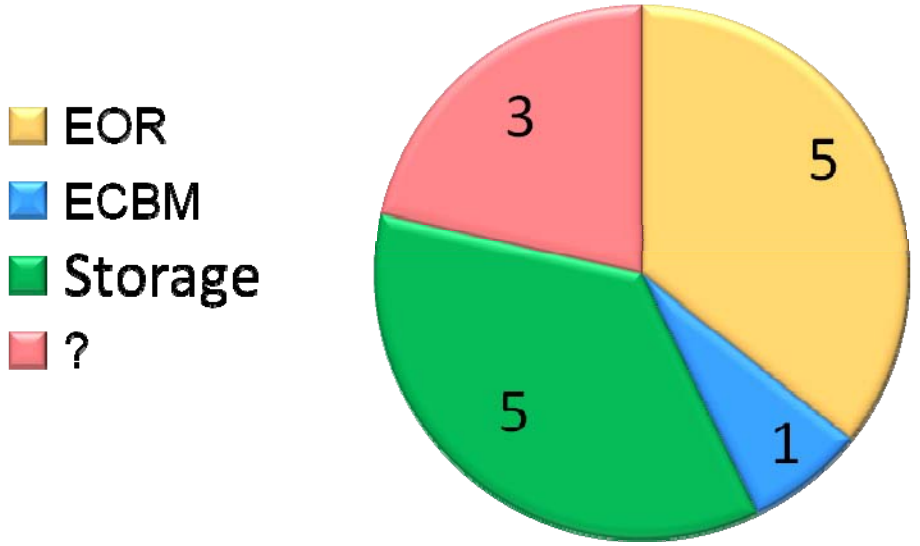
- 13 plants capturing from combustion processes
  - 11 post-combustion
  - 1 pre-combustion
  - 1 oxyfuel
- 9 projects source CO_2 from industrial processing (Natural gas separation, ammonia, LNG, hydrogen production)
- Multiple fuels represented
  - Hard coal
  - Lignite
  - Natural Gas
  - Industrial processes
- Over 10Mt of CO_2 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

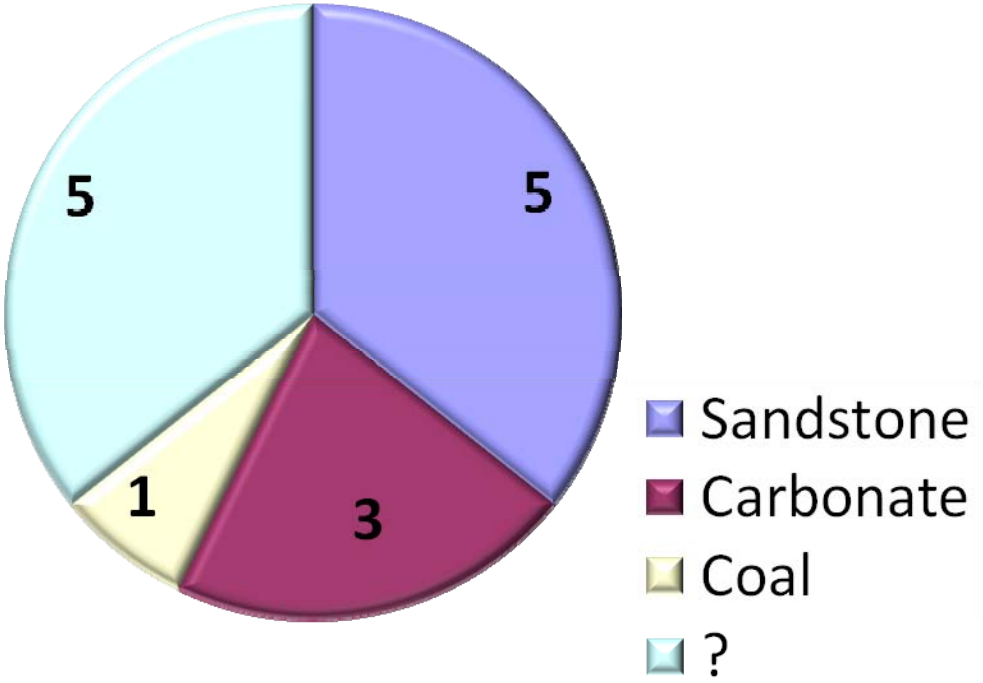
Extent of coverage – Injection

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

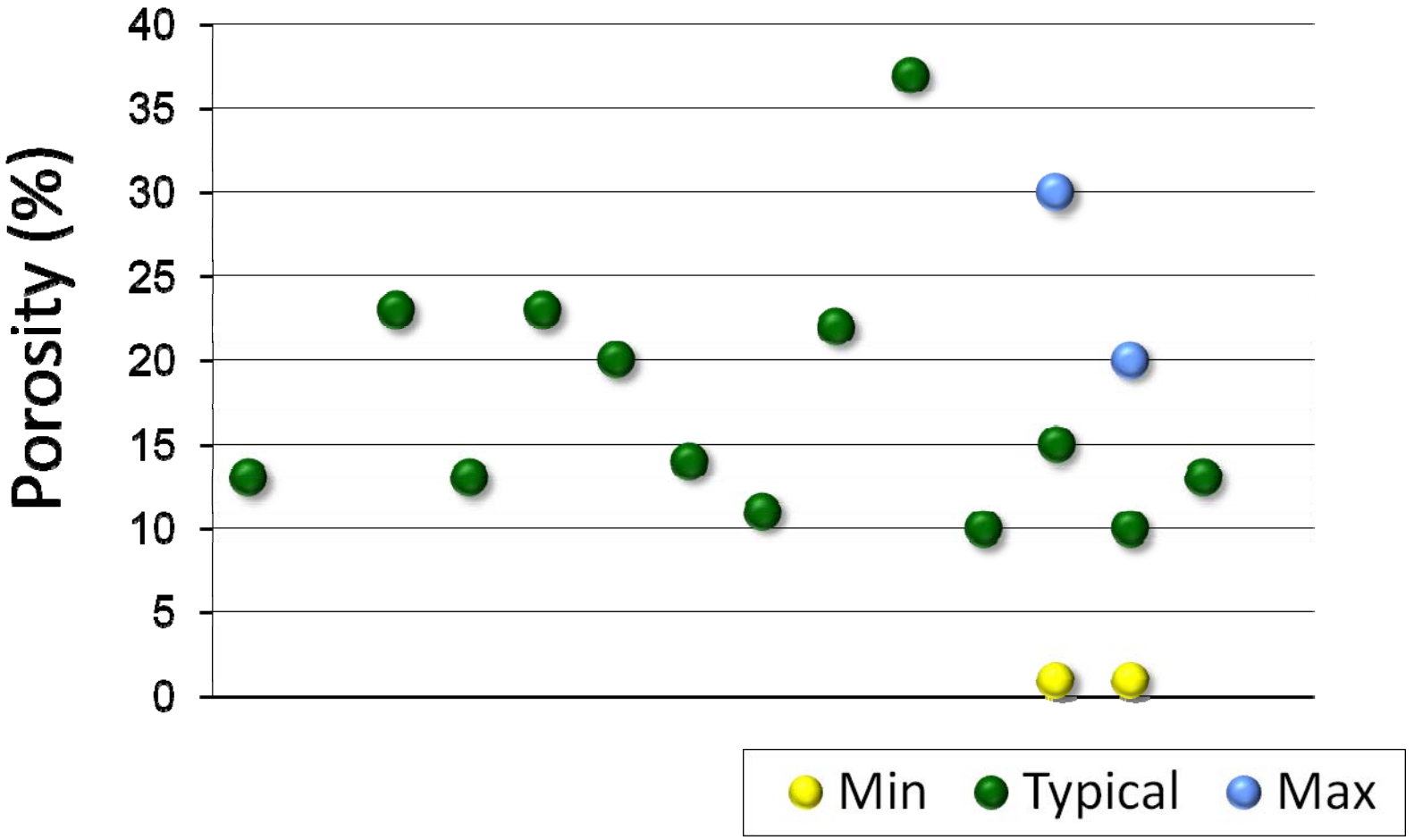


Extent of coverage – Storage Formations

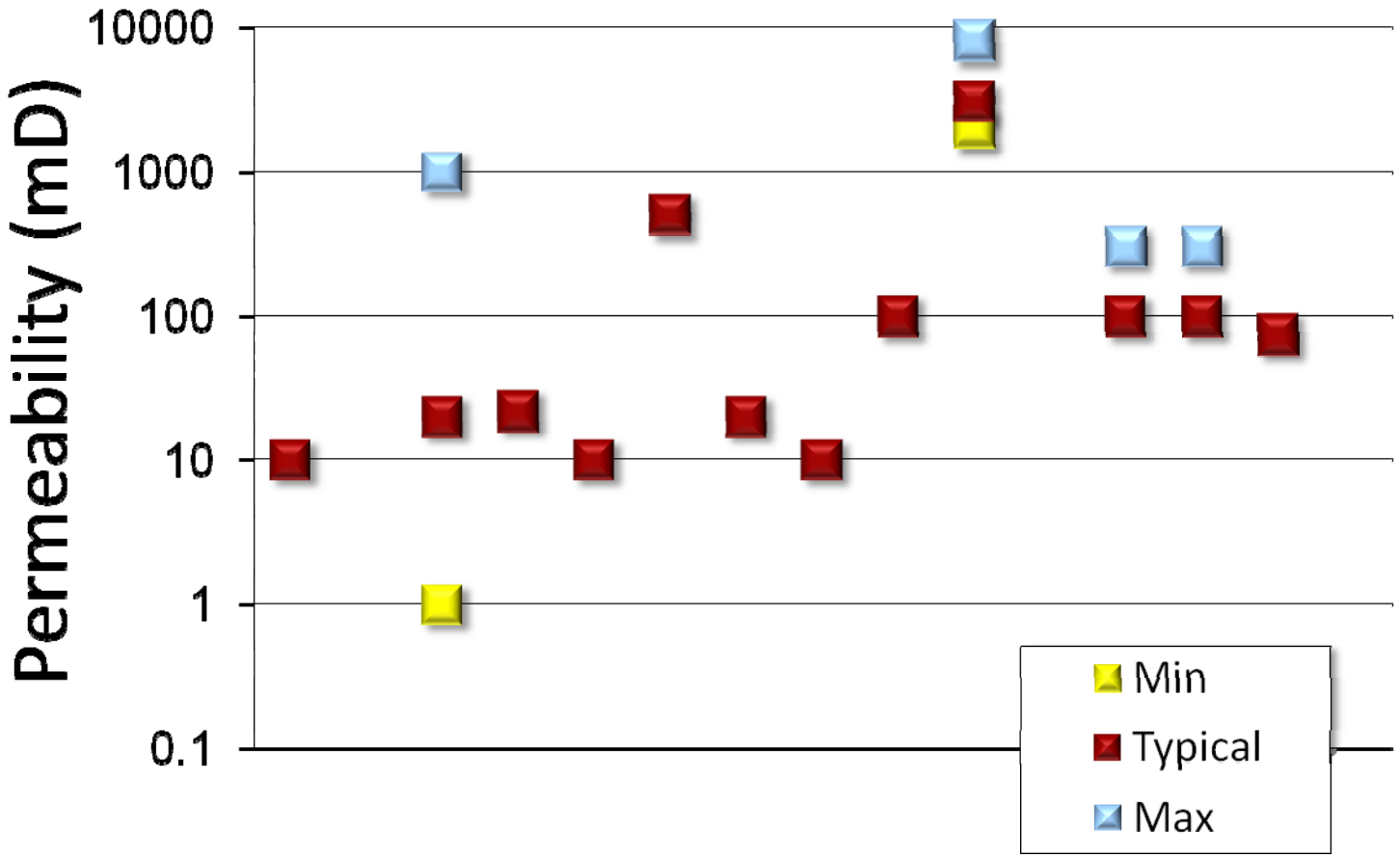
- A variety of storage formations
  - Sandstone
  - Carbonate
  - Coal



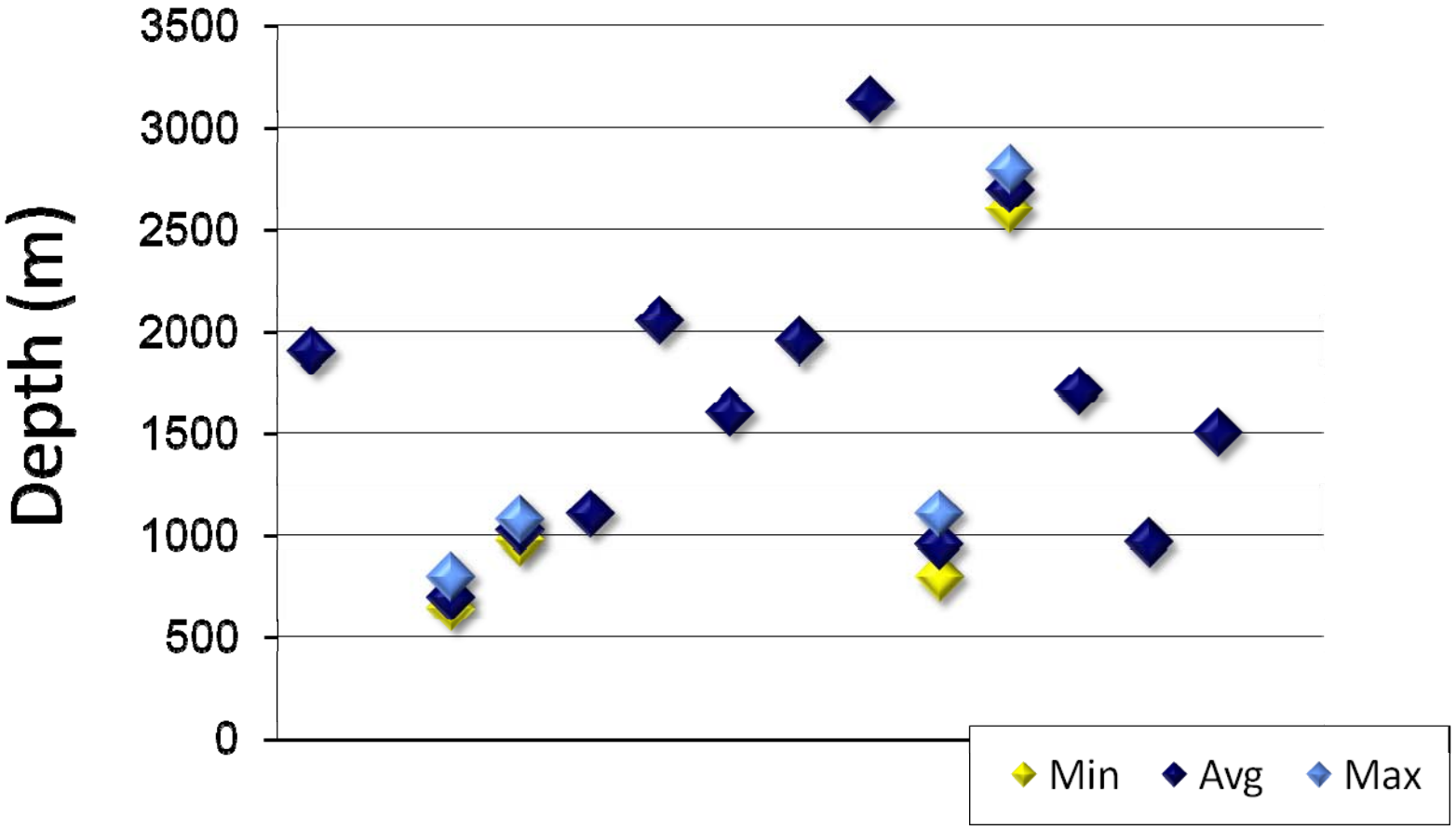
Porosity



Permeability



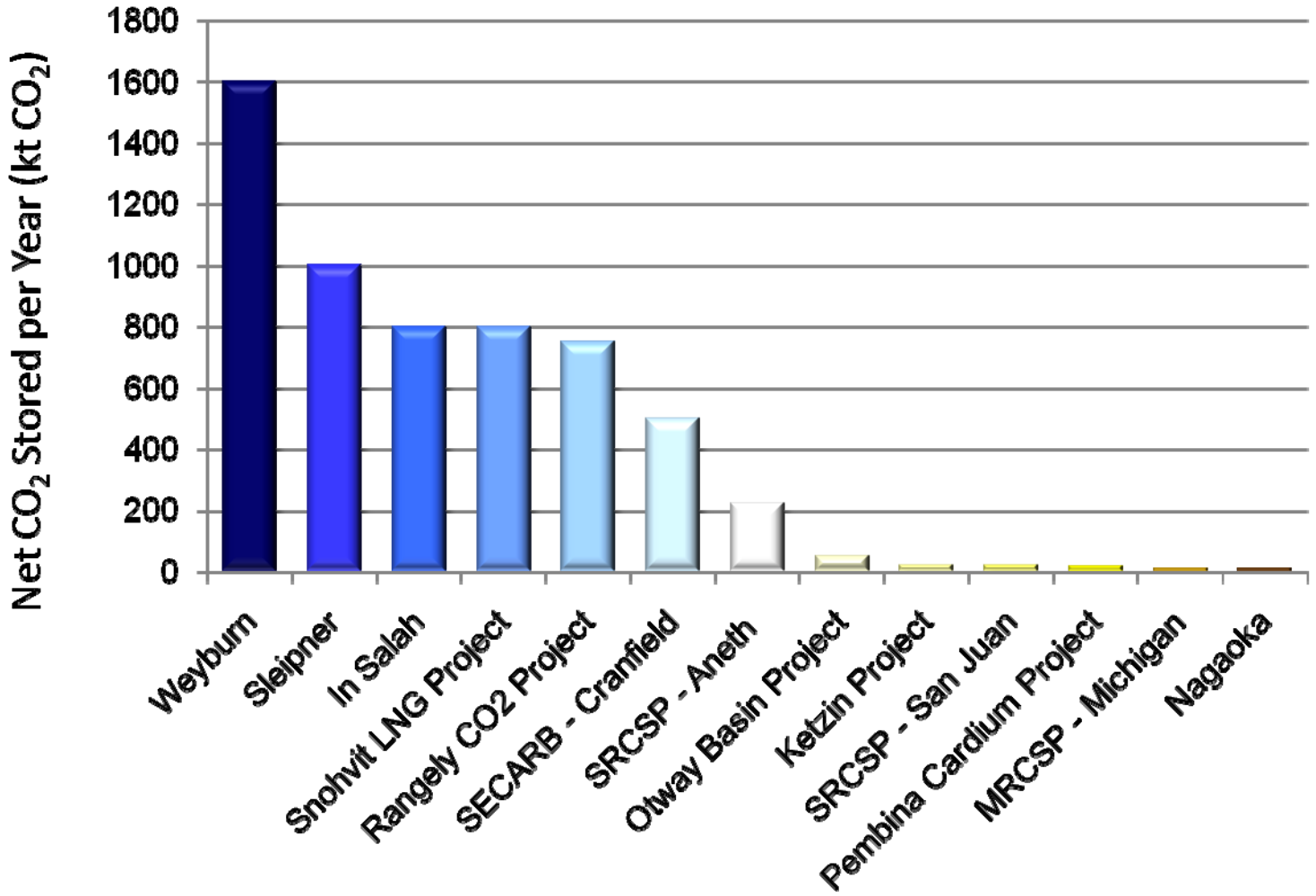
Reservoir Depth



Extent of coverage – Storage amounts

- There are six projects that store over 40,000t CO_2 per year
- All projects combine store almost 6Mt per year
- Total of 57 project years of CO_2 storage experience
- Over 40Mt of CO_2 stored

Net CO_2 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

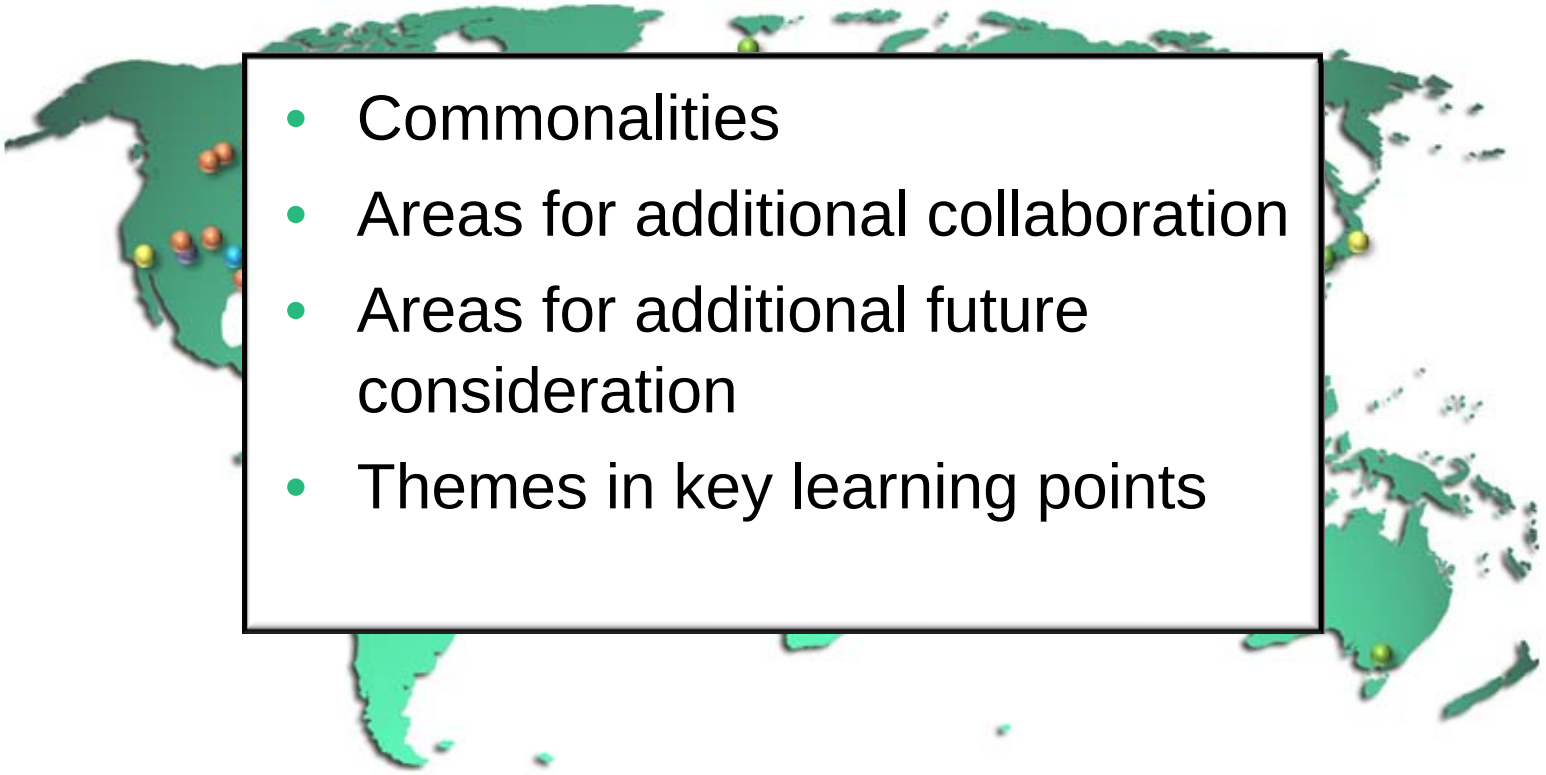
Not demonstrated in operational large projects

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 CO_2 per year

Learning From Projects
- preliminary and not yet complete



- 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 CO_2 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 CO_2 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
- CO_2 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