



# An update on CCS: Recent developments

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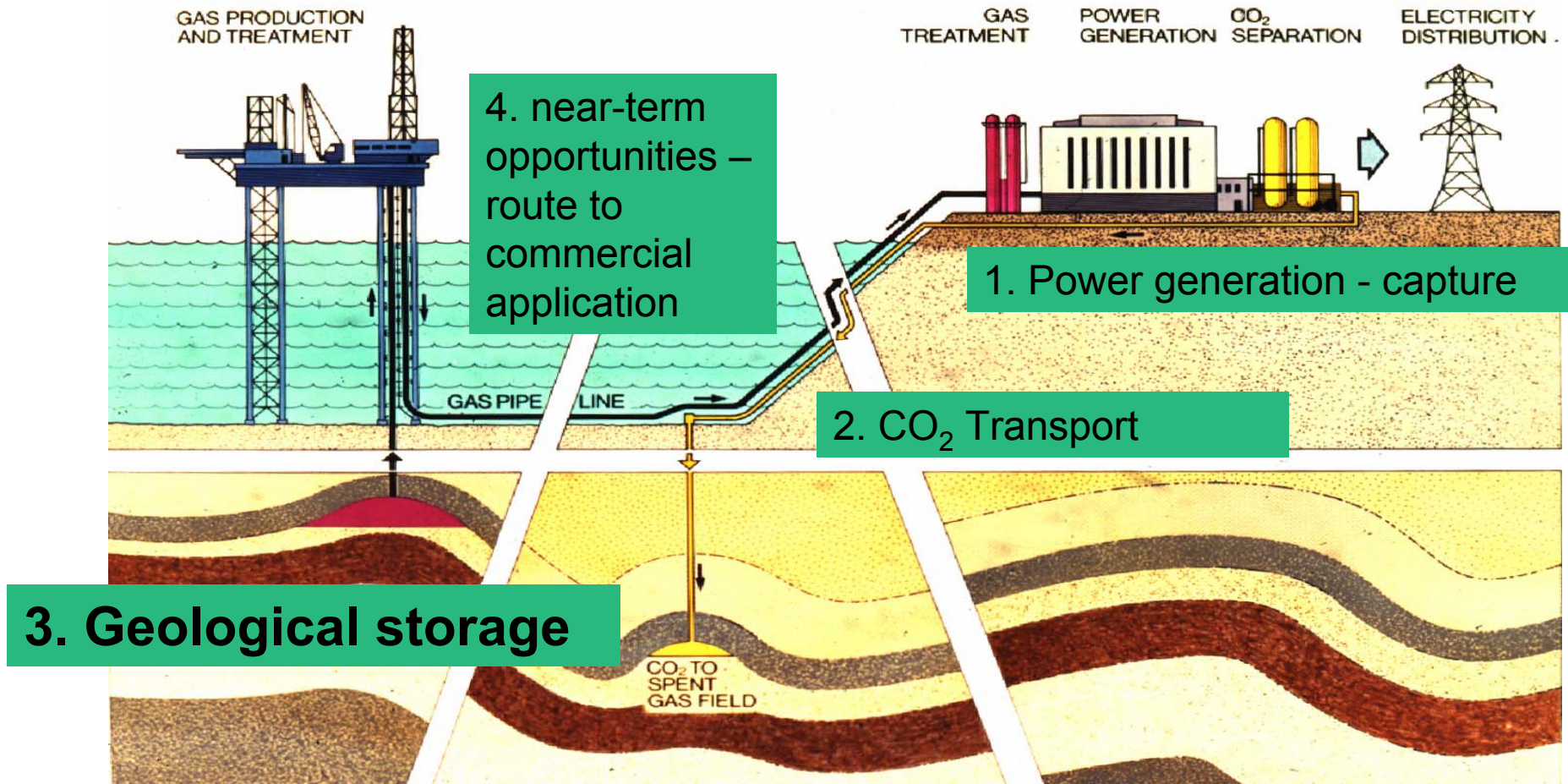
IEA Greenhouse Gas R&D Programme

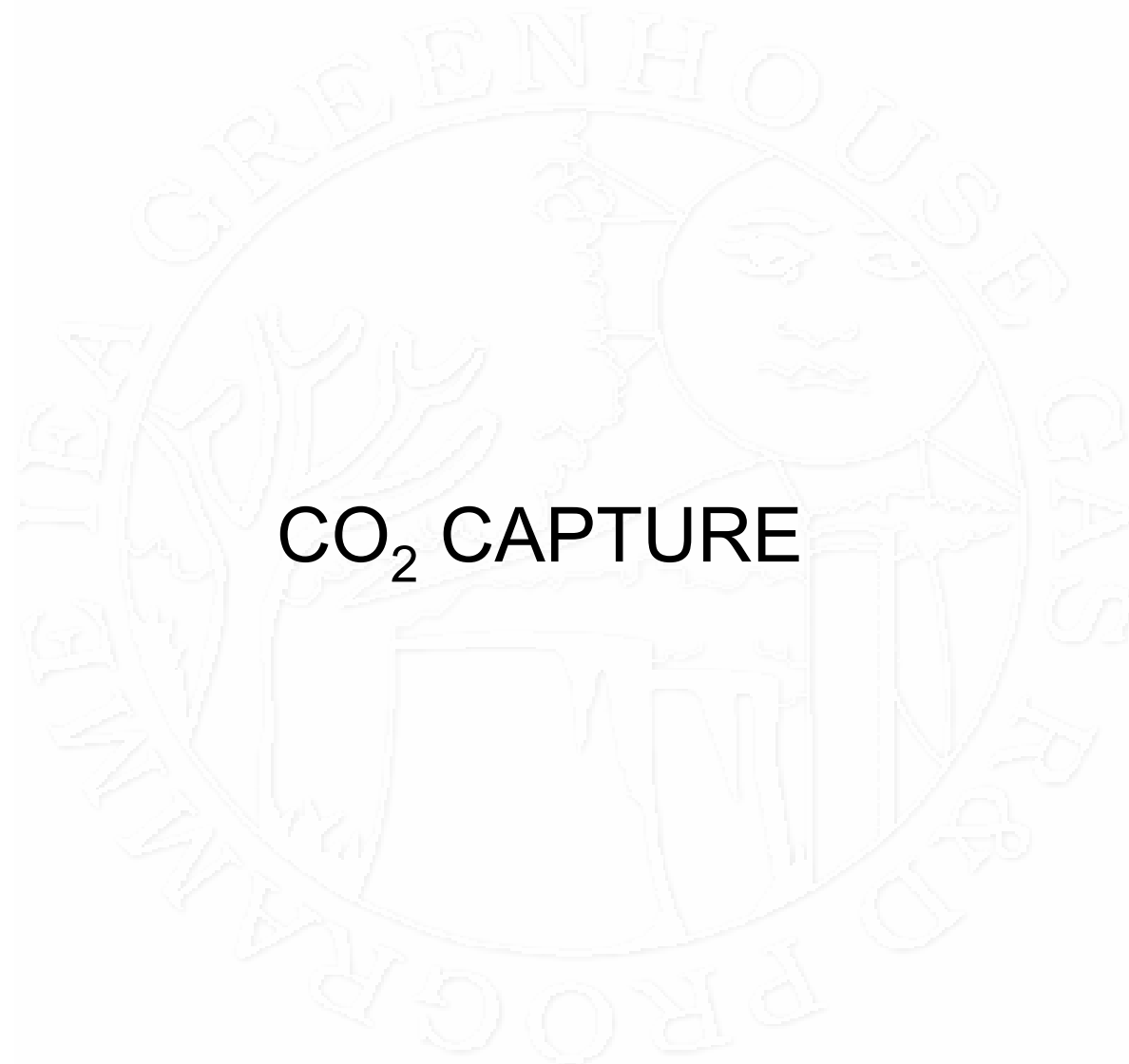
Presented at:

2<sup>nd</sup> IEA Workshop on Legal Aspects of storing CO<sub>2</sub>  
Paris, France, 17<sup>th</sup> October 2006



## CCS UPDATE: STRUCTURE OF PRESENTATION





# CO<sub>2</sub> CAPTURE



## Stationary sources of CO<sub>2</sub>\*

|                       |                 |
|-----------------------|-----------------|
| Power generation      | 4,942 (10.5 Gt) |
| Cement production     | 1,175 (0.9 Gt)  |
| Refineries            | 638 (0.8 Gt)    |
| Petrochemicals        | 470 (0.4 Gt)    |
| Iron & Steel industry | 269 (0.6 Gt)    |

\* Of at least 100,000 tonnes/year. Figures from IPCC Special Report on Carbon Dioxide Capture and Storage

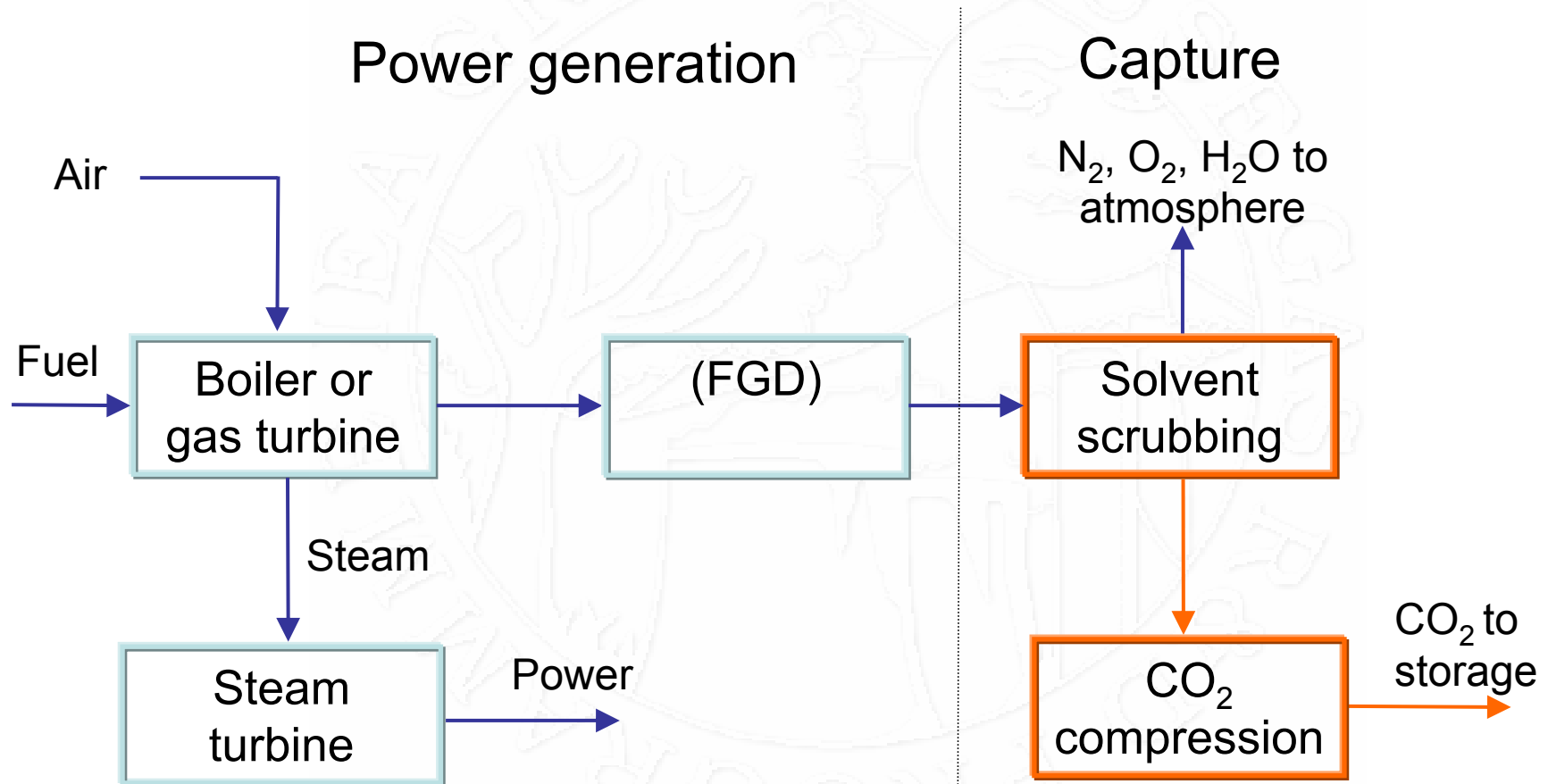


## Leading CO<sub>2</sub> capture technologies

- Capture of CO<sub>2</sub> from flue gases:
  - Post-combustion capture
- Burning fuel in oxygen instead of air:
  - Oxy-combustion
- Conversion of fuel to H<sub>2</sub> (and CO<sub>2</sub>) before combustion:
  - Pre-combustion capture



# Post-combustion capture: process





## Post-combustion capture: solvent

- Widely used on reducing gases, e.g. natural gas
- Less widely used for oxidising flue gases
- MEA<sup>1</sup> used in post-combustion capture plants
  - CO<sub>2</sub> is used in food & drink processing
- New solvents being developed
  - e.g. hindered amines
  - Lower energy consumption, solvent losses, <corrosion
- Low SO<sub>x</sub> (<10 ppm) and NO<sub>2</sub> (<20ppm) is needed
  - Possible with limestone-gypsum FGD and SCR

1. MEA: mono-ethanolamine



## Post-combustion capture: status



- Warrior Run power plant, USA
- 180 MW<sub>e</sub> coal fired circulating fluidised bed combustor
- 150 t/d of CO<sub>2</sub> captured from a slipstream
  - About 5% of the total



## Post-combustion capture: KEY ISSUES

- Corrosion
  - Stainless steel v carbon steel
  - Inhibitors can contain V, Sn, Sb (antimony)
- Solvent life
  - 2 US\$/tCO<sub>2</sub> (1,300 US\$/t MEA and use of 1.6kg MEA/tCO<sub>2</sub> )
  - Enhanced SO<sub>2</sub> removal (10ppm to 2ppm ?)
- Environmental impacts
  - Some degradation products known and regulated others are not.

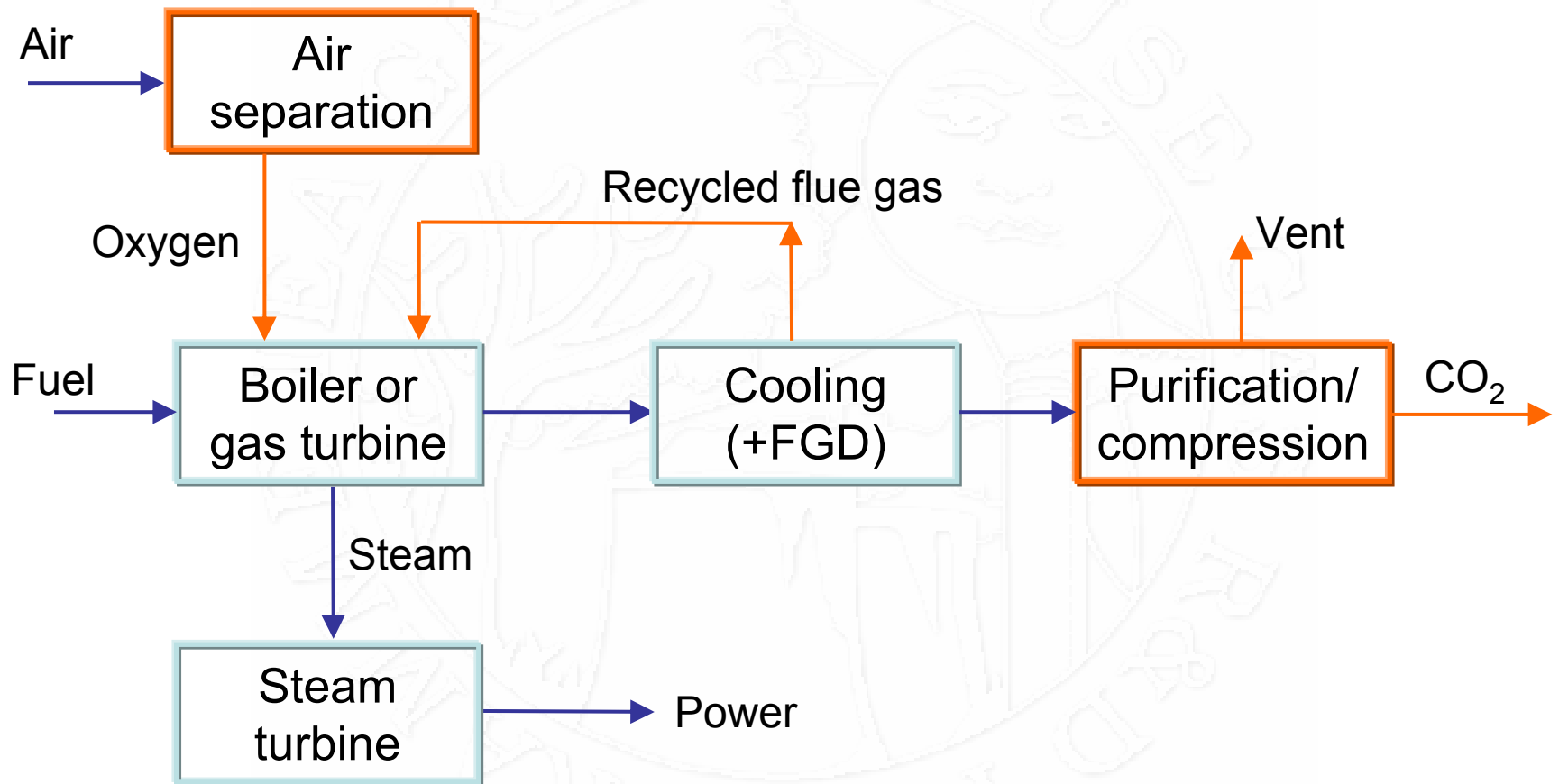


## Post-Combustion capture: summary

- Advantages
  - Existing combustion technology can be used
  - Retrofit to existing plants is possible
    - Retrofit to old inefficient plants is not attractive
  - Demonstrated at small power plants
- Disadvantages
  - Energy penalty has been relatively high
    - Penalty is being reduced by process developments
  - Solvents are degraded by oxygen and impurities
    - Environmental issues



## Oxy-combustion capture: process





## Oxy-combustion capture: status



5 MW<sub>e</sub> CES water cycle plant at Kimberlina, California



## Oxy-combustion capture: KEY ISSUES

- Leak prevention & build up of inerts
  - Boiler under slight vacuum –pressurised operation possible?
- Wet recycle
  - Acid corrosion implications
- Purity of oxygen supply
  - Inerts build up
- Fate of impurities (SO<sub>x</sub>, NO<sub>x</sub>, etc.)

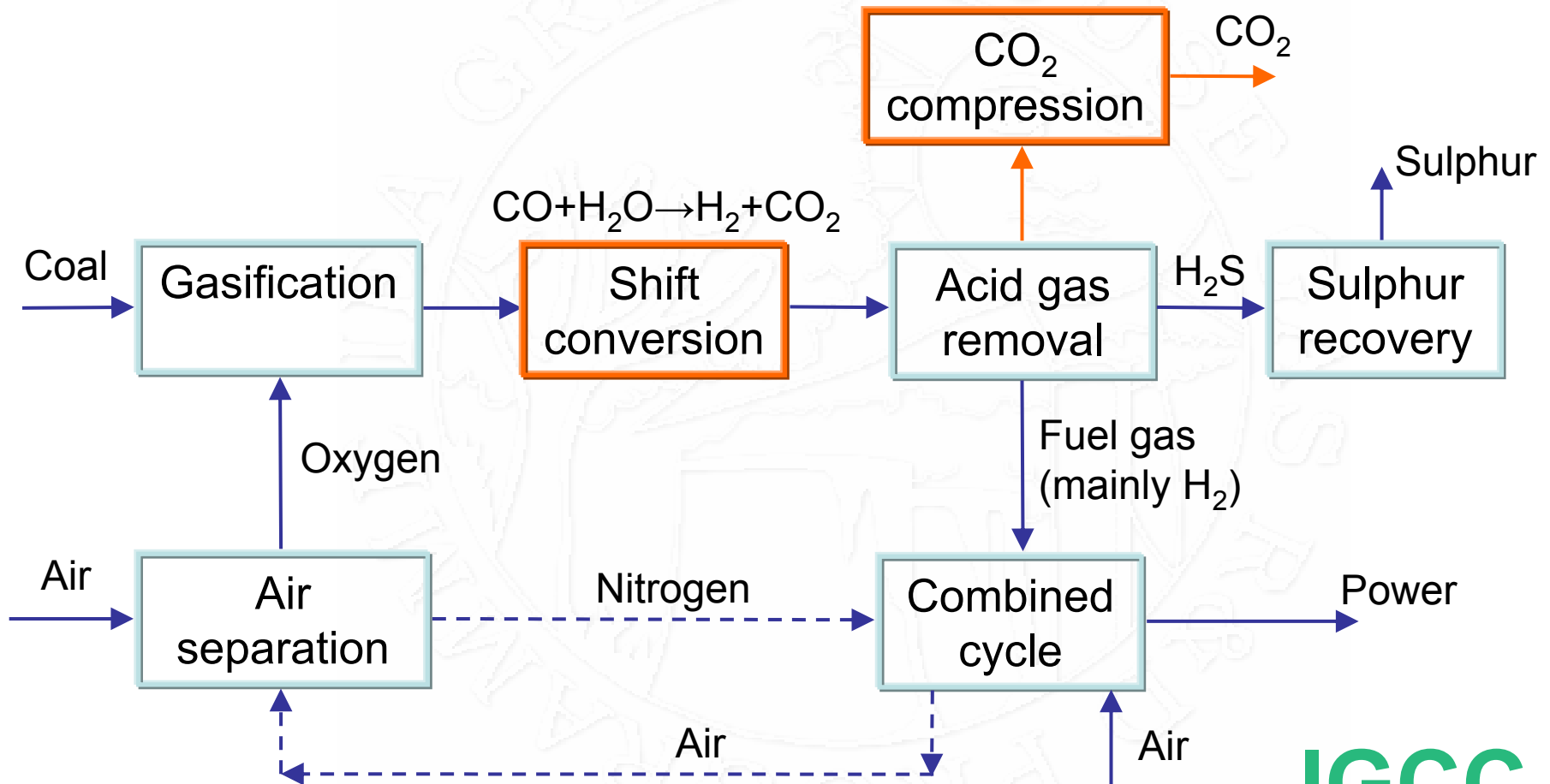


## Oxy-combustion capture: summary

- Advantages
  - Combustors could be fairly conventional
  - Possibility of compact boilers with lower quantities of flue gas recycle
  - Possibility of avoiding separate FGD step
  - Could give closest approach to 'zero emissions'
- Disadvantages
  - Only tested at a small scale
  - High cost of oxygen production
  - If gas turbines, new designs are needed



## Pre-combustion capture: process (non-gaseous fuel)



**IGCC**



## Pre-combustion status: IGCC without CO<sub>2</sub> Capture

- 4 coal-based IGCC demonstration plants (USA, Netherlands, and Spain)
- Availability has been poor but is improving
- IGCC is not, at present, the preferred technology for new coal-fired power plants
- At present the main commercial interest in IGCC is for use of petroleum residues



## Pre-combustion status: IGCC without CO<sub>2</sub> capture



Shell gasifier IGCC plant, Buggenum, Netherlands



## Pre-combustion capture: KEY ISSUES

- Integrated operation
  - Several processing units must all work
  - Turndown e.g. for load following
- Gasifier (or partial oxidation unit) availability
  - Maximum size
  - Spares requirement?
  - Burner and refractory life
- Hydrogen turbine
  - Can not used most advanced models



## Pre-combustion capture: summary

- **Advantages**
  - High CO<sub>2</sub> concentration and high overall pressure
    - Lower energy consumption for CO<sub>2</sub> separation
    - Compact equipment
  - Proven CO<sub>2</sub> separation technology can be used
  - Possibility of co-production of hydrogen
- **Disadvantages**
  - Unfamiliar technology for power generators
  - Coal-fired IGCC plants have had low availability
  - IGCC without CO<sub>2</sub> capture has generally higher costs than pulverised coal combustion

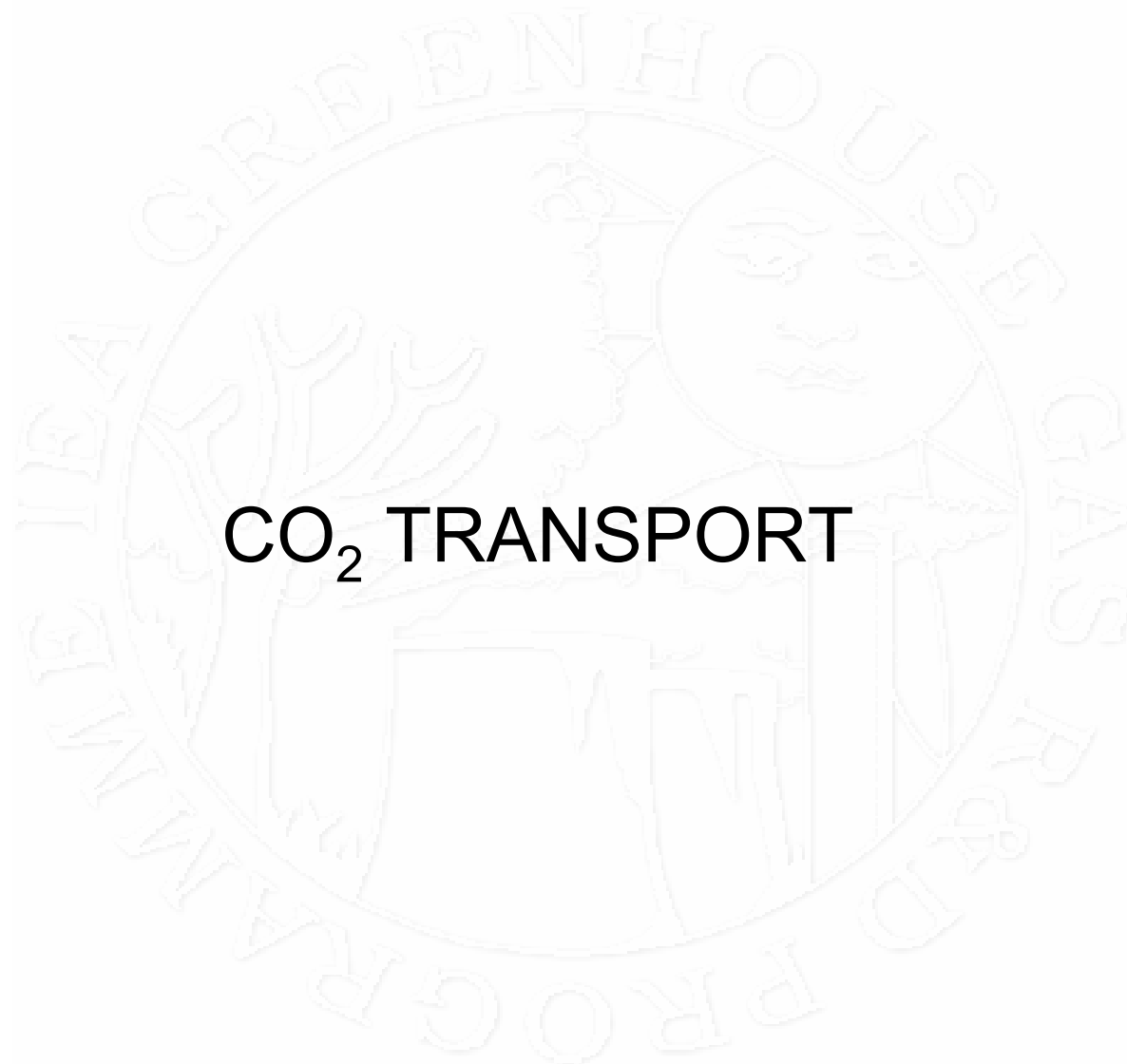


## CO<sub>2</sub> capture: summary

- CO<sub>2</sub> can be captured using 'existing' technology
  - 3 options to chose from
- Capture technology needs to be demonstrated at larger scales
- CO<sub>2</sub> capture reduces power plant efficiency by about 6-11 percentage points
- Cost of capture is about 1-3 US cents/kWh, excluding storage (\$20-60/t CO<sub>2</sub>-avoided)
- Cost-reduction likely from 'learning-by-doing'

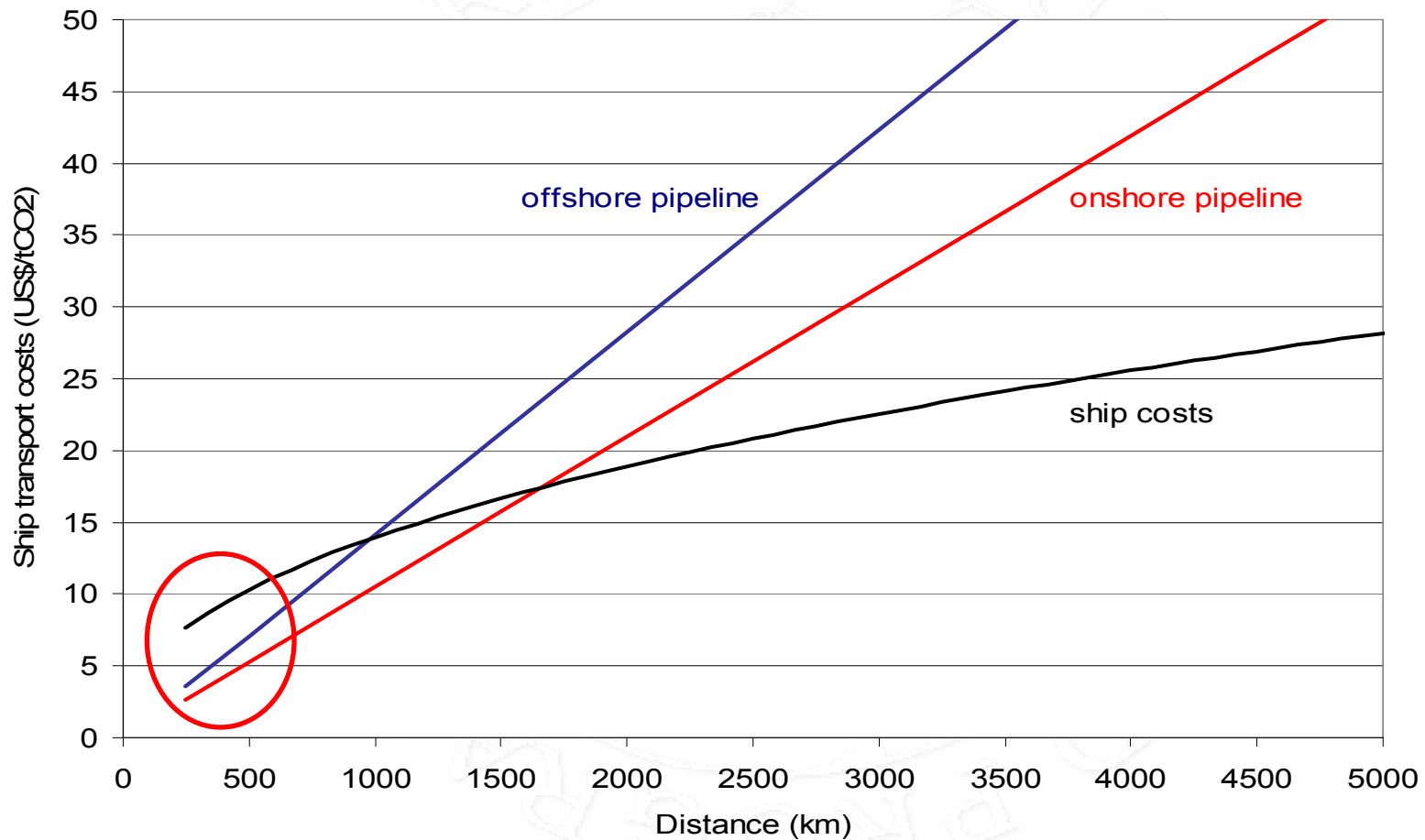


# CO<sub>2</sub> TRANSPORT





# CO<sub>2</sub> transmission: costs





## Pipeline transmission: status

- CO<sub>2</sub> pipeline transmission is well established
  - Large CO<sub>2</sub> pipelines have been in use since the early 1970s
  - CO<sub>2</sub> supplied for enhanced oil recovery
  - About 4000 km in use today
  - Most pipelines are in the USA (Texas/New Mexico)
  - Most of the CO<sub>2</sub> is from natural sources
  - Individual pipeline capacities up to 20 Mt/y



## Weyburn Pipeline



- USA to Canada
- CO<sub>2</sub> from coal gasification used for enhanced oil recovery
- CO<sub>2</sub> about 1% H<sub>2</sub>S and traces of other sulphur compounds, including mercaptans
  - Good for detecting small leaks



## Shipping CO<sub>2</sub> by tanker



CO<sub>2</sub> tanker



LPG tanker

- CO<sub>2</sub> tankers:
  - CO<sub>2</sub> transported as a liquid (>6 bar, <-55C)
  - Construction similar to LPG tankers
  - Attractive for long distances
  - 'Easier' than shipping LNG



## CO<sub>2</sub> transport: summary

- CO<sub>2</sub> pipeline transmission is well established
- Existing pipelines have a good safety record
- Ships can be attractive for long distance transport
- Costs <10\$/tCO<sub>2</sub> if the source is within 500km of the store



# CO<sub>2</sub> STORAGE

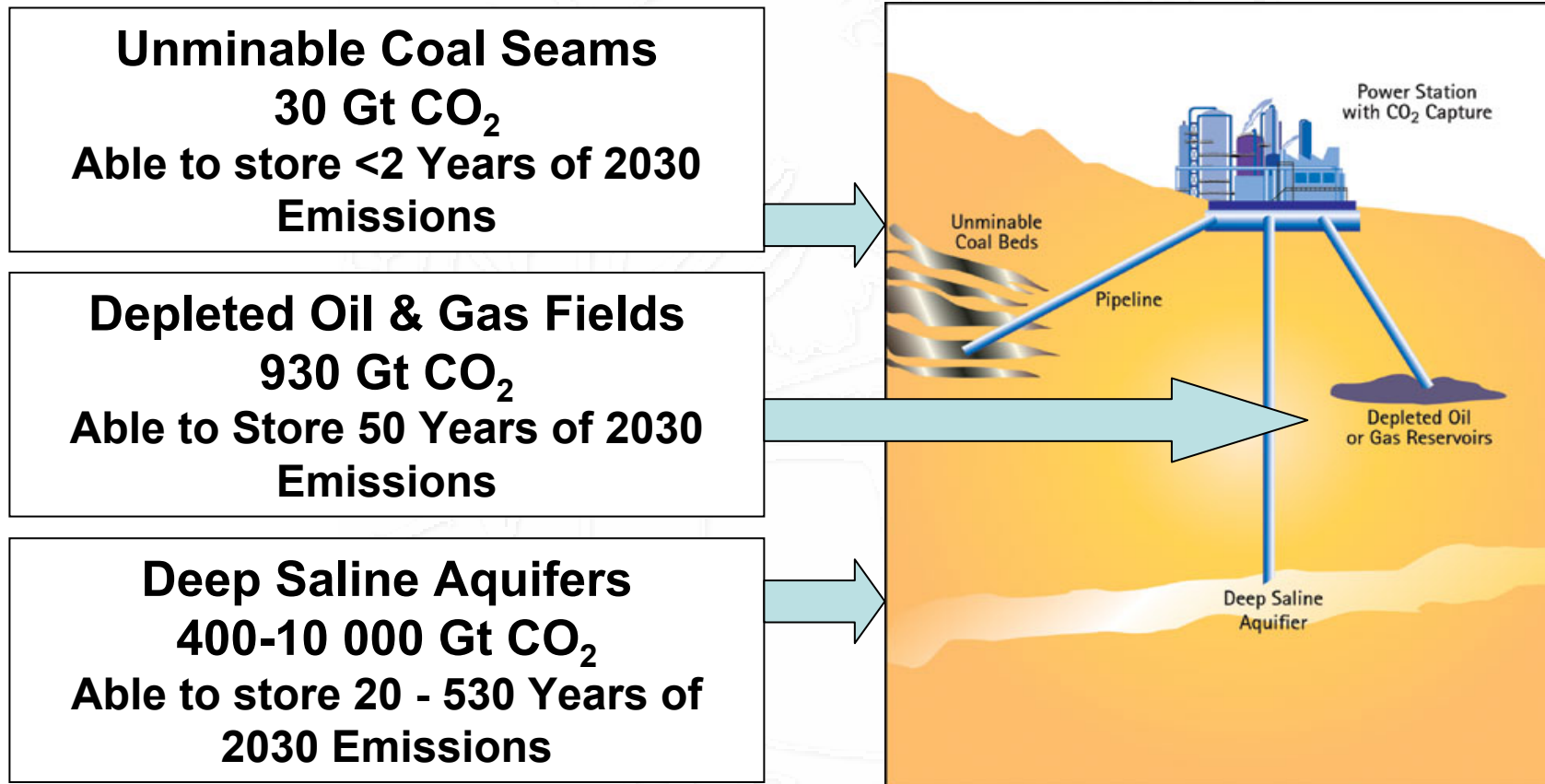


## CO<sub>2</sub> storage options

- Geological – covered in this presentation
- Ocean – unlikely to be environmentally acceptable in the near future
- Mineralisation – unlikely to be economically practicable in the near future



## Geological storage: Options



Note: CO<sub>2</sub> Storage capacity at cost of 20 US \$ per tonne of CO<sub>2</sub>



## Geological Storage

- Sufficient capacity available to store all CO<sub>2</sub> needed to stabilise emissions
- Will need to rely heavily on deep saline aquifers
- Need additional effort to quantify the storage capacity and integrity of deep saline aquifers



## Activities Underway on Capacity Assessment

| High Level Assessments   | Basinal Level Assessments                                      |
|--|--|
| <b>IEA GHG</b> - Northern Europe, North America, India         | <b>Canada</b> - Alberta Basin                                  |
| <b>EC</b> - GESTCO/GEOCAPACITY (Central and Eastern Europe)    | <b>USA</b> - Regional partnerships                             |
| <b>China</b> - NZEP activity funded by EC<br>Activity by USDOE | <b>UK</b> - Southern North Sea                                 |
| APEC - Assessment of <b>Pacific Rim Countries</b>              | <b>Australia</b> - Detailed assessment and<br>risking analysis |
| <b>Japan</b>   |  |

CSLF initiative to adopt a standard set of criteria for capacity assessment



## Costs of storage (US\$/tCO<sub>2</sub>)

| Storage formation  | IEA GHG results for Europe | IEA GHG results for North America | Range from IPCC SRCCS |
|--------------------|----------------------------|-----------------------------------|-----------------------|
| Saline aquifer     | 2                          | 12                                | 0.2 – 12              |
| Depleted gas field | 3                          | 12                                | 0.5 – 12.2            |
| Depleted oil field | 3                          | 17                                | 0.5 – 4               |



## Commercial-scale operations



Sleipner



Snøhvit



In-Salah



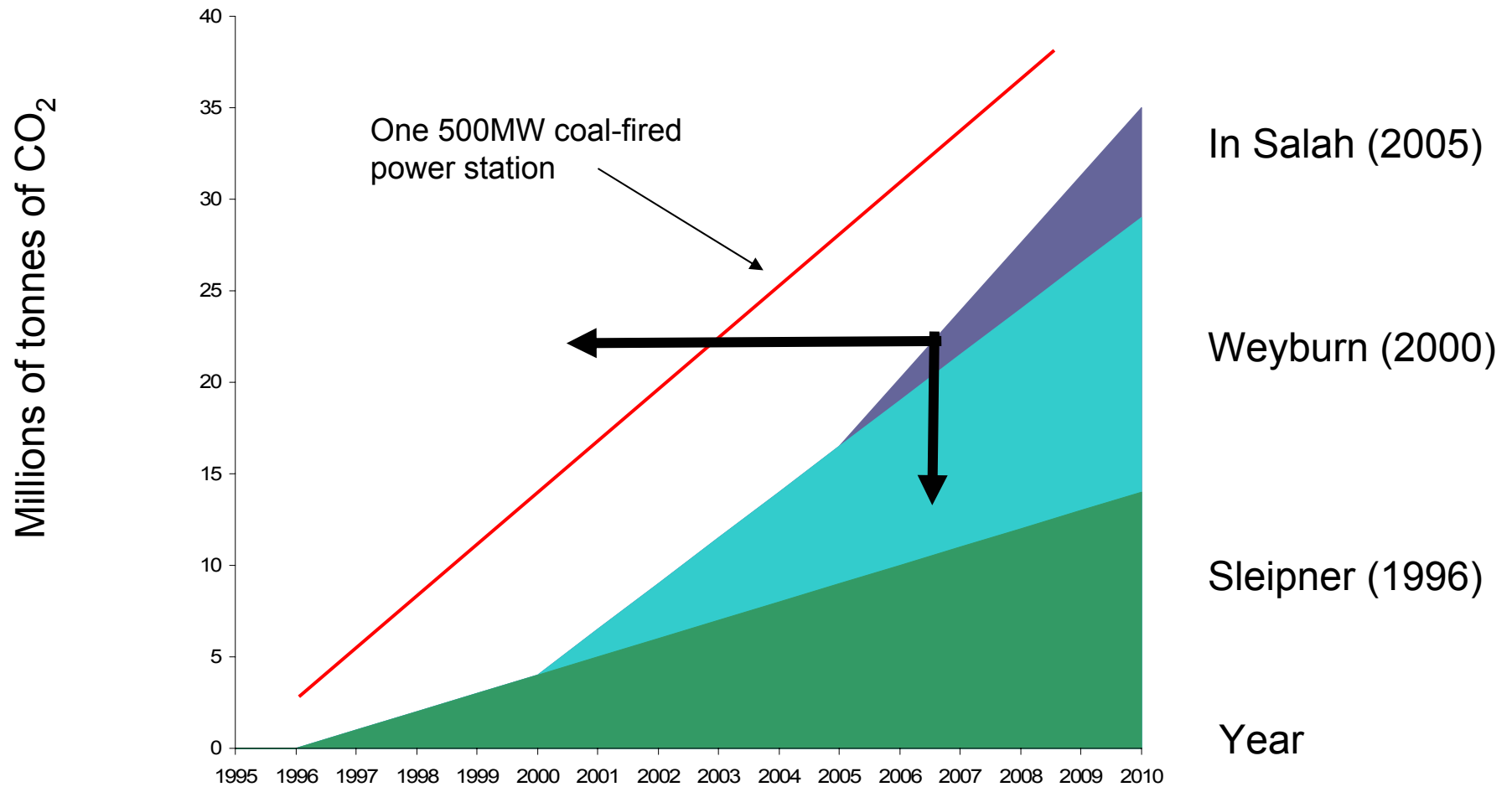
Weyburn

**NOT POWER GENERATION**

Images Courtesy of BP, Statoil, and PTRC



# Monitored CO<sub>2</sub> Stored Underground





## Current Status: CO<sub>2</sub> storage activity



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## Deep Saline aquifers

- Geology of oil and gas fields well known
  - Demonstrated sealing potential
  - Punctured by many drilling holes
- Aquifers are largely unexplored structures
  - Many will be 'virgin' structures
  - Want to avoid them being punctured by wells to retain their integrity
  - Have to drill cores to ensure the caprocks will seal
  - Need extensive programme of geological and geophysical characterisation before you can be sure they are suitable
    - Some parallels with natural gas storage industry



## Safety & Permanence

- Whenever CCS is discussed one of the key questions is asked is:
  - Is it safe?
    - Will the storage formations leak?
    - What are the environmental impacts if it leaks?
- This is a question we must answer satisfactorily
- Important issue to resolve to get general acceptance for this technology
  - Governmental commitment
  - Public awareness is low and could be a barrier to wide scale implementation



## CO<sub>2</sub> Containment

- Statistics show there will be fugitive emissions from pipelines and surface facilities
  - Low level and intermittent
  - Can quantify such emissions
  - Reported through national inventories
- The storage formation should be designed for zero seepage; but cannot say there will never be seepage incidents
- Preventative methods include:
  - Effective site characterisation
    - Geology, hydrogeology, faults and wells
  - Risk assessment
    - Health & Safety, short-term (project lifetime), long-term
  - Monitoring programme – pre and post injection
  - Remediation planning



## CO<sub>2</sub> Containment

- No evidence from any of the new large scale projects that seepage is occurring.
- One EOR project has reported surface seepage but there are doubts about the data
  - Biogenically converted methane
- Performance assessment studies suggest negligible seepage
  - Weyburn – simulations suggest 5000 years before surface seepage theoretically could occur
  - Sleipner modelling suggests all CO<sub>2</sub> will have dissolved by 3000 years
- No technical basis on which to quote a ‘seepage-rate’ for geological storage

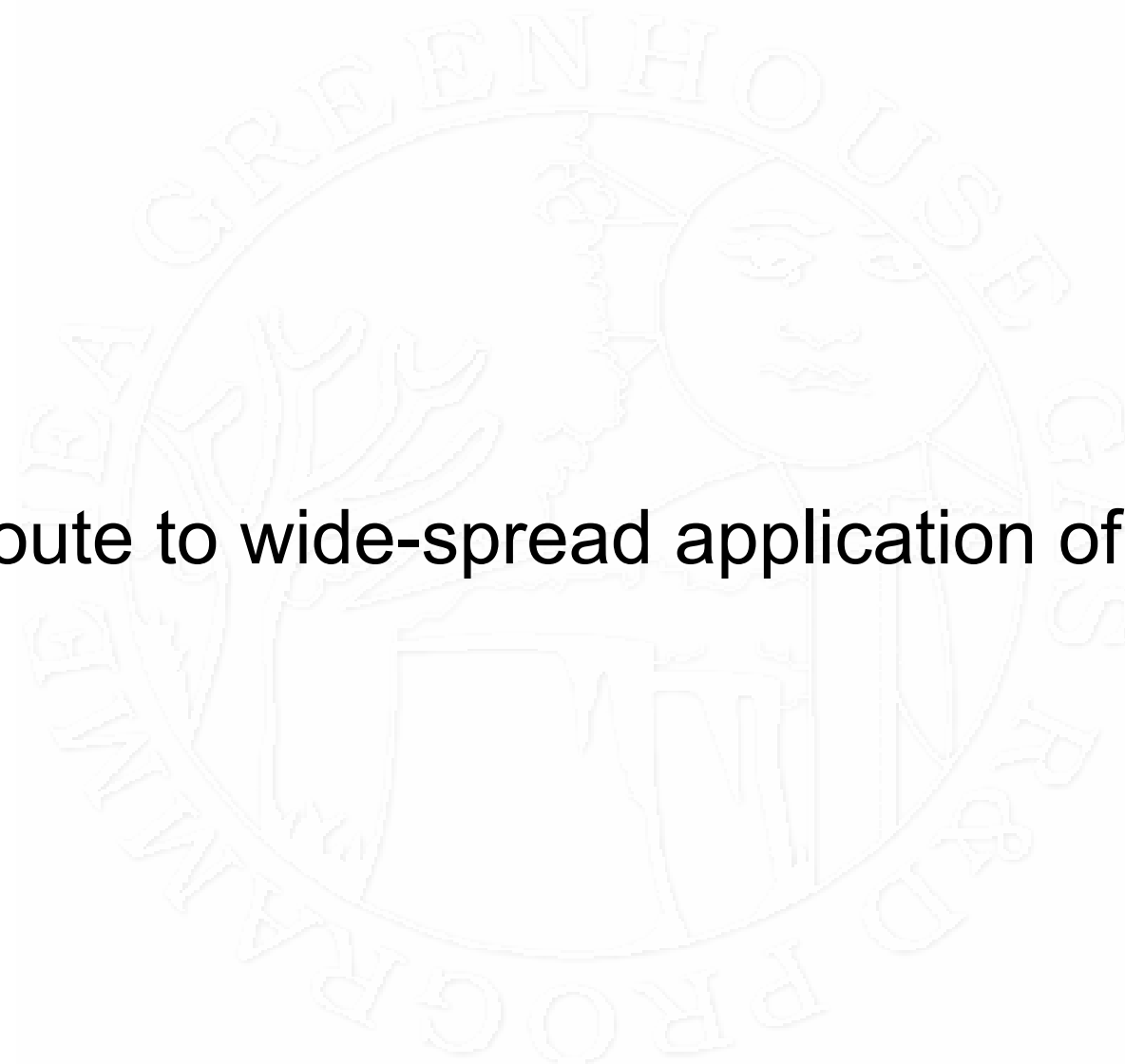


## Geological storage: summary

- Demonstration of storage more advanced than demonstration of capture
- Confidence more of an issue than cost
- Key issues:
  - Permitting/Licensing
  - Long term liability
  - Environmental Impact Assessment
  - Monitoring requirements
  - Remediation practices



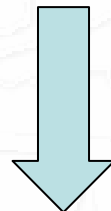
# The Route to wide-spread application of CCS





## The Challenge

How do we get from where we are now  
( $<10$  'commercial-scale' projects)



to wide-spread implementation with thousands of  
commercial CCS projects?



## A route to wide-spread application

- **Target for wide-spread application:** Power generation – coal – deep saline aquifers
- **I**ntroduce the technology – using near-term opportunities
  - 'cheap' CO<sub>2</sub>
  - EOR
  - Financial instruments (Kyoto, CDM, JI, ETS)
  - Clear necessary 'hurdles' – involve legislators & regulators, H&SE issues (trials planned in UK), acceptance
- **E**stablish the technology- by demonstration and development
  - International co-operation & funding
  - Establishing a value-chain
  - Infrastructure use and development
  - Establish national & international legal & regulatory frameworks
- **A**pply the technology – through international action
  - Carbon management
    - Allocation of responsibility for carbon between supplier and user
  - Supply security
    - capture ready power generation



## Creating a 'Value-chain'

- Norwegian initiative to create a CO<sub>2</sub> supply infrastructure
  - Part public sector/part private sector enterprise
  - Establish a CO<sub>2</sub> supply infrastructure for Norway to realise CO<sub>2</sub> -EOR potential
  - Leave behind a supply infrastructure that can then be used for CO<sub>2</sub> storage

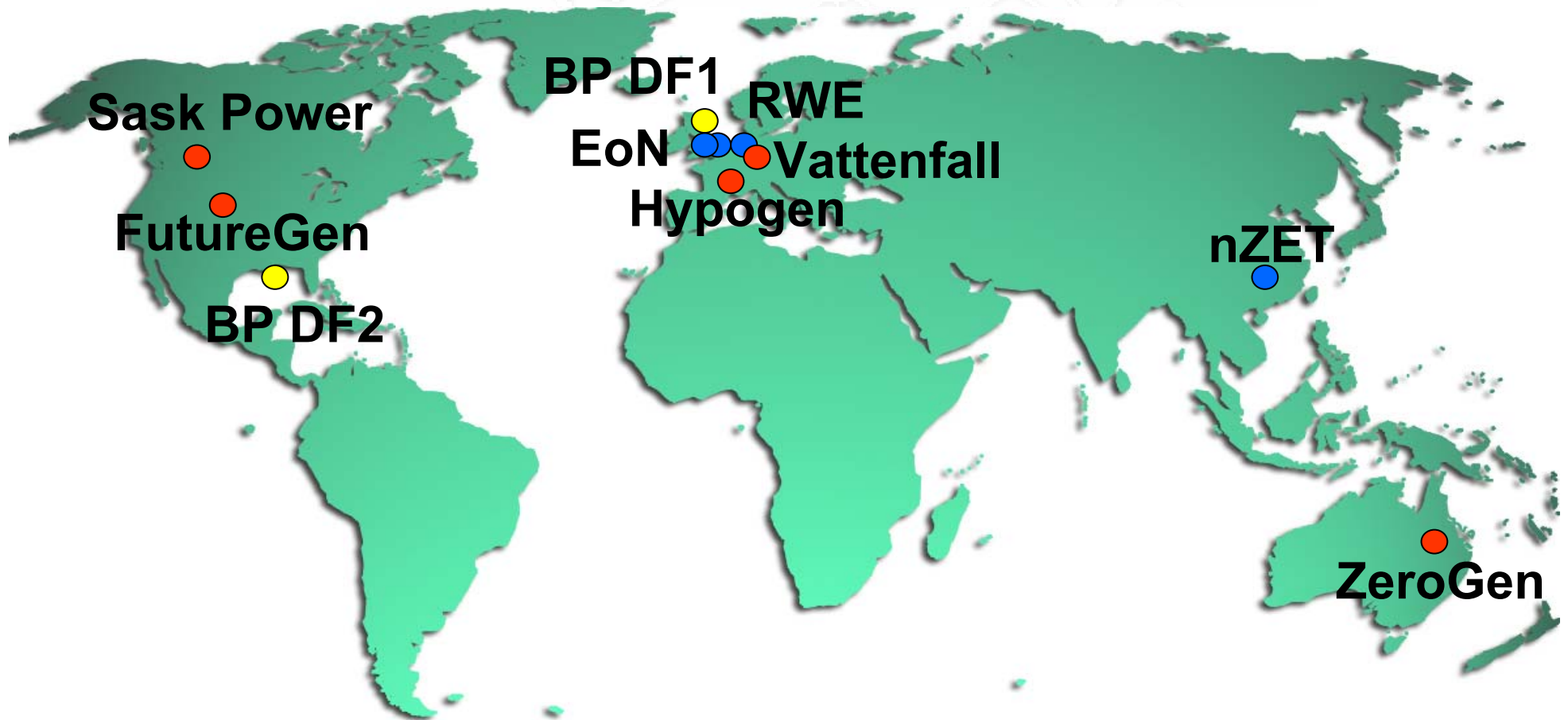


## Power Sector

- Power sector's business is to produce and sell electricity
- May prefer to act in the same way for CO<sub>2</sub>
  - Pipelines and geological activities not traditional skills in power sector
- How do we establish a storage industry to work with the power sector?
- Will emissions trading be sufficient to establish such an industry?
  - CSS as a CDM option would be a good start



## Power Sector CCS Projects



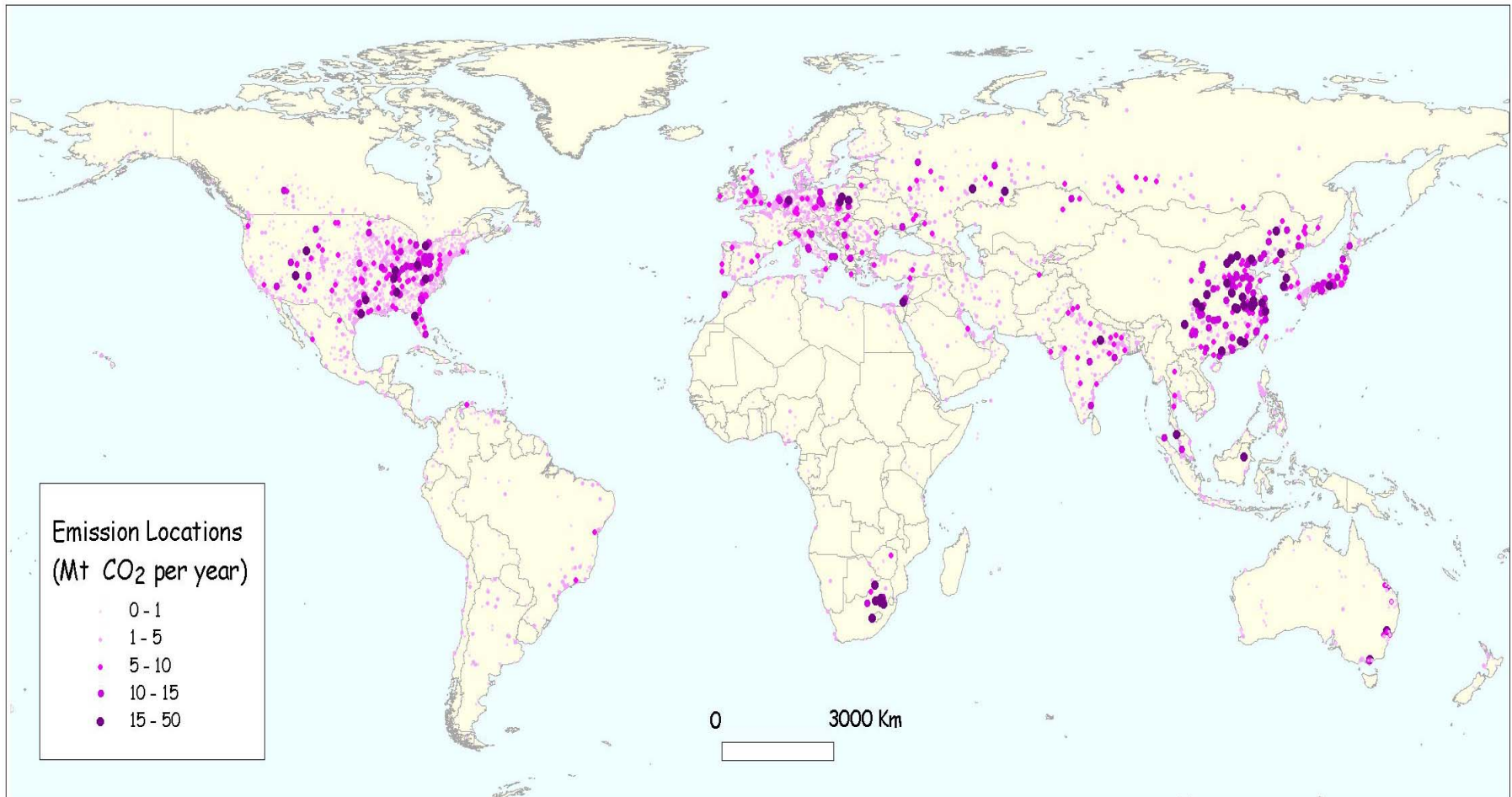


## Examples of planned CCS projects with power generation

- BP Miller-Peterhead DF1 project, UK
  - **475 MW** natural gas fired power plant, pre-combustion capture
  - CO<sub>2</sub> for EOR, Start up 2010
- BP Carson DF2 project, California
  - **500 MW** petroleum coke gasification, pre-combustion capture
  - CO<sub>2</sub> for EOR, Start-up 2011
- Shell/Statoil HALTEN project, Norway
  - **860 MW** natural gas power plant, post-combustion capture
  - CO<sub>2</sub> for EOR, Start-up 2011
- RWE project, Germany
  - **450 MW** coal IGCC, pre-combustion capture
  - Saline reservoir storage of CO<sub>2</sub>, Start-up 2014
- Future Gen project, USA
  - **275 MW** coal IGCC, pre-combustion capture
  - Saline reservoir storage of CO<sub>2</sub>, Start-up 2014



# Developing Country Involvement





## Developing Country Implementation

- Route through the Kyoto Protocol to establish CCS projects in developing countries is:
  - The Clean Development Mechanism (CDM)
- CCS inclusion as a CDM option was raised at COP11/MOP1 but a decision was deferred
  - Referred to UNFCCC Subsidiary Technical Committee met in Bonn, Germany in May 2006
  - Referred back to COP12/MOP2 in November 2007
    - Some resistance observed



## CONCLUSIONS

- The costs of CCS are not excessive and can be reduced by application of the technology.
- The main potential for cost-reduction is in the capture step.
- Confidence in geological storage needs consolidating.
- Demonstrations needed; particularly of capture at power stations.
- A 'road-map' to 'wide-spread' application is required.
- It is important that 'non-technical' barriers are identified early and resolved: financial, legal & regulatory, acceptance



# IEA Greenhouse Gas R&D Programme



## IEA GHG thanks you for your attention

