What is a Technology Roadmap?

"Technology roadmaps identify, evaluate and promote the development of collaborative projects within and between industries to fill technology gaps and/or capture technology related opportunities." (Scheer 2001)

"Technology Roadmapping identifies future product, service and technology needs for industry sectors and evaluates and selects technology alternatives." (AusIndustry 2003)

"Technology Roadmaps can contribute to the policy aims of Government." (DIST 2001)
Australia’s CO$_2$ capture and storage technology roadmap…

- is provided as an example of the way in which Australian stakeholders and researchers went about establishing CCS priorities.

- will shape Australia’s major RD&D direction over the next few years, but will also be regularly revisited in the light of Australia’s evolving needs and international trends.

- is not a definitive text on how to produce a technology roadmap nor is it a formal policy paper outlining what Australia will do in CCS over the next 30 years.
The Australian CCS Technology Roadmap has identified...

• Areas of technology strength
• Areas of technology weakness
• R&D that is of critical importance to Australia
• R&D that will be pursued
• R&D where a watching brief will be maintained
• R&D where it will seek to collaborate internationally
THE STAGES OF ROADMAPPING

CO₂ capture & storage

- Preliminary activities (Level 0)
- Technology roadmap (Level 1) – the “focus”
- CO₂ capture & storage technology application roadmap (Level 2)
- CO₂ capture & storage roadmap to the hydrogen economy (Level 3)
Schema for the Australian CCS Technology Roadmap illustrating the four levels of mapping related to degree of detail and timing and commercialisation.
Preliminary activities (Level 0)

- Australia's CO₂ Emissions
- GEODISC
- CO2CRC
Level 0 roadmap developed for GEODISC (after Cook et al, 2000)
Industries where greenhouse gas technologies might potentially be applied in Australia to stationary sources of CO₂.
48 basins were considered viable sites for study (out of > 300)

102 sites analysed

65 proved viable ESSCIs

22 sites not viable; 15 regional basin overviews

Potential ESSCI sites

Unproduced high CO₂ gas field

Emission node

GEODISC Basins

Location of Australian sites (ESSCIs - Environmentally Sustainable Sites for CO₂ injection) assessed for the CO₂ storage potential (after Bradshaw et al, 2001)
Preliminary gap analysis & technology assessment showed:

- Technology options for limiting CO₂ emissions are seen as increasingly important by industry and government.
- Any technology solution must embrace need to use fossil fuels for the foreseeable future.
- Cost of CO₂ capture must decrease considerably
- Australian emissions represent challenges & opportunities.
- Australia is geologically favourable
- A need to establish new collaborative links and funding – CO₂CRC was the preferred route.
The strategy adopted for CO2CRC was to:

- Assemble an outstanding multi-disciplinary-interdisciplinary team of technology based researchers to work with industry, whilst ensuring integration of socio-economic issues.

- Take a 'whole of industry' approach to CO₂ encompassing a variety of emissions from a range of sources.

- Work with leading national and international research teams to maximize technology transfer and research leverage.

- Focus on identification, development and application of the most cost-effective system(s) for capture of CO₂ from major stationary sources.
Vision of CO2CRC

The VISION is to develop cost effective carbon capture and storage technologies through collaborative research, that will help Australia decrease CO₂ emissions to the atmosphere from major stationary CO₂ sources, whilst continuing to derive benefit from its abundant fossil fuels and existing industrial base.
Technology roadmap (Level 1)

- Roadmapping process
- CO₂ capture roadmap
  - Technology themes
  - Australian perspective
  - Implications for capture R&D
  - Implications for CO2CRC capture program
- CO₂ Storage roadmap
  - Technology themes
  - Technology prioritization
  - Implications for storage R&D
  - CO2CRC Storage program
The Level 1 Technology Roadmap used both a Functional Analysis System Technique (FAST) and a 3rd generation R&D approach to ensure that all opportunities were identified, and that they:

- are realistic and timely
- utilize the Australian skill base
- take into account research activities elsewhere in the world
- are effectively incorporated into the CO2CRC program
- are compatible with national research priorities
General System FAST diagram for CO₂ capture
<table>
<thead>
<tr>
<th>Technology</th>
<th>Relative Importance Now</th>
<th>Relative Importance Future</th>
<th>Technology Impact</th>
<th>Relative position of Australian R&amp;D</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel absorbent solvents</td>
<td>Low</td>
<td>Med</td>
<td>Emerging</td>
<td>Favourable</td>
<td>Growth</td>
</tr>
<tr>
<td>Improved solvents</td>
<td>Med</td>
<td>Low</td>
<td>Key</td>
<td>Favourable</td>
<td>Mature</td>
</tr>
<tr>
<td>Novel inorganic membrane materials/manufacturing</td>
<td>Med</td>
<td>Med</td>
<td>Emerging</td>
<td>Favourable-Strong</td>
<td>Embryonic</td>
</tr>
<tr>
<td>Novel adsorbants (low temp. mesoporous adsorbants)</td>
<td>Low</td>
<td>Med</td>
<td>Emerging</td>
<td>Strong</td>
<td>Embryonic</td>
</tr>
<tr>
<td>Novel adsorbants (high temperature applications)</td>
<td>Low</td>
<td>Med</td>
<td>Emerging</td>
<td>Tenable</td>
<td>Embryonic</td>
</tr>
<tr>
<td>Chemical looping concepts</td>
<td>Med</td>
<td>Med</td>
<td>Emerging</td>
<td>Weak</td>
<td>Embryonic</td>
</tr>
<tr>
<td>Low temperature/cryogenic CO₂ separation</td>
<td>Med</td>
<td>Med</td>
<td>Key</td>
<td>Favourable-Strong</td>
<td>Growth</td>
</tr>
<tr>
<td>Hydrate formation/separation</td>
<td>Med</td>
<td>Med</td>
<td>Emerging</td>
<td>Tenable?</td>
<td>Embryonic</td>
</tr>
<tr>
<td>Improved / integrated flue gas/syngas treatment (pre-CO₂ capture)</td>
<td>Low</td>
<td>Low</td>
<td>Base</td>
<td>Weak-Tenable</td>
<td>Mature</td>
</tr>
</tbody>
</table>

**Categorization of some themes in CO₂ capture**
More particularly for O$_2$ separation though possible application in pre-combustion.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Natural Gas</th>
<th>Post-Combustion</th>
<th>Pre-Combustion</th>
<th>Oxyfuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvent Absorption</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Membranes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Adsorption</td>
<td>✓</td>
<td>✓</td>
<td>✓*</td>
<td>✓*</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hydrates</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Chemical Looping</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

* More particularly for O$_2$ separation though possible application in pre-combustion

**Categorization of technologies and their application to combustion and natural gas separation.**
<table>
<thead>
<tr>
<th>Technology Area/Theme</th>
<th>Competitive Positioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvents</td>
<td>Favourable</td>
</tr>
<tr>
<td>Membranes - polymeric and inorganic</td>
<td>Favourable/Strong</td>
</tr>
<tr>
<td>Adsorbents</td>
<td>Favourable</td>
</tr>
<tr>
<td>Cryogenics/Hydrates</td>
<td>Favourable/Strong</td>
</tr>
<tr>
<td>Chemical Looping</td>
<td>Weak</td>
</tr>
</tbody>
</table>

Relative positioning of Australian CO₂ capture R&D
Technology horizons for CO₂ capture

0 - 5 Years
- Solvents
  - incremental
  - improved contactors
- Selected Membranes

5 - 10 Years
- Novel Solvents
- Membrane
  - Gas
  - Absorption
  - Inorganic
- Hybrids
  - Adsorbents
  - Cryogenics

10 - 15 Years
- Membrane Reactor/Separators
- Novel Concepts
  - Chemical Looping
  - Advanced Adsorbents
<table>
<thead>
<tr>
<th>Functional Step</th>
<th>Technology Theme</th>
<th>Technology</th>
<th>Impact Now</th>
<th>Impact Future</th>
<th>Technical Maturity</th>
<th>Expertise Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safely and effectively inject CO₂</td>
<td>Geomechanics</td>
<td>Formation damage</td>
<td>Med.</td>
<td>High</td>
<td>Growth</td>
<td>CO2CRC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pore pressure; stress regime; rock strength; fault reactivation</td>
<td>Med.</td>
<td>High</td>
<td>Growth</td>
<td>CO2CRC</td>
</tr>
<tr>
<td>Injection process</td>
<td></td>
<td>Near well bore changes, hydrates</td>
<td>Med.</td>
<td>Low</td>
<td>Embryonic</td>
<td>CO2CRC / Internat.</td>
</tr>
<tr>
<td>Monitor and verify the stored CO₂</td>
<td>Remote sensing</td>
<td>CO₂ specific scanner for airborne use</td>
<td>Med.</td>
<td>High</td>
<td>Embryonic</td>
<td>CO2CRC</td>
</tr>
<tr>
<td></td>
<td>Verification</td>
<td>Modern analogues including leaky systems</td>
<td>High</td>
<td>Low</td>
<td>Growth</td>
<td>CO2CRC</td>
</tr>
</tbody>
</table>

Categorization of some technology themes relevant to CO₂ storage.
Transportation and conditioning of CO$_2$

- Pipeline technology
- Effects of contaminants
- Trucking, shipping and temporary storage technologies
- Issues relating to understanding the physical state of pipeline fluids
- Operational issues
- Environment, regulation and safety issues
- Compressor technology
Injection of CO\textsubscript{2}

- Technologies for assessing, modelling and predicting geomechanical effects during CO\textsubscript{2} injection;
  - pore pressure prediction
  - stress regime analysis and modelling
  - rock strength measurement and prediction
  - fault reactivation modelling

- Technologies for assessing, modelling and predicting other near-well bore formation damage during injection

- Technologies for assessing, modelling and prediction of near well bore chemical changes, inc. hydrate formation
CO₂ storage options

CO₂ Storage Options
1. Use of CO₂ in enhanced coal bed methane recovery
2. Deep unmineable coal seam
3. Depleted oil & gas reservoirs
4. Large voids and cavities
5. Use of CO₂ in enhanced oil recovery
6. Deep unused saline water-saturated reservoir rocks
7. Basalts as possible option
8. Reaction with brine
9. Formation of stable carbonate minerals
<table>
<thead>
<tr>
<th>Storage Option</th>
<th>Feasibility</th>
<th>Potential Capacity</th>
<th>Data Availability</th>
<th>Expertise</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline reservoir rocks</td>
<td>Very high</td>
<td>Very high</td>
<td>High</td>
<td>Very high</td>
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<tr>
<td>Depleted oil reservoirs</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Depleted gas reservoirs</td>
<td>Very high</td>
<td>Now - Low Future - High</td>
<td>High</td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Deep coal seems</td>
<td>Medium - low</td>
<td>Medium?</td>
<td>Low</td>
<td>Medium</td>
<td>2-3</td>
</tr>
<tr>
<td>Voids and cavities</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>4</td>
</tr>
<tr>
<td>Basalts</td>
<td>?</td>
<td>?</td>
<td>Low</td>
<td>Medium</td>
<td>3</td>
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<tr>
<td>Serpentinites</td>
<td>Low</td>
<td>?</td>
<td>Low</td>
<td>Medium</td>
<td>4</td>
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<tr>
<td>Enhanced oil recovery</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>2</td>
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<tr>
<td>Enhanced gas recovery</td>
<td>?</td>
<td>Low - medium</td>
<td>Low</td>
<td>Medium</td>
<td>2</td>
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<tr>
<td>Enhanced coal bed methane</td>
<td>?</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>2</td>
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<tr>
<td>Reaction with brines</td>
<td>High</td>
<td>Low?</td>
<td>Low?</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Use of carbonate minerals</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>3</td>
</tr>
</tbody>
</table>

Australia's position in technologies CO₂ storage (Priority 1 - highest, priority 4 - lowest)
CO₂ capture & storage technology application roadmap (Level 2)

- Pilot projects
- Demonstration projects
- Commercial projects
Pilot projects

At a smaller scale (5 - 10,000 tonnes CO$_2$), pilot projects offer scope for addressing specific issues such as
- CO$_2$ injectivity
- validation of models
- testing of monitoring capability
- assessment of impact of CO$_2$ on the deep environment.

Additionally, pilot projects were seen as an important component in communicating geosequestration issues (especially storage) to the public.
Demonstration projects

At a medium scale (50 – 100,000 tonnes CO₂) opportunities are being assessed for developing projects to demonstrate low emissions technology.

COAL 21 proposes for the construction of a black coal IGCC demonstration offering scope for CO₂ capture and storage as well as hydrogen generation to be commissioned around 2008.
Proposed commercial projects

- Gorgon (LNG)
- APEL (Brown coal – synfuels)
- GTLE
### Timetable for the proposed Gorgon Project

<table>
<thead>
<tr>
<th>Phase</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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<tr>
<td><strong>Concept Selection Phase</strong></td>
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<td>Market capture</td>
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<td>Technical evaluation</td>
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<td><strong>Concept Definition Phase</strong></td>
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<td>Market negotiations</td>
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<tr>
<td>Government and Environmental approvals</td>
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<td>Technical definition</td>
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<tr>
<td><strong>Execution Phase</strong></td>
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<td>(Design and Construction)</td>
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<tr>
<td>Offshore Gas Gathering</td>
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<tr>
<td>Onshore Gas Processing Facility</td>
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</table>

- **Concept Finalised**
- **BWI Use Approval**
- **EIA Approval**
- **Final Investment Decision**
- **Plant Start up**
- **1st Gas**
Technology roadmap (Level 2) showing pilot (5-10,000 tonnes), demonstration (50-100,000 tonnes) & commercial projects.

Commence CO₂ injection.
Level 3 technology roadmap for CCS showing likely progress towards the hydrogen economy
An emission free vision for the future.
SUMMARY
The Australian technology roadmap

**Level 0**, involved developing the national knowledge infrastructure and skill base in the four years prior to formulation of this roadmap.

**Level 1**, which has a 5-10 year time scale provided detailed technology assessments and gap analyses for R&D related to:

- CO₂ capture, storage & use
- Technology strengths & weaknesses
- R&D priorities that will be pursued by Australia through
  - Australian R&D
  - International collaboration
  - Maintaining a watching brief
SUMMARY
The Australian technology roadmap

Level 2, with a 10-20 year timescale, provided broad scale assessments of potential demonstration and application opportunities through proposals for:

- Pilot (small scale) R&D projects
- Demonstration (medium scale) R&D projects
- Linking R&D with commercial (large scale) projects

Level 3, with a 20-30 year time scale, developed a roadmap for the hydrogen economy, stressing the key role of CO$_2$ capture and storage, in a hydrogen economy initially fossil-fuel-based.
CO2CRC acknowledges the support of the following organisations:

Australian Government
Geoscience Australia
Australian Greenhouse Office
Department of Industry, Tourism and Resources
If you want to learn more about CO2CRC please contact:

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