The ICS Process

Carbon capture and storage by integrated mineralisation

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Richard Hunwick,
Managing Director
Integrated Carbon Sequestration Pty Ltd
(02) 9416 4513, or 0418 964 384
richard@hunwickconsultants.com.au
Why was ICS formed?

To strive to minimise the build-up of carbon dioxide in the Earth’s atmosphere:

- **Cleanly**, to minimise adverse environmental impact per MWh of electricity sent out.
- **Economically**, to keep energy prices as low as possible consistent with sustainability.
- **Fairly**, to avoid the premature shut-down of essential power generation infrastructure.
This presentation

- The CCS challenge.
- Geosequestration: not a panacea.
- Mineralisation: the alternative—but...
- Complete flue gas cleaning, *even mercury*.
- Not just for coal.
- The way ahead: our 2020 vision.
The global CCS challenge

- Coal-fired power generation and other CO$_2$ sources will grow for decades yet.
- The emerging consensus: cut greenhouse gas emissions as quickly and deeply as possible: 80% by 2050!
- Only with carbon capture and storage can these be reconciled.
- The challenge then becomes: for coal alone, how, and where in the world can we store 300 billion tonnes CO$_2$ by 2050?
Geosequestration: not a panacea

- High parasitic energy penalties.
- Who will assess sites to the extent required?
- CO$_2$ pipeline transport: harder than natural gas.
- Consequences of leaks (CO$_2$ is denser than air).
- Neighbours’ reactions (NIMBYs, NUMBYs).
- Liability issues: who will indemnify sites?

*The world needs another CCS option.*
The carbon geosequestration pathway

One needs to burn c. 50% extra coal to make up for CCS parasitic losses!
Mineralisation: the alternative?

- A natural process, as old as the Earth.
- Thermodynamically strongly driven.
- CO₂ returned to earth as carbonate rocks.
- The source rocks and carbonated rocks are both already abundant in the environment world-wide.
- Avoids geosequestration’s potential liability issues.
- Overseas work showed mineralisation can be speeded up enough for *ex situ* carbonation.
The geological carbon cycle

Nature’s oldest process for capturing carbon dioxide:

**Mineralisation:**

- Basic igneous (ultramafic) rocks slowly react (weather) with water and CO$_2$ in air to form magnesite (magnesium carbonate), plus silica.

- Products are thermodynamically stable (they include the world’s major magnesite mineral deposits).
The geological carbon cycle (cont.)

- Natural weathering, e.g. with serpentinite:
  \[ \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + 3\text{CO}_2 \rightarrow 3\text{MgCO}_3 + 2\text{SiO}_2 + 2\text{H}_2\text{O} + \text{heat} \]
  Serpentine \hspace{2cm} \text{Magnesium carbonate (magnesite)} \hspace{2cm} \text{Silica}

- Products are thermodynamically stable.
- Need c. 3 tonnes of serpentinite/tonne CO\(_2\);
  or, 6 tonnes (2.5 cubic metres)/tonne coal.

The challenge:
- Speed up natural processes from millions of years,
  to hours.
If this process had not been operating...

**Earth** and its atmosphere
- Average surface temperature 15°C
- Surface pressure 1 Bar
- 0.0000385% CO₂, 21% O₂, 78% N₂, 1% others.
- Mass of CO₂: 3,000,000,000,000 t

**Venus** and its atmosphere
- Average surface temperature 460°C
- Surface pressure 92-95 Bar
- 96.5% CO₂, 3.5% N₂, traces of others.
- Mass of CO₂: 450,000,000,000,000,000 t
No shortage of suitable rocks

The Upper Mantle is mostly the rock Peridotite, a blend of:
- **Olivine** (lighter olive-green) $\text{Mg}_2\text{SiO}_4$. and
- **Pyroxene** (dark band) $\text{MgSiO}_3$ (or $\text{Mg}_2\text{Si}_2\text{O}_6$).

Near the surface these minerals first react with water to form **Serpentine**: $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$.
This is more abundant in continental landmasses.
Note: Iron partly substitutes for magnesium in these minerals.
Persian Gulf and the Oman Ophiolite
Harz Mountains, central Germany
Marlborough ultramafics in relation to Bowen Basin
Serpentinite outcrop, note distinctive vegetation
Relative impacts from mining coal and rock

Open-cut coal

One tonne coal requires excavation of approx. 5 cubic metres of overburden and interburden.

Serpentinite

One tonne coal requires excavation of approx. 2.5 cubic metres of rock to absorb CO₂ from its burning.
The trouble with early mineralisation efforts

Need to burn twice as much coal to maintain the same sent-out electricity. For this reason, interest in mineralisation has waned—but is still there.
**Integrated Mineralisation: The ICS Process**

- No handling of pure CO$_2$ involved.
- Invented in Australia, in Sydney.
- Awarded Australian Patent 2008217572.
- Patent applications lodged in all major coal producing & consuming countries.
- Key reactions have been demonstrated.
- CSIRO team (Australia’s national research organization) undertook lab-scale trials.
- The chemistry works, the concept is sound.
ICS Process: No need to handle CO₂

An integrated process.
Eliminating these steps reduces parasitic energy consumption.
The ICS integrated mineralisation pathway

One needs to burn less than 25% extra coal to make up for CCS parasitic losses. Further improvements to energy balances anticipated.
The ICS Process:
The CO₂ flow path, from flue gases to emplaced mineral

- **CO₂–lean scrubbed flue gases**
- **CO₂–rich raw flue gases**
- **CO₂–lean**
- **CO₂–rich**
- **Silicate–rich mineral from quarry**
- **Carbonate–rich mineral to emplacement**

**CO₂ absorption from flue gases**

**CO₂ mineralisation**

**Closed-loop circulating ammonia/ammonium salt solution**
ICS Process, post-combustion retrofit

To Stack
Pre-treated rock
Recovered ammonia-rich scrubbing solution
Carbonated rock to emplacement

Boiler
ESP or fabric filters
Carbonation reactor
Ash, to blend with carbonated rock

Pre-treated rock
Solids-liquids separation
CO₂ scrubber
Capital and operating cost estimates
($US, to capture 24 million tonnes per annum CO₂)

Total capital cost (incl. 25% contingency): $3,800 million
(Annualised capital-related cost, incl. 15% real ROE: $400 million)
Total annual operating cost (incl. 25% contingency): $510 million
Total cost to capture 24 million tonnes CO₂/year: $910 million

Or: $38.00/tonne CO₂

Of which:

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<th>Activity</th>
<th>Cost/tonne CO₂</th>
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<td>Serpentinite quarrying, crushing, storage &amp; loading</td>
<td>$7.00</td>
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<tr>
<td>Grinding serpentineite &amp; slurry preparation (at power station)</td>
<td>$11.00</td>
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<tr>
<td>Post combustion capture (at power station)</td>
<td>$12.00</td>
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<tr>
<td>Carbonated mineral emplacement &amp; solution recovery</td>
<td>$8.00</td>
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<tr>
<td><strong>Total without rail transport:</strong></td>
<td><strong>$38.00</strong></td>
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With 200 km rail transport between quarry and power station, add: $12.00
Total including 200 km rail transport: $50.00
**Power plants with CCS: the development challenge**

Pre-commitment costs differ greatly between the alternative CCS approaches.
The ICS Process—other benefits

- Coal-fired electricity that is firm and base-load, with CO$_2$ emissions no higher than renewables.
- Major upwards revaluation of coal reserves.
- Valuable mineral by-products: value of Cr, Fe, Ni, PGM content of typical rocks adequate to pay for total (life-cycle) Process.
- Carbonated mineral by-product valuable as soil conditioner, fill, aggregate.
- A comprehensive flue gas cleaning system: SOx, NOx, particulates and mercury.
A comprehensive flue gas cleaning system

- Ammoniated solutions excellent for capturing SO\textsubscript{x} and NO\textsubscript{x} as well as CO\textsubscript{2}, form ammonium salts from these gases.
- Activated serpentinite highly porous with vast surface area, resembles activated carbon—an excellent absorbent.
- Prior to discharge, flue gases are cooled to control ammonia slip, so remaining volatiles condense.
Activation of serpentinite

Ultramafic rock: olivine, pyroxene minerals-based (hard, dense).

Serpentinitisation (natural process)

Serpentinite: serpentine minerals-based (softer, less dense).

Activation (heat & other processes)

Activated rock: reverts to olivine, pyroxene comp., very high total surface area.
Not just for coal

The ICS Process, an elegant solution for:

- Pre-combustion capture—CCGT.
- Pre-combustion capture for all hydrocarbon and carbohydrate fuels via IGCC.
- Integration with ammonia manufacture.
- With biomass, opportunity for a carbon sink.
- Removing CO₂ from raw natural gas, and any process gas stream.
Typical CCGT/IGCC power block

Air → Gas turbine → Stack

Steam from gasification plant → Steam turbine

Condenser: Cooling water to/from cooling tower

Gas/Syngas → Heat-recovery steam generator (HRSG) → CE pumps
ICS Process with pre-combustion capture

- Air enters the gas turbine
- Hydrogen is extracted
- Steam from a gasification plant is used
- Condenser recovers heat
- Cooling water is used for cooling
- Pre-treated rock
- Carbonation reactor
- Solids-liquids separation
- Carbonated rock is emplaced
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<tr>
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<th>Proof of concept (Complete)</th>
<th>Minimum-scale pilot (Current)</th>
<th>1% scale pilot plant (By 2015)</th>
<th>Commercial-scale demo. (By 2020)</th>
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Four stages to commercial demonstration
Highlights

The ICS Process:

- Promises a cost-effective and environmentally benign way to major reductions in global $\text{CO}_2$ emissions.
- Also a comprehensive flue gas cleaning system.
- Could have a *disruptive* impact on the world’s base metal mining industries.
- A business opportunity of comparable scale.

Thank you