Agenda

• Introduction

• Technology Overview

• Case Studies
Carbon Clean Solutions is headquartered in the UK, with offices in USA, Germany and India.

We have 25 facilities globally where our technology has been deployed.
Introduction to Carbon Clean Solutions

We’ve made industrial decarbonisation a commercial reality

Carbon Clean Solutions is an established global leader in providing CO₂ capture technology. Our advanced technology is proven to dramatically reduce the cost of carbon capture – enabling industrial emitters to reduce CO₂ emissions.
Our breakthrough technologies make carbon capture a commercial reality in a variety of industrial settings.

**Power**
- Flue gas and boilers

**Chemicals**
- Soda Ash, Urea, Methanol

**Renewables**
- Biogas and biofuels

**Oil and Gas**
- Gas treating & EOR

We can recover CO₂ for industrial reuse.

Our systems are proven at 25+ sites around the world: affordable carbon capture solutions can improve the bottom line while reducing greenhouse gas emissions.
Our technologies can achieve carbon capture at a cost of USD $40 per metric ton, a figure that continues to improve.

*Cost of CO₂ Capture: Today and Tomorrow

*Lifecycle cost: includes capital and operating costs, W. European location basis, excludes downstream CO₂ compression
Our focus is on providing the most cost-effective CO₂ capture and separation technology – basic engineering design and solvent.

Flexible business models help to drive projects at a local level with engineering, procurement, construction (EPC) partners.

Our engineering know-how and patented solvent chemistry makes it easier to design and execute CO₂ capture projects.

Our technology creates significant savings by driving down the operating and capital costs for CO₂ capture plants to $40/ton and a target of less than $40/ton.
Performance Chemistry

**Drop-In solvent for improved performance**

Our advanced solvents reduce operating costs, emissions, and waste for new and existing Co2 capture systems.

1. 10% reduction in thermal energy usage
2. *75% reduction in use of thermal energy
3. *30% reduction in capex due to 33% lower packing and 50% lower L flow
4. ‘PPB’ level solvent emissions in lean gas
5. *75% less solvent disposal
6. *75% less solvent disposal

*Conventional CO2 recovery benchmark is a monoethanolamine (MEA) based chemical absorption process*
Technology
Global Technology Case Studies

- University of Kentucky 0.6 TPD 2016
- Greenfield 4x50 TPD 2017
- Southern Power Co. 10 TPD 2015
- TCM 240 TPD 2015
- NW Europe <100 TPD 2016
- TNO Gas Treatment Pilot Validation
- Solvay 21 TPD 2012
- TAC’s 174 TPD 2016
- VCL’s 168 TPD 2017

Proven Globally ~ 31 Facilities
Validation Case Studies - CDRMax

TCM - Norway
240 TPD, 2015
Taking slipstream from Statoil’s refinery CHP & RCC flue gas
- ~3.8 vol% CO₂ and 16% vol% O₂
- ~10 vol% CO₂ and 8 vol% O₂

EON (TNO) - Netherlands
6.5 TPD, 2013
Taking slipstream from EON’s 250-MW coal-fired Maasvlakte power plant
- ~10.5 vol% CO₂ and 8 vol% O₂

Under NDA, North West Europe
< 100 TPD, 2016
Taking slipstream from 650-MW coal-fired power plant
- ~13 vol% CO₂ and 8 vol% O₂

Southern Power Co (NCCC) - USA
10 TPD, 2014
Taking slipstream from Southern Company coal-fired power plant and simulated natural gas combined cycle flue gas
- ~4 vol% CO₂ and 16% vol% O₂
- ~12 vol% CO₂ and 8 vol% O₂

Technology Validation
- Reliability & Solvent stability
- Corrosion
- Environmental emissions
- Energy penalty
100% Plant Reliability

- Successfully demonstrated CO$_2$ capture of more than 25,000 tons CO$_2$
- No loss of run time due to CDRMax solvent issues

Validation TCM Plant

Validation of 100% Plant Reliability at NCCC, E.ON, TCM & NWE plant
Superior Solvent Stability

Without solvent thermal reclaimer

Negligible solvent degradation

Validation TCM plant
Superior Solvent Stability

**MEA visual change in 1000 operating hours**

**APBS visual change in 1000 operating hours**

Validation E.ON plant (without solvent reclaimer)
Dissolution of metals from SS304 with CDRMax solvent is 90 times lower than MEA.
**Corrosion Data - NCCC**

Dissolution of metals from with CDRMax solvent MEA solvent comparison

<table>
<thead>
<tr>
<th>Metal</th>
<th>Fresh MEA</th>
<th>Fresh CDRMax</th>
<th>Aged MEA</th>
<th>Aged CDRMax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>&lt; 12</td>
<td>53.2</td>
<td>219</td>
<td>114</td>
</tr>
<tr>
<td>Barium</td>
<td>&lt; 12</td>
<td>&lt;10</td>
<td>265</td>
<td>11.8</td>
</tr>
<tr>
<td>Cadmium</td>
<td>&lt; 12</td>
<td>&lt; 5</td>
<td>&lt; 10</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Chromium</td>
<td>&lt; 12</td>
<td>42.2</td>
<td>45,090</td>
<td>2,120</td>
</tr>
<tr>
<td>Selenium</td>
<td>44.1</td>
<td>41.8</td>
<td>1,950</td>
<td>660</td>
</tr>
</tbody>
</table>

1) MEA testing in 2012 (Wheeldon, June 2012). No corrosion inhibitor. 316L SS. 300 hrs operations
2) CDRMax testing in 2014. No corrosion inhibitor. 316L SS. ~ 500 hrs operations.
## Corrosion Data - TCM

### Graphical Representation

The graph illustrates the average corrosion rate (mmpy) for various materials under different conditions. The x-axis represents different materials, including 304L, 316L, Cr22 Duplex, Inconel 600, Inconel 625, and S235. The y-axis shows the average corrosion rate in millimeters per year (mmpy).

- **Rich**: Darker bars representing high corrosion rates.
- **Lean (Bent)**: Lighter bars indicating lower corrosion rates.
- **Rich (Bent)**: Striped bars showing intermediate rates.

### Conditions and Results

#### Material Comparison
- **Carbon Steel**: Shows high corrosion rates.
- **Stainless Steels**: Generally lower rates compared to Carbon Steel.
- **High Cr SS**: Lower rates than Stainless Steels.

#### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Loading</th>
<th>T</th>
<th>P</th>
<th>pH</th>
<th>[CO2]</th>
<th>Linear Velocity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UoM</strong></td>
<td>Lean/Rich</td>
<td>°C</td>
<td>bar(g)</td>
<td>mol/mol</td>
<td>m/s</td>
<td>Hours</td>
<td></td>
</tr>
<tr>
<td><strong>Value</strong></td>
<td>Lean</td>
<td>119</td>
<td>5.5</td>
<td>10.4</td>
<td>0.13</td>
<td>1.1</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td>Rich</td>
<td>105</td>
<td>6.0</td>
<td>9.2</td>
<td>0.46</td>
<td>1.1</td>
<td>3500</td>
</tr>
</tbody>
</table>

#### Corrosion Conditions

- **0.02 – 0.10 Excellent**
- **0.10 – 0.50 Good**
- **0.50 – 1.00 Fair**
- **< 0.02 Outstanding**

#### Additional Notes

- **High Ni, Low Fe content**
- **Cr: 600 < 625**

### Average Conditions of Corrosion Coupon Exposure Environments at the TCM Campaign

The table provides the average conditions for the corrosion coupon exposure environments during the TCM campaign.
Average conditions of corrosion coupon exposure environments at the N.W.E. campaign

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Location</th>
<th>Temperature</th>
<th>Pressure</th>
<th>[CO2]</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>UoM</td>
<td>N/A</td>
<td>°C</td>
<td>bar(g)</td>
<td>mol/mol</td>
<td>Hours</td>
</tr>
<tr>
<td>Value</td>
<td>Absorber</td>
<td>23 – 46</td>
<td>0</td>
<td>0.41</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Stripper</td>
<td>107 – 123</td>
<td>0.3 – 1.3</td>
<td>0.12</td>
<td>1000</td>
</tr>
</tbody>
</table>
- Ammonia emissions indicator of the oxidative degradation
- CDRMax solvent top-up 8-10 times less than that for MEA
Far Below Current Emissions Permissible Limit

With CDRMax solvent 15-30 times less ammonia emissions than permissible limit

Successfully operated consistently within the permissible limit of solvent emissions.
55x times less aerosols emissions

CDRMax solvent exhibit inherent capability to limit aerosols solvent losses & meet stringent emission limits

Significant improvement in health & safety aspects

CDRMax aerosols emissions
28 mg/Nm³

MEA aerosols emissions
1587 mg/Nm³
Continuous Improvement in Energy Consumption

Energy comparison to MEA
(Coal fired post combustion CO\textsubscript{2} capture plant)

- E.ON Plant: 22% savings
- NCCC Plant: 25% savings
- NWE Plant: 35% savings
- Pilot Plant: 50% savings
Key Unique Selling Points (USP) of CDRMax Technology

**Reductions in capital and operating costs**
- 40% lower OPEX and 30% Lower CAPEX than conventional CO₂ capture technology

**Low solvent emissions**
- Atmospheric solvent emission at the ‘parts per billion’ (ppb) scale

**Solvent Technology Readiness Level (TRL) = 8/9**
- Technology proven and deployed at full scale
- Commercially available, globally

**High availability and reliable performance**
- No operational issues resulting in 100% plant availability and efficient performance

**Validated scale up models**
- Developed simulations and models for technology and process scale-up, which have been validated at all scales

**Extensive experience on any type of flue gases**
- Versatile solvent technology can be applied to any type of flue gas for efficient and economical CO₂ capture
Case Studies
10MW CO2 Capture to Chemicals Project in India

10MW Coal power plant CO2 capture:

• CO2 converted to chemicals
• FEED completed 2015
• Commissioning October, 2016
• CCSL’s engineering design
Pilot: 6.5 TPD at EON Benelux, Netherlands

1000 hour test campaign:
• Coal / biomass fired power plant campaign (CO$_2$ concentration 12 vol%)

Result Vs MEA campaign:
• Minimal degradation of solvent
• 15x reduction in corrosion
• 10x reduction in ammonia emissions
• 50x reduction in aerosol emission
Demo: 240 TPD at Technology Centre Mongstad, Norway

25,000 tons CO\textsubscript{2} captured over 3500 hours

2-Part campaign:
- Gas fired CHP campaign (CO\textsubscript{2} 3.6 vol%)
- Cracker gas campaign (CO\textsubscript{2} 13 vol%)

Result:
- CHP Emissions = PPB level solvent emissions
- Reliability = 100% plant availability
- Corrosion = ‘Outstanding’ quality for SS 304L
- No make-up of solvent
Specialty chemicals: greenfield project

Client: Vishnu Chemicals
Location: India
CO2 capture: 168 TPD
Project description: Produce own CO2 for use in production of Sodium Dichromate, Strontium Carbonate and Barium Carbonate, used in ceramic glazes.
Timing: Currently in construction, delivering in 2017
**Client:** KEA (Waste to Energy Plant Oslo city)

**Location:** EU

**CO2 capture:** 1500 TPD (75 MW) flue gases

**Project description:** Complete Decarbonisation of Waste to Energy Plant of Oslo city

**Timing:** Pre-FEED / FEED Stage
Large Scale CCUS Project – greenfield project

Client: Yara
Location: EU
CO2 capture: 1000 TPD (50 MW) flue gases
Project description: CO2 capture from reformer flue gases of Urea plant.
Timing: Pre-FEED / FEED Stage
Contact Us

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