PUERTOLLANO IGCC POWER PLANT. OPERATIONAL EXPERIENCE AND CURRENT DEVELOPMENTS.

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Pedro Casero, Elcogas, S.A.
THE ELCOGAS COMPANY

European company established in April 1992 to undertake the planning, construction, management and operation of a 335 MW ISO IGCC plant located in Puertollano (Spain)
Puertollano IGCC Power Plant - ELCOGAS

Process description

Coal preparation

Coal - N₂

HP Boiler

MP Boiler

Gasifier

Filtration

Water wash

Sulfur Removal

Sulfur Recovery

Air Separation Unit

Flue gas to stack

Steam

Hot combustion gas

Clean syngas

Fly ash

Water to treatment

Claus gas

Tail Gas

Sulfur (99.8%)

O₂

N₂

Waste N₂

Compressed air

Coal - Petroleum Coke - Limestone

HP Steam

MP Steam

Coal - N₂

Air - O₂

Clean syngas

Compressed air

Steam

Flue gas to stack

Cooling tower

GAS TURBINE

200 MWISO

STEAM TURBINE

135MWISO

Condenser

Air Separation Unit

N₂

O₂

Coal - N₂

Slag

Quench Gas

Clean syngas

Compressed air

Water to treatment

Water wash

Filtration

Gasifier

MP Boiler

HP Boiler

Coal preparation

Coal - N₂

Limestone

Petroleum Coke
Main design data

<table>
<thead>
<tr>
<th></th>
<th>COAL</th>
<th>PET COKE</th>
<th>FUEL MIX (50:50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%w)</td>
<td>11.8</td>
<td>7.00</td>
<td>9.40</td>
</tr>
<tr>
<td>Ash (%w)</td>
<td>41.10</td>
<td>0.26</td>
<td>20.68</td>
</tr>
<tr>
<td>C (%w)</td>
<td>36.27</td>
<td>82.21</td>
<td>59.21</td>
</tr>
<tr>
<td>H (%w)</td>
<td>2.48</td>
<td>3.11</td>
<td>2.80</td>
</tr>
<tr>
<td>N (%w)</td>
<td>0.81</td>
<td>1.90</td>
<td>1.36</td>
</tr>
<tr>
<td>O (%w)</td>
<td>6.62</td>
<td>0.02</td>
<td>3.32</td>
</tr>
<tr>
<td>S (%w)</td>
<td>0.93</td>
<td>5.50</td>
<td>3.21</td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>13.10</td>
<td>31.99</td>
<td>22.55</td>
</tr>
</tbody>
</table>

Puertollano IGCC Power Plant - ELCOGAS

Power output and emissions

<table>
<thead>
<tr>
<th>POWER OUTPUT</th>
<th>GAS TURBINE (MW)</th>
<th>STEAM TURBINE (MW)</th>
<th>GROSS TOTAL (MW)</th>
<th>NET TOTAL (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>182.3</td>
<td>135.4</td>
<td>317.7</td>
<td>282.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EFFICIENCY (LHV)</th>
<th>GROSS</th>
<th>NET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47.12%</td>
<td>42.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EMISSIONS</th>
<th>g/kWh</th>
<th>mg/Nm³ (6% Oxygen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>0.07</td>
<td>25</td>
</tr>
<tr>
<td>NO₃</td>
<td>0.40</td>
<td>150</td>
</tr>
<tr>
<td>Particulate</td>
<td>0.02</td>
<td>7.5</td>
</tr>
</tbody>
</table>
### Raw and clean gas data (2006 update)

<table>
<thead>
<tr>
<th></th>
<th>Raw Gas</th>
<th>Clean Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual average</td>
<td>Design</td>
</tr>
<tr>
<td>CO (%)</td>
<td>59.26</td>
<td>61.25</td>
</tr>
<tr>
<td>H₂ (%)</td>
<td>21.44</td>
<td>22.33</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>2.84</td>
<td>3.70</td>
</tr>
<tr>
<td>N₂ (%)</td>
<td>13.32</td>
<td>10.50</td>
</tr>
<tr>
<td>Ar (%)</td>
<td>0.90</td>
<td>1.02</td>
</tr>
<tr>
<td>H₂S (%)</td>
<td>0.81</td>
<td>1.01</td>
</tr>
<tr>
<td>COS (%)</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>HCN (ppmv)</td>
<td>23</td>
<td>38</td>
</tr>
</tbody>
</table>
Emissions in NGCC and IGCC modes

Natural gas (mg/Nm³ at 6% O₂ dry)
- EEC 88/609
- ELCOGAS Permit limits
- ELCOGAS 2006 average

SO₂: 29.2, 2.9, 291.7, 223.6, 22.3, 4.2, 0.5
NOₓ: 400, 200, 79.2, 200, 135.9, 5.0, 25.0, 0.4
Partículas: 650, 500, 50, 50, 25, 0.4

Coal gas (mg/Nm³ at 6% O₂ dry)
- EU Directive 88/609/EEC
- EU Directive 2001/80/EC
- ELCOGAS Permit limits
- ELCOGAS 2006 average

SO₂: 400, 200, 79.2, 200, 135.9, 5.0, 25.0, 0.4
NOₓ: 650, 500, 50, 50, 25, 0.4
Partículas: 50, 50, 25, 0.4

NGCC mode

IGCC mode
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Power plant main milestones

- Oct '96 - Commercial operation of CC with NG (1st CC in Spain)
- Mar '98 - 1st Switch-over to syngas in the GT. 1st production as IGCC
- Dec '06: 14,673 GWh (9,184 GWh with coal gas)
- March '07: New record on syngas: 958 hours
- 75,000 EOH Gas Turbine major overhaul
- Severe fault in main generation transformer of GT
- 50,000 EOH Gas Turbine major overhaul
## Variable Cost of Electricity (2006)

<table>
<thead>
<tr>
<th>Fuel mode</th>
<th>Fuel</th>
<th>Heat rate (kJ\textsubscript{HHV}/kWh)</th>
<th>Fuel cost (€/GJ\textsubscript{HHV})</th>
<th>Partial cost (€/MWh)</th>
<th>Total cost (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNCC</td>
<td>Natural gas</td>
<td>7,649</td>
<td>7.84</td>
<td>59.97</td>
<td>59.97</td>
</tr>
<tr>
<td>IGCC</td>
<td>Coal</td>
<td>2,934</td>
<td>2.19</td>
<td>6.43</td>
<td>18.01</td>
</tr>
<tr>
<td></td>
<td>Petcoke</td>
<td>5,994</td>
<td>1.44</td>
<td>8.63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NG aux</td>
<td>376</td>
<td>7.84</td>
<td>2.95</td>
<td></td>
</tr>
</tbody>
</table>
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Variable Cost of Electricity vs Fuel cost evolution

Variable cost of electricity produced with NG:
- 2003: 30.71 €/GJ HHV
- 2004: 29.37 €/GJ HHV
- 2005: 35.34 €/GJ HHV
- 2006: 59.97 €/GJ HHV

Variable cost of electricity produced with coal:
- 2003: 13.45 MWh/ €
- 2004: 14.55 MWh/ €
- 2005: 15.85 MWh/ €
- 2006: 18.01 MWh/ €

Cost of Natural:
- 2003: 30.71 €/GJ HHV
- 2004: 29.37 €/GJ HHV
- 2005: 35.34 €/GJ HHV
- 2006: 59.97 €/GJ HHV

Cost of coal:
- 2003: 13.45 MWh/ €
- 2004: 14.55 MWh/ €
- 2005: 15.85 MWh/ €
- 2006: 18.01 MWh/ €

Cost of pet coke:
- 2003: 0 €/GJ HHV
- 2004: 0 €/GJ HHV
- 2005: 0 €/GJ HHV
- 2006: 0 €/GJ HHV
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Availability 2006

- **IGCC**: 52.0%
- **GASIFIER**: 65.0%
- **POWER BLOCK**: 68.0%
- **ASU**: 80.8%

**Availability**
- **Planned Outages**: 17.2%
- **Unplanned Outages**: 15.0%
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IGCC unavailability 2004-2006

- GASIFICATION: 46%
  - GAS SATURATOR: 6%
  - WATER STEAM CYCLE: 19%
  - GAS TURBINE: 75%
  - ELECTRIC SYSTEMS: 78%
  - SERVICE SYSTEMS: 6%
- COMBINED CYCLE: 29%
  - GAS TURBINE: 75%
  - PURE NITROGEN PRODUCTION: 22%
  - OXYGEN PRODUCTION: 16%
  - WASTE NITROGEN PRODUCTION: 62%
- BOP: 19%
  - DCS: 16%
- ASU: 6%
  - START UP BURNER: 7%
  - FUEL FEEDING: 7%
  - GAS TREATMENT: 11%
  - SULFUR RECOVERY: 11%
  - COAL PREPARATION: 2%
  - FLY ASH: 14%
  - WATER STEAM: 30%
  - DCS: 16%
- FLIGHT ASH: 14%
- GAS TREATMENT: 11%
  - SULFUR RECOVERY: 11%
- OXYGEN PRODUCTION: 16%
- PURE NITROGEN PRODUCTION: 22%
- ASU: 6%
## Project title:
Advanced technologies of CO₂ conversion, capture and storage (PSE-CO₂)

## Programme:
*Spanish National Energy Programme (Ministry of Education and Research)*

## Coordinator:
CIEMAT

## Status:
Started on 2005.

## Target:
- Development of CO₂ capture technologies, allowing a sustainable use of coal for power production
- Development of conversion technologies that facilitate CO₂ capture
- Development of deep geological storage capacities for captured CO₂

## Structure:
*Composed by 5 sub-projects*
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PSE-CO2 S/1: Pre-combustion CO₂ separation technology

<table>
<thead>
<tr>
<th>Coordinator:</th>
<th>ELCOGAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partners:</td>
<td>University of Castilla la Mancha, Empresarios Agrupados, Técnicas Reunidas, INCAR-CSIC, CIEMAT</td>
</tr>
<tr>
<td>Target:</td>
<td>To validate at industrial, bench and laboratory scale the technologies of pre-combustion CO₂ capture associated to an IGCC Power Plant</td>
</tr>
</tbody>
</table>
| Rationale:    | - To test the concept of CO₂ capture in a industrial IGCC plant  
                - To help in the design of the next generation IGCC plant  
                - To maintain the concept of innovation that Elcogas plays in Europe |
| Approach:     | Assessment of commercial technologies for CO₂ separation (Pilot Plant Installation 1:50 scale)  
                Assessment of appropriate technologies but still not commercially available for CO₂ separation (bench & laboratory scale) |
| Budget:       | ~19 M€           |
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CO₂ capture and H₂ production Pilot Plant

**PURE H₂**

- H₂: 99,9%
- CO: 4 ppm
- Q: 1.987 Nm³/h

**TACIL GAS**

- H₂: 53.7%
- CO: 11.4%
- CO₂: 0.12%
- Q: 1.511 Nm³/h

**REACTOR 2**

- 350°C
- 480°C

**SHIFT conversion**

- H₂: 50.0%
- CO: 3.1%
- CO₂: 37.5%
- COS: 0 ppm
- H₂S: 8 ppm
- Q: 5606 Nm³/h
- P: 20 bar
- T: 135°C

**AMINES UNIT**

- H₂: 99.8%
- CO: 0.01%
- CO₂: 99.8%
- H₂S: 21 ppm
- Q: 2108 Nm³/h

**GAS PREPARATION**

- H₂: 0.2%
- CO: 0.01%
- CO₂: 99.8%
- H₂S: 21 ppm
- Q: 2108 Nm³/h

**REACTOR 1**

- 310°C
- 390°C

**H₂ rich gas**

- H₂: 79.9%
- CO: 4.9%
- CO₂: 0.05%
- H₂S: 0 ppm
- Q: 3498 Nm³/h

**Clean syn-gas**

- H₂: 21.9%
- CO: 60.4%
- CO₂: 2.7%
- COS: 12 ppm
- H₂S: 0.2 ppm
- Q: 3600 Nm³/h
- P: 20 bar
- T: 135°C

**Electrical consumption:** 1.389 kW
**MP steam consumption:** 4.5 t/h
**BP steam consumption:** 19 t/h
**Refrigeration water:** 320 t/h

**H₂:** 50.0 %
**CO:** 3.1 %
**CO₂:** 37.5 %
**COS:** 0 ppm
**H₂S:** 8 ppm
**Q:** 5606 Nm³/h
**P:** 20 bar
**T:** 135 °C

**GAS TO POST-TREATMENT**

- H₂: 99.9%
- CO: 4 ppm
- Q: 1987 Nm³/h

**H₂:** 79.9%
**CO:** 4.9%
**CO₂:** 0.05%
**H₂S:** 0 ppm
**Q:** 3498 Nm³/h
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P&ID Shift Converter Unit
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Pilot Plant implementation

Power Block
Air Separation Unit
Gasification unit

Pilot Plant for CO₂ capture and H₂ production
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Pilot Plant implementation
## Spanish Research Initiative in Biodiesel

<table>
<thead>
<tr>
<th>Project title:</th>
<th>Research Project on Biodiesel Support in Spain (PIIBE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programme:</td>
<td>Strategic National Consortia (Ministry of Industry)</td>
</tr>
<tr>
<td>Coordinator:</td>
<td>REPSOL-YPF</td>
</tr>
</tbody>
</table>
| Target:       | Move Spain into vanguard of R&D in renewable biodiesel sector  
|               | i) To reduce production cost down to those of gas-oil from petroleum  
|               | ii) To expand availability of local raw materials       |
| ELCOGAS ACTIVITY: | Leader of “**Biodiesel production through gasification**”: to assess the viability of biodiesel production through biomass gasification ⇒ execution of real co-gasification tests up to 10% with biomass (estimated biomass consumption of 3000 t during 2 years).  
|               | Started in 2006. Budget: 900 k€                         |

**Orujillo (olive oil waste)**  
**Almond shells**
PUERTOLLANO IGCC POWER PLANT.
OPERATIONAL EXPERIENCE AND CURRENT DEVELOPMENTS.

Thank you for your attention

Pedro Casero, Elcogas, S.A.
www.elcogas.es