ELCOGAS IGCC plant: Clean coal technology. Experience and Future
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INTRODUCTION: THE ELCOGAS COMPANY

Spanish company established in April 1992 to undertake the planning, construction, management and operation of a 335 MWe$_{ISO}$ IGCC plant located in Puertollano (Spain)
INTRODUCTION: THERMIE Programme
ELCOGAS opportunity

**European Commission support**
Thermie Programme creation to guarantee the future availability of clean electricity using coal

**Strategic reasons at national level**
Incorporation of the Puertollano Project to the Plan Energético Nacional 1991 - 2000:
- Energy primary source diversification
- Contribution to technological development
- Create/keep employment in the Puertollano area

**Technological development**
New alternatives for clean and efficient power generation with coal

**Environmental demand**
The growing social concern to the environmental impact of the classical coal power stations
More restrictive emissions limits
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PUERTOLLANO IGCC POWER PLANT DESCRIPTION

Process description

Coal preparation

HP Boiler
IP Boiler
Gasifier

HP Steam

Raw Gas

Filtration

Water wash

Sulfur Removal

Clean Syngas

Sulfur Recovery

(recovery of 99.8%)

Claus Gas

Water to treatment

Tail Gas

N2

O2

Fly ash

Slag

Air

O2

Sulfur

Waste N2

Compressed air

Coal - N2

PetCoke

Limestone

HP Steam

MP Steam

Flue gas to stack

Steam

Condenser

Cooling tower

STEA M TURBINE

135MWeISO

GAS TURBINE

200 MWeISO

Air Separation Unit

Claus Gas

Water to treatment

Waste N2

Compressed air

Steam

Flue gas to stack
**Fuel**

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

**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>
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<tbody>
<tr>
<td></td>
<td>182.3</td>
<td>135.4</td>
<td>317.7</td>
<td>282.7</td>
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<table>
<thead>
<tr>
<th>EFFICIENCY (LHV)</th>
<th>GROSS</th>
<th>NET</th>
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<tbody>
<tr>
<td></td>
<td>47.12%</td>
<td>42.2%</td>
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<table>
<thead>
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<th>EMISSIONS</th>
<th>g/kWh</th>
<th>mg/Nm³ (6% Oxygen)</th>
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<tr>
<td>SO₂</td>
<td>0.07</td>
<td>25</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.40</td>
<td>150</td>
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<tr>
<td>Particulate</td>
<td>0.02</td>
<td>7.5</td>
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# PUERTOLLANO IGCC POWER PLANT DESCRIPTION

## Raw and Clean gas data

<table>
<thead>
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<th>RAW GAS</th>
<th></th>
<th>CLEAN GAS</th>
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<td></td>
<td>Actual average</td>
<td>Design</td>
<td>Actual Average</td>
<td>Design</td>
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<tr>
<td>CO (%)</td>
<td>59.26</td>
<td>61.25</td>
<td>CO (%)</td>
<td>59.30</td>
</tr>
<tr>
<td>H₂ (%)</td>
<td>21.44</td>
<td>22.33</td>
<td>H₂ (%)</td>
<td>21.95</td>
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<tr>
<td>CO₂ (%)</td>
<td>2.84</td>
<td>3.70</td>
<td>CO₂ (%)</td>
<td>2.41</td>
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<td>N₂ (%)</td>
<td>13.32</td>
<td>10.50</td>
<td>N₂ (%)</td>
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<tr>
<td>Ar (%)</td>
<td>0.90</td>
<td>1.02</td>
<td>Ar (%)</td>
<td>1.18</td>
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<td>H₂S (%)</td>
<td>0.81</td>
<td>1.01</td>
<td>H₂S (ppmv)</td>
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<tr>
<td>COS (%)</td>
<td>0.19</td>
<td>0.17</td>
<td>COS (ppmv)</td>
<td>9</td>
</tr>
<tr>
<td>HCN (ppmv)</td>
<td>23</td>
<td>38</td>
<td>HCN (ppmv)</td>
<td>-</td>
</tr>
</tbody>
</table>
1) Pyrolysis:
Coal + heat $\rightarrow$ Combustion gases (CO, H₂, CO₂...)

2) Combustion:
- C + O₂ $\rightarrow$ CO₂
- H₂ + ½ O₂ $\rightarrow$ H₂O
- CO + ½ O₂ $\rightarrow$ CO₂

3) Gasification with combustion gases:
- 2C + O₂ $\leftrightarrow$ 2CO
- C + CO₂ $\leftrightarrow$ 2CO
- C + H₂O $\leftrightarrow$ CO + H₂
- CO + 3H₂ $\leftrightarrow$ CH₄ + H₂O
- C + 2H₂ $\leftrightarrow$ CH₄
- CO + H₂O $\leftrightarrow$ CO₂ + H₂
PUERTOLLANO IGCC POWER PLANT DESCRIPTION

Main equipment:
Gas turbine

Model V94.3
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**PROJECT MILESTONES**

- **1992**
  - Jun 1996: First synchronization of gas turbine
  - Oct 1996: Commercial operation with natural gas
  - Jun 1997: Performance test of the Air Separation Unit
- **Mar 1998**
  - Mar 1998: First switch over from natural gas to coal gas
- **Nov 2000**
  - Nov 2000: First 1,000 GWh produced with coal gas as IGCC
- **Sept 2003**
  - Sept 2003: 5,000 GWh produced with coal gas as IGCC
- **Dec 2013**
  - Dec 2013: Total 24,998 GWh

**BEST RESULTS.**

<table>
<thead>
<tr>
<th></th>
<th>IGCC</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum continuous operating hours</td>
<td>953.70 h</td>
<td>1,513 h</td>
</tr>
<tr>
<td>Maximum annual production</td>
<td>1,595 GWh</td>
<td>1,938 GWh</td>
</tr>
<tr>
<td>Cumulative operating hours</td>
<td>64,159 h</td>
<td>101,633 h</td>
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</tbody>
</table>
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  - Main equipment: Gas turbine

- **PROJECT MILESTONES**

- **OPERATIONAL DATA**

- **VALUES AND AREAS OF IMPROVEMENT FOR IGCC TECHNOLOGY**

- **THE FUTURE OF IGCC TECHNOLOGY**

- **R&D INVESTMENT PLAN. Lines**
OPERATIONAL DATA

- EMISSIONS
- ANNUAL ENERGY PRODUCTION
- COSTS
- IGCC AVAILABILITY
- IGCC UNAVAILABILITY
- IGCC PRODUCTION
- LESSONS LEARNT:
  - UNAVAILABILITY
  - PROJECT PHASE
OPERATIONAL DATA: Emissions 2013

**Natural gas (NGCC)**

- **SO2**: 29 mg/Nm³, 29 mg/Nm³
- **NOx**: 155.9 mg/Nm³
- **Particles**: 0.5 mg/Nm³

**Coal gas (IGCC)**

- **SO2**: 650 mg/Nm³
- **NOx**: 111.9 mg/Nm³
- **Particles**: 0.2 mg/Nm³

ELCOGAS power plant emissions in NGCC & IGCC modes
1st 5 years: Learning curve
2004 & 2005: Gas turbine main generation transformer isolation fault
2007 & 2008: ASU WN₂ compressor coupling fault and repair MAN TURBO
2010: 1,066 hours without operation due to non-profitable electricity price
2012: 1,498 hours in stand-by due to regulatory restrictions
2013: 4,392 hours in stand-by due to regulatory restrictions
### OPERATIONAL DATA: Cost

<table>
<thead>
<tr>
<th>Fuel mode</th>
<th>Fuel</th>
<th>Consume (GJ PCS)</th>
<th>Production (GWh)</th>
<th>Heat rate (GJ PCS/GWh)</th>
<th>Fuel cost (€/ GJ PCS)</th>
<th>Partial cost (€/ MWh)</th>
<th>Total cost (€/ MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT</td>
<td>Natural gas</td>
<td>52,348</td>
<td>3.183</td>
<td>16,446</td>
<td>13.95</td>
<td>229.38</td>
<td>229.38</td>
</tr>
<tr>
<td>NGCC</td>
<td>Natural gas</td>
<td>103,928</td>
<td>10.329</td>
<td>10,062</td>
<td>13.95</td>
<td>140.34</td>
<td>140.34</td>
</tr>
<tr>
<td>NGCC + ASU</td>
<td>Natural gas</td>
<td>967,576</td>
<td>88.201</td>
<td>10,970</td>
<td>13.95</td>
<td>153.01</td>
<td>153.01</td>
</tr>
<tr>
<td>NGCC+ASU+Gasifier</td>
<td>Natural gas</td>
<td>233,403</td>
<td>20.991</td>
<td>11,119</td>
<td>13.95</td>
<td>155.08</td>
<td>187.97</td>
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<tr>
<td></td>
<td>Coal</td>
<td>82,154</td>
<td></td>
<td>3,914</td>
<td>3.50</td>
<td>13.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>263,387</td>
<td></td>
<td>12,548</td>
<td>1.53</td>
<td>19.20</td>
<td></td>
</tr>
<tr>
<td>IGCC</td>
<td>NG auxiliary consumption</td>
<td>82,535</td>
<td>652.192</td>
<td>127</td>
<td>13.95</td>
<td>1.77</td>
<td>21.18</td>
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<tr>
<td></td>
<td>Coal</td>
<td>1,506,522</td>
<td></td>
<td>2,310</td>
<td>3.50</td>
<td>8.08</td>
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<tr>
<td></td>
<td>Petocke</td>
<td>4,829,949</td>
<td></td>
<td>7,406</td>
<td>1.53</td>
<td>11.33</td>
<td></td>
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</tbody>
</table>

**Note:** Net energy variable costs (average 2013)
OPERATIONAL DATA: IGCC Availability 2013

2013: 4,392 hours in stand-by due to regulatory restrictions
OPERATIONAL DATA: IGCC Unavailability 2013

- GAS TURBINE: 78%
- WATER STEAM CYCLE: 10%
- GAS SATURATOR: 12%
- COMBINED CYCLE: 56%
- ELECTRICAL SYSTEMS: 3.7%
- AUXILIARY SYSTEMS: 65.5%
- DCS: 30.9%
- WASTE NITROGEN PRODUCTION: 8.9%
- GAS OXYGEN PRODUCTION: 33.5%
- PURE NITROGEN PRODUCTION: 33.5%
- GASIFICATION: 29%
- ASU: 9%
- BOP: 7%

- MIXING & GRINDING PLANT: 3%
- DUST FUEL CONVEYING & FEEDING: 3%
- START-UP BURNER & FLAME MONITORS: 0%
- SLAGS: 9%
- GAS WET TREATMENT: 33%
- GASIFICATION: 29%
- ASU: 9%
- BOP: 7%

- GASIFICATION: 29%
- ASU: 9%
- BOP: 7%
- PURE NITROGEN PRODUCTION: 33.5%
- GAS OXYGEN PRODUCTION: 8.9%
- WASTE NITROGEN PRODUCTION: 57.6%
1. Gas Turbine

- Optimization of syngas burners to prevent overheating / humming and to accomplish more stability and remaining life of the hot components.

- Up to last design of syngas burner was installed in 2003 preventive inspections of hot gas path every 500 – 1000 syngas operating hours. High rate of ceramic tiles change.
2. Gasifier

- Water leakage of membrane tubes due to flow blockages or local erosion. Design of distributors. Chemical control. Particle filtration. Loose parts.
2. Gasifier (II)

- Gas leakage due to piping corrosion:
  - ✔ Proper selection of materials. To avoid “cold ends” and down time corrosion.

- Fouling of Waste Heat boilers:
  - ✔ Sticky fly ash (reduced by decreasing gas inlet temperature to cooling surfaces. More quench flow)
  - ✔ Fluffy fly ash (reduced by increasing the velocity of the gas)
OPERATIONAL DATA: Lessons learnt
Main unavailability during first 5 years (IV)

3. Grinding and mixing systems

Clogging in mills feeding and mixing conveyors. Two trains of 60%. Lack of robustness of equipment.
4. Solids handling (slag and fly ash)

Erosion of components by local high velocities. Substitution of parts for abrasion resistant materials. Revision of design and operating procedures.

5. Ceramic filters

Life time of filtrating elements is half of expected (4000 h). Very expensive cost. To improve by changing supporting design of elements.
6. Fuel dust conveying and feeding systems

Pressure control and fluidization stability. Design of fluidization systems and preventive maintenance of components.

7. COS catalyst

2 – 3 changes by year of alumina based catalyst. Water carryover. Change to Titanium oxide catalyst (3 – 4 years) and pre-heater installation.
OPERATIONAL DATA: Lessons learnt
Current maintenance cycle (2010 – 2013)

MAIN IGCC UNAVAILABILITY HOURS PER ISLAND, CURRENT MAINTENANCE CYCLE 2010 - 2013

- GASIFICATION
- COMBINED CYCLE
- ASU
- BOP

- 2010-2013
- 2013
- 2012
- 2011
- 2010
OPERATIONAL DATA: Lessons learnt
Actual maintenance cycle (2010 – 2013)

Turbine blades damages (Oct 2013)
OPERATIONAL DATA: Lessons learnt

Actual maintenance cycle (2010 – 2013)

Water steam systems:

Pipes breakages due to corrosion
**OPERATIONAL DATA: Lessons learnt**

**Actual maintenance cycle (2010 – 2013)**

<table>
<thead>
<tr>
<th>Slags:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two slags blockage (2011)</td>
</tr>
<tr>
<td>Slag accumulation in cone and heat exchangers (2012)</td>
</tr>
</tbody>
</table>
Quench gas recirculation:
Flooding in compressor aspiration pipe due to water leakages at IP economizer
OPERATIONAL DATA: Lessons learnt
Actual maintenance cycle (2010 – 2013)

Dry dedusting & fly ash systems:
Installation of new ceramic filters (2011)
OPERATIONAL DATA: Lessons learnt
Actual maintenance cycle (2010 – 2013)

Gas wet treatment:
Gas leakages due to corrosion
OPERATIONAL DATA: Lessons learnt
Actual maintenance cycle (2009 – 2012)

Gaseous O₂ production:
Issues related to cold box (partial operation) & carrier systems.
Freezing of heat exchangers
OPERATIONAL DATA

- EMISSIONS
- ANNUAL ENERGY PRODUCTION
- COSTS
- IGCC AVAILABILITY
- IGCC UNAVAILABILITY
- IGCC PRODUCTION

LESSONS LEARNT:
- UNAVAILABILITY
- PROJECT PHASE
### ELCOGAS IGCC PROJECT GENERAL SCHEDULE

<table>
<thead>
<tr>
<th>Year</th>
<th>Basic Engineering</th>
<th>Detailed Engineering</th>
<th>Supply main equipment</th>
<th>Erection Power Block</th>
<th>Commissioning PB with NG</th>
<th>Erection ASU &amp; Gasification</th>
<th>Commissioning ASU &amp; Gasification</th>
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<tbody>
<tr>
<td>1992</td>
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<td></td>
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</table>

- **Scheduled**
- **As was**

**Operational Data: Lessons Learnt**

- **Project Step – Organization**
  - Cabling, 37 km vs 1290 km
  - Auxiliaries, GT
  - Coal preparation, KU
### OPERATIONAL DATA: Lessons learnt

#### Project step – Organization

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps</td>
<td>419</td>
</tr>
<tr>
<td>Compressors &amp; fans</td>
<td>237</td>
</tr>
<tr>
<td>Conveyors &amp; Screw transporters</td>
<td>46</td>
</tr>
<tr>
<td>Heat exchangers</td>
<td>290</td>
</tr>
<tr>
<td>Tanks</td>
<td>300</td>
</tr>
<tr>
<td>VALVES</td>
<td>18442</td>
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<tr>
<td>Manual</td>
<td>16902</td>
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<tr>
<td>Act. Motorised</td>
<td>365</td>
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<tr>
<td>Act. Pneumatic</td>
<td>1124</td>
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<tr>
<td>Act. Hydraulic</td>
<td>51</td>
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<tr>
<td>Transformers</td>
<td>50</td>
</tr>
<tr>
<td>High voltage</td>
<td>6</td>
</tr>
<tr>
<td>6/0.4 KV</td>
<td>44</td>
</tr>
<tr>
<td>CCM 400V</td>
<td>21</td>
</tr>
<tr>
<td>Motors</td>
<td>617</td>
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<td>10.5 KV</td>
<td>1</td>
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<td>6 KV</td>
<td>30</td>
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<tr>
<td>400 V</td>
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<tr>
<td>km cabling</td>
<td>1290</td>
</tr>
<tr>
<td>Power &amp; control</td>
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</tr>
<tr>
<td>Auxiliaries</td>
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<td>Local instrument</td>
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<tr>
<td>Local PLC</td>
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<table>
<thead>
<tr>
<th>DCS</th>
<th>CC &amp; PB</th>
<th>BOP</th>
<th>ASU</th>
<th>Gasification</th>
<th>TOTAL</th>
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<td>4774</td>
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<td>2501</td>
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<td>1135</td>
<td>882</td>
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<td>Electronic cabinets</td>
<td>35</td>
<td>9</td>
<td>6</td>
<td>33</td>
<td>83</td>
</tr>
</tbody>
</table>
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VALUES OF IGCC TECHNOLOGY (I)

✓ **High efficiency.** Higher than other coal-based technologies & great potential of improvement: net 42% → 50%

✓ **Flexible feeding**
  - Coal (several qualities)
  - Alternative fuels (pet-coke, USW, biomass, etc.)
  - Availability of second fuel for combined cycle

Reliability of energy supply

✓ **Product flexibility** → power, $H_2$, $CO_2$, methanol, $NH_3$, gasolines, etc

Lower risk: Production as per market

VALUES OF IGCC TECHNOLOGY (I)
VALUES OF IGCC TECHNOLOGY (II)

✔️ **Environment:**
- Lower CO\textsubscript{2} emissions compared to other coal-based technologies. Higher potential to zero emission plants.
- Low acid gas emission (SO\textsubscript{2}, NO\textsubscript{x}) and particles. Similar or best than NGCC plants.
- Lower wastes. Slag, fly ash, sulphur and salts are by-products.
- Lower water consumption than other coal-based technologies.
- No dioxins/furans using organic fuels.
- Lower Hg emissions and best method to remove it.

✔️ **Economy:**
- Very competitive fuel compared to natural gas. Variable cost per kWh with coal is very low compared to natural gas.
- Lower cost of CO\textsubscript{2} capture (pre-combustion).
- Wastes are marketable products.

✔️ **Sustainability:**
- Coal reserves for more than 200 years and best geographical distribution.
- Almost any fuel with enough carbon can be gasified.
IMPROVEMENT AREAS OF IGCC TECHNOLOGY

Technology at demonstration state

- First four large coal-based plants (USA & EU, 1994 - 1998) show 60-80% of IGCC availability (> 90 % considering auxiliary fuel)
- Main unavailability causes related with its maturity lack in the past:
  - Auxiliary system design: solid handling, downtime corrosion, ceramic filters, materials and suitable procedures
  - Performance of last generation turbines with syngas or natural gas
  - Excessive integration between units. High dependence and start-up delay
  - More complex process compared to other coal-based plants. Learning is necessary. IGCC power plants using petroleum wastes show higher availability than 92%

High inversion cost

- Investment costs of existing plants varies 1,500-2,000 €/kW installed (1990-1998)
- Currently, its estimation varies 2,500-5,000 €/kW installed
INDEX

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  ▪ Process description
  ▪ Fuel and clean gas data
  ▪ Main equipment. Gasifier
  ▪ Main equipment. Gas turbine

■ PROJECT MILESTONES

■ OPERATIONAL DATA

■ VALUES AND AREAS OF IMPROVEMENT FOR IGCC TECHNOLOGY

■ THE FUTURE OF IGCC TECHNOLOGY

■ R&D INVESTMENT PLAN. Lines
FUTURE OF IGCC TECHNOLOGY

- Multi-fuel (coal, biomass, wastes)
- Multi-product (hydrogen, electricity, liquid fuels, chemicals)
- CO₂ capture and storage

Potential demonstrating of new process with synthesis gas partial flow.
FUTURE OF IGCC TECHNOLOGY

H₂ Production by coal gasification

Step 1: Syngas production from **Gasification**

```
Carbon compound + O₂ + H₂O \[\rightarrow\] CO + H₂ + Impurities
```

400-1600°C, 10-40 bar

Step 2: **Conditioning** → fly ash removal, particles and sulphur comp.

Step 3: “Shifting” or **water-gas reaction**

```
CO + H₂O \[\rightarrow\] CO₂ + H₂
```

Step 4: H₂ and CO₂ **separation**

- H₂
- CO₂

H₂ production from fossil fuels involves CO₂ generation ⇒ To talk about “clean” H₂ it is required to consider CCS.

- Fly ash
- Char
- Cl⁻
- CN⁻
- SH₂
- COS
- CO₂
- N₂ ...
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■ THE FUTURE OF IGCC TECHNOLOGY
■ R&D INVESTMENT PLAN. Lines
Since 2007 ELCOGAS has defined a R&D Investment Plan to develop IGCC technology in order to decrease the environmental impact of power production as main target.

ELCOGAS presents a yearly results report of that R&D Plan to Spanish government for evaluation.

**MAIN LINES OF R&D PLAN ARE:**

- \( \text{CO}_2 \) EMISSION REDUCTION IN UTILIZATION OF FOSSIL FUELS
- \( \text{H}_2 \) PRODUCTION BY GASIFICATION OF FOSSIL FUELS
- **DIVERSIFICATION** OF RAW FUELS AND PRODUCTS
- OTHER **ENVIRONMENTAL** IMPROVEMENTS
- **IGCC PROCESSES OPTIMIZATION**
- **DISSEMINATION** OF RESULTS
**Forum** participations. CO₂, H₂, and sustainability associations and Technological Platforms. European and Spanish. Coordinating working groups in Technological Spanish Platforms.

- Participation in **conferences**, seminars, congresses.
- **Consulting** services. Germany, China, Chile
- Attending and promoting technical **visits**. Generally international visits.
ELCOGAS R&D INVESTMENT PLAN
Optimization of IGCC process

Oriented to improve availability & costs

Elaboration of membrane water leakages at reaction chamber

Test materials

Gasifier materials/Syngas corrosion processes

Ceramic filters
Overview of the test rig for mercury and carbonyls analysis

Other environmental improvements


- Improvements in dry dedusting system.

- Improvements in **Sulphur** Recovery plant.
  In progress several modifications to improve availability and to reduce S emissions.

- Optimization of additives parameters.
  Internal research for improve the quality of subproducts

- **Emissions** reduction during start up and other **transitory** situations.
**ELCOGAS R&D INVESTMENT PLAN**

**Diversification of raw fuels and products**

- **Project FECUNDUS (RFCS-CT-2010-00009, 2010-2013)**
  Selection of biomass and undertake real co-gasification test (2 and 4% in weight of biomass) for asset its influence in CO₂ capture process.

- **Project PIIBE (ESP-CENIT).**
  To impulse biofuels technologies in Spain. ELCOGAS has coordinated the subproject about biodiesel from gasification by real co-gasification 10% of biomass and syngas characterization (F-T process in laboratory).

- **Meat and Bone Meal (MBM) co-gasification test (2001)**

- **Possibility to install a pilot plant in IGCC of Puertollano to develop process to obtain gasoline / diesel from syngas**

- **Availability to undertake tests of gasification of different fuels at large scale to help in design of new IGCC plants**
ELCOGAS R&D INVESTMENT PLAN

Diversification of raw fuels and products

Biomass co-gasification

Critical parameter for biomass selection was the behavior on the ELCOGAS grinding system

Biomass selection criteria:
- **Size**: < 25 mm
- **Humidity**: < 12 %
- **Price**: < 150 €/t
- **Availability in large quantities**

Battery of Biomass co-gasification tests

<table>
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<tr>
<th>Test Month/Year</th>
<th>BIOMASS</th>
<th>Biomass dosage ratio (% w)</th>
<th>Biomass tonnes (t)</th>
<th>Test Duration (h)</th>
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<td>Sept. 2009</td>
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<tr>
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<td><strong>TOTAL</strong></td>
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<td>4,987.3</td>
<td>1,647.7</td>
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</table>

Load during 8% olive oil waste co-gasification test
ELCOGAS R&D INVESTMENT PLAN

Diversification of raw fuels and products

Biomass co-gasification

Real tests with biomass

![Diagram showing biomass/common fuel ratio and tests duration]
ELCOGAS R&D INVESTMENT PLAN
Diversification of raw fuels and products

ELCOGAS has made some co-gasification studies with different MSWs/Industrial wastes supplied by waste management companies

Inorganic waste

- They can be fed to the mills (without any modification)
- Melting temperature similar to common fuel
- High content of ashes, chlorides and sodium
- LHV = 4,700 kcal/kg
Organic wastes (with and without pelletized)

- They cannot be fed to the existing mills because their combustion temperature is lower than the operating temperature of the mills, and because they are highly fibrous (money investment is required)
- High content of chloride
- LHV = 2,600 – 2,800 kcal/kg
Processed packaging and organic processed wastes

- They can not be fed to the existing mills because their combustion temperature is lower than the operating temperature of the mills (investment is required)
- Melting temperature similar to common fuel
- High content of ashes (organic wastes) and chlorides (packaging wastes)
- LHV (kcal/kg):
  - 2,700 (organic wastes)
  - 4,600 (packaging wastes)
Feeding point of wastes to the ELCOGAS process:
Existing and alternatives

ELCOGAS R&D INVESTMENT PLAN
Diversification of raw fuels and products

Current point, grindability

Alternative 1, particle size

Alternative 2, density

Waste
Limestone
Coal
Coke
Raw gas
N2
Clean H₂ production by gasification of fuels

- Collaboration in several projects (HYDROSEP (UE-RFCS) and SPHERA (ESP-CENIT))
- H₂ production optimization using the CO₂-H₂ Pilot Plant
- Possibility to collaborate with The National Center for Hydrogen “CNH2” (SPAIN)

CO₂ EMISSION REDUCTION

**IGCC Efficiency Optimization**

- Analysis of viability to improve efficiency based on Critical Assessment of Puertollano IGCC design.
- **Auxiliary consumption** optimization. New revision
- Development of tools to improve efficiency. Supervision on line of main (120) equipment efficiency. Installed and in tests
- Integration optimization. Improvement of controls to adjust heat & mass balances in real operation

And

**CO₂ capture for CCS with IGCC**
ELCOGAS R&D INVESTMENT PLAN - Line CO₂

PROJECTS ABOUT CO₂

- **DEMOCLOCK (European project 7PM no. 268112)**
  
  Demonstration of cost-effective medium size Chemical Looping Combustion through packed beds using solid hydrocarbons as fuel for power production with CO₂ capture.
  
  - Demonstration of the CLC technology (Chemical Looping Combustion) through a demo installation of 500 kW integrated in the Puertollano IGCC plant.
  - Led by SINTEF. Begins in 2011, 4 years of duration.
  - Demo installation on fabrication at the installations of a partner. Transporting to Puertollano on first semester 2014 in order to connect it to the IGCC plant. Subsequently, some tests will take place on it.

- **GREEN CC (European Project 7PM no. 608524)**
  
  
  Development of oxygen transport membranes in different industrial processes of highly demand energy. ELCOGAS activities are focused on evaluation studies about this technology as an alternative to cryogenics at ASU.
To demonstrate the **feasibility of capture of CO$_2$ and production of H$_2$** in an IGCC that uses solid fossil fuels and wastes as main feedstock.

To obtain **economic data** enough to **scale** it to the full Puertollano IGCC capacity in synthetic gas production.

**TARGETS**

**PARTICIPANTS & BUDGET**

ELCOGAS – UCLM – Ciemat – INCAR CSIC 14.5 M€ (initially 18.5 M€)

**COORDINATED**

Project of pilot plant in an existing IGCC of Puertollano (pre-combustion technology) is part of a **Spanish national initiative, “Advanced technologies of CO$_2$ conversion, capture and storage”** and it is coordinated with other related projects:

**Project # 2** is to explore oxyfuel combustion to be applied in the construction of a pilot plant (20-30 MW) to be built in El Bierzo, NW of Spain. CIUDEN

**Project # 3** is to study and regulate geological storage in Spain. IGME

**Project # 4** is to study public awareness of CCS technologies. CIEMAT
Puertollano IGCC power plant and pilot plant location

- PRENFLO Gasifier
- Coal preparation
- ASU
- New CO₂ capture pilot plant
- Sulphur Recovery
- Combined Cycle
COAL + COKE

GASIFICATION

Raw gas

FILTRATION SYSTEM

2% Syngas

PURIFICATION & DESULPHURATION

100 t/d CO₂ + H₂S (1.44%)

Recycle compressor

H₂ rich gas
37.5 % CO₂
50.0 % H₂
3.0 % CO

CO₂ & H₂ separation
(Chemical, aMDEA)

 Raw H₂ (80% of purity)

1.3 bar Tail gas

CO₂

40%

100 t/d

H₂ rich gas

Hydrogen purification (PSA)

99.99% H₂ @ 15 bar

Recycle compressor

SWEET SOUR

Flow (Nm³/h) 3,610 4,006
P (bar) 19.8 23.6
T (°C) 126 138
% CO₂ 60.45 53.72
%H₂ 21.95 19.57
%H₂O 0.29 10.40
%H₂S 0 0.70
% COS 0 0.11
ELCOGAS R&D INVESTMENT PLAN – Line CO₂

MILESTONES

First CO₂ tonne captured in 13th September 2010
1,000 tonnes of CO₂ captured
6 tonnes of H₂ produced

Engineering
CO₂ Unit
PSA Unit
Control
Reactors
Catalysts
Construction

Empresarios Agrupados
Linde-Caloric
Linde
Zeus Control
Técnicas Reunidas
Johnson Matthey
Local companies

PSA Unit
Electric & Control Building

Analysis shelter
CO₂ Wash Unit
Shifting Unit
ELCOGAS R&D INVESTMENT PLAN – Line CO₂

Shifting unit

<table>
<thead>
<tr>
<th></th>
<th>Flow kg/h</th>
<th>P bar</th>
<th>T °C</th>
<th>CO %</th>
<th>H₂ %</th>
<th>CO₂ %</th>
<th>H₂O %</th>
<th>H₂S %</th>
<th>COS %</th>
</tr>
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<tbody>
<tr>
<td>Coal gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet</td>
<td>3,677</td>
<td>19.8</td>
<td>126</td>
<td>60.45</td>
<td>21.95</td>
<td>2.66</td>
<td>0.29</td>
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<tr>
<td>Sour</td>
<td>3,999</td>
<td>23.6</td>
<td>138</td>
<td>53.72</td>
<td>19.57</td>
<td>2.70</td>
<td>10.40</td>
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<td>Shifted gas to separation unit</td>
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<tr>
<td>Sweet</td>
<td>8,732</td>
<td>17.3</td>
<td>274</td>
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<tr>
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<td>277</td>
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<tr>
<td>Sweet</td>
<td>5,055</td>
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<td>243</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sour</td>
<td>4,706</td>
<td>34.0</td>
<td>243</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</tbody>
</table>

General view of Shifting Unit

- **Coal gas**
  - Sweet: 3,677 kg/h, 19.8 bar, 126 °C, 60.45% CO, 21.95% H₂, 2.66% CO₂, 0.29% H₂O, 0.0% H₂S, 0.0% COS
  - Sour: 3,999 kg/h, 23.6 bar, 138 °C, 53.72% CO, 19.57% H₂, 2.70% CO₂, 10.40% H₂O, 0.70% H₂S, 0.11% COS

- **Shifted gas to separation unit**
  - Sweet: 8,732 kg/h, 17.3 bar, 274 °C, 1.68% CO, 28.37% H₂, 21.34% CO₂, 43.26% H₂O, 0.0% H₂S, 0.0% COS
  - Sour: 8,705 kg/h, 21.1 bar, 277 °C, 1.40% CO, 28.39% H₂, 21.53% CO₂, 42.73% H₂O, 0.74% H₂S, 0.0% COS

- **IP saturated steam to feed**
  - Sweet: 5,055 kg/h, 34.0 bar, 243 °C, 0.0% CO, 0.0% H₂, 0.0% CO₂, 0.0% H₂O, 0.0% H₂S, 0.0% COS
  - Sour: 4,706 kg/h, 34.0 bar, 243 °C, 0.0% CO, 0.0% H₂, 0.0% CO₂, 0.0% H₂O, 0.0% H₂S, 0.0% COS
### General view of Separation Unit

#### CO₂ Separation Unit

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<tr>
<th></th>
<th>Flow kg/h</th>
<th>P bar</th>
<th>T ºC</th>
<th>CO %</th>
<th>H₂ %</th>
<th>CO₂ %</th>
<th>H₂O %</th>
<th>H₂S %</th>
<th>COS %</th>
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</thead>
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<td>CO₂ product</td>
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<td>0.0</td>
<td>100</td>
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</tbody>
</table>
### PSA Unit

#### ELCOGAS R&D INVESTMENT PLAN – Line CO₂

**General view of PSA unit**

![General view of PSA unit](image)

<table>
<thead>
<tr>
<th></th>
<th>Flow Nm³/h</th>
<th>P bar</th>
<th>T °C</th>
<th>CO %</th>
<th>H₂ %</th>
<th>CO₂ %</th>
<th>H₂S %</th>
<th>COS %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H₂ from separation unit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet</td>
<td>1,431</td>
<td>15.2</td>
<td>40</td>
<td>4.63</td>
<td>79.37</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sour</td>
<td>1,412</td>
<td>19.1</td>
<td>40</td>
<td>4.02</td>
<td>80.44</td>
<td>0.5</td>
<td>0.0001</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>H₂ product</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet</td>
<td>795</td>
<td>14.7</td>
<td>43</td>
<td>0.0004</td>
<td>99.99</td>
<td>0.0001</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sour</td>
<td>795.1</td>
<td>18.6</td>
<td>43</td>
<td>0.0004</td>
<td>99.99</td>
<td>0.0001</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Tail gas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet</td>
<td>636</td>
<td>1.3</td>
<td>35.9</td>
<td>10.42</td>
<td>53.58</td>
<td>1.13</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sour</td>
<td>616.9</td>
<td>1.3</td>
<td>35.7</td>
<td>9.2</td>
<td>55.23</td>
<td>1.14</td>
<td>0.0002</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- **H₂ product**
- **Tail gas drum**
- **H₂ from separation unit**
- **Rich H₂ gas (40 % flow)**
- **Tail gas**

**Diagram:**

- H₂ product
- Tail gas drum
- Adsorbers
- H₂ from separation unit
- Rich H₂ gas (40 % flow)
- Tail gas
• The finance delay: MICINN (Spanish Science & Research Minister) and JCCM (Regional Government).

• Delay in main equipment supply: more than 12-14 months.

• Detailed engineering: conditioned by suppliers.

• PP construction step: delay due to safety permits since it is installed in an operating plant.

• Delay of commissioning: low availability of experimented personnel.
Characterization tests (PSE-CO2 project): 493 h
Co-gasification tests (FECUNDUS project): 426 h
Operator training: 202 h

Total accumulated hours: 1,121 h

Accumulated hours in sweet mode: 356 h
Accumulated hours in sour mode: 765 h
Total CO₂ captured: 3,500 t
Total H₂ of high purity produced: 6 t
**ELCOGAS R&D INVESTMENT PLAN – Line CO₂**

**Internal research: efficiency vs. capture rate**

**Reason:** Key relationship in order to obtain CO₂ capture cost at a new and better IGCC with capture integrated. **Method:** using models developed from operation. Steam ratio is used to adjust capture rate and the efficiency of the process is obtained. **Results:** (1) Capture rate between 85 and 96%, (2) high efficiency in sour mode (because of a lower steam consumption)

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**Pilot plant global parameters**  
(H₂O/CO molar ratios: 1.5 to 3.08; desorption T: 92.6°C)
**Reason:** Key relationship in order to obtain CO₂ capture cost at a new and better IGCC with capture integrated.

**Method:** using models developed from operation. Steam ratio is used to adjust capture rate and the efficiency of the process is obtained.

**Results:** (1) Capture rate between 85 and 96%, (2) high efficiency in sour mode (because of lower steam consumption)

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Some studies have been done with 1 reactor instead of 2 because the 95% of the conversion takes place on the first reactor. With this modification low capture rate was reached 71% obtaining a lower efficiency, but with an important saving of the equipment cost. The key for its suitability will be decided from the economical study.
**Scenario:** **retrofitting** of a capture unit based on the existent pilot plant in the IGCC plant in Puertollano, sweet and sour mode.

**Capital cost** (without PSA, scale factor, 25 years, Euribor 3 %)

**Fixed costs O&M** (Replacements, consumables, maintenance...)

**Net efficiency IGCC with capture** (Without capture: 42%)

**Variable costs:** \( \downarrow \) production = \( f \) (6,500 h; \( \downarrow \) \( \eta_{net} \); 40 €/MWh)

**CO\(_2\)** not emitted cost (Capture rate of 90%)

**CO\(_2\)** not emitted cost (with compression at 110 bar)

On a new IGCC with sour capture, the cost would be reduced in an important way because of a lower inversion cost (capture unit and sulfur removal unit in one single unit).
Co-production of H₂ with 40% capture in the pilot plant

Production just of electricity

284.5 MWe

Co-production of H₂ with 40% capture in the pilot plant

282.1 MWe

2.4 MWe of impact on the generated power due to the production of 2t/d of H₂ with capture of 40 t/d of CO₂

Net production IGCC Puertollano (MW)

Decision of co-production depending on market prices

• H₂ produced at 15 bar and 43 °C: conditioning needed for its commercialization, 0.2-0.3 €/kg additional.
• The H₂ production cost is competitive against other technologies: NG reformed ~ 1 €/kg, electrolysis ~ 3 €/kg.
• In the event of H₂ service station, the CSD (Compression, Storage, Dispensing) would add ~ 1.25 €/kg. H₂ current selling price at hydrogen filling stations: 8-15 €/kg.
1) The carbon capture pilot Project has been a **success**: first of its kind in the world, >90% capture rate achieved, and CO$_2$ capture cost can be <30 €/t

2) Commercial technology **at any scale** is available: the singularity comes from “integration in a existing IGCC plant”

3) Tests carried out show **room for improvement** in operating conditions and optimization of energy balance.

4) Carbon capture cost estimations come from **figures of a real project**.

5) From now on, the pilot is being used for **internal research**

6) But it is **also open** for international research projects and for other kinds of collaboration
ELCOGAS offers its IGCC plant and the pilot plant of CO$_2$ capture and H$_2$ production like platform for the development of technology and to prove processes and better designs of future plants, with a minimal inversion and with real contrast.
ELCOGAS IGCC plant: Clean coal technology. Experience and Future