Coal gasification in Spain – the future of sustainable coal

Francisco García Peña – ELCOGAS Puertollano IGCC plant
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2. Lessons learnt for the future
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1.4 CO$_2$ separation and H$_2$ production

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ELCOGAS is an Spanish company established in April 1992 to undertake the planning, construction, management and operation of a 335 MWeISO IGCC plant located in Puertollano (Spain)
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Description of the ELCOGAS IGCC process

- **Coal**
- **PetCoke**
- **Limestone**

**Coal preparation**

- **Coal - N₂**

**Gasifier**

- **Raw Gas**
- **Quench Gas**
- **Slag**
- **Fly ash**

**HP Boiler**

- **HP Steam**

**MP Boiler**

- **MP Steam**

**Filtration**

- **Water wash**
- **Water to treatment**
- **Air**
- **O₂**

**Heat Recovery Steam Generator**

- **Flue gas to stack**
- **Steam**
- **Hot combustion gas**

**Condenser**

- **Cooling tower**

**GAS TURBINE 200 MW ISO**

- **G**
- **N₂**
- **O₂**

**Sulfur recovery**

- **Sulfur (recovery of 99.8%)**
- **Waste N₂**

**Sulfur recovery**

- **Clean Syngas**
- **Tail Gas**

**Steam Turbine**

- **135 MW ISO**

**Air Separation Unit**

- **Compressed air**
- **Waste N₂**
Description of the ELCOGAS IGCC process

**Fuel design values**

Fuel design is a mixture 50/50 of coal/coke which now is 45/55. Moreover some tests with biomass were undertaken (meat bone meal, grape seed meal, olive oil waste).

<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>20.6</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>

With those fuels at 50:50, the whole plant demonstrated a gross efficiency of 47.2% and a net efficiency of 42%, under acceptance tests in 2000 year.

**Syngas composition**

<table>
<thead>
<tr>
<th></th>
<th>RAW GAS</th>
<th>Design</th>
<th>CLEAN GAS</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (%)</td>
<td>Real average</td>
<td>59.26</td>
<td>61.25</td>
<td>CO (%)</td>
</tr>
<tr>
<td>H₂ (%)</td>
<td>21.44</td>
<td>22.33</td>
<td>H₂ (%)</td>
<td>21.95</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>2.84</td>
<td>3.70</td>
<td>CO₂ (%)</td>
<td>2.41</td>
</tr>
<tr>
<td>N₂ (%)</td>
<td>13.32</td>
<td>10.50</td>
<td>N₂ (%)</td>
<td>14.76</td>
</tr>
<tr>
<td>Ar (%)</td>
<td>0.90</td>
<td>1.02</td>
<td>Ar (%)</td>
<td>1.18</td>
</tr>
<tr>
<td>H₂S (%)</td>
<td>0.81</td>
<td>1.01</td>
<td>H₂S (ppmv)</td>
<td>3</td>
</tr>
<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>
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1.5 Flexibility of feeding and products

2. Lessons learnt for the future
1st 5 years: Learning curve

2003: Major overhaul Gas Turbine findings
2004 & 2005: Gas turbine main generation transformer isolation fault
2006: Gas turbine major overhaul & candle fly ash filters crisis
2007 & 2008: ASU WN₂ compressor coupling fault and repair MAN TURBO
2010: No operation due to non-profitable electricity price (30-40 days).
2011: 100,000 EOH Major Overhaul
2012: 1,498 hours in stand-by due to regulatory restrictions. (3,969 in 2013)
ELCOGAS power plant emissions in NGCC & IGCC modes

**Natural gas (NGCC):**
- SO2: 29 mg/Nm³
- NOx: 250 mg/Nm³
- Particles: 4 μg/Nm³

**Coal gas (IGCC):**
- SO2: 20 mg/Nm³
- NOx: 650 mg/Nm³
- Particles: 50 μg/Nm³

Legend:
- EEC 88/609
- ELCOGAS Environmental Permit
- EU Directive 2010/75/EU DEI
- ELCOGAS 2012 average
## Operational data: Variable costs 2012

<table>
<thead>
<tr>
<th>Fuel mode</th>
<th>Fuel</th>
<th>Consume (GJPCS)</th>
<th>Production (GWh)</th>
<th>Heat rate (GJPCS/GWh)</th>
<th>Fuel cost (€/GJPCS)</th>
<th>Partial cost (€/MWh)</th>
<th>Total cost (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT</td>
<td>Natural gas</td>
<td>59.987</td>
<td>2,891</td>
<td>20.748</td>
<td>10.46</td>
<td>216.98</td>
<td>216.98</td>
</tr>
<tr>
<td>NGCC</td>
<td>Natural gas</td>
<td>249.495</td>
<td>22,154</td>
<td>11.262</td>
<td>10.46</td>
<td>117.77</td>
<td>117.77</td>
</tr>
<tr>
<td>NGCC + ASU</td>
<td>Natural gas</td>
<td>1,854.675</td>
<td>155,148</td>
<td>11.954</td>
<td>10.46</td>
<td>125.01</td>
<td>125.01</td>
</tr>
<tr>
<td>NGCC + ASU + Gasifier</td>
<td>Natural gas</td>
<td>351.147</td>
<td>33,373</td>
<td>10.522</td>
<td>10.46</td>
<td>110.03</td>
<td>128.69</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td></td>
<td></td>
<td>2.021</td>
<td>3.49</td>
<td>7.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>195.947</td>
<td></td>
<td>5.871</td>
<td>1.98</td>
<td>11.61</td>
<td></td>
</tr>
<tr>
<td>IGCC</td>
<td>NG auxiliary</td>
<td>257.700</td>
<td>992,811</td>
<td>260</td>
<td>10.46</td>
<td>2,71</td>
<td>26,30</td>
</tr>
<tr>
<td></td>
<td>consumption</td>
<td></td>
<td></td>
<td>2,555</td>
<td>3.49</td>
<td>8.91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td>2,536.891</td>
<td></td>
<td>7.422</td>
<td>1.98</td>
<td>14.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>7,368.734</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Net energy variable costs (average 2012)
Unavailability in 4 years maintenance cycle (2009–2012)

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 :

☒ Auxiliary system design: solid handling, downtime corrosion, ceramic filters, materials and 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%
Operational data: Costs

ACCUMULATED INVESTMENT COSTS

Million Eur

<table>
<thead>
<tr>
<th>Year</th>
<th>Fuel handling plant</th>
<th>Cooling system</th>
<th>Control system</th>
<th>A.S.U</th>
<th>B.O.P.</th>
<th>Combined Cycle</th>
<th>Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

REPRESENTATIVE YEAR (2008) OPERATING COSTS, WITHOUT FINANCIAL COSTS:

Total: 83,602 k€ (57.98 €/MWh)

- **Fixed costs:**
  - Total: 29,326 k€ (20.39 €/MWh)
- **Variable costs:**
  - Fuels: 54,276 k€ (37.59 €/MWh)
Cost Of Electricity ($€_{2012}/MWh$)
Benefit or lost before taxes is directly related to the existing regulatory framework

Regulatory “Gap” + payments by CO₂ not perceived

MLE Transition competition costs
PdV RD 134/2010

Law 15/2012

∑ Losts: Million € 110.7
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CO₂ capture & H₂ production: pilot plant

COAL + COKE

GASIFICATION

Raw gas

FILTRATION SYSTEM

PURIFICATION & DESULPHURATION

COMBINED CYCLE

Recycle compressor

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

IP STEAM

SHIFTING REACTORS

SWEET / SOUR

CO + H₂O → CO₂ + H₂

CO₂ & H₂ separation
(Chemical, aMDEA)

HYDROGEN PURIFICATION (PSA)

100 t/d

1.3 bar

Tail gas
40%

Pure H₂ (2 t/d)
99.99% H₂ @ 15 bar

CO₂ capture & H₂ production: pilot plant

Flow (Nm³/h) | SWEET | SOUR
---|---|---
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
CO₂ capture & H₂ production: pilot plant

Engineering: Empresarios Agrupados
CO₂ unit: Linde-Caloric
PSA unit: Linde
Control: Zeus Control
Reactors: Técnicas Reunidas
Catalysts: Johnson Matthey
Construction: Empresas locales
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2. Lessons learnt for future
### Battery of biomass co-gasification tests

<table>
<thead>
<tr>
<th>Test Month/Year</th>
<th>BIOMASS</th>
<th>Biomass dosage ratio (% wt)</th>
<th>Biomass (t)</th>
<th>Test Duration (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Meat Bone &amp; Meal</td>
<td>1-4.5%</td>
<td>93.3</td>
<td>15</td>
</tr>
<tr>
<td>2007-2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Olive oil waste</td>
<td>1-2 %</td>
<td>1,572.8</td>
<td>800.3</td>
</tr>
<tr>
<td>Mar 2009</td>
<td></td>
<td>4%</td>
<td>652.1</td>
<td>154</td>
</tr>
<tr>
<td>Jun 2009</td>
<td></td>
<td>6%</td>
<td>395.8</td>
<td>64.4</td>
</tr>
<tr>
<td>Sept 2009</td>
<td></td>
<td>8%</td>
<td>383.9</td>
<td>46</td>
</tr>
<tr>
<td>Nov-Dec 2011</td>
<td>Olive oil waste</td>
<td>10%</td>
<td>656.6</td>
<td>62</td>
</tr>
<tr>
<td>Oct-Nov 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct 2012</td>
<td>Grape Seed Meal</td>
<td>2%</td>
<td>179.3</td>
<td>127</td>
</tr>
<tr>
<td>Nov-Dec 2012</td>
<td></td>
<td>4%</td>
<td>425.7</td>
<td>119.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>4,987.3</strong></td>
<td><strong>1,647.7</strong></td>
</tr>
</tbody>
</table>
1. The ELCOGAS IGCC power plant

2. Lessons learnt for the future
   2.1 What is gasification?
   2.2 Gasification flexibility
   2.3 Engineering plant modifications
   2.4 “Demonstration project”
   2.5 CO₂ capture experience
Gasification itself is not the core, neither the root of the project nor plant problematic. On the contrary, they are the design & detailed engineering of the auxiliary systems. Each plant is different because they depend on:

- Available raw fuel
- Chosen gasifier technology
- Expected use of syngas
- Environmental regulations

So, Engineering & O&M expertise are crucial

- **Syngas production by gasification. Processes**

  - **Feeding**
    - Dry
    - Wet
  - **Gasification**
    - Fixed bed
    - Fluid bed
    - Entrained flow
  - **Cooling**
    - Heat exchangers
    - Direct with water
    - Chemical
  - **Particles separation**
    - Dry filtration
    - Wet filtration
  - **Scrubbing**
    - One step
    - Two steps
  - **Desulphurization**
    - COS hydrolyzation
    - Chemical absorption
    - Physical absorption
    - Adsorption
  - **Clean syngas**
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Gasification flexibility

Selection of the best gasification technology depending on:

- Fuel (C content, LHV, available quantities)
- Gasifier size required to obtain a competitive product
- Products required (H₂, Chemicals, Fischer-Tropsch liquids, energy w/ CO₂ capture, ..)

**Diagram:**

1. **Feedstock**
2. **Gasifier**
3. **Gas clean-up**
4. **Syngas**
   - **Power**
   - **Chemicals**
   - **Transportation fuels**
Gasification deployment

Accumulated world gasification capacity

Gasification by region

(Fuente: Higman Consulting, 2012)
Gasification Market Shares in China

- by syngas capacity
- including all constructed plants and contracted projects, as of Q3 2011

China Gasification Market Outlook 2011-2015

<table>
<thead>
<tr>
<th>Products</th>
<th>Capacity Million tonne/year</th>
<th>Syngas Demands Nm³/hour</th>
<th>Number of Gasifiers (5000 tonne/day per gasifier)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal to Liquids (CTL)</td>
<td>12</td>
<td>9,710,000</td>
<td>50</td>
</tr>
<tr>
<td>Coal to Olefins (CTO)</td>
<td>6</td>
<td>3,660,000</td>
<td>19</td>
</tr>
<tr>
<td>SNG</td>
<td>$23 \times 10^8$ Nm³</td>
<td>8,710,000</td>
<td>45</td>
</tr>
<tr>
<td>Ammonia</td>
<td>13</td>
<td>4,471,000</td>
<td>23</td>
</tr>
<tr>
<td>Methanol (excluding CTO)</td>
<td>10</td>
<td>2,290,000</td>
<td>12</td>
</tr>
<tr>
<td>Methanol to Ethylene Glycol (MEG)</td>
<td>3</td>
<td>1,500,000</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>30,341,000</td>
<td>157</td>
</tr>
</tbody>
</table>

(Fuente: EPRI, 2012)
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   2.5 CO₂ capture experience
ANNUAL EVOLUTION OF APPROVED DESIGN CHANGES

Engineering plant modifications

Commissioning of BOP & NGCC
Commissioning of ASU & Gasification and CCwSG
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   2.5 CO₂ capture experience
“Demonstration project“

Investment costs at ELCOGAS. Learning

REGULATORY SUPPORT is essential in a technology demonstration project at commercial scale

Total production cost
1. The ELCOGAS plant

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CO₂ capture: Real experience at ELCOGAS

Comparison between costs of CO₂ capture technologies

Source: DOE/NETL CCS RD&D ROADMAP (December 2010)
Real experience at ELCOGAS: results and learning

**CO₂ capture in IGCC plants**

- **With SWEET catalyst**
  - Fuel preparation
  - Gasification
  - Filtration and wet scrubbing
  - Desulphurization and sulphur recovery
  - Unity of CO₂ capture
  - Combined cycle

- **With SOUR catalyst**
  - Fuel preparation
  - Gasification
  - Filtration and wet scrubbing
  - Unity of CO₂ capture
  - Combined cycle

---

Based on our CO₂ capture pilot plant, we have scaled the cost of a CO₂ capture unit at scale 1:1 about 350 M€. Approximately, it represents the cost of the desulphurization and sulphur recovery units in an IGCC w/o CO₂ capture.

By installing an IGCC with CO₂ acid capture to store or use CO₂ together with ~1.5% H₂S, the investment costs are similar to those w/o CO₂ capture. And the only penalty is the decreasing efficiency:

- From 42% currently
- and from 50% near future
Summary

• Technology at commercial demonstration scale power plant requires a **long term regulatory frame**

• **IGCC** with or without CCS is a promising technology with the **minimum variable costs and the best environmental performance and** it can be adapted to multifuel and polygeneration

• Following IGCC generation must **learn from existing plants**

• Main **burden** for deployment is **high investment requires** a **long term regulatory frame**
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THANK YOU FOR YOUR ATTENTION

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