Coal gasification in Spain – the future of sustainable coal

Francisco García Peña – ELCOGAS Puertollano IGCC plant
1. The ELCOGAS IGCC power plant

2. Lessons learnt for the future
1. The ELCOGAS IGCC power plant

1.1 Introduction

1.2 Description of the IGCC process

1.3 Operational data

1.4 CO$_2$ separation and H$_2$ production

1.5 Flexibility of feeding and products

2. Lessons learnt for the future
ELCOGAS is an 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)
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   1.5 Flexibility of feeding and products

2. Lessons learnt for the future
Description of the ELCOGAS IGCC process

Coal preparation

Coal - N₂

Limestone

PetCoke

HP Boiler

MP Boiler

Gasifier

Raw Gas

Filtration

Water wash

Sulfur removal

Clean Syngas

GAS TURBINE
200 MWISO

HP Steam

MP Steam

Flue gas to stack

Steam

Heat Recovery

Steam Generator

135 MWISO

Cooling tower

Hot combustion gas

Condenser

Cooling tower

Air

O₂

N₂

Sulfur recovery

Sulfur recovery (recovery of 99.8%)

Tail Gas

Claus Gas

Waste N₂

Compressed air

Air Separation Unit

Coal

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N₂

Sulfur recovery

Sulfur recovery (recovery of 99.8%)

Tail Gas

Claus Gas

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>20.60</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></th>
<th>CLEAN GAS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real average</td>
<td>Design</td>
<td>Real average</td>
<td>Design</td>
</tr>
<tr>
<td>CO (%)</td>
<td>59.26</td>
<td>61.25</td>
<td>59.30</td>
<td>60.51</td>
</tr>
<tr>
<td>H₂ (%)</td>
<td>21.44</td>
<td>22.33</td>
<td>21.95</td>
<td>22.08</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>2.84</td>
<td>3.70</td>
<td>2.41</td>
<td>3.87</td>
</tr>
<tr>
<td>N₂ (%)</td>
<td>13.32</td>
<td>10.50</td>
<td>14.76</td>
<td>12.5</td>
</tr>
<tr>
<td>Ar (%)</td>
<td>0.90</td>
<td>1.02</td>
<td>1.18</td>
<td>1.03</td>
</tr>
<tr>
<td>H₂S (%)</td>
<td>0.81</td>
<td>1.01</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>COS (%)</td>
<td>0.19</td>
<td>0.17</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>HCN (ppmv)</td>
<td>23</td>
<td>38</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>
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Operational data: Annual energy production

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)
Operational data: Emissions 2012

ELCOGAS power plant emissions in NGCC & IGCC modes

Natural gas (mg/Nm³ at 6% O₂ dry)

Coal gas (mg/Nm³ at 6% O₂ dry)

SO₂
NOₓ
Particles

ELCOGAS Environmental Permit
EU Directive 2010/75/EU DEI
ELCOGAS 2012 average

SO₂
NOₓ
Particles

EEC 88/609
ELCOGAS Environmental Permit
EU Directive 2010/75/EU DEI
ELCOGAS 2012 average

Coal gas (IGCC)

Natural gas (NGCC)
### Operational data: Variable costs 2012

<table>
<thead>
<tr>
<th>Fuel mode</th>
<th>Fuel</th>
<th>Consume (GJ\textsubscript{PCS})</th>
<th>Production (GWh)</th>
<th>Heat rate (GJ\textsubscript{PCS}/GWh)</th>
<th>Fuel cost (€/GJ\textsubscript{PCS})</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 (by flare)</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>67.459</td>
<td></td>
<td>2.021</td>
<td>3,49</td>
<td></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></td>
<td></td>
</tr>
<tr>
<td>IGCC</td>
<td>NG auxiliar consumption</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>Coal</td>
<td>2.536.891</td>
<td></td>
<td>2.555</td>
<td>3,49</td>
<td>8,91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>7.368.734</td>
<td></td>
<td>7.422</td>
<td>1,98</td>
<td>14,67</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

Fuel handling plant
Cooling system
Control system
A.S.U
B.O.P.
Combined Cycle
Gasification

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 ($\text{€2012}/\text{MWh}$)
Benefit or lost before taxes is directly related to the existing regulatory framework

Regulatory “Gap” + payments by CO₂ not perceived

\[ \sum \text{Losts: Million € 110.7} \]
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2. Lessons learnt for future
CO₂ capture & H₂ production: pilot plant

COAL + COKE

GASIFICATION

Raw gas

Filtration System

Purification & Desulfuration

Syngas

Combined Cycle

Recycle compressor

H₂ rich gas

37.5 % CO₂

50.0 % H₂

3.0 % CO

100 t/d

CO₂ + H₂S (1.44%)

Raw H₂ (80% of purity)

40%

Tail gas

1.3 bar

Pure H₂ (2 t/d)

99.99% H₂ @ 15 bar

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

CO + H₂O → CO₂ + H₂

SHIFING REACTORS SWEET / SOUR

H₂ rich gas

CO₂ & H₂ separation (Chemical, aMDEA)

Hydrogen Purification (PSA)

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

IP STEAM

CO₂ capture & H₂ production: pilot plant
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>218.1</td>
<td>106</td>
</tr>
<tr>
<td>Nov-Dec 2012</td>
<td></td>
<td>4%</td>
<td>409.3</td>
<td>153.5</td>
</tr>
<tr>
<td>Oct 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov-Dec 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4,987.3</strong></td>
<td><strong>1,647.7</strong></td>
</tr>
</tbody>
</table>

Preselected biomass
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 CO$_2$ 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
1. The ELCOGAS plant

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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 with CO₂ capture, ..)

![Diagram showing the process of gasification with steps from Feedstock to Syngas, then branching to Power, Chemicals, and Transportation fuels.](image-url)
Gasification deployment

- Accumulated world gasification capacity

- Gasification by region

(Fuente: Higman Consulting, 2012)
Gasification deployment

**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 (3000 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>$25 \times 10^9$ 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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Engineering plant modifications

ANNUAL EVOLUTION OF APPROVED DESIGN CHANGES

Commissioning of BOP & NGCC
Commissioning of ASU & Gasification and CCwSG
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**“Demonstration project”**

**Investment costs at ELCOGAS. Learning**

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

**Total production cost**
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CO₂ capture: Real experience at ELCOGAS

Comparison between costs of CO₂ capture technologies

With acid CO₂ capture & current status of technology

~125

~25

30 for ELCOGAS retrofitting

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**
Coal gasification in Spain – the future of sustainable coal

Francisco García Peña – ELCOGAS Puertollano IGCC plant

THANK YOU FOR YOUR ATTENTION

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