Workshop for 11th European Gasification Conference

DESIGNING GASIFICATION PROCESSES FOR HIGH EFFICIENCY.

Francisco García Peña
Elcogas Engineering R&D Director
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- INTRODUCTION
- PUERTOLLANO IGCC POWER PLANT DESCRIPTION
- PROJECT MILESTONES
- OPERATIONAL DATA
- LESSONS LEARNT
The Elcogas company

European company established in April 1992 to undertake the planning, construction, management and operation of a 335 MWe\textsubscript{ISO} IGCC plant located in Puertollano (Spain)
INTRODUCTION
Origins of Elcogas project

Technological Development responding to environmental claims

- Growing social concern about the environmental impact generated on the classical plants which produce energy from coal.
- Emissions limits more and more restrictive.
- New alternatives to generate clean and efficient energy from coal.

Shareholders

- All the Elcogas shareholders belong to the European Union.

Strategic reasons

- Diversification of primary energy sources.
- Contribution to Technological Development.
- Clean use of local fuels.
INTRODUCTION

PUERTOLLANO IGCC POWER PLANT DESCRIPTION

PROJECT MILESTONES

OPERATIONAL DATA

LESSONS LEARNT
PUERTOLLANO IGCC POWER PLANT DESCRIPTION

Process description

1. **Coal preparation**
   - Coal
   - PetCoke
   - Limestone

2. **Coal - N₂**
   - HP Steam
   - MP Steam

3. **HP Boiler**
   - Raw Gas

4. **Gasifier**
   - Quench Gas
   - Slag
   - Fly ash

5. **Air Separation Unit**
   - O₂
   - Air
   - Waste N₂

6. **Filtration**
   - Water wash
   - Water to treatment

7. **Waste N₂**

8. **Sulfur Recovery**
   - Sulfur (recovery of 99.8%)
   - Waste N₂

9. **Sulfur Removal**
   - Claus Gas
   - Tail Gas

10. **Steam**
    - Steam

11. **Condenser**
    - Cooling tower

12. **Steam Turbine**
    - 135 MW

13. **Gas Turbine**
    - 200 MW ISO

14. **Flue gas to stack**

15. **Steam Generator**
    - 135 MW ISO

16. **Clean Syngas**

17. **Compressed air**
### Main Design Data

#### Fuel

<table>
<thead>
<tr>
<th></th>
<th>COAL</th>
<th>PET COKE</th>
<th>FUEL MIX (50:50)</th>
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<tbody>
<tr>
<td>Moisture (%w)</td>
<td>11.8</td>
<td>7.00</td>
<td>9.40</td>
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<tr>
<td>Ash (%w)</td>
<td>41.10</td>
<td>0.26</td>
<td>20.68</td>
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<tr>
<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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<tr>
<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>
<td>22.55</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>
</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>
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</thead>
<tbody>
<tr>
<td></td>
<td>47.12%</td>
<td>42.2%</td>
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</table>

<table>
<thead>
<tr>
<th>EMISSIONS</th>
<th>g/kWh</th>
<th>mg/Nm³ (6% Oxygen)</th>
</tr>
</thead>
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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>
</tr>
<tr>
<td>Particulate</td>
<td>0.02</td>
<td>7.5</td>
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</tbody>
</table>
### RAW GAS versus CLEAN GAS

<table>
<thead>
<tr>
<th>Component</th>
<th>Raw Gas (Actual Average)</th>
<th>Raw Gas (Design)</th>
<th>Clean Gas (Actual Average)</th>
<th>Clean Gas (Design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (%)</td>
<td>59.26</td>
<td>61.25</td>
<td>59.30</td>
<td>60.51</td>
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<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>
1) Pyrolysis:
Coal + heat $\rightarrow$ Combustion gases (CO, H$_2$, CO$_2$...)

2) Combustion:
- C + O$_2$ $\rightarrow$ CO$_2$
- H$_2$ + $\frac{1}{2}$ O$_2$ $\rightarrow$ H$_2$O
- CO + $\frac{1}{2}$ O$_2$ $\rightarrow$ CO$_2$

3) Gasification with combustion gases:
- 2C + O$_2$ $\leftrightarrow$ 2CO
- C + CO$_2$ $\leftrightarrow$ 2CO
- C + H$_2$O $\leftrightarrow$ CO + H$_2$
- CO + 3H$_2$ $\leftrightarrow$ CH$_4$ + H$_2$O
- C + 2H$_2$ $\leftrightarrow$ CH$_4$
- CO + H$_2$O $\leftrightarrow$ CO$_2$ + H$_2$
PUERTOLLANO IGCC POWER PLANT DESCRIPTION

Main equipment: GAS TURBINE

Model V94.3
INDEX

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PROJECT MILESTONES

1992  Main contracts award
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  First switch over from natural gas to coal gas
Nov 2000  First 1,000 GWh produced with coal gas as IGCC
Sept 2003  5,000 GWh produced with coal gas as IGCC
Dec 2011  Total: 22,675 GWh
          IGCC: 15,795 GWh

<table>
<thead>
<tr>
<th>BEST RESULTS.</th>
<th>IGCC</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Value</td>
<td>Value</td>
</tr>
<tr>
<td>Maximum continuous operating hours</td>
<td>953.70 h</td>
<td>1,313 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>57,106 h</td>
<td>91,944 h</td>
</tr>
</tbody>
</table>
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ELCOGAS power plant emissions in NGCC & IGCC modes

**Natural gas (NGCC)**

- **SO2**
  - EEC 88/609: 29,2 mg/Nm³
  - ELCOGAS Environmental Permit: 12,5 mg/Nm³
  - ELCOGAS 2011 average: 8,6 mg/Nm³
- **Particles**
  - EEC 88/609: 4,2 mg/Nm³
  - ELCOGAS Environmental Permit: 4,2 mg/Nm³
  - ELCOGAS 2011 average: 1,4 mg/Nm³
- **NOx**
  - EEC 88/609: 291,7 mg/Nm³
  - ELCOGAS Environmental Permit: 250,0 mg/Nm³
  - ELCOGAS 2011 average: 166,0 mg/Nm³

**Coal gas (IGCC)**

- **SO2**
  - EEC 88/609: 500 mg/Nm³
  - EU Directive 88/609/EEC: 400 mg/Nm³
  - EU Directive 2001/80/EEC: 200 mg/Nm³
  - ELCOGAS Environmental Permit: 25,9 mg/Nm³
  - ELCOGAS 2011 average: 50 mg/Nm³
- **NOx**
  - EEC 88/609: 650 mg/Nm³
  - EU Directive 88/609/EEC: 500 mg/Nm³
  - EU Directive 2001/80/EEC: 200 mg/Nm³
  - ELCOGAS Environmental Permit: 119 mg/Nm³
  - ELCOGAS 2011 average: 5 mg/Nm³
- **Particles**
  - EEC 88/609: 0,74 mg/Nm³
  - EU Directive 88/609/EEC: 0,5 mg/Nm³
  - EU Directive 2001/80/EEC: 0,5 mg/Nm³
  - ELCOGAS Environmental Permit: 5 mg/Nm³
  - ELCOGAS 2011 average: 0,74 mg/Nm³
OPERATIONAL DATA
Annual energy production

**IGCC, NGCC and Total yearly production**

<table>
<thead>
<tr>
<th>Year</th>
<th>IGCC GWh</th>
<th>NGCC GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>752</td>
<td>335</td>
</tr>
<tr>
<td>1999</td>
<td>1,171</td>
<td>836</td>
</tr>
<tr>
<td>2000</td>
<td>911</td>
<td>622</td>
</tr>
<tr>
<td>2001</td>
<td>1,533</td>
<td>1,391</td>
</tr>
<tr>
<td>2002</td>
<td>1,595</td>
<td>1,691</td>
</tr>
<tr>
<td>2003</td>
<td>1,712</td>
<td>1,744</td>
</tr>
<tr>
<td>2004</td>
<td>1,672</td>
<td>1,550</td>
</tr>
<tr>
<td>2005</td>
<td>1,672</td>
<td>1,389</td>
</tr>
<tr>
<td>2006</td>
<td>1,462</td>
<td>1,130</td>
</tr>
<tr>
<td>2007</td>
<td>1,150</td>
<td>1,371</td>
</tr>
<tr>
<td>2008</td>
<td>1,129</td>
<td>1,129</td>
</tr>
<tr>
<td>2009</td>
<td>1,293</td>
<td>1,150</td>
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<tr>
<td>2010</td>
<td>1,550</td>
<td>1,462</td>
</tr>
<tr>
<td>2011</td>
<td>1,672</td>
<td>1,389</td>
</tr>
</tbody>
</table>

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
**OPERATIONAL DATA**

**Cost**

<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>73.574</td>
<td>4,253</td>
<td>17.299</td>
<td>9,60</td>
<td>166,08</td>
<td>166,08</td>
</tr>
<tr>
<td>NGCC</td>
<td>Natural gas</td>
<td>193.062</td>
<td>19,861</td>
<td>9.721</td>
<td>9,60</td>
<td>93,32</td>
<td>93,32</td>
</tr>
<tr>
<td>NGCC + ASU</td>
<td>Natural gas</td>
<td>1,913.372</td>
<td>174,993</td>
<td>10.934</td>
<td>9,60</td>
<td>104,97</td>
<td>104,97</td>
</tr>
<tr>
<td>NGCC + ASU+ Gasifier (by flare)</td>
<td>Natural gas</td>
<td>339.750</td>
<td>33,057</td>
<td>10.278</td>
<td>9,60</td>
<td>98,67</td>
<td>129,96</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td>102.412</td>
<td></td>
<td>3.098</td>
<td>3,35</td>
<td>10,39</td>
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<tr>
<td></td>
<td>Pet coke</td>
<td>255.477</td>
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<td>7.728</td>
<td>2,70</td>
<td>20,91</td>
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<tr>
<td>IGCC</td>
<td>NG auxiliar</td>
<td>221.057</td>
<td>1.160,901</td>
<td>190</td>
<td>9,60</td>
<td>1,83</td>
<td>32,23</td>
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<tr>
<td></td>
<td>Coal</td>
<td>3,493.829</td>
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<td>3.010</td>
<td>3,35</td>
<td>10,09</td>
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<tr>
<td></td>
<td>Pet coke</td>
<td>8,716.378</td>
<td></td>
<td>7.508</td>
<td>2,70</td>
<td>20,31</td>
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</table>

**Note:** Net energy variable costs (average 2011)
6 months accumulated gross IGCC production

50,000 EOH Major Overhaul + 4 weeks delay (inner casing)

75,000 EOH Major Overhaul Air-WN compressor coupling breakdown

No operation. Non-profitable electricity price

100,000 EOH Major Overhaul
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)
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
IGCC Availability in 2011

<table>
<thead>
<tr>
<th></th>
<th>Availability</th>
<th>Planned Outages</th>
<th>Unplanned Outages</th>
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</thead>
<tbody>
<tr>
<td>IGCC</td>
<td>59,2%</td>
<td>21,5%</td>
<td>19,2%</td>
</tr>
<tr>
<td>Gasifier</td>
<td>73,1%</td>
<td>17,8%</td>
<td>9,1%</td>
</tr>
<tr>
<td>Power Block</td>
<td>85,3%</td>
<td>74,9%</td>
<td>5,5%</td>
</tr>
<tr>
<td>ASU</td>
<td>100%</td>
<td>12,8%</td>
<td>1,8%</td>
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</table>
OPERATIONAL DATA

IGCC Availability progression
OPERATIONAL DATA
Unavailability during last 4 years

Production of WN₂: Coupling repair in 2008
Gas Turbine: Major overhaul 100,000 EOH
OPERATIONAL DATA

Unavailability during last 4 years

Dry dedusting & fly ash systems: Installation of new ceramic filters.
OPERATIONAL DATA

Unavailability during last 4 years

Water steam systems: Pipes breakages due to corrosion.
OPERATIONAL DATA

Unavailability during last 4 years

Slags: Two slag blockage in 2011
OPERATIONAL DATA

Unavailability during last 4 years

Gas O₂ production: Issues related to cold box (partial operation) & carrier systems.
IGCC UNAVAILABILITY HOURS PER SYSTEM 2008-2011

Quench gas recirculation: Replacement of quench compressor seals.
OPERATIONAL DATA
Unavailability during last 4 years

Gas wet treatment: Gas leakages due to corrosion.
ELCOGAS IGCC PROJECT GENERAL SCHEDULE

<table>
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<td>Detailed engineering</td>
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<td>Supply main equipment</td>
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<td>Erection Power Block</td>
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<tr>
<td>Commissioning PB with NG</td>
<td></td>
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<tr>
<td>Erection ASU &amp; Gasification</td>
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<tr>
<td>Commissioning ASU &amp; Gasification</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- Cabling, 37 km vs 1290 km
- Auxiliaries, GT
- Coal preparation, KU

LESSONS LEARNT
Project steps. More facts
# LESSONS LEARNT

## Organization. More facts

<table>
<thead>
<tr>
<th>MECHANICAL</th>
<th>ELECTRICAL</th>
<th>I&amp;C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps</td>
<td>Transformers 50</td>
<td>Local instrument 7195</td>
</tr>
<tr>
<td>Compressors &amp; fans</td>
<td>High voltage 6</td>
<td>Local PLC 40</td>
</tr>
<tr>
<td>Conveyors &amp; Screw transporters</td>
<td>6/0.4 KV 44</td>
<td></td>
</tr>
<tr>
<td>Heat exchangers</td>
<td>CCM 400V 21</td>
<td></td>
</tr>
<tr>
<td>Tanks</td>
<td>Motors 617</td>
<td></td>
</tr>
<tr>
<td>VALVES</td>
<td>10.5 KV 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 KV 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>400 V 586</td>
<td></td>
</tr>
<tr>
<td>Manual</td>
<td>km cabling 1290</td>
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<tr>
<td>Act. Motorised</td>
<td>Power &amp; control 920</td>
<td></td>
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<tr>
<td>Act. Pneumatic</td>
<td>Auxiliaries 370</td>
<td></td>
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<tr>
<td>Act. Hydraulic</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>DCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC &amp; PB  BOP  ASU  Gasification TOTAL</td>
</tr>
<tr>
<td>Signals</td>
<td>8547   4385   4774   17648   35354</td>
</tr>
<tr>
<td>Functionals</td>
<td>6390 1220 2501 11273 21384</td>
</tr>
<tr>
<td>Alarms</td>
<td>2666   1135   882    3089   7772</td>
</tr>
<tr>
<td>Electronic boxes</td>
<td>35   9    6     33     83</td>
</tr>
</tbody>
</table>
LESIONS LEARNT
Summary

- Unavailability reasons are not related to IGCC concept but to first generation, without reference, project. Materials selection, redundancies, gas turbine development, logic controls, detailed engineering, …

- Energy Efficiency is the best of existing technology with coal, wastes or biomass in real averages during operation

- Environmental Efficiency is radically far of any existing technology with coal, wastes or biomass in real averages during operation

- To choose the most technologically risky equipment for a commercial scale demonstration project is not a good idea: Worst learning curve and difficult to major changes

- And …. 
LESSONS LEARNT

Improvement of IGCC technology

Technology Demonstration on a commercial scale

First Generation Developed technology

Investment

Extra cost 30 – 50 %

Total production cost

Cost (%)

100%

Year


50%

30%
LESSONS LEARNT
Improvement of IGCC technology

Investment costs at ELCOGAS. Learnt over cost

REGULATORY SUPPORT IS ESSENTIAL IN TECHNOLOGY DEMONSTRATION PROJECT AT COMMERCIAL SCALE

Total production cost
Advantages of this technologies have been proven:
- Lower Environmental Impact than other technologies that use coal (even local coal), biomass or wastes. Ready to the implementation of CCS.
- Extremely competitive variable production cost.
- Wide margin to improve investment, efficiency and availability in next generations
- Sustainable power generation.
- Technological capacity of Spanish and European industry proved and acknowledged.

Real assessment of disadvantages:
- Low availability. Is not true. In first generation all the plants are different and all of them have a availability >60%. In next generation > 85%

BUT IT IS ESSENTIAL THE REGULATORY SUPPORT TO PARTICIPATE IN THE DEVELOPMENT OF SUSTAINABLE POWER GENERATION TECHNOLOGIES AT COMMERCIAL SCALE.
THANK YOU

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