From clean coal power plants to the zero emissions power plants: 10 years of experiences of ENEL

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A New Age for coal with Carbon Capture and Storage (CCS)

Organized by SCI’s Science and Enterprise and Process Engineering Groups
Outline

- Enel’s profile
- Enel’s fuel mix
- Sulcis: Circulating Fluidized Bed Combustor
- Torrevaldaliga: coal power plant
- Improvement of efficiency and emissions of power plants fleet
- ENEL Group: Initiatives on CCS towards zero emissions
- Results in emissions reduction by power plants
- Final remarks
Enel today
An international, integrated energy operator

- Presence in: 40 countries
- Installed capacity: 97,839 MW
- Annual output: 295,7 TWh
- EBITDA: 16,7 bln €
- Customers: 60,5 million
- Employees: 73,702
- CAPEX 2013-2017: €27 billion

Data updated @ 31/12/2012

1st utility in Italy, 2nd largest in Europe by installed capacity
Present throughout the entire electricity and natural gas value chain
Although the importance of renewable energies is increasing both in terms of installed capacity and generated energy, conventional generation will continue to play a key role at least in the next decades.
Power generation systems retrofit
Sulcis 2 CFB on old coal unit (240 MW)

Main project data

- Gross power output (MWe) 350
- Net efficiency 40%
- SH Steam temperature 565°C
- RH Steam temperature 580°C
- Fuel (20% sulcis(♣) 80% south african coal)
- Emission SO2/NOx/Particulate 200(♣)/200/30 (mg/Nm3)
- Ashes to coal mine
- Biomass co-firing system since 2007 (8÷15 %)

- **1° start-up** July 4th 2005
- **Commercial operation** May 2006

(♣) Sulcis coal: 6% S - 17% ash -38% volatile
(♣) SO₂ = 200 mg/Nm³ with 0% of sulcis coal - 400 mg/Nm³ with 20% of sulcis coal
Torrevaldaliga Nord power plant: Enel’s best practice

HIGH EFFICIENCY POWER PLANT

- Net efficiency ~ 45 %
- Superheater steam outlet temperature 604 °C
- Reheater steam outlet temperature 612 °C
- Feedwater and condensate preheater station 7
- Condenser Back pressure 0.042 bar

Yesterday: 4 fuel oil units, 2640 MW
Units shut-down in 2006

Today: 3 coal units, 1980 MW
Commercial operation:
- Unit 4 January 2008
- Unit 3 August 2008
- Unit 2 August 2010
Torrevaldaliga coal power plant

Emission control technology state-of-the-art

**LOW EMISSION FLUE GAS TREATMENT LINE**

**NOx**
- Advanced combustion system
- High dust Selective Catalytic Reduction (SCR)
- Urea to ammonia Plant (Ammogen)

**Particulate**
- Fabric Filter
- Particulate removal efficiency > 99%

**SOx**
- Gas - Gas Heater (GGH) zero-leakage
- Wet Flue Gas DeSOx (FGD) limestone-gypsum
- SOx removal efficiency > 97%

<table>
<thead>
<tr>
<th>Emission Limit</th>
<th>TorreValdaliga</th>
<th>2001/80/CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOx mg/Nm³</td>
<td>≤ 100</td>
<td>≤ 100</td>
</tr>
<tr>
<td>NOx mg/Nm³</td>
<td>≤ 100</td>
<td>≤ 100</td>
</tr>
<tr>
<td>Particulate (mg/Nm³)</td>
<td>≤ 15</td>
<td>≤ 15</td>
</tr>
<tr>
<td>Salts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slurry (limestone + water)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

mg/Nm³: mg of substance per Nm³ of gas
Torrevaldaliga coal power plant

Emission control technology state-of-the-art

<table>
<thead>
<tr>
<th></th>
<th>SO2</th>
<th>NOx</th>
<th>Particulate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>17.7</td>
<td>8.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Reduction</td>
<td>-88%</td>
<td>-61%</td>
<td>-88%</td>
</tr>
</tbody>
</table>

Emissions related to 6,500 operating hours (ktons/year)

- 4 fuel oil units
- 3 coal units

BEST PRACTICE
Improving efficiency and emissions of coal units

Retrofit of the Brindisi Sud power plant

Brindisi Sud PP
4 x 660 MWe PC units

- Opposite fired boilers
- Low-NOx burners + OFA
- Supercritical, once through
- SH outlet temperature 538°C
- RH outlet temperature 540°C
# Improving efficiency and emissions of coal units

**Fabric filters today running in Enel’s Italian fleet**

<table>
<thead>
<tr>
<th>Plant</th>
<th>Capacity (MWe)</th>
<th>FF type</th>
<th>Installation</th>
<th>Supplier</th>
<th>Year</th>
<th>Bag Lenght [m]</th>
<th>Comp.</th>
<th>Emissions guarantees [mg/Nm3] (°)</th>
<th>Expected FF Emiss. in Operation [mg/Nm3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusina 1&amp;2</td>
<td>2 x 160</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>1999</td>
<td>8,5</td>
<td>2</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Genova 6</td>
<td>160</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>2003</td>
<td>9</td>
<td>4</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Sulcis 2 (*)</td>
<td>340</td>
<td>PJ, HP/LV</td>
<td>New (**)</td>
<td>Aster</td>
<td>2005</td>
<td>8,5</td>
<td>16</td>
<td>&lt;25</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Torrevald. 1+3</td>
<td>3 x 660</td>
<td>PJ, HP/LV</td>
<td>New (**)</td>
<td>TMK</td>
<td>2005</td>
<td>8</td>
<td>16</td>
<td>&lt;10</td>
<td>&lt;9</td>
</tr>
<tr>
<td>Brindisi S.# 3&amp;4</td>
<td>2 x 660</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>TMK</td>
<td>2010-12</td>
<td>8</td>
<td>4</td>
<td>&lt;20</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

(*) CFB Boiler  
(**) Over the old ESP foundations  
(°) hourly basis

- “Conversion” means “transformation” from an electrostatic precipitator to a fabric filter by using the existing casing.
- Acronyms: PJ pulse jet; HP/LV high pressure low volume type; TMK Termokimik spa Torrevald.: Torrevaldaliga North power plant.
# Improving efficiency and emissions of coal units

Fabric filters today running in Russia and South America

<table>
<thead>
<tr>
<th>Plant</th>
<th>Country</th>
<th>Capacity (MWe)</th>
<th>FF type</th>
<th>Installation</th>
<th>Supplier</th>
<th>Year</th>
<th>Bag Lenght [m]</th>
<th>Comp.</th>
<th>Emissions guarantees [mg/Nm³]</th>
<th>Expected FF Emiss. in Operation [mg/Nm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOCAMINA II</td>
<td>Chile</td>
<td>350</td>
<td>PJ, HP/LV</td>
<td>New</td>
<td>Slavex</td>
<td>2012</td>
<td>6,5</td>
<td>20</td>
<td>&lt;30</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Reftinskaya 5</td>
<td>Russia</td>
<td>300</td>
<td>PJ, IP/IV</td>
<td>Conversion</td>
<td>ALSTOM</td>
<td>2013</td>
<td>8</td>
<td>4</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Reftinskaya 7</td>
<td>Russia</td>
<td>500</td>
<td>PJ, HP/LV</td>
<td>Conversion</td>
<td>Clyde Bergmann</td>
<td>2014</td>
<td>8,5</td>
<td>16</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Reftinskaya 4</td>
<td>Russia</td>
<td>300</td>
<td>PJ, IP/IV</td>
<td>Conversion</td>
<td>ALSTOM</td>
<td>2015</td>
<td>8</td>
<td>4</td>
<td>&lt;50</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>

(°) Expected date / schedule to be confirmed.

Filters in Russia will be particularly challenging in terms of operation and maintenance considering the very high dust content of the coals (up to 40%).
### Other coal retrofit projects under evaluation

<table>
<thead>
<tr>
<th>Plant</th>
<th>Fuel</th>
<th>Location</th>
<th>Retrofit Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novaky</strong></td>
<td>Lignite</td>
<td>Slovacchia</td>
<td>NOx reduction</td>
</tr>
<tr>
<td>(2x110MWe)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Litoral</strong></td>
<td>Bituminous coal</td>
<td>Spain</td>
<td>NOx reduction</td>
</tr>
<tr>
<td>(2x580MWe)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Alcudia</strong></td>
<td>Antracite</td>
<td>Spain</td>
<td>NOx reduction</td>
</tr>
<tr>
<td>(2x130MWe)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>As Pontes</strong></td>
<td>Bituminous coal</td>
<td>Spain</td>
<td>NOx reduction</td>
</tr>
<tr>
<td>(4x365MWe)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

More than 3000MWe coal fired units under evaluation
ENEL Group: R&D towards zero emissions plants
Carbon Capture & Storage: Experiences matured

ENEL Group, since 2006, decided to take the lead in the development of CCS technologies in coal fired plants.

ENEL Group has developed several projects and pursues the development knowledge of technology options for CCS:

- Post-combustion CCS technology (pilot scale and power units feasibility)
- Oxy-Coal combustion atmospheric technology: (projects in Italy and Spain)
- Oxy-Coal combustion pressurized (Pilot project in Italy)
- Pre-combustion CCS technology: Electric Power from Hydrogen
- Algae cultivation facility to trap combustion gases: Pilot in Spain
- Calcium carbonate looping pilot plant 1.7 Mw (Spain)
- Pre-Feasibility study for application of post combustion capture technologies to coal fired plant in China (SINO-ITALY agreement)
CCS: Post-combustion Carbon Capture technology

CO2 capture pilot plant

Operation: since June 2010
**CCS: Post-combustion Carbon Capture technology**

**CO2 capture pilot plant : R&D activities**

- Operational experience with base solvent (MEA 20%- 30%+ inhibitors)
  - Assessment of the MEA absorption technology: (reliability, environmental impact, power consumption and capture performance)
  - Definition of operating procedures
  - Cost evaluation at different operating conditions for retrofit application.
  - Flue gas composition: CO2 stream and emissions

- Testing of advanced solvents and inhibitors
  - An experimental program to test some advanced solvents and inhibitors has been set up with the aim to reduce power consumption, limit solvent degradation and improve environmental performances.
  - The pilot plant is flexible enough to allow the test of different kind of innovative liquid solvents. Enel is available to discuss with developers the terms for testing them.
## CCS: Post-combustion Carbon Capture technology

**Large scale CCS : Porto Tolle feasibility study**

<table>
<thead>
<tr>
<th>Type of Project</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation</td>
<td>660 MWe</td>
</tr>
<tr>
<td>Primary fuel</td>
<td>Bituminous coal</td>
</tr>
<tr>
<td>Secondary fuel</td>
<td>Biomass</td>
</tr>
<tr>
<td>Power Generation Tech</td>
<td>USC-PC</td>
</tr>
<tr>
<td>% of flue gas treated</td>
<td>40%</td>
</tr>
<tr>
<td>CO₂ Capture Tech</td>
<td>Post Combustion Capture with Amine</td>
</tr>
<tr>
<td>Stored CO₂</td>
<td>1.000.000 ton CO₂/y</td>
</tr>
<tr>
<td>CO₂ Capture rate</td>
<td>90%</td>
</tr>
<tr>
<td>CO₂ Storage solution</td>
<td>Deep saline aquifer</td>
</tr>
<tr>
<td>Storage location</td>
<td>North Adriatic Sea</td>
</tr>
<tr>
<td>CO₂ value chain</td>
<td>Pure storage</td>
</tr>
</tbody>
</table>
## CCS: Post-combustion Carbon Capture technology

**MOST-IMELS –ENEL Cooperation Agreement CCS - CHINA  Phase 1**

<table>
<thead>
<tr>
<th>Power Station Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Plant</strong>:</td>
</tr>
<tr>
<td>TONG CHUAN</td>
</tr>
<tr>
<td><strong>Unit Capacity</strong>:</td>
</tr>
<tr>
<td>2X600MW</td>
</tr>
<tr>
<td><strong>Construction Year</strong>:</td>
</tr>
<tr>
<td>2007-2008</td>
</tr>
<tr>
<td><strong>Total Capacity</strong>:</td>
</tr>
<tr>
<td>1200MWe</td>
</tr>
<tr>
<td><strong>Power plant surface</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel</strong>:</td>
</tr>
<tr>
<td>SHAANXI Coal</td>
</tr>
<tr>
<td><strong>Cycle efficiency</strong>:</td>
</tr>
<tr>
<td>92.5%</td>
</tr>
<tr>
<td><strong>Max load</strong>:</td>
</tr>
<tr>
<td>637 MWe</td>
</tr>
<tr>
<td><strong>Steam Generator</strong>:</td>
</tr>
<tr>
<td>sub-critical</td>
</tr>
<tr>
<td><strong>Steam rate</strong>:</td>
</tr>
<tr>
<td>2070(T/h)</td>
</tr>
<tr>
<td><strong>Steam Pressure(Max)</strong>:</td>
</tr>
<tr>
<td>16.67Mpa</td>
</tr>
<tr>
<td><strong>Steam temperature</strong>:</td>
</tr>
<tr>
<td>538 °C</td>
</tr>
<tr>
<td><strong>Steam Turbine</strong>:</td>
</tr>
<tr>
<td>3 Stages</td>
</tr>
<tr>
<td><strong>Condenser</strong>:</td>
</tr>
<tr>
<td>Air cool</td>
</tr>
</tbody>
</table>
Oxy-Coal combustion atmospheric technology

Livorno 3 MW combustion facility

- 3 MW combustion test facility at Enel’s Livorno labs was modified to oxygen operation
- Oxy-coal atmospheric combustion tests were successfully performed with different flue gas recirculation ratios
- Results of the first experimental campaigns provided elements about feasibility of retrofit and combustion technology
Oxy-Coal combustion pressurized
An Italian technology option for zero-emissions plants

- **The combustion process:** coal combustion with oxygen under pressurized conditions

- **Project objective:** development and demonstration on industrial scale a patented pressurized coal-combustion process with the purpose to make it possible CO2 capture and storage with energy penalties lower than those of other CCS technology options

- **Timing:** started on 2006

- **Status:** Feasibility study and costing for a Zero Emission the demo plant completed

**ITEA:5 MW facility**
Pre-Combustion Carbon Capture Technology

Power from Hydrogen: Zero Emission IGCC

Fuel gasification and hydrogen separation

Hydrogen Fuelled Combined Cycle
Pre-Combustion Carbon Capture Technology

R&D on IGCC-CCS (Puertollano+Fusina)

Puertollano IGCC - Hydrogen ~ CO2

Fusina: Hydrogen fuelled Turbine
ENEL strategy implementation
A continuously growing commitment

Financial commitment for the environmental protection (M€)

Source: ENEL environmental report 2012
Results of ENEL strategy implementation
Emission reduction from 1990 to 2012 – Italian fleet

SPECIFIC EMISSIONS REDUCTION (g/KWh)

- SO\textsubscript{2} - 92%
- NO\textsubscript{x} - 86%
- DUST - 98%

ABSOLUTE EMISSIONS REDUCTION 2000-2012 (%)

- SO\textsubscript{2} - 92%
- NO\textsubscript{x} - 86%
- DUST - 98%
Trend on reducing emissions

Future targets

- **CO₂ (g/kWh)**
  - 2007*: 465 (−15%)
  - 2020: 395

- **SO₂ (g/kWh)**
  - 2010: 0.96 (−10%)
  - 2020: 0.86

- **NOₓ (g/kWh)**
  - 2010: 0.84 (−10%)
  - 2020: 0.76

- **Particulate (g/kWh)**
  - 2010: 0.52 (−50%)
  - 2020: 0.26

* Target set in 2007 being the year before Emission Trading System Phase II (2008-2012)
Final remarks

- ENEL is strongly committed to reduce emissions from fossil fuel power plants pursuing a strategy based on:
  - High efficiency technologies
  - Low NOx combustion systems coupled with SCR (only for coal)
  - FF progressively replacing ESP in coal plants
  - Operational excellence
  - R&D support to improve O&M processes and select BAT
  - Continuous financial commitment
  - R&D towards zero emissions

- The strategy implementation leaded to a massive emission reduction in the last years (-92% SO₂, -86% NOx -98% dust in Italy from 1990 to 2012)

- New projects will be launched in Countries where ENEL operates for further reducing the environmental impact of thermoelectric power plants

- ENEL is available to share lesson learnt and to support whom interested to the best practice on fossil fuel power plants
THE REAL REVOLUTION IS NOT TO CHANGE THE WORLD

RATHER THAN CHANGING THE PLANET,
WE HAVE ALWAYS PREFERRED TO CHANGE OURSELVES