ENEL Post-Combustion CCS Project: From Laboratory Research to Demonstration

Enel has a solid track record in implementing the best technologies to reduce emissions, included CO_2. Its outreach strategy aims at a decarbonised generation park by 2050. Renewables, nuclear and Carbon Capture and Storage (CCS) are the main technologies that Enel desire to implement.

Regarding CCS, Enel is carrying out R&D activities on all principal options that will be available from the short to long terms. The main effort has been concentrated on the post-combustion absorption process using amine-based solvents suitable for retrofit applications and because of the potential to significantly reduce the energy penalty.

To reach the target in this challenging timeframe, Enel decided to investigate all the principal aspects of the new technology. As starting activity, the implementation of a laboratory scale mini-pilot has permitted to investigate ammines degradation and to develop analytical methods to be used both for process control and degradation monitoring.

A large scale pilot plant, 10,000Nm^3/h size, has been constructed as a slip-stream of the Brindisi Sud Coal fired Power Plant. The pilot plant will separate CO_2 from a slip stream, after a pre-treatment stage, in order to test real operating condition. The design of the plant, with high flexibility, and design margin, has been optimised in order to test conventional MEA or commercially available sorbent.

The technology demonstration will follow by installing a CCS system on a USC 660 MWe unit at the Porto Tolle power plant. The post-combustion capture equipment will be designed to treat a flue gas corresponding to a quota equal to the 250 MWe electrical output and to separate about 1 Mt/y of CO_2, which will be transported to an off-shore saline aquifer.

The Porto Tolle Zero Emission project covers the design, procurement and construction of the CCS demonstration plant. In the framework of the project all the detailed studies related to CO_2 transport and to site characterisation will be carried out with the aim of verifying the feasibility of the injection and storage of CO_2 in a safe and detectable manner The project is co-financed by European Union's EEPR (European Energy Program for Recovery): contract awarded in 2009 with a total funding of 100 M€ covering R&D activity, CCS Engineering and geological surveys and injection test of CO_2 in the saline aquifer from July 2009 to July 2014.

The paper will present the results of the commissioning and base line test with MEA 20-30% on pilot plant as well as summary of the Porto Tolle Demonstration project

Il progetto ENEL di cattura e sequestro della CO_2 con tecnologia post-combustione: dalla ricerca di laboratorio al dimostrativo

L'affermazione commerciale delle tecnologie CCS passa attraverso una vasta attività di ricerca e sviluppo, condotta i laboratorio e su banchi sperimentali di taglia "pilota", per arrivare alla fase di "dimostrazione" in scala industriale.
Per raggiungere questo obiettivo, ENEL conduce da diversi anni un articolato programma di ricerca che culminerà nella realizzazione dell'impianto dimostrativo di Porto Tolle.
Una volta realizzato, l'impianto permetterà il trattamento in post-combustione del 40% della portata dei fumi provenienti da un'unità Ultra Super Critica da 660 MWe, ed il suo successivo sequestro off-shore della CO_2 separata

Cristiana La Marca, Angela Mangiaracina, Monia Politi, Giuseppe Sonato, Carlo Tabasso, Matteo Toschi

1. R&D activities

Each section of the CCS chain presents technology challenges, regarding the design or operating issues. In order to reduce the risk related to the implementation of new unproven technology at a commercial scale an intense R&D programme has been lunched to address a technology assessment of the main functional elements of the CCS chain, being the CO_2 capture technology, the CO_2 dense-phase transport and the CO_2 injection.
As the main important topics related to CCU consist in the introduction of new technologies (new solvents, degradation inhibitors,…), in the up-scaling and in the HSE impact, the following activities started:

- prescreening of solvent in a minipilot apparatus and
- the construction and operation of a CO_2 capture pilot plant treating 10.000Nm^3/h of coal-fired unit in Brindisi

other than a the pre-screening of available technology among the most referenced licensors at international level in post-combustion carbon capture.
An intensive experimental testing using MEA at different mass percentages, as well as advanced solvents with degradation inhibitors is in progress in the pilot test rig, allowing to gain knowledge related to capture process amine based, in terms of energy consumptions, emissions and waste production.

1.1. Mini Pilot: 2 Nmc/h

Enel has carried out test on a test rig (Fig. 1) able to process 2 Nm^3/h of gas, operating at the Enel Ricerca Brindisi labs in order to test CO_2 absorption-desorption from simulated flue gas using MEA solutions or other alternative solvents. The evaluation of the impact of the flue gas composition (O2, NOx, SOx) on the absorption solvent capacity and heat chemical stability

Cristiana La Marca, Angela Mangiaracina, Monia Politi, Giuseppe Sonato, Carlo Tabasso, Matteo Toschi
ENEL

FIGURE 1 Test rig operating at The Enel Ricerca Brindisi lab.
Fonte: ENEL

(degradation) on different solvents is in progress. Detailed characterisation of process blow-down have been performed as well as the definition of methodology for emission and waste water characterization.

The experimental apparatus consists of two columns: the absorber, where the gaseous and the liquid phases flow in countercurrent, and the desorber, a heated regenerator column. The absorber column consists of a glass tube (5 cm inner diameter, and 100 cm height) filled with randomly oriented ¼" Raschig ring (70 cm total packed bed height). This column could be also equipped with Mellapak 700Y structured packing or any other packing.

The desorber column consists of a stainless steel tube (5 cm inner diameter) presently filled with randomly oriented ¼" Raschig ring (94 cm packed bed height for the bottom part of the tube below the solution inlet, and 38 cm packed bed height for the upper part of the tube above the solution inlet). The plant is not equipped with a reclaiming section, therefore the duration of the tests is limited to 2 or 3 weeks, the minimum time needed for the degradation reactions to start and develop.

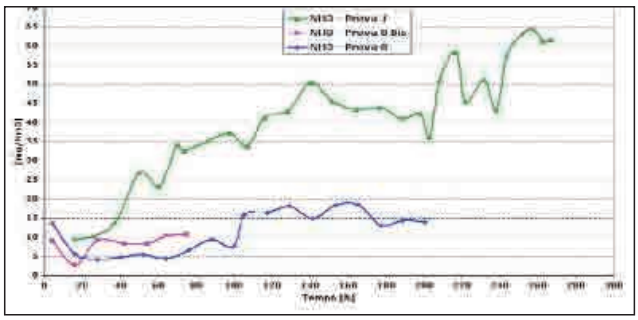

FIGURE 2 Concentration of NH_3 during the tests with different solvents
Fonte: ENEL

Degradation phenomena that occurs with amine solvents and the oxygen or other pollutants are monitoring by means of ammonia and TOC (Total Organic Compound) analysis in the gas out of the absorber and specific analysis of degradation products . The figure 2 shows the concentration of NH3 in the gas at the outlet of the absorber column, during the test of different amine mixtures.

1.2. Pilot: 10.000 Nmc/h

The second step of the research program consists in the design, construction and operation of a capture pilot plant treating 10.000 Nm^3/h (corresponding to 2.5 t/h of CO_2) of the flue gas at Enel's Brindisi coal fired power plant, in order to:

- gain experience in designing, construction and operation of the carbon capture unit;
- assess the environmental impact of the process (solvent and additives handling, waste management, composition of CO_2 stream and emissions).

The basic engineering of the plant has been completed at the end of 2008, and detailed engineering ended in April 2009.

FIGURE 3
Brindisi Pilot Plant
Fonte: ENEL

The permitting procedure for the construction of the pilot was concluded in February 2009.
The realization of the plant has been concluded at the beginning of 2010; the Commissioning has been carried out between May and September 2010 and the testing activities are ongoing.
The pilot plant is fed with desulphurized flue gas taken upstream and downstream the Gas – Gas Heater of the Unit 4, after the existing Wet Flue Gas Desulphurization system (WFGD). In order to be able to match flue gas purity conditions, needed to avoid excessive solvent degradation or other adverse impact on CO_2 capture plant operation, an additional WFGD and a Wet Electrostatic Precipitator (WESP) have been installed on the slip flue gas stream. This pre-treatment permits to control the SO_2 and dust concentrations before the CO_2 absorber inlet.
The WFGD is a standard spray tower scrubber, fed with a 25% w. limestone – water slurry prepared in the power plant FGD system. The WESP is of honeycomb type. To assure saturation condition industrial water is sprayed at WESP inlet.
The pre-treatment plant gives the possibility to partially bypass both the WFGD and the WESP. This allows to evaluate the effect of different pollutant levels on the operation of the CO_2 capture unit. The technology chosen for CO_2 capture utilizes a 20-30% (weight based) mono-ethanolamine aqueous solution to wash the flue gas stream.

1.2.1. Commissioning and baseline tests

The first campaign with the 20% (weight) MEA solvent has been carried out from June to September 2010, during the first campaign has been performed about 500 hours of equipments tests and also parametric tests, in order to match the optimum parameters at different flue gas flow rates.
From the 7th to the 9th of September 2010 has been carried out the performance tests. The pilot plant has been operated continuously for quite 100 hours.
For the performance tests 3 different operation conditions were tested:

- Nominal gas load: 10000 Nm^3/h
- Maximum gas load: 12000 Nm^3/h
- Minimum gas load: 3000 Nm^3/h

Guarantees	U.M.	3.000	10.000	12.000
WET -FGD				
SO_2 capture rate	%		≥95%	
Particulate+liquid entrainment	mg/N mc @ 6% O_2 dry	≤ 25	≤ 25	≤ 25
WET -ESP				
Particulate	mg/N mc @ 6% O_2 dry		≤0,25	
Capture Section				
CO_2 Capture rate - abs	%	≥85%	≥90%	≥85%
MEA out-abs	mg/N mc @ 6% O_2 dry	≤5	≤5	≤5
Liquid Entrainment - abs	mg/N mc @ 6% O_2 dry	≤20	≤20	≤20
NH3 - abs + stripper	mg/N mc @ 6% O_2 dry	≤100	≤100	≤100
CO_2 purity out stripper	%vol	≥99%	≥99%	≥99%

TABLE 1 Guaranteed value
Fonte: ENEL

The operation conditions were changed during the night while during the day the plant conditions were maintained constant. To monitor the performances of the plant a series of manual measurements were done from Enel laboratory:

- Flue gas flow rate at inlet and outlet CO_2 capture plant
- Gas sampling for Lab analysis to monitor guaranteed value
- Liquid sampling to evaluate solvent loading and concentration
- Steam alimented at the reboiler and condensate back to the power plant

In table 1 are reported the guaranteed value for the 3 different plant conditions.

The plant performances are very encouraging: all the guaranteed parameters have were respected except for the liquid entrainment out of the absorber.

In order to validate the process parameters mass and heat balance on the singular element and on the whole plant have been performed.

In particular a comparison between the CO_2 flow rate measured with the on line instrument, the gas balance and the liquid balance has been performed. The figure 4 shows the results of the material balances. The difference between the calculated value and the measured value has a maximum error (gap respect to the measured value) of 5%.

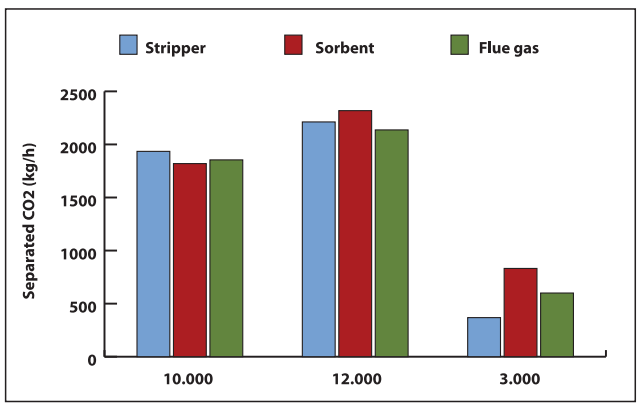

FIGURE 4 Mass balance check
Fonte: ENEL

	U.M	07_09	08_09	09_09
Gas Flow Rate	Nmc/h	10.000	12.000	3.000
CO_2 in abs	% vol dry	12,00	11,5	11,5
CO_2 Capture Rate	%	90	88	98
Solvent Flow rate	mc/h	52	60	25
CO_2 separated (liq)	kg/h	1.830	2.300	800
Reboiler Duty (liq)	Gj/ton CO_2	4,12	4,01	5,06

TABLE 2 Main process parameters and results
Fonte: ENEL

To complete the analysis of the capture section, the evaluation of the steam consumption for the regeneration was performed.

In table 2 are reported the main process parameters and the energy consumption for each operating point.

The tests condition were selected considering an optimization study realized with a numerical model developed in ASPEN Plus.

The specific heat consumption (4,12 GJ/tCO_2) was lower than expected (4,20-4,50 GJ/tCO_2). This difference is due at a good performance of the stripper and excellent recovery of heat in the cross heat exchanger.

1.2.2. MEA 30% tests campaign

The second campaign started the 15th of November. The campaign has been performed with a 30% wt MEA solvent. During the campaign, the parametric tests have been performed in order to find out the optimized operating conditions and to investigate the influence of the different parameters such as:

- Liquid to gas ratio;
- Regeneration Pressure;
- Lean loading;
- Gas flow rate;
- Packing height;
- Capture rate.

During a long-run test (500 h) operation the emission campaign was performed to detect MEA and some of its degradation products (NH3, TOC, VOC,

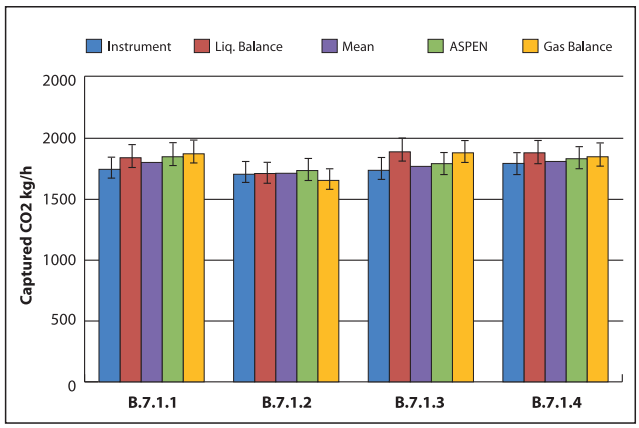

FIGURE 5 Comparison between the measured and the calculated captured CO_2
Fonte: ENEL

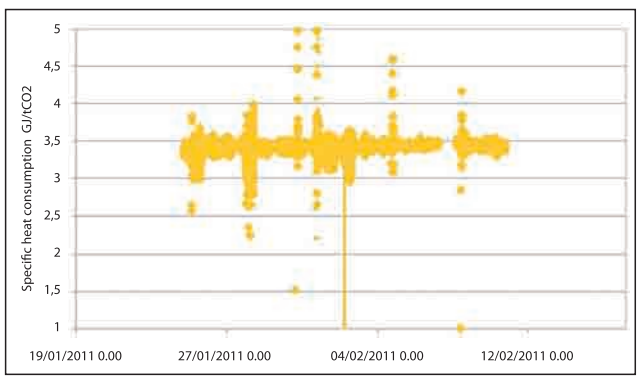

FIGURE 6 Specific heat consumption during the long run test
Fonte: ENEL

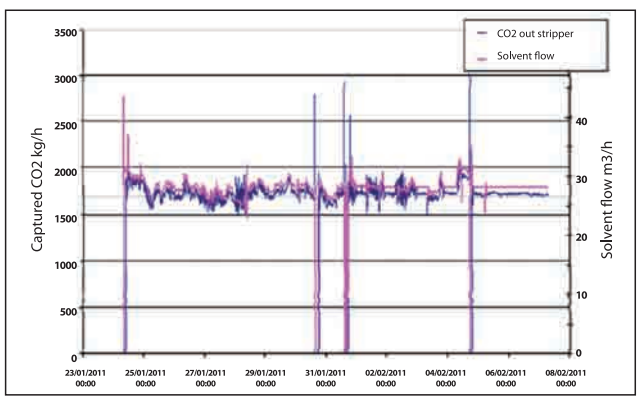

FIGURE 7 Efficiency control: captured CO_2 and solvent flow rate trends
Fonte: ENEL

and aldehydes) out of the absorber and the stripper. Mass balance closure was achieved: Figure 5 reports the comparison of the captured CO_2 measured at the stripper outlet, the one obtained from the liquid balance and the one obtained with ASPEN Plus. Also in this set of tests the results are quite in accordance with an error lower of 5 % respect to the mean value.
The specific heat consumption resulted around 3,45 GJ/tCO_2 (Fig. 6).
In order to keep the capture efficiency constant, during the long run test, a controller on this parameter was implemented. With this controller the solvent flow rate was varied in order to compensate the variation in the inlet conditions in terms of gas flow and CO_2 content.
Figure 7 shows the trend of the captured CO_2 measured at the stripper exit (flow meter) and the trend of the solvent flow rate alimented to the absorber. The two curves are very similar, and the CO_2 trends (blue curve) follow very close the solvent trend (pink curve). The solvent consumption during the period was estimated as 1.5 Kg/tCO_2.

2. Demonstration activities

The demo CCS plant will be installed on a USC 660 MWe unit at the Porto Tolle power plant which will be cofiring coal and biomass. The post-combustion capture equipment will be designed to treat a flue gas flow rate of 0.81 MNm^3/h, corresponding to a quota equal to the 250 MWe electrical output. The design CO_2 capture efficiency on mass basis of the Carbon Capture Unit (CCU) is 90% of the treated flue gas, to produce about 4500 t/day corresponding to approximately 1 Mt/y of CO_2 separated.

2.1 Carbon capture Unit

The CCU plant will be built in Porto Tolle Power Plant located in the area of the Po river south bank (Po di Pila), approx 160 km south of Venice.The Porto Tolle Power Plant, consisting of 4 heavy oil fired units, 660MWe each, will be converted from oil to high efficiency coal firing. The new plant will have a capacity

of about 2000 MW, consisting of 3 USC (Ultra Super Critical) units of 660 MWe; the CCU will be built on the area pertaining to the existing Unit 4, that will be dismantled (Fig. 8).

The demo plant will be able to treat a flue gas flow rate of 0.81 MNm3/h, corresponding to 40% of the flue gas coming out from Unit 3 (660 MWe) and to an equivalent capacity of 250 MWe net. The design CO_2 capture efficiency of the CCU on mass basis is 90% of the treated flue gas, producing about 4500 t/day corresponding to approximately 1 Mt/y of CO_2. In order to indentify the best capture technology Enel has carried out a technical qualification among a set of Companies considered as the most referenced in the field of Carbon Capture Projects worldwide providing process based on amines absorption. In fact, according to the target of demonstrating the CO_2 post-combustion capture on industrial scale by 2015 and provide commercial retrofit solution within the 2020, ENEL decided to select the Porto Tolle CCU technology among the first generation processes, including all the chemical absorption processes with amine solution which have been demonstrated in the oil and gas industry at industrial scale.

Technology suppliers were ranked according to a Scoring Matrix and eventually four of them were selected.

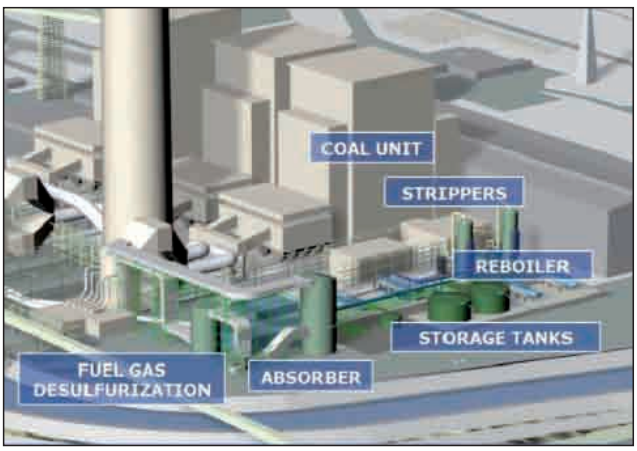

FIGURE 8 Porto Tolle Demo Plant
Fonte: ENEL

These companies have been invited to join Enel Carbon Capture Unit procurement process starting from the development of a FEED (Front End Engineering Design) and leading to a Licence Agreement. The elaboration of the FEEDs are now in progress. The completion of the technology provider selection is foreseen by 2011.

2.2 Compression & Transport

The separated CO_2 from the capture unit will be transported in supercritical conditions via a carbon steel pipeline, from an onshore terminal at Porto Tolle to an offshore injection platform through a subsea pipeline of about 100 km length.

At present an European bid for the FEED activities is ongoing. Subsequently, on and offshore surveys will be carried out to support the FEED development.

During the development of the FEED, the environmental impact and the interference with the existing subsea pipeline will be verified; in addition, in order to optimize the CO_2 transport system, different scenarios will be evaluated with the following main criteria:

- definition of pressures drops along the pipeline;
- pipeline routing;
- pipeline sizing optimization;
- pipeline corrosion study;
- dehydration study to prevent water condensation along the line;
- hydrate analysis and requirements on the compression package;
- cables routing (if any);
- off-shore installation topics.

2.3 Storage site selection and modeling

The study for the identification of suitable CO_2 storage structures in the North Adriatic sea was performed in two steps: a preliminary regional screening based on public data only and a detailed local one.

In this second phase of the study, following the Co-operation Agreement between Eni and Enel, Eni dataset (2D and 3D seismic data) and borehole information were used to provide a new detailed 3D

characterisation of the potential reservoir.
The most promising sites are saline aquifer structure, placed offshore northern Adriatic Sea and corresponding to the more external portion of the buried northern Apennine chain front. Detailed reservoir studies aimed at its characterization are in progress (dynamic flow, geochemical and geomechanical models). The approach includes the improvement at different levels: regional, local and near wellbore.
The dynamic flow simulations are ongoing in order to check on one hand the foreseen rate of injection (about 1 $MtCO_2/y$ for 10 years) and on the other hand the storage capacity. The models have been run to define the injection strategy and the injection pattern, to optimize the storage capacity and forecast the CO_2 plume migration. Moreover the modelling will check the impact of the boundary conditions, petrophysical properties of the reservoir and rock compressibility on the overpressure and on the CO_2 plume extension.
The final selection will be performed on the basis of injectivity evaluation to ensure the safety and integrity of the storage system.
In order to confirm the storage site characteristics in term of capacity, injectivity and containment the realization of an appraisal well and of CO_2 injection tests are foreseen. Technical Specification for the well design and construction are in progress and expected to be completed by the end of 2011. The completion of the CO_2 injection tests is due by mid 2012.
In the meanwhile, activities focused to quantify the baseline conditions, through the assessment of the natural pre-existing CO_2 concentrations and fluxes, and the local biological carbon cycling processes, in order to establish datasets against which operational monitoring data can be compared, are ongoing. This will facilitate dependable monitoring and early warning during the injection phase so that any necessary corrective measures could be taken.
The pre-injection monitoring survey of the selected storage site will be carried out in collaboration with OGS, INGV and RSE.

The off-shore baseline study is covering a ~ 400 km^2 area around the injection locations in water depths ranging from 13 to 40 m. Measurements conducted during this project include chemical, biological and physical analyses of both the water column and the near-surface sediments during four different periods of the year to define the ranges of baseline values in the area, both spatially and temporally.
Moreover additional information on off-shore baseline levels of dissolved CO_2 fluxes at the sediment-water interface in a coastal marine environment will be achieved through marine surveys using benthic chamber.

The evaluation of CO_2 on-shore "baseline" conditions has performed in terms of fluxes and concentration levels in soil gases and shallow aquifers, in order to distinguish natural gas fluxes from potential storage-related leakage. In addition the baseline pre-injection micro-seismicity will be evaluated. ●

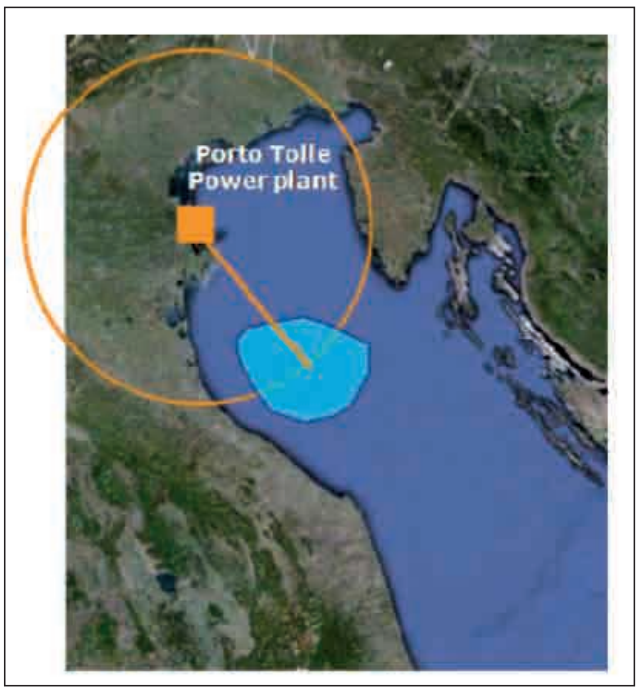

FIGURE 9 Storage Area
Fonte: ENEL