Prospects for coal and clean coal technologies in Italy

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Preface

This report has been produced by IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

IEA Clean Coal Centre is an organisation set up under the auspices of the International Energy Agency (IEA) which was itself founded in 1974 by member countries of the Organisation for Economic Co-operation and Development (OECD). The purpose of the IEA is to explore means by which countries interested in minimising their dependence on imported oil can co-operate. In the field of Research, Development and Demonstration over fifty individual projects have been established in partnership between member countries of the IEA.

IEA Clean Coal Centre began in 1975 and has contracting parties and sponsors from: Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, New Zealand, Poland, Russia, South Africa, Thailand, the UK and the USA. The Service provides information and assessments on all aspects of coal from supply and transport, through markets and end-use technologies, to environmental issues and waste utilisation.

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Abstract

Italy is one of the world's leading economies and a major European industrial player. Despite its on-going economic problems, the industrial sector remains the main driver of the economy. However, the country faces challenges that include poor economic growth and restricted competitiveness. Average electricity prices are higher than elsewhere in the EU – they continue to have a negative impact on the competitiveness of Italian industry. The high prices result largely from a heavy reliance on imported natural gas and highly incentivised renewables for power generation. Italy is one of Europe's biggest energy importers, importing much of its oil, natural gas, coal and electricity. This high level of dependence increases vulnerability in terms of security of supply. It is also expensive; in 2012, energy imports cost €65 billion.

With the aims of achieving a more secure, less expensive, and environmentally sustainable energy supply, and stimulating investment in the energy sector, a *National Energy Strategy* (NES) has been published. As options for diversification of energy sources are limited, this concentrates on the greater use of natural gas and renewables for electricity generation. Both options are likely to keep electricity costs high. Little consideration has been given to the increased use of coal, particularly for power generation. Recent years have seen three major coal-based power projects proposed – for a variety of reasons, none appear likely to proceed. However, a further project for the Sulcis area is currently being developed.

Through substantial investment, during the past decade, emissions of SO_2, NOx and particulates emanating from the coal-fired power sector have decreased significantly. The country now has a number of plants that are cleaner and more efficient than many of their counterparts elsewhere.

A number of Clean Coal Technologies (CCTs) are in use or under active development in Italy. There is also on-going activity in the area of carbon capture and storage (CCS). Significant technological advances have been achieved via projects that have ranged from small-scale RD&D to technology demonstration.

Acronyms and abbreviations

AEEG	Authority for Electricity, Gas and Water (Italian)
ASU	air separation unit
BFBC	bubbling fluidised bed combustion
boe	barrel of oil equivalent (one barrel of oil has the same energy content as 169.9 m^3 of natural gas
BOOS	burner out of service
CBM	coalbed methane
CCC	Clean Coal Centre (IEA)
CCGT	combined cycle gas turbine
CCT	clean coal technology
CCS	carbon capture and storage
CERSE	Committee of Research Experts for the Electricity Sector
CFBC	circulating fluidised bed combustion
CPU	central processing unit
CSLF	Carbon Sequestration Leadership Forum
CSP	concentrated solar power
CTL	coal-to-liquids
CV	calorific value
ECBM	enhanced coalbed methane recovery
EEA	European Economic Area
EERA	European Energy Research Alliance
EEPR	European Energy Programme for Recovery
EGP	ENEL Green Power
EMAS	Eco-management and Audit Scheme
ENCIO	European Network for Advanced USC Component and Integration Optimization
ENEL	Ente Nazional per l'Energia
EOR	enhanced oil recovery
ESP	electrostatic precipitator
ETS	Emissions Trading Scheme (EU)
EU	European Union
FBC	fluidised bed combustion
FEED	front end engineering design
FGD	flue gas desulphurisation
GDP	gross domestic product
GHG	Greenhouse gas
HELE	high efficiency, low emission
HFO	heavy fuel oil
HHI	Herfindahl Hirschmann Index
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
LCA	Life Cycle Assessment
LCPD	Large Combustion Plant Directive
LHV	lower heating value
LNB	low NOx burner
LNG	liquefied natural gas
LULUCF	land use, land-use change and forestry
MCR	maximum continuous rating
MEA	monoethanolamine

MISE	Ministry of Economic Development (Italy)
MIT	Massachusetts Institute of Technology (USA)
MIUR	Ministry of Education, University and Research (Italy)
MPa	Megapascals
MSW	municipal solid waste
Mtoe	million tonnes of oil equivalent
NES	National Energy Strategy (Italy)
NGCC	natural gas combined cycle
NREAP	National Renewable Energy Action Plan (Italy)
OEM	original equipment manufacturer
OGIP	original gas in place
PCC	pulverised coal combustion
PCI	pulverised coal injection
PES	primary energy supply
RDF	refuse derived fuel
RE	renewable energy
RFCS	Research Fund for Coal and Steel (EU)
SC	supercritical
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SNG	synthetic natural gas
TCS	The CO_2 Technology Centre Sulcis
UCTE	Union for the Co-ordination of Transmission of Electricity
UNFCCC	United Nations Framework Convention on Climate Change
USC	ultra-supercritical
US DOE	United States Department of Energy (USA)
ZLD	zero liquid discharge
ZEP	Zero Emissions Platform
ZEPT	Zero Emissions Porto Tolle

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1 Introduction

With a population of nearly 61 million, Italy has the fifth largest population in the European Union (EU). It is ranked amongst the world's leading economies and is a major European industrial player. There are six EU countries with large industrial sectors – around 75% of the EU's industry is concentrated in these six, namely Germany, Italy, France, the UK, Spain and the Netherlands. In Italy, despite the country's on-going economic problems, the industrial sector remains the main driver of the economy. The country has a diverse industrial sector that includes tourism, machinery, iron and steel, chemicals, food processing, textiles, motor vehicles, clothing, and heavy engineering. Italian industry employs more than 30% of the working population and accounts for 25% of the Gross Domestic Product (GDP) (SEMI Italia, 2014). However, it faces challenges that include poor economic growth and restricted competitiveness. The latter is hampered by high electricity costs that result largely from a heavy reliance on imported natural gas and highly incentivised renewables.

Italy is one of Europe's biggest energy importers, relying on imports to meet a significant proportion of its energy requirement. It imports much of its oil, natural gas and coal, and also brings in electricity from other countries. This high level of dependency increases the country's vulnerability in terms of security of supply. In recent years, this has been threatened on a number of occasions; for instance, at times, there have been problems in maintaining gas and oil supplies from Libya and Algeria (EIA, 2013). More recently, concerns over the security of gas supply have increased as a result of the on-going unrest in Ukraine – much of Italy's natural gas comes from Russia (at a cost of ~€30 billion a year) via Ukraine. Clearly, if this supply was curtailed, the impact on the Italian energy sector would be profound (Rowland, 2014). Compared to northern European countries, the current energy mix makes the Italian economy more exposed to the global geopolitical instabilities of the oil- and gas-producing countries (Cammi and Assanelli, 2012).

This heavy dependence on imported energy is also expensive. In 2011, the energy bill amounted to ~€62 billion. For many years, this has kept the trade balance deeply in the red (NES, 2013). In 2012, it reached a new high, at €65 billion. This equates to 4.2% of GDP – a decade earlier, it was around 1.5%. High energy costs continue to have a negative impact on the competitiveness of Italian industry (Euracoal, 2013). Average electricity prices are considerably higher than elsewhere in the EU. Thus, the Italian economy faces major challenges that include the high cost of imported fuels/energy, and the associated issues of security of supply. Inevitably, high electricity prices impact on the competitiveness of the industrial sector. For more than a decade, the economy has seen only limited growth and it remains unclear when the recovery will gather momentum. The government intends that the industrial and manufacturing sector will maintain a central role in the Italian economy. At the moment, the main priority is to achieve sustainable growth, but this can only take place if the competitiveness of the Italian economic system improves (NES, 2013).

The possibility of introducing nuclear generating capacity was rejected by a referendum in 2011. Partially in response to this, the Italian government announced a *National Energy Strategy* (NES). This was approved in March 2013. It aims to achieve a more secure, less expensive, and environmentally sustainable energy supply, and to stimulate investment in the energy sector (Europa, 2013). As options for diversification of energy sources are limited, the NES concentrates on the greater use of natural gas and renewables for electricity generation. Both options are likely to keep electricity costs high. Little consideration has been given to the increased use of coal, particularly for power generation.

At the moment, there are a number of factors that help keep up the price of Italy's electricity and hinder its economic competitiveness:

- the energy mix for electricity is relatively expensive as it is based mainly on imported natural gas and renewables. As it lacks nuclear power and coal makes only a modest contribution, it is significantly different to the average EU mix;
- average wholesale gas prices are higher than in other European countries. As much of Italy's electricity is generated by gas-fired power plants, this is reflected in the price of electricity. More than 80% of the country's energy needs are covered by imports. Hence, there are also concerns over security and independence of energy supply. The average for the EU 28 is 53%. Furthermore, gas supply is limited to a relatively small number of sources;
- some generators are operating in difficult economic conditions or are facing market transition. Most notably, there is over-capacity in the CCGT sector. This has resulted from a combination of decreased demand, the start-up of ~20 GW of new CCGT capacity (between 2005 to 2011), and increased production from renewables; and
- Italy has the highest incentives in Europe for renewables production. This accounts for more than 20% of the average electricity bill.

As the economy continues to struggle, there have been calls for the greater use of coal (Power Engineering International, 2012). During the past few years there have been three major coal-fired power projects proposed (Vado Ligure, Porto Tolle and Saline Joniche – *see* Section 6.3.1). At an investment of at least €5.5 billion, these would have added around 4.4 GW of capacity to the Italian grid. However, for different reasons, none of these are now expected to proceed. Assocarboni and other industry observers have suggested that Italy should look to coal in order to diversify its energy mix and combat 'uncompetitive and no longer sustainable' electricity prices (Platts, 2013). Largely as a result of the country's growing reliance on renewables coupled with imported natural gas, Italian companies currently face electricity prices that are up to 50% higher than the European average. There have been suggestions that the country should reduce its reliance on imported gas, and pursue a policy based on the greater use of coal and renewables, an option that has been adopted by other European countries such as the UK, Germany, Spain and Turkey. In 2013, all increased the proportion of coal in their respective energy mixes.

The rapid growth of renewables is not going hand-in-hand with the development of the transmission system – it is now of strategic concern to further develop this (particularly in southern regions) in order to avoid bottlenecks and facilitate power flows. National connections reinforcement, especially between the North and the South, would allow for a better use of the installed capacity. This scenario is not encouraging in terms of electricity costs for end-users. Inevitably, the further development of both renewables and of the transmission/distribution network will be costly and is likely to impact on electricity bills (Cammi and Assanelli, 2012).

2 The Italian energy sector

In the period up to 2030, Italy is expected to remain heavily dependent on fossil fuels. In 2010, about 86% of the country's energy requirement was met by fossil fuels, mainly oil (41%) and gas (37%). The country has some fossil fuel resources – for example, proved oil reserves are ~1.4 billion barrels. However, in 2013, domestic oil production amounted to only 5.6 Mt, whereas consumption was 61.8 Mt. Proved reserves of natural gas amount to ~0.1 trillion m^3. In 2013, domestic production was 7.1 billion m^3 (6.4 Mtoe), whereas consumption was 64.3 billion m^3 (57.8 Mtoe). Imported gas comes mainly from The Netherlands, Norway, Russia, Algeria, and Libya. In 2013, 51.6 billion m^3 was delivered via pipeline (BP, 2014). The Italian *National Energy Strategy* (NES – *see* Section 3) estimates that the country's potential hydrocarbon reserves amount to 700 Mtoe. However, as exploration has been at a low level for the past decade, actual levels could be higher (NES, 2013). Energy is also produced by a number of renewables-based technologies, and there is also a small amount of (subbituminous) coal production (discussed further in Section 4.1).

Italy is therefore heavily dependent on imported sources of energy. The country's import dependence is amongst the highest in the EU. The rate of dependency has been fairly constant over the past decade. In 2010, it was 84% (Europa, 2013), and in 2012, it was 81% (Statista, 2014). At 53%, the average figure for EU 28 states is significantly lower. Only four other EU countries have higher levels of dependency.

In terms of electricity generation, more than half of the country's electricity is produced using imported fuels; this makes Italy one of the EU countries most reliant on imported natural gas (Euracoal, nd). This situation seems likely to prevail for some time and will continue to impact on the national trade balance – for some years, the rising cost of energy imports has kept this in the red. The resultant high electricity prices remain an on-going problem, particularly for Italy's energy-intensive industries.

Italy's energy mix is considered to be reasonably diverse. However, as the country has no nuclear generating capacity, and as nuclear power has been ruled out for the foreseeable future, the shares of oil and gas are higher than the EU average. It also has very little indigenous coal production.

2.1 Oil

Oil is major source of energy in Italy. Its share in the energy mix is consistently higher than the EU average. However, consumption has been steadily decreasing over the last decade and its share in the energy mix has fallen from nearly 50% to ~40%.

The country has the fifth largest proved reserves of crude oil in Europe and Eurasia, after Russia, Azerbaijan, Kazakhstan, Turkmenistan, and the UK. At the end of 2013, proved reserves totalled 1.4 billion barrels (0.2 thousand Mt) (BP, 2014). Oil extraction started in Italy during the 1960s. Since the 1980s, domestic production of crude oil has remained almost constant – it now fluctuates between 5 and 6 Mt/y. Production is currently at its highest level since 2007. However, during the previous decade, overall consumption has decreased considerably (Figure 1).

Figure 1 Italian oil production and consumption (BP, 2014)

Eni is the major player in the sector, accounting for >50% of total crude oil production. Despite this indigenous supply, the country relies on imports for more than 90% of its oil, a level higher than the EU average. Italy is one of Europe's largest oil importers. Supplies come from a number of sources although more than 90% of oil and petroleum products come from non-European Economic Area (EEA) countries. Most crude oil comes from Libya, Azerbaijan, Saudi Arabia and Russia. In 2013, the country imported 1884 Mbbl/d of crude oil and refined petroleum products.

Historically, alongside oil-fired power generation, several Italian power plants were modified to fire Orimulsion (Table 1). This is a naturally occurring bitumen (70%) mixed with water (30%) and stabilised with a surfactant. It is marketed by the National Oil Company of Venezuela. Overall, more than 300 Mt was used in Italian plants. However, units have since been converted to other forms of firing – for instance, in 2004, the Fiume Santo plant was converted to coal firing.

Table 1 Orimulsion firing in Italian power plants

Power plant	Capacity (MW)	Fuel(s)
Brindisi Sud	4 x 660	Coal, heavy fuel oil, Orimulsion
Fiume Santo	2 x 320	Coal, heavy fuel oil, Orimulsion
S Filippo Del Mela	2 x 320	Heavy fuel oil, Orimulsion

2.2 Natural gas

Italy has the sixth-largest proved natural gas reserves in Europe (0.1 trillion m^3). However, over the past decade, production has generally followed a downward trend (Figure 2). From a peak in 2005, consumption has also declined, a reflection of the economic downturn and Europe's monetary problems.

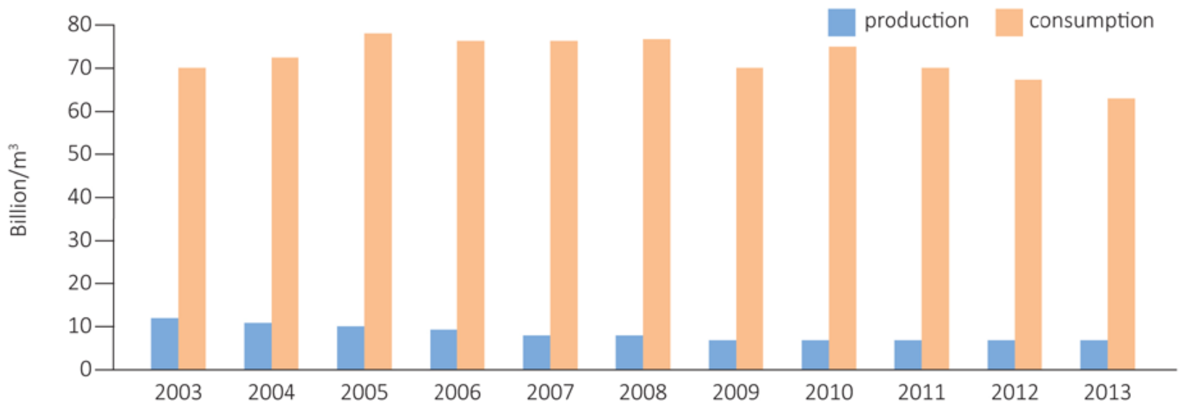

Figure 2 Italian natural gas production and consumption (BP, 2014)

Much of Italy's gas demand is met by imports, the bulk of which are supplied by pipeline. In 2013, 8.6 billion m^3 came from The Netherlands, 1.1 from Norway, 0.3 from other European sources, 24.9 from Russia, 11.4 from Algeria, and 5.2 from Libya (a total of 51.6 billion m^3). Gas from Algeria and Libya is imported via the Trans-Mediterranean (Enrico Mattei) and Greenstream pipelines respectively. Italy's imported gas sources are considered to be relatively diversified: the Herfindahl Hirschmann Index (HHI) for gas is the third lowest in the EU after Spain and France (a high HHI implies a supply dependent on a few large suppliers, whereas a low one indicates it comes from a larger number of smaller suppliers).

Much of the imported gas is directed to thermal power plants. In a typical year, around 46% of Italy's electricity is generated by gas-fired plants. This is a major factor in making the country one of the EU member states most dependent on imported gas; it has clear cost and security of supply implications. Italy currently has surplus combined cycle gas turbine (CCGT) generating capacity. As in a number of other European countries, some gas-fired plants face increasingly limited operating hours as the growing level of intermittent renewables forces conventional thermal plants into a grid-balancing role. This has an impact on profitability and also raises technical issues associated with frequent plant cycling.

Not all of Italy's gas comes via pipeline as some is also imported in the form of liquefied natural gas (LNG). In 2013, this amounted to 5.5 billion m^3. Of this total, 5.2 came from Qatar, with the balance from various European sources. There are several major LNG regasification terminals in operation: these are the Adriatic (the biggest), OLT, and Panigaglia terminals. Currently, these are under-utilised although throughput could be increased if needed. At least three more terminals are planned to come into operation within the next few years.

The Adriatic LNG Terminal is located in the northern Adriatic Sea, offshore from Porto Levante. At full capacity this is capable of delivering 8 billion m^3/y of gas. At the moment, some 80% of the terminal's capacity is utilised (by Edison for 25 years) to re-gasify LNG from Qatar's North Field. The OLT Terminal is located offshore of Toscana. This floating re-gasification unit is connected to the national network via a 36 km pipeline and has a re-gasification capacity of 3.75 billion m^3/y. The unit began commercial operations at the end of 2013. The Panigaglia plant is operated by GNL Italia and located near La Spezia. This has a re-gasification capacity of 3.5 billion m^3/y. It was Italy's first re-gasification plant, beginning commercial operations in 1971.

It has been suggested that Italy's gas import level will continue to rise for the foreseeable future, and that LNG could play a major role in this process (Cammi and Assanelli, 2012). However, there are indications that at some point in the future, the cost of LNG could increase significantly as greater volumes are directed to Asia. For example, in July 2015, Mitsubishi Heavy Industries received an EPC (engineering, procurement and construction) order from Indian Oil Corporation Ltd, India's largest oil company, to construct two LNG storage tanks. These will be the main facility at the first LNG receiving terminal to be constructed on India's east coast and could signal the start of significant LNG imports via this route.

2.2.1 Possible future developments in the oil and gas sector

Italy has aspirations to create a gas hub system in Southern Europe, turning it into both a consumer and gas transit country and helping it play a strategic role as Mediterranean Europe's gas hub – its geographical location is favourable for such an undertaking.

There are a number of on-going efforts aimed at developing and exploiting additional sources of gas. Understandably, as Italy's main gas provider, Eni (with gas sales of 95.32 billion m^3 in 2012) is active in this area. The company operates internationally and is heavily involved with the development of oil and gas resources in Kazakhstan, where it operates partially the Karachaganak field. It is also an equity partner in several areas of the north Caspian Sea that include the large Kashagan oil field. The latter was discovered in 2000 and holds estimated reserves of 38 billion barrels – production is expected to reach 1.5 million barrels per day. Since 2009, the development of Kashagan (one of the world's largest gas and condensate fields) and other fields on the Caspian shelf has been conducted by seven companies that include Eni (16.81% holding). Since the early 1990s, Eni has been active in the region and was one of the first international oil and gas companies to become established in Kazakhstan. In 2012 company operations in the country accounted for 6% of its total worldwide production of oil and natural gas. In recent developments, Eni has reinforced its ties with the country via a new deal with Kazakhstan's KazMumayGas (KMG) for joint (50% each) offshore exploration and production in Kazakh waters (Natural Gas Europe, 2014). Italy is the largest recipient of Kazakh oil and gas condensate. Annually, nearly 70 Mt of crude oil is exported from Kazakhstan, a quarter of which is directed to Italy.

Recently, as Algerian imports have declined and Libyan supplies become limited as a result of the unrest within that country, Italy has become increasingly dependent on Russian gas. This has prompted the country to look at other potential suppliers. Further unrest in Ukraine, a major transit route for Russian gas into Italy and the wider EU, has increased fears over security of supply. On several occasions, Russia has threated to cut off supplies to Ukraine. However, the Italian government has claimed that if supplies were disrupted, the country could respond quickly by increasing gas imports from Algeria, Libya and the Netherlands.

As noted, the Italian government has proposed making the country a southern European gas hub, capable of transiting African supplies into Europe. Italy aspires to become a landing point for new pipelines from Azerbaijan, the east Mediterranean, and Algeria, as well as a hub for ocean-going LNG tankers. The NES addresses the gas hub possibility, noting that over the next 20 years, Europe will significantly increase its level of gas imports (by about 190 billion m^3). This could present an opportunity for Italy to become an important crossroads for the entry of gas to Europe from the South. The NES suggests that this would reduce prices in Italy and improve security of supply (NES, 2013). Lower electricity prices would be particularly beneficial to Italian industry.

Thus, there are several major developments that could impact on future Italian gas supplies (Euractiv, 2014). These include:

- Completion of new pipelines. These include the Trans Adriatic Pipeline (TAP) that will bring gas from Azerbaijan to Italy, the Trans-Anatolian Gas Pipeline (TANAP), and the Eastern Mediterranean pipeline. The latter is an ambitious project to transport gas from Israel and Cyprus (from the Leviathan gas field) to Europe (Lamaro, 2014). BP is leading a consortium that is developing Shah Deniz 2, a huge natural gas field in the Caspian Sea. Its gas will be shipped through a southern gas corridor via TAP and TANAP.
- Development of the South Stream project, intended to transport Russian gas bypassing Ukraine. However, it now appears that the pipeline will terminate in Austria and not Italy, as previously hoped.
- Development of the 830 km long GALSI gas pipeline that would allow the transportation of 8 billion m^3 of gas/y from Algeria to Italy. Around 560 km would be offshore and 260 km onshore (Sardinia). The project has been promoted by a consortium that includes Sonatrach, Edison, Enel Produzione, SFIRS (owned by the Sardinia region), and Hera Group. However, the project is currently suspended.
- There is also the possibility of increasing imports of liquefied natural gas (LNG). The country has three major re-gasification terminals that have unused capacity.

Clearly, the development and operation of several of the above projects would reduce Italy's need for Russian gas. However, Russia's Gazprom is trying to convince Italy to continue taking Russian supplies through offers of cheaper gas. Suitably discounted prices could effectively lock out rival supplies from North Africa and the Caspian Sea, as well as shipped LNG. Prices were recently cut on Russian gas supplied to Eni – in May 2014, Gazprom granted Eni its first gas supply deal not indexed to oil prices.

Italy has traditionally taken around a third of its gas supplies from Russia, but with Algerian volumes reduced and Libyan supplies vulnerable because of conflict, Russian flows now account for around half of Italy's daily imports. Gazprom's re-pricing strategy threatens to render unprofitable Italian plans to become a landing point for new pipelines as well as develop as a southern European gas hub. Plans to expand gas pipeline links between Algeria and Italy have also stalled, as have efforts to link up with major gas finds in the eastern Mediterranean. Clearly, a continuation of this high level of dependence on Russian gas would do little to allay fears over possible issues of security of supply. The Gazprom deal gives Eni the opportunity to import more Russian gas and displace costlier supplies from rival sources. This is likely to maintain Russian gas imports at a high level. However, it could pose some risks given that Russian gas supplied to Italy has to transit Ukraine (Vukmanovic and Jewkes, 2014).

2.3 Renewable energy

Recent years have seen a significant growth in electricity generated from renewable sources. This has been fuelled strongly by generous incentives. However, these have generated considerable costs for the system and pushed up electricity bills. In particular, there has been a sizable increase in the amount of PV capacity added – since 2010 this has increased from 13 GW to nearly 18 GW. Incentives have played a large part in this; in 2012, incentives per unit were double or triple the levels in Germany and France. Those for wind were ~50% higher. Such incentives usually have a lifetime of 15–20 years. This has resulted in significant costs amounting to more than €10 billion/y on consumers' energy bills (>20% of the typical Italian electricity bill). However, in January 2015, it was announced that the government was planning to scrap incentives to solar power producers. A decree on renewable energy incentives for the next three years (due February 2015) is being produced – solar power will be excluded from this. The government considers that there is no longer a need to offer support to solar plants. New rules introduced in 2010 greatly increased subsidies – these rose from €750 million in 2010 to €3.8 billion in 2011 and €6.7 billion in 2013. It is not yet clear how the recent moves will affect some existing subsidy arrangements. Currently, there is a total incentives commitment of ~€170 billion (NES, 2013).

The present system of incentives is highly complex and has resulted partly as a result of different regulatory frameworks introduced over successive years. Various types of incentives have been superimposed and laws concerning single tariffs changed. This has altered the value of individual incentives, as well as the procedures necessary to access them (Cammi and Assanelli, 2012).

A range of renewables-based energy production systems is deployed in Italy (large and small hydro, wind, solar, geothermal, and biomass). Certain geographical areas favour some types – for example, wind power capacity is more concentrated in the south of the country. This raises concerns about grid stability as the increasing amount of electricity coming from intermittent non-programmable sources (primarily wind and solar) is becoming a challenge for the network infrastructure. Discontinuous production from renewables is concentrated in the south and centre-south of the country, and on the islands – this concentration may become even more pronounced in the future. By 2016, the electricity generated in this macro-region is expected to exceed the local peak demand. Demand is higher in northern Italy, so the existing transmission infrastructure linking the north and south of the country will require upgrading.

A high dependency on intermittent sources can create a number of problems. The most obvious is that because of this intermittency, electricity production may not correspond with periods of demand. Clearly, wind power only works when adequate wind is available. Solar power stops working at night. Other systems such as fossil fuelled plants must be available to take over generation as intermittent output drops.

Most major wind and solar facilities do not operate in isolation. Generally, they feed electricity into existing power grids or networks. Often, such grids are fed by a variety of different types of power plant – there may be various combinations of coal- and gas-fired power plants, some hydro, and possibly nuclear. The grid make-up and ratio between plant types is never the same – these factors differ from country to country, based on the local circumstances. On the face of it, the addition of a large amount of wind power into a grid, for example, can only be a positive development. However, a large input from intermittent sources into existing power systems can upset grid stability and have major impacts, particularly on the operation of thermal power plants within the system (Mills, 2011; Mills 2013).

For more than a decade, the use of renewables in Italy has increased steadily. In 2004, these provided 5.7% of total primary energy supply (PES) (Eurostat, 2014). In 2011, Italy's PES amounted to 7114 PJ – renewables provided 834.9 PJ of this (11.7%) (IRENA, 2013). In 2012, the share of renewables in (gross, final) energy consumption was 13.5%. The growth in renewables over recent years is shown in Figure 3. Total Italian consumption in 2013 was 158.8 Mtoe.

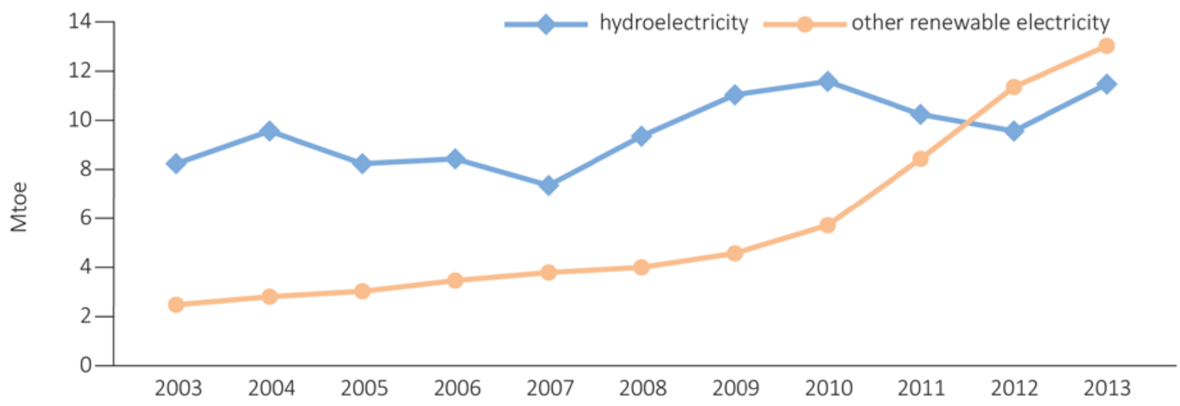

Figure 3 The growth of renewables (2003–13) (Mtoe) (BP, 2014)

At the moment, the share of renewables in the Italian energy mix is roughly in line with the EU average. Within the Italian *National Renewable Energy Action Plan* (NREAP) there is a binding target (stipulated in the EU Renewables Directive) of achieving a total share of renewable energies of 17% by 2020. This will include 39% in electricity generation, 17% in heating/cooling, and 14% in the transport sector (Europa, 2013). However, in order to meet these targets, it may prove necessary for the country to import renewable energy (Kovalyova, 2010).

There are a significant number of new renewables-based projects being developed (IRENA, 2013). These include:

- 78 MWe and 8 MW (thermal input) of biomass-fired capacity addition (5 projects)
- 40 MW of new geothermal capacity addition (1 project)
- 380 Ml/y of biodiesel capacity addition
- 254 Ml/y of bioethanol capacity addition
- ~900 MW of solar PV capacity addition (73 projects)

- 131 MW of solar thermal capacity addition (4 projects)
- ~2.45 GW of wind capacity addition

In terms of **electricity production**, renewables typically contribute between 25 and 29%. In 2011, hydro was responsible for 16%, with other renewables and wastes at 13% (total 29%) (Euracoal, 2013). However, on occasions, levels have been higher – at various points in 2013 and 2014, they reached between 39 and 49% (Qual Energy, 2014). In the latter case, a significant proportion was provided by hydro, still the country's most important renewable resource. In 2011, Italy's electricity generation amounted to 300.6 TWh – renewables accounted for 83 TWh of this (27.6%) (IRENA, 2013). 2012 saw further increases in the use of renewables for electricity generation, with the combined total of bioenergy, hydro, wind and solar increasing by 11.2% (TERNA, 2013). Between 2010 and 2012, wind power rose to 13.4 GWh (up 36.4%), and capacity increased from 5.8 to 7.97 GW. In 2012, net solar energy production reached 18.6 GWh (up 74.7%) (Figure 4).

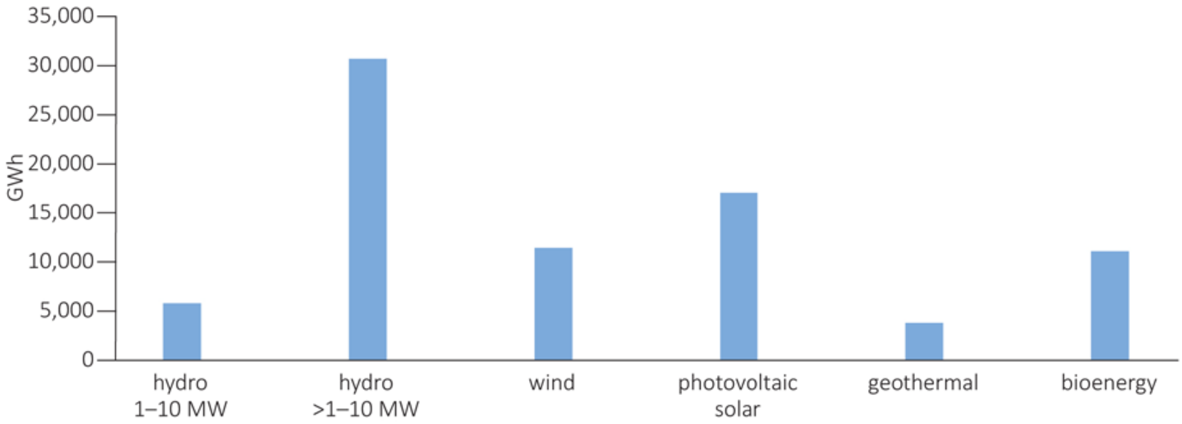

Figure 4 Renewable energy production (end 2012) (TERNA, 2013)

Recent years have seen a significant increase in the amount of solar power deployed. Output has risen from virtually zero in 2007, to 10.7 TWh in 2011. During the latter year, driven by lower equipment prices and generous incentives, the level of solar PV increased fivefold, reaching 12.8 GW (the global total was ~70 GW). Between 2010 and 2012, the number of individual PV installations increased to more than 478,000. In 2012, solar PV increased by 28.6% over the 2011 level (TERNA, 2013). But 2013 witnessed a slowdown in the market. The cancelling of further incentives in 2015 will also have an impact. In February 2015, it was announced that E.On had sold its Italian solar business to the private infrastructure investment fund manager F2i SGR. The sale comprised 49 MW of facilities built between 2010 and 2013. About 70% of the capacity is in Sardinia.

In 2012, renewables accounted for 27% of gross electricity consumption of 336 TWh; this mainly comprised 13.9 TWh from wind and 18.8 TWh from solar (Raizada, 2013). Italy has become the fifth largest in the world for electricity production capacity based on renewable sources (excluding hydropower).

The Italian government anticipates that in the future, renewables will play an even greater role in electricity generation. The various incentive mechanisms applied have been instrumental in attracting investment – in 2011, US$ 29 billion was invested in renewables. As noted, Italy has a complex system of incentives for renewable energy generated from solar, wind and biomass. Of particular note is a Ministerial Decree (July 2012) that introduced the *Fifth Energy Incentives Plan*. This revised the incentives system for producing electricity from PV facilities – in 2011, financial support to solar power projects was estimated at €5 billion. Simultaneously, new procedures were established aimed at supporting the production of electricity from other forms of renewables (of capacity >1 kW). At this time, the levels of support for solar, wind and biomass remained some of the highest in Europe, significantly above the average production costs (Europa, 2013). Support measures included a feed-in premium mechanism for solar power, tradable feed-in tariffs for small installations, green certificates, and tax rebates. The country's support scheme for renewables feeds through to the end-user, accounting for a significant part of the consumer's final bill. However, more recently, on several occasions, incentives for solar power have been reduced. The most recent development came mid-2014, with the announcement that the Italian government intended to reduce feed-in tariffs. The main aim is to reduce energy costs for mid-sized companies (Gehle, 2014).

Alongside wind and solar, the other renewable of increasing significance is biomass. At the moment, the share of biomass in the Italian energy mix is lower than in many other European countries. However, it is becoming larger. Biomass is used or proposed for a growing number of power generation projects (both alone and co-combusted). Over the previous decade, the number of biomass-only plants has grown at an average of more than 10%/y and average plant size has increased from ~3 MW to 5 MW. More than half of such installations are in Lombardy, Emilia Romagna and Campania. The amount of biomass theoretically exploitable in Italy is considerable. Estimates (2010 data) are shown in Table 2. In that year, there were nearly 70 biomass power plants operating. These needed nearly 4 Mt/y of solid biomass, represented mainly by woodchips and round-wood sourced from the management of domestic forests. However, imports (of palm kernels, shells, olive cake, and woodchips) also provided a portion of this (Cocchi, 2012).

Table 2 Estimated theoretical exploitable biomass (Cocchi, 2012 – citing ENEA data)

Material	Potentially available amount (kt/y)
Straw	15,710
Prunings	4906
Olive and grape residues	1320
Forest wood	2181

At the moment, Italy is the world's fastest growing market for wood pellets, used mainly for domestic and commercial heating. In 2013, pellet consumption reached 3.29 Mt. The biggest pellet suppliers are Austria, parts of Eastern Europe, and several EU counties such as Germany (Wood Pellet Association of Canada, 2014). Demand has been increasing at the rate of 400 kt/y. Most is imported. Italian production is

~55 kt/y – this remains limited because of competition for fibre by the panel-board industry and other biomass users. However, recent government policies aimed at supporting the use of local feedstocks may restrict future increases in the level of imports.

Italy's total installed biomass-based electricity generating capacity is now >2 GW. The most widely used feedstocks comprise MSW and solid biomass (ENEL, 2010). Examples of larger biomass-fired power/cogeneration plants are shown in Table 3. The Italian NREAP predicts that biomass use for electricity generation will increase, rising from 12% of renewables-based production in 2010, to 19% in 2020.

Table 3 Examples of larger biomass-fired power/cogeneration plants

Plant	Capacity (MWe)	Fuel(s)	Status
BiOlevano	18.5	Wood (up to 200 kt/y)	Start-up 2012. Supplies ~140 GWh/y
Crotone	2 x 10	Wood chips from forestry waste + other biomass (250 kt/y)	Start-up 2001
Cutro	16.5	Wood	Start-up 2003
Enna	18.7	Wood (eucalyptus)	Start-up 2013. Supplies ~128 GWh/y
San Marco	2 x 10	Wood, biomass (between 230 and 280 kt/y from dedicated energy crops and forestry wastes	Start-up 2002. Supplies ~160 GWh/y
Strongoli	40	Wood, biomass (~450 kt/y)	Start-up 2003. Some biomass imported via Corigliano Calabro and Crotone
Terni	10	Wood (~100 kt/y), RDF (250–300 t/d)	Start-up 2002. Supplies ~71 GWh/y
Fusine	5.7	Wood chips (~55 kt/y) + compressed sawdust	Start-up 2010
Zignago	17.9	Forestry wood, clean wood residues, agricultural waste (straw, miscanthus, maize)	Cogeneration plant – 4.5 MW for district heat
Brescia	70	MSW and biomass (~800 kt/y treated waste comprising ~275 kt/y biomass)	Cogeneration plant – 150 MWth for district heat. Produces 570 GWh/y electricity plus 568 GWh/y heat
Enna, Sicily	18.7	Wood	Bought from RWE by FriEl Green Power Cogeneration plant – 126 GWh/y

In terms of heat production, Italy is a big consumer of biomass. Firewood holds the highest market share (>80%) although the use of wood pellets continues to rise (Cocchi, 2012). The Italian NREAP suggests an important role for biomass in the future, especially in the heating sector – this is anticipated to increase from 1.6 Mtoe in 2010 to 5 Mtoe in 2020. Biomass is currently used in more than 250 district heating facilities throughout Italy (overall installed capacity >430 MWth) and new plants continue to be added.

Italy also has some geothermal power capacity. There are more than thirty geothermal plants with a total capacity of 843 MW of which, around 770 MW is currently operational. All are in Tuscany. Annually, these generate around 5–5.5 TWh. The biggest player is ENEL – the company operates one of the largest groups of such plants in the world (34 facilities totalling ~769 MW net). A recent addition is the company's new Rancia 2 geothermal power plant in Siena; once operational, this 17 MW plant will generate ~150 GWh/y.

2.3.1 Hybrid renewable energy systems

ENEL Green Power (EGP) is partnering with a US-based hybrid renewables project located in Nevada where the 2 MW Stillwater Concentrated Solar Power (CSP) Project is currently under construction. Once completed, it will operate alongside the existing 33 MW Stillwater geothermal power plant – this is already paired with a 26 MW PV facility. A Cooperative Research and Development Agreement has been signed by the project participants; these comprise the National Renewable Energy Laboratory and Idaho National Laboratory (Power Engineering International 2014a). The US Department of Energy Geothermal Technologies Office is also involved.

In Italy, a plant (in Tuscany) combining geothermal energy with biomass is also being developed. ENEL Green Power is building the Cornia 2 power plant in Castelnuovo Val di Cecina. This 13 MW geothermal power plant will use biomass to heat geothermal steam in order to increase energy efficiency and electricity output of the geothermal cycle. Around 5 MW of capacity from biomass will be added to the existing plant, boosting output by ~37 GWh. Overall, the addition of biomass will avoid the emission of 17 kt/y of CO_2. The project is due to be completed in 2015.

2.4 Nuclear power

There are no nuclear generating facilities in Italy and no plans for any. A referendum in 2011 firmly rejected the idea of re-starting a nuclear programme within the country.

3 Energy policy and the National Energy Strategy (NES)

The recent global economic crisis has hit Italy hard – after a decade of limited growth, Italian GDP has been reduced by over 5%. There is now a goal to resume sustainable growth, necessary to reinvigorate industry and reduce the country's large public debt. As part of this, the competitiveness of businesses and the economic system needs to be improved. Understandably, the energy sector will have a fundamental role to play in this process. Achieving more competitive and sustainable energy is therefore a major challenge for Italy. Against this background, in 2013, the government produced the *National Energy Strategy* (NES). As the country has limited domestic energy resources, it relies on imports to meet a large proportion of its energy needs. Thus, the issue of energy supply has long been of importance.

Recent years have seen the country facing a number of economic and social crises. This changing and uncertain environment has made it difficult for the government to fully define a long-term energy strategy. Over the past decade, Italian energy policy has been characterised by the introduction of a series of laws and regulations. The end-result has been the creation of a highly complex system of regulation covering the energy sector. This has been complicated further by the impact of the increasing, incentivised input from intermittent renewables on the profitability and operation of thermal power plants (particularly CCGTs). It has also increased the energy bills of retail consumers (Cammi and Assanelli, 2012).

The Government has therefore attempted to create a viable energy strategy for the future. The NES focuses on four main areas, namely improved energy efficiency, the creation of a Southern European gas hub, the further development of renewables, and the revival of domestic hydrocarbon production. However, for this strategy to be effective in creating the necessary framework, a number of conditions will need to be met. The main areas that need addressing are:

- administrative inertia – following a constitutional reform in 2001, decision- and law-making related to the energy sector became increasingly shared between central government and the regions. As a result, energy companies now operate under a system of decentralised management that is usually endowed with a small budget;
- the complex succession of laws promoting renewables;
- the lack of a global energy strategy for the country, plus the absence of Italy from the wider European energy scene; and
- energy and climate policy definition has been lacking. Decisions have been either delegated to tribunals or administrative bodies.

The uncertainty resulting from earlier policy choices (such as those favouring the use of natural gas for power generation, and current renewable policies) increases the instability of the sector and prevents the creation of an investment-friendly environment (Cammi and Assanelli, 2012).

The NES has identified a number of goals to be pursued in the coming years and discusses the basic decisions that will be needed. However, it acknowledges that future developments will take place within a free market environment; hence, it will be impossible to centrally control the driving forces. As such, it provides a set of analyses and energy policies, and suggests guidelines for future action. The overarching aim is to influence and improve the energy sector structurally in various ways, making it more effective in boosting economic growth and improving quality of life. A major goal is the development of a more competitive and sustainable energy sector. Italy needs to resume sustainable growth and the energy sector has a crucial role to play in this process. This is one of the most significant challenges for the future.

3.1 High electricity prices and fuel poverty

Energy prices in Italy are higher than in other European countries (Table 4). In all cases, the price of electricity becomes less (per unit) as the amount consumed increases. However, smaller Italian consumers pay much higher prices than most European competitors. Furthermore, although Italian prices decrease as the level of consumption increases, they are still amongst the most expensive for the biggest (industrial) users (only the Czech Republic and Slovakia are marginally higher) (Assanelli, 2012).

Table 4 Electricity prices for different bands of non-domestic consumption (less any tax components) (Euro cents/kWh) (Assanelli, 2012)

Country	<20 MWh	20 MWh	500 MWh	2 GWh	20 GWh	70 GWh	>150 GWh
Belgium	16.0	12.6	9.77	8.6	7.41	6.69	na
France	10.0	8.85	7.22	6.52	6.38	5.62	na
Germany	16.0	10.9	9.0	7.91	7.07	7.16	na
Greece	13.0	11.0	9.39	7.73	6.88	5.69	5.7
Netherlands	14.0	10.2	8.41	7.54	7.03	6.99	6.6
Poland	15.0	11.5	9.63	8.11	7.61	7.41	7.8
Spain	16.0	13.1	10.8	8.72	7.51	6.77	5.0
UK	12.0	11.0	9.39	8.56	8.15	8.08	7.8
Italy (no tax)	24.0	13.5	11.6	10.2	10.1	8.72	8.1
Italy (with taxes)	33.0	20.0	17.0	14.0	13.0	11.0	9.0

Although fuel poverty is usually associated with developing countries, even within Europe, as a consequence of high energy prices, many people are unable to adequately heat or power their homes. In Italy, the figure has been estimated to be more than 20%. As in other parts of the world, many EU coal-fired power plants generate electricity more cheaply than wind or solar power. Coal-generated electricity is also often 10–30% cheaper than gas (Tomczak, 2014). Increasing the amount of coal used in Italy could be instrumental in reducing the country's high electricity costs, bringing them more in line with other European nations, many of whom compete directly in the same market areas. This would also help reduce the strategic risks associated with the country's heavy dependence on imported oil and gas. Coal supplies are available from many parts of the world and unlike gas, are rarely disrupted by political or other events. For instance, Italy's pipeline gas imports from Libya dropped to zero as a consequence of the latter's civil war.

Recent studies have confirmed that amongst the various generation technologies, the levelised cost of electricity is lowest for coal-fired and CCGT plant (World Energy Council, 2013). Based on data produced by the Italian Regulatory Authority for Electricity and Gas (Ruscito, 2013), the cost of electricity from the different fossil fuels is:

- coal 2.18 €/kWh;
- oil 5.51 €/kWh;
- gas 6.34 €/kWh.

In general, apart from the lowest cost of electricity, coal is usually affordable and readily available. When suitably equipped, coal-fired plants can be tolerant of changes in coal type/quality, they can operate flexibly (base load, two-shifting, etc), have the potential for cofiring others fuels such as biomass, and can operate with low emission levels (such as Italy's Torrevaldaliga Nord plant). Some older coal-fired plants were designed primarily for base load operation and not for cycling duties. This can limit their operational flexibility, resulting in operational difficulties, reduced overall efficiency, increased wear and tear of plant components, and impaired operation of emission control systems. However, in many parts of the world, new operating procedures and hardware are being increasingly applied that allow flexible operation, often a necessity where such plants form part of a national electricity system. Newer units are usually more tolerant of cycling as necessary modifications are now frequently incorporated at the design stage (Hederson, 2014). Problems caused by rapid cycling and frequent start-ups and shut-downs are not limited to older coal-fired units, as gas-fired plants can also suffer issues such as increased wear (or even failure) of major plant components such as steam turbines. There is growing industry opinion that for some gas plants, this type of operation is likely to create a major problem for the future (Wride, 2014).

3.2 The issue of energy import dependency

Around the world, the most widespread primary energy reserves and resources comprise hard coal, lignite and uranium. However, these sources are not distributed equally. Consequently, some countries and regions, including the EU, are becoming increasingly dependent on imports. The EU's fossil fuel reserves amount to ~38,000 Mtce – these account for only 2.8–3.0% of the known global reserves, and consist mainly of lignite and hard coal. However, the EU has considerably more coal than oil or gas.

Within the EU, primary energy production has decreased substantially – there has been a downturn in the production of hard coal, lignite, oil, natural gas and nuclear energy. This has resulted in the EU becoming increasingly reliant on energy imports in order to meet demand. In 2012, imports of primary energy into the EU 28 exceeded exports by nearly 923 Mtoe; more than half (53.4%) of the gross inland energy consumption came from imported sources. During the 1980s, this figure was less than 40% – it peaked at 54.7% in 2008. Inevitably, the increasing dependency of the EU and some of its member states on energy imports (particularly of oil and gas) raises concerns over security of supply. Many states depend increasingly on energy imports from non-member countries (Eurostat, 2014).

Europe imports a sizable percentage of its coal requirement. The EU's dependency on imported coal is expected to increase from the current level of ~35% to >60% by 2030 (Italy's current coal import dependency is ~98%). Furthermore, by 2030, the EU is expected to reach an import dependency of 81% for natural gas and possibly 88% for oil. Overall, the share of imported energy is expected to increase from the current level of ~50% to ~70% (Christensen and others, 2012).

Although there are proposals to increase domestic production, the IEA forecasts that over the next two decades, European gas production in general is likely to decline gradually. Based on current trends, by 2030, the EU could be importing >80% of its gas. Partly as a response to political unrest in Ukraine and other parts of the region, there have been suggestions that Europe's (and Italy's) dependence on Russian gas should be reduced. Europe has been described as being 'dangerously dependent' on this source of supply, with many nations relying on Russia for >50% of their gas supplies. Potentially, some could be replaced by LNG; Italy's LNG import facilities are currently underutilised. However, in the future, LNG prices seem likely to increase. Growing amounts are being directed to Asia – in particular, supplies to China are rising (Bezdek, 2014). This could limit Italy's access to this source of gas.

In March 2014, the European Council Brussels Summit Meeting recommended that efforts should be intensified to reduce Europe's dependency. It also recommended that the EU accelerate diversification of its energy supplies – as part of this, the possibility of the increased use of clean coal technologies was proposed. It was suggested that in the near term, the EU could reduce its reliance on Russian gas by bringing 21 GW of recently idled coal-fired plants back into service (Bezdek, 2014). Clearly, most would require suitable upgrading and modernising and/or the addition of appropriate modern emission control systems. This strategy could have merit in some member states with significant idled capacity (such as the UK, Netherlands and Germany). However, even though Italy is heavily dependent on imported gas, it has only 383 MW of potentially suitable retired (non-ENEL) coal-fired capacity, hence the immediate impact here would be small (Bezdek, 2014).

Italy is high on the list of EU member states that depend heavily on imported energy. Only a handful are more dependent, some because of exceptional circumstances (Malta, Luxembourg, Cyprus and Ireland). In 2012, net imports of primary energy into Italy amounted to 133 Mtoe. This was only surpassed by Germany at 197 Mtoe (Eurostat, 2014).

3.3 Expected outcomes of the NES

The Italian industrial and manufacturing sectors will be at the centre of any economic resurgence, and the government intends for these to retain a central position in the Italian economy. In light of this, the NES has concentrated on a number of key areas. The main ones focus on significantly reducing energy costs in order to bring them in line with European levels by 2020, whilst at the same time, meeting or exceeding the environmental and decarbonisation targets established by the EU's 2020 Climate and Energy Package.

In addition, security of energy supply needs improving – reliance on expensive imported energy needs to be reduced. Finally, sections of the energy sector need re-structuring in order to foster sustainable economic growth. For the period up to 2020, the NES has identified seven priorities. Each has its specific supporting measures, some of which are already in motion or are in the process of being defined. These areas comprise:

- **Improving energy efficiency**. This would reduce fuel use, costs, environmental impact, and energy import dependency. It would also help encourage general economic development. An improvement in energy efficiency would negate some of the expected future increases in energy demand. The programme aims to save 20 Mtoe/y of primary energy, and 15 Mtoe/y of final energy. If achieved by 2020, consumption would be ~24% less than the European benchmark. Furthermore, about 55 Mt/y of CO_2 emissions would be avoided, and ~€8 billion/y less spent on fossil fuel imports;
- **Creation of a competitive gas market and Hub Southern Europe**. There may be an opportunity for Italy to become an important crossroads for the entry of gas to Europe from the South. This could help re-align Italian gas prices to those in the wider Europe and help the Italian CCGT fleet to regain competitiveness. It would also improve security of supply and reduce electricity imports;
- **Further development of sustainable renewable energy** (RE). There is a goal of exceeding the objectives of RE production in Europe (the EU '20-20-20' package). Thus, renewables will account for 19–20% of gross final consumption (compared to the EU objective of 17%), equal to 23–24 Mtoe/y of final energy. This would also avoid up to 50 Mt of CO_2 emissions. For electricity generation, the aim is for renewables to provide 34–38% of final consumption; this equates to ~120–130 TWh/y (or 10-11 Mtoe). However, concurrently, it will be important to reduce electricity bills;
- **Developing electricity infrastructure and the electricity market**. The slowdown in demand, excess CCGT generating capacity, plus increased production from renewables means that the sector is changing. The focus will remain on the further development of an efficient, free electricity market, fully integrated with the rest of Europe. The growing level of generation from renewables will also need to be fully integrated in the market and electricity grid;
- **Restructuring the refining industry and the fuel distribution sector**. For a number of reasons, the refining industry is in difficulty and requires transformation;
- **Improving the domestic production of hydrocarbons**. Although Italy has significant reserves of oil and gas, it still depends heavily on imported supplies. Better use of domestic resources would aid employment and boost economic growth. However, high environmental standards would need to be applied. There will be no developments in sensitive areas (offshore or onshore), nor the pursuit of shale gas projects; and
- **Modernising system governance**. A more effective and efficient decision-making system is needed to help meet the above objectives.

The NES anticipates that (by 2020) the effect of these measures will be to reduce fuel consumption and energy costs, increase the input from renewables, achieve or exceed European environmental targets, improve energy security, reduce imported energy, and enhance economic growth. In the longer term

(2030–50), broader changes are expected to be required to achieve sustainable development – these will not be restricted to the energy sector but will need to engage with society in general. With this in mind, the government intends to adopt a 'flexible' strategy in order to pursue a long-term low-carbon policy. This will focus on, and exploit any developments that could produce significant changes, such as lower cost generation from renewables, or the application of carbon capture and storage to thermal power plants.

In the period up to 2020, the NES foresees the gradual alignment of electricity prices and costs to European standards as well as full European integration, the continued development of a free electricity market, and further integration of energy from renewable sources. Through improvements in energy efficiency, energy consumption (both primary energy and electricity) is expected to fall, with the country's electricity consumption being contained. At the same time, the make-up of the sector is forecast to change gradually (Table 5).

Table 5 Predicted make-up of Italian energy sector in 2020

	Primary energy (%, Mtoe)		Electricity consumption (%)	
	2010	2020	2010	2020
Natural gas	41	35	44	35.4
Oil	37	30–32	3	~2
Renewables	11	22–23	22	35.4
Coal	9	8–9	16	15–16
Imports	2	~1	13	7–10
Total			346 TWh	345–360 TWh

The NES predicts that the biggest electricity providers will be gas and renewables, and suggests that these two could cover ~75% of the country's electricity consumption. The share of coal will remain essentially unchanged, while fuel oil will fall to near zero levels (NES, 2013). The renewables sector will account for the equivalent of 23% of primary energy consumption; fossil fuels will reduce from 86% to 76%. Renewables could equal or surpass natural gas to become the biggest player in the electricity sector (accounting for ~34–38% of consumption – compared to 23% in 2010). The anticipation is that the country will significantly reduce its dependence on imported forms of energy – import dependency is forecast to decrease from 84% to ~67%. This would reduce the country's external energy bill by ~€14 billion/y – this equates to ~1% of GDP. This alone should bring the trade balance back into surplus, after many years of deficit. Thus, in the period up to 2020, the hoped-for outcomes include the containment of electricity consumption. Overall demand may remain essentially flat or only increase slightly, with more electricity being generated by renewables.

In addition, energy imports will decrease and there will be improvements within the gas and oil production sector. The high import dependency of both has a major impact on energy security and system costs. Italy has significant gas and oil reserves. It is suggested that by 2020, domestic gas production could be increased by ~24 million barrels of oil equivalent per year (boe/y), and oil by 57 million boe/y. This could increase their contribution to the total energy requirement from ~7% to ~14%, mobilise investments of ~€15 billion, and save €5 billion per year (mainly because of lower imports).

However, there are a number of factors that could impact on any such future developments. These include the need to strengthen efforts in energy efficiency (ideally, primary consumption will fall by 17–26% by 2050), and the accommodation of the growing level of output from renewables – this could reach at least 60% of gross final consumption by 2050, with much higher levels in the electricity sector. RD&D into cost reduction will be important. During this transition, gas is likely to continue playing an important role. Other factors that may play a part include overcoming the economic and financial difficulties currently being experienced by some operators in the power sector, plus the necessity for any measures adopted to meet all environmental requirements.

3.4 The possible future role for coal in Italian electricity generation

The NES makes little reference to coal's future role, simply suggesting that its current contribution will remain roughly the same. As noted, Italian electricity costs and prices are considerably higher than the European average. The electricity generation mix, based mainly on gas and renewables differs significantly from the average European mix as it lacks nuclear capacity and has a low share of coal – both would be beneficial in reducing costs. Many competing economies rely on a wider mixture of technologies that often comprise various combinations of fossil fuels (predominantly gas and coal), nuclear power, large-scale hydro, and other renewables.

Clearly, the decision to adopt a particular type of electricity generating system can depend on many factors, some generic and others, more local in nature. All individual power generation technologies have inherent advantages and disadvantages. The main ones (within the Italian context) are summarised in Table 6.

Table 6 Advantages and disadvantages of different power generating systems

Technology	Advantages	Disadvantages
Natural gas	High energy content Rapid plant start-up/shut-down, flexible operation for some plants CO_2 emissions typically lower than coal and oil No solid wastes for disposal	Most gas imported – cost and security of supply issues Price can be volatile and influenced by outside events Currently, surplus CCGT generating capacity in Italy GHG emissions higher when considered on a LCA basis – CH_4 has high GHG potential Energy penalties at every stage of gas production and distribution Extensive infrastructure requirements (gas pipelines, etc) Stored and distributed under high pressure Explosive, potentially dangerous Industry concern over long-term power plant reliability issues resulting from frequent, rapid cycling
Oil	High energy content Well established handling procedures	High reliance on imported supplies Security of supply concerns Price volatility Energy penalties associated with production and distribution Extensive infrastructure requirements (tankers, pipelines, etc) Can be localised environmental problems around power plants
Renewables – wind, solar	Low GHG and other emissions Low day-to-day operational costs	Intermittent operation – peak production may not correspond with demand Individual units have limited capacity Electricity (per unit) is expensive – operating subsidies usually required
Renewables – biomass	Available in many places Can reduce fossil fuel use If produced sustainably, can be carbon-neutral Some wastes can be used as fuel, minimising disposal problems	Variable properties and seasonal availability Lower energy content (compared to coal, gas and oil) Large volumes may be needed Growing and harvesting costs Possibly extensive land utilisation CO_2 and possibly CH_4 emissions during production and use Processes not easily scalable
Nuclear	Low GHG emissions Reliable, large-scale base load operation	Ruled out in Italy for the foreseeable future Long construction time Expensive construction Uranium is expensive to mine and process; waste production Operational accident risks Issues of long-lived radioactive waste disposal Terrorist risks
Coal	Moderate, stable cost Widely available from multiple sources Low risk handling and transport Lowest cost electricity produced Well-established systems for pollutant control Cofiring often feasible	Coal handling and transport systems required Emissions of SO_2, NOx, particulates and CO_2 from plants lacking appropriate control systems (but all ENEL plants comply fully). Some plants operate best on base load. Increased cycling may cause operational problems if plant not designed appropriately CCS may be appropriate for some future plant operations

In 2013, some 43% of Italy's electricity was generated from natural gas, 37% from renewables, 7% from oil, and 13% from coal. Globally, more than 40% of the world's electricity is generated from coal-fired plants; in Europe as a whole, it is 29% (nuclear power generates a similar amount). Whereas many industrialised economies rely heavily on combinations of coal, gas, nuclear power, and renewables, Italy relies predominantly on gas and renewables. For many years, despite its established advantages, the use of coal has remained limited.

Through the use of modern emission control technologies and advanced steam conditions, coal-fired power generation can be both clean and efficient. Around the world, there are many examples that are characterised by high availability and efficiency, and have low environmental impact. Such plants are operating in, for instance, Denmark, Germany, North America, Japan, China, The Netherlands, and South Korea. In Italy, the Torrevaldaliga Nord plant has a net efficiency, in design condition, of ~45% (LHV). Up-to-date coal plants are now capable of achieving airborne pollution levels equivalent to those of a modern gas plant.

Globally, coal-fired plants are often expected to operate more flexibly than their predecessors, many of which were designed to operate solely on base load. Increasingly, plants are required to balance power grids by compensating for the variable electricity supply from intermittent renewable energy sources. For this, high flexibility is needed – plants need to possess resilience to frequent start–ups, meet major and rapid load changes, and provide frequency control duties (Henderson, 2014). There are now a number of features that can be incorporated to improve operational flexibility. These include improvements to boiler firing systems and pressure parts, the use of external steam preheating to reduce start-up times, reducing minimum load (by means such as modified evaporator designs, and addition of drains and bypasses), plus a range of possible alterations to the turbine and steam-water systems. The use of such measures helps minimise potential damage mechanisms resulting from frequent plant cycling. They provide technical solutions that allow conventional combustion-based plants to achieve the necessary flexibility without unacceptable loss of plant life and thermal efficiency. Clearly, the question of CO_2 emissions requires addressing; there are now a number of systems in development or being demonstrated that have the potential to overcome this. In many cases, associated energy penalties and costs are reducing, and operational reliability is improving.

Within Italy, there is currently over-capacity in the gas-fired generation sector, and whereas studies of 2012–13 suggested that coal might play a greater role in the future, others have proposed that coal demand could remain essentially flat or even diminish. In part, this cautious forecast has resulted from the sluggish performance of the Italian economy – this has reduced electricity consumption. In the period 2013–23, gas-fired power plants are forecast to continue providing just under half of Italy's electricity. During this period, Italy's overall power generation is expected to increase by an average of 1.2%/y. Different forecasts suggest different potential for fossil fuels (for instance, BMI, 2014). However, in the period leading up to 2020, the NES anticipates that the contribution from renewables will increase, the level of natural gas will decline, and that from coal will remain roughly the same (Figure 5).

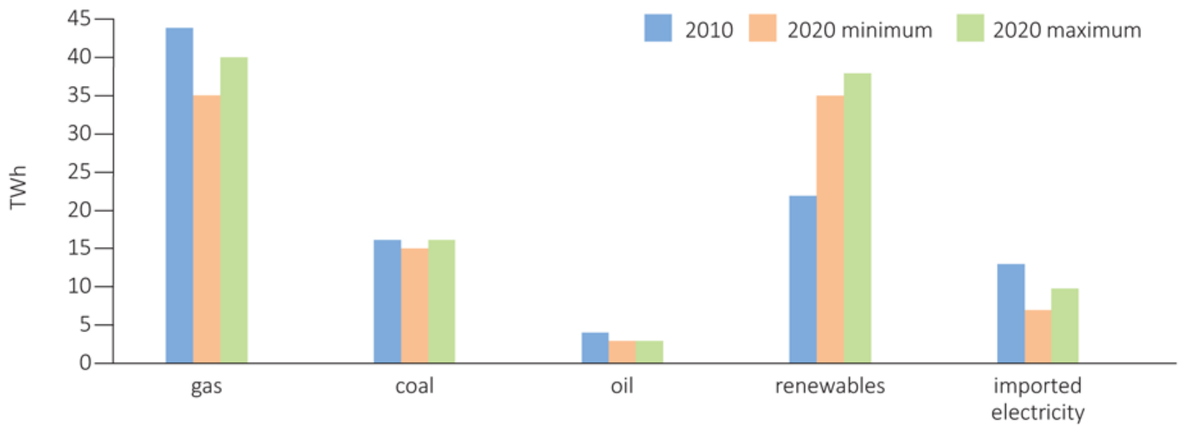

Figure 5 Mid-term perspectives: changes in energy mix (Ruscito, 2013)

Some Italian industry observers have advocated revising the NES such that the amount of coal used for power generation is increased. For instance, Assocarboni has suggested doubling the amount of coal used, and halving the use of natural gas (Sorgenti, 2014). Under such circumstances, the low, stable costs, plus widespread availability would make the greater use of coal increasingly attractive (Clavarino, 2014). It is asserted that if Italian power plants used as much coal as the rest of Europe, fuel costs on the entire amount would decrease by 10%. If all such plants used coal, it would fall by 20% (Assocarboni, nd). Many major Italian industrial and commercial users regard current electricity prices as unsustainable and have suggested that in order for the country to regain competitiveness and secure its power supply, a rebalancing of energy sources is needed (Woodward, 2013a). In particular, this would include replacing a proportion of gas-fired capacity with new coal-based systems.

There are quite compelling reasons for Italy to consider increasing its share of coal-fired power generation, bringing it more in line with the energy mix adopted in some other economies (*see* Table 7 – citing World Bank data). As noted above, many of these rely on a more diverse, balanced mix of technologies that incorporate fossil fuels, nuclear power, and renewables.

Table 7 Power generation mix of selected countries (%) 2011/12

	Oil	Nat gas	Nuclear	Hydro	Other REs	Coal
South Korea	4.1	22.9	29.3	0.7	0.6	42.2
Germany	1.5	11.5	16.3	3.5	18.9	46.9
India	1.2	10.3	3.2	12.4	5.0	67.9
UK	1.0	27.7	19.5	1.5	10.0	39.9
USA	0.7	29.8	18.7	6.5	5.6	38.3
Italy	6.3	46.1	–	14.2	16.3	16.0

Clearly, many major economies will not be in a position to move away from fossil fuels for some time – coal, oil and gas will remain major sources of energy in numerous countries. In fact, coal remains central to the global energy system. It is the world's largest source of electricity (~41–42% of global electricity) and is currently the largest source of primary energy. Coal's dominant position in the global energy mix is due largely due to the fact it is abundant, widely distributed across the globe (available in more than 100 countries), and affordable. Prices do not tend to change suddenly and are therefore generally predictable. Resources are estimated to be as much as 4–5 times greater than estimated reserves. Compared to competing fossil fuels such as oil and gas, coal can be transported, stored and handled with relative ease and safety.

The main issue for coal is CO_2. However, through the use of the best available technologies, CO_2 emissions from coal-fired plants can now be brought down to levels comparable with some gas-fired stations. The addition of CCS or inclusion of sustainably-produced biomass as part of the fuel feed would further reduce CO_2 levels. The use of low emission CCTs is an important option in meeting national and international emission targets. In the case of CO_2, the two main routes for reducing emissions are through the use of high efficiency, low emission power plants, and carbon capture and storage. Other plant emissions (particulates, SO_2 and NOx) can now be controlled by various well-established technologies. In 2011, around half all new coal-fired power plants used HELE (high-efficiency, low-emission) power generation technologies, predominantly supercritical (SC) and ultra-supercritical (USC) systems (World Energy Council, 2013).

4 Coal

Unlike many other economies, coal currently plays only a modest role in the Italian energy sector. In 2013, 14.6 Mtoe of Italy's primary energy supply (total of 158.8 Mtoe) was provided by coal – around three quarters of the coal consumed was for power generation. Oil provided 61.8 Mtoe, gas 57.8, hydro 11.6, and other renewables 13.0 (BP, 2014).

4.1 Coal reserves and production

Italy's actively exploited coal resources are limited to the Sulcis Iglesiente basin in south west Sardinia. This is the location of the only operational mine (Figure 6) and commercially exploited deposit. Sulcis resources are estimated to amount to between 610 and 620 Mt of subbituminous coal, with proven reserves at 10 Mt. Mining in the area has had a chequered career, and was stopped in 1972. However, it was re-started in 1997 and is currently carried out by Carbosulcis (controlled by Sardinia's regional government). However, the mining industry here continues to struggle and production has dwindled. In recent years, the mine has faced closure on a number of occasions. For example, in 2012, miners barricaded themselves underground in an effort to stave off closure.

Over the past two decades, coal production in Italy has seen a steady decline. From a peak of more than 2 Mt in 1982, output has now fallen to ~80 kt/y (IndexMundi, 2012). As noted, production is limited to the Carbosulcis mine in Sardinia – this produces high-sulphur subbituminous coal, all of which is supplied to ENEL's power plant in Portovesme. The mine relies heavily on sales to the plant. Because of the coal's high sulphur content, ENEL usually blends it with imported coals from Colombia and the USA.

Figure 6 The Carbosulcis mine in Sardinia. It produces high-sulphur subbituminous coal (photograph courtesy of Carbosulcis)

There is a tendency for properties of Sulcis coals to vary; however, 'typical' characteristics are shown in Table 8.

Table 8 Characteristics of Sulcis coal (Girardi, 2014; ENEL, 2015)

Property	%
Moisture	11–12
Ash	17–18
Fixed carbon	31–35
Sulphur	5–6
Chlorine	0.01–0.10
Hydrogen	1.3–5.2
CV (LHV) MJ/kg	19.3–20.8

Since 2005, there have been proposals for the Sulcis mine to be revamped as a combined mining and carbon capture site. The cost of achieving this has been estimated at around €200 million, to be invested over a period of eight years. Sardinia's regional government is backing these proposals that would include the construction of a new coal-fired power plant equipped with carbon capture and storage (CCS) technology. Assocarboni and other organisations have urged the government to support development of the mine using suitable clean coal technologies (CCTs). Potentially, annual coal production could reach 1.5 Mt.

Italy has long relied on imports to meet most of its coal demand. Although there have been some variations overs the years, annual coal consumption has generally fluctuated between 20 and 27 Mt (Figure 7). Since 2004, consumption has remained relatively constant. The vast majority was imported.

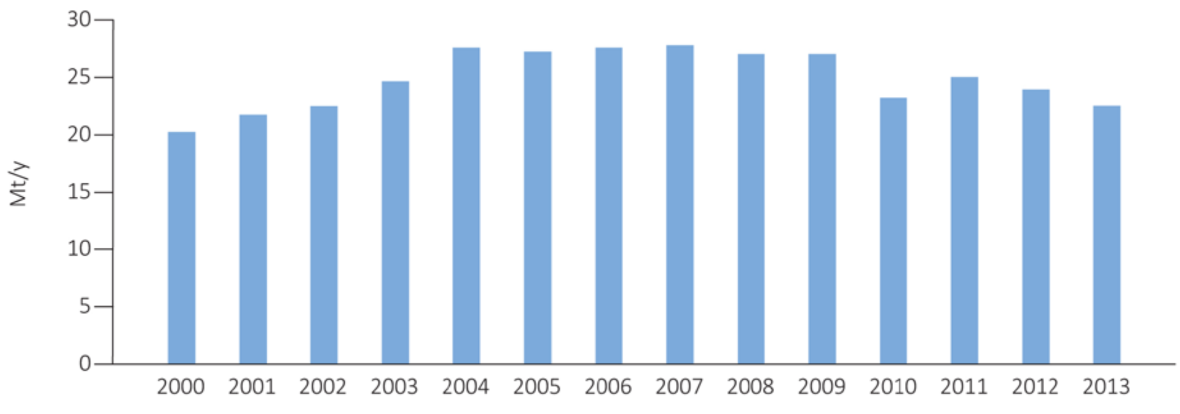

Figure 7 Italian coal consumption – steam + coking coal (Mt/y) (Ruscito, 2013; IndexMundi, 2012; Woodward, 2013a)

4.2 Imported coal

Within the EU, Italy is the third largest coal importer after Germany and the UK. In 2012, the EU 28 imported nearly 213 Mt of coal. Italy imported 24 Mt comprising steam coal, coking coal, and pulverised coal injection (PCI) coal. However, overall tonnage for 2014 was expected to be lower. Between January and August 2014, monthly coal imports varied between 1.3 and 2 Mt. In a typical year, the country imports 98% of its solid fuel needs. In 2012, 9.8% of Italy's primary energy was provided by coal. The bulk of this was used for power generation.

Compared to many EU countries, coal's current share in power generation remains low. Clearly, any new coal-fired capacity would be expected to apply CCTs (possibly with CCS added at a later date) so that environmental impacts would be minimised. Italian power generators already have a good track record in this respect – most plants meet all European environmental certification requirements (EMAS) and most are characterised by high efficiency levels. The past few years have seen a strong focus on innovation and fostering of investment in new clean coal technologies; recent CCT investment has totalled more than €7 billion (Woodward, 2013b).

While Italy relies almost entirely on imported coal from non-EEA suppliers, there remains a risk of price shocks (and security of supply issues) resulting from political or other events. However, the government and most observers consider that any lost coal supply could be replaced relatively quickly from alternative sources. Similarly, electricity imports are also high – despite being entirely intra-EU, any surge in import prices would put additional pressure on already expensive supplies to Italian end-users (Europa, 2013). Clearly, expensive electricity impacts on commercial competitiveness.

4.2.1 Steam coal

For more than a decade, steam coal imports have increased by more than 4%/y. In 2012, imports were 19.8 Mt – the biggest suppliers were the USA (6.64 Mt), Indonesia (3.78 Mt), South Africa (3.1 Mt), Colombia (2.76 Mt), and the Russian Federation (2.43 Mt), with smaller amounts coming from Australia, Canada, and Venezuela (IEA Coal Information, 2013). At the moment, around 80% of Italy's coal comes from Indonesia, South Africa and the USA. Historically, other suppliers have included China, and Poland. In 2012, amongst the power companies, ENEL was the biggest taker of steam coal (~13.6 Mt) (Figure 8). Smaller amounts were also bought by Tirreno Power, E.On, A2A, and Edipower (Ruscito, 2013). In 2013, the level of steam coal remained at ~19 Mt. Estimates for 2014 suggest that the amount of imported steam coal will be lower, possibly ~16 Mt – this will result mainly from the closure of the 660 MW Vado Ligure power plant (Clavarino, 2014). Clearly, if the new coal-fired power projects (noted in Section 6.3.1) had become a reality, coal demand would have increased. An overall annual total of around 25–26 Mt/y had been suggested.

Figure 8 Coal being unloaded at ENEL's Torrevaldaliga Nord power plant (photograph courtesy of ENEL)

Since 2011, coal supplies from the USA have risen significantly. Major consumers such as ENEL have increasingly bought from this source – the increased availability of US coals has resulted mainly from the shale gas boom within that country. Coal deliveries from Colombia have also risen in the past few years. During this period, most Italian coal-fired plants have essentially run at full capacity. The relatively low price of coal has made this a profitable exercise for ENEL and other Italian generators, as well as helped moderate electricity prices within the country (Moloney, 2013).

4.2.2 Coking coal

In 2012, Italy imported 4.57 Mt of coking coal. The main suppliers were the USA (2.46 Mt), Australia (1.36 Mt), and Canada (0.72 Mt). This amount was down slightly from the 2011 level of 5.6 Mt. It is forecast that by the end of 2015, imports will have fallen to around 4 Mt. This reduction stems mainly from production issues at the ILVA steel plants (see below) (Clavarino, 2014). The iron and steel sector is the recipient of most of the coking coal imports. Italy currently ranks 11th largest in the world for iron and steel production, producing 27.3 Mt of crude steel in 2012. Of this total, 34% was produced via blast furnace technology.

Annually, between 4.5 and 6 Mt of coking coal is used by the sector, mostly for coke oven operations. In 2011, 5.87 Mt of coking coal was consumed, 5.5 Mt of which was in coke ovens (IEA Coal Information, 2013). In that year, 4.35 Mt of coke was produced, of which 4.125 Mt was used within Italy. Some was also exported (273 kt in 2011). Each year, more than a million tonnes of PCI coal is also brought in for the iron and steel sector – in 2012, it was 1.46 Mt (IEA Coal Information, 2012).

Modest amounts of coke are sometimes imported (for example, 33 kt in 2011) (IEA Coal Information, 2012). Some has come from Polish suppliers. Coke is produced from imported coal at a number of major Italian facilities. These include:

Ilva (Riva Group) integrated steel works, Taranto – this is the largest plant of its kind in Europe. It produces 450 kt/y of coke. There are ten coke oven batteries and five blast furnaces; in 2000, a new battery with 43 ovens was completed by Thyssen Krupp Uhde of Germany. The Taranto site recently ordered a new bucket-chain continuous-ship unloader for handling iron ore and coal. The new system became operational in March 2015 and has a capacity of 2240 t/h of coal. It is capable of unloading vessels of up to 150,000 DWT. The supplier (Tenova Takraf) has also supplied similar systems to ENEL's Brindisi Sud and Torrevaldaliga Nord power plants.

Another Italian steel producer is **Lucchini**, with its main production unit in Piombino on the Tuscan coast. This was the second largest steel producer in Italy. However, for several years, the company has been in financial difficulties. It was announced in December 2014 that India's JSW Steel had made a binding offer for the company's core assets. The Piombino plant includes a blast furnace, a steel mill, a coke plant (battery of 45 ovens), three re-rolling mills and port facilities. When fully operational, it can produce ~2.5 Mt of steel a year. Reportedly, JSW Steel is also in the running to buy Italy's largest steel plant, Ilva.

Italiana Coke coking plant, San Giuseppe, Genoa – the plant produces around 500 kt/y of coke. This is made up of a number of different types/grades (metallurgical coke – 10/30 and 30/70 mm; foundry coke +90 mm, 90/140 mm, +140 mm, + 70/90 mm; and blast furnace coke 25/100 mm). An on-site 24 MW cogeneration plant burns coke oven gas.

4.2.3 Lignite

Historically, lignite was produced in Italy – most production was at locations in Tuscany (for example, in the Baccinello Basin). During World War II, as hard coal was scarce and expensive, many small previously closed lignite mines were re-opened. However, none are now worked commercially.

The last surviving mine was originally developed by Società Elettrica Selt-Valdarno and Società Romana di Elettricità, and later operated by ENEL. Lignite was supplied to the company's 2 x 125 MW Santa Barbara power plant. However, the deposits became progressively exhausted and lignite use ended in 1994. In 2006, the site was re-used for a new 390 MW CCGT power plant.

An on-going project of ENEL's is focused on the former Central Mercure power plant located in the municipality of Laino Borgo in the province of Cosenza. Set up in 1962, the plant comprised two 75 MW lignite-fired units, supplied from mines in Castelluccio Inferiore and Laino Borgo. The plant was later converted to fuel oil, but for technical and economic reasons, one unit was closed in 1993 and the second in 1997. Recently, one 35 MW unit has been converted to operate on locally-sourced biomass. The second unit will be demolished. The project cost is ~€70 million. The project is awaiting the Ministers Council's final deliberation; this will be followed by the New Regional Authorization Decree.

Small amounts of lignite are also sometimes imported. For instance, in 2011, 5000 tonnes were brought in from Germany (Italian GHG Inventory, 2013).

5 Italian electricity

The Italian electricity sector is undergoing significant change, with some generators experiencing difficult economic conditions, or facing market transition. Companies mostly reliant on combined cycle gas-fired production are suffering from high over-capacity. This has resulted from a combination of factors that include a general fall in demand, the significant increase in thermoelectric production capacity (with ~20 GW of new CCGT added between 2005 and 2011), and the increased production from renewables. The rapid growth of renewables (that benefit from dispatching priority) has been a major factor in the reduced exploitation of the fleet. Some new gas-fired plants have not yet been brought on line, and others are operating for only 1200–2000 h/y – most formerly worked for 5000–6000 h/y. In Italy, an important role for CCGTs is keeping the power system balanced, particularly in late afternoon. However, with the variable input from renewables, many plants are now forced to switch on and off more often, which impacts on their profitability. In the longer term, there may also be technical concerns.

Because of falling profit margins, some operators of gas-fired plant are in the process of selling assets or restructuring debt. In recent years, many have reduced load factors and are now hoping for additional capacity payments to keep them operational until a planned capacity market starts in 2018. A decision on top-up capacity payments is currently resting with the Italian Authority for Electricity, Gas and Water (AEEG); it has been approved by both the senate and the chamber of deputies. Once the new system is in place, companies will be able to auction off back-up capacity. This will replace the current capacity payment system, where plant operators are paid a flat rate that is insufficient to maintain profitability. The new system is expected to widen the peak hours range for production from fossil-fuelled plants (Roix, 2014). The development of a common European regulatory framework for the allocation of generating capacity (capable of supporting peak loads) along with the strengthening of the connections with neighbouring countries, would open up possibilities for the greater exploitation of this currently under-used generating resource (Cammi and Assanelli, 2012).

The country's total electricity consumption (generation + imports) for 2011 is shown in Table 9. In that year, total electricity supplied was 334.6 TWh.

Table 9 Italian electricity net generation (2011) (GSE, 2013)

Technology		TWh	% of total	Total (TWh)
Hydro		45.3	13.5	Renewable = 82.2
Bioenergy	Biomass	4.3	1.3	
	Biogas	3.2	1.0	
	Bioliquids	2.6	0.8	
Geothermal		5.3	1.6	
Wind		9.8	2.9	
Solar		10.7	3.2	
Conventional thermal	Coal	40.7	12.1	Conventional thermal + pumped storage hydro = 207.7
	Nat gas	140.6	42.0	
	Others	24.5	7.3	
Pumped storage hydro		1.9	0.6	
Net imports		45.7	13.7	Imports = 45.7

In 2012, total installed generating capacity increased by 5.8 GW to a total of 124.2 GW. Within this, the share of renewables increased by 11.2%. However, of the fuels employed for thermoelectric production, natural gas was the most used – this generated 125.4 TWh. It was followed by coal at 44.7 TWh, an increase of nearly 10% over 2011 (TERNA, 2013).

Of the 334.6 TWh produced in 2011, there were 20.8 TWh of grid losses. Thus, total consumption amounted to 313.8 TWh. A breakdown of consumption is shown in Table 10. The country's overall level of demand in 2012 was comparable to that in 2004–05. The largest consumer remained the industrial sector.

Table 10 Electricity consumption (2011) (GSE, 2013)

Sector		TWh	% of total	Total (TWh)
Agriculture		5.9	1.9	
Industry	Iron & steel	18.6	Total industry = 44.6	Total industry = 140.0
	Engineering	21.3		
	Energy and water	16.8		
Service sector	Commerce	24.1	Total service sector = 31.1	Total service sector = 97.7
	Public admin.	4.6		
	Public lighting	6.4		
Households		70.1	22.4	

In 2012, nearly 87% of the country's electricity was generated by Italian power plants (285.1 TWh), with the balance (43.1 TWh) being imported from various neighbouring countries (TERNA, 2013). Italy imports ~13–14% of its requirement every year, making it the leading importer of electricity in Europe. The Italian transmission grid is connected to the rest of the UCTE (Union for the Co-ordination of Transmission of Electricity) power system via 22 interconnection lines (including 4 with France, 12 with Switzerland, 1 with Austria, 2 with Slovenia, and 1 with Greece) (Power Engineering International, 2012).

France and Switzerland are the biggest suppliers – in 2012, imports amounted to 14.3 TWh and 25.6 TWh respectively.

5.1 Growing private sector involvement

In March 1999, a legislative decree (the *Bersani Decree*) was issued for the liberalisation of the Italian energy market. This resulted in the appearance of new players, many of whom developed new CCGT greenfield power plants.

Over the past few years, the Italian energy sector has changed radically. The EU's Internal Market in Electricity Directive (2009/72/EC) led to the gradual opening up of internal markets and the creation of a single European energy market. This was completed in 2007. A consequence of harmonising the energy markets was the separation of electricity generating and supply companies from the transport and distribution network. This led to the dismantling of the vertically integrated structure of ENEL, the public company that previously owned and controlled most aspects of energy production. ENEL was subsequently privatised in stages and divided into various separately controlled entities that now manage the different phases of the energy process (Rinolfi, 2013). ENEL remains the largest Italian energy utility (partially privatised, with 25.5% owned by the Italian Ministry of Economy and Finance). However, there are now other utility companies active in the sector. These include a number of major European players (PEI, 2012). The main ones involved in electricity generation in 2012 are shown in Figure 9.

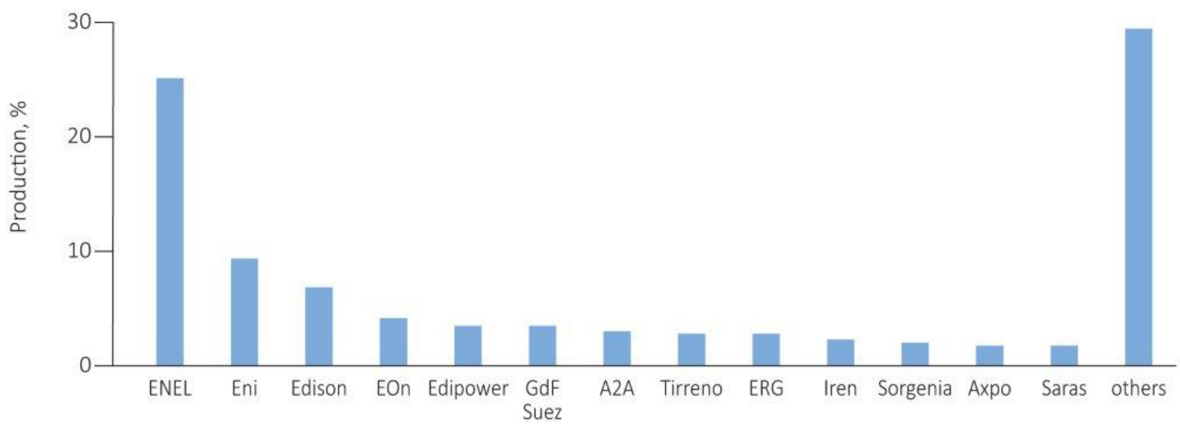

Figure 9 Main Italian power generators (2012)

The Italian Government intends to reduce the country's budgetary deficit by speeding up its privatisation plans. At the end of 2013, it was announced that a scheme was being developed to privatise more state-owned assets; this includes parts of the energy sector. This privatisation push is part of the economic recovery plan and is being driven by the need to reduce the country's sizeable public debt (more than €2 trillion). Reportedly, this is Italy's largest such programme since the late 1990s – it aims to raise €12 billion. The announcement also noted that 49% of TERNA (the primary owner of the national high-voltage electricity transmission grid) would be privatised. However, there are not yet any details as to how or when this might proceed. Other major energy sector privatisation activities include:

- the sale of up to 49% of the state-held energy holding group CDP Reti. The Group (currently wholly held by state investment company Cassa Depositi e Presiti) owns 30% of gas distributor Snam S.p.A. It will also get a 29.9% interest in TERNA. The deal was expected to be finalised by the end of 2014;
- in May 2014, it was announced that the Treasury was considering selling 10% of the multinational oil and gas company Eni S.p.A, and 10% of ENEL. Eni is currently estimated to be worth €68.7 billion while ENEL is valued at €39.4 billion. CDP owns 26.4% of Eni and the government holds directly 3.9% (Power Market, 2014). The possible sales may start in 2016;
- in July 2014, it was announced that the government was close to finalising a deal with China State Grid to sell a 35% stake in the Italian grid. This will involve a total investment of €2 billion by the Chinese group. It is the latest in a series of investments by Chinese firms in Italy's biggest state-run companies, following small-stake purchases in Eni and ENEL; and
- in May 2014, Chinese company Shanghai Electric agreed to buy a 40% stake in Treasury-controlled Ansaldo Energia (Williams, 2014).

In recent years, the number of foreign companies involved with the Italian energy sector has grown. For instance, at the end of 2011, French utility EdF, Europe's biggest power generator, decided to increase its stake in Italian energy company Edison. EdF paid €700 million to increase its holdings from 50% to 81%. EdF acquired the new shares from a holding company controlled by the Italian regional utility A2A (Sylvers, 2011).

As part of the move to reduce electricity prices, the Italian government is attempting to take local government out of utilities. It is also promoting mergers to create larger, more efficient companies that would be more attractive to foreign buyers, such as Chinese utilities. In October 2014, the government introduced a budget aimed at stimulating the economy. This proposed offering incentives to public owners to sell their stakes in local service companies. The intention is that the number of local utilities will be slashed, making it easier for bigger players to gain critical mass and compete at home and abroad. Italy has around 8000 local service companies controlled by town and regional authorities and the government is looking to save €2–3 billion by reducing these to around 1000. A previous review suggested that consolidation amongst the >1500 companies operating in energy, water and waste could reduce their numbers by ~80–90%. The government is eager for the big listed regional utilities (A2A, Hera Iren and Acea) to play a role in the integration process to create larger, stronger companies (Jewkes, 2014). Consolidation is viewed as critical for a sector that is largely made up of small, undercapitalised companies that need economies of scale to make them more efficient.

Alongside interest by the larger regional players in increasing the size of their respective companies, there is also growing attention from foreign investors. For instance, companies such as GDF Suez (already a shareholder of Acea) have expressed an interest in parts of the Italian utilities market. Also, EdF (that already owns Edison) could be interested in expanding further. Reportedly, some Chinese investors are also monitoring the situation. In recent years, China's power groups have been buying up overseas assets, taking advantage of the Eurozone crisis. For some time, the Italian government has been encouraging China to increase investment in Italy (Jewkes, 2014).

Not all proposed developments have come to fruition. For instance, in October 2014, it was announced that GDF-Suez would not proceed with a proposed takeover of E.On's Italian power assets (hydroelectric, solar and wind plants, as well as gas client portfolio). E.On Italia has 6 GW of installed power capacity in the country. However, reportedly, ENEL and EdF-backed Edison are now interested in the company's Italian client portfolio, as are some other regional utilities such as Hera and A2A. Overseas involvement is also increasing in a number of Italian power engineering companies. For instance, in May 2014, it was announced that the Chinese company Shanghai Electric Group had agreed to pay €400 million for a 40% stake in Ansaldo Energia. As part of this, two production JVs (for gas turbine production) and a research centre are planned in China. The new arrangements will allow Ansaldo to boost sales by entering the huge Asian market. It will give Shanghai access to the Italian company's technology. Ansaldo has also signed a cooperation deal with Doosan to develop a new gas turbine. In September 2014, US-based Westinghouse Electric Company announced it had completed its acquisition of Mangiarotti S.p.A., the Italy-based manufacturer of components for the power, oil and gas industries.

5.2 Electricity generation

With the exception of nuclear power, the Italian power sector encompasses all major forms of generating technology. The make-up of the generating sector is shown in Table 11. In 2012, the total electricity supplied amounted to 328.2 TWh. However, demand outstripped the supply available from Italian plants leading to a deficit of 43.1 TWh – this was met via electricity imports. There has been a growing deficit since the mid-1970s; in 1973, this was only 879 GWh. In recent years, total (gross) annual power consumption has usually been between 300 and 330 TWh. Coal-fired stations have typically generated 44–47 TWh of this total. The country's electricity balance for 2012 is shown in Table 12.

Table 11 Status of power plants (as of end of 2012) (TERNA, 2013)

	Producers	Autoproducers	National total
Hydro			
No of plants	2908	69	2977
Gross maximum capacity (MW)	22,116.8	132.2	22,249.0
Thermal plants			
No of plants	3045	508	3553
Gross maximum capacity (MW)	77,096.8	4291.1	81,345.8
Wind plants			
No of plants	1054	–	1054
Gross maximum capacity (MW)	8119.4	–	8119.4
PV plants			
No of plants	478,331	–	478,331
Gross maximum capacity (MW)	16,419.8	–	16,419.8

Table 12 Italian electricity balance – gross production for 2012 (GWh) (TERNA, 2013)			
	Market participants*	Autoproducers	Total for Italy
Hydro	43,280.7	573.3	43,854.0
Conventional thermal	202,078.2	15,483.2	217,561.4
Geothermal	5591.7	–	5591.7
Wind	13,407.1	–	13,407.1
PV	18,861.7	–	18,861.7
Total production	283,219.5	16,056.5	299,275.9
Net imports	43,103.4	–	43,103.4
Total energy supplied	315,519.7	12,628.0	328,219.8
* Producers, distributors and traders			

5.3 Existing coal-fired power plants

The main Italian coal-fired fleet comprises the power plants shown in Table 13. Major gas- and oil-fired plants are shown in Table 14 and Figure 11. Total coal-fired capacity is ~9.7 GW (Ruscito, 2013). Nine of these coal-fired plants use modern technology and consequently, achieve high levels of efficiency. The average efficiency of the existing coal-fired power fleet is ~40%, which compares well with the overall European average of 35% (Assocarboni, nd-b; ENEL Sustainability Report, 2009). However, ENEL's Torrevaldaliga Nord plant can achieve up to 45%. This particular plant was converted from oil-firing, and now uses steam conditions of 610°C/25.9 MPa–600°C/25.1 MPa (ENEL, 2015). Understandably, the efficiency of older plants is somewhat lower – for instance, the 330 MW units at the Vado Ligure station (currently closed for environmental reasons) had an efficiency of ~36.5%. The Sulcis 2 CFB plant is ~40%.

Table 13 Major Italian coal-fired power plants (Ruscito, 2013; Assocarboni, nd-a; Platts, 2013)				
Station	Operator	Coal-fired capacity (MW)	Fuel(s)	Comments
Brindisi Sud (Federico II)	ENEL	2640 (4 x 660)	Coal	Suppliers: Ansaldo, Tosi, Belelli, Fisia, TIBB
Brindisi Nord	Edipower	640 (2 x 320)	Coal, oil	Opted out of LCPD
Fiume Santo	E.On/EPH	640 (2 x 320)	Coal, oil	New 410 MW USC coal-fired unit proposed
Fusina	ENEL	640 (2 x 320) 340 (2 x 170)	Coal, RDF (Units 3–4)	Suppliers: Tosi, Marelli, TIBB, Fisia-BE
Monfalcone	A2A	330 (2 x 165)	Coal, biomass (Unit 2)	FGD installed in 2008. Plant opted out of LCPD New 800 MW CCGT being installed
Sulcis Grazia Deledda, Sardinia	ENEL	600 (1 x 350, 1 x 240)	Coal, oil, biomass	Main suppliers: Ansaldo, Alstom, Toshiba Some coal supplied by Carbosulcis
Torre Nord	ENEL	1980 (3 x 660)	Coal	Main suppliers: Babcock-Hitachi, Ansaldo, MHI
Vado Ligure	Tirreno Power	660 (2 x 330)	Coal, oil	Coal units shut down for environmental reasons New 460 MW coal-fired unit proposed
Genoa	ENEL	155	Coal	
La Spezia	ENEL	600	Coal	Main suppliers: Tosi, Marelli, Babcock & Wilcox
Bastardo	ENEL	2 x 75	Coal	
Brescia	ASM	70	Coal	

Table 14 Major Italian gas- and oil-fired plants

Station	Operator	Capacity (MW)	Fuel(s)	Comments
Lamarmora	A2A	31, 33, 75	HFO, gas, coal	Main suppliers: Breda, Tosi, Macchi, Ansaldo, AEG
La Casella	ENEL	4 x 387	Gas	Main suppliers: Ansaldo, Tosi, Marelli, Breda, Siemens, Alstom
Montalto di Castro	ENEL	2 x 660	Gas, HFO	Main supplier: Ansaldo, Tosi, Fiat, Nuovo Pignone, ABB, TIBB
Ottana	Ottana Energia	2 x 70	HFO	Main suppliers: Ansaldo-Breda, Tosi Captive power plant. In 2001, acquired by AES Corp.
Porto Corsini	ENEL	2 x 384	Gas	Fiat, Ansaldo
Ponti sul Mincio	A2A	80, 175, 250	Gas, HFO	Main suppliers: Breda, Tosi, Ansaldo, GE
San Filippo del Mela	Edipower	4 x 160, 2 x 320	HFO	Main supplier: Ansaldo
Sermide	Edipower	4 x 320	Gas, fuel oil	Enelpower added 3 x 250 MW GE 9001FA gas turbines to repower Units 3 and 4
Tavazzano	Endesa	4 x 320	Gas, fuel oil	Main suppliers: Sulzer, Ansaldo, Siemens, Tosi
Torrevaldaliga Sud	Tirreno Power	192, 4 x 335	Gas, HFO	Main suppliers: Ansaldo, Tosi

In January 2015 it was announced that E.On was to divest its coal and gas generation assets in Italy to Czech energy company EPH (Energetický a Průmyslový Holding). The overall package will amount to ~4.5 GW of generating capacity. This will include the coal-fired 640 MW Fiume Santo plant (Figure 10), plus ~3.9 GW of gas-fired power capacity comprising six plants located on the Italian mainland and Sicily. The transaction is subject to the approval of the EU Competition Authority; it is expected to close in the second quarter of 2015.

Figure 10 The coal-fired Fiume Santo power plant (photograph courtesy E.On)

Figure 11 ENEL's Porto Corsini 750 MW CCGT power plant in Ravenna

5.4 Power plant modernisation and rehabilitation

The liberalisation of the Italian energy sector resulted in the construction of a number of new high-efficiency CCGT power plants – by the end of 2009, around 18 GW of new gas-fired generating capacity had been added. In order to maintain their competitiveness in this changing market environment, some operators of existing coal-fired units (many of which were built during the 1960s and 1970s) were spurred into modernising and/or updating their plants. Over the past decade, many coal-fired power plants have been suitably modernised in order to improve performance and/or reduce environmental impacts. A series of programmes was undertaken that significantly increased plant efficiency and reduced emissions. The Italian generation fleet is regarded as one of the most efficient in Europe (Torre, 2010).

The sector is now significantly different to pre-liberalisation. In 1998, total installed capacity was 54 GW, comprising mainly coal- and oil-fired plants (Table 15). Most were subcritical although there were a number of supercritical units in operation.

Table 15 Make-up of the Italian power generation fleet in 1998 (Torre, 2010)

No of units	Capacity (MW)	Efficiency (%, LHV)	Details
25	120/160	34–36	Subcritical Suppliers Ansaldo, F Tosi, Rateau, BBC
60	240/350	36–37	Subcritical Suppliers Ansaldo, F Tosi, Rateau
17	600/660	38–39	Supercritical Suppliers Ansaldo, F Tosi

Although the liberalisation of the sector resulted in the addition of new CCGT capacity, the modernisation and/or upgrading of existing coal-fired assets was sometimes viewed as an attractive alternative – for instance, this often included the re-use of existing infrastructure, buildings, and transmission systems. Plant modernisation inevitably improved environmental performance.

Various measures were adopted to increase the efficiency of coal-fired plants. In many cases, this entailed the upgrading of steam turbines. A common problem with ageing coal-fired units involves erosion of the steam turbine's blade path. Through the use of modern design tools and manufacturing practices, it is possible to redesign the steam path and optimise the HP or IP steam path – this can achieve an additional 3 to 5% in design efficiency. Installation of more efficient blading increases the steam/power output and improves the unit's overall heat rate. Improving heat rate is considered to be a cost-effective tool for controlling CO_2. Estimates by Electric Power Research Institute (EPRI) of the USA suggest that a 1% heat rate reduction results in a 1% reduction in CO_2 emissions (Power Engineering, 2015). In Italy, techniques adopted to improve turbine performance included the use of modern 3D blades and larger last stage blading (often based on newer materials of construction).

Plant upgrades to Italian power plants have included:

- **Sulcis 2** (260 MW). The plant started up in 1966; the original equipment manufacturer (OEM) was Rateau Schneider. The steam turbine was a tandem compound arrangement with HP and IP separated sections and a double flow LP section. Steam conditions were 538°C/16.8 MPa – 538°C/3.6 MPa (ENEl, 2015). In 2002, the modernisation of the plant included the replacement of the existing boiler with a CFBC unit. The old steam turbine was also switched to a new Ansaldo (reaction type) unit. Benefits included a boost in gross power output to 350 MW, gross efficiency was increased to 40%, and CO_2 emissions were significantly reduced.
- **Fusina 3 and 4**. The plant started up in 1974 – the OEM was Tosi/Westinghouse. In 1995 and 1996, an environmental retrofit was carried out with the installation of FGD, SCR, ESP and low NOx burners.
- **Brindisi Sud (Federico II).** Initial plant operations began in 1991. The OEM was Tosi/Westinghouse. As part of a programme to improve efficiency and reduce emissions, a retrofit programme was undertaken. This included the replacement of the steam turbine low pressure inner blocks and the adoption of improved 3D optimised blading (on Unit 3). Other activities undertaken included upgrading of coal mills and revamping of the plant's ESPs (replaced with fabric filters – Units 3 and 4 by Termokimik, in 2010 and 2012 respectively) and an SCR system on Unit 4 (Benelli, 2013; ENEL, 2015). In addition, the blow down from the absorber, along with other wastewaters, is now sent to a new Zero Liquid Discharge (ZLD) plant. Further recent improvements have included the erection of sealed coal storage domes (expected to be in operation by September 2015), the installation of two new stacker/reclaimer machines, and new coal conveyers (Figure 12).
- **Brindisi Nord.** As well as turbine improvements, various environmental upgrades were made in order to meet more stringent air emission limits. For instance, this included the installation of an SCR system by Termokimik Corporation.
- **La Spezia.** In order to reduce energy consumption and improve environmental efficiency, a series of modifications were made to the plant's 600 MW coal-fired unit. This included modification of air preheaters and the installation of eight transformers for the ESPs in order to reduce particulate emissions (ENEL Sustainability Report, 2009). The FGD unit was also improved by the installation of new twin nozzles. In addition, the blow down from the absorber, along with other wastewaters, is now sent to a new Zero Liquid Discharge (ZLD) plant. Further activities aimed at reducing plant emissions (focused on the FGD, SCR and ESPs) are planned for 2016.

Figure 12 The Brindisi Sud (Federico II) power plant (photograph courtesy of ENEL)

Systematic upgrades continue to be made to Italy's power plants. For example, in 2013, ABB was contracted to re-equip ENEL's 240 MW coal-fired Grazia Deledda plant at Sulcis 3 with its automation and control system. This has improved plant efficiency. This new control system includes a high-performance controller, as well as burner and FGD management systems, and plant instrumentation (ABB, 2013).

5.5 Environmental issues – power generation

The emission standards for air pollutants from industrial processes were first set in a Decree of the President of the Italian Republic (DPR No. 203, 1988) – this transposed EU Directive 84/360/EC into Italian law. The standards were later supplanted by Legislative Decree 152/2006 (No.152, 2006) which implemented EU Directive 2001/81/EC. This came into force in April 2006. In 2014, Decree No. 46 was issued – this transposed EU Directive 2010/75/EU into Italian law. The emission limit values foreseen by this Decree will come into force in January 2016.

The current emission limits for coal-fired power plants are dependent on a number of factors such as plant age and thermal capacity. However, for existing plants with a rated thermal input equal to or greater than 300 MWth, current legal limits are:

- SO_2 – 200 mg/m^3;
- NOx – 200 mg/m^3;
- particulates – 20 mg/m^3.

During the past decade, through heavy investment, Italy has significantly reduced its emissions of SO_2, NOx and particulates emanating from the coal-fired power sector. The country now has a number of power plants in operation that are cleaner and more efficient than many others in Europe. Nine of the main plants have European *Eco-Management and Audit Scheme* (EMAS) certification. This equates to ~9.5 GW of installed generating capacity (around 85% of Italy's coal-fired generating capacity). The result of this investment in modern environmental control systems has significantly reduced the levels of classic pollutants emitted (Assocarboni, nd-a).

For some years, emissions of both NOx and SO_2 have fallen steadily. Between 1990 and 2011, SO_2 fell by 89% and NOx by 54% (Figure 13) (Italian GHG Gas Inventory, 2013).

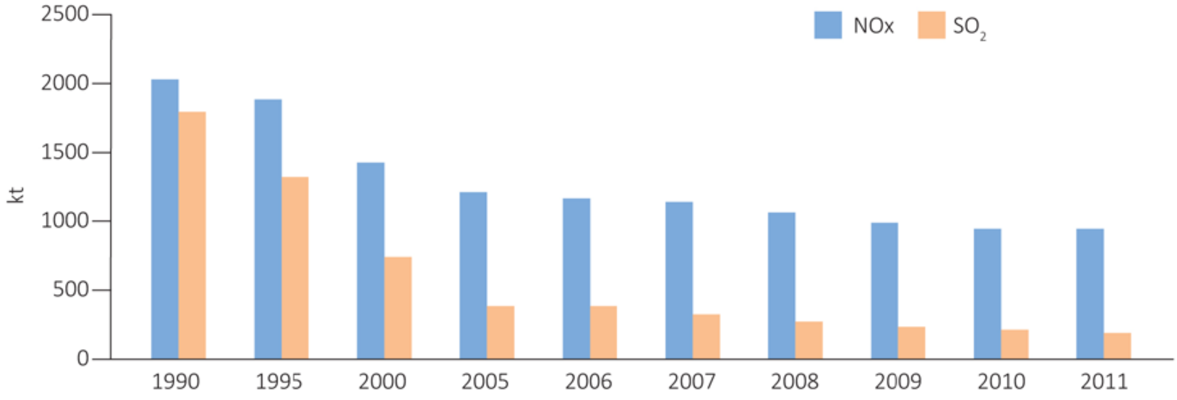

Figure 13 Total emissions of NOx and SO_2 (kt) (Italian GHG Inventory, 2013)

Over the past decade, operators of coal-fired power plants have undertaken emission reduction programmes and systematically improved control systems. For example, ENEL's environmental strategy has focused on reducing NOx emissions via the installation of low NOx combustion systems coupled with SCR, reducing SO_2 emissions through the retrofitting of FGD systems, and switching from ESPs to fabric filters/bag houses in order to further reduce particulate emissions. Between 1990 and 2012, these moves significantly reduced emissions from ENEL coal-fired power plants – SO_2 emissions fell by 96%, NOx by 91%, and particulates by 98% (Benelli, 2013; ENEL, 2015). In 2012, emissions to air resulting from ENEL's power generation activities amounted to 20.2 kt of SO_2, 20.37 kt of NOx, and 671 tonnes of particulates (ENEL Environmental Report, 2012 – p158). These had fallen from 2009 levels of 26.1 kt of SO_2, 24.7 kt of NOx, and 1.2 kt of particulates. The bulk of these were generated by coal-fired power plants.

Other generators have also installed improved emission control systems; for instance, at the Fiume Santo plant (Units 3 and 4), E.On installed measures to minimise plant emissions. Since the 1980s, air quality in and around the plant has been monitored by a network of sampling stations. The plant has been equipped with an environmental management system, and since 2005 has been listed in the EU EMAS Register (E.On Italia, 2012). Examples of emission control systems deployed at major Italian power plants are shown in Table 16.

Table 16 Power plant emission control systems (Benelli, 2013; Platts, 2013)

Power plant	SO_2 control	NOx control	Particulate control
Torre Nord 5–7	FGD (MHI)	Advanced combustion system, SCR, urea-to-ammonia plant (Ammogen)	Fabric filter
Brindisi Sud 1–4	FGD (Fisia–IDRECO, EURIALO)	Overfire air, SCR, LNB	Fabric filter-ESP
Brindisi Nord 1–4		SCR	ESP
Fusina 1–4	FGD	Overfire air, SCR, LNB	Fabric filter-ESP
Genoa (Genova)		Overfire air	Fabric filter
Monfalcone 1, 2	FGD (MHI)		ESP
Fiume Santo 3, 4	FGD	Overfire air, SCR, BOOS (oil units)	ESP
Vado Ligure	FGD (MHI)	SCR, LNB, reburning	ESP
Sulcis 3	FGD (MHI/Ansaldo)	SCR, LNB	ESP
Sulcis 2A (CFBC)	Furnace sorbent injection	Primary methods	Fabric filter
La Spezia 3	FGD	LNB, SCR	ESP
Bastardo 1, 2		LNB	ESP

Most of the **flue gas desulphurisation** (FGD) units fitted to Italian power plants have been based on systems supplied by MHI. Some were built in conjunction with Italian partners. For instance, the DCFS (Double Contact Flow) FGD system for ENEL's Torrevaldaliga Nord plant was built with Demont, a construction company and MHI licensee. MHI was responsible for much of the basic and detailed engineering of the system, and Demont undertook plant construction. Demont was also involved with several similar MHI FGD projects elsewhere in Italy. A number of FGD units were also supplied by Italian company IDRECO – for instance, during the 1990s, the company provided two wet FGD units to the Brindisi Sud plant, and two more to the Fusina station (IDRECO, nd). In a typical year, ENEL's coal-fired power plants use ~ 260 kt of limestone for FGD operations (ENEL Sustainability report, 2009). In 2012, it was 381 kt (ENEL, 2015).

On the R&D front, Sulcis coal mineral matter has been examined for its potential use in the dry desulphurisation of coal-derived flue gas. Small-scale experimental testing was carried out under various conditions – it was confirmed that it could be an effective reactant for dry desulphurisation (Mura and others, 2005).

The bigger power plants all feature some form of **NOx control technology**. This mainly takes the form of combustion modifications, low NOx burners and/or SCR units. Since the mid-1990s, nearly 19 GW of coal-, oil- and gas-fired plants have been retrofitted with SCR technology (Table 17). Combustion modifications have been made to various plants in order to minimise NOx emissions and improve plant performance. For instance, in 2000, as part of a major refit, ENEL's La Spezia plant was suitably re-equipped. A major objective was to implement primary low NOx measures such that emissions would meet upcoming EU emission limits. Thus, an advanced combustion system was supplied by BWE – this significantly widened the range of coals that could be accommodated. The system comprised WR (wide range) burners (36 burners arranged in boxer firing configuration), an OFA (overfire air) system, dynamic classifiers, and an optimised fuel distribution system. NOx levels were reduced to less than 550 mg/m^3 at the inlet of the SCR. In addition, there was a reduction in unburned coal-in-ash to ~3%. Other technology vendors who have been involved in the supply of low NOx burners and/or SCR systems have included Babcock-Hitachi, IDRECO, K W Huls, Termokimik, BEL, Frauenthal, and Ansaldo (Platts, 2013). Annually, ENEL power plants typically consume ~19 kt of ammonia (~18 kt in 2012) mainly for deNOx operations (ENEL sustainability report, 2009; ENEL, 2015).

Table 17 SCR units deployed on coal-fired power plants

Plant	Units	Main fuel	Catalyst type	Catalyst manufacturer	Configuration	DeNOx reactors
Brindisi Sud	4 x 660 MW	Coal	Plate	Hitachi	High-dust	4
Fusina	2 x 320 MW	Coal	Honeycomb	KW Huls	High-dust	3
Montalto di Castro	2 x 660 MW	Gas	Honeycomb	Termokimik	High-dust	3
Rossano Calabro	4 x 320 MW	Gas	Plate	Hitachi	High-dust	8
La Spezia	600 MW	Coal	Honeycomb	IDRECO, Frauenthal	High-dust	3
Sulcis 3	240	Coal	Honeycomb	Frauenthal	Tail-end	2
Termini Imerese	320 MW	Gas	Honeycomb	Fisia	High-dust	4
Torre Nord*	3 x 660 MW	Coal	Honeycomb	Babcock Hitachi	High-dust	4
Fiume Santo	2 x 320 MW	Coal			High-dust	

As in many other countries, Italian plants have relied mainly on ESPs for reducing **particulate emissions**. And whereas some still do, in order to reduce levels further, others have been re-equipped with fabric filters/bag houses. As part of its corporate strategy to reduce emissions from its power plants, ENEL is progressively replacing ESPs in its coal plants with fabric filters. These are of the pulse jet, high pressure, low volume type (Benelli, 2013). The Italian company Termokimik has undertaken many of the ESP-to-fabric filter conversions (such as those at Torrevaldaliga Nord). In terms of particulate emissions, this is now regarded as one of the most efficient plants in the world – the emission limit value is 15 mg/m^3 (hourly average). Advantageously, such conversions re-use much of the existing ESP structure and casing, thus minimising capital costs. Termokimik's fabric filters are claimed to have a high removal rate (99.9%) and be capable of achieving emission levels as low as 2 mg/m^3. ESPs supplied by vendors such as Sadelmi (ABB), Flakt, Walther and Alstom, are still in use on several ENEL plants as well as those of other generators such as A2A and E.On.

The monitoring of power plant emissions is carried out by various means. Levels of SO_2, NOx and particulates emitted from ENEL plants are measured continuously, as established by law. Other generators adopt similar techniques. For example, at E.On's Fiume Santo plant, levels of air and soil pollution are controlled by means of a monitoring network around the station; this covers about 30 km^2. This particular plant has a registered environmental management system and is ISO 9001 certified for combustion, fly ash production and discharge. ENEL also operates comprehensive monitoring networks around some of its power plants. In some cases, these are managed by the local authority.

The SNOX process is also in use in Italy, although currently limited to a petcoke-fuelled power plant. This regenerative, catalytic cleaning process simultaneously removes up to 99% of SO_2 and SO_3, up to 96% of NOx, and essentially all particulates from flue gases. The process is used at a coal-fired plant in Denmark and also the 300 MW petcoke-fired power facility at the Agip Petroli refinery in Gela, Sicily. The SNOX plant was supplied on a turnkey basis by Snamprogetti and handles up to 1,200,000 m^3/h of flue gas from four downshot boilers. It went into operation in 1999 (Schoubye and Jennes, 2007).

Historically, other emission control technologies have been investigated for their potential on coal-fired power plants. For instance, the *Pulsed Corona Discharge* technique has been considered – this is based on the application of narrow voltage pulses to an electrode structure similar to that of an ESP and can simultaneously remove NOx and SO_2 from flue gas. A pilot plant was built at the Thermal Nuclear Research Center in Pisa and trialled on a slipstream fed from the flue gas duct of a coal-fired power plant. However, it is not currently in commercial operation in Italy.

In terms of reducing pollutant emissions, the conversion of ageing oil-fired generating capacity with state-of-the-art coal-fired plant has been shown to be beneficial. For example, as noted earlier, emissions of classic pollutant have been significantly reduced at the Torrevaldaliga Nord station. The SO_2 emission limit value is 100 mg/m^3 (hourly average), NOx is 100 mg/m^3, (hourly average), and particulates 15 mg/m^3 (hourly average) (Benelli, 2013). In practice, emissions when operating are lower than limit values. Had the proposed oil-to-coal conversion proceeded at Porto Tolle, emissions were also expected to be low (Table 18). The plant was to have featured FGD, SCR and fabric filter systems. Plant efficiency was expected to have increased from 39% to 45%.

Table 18 Expected emissions from Porto Tolle power plant (mg/m^3)

	Existing oil plant	Proposed coal plant
SO_2	400	100
NOx	200	100
Particulates	50	15

The most notable recent environmental issue has centred on Tirreno Power's Vado Ligure power plant in the northern district of Savona. In March 2014, a judge ordered the shut-down of the plant's two 330 MW coal-fired units. It was claimed that these were the cause of premature deaths and disease in the surrounding area. Operation of the company's 800 MW CCGT power plant was unaffected by the ruling. Tirreno Power has countered that the study on the plant's health effects was biased and is appealing the case. However, in July, an appeal to release the seized coal-fired units was rejected by the courts. Tirreno Power has offered to make changes that will reduce emissions. At the end of 2014, the Environment Ministry was examining these proposals to decide whether to grant a new environmental authorisation.

5.5.1 Utilisation of power plant solid residues

During normal operation, coal-fired power plants generate a number of solid residues. These generally comprise fly and bottom ashes from the combustion stage and, if equipped with SO_2 control equipment, residues from FGD operation. Within Europe as a whole, 60 Mt/y of coal combustion residues are generated. The bulk of this comprises 66% fly ash, 10% bottom ash, and 18% FGD residues.

A typical 660 MW coal-fired unit produces ~20 t/h of fly ash, usually captured by either ESP or fabric filter. Within Europe, around 40 Mt/y are generated. Most power plants stockpile no more than a week's ash production. Because of increasing limitations on landfilling, much of this is now directed towards utilisation, rather than disposal. Fly ash is commonly utilised in construction products, or used as secondary raw material in the production of blended cements and concrete mixtures (as a pozzolanic addition and micronic filler); it improves mechanical properties and durability of the final products (Belz and Caramuscio, 2013). In Italy, the total amount of ash generated by ENEL's coal-fired power plants is ~59 kt. Of this, 33 kt is recycled (Ferone and others, 2013; ENEL Environmental Report, 2012). Similarly, in 2013, most of the ash produced by Edipower's coal-fired plants was recycled, as was that from plants operated by Tirreno Power and E.On. Most was recycled into construction materials. Overall, there is a high degree of fly ash utilisation within the country.

Fly ash is used in a range of materials such as cement, ready-mix concrete and aggregates, produced by Italian cement manufacturers such as Italcementi Group and Cementir Italia. Some fly ash is also exported to overseas markets. For example, STEAG Power Minerals recovers and exports fly ash from several plants in Civitavecchia and Brindisi. Since the start of this arrangement in 2009, more than 600 kt of ash has been recovered, transported and recycled. Most goes to the concrete and cement industries in the UK and Belgium.

The other solid residue produced in significant quantities is gypsum from FGD operations. Italian coal-fired plants generate around 0.45 Mt/y of gypsum – of this total, around 0.36 Mt is utilised (Ferone and others, 2013). There are many uses for FGD gypsum that include agriculture, road construction, mining applications, cement production, water treatment and glass making. However, the biggest outlet is for the production of wallboard. In Italy, this is produced by a number of major manufacturers such as Knauf and BPB Italia. Gypsum produced at the Torre Nord plant is sold to Lafarge.

5.6 Italian power plant engineering capabilities

Italy boasts a number of major companies involved in the development and construction of complete power plants and/or the supply of major plant component and systems to the power sector. One of the biggest players is Genoa-based **Ansaldo Energia**. The parent company (Ansaldo) was taken over by Finmeccanica in 1993. Ansaldo Energia manufactures different types of thermoelectric power systems and components and has supplied generating capacity in excess of 166 GW in over 90 countries. Main product ranges include gas turbines (70–280 MW), non-reheat and reheat steam turbines (80–1200 MW) and generators. Various materials of construction are available to handle different steam conditions up to

USC parameters (600°C/620°C). Turnkey combined cycle power plants are also available (100–1600 MW). Most major components for gas and steam turbines are manufactured in-house whereas other parts, such as heat recovery steam generators (HRSG), condensers and plant auxiliaries, are normally purchased from selected suppliers. In May 2014, Chinese company Shanghai Electric agreed to buy a 40% stake in Ansaldo Energia (Williams, 2014).

Ansaldo Caldaie S.p.A. (part of the SOFINTER Group since 2001) is the largest Italian original technology boiler manufacturer. It provides a range of equipment that includes coal-, oil- and gas-fired utility boilers; burner systems; HRSGs for CCGT power plants; biomass and waste-to-energy boilers; and environmental equipment such as low NOx firing systems. The company has supplied more than 1000 boilers that combined, total more than 80 GW in capacity – this includes 24 GW of coal-fired boilers. The main boiler factory is located in Gioia del Colle. This specialises in the manufacture of pressure parts such as utility boiler membrane walls, coils, drums, headers and HRSGs. Completed major projects include the supply of three 660 MW USC coal-fired boilers to ENEL's Torrevaldaliga Nord power plant (Babcock Hitachi licence). SOFINTER Group operates a combustion research centre (CCA Centro Combustione Ambiente) focused on the development of advanced combustion techniques. The company also owns (through its subsidiary, ITEA) the ISOTHERM pressurised flameless oxycombustion technology. Ansaldo Caldaie recently changed its name to AC Boilers.

Formerly part of Ansaldo Caldaie, Franco Tosi was subsequently transferred to the Cast Group, becoming **Franco Tosi Meccanica S.p.A.** Located in Legnano near Milan, the company manufactures steam turbines and a range of other equipment for coal- and biomass-fired power plants. It also offers heat exchangers, cogeneration plants, CCGTs, district heating systems, and various renewable energy systems. A range of standardised steam turbines is also offered (300 to 850 MW). Larger units are available for supercritical conditions (600°C/620°C). However, in July 2013 the company was declared insolvent – it has since received a rescue package from the Italian government.

Saipem is an operating subsidiary of Eni S.p.A. and is headquartered in Milan. During the past decade, a number of construction and engineering companies have been acquired, becoming part of the group – this included Snamprogetti (now the ecology division). Saipem operates as an international turnkey contractor, working predominantly in the oil and gas sector, offering a range of EPC, management and construction services. Environmental projects are also undertaken as is the provision of appropriate equipment and services. The company is involved in power generation projects based on both fossil fuel and renewables. It also offers carbon capture and storage equipment and has participated in a number of major CCS projects worldwide. This has included collaboration with Eni/ENEL on several CCS-related demonstrations.

Snamprogetti S.p.A. (part of Saipem S.p.A since 2008) is engaged in the engineering and construction of power facilities and a range of industrial process plants. The company operates as an EPC contractor for the design and implementation of major projects mainly for oil refineries and the gas sector. This includes onshore and offshore systems and infrastructure, power plants, and environmental control equipment.

The company was heavily involved in the development and construction of Italy's refinery-based IGCC plants, currently operating (ISAB, ENI Sannazzaro, Sarlux, etc). Historically, Snamprogetti manufactured numerous fluidised bed grate furnace incineration plants for MSW and other fuels.

In 1993 as part of the privatisation of the parent company Eni, Florence-based **Nuovo Pignone** was sold to General Electric (GE). It now forms part of GE's Oil & Gas Division and produces a range of equipment mainly for the oil and gas sector. This includes turbomachinery, heat exchangers, compressors, pumps, static equipment and metering systems. Equipment for gas re-injection for enhanced oil recovery is also offered. A range of steam turbines (5–100 MW) is produced for power generation and other applications.

The Italian engineering company of **Demont** was set up in 1972, with the main focus on the erection and maintenance of petrochemical and power plants. The company now operates from a number of locations in Italy and provides a range of services that include the design, supply, installation, start-up and maintenance of energy producing systems. Important areas of activity encompass fossil fuel and biomass-fired plants, district heating systems, and CCGT power plants. The company produces prefabricated pipework, ductwork, steel structures, boilers, HP/LP steam drums, deareators and heat exchangers. Services and components have been supplied to many power plants in Italy and overseas. Flue gas clean-up systems such as FGD and SCR units are also available. Recent environmental projects have included the installation of a hybrid-type SCR plant plus combustion system update at the Priolo Gargallo Impianti Nord power plant. The company was also heavily involved with the supply and erection of FGD plants at the Torrevaldaliga Nord and Vado Ligure power stations.

Techint Engineering & Construction is based in Milan. It operates as an EPC contractor and provides operation and management services for large-scale projects. The company has been involved in a number of major Italian power projects where it has provided EPC services and/or boiler erection; this has included the Brindisi Sud and Montalto di Castro steam power plants. There has also been heavy involvement on the development of a number of Italian CCGT plants that have included units at Piacenza (800 MW), Dalmine (120 MW), and Termini Imerese (960 MW).

Other Italian companies specialise in the manufacture of components destined for the international power market. For instance, **C*Blade S.p.A. Forging & Manufacturing** of Maniago produces various types of blade for steam and gas turbines. These are offered in a range of different materials that include stainless steels, titanium and nickel alloys. Depending on end-use requirements, these can be treated further via hardening, stellite brazing or cladding, shot peening or coating. The company's steam and gas turbine blades are in operation in several hundred power plants around the world. Similarly, **Marelli Motori S.p.A.** of Arzignano manufactures a range of generators for the power and cogeneration sectors. These have been supplied to numerous overseas projects. Other services are also provided by Italian firms. For example, **MGM Engineering & Contracting S.r.l.** of Milan produces technical assessment and feasibility studies, FEEDs, and plant/process designs for thermoelectric power plants and cogeneration systems.

There are also a number of major multinational players that maintain a presence in Italy. For example, **Foster Wheeler Italiana S.r.l.** is headquartered in Milan and is one of Italy's major engineering and contracting companies. Services available include project studies, FEEDs, project management, and EPC for the oil and gas and power sectors. This encompasses different types of power plant (fossil-fuelled and renewables), as well as gasification-based plants for energy and chemicals production. The company has developed a strong position in the Italian build, own and operate (BOO) market for CCGTs (such as the 400 MW Teverola plant north of Naples) and renewables. Similarly, with various Italian facilities, **Siemens** is also active in the country, providing services to the energy sector. These include the supply of components such as transformers, turbine upgrades and maintenance, as well as the provision of EPC services to energy-producing projects that include fossil fuel-fired plants and renewables. **Alstom Power Italia** also remains active in Italy, operating from 12 production sites. In recent years, a number of Italian engineering and electrical engineering companies (such as Ercole Marelli and Tecnomasio Italiano) have become part of Alstom. The company designs and supplies power plants and produces strategic components such as turbines, generators, environmental control systems and boilers. It has been responsible for the installation of 40% of Italy's turbo-generators. Alstom also offers the maintenance and modernisation of major plant components such as steam and gas turbines. A range of components is also produced for the power transmission system.

Maire Tecnimont S.p.A. is the parent company of this Italian group. The latter consists of more than fifty operating companies active in the engineering and contracting sector. The company operates (both in Italy and more than 30 other countries) in areas that include the oil and gas, and power generation sectors (both fossil fuels and renewables). A range of turnkey and EPC-related services are offered. Tecnimont often partners with other specialist firms. For example, Tecnimont, together with Techint and Siemens, undertook the EPC and commissioning of a GTCC power plant (the 840 MW Turbigo plant at Piacenza, based on two Siemens gas turbines) for Edipower. There have also been a number of coal-based power projects. Numerous overseas projects have included two 370 MW coal-fired power stations in Chile (via a Tecnimont-led consortium including Tecnimont do Brazil, Tecnimont Chile, and SES), and two 385 MW coal-fired power plants in the Dominican Republic (via a consortium comprising Norberto Odebrecht, Tecnimont and Enginiera Estrella).

There are a number of Italian companies who manufacture and supply various types of emission control systems aimed at the power sector. Systems are available for the control of the main coal-fired power plant emissions (SO_2, NOx, and particulates). A major player is the Milan-based contracting and engineering firm of **Termokimik Corporation**. Amongst its services, the company offers flue gas deSOx, deNOx and particulate capture systems for power plant and industrial facilities. Termokimik has been particularly successful in the area of SCR and SNCR, having equipped more than 21 GW of capacity worldwide. Depending on the application, fuel and process temperature, two main configurations for SCR can be provided. High-dust SCR (high-temperature) variants are usually supplied for power and cogeneration plants, whereas Tail-end SCR (low-temperature) units are often used for waste incineration applications. Catalysts can be tailored to meet specific requirements. The company has also been responsible for converting many existing ESP units at Italian power plants to fabric filters.

Founded in 1976, IDRECO is an integrated group of companies, technically led by **IDRECO S.p.A**. A major focus has been on environmental protection and the company produces a range of turn-key installations for waste and industrial water treatment. Alongside this, its air pollution control division designs and manufactures equipment for the clean-up of classic power plant emissions. Systems available include deNOx and deSOx plants, ESPs and fabric filters. IDRECO FGD units are of the wet limestone variety. NOx control systems are based on SCR technology. Numerous power plant flue gas clean-up projects have been undertaken in Italy. These have included the provision of FGD units to power plants such as Brindisi Sud (Units 1 and 2) and Fusina, and high-dust SCR units to plants at Fiume Santo and La Spezia. As noted above, flue gas clean-up systems such as FGD and SCR units are also available from a number of other Italian companies such as **Demont**.

6 Clean Coal Technologies (CCTs)

The potential of clean coal technologies has long been recognised in Italy and a number of important projects have been undertaken with the aim of generating electricity from clean and efficient coal-fired power plants. These have included the conversion of several major plants from Orimulsion or oil to clean coal firing, the introduction of CFBC technology on a commercial scale, the deployment of modern emission control systems (such as FGD and SCR), and the use of advanced supercritical/ultra-supercritical steam conditions in PCC plants. Other RD&D efforts remain on-going. There have also been several major clean coal-based projects that, for various reasons, failed to materialise (Vado Ligure, Porto Tolle and Saline Joniche). Other areas such as co-utilisation of coal and biomass/wastes, gasification, and coal-to-liquids continue to be the focus for research and development by a number of Italian organisations and universities.

The most recent major CCT development came in August 2014 when it was announced that the Italian government was to provide €30 million to help establish the CO_2 Technology Centre of Sulcis at Sotacarbo's (Società Tecnologie Avanzate Carbone S.p.A) research centre in Carbonia, Sardinia. Sotacarbo was established in 1987 to exploit coal through the development of advanced CCTs and other techniques. The latest activities form part of the 10-year *Electricity System Research* programme and are expected to play a key role in redefining future Italian energy policies. The Centre's development has been encouraged by both the Region of Sardinia and the Italian government. Research will be focused in five main areas, namely:

- zero emission technology for coal and biomass power generation;
- liquid fuels from coal;
- carbon capture and storage (CCS) technologies;
- the integration of renewable power generation with power plants using fossil fuels; and
- oxycombustion technologies.

The main challenge for the new centre will be to develop solutions that meet the demand for research, innovation and development of advanced energy technologies – this research will be increasingly directed to industrial applications. A number of national and international projects are already underway at the centre.

6.1 Comparing power generation systems via Life Cycle Assessment (LCA) studies

Historically, the selection of a power generation technology has been dominated by efforts to determine the least cost option (Widiyanto and others, 2002). When addressing environmental impacts from such systems, there has been a tendency to concentrate almost solely on the power plant stage, giving little consideration to the remainder of the production chain. This approach has often failed to paint a full environmental picture of the cycle, as significant impacts can result from other stages. Although in the case of coal-fired plants, the bulk of emissions are produced at the combustion stage, this may not be the case with other technologies. For instance, with gas-fired systems, significant methane emissions can occur during gas production, processing and transport, prior to combustion. Without the application of LCA, these other stages may not be considered fully (CISS, 2000; Nalbandian, 2015).

Coal-fired power plants are often assumed to emit much higher levels of greenhouse gases (GHG) than gas-fired units. However, if the impacts of the entire production/use chain are taken into account, the issue may not be so clear cut. Various LCA studies have examined the full chain for coal- and gas-fired plants. Unsurprisingly, these confirm that at the point of combustion (in the power plant) CO_2 emissions from conventional coal-fired plants are higher than those from gas-fired facilities. Up to 97% of life cycle emissions from coal can occur at the point of combustion (Mills, 2005). However, over the full life cycle, total emissions from gas-fired plant may be significantly higher than is often perceived. Of particular importance is the composition of the original gas, plus the effectiveness of its extraction and distribution. CO_2 and other emissions (such as CH_4) from various non-combustion stages in the chain can have a significant impact on the overall level of emissions per unit of electricity produced. This has not always been taken into account (for example, see Nalbandian, 2015).

Like coal, the largest contributor in the natural gas combined cycle (NGCC) chain is the power plant – some LCA studies have suggested that this stage is typically responsible for 84–86% of the total. However, there may also be major impacts at others stages such as gas extraction, transmission, and distribution. Fugitive methane emissions can be significant and comprise intentional and unintentional emissions or leaks that may originate at various stages of the process; for example, gas flaring or venting. Emissions produced during flaring are mainly water and CO_2, whereas with venting, they can comprise CH_4, CO_2, VOCs, sulphur compounds (mainly H_2S), and various other impurities (Zerlia, 2005).

LCA studies have suggested that GHG emissions for conventional pulverised coal-fired power generation fall between 762 and 1310 h CO_2-e/kWh. Those for natural gas combined cycle (NGCC) fall between 390 and 690 CO_2-e/kWh (Mills, 2005).

A number of studies comparing different systems have been undertaken. For example, in Italy, the Experimental Station for Fuels in Milan examined the topic, studying both combustion and pre-combustion phases for different fossil fuels. These studies concluded that when all associated issues were taken into account, the gap between gas- and coal-fired plants was not as wide as often perceived. Thus, for gas-fired generation, total GHG emissions fell between 510 and 670 gm of CO_2-e/kWh (based on imported gas), and 420 gm of CO_2-e/kWh if the gas was produced in Italy. As noted, pre-combustion phases can have a significant impact on the final figure. Thus, GHG emissions were much higher if Russian gas was used. For Italian-produced gas, pre-combustion emissions were lower – most were generated at the combustion phase. For coal-based generation, GHG emissions were between 780 and 910 gm of CO_2-e/kWh (Barabino and Partners, 2012). Pre-combustion emissions were higher if the coal came from a deep mine. For surface mining, nearly all GHG emissions were associated with the combustion stage (Assocarboni, 2014).

Directly comparing power generation emissions on an LCA basis can be problematic – different methodologies may be applied, and there are often site-specific factors. There may also be differences in the boundaries adopted and assumptions made. Hence, although there is some disparity in the numbers cited from earlier studies and those of the Experimental Station for Fuels, this is not unusual. The overall conclusions are similar and suggest that when the full life cycle is taken into consideration, the gap between poorer performing NGCC plant and better coal plants is not as great as is often portrayed (Barabino and Partners, 2012). The application of CCTs such as IGCC or USC, or deployment of CCS, would close the gap further. There are also other technologies and strategies that could possibly further improve the position of coal (such as integration with renewables or other industrial operations) (Wibberley, 2001). Clearly, the use of state-of-the-art coal-fired power generation systems of high efficiency effectively reduces the amount of coal consumed per unit of electricity generated (hence reduces CO_2 emissions).

Thus, LCA studies have compared gas and coal-fired generation systems and generally agree that, in terms of emissions of SO_2, NOx, particulates and CO_2, the former has less environmental impact. However, on a full life cycle basis, the amount of GHG emissions produced by NGCC systems can be influenced significantly by, for instance, the composition of the original natural gas used. Thus, gas will have less environmental impact than coal, provided that the original source of gas is low in CO_2, venting and flaring are avoided, and losses in transport and distribution are low. Studies have suggested that in some situations, these emissions could result in gas-based power generation having similar or even greater greenhouse gas emissions than for equivalent coal-based capacity (Nalbandian, 2015)

In the case of oil-fired power plants, LCA suggests that emissions of SO_2 will be higher, whereas NOx and particulates will be lower than comparable coal plants. Life cycle GHG emissions for oil-fired plant using a conventional steam cycle fall between 686 and 937 gCO_2-e/kWh. This range reflects the variety of sources of oil, the type and scale of the power plant, and the type of emission control processes deployed (low NOx burners, SCR, FGD, etc). There can be significant variation, dependant on the characteristics of individual fuels and power plants (Mills, 2005). Like natural gas supply (particularly from overseas sources), there may be many stages in oil production and processing where firm environmental and other data are lacking.

LCA studies continue to consider different aspects of power generation. For example, Italian studies have examined areas (such as overall primary energy consumption and environmental emissions) of various configurations of PCC plant equipped with post-combustion CCS. In this case, the CCS system comprised post-combustion capture using MEA, followed by CO_2 compression, transport by pipeline, and storage in a geological reservoir. It was demonstrated that the use of CCS increased primary energy and raw materials consumption, as well as atmospheric acidification. This resulted from the additional auxiliary infrastructure and the reduction in net generating plant efficiency. However, CO_2 reductions of ~70% could be achieved (Cau and others, 2009).

6.2 Coal cleaning processes

As Italy has only one operational coal mine (Nuraxi Figus, Sulcis, Sardinia) there is limited application of coal cleaning processes. The subbituminous coal produced here is cleaned using a Tri-Flo (heavy media separation type) preparation plant, capable of treating up to 1000 t/d. This is a compact multi-stage cylindrical separator that is usually applied in difficult heavy medium separations or where a three-product separation is required. The Carbosulcis washery uses a number of Tri-Flow units in series (Bozzato and others, 2011).

Historically, with a view to improving their characteristics, a number of techniques have been applied to Sulcis coal and tailings. For instance, the recovery of coal from waste fines (sourced from the processing plant tailings basin) was investigated via a selective flotation process that used a 50/50 mixture of heavy and light fuel oils as collector. It was concluded that, on average, concentrates with an ash content of between 20% and 30% could be obtained; this corresponded to a CV of around 24.3 MJ.kg and 20.9 MJ/kg respectively. Yields, ranged from 25% to 35%, with coal recoveries of between 50% and 60% (Amorino and others, 2005). Potentially, both materials could be viable fuels for pulverised coal combustion- (PCC) or fluidised bed combustion- (FBC) based power plant applications.

The removal of mineral matter from Sulcis coal has also been examined using various chemical leaching techniques. Some leaching-based processes can produce coals with very low mineral contents, with several claiming to be capable of removing up to 95% of mineral matter present. Acid leaching looked promising and preliminary work was carried out to assess the amenability of Sulcis coals to leaching with acids (HCl and HF). One coal used contained 40% mineral matter (essentially clays) and the other, 31% (with a high concentration of CaO). Both contained high levels of iron and of pyrite. However, it was determined that neither acid alone was particularly effective. Better results were obtained using a 2-stage process (Mura and others, 2005). At the moment, there is no commercial application of these techniques.

6.3 Supercritical PCC power plants

Supercritical (SC) and ultra-supercritical (USC) technology is in use in many parts of the world – in most industrialised countries, it has become the norm for new coal-fired plants. These are far more efficient than traditional units based on subcritical steam conditions. SC/USC is recognised as one of the higher efficiency, lower emissions (HELE) coal technologies. Supercritical plants are currently operating in around 20 countries. This includes several in Italy:

- Torrevaldaliga Nord – *see* case study below;
- Brindisi Sud – this ENEL plant comprises four 660 MW (627 net) supercritical coal/oil-fired boilers. Commercial operation firing coal began between 1998 and 2001. Ansaldo were heavily involved in the project and were responsible for engineering, manufacturing, supply, erection and start-up of the four 2160 t/h once-through SC boilers. Steam conditions used are 25.5 MPa/540°C/540°C; and
- other SC capacity – there are also several oil and/or gas-fired power plants that use supercritical conditions. These include ENEL's (4 x 660 MW) heavy fuel oil-fired Porto Tolle plant, and the (4 x 660 MW) gas/oil-fired Montalto di Castro power station.

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Case study – Torrevaldaliga Nord

Italy's cleanest, most efficient coal-fired power plant

ENEL's state-of-the art Torrevaldaliga Nord plant in Civitavecchia near Rome is one of the most advanced coal-fired power plants in the world. Formerly based around four oil-fired units, the plant was converted to advanced coal-firing. In 2005, the oil units were closed down and between 2009 and 2010, three new 660 MW USC coal-fired units (total 1980 MW) were brought on line. During this repowering exercise, the old boilers and steam turbines were replaced and a new flue gas cleaning train installed. However, some plant systems were reused: these included the condenser, condensate-feedwater system, electric generator, transformers and electrical substation (Figure 14).

Figure 14 The Torrevaldaliga Nord plant under construction (photograph courtesy of ENEL)

The plant was designed to operate principally on base load mode. However, the new units can accommodate programmed variations of between 40% and 100% of plant MCR (maximum continuous rating) at a gradient of 1% MCR/min.

The repowered and modernised plant now has a net efficiency (in design conditions) of ~45% (LHV). A major element in this are the high steam conditions used. The 1918 t/h steam once-through USC boilers were built and installed by a consortium of BHE, Ansaldo Caldaie, and Demont Srl. Other major equipment (such as steam turbine and deSOx system) was supplied by MHI.

The plant is in a coastal location and is fired on imported bituminous coal. The design fuel has a CV of ~25 MJ/kg (LHV) and ash content less than 16%. However, it is possible to fire a wide range of world traded coals, the only limitation being that the sulphur content should be less than 1%.

During the plant's conversion, a new coal jetty was constructed. Coal is now unloaded from Panamax and Post Panamax vessels by means of continuous ship unloaders, and transported via a sealed transport and handling system (closed belt conveyors) – this ensures that the coal remains in a contained environment. It is taken to two closed dome coal storage buildings. Each can hold 150 kt of coal (Figures 15 and 16). As well as accommodating the import of coal and limestone for the plant's FGD systems, the site's coastal handling facilities are also responsible for the clean removal of plant ash from the fabric filters, and gypsum produced by FGD operations. Ash is utilised in cement manufacture; gypsum is sold to Lafarge for plasterboard production. All is transported by ship.

Figure 15 The coal storage domes and coal conveying systems under construction at the Torrevaldaliga Nord plant (photograph courtesy of MERO)

Figure 16 The completed coal storage domes at Torrevaldaliga Nord (photograph courtesy of MERO)

Through the use of advanced emission control systems, the Torrevaldaliga Nord plant produces very low levels of classic pollutants. It is an example of a modern coal-fired plant that is capable of achieving airborne pollution levels equivalent to those of some gas-fired units. The conversion from oil to coal firing resulted in a 61% drop in NOx emissions, an 88% reduction in emissions of SO_2 and particulates, and an 18% reduction in CO_2 emissions.

NOx emissions are controlled using advanced combustion and high-dust SCR systems. Ammonia for the SCR system is produced from an on-site Ammogen urea-to-ammonia plant. These measures ensure that NOx emissions remain well below legal requirements. The FGD deployed comprises a common wet limestone milling system, three limestone-gypsum forced oxidation absorbers, and a common gypsum dewatering system (of three hydro cyclone-vacuum belt filters). The FGD units were supplied by Mitsubishi and have an SO_2 removal efficiency of >97%. As a result of strict Italian and EU environmental regulations, FGD wastewater cannot be discharge into the sea. Thus, a Zero Liquid Discharge (ZLD) plant has been added so that no industrial wastewater discharges are released from the entire plant.

Particulate emissions are handled by fabric filters. Each boiler is equipped with a bag filter of twin-body configuration. Each filter is composed of 16 compartments and 13,824 individual bags. The total filtering surface is >50,000 m^2. Particulate removal efficiency is in excess of 99%.

The emission limits as specified by the EU LCPD are 200 mg/m^3 for SO_2 and NOx, and 20 mg/m^3 for particulates. The plant's design limits are 100 mg/m^3 for SO_2 and NOx, and 8 mg/m^3 for particulates (hourly basis). On a daily basis, they are 80 mg/m^3 for SO_2 and NOx, and 9 mg/m^3 for particulates (ENEL, 2015) – thus, all fall well below legal limits.

Torrevaldaliga Nord is the prime example of ENEL's and Italy's best practice. It is characterised by high efficiency and reliability, flexible operation, and low environmental impact. It is proof of what can be achieved with coal-fired power generation when proven state-of-the-art procedures and technologies are adopted.

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6.3.1 New coal-based supercritical power projects

In recent years, there a number of major coal-based power projects have been proposed. These included the conversion of several oil-fired plants. State-of-the-art CCT technology was proposed for these. If all had been implemented, it would have increased coal's share in the nation's energy mix to from ~12% to 16% (Woodward, 2013b). Such conversions would have created 4–5 GW of new coal-fired generating capacity. However, for a variety of reasons, all have now been either deferred or cancelled (ENEL, 2015). The projects comprised:

- **Porto Tolle –** this centred on ENEL's 1.98 GW power plant located on the Adriatic coast. If converted from oil firing, this would have had an efficiency of 45%, putting it on a par with the already-converted Torrevaldaliga Nord plant. Compared to the existing oil-fired plant, this high efficiency would have effectively halved overall CO_2 emissions. In addition, plans were developed for CO_2 capture from one of Porto Tolle's three units – this was to be stored in an off-shore saline aquifer. The state-of-the-art emission control systems planned would have reduced the current levels of SO_2, NOx and particulates by between 70% and 80%.

In January 2011, the project received authorisation from the Minister of Economic Development and the Ministry of the Environment for the conversion of the old oil-fired units. Some €2.5 billion in new investment was proposed. It was claimed that the new coal plant would be one of the most advanced in the world. However, various legal challenges delayed authorisation of the project and it is now unlikely to proceed (ENEL, 2015).

- **Vado Ligure power plant, Savona –** Tirreno Power was authorised to build a new 460 MW high efficiency power station in Savona. This would have involved converting an existing oil-fired plant. Authorisation for the project was granted in 2011 and environmental authorisation later obtained. In March 2012, the Italian Ministry of Economic Development authorised the plant expansion and modernisation project. This provided for the possible overhaul of the two existing 330 MW coal-fired units (currently shut down for environmental reasons) once the new 460 MW unit (VL6) has been completed – VL6 was expected to achieve an efficiency of 47.4%. However the project will no longer proceed.

An extensive feasibility study for the new unit was undertaken by Tractabel Engineering. This concentrated on the partially dismantled Unit 2 and its repowering with USC technology. The study also produced the technical specifications for the boiler, steam turbine islands, and flue gas system.

- **Saline Joniche power plant –** this proposal was for a 1.32 GW (2 x 660 MW USC units) station to be located in Calabria. It was to be cofired on coal and biomass. The project was launched by SEI S.p.A, an Italian subsidiary of Swiss company Repower, with support from Italian business partners Hera S.p.A., Foster Wheeler Italiana and Apri Sviluppo. The project aimed to repower and convert an existing oil-fired power plant. Despite local opposition to the project, in 2013, environmental authorisation for the two new units was granted. It was anticipated that plant emissions of the converted plant would be low (Table 19). However, Repower subsequently withdrew and the project was cancelled.

Table 19 Emission limits for Saline Joniche power plant project

Emission	Maximum levels (mg/m^3)
NOx	90
SO_2	80
CO	120
Particulates	10

- **Rossano Calabro –** this centred on an 800 MW oil conversion project proposed by ENEL. Reportedly, much of the existing oil-fired plant (four boilers) was to be demolished and replaced with either two 660 MW or a single 800 MW coal-fired unit. Cofiring with 5% biomass was suggested. Additional capacity would have been provided by a 460 MW unit fuelled by methane, solar thermal and biomass.

- **Fiume Santo –** this project was proposed by E.On. In 2006, the company filed an application seeking permission to build a new 410 MW coal group at the Fiume Santo plant. The unit was planned to replace two oil-fired units and to use USC steam conditions. Authorisation was granted. However, the project has since been cancelled. Reportedly, E.On also considered cocombusting biomass in the plant's existing coal units. The Fiume Santo plant is currently at the centre of a proposal for transfer to Czech energy company EPH.

There has also been a proposal for a new (rather than converted) coal-based project:

- **Sulcis PCC project (Sulcis Iglesiente Project) –** this centred on a 450 MW demonstration plant equipped with CCS. In 2011, Sotacarbo released a feasibility study for the plant. This concluded that the best option would be for a USC PCC unit equipped with SNOX technology (for the simultaneous removal of SO_2 and NOx). It was suggested that government subsidies would be provided to the plant operator for 20 years. However, this triggered an EC inquiry regarding the plant's compliance with EU state aid rules. The project was subsequently cancelled by the Italian government.

The Sotacarbo feasibility study examined four possible options for a medium scale (400 to 450 MW) plant (USC PCC, CFBC, SC PFBC, and IGCC based on Shell gasification technology). Several possible flue gas clean-up options were also considered. Preliminary analysis narrowed the choice of technology to IGCC or USC PCC. The latter was subsequently selected as the technology of choice. This would use a boiler operating at ~25–28 MPa and 580–600°C. Particulates would be captured using a fabric filter. The SNOX system would remove SO_2 and NOx – sulphur species would be converted to saleable sulphuric acid, and NOx to nitrogen. Overall plant efficiency (without CCS) was estimated at ~45%.

The plant was to have incorporated a suitable CCS demonstration project. The system proposed was post-combustion (using MEA – monoethanolamine) with a CO_2 capture efficiency of ~90%. This would have treated 67% of the plant's flue gas, which equated to ~300 MW of its overall output. CO_2 storage options considered included saline aquifers beneath the Sulcis coal basin, and via enhanced coalbed methane production. Potentially, the Sulcis basis would be amenable to both techniques (Loria and others, 2011). However, the Italian government suspended the 450 MW project after the EC launched an enquiry (in November 2012) in order to verify the plant's compliance with EU state aid rules (Serra, 2015).

As noted, the proposed 450 MW project has been suspended. However, under the terms of Italian Law n. 9 (of 21st February 2014) a new demonstration unit of 350 MWe is to be built in the Sulcis area. This will focus on a demonstration of pressurised oxycombustion technology. When operating in CCS mode, the demonstration plant will receive funding of €30/MWh (up to 2100 GWh/y) corresponding to a maximum of €1.2 billion over a 20 year period (Pettinau, 2015). In 2016, an international competition will select the technology provider for the new plant.

6.3.2 Supercritical RD & D in Italy

Around the world, research into different aspects of SC/USC technology continues. Much of this is focused on the development of new materials of construction capable of withstanding extreme steam conditions for long periods. Some of this work is being undertaken via international multi-partner programmes and projects. Italy has been involved in a number of these; for instance, ENEL is one of the 26 partners in the COMTES+ Programme (including ENCIO and HWT II projects). The objective is to verify the feasibility (under real operating conditions) of new components capable of sustained operation at steam temperatures >700°C. Compared to current 'average' EU power plants, adoption of these conditions would lead to a reduction of 28% in coal consumption; there would also be a corresponding drop in CO_2 emissions of 260 gCO_2/kWh of electricity generated. The programme is being partially supported by public funding.

The COMTES+ project is following on from the earlier AD700 programme. This multi-partner initiative aimed to drive forward technology via the development of advanced materials for steam boilers capable of operating at up to 700°C and beyond. Italian members included Ansaldo Caldaie, Ansaldo Ricerche, Centro Sviluppo Materiali S.p.A, CESI S.p.A, and ENEA CRF. As part of the associated COMTES 700 programme, a Component Test Facility was developed to test the high temperature durability of new materials, with a view to realising coal-based power plant efficiency in excess of 50% (Folke and others, 2005). ENEL Ingegneria e Innovazione S.p.A. was involved as a partner (COMTES 700, 2013).

Alongside these activities, performance and techno-economic assessments have also been carried out to investigate SC and USC plant configurations and operation. For example, Sotacarbo and others have undertaken a number that have compared the viability of both SC and alternative advanced technologies such as IGCC. These have included:

- techno-economic studies comparing different technologies for a CCS-equipped power plant integrated with the Sulcis subbituminous coal mine. These examined the potential of different CO_2-free power plant configurations, namely USC PCC, CFBC, IGCC, and oxycombustion technologies. The reference case was a 660 MW plant (without CCS), integrated closely with the Sulcis mine. It was determined that coal gasification would be the most profitable technology for a CO_2-free plant. SC combustion was competitive where partial CO_2 capture was required (Pettinau and others, 2012);
- techno-economic comparisons between coal combustion and gasification technologies (without and with CCS). The performance of three coal-fired power generation technologies was compared. These comprised USC plant with conventional flue gas treatment, USC plant equipped with SNOX technology, and an IGCC plant based on a slurry-fed entrained-flow gasifier. Each technology was based on a commercial scale of 1000 MWth and analysed both with and without CO_2 capture. It was determined that without CCS, USC was more efficient and cost-competitive than IGCC. CCS energy penalties were more relevant for USC than IGCC. Higher SNOX system costs were partially compensated for by better USC performance. The USC plant considered featured steam conditions of 30 MPa/610°C (Tola and Pettinau, 2013). This plant, in its hypothetical configuration, without a gas treatment section, had a net power output of 452 MW and a net efficiency of 45.2%;
- performance evaluation of high-sulphur coal-fired USC plant integrated with SNOX and CO_2 capture sections. This involved the analysis and modelling of various configurations of USC power plants (1000 MW, 27.5 MPa/600°C/610°C steam). Performance assessments were carried out using this

combination for different mixtures of low- and high-sulphur coals. It was concluded that SNOX provided performance advantages over conventional flue gas clean-up systems, and a high share of Sulcis coal in the blends would be advantageous. When post-combustion MEA-based CO_2 capture was added, there was a 10.5 percentage point energy penalty; overall efficiency was reduced to ~34.5%. However, CO_2 emissions were significantly reduced (100 g/kWh compared to ~750 g/kWh) (Cau and others, 2013).

A number of universities have also been involved in SC/USC-based projects. These have included the universities of Rome, Cagliari, Pisa, Padua, Florence, Padova and Calabria.

6.4 Fluidised bed combustion

Italy is a member of the IEA Fluidized Bed Conversion Implementing Agreement. This focuses on co-operation in the field of FBC conversion of fuels applied to clean energy production and provides a framework for international collaboration on energy technology development and deployment (IEA-FBC, 2003). Italy is represented by ENEL, the University of Salerno, and the Istituto di Ricerche sulla Combustione.

Several Italian universities and other organisations have undertaken FBC-based studies. For example, at laboratory scale, the Istituto di Ricerche sulla Combustione has examined different aspects of the FBC combustion (and gasification) of coal and wood (Scala, 2013). The Institute has also been involved in CFB-based oxyfuel combustion studies. Recent topics have included the combustion of coal char particles and the attrition of limestones during sulphation under simulated oxyfuel conditions (Chiron and others, 2012). Other partners active in this area include the National Research Council, CNR, and the universities of Naples Federico II, dell' Aquila, Salerno, Sassari, and Teramo.

6.4.1 Commercial application of fluidised bed combustion

Italy's only major coal-fired circulating fluidised bed combustion (CFBC) facility is located at the Sulcis power plant in Sardinia. The CFB replaced an outdated 240 MW PCC unit at the site. The plant (enlarged to 340 MW) uses a CFB boiler supplied by Alstom Power and was designed to operate on a range of imported and local high-sulphur coals. Alstom also supplied plant ancillaries such as fabric filter, air and flue gas fans, coal crushers, hot and cold ash conveyer systems. Denitrification is carried out inside the furnace – this is achieved through the use of lower operating temperature inside the furnace, plus the dosing of ammonia into the units three output cyclones. Enelpower was involved as main contractor. The local coal supply comes from the Sulcis mine. As this has a high sulphur content, CFB technology was chosen as being the most adaptable, without the need for external FGD or denitrification. Normally (as required by law), the plant is fired on a blend of no more than 20% Sulcis coal with 80% Colombian coal (Benelli, 2013; ENEL, 2015). The Sulcis coal supplied has a sulphur content of ~6%, ash content of 17%, and a volatiles content of 38%. Since 2007, the plant has also been cofiring around 15% (thermal input) of biomass.

Commercial operations began in 2005. At the time of its installation, the CFB boiler was one of the largest of its type in the world. It produces 1026 t/h of superheated steam at 24.5 MPa/565°C and 836 t/h of reheat steam at 580°C. These high outlet temperatures help maintain a plant efficiency of ~40%. During the plant's repowering, some of the existing unit's balance of plant was retained, although all such systems were suitably refurbished and/or updated. When firing the 20% Sulcis/80% Colombian coal blend, SO_2 emissions are usually less than 400 mg/m^3. When using Colombian coal alone, SO_2 levels are ~200 mg/m^3, with NOx emissions of ~200 mg/m^3 (Harghel and others, 2005; Benelli, 2013). Particulate emissions are controlled by a high efficiency fabric filter that maintains levels below the 10 mg/m^3 limit.

Elsewhere, there is also some commercial application of CFB combustion of biomass in Italy. One of the larger projects is the Strongoli power plant of BiomassItalia, where two 40 MWth, 81 t/h steam CFB boilers are in operation. These were supplied by SES and came on line in 2003. The boilers are of self-supporting, natural circulation type, with membrane walls and fluidised bed furnaces. Steam conditions are 9.5 MPa/515°C (SES, 2014). The main fuel is biomass with a CV that ranges between 7.2 and 13.2 MJ/kg.

There are also a number of smaller bubbling and circulating FBC units in operation in different parts of Italy. Many burn RDF although others use paper sludge, wood or bark. Most have a capacity of between 10 and 30 MWth (IEA-FBC, 2003). Several, such as the 18.6 MWe AGAC facility at Reggio Emilia have recently been closed and are being replaced with newer systems that focus more on the recycling of materials. This particular plant was originally designed to recuperate heat from an RDF incinerator and a coal-fired FBC.

6.5 Co-combustion of coal/biomass

Co-combustion has been the focus of research for a number of Italian organisations such as ENEL. The latter has been active in a number of related areas and several forms of biomass have been examined. ENEL considers biomass to have significant potential for the production of low carbon energy – the company currently operates 83 MW of dedicated biomass-fired plants spread across Italy, Spain, Canada and Slovakia. Within Italy, projects are in hand to develop standardised biomass combustion units. ENEL is also active in the co-combustion of coal with biomass and waste-derived fuel in existing utility-scale power plants. The main projects comprise:

- **Sulcis CFB power plant –** since 2007, the Sulcis plant has cofired biomass with the coal feed. It has a nominal fuel feed of ~119 t/h. The Alstom-supplied CFB boiler was modified to enable the cofiring of up to 15% thermal input of three different biomass materials with Sulcis and imported coals. A stand-alone biomass feeding system was installed.

Initial pilot plant testing of the proposed coals, biomass and limestone was undertaken at Alstom's test facility in the USA. Wood chips and agricultural waste (olive pits and pressings) were cofired with coal at up to 15% of the total heat input. It was determined that by limiting the quantity of biomass to 8%, the Sulcis plant's steam capacity and temperature would be unaffected.

- **Fusina power plant, Venice** – since 2004, the plant has been cofiring 5% RDF with coal in Units 3 and 4. Both are 320 MW tangentially-fired pulverised coal boilers. The maximum RFD feed rate is 9 t/h – this has a moisture content of up to 15%, and ash content of 15–20%. The RDF is mixed with the coal feed after the coal milling stage. Cofiring at up to 5% has no significant impact on boiler operation. Furthermore, emissions are largely unaffected, and the ash produced remains suitable for concrete manufacture. It is anticipated that RDF levels up to 10% should be sustainable (Gasperetti, 2013). The plant is authorised to burn up to 70 kt/y of RDF – in 2012, 58 kt was consumed. By replacing part of the coal feed with RDF, coal consumption is typically reduced by ~40 kt/y. Around 55 kt/y of CO_2 emissions are avoided.

Other power generators with an interest in biomass cofiring include SEI, main proponent of the cancelled 1.32 GW Saline Joniche power plant in Calabria. This would have cofired coal and locally-produced biomass. Similarly, ENEL's proposed oil-to-coal conversion at Porto Tolle (also cancelled) envisaged biomass cofiring on two units (Barbucci, 2009). The generator A2A is also involved in cofiring biomass – the company's Monfalcone power plant includes two 165 MW coal-fired units that are capable of cofiring.

Apart from ENEL's Sulcis CFB power plant, cofiring in CFBCs has also been examined by others such as Sotacarbo. For example, the technical and economic feasibility of co-combusting coal and pre-treated waste (Municipal Solid Waste – MSW) in a CFBC for electricity generation was examined. The technology selected was atmospheric pressure internal circulation CFBC. Work focused on the engineering, design, construction and operation of a proposed 12 MWe demonstration plant in Sardinia. The main drivers were to reduce waste disposal problems, coupled with ways to minimise CO_2 emissions from the use of coal (Sotacarbo, 2002). The proposed plant was to be fired on a combination of MSW (produced by the 25 towns of Sulcis Iglesiente), sewage sludge, and coal.

The co-combustion of coal and Sulcis MSW in a CFBC was also examined as part of an EU Thermie project. The project partners were Sotacarbo, Sondel PROTECMA, and Austrian Energy and Environment. The proposed plant was to have generated ~85 GWh/y and fire a combination of 196 t/d of MSW, 74 t/d of DWF (dry waste fraction) and 19 t/d of coal (Sotacarbo, 2005).

6.6 Gasification and IGCC

Historically, much Italian coal gasification-based research has focused on the use of coal from the country's sole remaining indigenous source of supply, namely the Sulcis basin in Sardinia. Over the past two decades, several different coal-fuelled projects have been proposed for the region. During the early 1990s there was a proposal for a combined (Sulcis) coal gasification/seawater desalination project. This planned to recover discharged thermal energy and direct it to water cooling condensers feeding a desalination plant. However, the project did not proceed.

In 1994, government support and funding was authorised for development of an IGCC plant using Sulcis coal. This obtained a favourable Environmental Impact Assessment. However, technical and economic difficulties led to the withdrawal of support for the project. In 2003, this was followed by proposals for the development of an IGCC plant based on the use of Shell gasification technology. This was designed to gasify 5000 t/d of coal blends consisting of local and imported coals (Rezaiyan and others, 2003).

In 2005, the possibility of a project at Sulcis was revived although the scope was widened to include technologies other than gasification. One study examined a plant (based on several different technology options) to be fired on at least 50% Sulcis coal (Loria and others, 2011). In 2008, the European Commission objected to the proposed plant on the grounds that government price support created unfair barriers to competition. The project was subsequently withdrawn and in 2009 a revised version was proposed (Progetto Integrato CCS Sulcis). This called for a 350–450 MW demonstration plant that would incorporate CCS. In 2011, Sotacarbo released a feasibility study for the proposed plant. This recommended a 450 MW ultra-supercritical PCC unit equipped with SNOX technology for the removal of SO_2 and NOx (*see* Section 6.3).

An important Italian gasification test facility is that of Sotacarbo, built in Carbonia between 2007 and 2008. This flexible test platform includes a 5 MWth demonstration plant (700 kg/h throughput) and a fully equipped 200 kWth pilot plant (35 kg/h) (Figure 17). Both are based on fixed bed, updraught, air-blown (Wellman-Galusha-type) technology. Both are equipped with a range of syngas clean-up systems. Raw syngas from the gasification process can be sent to a wet scrubber, a first cold gas desulphurisation stage, and an ESP. Downstream from the ESP, syngas can be directed to various applications (Maggio, 2010). Important studies have been undertaken using these facilities – for instance, the production of CO_2-free hydrogen using a mixture of oxygen and CO_2 as gasification agent. This increased the CO_2 partial pressure in the carbon capture section, increasing its effectiveness.

Figure 17 Part of the Sotacarbo gasification test facility at Carbonia (photograph courtesy of Sotacarbo)

Using its gasification test platform, Sotacarbo has carried out a number of research projects focused on hydrogen production for distributed power generation and has investigated various integrated gasification and syngas treatment process configurations for the CO_2-free combined production of hydrogen and electricity, suitable for application in medium and small-scale commercial plants (Pettinau, 2009). To date, more than 2500 hours of testing has been carried out on the pilot unit using a variety of gasification conditions. A number of different fuels and fuel blends have been tested that include Sulcis coal and wood chips. The extended period of operation using the different fuels has allowed optimisation of the gasification process and syngas cleaning units. A zinc-based hot gas clean-up process has proved very effective. This includes COS hydrogenation and H_2S adsorption – final concentration of sulphur compounds is typically less than 1 ppm (vol), even when high-sulphur coals are used. This effectiveness suggests the possibility of integrating the plant with a molten carbonate fuel cell system, fed directly with clean syngas, for high efficiency cogeneration applications (Cali and others, 2013). These recent findings have confirmed earlier work (Pettinau and others, 2009; Ferrara and others, 2011).

Research into the possibilities of gasifying low quality Sulcis coal remains on-going. For example, in 2013-14, Sotacarbo and Hungarian coal producer Ormosszen, jointly set up the Carbon [I/O] Project to investigate the utilisation of Sardinian subbituminous coal and Hungarian brown coal. The two companies signed a cooperative agreement to develop novel ways to exploit such low rank coals in an environmentally friendly manner. Preliminary investigations are focusing on the potential of both coals for power generation and the production of heat and clean gaseous and liquid fuels. A programme of testing has been carried out using Sotacarbo's fixed-bed pilot gasifier. This confirmed that the process was well suited to both types of coal. Despite the high sulphur content (7–8%) of the different coals, effective desulphurisation allowed the production of a clean syngas. A two-stage roadmap has been developed for the project. Stage I aims to promote the Europe-wide introduction of state-of-the-art technology for the clean transformation of such coals into electricity, heat and chemicals. As part of this, the possibility of producing methanol in Hungary will be assessed (Woodward, 2013b). Stage II will focus on the development and implementation of selected technologies, based on stakeholders' interests and energy market needs. In Hungary, the Department of Combustion Technology and Thermal Energy in the University of Miskolc is also involved in the venture (Rowland, 2014).

Recent Italian studies have focused on the modelling and evaluation of integrating coal-based SNG plants with CCS. Thus, work carried out by ENEA and the University of Rome 'La Sapienza' analysed two coal-based SNG production variants. The studies evaluated plant performance, determined the optimum process configuration, and suggested ways to improve thermal efficiency. Gasifier options considered were of the fixed bed (dry bottom) and updraft varieties. It was assumed that any such plant would be located in the Sulcis basin. Simulations were carried out using the commercial software *AspenPlus*. Both proposed systems were modelled with and without the addition of CCS – captured CO_2 would be stored in coal measures in the Sulcis basin. In terms of energy efficiency, comparative performance analysis showed similar efficiencies for the two cases considered. Where the CO_2 capture process was tightly integrated into the SNG plant, the addition of CCS was found to result in only a modest decrease in efficiency (Bassano and others, 2014).

Several multi-partner projects have focused on ways to clean the syngas generated by coal gasification. For instance, the CLYCARGAS project concentrated on the development of purification technologies, with particular emphasis on the removal of tar and sulphur compounds. It was funded by the European Commission within the Research Fund for Coal and Steel. The project was coordinated by Centro Sviluppo Materiali. Other Italian organisations involved were Sotacarbo, ENEL, and Technip KTI.

Italian interest has not been limited to coal-based gasification systems. In 1988, Termiska Processer AB (TPS) licensed their atmospheric pressure, air-blown CFB gasification process to Ansaldo Aerimpianti S.p.A. In 1992 the company installed a commercial, two-bed unit in Grève-in-Chianti. This has a capacity of 30 MWth and is fuelled on pelletised RDF produced from MSW. There are also seasonal additions of shredded woodwaste and agricultural wastes. The CFB gasifiers are coupled directly to tar-cracking vessels. The gasification plant has a total capacity of 200 t/d of pelletised RDF, which is fed into the lower sections of two CFB gasifiers. The raw gas produced passes through two stages of solids separation before being fed to the boiler. Steam generated is fed to a 6.7 MWe steam turbine. Alternatively, part of the gas produced can be supplied to a nearby cement factory for firing in cement kilns. Flue gas from the boiler is cleaned in a 3-stage dry scrubber system before being exhausted through the stack.

Between 1992 and 1999, a Thermoselect-HTR plant was in operation in Italy. The HTR process combines slow pyrolysis with high-temperature gasification and ash melting. It accepts unsorted waste, with minimal or zero feedstock preparation/pre-processing and integrates various material recovery steps. The process was first demonstrated on a commercial basis at a scale of 95 t/d in Fondotoce in Italy (Gasification Technologies Review, 2013).

Although there are no coal-based IGCC plants currently operating in Italy, within the oil refining sector, there are four plants that utilise various refinery residues for the generation of electricity and the production of hydrogen and various petrochemical-derived products such as methanol. These refinery-based IGCC plants are summarised in Table 20.

Table 20 Italian refinery-based IGCC plants

Plant	Gasification technology	Feedstocks	Output (MWe)	Other outputs
SARLUX, Sarroch, Sardinia (SARAS)	Texaco (GE) quench	Visbreaker tar and other residuals	548	Steam, hydrogen, sulphur
ISAB Energy, Priolo, Sicily	Texaco (GE) quench	Residual asphalt	512	Steam
Api Energia, Falconara	Texaco (GE) quench	Visbreaker tar and other residuals	282	Steam, sulphur
ENI Sannazzaro	Shell	Bitumen, surplus HFO, visbreaker tar	260	Steam, hydrogen, sulphur

6.6.1 Cogasification of coal and biomass

A number of studies have examined the suitability of different types of biomass as gasification feedstocks. For instance, the Istituto Ricerche sulla Combustione and the Università degli Studi di Napoli Federico II investigated the oxygen/steam gasification of coal with wood pellets and olive husk. Testing was carried out in a small bubbling fluidised bed reactor. A range of different operating conditions (such as equivalent ratio, steam oxygen ratio, and bed temperature) was assessed, and the resultant syngas analysed (Ruoppoloa and others, 2013). A comparison between air/steam and oxygen-enriched steam gasification was also carried out.

Sotacarbo has also examined the suitability of coal and biomass combinations for cogasification. For example, the company was involved in the €2.2 million COCACORK project (2005–08) that used a novel rotary kiln gasifier for catalytic cogasification. Funding was provided by the European Research Fund for Coal and Steel. The project focused on the testing of syngas produced from combinations of coal, biomass and wastes. Italian partners comprised Centro Sviluppo Materiali (co-ordinator), Sotacarbo, and ENEL.

Sotacarbo is currently developing several research projects aimed at optimising a coal and biomass gasification process, intended mainly for small- and medium-scale power generation and hydrogen production applications. Work is being undertaken using the Sotacarbo test platform. As part of this, a number of different coal and biomass materials have been assessed. These have included South African subbituminous coal, Sulcis high sulphur coal, lignites from Alaska and Hungary, plus pine wood chips (Frau and others, 2014).

Fluidised bed cogasification of coal, biomass and wastes (combined with CO_2 capture) has also been addressed. For example, the FLEXGAS project examined a range of issues associated with the cogasification of such blends using fluidised bed gasification (and CO_2 capture); CNR and Ansaldo Energia were involved along with Centro Sviluppo Materiali and ENEL. Other research organisations and universities that have undertaken cogasification studies include the universities of Cagliari, Salerno, Naples-Caserta, Rome, and Padova. Other studies have been undertaken by, for instance, the Istituto Ricerche sulla Combustione and the department of Chemical Engineering of the University di Napoli Federico II. They investigated the fluidised bed cogasification of wood and olive husk/coal pellets (Ruoppolo and others, 2013).

7 Carbon capture and storage (CCS) activities

Italian organisations are, or have been, involved in a number of CCS-related projects. The three main routes (pre-combustion CO_2 capture, post-combustion capture, and oxyfuel technology) have all been addressed. For example, in the case of oxyfuel technology, a 350 MWe coal-fired power/CCS demonstration project is being developed for the Sulcis area.

Italy is a party to the UNFCCC and the Kyoto Protocol (as an Annex I party). As such, it is committed to developing, publishing and annually updating national emission inventories of greenhouse gases (GHG), as well as formulating and implementing programmes to reduce these. Under the EU burden-sharing agreement for the Kyoto Protocol, Italy committed to a 6.5% reduction of its GHG emissions by 2008–12, relative to 1990 levels (Hogan and others, 2012). The country's GHG reduction target for the period 2013-20 is 20%.

Between 1990 and 2011, Italy's GHG emissions (excluding emissions and removals of CO_2 from land use, change and forestry – LULUCF) fell by 5.8%, from 519 to 489 MtCO_2-e. In 2009, GHG emissions were 5.2% below the Kyoto base year, excluding LULUCF net emissions (EEA, 2011). Italy has a specific target for sectors not included in the EU Emissions Trading Scheme (ETS): by 2020, there is a goal of reducing emissions to 13% below 2005 levels. In addition, the 2009 EU Renewables Directive requires that the country achieves a 17% share of energy from renewable sources in gross final energy consumption by 2020. In 2011, the government announced the start of development of a 20-year energy strategy aimed at meeting these goals.

The Institute for Environmental Protection and Research (ISPRA) is the single entity in charge of the preparation and compilation of the national GHG emission inventory. The Ministry for the Environment, Land and Sea is responsible for the endorsement of the inventory and for the communication to the Secretariat of the UNFCCC and the Kyoto Protocol.

In September 2011, Italy transposed the EU Directive on Geological Storage of Carbon Dioxide (Directive 2009/31/EC). This establishes a legal framework for the environmentally safe geological storage of CO_2 but does not address capture or transport in great detail. It lays down extensive requirements that cover the entire lifetime of a storage site. MISE is collecting and handling all CO_2-related data concerning exploitation and storage activities, and a national committee is managing the latter.

Italy's dominant GHG gas is CO_2 – in 2011, this accounted for 84.7% of total (CO_2-e) emissions. The energy sector is the biggest contributor. However, between 1990 and 2011, emissions from the sector fell from 417 Mt to 404 MtCO_2-e. During the same period, GHG emissions from industrial processes fell from 38 Mt to 31.6 Mt – CO_2 made up 20.2 Mt of this total. Agriculture was responsible for emissions amounting to 33.5 MtCO_2-e, although LULUCF produced a reduction of some 30.6 MtCO_2-e (Italian GHG Inventory, 2013).

The commercial scale deployment of CCS will be an important factor in tackling climate change and the way that fossil fuels such as gas, coal and oil are used in the future. The Global CCS Institute has stressed that any effective response will require the use of CCS, and the UN International Panel on Climate Change (IPCC) has opined that the widespread application of CCS technologies would make it possible for the large-scale use of fossil fuels to continue. It has noted that the costs of any serious effort to significantly reduce emissions would be much higher without CCS; deployment of the technology is advocated as an alternative to the phasing out of fossil fuels by 2100. The IPCC estimates that without CCS, the cost of the large emissions cuts required would more than double. Recent findings from the Global CCS Institute indicate that worldwide, since 2011, the deployment of CCS has grown by 50%, with substantial progress being made since 2013. This has included the start-up of the world's first coal-fired utility-scale power plant equipped with CCS (Power Engineering International, 2014b).

In the case of coal-fired power plants, suitably equipped modern units are capable of operating with very low levels of conventional emissions. The current challenge is to reduce CO_2 emissions and there are several possible routes to achieving this. Clearly, the deployment of CCS is one. The other is via improving plant efficiency. By this means, the amount of CO_2 produced per unit of electricity can be reduced significantly. In recent years, the construction of a large number of new coal-fired plants has increased the average efficiency of the global generating fleet from 30% to 33%. The process of replacing older low efficiency plants with high efficiency units capable of achieving 45–50% can make an important contribution in decreasing global CO_2 emissions. Thus, reducing CO_2 emissions via gradual technological development is an important option (Christensen and others, 2012). Higher plant efficiencies are being achieved through, for instance, the growing adoption of supercritical/ultra-supercritical steam conditions – there are a number of on-going projects aimed at increasing these still further. Such advanced steam conditions can be applied to coal-, oil- and gas-fired plants; several Italian organisations are active in this area.

The main drivers for the development and application of CCS in Italy are focused on sustainable development coupled with the sustainable use of fossil fuels. CCS forms part of the latter and is considered to be an important factor in the eventual transition to a decarbonised society. The Italian NES acknowledges the importance of CCS and refers to it as a 'research priority'. It is highlighted as part of the initiative that covers materials and energy efficiency, plus their technology transfer. It includes the development of CCS projects (in accordance with European strategy and programmes) aimed at accelerating innovation in power plants. Thus, CCS is viewed as an opportunity for Italian industry, but also for the energy system – potentially, the technology could be applied to coal-, oil- and gas-fired power plants.

Usefully, a project featuring the latter is under way in the UK, where SSE and Shell are developing the world's first full-scale natural gas-based CCS project (at Peterhead). Up to 10 Mt of CO_2 could be captured and piped offshore. The technology clearly has potential for deployment in other countries (such as Italy) where gas-fired units make up a significant portion of the national generating fleet. In Italy, a feasibility study has been completed for post-combustion capture on an existing 120 MW gas-fired cogeneration unit operated at Dalmine by steel producer Tenaris.

7.1 The National CCS R&D Programme

For around 15 years, as part of national and international CCS research programmes, Italian universities and research providers have studied CO_2 capture and storage. Funding has been provided by several EU Framework programmes (FP5, FP6, FP7), as well as the Italian Ministry of Education, University and Research (MIUR), and The Ministry of Economic Development (MISE). Significant technological advances have been made via a range of activities that have spanned small-scale RD&D and pilot-scale operation, to technology demonstration. There has been Italian involvement in a number of major multi-partner EU projects that have included:

- CASTOR (CO_2 from CApture to STORage);
- INCA-CO2 (INternational Co-operation Actions on CO_2 capture and storage);
- GeoCapacity (Assessing European capacity for geological storage of CO_2);
- CO2 GeoNet (European Network of Excellence on the geological storage of CO_2);
- CO2ReMoVe (CO_2 geological storage: Research into monitoring and verification technology);
- RISCS and CO2CARE (Research into impacts and safety in CO_2 storage);
- SiteChar (Characterisation of European CO_2 storage);
- CGS Europe (Pan-European coordination action on CO_2 geological storage); and
- ECO2 (Sub-seabed CO_2 storage: Impact on marine ecosystems).

Italian participants have included ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Eni, Carbosulcis, Sotacarbo, ERSE, OGS (National Institute of Oceanography and Experimental Geophysics), RSE (Ricerca Sistema Energetico), ENEL, plus a number of universities. Examples of recent major initiatives are noted in Table 21.

In the coming years, there are a number of CCS-related objectives that will be addressed. As elsewhere, many will focus on reducing the financial and energy penalties imposed by CCS technologies. A national law (Law 99/2009 – *Regulations for the development and internationalization of enterprises and on the subject of energy*) covers funding aspects for industrial innovation and competitiveness, and energy policy. This includes the demonstration of CO_2 capture and permanent storage in deep geological formations, the development of a coal-fired power plant incorporating CCS, plus RD&D plans for further technology development.

Table 21 Italian national CCS programme (Girardi, 2012)

	Project	Regional funding*	EC funding
Demonstration	Porto Tolle. ENEL		NER 300 and other
	Sulcis 400 MWe. Sotacarbo-ENEA	X	NER 300 and other
Pilot project	Precombustion (and CTL). Sotacarbo/ENEA	X	other
	CBM-ECBM in Sulcis Basin. Carbosulcis-Sotacarbo-ENEA	X	other
	Brindisi post comb, ENEL		other
	Oxycombustion. ITEA		other
R&D project	Precombustion. ENEA-Sotacarbo-ERSE	X	X
	Post-comb, ERSE-ENEA-ENEL	X	X
	Oxycombustion. ENEA-ITEA-Sotacarbo-CNR	X	X
	ECBM-well-aquifers. ENI-Carbosulcis-OGS-ENEA	X	X
International co-operation			
Italian organisations are participants in:	CSLF(Carbon Sequestration Leadership Forum) ZEP Technology Platform EERA (European Energy Research Alliance) COSCO (Coal & Steel Committee) – Research Fund for Coal and Steel EII (European Industrial Initiatives) for SET Plan IEA (via Sotacarbo)		
* Sardinia			

Several government ministries are involved in national programmes that support CCS-related activities. Thus, areas supported by MISE include:

- CERSE programme (Committee of Research Experts for the Electricity Sector) for technology innovation of the electricity system;
- efficiency improvement of SC and IGCC systems;
- combined production of hydrogen and power with CCS;
- identification of potential national capacity for CO_2 storage;
- ECBM site tests in Sulcis area of Sardinia;
- CO_2 capture technologies – pre- and post-combustion (solid sorbents, membranes); and
- coal-to-liquids developments.

ENEA and Sotacarbo are both involved in various aspects of the CERSE programme (Girardi, 2012). This is co-funded by MISE and includes:

- coal-fired power plants for combined electricity and hydrogen production. Main goals include R&D on pre-combustion capture and CO_2 storage (ECBM/saline aquifers), pilot-scale testing, support for Italian industry in order to increase involvement/competitiveness at the international level, and defining the Italian national path on CCS;

- experimental and modelling activities on pre-combustion capture technologies and CO_2 storage (with ECBM and saline aquifers);
- development of the Italian national CCS roadmap – this covers all main stages of the CCS process. Associated activities have included feasibility studies on coal-fired power plants (both with and without CCS), studies on CO_2 storage opportunities, and the extension of previous CCS R&D programmes in Sardinia;
- coal gasification with CCS (ENEA/Sotacarbo). Main goals include test rig operations (gasification and CO_2/H_2 separation) to develop advanced gas cleaning and CO_2 separation processes, as well as gasification processes using mainly CO_2. Also, study of existing installations equipped with CO_2 capture systems with a view to constructing a demo installation in Sardinia. Also feasibility of CO_2 storage in the Sulcis coal basin;
- development of membranes for the separation of hydrogen from syngas; and sorbent solids suitable for the capture of CO_2 from flue gas (RSE);
- oxycombustion for coal-fired power plants (ENEA);
- feasibility analysis for a 48 MWth oxycombustion demonstration project; and
- characterisation of CO_2 storage sites (RSE). Goals include identifying areas with potential for geological storage of CO_2, creating a Geographic Information System for the National Inventory of Potential Storage Sites, and refining calculation systems.

MISE and the Ministry of Research are also engaged in various projects. Thus, the latter oversees a research programme that has included a number of major initiatives (Table 22).

Table 22 Examples of CCS-related projects funded by MISE and the Ministry of Research

Project	Topics	Partners
ZECOMIX (Zero Emission CarbOn MIXed) project	Pilot-scale investigation of pre-combustion technology, combined with coal gasification, syngas treatment, CO_2 capture with solid sorbents, hydrogen production, and combustion for power generation. A major objective was the investigation of the CaL technology – a promising option for high temperature decarbonisation of coal/biomass-derived syngas (Scaccia and others, 2014)	Project undertaken at the ENEA Research Centre, Rome. Involved ENEA, University of L'Aquila, the Sustainable Combustion Laboratory (UTTEI-COMSO), Energy Efficiency UTEE-GRT, ENEA-CCEI Umbria
COHYGEN - pre-combustion technology	Project started in 2003 – examined the production of hydrogen and clean fuel gas (high deS) from coal, and CO_2 capture from syngas using solvents. Aims included the improvement and optimisation of coal gasification, improvements in gasifier performance and desulphurisation techniques, and evaluation of different CO_2 separation technologies	Project carried out at the Sotacarbo Research Centre. Project partners comprised Sotacarbo, ENEA, the University of Cagliari, and Ansaldo Ricerche
CARBOMICROGEN	The project ran between 2007 and 2011. It covered small power generation systems based on syngas and hydrogen generated by coal and/or biomass, equipped with CCS systems	ENEA, the University of Cagliari, Ansaldo Ricerche, Ansaldo Fuel Cell, Sotacarbo, and Centro Sviluppo Materiali

MISE is continuing to fund CCS R&D activities under the auspices of the national fund *Applied Research for Electric Power System*. Between 2012 and 2014, this provided €20 million to CCS capture and storage-related projects. Also, as noted above, the Sardinia region is pursuing initiatives aimed at the co-financing of CCS activities in the Sulcis coal basin. These comprise a demonstration project (with up to 1 $MtCO_2/y$ to be captured and stored) and a pilot project (with up to 100 $ktCO_2/y$). Historically, MISE has financed numerous projects that have brought together national stakeholders with the overarching aim of increasing the competitiveness of Italian industry. This has included support for international initiatives such as the Carbon Sequestration Leadership Forum (CSLF) and the European Technological Platform for Zero Emission Fossil Fuel Power Plants (ZEP).

There are also several on-going research programmes involving other ministries or government organisations that include the *Industry 2015 R&D programme* – this started in 2006 and runs until 2015. It aims to promote industrial innovation in order to improve the competitiveness of Italian industry. The programme includes a fund for enterprise finance. Areas covered include energy efficiency and some aspects of oxycombustion (Girardi, 2012). Recently completed, the *National Research Plan (PNR)* ran between 2010 and 2013. This involved the Ministry of Education, University and Research, and MISE. It focused on sustainability of development and covered several application sectors. Relevant areas included renewable energies, environment, energy, and materials (Innocenzi, 2013).

The NES notes that CCS systems currently carry high financial and energy penalties, but agrees that in the longer term, the technology is likely to have an important role to play. Italy intends to continue contributing to research in this field, and to monitor closely its wider development (NES, 2013).

7.2 The CO_2 Technology Centre Sulcis for Zero Emission – Clean Energy

An important national asset in the successful development and application of CCS is the newly-formed CO_2 Technology Centre Sulcis. This is based at the existing Sotacarbo research centre in Carbonia, and is focusing on zero-emission processes for the production of clean energy. A 10-year R&D programme on advanced coal-fired processes and CCS is underway. The programme started at the Centre in January 2014. It encompasses five main project areas (Table 23). Funding is being provided by the Italian National Government (€3 million per year for 10 years) and the Regional Government of Sardinia (€9 million per year for the first 3 years), in line with recommendations made in the NES. This funding will be applied to oxycombustion and other capture techniques. Work will include the development of a 48 MWth pressurised oxycombustion pilot plant – testing of the latter should be completed by the middle of 2017. This will be followed by large-scale demonstration on a coal-fired power plant. CO_2 storage is also being addressed – the initial step will be to identify and characterise a suitable site; this should be completed by the end of 2016.

Sotacarbo has a range of appropriate test facilities that include a gasification pilot plant equipped with a CO_2 capture stage, and a hydrogen production and CO_2 separation line. There is also a GAIA (Greenhouse gas absorption in amine-based solvents pilot plant) bench-scale unit used to carry out process testing of CO_2 capture from syngas (pre-combustion capture) or flue gas (post-combustion capture) (Figure 18). The plant is used to assess the performance of different capture processes and types of solvents (predominantly amines) as well as regeneration tests (Maggio, 2012).

Figure 18 The Sotacarbo GAIA facility

A 350 MWe coal-fired power and CCS demonstration project has been proposed for the Sulcis area (Maggio, 2014). This will capture 1–2 $MtCO_2$/y for storage in aquifers or coal seams in the Sulcis basin – this contains an estimated >1 Gt of subbituminous coal. CO_2 produced by the plant would be captured and used for the planned storage investigations. Construction should start in 2017.

Table 23 CO_2 Technology Centre of Sulcis project areas

Project area	Objectives and status	Funding (million €)
Pre- and post-combustion CO_2 capture testing	Capture tests from flue gas or syngas from coal/biomass gasification in the Sotacarbo lab and other research facilities	3.7 for first 3 years
Coal-to-liquids pilot plant	Test rig for indirect coal liquefaction	2.5 for first 3 years
Power generation from biomass gasification (with CO_2 capture)	Biomass gasification demo plant for the development of small-scale CO_2-free commercial units	4.7 for first 3 years
Pressurised oxycombustion pilot plant	Development of advanced pressurised (1 MPa) oxycombustion technology 50 MWth pilot plant to be built in the Sulcis area. Testing completed by mid-2017. The project will also involve the existing ISOTHERM 5 MWth pilot unit of ITEA (at GdC)	32.4 for first 3 years
CO_2 storage	Characterisation of Sulcis coal basin; underground laboratory to perform CO_2 storage tests (in aquifers and for ECBM). First stage to be completed by the end of 2016	4.7 for first 3 years, plus funding for drilling of wells

7.3 Post-combustion CO_2 capture activities

Zero Emission Porto Tolle (ZEPT) project, Brindisi

The ZEPT project was funded by the European Energy Programme for Recovery (EEPR) during the period 2009–13. It encompassed the design, procurement and construction of a demonstration CCS plant as well as detailed site characterisation, necessary to confirm the feasibility of CO_2 injection and storage in a safe and verifiable manner.

The main aim was the conversion of old oil-fired generating capacity to clean coal + CCS operation. This was to have involved the installation of a CCS demonstration plant on a 660 MW USC unit of the Porto

Tolle power plant (cofiring coal and biomass). The amine-based post-combustion capture unit was designed to treat a flue gas flow rate of 0.8 Mm^3/h, equivalent to a net electrical output of 250 MW. Around 1 $MtCO_2/y$ (capture efficiency >90%) was to be captured and piped to an off-shore deep saline aquifer. However, the government approval for the project was subsequently reversed – the Italian State Council decided to annul the environmental permit for the power plant. Request for termination was accepted by the European Commission in August 2013. Although this situation still prevails, a considerable body of useful information was amassed during the course of the project. This included (ZEPT, 2014):

- completion of FEED for the capture unit; ranking of technology suppliers;
- completion of feasibility study for pipeline routing and risk assessment;
- assessment of the real storage capacity of the selected structure;
- validation of the methodology used for site selection;
- development of a methodology for the definition of a monitoring plan;
- development of pilot activities for CO_2 capture to support the selection of the best technology solutions (energy penalty, environmental impact, solvent handling); and
- completion of detailed cost estimates (Capex and Opex) of the capture, compression, transport and injection systems.

The project consisted of three distinct stages. Stage I comprised (ENEL) laboratory studies and test rig operation, and Stage II focused on the design and development of a CO_2 capture pilot plant treating flue gas at the Brindisi power plant (this was on-going when the EEPR funded project began). The pilot plant was installed on Unit 4, and consisted of a flue gas pre-treatment section (to remove particulates and SO_3, and to reduce SO_2 levels to <20 mg/m^3) and a CO_2 separation unit. The plant treated 10,000 m^3/h, capturing ~2.5 t/h of CO_2. Stage II was completed in April 2010.

In order to assess environmental, operating and process issues related to CO_2 capture, a series of tests was carried out using (20–30%) monoethanolamine with inhibitors, and other potential solvents. The main objectives were to gain experience in the design, scale-up, construction and operation of the capture unit, and to assess the environmental impact of the process. Stage III would have been the engineering and construction of the demo plant – this would have included the capture unit, plus the compression and transport system, and storage sections. However, as noted, the activity was suspended due to the permitting issues associated with the Porto Tolle power plant conversion (ZEPT, 2014).

Apart from efforts within Italy, ENEL has also been involved in overseas activities aimed at the development and deployment of carbon capture systems. A major initiative was a pre-feasibility study that examined the application of post-combustion capture technologies to Chinese coal-fired plants (as part of the Sino-Italy agreement). This was carried out under the auspices of The Global Sustainable Electricity Partnership (formerly e8) – this focuses on jointly identifying effective and meaningful partnerships that support and promote the global deployment of low and zero-emitting electricity technologies at national, regional and international levels.

Under a partnership agreement (of 2009) to apply CCS technologies in China, the Chinese Ministry for Science and Technology and the Italian Ministry for the Environment began cooperation on the capture and storage of CO_2. As part of this, ENEL undertook a feasibility study for the construction (at a Chinese coal-fired plant) of a CO_2 capture system, followed by its injection into an oilfield for EOR. ENEL has shared with its Chinese partners the experience gained in the design and construction of the Brindisi post-combustion pilot plant.

7.4 Pre-combustion CO_2 capture

ENEL has been involved in coal gasification via joint participation with Endesa at the latter's IGCC plant at Puertollano in Spain (closed in 2013). The two companies collaborated on gasification and pre-combustion capture. ENEL then focused on systems for generating power using hydrogen produced during the separation process. As part of this, in 2004, the company launched the hydrogen-fuelled 16 MW Fusina power plant project (Hydrogen Fuelled Turbine). Construction began in 2008 and the plant became fully operational in 2010. It was the world's first commercial-scale power station fuelled on pure hydrogen – this is supplied from the Porto Marghera petrochemicals plant. In 2011 alone, the plant operated for more than 1000 hours. In order to utilise hydrogen, ENEL (with General Electric/Nuovo Pignone) developed a new combustion technology, plus novel materials and components. Some activities at the Fusina plant form part of an international project (H2-IGCC) – participants include ENEL and other major players, plus several European universities and research centres.

7.5 Oxyfuel combustion

Another promising concept for reducing CO_2 emissions is that of oxyfuel combustion. As the name suggests, fossil fuels are burned in oxygen instead of air. The resultant flue gas stream comprises mostly CO_2 and water vapour, which are easily separable. As noted above, oxyfuel combustion forms an integral part of Sotacarbo's on-going R&D programme and will involve the development of a 48 MWth pressurised oxycombustion pilot plant.

With the aim of demonstrating the feasibility of oxyfuel technology, initial Italian investigations were undertaken in ENEL's experimental 3 MWth combustion test facility at Livorno. Combustion tests were successfully carried out at atmospheric pressure using different flue gas recycle ratios. The test programme produced relevant data on the technology (Benelli, 2013). In the meantime, it was determined that operation under pressure would provide a number of efficiency and operational advantages. An important advance in this area was the development of flameless pressurised oxycombustion (ISOTHERM) technology.

7.5.1 *ISOTHERM* technology

In 2004 ITEA introduced a novel concept called flameless pressurised oxycombustion (FPOC). In 2006, ENEL and ITEA began collaborating on the development of the system that uses high temperature, oxygen-enriched air and pressurisation to produce a flameless oxycombustion reaction. This generates a

CO_2-rich, capture-ready gas stream. The associated energy penalty is lower than competing capture systems. Initial testing was carried out in a 5 MWth facility in Gioia del Colle (GdC) (Figure 19).

Figure 19 ITEA's 5 MWth ISOTHERM pilot unit located at Gioia del Colle (photograph courtesy of ITEA)

In the ISOTHERM system, coal is fed in slurry form to a pressurised combustor where it meets a premixed stream of pressurised oxygen and recycled flue gases. The coal is combusted throughout the reactor volume with no flame front – this yields uniformly high temperatures of 1400°C to 1700°C at 1 MPa pressure. The reactor is refractory lined, thus minimal heat transfer occurs. Instead, hot flue gases are directed to a separate steam generation vessel in which the evaporative and superheating heat exchange surface is located. There is no radiative heat transfer section. Flue gases exiting the combustor are quenched to 800°C against cooler downstream flue gases as they are recycled to the combustor. They are then directed to an acid condenser where the moisture content is condensed, providing heat for feedwater heating. The only flue gas post-treatment required is neutralisation of acidic compounds. Operational experience suggests that commercial-scale systems would be fuel-flexible, simple, readily automated, operator-friendly and compact.

In the process, all incoming fuel is essentially converted to CO_2 and H_2O only (no by-products). In addition, the high and uniform temperature means that ashes melt in a single process, before coalescing into large zero-carbon droplets that fall into a quench bath at the bottom of the combustor. These are inert and non-leachable (Modern Power Systems, 2014). All fuel types (solid, liquid and gaseous) can be treated in a single combustor that eliminates a wide range of problematic combustion by-products (such as dioxins, particulates, SOx, NOx, CO, SO_3, and fly and bottom ashes). The exhaust gases leaving the combustor are very clean, containing <10 mg/m^3 of particulates and <30 mg/m^3 SOx. This greatly reduces the risk of erosion and corrosion to downstream heat exchange surfaces, a problem sometimes encountered with conventional pressurised combustion. An additional benefit of the low levels of flue gas contaminants is the ability to recycle flue gases without any pre-treatment and the potential to simplify the central processing unit (CPU). In practice, untreated flue gases are recycled in two loops: a long loop that goes to the combustor and is mixed with oxygen, and a short loop that is added to the combustor exit gases in a tempering step (to control their temperature) (Lockwood, 2014).

Figure 20 shows part of the 50 MWth large pilot engineering package, specifically developed for Sotacarbo's CO_2 Technology Centre Sulcis for Zero Emission in Sardinia. Apart from pressure neutralisation, the resultant CO_2 stream is capture-ready. The pilot will be used to expand the range of low rank coals that can be used, as well as provide operating experience and validation/optimisation of industrial-scale (500-700 MWth) combustors.

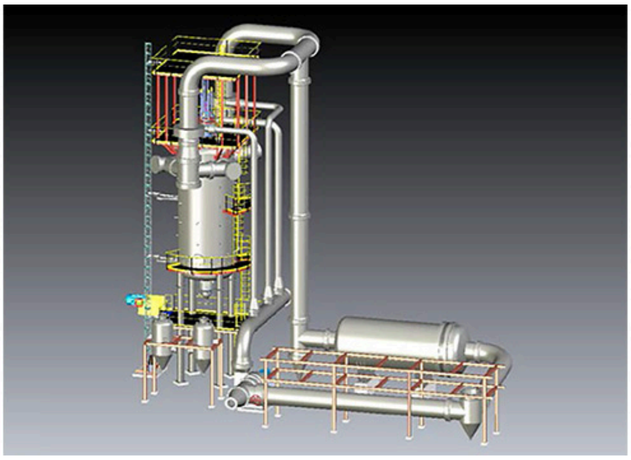

Figure 20 Schematic showing part of the 50 MWth large pilot engineering package developed for Sotacarbo's CO_2 Technology Centre Sulcis for Zero Emission (photograph courtesy of ITEA)

A number of advantages of the pressurised system were determined:

- wide combustor operating range – from 5% to 100% combustor load at constant performance;
- applicability of the process to low rank coals;
- reduced fire risks associated with coal milling – the process uses wet grinding and no pulverisation;
- no emissions concerns during transients; and
- good operational flexibility – less than 30 minutes needed to go from standby to full load.

The ISOTHERM system has potential for use in power generation applications. ITEA has conducted its own analyses of planned scale-up to 50 MWth pilot and 320 MWe demonstration plants, both operating at 1 MPa. The demonstration plant has been designed to have a net efficiency of 35.4% (using supercritical steam conditions of 25 MPa/605°C). Cost analysis suggests a total capital cost of US$ 930 million – the largest costs are for coal logistics and slurrying, followed by the pressurised system and the air separation unit (ASU) (Lockwood, 2014).

ENEL collaborated with US researchers (at MIT) to examine the development of the proposed 320 MWe plant. A detailed technical and economic analysis was produced, based on a supercritical unit of 875 MWth. The design included an ASU and central processing unit, and employed flash separation. Fuel comprised coal water slurry (35% wt. water) that would be injected with steam from the high pressure turbine to atomise the coal particles, and fed to the refractory-line reactor. Combustion would take place at 1 MPa/1400–1600°C. Some 2% of heat lost from the reactor would be used to preheat feedwater. The flue gases leaving the combustor would be ~48% water (vol) compared to 8.7% in air. This would condense at 150°C, as opposed to 80°C at atmospheric pressure. The heat recovered in the condenser would allow 63% less steam to be taken from the low pressure turbine for feedwater heating.

Different capacity ISOTHERM units could have potential for a number of applications. For example:

- 20–100 MWth – for oil field application, generating a CO_2 stream for enhanced oil recovery operations;
- 100–300 MWth – potential for cogeneration applications and district heating zero-emission plants. This would use an integrated system of coal-water slurry, oxygen and CO_2 pipelines; and
- 300–1500 MWth coal-fired zero-emission plants based on modular components. This option appears to offer a cost-effective option for green field applications. Modularity could allow easier retrofitting (Benelli and others, 2014).

In a recent development (June 2014), it was announced that US-based ThermoEnergy Corporation had entered into a patent and royalty sharing agreement with ITEA on clean coal technology. The companies plan to collaborate in order to promote, finance, design and construct a 50 MW pilot plant to be followed by a 320 MW commercial-scale facility in the USA. They intend to combine ThermoEnergy's high-pressure patents with ITEA's lower pressure patents in order to obtain broader market coverage. The system will be developed and marketed by Unity Power Alliance LLC, a joint venture between the two companies. This is being discussed with the Italian government, an Italian utility, the US DOE, and others about possible funding. The 50 MW pilot plant is expected to cost US$50 million. Unity Power Alliance aims to start this in 2015 (Boston Business Journal, 2014).

Clearly, as with other energy-producing processes that need a supply of oxygen, the ASU would be responsible for a significant part of the energy penalty. However, Italy is involved in several initiatives developing alternative methods for producing oxygen (and hydrogen). For example, an EU FP 7 project (DEMOYS) is investigating the use of dense membranes for efficient oxygen and hydrogen separation. This project (2010–14) involved the Università degli Studi di Genova, Politecnico di Milano, Rezia Energia Italia, and Foster Wheeler Italiana. The latter is evaluating the cost of electricity and CO_2 capture in membrane-integrated power plants.

7.6 CO_2 storage activities

Various Italian organisations have been involved in CO_2 storage studies. These have included ENEA, RSE, OGS, Univeristà di Roma 'La Sapienza', INGV, ISPRA, Sardegna Ricerche, CNR Geoscienze Roma, CNR IGG Pisa, Ingegneria Industriale, Sotacarbo, Assocarboni, the National Institute of Oceanography and Applied Geophysics (OGS), Eni Tecnologie, Instituto Nazionale di Geofisica, National Research Council of Italy, and the Universities of Cagliari and di Perugia. Industry involvement has come from companies such as ENEL, Eni, Ansaldo, Carbosulcis, ITEA, Techint, and Foster Wheeler.

Over the past decade, a number of projects and programmes have examined different aspects of CO_2 storage in Italy (Rütters, 2013). In 2005, preliminary studies were made by Sotacarbo and INGV on ECBM and storage in aquifers. This was followed in 2008 by further analysis and a feasibility study (undertaken by Sotacarbo) that examined CO_2 storage. Subsequently, the Government of Sardinia provided funding towards further studies carried out by Carbosulcis with the support of Sotacarbo. Carbosulcis also undertook exploratory drilling activities. Initiatives to characterise the Sulcis area have continued.

Since the formation of the CO_2 Technology Centre of Sulcis, all activities on CO_2 storage in the Sulcis coal basin have been coordinated by Sotacarbo. There is ongoing collaboration with members of CO2GeoNet, namely Carbosulcis, OGS, IFPEN, TNO, BRGM, Imperial College, and the University of Rome. In addition, there is collaboration with the University of Cagliari and RSE. The work is focusing on the petro-physical characterisation of rock samples and the numerical simulation of short-, medium- and long-term fluid dynamics (100 years after the start of the injection phase) in order to evaluate the diffusion of the CO_2 plume. As part of this, OGS will process and analyse seismic data generated by Geotec. ENEA and the University of Rome are collaborating on developing a monitoring network – this project is underway and is monitoring geochemical activities via the installation of units assessing the acquisition of free and/or dissolved CO_2 data. This will help define the baseline and identify potential preferential pathways for gas migration (Girardi and others, 2014).

Historically, Italian involvement in major CO_2 storage-related projects has included:

- the EU Geocapacity project (2006–09) – this assessed European capacity for geological storage of CO_2. It included the first regional attempt to evaluate the storage potential in deep saline aquifers in Italy. Data for some aspects (for instance, detailed geological and petrophysical data) were lacking. However, 14 suitable storage locations were identified, with a combined capacity of 11 $GtCO_2$;
- Potential in Italy: Cesi Ricerca (now ERSE) project. MISE tasked CESI to produce an estimate of Italy's CO_2 storage potential. Saline aquifer sites were identified and classified by the quality of their caprock (thickness and lithology) (Politi, 2010);
- SIBILLA feasibility study – this project (which formed part of a larger one) was to demonstrate the commercial and technical feasibility of geological storage of CO_2 coupled with enhanced oil recovery in the Marche and Adriatic Sea. The study was completed in 2005 although capture and oil recovery aspects are expected to continue to ~2015. The project examined the capture of 1.5 $MtCO_2$/y produced by the refinery residue-fuelled Texaco gasifier/IGCC plant that forms part of api Energia's Falconara oil refinery. The recovery of an additional ~6 million barrels of crude oil is expected over the course of the project. The CO_2 geological storage sites assessed were both on-shore and off-shore, mostly in deep (>800 m) saline, naturally-fractured carbonate aquifers located under a thick cap-rock;
- ENEL's proposed Zero Emission Porto Tolle (ZEPT) Project – captured CO_2 was to be transported via a 100 km long pipeline to an offshore injection platform. Pre-FEED studies were undertaken based on a saline aquifer reservoir located ~25 km from the Adriatic coast. However, the project was cancelled. Eni has also carried out feasibility studies and a pilot injection project focused on a depleted hydrocarbon field. Injection of some 8000 t of CO_2 over a three-year period was proposed; and CO_2 storage in the Sulcis area – ECBM/aquifers pilot tests. The project is focused on the testing (at pilot scale) of CO_2 storage in deep coal layers and in the underlying aquifers in the Sulcis coal basin,

managed by Carbosulcis. The region is characterised by the presence of two superimposed formations, both of which are appropriate for CO_2 storage (ECBM and deep aquifers). In Italy, this combination is unique. The upper formation would provide additional safety in the form of a secondary, higher-level barrier should storage be conducted in the lower layers (Girardi, 2012). Thus, two different storage technologies are proposed: storage in saline aquifers below the Sulcis coal basin, and storage via ECBM. Storage in the aquifers would involve injection of compressed CO_2 at a depth of about 1000–1200 m. In the same area, the ECBM concept would be tested at ~800–1000 m; compressed CO_2 would be injected into unmineable coal seams.

More recently, the *CO_2 Technology Centre Sulcis for Zero Emission – Clean Energy* has begun a three-year (2014–16) programme focused on the characterisation of the Sulcis coal basin. Part of this investigation will be undertaken in an underground laboratory where testing will be carried out on CO_2 storage in aquifers as well as via ECBM techniques. The project has been awarded €4.7 million for its first 3 years of operation, plus additional funding for the drilling of wells. The main elements of the Centre's CO_2 storage programme are summarised in Table 24.

Table 24 CO_2 Technology Centre Sulcis storage-related activities (Girardi and others, 2014)

Year	Task	Main activities
1	Site characterisation	Hydro-geologic overview of the coal basin Geochemical surveys Structural geology and fault analysis Natural seismic activity via monitoring network Reprocessing of available seismic profiles Laboratory characterisation of rock samples from caprock and selected limestone formations
2	Exploration wells	Drilling of deep exploration well (1000–1200 m) Drilling of shallow exploration wells near faults Multi-channel seismic reflection from the surface and vertical seismic profile for correlation with the well data Development of both static and dynamic geological models of the reservoir
3	Injection tests	Pilot-scale CO_2 injection tests Installation of monitoring network to assess any induced seismicity Geochemical and geophysical monitoring to assess the eventual leakage/migration of stored CO_2 Design, setting up of underground laboratory (in existing mine tunnels)

In Italy, the main storage options considered have comprised saline aquifers and hydrocarbon fields. For the former, 14 possible storage areas were identified in the major sedimentary basins. Potential reservoirs had individual capacities ranging between 30 and >1300 Mt. Initial conservative estimates suggest that these formations could accommodate Italy's entire CO_2 emissions for at least fifty years. The Geocapacity project estimated that total storage capacity was ~11 Gt. Other studies have suggested a total of 13.3 Gt (Caliri and Panei, 2012). Considering Italy's overall annual production of CO_2, storage capacity is not considered to represent a constraint for the deployment of CCS (Caliri and Panei, 2012; Energy Modeling Forum 28, 2013).

In the case of hydrocarbon fields, estimates of the potential storage capacity of 14 depleted fields (representing only a small proportion of the total number potentially available) were made (Table 25).

Table 25 Potential CO_2 storage capacity in hydrocarbon fields

	Minimum	Maximum
Gas reservoirs	1.6 Gt	3.2 Gt
Oil reservoirs	210 Mt	226.5 Mt
Sulcis coalfield (ECBM)		
onshore	29 Mt	
off shore	42 Mt	

8 Coalbed methane/ECBM

The recovery of coalbed methane has been investigated on mainland Italy as well as on the island of Sardinia. In 2006, UK-based oil and gas company Independent Resources Plc (IRP) drilled and cored the country's first mainland CBM stratigraphic borehole. The *Fiume Bruna Coalbed Methane Project* lies within the company's Fiume Bruna and adjacent Casoni licenses, located in the former mining areas of Tuscany. Coal here is low-sulphur subbituminous. As part of the initial work, gas content and adsorption characteristics of the underlying coal were determined. This was followed by further investigations and drillings, as well as examination of a large number of vintage boreholes, produced by past mining activity (mining ended in the late 1950s). Data obtained has been used to construct a regional depositional model of the Fiume Bruna basin and beyond. The company's exploration permit for Fiume Bruna covers an on-shore area totalling 247 km^2 – this encompasses the second most important coal mining area in Italy.

The Casoni exploration permit consists of an area totalling 142 km^2 and is located just to the south of the Fiume Bruna block. Average gas content of 4.7m^3/t and an average density of 1.41 g/cm^3 have been determined for the two blocks. Original gas in place (OGIP) and gross prospective gas resources are (mean) estimated to be 15.2 and 4.5 billion m^3 respectively. If necessary funds can be raised, a new drilling programme will begin in 2015. ECBM produced via the injection of captured CO_2 into the formation could produce greater volumes of methane whilst simultaneously storing CO_2.

IRP has cooperated with US-based Norwest Questa Engineering in its exploration of Fiume Bruna. The original scope of the project has since been extended and now, the gas-saturated coal and shale basin is interpreted to extend from the Fiume Bruna license area south to the company's Casoni license area. Originally proposed as a CBM project, it has since been reclassified, as the deposits have been found to respond more like shale gas than a classic high permeability CBM coal.

ECBM has also been examined in the Sulcis region of Sardinia where Sotacarbo, Carbosulcis, and others are evaluating the feasibility of methane recovery (ECBM) coupled with CO_2 storage in coal deposits unsuitable for conventional mining activities. An important part of this has been the *PROMECAS project* (Project for Methanization of Sulcis Coal). One outcome has been the production of a pre-feasibility study for ECBM production in Sulcis. Project participants comprised Sotacarbo, Carbosulcis, The National Institute of Geophysics and Volcanology (INGV), ENEA, and the University of Cagliari (along with sub-contractors IES srl and ETH Zurich). The project consisted of three phases:

- Phase I – mineralogical, chemical and physical characterisation of Sulcis coal;
- Phase II – survey of geological and hydrogeological aspects of the deep Sulcis coalfield (800-2000 metres in depth). Also, verification of ECBM technology applicability; and
- Phase III – selection and evaluation of engineering solutions. It will include a survey of CO_2 sources in the region.

It is anticipated that ~1 Gt of coal will be useable for CO_2-ECBM in the Sulcis area. The CO_2 storage potential (using ECBM techniques) is considered to be the largest of its kind in Italy. Preliminary data indicates that Sulcis coal could absorb considerable quantities of CO_2, with injection lasting for many years. Estimates suggest that up to 11,200 Mm^3 of (CBM) gas could be produced, along with 8800 Mm^3 of gas via ECBM production (thus, a total of ~20,000 Mm^3). The project could have a duration of about 5–7 years for CBM and 20 years for ECBM (Carbosulcis, nd; Methane to Market Partnership, nd). As part of the project, the feasibility of underground gasification based on abandoned mines in the region was examined by an Australian company.

9 Summary

Italy's economy and energy sector

Italy is ranked amongst the world's leading economies and is a major European industrial player. Despite the country's on-going economic problems, the industrial sector remains the main driver of the economy. Italian industry employs more than 30% of the working population and accounts for 25% of GDP. However, it faces challenges that include poor economic growth and restricted competitiveness – the latter is hampered by high electricity costs. The government intends that the industrial and manufacturing sector will maintain a central role in the Italian economy. The main priority is to achieve sustainable growth, but this will only happen if the competitiveness of the Italian economic system improves.

Factors that help keep the price of Italy's electricity high and hinder its economic competitiveness include:

- The energy mix for electricity is based mainly on imported natural gas and renewables. As it lacks nuclear power and coal makes only a modest contribution, this is significantly different to the average EU mix.
- Average wholesale gas prices are higher than in other European countries. As much of Italy's electricity is generated by power plants fired on imported gas, this is reflected in the price of electricity.
- Some generators are operating in difficult economic conditions or are facing market transition. Most notably, there is over-capacity in the CCGT sector. This has resulted from decreased demand, the start-up of ~20 GW of new CCGT capacity (between 2005 to 2011), and increased production from renewables. The rapid growth of renewables (that benefit from dispatching priority) has been a major factor in the reduced exploitation of the fleet. Some new gas-fired plants have not yet been brought on line and others are operating for only 1200–2000 hours a year.
- Italy has the highest incentives in Europe for renewables production. These account for more than 20% of the average electricity bill.

For more than a decade, the use of renewables (large and small hydro, wind, solar, geothermal, and biomass) in Italy has increased steadily, fuelled strongly by generous incentives. These continue to generate considerable costs for the system and push up electricity bills. Incentives add >€10 billion/y to consumers' energy bills.

Italy is one of Europe's biggest energy importers, importing much of its oil, natural gas, coal and electricity. This increases the country's vulnerability in terms of security of supply – in recent years, this has been threatened on a number of occasions. It is also expensive. In 2012, energy import costs reached a new high of €65 billion. For many years, this has kept the trade balance deeply in the red. For more than a decade, Italy's energy import dependency has been >80%. The average for the EU 27 is 53%. Only four other EU countries have higher levels of dependency.

The possibility of introducing nuclear energy was rejected by a referendum in 2011. Partially in response to this, the Italian government announced a *National Energy Strategy* (NES) with the aim of achieving a more secure, less expensive, and environmentally sustainable energy supply. A major priority is to reduce the cost of the country's electricity. As part of this, the NES has identified a number of goals for the coming years. The overarching aim is to structurally influence and improve the energy sector in various ways, making it more effective in boosting economic growth. Italy needs to resume sustainable growth and the energy sector has a crucial role to play in this process.

The NES concentrates on the greater use of natural gas and renewables for electricity generation. Both are likely to keep electricity costs high. Reducing the reliance on imported gas by increasing the use of coal for power generation could provide significant economic benefits as well as broaden the energy mix. However, the NES pays little attention to this idea. Rather, it focuses mainly on gas-fired generation, coupled with greater use of (mostly) subsidised renewables; both are viewed as expensive options. Potentially, as in many other countries, coal-fired generation has the potential to produce cheaper and more secure electricity. Clearly, any new coal-fired capacity would be expected to apply CCTs (and possibly CCS) so that environmental impacts would be minimised. Italian power generators already have a good track record in this respect. The current coal-fired fleet has a combined capacity of ~9.7 GW. Nine of these plants use modern technology and achieve high levels of efficiency. The average fleet efficiency is ~40% which compares well with the overall European average of 35%. However, ENEL's Torrevaldaliga Nord power plant can reach 45%.

Unlike in many other industrialised countries, coal currently plays only a modest role in the Italian energy sector. In 2013, 14.6 Mtoe of Italy's primary energy supply (total of 158.8 Mtoe) was provided by coal – around three quarters of this was used for power generation. Oil provided 61.8 Mtoe, gas 57.8, hydro 11.6, and other renewables 13.0.

In recent years, there have been several new major coal-based power projects proposed. At an investment of >€5.5 billion, these would have added around 4.4 GW of capacity to the Italian grid. However, various difficulties mean that the three largest projects are deferred/cancelled. These power plants would have been expected to operate flexibly and emit very low levels of classic pollutants. In the future, the deployment of carbon capture and storage (CCS) technology is also likely to be an important factor.

Apart from further increases in renewables, the current energy mix may not change significantly for some time. In the period up to 2030, Italy is likely to remain heavily dependent on fossil fuels, with much of the energy requirement being met by imports. The country possesses some hydrocarbon reserves although consumption greatly outstrips indigenous production. The bulk of oil and gas is imported.

Coal and electricity generation

Italy's only active coal mine is that of Carbosulcis in south west Sardinia. Sulcis resources are estimated to amount to between 610 and 620 Mt of subbituminous coal, with proven reserves at 10 Mt. There are proposals for the existing mine to be revamped as a combined mining and carbon capture site, linked with a coal-fired power plant equipped with carbon capture and storage (CCS) technology.

Italy has long relied on imports to meet most of its coal demand. Annual consumption has generally fluctuated between 20 and 27 Mt. Both steam and coking coal are imported. Within the European Union, Italy is the 3rd largest coal importer after Germany and the UK.

In 2012, nearly 87% of the country's electricity was generated by Italian power plants (285.1 TWh); the balance (43.1 TWh) was imported from various neighbouring countries. Italy imports ~13–14% of its requirement every year, making it the leading importer of electricity in Europe. France and Switzerland are the biggest suppliers.

Clean Coal Technologies (CCTs)

Through heavy investment, during the past decade, Italy has significantly reduced the emissions of SO_2, NOx and particulates emanating from the coal-fired power sector. The country now has a number of coal-fired power plants that are cleaner and more efficient than many of their counterparts elsewhere in Europe. Nine of these have the European *Eco-Management and Audit Scheme* (EMAS) certification. This equates to ~9.5 GW of installed generating capacity (around 85% of Italy's coal-fired capacity). Most major plants have been equipped with comprehensive FGD and NOx control systems.

A number of CCTs are in use or under active development in Italy. These include the introduction of CFBC technology on a commercial scale, the deployment of modern emission control systems (such as FGD and SCR systems), the co-combustion of coal and biomass/wastes, and the growing focus on the use of advanced supercritical/ultra-supercritical steam conditions in PCC plants. An important recent CCT-/CCS-related development was the announcement that the Italian government is providing €30 million to help establish the CO_2 Technology Centre of Sulcis, located at Sotacarbo's research centre in Sardinia; an on-going programme focused on a number of CCT- and CCS-related areas is now underway.

Sotacarbo operates a gasification test facility at Carbonia in Sulcis. This test platform includes several fully equipped gasifier trains that feature different syngas clean-up systems. The facility has been used extensively for a number of research projects. Other Italian research providers and universities have also been involved in gasification/IGCC-based research and modelling activities. Although there are no coal-based IGCC plants currently operating, within the oil refining sector, there are four such plants that utilise various refinery residues for the generation of electricity and the production of hydrogen and various petrochemical-derived products such as methanol.

Historically, much Italian coal gasification- and IGCC-based research has focused on the use of Sulcis coal, and several different coal-fuelled projects have been proposed for the region. There was a proposal for 450 MW ultra-supercritical PCC demonstration project that would have incorporated CCS and SNOX technologies. However, this was cancelled. However, a new 350 MW project with CCS is being developed for the Sulcis are.

Carbon capture and storage

Italy is a party to the UNFCCC and the Kyoto Protocol (as an Annex I party). Under the EU burden-sharing agreement for the latter, the country committed to a 6.5% reduction in GHG emissions by 2008–12, relative to 1990 levels. The target for the period 2013–20 is 20%. In recent years, Italy's GHG emissions have declined. The dominant GHG gas is CO_2 – the energy sector is the biggest contributor.

The main drivers for the development and application of CCS are focused mainly on reducing CO_2 emissions, improving the efficiency of energy production, and the sustainable use of fossil fuels. CCS is viewed as an important factor in the eventual transition to a decarbonised society. The NES acknowledges its importance, referring to it as a 'research priority'. Italy intends to continue R&D in this field, and to monitor closely associated development activities elsewhere.

For around 15 years, as part of national and international research programmes, Italian researchers and universities have studied CCS. Funding has been provided by several EU Framework programmes and Italian Ministries. Significant technological advances have been achieved via a number of activities that have ranged from small-scale RD&D to technology demonstration.

An important national asset in the field of CCS is the newly-created CO_2 Technology Centre Sulcis, where a 10-year R&D programme on advanced coal-fired processes and CCS is underway. Funding is being provided by the Italian National Government and the Regional Government of Sardinia, in line with recommendations made in the NES. This will be applied to oxycombustion and other capture techniques aimed at coal and biomass-fired plants, and industrial processes. A 350 MWe coal-fired power/CCS demonstration project has been proposed for the Sulcis area – this would capture 1–2 $MtCO_2$/y for storage in aquifers or coal seams in the Sulcis basin. Construction could start in 2017.

There have been a number of different CCS-related initiatives undertaken in Italy. In the area of post-combustion CO_2 capture, these have included the Zero Emission Porto Tolle (ZEPT) project.

Pre-combustion CO_2 capture and gasification has been explored via collaboration between ENEL and Endesa, focused on the latter's IGCC plant at Puertollano in Spain. ENEL subsequently successfully developed the Fusina power plant, the world's first commercial-scale hydrogen-fuelled power station.

An alternative approach is the use of oxyfuel combustion and several Italian organisations have been engaged in this. The technology also forms part of Sotacarbo's on-going R&D programme. An important advance has been the development of flameless pressurised oxycombustion (ISOTHERM) technology, developed by ITEA. This uses high temperature, oxygen-enriched air and pressurisation to produce a flameless oxycombustion reaction – a CO_2-rich, capture-ready gas stream is generated. Associated energy penalties are lower than competing capture systems. Potentially, the technology could be applied in a number of ways (power generation, cogeneration, or EOR). ENEL has collaborated with US researchers to examine the development of a 320 MWe plant. A detailed technical and economic analysis was produced, based on a supercritical unit of 875 MWth.

In a recent development (June 2014), it was announced that US-based ThermoEnergy Corporation had entered into a patent and royalty sharing agreement with ITEA on clean coal technology. The companies plan to collaborate in order to promote, finance, design and construct a 50 MW pilot plant to be followed by a 320 MW commercial-scale facility in the USA.

Various Italian organisations have been involved in different aspects of CO_2 storage. Over the past decade, a number of projects have examined areas of CO_2 storage in Italy. The possibility of storage in deep saline aquifers, depleted hydrocarbon reservoirs, and coalbeds has been investigated. Work is continuing at the CO_2 Technology Centre Sulcis where a 3-year programme is underway to further explore the possibilities of storage in the Sulcis coal basin (coupled with ECBM production).

The recovery of coalbed methane has also been investigated on mainland Italy as well as Sardinia. The former was focused on the *Fiume Bruna Coalbed Methane Project*, located in the former mining area of Tuscany. This proposes combining CO_2 storage with ECBM production. A new drilling programme may begin here in 2015. On Sardinia, Sotacarbo, Carbosulcis, and others have been engaged in a project aimed at evaluating the feasibility of methane recovery coupled with CO_2 storage in coal deposits unsuitable for conventional mining activities. The CO_2 storage potential is considered to be the largest of its kind in Italy. Preliminary data suggests that the Sulcis coal basin could absorb considerable quantities of CO_2, with injection lasting for many years.

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