Prospects for coal and clean coal technologies in Turkey

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IEACCC Ref: CCC/239

ISBN: 978–92–9029–560–0

Published Date: July 2014

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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, Canada, China, the European Commission, Germany, India, Italy, Japan, New Zealand, 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.

Abstract

Turkey has one of the world's fastest growing economies. Rapid economic expansion, rising population, and growing industrialisation have triggered a general increase in energy demand.

During the last decade, natural gas and electricity requirements have soared. Over the next ten years, the current level of energy demand is expected to double. In order to meet this, significant investment in the energy sector will be required.

Like many countries, Turkey faces energy supply issues. Indigenous energy resources are limited almost exclusively to lignite and smaller amounts of hard coal. As a result, there is a heavy dependence on imported sources of energy. More than 90% of Turkey's oil and 98% of its natural gas is imported, as is much of the hard coal consumed. The cost is considerable, accounting for around a quarter of the country's overall annual import bill. A major government objective is to reduce this, particularly through the greater use of domestic lignite, widely available in many parts of the country.

To help facilitate this, the government is pursuing a coal strategy and has introduced incentives to encourage the greater utilisation of this resource. Many new power generation projects are in the pipeline, a significant number fired on lignite. However, there are also a number of major projects that will rely on imported hard coal.

Many existing state-owned coal-fired power assets (and coalfields) are in the process of being transferred to the private sector. Some power plants require modernising and this is being factored into their selling price. The current coal-based generating fleet comprises plants based on conventional pulverised coal or fluidised bed combustion technology. Some newer projects plan to use supercritical steam conditions and all major power plants will be required to install effective emission control systems.

The further development and application of a range of clean coal technologies is being pursued by a number of Turkish utilities, technology developers, and universities. There is increasing involvement with international projects and, in many cases, growing links with overseas counterparts.

Acknowledgements

Pelin Haberal	Ministry of Energy and Natural Resources of Turkey
Dr Nejat Tamzok	Turkish Coal Enterprises
Ayse Ceri	Republic of Turkey Prime Ministry Investment Support and Promotion Agency (ISPAT)
Dr Jürgen Fröhlich	STEAG GmbH
Hasan Guerpinar	Hitachi Power Europe GmbH
Gülben Gülcan	ISKEN-Iskenderun Enerji Üretim ve Tic. A.Ş.
Berker Yetisti	CVP Machinery Marketing Ind. & Foreign Trade Ltd. Co, Izmir

Acronyms and abbreviations

BAT	best available technology
BFBC	bubbling fluidised bed combustion
BOO	build-own-operate
BOP	Balance of plant
BOT	build-own-transfer
BP	British Petroleum
CAGR	compound annual growth rate
CBM	coalbed methane
CBTL	coal-biomass-to-liquids
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CCT	clean coal technologies
CFBC	circulating fluidised bed combustion
CFBG	circulating fluidised bed gasification
CMEC	China Machinery Engineering Corporation
CNEEC	China National Electricity and Engineering Company
CTL	coal-to-liquids
CV	calorific value
ECBM	enhanced coalbed methane recovery
EIA	environmental impact assessment
EMRA	Turkish Energy Market Regulatory Authority
ENGR	enhanced natural gas recovery
EOR	enhanced oil recovery
EPC	engineering, procurement and construction
EPDK	Energy Market Regulatory Agency
ESP	electrostatic precipitator
EU	European Union
EÜAŞ	Electricity Generation Company
FBC	fluidised bed combustion
FDI	foreign direct investment
FGD	flue gas desulphurisation
FT	Fischer-Tropsch
GE	General Electric Corporation
GHG	greenhouse gas
GMI	Global Methane Initiative
HWBR	hot windbox repowering
IÇDAŞ	Icdas Elektrik Üretim ve Yatirim AS
IEA	International Energy Agency
IED	Industrial Emissions Directive
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IPPC	integrated pollution prevention and control
ISPAT	Republic of Turkey Prime Ministry Investment Support and Promotion Agency
ITU	Istanbul Technical University
LAP	Turkish Lignite Exploration Mobilization Project
LCPD	EU Directive on Large Combustion Plants
LHV	lower heating value

LNB	low NOx burner
LNG	liquefied natural gas
MAM	(TÜBITAK) Marmara Research Center (Marmara Araştirma Merkezi; sometimes referred to as MRC)
MENR	Ministry of Energy and Natural Resources
METU	Middle East Technical University
MHI	Mitsubishi Heavy Industries
MTA	Turkish General Directorate of Mineral Research Exploration
Mtoe	million tonnes of oil equivalent
MU	Muğla University
NCCAP	National Climate Change Strategy for Turkey
NGCC	natural gas combined cycle
O&M	operations and maintenance
OECD	Organisation for Economic Co-operation and Development
OIB	Turkish Privatization Administration
PCC	pulverised coal combustion
PCI	pulverised coal injection
PFBC	pressurised fluidised bed combustion
PV	photovoltaic
SCR	selective catalytic reduction
SCST	Supreme Council for Science and Technology
SNG	synthetic natural gas
TAEK	Turkish Atomic Energy Authority
TEAS	Turkish Electricity Generation and Transmission Corporation
TEYDEB	Technology and Innovation Support Programs Directorate
TKI	Turkish Coal Enterprises
TL	Turkish Lira (1 Lira = US$0.47 – as of April 2014)
TPAO	Turkiye Petrolleri A.O.
TPES	total primary energy supply
TTK	Turkish Hardcoal Enterprises
TÜBİTAK	The Scientific and Technological Research Council of Turkey
TURKSTAT	Turkish Statistical Institute
UCG	underground coal gasification
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change
USTDA	US Trade and Development Agency
WEC	World Energy Council

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1 Introduction

Turkey is a founding IEA member country (from 1974) and since 2005, has been in membership accession talks with the European Union (EU). With its rapidly growing economy, the country has become one of the fastest growing global energy markets.

Over the last twenty years, Turkey has experienced rapid economic expansion, an increasing population, and rising industrialisation. These factors have been instrumental for growth and have led to a general increase in energy demand. During the last decade, in terms of natural gas and electricity demand increase, Turkey has been only second after China. In fact, there has been rapid demand growth in all segments of the energy sector. However, like many countries, Turkey faces a number of energy supply issues. Set against a background of growing demand and increasing dependence on expensive energy imports of oil and natural gas, these centre mainly on security of supply and achieving sustainable development. The cost of Turkey's imported energy is considerable (Figure 1). In 2011, total energy imports amounted to more than US$54 billion, increasing further in 2012 to US$60 billion. In that year, energy imports accounted for a quarter of the country's total import bill. The International Monetary Fund forecasts that by 2017, energy import costs will exceed US$70 billion per year (Daly, 2013).

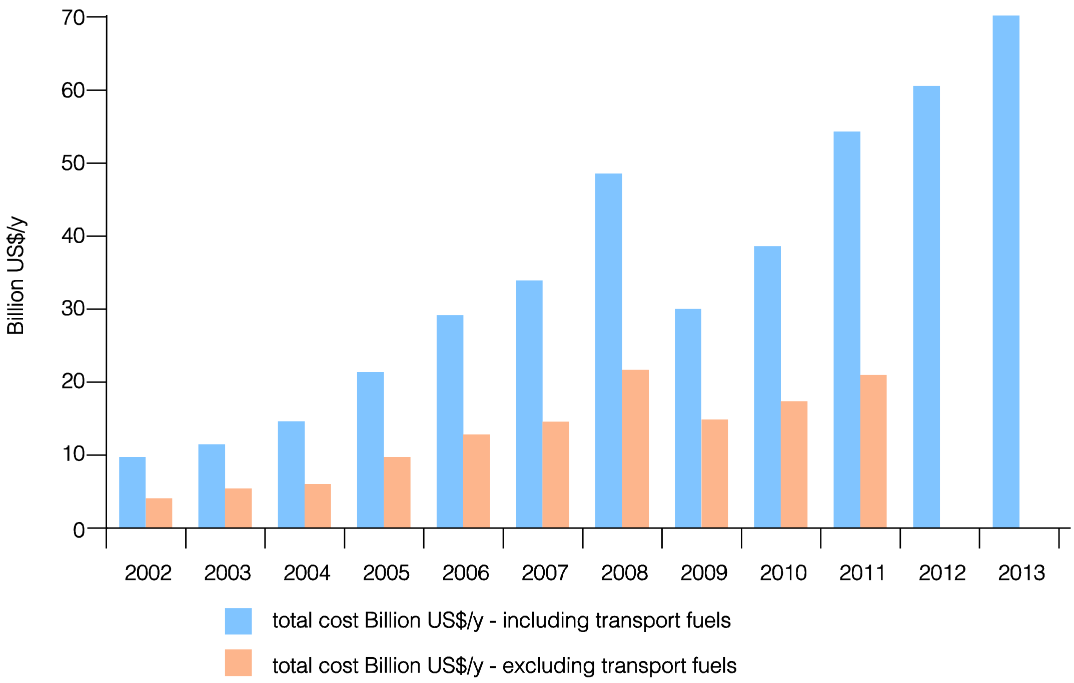

Figure 1 Cost of Turkish energy imports (Turkyilmaz, 2013)

Turkey has the fastest growing global economy. This is currently the 16th largest in the world and the 6th largest in Europe. Remarkably, despite the recession that has impacted on many national economies, recent annual economic growth has been considerable. In the last decade, growth in total primary energy supply (TPES) has been 4.3%/y. Forecasts suggest that energy demand will continue to increase for the foreseeable future. To meet this, the country will need to make significant additions to its energy infrastructure. This will include an addition of at least 50 GW of new generating capacity (Lally and Cetinkaya, 2011).

Recent years have seen national electricity demand increase by as much as 8.5%/y. Between 2002 and 2010, energy transmission and peak capacity increased by nearly 60% (World Bank, 2013). Much of this substantial increase in demand was met by new natural gas-fired power plants although as these rely mainly on imported gas, this has had serious repercussions on the national trade balance. Efforts are now under way to reverse this trend by reducing energy imports and making greater use of indigenous energy resources. As part of moves to facilitate this, the Ministry of Energy and Natural Resources (MENR) has adopted the following 'coal strategy':

- increased diversification of primary energy sources to reduce import dependency and improve security of supply through the greater use of indigenous sources;
- in the period up to 2023, full utilisation of confirmed lignite and hard coal reserves for electricity generation;
- a larger number of coal-fired power plants using indigenous coal/lignite;
- further exploration of new coalfields and increased coal production; and
- utilisation of Clean Coal Technologies (CCTs) to minimise the adverse effects of coal on the environment.

Although *per-capita* energy use in Turkey is comparatively low, the MENR expects that for the foreseeable future, the country's young population and expanding economy will continue to drive up energy demand. Over the past decade, electricity generation has increased from 78.3 Mtoe in 2002, to 120 Mtoe in 2012, an increase of 53% – the rate of increase was only surpassed by China. Over the next ten years, demand is expected to double again. The country is set for an energy boom and during this period, a government goal is to double investment in the country's energy infrastructure. It has also expressed a willingness to fully integrate its energy systems with the rest of Europe.

Alongside the greater use of indigenous coal resources, energy supply will also be boosted by the construction of new nuclear generating capacity, plus greater investment in renewable energy sources such as wind, solar and geothermal (Ross, 2013). Clearly, a major objective is to reduce the high dependence on imported gas and oil. At the moment, >90% of Turkey's oil and 98% of its natural gas is imported, mainly from Iran and Russia. Much of the hard coal used is also imported. The country's indigenous fossil fuel resources are limited almost exclusively to lignite and smaller amounts of hard coal. In 2012, 74.3% of the country's primary energy needs were met by imports (CoalGuru, 2013). Despite efforts to move away from imported gas, within the next few years, the country's gas demand is expected to carry on increasing and to exceed its 51.8 billion m^3/y import portfolio.

The limited availability of natural gas within the region has resulted in a heavy reliance on the use of expensive imported supplies and this has a major impact on Turkey's balance of payments. This is considered to be a major macro-economic risk. As a result, the Turkish Government has launched a strategy to re-direct investment in power generation away from gas to coal. 2012 was designated 'domestic coal year', backed by a government policy initiative that gave increased priority to the use of domestic lignite resources for electricity generation. Strategies and action plans were developed and project applications started. Incentives for investors in gas-fired power plants were cancelled. In May 2013, the government added hard coal production to its investment incentive scheme. This has various multi-layered mechanisms that support investments according to their type, scale and geographical region. The scheme already covered the country's low calorific value lignites – this latest revision now incorporates higher calorific value coals.

As Turkey's coal reserves are underused, the government is taking steps to promote these to both domestic and foreign energy investors (Invest.gov.tr, 2013a). Impetus has been created by the introduction of new incentives to encourage development of coal-fired generating capacity and liberalisation of Turkish coalfields and other assets. The MENR considers that the increased utilisation of indigenous coal is crucial; it views this as the energy source of greatest importance for future power generation. These measures appear to be having some effect - applications for new gas-fired plants have fallen, with investors withdrawing or cancelling some proposed projects (Business News Europe, 2013). Simultaneously, applications for coal-fired plants have increased dramatically.

Despite the widespread availability of indigenous lignite, up to a few years ago, the pace of development of coal-fired power plants in Turkey was relatively slow. However, there are now a significant number of projects at various stages in their development and/or construction. There is an ambitious goal of achieving an additional 18 GW of coal-based installed generating capacity within the present decade (Invest.gov.tr, 2013b), although this may be unattainable. There is also an overarching goal of reaching more than 100 GW of total installed generating capacity by 2023, possibly double that of today's total of 64 GW (Altunyuva, 2014).

Over the next decade, a major aim is to reduce the country's share of electricity generated by gas-fired stations from ~40% to less than 30%. The potential cost savings that could be accrued by a partial switch from imported natural gas to indigenous coal are considerable. For instance, estimates made in 2009 suggest that the Afşin-Elbistan lignite field has the potential to generate 2 billion MWh of electricity. Generating this using imported gas (requiring 400 billion m^3) would cost US$137 billion. Thus, greater exploitation of the Afşin-Elbistan lignite reserves alone could reduce energy imports by this amount (Bozkurt, 2009). Subsequent increases in gas prices will now have pushed this figure higher. Thus, the country's current balance deficit would be improved through the greater use of lower cost indigenous lignite/coal, plus the further opening up of reserves to the private sector. There is an on-going process of privatising much of the power sector and some coalfields, plus encouraging private investment in these sectors. Collaboration with overseas technology developers, suppliers and investors will play an important role in this.

Current estimates suggest that Turkish coal resources exceed 13 Gt, comprising 11.8 Gt of lignite and 1.3 Gt of hard coal. Proven reserves are thought to amount to ~10 Gt of lignite and >530 Mt of hard coal (Euracoal, 2013). However, further exploration is on-going and additional reserves continue to be discovered. Recent new discoveries include 1.8 Gt of lignite in the Central Anatolian province of Konya, capable of powering 5 GW of generating capacity for 30 to 40 years (Hürriyet, 2013). July 2013 saw the announcement that a further 950 Mt of lignite reserves had been discovered in the western province of Afyon, capable of supporting 3.5 GW of power generation projects. More discoveries are anticipated. In order to further incentivise Turkish coal, in 2012, the government announced that it will be given free of charge to 'serious' investors for a period of 30 years, provided that it is used for power generation. Investors will be supported for an initial period, although the government retains the right to revoke any such arrangement after six months.

Much of Turkey's current lignite production is supplied directly to power plants (in 2012, this was 82%, by tonnage), with most of the balance going to industrial users. Indigenous hard coal is supplied mainly to the power sector, coking plants, and the iron and steel sector. Lignite production greatly exceeds that of hard coal. For instance, during the first quarter of 2013 (January-March), Turkey produced just over 459 kt of hard coal and 13.53 Mt of lignite (TURKSTAT, 2013a,b). During the same period, more than 1 Mt of coke was also produced from a combination of domestically-produced and imported hard coals. The destination of this output for the first and second quarters is shown in Table 1.

Table 1 Destination of solid fuels. First (Jan-Mar 2013) and Second (Apr-Jun 2013) quarters (Mt) (TURKSTAT, 2013a,b)

	Power plants		Coking plants		Iron and steel sector		Other industry		Other	
	Q1	Q2	Q1	Q2	Q1	Q2	Q1	Q2	Q1	Q2
Hard coal	2.72	2.18	1.28	1.54	0.336			0.57	1.64	1.08
Lignite	11.86						0.90	0.79	0.37	0.39
Coke					1.18	1.21	0.02	0.02	0.002	0.008

Production of hard coal remains limited. Consequently, ~90% of the hard coal currently consumed is imported mainly from Russia, Colombia, Australia, and the USA. This is directed to various thermal power plants, steel works, and industrial sites, although some is also used for domestic heating (Euracoal, 2013). As new coal-fired power generation projects come on line, the overall tonnage of hard coal imports is expected to grow further.

2 The Turkish energy sector

As with many industrialised countries, Turkey relies on a combination of fossil fuels (oil, natural gas, hard coal and lignite) and renewables for its energy supply. Oil has long been a major energy source – in 2011, it accounted for 28% of the country's total primary energy supply (TPES). The share of natural gas was 32%, and that of coal, 30%. Renewable energies (including hydro) currently provide around 10%, although the government hopes to increase this to 30% by 2023. There are also plans to introduce nuclear power.

Primary energy supply provided by domestic production is around 29% (46 Mt of coal equivalent), with the balance provided by imported supplies (Tamzok, 2013). The largest components comprise domestic lignite/coal (~54%) and hydropower (~14%), followed by wood and wastes (~14%), and oil and non-hydro renewables (~8% each).

2.1 Oil

Oil is produced mainly in the southeast and northwest of the country. Since its peak in 1991, output has declined as reserves have become increasingly depleted. In 2012, the country produced only 45 thousand barrels/day of crude oil, mostly from the Hakkari Basin. However, demand was 670.3, resulting in imports of 625.4 (an import dependency of 93.3%). The biggest suppliers of crude oil were Iran (39%), Iraq (19%), Saudi Arabia (15%) and Russia (11%) (IEA Turkey, 2013). Although currently the biggest supplier, the imposition of sanctions on Iranian crude oil exports could change this picture (Hürriyet, 2013). Reportedly, Turkey intends to reduce imports from this source, replacing them with increased quantities from Saudi Arabia and Libya. As the country's economic expansion gathers pace, over the next decade, oil imports are expected to double. Significant volumes of oil are imported by pipeline and in tankers via the Turkish Straits (Figure 2).

Figure 2 Oil tanker approaching Istanbul

Currently, most oil production takes place in the Batman and Adiyaman Provinces in the southeast of the country. The country has proven oil reserves of ~270 million barrels, mainly in the Hakkari Basin, although there are also known deposits in Thrace in the northwest. There may also be significant reserves under the Aegean and Black Seas. Potentially, production from the latter could be significant. Turkiye Petrolleri A.O. (TPAO), the Turkish national oil company, is exploring offshore areas that may hold between 7 and 10 billion barrels of oil. To facilitate this, the company has formed joint ventures with ExxonMobil and Petrobras. The MENR has a goal of starting commercial production in the Black Sea by 2016. TPAO also plans to develop hydrocarbon resources in the Mediterranean and in 2011, signed an agreement with Shell for exploration in the region and the southeast part of the country.

2.2 Natural gas and liquefied natural gas (LNG)

In 2012, Turkey's gas demand was ~125,000 m^3/d. However, indigenous production was minimal and net imports were 45.3 billion m^3/y (with exports of 0.6 billion m^3). This resulted in an import dependency of more than 98% (IEA Turkey, 2013).

Turkey has four international gas pipelines in operation with a total import capacity of some 46.6 billion m^3. There are plans to diversify gas import pathways via construction of new major cross-border pipelines and LNG terminals. Given that electricity demand is expected to continue increasing until at least 2020, and despite efforts to promote other forms of energy, gas demand will continue increasing for some time. The MENR estimates that up to 2017, this will increase at an average of 1 billion m^3/y. From 2018 to 2020, demand growth could double to 2 billion m^3/y. This would produce a compound annual growth rate (CAGR) of 2.9% (from 2012 to 2020). Clearly, most of the gas consumed will continue to be imported.

Between 1990 and 2008, there was a tenfold increase in the amount of gas used for power generation. Russia was the largest supplier, responsible for 58% of the country's total. This was followed by Iran (19%), Algeria (9.5%) and Azerbaijan (8.7%). In 2011-12, gas provided around 44% of Turkey's electricity. Within Turkey, gas is produced from fourteen operational gas fields, the largest being in north Marmara. Several gas fields have also been brought on stream in the Black Sea – these include the Akcakoca, East Ayazli, Akkaya, and Ayazli fields. Three companies are responsible for the bulk of production, namely TPAO, BP, and Shell. A possible future source could be the Levant Basin, where large reserves are believed to lie deep under the seabed. However, poor relations with some neighbouring countries could make development of this resource problematic (Neuhof, 2013).

Although most plans for gas import projects are focused on pipeline supplies, Turkey also imports liquefied natural gas (LNG) from Algeria, Nigeria, Qatar, Egypt, and Norway. This is offloaded at the country's two LNG regasification terminals at Marmara Ereglisi in Tekirdag, and the Aliaga terminal in Izmir.

Most imported gas is supplied to Turkey's gas-fired power plants, the largest of which is the 3.83 GW combined cycle plant in Adapazari. Even though emphasis on new power plant construction is expected to switch increasingly to indigenous lignite and hard coal, new gas-fired facilities are still coming on line. For instance, in September 2013, the Greek company METKA (with its Turkish subsidiary, Power Projects) completed construction of the 870 MW Samsun combined cycle power plant. Furthermore, in January 2014, Siemens of Germany received an order (from Enerjisa, a joint venture of Sabanci Holding and E.ON) for a 600 MW combined cycle turnkey plant in Bandirma, Balikesir province. Completion is scheduled for 2016. Other major projects are also at various stages of development and/or construction and will come on line during the next few years.

Although natural gas is important for Turkish power generation, the country also has ambitions to establish itself as a gas-trading hub between the Middle East, Azerbaijan and Europe.

2.3 Nuclear energy

The introduction of nuclear power is an important component of Turkey's strategy to diversify its energy mix and reduce its high dependence on imported energy. Since the 1970s, there have been a number of proposals for the development of a nuclear sector, although recently, in light of the country's aims for economic growth, these have attained greater importance. In 2007, a new law concerning 'Construction and Operation of Nuclear Power Plants and Energy (electricity) Sale' was passed by the Turkish parliament and subsequently approved by the President. The bill provided for the Turkish Atomic Energy Authority (TAEK) to set the criteria for building and operating any new plants. Recent developments have seen Russia take a leading role in furthering the development of Turkey's nuclear sector. Construction and operating licences for the first project (at Akkuyu) have been applied for and are expected to be granted mid-2014. A second plant (at Sinop) is to be built by a Franco-Japanese consortium.

Four VVER reactors, each of 1200 MW, are planned for the US$20 billion Akkuyu plant, to be built near the port of Mersin. The start of construction of the first unit is scheduled for 2015, with commercial operation beginning in 2020. The other units may be completed between 2021 and 2023.

In 2010, an inter-governmental agreement between Turkey and Russia was signed, enabling ROSATOM (the Russian State Atomic Energy Corporation) to build, own and operate (BOO) the new plant - this will be the first foreign plant built on this basis. The company formed to take the project forward is Akkuyu NPP JSC (Akkuyu Nukleer Santral/NGS Elektrik Üretim A.S). However, in July 2013, the plant's environmental impact assessment (EIA) report was rejected by the Environment and Urban Planning Ministry, citing deficiencies in form and content. This could delay the start of construction by up to a year. However, a revised version of the report is now with the ministry awaiting approval. Without this, Atomstroyexport, ROSATOM's main contractor for building reactors, cannot launch tenders for an estimated US$7.5-8 billion worth of subcontracts.

Four reactors are also planned for the US$22–25 billion Sinop plant, to be located on the Black Sea coast. These will be Atmea 1-type units, each of 1150 MW. A date of 2017 has been proposed for the start of construction, with the first two units coming online in 2023-24 (World Nuclear, 2013). A consortium led by Mitsubishi Heavy Industries (MHI) and Areva, with ITOCHU Corporation, will construct the reactors (total capacity of ~4.6 GW). These are likely to be the first reactors of this type and are designed for load following. The plant is expected to produce 4.5 MkW of electricity. In January 2014, it was announced that MHI was to establish a new business unit, specifically to step up its involvement in the Sinop project. GdF Suez will be the plant operator.

There are also proposals for a third plant. The site for this has not yet been revealed although Igneada, Ankara and Tekirdag have all been suggested as possible candidates. The MENR plans to announce the location once agreement for the development of the Sinop plant has been finalised. It has been estimated that by 2023, based on two operational stations, nuclear power could be producing ~10% of Turkey's electricity. In addition to the Akkuyu and Sinop projects, the government has announced plans for the possible eventual construction of three more nuclear power plants, each with four reactors, to be operational by 2030. It hopes that by this date, at least 15% of the country's electricity will be supplied by this means.

Turkey has modest uranium resources, including 7400 tU amenable to mining by *in situ* leaching. In 2013, a preliminary economic assessment of the country's Temrezli ISL Advanced Uranium Development and Exploration Project envisaged production of up to 420 tU/y over ten years. Indicated resources at Temrezli are 4200 tU, and inferred resources 2500 tU, all at 0.01%U (World Nuclear, 2013).

2.4 Renewable energy sources

In recent years, the country has introduced various strategies aimed at increasing the production of energy from renewable sources (hydro, biomass, wind, geothermal and solar) particularly by Turkish companies. To encourage this process, there are now several action plans in place and an ambitious target for the country to generate 30% of its electricity from renewables by 2023 (World Bank, 2013; Kayahan, 2012). Renewables represent the second-largest domestic energy source after coal. Currently, the biggest renewables contributions to national electricity generation come from hydro, wind and geothermal (ISPAT, 2013).

To achieve the 30% goal, an estimated US$40 billion in investment will be needed and major developments are expected with all types of renewables (Lally and Cetinkaya, 2011). To date, the World Bank Group has provided more than US$1 billion for renewable energy and energy efficiency projects in Turkey (World Bank, 2013). It is likely that sector requirements will be met by a combination of Turkish and overseas technology suppliers. Increasingly, some of the latter are becoming engaged in the Turkish market. For example, General Electric (GE) and Siemens are now active in the Turkish wind power sector. However, there have been some concerns that regulations and bureaucratic procedures need streamlining in order to encourage greater investment in the sector (Oxford Business Group, 2012). Licensing issues associated with, for instance, new wind farms, have been cited as an obstacle (Sokollu, 2013).

The increased deployment of renewables is expected to simultaneously increase domestic energy generation, decrease national CO_2 emission levels, and spur commercial activity within Turkey's energy companies. However, apart from hydropower schemes, the country's renewable energy potential remains largely underutilised. It is one of the windiest and sunniest places in Europe, yet despite its large solar and wind energy potential, such resources have only been developed in small pockets (Harte, 2012). Only around 5% of the estimated wind potential is currently utilised. Similarly, there is considerable untapped potential for hydropower and geothermal applications. Table 2 provides an estimate of Turkey's renewable energy potential.

Table 2 Renewable energy potential in Turkey (Kaya and Çanka Kiliç, 2012)

Energy type	Purpose	Overall potential	Technical potential	Economic potential
Solar	Electrical (TWh) Thermal (Mtoe)	977,000 80,000	6105 500	305 25
Hydropower	Electrical (TWh)	430	215	124.5
Wind – land based Wind – off-shore	Electrical (TWh) Electrical (TWh)	400 –	110 180	50 –
Wave	Electrical (TWh)	150	18	–
Geothermal	Electrical (10^9 kWh) Thermal (Mtoe)	– 31,500	– 7500	1.4 2843
Biomass	Total (Mtoe)	120	50	32

Government sources suggest that within the next decade, significant investment will be made within the renewables sector. This has been cited as a major component in supporting Turkey's economic growth (Nicola and Sulugiuc, 2013) and analysis suggests that there are significant opportunities for the country to greatly increase the deployment of renewable sources (Harte, 2012). Assuming that the ambitious 30% target for 2023 can be met, renewables-based installed generating capacity will then comprise ~ 40 GW of hydro, 20 GW wind, 3 GW utility-scale solar, and 600 MW of geothermal (ISPAT, 2013a). The current status of the individual renewable technologies is reviewed below.

- **Wind power**

Wind power currently makes up 2.3 GW of the country's total installed capacity (Figure 3). This is expected to have risen to 2.8 GW by the end of 2014 (Altunyuva, 2014). However, the Turkish Government has a goal of achieving 20 GW by 2023. Capacity is expected to grow at between 500 and 1000 MW/y, reaching more than 5 GW by 2015. The country has an estimated potential of between 40 and 48 GW on-shore wind capacity; at the moment, 11 GW has been licensed (Nicola and Sulugiuc, 2013) and the number of Turkish wind farms in operation is increasing.

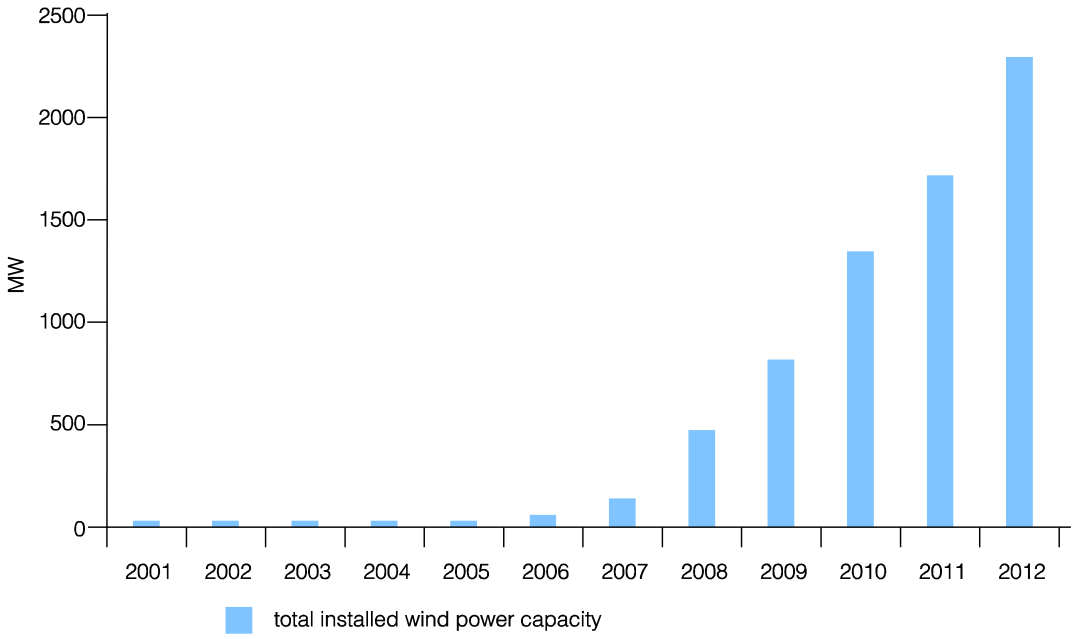

Figure 3 Growth of wind power in Turkey (Turkyilmaz, 2013)

Some projects are being developed jointly between overseas technology suppliers and Turkish companies. GE and Siemens are particularly active in the sector and have supplied wind turbines for a number of major projects. For example, GE is providing 31 of its latest generation units for a major project being developed near Istanbul by Fina Enerji, due online in 2013. In other developments, Güris Group is co-operating with Siemens on three new wind projects. This includes delivery of 53 turbines (total capacity 165 MW) for new onshore power plants in Muğla, Edirne-Tekirdag and Kirklareli. Commissioning of these is expected between 2014 and 2015. One of the latest projects to be completed (in May 2013) was a €153 million wind farm in the north western province of Balikesir, developed jointly between E.ON and Sabanci Holding. Numerous other projects are at various stages in their development.

- **Solar power**

Turkey has high solar irradiation and actually receives more sunshine than Spain or California. Solar energy potential has been estimated to be 26.4 Mtoe (thermal) and 8.8 Mtoe (electrical), or 380 TWh/y. Historically, solar power has seen a very low level of deployment, with only 5 MW of installed PV systems generating power (Harte, 2012). However, development of the sector has recently received some impetus and in 2013, the Energy Market Regulatory Authority (EMRA) issued the country's first licenses (required for any power-generating installation >500 kW) for solar power plants. The process was greatly oversubscribed by both Turkish and overseas investors, with total applications some fifteen times higher (a total of 9 GW) than the market regulator's limit of 600 MW. Nearly 500 companies applied; these included major Turkish energy players, as well as Spanish, Italian, British and German companies (Erdil, 2013). EMRA set out terms and conditions for licensing. For instance, agricultural lands will not be made available, a maximum of two hectares can be allocated for each 1 MW project, and the total annual solar radiation cannot be less than 1620 kWh/m^2. By 2023, the country aims to have 3 GW of utility-scale installed solar capacity.

- **Hydropower**

Turkey's topography is highly conducive to hydroelectric power generation. It has many rivers, five separate watersheds, and 25 river basins. In 2012, the country ranked 10th in the world for installed hydro-based generating capacity, with 1.85% of the global total. It is home to >10% of all European hydropower. Hydropower has long been Turkey's most important renewable energy source, making up a third of the country's installed generating capacity. Over the past decade, hydro capacity has increased steadily from 12.2 GW in 2002, to the current figure of >19 GW. This is more than a third of Turkey's current installed generating capacity (ISPAT, 2013) and around 87% of national renewable energy capacity.

The country currently uses between 36 and 40% of its estimated hydro potential, generating ~46 GWh/y mainly from reservoir-based hydroelectric plants. Over the past decade, capacity has increased at an average rate of 3.6%/y. There is a target to achieve 40 GW of hydro-based capacity by 2023 (ISPAT, 2013a). A number of projects, most of which fall between 200 MW and 2.4 GW, are currently being built by both the private and the public sectors. Around 20 GW of new capacity is expected to be created by the private sector. The largest individual facility is the Atatürk plant in the province of Şanliurfa.

Despite some opposition on environmental grounds, the Turkish Government is committed to pushing forward the building of more hydroelectric plants, and associated bureaucratic and licensing processes are in the process of being streamlined in order to speed up project development.

- **Geothermal**

Turkey's geothermal energy potential is ranked 7th in the world. Tectonically active areas are concentrated along lines of high stress that include faults in north, east and western Anatolia. Geothermal energy exploration started in the 1960s, focused initially on the potential of high enthalpy fields for power production in the Kizildere and Germencik areas. High enthalpy geothermal sources are primarily in parts of western Anatolia where the Earth's crust is thinner. So far, more than 170 geothermal fields have been explored.

Installed geothermal power generation capacity is currently 162 MWe, while that of direct use installations is ~795 MWth (Turkyilmaz, 2013). The latter is used mainly for district heating schemes, the first of which came on line in 1987. Since then, around 20 further district and greenhouse heating projects have been added. Turkey currently ranks 5th highest in the world for direct geothermal use and installed capacity. In terms of power generation, existing capacity is split between seven main sites, with individual unit capacity ranging from 7 to 47 MW (Serpena and others, 2010).

The country's overall geothermal potential is estimated to be between 31.5 and 38 GW and a number of new projects are being developed to capitalise on this. There is a target to achieve 600 MW of generating capacity by 2023. Licensed projects at the investment stage amount to 331 MW (Turkyilmaz, 2013). One of the largest on-going projects is a 60 MWe + 50 MWth cogeneration plant being developed in the

Kizildere geothermal field by Zorlu Energy Group. The project is based on an existing 20 MW geothermal power unit, originally built during the 1980s (Mertoglu and others, nd).

In other developments, a consortium comprising Exergy, Atlas Copco Energas, and SPIG is supplying four power trains (80 MW) for Turkish company Çelikler Jeothermal Elektrik Üretim. Two are for the expansion of an existing geothermal power plant project in the Pamukören area, and the other two for a new project near Sultanhisar.

- **Biomass**

For many centuries, fuel wood, forestry/logging wastes, and agricultural crop residues have been used in Turkey, mainly for heating purposes. The country also has 237 MW of installed generating capacity based on biomass. As a result of projects developed during the past decade, the country avoids an estimated US$5.5 billion of imported natural gas each year.

The greater use of biomass is viewed as a viable route to increasing power generation from indigenous resources, as well as helping to reduce national CO_2 emissions. Although bioelectricity currently provides only 0.1% of Turkey's total electricity, it is regarded widely as a promising near-term option. Total biomass energy potential is estimated to be more than 32 Mtoe, with a total recoverable potential of 17 Mtoe (Saracoglua, 2010; Kayahan, 2012). Biomass consumption is currently 4.8 Mtoe/y, around 4.9% of the national primary energy supply. Some 22% of this total comes from wood-based biomass, 23% from biogas, and the remainder from municipal solid waste.

Of the various sources, wood-derived biomass has the greatest potential, particularly in the form of forest residues. The Turkish General Directorate of Forests estimates that between 5 and 7 Mt/y of biomass is currently extracted from the country's forests. Forestry management differs from many other European countries in that most forests are under state supervision, and protected and managed by the General Directorate.

A major source of biomass for energy production could be the country's 4 Mha of degraded coppice forests. Improving the productivity of these, effectively converting them to 'energy forests', is considered to be as important as forestation. Such measures would avoid the destruction of more productive forests, allowing them to focus on timber production (Saracoglua, 2010). Thus, biomass for energy production would be mainly in the form of excess wood and wood wastes, forest thinnings, plus residues (such as wood chips) from forestry and downstream processing industries. As in other countries, some parts of the timber and pulp and paper sectors already generate heat and steam by burning wood-derived processing/manufacturing residues, some meeting up to 60% of their energy needs in this manner.

In the area of biomass-based RD&D, the main areas of focus are small-scale gasification/combustion systems for local electricity generation (100–500 kWe), centralised large-scale electricity generation for areas with a high biomass potential (via cofiring), scale-up and commercialisation of existing pilot-scale biogas applications, biomass upgrading processes (pelletising/briquetting), and the production of transport fuels from biomass. The Marmara Research Center is involved in several on-going national and international projects that encompass biomass combustion, gasification, biogas and bio-based liquid fuels (Kayahan, 2012).

On the commercial front, a number of biomass combustion plants are already operating or under development. As noted above, some industrial plants already utilise process wastes for energy production. The country's first biomass-fired cogeneration plant (32 MWth + 10 MWe) came online in 2008 in Caycuma, supplying a paper factory (Karataş and Gül, 2011). However, there is now a gradual move towards the adoption of more advanced systems. For instance, a 90 MW turnkey power plant based on fluidised bed combustion is being built near Istanbul by Outotec (formerly EPI of the USA). The plant is due on line in 2014 and will fire packaging paper, cardboard, waste paper, and process wastes such as paper sludge, biological sludge and rejects (Outotec, 2012). Successful operation could encourage the replication of such systems at other industrial facilities.

- **Hybrid energy projects**

In Turkey, a renewable energy resource is defined under the Renewable Promotion Law No 5346.

Under the terms of this, hybrid power plants are defined as power plants that utilise two or more sources, at least one of which must be a renewable technology. Such plants are eligible for the renewable support mechanism, although this support is confined to the renewable component of the system (Gozen, 2013).

By integrating different technologies in order to recover the highest possible amount of energy, multi-generation energy production systems have potential for high efficiency (Mills, 2013). A number of concepts for combining Turkish coal/lignite with renewables have been suggested. However, as yet, none appear to have been deployed commercially. Examples of hybrid systems proposed include:

Geothermal-lignite gasification

Turkey has both geothermal energy and lignite reserves. In some cases, these are co-located, increasing the potential for systems that combine them in some way, particularly for cogeneration applications. A novel concept for a hybrid lignite-geothermal plant feeding a district heating system and hydrogen production facility has been suggested. The proposed location is the city of Aydin. In this concept, lignite is first introduced into a partially fluidised bed gasifier. The product gas is then passed to a fluidised bed gas cleaning unit to produce clean synthetic natural gas (SNG) and finally, hydrogen. The by-products (char and ash) are fed to a fluidised bed combustor to raise steam and generate power. Waste heat from all process steps is collected and utilised in the district heating system, along with heat recovered (following power generation) from adjacent geothermal production wells (Kilkis, 2011).

Solar-coal gasification

A solar-based multi-generation system combining coal gasification with solar power has been proposed. This would generate electricity, produce hydrogen, and provide heating and cooling possibilities. The coal gasification system would be integrated with a solar power tower to utilise concentrated solar energy. The clean syngas produced from the system would be stored for electricity generation purposes. A range of different operating conditions was studied in order to determine the optimum system performance. Potentially, a maximum energy efficiency of 54% could be attained (Ozturka and Dincerb, 2013).

The Dervish plant (wind, solar, gas turbine)

Although not coal-based, in 2011, GE announced a 530 MW project with the Turkish company MetCap Energy Investments. The *Dervish* plant is being built in Karaman and features a 22 MW GE wind farm and 50 MW solar power tower, coupled with GE's new *FlexEfficiency* gas turbine technology (Lally and Cetinkaya, 2011). The latter is designed to rapidly increase or decrease power fed into the grid in response to intermittent production from sources such as wind and solar. The project is being referred to as the world's first 'Integrated Renewables Combined Cycle' system. It is claimed that the Karaman plant will be 69% efficient. The solar fields deployed will generate steam that will be fed to the plant's steam turbine to generate additional power, minimising natural gas consumption. The plant is scheduled to come on line in November 2015. A GE and GAMA Power Systems Engineering and Contracting consortium is providing EPC services.

2.5 Growing international involvement in the Turkish energy sector

New investment is needed to meet Turkey's growing energy demand, especially for natural gas supply and electricity generation. With the latter, at the end of 2013, installed generating capacity was ~64 GW. The aim is to increase this to between 112 and 125 GW by 2023. This will clearly require considerable investment by generators and other organisations. However, estimates of the total needed vary significantly. Some suggest around that for the period between 2005 and 2030, US$53 billion will be required for electricity generation - this comprises US$5.6 billion for 2005–10, US$20.1 billion for 2011-15, and US$27.5 billion for 2016-20 (Kilic and others, 2013). ISPAT suggests that US$125 billion will be needed over the next 15 years (Altunyuva, 2014). However, other estimates are higher. For instance, the Turkish Energy Market Regulatory Authority estimates that the required investment for power generation will be between US$225 and US$280 billion for the period 2010-20 (Türkyilmaz, 2013).

In recent years, Turkey has become an attractive destination for foreign direct investment (FDI) in general. In 2007, the FDI inflow was US$22 billion and in 2012, it was US$11 billion. In the period 2003-12, FDI amounted to a total of US$125 billion (Altunyuva, 2014). Much current investment comes from EU member states, followed by North America and Asia. FDI clearly extends to the energy sector.

Turkey's well-regulated and strong banking sector has helped the country avoid the worst of the global economic downturn, and major financial institutions are willing to finance profitable projects. Amongst the major Turkish banks, as of 2012, Yapi Kredi had provided US$4 billion funding for 138 different energy projects, and Garanti Bank, US$800 million for 15 new projects. A total of US$6.2 billion was allocated to the energy sector.

During the past few years, major international players have become increasingly involved in the provision of energy. Interest continues and the number of such organisations investing directly in the sector continues to grow. Examples of bigger investments are noted in Table 3. There is also extensive and increasing collaboration between Turkish companies and overseas technology providers involved in many of the major new coal-fired power projects being developed (*see* Section 4.4).

Table 3 Examples of major overseas investment projects in the Turkish energy sector (thermal power plants)

Year	Project
2009	RWE of Germany investment in CCGT power plant
2010	AES of the USA joint venture with Koç Entek to develop and operate power generation projects AES and Koç Holding have equal interests in Entek Elektik Üretim A.S (Entek)
2011	Zhejiang Energy Group of China and Polat Madencilik joint venture to develop a coalfield and construct a lignite-fired power plant
2011	GDF Suez investment in natural gas distribution and operation of Baymina Enerji and Uni-Mar Marmara CCGT power plants
2012	Harbin joint venture formed with Hattat Group to operate coal mines and develop coal-fired power plants
2012	Goldman Sachs – Aksa Enerji joint venture. Goldman Sachs Group bought 13.3% of Aksa Enerji Üretim A.S (AKSEN), one of Turkey's biggest power producers
2012	INTER RAO Group of Russia acquired 478 MW gas-fired power plant from AEI
2013	E.ON-Enerjisa joint venture. E.ON SE acquired 50% of Enerjisa Enerji. Sabanci, a major Turkish conglomerate, owns the other 50%. Enerjisa plans to have 7.5 GW of capacity in operation by 2020
2013	EÜAŞ-TAQA tie-up. Plans for TAQA to invest heavily in Turkish mines and lignite-fired power plants But project currently on hold
2013	ACWA of Saudi Arabia and Eser spent $930 million on the 800 MW Kirikkale CCGT power plant project South Korea's Samsung C&T is responsible for EPC
2013	GDF Suez-led consortium with International Power and Mimag Energy to build new coal-fired power plant in Adana

In some cases, investment opportunities encompass both mining operations and power generation. Again, interest is coming from overseas investors. For example, in 2011, China's state-owned energy company Zhejiang Energy Group signed a protocol with Turkish company Polat Madencilik, to develop a coalfield and construct a lignite-fired power plant in the province of Aydin. Stage I of the project is focussing on the production of 3 Mt/y of lignite from Polat Madencilik's mines, while Stage II will involve the development of one 660 MW or two 300 MW generating units (Invest.gov.tr, 2011). Other Chinese companies are also becoming increasingly involved. For example, in May 2013, the Turkish company Hattat Holding agreed a deal with Harbin Electric International to build a new US$2.4 billion 2.6 GW coal-fired power plant in Amasra, in the province of Bartin (Invest.gov.tr, 2013b).

In 2013 it was announced that the Abu Dhabi National Energy Company (TAQA) intended to invest heavily in Turkish lignite-fired power plants. TAQA signed a co-operation deal worth US$12 billion with

Turkey's Electricity Generation Company (EÜAŞ) to jointly develop coalfields in the Afşin-Elbistan region, and operate a lignite-fired power project in the south eastern region. TAQA aimed to eventually build and operate 7–8 GW of generating capacity, capable of meeting about 10% of Turkey's increased electricity demand. The project also included the renovation of existing power plants in the Afşin-Elbistan lignite field. However, in August 2013, TAQA decided to delay the project. The Turkish Government has since announced that it is in talks (on-going) with other potential investors for the scheme.

Some power generation projects are being developed via overseas/Turkish consortia. For example, in January 2013, a consortium led by French company GDF Suez announced plans to invest in Turkish coal-fired power plants. As part of this, a new 1320 MW plant is to be built in Adana at a cost of US$950 million. This will probably use imported coal. GDF Suez will be the majority partner, with its subsidiary International Power and the Turkish Mimag Energy as minority stakeholders (Invest.gov.tr, 2013c).

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Alongside energy production from oil, natural gas and the various renewables noted above, lignite and coal (both indigenous and imported) are major components of Turkey's energy production. These are examined in the following chapters.

3 Turkish coal

The country has deposits of hard coal and lignite and both are produced commercially. In Turkey, the term 'lignite' is used conventionally to describe **any** low rank coal. Thus, it also covers a number of indigenous coals that, according to some international classifications, actually rank as subbituminous. Examples that meet these criteria include some higher quality lignites from Tunçbilek, Soma, Gediz and Celtek. Despite this, all coals apart from hard coals mined in the Zonguldak Basin are traditionally referred to as 'lignite' (Şengüler, 2001). The term 'hard coal' is generally used to refer to bituminous coals. This terminology has been continued in the present report.

Turkey has deposits of both hard coal and lignite, although reserves of the latter are significantly greater. Lignite deposits extend throughout much of the country whereas hard coal is limited to one specific region (Figure 4).

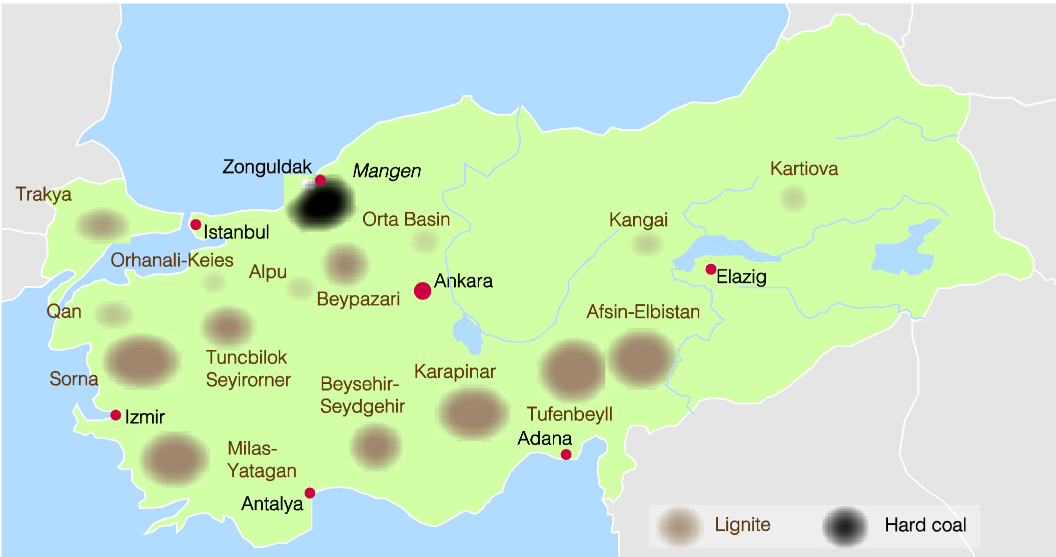

Figure 4 Location of main Turkish lignite and hard coal deposits

At the end of 2012, hard coal resources were estimated to be 1335 Mt (534 Mt proven), with lignite at 11,507 Mt (Dietrich, 2013; Euracoal, 2013) (Table 4). Thus, at nearly 12 Gt, lignite far outweighs the hard coal total of ~1.3 Gt (Tamzok, 2013). However, despite considerable progress over the past decade, large areas of the country have yet to be explored fully. In others, evaluation has only been carried out at relatively shallow depths. Potentially, hard coal and lignite reserves could be much greater than current estimates suggest.

Table 4 Turkish lignite and hard coal reserves (Dietrich, 2013, citing MENR data)

	Lignite (Mt)	Hard coal (Mt)
Possible	262	368
Probable	1345	432
Proven	9900	534
Total	11507	1335

The MENR, in co-ordination with its affiliated institutions and other public and private entities, is responsible for the preparation and implementation of coal-related energy policies, plans and programmes. Through a number of different subsidiaries, it maintains control over coal mines, power stations, and the electricity grid. There are also a number of other organisations involved in the administration and operation of the coal sector, each with a range of responsibilities and activities (Figure 5).

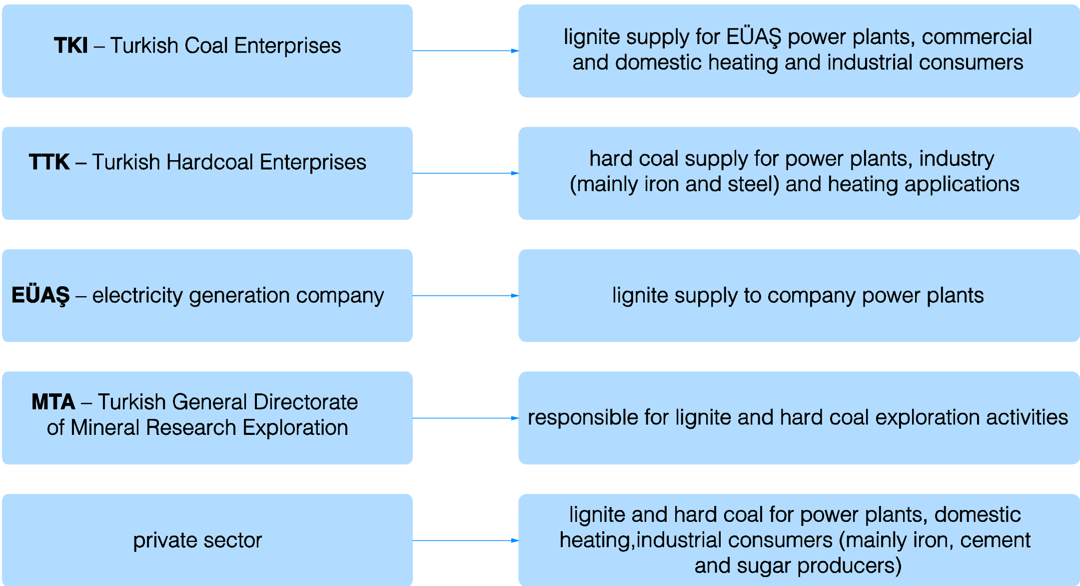

Figure 5 Main organisations involved in Turkish coal sector

3.1 Lignite

Lignite is Turkey's most important indigenous energy resource. Deposits are spread across much of the country, with reserves available in all geographical regions and in more than 40 provinces. There are a number of variants. Paleogene-Neogene lignite basins are present across west and central Turkey. Paleogene deposits are older and encompass Eocene and Oligocene types. Neogene lignites are younger than those of the Paleogene period and include Pliocene and Miocene types. Generally, Eocene lignites are found in the north, with seams up to six metres in thickness. Oligocene and Miocene types occur in the northwest and west of the country respectively (Mobbs, 2010). The older lignites tend to have a higher heating value and sulphur content, whereas the youngest ones have high ash and moisture contents. The Oligocene is characterised by numerous thin seams whereas Miocene lignites form larger deposits with seams of up to 25 metres in thickness. In central and eastern parts of the country, there are large Pliocene deposits with a few seams averaging 40 metres in thickness. Some of the biggest lignite deposits are located in the Afşin-Elbistan basin of south-eastern Anatolia, near the city of Maraş, where around 5 Gt is considered to be economically recoverable.

Turkey's lignite reserves are apportioned between several organisations (Figure 6).

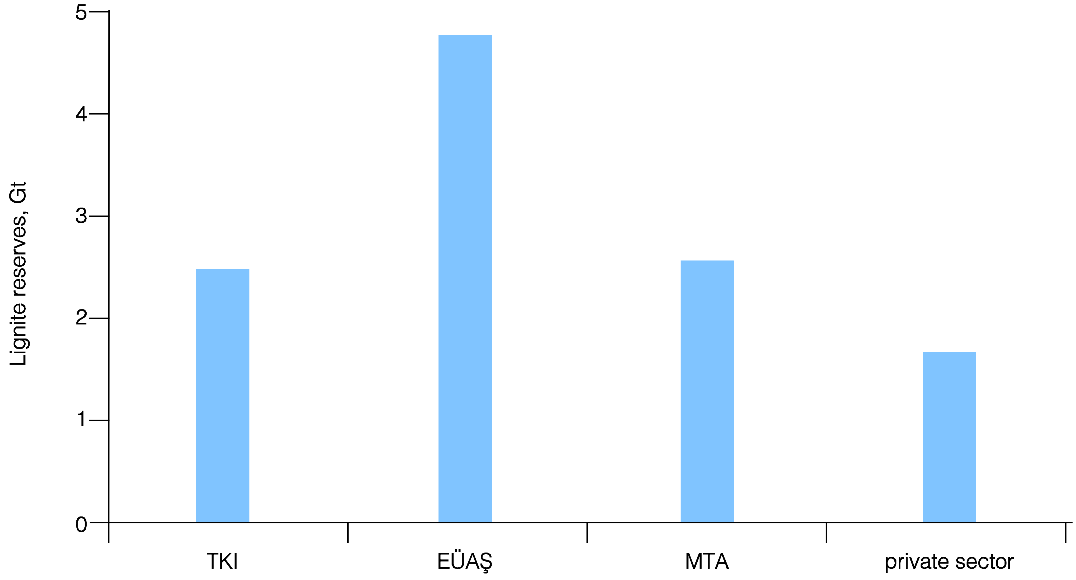

Figure 6 Ownership of Turkish lignite reserves (Gt)

Nearly 90% of lignite reserves are operated by public sector organisations. TKI holds around 23%, EÜAŞ 48%, MTA 18%, and the private sector 11% (ISPAT, 2013b). Much of Turkey's lignite production (>82%) is used for power generation, with around 9% used by industry, and a further 9% for heating applications. In a 'typical' year, TKI produces ~33 Mt of saleable lignite, EÜAŞ ~36 Mt, and the private sector, ~7 Mt/y. In 2011, TKI produced 33.4 Mt of lignite, and EÜAŞ, 31.6 Mt (Deloitte Turkiye, 2013). The main confirmed lignite reserves and their potential are shown in Table 5.

Table 5 Major Turkish lignite reserves (Şengüler, 2001, 2010; Gunes, 2012; ISPAT, 2013b; Turkyilmaz, 2013)

Coalfield	Age	Total reserve (Mt)	Recoverable reserve (Mt)	Possible power plant capacity (MW)	Comments
Afşin-Elbistan	Pliocene	4875	4840	8455	Biggest lignite basin. Split into a number of fields. Considerable potential for further exploitation. Seams vary between 5 and 58 metres in thickness
Adana-Tufanbeyli	Pliocene	423	350	1050	
Adiyaman-Golbasi	Pliocene	51	46	150	
Ankara-Çayirhan	Miocene	308	190	500	Possibly up to 350 Mt reserves
Bingol-Karliova	Pliocene	89	28	100	Possibly up to 100 Mt reserves
Bolu-Göynük	Eocene	38	36	65–150	
Bursa-Orhaneli	Miocene	116	70	270	
Çankiri-Orta	Pliocene	70	65	135	
Konya-Ilgin	Miocene-Pliocene	143	125	500	
Konya-Karapinar	Miocene-Pliocene	1883	1275	3900	
Konya-Beysehir	Miocene-Pliocene	220			Some reserves not economically accessible
Kütahya-Tunçbilek	Miocene	269	170	450	
Kütahya-Seyitömer	Miocene	176	172	150	Reserves of lignite and bituminous marl. Can be blended for CFBC use
Manisa-Soma	Miocene	752	575	1050	Used for power plants, domestic heating and industrial uses
Tekirdag- Saray	Oligocene	129	40	1275	
Çan (Çanakkale)	Miocene	45–83			Used for power plants, domestic heating
Muğla	Miocene	625		1680	Reserves in various sectors
Kangal-Sivas	Pliocene	150			Reserves at Etyemez, Hamal and Kalburcayiri
Thrace basin	Oligocene	800			

An estimated 40% of Turkey's quoted economically exploitable lignite reserves are located in the Afşin-Elbistan basin. There are also important deposits in Soma, Cayhiran, Tunçbilek, Seyitömer, Bursa, Çan, Muğla, Beypazari, Sivas and Konya Karapinar (Euracoal, 2013; Şengüler, 2010) (Table 5). In 2005, an on-going national project (the Lignite Exploration Mobilization Project - LAP) was initiated to further develop existing reserves and to locate new deposits. This has since focused mainly on six regions and explored 10,000 km^2. The main fields where reserves were increased or new ones discovered between 2005 and 2012 are shown in Table 6. In late 2012, further reserves were also discovered in Isparta and Denizli.

Table 6 Additional Turkish lignite reserves discovered (Gunes, 2012; Sabah.com, 2013)

Increase	Location
1.3 billon tonnes	Kahramanmaraş-Afşin-Elbistan Field
515 Mt	Kahramanmaraş-Afşin-Elbistan; Elbistan MTA Licensed Fields
172-205 Mt	Manisa-Soma
498 Mt	Thrace Basin
1.3–1.8 billion tonnes	Konya-Karapinar
275–777 Mt	Eskişehir-Alpu
545 Mt	Afyon-Dinar
495 Mt	Trakya Çerkezköy
140 Mt	Pinarhisar-Vize
16 Mt	Malatya-Yazihan

Thus, since 2005, Turkey's proven lignite reserves have increased substantially, largely as a result of the detailed exploration activities undertaken in the Afşin-Elbistan basin. Funding for this was provided by EÜAŞ and exploration carried out by MTA. Similar activities were also financed by TKI and undertaken by MTA in other basins. The exploration process has so far added 5.8 Gt to Turkey's lignite reserves.

TKI was originally established in 1957 with the aim of exploring and extracting various types of energy-producing minerals that included lignite, peat, shale and asphaltite. Around 16% of Turkey's lignite reserves (around 2.2 Gt), as well as 30% of lignite production capacity is owned by TKI. Most output is supplied to power plants and in recent years, sales to the power sector have increased in line with the country's rising energy demand. TKI currently supplies four thermal plants belonging to EÜAŞ and its subsidiaries – these have a total installed capacity of 1.9 GW, around 24% of Turkish lignite-based power generation.

In 2009, TKI's strategic plan for lignite production covering the years 2010 to 2014 was produced. The major objectives focused on increasing production (from both existing and new sites) and market share, whilst improving profitability by decreasing costs and boosting productivity. Other aims were to apply the latest technologies to upgrade company equipment, to increase emphasis on R&D to develop new technologies and reduce costs, and to increase product diversity.

A significant number of individual lignite mines are in operation. Most lignite is mined by state-owned companies, with more than 90% produced by TKI and EÜAŞ. The greatest concentration of mines is in the northwest region around the towns of Soma, Seyitömer and Çan. Most lignite is produced from opencast mines, although there is some underground mining, mainly in the Soma, Tunçbilek and Beypazari basins. A number of underground mines operate longwall systems, with significant operations at Tunçbilek and Soma (both worked in conjunction with surface mines) and at the privately-owned Çayirhan mine operated by Park Holdings. However, the bulk of production (~90%) comes from surface mines – their scale allows lignite to be produced at a relatively low cost, making it competitive with imported energy resources (Euracoal, 2013). TKI operates around thirty opencast and nine deep mines. Major individual mines operated by company subsidiaries are shown in Table 7.

Table 7 Major individual lignite mines operated by TKI subsidiaries

Mine	Province	Operator	Capacity (Mt/y)	Comments
Bursa mine, Orhaneli	Bursa	Bursa Linyitleri Isletmesi Mudurlu	1	
Çan lignite mine	Çanakkale	Çan Linyitleri Isletmesi Mudurlu	1.8	
Soma mine	Manisa	Ege Linyitleri Isletme Muessesesii Mudurlugu	10.5	
Tunçbilek Mining Center, Tavşanli	Kütahya	Garp Linyitleri Isletme Muessesesii Mudurlugu	7	
South Aegean lignite mine, Yatağan	Muğla	Güney Ege Linyitleri Isletme Muessesesii Mudurlugu	4.9	Transferred to the Privatisation Administration
Ilgin lignite mine	Konya	Ilgin Linyitleri Isletme Muessesesii Mudurlugu	0.3	
Seyitömer lignite mine	Kütahya	Up to 2013, was operated by Seyitömer Linyitleri Isletme Muessesesii Mudurlugu. Now Atatürk Insaat	8	Now privatised
Yeniköy lignite mine, Oren	Muğla	Yeniköy Linyitleri Isletme Muessesesii Mudurlugu	8.5	Transferred to the Privatisation Administration

In Turkey, TKI's surface mining is carried out using various techniques - larger opencast operations such as the existing Afşin-Elbistan mine use bucket wheel excavators, whereas some smaller mines rely on draglines. Some of the bigger EÜAŞ mines are linked directly to captive power plants. As part of the on-going national privatisation process, some mines are being sold, packaged with specific power plants. A major part of the government's strategy to reduce the country's high dependence on imported energy is to make greater use of indigenous lignite reserves. To this end, an existing law is being used that permits the privatisation of state-owned lignite fields. So far, the Soma field has been privatised (Coal Age, 2012), and in June 2012, the Adana-Tufanbeyli lignite deposit was leased to the private sector for electricity generation. This was followed in August by the Denis deposit. Activities are under way aimed at the leasing of other deposits.

As well as TKI, lignite is also produced by the state-owned EÜAŞ that operates power plants with a total installed capacity of 23.8 GW (36.8% of Turkey's total). This comprises 17 thermal power plants (10.8 GW) and 67 hydro facilities. Various company assets are currently in the process of being privatised – this was scheduled to be completed by the end of 2013, although the process has now been extended. In 2012, EÜAŞ produced 36 Mt of saleable lignite mainly for three of its own power plants (Euracoal, 2013). The company owns lignite reserves amounting to ~8.5 Gt, some of which are being privatised via a transfer of operating rights agreements (ISPAT, 2013b). Private companies will build power plants in exchange for permission to use lignite reserves owned by TKI.

Over the past few decades, there have been some fluctuations in annual Turkish hard coal and lignite production (reflecting prevailing economic and other factors), although in the case of lignite, the overall trend has been upwards. Figure 7 shows the output of the different coal types between 1990 and 2012.

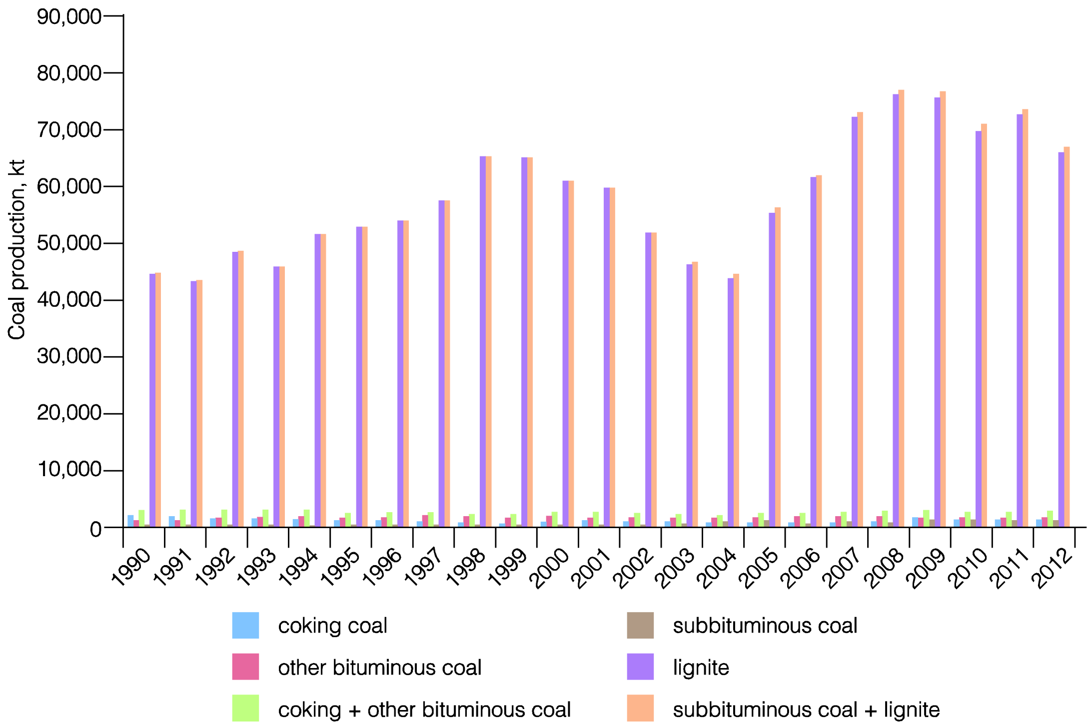

Figure 7 Turkish coal production, 1990-2012 (IEA Coal Information, 2012)

The output from the main individual lignite fields is shown in Table 8.

Table 8 Lignite production from main coalfields (2011) (Tamzok, 2013)

Coalfield	Annual output (kt)
Tekirdag	990
Edirac	350
Çanakkale	1210
Balıkesir	594
Manisa	12,700
Muğla	14,110
Bursa	950
Kütahya	15,420
Ankara Beypazari	5400
Amasya	516
Sivas	5040
Kahraman Maraş	21,600
Şirnak	1180

During 2013, Turkey and the United Arab Emirates (UAE) agreed a US$12 billion deal to jointly develop coalfields in Afşin-Elbistan in south-eastern Anatolia for power generation (Invest-gov.tr, 2013d). The agreement between Abu Dhabi-based TAQA and EÜAŞ would have been the biggest Arab investment in the Turkish energy sector, and the second-biggest investment made in Turkey after the two proposed nuclear power plant projects. However, TAQA has since deferred the project and reportedly, may now be replaced by alternative investors.

3.2 Private sector lignite producers

One of the larger private mining companies is Soma Holding; this operates in the Geventepe and Eynez regions, and produces around 6 Mt/y of lignite from underground mines, mainly around Soma. All production is supplied to TKI. Much of the raw output is washed in the company's 10 kt/d capacity washery. Some of higher CV fine coal generated from this is dried and formed into briquettes in a 120 kt/y capacity briquetting plant. These are sold for a range of heating applications.

In some cases, the influence of the private sector has dramatically improved the efficiency of operations. For example, following its privatisation, Park Termik (a subsidiary of the Ciner Group) took over an existing 310 MW power plant/coal mine project in Çayirhan. Since, daily output from the underground mine has risen from 500 to 7000 tonnes (Engineering & Mining Journal, 2012).

Reportedly, the mine is now one of the most productive subterranean enterprises in Europe. The availability and efficiency of the associated power plant has also increased significantly.

3.3 Hard coal

Unlike lignite, hard coal deposits and commercial production is limited to a single region, the Zonguldak basin in the north-west of the country, situated between Eregli and Amasra on the Black Sea coast

(Hürriyet, 2013). The Zonguldak coalfield is structurally complex and comprises a belt of carboniferous coal measures containing more than 20 mineable coal seams that range between 0.7 and 10 metres in thickness. Coal resources in the basin are estimated to amount to 1.316 Gt, of which more than 520 Mt is considered proven. Of this total, the Bartin-Amasra area holds reserves of 407 Mt (125 Mt recoverable) and the Zonguldak region holds 909 Mt (322 Mt recoverable) (Turkyilmaz, 2013). The current national hard coal production of ~3 Mt/y meets only a tenth of the annual demand, the balance being met by imports (*see* Section 3.4). Some 38% (34% Mtoe) of (indigenous + imported) hard coal is consumed by thermal power plants, 30% (33% Mtoe) by industry, and the remainder used for heating. As would be expected, the calorific value of Turkey's hard coal is higher than that of its lignites.

Turkish Hardcoal Enterprises (TTK) is responsible for the country's hard coal – essentially all Turkish reserves are owned by the company. TTK was established in 1983 and operates in a similar manner to TKI. It is the country's main hard coal producer; the private sector provides only around 8% of the total. However, about 35% of production reported by TTK is mined by private companies working under subcontract. In reality, the company effectively has a monopoly on the production, processing and distribution of hard coal, although there are no legal restrictions on private sector involvement. As the coal basins are widely dispersed, TTK established five production areas. From west to east these comprise Armutçuk, Kozlu, Üzülmez, Karadon and Amasra. The coalfields are in the process of being privatised – the private sector has so far taken over a significant portion, most of which are now being operated on a royalty basis.

The geological structure of the Zonguldak basin is complex, making mechanised production difficult. The geology is characterised by steeply dipping seams that in some areas, lie beneath the Black Sea. Strata are highly disturbed by major and minor faults and folds and contain large volumes of methane.

As a result of such issues, the possibility of using highly mechanised mining systems is limited and generally, labour-intensive conventional production methods are employed (Euracoal, 2013).

Zonguldak coals have a tendency for spontaneous combustion and this has caused a number of serious mine fires in the region. For instance, between 1990 and 2000, six fires occurred in the Gelik Mine of Karadon Colliery, 12 km east of Zonguldak. Spontaneous combustion was responsible for at least some of these. On occasions, methane has been responsible for mine fires and explosions.

Some Zonguldak coals have coking properties and are suitable for metallurgical applications; for instance, coking coal is produced from the Kozlu, Üzülmez and Karadon underground mines. However, when used alone, it is unsuitable for producing coke for use in large blast furnaces. The best coals for coke making contain 24–26% (daf) volatile matter. Suitable Turkish reserves are inadequate and domestic production capacity is too low to meet national coke requirements. In practice, for coke making, local coals are sometimes judiciously blended with imports. Zonguldak coking coals are supplied mainly to regional steel mills (Eurasian Coal Portal, 2012).

Much of the Zonguldak field's annual output is produced by TTK's five underground mines (2.6 Mt in 2011), with the balance coming from private companies based on sites obtained from TTK, mostly operated on a royalty basis. The major hard coal mines operated by TTK subsidiaries are shown in Table 9.

Table 9 Hard coal mines operated by TTK subsidiaries

Mine	Operator	Capacity (kt/y)
Armutçuk mine, Eregli province	Armutçuk Taskomuru Isletme Muessesesi	400
Amasra mine, Bartin province	Armutçuk Taskomuru Isletme Muessesesi	300
Karadon mine, Kilimli, Zonguldak province	Karadon Taskomuru Isletme Muessesesi	450
Kozlu mine, Zonguldak province	Kozlu Taskomuru Isletme Muessesesi	600
Üzülmez mine, Asma, Zonguldak province	Üzülmez Taskomuru Isletme Muessesesi	500

Restructuring and privatisation efforts to increase production are under way, and output is forecast to increase from current levels of 3 Mt/y, to nearly 12 Mt/y in 2023 (Table 10). However, some industry observers regard this level as over-optimistic.

Table 10 Hard coal production from Zonguldak coal basin (kt) (Biçer, 2012)

Year	State-owned production	Private sector				Total
	TTK output	Large scale production areas			Small scale producers	
		Alalcaagzi-Kandilli	Amarsa-B	Bağlik İnağzi		
2012	2000	200	500		352	3052
2013	2220	250	2500		368	5338
2014	2940	250	2500		391	6081
2015	3024	450	2500		64	6038
2016	3150	450	3000		26	6626
2017	3360	450	3000		29	6839
2018	3570	450	3500	2000	8	9528
2019	3780	500	3500	2000	9	9789
2020	4200	500	3500	2200	13	10,413
2021	4545	500	3500	2400	44	10,989
2022	4850	500	3500	2600		11,450
2023	5000	500	3500	2800		11,800

TTK is passing on some of its concessions to the private sector through tenders. It is anticipated that in the coming years, private companies (such as Soma Group) will make a much larger contribution – private capital has the potential to dramatically increase hard coal production. Already active in lignite mining, in 2011, Soma Group won the tender for operation (in return for royalties) of the Zonguldak Bağlik-İnağzi field. This holds an estimated 136 Mt of coal. At a cost of US$200 million, the company is developing an underground mine (with reserves of 90 Mt of coking coal). This will take six years to develop, but once fully operational, should produce 2 Mt/y of coal. This will be recovered from depths varying between 400 and 1000 metres. Project development studies were started in January 2012 and expertise in deep mining techniques is being sourced from continental Europe.

3.4 Lignite and hard coal characteristics

Many Turkish lignites are of poor quality. Most confirmed deposits have low calorific values (CV) and many contain high levels of ash, volatile matter, moisture and sulphur. Depending on the source, CV can vary significantly, even within the same area; examples from different parts of the country are shown in Table 11. Around 70% of reserves have a CV of less than 8.37 MJ/kg, with some below 6.26 MJ/kg. Around 17% are between 10.5 and 12.6 MJ/kg. Only 6–8% exceed 12.6 MJ/kg (Şengüler, 2010; Euracoal, 2013).

Table 11 Variation in calorific value of Turkish lignites (Şengüler 2010; Gunes, 2012)

Location		Calorific value (LHV) (MJ/kg)
Province	District	
Adana	Tufanbeyli	5.4–8.1
Adiyaman	Golbasi	5.8
Ankara	Beypazari	8.4–13.0
Aydin	Center	13.6
Balikesir	Balya	2.1–14.6
Bingol	Karliova	6.1
Bolu	Göynük	9.8
Bolu	Himmetoglu	9.8–11.5
Bursa	Keles	8.0–9.8
Çanankkale	Çan	12.6–>16.8
Çankiri	Orta	4.0–4.2
Corum	Alpagut	13.2
Corum	Osmancik	6.2
Denizli	Dinar	6.2
Edirne	Uzunkopru	17.6
Eskisehir	Alpu	8.8
Istanbul	Catalca, Silivri	6.3-8.7
Karaman	Ermenek	16.8
K Maraš	Ebilstan	4.3–5.0
K Maraš	Ebilstan	4.0–4.7
Kirklareli	Pinarhisar	16.8
Konya	Beysehir, Ligin	4.6–16.8
Kütahya	Seyitömer	8.7–10.5
Kütahya	Tavşanli	10.7
Kütahya	Tunçbilek	9.2–20.5
Manisa	Soma, Kirkagac	8.7–20.5
Manisa	Eynez	12.6–18.4
Muğla	Milas	6.9–9.5
Muğla	Yatağan	8.0–11.3
Tekirdag	Cerkezkoy	8.7
Tekirdag	Center	9.1–12.0
Tekirdag	Saray	8.4–10.5
Sivas	Kangal	5.0–5.4

It is not only calorific values that can differ widely, as other properties often do likewise. Thus, there can be significant variations in moisture, ash, volatiles, fixed carbon, and sulphur contents (Table 12)

Table 12 Range of properties of Turkish lignites (%) (Şengüler, 2010)

	Moisture	Ash	Volatiles	Fixed carbon	Total sulphur
Minimum	1.20	5.21	8.93	8.86	0.21
Maximum	57.66	59.09	43.84	44.14	10.66

As properties can vary between (or even within) geographical locations, this is often reflected in the specification of the lignite supplied to individual power plants (Table 13). Sometimes, appropriate features will have been incorporated at the plant's design stage in order to take this variability into account. However, at times, the variable nature of some lignite supplies has resulted in operational problems and reduced plant efficiency. Unsurprisingly, fuel supply specifications for individual plants differ, with ash levels ranging between 20% and 57%, moisture content between 21% and 38%, and sulphur content between zero and 4.8% (Alonso, 2012).

Table 13 Coal specifications for selected power plants (Alonso, 2012)

Power plant/units	Coal supplied by TKI			
	Ash (%)	Moisture (%)	Sulphur (%)	Particle size (mm)
Orhaneli	33	35.2		0–500
Seyitömer, 1,2,3	38.5	37.6	0.69	0–200
Seyitömer 4	49.5	37.6	0.72	0-200
Tunçbilek A	19.8	24.2		0.5–18
Tunçbilek B	46.2	26.4	1.7	0–1000
Soma A	29.7	24.2		0–30/0–0.5
Soma B – 1,2,3,4	35.2	23.1	0.88	0–200
Soma B – 5,6	57.2	20.9	1.06	0–200/0–1000
Çan	32.3	23.7	4.84	0–1000
Yatağan – 1,3	22	37.4	1.53	0–200/0–600
Yeniköy – 1,2	32	32	1.83	0–600
Kemerköy – 1,2,3	31.9	36.3	1.73	0–600

In the case of hard coals, deposits and commercial production is limited to the Zonguldak basin. Coals from here have higher CV than lignites. These fall typically between 22 and 30 MJ/kg (Anac, 2009). Ash contents vary between 10% and 15%, moisture content between 0.5% and 18%, and volatile content between 23–26%. Sulphur levels are generally between 0.8% and 1%.

3.5 Hard coal imports

Each year, Turkey imports around 27–30 Mt of hard coal. In a 'typical' year, around 19% of hard coal imports are used for electricity generation, 22% for coke production, 29% by industrial users, and 30% for domestic heating (Tamzok, 2013). However, the level of imports is expected to increase as new thermal power plants come on line and iron and steel production expands. In the near term, an estimated additional 2–2.5 Mt/y of steam coal will be required for power generation (Coal Age, 2012; Deloitte Turkie, 2013).

Steam coal is usually imported from Russia, Colombia and South Africa, with smaller amounts from several former Soviet Union countries. Overall, Russia is the biggest individual supplier. Coking coal is also imported – major suppliers include the USA, Canada and Australia. In 2012, imported steam and coking coal amounted to 29.5 Mt. Around 4 Mt of petcoke was also imported; most of the latter originated from US refineries and was used by the Turkish **cement industry**. The cement sector also imported 2 Mt of undersized steam coal, 0.5 Mt of steam coal, and also consumed 0.5 Mt of domestic lignite (Sabri Oral, 2013). In 2011, the sector used 7.7 Mt of coal (Deloitte Turkiye, 2013).

In 2012, Turkey's hard coal imports increased by 25% above the 2011 level (Hellenic Shipping, 2013). During the first quarter of 2013, these amounted to 6.3 Mt. Much of the coal imported during this period was supplied to the **iron and steel sector** (TURKSTAT, 2013a). This also imported 0.5 Mt of pulverised coal injection (PCI) coal and 0.5 Mt of anthracite coke breeze, both from Russia (Sabri Oral, 2013). In 2012, total coal consumption by the sector amounted to ~7.3 Mt.

The Turkish steelmaking sector is currently the 8th largest producer in the world, recently overtaking Brazil and Ukraine, and the 2nd largest in Europe after Germany. Each year it produces 35–36 Mt of steel products. Total coking coal consumption is usually around 5.5 Mt/y, much of which is imported. Only around 10% (~0.5 Mt/y) of this demand is met from domestic sources. Most coking coal is used in the Erdemir, Isdemir and Kardemie integrated steel plants (Biçer, 2012). Although the rate of increase has fluctuated in recent years, output from the steelmaking sector has continued to rise in line with the country's growing economy. In 2011, it grew by 17%, and in 2012, by 5.2%. The country has maintained its position as the country with the highest production increase amongst the top ten steel producers. As demand for steel continues to increase, coking coal imports are expected to rise further. Recent years have seen a number of projects undertaken to increase the production of coke for the country's steel mills. For instance, there has been a major modernisation programme undertaken on coke ovens at the Isdemir steel plant, the largest in Turkey. This has 69 coke ovens. Modernisation and rebuilding has involved both Turkish and overseas contractors.

Imported hard coal is also supplied to the **power sector.** Hard coal-fired plants currently produce around 12% of Turkey's electricity. Domestic coal provides a further 1–2%. At the end of 2012, plants with a combined capacity of nearly 4 GW were being fired on imported coal. A further 2.28 GW of capacity had also been commissioned. Industry observers suggest that Turkey will become one of the world's fastest growing coal importers. The country is eager to diversify its supply and fortuitously, due to its geographical location, has the potential to gather coal supplies from most global resources (Coal Age, 2012). At the moment, only one larger power plant, plus a few smaller industrial units are fired on indigenous hard coal. Others, such as the 1320 MW Çatalağzi Eren and 1200 MW Iskenderun Sugozu power plants (Figure 8) rely on imports (Figure 9) (Biçer, 2012). A number of similar plants under construction will also rely entirely on imported supplies.

Figure 8 The 1320 MW Sugozu power plant. The plant consumes up to 30 kt/d of imported hard coal (photograph courtesy of STEAG)

Figure 9 The Sugozu import terminal in the Gulf of Iskenderun, one of the world's largest floating coal trans-shipment terminals. It handles 3 Mt/y of coal delivered mainly by Capesize vessels from Colombia and South Africa (photograph courtesy of ISKEN)

Hard coal is also imported for **domestic heating**. There is some evidence that this market has recently increased as natural gas prices have risen. In 2012, around 16.5 Mt of coal and lignite were used for household heating; nearly 11.8 Mt of this total was imported hard coal. The main suppliers were Russia (6.5 Mt), China (1.5 Mt) and South Africa (1.5 Mt) (Sabri Oral, 2013). Typical (sized 50–200 mm) products from Russian suppliers have a moisture content of between 3.5% and 9.5%, ash content of 5–9%, sulphur content of 0.3–0.5%, volatiles content of 19–24%, and CV of between 24.5 and 29.7 MJ/kg.

In 2012, imported hard coal consumed by **other industrial users** (such as sugar producers and textile factories) amounted to 8.3 Mt.

Coal imports arrive via a number of Turkish ports. These are classified into three groups, namely governmental, municipal and private ports. The first group, general-purpose governmental ports, are operated by several state economic enterprises – these are under the control of the Ministry of Transport but operate on an independent basis. The second group are municipal ports, managed by the Municipalities – most are comparatively small and serve local needs. The third group comprises special private ports, often catering to the needs of a specific industrial user. For instance, the ZETES-1 and 2 power plants rely on hard coal imports mainly from Brazil, Australia, Ukraine and Russia. The ZETES-3 project currently under development will do likewise. The plants are supplied via a new coal port (Eren Harbour) built between 2008 and 2011 by power generator Eren Enerrj Elektrik Üretim A.S (Eren Holding). This is now the largest on the Black Sea coast, capable of handling ships of up to 170,000 (deadweight) tonnes. Coal is also imported at other locations on the Black Sea coast that include Zonguldak Sea Port, Amasra Port, Ereğli Port and Bartin Port. Other major coal-handling facilities will include the Gemlik and Gebze Terminals near Istanbul (both due for completion in 2014), and the Toros Gubre terminal on the Mediterranean coast.

3.6 Coal preparation

A coal preparation plant is a facility that washes coal to remove soil and rock, crushes it into graded sized pieces, and prepares different grades for transport to market. Depending on the specification and end-use, both Turkish lignites and hard coals may be washed and/or screened prior to transport or use. A range of different products is available. For instance, TKI produces around sixty lignite variants, each with a different specification, tailored to specific market applications (domestic, commercial, industrial and power generation). Thus, product moisture levels range between 12% and 45%, ash between 7% and 49%, and sulphur between 0.6% and 4%. CV varies between 6 and 22 MJ/kg (TKI Strategic Plan 2010-2014, 2009). Some products are only screened or washed, whereas others are both screened and washed. Screened products are available from fines up to 100 mm lumps. Between them, TKI screening facilities are capable of treating more than 52 Mt/y of lignite. The largest individual screening facilities are the G Point and Ozdoganlar plants, each of which is capable of processing up to 20 kt/d.

There are currently around 45 coal preparation plants in operation in Turkey, with capacities ranging from 50 to 1000 t/h. Twelve of these treat bituminous coal, and the rest cover about 40–45% of the country's lignite production. (Ozbayoglu, 2013).

3.6.1 Lignite cleaning

Many Turkish lignites have high ash contents, although once washed, some (such as those from Tunçbilek and Soma) are able to compete with imported coals (Şengüler, 2010). Not all production is washed, although for some applications, cleaning is necessary to increase calorific value and minimise combustion- and environmental-related issues. Washing increases the value of the end-product and helps reduce associated transport costs by removing inert materials present (Biçer, 2012). As the amount of lignite used in Turkey has grown in recent years, so the deployment of washeries has increased. By 2008, around 40–45% of the country's total lignite production was being washed (Ersoy, 2008). Current levels are higher (Ozbayoglu, 2013). Most lignite preparation plants are based on dense medium separation facilities. Static (drums, baths, vessels) and dynamic heavy medium (cyclones) equipment is generally used to treat coarse coal (+18 mm) and fine coal (0.5–18 mm) respectively. Some lignite washery coarse circuits are based on drum separators or Drewboys (float-sink systems) with dense medium cyclones generally deployed for fine circuits (Güngör, 2010).

Lignite washeries are sited in many locations, with larger facilities operating in Soma, Tunçbilek, Çayirhan, Seyitömer, Muğla, Corum, Tekirdag, Istanbul, Azdavay, Balikesir, Kepsut, Dodurga, and Merzifon. Most of the bigger units have been built and brought on line since 2004. Individual plants have outputs between 50 and 800 t/h – the largest individual units are located at the 4.8 Mt/y throughput Dereköy facility operated in Soma by Ciftay Mining (set up by Ciftay on a build-operate basis), and the 700 t/h (4.2 Mt/y) TKI plant at Tunçbilek. The Dereköy plant consists of heavy medium drum, heavy medium cyclone, and spiral concentrators. It uses two parallel circuits, each of 400 t/h capacity.

In order to better compete with imported coal, TKI is installing additional lignite washing, packing and briquetting facilities. Washing capacity of TKI and its contractors has reached just over 24 Mt/y (Table 14), packing capacity is 7 Mt/y and briquetting capacity is 270 kt/y. TKI has a number of washeries (some of which are operated via various commercial arrangements) by the private sector. For instance, Imbat Mining operates a large washery (500 t/h) at Soma in conjunction with an underground mine. Under the terms of the agreement with TKI, in the period up to 2018, Imbat will produce a minimum of 1.5 Mt/y of lignite; 15% of this will be supplied to TKI as a commission. TKI will also purchase the remainder of the mine's output. This is the first such agreement in Turkey and others may follow. At the end of the agreement, more than 20 Mt of lignite is likely to have been mined and washed at the site.

Main TKI washeries are listed in Table 14. New washing capacity continues to be added to the sector. For instance, the entire lignite supply for the Yunus Emre power plant currently under construction at Eskişehir will be washed prior to use. This will be the first time in Turkey that a plant's entire supply will be washed. The washery will be the largest in the country (Adularya, 2010).

Table 14 Main TKI washeries (TKI Strategic Plan 2010-2014, 2009)						
Facility	Location	Date of commissioning	Capacity			Comments
			t/h	t/d	Mt/y	
Dereköy	Isiklar Dereköy	2006	800	16,000	4.8	
Mobil	Denis	2005	150	3,000	0.9	
Imbat	Eynez	2004	600	12,000	3.6	
Soma	Soma	2005	360	7,200	2.16	
Seyitömer	Seyitömer	2006	300	6,000	1.8	Now Privatised
Orhaneli	Orhaneli	2007	150	3,000	0.9	
Tinaz	Tinaz	2008	200	4,000	1.2	In Privatizsation Administration
Sekkoy	Sekkoy	2007	230	4,600	1.38	In Privatization Administration
Tunçbilek	Tunçbilek	1957	700	14,000	4.2	
Ömerler	Ömerler	1993	600	12,000	3.6	
TKI Total			4090	81,800	24.54	

A number of projects have investigated the recovery of ultrafine coal from lignite tailings. This has the potential to improve process economics and help recycle processing water. Fine tailings from washeries are often fed to settling ponds without treatment, and in some cases, considerable quantities have been accumulated. Some still contains sufficient fine coal to have potential as a source of energy. TKI and others have investigated this. For instance, around half of the lignite produced in Tavşanli in Kütahya Province is supplied directly to regional power plants, with the remainder treated in washeries at Tunçbilek and Ömerler. Here, a technique was successfully developed to upgrade washery tailings, creating a product with an ash content of 19% and CV of ~25 MJ/kg. Subsequently, a 75 kt/y capacity commercial production unit was constructed. This now produces a saleable fine coal product that is blended with supplies of low CV lignite and sold to power plants and other industrial users. The technique has since been replicated at other washeries (Erdem and others, 2012).

Several other promising techniques have also been evaluated. For instance, the effectiveness of the 'Falcon Concentrator' and the Multi Gravity Separator (MGS) has been examined. Using a feed coal with an ash content of 66% and CV of 7.7 MJ/kg, the former proved capable of producing a product with an ash content of 40% and CV of 17.7 MJ/kg. Output from the MGS had an ash content of 23% and a CV of 23.8 MJ/kg (Sabah and others, 2010a). Thus, both systems were deemed viable. The MGS has also proved successful in recovering fine coal particles from Zonguldak hard coal tailings (Sabah and others, 2010b).

More advanced lignite washeries are gradually being introduced in Turkey. For example, Turkish company CWP Coal Washing Plants Machinery Industry & Trade Co (CWP) of Izmir, is installing a 150 t/h washery based on the company's *Tri-GFC* (Three Product Gravity Feed Cyclone Separator) technology for the Eski Celtek Coal Directorate in Amasya. This will be the first such application in Turkey (Figure 10). The plant, due for commissioning shortly, will produce washed lignite of different sizes (18–100 mm coarse, 12–18 mm, 10–12 mm, 0.5–10 mm fine, and +0.15–0.5 mm clean slurry). Preliminary testing has confirmed the plant's effectiveness and the system may be replicated at other sites.

Figure 10 The novel 150 t/h CWP *Tri-GFC* 150 t/h lignite washery under construction in Amasya (photograph courtesy of CWP)

The use of dry beneficiation of lignite using several techniques has also been investigated. With established conventional wet cleaning techniques, there can sometimes be difficulties in obtaining water supply, there are costs associated with the dewatering of coal fines, plus a requirement for waste slurry disposal. To address these issues, a pilot-scale Allair Jig (using only air) and AKW Akaflow (novel fluidised bed-based dry gravity fines separator) were used to 'dry' clean Soma-Imbat lignite with an ash content of >40%. The results confirmed that dry separation for this particular type of lignite was possible with relatively good recovery rates (Boylu and others, 2010). Ash levels were reduced to ~15%. Such techniques could be particularly beneficial in arid areas lacking adequate water supplies.

Although CWP is currently the main domestic manufacturer of coal cleaning equipment, historically, various other companies have also been involved. For instance, the 600 t/h (3.6 Mt/y) TKI plant at Ömerler, Tunçbilek, was built on a turnkey basis by the Turkish firm of Tekfen Construction and Installation (CLI). Other Turkish companies have also provided EPC services. For example, with manufacturing facilities in Izmit, SANTEK has acted as EPC contractor for a number of major Turkish coal washeries that include the Soma Coal Enrichment Plant at Manisa, the Kemerburgaz Coal Washing Plant near Istanbul, and the Yeniköy Coal Enrichment Plant.

In some cases, existing washeries have been revamped in order to improve their performance and profitability. For example, the Tunçbilek Coal Preparation Plant was set up in 1957 as part of TKI's Western Lignite Establishment. In recent years, through a four-year programme of process modification and engineering upgrades, productivity has been increased significantly. The plant is now capable of processing up to 4.2 Mt/y and its annual income has increased by US$15.6 million (Gitmez and others, 2010).

There have been commercial links with some overseas technology suppliers. For example, TKI's 800 t/h (5 Mt/y) washery at Manisa in Soma was opened in 2005-06. It was designed and built by an English Dorr-Oliver Company-led consortium. Various parts of the US$15 million plant were provided by English Conn-Welt, American CMI and Swiss Metso.

Co-operation on coal cleaning now also extends to the governmental level. In 2011, India was invited to participate in the development of Turkey's new coal-fired power plants. As part of this arrangement, India offered to provide technical assistance with the development of Turkish hard coal and lignite washeries.

3.6.2 Hard coal cleaning

As hard coal production is limited to the Zonguldak region, all associated washeries are sited in this region. Because of the widely dispersed nature of the hard coal basins, TTK originally established five production areas from west to east: Armutçuk, Kozlu, Üzülmez, Karadon and Amasra.

Coking coal is produced mainly from underground mines in Kozlu, Üzülmez and Karadon. Coal from the Armutçuk mine is used for pulverised coal injection (PCI) applications, and steam coal is produced at Amasra. The CV of coal produced by TTK mines generally varies mainly between 26 and 31 MJ/kg. Around a dozen hard coal washeries are currently in operation, mostly with capacities of between 60 and 300 t/h. Major TTK washeries are in operation at Armutçuk, Amasra, Kozlu-Üzülmez, and Çatalağzi. There are also a number operated by private companies. For instance, Deka Mining operates four mines in Zonguldak on a royalty basis. The company's washery has four circuits consisting of heavy media fine and coarse (Drewboy) coal washing plants, heavy media gravity feed cyclone, and spiral washing plant. It produces 500 t/d of coking coal (0–300 mm) for industrial customers and for household heating (Figure 11).

Figure 11 The 500 t/d Deka Mining hard coal washery, Zonguldak (photograph courtesy of CWP)

Some older washeries have been replaced with newer more efficient units. For instance, Park Energy built two modular 300 t/h washeries at the Üzülmez and Kozlu collieries. Both use Drewboy units for coarse coal separation (10–100 mm), dense medium cyclones for small coal (0.5–10 mm) and filtration units for fines (0–0.5mm). The ash content of the cleaned coal from the Drewboy is 12–13%. Coal from the dense medium cyclones has an ash content of 8-9% and is used in coke ovens. Rotary vacuum disc filters are used for reclaiming slimes; filter slimes and middlings are blended and supplied to the Çatalağzi Power Plant (Biçer, 2008). Such modular plants can be relocated and take only 4–5 months to fully assemble and commission. They have proved to be more economic and efficient that some older designs and a number are now in use.

In other cases, existing washeries have been suitably modernised and upgraded. This has increased capacity and significantly reduced operating costs. For instance, in 2005, the operating costs of the Zonguldak washery were 8.5 US$/t of coal. Plant improvements have since reduced this to US$2.45. Plant efficiency was also boosted, with yields increasing from 45–50% to 65–70% (effectively, a 20% increase in saleable output) (Biçer, 2008). This resulted from the installation of new high efficiency filtration units that capture much greater quantities of fine coal – this is now sold to power plants, producing additional income. As in some other washeries, energy consumption was also significantly reduced, falling from10-11 kWh/t to 4–4.5 kWh/t. The latter is now typical of newer washeries. Such levels of efficiency and effectiveness are now considered standard practice in washeries operated for TTK by the private sector.

4 Turkish power generation sector

There is a close correlation between Turkish economic growth and electricity demand. In 2011, this was 5.5% and 6% respectively (Kilic and others, 2013). Turkey's booming economy has created one of the fastest growing energy markets in the world and electricity requirements have soared (Figure 12). For the decade 2002-12, the average compound annual growth rate was 6.2%. For 2007-12, it was 7.5%. Between 2010 and 2011, electricity demand increased by 8.5%.

Per capita electricity demand has also been rising and is expected to increase further. *Per capita* household consumption has risen from 0.8 MWh/y in 1990 to the current level of 2.3–3.2 MWh (the EU average is 6.5 MWh). The MENR suggests that under a high growth scenario (of 8%), electricity production could reach ~500 TWh in 2020. At a lower level of growth (6.1%) 406 TWh is suggested (World Nuclear, 2013).

There is an ambitious target for 2023 (the centennial foundation of the Republic) for the country to have between 112 and 125 GW of installed generating capacity. This will include some 18.5 GW of new coal-fired capacity located within the country's coal basins. The Turkish Government is in the process of privatising what remains of the publicly-owned electricity sector, gradually transferring16 GW of state-owned EÜAŞ's installed generating capacity. This includes all lignite-fired power plants operated by the company (Gunes, 2012). In 2012, EÜAŞ capacity comprised 49.3% hydro, 16.6% natural gas, 31.3% lignite and hard coal, and 2.8% liquid fuels.

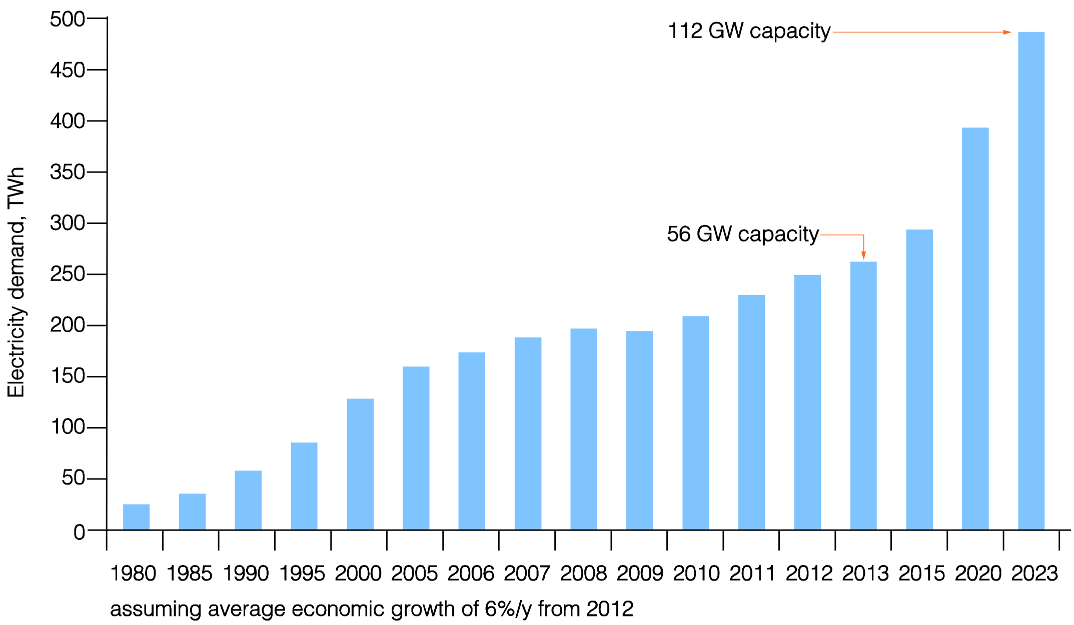

Figure 12 Growth potential of Turkish electricity market – electricity demand, 1980-2023 (TWh) (ISPAT, 2013; Turkyilmaz, 2013)

A breakdown of Turkey's total installed generating capacity (~57 GW at the beginning of 2013) is shown in Figure 13.

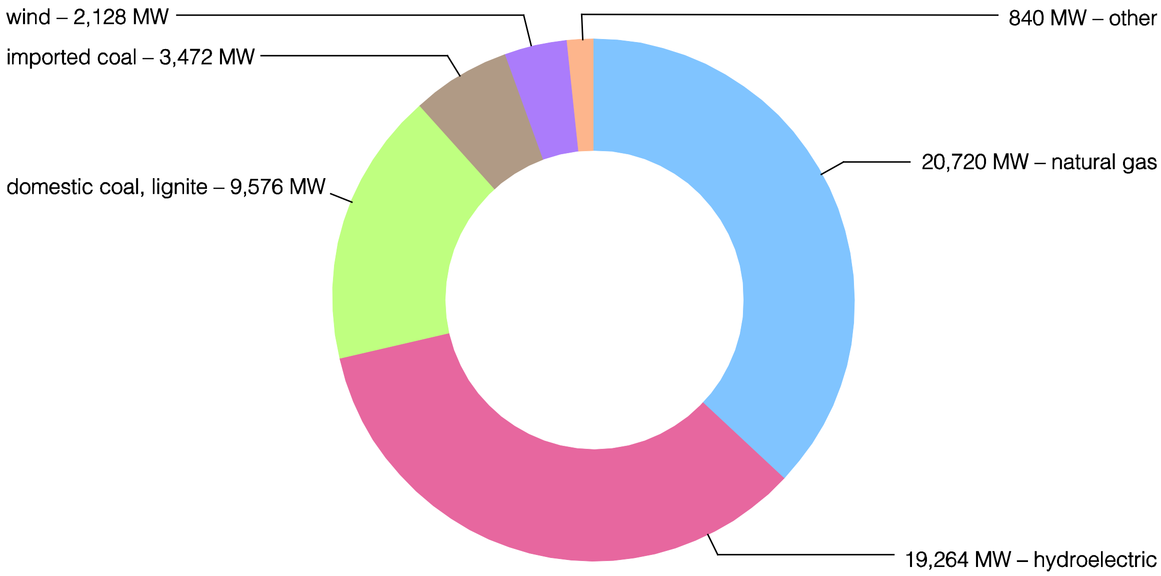

Figure 13 Total installed generating capacity (MW) (ISPAT, 2013)

Thermal and hydroelectric generation currently provides most of Turkey's electricity. In 2012, gas-fired plants generated 43.6%, followed by hydro (24.2%). Domestic lignite and hard coal provided 16.2%, with imported hard coal providing a further 12.2%. Small amounts were also provided by oil, asphaltite, wind, and geothermal (ISPAT, 2013; Turkyilmaz, 2013). The output from some technologies can sometimes vary, depending on the amount of hydropower available at the time.

Thermal plants have long been major players in Turkey's power sector. During the last decade, the number of natural gas-fired power plants increased substantially and these now make up more than half of the conventional thermal capacity. Although in a typical year, coal may supply only 23–28%, this masks its greater importance in less-developed parts of the country (mainly eastern, and parts of central Turkey) that lack gas or oil pipelines.

There are on-going developments aimed at adding more renewables and nuclear power to the country's energy mix. Under the terms of an Energy Supply Security Strategy Paper approved in 2009 by the Turkish High Planning Council, by 2023, the country's electricity will be produced as follows:

- 30% from coal and fuel oil;
- 30% from hydro and other renewables;
- 30% from gas; and
- 10% from nuclear.

In 2001, the Turkish Government enacted an Electricity Market Law that began the process of liberalising power generation and distribution activities. Under this, the state-owned Turkish Electricity Generation and Transmission Corporation (TEAS) was split into separate generation, transmission, distribution, and trade companies. The goal was the eventual privatisation of the generation and trade companies. Since this restructuring, Turkish electricity generation and consumption have both increased. Around 25 GW of additional generating capacity has been added, leading to the current total of ~64 GW. In particular, significant growth occurred between 2002 and 2008 (Hürriyet, 2013). Government sources suggest that the present generating capacity may again redouble by 2023 (Nicola and Sulugiuc, 2013). In 2012, Turkey's net power generation amounted to ~240 TWh, virtually all of which was consumed within the country (Sari, 2013).

Thus, the Turkish electricity generation system, formerly dominated by EÜAŞ, is being progressively opened up to private power generators. During 2012, EÜAŞ operated a total of 7.46 GW of lignite-fired plants and 300 MW fired on hard coal. Lignite plants generated a total of 29.86 GWh, and hard coal plants 1.476 GWh. In the same period, natural gas plants produced 20.74 GWh (EÜAŞ, 2013). Coal-based plants consumed 48.9 Mt of lignite and 1.25 Mt of hard coal. In 2012, EÜAŞ thermal power plants (coal, lignite, natural gas and oil) were responsible for generating 22% of Turkey's electricity, between them, generating a total of 52.5 GWh. The contribution of individual coal and lignite plants is shown in Table 15 and their locations shown in Figure 12.

Table 15 EÜAŞ hard coal and lignite-fired generating capacity (2012) (EÜAŞ, 2013)

Fuel type	Plant	Location	Installed capacity (MW)	Generation (GWh)	% contribution to total Turkish generation
Hard coal	Çatalağzi	Zonguldak	300	1476	0.62
Lignite	Afşin-Elbistan A	K Maraš	1355	2960	1.24
Lignite	Afşin-Elbistan B	K Mara	1440	4623	1.93
Lignite	Çan	Çanakkale	320	1449	0.61
Lignite	Orhaneli	Bursa	210	941	0.39
Lignite	Seyitömer*	Kütahya	600	3280	1.37
Lignite	Tunçbilek	Kütahya	365	1555	0.65
Lignite	Kangal*	Sivas	457	1268	0.53
Lignite	Soma A & B	Manisa	1034	5074	2.12
Lignite	Kemerköy	Muğla	630	2826	1.18
Lignite	Yeniköy	Muğla	420	2897	1.21
Lignite	Yatağan	Muğla	630	2982	1.25

*now privatised

Figure 14 EÜAŞ thermal power plants in 2012

Between 2001 and 2009, publicly-owned generation dropped from 78% to 46%, with a number of coal-fired power plants being privatised. These included the 600 MW lignite-fired Seyitömer plant, acquired for US$2.2 billion by Çelikler Holding, and the 457 MW lignite-fired Kangal plant, bought for US$985 million by a Konya/Seker-Siyahkalem joint venture. The next plants to be sold will be the 300 MW hard coal-fired Çatalağzi plant, probably followed by the lignite-fired Soma and Çan plants (Deloitte Turkiye, 2013).

As part of the wider privatisation process, 13 thermal power plants and 28 hydroelectric plants have been grouped for sale into 9 portfolios. Only some include coal/lignite-fired plants (a total of 9.263 GW). The relevant ones comprise:

- Portfolio 1 Afşin-Elbistan A and B;
- Portfolio 3 Kangal, Tunçbilek and Çatalağzi;
- Portfolio 4 Orhaneli; and
- Portfolio 5 Kemerköy, Yatağan and Yeniköy

The intention is that these portfolios will be sold after the completion of the sale of the EÜAŞ 1200 MW gas-fired Hamitabat power station and three other coal-fired plants. Various state-owned coalfields are also in the process of being privatised. The Turkish Ministry of Privatization Administration (OIB) recently set a timeline for the divestment of state-owned power generation assets. The aim is to complete the privatisation of Turkey's thermal power plants by 2015. To complete this divestment, a total of 12 GW of state-owned coal- and gas-fired power plant capacity is in the process of being auctioned. The private sector currently owns ~55% of power generation assets although the near-term aim is for this to be at least 85%. The remainder may be classified as 'strategic assets' that could remain in the hands of the state (Gas to Power Journal, 2013).

Investment in Turkey's power sector is increasing rapidly. This has resulted mainly from the gradual liberalisation of the energy market, the formation of established standards, the need for 4–4.5 GW/y of additional generating capacity, the on-going privatisation of publicly-owned power plants and coalfields, and the introduction of incentives for energy investments. As a result, a number of major Turkish and overseas organisations are investing heavily in the sector. However, reportedly, some new power projects have encountered difficulties such as delays in obtaining Environmental Impact Assessments, excessive red tape, high capital cost requirements, uncertainties concerning the liberation of the market, and carbon emissions costs (Coal Age, 2012).

4.1 Coal-fired power generation

The amount of electricity generated each year by coal-fired power plants can vary, often reflecting the scale of hydropower available at the time. In a typical year, between 25% and 30% of the country's electricity is generated by lignite and hard coal plants. In 2011, lignite was used to generate 17%, with indigenous and imported hard coal producing 11% (Dietrich, 2013). In terms of installed generating capacity, domestic lignite and hard coal amounts to 17.1%, with imported coal at 6.2% (ISPAT, 2013).

Historically, most major lignite- and hard coal-fired power plants have used variants of conventional pulverised coal combustion (PCC) technologies, based mainly on subcritical steam conditions. For some, steam temperatures and pressures are relatively low (Table 16). There are also a number of fluidised bed combustion (FBC) plants operating, fired on lignite and/or hard coal.

Table 16 Steam conditions adopted for selected subcritical lignite-fired PCC power plants (Platts, 2013)

Plant	Main steam/reheat temperatures (°C)	Steam pressure (MPa)
Afşin-Elbistan A	530/530	18.5
Afşin-Elbistan B	530/530	19.0
Kangal 1, 2, 3	535/535	13.2
Soma B (1–6)	535/535	13.3
Çan 1 and 2 (CFB)	543/542	17.4
Yatağan 1–3	535	13.2
Yeniköy	535	13.2
Çayirhan	535/535 535/535	17.0 13.2
Orhaneli	540/540	12.8
Seyitömer	539/539 540/540	13.2 14.0
Kemerköy	535/535	13.2
Çatalağzi	535	13.5

Recently, attention has switched increasingly to the adoption of supercritical steam conditions (*see* Section 4.1.2). Currently, most of these new proposed projects are for hard coal-fired plants although at least one is for a station that fires both lignite and hard coal (new Units 4 and 5 at the Biga site) where steam conditions of 24.2 MPa/566°C/566°C are proposed (Platts, 2013).

In mid-2012, the government announced that the country's coal resource was enough to support 17 GW of new coal-fired generating capacity, equivalent to nearly a third of the country's current installed capacity. To further encourage a switch from gas to coal, it called for tenders for 5–6 GW of new plants during 2012, with up to 17 GW by 2023.

4.1.1 Lignite-fired generating capacity

The different lignite fields support varying numbers of power plants that reflect the scale of the lignite reserves available and the current level of production. Individual power plant capacity varies between 210 and 1440 MW. Annually, the largest plants (the two Afşin-Elbistan stations – Figure 15) each consume 18 Mt of local lignite (Table 17). Other major lignite-fired plants are shown in Figures 16 and 17.

Figure 15 Afşin-Elbistan B thermal power plant (photograph courtesy of TKI)

Figure 16 Yatağan thermal power plant (photograph courtesy of TKI)

Figure 17 Yeniköy thermal power plant (photograph courtesy of TKI)

Table 17 Major lignite-fired power plants in operation (Şengüler, 2010; Gunes, 2012; IEA Turkey, 2009)

Plant	Location	Start-up	Capacity (MWe)	Lignite consumption (Mt/y)	Main equipment/EPC suppliers
Afşin-Elbistan A	Kahramanmaraş	1984-87	1355 (3 x 340, 1 x 335)	18	DBAG, BBP, Alstom, MELCO, ZVVK, MHI, BBC, ENKA/TEF, STEAG, Flakt, Babcock
Afşin-Elbistan B	Kahramanmaraş	2006-07	1440 (4 x 360)	18.5	DBAG, BBP, Alstom, MHI, MELCO, GAMA-Tekfen-Tokar JV, ZVVK, ENKA/TEF, STEAG, BBC
Kangal	Sivas	1989-2000	450 (2 x 150, 1 x 150)	5.4	Ganz-Danubius, MHI, Melco, Transelektro, Guris, GAMA
Soma B	Manisa	1981-86	1034 (6 x 165)	8.0	Akon, GAMA, Skoda Export
Tunçbilek B	Kütahya	1978	300 (2 x 150)	2.4	Elektrim, KWU
Biga CFB plant*	Çanakkale	2005-09	405 (3 x 135)	—	Dongfang, Shanghai, Jinan, CMEC, Mimag-Samko, FEIDA
Çan CFB plant	Çanakkale	2004	320 (2 x 160)	1.8	Alstom, Teknotes
Çayirhan 1,2 Çayirhan 3,4	Ankara	1987-2000	620 (2 x 150, 2 x 160)	1, 2 – 1.78 Mt 3, 4 – 2.5 Mt (total 4.3)	Biro, MHI, MELOCO, VEMOS, Lurgi, Bishoff, Guris
Kemerköy	Muğla	1993-97	630 (3 x 210)	5.0	Rafako, Zamech, Dolmel, ENKA, Energomontaz-Polnoc
Orhaneli	Bursa	1992	210	1.34-1.5	Steinmuller, LMZ, Electrosila, TML
Seyitömer	Kütahya	1973-89	600 (4 x 150)	7.1	Stein, Deutsche Babcock, Tosi, BBC, Ansaldo, MHI, Melco, ABB, Lahmeyer, Dogus
Yatağan	Muğla	1984-86	630 (3 x 210)	4.9-5.35	Rafako, Zamech, Dolmel, Enka
Yeniköy	Muğla	1986-87	420 (2 x 210)	3.7	Rafako, Zamech, Dolmel, Enka
Tufanbeyli CFB plant**	Adana	2015	450 (3 x 150)	7.2	ITOCHU, SK Engineering and Construction, Prota

* also fires hard coal ** still under construction; start-up in 2015

4.1.2 Hard coal-fired generating capacity

Turkey also has a number of plants that fire hard coal (Table 18). At the moment, only one significant plant (Çatalağzi) is supplied from indigenous sources, although the privatised Turkish steel producer Kardemir (Karabük Iron and Steel Works) also generates some of its own electricity from 35 MW of generating capacity fired on domestically produced hard coal. All other major hard coal-fired plants rely on imported supplies. At the end of 2012, coal-fired power plants using imported coal had a total capacity of 3,984 MW. As the price of many internationally-traded coals has fallen, interest has increased in building power plants fired on imports.

Table 18 Turkish hard coal-fired power plants (Sengular, 2010)

Plant	Location	Start-up	Capacity (MWe)	Coal supply	Main equipment/EPC suppliers
Çatalağzi	Zonguldak	1990-91	300 (2 x 150)	Washed, indigenous 1.6 Mt/y	MV, Ganzrock, MHI, EVT, Kutlutas, ERÕTERV-ERBE, Ganz-Danubius
Sugozu	Iskenderun, Adana	2003	1320 (2 x 660)	Up to 30 kt/d Imported	BBP, Siemens, GAMA, Tefken
ZETES-1(CFB)	Zonguldak	2010	160	Imported	Tlmače, Siemens, Istroenergo Group, Mastir Enerji
ZETES-2	Zonguldak	2010	1200 (2 x 600)	3.5 Mt Imported	Dongfang, Shanghai, CMEC, Mimag-Samko, Mastir, Heilongjiang
Biga CFB plant, Karabigha Ichdash	Çanakkale	2005-9	270 (3 x 135)	Imported	Dongfang, Shanghai, Jinan, Mimag-Samko, FEIDA
Zonguldak Çatalağzi TPP, Eren Holding	Zonguldak	2010	1360 (1 x 160, 2 x 600)	Imported	CMEC
Projects in development					
Izdemir Energy power plant	Aliağa Izmir	2014-15	350	895 kt/y Russian coal	
Amasra supercritical power plant	Bartin		1300	Indigenous Amasra coal	AVIC, Hema
Anadolu Group, Gerze power plant	Gerze	2018?	1200 (2 x 600)	8000 t/d Russian coal	

Many Turkish plants built during the past decade (as well as those currently under construction) have involved collaboration in some way with overseas technology suppliers. Initially, many of these were from Europe although latterly, involvement with suppliers from Asian countries such as China, Japan and South Korea has increased.

Apart from FBC-based plants, major power stations rely on conventional PCC technology using subcritical steam conditions. Only one operational plant (ZETES-2) currently uses supercritical conditions although a number of projects in development and/or under construction will do likewise. ZETES-2 has two 600 MW supercritical units, the first of which came on line in 2010. Major supercritical projects being developed are listed below. Some of the bigger capacity lignite-fired proposals may also adopt supercritical technology.

- **ZETES-3 power plant, Zonguldak**

At the end of 2010, the first of the two 600 MW ZETES-2 supercritical units came on line using steam conditions of 24.2 MPa/566°C/566°C. This was followed by the signing of a contract (in January 2013) for the 1200 MW ZETES-3 supercritical project. This contract is between Chinese supplier Harbin Electric International (HEI) and Eren Enerji Elektrik Üretim (EREN). ZETES-3 is the first co-operative EPC project between the two companies. Plant construction is scheduled to take 33 months.

- **Izdemir Energy power plant, Aliağa Izmir**

A contract for construction of this 350 MW supercritical project was signed in April 2011. Currently under construction, the US$350 million plant is being built for Izdemir Enerji, the power generation subsidiary of Izmir Demir Çelik Sanayi (IDC), a major privately-owned Turkish steel company. It will be fired on ~895 kt/y of imported hard coal. The plant will produce 1015 t/h of steam and is expected to have an efficiency of 45% (LHV). The superheater outlet temperature will be 571°C, with an outlet pressure of 25.3 MPa. Particulate emissions will be less than 10 mg/m^3, with emissions of SO_2 and NOx below 200 mg/m^3. Plant construction will take three years – commissioning is scheduled for May 2014. The plant is expected to have an operating lifetime of at least 30 years.

- **AYAS-1 power plant**

The project is being developed by AYAS Enerji (AYAS Enerji Üretim ve Ticaret A.S). In 2009, CMEC and Evonik Steag Gmb Corporation of Germany signed an EPC contract for the 600 MW AYAS-1 supercritical plant. CMEC will serve as the general contractor and undertake overall project planning, main structure design, civil construction, procurement, and installation, as well as provision of all auxiliary facilities and services. This is the third 600 MW supercritical unit that CMEC has exported to Turkey. The project has now received the necessary permits and start-up is scheduled for 2016.

- **Amasra supercritical power plant, Bartin**

In February 2012, the Turkish engineering and manufacturing firm Hema Endustri (a subsidiary of Hattat Holding) and China's Aviation Industries (Avic) signed a US$1 billion framework agreement for the construction of a 1.3 GW hard coal-fired power plant in Amasra, Bartin. Hema will build the plant and Avic will provide engineering, coal production equipment, and power plant construction expertise. Hema has a generation licence from the energy regulator EPDK, although an environmental impact assessment has yet to be granted. Once this is in place, construction will start; this will take around four years. The project may be increased to 2.6 GW, and the Turkish Energy Ministry has suggested that potentially, it could be gradually enlarged to 4 GW. Hema has an agreement with TTK to excavate three coal pits in Amasra to supply the plant. During the initial phase, 5 Mt/y will be produced although this could rise to 10 Mt/y during the second phase.

- **ICDAS Çanakkale Bekirli TPP, Biga**

ICDAS Electricity and Energy Manufacturing is developing a 2 x 600 MW project at Berkirli in Biga. This will be fired on imported hard coal. Major equipment is being supplied by CMEC. A number of Turkish and Chinese companies are involved in the plant's construction that began in 2011. The project is being developed in several stages (first unit, second unit, FGD facility). The plant will use a sea water-based desulphurisation system for SO_2 control and an SCR unit for NOx control. Unit 1 was commissioned in 2011. Unit 2 was scheduled for commissioning in 2013.

- **Gerze power plant**

A US$1.7 billion 1200 MW supercritical plant has been proposed by the Anadolu Group for the town of Gerze. The company has been granted a 49-year licence for the plant which is expected to generate 8.4-8.7 TWh of electricity, meeting around 4% of the country's current demand. However, an Environmental Impact Assessment (applied for in 2011) has yet to be approved. A start-up date of 2018 has been suggested but given the local opposition to the project, this seems optimistic. The plant will use two 600 MW once-through supercritical boilers with reheat. Steam data are 28.5 MPa/600°C/610°C. Fuel will be 8000 t/d of imported Russian hard coal. The plant will be equipped to meet all current EU emission limits. Lahmeyer International of Germany has carried out pre-feasibility studies for the project.

- **CENAL Electricity power plant, Çanakkale**

This 1320 MW supercritical plant will be owned and operated by Turkish companies Cengiz Holding and Alarko, working jointly as CENAL Electricity Generation Company. The project is being designed in China but built using local construction companies. Hatch of Canada has been engaged to provide engineering services for CENAL. The facility will use sea water for cooling and includes state-of-the-art emission control technologies capable of meeting the latest Turkish standards. Construction began in February 2013 and commercial operations should start in 2016.

4.2 Fluidised bed combustion

The advantages of fluidised bed combustion have been well established and the technology is now used widely on a commercial basis. A major advantage of FBC is its fuel-flexibility, although performance testing is still sometimes required when different feedstocks (or combinations of feedstocks) are under consideration. The properties of Turkish lignites can vary widely with geographical location, hence the importance of testing prior to large scale application. Within the country, the potential of lignite-fired FBC technology has been recognised – some of Turkey's large lignite reserves have proved suitable for fluidised bed combustion and a growing number of FBC power/cogeneration plants are in operation or under development. Both bubbling fludised bed combustion (BFBC) and circulating fluidised bed combustion (CFBC) units are deployed commercially.

4.2.1 Bubbling fluidised bed combustion

BFB boilers tend to be of smaller capacity than their CFB counterparts and are often used for power and/or steam raising duties on industrial sites. Coal-fired BFB boilers are offered by several Turkish companies, and a number of units are operating within the country, used mainly for various industrial applications. Other BFBC units fire various biomass-type wastes such as chicken litter, wood chips and bark.

Selnikel offers BFB boilers based on technology licenced from EckRohrKessel GmbH of Germany. Reportedly, these units are well suited to operating on low CV coals and other low-grade feedstocks. Capacity ranges from 6 to 50 t/h of steam. Combustion efficiency of up to 99%, with low NOx and SO_2 emission levels are claimed.

The Yildiz Boiler Company offers small bubbling fluidised bed boilers, many of which have been installed at commercial and industrial sites within Turkey. Most supply between 10 and 50 t/h of steam. Their design is based on technology licensed from Lentjes of Germany.

MEK (part of the Mimsan group of companies) also manufactures bubbling FBC boilers used mainly for steam raising on industrial sites. These use multi-cyclones and an ESP for particulate control. Various fuels can be used that include low CV lignite and various wastes and biomass. An example of the company's technology is the bubbling FBC boiler installed at the GAP Textile Factory, Malatya, where two units each generate 20 t/h of process steam. MEK also produces CFBCs (*see* below) and reciprocating grate boilers.

4.2.2 Circulating fluidised bed combustion

Within Turkey, CFBC-related R&D is undertaken mainly by the TÜBİTAK (The Scientific and Technological Research Council of Turkey) Marmara Research Centre (MAM). This has several test facilities that include a 30 kW CFB system that can operate up to 1000°C with air or an oxygen-rich atmosphere. It can fire coals alone or in combination with other feedstocks. The Centre also houses a pilot-scale (750 MWth) CFB combustor, operable up to 2.4 MPa pressure; it can generate 800 kg/h of steam. Again, cofiring is possible (Ergintav and Akgün, 2013). Both indigenous lignites and hard coals have been tested in these facilities (Urkan and Arikol, nd). The performance and suitability of Turkish lignites for CFBC applications has also been evaluated by several overseas organisations. For instance, EERC of the USA has tested them for FBC use.

Turkey has some in-house CFBC manufacturing capacity. For instance, based in Malatya, MEK (part of the Mimsan Group) manufactures, supplies and commissions CFB boilers of varying capacity, mostly for industrial applications. As well as different lignites and hard coals, these can also accommodate various wastes and biomass that includes cotton waste, sunflower husk, wood chips, and chicken litter. The company claims to be the most experienced Turkish company for FBC applications. Examples of CFB boilers operating in Turkey include two units installed at the Petlas Tire Company, each of which produces 32.5 t/h of superheated steam (3.8 MPa, 450°C) and generate 5.5 MW of electricity. A similar 20 t/h steam unit is in operation at an industrial site in Rize.

Most larger FBC-based Turkish plants, used for utility-scale power generation/cogeneration, have so far relied mainly on technology provided by established overseas suppliers such as Alstom, Dongfang and CMEC of China, SES Tlmače, and Andritz Energy & Environment, although various Turkish companies continue to be involved in project construction and EPC duties.

4.2.3 Commercial fluidised bed power plants

The use of fluidised bed combustion technology is well established in Turkey, with a number of power and/or cogeneration plants in operation. Others are proposed or under development. All have been based on technology from overseas suppliers, although often working in conjunction with Turkish partners (usually as EPC contractors). Most plants are fired on indigenous lignite and/or hard coal although some operate on indigenous/imported hard coal blends. Major projects comprise:

- **Çan CFBC plant, Çanakkale**

The plant houses the first fluidised bed boilers installed in Turkey. In 1998, Alstom was awarded a turnkey contract by TEAS to supply two 160 MW CFB boilers, turbines, generators, and control systems. The plant went on line in 2004. EPC for the turnkey project was provided by a consortium of Alstom and Teknotes. The unit burns around 1.75 Mt/y of local high-sulphur (>8%) lignite, trucked in daily from several opencast mines in the area. The plant uses limestone for SO_2 control and employs a dry cooling tower. It has an efficiency of around 40% and generates 482 t/h of steam at a pressure of 17 MPa and temperature of 540°C. Before initial plant start-up, the local lignite was tested at RWE's Niederaussem power plant in Germany. This confirmed that it was a suitable FBC fuel and was capable of meeting Turkish emission limits.

- **IÇDAŞ Steel Works, Biga, Çanakkale**

The plant comprises three 135 MW FBC units operated by Icdas Elektrik Üretim ve Yatirim A.S. These are fired on lignite and hard coal (CV of 25 MJ/kg) and came on line between 2005 and 2009. Chinese companies were heavily involved in the project; this included boiler supplier Dongfang, and turbine suppliers Shanghai and Jinan. The plant features China's first export, large-scale CFB boiler. Construction time for each unit was between 33 and 40 months.

- **Park Termik power plant, Silopi, Şirnak**

This 135 MWe power plant is operated by Silopi Elektrik Üretim A.S, and came on line at the end of 2008. CMEC of China was the main contractor. The plant is fired on asphaltite, a hydrocarbon of petroleum origin. Park Elektrik has the operational rights of the Silopi asphaltite mine until 2033. Based on TKI estimates, the asphaltite reserve in Silopi is ~35 Mt.

- **Seydisehir power plant, ETI Aluminyum (Turecko)**

The 13 MW lignite-fired plant was built by SES Tlmače for ETI Aluminyum. Commissioning was carried out in 2009. The CFB boiler is of a double-pass design, self-supporting, with a drum and natural circulation. An external heat exchanger is used for combustion temperature control. The unit generates 120 t/h of steam at a pressure of 4 MPa and temperature of 438°C.

- **Zonguldak-Çatalağzi power plant, Zonguldak (ZETES-1)**

This 160 MW plant is operated by Eren Enerji Elektrik Üretim. It is fired on bituminous coal, was commissioned in 2010, and came on line in 2011. The single CFB boiler generates up to 465 t/h of steam at a pressure of 16.5 MPa and temperature of 563°C. The boiler is of a three-pass design, self-supporting, with a drum, natural circulation, and steam reheater. The unit was designed to operate on coals with a CV of between 18.8 and 27 MJ/kg. Coals from the Ukraine, Russia, Columbia and South Africa are burned regularly. When supplies of these have been lacking, local coals have also been used. Major technology suppliers included SES Tlmače (CFB boiler) and Siemens (turbine, generator). EPC was carried out by Istroenergo Group and Mastir Enerji. The plant forms the first phase of a US$1.6 billion coal-fired project, being financed largely by Turkish banks. As well as the power plant, the project includes a new coal port, the largest on the Black Sea coast.

- **Konya Sugar Corporation, Cumra**

Two 55 MWth lignite-fired CFB boilers of the internal recirculation type were supplied by Babcock & Wilcox for this industrial site. They were built on a turnkey basis between 2003 and 2004.

Each produces 75 t/h of steam at 4.3 MPa/430°C. The main contractor was GAMA Power Systems, who was responsible for civil and structural works, plant construction, start-up, and commissioning.

4.2.4 FBC projects in development or under construction

- **Göynük Power Plant, Bolu**

In 2012, SES Tlmače signed a contract for a second 135 MW CFB boiler for AKSA Enerji Üretim.

SES is providing EPC and manufacturing services and technical assistance during boiler commissioning. Both boilers will be fired on local lignite and generate 373 t/h of steam at a pressure of 14.9 MPa and temperature of 540°C. The first boiler is scheduled for commissioning in August 2014, and the second in February 2015. The project is being funded by Turkish banks and the client. The lignite being used has a CV of between 9.2 and 11.7 MJ/kg, with a moisture content of ~30%, and ash content of 26–31%.

- **Yunus Emre Thermal Power Plant, Eskişehir**

The plant is owned by Adularya Energy, a member of Naksan Holding. Reportedly, this is the first private sector combined (underground) mining and power project in Turkey. The project features two 145 MW

CFBC units, fired on local lignite. The FBC boilers and flue gas cleaning systems are being supplied by Andritz Energy & Environment. The EPC contractor is Vitkovice Power Engineering of the Czech Republic. Project financing was provided by the Czech Export Bank. In 2012, Vitkovice awarded a US$35 million contract to ABB to provide turnkey electrical and automation systems for the 290 MW plant.

The first unit is due on line in 2014, with the second unit later in the same year. The plant has been equipped with FGD and is claimed to be the first Turkish plant to comply fully with the latest EU emission standards. Reportedly, for the first time in Turkey, the entire lignite supply will be washed and enriched before being supplied to the plant. The washery being built will be the largest in the country (Adularya, 2010).

- **Şirnak Thermal Power Plant Project**

Galata Energy (a subsidiary of Global Energy) is developing a 2 x 135 MW CFB boiler power plant in southeast Turkey. Fuel for the plant will be supplied from an opencast asphaltite mine owned by Geliş Madencilik. Local asphaltite reserves are estimated at 40 Mt, enough to supply the power plant for 30 years. In December 2011, an EPC and O&M (operation and maintenance) contract was agreed with China National Electricity and Engineering Company (CNEEC). CNEEC will also take a 10% stake in the plant and will be responsible for the operation and maintenance during the first four years. Construction began in 2012, and is expected to take 30 months to complete. Once operational, the plant will generate 2 TWh/y. It is thought that asphaltite reserves in the region have the potential to supply up to 2 GW of generating capacity.

- **Tufanbeyli Thermal Power Plant, Adana**

At 450 MW, this will be one of the larger privately-owned, lignite-fired power plants in Turkey. Three 150 MW CFB boilers are being installed. These will fire lignite and use limestone for SO_2 control, both sourced locally. As part of the proposal for the plant, combustion testing of Tufanbeyli lignite was previously carried out by EERC in the USA (Jain and others, 2007).

In 2011, Enerjisa Enerji Üretim A.S. awarded the EPC contract for the project to the Korean consortium of ITOCHU and SK Engineering & Construction. The project is part of Enerjisa Enerji's plan to expand its energy production capacity up to 5 GW by 2015, with the aim of eventually acquiring a 10% share of the Turkish power generation market (ITOCHU, 2011). Completion is scheduled for February 2015. In April 2013, E.ON acquired 50% of Enerjisa Enerji from Vienna-based Verbund A. G.

- **Kipas cogeneration plant, Kilili, Kahramanmaraš**

Kipas is investing in €260 million in a new greenfield corrugated paper and cardboard facility. The plant will use 100% recovered paper and cardboard as raw material. Electricity and steam for the process will be supplied by a captive 50 MW coal-fired CFB-based cogeneration plant. This will also supply ~132 MW heat for the process. It will be fired on a mixture of local and imported Russian coals. Ash and flue gas treatment by-products will be fully-utilised by the Kipas cement factory.

- **Projects in Çankiri-Orta**

The Çankiri Orta Thermal Power Plant (the *YOTES Project*) is being developed near Çankiri, around 100 km north of Ankara. This 400 MW plant (3 x 133 MW), currently under construction for 3S Enerji in Maden Üretimi A.S, features three CFB boilers manufactured by SES Tlmače. Each boiler will generate 365 t/h of steam. The contract for the first two boilers was signed in 2010, with delivery scheduled for March 2013. Commissioning of the first unit is expected in 2014. CKD Group of the Czech Republic is providing EPC services and supplying balance-of-plant (BOP) components for the project.

Reportedly, Elektrik Üretim ve Madencilik is also developing a165 MWe CFB lignite-fired minemouth power plant in the area.

In July 2013, it was announced that the Turkish Government had agreed terms for a 237 MW built-operate-transfer (BOT) lignite-fired power plant. A deal was signed with US-based Trinity Partners International of Pennsylvania. Trinity Partners and Ahlstrom Development Corporation will build and operate the plant for 26 years before handing it over to Turkish power utility TEK. The consortium will use Ahlstrom's FBC technology. As the plant will meet World Bank and Turkish emission standards, flue gas scrubbing will not be required. The privately-financed project is expected to cost US$500 million and includes the development of a 100 Mt coal deposit.

- **Hidro-Gen Soma Thermal Power Plant, Soma, Manisa**

In February 2014, it was announced that Foster Wheeler's Global Power Group was to design and supply two CFB boiler islands and flue gas scrubbers for this new project. The contract was awarded by Harbin Electric International, which is acting as EPC contractor for the project. Hidro-Gen is a subsidiary of the Turkish Kolin Group. Foster Wheeler will supply two lignite-fired 255 MWe steam generators and auxiliary equipment for the boiler islands, and flue gas cleaning systems with CFB scrubbers and ESPs. Siemens is supplying two SST5-5000 HM-N steam turbines with the associated auxiliary and ancillary systems. Project costs are estimated at around US$1 billion. Commercial operation is scheduled to start at the beginning of 2017. Foster Wheeler/Harbin anticipate the development of further similar projects in Turkey.

4.2.5 Fluidised bed combustion of coal and oil shale combinations

Alongside its coal deposits, Turkey also possesses significant deposits of oil shale. This is thought to constitute the second largest solid fossil fuel reserve after lignite. As part of the country’s drive to increase energy production from indigenous resources, these are now becoming the focus of increased attention.

Most of Turkey’s oil shale resources are distributed in middle and western Anatolia. The total reserve has been estimated at between 3 and 5 Gt, with proved reserves of around 2.2 Gt (WEC, 2010). Of this total, the geologic reserve is estimated to amount to 0.5 Gt, with possible reserves of 1.7 Gt. In terms of quality, amount and exploitability, four major deposits have been identified: Beypazari (Ankara), Seyitömer (Kütahya), Himmetoğlu and Hatildağ (Bolu).

In some other parts of the world (such as Estonia), oil shale is already used as a feedstock for fluidised bed combustion power plants. It is also being considered for FBC-related use in Turkey, but possibly blended with coal. Advantageously, shales usually contain high levels of carbonate minerals that have the potential to provide an SO_2 adsorption medium during combustion. If blended in suitable proportions with high sulphur lignites, this could avoid the need for limestone addition during fluidised bed combustion. Previous research in, for instance, the USA, has demonstrated that the addition of ground oil shale during fluidised bed combustion can enhance power generation by:

- serving as a natural, effective acid-gas absorbent;
- creating a cementitious ash that materially reduces the potential for the leaching of hazardous materials, and possibly serving as a viable building material; and
- adding heating value to the fuel input.

4.3 Environmental issues

Industrial air pollution continues to be a serious problem for some parts of Turkey and a challenge for public policy. Of most concern are emissions of SO_2, followed by NOx. Around two thirds of SO_2 and a third of NOx emissions are generated by fuel combustion and the power generation sector. Historically, two major pieces of air quality legislation were introduced. In 1986, the first act limited emissions of smoke, dust, gas and vapour generated by all types of industrial activity. Legislation of 2006 defined this more closely to industrial processes and thermal power plants.

Turkey is now in the accession process to the European Union (EU) and is bringing its national environmental legislation in line with that of the EU. As a candidate country, harmonisation of Turkish legislation on coal with that of the EU (such as the Large Combustion Plants Directive, LCPD, 2001/80/EC, 2001) is under way. All new power plants must now comply with the LCPD. All thermal power plants are (and will continue to be) regulated under Turkish legislation that has transposed the LCPD (transposed into Turkish law by By-Law No. 27605 of 8 June 2010). In the future, all such plants will be subject to Turkish legislation that will transpose the EU's Integrated Pollution Prevention and Control (IPPC) Directive (2008/1/EC, 2008) – this requires the application of best available technology (BAT).

4.3.1 Emission control systems on hard coal- and lignite-fired power plants

All new hard-coal plants will be required to install and operate:

- FGD capable of capturing at least 90% of SO_2 combustion emissions;
- low-NOx burners, staged-air supply and (subject to review), selective catalytic reduction (SCR) for NOx control; and
- particulate control systems.

If not already equipped, and if it is practicable to do so, existing plants will be expected to retrofit FGD, low-NOx burners and staged-air supply.

As with hard coal plants, new lignite-fired plants will also require appropriate SO_2 and NOx controls. Although some existing plants already have effective control systems, some do not. In the case of the latter, plant operators have until 2019 to install suitable emission control technologies. The alternative is to formally opt out of the transposed LCPD, subject to accepting a limit of 20,000 operating hours between July 2011 and December 2019. However, it is understood that operators have adopted a policy of not pursuing LCPD opt-out (EuropeAid, 2012).

The more recent Industrial Emissions Directive (EU Directive 2010/75/EU – IED) is in the process of replacing a number of existing directives that include the LCPD and IPPC. The IED commits EU member states to controlling and reducing the impact of industrial emissions on the environment. It will repeal the LCPD from January 2016, and other directives from January 2014. Efforts leading to its full transposition are under way.

Prevailing and proposed emission legislation (applicable to new-build plants) is summarised in Table 19. SO_2 emission limits for thermal power plants licensed between June 1987 and November 2002 are 2000 mg/m^3 for plants between 50 and 100 MW, between 400 and 2000 mg/m^3 for plants between 100 and 500 MW, and 400 mg/m^3 for plants >500 MW.

Table 19 Turkish emission limits for particulates, SO_2 and NOx (new plants) (Alonso and others, 2012; also CCC website)

	Emissions (mg/m^3, 6% O_2)								
	Particulates			SO_2			NOx		
Legislation	IAPC	LCPD	IED	IAPC	LCPD	IED	IAPC	LCPD	IED
50–100 MWe	100	50	20	2000	850	400	800–1800†	400	300‡
100–300 MWe		30		1300	200	200		200	200
>300 MWe			10	1000		150*			150§

Notes:
IAPC = By-law on Industrial Air Pollution Control LCPD = Large Combustion Plant Directive
IED = Industrial Emissions Directive - not currently applied in Turkey.
* 200 for CFBC † must be below 800 for solid fuel fired plants ‡ 400 for pulverised lignite
§ 200 for pulverised lignite

With regard to the requirements of the LCPD, 'existing plants' are deemed to be those that had received any kind of permission prior to the issue date of the LCPD regulation. From 2019, the limits laid down in the regulation will become effective. A nine-year transition period has been set for existing Turkish plants to meet the new emission requirements. However, new plants are expected to comply with the limits as soon as they come into operation (Tekindor, 2011).

Turkey has a clean air network that includes 123 stations that monitor and generate data on air emissions (mainly PM_{10} particulates and SO_2). There is at least one station in every province although most are located in provincial city centres. Only 25 stations also measure NOx emissions. Air pollution (particularly SO_2, NOx and particulates) from industry and power generation remains an issue in several parts of the country. Since 1990, overall emissions of SO_2 have increased significantly. In that year, Turkey emitted

765 kt of SO_2. By 2000, this had increased to 2014 kt and by 2010, it was 3260 kt; NOx emissions had increased to 930 kt (EuropeAid, 2012). Electricity generation/fuel combustion is responsible for almost two-thirds of the country's SO_2 and a third of its NOx emissions. Although recent years have seen some improvements, air pollution remains an environmental problem, particularly in some urban locations and industrial regions. Parts of Turkey now have some of the highest PM_{10} and SO_2 values in Europe (Orhan, 2012). However, emissions in other areas are much lower and in most, they meet legal requirements.

The Turkish power sector includes more than thirty lignite-fired plants with individual capacities of more than 300 MW. Emission rates and specific emissions (per MWh) of pollutants depend on whether or not a particular plant has installed appropriate abatement technologies. Retrofitting such plants to meet the requirements of IPPC/IED will entail significant investment. The cumulated pollution abatement cost for the Turkish electricity sector for the period 2010 to 2025 is estimated to be in excess of €18 billion per year (at 2010 prices) (EuropeAid, 2013).

Over the course of the past two decades, many of Turkey's bigger coal-fired power plants have been equipped with some form of FGD system. From 1986, the installation of FGD equipment became mandatory for all new hard coal- and lignite-fired power plants. Prior to this, during the period 1975-85, efforts to minimise the impacts of SO_2 emissions focused mainly on minimising levels at ground level via the manipulation of stack height, flue gas temperature and velocity (Kilic and others, 2013). As limestone is cheap and easily accessible in Turkey, variants of the wet limestone process have been deployed for most new and retrofitted FGD units. Individual Turkish FGD units consume between 12 and 49.5 t/h of limestone. The largest individual consumption is by the three units at the Yatağan power plant. Capture efficiency for Turkish FGDs is generally >95%.

As elsewhere, retrofitting an FGD unit into an existing power station can cost more than building one at a new plant – analysis suggests that under some circumstances, a retrofit unit can cost up to a third more (Europe Aid, 2012; Kilic and others, 2013). Although data is not available for all Turkish power plants, over the past two decades, as technologies have improved, there has been a downward trend in FGD costs (per MW output). Selected examples are shown in Table 20.

Table 20 Power plant FGD costs per MW output (Kilic and others, 2013)

Plant	Completion date	Cost (US$/MW)
Çayirhan (1 and 2)	1991	258,820
Orhaneli	1998	280,572
Kemerköy	2002	176,407
Afşin-Elbistan B	2005	134,405
Yatağan	2007	172,270
Yeniköy	2008	163,210

The first Turkish FGD installation was on the lignite-fired Çayirhan station. This was built on a turn-key basis by a consortium comprising Bischoff-Kloecner-Lentjes of Germany and a Turkish partner, and came online in 1991. The unit was fully financed by foreign sources. This was followed by similar retrofits at other power plants that included Orhaneli, Yatağan, Kangal, Yeniköy and Kemerköy (Şengüler, 2001)

(Figure 18 and Table 21). So far, ~4.4 GW of lignite-fired power plant capacity has been retrofitted with FGD.

Figure 18 Kemerköy thermal power plant. The plant is equipped with three limestone-gypsum FGD units (photograph courtesy of TKI)

Table 21 Emission control systems on lignite-fired power plants (Kilic and others, 2013: Platts, 2013)

Plant	SO_2 control	NOx control	Particulate control
Lignite-fired			
Afşin-Elbistan A	2 x LG FGDs from MHI		ESPs from Flakt
Afşin-Elbistan B	4 x dry lime FGDs from MHI		ESPs from ZVVK
Kangal	3 x LG FGDs (one from MHI)		ESPs from Walther
Soma B	None		ESPs
Tunçbilek B	None		ESPs
Çayirhan	2 x LG FGDs from Lurgi 2 x LG FGDs from Bischoff		ESPs from VEMOS
Kemerköy	3 x LG FGDs from Babcock & Wilcox		ESPs
Orhaneli	Wet limestone FGD from TEKNOTES/ Noell/KRC		ESPs
Seyitömer	None		ESPs from Flakt. Updated
Yatağan	3 x LG FGDs (Guris retrofit)		ESPs
Yeniköy	3 x LG FGDs (Bischoff retrofit)		ESPs
Yunus Emre CFBC	Andritz dry FGD (Turbo-CDS). Start-up 2013		ESP
Hard coal-fired			
Iskenderun, Sugozu	2 x LG FGDs from Bischoff	LNB	ESPs
ICDAS Bekirli TPP, Biga	Seawater FGD	SCR	ESPs
Çatalağzi	None		ESPs
ZETES-2	None	SCR	ESPs
ZETES-3	LG FGD from Harbin	SCR	ESPs

LG = limestone gypsum

An FGD installation will normally be expected to remove at least 90% of the SO_2 present in the flue gas. However, a potent barrier to achieving this in some lignite-fired plants is that the properties (such as moisture, ash and sulphur content, and CV) of domestically-produced lignite can be very variable. This can cause FGD operational instability, resulting in difficulties of process control and an overall reduction in process performance (Europe Aid, 2012).

With most of the older lignite-fired (PCC) power plants, tangential firing systems are used. As a result of lignite's low ash fusion temperature, temperatures in boiler combustion chambers remain relatively low. Consequently, NOx emission values generally meet prevailing emission limits. Hence, the adoption of NOx control has been limited mainly to the use of primary measures and/or combustion modifications. Measures to control emissions from hard coal-fired plants extend to the use of low NOx burners (LNB) and/or selective catalytic reduction (SCR) systems.

Although some larger power plants now have FGDs, several of the older facilities and some smaller units still lack adequate emission control systems. However, most are expected to be suitably re-equipped and rehabilitated as they are sold into the private sector. The lack of such equipment is usually factored into the purchase price. Newer plants in development or under construction will be equipped with comprehensive emission control systems to reduce SO_2, NOx and particulate emissions. However, in a number of cases, the specific details of the systems proposed have not yet been made public.

4.3.2 Utilisation of combustion wastes

Lignite-fired power plants make a major contribution towards meeting the country's electricity needs. Large tonnages, often with high ash content, are used and consequently, significant amounts of combustion residues such as fly ash and bottom ash are produced. Ash and slag disposed from coal-fired power plants, plus gypsum from FGD units make up most of the solid wastes that result from power generation. These are covered by the Turkish *Regulation of Dangerous Waste* issued in 1995 by the Ministry of the Environment.

Annually, Turkish thermal power plants generate more than 20 Mt of such residues (mainly fly ash and bottom ash). If these have the appropriate properties, they have the potential for utilisation in the manufacture of cement, ceramics and other materials. Thus, some fly ash is utilised for cement and concrete manufacture (for example, from the Sugozu and Çatalağzi power plants). Ash from the MEK-supplied BFB combustion plant located at the GAP textile factory in Malatya is also utilised for cement manufacture. The utilisation of bottom ash can be more problematic and it is often landfilled. Reportedly, only around a third of Turkish residues are utilised, the remainder being landfilled or directed to slurry ponds. However, this option is becoming increasingly unsustainable as a consequence of new landfill taxes. It is becoming more difficult to obtain permits and land for new waste depositories (Aksoya and others, 2013).

Utilisation of fly ash captured by ESPs is sometimes limited as a consequence of its high unburned carbon levels – these can be as high as 15%. The standard specification adopted in many countries limits levels to between 5% and 12% and the ASTM C618 specification limits it to 6%. Historically, Turkish efforts to minimise carbon levels of such residues (hence increase the potential for utilisation) has been limited, although some exploratory work has been undertaken. For instance, bottom ash from the Seyitömer power plant was treated using a novel two-stage flotation technique in order to separate unburned carbon present. The final product had a carbon content in excess of 65%, making it suitable for blending into a power plant coal feed. The remaining fraction had a carbon content of less than 6%, thus meeting specifications for use as a cement additive (Koca and others, 2008). Such work helped confirm that with the adoption of appropriate treatment systems, disposal problems can be minimised and problem waste materials can have the potential to be transformed into a useful revenue stream.

Efforts to find a solution to reducing the sometimes high unburned carbon-in-ash levels have continued in Turkey via a number of projects. Recent investigations have confirmed earlier findings in that flotation methods can be used to reduce these to more acceptable levels. For instance, combustion wastes from the Tunçbilek power plant containing more than 14% unburned carbon were cleaned via froth flotation in order to obtain a carbon-enriched fraction (carbon content >46%) suitable as a power plant fuel. Furthermore, the carbon content of the residual material was reduced to less than 6%, again, making it suitable for use by the cement sector (Aksoya and others, 2013).

4.3.3 Utilisation of FGD residues

Much of the gypsum resulting from power plant FGD operations is not utilised, but is disposed of to landfill or used for backfilling coal mining sites (Kilic and others, 2013). Often, it is mixed with other combustion residues prior to disposal. Water present in the gypsum supplies the moisture required for conveying such ash/gypsum mixtures. For instance, the lignite-fired Afşin-Elbistan A power plant has two FGD units that produce gypsum. As there is no market for this, it is mixed with ash and slag from the plant and conveyed for disposal in the local lignite mining area. Transport to disposal points is usually by closed conveyors. Around 5.5–6 Mt of gypsum/ash mixture is produced each year. Testing of ashes from the plant by Middle East Technical University determined that they are classified as non-hazardous, hence suitable for landfilling. Furthermore, as gypsum sludge is alkaline, it tends to immobilise any heavy metals present, preventing their leaching and subsequent migration to groundwaters. The amount of gypsum generated by major coal-fired Turkish power plants is noted in Table 22. In total, nearly 1 Mt is produced each year.

Table 22 FGD gypsum produced by Turkish power plants (Yilmaz, 2006)

Plant	Gypsum	
	Sulphur content (%)	Amount (t/y)
Çayirhan	3.86	121,700 130,000
Orhaneli	1.64	36,200
Afsin-Elbistan	2.00	303,000
Kemerköy	1.33	88,000
Yatağan	2.57	170,200
Kangal	3.20	53,000
Iskendurun, Sugozu	0.6–0.8	97,100
Total		999,200

However, not all gypsum is landfilled. For instance, the Sugozu plant is fired on imported hard coal. In this case, gypsum produced by FGD operations is utilised for wallboard manufacture. Annually, 30 kt of gypsum from the plant is transported to Toros Harbour (by Ekton) for export via sea-going vessels (Isken, 2013).

4.4 New coal-fired power plant developments

In 2013, there were a significant number of new projects that had advanced to the licensing stage (Table 23). The total number of individual projects (including asphaltite, renewables, and nuclear) at various stages in the licensing process currently amounts to 716 (a total of 64.66 GW installed capacity). Of this total, 19.24 GW have so far been approved (Deloitte Turkiye, 2013). The Energy Market Regulatory Agency (EPDK) has approved applications for more than 40 new projects, each of at least 100 MW.

Table 23 Thermal projects involved in the licencing process (Deloitte Turkiye, 2013)

Type	Application phase		Examination evaluation		Approved		Total	
	Number	Installed capacity (MW)	Number	Installed capacity (MW)	Number	Installed capacity (MW)	Number	Installed capacity (MW)
Lignite	2	1147	0	0	1	135	3	1282
Hard coal	14	10,369	8	3550	4	2295	26	16,216
Natural gas	63	10,008	40	12,100	45	11,050	148	33,158

In recent years, the private sector has been responsible for more than 75% of the generating capacity additions made and has played a key role in increasing the country's total from 32 GW in 2002 to the current level of 64 GW. On a cumulative basis, between 2003 and 2012, private sector additions amounted to 16.4 GW (EPDK, 2012).

A number of new projects combine power generation with coal production. Some new generating capacity will be sited within existing lignite production areas. However, much of the potential for new capacity lies in lignite fields that are not yet being fully exploited. For instance, reserves of 1.8 Gt have been identified in the Konya-Karapinar field, sufficient to supply a total plant capacity of 5.8 GW. Similarly, the Kahramanmaraş-Elbistan field holds 515 Mt, capable of supplying 1 GW of new capacity. The Thrace Field holds 390 Mt and could supply 1.4 GW (Gunes, 2012). Overall, there is the potential for developing more than 20 GW of new coal-fired generating capacity primarily in Tekirdag, Bursa, Manisa, Muğla, Zonguldak, Ankara-Beypazi, Beysehir, Karapinar, Tufanbeyli, Kahraman-Maraš, Karliova, and Sivas (Tamzok, 2012). Larger individual proposed developments are noted in Table 24.

Table 24 Proposed major coal-fired power plant/mine developments (Yang and Cui, 2012)

Project	Capacity (MWe)	Status
EÜAŞ + TAQA, Afsin-Elbistan	Up to 7 GW	Projects worth US$12 billion proposed. TAQA to take over and expand existing 1400 MW Afşin-Elbistan B plant and develop several others (+ mines). But project delayed/deferred
Hattat power plants and mines, Bartin	3 x 660	Project includes US$300 million for developing coal mines. Also involves China Power Investment Corp and Avic International. Hattat and Harbin Electric International also plan to build a 2.6 GW power plant in Amasra, fired on local hard coal
TurkPower Thermal Power Plant and mine, Konya	500	US$1.26 billion proposal being taken forward by TurkPower Corporation. Lignite mine forms part of package. Reserves of ~152 Gt, sufficient for 42 years operation. Exploration studies conducted by North American Coal Corporation
Tufanbeyli thermal power plant, Adana	600	TEYO investing in plant - will pay US$50 million for lease. Project cost US$1.2 billion. Completion in 6 years. Will generate 3.6 billion kWh
Afyon thermal power plant	3500	Lignite-fired. US$5 billion investment. Province has 950 Mt lignite reserves
Karliova power plant, Bitlis	240	Coalfield transferred to private sector on condition that a coal power plant (cost US$ 700 million) is built
AYAS Enerji Power Plant	635	Being developed by Ayas Enerji. Project permitted
Akdeniz Enerji Power Plant	1600	Being developed by Nurol Enerji. Permits being applied for. Imported coal-fired
Hakan Enerji TPP	110	Being developed by Hakan Enerji
Sedef Energy Power Plant	615	Being developed by Ipekyolu Enerji. Applying for permits
Adana, Yumurtalik ilçesi	1480	Being developed by Atagur Enerji. Applying for permits
Adana, Yumurtalik ilçesi	600	Being developed by ICTAS Enerji. Applying for permits
Adana, Yumurtalik ilçesi	600	Being developed by Diler Elektrik. Applying for permits
Adana, Yumurtalik ilçesi	1215	Being developed by Sarp Elektrik. Applying for permits
Yumurtalik	1320	Being developed by GDF-Suez-led consortium (Ada Enerji) with International Power and Mimag Enerji. Imported hard coal
Ada Power Station	1320	Being developed by Ada Enerji. Applying for permits
Afşin-Elbistan C	1400	Being developed by EÜAŞ. Project announced. Lignite fired
Afşin-Elbistan D	1200	Being developed by EÜAŞ. Project announced. Lignite fired
Izdemir Enerji Power Plant	350	Being developed by İzdemir Enerji. Imported hard coal. Under construction
Aliağa, İzmir Power Station	800	Being developed by ENKA. Lignite fired. Applying for permits
Bartin Power Station	1320	Being developed by Hema Elektrik. Applying for permits
Balikesir İli, Bandırma İlçesi	1200	Being developed by Karat Elektrik. Applying for permits
Balikesir İli, Gönen İlçesi	300	Being developed by TGR Enerji. Applying for permits. Lignite fired
Bodrum-Muğla Plant	630	Being developed by Yeniköy Elektrik. Under construction. Lignite fired
Bolu ili, Göynük ilçesi	2 x 135	Being developed by Aksa Enerji. Applying for permits/under construction. Lignite fired
Çanakkale ili, Biga ilçesi/ Karaburun Termik Santrali	137	Being developed by Sarıkaya Enerji. Applying for permits
Çanakkale ili, Biga ilçesi/ Karaburun-2 Termik Santrali	670	Being developed by Sarıkaya Enerji. Applying for permits
Karabiga Coal Fired Plant	1380	Being developed by Cenal Elektrik. Applying for permits
Kirazlidere Thermal Plant	610	Being developed by Filiz Enerji. Applying for permits
Çanakkale Power Station	1215	Being developed by ICDAS. Applying for permits. Lignite fired
Çankiri	170	Being developed by Calık Enerji. Under construction. Lignite fired
Çankiri ili, Orta ilçesi/ Orta Anadolu Termik Santrali	137	Being developed by Bereket Enerji. Applying for permits. Lignite fired
Çankiri Power Station	380	Being developed by 3S Enerji. Under construction. Lignite fired
Elazığ ili, Kovancılar ilçesi, Yarimca beldesi	200	Being developed by Yildirim Enerji. Applying for permits

Table 24 continued		
Eskişehir Power Station	300	Being developed by Adularya Enerji. Applying for permits. Lignite fired
Gerze, Sinop Power Station	1200	Being developed by Anadolu Group. Applying for permits. Lignite fired. But local opposition to project
Hatay ili, Dörtyol ilçesi, Yeniyurt mevkii	330	Being developed by Kamertan Mining and Electricity Production Company. Applying for permits
Hatay ili, Erzin ilçesi, Aşağı Burnaz mevkii	936	Being developed by Selena Electricity Production. Project permitted
Iskenderun	2000	Being developed by Yildirim Enerji. Applying for permits
Iskenderun Power Station	1200	Being developed by Atlas Enerji. Under construction. Lignite fired
Izmir İli Kınık İlçesi/eynez termik santrali	660	Being developed by Polyak Eynez. Applying for permits. Lignite fired
Izmir İli, Aliağa İlçesi	800	Being developed by Enka Enerji. Project permitted. Lignite fired
Izmir ili, Aliağa ilçesi, Habaş Termik Santrali	618	Being developed by Habas Industrial and Medical Gases Production Industries. Applying for permits
Socar Power TPP	610	Being developed by Socar Power. Applying for permits
Kandilli Power Station	1320	Being developed by Hema Elektrik. Applying for permits
Kangal, Sivas Power Station	100	Being developed by Tam Enerji. Applying for permits. Lignite fired
Konya ili, Ilgın ilçesi	500	Being developed by Park Enerji. Applying for permits. Lignite fired
Konya Power Station	2600	Being developed by Alkim. Applying for permits. Lignite fired
Yunus Emre Power Station	290	Being developed by Adaluria Energy Electricity Generation and Mining Inc. Under construction. Lignite fired
Mersin ili, Gülnar ilçesi	373	Being developed by Bugra Enerji. Applying for permits
Tabiat Enerji TPP	1320	Being developed by Tabiat Enerji. Applying for permits
Enyat Enerji Power Plant	150	Being developed by Enyat Enerji. Applying for permits
Silopi-Şirnak Power Station	400	Being developed by Silopi Elektrik. Under construction. Lignite fired
Sinop ili, Gerze ilçesi	1020	Being developed by Anadolu Group. Project permitted. Lignite fired
Şirnak ili, Silopi ilçesi, Sereder Sırtı Mevkii/Silopi Elektrik Santrali	137	Being developed by Şirnak Elektrik Üretim A.Ş. Applying for permits. Lignite fired
Şirnak Power Station	275	Being developed by Galata Enerji, Under construction. Lignite fired
Sivas ili, Kangal ilçesi, Etyemez Köyü Mevkii	100	Being developed by Tam Enerji. Under construction. Lignite fired
Luminer Enerji TPP	180	Being developed by Luminer Enerji. Applying for permits. Lignite fired
Tufanbeyli Power Station		Being developed by Enerjisa. Project permitted. Lignite fired
Zonguldak ili, Çatalağzı beldesi	320	Being developed Modern Enerji. Applying for permits
Kireclik TPP	1320	Being developed Bati Karadeniz Elektrik Üretim A.Ş. Applying for permits
Biga	1320	Being developed by Bilgin Enerji-led consortium

4.5 Power plant modernisation and rehabilitation

Unless remedial action is taken, as power plants age, their efficiency and reliability declines, emissions rise, and forced outages increase. This situation is common to many ageing coal-fired fleets around the world. Some of Turkey's lignite-fired plants are nearing the end of their planned lifetime, hence the need for rehabilitation and/or modernisation. Restoring such plants to optimum operation can take several routes that may focus on maintaining and/or upgrading the existing systems, or by capitalising on the latest technological advances, lead to significant operational improvements.

Turkish power plant rehabilitation was identified as an important issue some years ago and over the course of several decades, a number of major schemes have been implemented. These are continuing.

A number of problem areas were identified that impact on overall efficiency and reliability (Gunes, 2012). These included:

- lack of investment;
- lack of qualified staff and in-house expertise;
- inadequacies in the supply of lignite (both quantity and quality);
- increased maintenance, repair and generation costs resulting from fuel-related problems;
- load drops caused by use of lignite with CV below plant design value; and
- failure to achieve optimum combustion conditions.

Measures to address most of these issues have since been identified. They include optimisation of combustion conditions, improvements in mill operation, burner adjustments, and elimination of leakages from flue gas-air and water-steam systems (Dietrich, 2013). Major rehabilitation activities have focused on a range of plant systems that have included boilers, ESPs, ash conveyor systems, oil combustion systems, and cooling towers.

With the aim of regaining lost generating capacity, Yildiz Technical University examined issues associated with rehabilitating (rather than totally replacing) an existing conventional 200 MW Turkish PCC power plant. The study considered options for replacing the boiler and associated systems, and the addition of an FGD unit. The alternative of repowering with a CFB boiler was also examined. The payback periods for the various options considered were calculated for different technical and economic parameters (such as power loss, load factor, electricity price, and discount rate) and current and future emission costs were factored into the analysis. The results showed that, especially where the power loss from an existing plant was high, the costs of replacing the boiler and adding FGD would be amortised in a short time - the greater the power loss, the shorter the payback period. Similarly, repowering with a CFB boiler would be advantageous (Cetin and Abacioglu, 2013).

4.5.1 Industry efforts

With the aim of improving energy efficiency by recovering the performance of its depreciated power facilities, for more than a decade, EÜAŞ has been undertaking large scale rehabilitation works on a number of its plants. The main aims have been to regain generation capacity, increase availability and reliability, reduce generation costs, and comply with new environmental regulations. As in-house expertise was initially lacking, some rehabilitation work was carried out in conjunction with overseas technology suppliers. Originally, ten plants were identified – these had been in constant operation for between 20 and 25 years. One of the first exercises began in 1993 and focused on Units 4 and 5 of the Tunçbilek Thermal Power Plant. Full rehabilitation was carried out by the consortium of Gülermak and Ansaldo GIE of Italy. Works took 28 months to complete and included significant modifications to the firing system, new high pressure boiler piping, and the installation of high capacity ID fans and air ducts. On completion, output from each unit was increased from 90 MW to 150 MW.

Some rehabilitation exercises have resulted from the need to compensate for unsatisfactory features introduced at the plant's design and construction phase. For instance, several thermal power plants (for instance, Yatağan, Yeniköy and Kemerköy) were originally designed and built by an eastern European company. It transpired that inadequate expansion control mechanisms had been built in, resulting in damaged boiler water wall tubes and heavily distorted boiler walls and top. The number of soot blowers was also inadequate, contributing to a significant drop in output. In addition, the plant had been designed to run on lignite with a CV of around 8.4 MJ/kg. However, in practice, local (uncleaned) supplies had a CV of only 4.2 MJ/kg. Lignite cleaning and screening was subsequently introduced to reduce the ash levels. This increased the CV, minimised the milling of inert materials, and reduced the amount of supplementary fuel oil required.

Similar issues were also identified in the Kangal Thermal Power Plant. Following the plant's original construction, various design, fabrication and operational shortcomings were identified. There were not resolved during commissioning and consequently, the plant operated below design capacity and soon experienced component failures. Transelectro and Siemens subsequently received a rehabilitation order, valued at €56.6 million. The State Planning Organization allocated TL 130 million for the rehabilitation of the plant – this has now been completed and each of the plant's three units now generates 150 MW, as originally intended. The plant was sold to the private sector in early 2013.

Rehabilitation can encompass many areas of a plant. For example, in 2012, the 600 MW Seyitömer Thermal Power Plant was sold into the private sector. This requires an investment of US$200 million to replace the existing undersized ESPs with bigger units, the addition of an FGD system, plus upgrading of instrumentation and control systems. It is anticipated that this will allow for the restoration of availability and efficiency and enable the plant to meet all environmental requirements by 2018.

Various state-owned plants have suffered through lack of funds. Consequently, some now have low availabilities, low operation efficiencies, and lack the necessary emission control systems required to meet the latest EU limits. When these are sold into the private sector, the new owners will be expected to undertake the appropriate measures to address these issues. Plant deficiencies are usually factored into the selling price. Rehabilitation activities may require the plant to be taken out of service, resulting in a loss of income. This is also taken into account when setting the selling price.

Historically, not all Turkish rehabilitation exercises have progressed as planned. For instance, in 2005, a tender was issued for the rehabilitation of the Afşin-Elbistan A power plant. For some years, this had performed below design capacity (up to a maximum of 75%). The reasons for this included general wear, changes in lignite quality, and issues of operations and maintenance practice. The scope of the work called for the repair, replacement and upgrading of numerous plant systems needed to restore reliability, availability, power output and efficiency. It covered the boilers and firing system, piping, balance of plant (mechanical and electrical), ESPs, control and instrumentation, ash and coal handling, and civil works. However, in 2009, Turkey returned a €280 million loan to the World Bank after failing to organise a tender to rehabilitate the plant in line with the lender's standards. However, efforts to improve its performance continue, and in 2012, Alstom was awarded a €13 million contract to service and maintain various elements of the plant. The scope of services requested by EÜAŞ includes the repair, overhaul and rewind of Unit 3's steam turbine generator, provision of repair and major overhaul services for the steam turbines, and supply of turbine spare parts. Work was scheduled to be completed by the end of 2013.

The involvement of overseas technology providers and other organisations has recently extended further. In 2012, it was announced that South Korea would provide rehabilitation services to an (unnamed) Turkish coal-fired power plant. Similarly, although delayed/deferred, TAQA of Abu Dhabi proposed to operate a joint venture with Elektrik Üretim that would encompass power plant upgrading. There is also a co-operative agreement between Turkey and India that includes plant rehabilitation. In addition, power plant modernisation issues are being pursued through a co-operative agreement (via the Turkish-German Energy Forum, set up in 2012) between the Turkish MENR, and the German Ministry of Economics and Technology. The German working group established (*Conventional power stations, modernization of power stations and lignite extraction*) is being co-ordinated by VGB. A range of stakeholders is involved.

The repowering of Turkish coal-fired power plants has also been addressed by a number of studies that have examined the possibilities of totally replacing existing conventional PCC boilers with newer technologies such as fluidised beds or IGCC systems. Other studies have examined the potential for adopting systems where more of the existing systems are retained. For instance, the hot windbox repowering (HWBR) of parts of the lignite-fired Soma power plant was investigated. HWBR technology consists of installing one or more combustion turbines that exhaust into the windbox of an existing boiler. Potentially, it can add up to 25% additional capacity to a unit, improve the efficiency by 10–20%, improve part load efficiency and cycling capability, and reduce NOx emissions. The potential for deploying HWBR was examined and modelled for one of Soma's smaller PCC units. A fresh air dilution hot windbox repowering case was simulated and the results compared. In the simulations, after repowering, net power was increased by between 11% and 27%, and CO_2 emissions per unit of electricity generated reduced by ~7% (Yilmazoğlu and Durmaz, 2013). However, at the moment, there do not appear to be any immediate plans to deploy the technology on a commercial basis in Turkey.

4.6 Turkish power plant engineering and construction capabilities

There is a strong general engineering base in Turkey. Some 31 of the world's biggest 225 construction companies are Turkish. However, historically, in terms of power plant construction capabilities, the country's large-scale manufacturing capabilities were limited to a handful of Turkish companies, and there was a heavy reliance on overseas technology developers and suppliers. Major components and systems for many of Turkey's coal-fired power plants were provided from outside the country although various Turkish organisations were involved in the supply of materials, general engineering, or as EPC contractors. Commercial connections and other co-operative links have since been established between a number of international suppliers and Turkish companies and this is helping to increase expertise and capabilities within the country. This is being further strengthened by the establishment of various manufacturing licensing agreements between Turkish and overseas firms.

In the past, most power plant component suppliers tended to be Europe-based, although more recently emphasis has shifted towards Asian suppliers – for instance, South Korea and particularly, China. Asian companies have also acted as EPC contractors for some Turkish projects. However, in many cases, Turkish companies have remained involved in some way, either as suppliers or contractors. Major Turkish companies now active in the development and construction of thermal power plants are as follows:

- **Hattat Holding**

Hattat is active in both coal mining and power plant construction. It is building two coal-fired power plants with a total installed capacity of 2.6 GW. EPC activities are being undertaken for a US$1.5 billion 1320 MW coal-fired plant being built in the northern Turkish province of Bartin. The project will also involve extracting >5 Mt/y of hard coal near Amasra, where mining is scheduled to begin in 2014.

Commercial links have been established with several overseas technology suppliers that include China Avic International Holding. In 2012, Hattat and Chinese power plant equipment manufacturer Harbin Electric entered into a partnership deal for the supply of boilers, generators, turbines and other power plant components. This arrangement covers all main generating technologies (hydro, wind, coal, natural gas, and nuclear). A new US$250 million manufacturing plant is being established in the western province of Tekirdag. Both companies will have equal shares in the investment, aimed at minimising Turkey's dependence on imported equipment and machinery.

- **GAMA Holding**

GAMA is the Turkish representative of Babcock & Wilcox of the USA and was the first major Turkish company to take on power plant construction. It has been qualified by the World Bank for the construction of industrial plants and was the first to undertake such turnkey projects in Turkey. A 2002 corporate restructuring resulted in the formation of a number of companies, all involved in power plant construction and operation (GAMA, 2013). These include:

- GAMA Enerji – half owned by General Electric Financial Services. Active in water supply and hydroelectric power operations. The company has acted both as a construction company and an investor for various domestic and overseas power projects;
- GAMA Power Systems - undertakes project design and EPC activities for steam boilers and energy facilities and provides operation and maintenance services. The company is engaged in EPC for various power plants in Turkey and overseas; and
- GAMA Industry – carries out turnkey construction works in several major infrastructure sectors that include thermal power plants and industrial facilities.

- **Çalik Enerji**

The company operates in two main areas, namely power systems, and oil and gas supply. In the former, activities include turnkey services for hydroelectric, wind and thermal power plants. Commercial activities extend beyond Turkey and include project development in neighbouring countries. In Georgia, Çalik is working on the country's first combined cycle power plant (the 230 MW Gardabani plant). This is being built on a turnkey EPC basis and will be completed in 26 months. In Turkmenistan, a pre-contract has been signed for the development of a 750 MW gas-fired power plant. In Uzbekistan, the 478 MW Navoi NGCC plant was completed in 2012. And in Iraq, the construction of two major gas-fired power plants is under way.

Some overseas projects are being undertaken on a consortium basis (Calik Enerji, 2013). For instance, Çalik forms part of a consortium comprising Techint of Italy and General Electric developing the 1600 MW Al Anbar NGCC power plant in Iraq. Elsewhere, invitations for power generation facilities planned for 2014-15 have been received from Malaysian, Turkish and Chinese companies.

- **Selnikel**

Based in Ankara, the company manufactures a range of power generation-related equipment. This includes water tube steam and hot water boilers, bubbling and circulating fluidised bed coal-fired boilers, waste heat recovery boilers, industrial fans and burners, pressure vessels, combustion management systems, and natural gas transmission systems. The company also undertakes turnkey projects that encompass the design, manufacture, installation and commissioning of such systems.

Some production is undertaken via licensing arrangements with overseas technology suppliers. This includes several designs of corner tube boiler and bubbling fluidised bed boiler developed by ERK EckRohrKessel GmbH of Germany. Technical agreements are also in place with other German companies that include Heinrich Nickel, Ray Ol Und Gasbrenner, Blohm Voss Industrie, Eisenwerk Baumgarte, and Babcock BSH-AG. Similar arrangements are also in place with companies in the UK and Denmark.

- **Mimsan Industrial Boilers (MEK)**

Based in Malatya, MEK is part of the Mimsan Group of companies, and was established for the supply and commissioning of industrial boilers and energy-related equipment designed and manufactured within the group. This includes steam boilers, bubbling and circulating fluidised bed combustors, reciprocating grate boilers, cogeneration systems, and ESPs, desulphurisation units, bag filters, and multi-cyclones. Combustion units are available for hard coals, lignites, and a range of biomass and wastes. The company also manufactures power plants components such as membrane walls, steam drums, superheaters, and economisers.

- **Yildiz Boiler Company**

The company manufactures a range of power plant and industrial equipment that includes fire tube and water tube boilers, cogeneration units, heat recovery boilers, and fluidised bed boilers. The latter are designed to operate on fine coal and have been produced since the 1980s under license from Lentjes of Germany. More than 150 such units have been installed in Turkey, mainly on industrial sites. These are available with a capacity of up to 50 t/h steam at 4.2 MPa/450°C.

- **ENPRO**

ENPRO provides EPC and engineering services for power plant projects in Turkey and other countries in the region. Services offered cover conceptual, basic and detailed design, as well as the production of feasibility and due diligence studies, project management, and provision of inspection and maintenance services. The company also manufactures a number of power plant components such as bypass systems, expansion joints, and structural steel.

- **EVER Industry**

Ankara-based EVER Industry is the contracting arm of the EVER Group of companies and focuses on power generation and major construction projects. The company offers services that include EPC and project management, plant system supply, and general contracting. EPC is offered for a wide range of plants based on equipment from most major technology suppliers. Expertise extends to gas turbine-based simple cycle and combined cycle power plants of up to 900 MWe, and cogeneration/district heating systems. The company offers complete turnkey plant construction, testing and commissioning. EPC and other services are also offered for conventional thermal power plants that include oil-fired and pulverised coal fired plants, and fluidised bed boiler-based plants.

- **SANTEK**

Istanbul-based SANTEK is an engineering, fabrication and erection company involved in the turnkey construction of industrial and power/cogeneration plants. The company operates a steel construction and pressure vessel fabrication facility in Izmit. This produces heavy steel work, heat exchangers, industrial steam boilers, pressure vessels and specialised equipment for industrial facilities. Boilers produced include large high-temperature/pressure units (drum type, subcritical and supercritical once-through types, and fluidised bed combustion boilers). Equipment for flue gas cleaning and CO_2 separation is also available. The company has been involved in the construction of several Turkish combined cycle power plants that include facilities at Adapazari, Gebze, and Kemalpaşa in Izmir. Overseas orders have included two similar plants in Spain. During the 1990s, the company also acted as EPC contractor for coal enrichment plants at Soma, Kemerburgaz, and Yeniköy.

- **STFA Construction**

Headquartered in Istanbul, the company offers civil, electrical, and mechanical engineering consulting, and provides specifications for thermal power plant EPC contractors. Other services include project scheduling and monitoring, procurement management, and start-up and commissioning. For power projects, STFA usually creates a team with selected specialised partners and subcontractors. Coal-fired power projects have included that 210 MW Orhaneli Thermal Power Plant.

- **Eser Holding**

ESER Holding is a group of Turkish companies that operates in construction, engineering, industry and energy. As well as operating within Turkey, the company is active in the Middle East, Central Asia, Eastern Europe and Africa. Expertise covers most forms of power generation and includes design, construction and commissioning services. On-going Turkish power projects include a joint venture with Saudi Arabia's ACWA Power to develop an 800 MW natural gas power plant in Kirikkale province. Eser will own 30% of the plant, due to start up in 2014.

- **ERG Construction Trade and Industry Co Inc**

ERG engages in the design, planning, and construction of various projects that include thermal power plants. The company were responsible for providing the coal preparation and ash discard systems of the Sivas Kangal Thermal Power Plant and were involved in modernisation and enlargement of the Afşin-Albistan power plant.

- **Zorlu Group**

Istanbul-based Zorlu is part of the Zorlu Enerji Group. It was set up as the country's first major operations and maintenance (O&M) company. Services offered include installation, commissioning, start-up, and long term servicing. All types of thermal power plants are covered, including coal-based.

5 Clean coal technologies (CCT)

Historically, the commercial scale deployment of clean coal technologies in Turkey has encompassed mainly fluidised bed boilers, supercritical pulverised coal boilers, various environmental control technologies (such as FGD units), and a number of coal cleaning systems. However, as the national focus has shifted towards the greater use of indigenous lignite and hard coal, interest in the wider deployment of CCTs has increased. This has now reached ministerial level. As part of the Strategic Plan (2010-2014) for TKI, the Minister of Energy and Natural Resources (Taner Yildiz) noted that:

In taking advantage of coal, the utilisation of advanced technologies and consequently the research and development studies in this field carry great importance in each stage from exploration to the final utilisation. We deem it strategically important to carry out studies that would contribute to the efficient utilisation of coal in both thermal power plants and heating and industry with minimum damaging effects, besides its enrichment by means of the research and development studies to be conducted by using scientific methods. Within this scope, the projects that are developed by means of networks of co-operation to be established in the field of clean coal technologies, including the technologies for production of electricity, fuel oil, hydrogen and chemicals, primarily by gasification of coal, will be brought to life with speed.

The minister also stated that the government would support the development of appropriate R&D laboratories and programmes.

Despite the generally low quality of many Turkish lignites, as a major indigenous resource, recent years have seen a growing interest in their potential for increased energy production. Through the judicious application of the appropriate CCTs, there is the potential for this to be produced with high efficiency and low environmental impact. Lignites have long been recognised as having significant potential as feedstocks for various clean coal-based systems (Akgün and others, 2008).

There is in-house expertise on various forms of CCT within a number of Turkish utilities, technology suppliers, and universities. There have also long been commercial and other links between some international technology providers and their Turkish counterparts. Furthermore, as the Turkish energy sector is increasingly opened up to the private sector, co-operation and interaction with overseas organisations is growing. This now extends to RD&D activities. The main focus for this is TÜBİTAK, the Turkish Science and Technology Research Institute (Türkiye Bilimsel ve Teknolojik Araştirma Kurumu). Established in 1963, it is the leading agency for the management, funding and conduct of research in Turkey. It is responsible for promoting, developing, organising, conducting and co-ordinating R&D in line with national targets and priorities. TÜBİTAK acts as an advisory agency to the Turkish Government on science and research issues, and is the secretariat of the Supreme Council for Science and Technology (SCST), the country's highest science and technology policy-making body. There are 15 different research institutes and centres attached to TÜBİTAK, covering a range of topics. These include the Marmara Energy Institute (MAM). TÜBİTAK represents the country in international research efforts that include membership of the EU Framework Programmes.

As with others centres, the Marmara Energy Institute continues to forge new links with other organisations. For instance, in 2012, a Memorandum of Understanding was signed with the Korea Institute of Energy Research (KIER) for collaboration on Clean Coal Technologies. TKI and Hacettepe University were also involved.

Turkish clean coal technology options and activities are explored in the following chapters.

5.1 Gasification

5.1.1 R&D Activities

Turkish lignites continue to be the focus of gasification R&D activity for a number of organisations. These include the state-owned TKI that owns a considerable tonnage of higher-grade lignite, and produces some 35–40 Mt/y. For over a decade, the company has been engaged in research and development on a range of lignite-related topics that have included gasification. TKI's gasification-based R&D is concentrated in three related categories, namely conventional gasification plus associated downstream syngas processing – gas cleaning, conditioning and separation (Ziypak, 2011), underground gasification, and advanced processes (such as plasma gasification and the production of methane via coal biotechnology). A summary of gasification-based activity is given in Table 25.

Table 25 TKI gasification activities (2012) (Tamzok, 2013)

Project	Partner organisation	Coal specification	Objectives
Soma-Eynez Gas	Worley Parsons, USA	Soma washed coal: >18.42 MJ/kg >12.56 MJ/kg	Preparation of feasibility project. 800 million m^3 of SNG production capacity power plant
UHDE Project. PRENFLO PSG-PRENFLO PDQ-HTW Tech Gasification project	Thyssen Krupp/UHDE GmbH, Germany	Soma Eynez Basin coal. >18.42 MJ/kg	SNG (800 million m^3/y) ethanol (400 kt/y) urea (560 kt/y)
Underground coal gasification feasibility study	Lawrence Livermore National Laboratory, USA	TKI coal basins	Preparation of feasibility studies on UCG of TKI lignite reserves
Underground coal gasification	Linc Energy, Australia	MTA's Thrace basin	Production of gas via UCG
MicGas Coal Biotech Project	ARCTECH Inc, USA	Low CV lignites, Bursa Davutlar coal basin	Biotechnology
Pilot-scale plasma lignite gasification plant	Anadolu Plazma Technology Center	Low CV lignites	Gasification of low CV TKI lignites

To investigate conventional gasification, TKI designed and built a 250 kg/h pilot-scale entrained flow gasifier, plus a smaller 20 kg/h variant. The pilot-scale gasifier comprises five main units, namely coal preparation section, oxygen and nitrogen reservoirs, feed water preparation/cooling unit, gasifier (atmospheric pressure, 1500°C), and water clarifying and ash treatment unit. Entrained flow technology was selected on the basis that it allows most coal types to be processed, good syngas yields can be obtained, the high temperature avoids ash caking problems, and tar and phenol formation can be minimised.

TKI has also partnered with other Turkish organisations such as the Marmara Energy Institute. Both are co-operating on a project to investigate the entrained flow gasification of Turkish lignites for application as part of an IGCC facility, or the production of methanol and other liquid products. Different lignites are being tested in a 1.7 MWth oxygen-blown dry feed gasifier (Ergintav and Akgün, 2013). The project scope encompasses the development of fuel feeding, gasification, gas cleaning and conditioning/separation. The eventual aim is to scale-up the full system to demonstration scale (*see* Section 5.3). Facilities at the Marmara Energy Institute include laboratory-scale and pilot-scale bubbling fluidised bed gasifiers, and a pilot-scale downdraft fixed bed gasifier (Ergintav and Akgün, 2013). The Institute has previously been involved in several EU 7th Framework projects that have included the design and manufacture of 250 and 400 kWe fixed bed and 2 MWe fluidised bed gasifiers.

Coal-derived syngas normally contains contaminants that require removal prior to its use as a fuel for gas turbines or fuel cells, or as a feed for FT synthesis, ammonia or methanol production. MAM has been developing techniques for removing these. Both hot and cold gas clean-up systems have been developed to clean syngas generated by the Centre's gasifiers. For instance, sulphur species have been removed using dolomite at >750°C. Through the use of a combination of techniques, H_2S levels can be reduced to less than 1 ppmv (Aksoy and others, 2012).

Along with Hacettepe University, TKI is also a partner in an on-going EU 7th Framework Programme project (Clean Coal Technologies. ENERGY. 2011.1) entitled *Optimizing gasification of high-ash content coals for electricity generation* (OPTIMASH). This started in 2011 and also involves Thermax and the Indian Institute of Technology in Madras (IITM), ECN from the Netherlands, and CNRS-ICARE from France. The project aims to select and optimise the efficiency and reliability of gasifiers fuelled with high-ash coals, with a view to application as part of an IGCC. Several candidate technologies are under consideration (Tamzok, 2013; European Commission FP7, 2013) although high pressure circulating fluidised bed gasification (CFBG) is currently the target technology. The objective is to develop a 1 MWth pilot gasifier capable of producing a syngas flow at a pressure of 1 MPa. Both Indian and Turkish high-ash coals are being examined and their characteristics used to model the process. Other objectives include optimisation of the coal preparation system, study and evaluation of thermal and physical properties of the gasification phase, optimisation of process efficiency and reliability, and system scale-up. Each project partner is undertaking different tasks. CNRS-ICARE is contributing to gasification kinetics modelling and scale-up issues, ECN is assessing different candidate gasifiers and carrying out gasification experiments, and Hacettepe University (Department of Mining Engineering) and TKI are assessing coal washability characteristics and designing the optimum pilot coal washing plant. IITM is setting up the high pressure CFBG pilot plant, and Thermax is handling the plant's design, manufacture and testing. So far, physical and chemical characterisation of selected coals has been carried out, and their washability limits determined. Gasification kinetics have been investigated under various conditions, and kinetic models developed. Small-scale gasifiers are being built and tested and detailed engineering design of the pilot plant is under way (Gökalp, 2013).

Coal gasification research is also undertaken by the Energy Center of Koç University Tüpraş (KÜTEM). This was established in 2012 with funds from Turkish oil refiner Tüpraş primarily to address Turkish energy-related challenges. Main areas of interest are the development of new coal utilisation technologies for low rank Turkish lignites, synthetic fuel production from coal-derived SNG, and development of associated technologies for gas separation and clean-up.

The private sector is also involved in gasification R&D. In 2011, Zorlu Energy, a subsidiary of Turkey's Zorlu Group, completed construction of a 2 MW pilot-scale fluidised bed gasifier and associated R&D unit. This is operated in partnership with TÜBİTAK. The latter's Technology and Innovation Support Program Directorate (TEYDEB) awarded Zorlu a TL 1.5 million interest-free loan towards meeting the total cost of TL 9 million needed to build and run a development centre for the study of electricity production via coal gasification. Zorlu Energy is an independent power producer with gas-fired, hydropower, wind and geothermal assets. The company is focusing its investments in renewables and coal to create a more balanced generation mix, reducing its gas-heavy portfolio.

A feasibility study (funded by the US Trade and Development Agency – USTDA) on the gasification of Turkish lignites was completed in 2011; USDTA provided a grant to TKI for the work. The study examined the technical, economic and financial feasibility of converting Turkish lignites to pipeline-quality SNG via gasification, and its subsequent addition to the national gas transmission grid or use in an IGCC facility.

Because of the scale of their potential, some overseas testing of Turkish lignites has also been carried out. In 2013, a series of tests were carried out by Synthesis Energy Systems (SES) at the Gas Technology Institute in Des Plaines, USA. Three Turkish lignites, under consideration for clean coal-based power generation projects in Turkey, were tested using SES' proprietary fluidised bed gasification technology; single pass carbon conversions of between 96% and 99.5% were achieved. The projects are being developed by Tuten Ltd for an unnamed Turkish utility company looking to expand its clean energy portfolio. The positive results obtained should enable the company to move towards the use of local, low-grade/low-cost lignite, unsuitable for conventional power generation. SES, Tuten and Istroenergo Group, a Slovakia-based EPC company, have developed a conceptual-level design solution for 50 MW and 100 MW sized power generation modules based on the use of low quality lignite. Syngas generated would be fired in a General Electric LM2500+G4 aero-derivative gas turbine in a combined cycle configuration (American Fuels Coalition, 2012; Minchener, 2013).

In 2011, TKI engaged the investment banking firm Taylor-DeJongh (TDJ) to evaluate a lignite-based gasification project for the production of SNG. This would be fed into the country's natural gas grid. Working with WorleyParsons, TDJ developed a preliminary financing plan and assessed the project's financial feasibility. With the aim of minimising natural gas imports, at the end of 2012, a 250 kg/h pilot plant was set up by TKI in the Tavşanli district of the city of Kütahya (Figure 19). This is gasifying local lignite to produce SNG. It is anticipated that a second unit may also be set up in Manisa (Natural Gas Europe, 2013). The project is being conducted in co-operation with TÜBİTAK. The Kütahya facility was completed in January 2011 and became operational in December 2012. Syngas produced from various

TKI lignites will eventually be cleaned using a number of different techniques. Following this stage, possibilities for the production of methanol, various chemicals, liquid fuels and electricity will be investigated. TKI is exploring the system's potential to eventually produce 1–1.5 billion m^3/y of SNG, sufficient to meet almost 10% of Turkey's natural gas requirements.

Figure 19 The TKI Kütahya gasification pilot plant (photograph courtesy of TKI)

Modelling the impacts of different gasification operating parameters for the production of SNG via gasification was undertaken previously (using TKI data). The work involved Gazi and Niğde Universities, and the TOBB University of Economics and Technology. The model developed allows the selection of the most appropriate operating parameters for generating SNG, suitable for a range of end uses (Biyikoğlu and others, 2010).

The gasification of biomass (sometimes in conjunction with coal) has been the focus of activities of a number of Turkish organisations that has included MAM, Marmara University, Istanbul Technical University, Middle East Technical University, Anadolu University, Bosphorus University, the Institute of Environmental Sciences, and Bartin University (Karataş and Gül, 2011).

5.1.2 Commercial-scale gasification activities

In 1959, at Kütahya, AZOT Fertilizers started up two Winkler fluidised bed gasifiers as part of its ammonia production facility. These operated successfully for more than 20 years with high reliability and low maintenance. Total design capacity was 24,000 m^3/h. At times, they operated with coals containing 50% ash.

Recently, Turkey's large lignite reserves in the Aegean province of Manisa have become the focus for a proposed gasification project. Manisa's Soma district holds around 800 Mt of lignite, one of the largest such deposits in the world. The main project proponent is US-based Energy Allied International, although

Turkish organisations are also likely to be involved. The company intends to invest up to US$3 billion in energy and petrochemicals in Turkey. In May 2013, it was announced that an agreement was close to being finalised for the large-scale investment to produce chemicals such as ammonia and sulphuric acid via the gasification of domestic lignite. Reportedly, the planned strategic investment would reduce Turkey's imports by US$1.5 billion a year.

5.1.3 Integrated gasification combined cycles (IGCC)

There are currently no IGCC facilities operating in Turkey although Turkish lignites (such as those from the Afşin-Elbistan basin) have been considered for such use. For instance, this type of application formed part of a US Trade and Development Agency-funded study that examined a range of technical, economic, and financial feasibility issues. TKI (sometimes in conjunction with other Turkish and overseas partners) has also considered engaging in projects focused on the use of lignite for IGCC applications. TKI remains a partner in an on-going EU project, the aims of which include the assessment and selection of the most promising gasification technology for IGCC applications using high-ash coals.

The potential for using Turkish lignites as feedstock for an IGCC remains a focus for study. For instance, recent work undertaken by Gazi University simulated the use of seven different Turkish lignites for IGCC applications. A major aim was to compare the performance of each type in the same gasifier. The study modelled the use of a gasifier island comprising a Texaco-type gasifier (slurry fed, oxygen blown) with cold gas cleaning. A Mitsubishi 701F gas turbine was used. Of the various lignites assessed, Yeniköy lignite was found to be the best in terms of overall efficiency (44.2%). It also produced the lowest CO_2 emissions (Amirabedin and others, 2013). This information could be useful in helping select suitable locations for commercial plants.

5.2 Coal-biomass co-utilisation

Renewable energies are of increasing importance in Turkey. In particular, biomass is a major domestic energy resource, with the potential for much greater use. As in many other countries, Turkey generates a range of biomass-derived materials that can be applied to energy production. The main ones comprise agricultural crop residues, forest residues, agro-industrial residues, animal wastes, and municipal solid waste. Residues from crops and forestry operations appear to hold the greatest promise. Turkish forests, about half of which are productive, cover about 21 million hectares (Olgun, 2008).

Some 60% of the country's current level of renewable energy comes from biomass and animal waste, and 33% from hydro. Although estimates vary, some suggest that the annual biomass potential of Turkey may be around 32 Mtoe, and the total economically-recoverable bio-energy potential is ~17 Mtoe (Table 26). However, other estimates are considerably higher. A detailed breakdown of the types and quantities of biomass available is given in Table 27.

Table 26 Turkish biomass potential (Olgun, 2008)		
Biomass	Annual potential (Mt)	Energy value (Mtoe)
Annual crops	54.4	15.5
Perennial crops	16.0	4.1
Forest residues	18.0	5.4
Agro industry residues	10.0	3.0
Wood industry residues	6.0	1.8
Animal wastes	7.0	1.5
Other	5.0	1.3
Total	116.4	32.6

The energy potential of the total annual field crop and associated residues has been estimated to amount to 227,983,298 GJ. Maize production accounts for 33% of this, wheat 27.6%, and cotton 18.1%. The potential of total annual fruit production and associated residues is 75,053,866 GJ – hazelnut production accounts for 55.8%, and olive growing, 25.9% (Başçetinçelik and others, 2007).

Table 27 Turkey's annual biomass potential (Başçetinçelik and others, 2007)									
Residue	Production (t)	Area (ha)	Yield (kg/ha)	Total residues (theoretical, t)	Actual (t)	Available residues (t)	Avail-ability (%)	CV (MJ/kg)	Total CV (GJ)
Wheat straw	22,439,042	9,424,785	2381	29,170,755	23,429,907	3,514,486	15	17.9	62,909,300
Barley straw	8,327,457	3,732,992	2231	9,992,948	8,963,012	1,344,452	15	17.5	23,527,908
Rye straw	253,243	145,907	1736	405,188	358,040	53,706	15	17.5	939,855
Oat straw	322,830	150,459	2146	419,678	321,236	48,185	15	17.4	838,425
Maize: - stalks - cop	2,208,601	569,109	3910	 5,911,902 596,592	 4,970,259 1,907,307	 2,982,155 1,144,384	 60 60	 18.5 18.4	 55,169,873 21,056,667
Millett stalks	7283	3605	2020	10,196					
Rice: - straw - husk	331,563	59,879	5537	 582,555 88,527	 209,532 77,747	 125,719 62,198	 60 80	 16.7 12.98	 2,099,510 807,327
Tobacco stalks	181,382	222,691	814	362,763	410,778	246,467	60	16.1	3,968,113
Cotton: -stalks -gin.res	2,292,988	680,177	3371	 6,317,181 481,527	 2,520,281 732,220	 1,512,169 585,776	 60 80	 18.2 15.65	 27,521,470 9,167,391
Sunflower stalks	836,269	545,963	1532	2,341,554	2,259,121	1,355,472	60	14.2	19,247,709
Groundnuts: -straw -shell	55,241	25,167	2195	 127,054 27,621	 28,638	 22,910	 80	 20.74	 475,155
Soybeans straw	28,795	15,064	1912	60,468	21,872	13,123	60	19.4	254,595

Biomass alone or combined with other fuels such as hard coal or lignite, can be used to produce heat and/or electricity, or gasified to generate SNG. The use of biomass is well established in Turkey and it currently provides around 5% of primary energy demand. Wood-related industries and household heating consume the largest amounts. Wood is the primary heating fuel in 6.5 million Turkish homes. Within a commercial context, the lumber, and pulp and paper industries frequently burn their own wood-derived wastes on site, often meeting up to 60% of their energy needs in this way.

In 2010, Turkey introduced two new regulations aimed at encouraging the greater use of biomass for electricity generation:

- authorisation is no longer required by individual producers/users for electricity generation up to 500 kWe based on renewable energy sources such as biomass. Small scale electricity generation/cogeneration for local applications is allowed. Individuals can generate electricity for their own consumption or sell directly into the grid; and
- electricity generated using renewable energy sources is now supported by feed-in tariffs (Karataş and Gül, 2011).

Such moves are encouraging the greater use of biomass within the country.

As Turkey's biggest energy resource is lignite, for some years, there has been a strong R&D focus on the use of lignite/biomass combinations, both for cogasification and co-combustion. This is being encouraged by several national initiatives that extend up to 2023. These include the development of clean and efficient combustion and gasification technologies based on combinations of lignite/coal and biomass. The gasification of biomass alone has also been examined by a number of projects. For instance, as part of the EU 6th Framework Programme, a multi-partner consortium led by MAM examined issues associated with *Integrated Biomass Gasification with Power Technologies* (BIGPOWER). Fixed bed downdraft gasification was used. A number of other Turkish organisations also participated.

5.2.1 Co-combustion

Various studies have investigated the co-combustion of Turkish lignite and hard coal with biomass. Biomass cofiring represents an attractive possibility for coal/lignite-fired power plants as it can utilise local renewable resources, whist simultaneously reducing emission levels. Furthermore, relatively few plant modifications may be required for an existing coal-fired power station to switch to cofiring.

Cofiring investigations have been under way for some years, many focused on circulating fluidised bed combustion technology. For example, in 2005, a 3-year UNDP-financed project examined the co-combustion of biomass and biomass/coal mixtures in a CFB combustor. The project was managed by the MENR, and involved Middle East Technical University (METU), MAM, the Ministry of Agriculture and Rural Affairs, and GAMA Power. Main aims were to decrease the country's dependence on energy imports through the greater use of domestic resources, to use biomass as an alternative resource, and to ensure that such fuel combinations could meet prevailing air quality standards. This was followed by another project (2008-11) that also investigated the use of lignite/biomass combinations in a CFBC. This concentrated on examining innovative aspects of process design and gas clean-up issues.

Some national projects have addressed this area; for instance, *Combustion of Biomass and Lignite in a Circulating Fluidized Bed*, 2007-11 (IEA Bioenergy, 2012). Co-ordinated by METU, the project encompassed the design of CFBC and gas cleaning systems for cogeneration applications.

Turkey was also a member of the Integrated European Network for Biomass Cofiring, NETBIOCOF (2005 to 2008) operated under the auspices of the 6th EU Framework Programme.

In 2004, studies examined the possibilities of cofiring Tunçbilek lignite with olive waste in a CFBC (Atimtay and Topal, 2004). In other studies, the co-combustion of lignite with olive cake and sewage sludge in a CFBC was examined. This concluded that the fuel combination could be burned effectively in this manner. In particular, olive cake was considered to be a good additive for the combustion of lower quality fuels (Toraman and others, 2004). More recently, the co-combustion (also in a CFBC) of high-sulphur lignite with hazelnut shells and woodchips was examined by METU, MAM, and Istanbul Technical University. Combustion tests for each fuel and mixture focused particularly on the effect of excess air ratio on flue gas emissions. As the amount of biomass in the fuel mixture increased, combustion occurred more in the freeboard; maximum temperatures were attained here, rather than the bed. In addition, CO emissions increased in line with higher biomass content. This would require the addition of secondary air to the system in order to minimise CO and hydrocarbon emissions and to increase the combustion efficiency (Atimtay and others, 2010).

In recent years, consideration has been given to several proposals for commercial scale co-combustion. These have included the possibility of cofiring Turkish lignite with municipal waste in a CFB boiler (in, for instance, Bursa). However, even though results from feasibility studies have been positive, there do not yet appear to be any commercial cofiring projects in operation.

Cofiring has not been limited to CFBC applications, and has also been considered for application to existing PCC power plants. Thus, technical and environmental studies examined the potential for cofiring dried agricultural residues in the lignite-fired Soma power plant. Two technologies were evaluated, namely direct cofiring, in which biomass would be mixed with lignite in the same mill and fed into the boiler furnace, and parallel cofiring, in which biomass would be fired in a separate circulating fluidised bed boiler – steam produced would be fed into the steam network of the power plant. The investigations indicated that both methods of cofiring could be beneficial in decreasing lignite consumption and plant emissions. Olive (cake) waste, in particular, had a positive effect on general performance and emissions. In direct cofiring, fuel consumption, CO_2, SO_2 and particulate emissions fell by 20, 4, 19 and 18% respectively. With parallel cofiring, the reductions were 26%, 3%, 20% and 25% (Amirabedin and McIlveen-Wright, 2013; Yilmazoglu and others, 2013).

5.2.2 Cogasification

A number of coal/biomass cogasification R&D investigations have been undertaken at the Marmara Research Centre. These have included several national projects that examined the cogasification of coal and biomass mixtures and addressed associated gas cleaning issues. The first major project in this area, using bubbling fluidised bed gasification, ran between 2005 and 2008. The main aim was the investigation of gasification and gas cleaning technologies (using selected Turkish biomass feedstocks with lignite) plus upstream and downstream processing. The scope of the project included evaluation of potential cogeneration applications and the design and development of novel gasification technologies and gas clean-up systems. A 100 kWe (450 kWth) fluidised bed gasifier was designed and built for the project. Further work examined the use of similar combinations in fixed bed and CFB gasifiers.

As part of the TÜBİTAK 1007 research programme, an on-going 4-year project (the *Trijen Project*) is investigating the cogasification of local coals and biomass for the production of Fischer-Tropsch (FT) liquids (*see* Section 5.3).

5.3 Coal-to-liquids

As Turkey's economy continues to grow, so does its demand for crude oil-based products.

With very limited domestic reserves, the country relies heavily on imports. Turkey has just six refineries with a combined processing capacity of 714,275 barrels per day. However, more than 90% of the national oil requirement is met by imports. The level of imports is forecast to double over the coming decade.

Potentially, the production of liquid oil products from alternative sources would help minimise the country's high import dependence and enhance its energy security, and in recent years, several projects have addressed this area. Consideration has been given to the possibility of using domestic lignite as a source of liquid transport fuels. The feasibility of producing these (via gasification) from combinations of lignite with biomass has also been examined. TKI has undertaken several gasification-based R&D projects that have encompassed feasibility assessments and laboratory- and pilot-scale studies. An R&D facility has been established (Ziypak, 2011). The production of liquid fuels formed part of a TKI/MAM project (2011-13) that focused on the entrained flow gasification of Turkish lignite. Coal-to-liquid technology (via syngas production and FT synthesis) forms part of MAM's on-going R&D programme.

As part of the TÜBİTAK 1007 research programme, an €8.5 million, 4-year project (the *Trijen Project*) investigated the cogasification of local lignite and biomass (hazelnut shells, olive cake, wood chips) for the production of FT liquids. The project ran between 2009 and 2013, with work being undertaken by a consortium comprising TKI and the General Directorate of Electrical Power Resources Survey & Development Administration, in conjunction with MAM, ITU, MU, HABAS, and UMDE. The main aim was the development of an environmentally- and economically-viable process for the production of liquid fuels from domestic lignite and biomass, followed by technology demonstration at pilot scale (Akgun and others, 2009). Research areas included laboratory tests, detailed process design, engineering, manufacturing, commissioning, and testing at pilot scale. The programme examined fuel feeding, gasification, syngas cleaning, conditioning (steam and shift reactors) and separation, CO_2 separation, and FT processing. A coal-biomass-to-liquids (CBTL) production process based on a fluidised bed gasification pilot plant (1000 kWth) was developed. Both CFB and PFB gasification was studied at laboratory-scale and a design produced for a larger 1.1 MWth pilot-scale bubbling fluidised bed gasifier. A major work package of the project was the production of liquid fuels via FT synthesis and efforts were directed to FT catalyst development and fixed bed and slurry phase reactor applications. Production focused mainly on the low temperature (180–250°C) FT process, using a slurry phase reactor and novel Fe-based catalysts (Ziypak, 2011). Synthetic diesel was produced successfully.

Liquid fuel production from coal and biomass also forms part of the Turkish National Project TARAL 1007 (2009-2014) (Ergintav and Akgün, 2013). Modelling studies using the engineering simulation software tool *Aspen HYSYS* have been carried out by MAM. These examined the optimum process configuration design and operational parameters for a CBTL production process, based on the gasification of Soma lignite. FT conditions adopted were a pressure of 2 MPa and temperature of 260°C (Gul and others, 2010).

5.4 Underground coal gasification (UCG) activities

For some years, both lignites and hard coals have been the focus of UCG studies in Turkey. However, because of the scale of the resource, work on lignite has dominated. Some of TKI's considerable lignite reserves are not currently technically and/or economically mineable, hence the company has long maintained an interest in this area. Such deposits have been shown to gasify well and are considered to be possible candidates for UCG. Consequently, TKI has undertaken research and created a programme focused on developing commercial-scale projects.

Many issues can affect the viability of an individual project such as site selection, technical issues (seam thickness, moisture content, etc) and identification of applications for the product gas. Consequently, appropriate RD&D activities are deemed necessary before on-site developments begin. As part of this, TKI completed a laboratory scale project and conducted a feasibility study examining the possibilities of using UCG within a Turkish context. As part of this, simulation studies were carried out in co-operation with Kosice Technical University Faculty of Berg, Slovakia. Soma lignite was used; this had a CV of 11 MJ/kg, moisture content of 13.9%, ash content of 35.3%, and volatile matter content of 33%. Testing confirmed that, depending on the conditions used, product gas with a CV of between 9 and 20 MJ/m^3 could be produced. The highest was obtained using air with an oxygen content of 80% (Ziypak, 2011). Other lignite-based UCG-related activities have included:

- UCG feasibility studies for TKI were undertaken by Lawrence Livermore National Laboratory of the USA. A major aim was to assist in the selection and characterisation of locations suitable for a UCG facility (Yürek and Het, 2010). Cobanbey, in the Elbistan lignite reserve, has since been selected as the preferred location for a pilot study, and the linked vertical well method has been suggested as a candidate technology;
- with a view to developing a UCG project in Turkey, Clean Coal Limited of the UK has recently undertaken detailed geological assessments, pre-commercial site selection, and regulatory assessments, and carried out geological and hydrogeological site exploration activities;
- the potential for UCG of lignites in the Thrace basin has been examined for the Turkish Petroleum Company. Geological, geophysical and chemical studies were undertaken on selected lignite beds; the locations were determined during natural gas drilling (Anac and others, 2009); and
- TKI and Hacettepe University have collaborated on 3D modelling of lignite seams and subsequent underground mine design. The Soma, Tunçbilek and Yatağan lignite basins were selected. Studies noted that some lignite seams in these basins are subject to severe tectonic movement (Anac and others, 2009). In some locations, this may limit the potential of UCG.

The UCG of hard coal is the focus of activities being undertaken by Carbon Energy via a 50/50 joint venture (Clean Coal Amasra Ltd) set up in 2011 with Hema Endustri (a subsidiary of Hattat Group). The aim is to develop UCG projects in Hema's coal reserves in Amasra in northern Turkey (The Amasra Project). Hema has mining and CBM rights over the project area. Carbon Energy is responsible for initial pilot costs, while the joint venture company is responsible for production royalties to TTK. Permission to develop a pilot UCG project is covered by the existing rights granted to Hema. So far, CSGEPS of Australia has completed reserve estimation studies for the project test area.

5.5 Coalbed methane (CBM) utilisation

Potentially, Turkey has significant coalbed methane resources – recent estimates suggest ~3000 billion m³. In particular, methane from the Zonguldak region is considered to have the potential to play a role in energy production. Recent years have seen increased interest in the collection and utilisation of CBM for electricity generation. Some of the seams in the Zonguldak coalfield contain high levels of methane. Studies carried out in 2002 confirmed that some contained up to 10 cm³ of methane per gram of coal, indicating a viable CBM potential (Yalcin and others, 2002).

Assessment activities aimed at quantifying the scale of the potential resource have been undertaken in different parts of the country. For example, between 1997 and 1999, a major coalbed methane resource assessment was carried out for DanOil LLC and its joint venture partner Data Su. The commercial coalbed methane potential was determined for a 6100 square mile lease area, and a number of drilling targets recommended.

Simulation studies undertaken in 2008 indicated that the Bartin-Amasra coalfield in the Zonguldak basin held a possible reserve of 2.04 billion m³ of methane, a probable reserve of 1.33 billion m³ and proven reserves of 0.85 billion m³. Almost 10% of the total gas in place was found to be as free gas (Sinayuc and Gumrah, 2008).

With the idea of using CBM to generate electricity, TTK set up the *Coal Bed Methane Project*. In 2005, TTK tendered out coalbed methane projects for two areas to Hema Natural Energy Resources. As part of this programme, numerous boreholes were drilled (Biçer, 2012). With the aim of improving permeability, coal fracturing was carried out in five of these. This was achieved by injecting silica gel and silica sand into the coal seams. Most CBM wells require hydraulic fracturing to produce at commercial gas rates. Gas flows so far achieved are summarised in Table 28. Work is continuing.

Table 28 CBM gas flows achieved (Biçer, 2012)

Well	Daily gas rate (m^3/d)	Final target (m^3/d)
Amasra Bedesten	700–1000	28,000
Oner	1200	27,000
Amasra Tarlaagzi	700	15,000
Bağlik	800–1000	13,000

TACROM of Romania carried out a campaign of fracturing at several locations in Turkey with a view to assessing CBM production. This provided useful data on the location of reservoir production spots.

Several joint initiatives have been undertaken with US-based organisations. In 2009, Aksa Enerji announced that it was working with US companies to investigate the application of CBM technology.

And in 2011, as part of its activities to support clean energy production, the US Trade & Development Agency (USTDA) signed a grant for US$450,000 for CBM development in Turkey. TTK is pursuing this via a CBM recovery and utilisation project. The grant was awarded to Hema Natural Energy Resources to evaluate critical aspects of a combined CBM extraction and power generation project in Hema's coalfield. In December 2012, it was announced that the US-based Advanced Resources International had been awarded a contract to develop a feasibility study for the project. The study is focusing on a combined CBM/power generation project based on Hema's 5000 km^2 CBM lease in the Zonguldak region.

In 2013, research sponsored by the US Environmental Protection Agency (EPA) began, focused on the Zonguldak Basin. As noted, the basin contains some very gassy coal seams and consists of three major regions (Armutçuk, Zonguldak and Amasra). Of these, the Amasra coalfield is considered the most favourable for CBM recovery, as major coal seams here are deeper. Hema Enerji is already developing coalbed methane production facilities in the area. The on-going study aims to develop a reservoir model to predict the potential CBM recovery from the CBM-2 well, the only producing CBM well so far drilled by Hema in the Amasra coalfield. As part of this study, the model developed suggested an average production rate of 143 m^3/d for ten years. The total amount of methane produced during this period would be 0.53 million m^3 (Baris and others, 2013).

In 2010, Turkey became a member of the Global Methane Initiative (GMI). This commitment is focused on the effective control of excessive coal mine methane and the minimisation of associated global warming impacts. Alongside this, where methane is present in sufficient concentrations, its potential as an energy source is also being examined. To this end, TKI has established a research team tasked with bringing coal mine methane drainage systems and gas power plants to Turkey (GMI, nd).

CBM investigations have not been limited to Turkish hard coals. For example, in 2008, in TKI's underground lignite mining operations in the Soma region, high methane emissions were detected. In pockets, these were determined to be between 5% and 10%. In mine ventilation air, between 0.10% and 0.21% was found, although in places, levels were much higher. The (Miocene) Soma basin is estimated to contain at the least one billion tons of lignite and about half of this reserve is present at depths greater than 600 metres. In 2010, further studies examined the potential of CBM recovery within the basin. The seam selected (KM2) has an average thickness of about 20 metres and for several decades, has been mined by opencast and underground mining in the northern and central parts of the basin respectively. Coal exploration (via exploratory drillings) has since been extended to the southern region. Boreholes encountered the KM2 seam at 900–940 metres depth. The wellhead gas content measurements indicated that as much as 4 m^3 gas/tonne of (lignite to subbituminous) coal was present at this depth. The gas was predominantly methane (>99.4%). These results were deemed encouraging and further investigations are under way in the region (İnan and others, 2010).

For obvious safety reasons, methane requires draining from coal mines and a project is under way investigating the possibilities of producing energy from mine ventilation air. As noted above, this frequently contains low levels of methane (often <0.5%) exhausted from underground operations by surface fans. Capturing and utilising this would help minimise greenhouse gas-related effects and open up possibility for its utilisation. To address this, TTK set up the *Ventilation Air Methane (VAM) Project*, initially for the Amasra mine. Metanox Electric Production Company is building a demonstration plant that will generate electricity from methane recovered in this way. If the technology proves successful, it may be replicated in other TTK production areas.

5.6 Shale gas

Turkey possesses some shale gas although estimates of the scale of such reserves vary considerably.

Some suggest that the country could hold considerable quantities. For instance, the US Energy Information Agency has estimated that the Dadaş Shale in the southeast Anatolian Basin and the Hamitabat Shale in the Thrace Basin contain 4.6 trillion m^3 of 'risked' shale gas in-place. Potentially, some 650–680 billion m^3 is considered to be technically recoverable (EPDK, 2012). The Turkish Association of Petroleum Geologists estimates that shale gas reserves are 1800 billion m^3 and with an annual production of 45 billion m^3, could satisfy 40 years of natural gas consumption (Daly, 2013). However, some areas are yet to be fully explored – for instance, there may be considerable shale gas resources in the Sivas and Salt Lake basins. However, the government has stated that it is not yet feasible to provide firm estimates of national reserves before the completion of on-going exploration activities. Organisations (such as Shell) actively engaged in on-site investigations have confirmed that the picture will only become clearer once the on-going drilling programme has progressed further. The Turkish Government is collaborating with Shell's drilling programme in several areas.

The state-owned Turkish Petroleum Corporation (TPAO) is conducting joint operations with Shell for shale gas in the Mediterranean, Black Sea and the eastern province of Diyarbakir. Shell and TPAO began exploring for shale gas in Diyarbakir's Saribuğday-1 natural gas field in September 2012. TPAO may also begin co-operation with ExxonMobil. In late 2013, hydraulic fracturing began in the Thracian and south eastern regions, where a significant proportion of the country's reserves are thought to be located. However, overall, shale gas operations are still at an early stage in their development and it could take between 10 and 15 years before commercial production gets under way. Government announcements of July 2013 suggested that this would probably take place post-2020.

5.7 CCS activities

For many years, at only 3 tonnes, Turkey's *per capita* CO_2 emissions were much lower than the OECD average of 10 tonnes. Historically, the total amount of CO_2 emitted remained fairly constant until 1994. However, since then, levels have increased sharply. Between 1990 and 2004, these grew by 22% whereas in the same period, OECD levels increased by only 4%. Those in the IEA Europe region fell by 3%. Energy production was responsible for much of the Turkish increase – in 2011, the sector was responsible for nearly 80% (TurkStat, 2013b) (Figure 20). Significant increases were also reported for Turkish manufacturing industries such as cement, and iron and steel production.

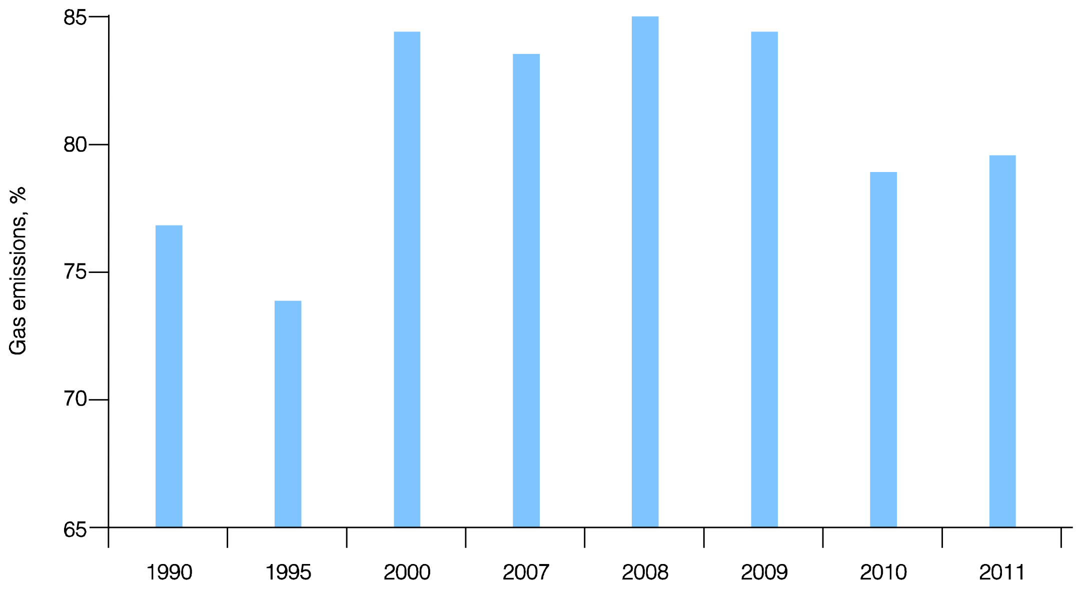

Figure 20 Contribution of energy sector to total Turkish greenhouse gas emissions

IEA analysis projects that in the absence of new policies or with no constraints in supply resulting from increased fossil fuel usage, Turkish CO_2 emissions will soon increase by 142% above 2009 levels (Kok and Vural, 2012). Turkey's greenhouse gas emissions are now amongst the highest of industrialised countries and economies in transition. The bulk of CO_2 emitted comes from fossil fuel combustion (TurkStat, 2013c). In 2011, total fuel combustion-related CO_2 emissions amounted to 294.6 Mt. This comprised 83.8 Mt from liquid fuels, 116.5 Mt from solid fuels, and 94.4 Mt from gaseous fuels. Emissions from public electricity and heat production plants amounted to 116.2 Mt, mainly 66.2 Mt from solid fuels and 49.1 Mt from gaseous fuels. Within the industrial and manufacturing sectors, iron and steel was responsible for 8.2 Mt, non-ferrous metals 1 Mt, chemical production 6.2 Mt, cement manufacture 18.8 Mt, fertiliser manufacture 1.5 Mt, and sugar production 2 Mt (UNFCC, 2013).

5.7.1 CCS-related policy and legislation

In 2004, Turkey ratified the United Nations Framework Convention on Climate Change (UNFCCC) and in 2009, the Kyoto Protocol. As an Annex I party to the Convention, Turkey is required to develop annual inventories on emissions and removals of greenhouse gases not controlled by the Montreal Protocol, using the Revised Intergovernmental Panel on Climate Change (IPCC) Guidelines and IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas (GHG) Inventories. The Inventory covers all emissions and removal sources described in IPCC Guidelines.

In 2010, the National Climate Change Strategy for Turkey – NCCAP (for the period 2011-23) was approved by the Higher Planning Council. The 'National Vision' embodied in this is for Turkey to fully integrate climate change-related objectives into its development policies, disseminate energy efficiency, increase the use of clean and renewable energy resources, and actively participate in the wider effort to tackle climate change. A strategic target is for the country to fully engage in global efforts to counter climate change and to integrate appropriate mitigation policies and measures consistent with UNFCCC principles and the country's 'special circumstances'. General objectives include:

- to contribute to global greenhouse gas emission mitigation policies and measures, within its own capacity, by limiting the rate of growth of national greenhouse gas emissions, without disrupting its development programme aligned with sustainable development principles;
- to increase national preparedness and capacity in order to avoid the adverse impacts of global climate change and to adapt to these impacts; to share emerging experiences and knowledge from such efforts with other countries in the region; and to develop bilateral and multilateral joint research projects for mitigation and adaptation;
- to comply with the design and implementation of global strategic objectives of mitigation, adaptation, technology transfer and finance that accounts for responsibilities of the parties, and to take active role in international activities;
- to increase access to the financial resources required for undertaking mitigation and adaptation activities; and
- to develop national research and development and innovation capacities towards clean production and to establish national and international financial resources and incentive mechanisms aimed at increasing competitiveness and production in this area by taking into consideration current Turkish technology and development levels.

Specific technical goals of the action plan are noted in Table 29.

Table 29 Major objectives of the Turkish National Climate Change Action Plan (NCCAP)

Purpose	Objective
Reducing energy intensity	Reduce primary energy intensity by 10% (compared to 2008) by 2015 through the use of implemented and planned policies and measures
	Develop energy efficiency capacity by 2015
	Support R&D activities on energy efficiency
	Increase incentives offered by MENR for energy efficiency applications by 100% up to 2015
Increase the share of clean energy in energy production and use	Increase the share of renewable energy in electricity production
	Develop capacity by 2015 to increase utilisation of renewable energy sources
	Ensure technological development by 2020 for energy production from renewable energy resources
Limit GHG emissions originating from use of coal in electricity production through use of clean coal technologies and energy-increasing measures	Increase the average cycle efficiencies of existing coal-fired power plants until 2023

A major objective is to minimise GHG emissions originating from the use of lignite and hard coal for electricity generation through the greater deployment of CCTs and the adoption of measures to increase energy efficiency. This is to be achieved mainly by increasing the average cycle efficiency of the coal-fired power plants that make up the Turkish fleet. Specific goals are shown in Table 30.

Table 30 Actions to increase efficiency of coal-fired power generation (Turkish National Climate Change Action Plan, 2011-23(2012))

Action area	Actions	Time period	Co-benefits	Outputs and performance indicators	Responsible/ co-ordinating organisation	Relevant organisations
Rehabilitation of existing lignite power plants and disseminating the use of CCTs	Continuing maintenance, improvement and modernisation of existing power plants, plus use of new technologies to increase efficiency and production capacity	2011-2020	Energy supply security, high quality employment	Completion of improvement activities in power plants	EÜAŞ	MENR, TKI, TTK, MTA, TÜBİTAK , PA, private investors, Universities
	Seek opportunities for use of clean technologies, and improve costs and implementation in existing power plants	2011-2014	New employment opportunities	Due diligence analysis with cost-benefit analyses	EÜAŞ	MENR, TKI, TTK, MTA, TÜBİTAK , PA, private power plants, Universities
Using CCTs in new coal-fired power plants	Engage local universities, organised industrial zones, development agencies, etc to ensure that CCTs are used in small-reserve local power plants	2011-2023	New employment opportunities, know-how, technology	Establishment of regional coal research centres	MENR	MOF, TKI, EÜAŞ, TTK, MTA, TÜBİTAK , universities, private sector
	Identify technical criteria for utilisation of CCTs in new power plants using domestic lignite, and take measures to promote implementation	2011-2015	Reduction of environmental pollution, improvement of air quality	Making legal arrangements regarding technical criteria for CCT applications	MENR	MEU, TKI, EMRA, TÜBİTAK , TTK, MTA, TUSIAD, NGOs, private sector
Promoting use of cogeneration and regional heating systems	Ensure full alignment with EU cogeneration regulations	2011-2014	Alignment with EU	Publication of cogeneration regulation in Official Gazette	MENR	EMRA, TÜBİTAK , MEUA, sectorial NGOs, private sector
	Ensure incentives are provided for spreading high-efficiency co/tri-generation and regional heating practices	2011-2015	Raising public awareness	Introductory guide	MENR	MoD, UoT, TOKI, EMRA, municipalities, sectorial NGOs, private sector
	Make legal arrangements for disseminating utilisation of residual heat, and carry out information activities	2011-2015	Capacity building	Increase in residual heat utilisation	MENR	EMRA, TÜBİTAK , municipalities, sectorial NGOs, private sector

5.7.2 Turkish involvement in CCS-related R&D

Turkey has been involved in a number of major European initiatives and there is expertise on carbon capture and storage within a number of Turkish organisations. Notable Turkish CCS activities include:

- **CGS CO_2 Geological Storage (CGS) EUROPE project**

This three-year Co-ordination Action (under the EU 7th Framework programme) ran between 2010 and 2013 and concentrated on the geological storage part of the CCS chain. The overall objective was the establishment of a credible, independent, long-lasting and representative pan-European scientific body of expertise on CO_2 geological storage. There was a strong focus on networking (via for instance, the CO2GeoNet Association, CO2NET EAST, and ENeRG networks) and enhanced co-operation both within European member states and further afield. Twenty four participating organisations active in CO_2 storage matters were involved (Petrov, 2012). Turkey was represented by METU-PAL, the Petroleum Research Center of the Middle East Technical University.

- **CCS EII Implementation Plan, 2010-2015**

Turkey is an active member of the European Industrial Initiative (EII) on CO_2 Capture and Storage (CCS) Implementation Plan, 2013-2015. This is aimed at supporting the EU CCS demonstration programme.

- **Strategic Energy Technology (SET) Plan**

The SET-Plan officially started in 2010 and aims to build a platform of co-operation across Europe to promote collaboration between technology developers and the public sector on the European scale. This should produce important economies of scale, a reduction in the duplication of effort and a leveraging of RD&D investments in the private sector. It is governed by the SET-Plan Steering Group comprising representatives from the EU member states, chaired by the European Commission. Turkey participates as an observer.

Turkish commercial expertise

Turkey has experience of handling and transporting CO_2 on a commercial scale. In 1986, CO_2 injection for enhanced oil recovery (EOR) began at Bati Raman in Turkey, the first such application outside North America. Here, naturally occurring CO_2 was used, delivered via a 1 Mt/y pipeline. The use of CO_2 as an immiscible flood has allowed an increase in recovery of 300% over initial estimates. Subsequently, the technique was extended to the Bati Kozluca oil field, where six injection wells started up in May 2003. Additional wells have since been drilled and operations continue (Kok and Vural, 2012). Thus, Turkey has some technical expertise and experience in this area. Although the CO_2 being used comes from natural formations, there is no technical reason why CO_2 captured from the power and industrial sectors could not be utilised in this manner.

In 2012, a draft Turkish CCT and CCS roadmap was produced. This identified the country's major CO_2 emitters as fossil fuel power plants, cement and iron-steel factories, and oil refineries. Potential CO_2 storage areas were identified as oil and natural gas fields, and lignite and hard coal reserves. Further analysis is still needed for basalt and deep saline aquifers. By matching local point sources with potential CO2-EOR, CO2-ENGR (enhanced natural gas recovery) and CO2-ECBM (enhanced coalbed methane recovery) activities, a number of possible opportunities for both capture and storage sites were identified (Table 31).

Table 31 Potential CO_2 capture and storage locations (Kok and Vural, 2012)	
Storage location	CO_2 sources
Manisa Soma lignite reserve	Thermal power plants, iron-steel and cement factories, and oil refineries in Izmir, Manisa and Aydin
Kütahya Tavsanhi lignite reserve	Coal-fired power plants around Kütahya
Bursa lignite reserve	Coal-fired power plants, iron-steel factories in Bursa, and iron-steel factories and oil refinery in Kocaeli
Çayirhan and Kirsehir lignite reserves	Coal-fired power plants in Ankara and refinery in Kirsehir
Muğla-Yatağan lignite reserve	Coal power plants around Muğla
Zonguldak hard coal reserve	Coal power plants, iron-steel works in Zonguldak
Natural gas and oil fields in Thrace	Coal plants around Kirklareli
KahramanMaraš-Elbistan lignite reserve	Power plants in KahramanMaraš, iron-steel works in Osmaniye and Hatay

In the power sector, the biggest individual CO_2 emitters were identified as the Elbistan A and B, and Soma B power plants. These were followed by the Kangal, Yatağan, Kemerköy and Seyitömer stations.

5.8 Oxyfuel combustion activities

Historically, work on oxyfuel coal combustion has concentrated mainly on hard coals. Clearly, within a Turkish context, application to lignites would significantly increase the potential of the technology. Reasons cited for this approach include improvement in the efficiency of lignite combustion, the possibility of retrofitting, lower NOx emissions, easier CO_2 capture, and possibilities for utilising the resultant CO_2 stream for EOR or ECBM applications.

In 2008, a multi-partner project (SOMALOX) was submitted as part of the EU 7th Framework Programme (FP7 ENERGY, 2008-12) involving five Turkish organisations that included TKI and EÜAŞ. This focused on the possibilities of retrofitting a 22 MW unit of the Soma A lignite-fired power plant for oxyfuel combustion. A combined RTD/demonstration approach was developed to validate the feasibility of retrofitting and assessing some innovative options for efficiency improvement of oxy-fuel combustion. Major goals included optimisation of the oxyfuel combustion process, fuel handling and safety, oxyfuel burner design, and evaluation of retrofitted system, plus its efficiency and environmental performance, including the quality of the CO_2 stream for various CCS options (Gökalp, 2010). Demonstration goals included a full retrofit of an existing pulverised lignite power plant and validation of its scalability (Gökalp and Ersoy, 2010). Other studies have since considered the wider possibilities of retrofitting oxyfuel technology to other Turkish pulverised lignite fired power plants. More recently, studies have been broadened to include the possibility of co-combusting blends of low CV Turkish lignite with biomass (such as municipal waste and olive residue) under oxyfuel conditions (Atibeh and Yozgatligl, 2012).

6 Summary

Turkey has one of the world's fastest growing economies, currently the 6th largest in Europe and the 16th largest in the world. In recent years, annual economic growth has been between 9% and 11%. Rapid economic expansion, growing population, and increasing industrialisation have triggered a general increase in energy demand. During the last decade, the rate of increase in demand for natural gas and electricity has been only second after China. In the next decade, the current level of energy demand is expected to double.

Turkish *per capita* energy consumption still lags behind most developed countries – it is only around a third of the OECD average. However, in the near, given the country's rapid and stable economic growth, this gap is expected to narrow.

Like many countries, Turkey faces a number of energy supply issues. Set against a background of growing demand and increasing dependence on expensive imports of oil and natural gas, these centre mainly on security of supply and achieving sustainable development. The cost of Turkey's imported energy is considerable, accounting for around a quarter of the country's overall annual import bill.

Around 72% of the country's primary energy needs are met by imported oil and gas, and a major government objective is to reduce this high import dependency. At the moment, >90% of Turkey's oil and 98% of its natural gas are imported, mainly from Iran and Russia. Much of the hard coal consumed is also imported. Turkey's indigenous energy resources are limited almost exclusively to lignite and smaller amounts of hard coal. The continuous rise in energy demand makes it imperative for the country to meet more of its energy needs from its own resources, in particular, lignite.

In recent years, Turkey's electricity demand has increased by up to 8.5%/y. Much of this increase has been met by new natural gas-fired power plants, although as these rely mainly on imported gas, this has had serious repercussions on the national trade balance. As part of a move to reduce imports, the Ministry of Energy and Natural Resources (MENR) has adopted a coal strategy aimed at increasing the use of indigenous hard coal and lignite for power generation, with an emphasis on the adoption of clean coal technologies. 2012 was designated 'domestic coal year', backed by a government policy initiative that gave increased priority to the use of domestic lignite. Strategies and action plans have been developed and project applications started. A significant number of coal-based power projects have been proposed or are under development or construction. Alongside these moves, there will also be greater deployment of renewable energy technologies, plus the addition of nuclear power to the energy mix. Over the next decade, a major aim is to reduce the share of electricity generated by gas-fired stations from ~40% to less than 30%.

During the last decade, Turkish energy markets have been undergoing tremendous changes. These have included liberalisation, opening up to private participation, and restructuring to establish a competitive market. Increasingly, state-owned power generation assets and coalfields are being sold to the private sector. Between 2001 and 2009, publicly-owned generation dropped from 78% to 46%, with a number of major coal-fired power plants being privatised. As part of the wider privatisation process, 13 thermal power plants and 28 hydroelectric plants have been grouped for sale into nine portfolios, although only some include coal/lignite-fired plants (a total of 9.263 GW).

In order to meet the increasing electricity demand, large investments will be required. An estimated 50 GW or more of additional generating capacity will be needed to meet the country's growing needs. Turkish policymakers have prioritised the increasing role of the private sector in making the necessary investments, and a favourable investment environment has been established. There is a goal of achieving an additional 18 GW of coal-based installed capacity within the next decade.

Current estimates suggest that Turkish coal resources exceed 13 Gt (11.8 Gt of lignite and 1.3 Gt of hard coal). Proven reserves are estimated at ~10 Gt of lignite and >530 Mt of hard coal. However, despite considerable progress over the past decade, large areas of the country have yet to be explored fully. In others, evaluation has only been carried out at relatively shallow depths. Potentially, hard coal and lignite reserves could be much greater than current estimates suggest. On-going exploration has so far added 5.8 Gt to Turkey's lignite reserves. Even though often of poor quality, lignite remains the country's most important indigenous energy resource. Most deposits have low calorific values and many contain high levels of ash, moisture and sulphur. Furthermore, properties can vary significantly, even within the same geographical area. Around 70% of reserves have a CV of less than 8.37 MJ/kg.

Lignite deposits are spread across much of the country, with reserves available in all geographical regions and in more than 40 provinces. Nearly 90% of lignite reserves are owned and/or operated by public sector organisations (TKI, EÜAŞ and MTA). Two of these are lignite producers; in 2011, TKI produced 33.4 Mt, and EÜAŞ, 31.6 Mt. In a typical year, the private sector produces ~7 Mt. The greatest concentration of lignite mines is in the northwest region around the towns of Soma, Seyitömer and Çan. Most output comes from opencast mines, some of which are linked directly to captive power plants. Lignite-fired plants have a strong competitive advantage in terms of price, supply, investment and operating costs.

As part of the on-going national privatisation process, some mines are being sold, packaged with specific power plants. In June 2013, TKI's Seyitömer coalfields were transferred to the Çelikler Seyitömer Electricity Generation Company, along with the Seyitömer power plant, under the contract of transfer of operating rights. In August of the same year, the Sivas-Kangal coalfields (previously operated for EÜAŞ by the private sector) and Sivas-Kangal Thermal Power Plant were transferred to the Konya Şeker-Siyahkalem Joint Venture Group. Also included in the privatisation programme are the Çatalağzi power plant (fed by hard coal from TTK), and TKI's Muğla coalfields, along with the Kemerköy, Yeniköy and Yatağan power plants. Assuming that no major obstacles are encountered, the Soma, Çan, Orhaneli and Tunçbilek coalfields (with their associated power plants) are likely to become part of the process in the near future. A different privatisation process is expected to be adopted for the Afşin-Elbistan lignite basin, Turkey's most important lignite resource. Here, it seems likely that a public-private partnership model (that includes international collaboration) will be adopted. Despite the recent failure of the agreement between EÜAŞ and TAQA, it is reported widely that a similar arrangement is being discussed with alternative overseas collaborators (Tamzok, 2013).

Unlike lignite, hard coal deposits and commercial production is limited to a single region, the Zonguldak basin in the north-west of the country, situated between Eregli and Amasra on the Black Sea coast. Coal resources in the basin are estimated to amount to 1.316 Gt, of which 530 Mt is considered proven. The current national hard coal production of ~3 Mt/y meets only a tenth of the annual demand, the balance being met by imports.

Annually, Turkey imports around 27–30 Mt of hard coal. In a 'typical' year, around 19% of hard coal imports are used for electricity generation, 22% for coke production, 29% by industrial users, and 30% for domestic heating. Imports are expected to increase as new thermal power plants come on line and iron and steel production expands. An estimated additional 2–2.5 Mt/y of coal will be required for new power projects scheduled to come on line in the near future. Coking coal comes mainly from the USA, Canada and Australia. Most steam coal comes from Russia, Colombia and South Africa.

Turkish Hardcoal Enterprises (TTK) is responsible for the country's hard coal – essentially all hard coal reserves are owned by the company. It is Turkey's main hard coal producer; the private sector provides only around 8% of the total. However, about 35% of production reported by TTK is mined by private companies working under subcontract. In reality, the company dominates the production, processing and distribution of hard coal, although there are no legal restrictions on private sector involvement. Restructuring and privatisation efforts to increase production are under way. There is an ambitious target to increase the current level of 3 Mt/y, to nearly 12 Mt/y in 2023.

Depending on the specification and end-use, both lignites and hard coals may be washed and/or screened prior to use. There are currently around 45 coal preparation plants in operation, with capacities ranging from 50 to 1000 t/h. Twelve of these treat bituminous coal, and the rest cover about 40–45% of the country's lignite production.

Turkey's booming economy has created one of the fastest growing energy markets in the world and electricity requirements have soared. In 2012, around 239 TWh was produced, an increase from 229 TWh in the previous year. The compound annual growth rate for the decade 2002-12 was an average of 6.2%. For 2007-12, it was 7.5%. *Per capita* electricity demand has also been rising in line with economic growth and is expected to increase further.

Thermal and hydroelectric generation currently provides most of Turkey's electricity. In 2012, gas-fired plants generated 43.6%, followed by hydro (24.2%). Domestic lignite and hard coal provided 16.2%, with imported hard coal providing a further 12.2%. Small amounts were also provided by oil, asphaltite, wind, and geothermal. However, there are plans to add nuclear power to the mix. By 2023, a government goal is for ~30% of the country's electricity to be produced from lignite/hard coal, 30% from gas, 30% from from hydro and other renewables, and 10% from nuclear. There is an ambitious target for 2023 (the centennial foundation of the Republic) for the country to have between 112 and 125 GW of installed generating capacity. This will include some 18.5 GW of new coal-fired capacity located within the country's coal basins.

Historically, most major lignite-fired and hard coal-fired power plants have used variants of conventional pulverised coal combustion (PCC) or fluidised bed combustion (FBC) technologies, based mainly on subcritical steam conditions. For some, steam temperatures and pressures remain relatively low. However, recently, the focus has switched increasingly to the adoption of supercritical steam conditions and a number of new projects are being developed. Currently, most of these proposals are for hard coal-fired plant although at least one is for a lignite-fired station. A number of new FBC-based projects are also being developed, mostly lignite fired.

Industrial air pollution continues to be a serious problem for some parts of Turkey and a challenge for public policy. Of most concern are emissions of SO_2, followed by NOx. Around two thirds of SO_2 and a third of NOx emissions are generated by fuel combustion and the power generation sector. All new coal-fired power plants will be required to install and operate FGD systems capable of capturing at least 90% of SO_2 produced, with low-NOx burners, staged-air supply and (subject to review), selective catalytic reduction (SCR) for NOx control. Effective particulate control systems will also be required. A number of older facilities and some smaller units still lack adequate emission control systems. However, most are expected to be suitably re-equipped and rehabilitated as they are sold into the private sector. The lack of such equipment is usually factored into the purchase price.

Annually, Turkish thermal power plants generate more than 20 Mt of solid combustion residues (mainly fly ash and bottom ash). Reportedly, only around a third is currently utilised, the remainder being landfilled or directed to slurry ponds. There is also some utilisation of FGD gypsum for building products.

The commercial scale deployment of clean coal technologies in Turkey encompasses mainly fluidised bed boilers, supercritical pulverised coal boilers, various environmental control technologies (such as FGD and SCR units), and a number of coal cleaning systems. However, as the national focus shifts towards the greater use of indigenous lignite and hard coal, interest in the wider use of CCTs is increasing. This has now reached ministerial level and their increased deployment is being encouraged by various means.

There is in-house CCT expertise within a number of Turkish utilities, technology suppliers, and universities. There have also long been commercial and other links between some international technology providers and their Turkish counterparts. The main focus for CCT RD&D activities is TÜBİTAK, the Turkish Science and Technology Research Institute (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu). TÜBİTAK acts as an advisory agency to the Turkish Government on science and research issues, and is the secretariat of the Supreme Council for Science and Technology (SCST), the country's highest science and technology policy-making body. There are fifteen different research institutes and centres attached to TÜBİTAK, covering a range of topics. CCT activities under way in Turkey encompass mainly hard coal/lignite gasification, IGCC, coal-biomass co-utilisation (co-combustion and cogasification), coal-to-liquids, underground coal gasification, coalbed methane utilisation, and carbon capture and storage.

7 References

Adularya (2010) *Adularya. Fields of activity - thermal*. Available from: http://www.adularya.com/faaliyet-alanlari/termik/?lang=en Ankara, Turkey, Adularya Enerji Elektrik Üretimi ve Madencilik A.S, 2 pp (2010)

Akgün F, Çağlayan E, Durak Y (2008) Clean Coal Technologies. *Turkish-American Clean Energy Conference*, Istanbul, Turkey, 29-30 Jan 2008, 20 pp (2008)

Aksoy P, sik-Gulsac I, Er O, Sarioglan A, Ay S, Uresin E, Argonul A, Cetin Y, Akgun F, Atakul H (2012) Integrated hot and cold synthesis gas clean-up. *29th Annual International Pittsburgh Coal Conference*, Pittsburgh, Pensylvania, USA, 15-18 Oct 2012, 6 pp (2012)

Aksoya D O, Kocaa S, Kocab H (2013) Carbon recovery from coal combustion wastes to reduce negative environmental effects. *Annual World Conference on Carbon - Carbon 2013*, Rio de Janeiro, Brazil, 14-19 July 2013, 5 pp (2013)

Alonso J F (2012) *BAT Guide for coal and lignite large combustion plants*. Project TR-2008-IB-EN-03. Mission no: 2.1.4.a.3. Available from: http://www.csb.gov.tr/db/ippceng/icerikbelge/icerikbelge864.pdf Turkish Ministry of Environment and Urbanism, Ankara, Turkey, 156 pp (June 2012)

Altunyuva F (2014) Istanbul, Turkey, ISPAT, *personal communication* (20 Feb 2014)

American Fuels Coalition (2012) *Turkish coals studied for gasification potential. Synthesis Energy Systems completes testing of Turkish lignite coals for small scale power generation projects*. Available from: http://www.americanfuelscoalition.com/2012/06/25/turkishgasification/ (25 June 2012)

Amirabedin E, Zeki Yilmazoglu M, Baskaya S (2013) Exergetic evaluation of an integrated gasification combined cycle power plant simulated by seven different types of Turkish lignite. *Turkish Journal of Engineering & Environmental Sciences*; **37**: 42-55 (2013)

Amirabedin E, McIlveen-Wright D (2013) A feasibility study of co-firing biomass in the thermal power plant at Soma in order to reduce emissions: an exergy approach. *International Journal of Environmental Research*; **7** (1):139-154, Winter (2013)

Anaç S (2009) Present situation of coal in energy policy of Turkey and Turkish coal industry. *26th Annual International Pittsburgh Coal Conference*, Pittsburgh, Pennsylvania, USA, 20-23 Sept 2009, 20 pp (2009)

Anac S, Unver B, Yurek S, Tercan E, Hindistan, M.A, Ozdingis M, Halicioglu B S, Ertunc G, Akcan E (2009) Modelling of deep lignite seams for conventional production and underground coal gasification in Turkey. *26th Annual International Pittsburgh Coal Conference*, Pittsburgh, Pennsylvania, USA, 20-23 Sept, 9 pp (2009)

Atibeh E A, Yozgatligl A (2012) A study on catalytic pyrolysis and combustion characteristics of Turkish lignite and co-processing effects with biomass under oxy-fuel conditions. *International Symposium on Combustion,* 29 July-2 Aug 2012, Warsaw, Poland, 4 pp (2012)

Atimtay A T, Topal H (2004) Co-combustion of olive cake with lignite coal in a circulating fluidized bed. *Fuel*; **83** (7-8); 859-867 (May, 2004)

Atimtay A T, Varol M, Olgun H, Unlu A, Bay B, Kayahan U, Ataköl H, Çelebi M C (2010) Co-combustion of various biowastes with a high-sulfur Turkish lignite in a circulating fluidized bed combustor. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 6 pp (2010)

Baris K, Keles C, Ripepi N, Luxbacher K, Karmis M, Gurpinar S (2013) Modeling of various degasification techniques: A case study from the Amasra coal field, Turkey. *23rd International Mining Congress & Exhibition of Turkey*, Antalya, Turkey, 16-19 April 2013, 12 pp (2013)

Başçetinçelik A, Öztürk H H, Cengiz Karaca C, Kaçira M, Ekinci K, Kaya D, Baban A, Güneş K, Komitti N, Barnes I, Nieminen M (2007) *Exploitation of agricultural residues in Turkey*. Agro-Waste - Life 03 TCY/TR/ 000061. Available from: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=AgroWaste_Guide.pdf 76 pp (2007)

Biçer N (2008) Turkish Hardcoal Enterprise (TTK) modular coal-processing plants applied to Zonguldak hardcoal. *Turkish-American Clean Energy Technologies Conference*, Istanbul, Turkey, 29-30 Jan 2008, 40 pp (2008)

Biçer N (2012) Advancing project in the hard coal mining industry in turkey. *Turkey Mining Summit 2012*, 4-7 June 2012, Istanbul, Turkey, 45 pp (2012)

Biyikoğlu A, Zühtü Uysal B, Güngör A, Kasnakoğlu C, Özbayoğlu M (2010) Effect of operation parameters on gasification for the production of synthesis gas. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 2 pp (2010)

Boylu F, Çetinel T, Çinku K, Kurulu Ö, Yalçın N, Çelik M S (2010) Development of dry a beneficiation scheme for Soma-Imbat lignite by Allair Jig and Akaflow. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 6 pp (2010)

Bozkurt A (2009) *Clean coal technology needed in Turkey*. Available from: http://www.todayszaman.com/columnistDetail_getNewsById.action?newsId=190166 Istanbul, Turkey, Today's Zaman, 2 pp (17 Oct 2009)

Calik Enerji (2013) *Energy*. Available from: http://www.calik.com/en/sectors/energy Istanbul, Turkey, Calik Holding, 1 pp (2013)

Cetin B, Abacioglu M (2013) Economic analysis for rebuilding of an aged pulverized coal-fired boiler with a new boiler in an aged thermal power plant. *Advances in Mechanical Engineering*; Article ID 270159; June 2013, 6 pp (2013)

Coal Age (2012) *Coal exporters and buyers meet in Istanbul*. Available from: http://www.coalage.com/index.php/features/2392-coal-exporters-and-buyers-meet-in-istanbul.html Jacksonville, Florida, USA, Coal Age (5 Dec 2012)

CoalGuru (2013) Turkey offers local coal production to cure CAD [Current Account Deficit]. Available from: http://www.coalguru.com/other_asia/turkey_offers_local_coal_production_to_cure_cad/10113 New Delhi, India, Coal Guru (31 May 2013)

Daly J (2013) *Will shale gas eventually make Turkey energy independent*? Available from: http://oilprice.com/Energy/Natural-Gas/Will-Shale-Gas-Eventually-Make-Turkey-Energy-Independent.html OilPrice.com, 2 pp (1 July 2013)

Deloitte Turkiye (2013) *The energy sector: a quick tour for the investor*. Available from: http://www.invest.gov.tr/en-US/infocenter/publications/Documents/ENERGY.INDUSTRY.pdf Istanbul, Turkey, Deloitte Turkiye, 58 pp (July 2013)

Dietrich A (2013) Steps and challenges faced during development of coal/lignite-fired power plant projects in Turkey. *19th International Energy & Environment Fair and Conference*, Istanbul, Turkey, 24 April 2013, 30 pp (2013)

Engineering & Mining Journal (2012) Turkey's move to unleash its mining potential. *Engineering & Mining Journal*; **213**; 1; 58-60. Available from:

http://www.gbreports.com/admin/reports/EMJ-Turkey2012.pdf Jacksonville, Florida, USA, Engineering & Mining Journal (2012)

EPDK (2012) *Turkish energy market: An investor's guide 2012*. EPDK - Energy Market Regulatory Authority. Available from: http://www.epdk.gov.tr/documents/strateji/rapor_yayin/yatirimciel_kitabi/Sgb_Rapor_Yayin_Yatirimciel_Kitabi_Eng_2012_Mb3JG91tFh1B.pdf Ankara, Turkey, Energy Market Regulatory Authority, 63 pp (2012)

Erdem A, Gülmez A, Altun O, Toprak S, Olgun Z, Gitmez A (2012) *Fine coal recovery from the Ömerler washery tailings and plant applications*. Available from: http://www.arber.com.tr/imps2012.org/proceedingsebook/Abstract/absfilAbstractSubmissionFullContent429.pdf General Directorate of Mineral Research and Exploration (MTA), and General Directorate of Turkish Coal Enterprises, Ankara, Turkey, 6pp (2012)

Erdil M (2013) *First solar power plant race waters investors' mouths*. Available from: http://www.Hürriyetdailynews.com/first-solar-power-plant-race-waters-investors-mouths.aspx?pageID=238&nID=48927&NewsCatID=348 Istanbul, Turkey, Hürriyet News (20 June 2013)

Ergintav S, Akgun F (2013) Activities of Marmara Research Center. *16th Meeting of COMSATS Coordinating Council*, Accra, Ghana, 2-3 May 2013, 45 pp (2013)

Ersoy M (2008) Carbon capture and storage in Turkey. *Cleaner Electricity Production Forum – Carbon capture and storage*, Geneva, Switzerland, 18 Nov 2008, 37 pp (2008)

Euracoal (2013) *Turkey*. Available from: http://www.euracoal.com/pages/layout1sp.php?idpage=475 Brussels, Belgium, Euracoal, 1 pp (2013)

EÜAŞ (2013) *EÜAŞ thermal power plants*. Available from: http://www.euas.gov.tr/Sayfalar/Eng/TermikSantraller.aspx Ankara, Turkey, EÜAŞ, 2 pp (2013)

Eurasian Coal Portal (2012) *Turkey*. Available from: http://www.eurasiancoal.com/countries/turkey.html London, UK, Ignatov and Company Group, 1pp (2012)

Europe Aid (2012) T*echnical assistance for improving emissions control.* TR0802.03-02/001. EuropeAid/128897/D/SER/TR. Final Report - Part 2: Main technical results. Brussels, Belgium, EuropeAid, 135 pp (21 Oct 2012)

EuropeAid (2013) *Technical assistance service for IPPC – integrated pollution prevention and control in Turkey*. TR0802.04-02/001. EuropeAid/129470/D/SER/TR. Brussels, Belgium, EuropeAid, 192 pp (June 2013)

European Commission FP7 (2013) *ENERGY 2011 6.1-1 Optimizing gasification of high-ash content coals for electricity generation - OPTIMASH*. Available from: http://ec.europa.eu/research/iscp/pdf/energy-gokalp_en.pdf Brussels, Belgium, European Commission, 16 pp (2017)

GAMA (2013) *GAMA Holding*. History and company profile. Available from: http://www.GAMA.com.tr/en/GAMA-holding/corporate/about-us/history-and-company-profile/112 Ankara, Turkey, GAMA Holding, 2 pp (2013)

Gas to Power Journal (2013) *Turkey aims to privatize all thermal power plants by 2015*. Available from: http://remziyeyilmaz.blogspot.co.uk/2013/03/turkey-aims-to-privatize-all-thermal.html London, UK, Gas to Power Journal, 1 pp (15 March 2013)

Gitmez A, Zehra Taksuk F, Albayrak F (2010) The evaluation of the contributions to the productivity of the process changes at Tunçbilek Coal Preparation Plant. Western Lignite Establishment

(GLI). *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 6 pp (2010)

GMI (nd) *Specific strategy for Turkey and for Turkish Coal Enterprises (TKI)*. Available from: https://www.globalmethane.org/documents/coal_cap_turkey.pdf Global Methane Initiative, 5pp (nd)

Gökalp I (2010) *Review of ICARE-CNRS activities on facilitating CO_2 capture from the combustion of fossil fuels*. Available from: http://cleancoal.polsl.pl/pdf/Gokalp.pdf Orleans, France, Centre National de la Recherche Scientifique – CNRS Institut de Combustion, Aérothermique, Réactivité et Environnement – ICARE, 48 pp (2010)

Gökalp I, Ersoy M (2010) Oxy-fuel combustion: A technological option for retrofitting existing pulverized lignite fired power plants in Turkey. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 2 pp (2010)

Gökalp I (2013) *From the ashes* [OPTIMASH project]. Available from: http://www.paneuropeannetworks.com/GOV7/files/assets/basic-html/page208.html Pan European Networks - Government, 2 pp (2013)

Gozen M (2013) Determining the share of renewable based electricity generation from co-fired power plants (The difficulties and challenges in the promotion of co-fired power plants). *ERRA Licensing/Competition Committee Meeting*, Abu Dhabi, United Arab Emirates, 6-7 Feb 2013, 6 pp (2013)

Gul S, Ersoz A, Baranak M, Faruk Gul O, Akgun F (2010) Comparative evaluation of different coal to liquid process conditions via Fischer-Tropsch synthesis. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 5 pp (2010)

Güneş C (2012) *Contributing lignite coal fields to the economy*. Available from: http://www.deloitte.com/assets/Dcom-Turkey/Local%20Assets/Documents/turkey_tr_energy_lignite_140512.pdf Istanbul, Turkey, Deloitte Turkiye, 52 pp (April 2012)

Güngör K (2010) *Production of heavy-media-quality magnetite concentrate from Kedkköprü iron ore tailings*. Available from: http://etd.lib.metu.edu.tr/upload/12611830/index.pdf Ankara, Turkey, Middle East Technical University, School of Natural and Applied Sciences, 106 pp (May 2010)

Harte J (2012) *Turkey ripe for renewable energy boom – so why the delay*? Available from: http://www.greenprophet.com/2012/09/turkey-ripe-for-renewable-energy-boom-so-why-the-delay/ (15 Sept 2012)

Hellenic Shipping (2013) *Turkey coking coal imports up 25pct in 2012*. Available from: http://www.hellenicshippingnews.com/News.aspx?ElementId=6fdeeab4-9f65-408a-a1cd-a367f51308bc Piraeus, Hellas, Greece, Hellas Shipping News (25 Feb 2013)

Hürriyet (2013) *Energy dependence to grow in Turkey*. Available from: http://www.Hürriyetdailynews.com/energy-dependence-to-grow-in-turkey.aspx?pageID=238&nid=40585 Istanbul, Turkey, Hürriyet Daily News (11 June 2013)

IEA Bioenergy (2012) *Country report, Turkey*. 1st Task Meeting, triennium 2010 – 2012. Working Group Meeting - Biomass Combustion and Cofiring. 4-5 May, 2010, Lyon, France. Available from: http://www.ieabcc.nl/meetings/32_17_meeting_lyon_full_report.pdf International Energy Agency, Bioenergy Agreement, Task 32 (2012)

IEA Turkey (2013) *Oil and gas security 2013. Emergency response of IEA countries*. Turkey. Paris, France, International Energy Agency, 19 pp (2013)

Inan S, Dikbaş A, Ergintav S, Duygun F, Namık Yalçın M, Tirpan K, Yaşar K, Okandan E, Baysal M, Yürüm Y, Saatçılar R, Yilmaz M, Riza Toygar A, Kösebalaban A, Anaç S, Duran H, Onbaşi M, Ersoy M, Atasayar M, Ergüder I (2010) Coalbed gas potential in the Miocene Soma Basin (Western Turkey). *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 6 pp (2010)

Invest.gov.tr (2011) *Chinese firm in major mining-energy investments in Turkey*. Available from: http://www.invest.gov.tr/en-US/infocenter/news/Pages/290911-chinese-zhejiang-investment-mining-energy-turkey.aspx Ankara, Turkey, Invest.gov (29 Sept 2011)

Invest.gov.tr (2013a) *Turkey expands incentives for coal production*. Available from: http://www.invest.gov.tr/en-US/infocenter/news/Pages/310513-turkey-coal-production-incentives-expanded.aspx Ankara, Turkey, Invest.gov (31 May 2013)

Invest.gov.tr (2013b) *Turkish and Chinese companies ink USD 2.4 billion coal-based power plant deal*. Available from: http://www.invest.gov.tr/en-US/infocenter/news/Pages/150513-hattat-harbin-electric-coal-fired-plant-turkey.aspx Ankara, Turkey, Invest.gov (15 May 2013)

Invest.gov.tr (2013c) *French company GDF Suez announced plans to invest in coal-fired plants in Turkey*. Available from: http://www.invest.gov.tr/en-US/infocenter/news/Pages/290113-gdf-suez-investing-in-turkey-energy-plant.aspx Ankara, Turkey, Invest.gov (29 Jan 2013)

Invest.gov.tr (2013d) *Turkey-UAE sign USD 12 billion energy project*. Available from: http://www.invest.gov.tr/en-US/infocenter/news/Pages/040113-turkey-uae-ink-usd-12-billion-energy-deal.aspx Ankara, Turkey, Invest.gov (4 Jan 2013)

Isken (2013) *Sugozu Power Plant*. Available from: http://www.isken.com.tr/images/kataloglar/detailed_brochure.pdf Ankara, Turkey, Sugozu Enerji Santali, 4 pp (2013)

ISPAT (2013a) *Republic of Turkey Prime Ministry. Investment Support and Promotion Agency of Turkey. Turkish renewable energy market - investment opportunities and incentives*. Available from: http://corrente.gse.it/Lists/GSE%20Contenuti/Attachments/698/ISPAT_Avci.pdf Ankara, Turkey, ISPAT, Investment Support and Promotion Agency of Turkey, 10 pp (Jan 2013)

ISPAT (2013b) *Investment Support and Promotion Agency of Turkey. Turkish energy market investment opportunities and incentives*. Available from: http://www.torukotoushi.jp/docs/category5/category5_427b.pdf Ankara, Turkey, ISPAT, Investment Support and Promotion Agency of Turkey, 12 pp (March 2013)

ITOCHU (2011) *ITOCHU is awarded [contract] for coal fired power plant in Tufanbeyli*, Turkey. Available from: http://www.ITOCHU.co.jp/en/news/2011/110517.html (May 17, 2011)

Jain S, Hajicek D R, Gunderson J R, Henderson A K, Sollom S E, Stanislowski J J (2007) *Circulating fluidized-bed combustion and combustion testing of Turkish Tufanbeyli coal*. JV Task 108. Final Report. 2007-EERC-08-07, Grand Forks, North Dakota, USA, Energy & Environmental Research Center, University of North Dakota, 78 pp (Aug 2007)

Karataş H, Gül S (2011) *Gasification survey country: Turkey*. Available from: http://gasificationofbiomass.org/app/webroot/files/file/country_reports/Turkey.pdf Kocaeli, Turkey, TÜBİTAK - Marmara Research Center, 4 pp (25 Jan 2011)

Kaya D, Çanka Kiliç F (2012) Renewable energies and their subsidies in Turkey and some EU countries. Germany as a special example. *Journal of International Environmental Application & Science*; **7** (1): 114-127 (2012)

Kayahan U (2012) Bioenergy in Turkey. *IEA Bioenergy*; **24** (1); 8 pp (4 June 2012)

Kiliç O, Acarkan B, Selim A (2013) FGD investments as part of energy policy: A case study for Turkey. *Energy Policy*: **62**; Nov 2013; 1461-1469 (Nov 2013)

Kilkis B (2011) A lignite-geothermal hybrid power and hydrogen production plant for green cities and sustainable buildings. *International Journal of Energy Research*; **35** (2); 138-145 (Feb 2011)

Koca S, Ucar R, Koca H (2008) *Zero-waste recycling of coal combustion residues*. Available from: http://bildiri.anadolu.edu.tr/papers/bildirimakale/1382_b362k60.pdf Eskişehir, Turkey, Osmangazi University, Mining Engineering Department, 4 pp (2008)

Kok M V, Vural A (2012) The clean coal and carbon capture and storage technology of Turkey. *Energy Sources*, Part A, Recovery, utilization and environmental effects; **34 (6)**; 531-539 (2012)

Lally M, Cetinkaya A S (2011) *Spotlight on Turkey: U.S. business opportunities in renewable energy and energy efficiency into 2014*. Available from: http://export.gov/california/build/groups/public/@eg_us_ca/documents/webcontent/eg_us_ca_037146.pdf Ankara, Turkey, U.S. Embassy Commercial Service, 2 pp (2011)

Mertoglu O, Baki N, Kaya T (nd) *Exothermal application experiences in Turkey*. Available from: https://pangea.stanford.edu/ERE/pdf/IGAstandard/EGC/szeged/I-4-02.pdf California, USA, Stanford University, 8 pp (nd)

Mills S J (2013) *Combining renewable energy with coal*. CCC/223. London, UK, IEA Clean Coal Centre, 117 pp (Sep 2013)

Minchener A J (2013) *Challenges and opportunities for coal gasification in developing countries*. CCC/225. London, UK, IEA Clean Coal Centre, 76 pp (Oct 2013)

Mobbs P M (2010) *The mineral industry of Turkey*. 2010 MineralsYearbook. Available from: http://minerals.usgs.gov/minerals/pubs/country/2010/myb3-2010-tu.pdf Washington, DC, USA, U.S. Department of the Interior, U.S. Geological Survey, 14 pp (2010)

Natural Gas Europe (2013) *Turkey looks at CBM to assist in energy security*. Available from: http://www.naturalgaseurope.com/turkey-coal-bed-methane 1 pp (Feb 2013)

Neuhof F (2013) *Turkey's big thirst for new power*. Available from: http://cnpublications.net/2013/01/13/turkey-to-use-more-coal-energy/ New York, USA, CN Publications (14 Jan 2013)

Nicola S, Sulugiuc G (2013) *Turkey sees 'huge' clean-energy investment as demand bucks trend*. Available from: http://www.renewableenergyworld.com/rea/news/article/2013/02/turkey-sees-huge-clean-energy-investment-as-demand-bucks-trend Renewable Energy News, 1 pp (4 Feb 2013)

Orhan G (2012) Lack of evidence as evidence: The case of air pollution in Turkey. *The 2012 Berlin Conference on the Human Dimension of Global Environmental Change: Evidence for Sustainable Development*. Berlin, Germany, 5-6 Oct 2012, 16 pp (2012)

Olgun H (2008) TÜBİTAK MRC Energy Institute. Biomass/coal gasification and combustion activities and future projects. *Biogastech Workshop*, Gebze, Kocaeli, Turkey, 9-11 April 2008, 38pp (2008)

Outotec (2012) *Outotec to deliver a 90 MW biomass power plant in Turkey*. Press release. Available from: http://www.outotec.com/en/Media/News/2012/Outotec-to-deliver-a-90-MW-biomass-power-plant-in-Turkey/ Espoo, Finland, Outotec, 1 pp (16 Nov 2012)

Oxford Business Group (2012) *Turkey: Challenges in renewables*. Available from: http://www.oxfordbusinessgroup.com/economic_updates/turkey-challenges-renewables London, UK, Oxford Business Group, 2 pp (17 Dec 2012)

Ozbayoglu G (2013) Removal of hazardous air pollutants based on commercial coal preparation plant data. *Physicochemical Problems of Mineral Processing*; **49** (2); 621–629 (April 2013)

Ozturka M, Dincerb I (2013) Thermodynamic assessment of an integrated solar power tower and coal gasification system for multi-generation purposes. *Energy Conversion and Management*; **76**; 1061-1072 (Dec 2013)

Petrov P (2012) EC support to carbon capture and storage. Research perspective. CO_2 capture and storage. *Regional Awareness-Raising Workshop*, Ankara, Turkey, 13-14 June 2012, 19 pp (2012)

Platts (2013) *World Electric Power Plants Database*. Available on line via: http://www.platts.com/products/world-electric-power-plants-database New York, USA, Platts, McGraw Hill Financial (Oct 2013)

Ross K (2013) *Turkey poised for energy boom says minister*. Available from: http://www.powerengineeringint.com/articles/2013/06/turkey-poised-for-energy-boom-says-minister.html Tulsa, Oklahoma, USA, Power Engineering International (4 July 2013)

Sabah E, M. Çan F, Özgen S, Kocatepe A (2010a) Study to recover coal from Turkish lignite fine coal tailings: Comparison of Falcon Concentrator and Multi Gravity Separator (MGS). *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 6 pp (2010)

Sabah E, M. Çan F, Özgen S, Kocatepe A (2010b) Studies of a Multi Gravity Separator (MGS) to produce clean coal from Turkish lignite and hard coal fine tailings. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 5 pp (2010)

Sabah.com (2013) *Turkey's coal and lignite reserves on a rise.* Available from: http://english.sabah.com.tr/economy/2013/07/24/turkeys-coal-and-lignite-reserves-on-a-rise Istanbul, Turkey, Sabah.com (24 July 2013)

Sabri Oral M (2013) *Solid fuel imports of Turkey*. Available from: http://www.docstoc.com/docs/150548943/Slayt-1 22 pp (30 March 2013)

Saracoglua N (2010) The biomass potential of Turkey for energy production. Part I. *Energy Sources, Part B: Economics, Planning, and Policy*. DOI: 10.1080/15567240802532981N; **5** (3): 272-278 (2010)

Sari S (2013) *Current nuclear power situation in Turkey*. Technical Meeting on CNPP, Vienna, Austria, 18-21 March 2013. Available from: http://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-03-18-03-21-TM-NPE/22.sari.pdf Istanbul, Turkey, The Ministry of Energy & Natural Resources (MENR), 21pp (2013)

Scheffknecht G, Selçuk N (2003) Design of a 2 x 160 MWel CFB boiler utilizing high sulfur Turkish lignite. FBC2003-108. DOI: 10.1115/FBC2003-108. *17th International Conference on Fluidized Bed Combustion*, Jacksonville, Florida, USA, 18-21 May, 8 pp (2003)

Şengüler I (2001) Lignite and thermal power plants for sustainable development in Turkey. *World Energy Council 18th Congress*, Buenos Aires, Brazil, 10 pp (Oct 2001)

Şengüler I (2010) Lignite explorations in Turkey: New projects and new reserves. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 28 pp (2010)

Serpena U, Aksoyb N, Öngürc T (2010) Present status of geothermal energy in Turkey. SGP-TR-188. *35th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, California, USA, 1-3 Feb, 8 pp (2010)

Sinayuc C, Gumrah F (2008) Modelling of ECBM recovery from Amasra coalbed in Zonguldak Basin, Turkey. Document ID 2008-081 DOI. *Canadian International Petroleum Conference*, 17-19 June, Calgary, Alberta, Canada, 13 pp (2008)

Sokollu S (2013) *Turkey invests big in nuclear power*. Available from: http://www.dw.de/turkey-invests-big-in-nuclear-power/a-16824428 Bonn, Germany, Deutsche Welle, 1 pp (20 May 2013)

Tamzok N (2013) *On the brink of Change: Turkish coal industry*. Available from: http://enerjigunlugu.net/komurde-yapi-degisirken_5720.html Ankara, Turkey, Energy Diary, 3 pp (Nov 2013)

Tekindor G (2011) *Regulation on energy and large combustion plants in Turkey*. Available from: http://www.csb.gov.tr/db/necen/editordosya/file/NEC/Stakeholder_Workshop/Regulation_on_Energy_and_Large_Combustion_Plants_in_Turkey_EN.pdf Ankara, Turkey, Ministry of Environment and Urbanization, 16 pp (Sept 2011)

TKI Strategic Plan, 2010-2014 (2009) *Turkish Coal Enterprises*. Available from: http://www.tki.gov.tr/dosyalar/TK%C4%B0StrategicPlan2010-2014.pdf Ankara, Turkey, Ministry of Energy and Natural Resources, 147 pp (Dec 2009)

Toraman O Y, Topal H, Bayat O, Atimtay A T (2004) Emission characteristics of co-combustion of sewage sludge with olive cake and lignite coal in a circulating fluidized bed. *Journal of Environmental Science and Health*. Part A - Toxic/Hazardous Substances and Environmental Engineering; **39** (4); 973-986 (April 2004)

Turkish National Climate Change Action Plan, 2011-2023 (2012) *Republic of Turkey - Climate Change Action Plan 2011-2023*. Available from: http://iklim.cob.gov.tr/iklim/Files/IDEP/%C4%B0DEP_ENG.pdf Ankara, Turkey, Ministry of Environment and Urbanization, 149 pp (2012)

Turkyilmaz O (2013) Turkey energy outlook. *WEC regional meeting for Central and Eastern Europe*. WEC RMCEE. 18-21 March, 2013, Bucharest, Romania. Available from: http://www.cnr-cme.ro/evenimente/2013/WEC_CEE_Regional_Meeting_2013/Turkey%20Energy%20Outlook.pdf 49 pp (2013)

TURKSTAT (2013a) *Solid Fuels, I*. Quarter. No: 13541. Available from: http://www.turkstat.gov.tr/PreHaberBultenleri.do?id=13541 Ankara, Turkey, Turkish Statistical Institute (5 July 2013)

TURKSTAT (2013b) *Solid Fuels, I*. Quarter. No: 13601. Available from: http://www.turkstat.gov.tr/PreHaberBultenleri.do?id=13601 Ankara, Turkey, Turkish Statistical Institute (4 Oct 2013)

TURKSTAT (2013c) *National greenhouse gas inventory report 1990-2011. Annual Report submission under the Framework Convention on Climate Change*. Available from: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php Ankara, Turkey, Turkish Statistical Institute, 132 pp (2013)

UNFCC (2013) *2013 Annex 1 Party GHG Inventory Submission*. *v1.1 Turkey*. Available from: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php Bonn, Germany, UNFCCC Secretariat (12 April 2013)

Urkan M K, Arikol M (nd) *Burning times of volatiles from Turkish coals during fluidized bed combustion*. Fuel DOI: 10.1016/0016-2361(94) 90022-1.TÜBİTAK. Available from: http://www.researchgate.net/publication/222027267_Burning_times_of_volatiles_from_Turkish_coals_during_fluidized_bed_combustion Kocaeli, Turkey, TÜBİTAK, Marmara Research Institute, 6 pp (nd)

WEC (2010) *Survey of Energy Resources 2010*. World Energy Council, London, UK, 618 pp (Nov 2010)

World Bank (2013) *Wind, water, and steam – a triple win for Turkey's energy sector*. Available from: http://www.worldbank.org/en/news/feature/2013/05/30/wind-water-steam-a-triple-win-for-turkey-energy-sector Washington DC, USA, World Bank Group, 2 pp (30 May 2013)

World Nuclear (2013) *Nuclear Power in Turkey*. Available from: http://world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/#.UcGkVUZwaM8 London, UK, World Nuclear Association, 2 pp (June 2013)

Yalcin M, Sedat I, Gülbin G, Ulrich S, Rainer G (2002) Carboniferous coals of the Zonguldak basin (northwest Turkey): Implications for coalbed methane potential. *AAPG bulletin*; **86** (7); 1305-1328 (2002)

Yang A, Cui Y (2012) *Global coal risk assessment: Data analysis and market research*. WRI Working Paper. Available from: http://pdf.wri.org/global_coal_risk_assessment.pdf Washington DC, USA, World Resources Institute, 76 pp (Nov 2012)

Yildirim A, Dogan S (2010) Underground coal gasification and applicability to Thrace Basin lignite in Turkey. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 7 pp (2010)

Yilmaz Ö (2006) *Hazardous waste inventory of Turkey*. Available from: http://etd.lib.metu.edu.tr/upload/12607041/index.pdf Ankara, Turkey, Middle East Technical University, 311 pp (Jan 2006)

Yilmazoğlu M Z, Ali Durmaz A (2013) Hot windbox repowering of coal-fired thermal power plants. *Turkish Journal of Engineering and Environmental Sciences*; **37** (2013); 33-41 (2013)

Yürek S, Het K (2010) Studies on gasification of Turkish lignite via underground coal gasification. *27th Annual International Pittsburgh Coal Conference*, Istanbul, Turkey, 11-14 Oct 2010, 2 pp (2010)

Zeki Yilmazoglu M, Calisir T, Amirabedin E (2013) Direct and indirect cocombustion of lignite and biomass. *6th PSU-UNS International Conference on Engineering and Technology* (ICET-2013), Novi Sad, Serbia, 15-17 May 2013, 5 pp (2013)

Ziypak M (2011) Development of gasification and activities in Turkish Coal Enterprises *28th Annual International Pittsburgh Coal Conference*, Pittsburgh, Pennsylvania, USA, 12-15 Sept 2011, 58 pp (2011)