CHAPTER 6

Power Generation from Coal, Oil, Gas, and Biofuels

Arash Farnoosh

1 Introduction

This chapter provides an introduction to the economics of electricity generation based on four different energy sources: coal, oil, natural gas, and biofuel. It covers the various technologies of power production and their key economics characteristics including CAPEX, OPEX, dispatchability, flexibility, location, and expected service life. The formula and calculations are provided for further analysis of power generation projects in view of optimizing the choice of technology. Some conclusions are drawn from comparative analysis of coal-, oil-, gas-, and biofuel-fired power generation units.

Thermal power has always accounted for a large proportion of the world's power generation. It has been above 60% since the 1990s. Since 1875, when the world's first thermal power plant was built at the *Gare du Nord* station in Paris, which supplied the lighting nearby, the world's power industry has gradually evolved toward better performances and larger capacities.

Currently, the world's largest coal-fired power plant by installed capacity is the Toketo power plant in China, the largest gas-fired power plant is Russia's Surgut plant, and finally, the largest oil-fired power plant is Saudi Arabia's Shoaiba power station (Table 6.1).

Coal, oil, and natural gas have always been the main energy sources to produce electricity (Fig. 6.1). Although with the increase of environmental

A. Farnoosh (✉)
IFPEN, IFP School, Paris, France

SciencesPo—Paris School of International Affairs, Paris, France
e-mail: arash.farnoosh@ifpen.fr

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Table 6.1 The world's top 10 thermal power plants

Power station	*Fuel*	*Installed capacity (MW)*
Toketo, Inner Mongolia, China	Coal	6720
Taian power station, South Korea	Coal	6100
Tanjin power station, South Korea	Coal	6000
Taichung power station, China	Coal	5700
Shoaiba, Saudi Arabia	Oil	5600
Surgut-2 power station, Russia	Natural Gas	5597
Belchiatov, Poland	Coal	5300
Jebel Ali Power and Desalination Plant, UAE	Natural Gas	5163
Higashi-Niigata power station, Japan	Natural Gas	5149
Jiaxing power plant, China	Coal	5120

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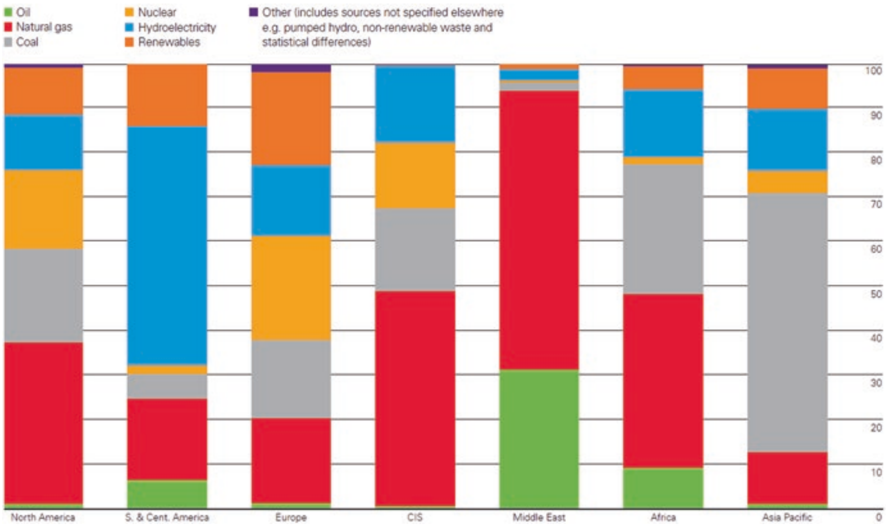

Fig. 6.1 Regional electricity generation by fuel (in percentage) in 2019. BP Statistical Review of World Energy 2020

protection awareness, renewable energy has gradually come into play, the position of fossil energy sources in producing electricity is still unshakable.

Coal accounts for around 40% of electricity production globally, making it the most important power generation fuel in the world, and is a major source of carbon dioxide emissions. It has achieved its pre-eminence because it is cheap and widely available. Coal has been used as a source of energy for over 4000 years, but electricity production from coal only began at the end of the nineteenth century. Initially, it was based on steam engines, but with the development of the steam turbine, coal became the major means of electricity generation during the twentieth century. Many nations have built their prosperity based on coal. The largest users of domestic coal for power generation are China, the United States, and India.

Currently, natural gas power accounts for 23.23% of total electricity generation and is forecasted to grow constantly. Due to the growth of global carbon emissions and the intensification of greenhouse effects around the world, several countries are actively taking measures to abate emissions. These have frequently used natural gas to replace coal, as its associated carbon dioxide emissions are 54% of those originating from coal-fired plants on average.

In a gas-fired power station, air goes through a compressor, is mixed with natural gas in the combustion chamber, and burned. The hot combustion gases expand, driving the gas turbines and turning the generators to produce electricity. The waste gases are emitted to the atmosphere through the stack but can also be recycled in a steam generation unit so as to run a steam turbine in parallel. (This is called a combined cycle gas turbine plant, or CCGT.)

Oil can be used for power generation in a plant very similar to a natural gas one.

Whether it is coal, natural gas, oil, or biomass energy, they all have a common feature, that is, they turn the turbine through combustion so that thermal energy can be converted into mechanical energy and then further converted into electric energy, thus realizing the transition from primary to secondary energy. Natural gas can be recycled through air cycling and condensation.

From the environmental protection point of view, natural gas and biomass are cleaner than coal concerning CO_2 emission. However, from the perspective of the total cost of electricity produced, a coal plant is the cheapest, and a gas-fired plant comes just after, because gas is more expensive to produce, transport, and store, even though it is the most efficient among all other types of power plants.

In the following, we discuss the power generation process of these different types of power plants in details.

2 Alternative Electricity Generation Options

2.1 Coal Power Plants

2.1.1 The History of Coal-Fired Power Generation

The use of coal for power generation began in the United States in the 1880s, based on the same technology that was then used to create mechanical power from the steam engine. Coal was burned to raise steam and the steam used to drive an engine, which in turn drove a dynamo or alternator, which produced electricity. The first fully commercial electric power station was the Pearl Street station in New York, which was built by Thomas Edison and started operating in 1882. The Pearl Street plant used a Porter Allen reciprocating steam engine and dynamo to produce a direct current, which supplied power only for lighting.

The next major advancement was the steam turbine, which was invented by Charles Parsons in 1884. Steam turbines allowed more efficient energy conversion and higher outputs. During the twentieth century, coal-fired power stations using steam turbines became the most important source of electricity across the globe. They remain the single most important source of electricity in the second decade of the twenty-first century.

2.1.2 Global Coal-Fired Electricity Generation

World coal production increased in 2018 by 250 Mt., an increase of 3.3%, driven by increases in steam and coking coal production.

Global coal production increased by 4.3% in 2018, significantly above the 10-year average of 1.3% (Fig. 6.2). Production growth was concentrated in Asia Pacific (163 Mtoe) with China accounting for half of global growth and Indonesian production up by 51 Mtoe. China has been the world's leading coal producer since 1985 and retained the top spot in 2018, producing 3550 Mt. of coal in total, 4.5% higher than in 2017. Production in the United States decreased by 2.5% in 2018, continuing the long-term trend that has seen it fall by more than one-third since 2008.

Coal consumption increased by 1.4% in 2018, the fastest growth since 2013. Growth was again driven by Asia Pacific (71 Mtoe), and particularly by India (36 Mtoe). This region now accounts for over three-quarters of global consumption, while 10 years ago it represented two-thirds.

At a global level, coal still accounts for 38% of power generation, the same share as two decades ago. Coal continues to be primarily used, at 66.5%, for electricity production and commercial heat. However, in OECD countries, the share of electricity and heat produced from primary coal as a fuel fell to 25.2% in 2018, down from 44.4% in 1985.

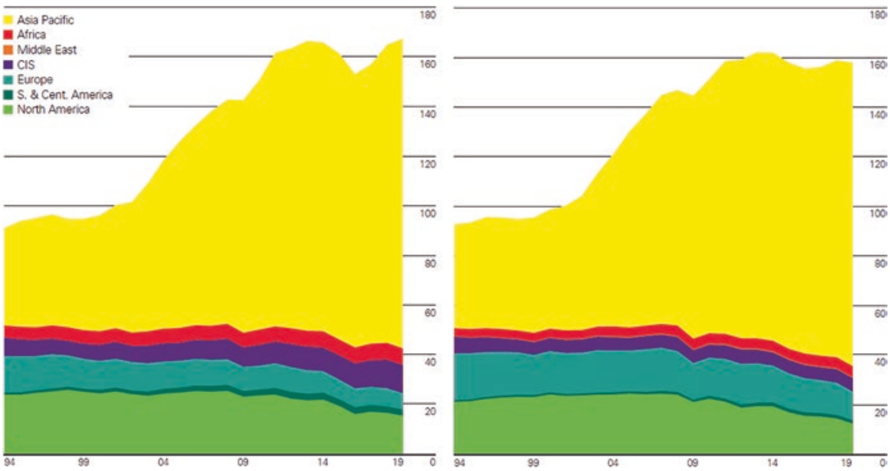

Fig. 6.2 Coal: Production (left) and Consumption (right) by region (Million tonnes oil equivalent). BP Statistical Review of World Energy 2020

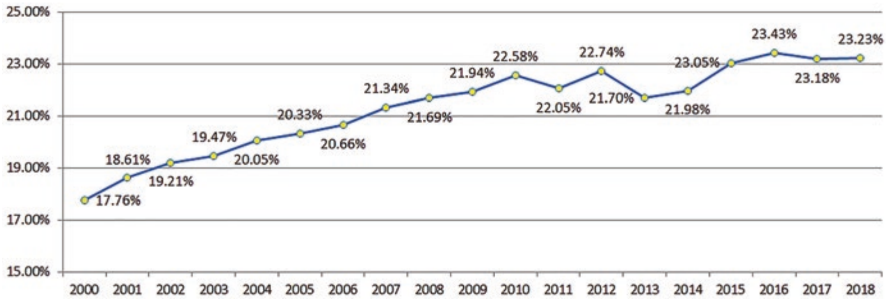

Fig. 6.3 The share of natural gas power generation in global total electricity generation. BP Statistical Review of World Energy 2020

2.2 Global Gas Power Generation

2.2.1 Status Quo

It can be seen from the line chart (Fig. 6.3) that the share of natural gas compared to other power generation sources globally has shown a gradual upward trend in the past two decades. Due to the growth of carbon emissions and intensification of the greenhouse effect around the world, several countries have used natural gas to replace coal.

The shale gas revolution in the United States has led to a sharp increase in natural gas supply and drop in prices, thus significantly reducing the cost of natural gas; this, coupled with the fact that natural gas power plants are easier and lower cost to build than coal-fired power plants and have less pollution emissions, resulted in a sharp increase in the proportion of natural gas power generation. In 2019, the United States gas power generation accounted for 27% of the world's total generation from gas, and for 6% of world's total power generation.

Russia is also rich in natural gas resources and suitable for gas power generation but ranks second in the world. Ranked third, Japan uses imported liquefied natural gas to boost its gas power generation, which itself has stimulated the development of the global LNG industry. However, Japan has the largest number of gas-fired power stations, which began using imported liquefied natural gas to generate electricity as early as the 1970s. Seven of the world's top 10 gas power stations are situated in Japan.

There are great differences in the share of natural gas power generation in the energy mix in different regions of the world (Table 6.2). The share of natural gas in power generation is the highest in the Middle East (around 63%) followed by the CIS countries (mainly Russia and Ukraine). Due to the great differences in oil and natural gas reserves among different countries, the proportion of natural gas power generation in each country is also quite different (Table 6.3). In 2019, natural gas power generation accounted for 3%

Table 6.2 Share of natural gas power generation in total power generation in the world in 2019

	North America	*S. & Cent. America*	*Europe*	*CIS*	*Middle East*	*Africa*	*Asia Pacific*
Total power generation (terawatt-hours)	5426	1329	3993	1431	1264	870	12,691
Gas power generation (terawatt-hours)	1976	245	768	693	793	340	1483
Percentage	36%	18%	18%	48%	63%	40%	12%

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Table 6.3 Share of natural gas power generation in the total power generation in 2019 (in selected countries)

	US	*Canada*	*Germany*	*UK*	*Russia*	*Iran*	*South Africa*	*China*	*Japan*	*India*
Total power generation (terawatt-hours)	4401	660	612	324	1118	319	253	7503	1037	1559
Gas power generation (terawatt-hours)	1701	69	91	133	520	200	2	236	362	71
Percentage	38%	10%	15%	40%	47%	63%	1%	3%	35%	5%

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of China's domestic electricity generation, compared with 38%, 47%, and 35% in the United States, Russia, and Japan, respectively.

This is also related to domestic resources and energy policies. For example, in countries such as Turkmenistan, Qatar, and Malaysia, natural gas production is quite high, while coal and water resources are limited, and natural gas power generation accounts for more than 70% of total electricity production. Countries such as Argentina and the Netherlands, despite their high natural gas production, have other sources of electricity, and around 50% of their electricity is produced by gas. Countries with 20% to 40% of power production from gas are the United Kingdom, Japan, and Italy, while countries such as South Korea and Hungary account for 10% to 20%.

2.2.2 Future Plans

The trend of global natural gas power generation in the future may depend on the policy adjustment of countries to deal with global climate change and the flexibility of natural gas power generation required by the instability of new renewable sources (wind and solar), but the price of natural gas is high and discourages its larger application to power generation.

On the whole, natural gas power generation has many advantages, such as energy saving and emission reduction, improving power supply security, cutting peaks and filling valleys of power and gas supply, and promoting the development of a circular economy, which is an irreversible trend in the field of modern energy. With the growth of global power consumption in the future, the absolute amount of natural gas consumption for power generation is bound to grow further. Although the growth rate has slowed, it will still account for the largest share of added power generation capacity in the world in the next decade or so.

According to multiple scenarios, the overall rise in global electricity demand drives the rise in natural gas demand; notwithstanding the fact that the proportion of natural gas in the power industry is likely relatively flat at about 20%.

2.3 Biofuel-Based Power Generation

2.3.1 Current Situation

Biomass, which is a renewable energy source that has the potential of being CO_2 neutral, is normally used for power generation in association with other fuels in so-called co-firing systems.

There are several successful co-firing projects in many parts of the world, particularly in Europe and North America. However, despite their remarkable commercial success in Europe, most of the biomass co-firing in North America is limited to demonstration levels.

Biofuels can be divided into four categories. First-generation biofuels can be produced from rapeseed, grains, potatoes, sugar beets, and canes. These biofuels are made from oil-based plants, starch crops, and sugar. The fuel industry has to compete with the nutrition and fodder industries for these products. On the other hand, the production of second-generation biofuel is essential for limiting food versus fuel competition by using non-edible oil feedstock such as agricultural waste and residues. Second-generation biofuels are produced from non-nutrition products, mainly from straw, miscanthus, sedges, and energetic plantations, mostly from agriculture and forestry residues. The third-generation biofuels derived from oleaginous microorganisms have also gained attraction recently as the potential feedstock in generating fuel for energy production. They do not compete with food crops on arable land. Algae can be cultivated in wastewater and other residual water. Finally, fourth-generation biofuels are produced from genetically modified (GM) algae to enhance biofuel production. Although GM algae biofuel is a well-known alternative to fossil fuels, the potential environmental and health-related risks are still of great concern.

2.3.2 Process and Technology Status

Co-firing is regarded as the most attractive short-term option for power generation from biomass. It is defined as the blending and simultaneous combustion of biomass with other fuels, such as coal or natural gas, to raise steam and generate electricity. Biomass co-firing in coal power plants is by far more widespread and extensively proven than in gas-fired plants. Co-firing can play an important role in increasing the share of biomass and renewable sources in the global energy mix and reducing greenhouse gas (GHG) emissions. It also creates opportunities in industries like forestry, agriculture, construction, manufacturing, food processing, and transportation to better manage large quantities of agricultural and wood waste. The cost of adapting an existing coal power plant to co-fire biomass is significantly lower than the cost of building new systems relying only on biomass. Although a biomass dedicated plant offers significant environmental benefits, relying solely on biomass is risky due to unpredictable feedstock supply. Other constraints of generating power solely from biomass are the low heating values and the fuel's low bulk densities, which create the need to transport large volumes of biomass.

Co-firing includes three major technologies: direct, indirect, and parallel. The approaches differ in terms of the boiler system design as well as the percentage of biomass to be co-fired.

Direct co-firing is the simplest, cheapest, and commonest option. Biomass can either be milled jointly with the coal (i.e. typically less than 5% in terms of energy content) or pre-milled and then fed separately into the same boiler. Common or separate burners can be used, with the second option enabling more flexibility with regard to biomass type and quantity. Figure 6.4 shows that in direct co-firing technology, biomass is fed directly into the furnace after being milled either together with the base fuel or separately.

Indirect co-firing is a less common process in which a gasifier converts the solid biomass into a fuel gas that is then burned with coal in the same boiler. Though more expensive because of the additional technical equipment (i.e. the gasifier), this option allows for a greater variety and higher percentages of biomass to be used. Gas cleaning and filtering is needed to remove impurities before burning, and the ashes of the two fuels remain separate.

Finally, parallel co-firing requires a separate biomass-fired boiler that supplies steam to the same steam cycle. This method allows for high biomass percentages and is frequently used in pulp and paper industrial facilities to make use of by-products from paper production, such as bark and waste wood. In parallel, biomass co-firing technology, as shown in Fig. 6.5, biomass

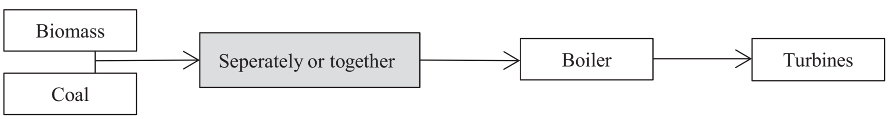

Fig. 6.4 Direct biomass co-firing technologies

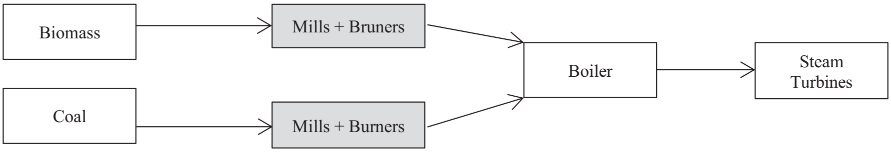

Fig. 6.5 Parallel biomass co-firing technologies

pre-processing, feeding, and combustion activities are carried out in separate biomass burners. Parallel co-firing involves the installation of a completely separate external biomass-fired boiler in order to produce steam used to generate electricity in the power plant.

2.4 Oil-Fired Power Stations

2.4.1 Role at Present

Similar to natural gas, oil is burned at power plants to create heat, which is then used to raise steam and turn turbines and create electricity. There are three kinds of oil products mostly used as power plant fuel: crude oil, diesel oil, and heavy fuel oil.

Crude oil is extracted directly from the oil well in the purest condition. It forms the basis of all petroleum products, and it has more than 500 components. According to its sulfur content, crude oil can be "sweet" (low sulfur content) or "sour" (high sulfur content).

Diesel oil is a blend of different middle distillates derived from the crude oil refining process. It is usually composed of light and heavy gas oil, light and heavy cycle oil, as well as vacuum gas oil.

Heavy fuel oil (HFO), also known as "residual fuel oil", is based on the high viscosity, tar-like mass, which remains after the distillation and subsequent cracking of crude oil in the refining process. As a residual product, HFO is relatively inexpensive—it typically costs 30% less than distillate fuels and less than crude oil.

Oil-fired power plants commonly emit nitrous and sulfur oxides, methane, mercury compounds, and significant amounts of carbon dioxide. Similar to gas-fired and coal-fired plants, oil-fired plants require large quantities of water for the production of steam and for cooling. The use of oil at power plants also results in residues called sludge that are not completely burned and therefore require disposal in landfills.

Roughly, 70% of oil-fired electric generating capacity that still exists today was constructed prior to 1980. Utility-scale generators that reported petroleum as their primary fuel comprised only 3% of total electric generating capacity at the end of 2018 and produced less than 1% of total electricity generation.

Power plants that burn petroleum liquids (such as distillate or residual fuel oils) are generally used for short periods during peak electricity demand. Otherwise, oil-fired power plants operate mostly at low capacity factors because of the high price of petroleum relative to other fuels, air pollution restrictions, and lower efficiencies of their aging generating technology. Most oil-fired generators are either turbines or internal combustion engines used to supply power only at peak electric power demand or when natural gas prices rise due to local natural gas demand.

2.4.2 Oil-Fired Plants in Different Countries

In the United States, more than 68% of the 36.4 GW of domestic oil-fired generating capacity is located in 10 states, primarily in coastal states with access to marine ports. When these plants were built around the 1970s, coal-fired generators were the main sources of electricity. However, coastal states (e.g. Florida) are relatively far from coal production areas. Since coal is primarily transported by rail, the cost of long-haul coal transport may not be competitive in these areas compared with oil delivered by marine modes. A fundamental shift in the perception of oil as a utility fuel occurred not only in the United States but in the whole world during the 1970s, when world oil markets experienced sharp price increases. Supply shortages during the main oil shocks (Arab Oil Embargo, the Iranian Revolution, and the Iran-Iraq war) also discouraged oil-fired electricity generating capacity additions globally.

However, in Saudi Arabia, the Shoaiba oil-fired power facility, located on the Red Sea coast, is the largest oil-fired power plant and second largest thermal power plant in the world. The Shoaiba project is a distinctive Saudi Arabian one. As a matter of fact, currently, very few countries are building oil-fired power plants, in part because of environmental concerns as oil burning is a significant contributor to greenhouse gas emissions. They are also unpopular because of price and supply uncertainty, which is not at all the case of Saudi Arabia, with huge domestic oil supplies.

Iran, possessing significant fossil fuel resources, has also consequently invested in utilization of thermal systems for electricity generation. Almost 90% of the required electric energy is produced via thermal power plants. Natural gas (66%) is the largest source of fuel for electricity generation (which is also the case in most other Persian Gulf countries) followed by heavy oil (17.4%) and gas oil (6.6%) (Table 6.4).

Last but not the least, Japan is also among the large users of oil-fired power plants mainly due to its geographical situation. For example, the Kashima Power Station located on Japanese coast, about 50 miles north-east of Tokyo, is the world's second largest oil-fired (and gas-fired) thermal power station with 5204 MW of installed capacity.

Table 6.4 The world's largest oil-fired power plants

No.	*Power station name*	*Countries*	*Installed capacity (MW)*	*Fuel*	*The company of affiliation*
1.	Shoaiba oil-fired CCGT power plant	Saudi Arabia	5600	Crude oil	Saudi Electricity Company
2.	Kashima Power Station	Japan	4400	Fuel oil, natural gas	Tokyo Electric Power Company
3.	Anegasaki Power Station	Japan	3600	Crude oil, fuel oil, natural gas	Tokyo Electric Power Company
4.	Hirono Power Station	Japan	3200	Crude oil, fuel oil, coal	Tokyo Electric Power Company
5.	Yokosuka Thermal Power Station	Japan	2276	Light oil, natural gas	Tokyo Electric Power Company

http://dy.163.com/v2/article/detail/EEM9SO3F05484WS6.html

Source: https://www.power-technology.com/features/feature-giga-projects-the-worlds-biggest-thermal-power-plants/

3 Economic Characteristics

3.1 Economic Analysis

3.1.1 Fixed and Variable Costs

The fixed costs of an electricity plant project consist of capital expenditure (CAPEX) and fixed operating and maintenance cost (OPEX).

1. **CAPEX**

Capital expenditure occurs during the construction phase of the project before its commissioning and is expressed in monetary units (Euro, US dollar, or whatever currency is selected) per kW of installed or nominal capacity. Capital expenditure must be broken down by its components based on various technical life durations and equity investors (e.g. utility company, private equity holder, consumer…).

CAPEX varies for different projects and technologies. As it can be seen in Table 6.5, capital expenditures for coal and biofuels plants are far greater than those for other traditional fossil fuel power plants, and among all technologies, natural gas power generation is the most competitive.

2. **OPEX**

Operating expenses (OPEX) are cash expenditure that occur every year and may be either fixed (if independent of production) or variable (if linked to production). They are expressed in monetary unit per annum and per kW of installed or nominal capacity for fixed OPEX and per kWh of produced power for variable OPEX.

Table 6.5 Range of CAPEX for mid-scale generation projects

		Coal	*Natural gas*	*Biomass combustion electricity plant*	*Biogas digester and electricity generator*	*Diesel generator*
CAPEX ($/kW)	Min	3600	900	2500	3000	1000
	Max	5000	1300	4500	6500	1300

Source: Sustainable Energy Handbook, simplified financial models module 6.1, 2016

Table 6.6 Range of OPEX for mid-scale projects

		Coal	*Natural gas*	*Biomass*	*Biogas*	*Diesel*
Fixed OPEX(% of CAPEX)	Min	1.0%	0.5%	4.0%	5.0%	2.0%
	Max	1.5%	1.6%	6.0%	8.0%	4.0%
Variable non-fuel OPEX ($/kWh)	Min	–	–	0.002	0.020	0.014
	Max	–	–	0.004	0.030	0.028
Variable fuel OPEX ($/kWh)	Min	0.004	0.002	0.005	0.014	0.300
	Max	0.007	0.006	0.022	0.058	0.500

Source: Sustainable Energy Handbook, simplified financial models module 6.1, 2016

It is clear in Table 6.6 that both fixed and variable OPEX is higher for a biofuels plant than for a fossil fuel plant, and again natural gas plant is most advantageous. Part of the OPEX cost is variable (per kWh of output) as it is linked to the consumption of basic commodities such as cooling water, chemicals, lubricants, replacement of wearing parts and of course fossil fuel. Due to fixed operating cost, if the plant's output is lower than expected, the project owner/operator is exposed to the risk of a higher average cost per kWh; the latter may exceed the revenue from the power purchase agreement that is usually strictly proportional to the kWh output. For a new project, the OPEX is the full operational cost of the project. For a rehabilitation/strengthening or an expansion/extension project, the OPEX is the marginal operational cost incurred by the project.

3. **Total Cost**

The total cost of production of an installed technology (€/MWh) includes fixed and variable costs:

$$C_{total} = \frac{C_f}{\eta} + [\frac{P_{CO2}}{\eta} * \frac{1}{E}] + VCOM + \frac{FCOM}{U} + \frac{aI}{U.}$$

where
C_f is the fuel cost given in €/MWh,
η is the total thermal efficiency,[1]

[1] Efficiency of thermal power plants are different for various technologies and could be also different within the same technology as it depends on the design and engineering of the thermal

P_{CO2} is the emitted CO_2 price in €/t, in jurisdictions where a carbon tax or emission trading system is in force,

1/E is the emission factor of the considered fuel in t/MWh,

VCOM is the variable cost of operation and maintenance in €/MWh

and *FCOM* is the fixed part,

a is the annuity corresponding to the *i* (interest rate), and *I* is the unit investment cost in €/MW,

U is the utilization ratio in hours/year.

We understand easily from the formula that the total cost of a power unit with heavy investment cost is much more sensitive to the utilization time compared to that of a unit with lower initial investment cost, even if the latter's fuel cost is more expensive.

It is the same for the sensitivity to the interest rate *i,* or the number of years over which the power unit is amortized.

3.1.2 Life Duration and Revenue

For some technologies, capital expenditure (CAPEX) may be a recurrent expense as reinvestment has to be factored periodically (e.g. every 5 or 10 years), in order to replace specific components that have a shorter life than the useful life of the project. This is the reason why CAPEX is broken down by components with shorter technical life duration than the economic life of the project. It may also be useful to separate components that receive a performance guarantee from the manufacturer for a shorter period than the economic lifetime of the project. In this latter case, it is assumed that the component must be replaced at the extinction of the guarantee period.

The revenue generated by the project is calculated on an annual basis and starts at the commercial commissioning of the project. This revenue will offset the project costs and is usually calculated as a physical quantity of energy generated by the project (or off-taken by a paying consumer) multiplied by a unit price.

3.1.3 Basic Economic Indicators

1. Pay-Back Period

The pay-back period calculates how many years are necessary to cover the CAPEX with the net annual revenue that consists of the annual income minus the annual OPEX charges. The economic sustainability of a project is subject to the pay-back period being shorter than the project economic life.

units. On average, it is between 40% and 44% for coal plants, 20% to 25% for biofuel/gas plants, 35% to 40% for single gas turbines (oil or gas-fired), and from 55% up to even 63% for combined cycles which are the most efficient thermal power plants. (IEA 2018).

2. Internal Rate of Return

The internal rate of return calculates the interest rate that makes equal to zero the net present value of all cash flows, both negative (costs) and positive (revenue), over the period of revenue certainty.

$$\sum_{t=1}^{n} \frac{(R_t - C_t)}{(1+i)^t} = I_0$$

where R_t is the revenue in year t; C_t is the total cost in year t; i equals to internal rate of return, and I_0 is the initial investment (or overnight cost in the electricity jargon).

In the first year, the cash flow consists of the CAPEX and is negative. From the second year until the end of the time series, the cash flow consists of the revenue minus the OPEX (minus the reinvestment cost if applicable). To be financially viable, the investment should have an internal rate of return exceeding the weighted average cost of capital (WACC).

3. Net Present Value (NPV)

The last, but absolutely not the least, criteria is the Net Present Value (NPV) of the project over its economic lifetime. The cash flow schedule is the same as for the calculation of the internal rate of return from second year onward.

$$NPV = \sum_{t=1}^{n} \frac{(R_t - C_t)}{(1+i)^t} - I_0$$

where R_t, revenue in year t; C_t, costs in year t; i, discount rate; I_0, initial investment. For the project to be economically viable, the NPV must be positive.

3.2 Financial Analysis

The total amount to be financed includes the capital investment cost as described in the economic analysis section plus the specific financing cost that occurs during the construction period, which is called interest during construction (IDC). During the construction period, the project cannot reimburse financial charges from revenue. Therefore, this cost has to be factored in the project cost used to calculate the funding requirements.

There are three types of sources for funding: equity, loans, and in some cases grants. Equity is the money committed by the owners of the project from their own sources or through an equity partner. Loans are funds committed by banks against a predetermined repayment schedule. Grants are funds provided by a donor with no obligation of repayment (assuming that such a donor is available).

1. Weighted Average Cost of Capital (WACC)

The Weighted Average Cost of Capital (WACC) is the equivalent discount rate applicable to the project cost that will be sufficient to repay the loans and generate the expected return on equity. The WACC is calculated over the loan duration as follows:

$$\text{Share of loan} \times \text{loan interest rate} + \text{share of equity} \times \text{duration of loan} \times \text{expected return on equity} + \text{share of grant} \times 0$$

In the above formula, the higher is the share of grant, the lower will be the WACC (as a result of a lower share of loan + equity).

2. Levelized Cost of Electricity (LCOE)

The Levelized Cost of Electricity (LCOE) is calculated by adding the annuitized capital cost to the annual operating expense, and dividing by the quantity of electricity generated. The LCOE should be inferior to the electricity price—otherwise, the project will generate a loss.

$$PV\ of\ Total\ Costs = \sum_n \frac{total\ capex\ and\ opex\ costs}{(1+i)^n}$$

$$PV\ of\ Electricity\ Generation = \sum_n \frac{total\ net\ electricity\ generation}{(1+i)^n}$$

$$LCOE = \frac{PV\ of\ Total\ Costs}{PV\ of\ Electricity\ Generation}$$

where i is the discount rate and n the lifetime of the power plant.

3.3 Dispatchability and Flexibility

There are two main types of power station in the world: base-load generator units and peaking stations. Base-load generators (the majority of coal power plants) are useful where there is a steady demand and a stable source of fuel, such as coal or gas, to power the generators. Electricity peaking stations (Table 6.5), also called peak-lopping plants, are power plants designed to help balancing the fluctuating power requirements of the electricity grid. Peaking stations typically operate in standby mode, and when there is a peak in demand for power from the electricity grid, they receive a signal to commence operation. Due to their flexibility and robustness, they are able to provide a rapid response to fluctuating demand. They are then turned off as demand declines.

For example, oil-fired generators tend to be used to meet electricity demand during peak hours, and they generally have lower capacity factors and higher heat rates than most other types of power plants. They are installed in places where there is no easy access to alternative power sources and are mainly used as backup for uninterrupted power supply whenever there are outages. Moreover, these plants require only a small area to be installed and offer higher thermal efficiency compared to coal-fired power plants.

In general, liquid fuel power plants have great dispatchability to supply electricity to the grid within seconds and can reach full capacity in minutes. Additionally, they have tremendous fuel flexibility, with the possibility of running with heavy fuel oil, light fuel oil, crude oil, emulsified fuels, or liquid biofuel. Some oil-fired power plants are capable of switching between fuels, potentially complicating the calculation of capacity factors. For instance, plants that normally burn natural gas may choose to burn oil (or oil products) during times of high natural gas demand.

Natural gas power stations are also very flexible and their ramping time (from zero to full capacity) is short. The operation of single cycle mode, in which only one gas turbine is running, takes only about 10 minutes from start-up to full load and the combined cycle (running simultaneously both gas and steam turbines) takes 40–50 minutes. A natural gas power plant has good regulation performance and can operate in the range of 25% to 100% output without any problem. For example, a GE HA class gas combined cycle plant with an installed capacity of 570 megawatts can start in less than 30 minutes and increase or reduce the load at a rate of 60 megawatts per minute. Under some load conditions, provided that the load is at least 200 MW, it can still meet the emissions standard and stabilize the power supply and can also form a reliable backup with intermittent sources (e.g. wind & solar) to promote the rapid growth of renewable energy. Besides, it can operate as flexibly as a liquid fuel power plant. It is also available in multi-fuel versions. When the gas supply is uncertain, or prices are volatile, it is possible to switch from gas to liquid fuel, and vice versa, even during operation.

It is worth to mention that at present, gas power generation has some unique advantages compared to all other source of electricity. An example is the world's first battery-gas turbine hybrid power generation system deployed by GE and Southern California Edison. It integrates a 10-megawatt lithium-ion battery energy storage system and a LM6000 aviation gas turbine, as well as the corresponding control system, allowing the gas turbine to be in rotating standby mode without using fuel and responding immediately to changing power dispatching requirements. When peak shaving is not needed, the gas turbine is in a rotating standby state (connected to the battery), and when the peak shaving is required, the gas turbine is immediately awakened from the rotating standby state through the advanced control system, and the gas turbine is quickly started with load, and the power is immediately transmitted to the power grid.

3.4 Location

Coal power generation location is more restrictive compared to other technologies because coal is a solid and its transport cost is high, while its combustion efficiency is lower than for other technologies. Usually coal plants are located near coal mines and the choice of different means of transport will affect the location of the plant area as well as the size and form of the required land plot, especially for a large power plant. The transportation mode should allow for large volume, low freight, high speed, and flexibility, which will make the location of coal plant all the more difficult.

On the contrary, oil is easy to transport with multiple transportation options including by pipeline and by ship; therefore, oil-fired plants are usually located in coastal areas. A gas-fired power plant is characterized by little land occupation and is very suitable for countries and areas with dense population and scarce land resources. Compared with coal-fired power plants, gas power generation equipment is more compact and does not occupy a large area. Besides, it consumes one-third of the water needed for a coal-fired power plant.

3.5 Expected Service Life

Thermal power plants are designed for an economic lifetime of 30 to 40 years, but some plants have been also used beyond their design life in certain areas. The critical components are the boiler and the turbine. The operation of thermal power generation is faced with both tangible and intangible aging processes. Tangible or physical aging refers to the equipment operating under high pressure and temperature, and bearing mechanical stress, resulting in physical and chemical changes, such as wear, creep, corrosion, and so on, gradually making the equipment unable to continue operating safely under the required design parameters. Invisible aging refers to technological progress. The advent of more efficient or less labor-intensive production equipment means that older equipment will operate under less and less economic conditions. The physical aging of some equipment (such as condenser copper pipes, heater pipes, boiler heating surface pipes, turbine blades, furnace walls, etc.) can be removed during overhaul. However, it is often the aging of these important equipment components that determines the technical and consequently economic lifetime of thermal power plants. Operating experience shows that the service life of equipment operating under 450 °C is between 40 and 50 years. For equipment operating at temperatures above 450 °C, the operating hours could even be reduced to 100,000 hours.

Both gas and steam turbines are devices that drive the rotor to rotate at high speed through high-pressure gas with high temperature and humidity.

The difference is that the pressure and temperature of gas in the gas turbine is higher than in the steam turbine. Taking the GE PG9351FA Class F gas turbine as an example, the gas temperature entering the turbine from the combustion chamber is 1327 °C and the exhaust gas temperature is 609 °C. This working environment at such high temperature and thermal stress aggravates the periodic damage to gas turbines. The material of thermal parts is deformed due to low cycle fatigue[2] and thermal stress, which increases the failure probability of different components and seriously affects the service life of the equipment. Moreover, for two-shaft peak shaving generators, frequent start-up and shut-down is also one of the main causes of shorter life. For gas-steam combined units, the life of the gas turbine, waste heat boiler, and steam turbine could be seriously affected by peak shaving operation. Finally, we should mention that the reliable operation and reasonable maintenance of gas turbine affects not only the safety but also the economy of the whole unit.

4 Conclusion

This chapter illustrated the fundamentals of power generation economics from different fossil sources. It started with the largest fossil-fuel-fired power plants in the world followed by introduction and technology performance of each source (coal, natural gas, biofuels, and oil) of electricity generation. Then economic analysis is introduced and discussed regarding the CAPEX, OPEX, indicators like NPV, IRR, and LCOE in addition to other techno-economic characteristics like dispatchability, flexibility, and expected life service of each technology. The conclusion that can be drawn from the above discussions and the related recommendation is as follows:

While general technology cost assessments can provide rough estimates, the actual cost of each technology is highly dependent on project-specific factors. Power sector planners should not underestimate the level of uncertainty when it comes to technology costs or future operating costs. Country-level analysis can provide a more accurate picture of the relative costs of each technology, but even then any forecast should be treated with care. Rather than attempting to pick the "best" technology, they should instead determine which technologies and fuels are well suited to their particular circumstances and then seek to create a diversified portfolio of options. Doing so can protect against major disruptions in any technology or fuel and help to balance capital and operational costs while mitigating environmental impacts.

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[2] Low-cycle fatigue is the regime associated with a load amplitude high enough to cause the fracture of a part after a limited number of cycles (typically less than 10^5 cycles).

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