B. Increase flexibility in coal-fired electricity generation

Coal-fired electricity generation - worldwide tendency.

In 2017, coal generation rose by 3%, after falling the previous two years (-2% and -3%, respectively). There was significant growth in coal generation in Asia, particularly in China and India, and decline elsewhere, including in the United States and the European Union. Coal-fired power generation remains the largest source of electricity generation worldwide, with a share of around 37%.(International Energy Agency, 2019)

Coal-fired power generation in the United States continued its decline in 2017 (-33 TWh) as competitive gas generation and renewables – benefiting from tax credits, state-specific expansion targets and cost reductions – further squeezed coal out of the generation mix. Coal generation in the European Union decreased (-22 TWh), mainly due to low gas prices and carbon policies that prompted fuel switching to gas. In the United Kingdom, a phase-out of coal by 2025 has been announced.(International Energy Agency, 2019)

China, India and Southeast Asia led an overall increase in coal-fired electricity generation in non-OECD countries in 2017. China's coal power generation increased by 4% due to rising electricity demand (+6%). Low power plant utilisation rates are an indication of persisting coal overcapacity in China, where generation from gas and renewable energy sources continued to grow. Coal-fired electricity generation in India rose by 13%, a substantial rebound of growth in the country, due mainly to strong growth in power demand (+12%). Southeast Asian economies saw strong coal generation growth as well in 2017(International Energy Agency, 2019).

Closing coal stations

There are 2 opposite processes going on all over the world: 1. Refusal to use coal to generate electricity; 2. The development of the coal industry and building new coal-fired plants.

In Europe, only two countries - Germany and Poland - are jointly responsible for 51% of the installed capacity of the EU and 54% of emissions from coal-fired power plants (Climate Analytics, 2017). Many European countries have either announced dates for the phase out of coal or have developed special national rules to achieve this goal. Great Britain, Finland, France have significantly reduced the production of electricity from coal in recent years and announced the gradual abandonment of coal in the next 10-15 years. Poland, Greece are building or planning to build new coal-fired power plants.

In the US, low profitability of coal stations leads to their closure (Buchsbaum, 2018; Union of Concerned Scientists, 2017). The share of electricity produced by coal-fired plants decreased to 30.1% in 2017. In the period from 2018 to 2022 it is planned to shut down another 19.8 GW of capacity of coal-fired power plants (Buchsbaum, 2018).

Countries such as China, Indonesia, India, to a lesser extent Turkey, Japan continue to build up their fleet of coal stations (Dunne, 2019; Timperley, 2019, 2018a, 2018b).

Flexibility and modernization

In some countries, the development of renewable energy is hampered after reaching a certain level of penetration due to the belief that the existing energy system cannot cope with the weather-dependent production of wind and solar energy.

Although traditional power grids were not designed to adapt to rapidly changing supply side schemes, system operators around the world have learned how to use various flexible resources that complement growing shares of variable renewable energy.

Modern coal-fired power plants can operate at minimum load levels of 25–40 percent of the rated load. Modern lignite power plants can reach a minimum load of 35–50% of the nominal load.

In contrast, power plants built ten to twenty years ago in industrialized countries had minimum load levels ranging from 40 percent (hard coal) to 60 percent (brown coal).

Modernization can reduce the minimum load even more; for example, in Germany, minimum load levels of 12 percent were achieved.

Modernization of the system at the Weisweiler power plant in Germany has reduced the minimum load levels of two power units with a capacity of 600 MW by 170 MW (G block) and 110 MW (H block). This upgrade also had a positive effect on the rate of rising, which was increased by 10 MW / min. The cost of modernization is about 60 million euros per unit of generation. At the Bexbach hard coal power plant (721 MW), the minimum load was reduced from 170 MW (22% from PNom) to 90 MW (11% from PNom) by switching from two mills to one mill. The fire resistance of the boiler and the allowable heat load on the components are two main limitations to increase flexibility (Agora, 2017).

Countries with large and aging coal-fired power plants that were designed to handle base load have great potential for modernizing efficiency and flexibility measures.

In systems with a high share of renewable energy, coal-fired power plants with a combined cycle benefit from the implementation of flexibility measures with a maximum potential margin increase of 14%. However, this does not apply to power plants operating on lignite. The integration of variable renewable energy sources into a system with a large number of old power plants operating on different types of coal leads to the fact that the flexibility of the power plant is of considerable importance, especially because there are no other available flexibility options on a large scale (Kopiske et al., 2017).

Price of modernization

The investment costs necessary to modify the flexibility should be considered separately in each case. They can be approximately estimated at 100-500 euro / kW. Upgrading typically increases the technical life of a power plant by about 10–15 years. For comparison, the cost of building new coal-fired power plants with a service life of more than 40 years at night ranges from 1,200 € / kW to more than 3,000 € / kW if CCS technology is introduced (Agora, 2017).

CO2 emission

In the long run, fossil fuel-fired power plants, especially coal-fired ones, will need to be replaced with generally less energy-intensive technologies to achieve international CO_2 reduction targets.

Flexible coal is not clean, but it makes existing coal plants more flexible, which allows integrating more wind and sun energy into the system.

From an environmental point of view, such modernization is justified if the coal-fired power plant is must-run plant that would have stayed operational in any case to provide system services. (Agora, 2017)

In another way, the CO_2 emission increase drastically. Otherwise, CO_2 emissions increase due to the improved competitiveness of coal plants compared to other technologies. Therefore, the goal of limiting CO_2 emissions in the energy sector should be addressed through effective policies to reduce CO_2 emissions.(Agora, 2017)

H-class turbines

One of the most important components of a power plant is a gas turbine. Today, the latest generation of gas turbines is the High-Efficiency Gas Turbines manufactured by companies such as Siemens, GE.

The first samples were released about ten years ago, but only in the last 5 years, the introduction of turbines of this class began more actively. For example, Asia's first high-efficiency gas turbine was installed in the Republic of Korea at the Dangjin 3 power plant (formerly Bugok 3) in 2013. Now the H-class is used worldwide: for example, many turbines are installed in the U.S. South and Southeast Asia (South Korea, Republic of China (Taiwan), Singapore, Hong Kong, Pakistan).

In Brazil, Porto de Sergipe power plant, in Barra dos Coqueiros, has three H-class gas turbines and three generators that can generate 1,516 MW (GE Newsroom, 2018), making it the largest gas-fired power plant in the country. Brazil has a significant amount of wind and hydropower, so this station will play an important role in ensuring rapid response to fluctuations in demand for the power system and rapid adaptation to weather changes.

H-class turbines were designed to provide flexibility in operation. Due to the very fast load changes, they are suitable for compensating for load fluctuations in the network and creating a reliable power grid. These turbines have a short start-up time (less than 30 minutes) and high operational flexibility, as well as low emissions and the ability to work under partial load.The turbine can be also used in a combined heat and power plant (CHP). An example is the CHP at the location Lausward in Germany. There the overall fuel efficiency of the natural gas used thus climbs up to 85 percent (Siemens, 2019).

HELE coal-fired generators

Improvements in the efficiency of coal-fired power plants can be achieved with HELE (high-efficiency, low-emissions) technologies including ("High efficiency low emission coal," 2015):

- Supercritical & Ultrasupercritical Technology

New pulverised coal combustion systems – utilising supercritical and ultra-supercritical technology – operate at increasingly higher temperatures and pressures and therefore achieve higher efficiencies than conventional PCC units and significant CO_2 reductions. Supercritical steam cycle technology has been used for decades and is becoming the system of choice for new commercial coal-fired plants in many countries.

- Integrated Gasification Combined Cycle (IGCC)

An alternative to achieving efficiency improvements in conventional pulverised coal-fired power stations is through the use of gasification technology. IGCC plants use a gasifier to convert coal (or other carbon-based materials) to syngas, which drives a combined cycle turbine. More information can be found on the gasification section.

- Fluidised Bed Combustion

Fluidised Bed Combustion (FBC) is a very flexible method of electricity production – most combustible material can be burnt including coal, biomass and general waste. FBC systems improve the environmental impact of coal-based electricity, reducing SO_x and NO_x emissions by 90%.

HELE coal-fired generators need to be the minimum specification acceptable for new-build and replacement coal plants.

Coal-fired generation technology is mature, relatively low cost, and widely available. Continual research and development over many decades have lifted efficiency from 20% in old subcritical plants to as high as more 40% in the latest ultrasupercritical plants. These improvements in efficiency have also seen greenhouse gas emissions fall per unit of output by upward of 25%. It is entirely sensible that all new coal-fired generators should be ultra-supercritical.

While there are clear environmental benefits to deploying HELE technologies, around 18% of coalfired capacity currently under construction or under development will use subcritical technology. In Africa, this figure increases to 28% of capacity in the project pipeline (WCA, 2016).

Japan and South Korea are world leaders in having relatively young, highly efficient coal fleets. They are active in developing HELE technologies, such as advanced ultrasupercritical (AUSC) and integrated gasification combined cycle (IGCC) plants (Barnes, 2019).

E. Opportunities in combined heat and power (CHP), gasification and coal to develop other technologies or products (such as liquids or chemicals)

Coal gasification

Coal gasification offers a versatile and relatively clean method of converting coal into not only electricity but also hydrogen and other valuable products.

There are more than 272 operating gasification plants worldwide with 686 gasifiers. There are currently 74 plants under construction worldwide that will have a total of 238 gasifiers and produce 83 MWh. Thirty-three gasification plants are located in the United States. Currently, China has the largest number of gasification plants. The gasification capacity (both operational and under construction) in the Asia/Australia region now exceeds the rest of the world put together. (See Figure 1) The prime movers behind this current and expected growth are the chemical, fertilizer, and coal-to-liquids industries in Asia (primarily China, India, South Korea, Malaysia, and Japan) (See Figure 2). This is followed by South Africa and Qatar. About 25% of the world's ammonia and over 30% of the world's methanol are now being produced via gasification. Gasification for liquid and gaseous fuels is becoming increasing important. While the demand for transportation fuels (particularly gasoline) has declined in the United States, the demand has been increasingly sharply in other parts of the world, primarily Asia. Gasification for substitute natural gas has also shifted to Asia because the natural gas (LNG) is extremely expensive in Asia and Africa.

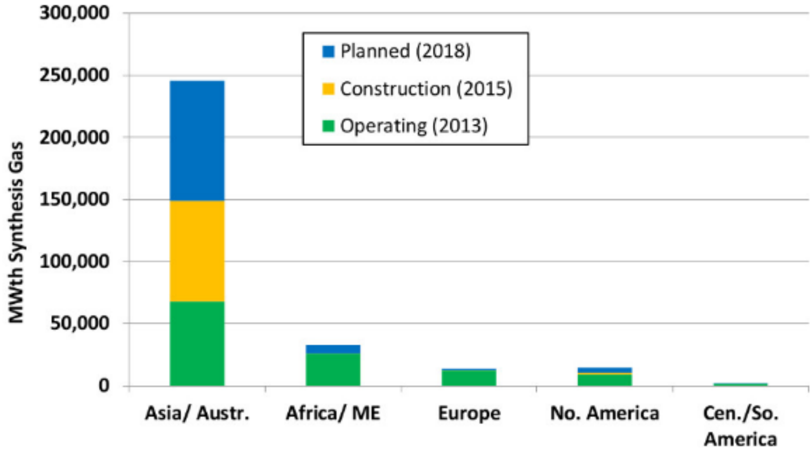

Figure 1 Gasification capacity by geographic region.
Source: https://www.globalsyngas.org/resources/the-gasification-industry/

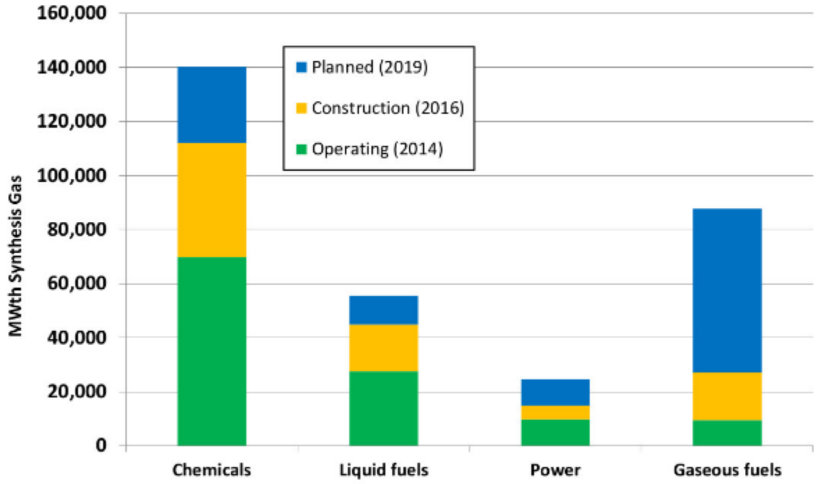

Figure 2 Gasification by application.
Source: https://www.globalsyngas.org/resources/the-gasification-industry/

There are two developing countries where coal conversion projects to produce chemicals, gaseous and liquid fuels have been taken forward strongly. The first is South Africa, which established the world's only commercial-scale coal-to-liquids and coal-to-chemicals facilities at Secunda and Sasolburg respectively. The other is China, where there is a major gasification-based coal conversion development and deployment programme that is set to become a significant, large-scale commercial element in the nation's energy development plans. (Minchener, 2013)

In China there has been a move to apply coal gasification to produce olefins as a means to establish higher value-added markets for plastics and fibres. Alongside these scale-up and new market activities, there is a continuing assessment of other coal-to-chemicals techniques, with research and development of coal-to-glycol and coal-to-aromatics processes under way.(Minchener, 2013)

Co-gasification

The gasification of coal began in the 1800s century, and many developments are stated in the last 200 years, and since then coal is considered as a potential feed for gasification to produce syngas and liquid fuel (Chmielniak and Sciazko, 2003)

Co-gasification of coal and biomass seems to be an attractive technology to produce heat, power, liquid and gaseous biofuels using synthesis gas. Co-gasification of coal and biomass is emerging as potential clean fuel technology to achieve high thermodynamic efficiency with relatively low CO_2 emission. Co-gasification has higher efficiency than the solitary coal gasification because the cellulose, hemicellulose and lignin content of biomass help to ignite and enhance the rate of gasification.

It was found out that binary coal-biomass blends with biomass ratios (BR) higher than 5% lead to more than 80% cold gas efficiency, and that blends with less than 35% BR can generate gaseous products suitable for chemical synthesis. (Rodrigues et al., 2016)

UCG

Underground coal gasification (UCG) is one approach to energy production that may allow for emissions and other environmental impacts to be effectively managed. Decarbonization could be achieved by gasifying coal and reforming the syngas product to hydrogen (H_2, a clean energy carrier) and safely store the carbon dioxide (CO_2).

Технология UCG имеет долгую историю. More recently, momentum has grown yet again as countries including China, the U.S., Canada, Argentina, and Chile have commenced UCG projects.

The primary reason to gasify coal underground is the low cost of energy production.

Additional UCG benefits include:

- It is applicable to very large, deep resources that can consist of low-quality coal not suited for conventional mining (normally conventional mining occurs above 1000 m). The estimated amount of usable coal at such depths could equal or exceed all current mineable coal resources and be a game changer for global energy supply.
- The energy is produced as syngas, which is readily cleaned using existing processes and transported via pipelines.
- Multiple uses exist for syngas, such as a fuel for power station gas engines to produce electricity, or chemical feedstock for the production of fertilizers, diesel and gasoline, and methanol derivatives such as olefins and plastics. Syngas can also be readily processed into natural gas.
- Compared to coalbed methane extraction from the same coal seam, UCG generates over 60 times more energy.
- UCG offers a small environmental footprint with little surface impact and minimal waste generation.
- The health and safety issues associated with people working underground can be avoided.

UCG technology has several difficulties, such as:

- Insufficient knowledge of the site geology
- Inability to drill boreholes with necessary precision
- Operating with inappropriate gasification parameters
- Lack of understanding of the impact of the gasification process on the surrounds of the underground cavity. (Gemmell, 2016)

Modern UCG technologies have evolved to ensure destruction of potential contaminants as part of the gasification and decommissioning processes, as well as managing operating pressures to protect groundwater. One of them is the “Clean Cavern” concept. This is the process whereby the gasifier is self-cleaned via the steam produced during operation and following decommissioning (during decommissioning while the ground retains heat steam continues to be generated). Another important practice is ensuring that the pressure of the gas in the gasifier is always kept below that of the groundwater surrounding the gasifier cavity. (Mallett, 2015).

UCG is still commercially used in Uzbekistan since 1964 (Angren coal deposit). Currently, the UCG technology is seriously considering and implementing such countries as China, India, Australia, South Africa.

Non-combustion uses of coal-gasification products

Coal is used predominantly for power generation, steel and chemicals production. The chemicals are obtained from coal tar pitch and by gasification to produce methanol to olefins. The markets for products derived from coal tar pitch, such as dyes, preservatives and fungicides, are growing slowly but are mature, while coal gasification to chemicals has seen recent expansion in China against a background of growing environmental challenges (Reid, 2018).

The growth of renewable energy technologies leads to an increase in demand for rare-earth elements, and new technologies are being developed to extract these minerals from coal. There is a growing demand for activated carbon used to purify water, adsorb mercury and possibly carbon sequestration. The electrode market is mature, but the rising cost of graphite can lead to increased use of coal products for the manufacturing of steel, silicon, and aluminium. The emergence of new technologies using coal as a raw material is associated with the development of green energy production, electrification, energy storage, carbon sequestration, and low-emission energy production (Reid, 2018).

The equivalent of about 5.5 quadrillion British thermal units of fossil fuels were consumed for non-combustion purposes in the United States in 2017. Over the past decade, non-combustion consumption of fossil fuels has typically accounted for about 7% of total fossil fuel consumption and about 6% of total energy consumption in the United States. In 2017, carbon dioxide (CO2) emissions would have been 196 million metric tons (about 4%) higher if non-combustion fuel use would have been combusted (Francis, 2018).

The aromatic molecular structures present in coals could be ideal feedstocks for the emerging aromatic polymers and engineering plastics. Here the concern is that the traditional source of coal chemicals--the liquids from metallurgical coke production in by-product coke ovens--are steadily decreasing. At the very time at which opportunities are increasing for new applications of coal chemicals, the sources of those materials are decreasing (Song and Schobert, 1996).

Combined heat and power cogeneration (CHP)

Combined heat and power (CHP) systems, also known as cogeneration, generate electricity and useful thermal energy in a single, integrated system. CHP is not a technology, but an approach to applying technologies. CHP is not a technology, but an approach to applying technologies. Heat that is normally wasted in conventional power generation is recovered as useful energy, which avoids the losses that would otherwise be incurred from separate generation of heat and power. While the conventional method of producing usable heat and power separately has a typical combined efficiency of 45 percent, CHP systems can operate at levels as high as 80 percent. New turbines are now cost effective for systems down to 500 kW and reciprocating engines for systems down to 50 kW, dramatically expanding the number of sites where CHP can be installed (ACEEE, 2015).

In 2016, 3907 TWh of electricity and 2783 TWh of heat at CHP plants were generated worldwide. Heat and electricity generation in the leading countries in the use of CHP are presented in Table 1. (IEA, 2018).

CHP 2016	Ktoe		TWh	
	Electricity	Heat	Electricity	Heat
China	150628	89886	1752	1045
Russia	59659	70383	694	819
US	27284	12133	317	141
Germany	10702	8127	124	95
Finland	1860	2949	22	34
Netherlands	3589	2487	42	29
Denmark	1459	2175	17	25

Table 1 Heat and electricity generation in CHP leading countries

CHP offers local, regional, national benefits, including reduced energy operating costs, increased energy efficiency, lower greenhouse gas emissions, stronger critical energy infrastructure, and improved resiliency, as well as increased manufacturing competitiveness and greater economic growth.

A range of technical, financial, political, and regulatory issues influence how much CHP potential is achieved.

CCHP - Trigeneration

Trigeneration or combined cooling, heat and power (CCHP), is the process by which some of the heat produced by a cogeneration plant is used to generate chilled water for air conditioning or refrigeration. An absorption chiller is linked to the combined heat and power (CHP) to provide this functionality. For this purpose, absorption bromide lithium coolers are used. Quadgeneration takes this process one step further with the addition of systems to purify carbon dioxide from the engine exhaust. Combined cooling and power (CCP) is where electricity and cooling are utilised alone.

This approach allows the use of a generating installation all year round, thereby not reducing the high efficiency of the power plant in the summer, when the need for heat generation decreases.

There are several benefits to trigeneration including:

- Greater efficiency – a single fuel source for several forms of energy
- They can be used as a backup power system
- Reduced fuel and energy costs
- Lower electrical usage during peak summer demand
- Engine heat can be used to produce steam of hot water for onsite use
- Significant reductions in greenhouse gas emissions compared to electricity produced from coal, whilst delivering the same amount of energy
- No harmful chemical pollutants since water is used as the refrigerant
- Beneficial for improving building's energy efficiency ratings.

Bibliography

ACEEE, 2015. Combined Heat and Power (CHP) [WWW Document]. Am. Counc. Energy-Effic. Econ. ACEEE. URL https://aceee.org/topics/combined-heat-and-power-chp (accessed 4.10.19).

Agora, 2017. Flexibility in thermal power plants – With a focus on existing coal-fired power plants. Agora Energiewende 116.

Barnes, I., 2019. HELE Technologies in Japan and South Korea, CCC/293. IEA Clean Coal Cent. URL https://www.iea-coal.org/hele-technologies-in-japan-and-south-korea-2/ (accessed 4.9.19).

Buchsbaum, L.M., 2018. America's coal plants closing despite Trump. Energy Transit. Glob. Energiewende. URL https://energytransition.org/2018/06/americas-coal-plants-closing-despite-trump/ (accessed 4.5.19).

Chmielniak, T., Sciazko, M., 2003. Co-gasification of biomass and coal for methanol synthesis. Appl. Energy, Energex 2002 - Coal and Clean Coal Technologies - Topic II 74, 393–403. https://doi.org/10.1016/S0306-2619(02)00184-8

Climate Analytics, 2017. A STRESS TEST FOR COAL IN EUROPE UNDER THE PARIS AGREEMENT SCIENTIFIC GOALPOSTS FOR A COORDINATED PHASE-OUT AND DIVESTMENT [WWW Document]. URL https://climateanalytics.org/publications/#page-3 (accessed 4.5.19).

Dunne, D., 2019. The Carbon Brief Profile: Indonesia [WWW Document]. Carbon Brief. URL https://www.carbonbrief.org/the-carbon-brief-profile-indonesia (accessed 4.5.19).

Francis, M., 2018. About 7% of fossil fuels are consumed for non-combustion use in the United States - Today in Energy - U.S. Energy Information Administration (EIA) [WWW Document]. US Energy Inf. Adm. URL https://www.eia.gov/todayinenergy/detail.php?id=35672 (accessed 4.9.19).

GE Newsroom, 2018. GE Power Announces New Achievements by HA Gas Turbine and Services Upgrades [WWW Document]. GE Newsroom. URL https://www.genewsroom.com/press-releases/ge-power-announces-new-achievements-ha-gas-turbine-and-services-upgrades-284394 (accessed 4.8.19).

Gemmell, C., 2016. Independent Review of Underground Coal Gasification – Report 239.

GSTC, n.d. The Global Syngas Technologies Council [WWW Document]. Glob. Syngas Technol. Counc. URL http://www.globalsyngas.org (accessed 4.8.19).

High efficiency low emission coal [WWW Document], 2015. . World Coal Assoc. URL https://www.worldcoal.org/reducing-co2-emissions/high-efficiency-low-emission-coal (accessed 4.9.19).

IEA, 2018. Statistics World - Total Primary Energy Supply (TPES) by source [WWW Document]. Int. Energy Agency IEA. URL https://www.iea.org/statistics/index.html?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=table&dataTable=BALANCES (accessed 4.10.19).

International Energy Agency, 2019. Recent trends in coal-fired power generation [WWW Document]. URL https://www.iea.org/tcep/power/coal/ (accessed 4.2.19).

Kopiske, J., Spieker, S., Tsatsaronis, G., 2017. Value of power plant flexibility in power systems with high shares of variable renewables: A scenario outlook for Germany 2035. Energy 137, 823–833. https://doi.org/10.1016/j.energy.2017.04.138

Mallett, C., 2015. Underground Coal Gasification: An Overview of an Emerging Coal Conversion Technology. Cornerstone 72.

Minchener, A., 2013. Challenges and opportunities for coal gasification in developing countries 76.

Reid, I., 2018. Non-energy uses of coal, CCC/291. IEA Clean Coal Cent. URL https://www.iea-coal.org/non-energy-uses-of-coal-report-ccc291/ (accessed 4.9.19).

Rodrigues, R., Muniz, A.R., Marcilio, N.R., Rodrigues, R., Muniz, A.R., Marcilio, N.R., 2016. EVALUATION OF BIOMASS AND COAL CO-GASIFICATION OF BRAZILIAN FEEDSTOCK USING A

CHEMICAL EQUILIBRIUM MODEL. Braz. J. Chem. Eng. 33, 401–414. https://doi.org/10.1590/0104-6632.20160332s00003479
Siemens, 2019. Siemens H-class gas turbines achieve one million operating hours [WWW Document]. Siemens. URL https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2019/power-gas/pr2019020162pgen.htm&content[]=GP&content[]=PG (accessed 4.8.19).
Song, C., Schobert, H.H., 1996. Non-fuel uses of coals and synthesis of chemicals and materials. Fuel 75, 724–736. https://doi.org/10.1016/0016-2361(95)00295-2
Timperley, J., 2019. The Carbon Brief Profile: India [WWW Document]. Carbon Brief. URL https://www.carbonbrief.org/the-carbon-brief-profile-india (accessed 4.5.19).
Timperley, J., 2018a. The Carbon Brief Profile: Japan [WWW Document]. Carbon Brief. URL https://www.carbonbrief.org/carbon-brief-profile-japan (accessed 4.5.19).
Timperley, J., 2018b. The Carbon Brief Profile: Turkey [WWW Document]. Carbon Brief. URL https://www.carbonbrief.org/carbon-brief-profile-turkey (accessed 4.5.19).
Union of Concerned Scientists, 2017. New Analysis Finds About 20 Percent of US Coal-Fired Electricity Generation Comes from Uneconomic Plants [WWW Document]. Union Concerned Sci. URL https://www.ucsusa.org/press/2017/new-analysis-finds-20-percent-us-coal-generation-from-uneconomic-sources (accessed 4.5.19).
WCA, 2016. WCA Report: The Power of High Efficiency Coal [WWW Document]. World Coal Assoc. URL https://www.worldcoal.org/reducing-co2-emissions/wca-report-power-high-efficiency-coal (accessed 4.9.19).