EMD Coal Committee
2021 Annual Report

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Executive Summary

Although demand for coal continues to be strong in China, India, and southeast Asia, world coal consumption and production has been flat. World production in 2019 barely exceeded 2014 levels and consumption slightly declined since peak levels in 2013. Although coal production increased in China, Australia, and South Africa in 2019, India and the United States experienced declines. The United States had a nearly 7% decline in coal production in 2019, mainly because of diminished demand for coal for electricity coupled with increased reliance on natural gas for electricity. In the European Union, a 15% decrease in coal production was caused by several factors that included climate policies, high carbon prices, increased competition from renewables and gas, and the end of coal subsidies.

Despite its diminished role in power generation, coal is an important potential source for several resources that include rare earth elements (REEs), graphene, and steel manufacture. Continued developments in coal technology such as improved recovery in underground coal gasification and coal-to-liquids promise to maintain coal as a diverse energy mineral source for the future, although its role in electricity generation continues to subside.

World Coal Production and Consumption

According to the 2020 IEA coal report, worldwide coal demand fell by 1.8% after two years of moderate growth (IEA, 2020). This downward trend was mainly the result of a poor demand for electricity growth, competition from low natural gas prices, and a growth in electricity generation from renewable-energy sources. Global electricity generation increased by only 1% in 2019. This was the lowest rate of increase since 2009. The United States and the European Union experienced significant fuel switching from coal to natural gas for power generation. There was a decline in electricity generation from coal in India in 2019, the first year in four decades in which coal-fired power generation declined in this country. This was the result of a slowdown in India's overall economy, higher-than-average power generation from hydropower, and expansions in power sources from solar and wind. In contrast, modest growth of coal-fired power generation occurred in China and southeast Asia, although at an insufficient rate to offset declines in the rest of the world. In 2020, the Covid-19 pandemic also adversely affected coal demand, as with demand for many other energy-based commodities. Coal exports fell by slightly more than 10%. Approximately two-third of this decline in exports came from thermal coal for power generation.

Enerdata (2020) reported that global coal production was stable, even though coal production in China increased by 4%. China accounted for almost 50% of the global coal production in 2019 (Fig. 1). The only other countries that saw an increase in coal production were Australia and South Africa. The United States experienced a nearly 7% decline in coal production in 2019 because of diminished demand for coal for electricity. In the European Union, a 15% decrease in coal production was the result of several combined factors that include climate policies, high carbon prices, increased competition from renewables and gas, and the end of coal subsidies.

Figure 1. Worldwide coal production in million metric tons in 2019. Modified from Enerdata (2020).

The near- and mid-term outlooks by IEA (2020) are uncertain. A main factor to consider is possible lower imports of Australian coal by China. Another important factor is possible development of greater thermal coal production in India, which has recently exceeded coal production in the United States and which now represents the second-ranked coal producing county in the world.

The IEA (2020) forecast to the year 2025 calls for an overall flattening of coal demand at the global level. Demand in Europe and North America is projected to decline, but since the combined coal consumption of these two regions accounts for only 10% of global use, the projected decline in demand in these two regions will have only a limited impact on the level of global coal use. In the United States, many companies are planning a shift away from use of thermal coal to other energy sources such as natural gas and renewables as a result of sharp declines in coal's role in power generation.

Coal demand in China is approaching a flattening of the overall demand curve, although this trend may be modified, following release of China's14th Five-Year Plan. In contrast, both India and southeast Asia are expected to show increases in coal demand as new coal-fired capacity comes online. However, expected increases in India may be dampened by the severe Covid-19 epidemic in 2021.

Coal Production in the United States

Coal production in 2020 in the United States decreased sharply from 2019 levels (Energy Information Administration, 2021). Graphs of important coal-import and coal-export data are presented in figures 2 to 4. Highlights from the fourth quarter of 2020 include:

- U.S. coal production during the fourth quarter of 2020 was 134.2 million short tons (MMst) (121.7 million metric tons). This was 1.2% lower than the previous quarter and 18.8% lower than the fourth quarter of 2019. Production in the western region represented about 57.2% of total U.S. coal production in the fourth quarter of 2020. It totaled about 76.8 MMst (69.7 million metric tons) (17.9% lower than the fourth quarter of 2019).
- U.S. coal exports for the fourth quarter of 2020 (19.1 MMst) (17.3 million metric tons) increased 25% from the third quarter of 2020. The average price of U.S. coal exports during the fourth quarter of 2020 was $83.1 per short ton.
- The United States continued to import coal mainly from Colombia (73.3%), Indonesia (10.6%), and Canada (9.4%). No imports from Australia were recorded for the fourth quarter of 2020. U.S. coal imports in the fourth quarter of 2020 were 1.3 MMst (1.2 million metric tons). The average price of U.S. coal imports during the fourth quarter of 2020 was $71.11 per short ton.
- Steam coal exports totaled 7.8 MMst (7.1 million metric tons) (54.1% higher than the third quarter of 2020). Metallurgical coal exports were 11.3 MMst (10.3 million metric tons) (10.5% higher than the third quarter of 2020).
- U.S. coal consumption was 122.8 MMst (111.4 million metric tons) in the fourth quarter of 2020, 17.3% lower than the 148.6 MMst (134.8 million metric tons) reported in the third quarter of 2020 and 6.9% lower than the 132 MMst (119.7 million metric tons) reported in the fourth quarter of 2019. The electric power sector accounted for about 91.3% of the total U.S. coal consumption in the fourth quarter of 2020.
- In the fourth quarter of 2020, coal stocks grew to 166 MMst (150.6 million metric tons) from 161.7 MMst (146.7 million metric tons) at the end of the third quarter of 2020 (a 2.6% increase). Stocks in the electric power sector increased to 132.7 MMst (120.4 million metric tons) from 129.1 MMst (117.1 million metric tons) at the end of the third quarter of 2020.

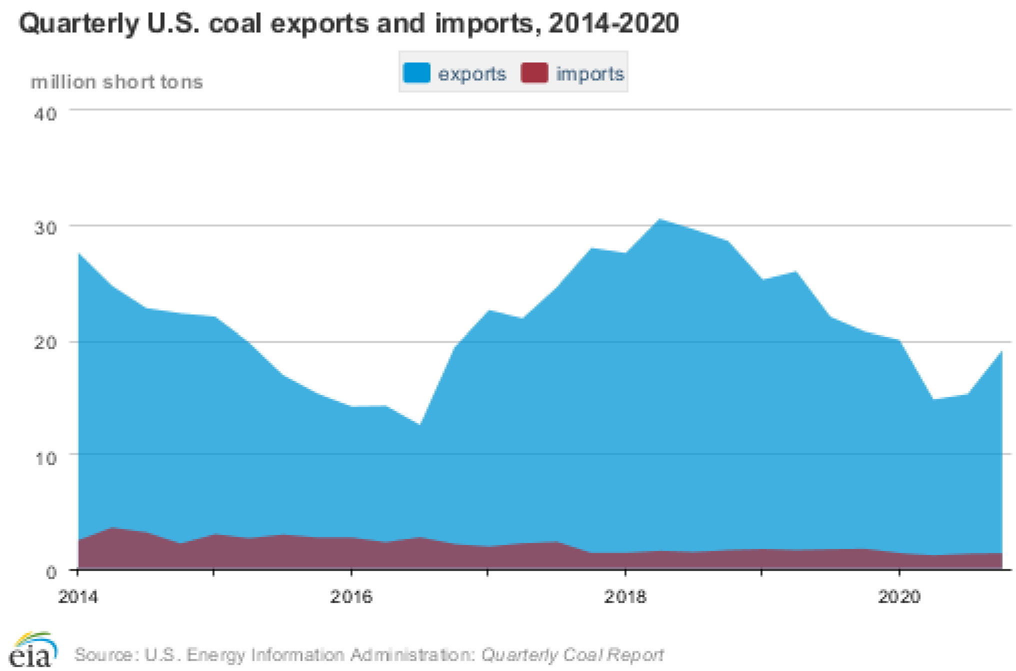

Figure 2. Quarterly U.S. coal exports and imports, 2014 to 2020. From the Energy Information Administration (2021).

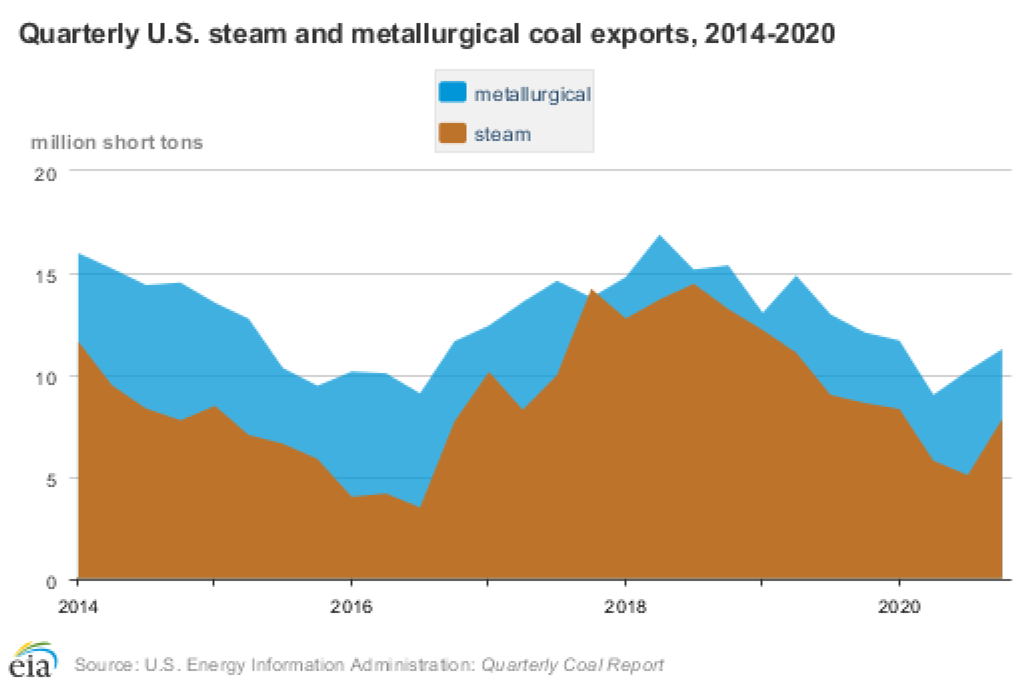

Figure 3. Quarterly U.S. steam and metallurgical coal exports, 2014 to 2020. From the Energy Information Administration (2021).

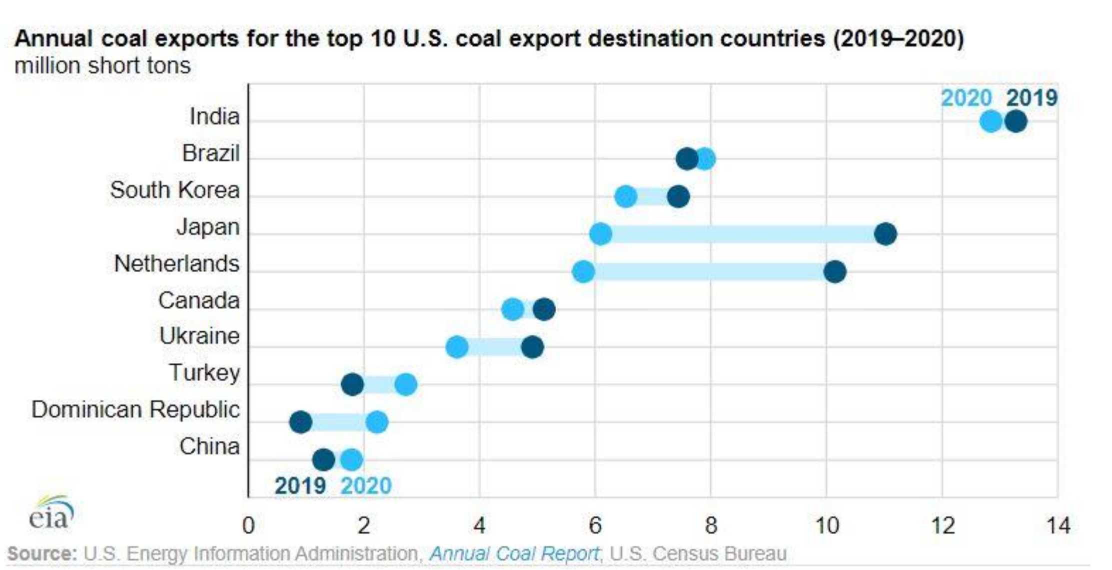

Figure 4. Annual coal exports for the top ten U.S. coal-export destination countries, 2019 to 2020. Values on x-axis are million short tons. From the Energy Information Administration (2021).

Resources from Coal

Although coal as a source of electric power has been steadily diminishing in importance in the United States and the European Union, it has the potential for being an important source of graphene and rare earth elements (REEs). This report presents basic data from these commodities (Powell and Beall, 2015; U. S. Department of Energy, 2017), described in greater detail by Campbell et al. (2019 and 2020).

Rare Earth Elements

Rare earth elements (REEs) have numerous and varied applications in lasers, electrical components, glass, magnetic materials, and industrial processes. Coal and coal byproducts have the potential for being significant sources of REEs, particularly heavy REEs (HREEs), which include terbium (atomic number 65) through lutetium (atomic number 71), and also yttrium (atomic number 39) (Powell and Beall, 2015). Extraction of REEs from coal is typically done from coal after combustion because they are fully mixed with organic material in the form of fine particles. Rare-earth concentrations in the lowest-density fractions indicate that (1) finely dispersed, ash-based material in coal has the greatest affinity for REEs and (2) REEs are bound within the organic matrix by adsorption with humic acid components. Although REE concentrations in coal and coal byproducts are typically lower than those encountered in other host rocks that are commercial supply sources of REEs, the concentration of HREEs in coal may be comparable to those in commercially conventional sources (see Campbell et al., 2020, p. 8-9).

Initial resource estimates indicate that approximately 6 million metric tons of REEs could be produced from coal in western coal basins in Montana, Colorado, Wyoming, Utah, New Mexico, and Arizona (U.S. Department of Energy, 2017). In addition, 4.9 million metric tons of REE resources (cutoff grade of 500 parts per million [ppm]) from coal and coal byproducts are potentially available in Pennsylvania, West Virginia, Kentucky, and Virginia. Technically recoverable amounts of REEs in coal in the U.S. are estimated to exceed 10 million metric tons, not including additional potential resources in coal-ash and coal-mine refuse materials from the approximately 250 coal-preparation plants that have recently been operating (U.S. Department of Energy, 2017).

Graphene

Graphene is an allotrope (structurally different forms of the same element) of carbon consisting of a single layer of atoms arranged in a two-dimensional honeycomb lattice (Geim and Novoselov, 2007; Peres and Ribeiro, 2009). Graphene is an important commodity for use in semiconductors, electronics, electric batteries, and composite materials (Conca, 2013). Graphene has strong electronic transfer properties, great strength and stiffness, and excellent thermal conductivity (Berber et al., 2000; Dikin et al., 2007; Morozov et al., 2008). Coal may be a good source of graphene as the raw material for chemical extraction because it is relatively inexpensive and abundant.

Additionally, coal is a molecular solid while graphite is a lattice solid without weak bonds, so the refinement and treatment process can be simplified, without use of caustic and hazardous chemicals such as H_2O_2 and $KMnO_4$ (Wu et al., 2013). The principal carbon source for graphene is leonardite within low-grade lignite deposits (Powell and Beall, 2015). However, graphene can also be extracted from higher coal ranks and byproducts, including bituminous coal, coke, and anthracite (Ye et al., 2013).

The global market for graphene was $9 million USD in 2012 (Azonano, 2014). Demand for graphene is dominated by semiconductor electronics, batteries, and composite materials, which together account for approximately 60% of total graphene use. Demand is expected to increase because graphenes are an important source of lithium battery anode materials that improve battery performance. The annual demand for graphene for lithium ion batteries is projected to increase to over 3,000 tons (Azonano, 2014).

China, which has the largest graphite reserves in the world, is expected to be the global leader in graphene production. Graphene production in China has already grown at impressive levels. For example, Sichuan Jinlu Group, in collaboration with the Institute of Metal Research Chinese Academy of Sciences, has recently completed pilot tests of a production line of 1.5 tons. Nanjing XFNano Material Tech produces multilayer graphene at a level of 50 kg per day. Other important organizations include Ningbo Morsh Technology. Its graphene production line is reported to be one of the largest in the world, with an investment exceeding $16 million USD). Ningbo Morsh Technology's annual capacity is approximately 300 tons and its future plans for graphene-enhanced composites (plastics) are 2,000 tons per year The company also reports it can produce 2,000 tons per year (Graphene-Info, 2021).

Coal Technology

Underground Coal Gasification

In-situ coal gasification, also known as underground coal gasification (UCG), involves the subterranean combustion of coal seams to produce gas, similar to those produced in gasifier reactors (National Energy Technology Laboratory, 2021a). An advantage of this process is that unmineable coal seams can serve as sources for gas production, meaning that costs otherwise incurred in conventional coal mining can be avoided. UCG injection wells are drilled into unmined coal seams, with air or oxygen, as well as water, injected into the seam. High temperatures (about 1,200°C) from combustion produces hydrogen, carbon monoxide, carbon dioxide, and minor amounts of methane and hydrogen sulfide. These products are then brought to the surface through one or more production wells located ahead of the combustion zone (Fig. 5).

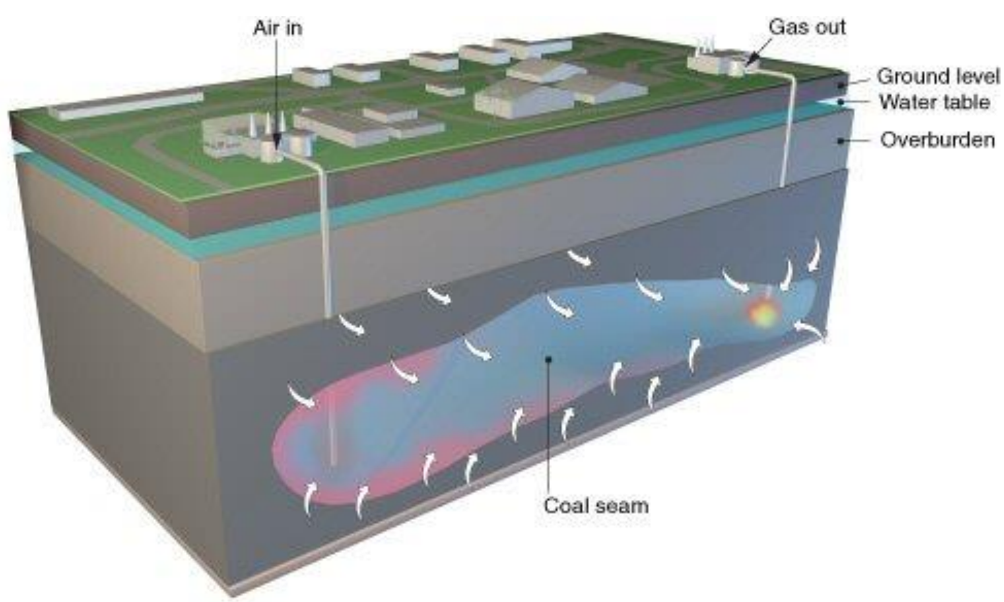

Figure 5. Underground coal-gasification process. From the National Energy Technology Laboratory (2021a).

UCG increases access to coal resources deemed to be too deep or difficult to mine. Only one-sixth to one-eighth of the world's coal reserves are economically mineable. Both tar and ash content of UCG syngas are greatly lower than those obtained from surface gasifiers. Moreover, because coal processing in UCG is maintained underground, surface and air emissions are commonly reduced. In addition, syngases from UCG can be processed and CO_2 separated for sequestration or for other processes. Major targets for carbon storage include deep saline aquifers, active or depleted oil and gas fields, and unmineable coal seams.

However, these advantages from UCG can be offset by other factors. These include subsidence and potential leaching of toxic material into groundwater. Subsidence can be mitigated through selective gasification of seam areas, much like room and pillar underground mining practices. Controlling leaching also requires extensive analysis, such as keeping pressure in the gasifier at levels lower than pressure in the coal seam and in surrounding strata. As a result, there is no drive for groundwater flow from the gasifier chamber or loss of product or contaminants into the surroundings.

Two different methods of UCG are commercially available. One method, based on technology from the former Soviet Union, uses vertical wells and a method similar to reverse combustion to open the internal coal pathways. Another method that has been employed in the United States and western Europe, uses several inseam boreholes. This method involves a moveable injection point (controlled retraction injection point [CRIP]) and uses oxygen or enriched air for gasification (Fig. 6).

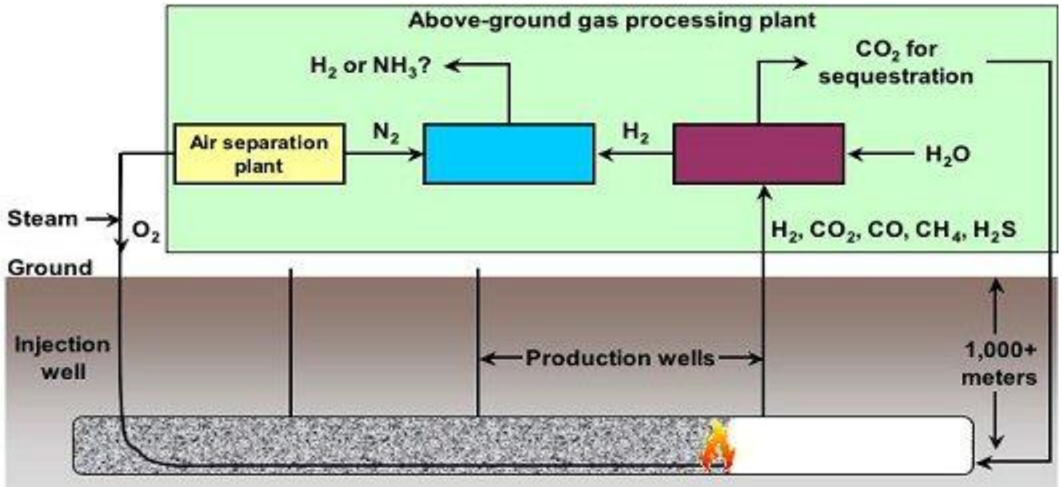

Figure 6. Schematic of the controlled retraction injection point (CRIP) process of underground coal gasification. From the National Energy Technology Laboratory (2021a).

With increasing demand for natural gas and chemical products and increasing concerns over mining practices, interest in UCG has been revived across the globe (Fig. 7). Prominent examples are in Australia, South Africa, the United Kingdom, India, and China. The most recent large demonstration project (Chinchilla) operated in Queensland from 1997 to 2003. Approximately 35,000 metric tons of coal were gasified without observed subsidence nor groundwater contamination. The project resulted in 95% coal-resource recovery. Plans in Australia are currently underway for wider commercial application of UCG. A pilot-scale UCG project in Majuba Coal Field north of Johannesburg commenced an underground coal-seam ignition in January, 2007. The coal seam supplies a 4,200-megawatt (MW) power plant. Additional plans include a 1,200-MW UCG plant. The United Kingdom (UK) has undertaken a five-year effort to determine the feasibility of using the technology for UCG. A new UCG Partnership in the UK includes members from more than eight countries. UCG interest in India remains high. India has enormous coal resources and a shortage of natural gas compared to coal. At least three UCG- pilot projects are now in the planning stages. UCG has been investigated in China since 1985. UCG field trials in Liaohe oil field in Liaoning Province are underway with the goal of commercialization. In the United States, research and development in UCG has occurred mainly in the private sector, although the State of Indiana has recently been conducting research (Varma, 2010).

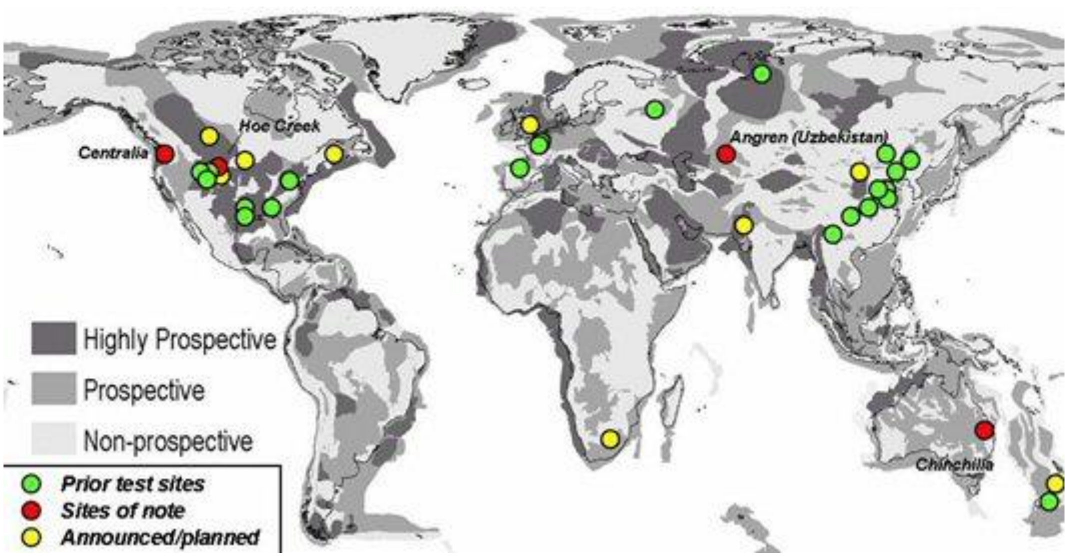

Figure 7. World distribution of UCG activity. From the National Energy Technology Laboratory (2021a).

Coal to Liquids

The goal of coal-to-liquids (CTL) technology is to convert coal into liquid fuels such as gasoline, diesel and jet fuel (Fig. 8). Materials for conversion to liquids include locally mined coal, waste coal, coal fines, and biomass. The CTL process is well-established and typically consists of an initial stage of indirect coal liquefaction through gasification of coal and biomass materials to produce syngas, in turn feedstock for Fischer-Tropsch (F-T) synthesis to make liquid hydrocarbons. These liquid hydrocarbons are then refined into waxes, motor oils, and liquid fuels, whereas syngas can be converted to methanol as well as a wide variety of other chemicals. Details of CTL conversion processes, together with a history of technological developments, are summarized in National Energy Technology Laboratory (2020).

Rationale for CTL manufacture in the United States includes (1) use of diverse sources for energy production, (2) abundant coal resources available for manufacture, and (3) energy security. However, the future of CTL in the United States is limited by its high cost compared to conventional petroleum-based fuels, being competitive only with crude oil prices over $70 per barrel. Moreover, the CTL process produces greenhouse gases.

The National Energy Technology Laboratory (NETL) has been pursuing development of liquid fuels from coal for many years (National Energy Technology Laboratory, 2020, 2021b). For example, commencing in 2013, with a grant of $20 million USD, NETL has coordinated efforts with the U.S. Air Force for cost-effective development of jet fuel from coal. A number of CTL projects have been proposed in the United States since the year 2000. Most were proposed during periods of combined high oil and gas prices and have subsequently been canceled during time of low oil and gas prices. However, some CTL projects are under consideration (Table 1).

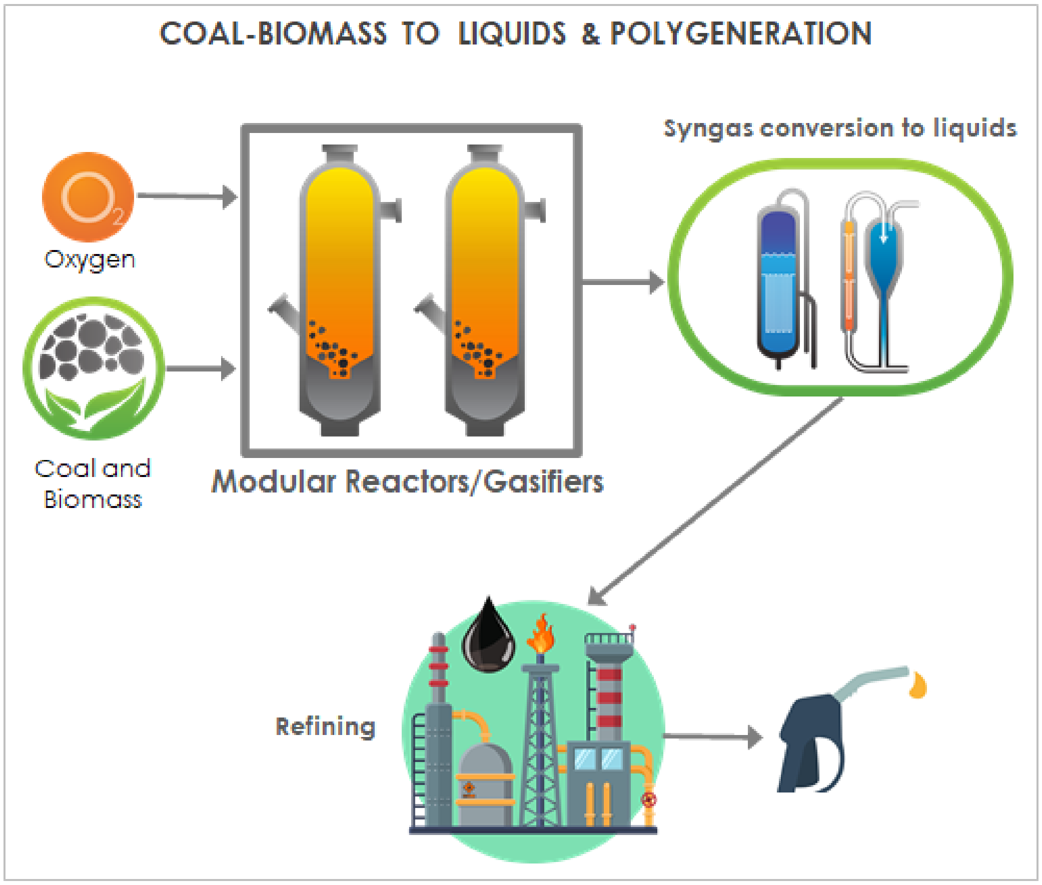

Figure 8. Schematic of coal-biomass to liquids and polygeneration. From the National Energy Technology Laboratory (2021b).

Project	Developer	Location	Products	Status
Direct Liquefaction Coal to Liquids Facility	Domestic Synthetic Fuels I, LLC	Point Pleasant, Mason County, West Virginia	2,500 tpd of coal to 6,840 bpd ultra-low-sulfur diesel fuel, 2,450 bpd reformate, 613 tpd flaked residue	Construction permit granted in September 2019.
Adams Fork Energy - TransGas WV CTL	TransGas Development Systems	Mingo County, West Virginia	7,500 tpd of coal to 18,000 bpd gasoline and 300 bpd LPG	Permitted (no new information since 2015)
Direct Coal Hydrogenation Facility	Riverview Energy	Dale, Indiana	1.6 MM tonnes of high sulfur coal and natural gas to approximately 4.8 MM bbl of ultra-low sulfur diesel and 2.5 MM bbl of naphtha annually	Granted a Title V Air Permit in 2020.

Table 1. Currently planned CTL projects in the United States. From the National Energy Technology Laboratory (2020).

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