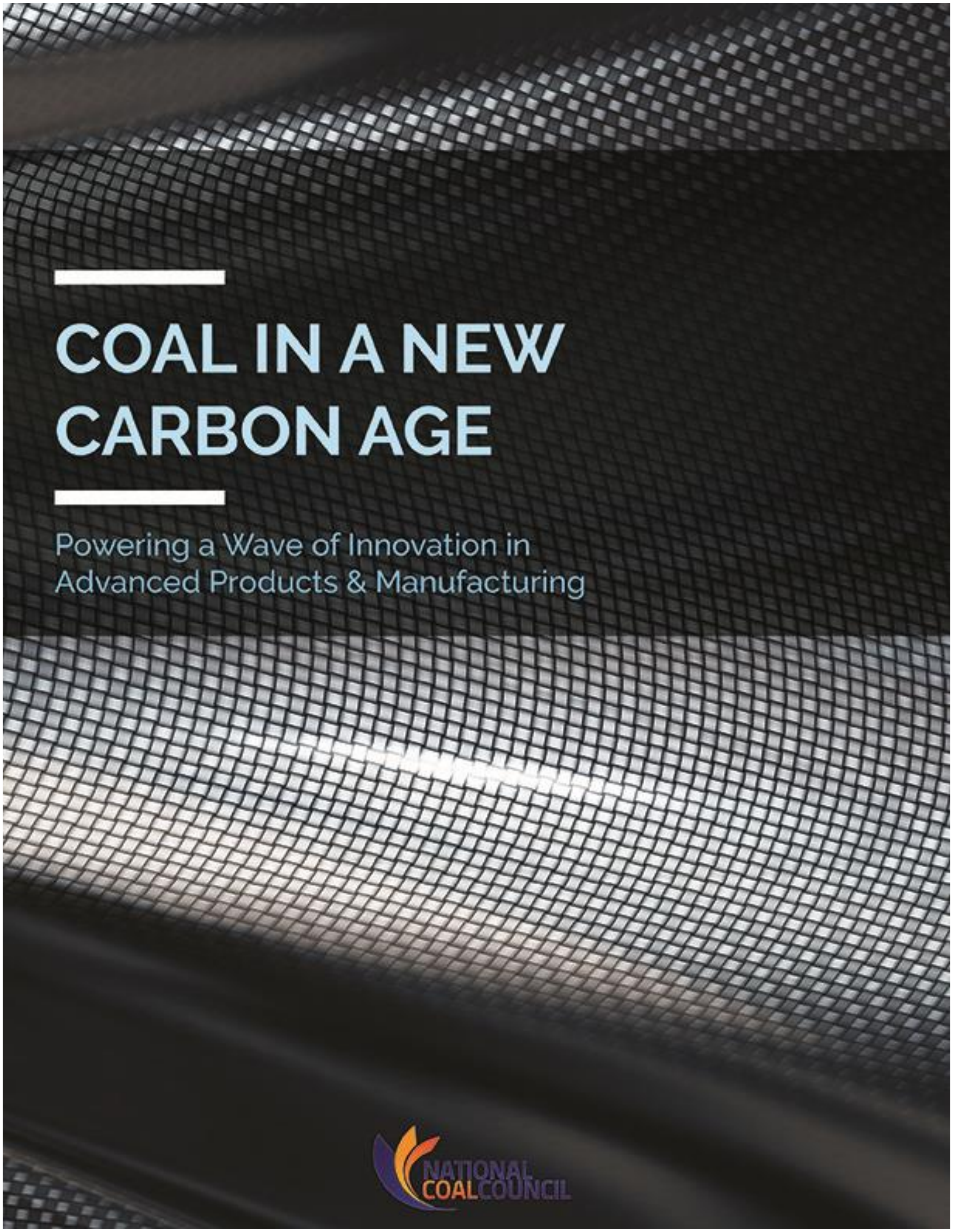
COAL IN A NEW CARBON AGE
Powering a Wave of Innovation in Advanced Products & Manufacturing
NATIONAL COALCOUNCIL

APPENDICES

Coal In a New Carbon Age

Powering a Wave of Innovation in Advanced Products & Manufacturing

Appendices

May 2019

The National Coal Council is a Federal Advisory Committee established under the authority of the U.S. Department of Energy. Individuals from a diverse set of backgrounds and organizations are appointed to serve on the NCC by the U.S. Secretary of Energy to provide advice and guidance on general policy matters relating to coal and the coal industry. The findings and recommendations from this report reflect a consensus of the NCC membership, but do not necessarily represent the views of each NCC member individually or their respective organizations.

Access the Main Report at:

https://www.nationalcoalcouncil.org/studies/2019/NCC-COAL-IN-A-NEW-CARBON-AGE.pdf

APPENDIX A
Markets for Coal in the New Age of Carbon: Technology and Market Descriptions

This appendix provides a more detailed overview of the technology pathway and market descriptions. A rough outline of the main technology pathways are shown below in Figure A-1.

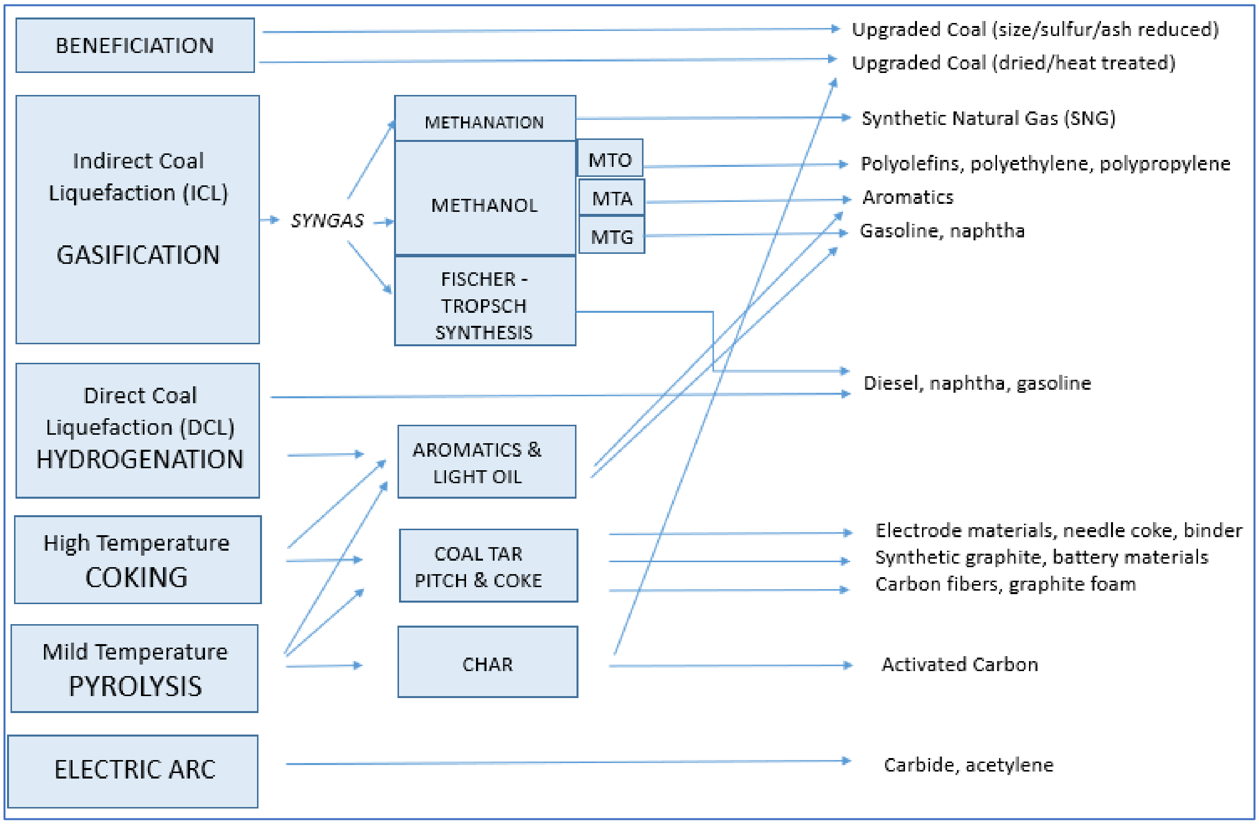

Figure Appendix A-1. Main Coal Processing Pathways

The general outline for this section is as follows:

- Coal Beneficiation
- Coal to Liquids
  - *Indirect Coal Liquefaction to Chemicals (olefins, aromatics, ammonia)*
  - *Indirect Coal Liquefaction to Fuels (FT, MTG, SNG)*
  - *Direct Coal Liquefaction to Fuels (diesel, gasoline, jet fuel)*
  - *Direct Coal Liquefaction to Chemicals (aromatics and light oil)*
  - *Coal to Liquids Coking (light oils, coal tars)*
  - *Coal to Liquids Pyrolysis (light oils, char, coal tars)*
- Coal to Carbon Products
  - *Activated Carbon*
  - *Coal to Carbon Fiber*
  - *Coal to Graphite and Electrodes*
  - *Coal Use in Metallurgical Applications*
  - *Coal to Carbides*
  - *Coal to Graphene*
  - *Coal to Building Products (coal fly ash, coal combustion residuals, coal plastic composites)*
  - *Coal to Carbon Foam*
  - *Coal to Carbon Black*

- Coal-derived Rare Earth Elements and other Critical Minerals
- Life Sciences and Medical
- Biotech and Agricultural Uses

Coal Beneficiation

As used in this report, coal beneficiation relates to the upgrading of coal quality. Coal quality is a significant determinant of a coal product's competitiveness, whether in domestic or international markets and whatever the application. The International Energy Agency (IEA)-affiliated IEA Clean Coal Centre published a report in 2017 which reviewed numerous beneficiation technologies, and estimated expense to be between $2 and $10 per ton of coal (Figure Appendix A-2).

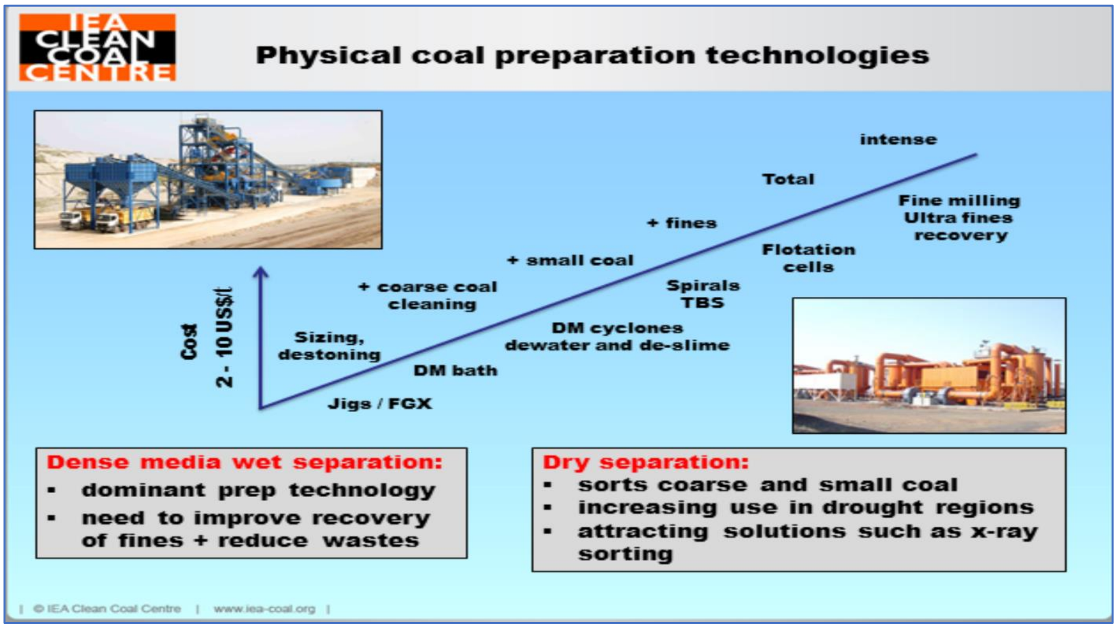

Figure Appendix A-2. Coal beneficiation methods and technologies (Reid, 2018)

This figure largely covers standard coal preparation (prep) as commonly practiced at operating coal production facilities across the globe, to improve and provide consistency in coal quality. In addition to potentially improving existing technologies, it is expected that new opportunities for expanded coal use may also result from the upper end "intense" portion of the IEA chart; i.e., higher temperature processing, finer milling and ultra-fines recovery.

Several technologies are focused on innovative applications of drying technologies and serve the added beneficiation benefits of removing unwanted impurities such as mineral matter and/or trace metals. Other beneficiating technologies are focused on upgrading coals beyond the levels typically achieved by traditional coal prep plants. Common characteristics of these technologies include (i) the use of fine coal slurry material (either from a fine coal process or waste stream, such as the thickener underflow, at a coal prep plant, or from an existing fine coal slurry refuse impoundment) as a feedstock, (ii) the production of a finished product that includes certain quality advantages – i.e., reduced ash content, reduced sulfur content, reduced moisture content, and/or increased heat content – relative to a typical washed coal product, and/or (iii) the production of a product having a fine or ultrafine size consist.

Technologies such as these have the potential to produce beneficiated coal products with sufficiently low levels of impurities – particularly ash – to be used in specialty applications such as incorporation into liquid fuels, utilization in smelting operations, or production of high-purity carbon products[1]. Recent studies point toward achieving low enough levels of contamination, particularly moisture and ash as key challenges for success, which could potentially be met with micronized refined coal (MRC) beneficiation techniques[2,3]. Moreover, to the extent that these technologies are able to utilize fine coal waste as a feedstock, they have the potential to significantly improve the environmental profile of coal mining operations by reducing the need for fine coal slurry impoundments.

Coal Quality Requirements. Coal quality requirements for non-conventional markets can differ significantly from those required for power generation applications. Coal in the latter use is a source of energy, with its calorific value being the key quality parameter. Additional quality requirements can derive from the effect of moisture and ash content on shipping costs and plant equipment, as well as the effect of volatile matter content and ash composition on plant-specific ignition characteristics and slagging and fouling behavior, respectively.

Coal quality requirements for non-conventional markets are governed by its use in equipment such as gasifiers, its use as a metallurgical reductant, and its use as a source of pitch and carbon. Example quality parameters include the following:

<u>Ash Content</u>
Some applications – notably use as feedstock for granular activated carbon and reductant for silicon metal smelters – can require ash contents below 2 wt%. Needle coke and anode coke for electrode applications have even lower ash content requirements, and may also have maximum levels of individual impurities, such as vanadium (V), iron (Fe) and titanium (Ti). For some gasifiers, ash in the feedstock imposes a thermodynamic penalty which can impact coal use in CTL and CTC applications. The ash content in coal products used in pyrometallurgy is also a thermodynamic penalty.

<u>Ash Composition</u>
In some applications requiring very low ash contents there are limits on the presence of individual impurities. Broadly, for both gasification and metallurgical applications, ash composition will govern the requirements for adding flux in order to maintain slag fluidity. In the case of fluid bed gasification systems, the ash composition and its distribution across the composite coal will influence its propensity for agglomeration, and may preclude the suitability of a given coal source for this application.

[1] http://dels.nas.edu/resources/static-assets/besr/miscellaneous/Open-Session-Materials/CER/2018/October/Arnold,%20Barbara.pdf
[2] http://www.isamill.com/en/downloads/TechnicalPapers/Sedgman%20lecture%2010%20June%202015.pdf
[3] http://www.arq.com/docs/arq_white_paper_dec_17.pdf

Volatile Matter Content
Many applications for coal products in extractive metallurgy have requirements for volatile matter content. Coal beneficiation processes that use physical separations and thermal processing below 600ºF will not significantly influence volatile matter content. However, coal across the full range of volatile matter contents is mined in the U.S., and changing the volatile content of coal could result in having the new product compete with existing U.S. mined coals.

Moisture
Moisture can be undesirable in metallurgical applications, resulting in a thermodynamic penalty and, potentially, a significant safety hazard. Coal is currently thermally dried for some metallurgical applications. Inherent moisture can also be a penalty in gasification applications for liquid fuels or chemicals, where slurry-fed gasification systems are used. Excessive inherent moisture can make it impossible to keep the gasifier feed slurry at the optimum water content. On the other hand, extracted water can be recovered for later use within a gasification plant and/or coal-to-products conversion plant.

Coal Beneficiation - Market Attributes

At the time of this writing, a large-sized coal prep plant would typically be operating at a 500~1,500 tons per hour scale. The economic viability of these projects depends heavily on cost of steel and is anticipated to provide an ROI greater than 15%.

- Probability of Technical and Commercial Success – Estimated to be $\geq$ 80% for any new technology deployments since significant coal beneficiation plants are present and commercially successful in improving the quality of thermal and metallurgical coals. Research and development to enhance coal quality to more stringent specifications necessary for coal-derived advanced materials and products is required to adapt lower TRL technologies into existing commercially operating coal beneficiation plants.

- Cycle Time to deploy first commercial for new technology estimated to be 2~3 years

- Regulatory Attributes - Highly flexible plant operational capabilities, with minor to moderate regulatory hurdles/uncertainty, when deployed at existing commercial beneficiation plants.
    - Water: Coal beneficiation is expected to be water generating when deployed a drying mode that captures the incipient moisture released from coal
    - Air / CO_2: Air emissions are dependent on the thermal energy (heat) source employed. If coal is burned, then emissions will need to be considered and captured. For co-location with waste heat sources such a low-grade waste heat from cement or thermal power plants, then additional emissions are minor. Use of renewable electricity for heating is expected to result in near-zero air emissions.

Coal to Liquids

Coal-derived liquids first came to prominence in the 1850s, when kerosene was first distilled from coal tars for use as kerosene fuel in lanterns. These early coal-derived products ushered in the first coal liquefaction processes and the first modern industrial distillation practices. The one key advantage of converting solid carbonaceous materials, such as coal, into liquid fuels and chemicals is the improvement in ease of use – via pipeline transportation – and efficiencies in processing – in much the same way that liquids and gases are handled in the oil and gas sector today.

The key technical challenge for converting coal at high yield to liquids is coal's natural physical state, which is a highly carbonaceous solid. It is deficient in hydrogen (H_2) relative to typical petroleum-derived liquid transportation fuels.

From a technical perspective, coal liquefaction processes are viable, and hydrogen plays a key role for converting coal into desirable hydrocarbon liquids. From an economic perspective, the need for H_2 adds to processing costs. The three main liquefaction processes include:

1) direct coal liquefaction (DCL) process via hydrogenation/solvolysis;
2) indirect coal liquefaction (ICL) process via production, and subsequent chemical conversions of synthesis gas (syngas); and
3) thermal pyrolysis processing of coal.
    a. the low temperature pathway is focused on liquids as the desired products
    b. the high temperature coking pathway is focused on metallurgical coke as the desired product, with a relatively small yield of co-product liquids.

Processes that produce liquid fuels, chemicals, and synthetic natural gas (SNG) from coal can involve prior conversion of the coal to syngas (through coal gasification). Cleaned and chemically adjusted syngas is used as feedstock for chemical reactions that can produce fuels and chemicals. Among the fuels that can be produced are diesel fuel and methane (SNG). Chemicals that can be produced include methanol and ammonia (NH_3). Methanol can be used as feedstock for both chemical and fuel production such as olefins, gasoline, or dimethyl ether (DME). Ammonia, either itself or following conversion to urea, is a building block for fertilizers for agricultural markets. Urea is also used for diesel engine emission control to capture nitrous oxides (NOx) combustion products.

Indirect Coal Liquefaction to Chemicals (Olefins, Aromatics, Ammonia). ICL to chemicals – via methanol-to-olefins (MTO), methanol-to-propylene (MTP) and methanol-to-aromatics (MTA) – is a multi-step process illustrated in Figure Appendix A-3. This begins with coal gasification to produce syngas, followed by conversion of syngas to methanol, and then followed by conversion of methanol to olefins, propylene, or aromatics. The MTO process produces ethylene and propylene while the MTP process produces propylene, and the MTA process produces aromatics such as benzene, toluene, and xylenes (BTX).

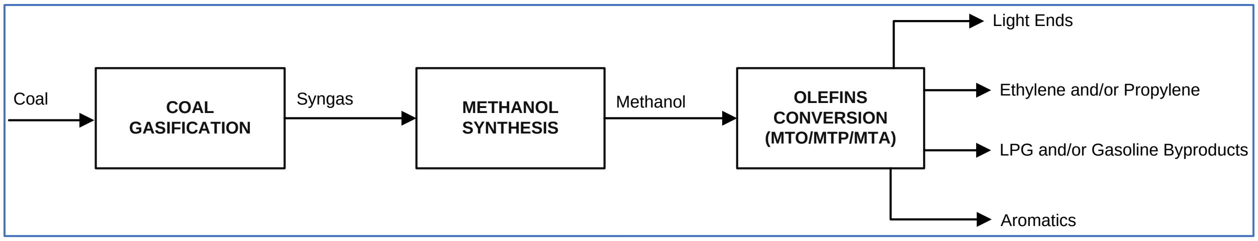

Figure Appendix A-3. Gasification-Based Coal to Chemicals Processes

The coal gasification process is a partial oxidation process. Because the gasification reaction only uses a fraction of the theoretical oxidant (air or pure oxygen) needed for complete combustion of coal to carbon dioxide (CO_2) and water, a mixture of primarily carbon monoxide (CO) and H_2 or syngas is formed. The composition of syngas can be adjusted depending on the downstream need of the gas. The major coal gasification technologies are based on fluidized bed, fixed-bed or entrained-flow processes and are available from many major technology licensors.

Methanol synthesis combines H_2 and CO to produce methanol via an exothermic reaction typically on a copper-based catalyst. The methanol synthesis process generally produces steam in a water cooled reactor that can be used in other parts of the process. Crude methanol, a mixture of methanol and water, is then typically sent to the methanol conversion process (MTO or MTA). There are seven major licensors of methanol synthesis technology and they include Air Liquide/Lurgi, Casale, Haldor Topsøe, Jacobs, Johnson Matthey, Mitsubishi, and Toyo.

MTO and MTP conversion technology can produce mixed light olefins (ethylene and propylene) or only propylene depending on the catalyst used and the technology offered. China remains the only country in the world operating MTO and MTP processes. MTO entered commercial operation in 2010 and MTP was commercialized shortly thereafter in 2011. Major licensors of MTO technology are SYN Energy, UOP, and Sinopec. Licensors of MTP technology are Air Liquide/Lurgi, and a joint venture group (Tsinghua University, China National Engineering Group Corporation (CNCEC) and Anhui Huaihua Group).

MTA technology produces a mixed aromatics stream composed of BTX. A fluidized bed MTA process was developed by Tsinghua University and Huadian Coal Industry Group. A fixed bed MTA process was developed jointly by the Shanxi Institute of Coal Chemistry.

Ammonia (NH_4) synthesis combines H_2 and nitrogen (N_2) to produce ammonia via an exothermic reaction. Ammonia is recovered by cooling and condensing liquid ammonia and serves as the key precursor for urea and other nitrogen-bearing fertilizers. Major licensors of ammonia synthesis technology include KBR, Casale, Haldor Topsøe, and thyssenkrupp.

Olefins and aromatics are the basic building blocks for most of the petrochemical industry. The commercially important olefins are ethylene and propylene, and the commercially important aromatics are benzene and para-xylene. Global consumption of ethylene, propylene, benzene, and para-xylene in 2018 is estimated to be 160 million tons, 109 million tons, 50 million tons, and 47 million tons, respectively. The primary use of ammonia is in fertilizer applications, either directly applied or as an intermediate for the production of nitrogenous fertilizers. Global consumption of ammonia in 2018 is estimated to be 179 million tons.

Indirect Coal Liquefaction to Chemicals - Market Attributes

- U.S. Competitiveness - Coal-based MTO plants for the production of olefins (ethylene and propylene) were commercialized in China, supported by government efforts to reduce the country's dependence on petroleum and petrochemical imports. While coal is also an abundant natural resource in the U.S., coal-based production of olefins is currently not competitive with conventional steam cracking processes which have lower capital intensity.

  Furthermore, with the advent of shale gas in the U.S., ethane and NGL cracking have emerged as the lowest cost production route for olefins. Low cost natural gas is also the primary driver for ammonia plants in the U.S., which are based on steam reforming technology that consumes natural gas rather than gasification technologies that consume coal.

  Conventional routes to benzene and para-xylene in the U.S. are based on naphtha reforming due to the large gasoline production capacity in the region. At today's relatively low oil prices, naphtha-based aromatics have more competitive production costs than coal-based MTA processes that consume large volumes of methanol per unit of aromatics produced. There are no MTA plants in operation in the U.S.

- Current Gross Market Revenue Size **-** Based on 2018 global consumption of ethylene, propylene, benzene, and para-xylene and assuming United States average 2018 prices, the gross revenue for these products is approximately $330 billion. Considering ammonia will add another $54 billion.

- Current Gross Coal Volume Size - Estimated coal consumption into olefins (ethylene and propylene) production in 2018 is approximately 25 million tons. Approximately 10 million tons is consumed in MTA plants, and 90 million tons consumed in ammonia production. All coal consumption in these applications is in China.

- Future Potential Gross Coal Volume Size - Ethylene demand is expected to grow at an annual rate of 3.6 percent between 2018 and 2028, while propylene is expected to grow at 4.2 percent annually across the same period resulting in 123 million tons per year of incremental ethylene and propylene demand. Current coal-based olefins make up about 4 percent of global olefins capacity. The potential coal consumption through 2028 based on providing 4 percent of incremental olefins demand with coal-based capacity is 15 to 20 million tons of coal.

  Benzene demand is expected to grow at an annual rate of 2.7 percent between 2018 and 2028, while Para-xylene is expected to grow at 4.4 percent annually across the same period resulting in 40 million tons per year of incremental benzene and para-xylene demand. There is currently no coal-based aromatics production capacity. The potential coal consumption based on capturing 3 percent of incremental aromatics demand with coal-based capacity is 5 million tons of coal.

  Ammonia demand in China is expected to grow at 2.2 percent between 2018 and 2028. Assuming all additional production is satisfied by coal-based ammonia, the additional consumption of coal is 20 to 25 million tons.

- Required Investment Scale (Est) - MTO, MTP, and MTA technologies all require methanol as an intermediate which should be designed with a world-scale production capacity of 5,000 tons per day of methanol (or greater) to take advantage of economies of scale. On this basis, coal consumption of the upstream gasifier will be around 6,000 tons per day. Derivatives capacity via MTO is 600,000 tons per year of olefins (ethylene and propylene), MTP is 470,000 tons per year of propylene, and MTA is 420,000 tons per year (based on para-xylene). An investment in a plant to produce the full value chain from coal to olefins or aromatics in the U.S. is between $3.5 and $4 billion.

  Coal-based ammonia production based on large scale coal gasification plants similar in size to that which would support MTO, MTP, and MTA plants (i.e. 6,000 tons per day of coal consumption) will produce about 1.5 million tons per year of ammonia with a capital investment between $3 and $3.5 billion.

- Market Conditions for Profitability - The production of methanol or ammonia from coal is not strongly influenced by crude oil price fluctuations. As such, the cost of ammonia and the cost of producing of methanol to the derivative plant (MTO, MTP, or MTA) are relatively stable. These derivative technologies, however, produce byproducts whose prices are influenced by crude oil prices. High crude oil price will provide higher byproduct values, thus reducing the cost of production of olefins or aromatics produced by MTO, MTP, or MTA, making them more competitive at high oil prices compared to low oil prices.

  In the U.S., for MTO, MTP or MTA, all three coal-based technologies will require oil prices in excess of Nexant's high oil scenario ($90/bbl based on Brent Crude Oil) to achieve a positive return on capital. The greatest hurdle to economic viability is the high capital investment required for the multiple steps required to convert coal to olefins or aromatics.

  For ammonia production using coal, which does not produce byproduct hydrocarbons influenced by oil price, cost of production based on $13/ton (metric ton) coal from the Powder River Basin is near parity with conventional production at $3/MMBTU natural gas. Investment cost for the coal-based ammonia plant, however, is nearly twice that of the gas-based plant.

- Probability of Technical and Market Success - Probability of technical success is 100 percent since ammonia, MTO, MTP, and MTA technologies are already in commercial operation. Probability of market success in the U.S. is currently very low due to the availability of lower cost (capital and production cost) alternative production routes.

- Cycle Time to Deploy First Commercial Unit - Ammonia, MTO, MTP, and MTA technologies are commercially available technologies. These are akin to large integrated petrochemical facilities and commercial project development time would be roughly 3-5 years.

- Regulatory Attributes, Emissions/Water Savings - Reuse of process water is fundamental to minimizing water consumption and discharge from the gasification, MTO or MTA process. In the gasification process, water is given a two-step treatment to remove dissolved gases (primarily acid gases) where carbon dioxide and hydrogen sulfide are removed. The majority of process water is recycled to the slurry preparation area or directly to the gasifier.

Indirect Coal Liquefaction to Fuels (FT, MTG, SNG)

Indirect coal liquefaction process can convert coal into fuels; for example, 1) into gasoline via methanol to gasoline (MTG), 2) into diesel via Fischer Tropsch (FT) conversion of syngas, 3) into synthetic natural gas (SNG) via methanation. Analogous to ICL to chemicals processes described in the previous section, these are all multi-step processes starting with coal gasification to produce synthesis gas.

Indirect Coal Liquefaction to Fuels (FT, MTG, SNG) – Market Attributes

- U.S. Competitiveness - Coal-based FT, MTG and SNG plants for the production of fuels (diesel, gasoline, methane) have been commercialized in the past 10-15 years in China, supported by government efforts to reduce the country's dependence on petroleum and natural gas imports. While coal is also an abundant natural resource in the US, coal-based production of fuels is not currently considered to be competitive with conventional petroleum refining and abundant natural gas supplies. Shale gas and shale oil in the U.S. have emerged as the lowest cost production routes for liquid transportation fuels and natural gas in the US. There is one large-scale SNG plant in operation in the USA that started up in 1984[4] and has demonstrated the ability to produce a slate of products including synthetic natural gas (SNG), ammonia-based fertilizers and CO_2 for enhanced oil recovery. No new projects have been announced.

- Current Gross Market Revenue Size - The target markets for coal-to-fuels is vast. Based on 2018[5] global consumption of crude oil and natural gas estimates, and assuming global average 2018 prices, the gross revenues for these two products are approximately $2.5 trillion and $500 billion respectively

- Current Gross Coal Volume Size - Estimated coal consumption for fuels production in 2018 was approximately 60 million tons[6]. With the exception of the Great Plains SNG plant in North Dakota and the Eastman Coal Gasification plant in Tennessee[7] nearly all other coal consumption in these coal gasification applications are in South Africa and, most predominantly, in China.

- Future Potential Gross Coal Volume Size - Current coal-based MTG gasoline fuels make up less than an estimated one percent of global fuels capacity. Although liquid transportation fuel demand is set to grow at a modest rate between 2018 and 2028, it is not expected that ICL to fuels projects will meet added demand.

Direct Coal Liquefaction to Fuels (diesel, gasoline, jet fuel). DCL[8] involves the solvent extraction of organic material from coal and the hydrogenation of the extracted material. Like the family of ICL processes, it can produce fuels and chemicals. Following the oil crisis of the 1970s, significant coal liquefaction R&D was undertaken in Australia, Europe, Japan and the U.S., although much of this development was subsequently put on hold as oil prices stabilized from the mid-1980s and through the 1990s. These included major coal liquefaction processes such as and illustrated in Figure Appendix A-4.

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[4] https://www.dakotagas.com/about-us/history/1980-1986
[5] https://www.statista.com/statistics/271823/daily-global-crude-oil-demand-since-2006/
[6] Estimates by this report
[7] https://en.wikipedia.org/wiki/Eastman_Chemical_Company
[8] Burke,F. P., Brandes, S. D., McCoy, D. C., Winschel, R. A., Gray, D. and Tomlinson, G., "Summary Report of the DOE Direct Liquefaction Process Development Campaign of the Late Twentieth Century: Topical Report" July 2001, DOE Contract DE-AC22-94PC93054.

• Exxon Donor Solvent (Exxon, USA) • H-Coal (HRI, USA) • NEDOL (NEDO, Japan)	• Solvent Refined Coal (SRC-I/II) (Gulf Oil, USA) • Kohleoel (Ruhrkohle, Germany)

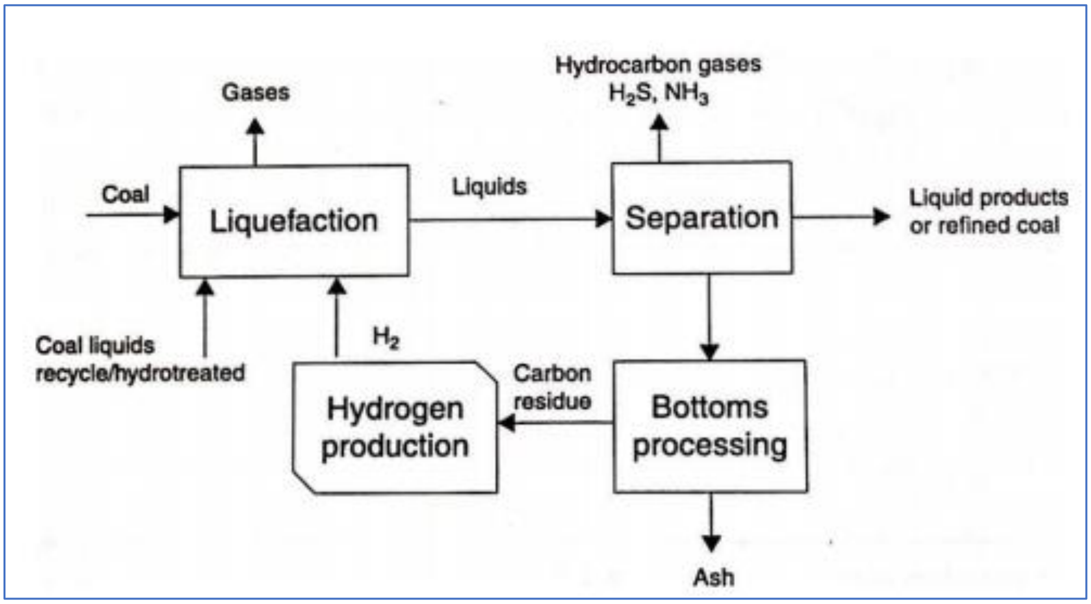

Figure Appendix A-4. Typical Direct Coal Liquefaction process[9]

DCL processes are fully developed and commercially utilized technology today in China, but have not yet been deployed at a commercial scale in the U.S. Coal conversion to liquids fuels provides a market opportunity to utilize U.S. coal resources to reduce and/or eliminate the net import balance of crude oil and petroleum products, produce strategic domestic fuels for national security and create new employment opportunities in economically distressed coal producing regions of the U.S.

Additionally, DCL creates synergistic opportunities with U.S. natural gas, by using the H_2 in CH_4 required for the DCL process. The synergies are especially evident in the Appalachian coal seams that overlay Marcellus shale gas production, and other regions where coal and natural gas are found nearby.

DCL can process a wide range of U.S. coal resources including bituminous, sub-bituminous and lignite. The liquid fuel yields are in the range of 4.0-4.5 barrels of oil per ton of bituminous coals and 3.5-4.0 barrels per ton for sub-bituminous coals and lignite. A DCL facility is very much the same as a petroleum refinery, refining coal instead of crude petroleum oil. The core conversion DCL process technology is a derivative of processes used in refineries for decades. After the coal is converted to liquid, the processing facility is identical to a petroleum refinery, with distillation processing to separate the fuel products and conventional refining processes to produce clean liquid fuels that meet U.S. EPA fuel standards for gasoline and ultra-low-sulfur diesel.

[9] Khan, M. R. (Ed.).(2011). Advances in clean hydrocarbon fuel processing: science and technology. Woodhead Publishing Series in Energy, 15-29.

Direct Coal Liquefaction to Fuels (diesel, gasoline, jet fuel) – Market Attributes

- U.S. Competitiveness – Vast coal resources and abundant low-cost natural gas. For DCL coal-to-liquids, this provides significant synergy, with the ability to produce low-cost hydrogen for the hydrogenation requirements of DCL.

- Required Investment Scale (est.) - The investment cost for a minimum sized commercial DCL facility with a production capacity of 10,000 BPD of liquid fuels (from 2,500 TPD of coal) is around $1 billion. A maximum sized single DCL train can process about 8,000-10,000 TPD of coal producing about 32,000-40,000 BPD of liquid fuels. The economic viability of these projects depends on the price of oil.

- Market Conditions for Profitability (est.) - The minimum price of oil required for a profitable DCL facility is in the range of $50-60/bbl.

- Probability of Technical and Commercial Success - Low or no technical risk based on DCL commercialization outside of the US. Market success is dependent on sustained oil price above $50-60/bbl.

- Cycle Time to deploy commercial project - Commercial project development time is 3-5 years.

- Operational viability, regulatory hurdles/uncertainty: Highly flexible plant operational capabilities with minor to moderate regulatory hurdles/uncertainty when deployed at existing commercial facilities.

- Water: Requirements are similar to existing petroleum refineries. Modern designs maximize water recovery and re-use in the facility. Main make-up water requirement is for evaporative losses of cooling water, which are minimized by maximum heat recovery and air cooling.

- Air/CO_2: DCL facility air emissions are within all state and U.S. EPA minor source requirements for permitting. The main source of CO_2 emissions from a DCL facility is from the hydrogen-producing unit and existing technologies are available for CO_2 capture.

- End-use products meet all U.S. EPA standards for gasoline (Tier 3) and diesel (ultra-low-sulfur).

Direct Coal Liquefaction to Chemicals. DCL is particularly well suited to the co-production of certain chemicals[10]. This is due to the fundamental chemical structure of coal. Coal has a very complex structure but within that structure are aromatic compounds (BTX isomers) that are high volume (about 100 MTPY) chemical commodities, used to produce plastics products and synthetic fibers. Since DCL involves the direct conversion of CTL, it is able to remove and retain the aromatic compounds from the coal. Once the coal is converted to liquid, conventional oil refining technologies can be used to produce high yields of high purity BTX chemicals.

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[10] [10] Burke,F. P., Brandes, S. D., McCoy, D. C., Winschel, R. A., Gray, D. and Tomlinson, G., “Summary Report of the DOE Direct Liquefaction Process Development Campaign of the Late Twentieth Century: Topical Report” July 2001, DOE Contract DE-AC22-94PC93054.

Today, most of the BTX is derived from petroleum. A small amount (< 5%) is coal-derived from coke oven light oils, mainly in China. The U.S. is a net importer of benzene and net exporter of xylenes. The importance and value of these chemical commodities is reflected by a growing trend in the oil refining industry today: Crude Oil to Chemicals (COTC). There are several announced COTC projects worldwide. Figure Appendix A-5 illustrates one such project in China.

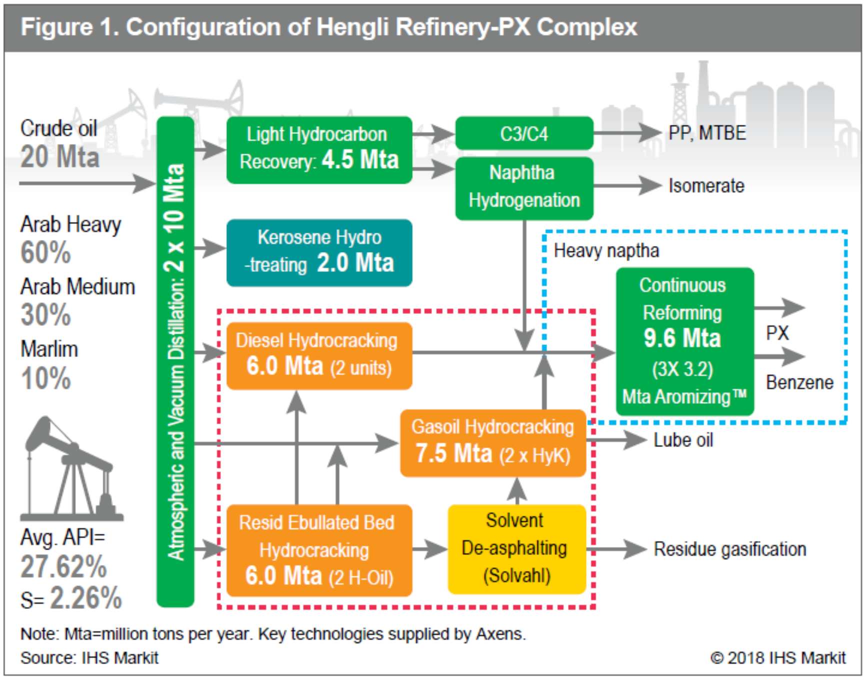

Figure Appendix A-5. Typical Configuration for Crude Oil to Chemicals (Naphtha Aromatics)

(Note this figure is copyrighted by IHS Markit[11])

Direct Coal Liquefaction to Chemicals – Market Attributes

- Configuration above outlines the possibility to produce 4-16 Million tons per year of benzene, toluene and xylenes (BTX) from coal, when coal is substituted as feed stock for crude oil. This BTX can be refined to produce high purity benzene and paraxylene (PX) which are the largest volume commodities in the BTX family of aromatic chemicals, and highest value.
- The major impact is on the investment cost for and revenue from the DCL facility. The investment cost is increased by 15% for the DCL facility. As high value chemical commodities are produced the revenue is increased by 30%.
- In terms of profitability compared to crude oil pricing, production of chemicals from coal can reduce this by about $10/barrel compared to fuels production, or about $40-50/barrel.

[11] Johnson, D. and Chang, R.J., "Crude oil-to-chemicals projects presage a new era in global petrochemical industry," Posted 06 August 2018 by IHS Markit , https://ihsmarkit.com/research-analysis/crudeoil-chemicals-projects.html

Coal to Liquids Coking (light oils, coal tars). Coal tar and coal tar pitch are produced as byproducts of high temperature (1000ºC) coke-making. In the early 20th century, large quantities of light oils and coal tars were used as feedstocks for other industrially important chemicals including wood preservatives, synthetic dyes, explosives and early plastics. They have had many uses industrially, including in consumer products, and were largely displaced by petroleum-derived substitutes in the mid-20th century. Coal tar pitch products, which are distillate products of coal tar, are used today primarily as binders for aluminum smelting electrodes, in roofing materials, surface coatings and pavement sealants.

In the U.S. the availability of coal-derived tars and light oils has steadily decreased, due to the off-shoring trend of the steel making industry, together with a trend toward new means of steel production via 'mini mills' which do not require as much coke. Additionally, there's been a trend toward non-recovery coking operations, whereby coke-oven byproducts are consumed as fuels to supply heat for the coking operation versus recovery for their chemical product value.

The fate of this route for coal products expansion is tied closely to fate of the metallurgical coking industry, and because the co-product amounts of coal tar are relatively low (3~4% yield), we would not expect to see new coking facilities built solely on the economics of the coal tar value alone. Instead we could envision the development of on-purpose coal tar production.

Coal to Liquids Pyrolysis (light oils, char, coal tars) – Coal-derived tars can also be produced via mild-temperature (500ºC) pyrolysis of coal. One such process, developed with DOE support in the 1990s, was known as the Encoal Process[12,13,14]. The main focus of the Encoal work was on the production of a boiler-compatible char fuel and refinery compatible liquids. During the 2000s, additional work[15, 16] focused on characterization, and upgrading of the liquids.

Although the Encoal work did not lead to commercialization in the U.S., a sizeable coal-based mild-temperature pyrolysis industry has emerged in China in recent years to produce liquids to be used mostly as blend stocks in transportation fuels and coal char or semi-coke to be used as blend stock in metallurgical operations. It was estimated[17] that 4 million metric tons per year (MMTPY) of low-temperature pyrolysis coal tar is produced annually in China. One of the leading producers is the Shenhua Company, which has commercialized its CoalRef® suite of process technologies [18, 19].

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[12] DOE/ME/27339-4088; The ENCOAL® Project Initial Commencement Shipments and Utilization of both Solid and Liquid Products, ENCOAL CORPORATION, March 1995

[13] DOE/FE-0409; ENCOAL® MILD COAL GASIFICATION PROJECT - PROJECT PERFORMANCE SUMMARY; ENCOAL CORPORATION, CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM, November 1999

[14] DOE/NETL-2002/1171; The ENCOAL® Mild Coal Gasification Project: A DOE Assessment; U.S. Department of Energy, National Energy Technology Laboratory, March 2002

[15] E. R. Skov, D. C. England, J. C. Henneforth and F. G. Rinker; Syncrude and Syncoal Production by Mild-Temperature Pyrolysis Processing of Low-Rank Coals; AIChE Spring National Meeting, Houston, Texas, April 2007

[16] E. R. Skov, D. C. England, F. G. Rinker and R. J. Walty; Coal-Tar Chemicals and Syncrude Oil Production from Low-Rank Coals Using Mild-Temperature Pyrolysis; AIChE Spring National Meeting, Houston, Texas, April 2007

[17] Estimate based on total amount (20 million tons) in China https://www.globenewswire.com/news-release/2019/02/26/1742153/0/en/China-Coal-Tar-Industry-Report-2019-2025.html , less the amount (16 million tons) attributed to metallurgical coking https://www.itaorg.com/conference-pdfs/presentation08-day1-Zhang.pdf

[18] Clean Coal Applications…NICE Perspectives; Chang Wei, National Institute of Clean and Low Carbon Energy (NICE), Shenhua Group, 02 February 2015 https://slideplayer.com/slide/6282071/

[19] http://www.nicenergy.com/en/html/RD_field/focusfield/

Coal to Liquids Pyrolysis (light oils, char, coal tars) – Market Attributes

- U.S. Competitiveness – China has invested significant resources into low temperature pyrolysis with a first to market vs other countries, apparently building upon the Encoal base technology from U.S.
- Current Market Size – estimated 4 million tons of coal / year
- Future Potential Gross Coal Vol Size – This is considered to be a mixed opportunity, on the one hand there would appear to be growing market for specialty coal tar pitches, but on the other hand the coal char coproduct (>75%) may grow at a more metered pace.
- Required Investment Scale (est.) - Expected to be less capital intensive than traditional coal liquefaction (ICL and DCL) processes because the operating pressures are not elevated and there is no need for hydrogen co-feed.
- Market Conditions for Profitability(est.) - Based on the current State-of-the-Art, coal pyrolysis is competitive with petroleum at approximately $50/bbl
- Probability of Technical and Commercial Success - Technology is currently being practiced in China and other countries. However, to penetrate the U.S. market, the current state of the art would need to be improved by increasing yields or modularization to reduce capital cost.
- Cycle Time to deploy first commercial - 2 to 5 years
- Regulatory Attributes:
    - Water – the process is net positive water.
    - Emissions – depending on site conditions, plants could be near zero emissions.
    - End-use products would improve U.S. energy security and competitiveness.

Coal to Carbon Products

Carbon materials have many general properties which makes them attractive in various applications. Conventional carbon materials include graphite, carbon black and activated carbon materials. New carbon materials with tailored properties have recently been developed, including carbon fibers (CFs), highly oriented graphite and many others. Most recently, even more sophisticated nano-sized or nano-structured carbon materials such as graphene have been produced. All can be produced from coal, and in many cases, coal is a preferred precursor due to its high carbon content.

These coal-derived products serve in a diverse set of end-use applications covering aerospace, defense, automotive, environmental, agricultural, industrial electrodes, battery storage and others, building products and others. All are mainly in specialty applications with high performance criteria, such as exceptionally high durability, strength, electrical conductivity, thermal conductivity, corrosion resistance and light weight properties. These materials are often used in their pure form, and emerging as key components in mixed material composites, in alloying, and as additives in commodity materials such as concrete and asphalt used in construction and transportation sectors.

Graphene is one of the newest materials joining the ranks as a coal to carbon product, as an actively researched focus area. It is being considered as a new material in many of the sectors mentioned above and specialty applications in the field of medicine. These and other related coal-to-carbon product summaries have been reported in recent years by the UK-based IEA Clean Coal Centre [20,21], which is supported by the IEA.

The focus on coal-to-products (C2P) initiatives is not entirely new. With DOE support, roughly 25 years ago, the CPCPC[22] was formed to research new C2P initiatives, especially in the field of advanced carbon materials. The consortium was established with West Virginia University (WVU) as its charter member, DOE providing base funding, and Pennsylvania State University (Penn State) managing the academic-industrial partnership.

The consortium's activities included collaboration with both the coal production and carbon manufacturing industries, as well as the DOE and other academic institutions. In addition to producing research results relevant to the use of coal for producing carbon products, the consortium also helped produce a pool of graduates with the required skill sets to work in the carbon industry.

The consortium generated a body of research results which are relevant to the production of carbon products from coal.

• Activated Carbons	• Coatings for Solar Collectors
• Adsorbents for Flue Gas Cleaning	• Graphites
• Anode Coke	• Microporous Carbons for Hydrogen Storage
• Carbon Electrodes for Batteries and Fuel Cells	• Nanofiber Sheets
• Carbon Fibers	• Nanoporous Carbons for Ultracapacitors
• Carbon Foams	• Needle Coke
• Carbon Nanotubes	• Pitches, Including Mesophase Pitches
• Catalysts	• Solvent Extraction Products

Table Appendix A-1. CPCPC Research & Development focus topics

The consortium also provided market size estimates for leading coal-to-product opportunities in the 2011 timeframe, for pitch, anode coke, needle coke, carbon black, carbon fiber and others.

Activated Carbon

Activated carbon is a form of carbon generated via thermal or chemical processing of a carbonaceous feedstock such as coal (also wood and coconut shells), resulting in a porous material with high surface area. Its key forms include granular, powdered, extruded and fiber. Applications include purification of liquids and gases, from water treatment to in-duct removal of toxic compounds in gases and power plant exhaust emissions and to filtration media for breathing masks.

[20] Non-Fuel Uses of Coal, Herminé Nalbandian, IEA CCC Ref: CCC/236 ISBN 978-92-9029-556-3; IEA Clean Coal Centre, May 2014

[21] Non-Energy Uses of Coal, Ian Reid, IEA CCC Ref: CCC/291 ISBN 978–92–9029–614-0; IEA Clean Coal Centre, Nov 2018

[22] Enhanced Hydrogen Economics via Coproduction of Fuels and Carbon Products DE-FC26-06NT42761; Final Report Period of Performance, 1 Apr 2006 - March 31 2011; 11 October 2011 Sponsored by: U.S. Department of Energy National Energy Technology Laboratory

Activated carbon has many applications, driven by both health and environmental considerations. There are well-developed markets and technologies for the current applications, with many different products designed for specific uses. Feedstocks for activated carbons vary, and can include raw or beneficiated coal depending on the product characteristics required. Potential expansion areas are described in this section. The IEA Clean Coal Centre[23] has stated activated carbon costs range by a factor of ten, from about $0.23 to $2.30/lb. New activated carbon products and applications will likely be within this range.

Activated Carbon – Market Attributes

- U.S. Competitiveness – Activated carbon could be developed as a First-to-market vs other countries in terms of its potential use as a regenerable sorbent for carbon capture, utilization, storage (CCUS). Activated carbon serves as important health, safety and environmental products due to its use in air purification and water purification
- Current Gross Market Rev Size (Target Market) - The current global market for activated carbon is estimated at $2.8 billion, with growth to over $6 billion by 2025.
- Current Gross Coal Vol Size - Current domestic use of activated carbon approaches the equivalent of 1.3 million tons of coal. Translating this to global use suggests potential of about 5.7 million tons of coal worldwide. Assuming half of activated carbon is produced from non-coal feedstocks, the total current coal usage is estimated at 2.8 million tons.
- Future Potential Gross Coal Vol Size - Various new markets, detailed below, provide expansion potential.
- Required Investment Scale (est.) - The incremental investment to make differentiated products is small compared to that in the overall production facilities, which are currently under-utilized. The appropriate developmental investments could result in products designed to address key new markets. Relatively small investment levels (on the order of $1 million or less) can result in a high probability of success for new activated carbons.
- Cycle Time to Deploy - The target new markets discussed below vary in their implementation timeframe. While use of activated carbon for disinfectant byproduct control (DBP) applications is needed now, there is also market growth described. An area of tremendous potential growth that is farther out in time is deployment of activated carbon as solid sorbents for CO_2 control (CCUS).
- Regulatory Attributes - The use of activated carbon is heavily driven by regulations. From air toxics control to water standards, improving health and the environment is often the primary goal. Purification is needed in many forms in industrial processes, and product quality is also a driver in pharmaceutical and other uses. Manufacturing of activated carbon from coal can be accomplished with a small environmental footprint, and BACT standards in the U.S. dictate stringent emissions levels. At least one major manufacturer also recovers the process heat for power generation on-site, offsetting CO_2 emissions significantly.

[23] Non-Energy Uses of Coal, Ian Reid, IEA CCC Ref: CCC/291 ISBN 978–92–9029–614-0; IEA Clean Coal Centre, Nov 2018

- Growth Areas - Domestic growth opportunities for activated carbon include developing new applications, driven in part by regulations such as disinfectant byproducts or utilization in new applications such as solid sorbents for CO_2 control. Water treatment in industrializing countries represents a larger long-term potential market. Other opportunities for market growth include the fracking industry[24] and soil remediation[25, 26]. See Figure A-6 below for overall N. America growth projections.

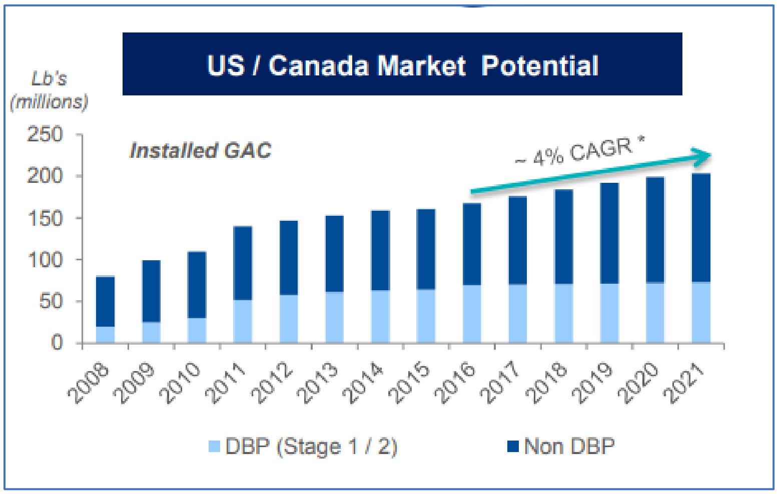

Figure Appendix A-6. North American Activated Carbon Growth Projections
(Note this figure is copyrighted by Calgon[27])

Additional markets are described by IHS in their Chemical Economics Handbook[28]. Gas stream applications are expected to continue to grow, such as removal of H_2S from biogas streams as applied to landfills, anaerobic digesters, and wastewater treatment plants. A new emerging use for activated carbon is in capacitors and batteries for energy applications (e.g., batteries used in hybrid vehicles). Although the energy field is a long-term application, this could be a significant market for activated carbon in the future. Similar to the significant recent growth in demand spurred by the implementation of the Mercury and Air Toxics Standards (MATS) in the U.S., and specialty products developed to meet that demand, the Minamata convention is continuing to be implemented around the world, driving further utilization of activated carbon.

A new application yet to be fully realized is the potential for carbon capture. The IEA Clean Coal Centre[29] reports that removal at higher temperatures than amine solvent-based systems can allow highly efficient adsorption of CO_2 from syngas (pre combustion) streams. This work is in the trial stage.

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[24] https://www.mordorintelligence.com/industry-reports/united-states-activated-carbon-market
[25] https://www.futurity.org/activated-carbon-polluted-soil-1567692/
[26] https://www.epa.gov/sites/production/files/2018-04/documents/100001159.pdf
[27] http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NjYyODk2fENoaWxkSUQ9MzcwMDgxfFR5cGU9MQ==&t=1
[28] https://ihsmarkit.com/products/activated-carbon-chemical-economics-handbook.html
[29] Non-Energy Uses of Coal, Ian Reid, IEA CCC Ref: CCC/291 ISBN 978–92–9029–614-0; IEA Clean Coal Centre, Nov 2018

Coal to Carbon Fiber
Carbon fibers are fibers about 5-10 micrometers in diameter, composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

Carbon fibers are usually combined with other materials to form a composite. When impregnated with a plastic resin and baked, it forms carbon-fiber-reinforced polymer (CFRP) which has a very high strength-to-weight ratio, and is extremely rigid although somewhat brittle. Carbon fibers are also composited with other materials, such as graphite, to form reinforced carbon-carbon composites, which have a very high heat tolerance. Currently, 90% of carbon fiber is produced from petroleum-derived polyacrylonitrile (PAN) and less than 5% of carbon fiber worldwide is currently produced from petroleum and coal-tar pitch.

The graphitic pitch-based carbon fibers, however, have the most commercially desirable properties, being distinguished by high mechanical stiffness (high modulus), high heat and electric conductivity, zero coefficient of thermal expansion, and high dimensional stability. The use of these high and ultra-high modulus (HM/UHM) pitch-derived carbon fibers can improve the efficiency of electronics, energy storage solutions, and industrial processes across the board, and enable and support adoption of new construction and energy technologies. The use of pitch-based carbon fiber, however, is currently limited to the most demanding applications in aerospace, defense, and high-end sports equipment industries, because of its high cost of production. Market prices exceed $80/kg – 4-5 times more costly than regular PAN-based carbon fiber, but emerging new technologies may reduce the costs below those of incumbent PAN-based fibers.

Coal to Carbon Fiber – Market Attributes

- U.S. Competitiveness - Carbon fiber is a strategic material, indispensable to the United States' security and competitiveness in the global arena. The total aerospace and defense market volume of carbon fibers in 2018 was an estimated 15,500 tons (i.e. ~40% of total U.S. carbon fiber consumption). Fast growing applications are in infrastructure, energy, and transportation for the purposes of reducing the use of energy-intensive, and heavy materials, such as steel and concrete. Other fast growing applications include in the advanced hydrogen economy, improving the efficiency of automobiles, and lowering the costs of distributed renewable wind energy generation.

- Current Gross Market Rev Size - The global carbon fiber market estimates:
    - 2016 $1.96 billion; 2016-2022 CAGR: 11%; 2018 tonnage: ~78,500 tonnes (est)

- Primary Growth Opportunities:
  - Carbon fiber for automotive use:
    - Transportation sector is responsible for 27% of the nation's carbon emissions, 29% of total energy consumption, and 70% of petroleum consumption.
    - Reducing the weight of vehicles will significantly reduce reliance on imported energy and vehicle-related pollution. Carbon fiber has the highest weight reduction potential, as it is 50% lighter than steel with same strength and stiffness
    - Carbon fiber use in the automotive industry is currently hindered by the high cost (570% the cost of steel today)
    - Present global market: $250 million
    - Projected global market by 2028: $3 billion (if only 1% of the luxury car segment were carbon fiber)
  - Carbon fiber in construction / infrastructure:
    - UHM (coal-derived carbon fibers) widely used in Japan for seismic reinforcement and repair of concrete structures
    - Piloted in the United States for non-disruptive reinforcement of concrete overpasses.
    - Reinforcement of steel beams is another high impact application
    - Non-corrosive cost-effective carbon laminate reinforcement eliminates costly capital repairs or bridge replacement.
    - Benefits include, the reduction in the use of steel and concrete for new construction, and enables long term non-intrusive repairs in reinforcement projects.
    - 2018 use (United States): 17,500 tons; 2018-2023 CAGR%: 10.4%
  - Carbon fiber in energy:
    - Higher stiffness and lower mass are crucial parameters for wind turbine blades exceeding 40 m in length. Use of carbon fiber allows blades to reach lengths of 100 m, increasing generation efficiency and allowing more wind energy to be harvested per generator
    - Other energy applications include:
      - Cryogenic pressure vessels for transportation of hydrogen, LNG and other industrial gases and fuels;
      - Efficient, temperature-resistant heat conductors for solar concentrators,
      - High-conductivity and high-purity electrodes for energy storage solutions,
      - Corrosion-resistant, chemically inert heat exchangers and conduits for various energy and chemical processes.
    - 2018 use (United States): 10,400 tons; 2018-2023 CAGR%: 11.8%

- Current Gross Coal Vol Size - Coal tar, a by-product of metallurgical coal coking, is used to make carbon by only two companies (Nippon Steel and Mitsubishi) who produce coal-derived ultra high modulus (UHM) carbon fiber.
    - UHM fibers are 4-5 times more costly than regular carbon fiber, and are estimated to account for ~5% of the total carbon fiber market; translating into an annual production of 1,100 tons
    - For high-temperature metallurgical coking, yield of coal tar pitch is roughly 50 lbs per ton of feed coal,
    - Gross coal requirement to produce 1,100 tons of coal-derived carbon fiber can be estimated at 0.15 million tons today, this estimate is based on using relatively low coal tar yields (4%) from metallurgical coking operations; if instead, new on-purpose pitch production facilities could be built with order of magnitude higher yields (25%~50%) then this would reduce requisite coal feeds proportionally, same logic prevails throughout this section.

- Future Potential Gross Coal Vol Size - Projected global demand for carbon fiber is expected to exceed 260 thousand metric tons by 2025
    - If all this demand was satisfied in its entirety with coal-derived carbon fiber, then this demand would correspond to 38.2 million tons of coal / year assuming coking ovens as the source of coal tar pitch, or a factor of ten less, if assuming commercialization of higher-yielding emerging technologies.
    - Note that achievement of 100% market share is not possible in practice and simply used here as a basis for sizing the market opportunity.

- Required Investment Scale - A spinning plant with nominal capacity of 500 tons of graphitic pitch-based carbon fiber may have a total estimated CAPEX range of $50M and $100M USD.

- Market Conditions for Profitability - N/A: Carbon material prices are disconnected from the oil prices. Price of feedstock (coal tar pitch) may be partially correlated to the oil price at high oil prices, but for the high-margin carbon products, the feedstock price is negligible.

- Probability of Technology and Market Success - Both the carbon fiber process and the carbon fiber markets exist and are commercially proven. The markets are growing, and can be further spurred with improvements in processes and technologies that would lower costs of feedstock and processing.

- Cycle Time to Deploy First Commercial Applications - Technologies and processes are available now and are in commercial operation in Japan (Nippon Steel, Mitsubishi) and, utilizing analogous petroleum pitch feedstock, in the United States. A new 500 ton/year spinning plant could be deployed in 24 months.

- Regulatory Attributes and Emissions/Water Savings
    - Yield losses due to volatilization occur during spinning and high temperature treatment steps (carbonization and graphitization) processes, these are considerably less when processing coal-based fibers than for PAN-based fibers; both processes retain the requisite compliant emission control devices. SO_X, NO_X and fugitive emissions of VOCs and PAHs need to be addressed in new plant construction.
    - Carbonization and graphitization are high temperature energy intensive processes.
    - Lightweight, advanced carbon materials such as carbon fibers have been identified by the Department's Office of Energy Efficiency and Renewable Energy (EERE) to improve vehicle efficiency by reducing weight, resulting in considerably lower emissions. In addition, carbon fibers are being used to improve building energy efficiency and to strengthen fiber reinforced concrete, which enables the use of less cement and results in lower CO_2 emissions attributable to cement production.

Coal to Graphite and Electrodes

Graphite is a naturally-occurring form of crystalline carbon. It is extremely soft, cleaves with very light pressure, and has a very low specific gravity. In contrast, it is extremely heat resistant and nearly inert in contact with almost any other material. These extreme properties give it a wide range of uses in metallurgy and manufacturing. Graphite is used in pencils, lubricants, crucibles, foundry facings, polishes, arc lamps, batteries, brushes for electric motors, and cores of nuclear reactors, and is on the list of strategic materials.

Graphite's electrical conductivity properties are ushering in a large new market in the field of energy storage applications, which is growing rapidly thanks to ubiquitous consumer electronics and the growing market share of electric vehicles and intermittent (renewable) power generation.

Naturally occurring graphite (mined extensively in China, India, Brazil, North Korea, and Canada) has significant impurity and ash contents (> 5%) and therefore must be purified extensively for the most demanding applications. Extensive processing raises its final price by a factor of 15-20 and makes synthetic graphite a competitive and attractive alternative, especially for demanding energy storage applications.

Synthetic graphite is a man-made substance manufactured by the high temperature processing of amorphous carbon materials. Many types of amorphous carbon are used as precursors to graphite, and can be derived from petroleum, coal, or natural and synthetic organic materials.

The main markets are for carbon electrodes including 1) electric arc furnace (EAF) electrodes in the steel, ferroalloy, and silicon metal industries, 2) carbon anodes in Aluminum smelting operations, 3) and as anodes for lithium-ion batteries. In the case of the EAF electrodes for steel industry, these are graphite electrodes. In the other applications, electrodes may not be graphitized which is an important distinction as the graphitization properties of the coal-derived carbon feedstocks can be less important and thereby potentially increase markets for coal products.

Two feedstocks common to the production of these electrode products include “binder” and “aggregate” or “filler.” Binders are pitches, produced from either coal tar (recovered from coke production) or petroleum products. Aggregates are typically solid carbons, derived from coal or petroleum, depending on the material requirements. In addition to pitch, cokes for use as aggregate can be derived from coal (pitch is the intermediate), or coal itself. In the latter case, calcined anthracite is used as aggregate for cathodes for aluminum smelters, and for electrodes for ferroalloy and silicon metal production. Anodes for aluminum smelters require a very low ash content to maintain product purity, and anode coke for aluminum production is typically produced from low ash content petroleum products.

Anodes for aluminum reduction furnaces are produced from anode coke, which requires a very low ash content, and pitch, with the anodes being consumed in the smelting process. Anode cokes are produced from petroleum products.

Graphite (EAF) electrodes for the steel industry require high conductivity and resistance to chemical attack in the furnace environment and then graphitized. This requires the use of needle coke as the aggregate which commands a significant price premium over other carbon feedstocks. Other synthetic graphite products such as anodes for batteries can share these feedstock requirements.

Coal to Graphite and Electrodes – Market Attributes

- U.S. Competitiveness - Graphite is a strategic material as classified by the Defense Logistics Agency. Graphite supports core industries such as aluminum smelting (cathodes) and EAF steelmaking (electrodes), and a number of advanced and emerging technology industries, such as: nuclear, space, electric vehicles and energy storage.
    - China dominates both natural and synthetic battery-grade graphite supply lines
    - Abundant coal resources and low energy costs give a natural advantage to the United States in the energy-intensive production of this important, strategic material

- Current Gross Market Rev Size - The global graphite market estimates:
    - $12.5 billion in 2016, projected to be $18.2 billion in 2021
    - CAGR of 7.7% from 2016 through 2021.

- Top Applications:
    - Industrial electrodes (EAF) for steel production result in a consumption ratio of about 1 and 3 kgs of graphite per ton of steel produced, resulting in an estimated global demand of 750,000 tons of per year.
    - Lithium-ion batteries for automotive and other applications typically contain about 1 kg of graphite per kWh of battery capacity. A single Tesla battery pack is estimated to contain as much as 85 kg of graphite. Current graphite demand for the electric vehicle market is roughly 30,000 tons per year, projected to reach 40,000 tons per year by 2020.
    - Non-graphitic carbon anodes for Aluminum production result in consumption ratio of about 0.40 and 0.45 kg non-graphitic carbon consumption per 1 kilogram of Aluminum produced. Roughly 60 million tons of primary aluminum was produced in 2018.

    - If 15% of these anodes are derived from coal tar pitch, then
        - 2015 demand: 5 million ton/year
        - 2020 projected demand: 6.2 million ton/year
    - If 65% is from calcined petroleum coke (with opportunity to replace with coal tar coke), then
        - 2015 demand: 22.8 million ton/year
        - 2020 projected demand: 27-29 million ton/year

- Current Gross Coal Vol Size - Industrial electrodes presently account for most of the coal-derived synthetic graphite market.
    - At present, needle coke is predominantly produced by the delayed coking of petroleum-derived decant oils (estimated 84% in 2010). The balance is produced from coal tar with 55-85% yield: 120,000 tons of needle coke requiring 0.2 million ton/year of coal tar
    - Aluminum production presently requires 5 million ton/year of coal tar

- Coal tar is a by-product of metallurgical coal coking. Yield of coal tar are roughly 50 lbs per ton of feed coal. Gross coal requirement to satisfy industrial electrode demand is 104 million tons of coal with metallurgical coal tar as the carbonization feedstock. Assuming new emerging on-purpose coal tar technologies of the future could increase coal tar yield by factor of ten, then the gross coal requirement to satisfy industrial electrode demand would be reduced by a factor of ten.

- Future Potential Gross Coal Vol Size – If all industrial electrodes could be entirely from coal-derived, then the
    - Aluminum industry could require 35 million ton/year of carbon anodes, and if an assumption is made that the yield from coking coal to carbon anode is only about 2.7%, then this corresponds to 1300 million tons of coal use *(presuming that new emerging technologies for production of coal liquids can increase yield by a factor of then, then approximately 130 million tons of coal would be consumed)*)
    - Steelmaking requires 750,000 ton/year of graphite corresponding to 27 million tons of coal / year *(2.7 million tons of coal, presuming new emerging technologies for production of coal liquids following similar logic as above)*

- Projected demand for graphite for energy storage may reach 400,000 ton/year by 2020.
    - Satisfied with coal-derived graphite, this demand would correspond to 14.5 million tons of coal / year *(1.45 million tons of coal if emerging technologies are used for production of coal liquids)*

- Required Investment Scale (est.) - For example, deployment of a 60,000 ton/year graphite electrode and cathode plant cost SGL Carbon[30] 200 million euro in 2009-2011.

[30] http://www.sglnewsroom.com/pdf/en/reports/report-detail-page.7044.pdf

- Market Conditions for Profitability - N/A: Carbon material prices are disconnected from oil prices. Price of feedstock (coal tar) may be correlated during times of high oil prices, but for the high-margin carbon products, the feedstock price is negligible.

- Probability of Technology and Market Success - Technologies (industrial electrode and energy storage) and respective markets are well established. Markets for incumbent technology (industrial electrodes) and emerging technology (EV batteries and energy storage) are both growing.

- Cycle Time to Deploy First Commercial Applications - Technologies are available now and are in commercial operation in Asia.

- Regulatory Attributes and Emissions/Water Savings
    - Graphitization is an energy intensive process.
    - SO_X, NO_X and fugitive emissions of VOCs and PAHs need to be addressed in new plant construction.

Coal Use in Metallurgical Applications

Metallurgical processes have used coal for centuries. Coal products are used today in both ferrous- and non-ferrous metals production worldwide, including coal produced in the U.S. The term "metallurgical coal" is commonly applied to coal that is fed to coke ovens. The resultant coke is used primarily in ironmaking blast furnaces, and to a lesser extent for other iron and steel applications and in non-ferrous extractive metallurgy. However, coal products are used in other metallurgical processes without coking. As such, the term "metallurgical coal" herein refers to any coal that finds its way into an extractive metallurgy value chain, and the term "coking coal" is used for coal that is destined for a coking process.

Non-ferrous metal smelting covers three key areas: 1) Aluminum smelting – consumption of pre-baked anode material, 2) EAF Steelmaking – consumption of EAF electrode material (synthetic graphite), 3) EAF Silicon and Ferrosilicon smelting – consumption of EAF electrode material (synthetic graphite). Aluminum smelting and EAF steelmaking have been covered elsewhere in this report. Additional details for silicon and ferrosilicon smelting as additional consumption of both carbon electrode materials and carbon reductant materials are covered in a recent DOE-supported report[31].

Coal to Carbides

Coal has been part of the global chemical industry since its earliest days. Calcium carbide, for instance, is made by reacting lime with coke – a coal derivative. Acetylene is easily derived from the calcium carbide and yields a range of materials including vinyl chloride for polyvinyl chloride (PVC) plastics and butanediol-based intermediates for spandex polymers. Although the rest of the world has largely switched to petrochemical-based vinyl's, to this day 30 million tonnes of PVC, a major portion of China's PVC, is made from acetylene via this coal-based route.

[31] Rozelle, P.L., E.W. Leisenring, and M.H. Mosser, 2018, "Coal Upgrading Technologies and the Extraction of Useful Materials from Coal Mine Products: History and Opportunities", U.S. DOE Office of Fossil Energy, 10.2172/1457712.

Before the petroleum age, acetylene-derived chemicals were the pillar for industrial chemistry. But since the emergence of an alternative feedstock of petroleum-derived ethylene, there's been a progressive reduction in coal-based acetylene production.

Acetylene still holds the promise of serving as a feedstock for aromatics and polyaromatics by new processing routes and new interests in polycyclic aromatics and nanomaterials, such as carbon blacks, which can be derived from acetylene. Other emerging technologies include graphene and carbon nanotubes produced from precursor acetylene. Additionally, new non-calcium lower-temperature routes are being explored as a means increasing the energy efficiency of acetylene production.

Coal to Carbides – Market Attributes

Calcium carbide is mainly produced and consumed in China. The U.S. currently has limited calcium carbide production, with only one large producer[32] based in Louisville, KY. The availability of low costs natural gas liquids (ethane) in the US, has created a very competitive ethylene position in the U.S. and favors the petroleum-derived routes currently here in the US. Carbide production cost reductions, by advancing the current state of the technology, could potentially improve competitiveness; e.g. preliminary research has shown that other alkali metals (or possibly catalysts) could be used to lower the processing temperature and improve efficiency by eliminating the requirement for high energy consuming electric arc furnace.

Coal to Graphene

Graphene has been called a "wonder material", as it offers an unrivalled combination of tensile, electrical, thermal and optical properties. Graphene is flexible and very strong, and in one aspect it is tougher than a diamond and stronger than steel. It is also transparent, impermeable to gases and liquids, and an excellent conductor – even better than gold and copper. These qualities could enable a vast array of breakthrough applications, from ultra-lightweight manufactured products and flexible displays to high-capacity batteries and memory chips to improved water desalinization. Graphene can be made from both anthracite[33] and bituminous coals[34].

Graphene could be increasingly incorporated into manufactured products. For example, it could reduce the weight of vehicles, cutting down both fuel consumption and resulting emissions. It is transparent: 97% of light passes through it and it is electrically conductive. This could make it very useful for developing the next generation of electronic devices such as solar panels and batteries. Incorporating graphene into batteries could increase performance via higher energy density, enabling longer cycle times in between recharging.

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[32] http://www.carbidellc.com/

[33] Sasikala, S.P., L. Henry, G.Y. Tonga, K. Huang, R. Das, B. Giroire, S. Marre, V.M. Rotello, A. Penicaud, P. Poulin, and C. Aymonier, 2016, "High Yield Synthesis of Aspect Ratio Controlled Graphenic Materials from Anthracite Coal in Supercritical Fluids", ACS Nano, Volume 10, 5293-5303.

[34] Awasthi, S., K. Awasthi, A.K. Ghosh, S.K. Srivistava, and O.N. Srivistava, 2015, "Formation of Single and Multi-Walled Carbon Nanotubes and Graphene from Indian Bituminous Coal, Fuel, Volume 147, 35-42.

Coal to Graphene – Market Attributes

The global graphene market was estimated at $25 million in 2015, and is expected to reach $300 million by 2022, growing at a CAGR of ~44% from 2015 to 2022.

Graphene has gained a foothold in the market in various touchscreen and electronic applications. Additional applications are being developed in the medical technology sector, as further described in the Life Sciences section of this report.

One hurdle for the fledging graphene products is manufacturing of large quantities at scale, in various formats, with high yield and purity and at affordable production costs in order to allow for broader market uptake. This challenge may ultimately be resolved with the use coal as feedstock. Coal is potentially a more economic feedstock than its leading competitor, natural occurring graphite.

In China, a noticeably large effort has been afforded to research and development of this potentially disruptive material. More than 50% of all global graphene related patents currently go to China.

Coal to Building Products (coal fly ash, coal combustion residuals, coal plastic composites).

Coal combustion residuals (CCR) is the latest term of art for the mineral component found in coal or the flue gas desulfurization byproducts resulting from coal combustion for electricity generation. Whether coal is combusted, gasified or treated chemically, the resulting mineral component has value in the construction products industry. Common uses for CCRs include additives to concrete, cement manufacturing, highway construction, wallboard manufacturing, roofing, abrasives, agriculture and various environmental treatment applications.

Historically most coal has been combusted for electricity generation. Extensive regulatory programs and utilization markets have developed around the CCRs produced by the combustion process. CCRs used in a beneficial applications also referred to as CCPs.

Coal plastic composites is an emerging area of potential coal use. In this developing application coal is contemplated as a replacement for wood filler in wood-plastic composites such as in outdoor decking and other uses. Given the early stage of these technologies the reader is referred to the compendium where additional details may be provided by individual technology providers/developers.

Coal to Building Products (coal fly ash, coal combustion residuals, coal plastic composites) – Market Attributes

The American Coal Ash Association (ACAA) performs an annual survey on CCR production and utilization. Based on the latest annual survey[35] (2017 data), a total of 111 million tons of CCRs were produced within the electric generation industry. Of that total production, 71.8 million tons or 64.4 %, were utilized in various beneficial uses.

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[35] Coal Ash Recycling Reaches Record 64 Percent Amid Shifting Production and Use Patterns, Nov 2018, press release, American Coal Ash Association https://www.acaa-usa.org/Portals/9/Files/PDFs/Coal-Ash-Production-and-Use-2017.pdf

- Market - The U.S. market for CCPs is currently about 70-75 million tons, with the opportunity to grow to a 100 million tons per year. Within each of the major usage categories, the penetration level for the market is low. As an example, the use of CCPs in concrete could be doubled by improvements to consistency of quality and expansion of the available sources with beneficiation technologies. Use of power plant gypsum in wallboard plants only has approximately 50% penetration of U.S. wallboard manufacturing.

- Gross Market Value - The market size for the combined uses is estimated to be greater than the total CCRs produced in the U.S. or greater than 150 million ton per year. It is estimated that the current market value is between $3 and $5 billion per year. Ironically, the value of CCPs to the U.S. market may have more indirect value than the purchase price of the CCPs. For the current CCPs utilization rate, the avoided costs for disposal are also in the range of $3 - $5 billion dollars per year. The intrinsic value of CCPs used in concrete products has the added bonus of reducing about 1 ton of CO_2 emissions per ton CCP utilization as a cement substitute. The CO2 savings which could be valued at $20-$50 per ton or up to $1.5 billion in total.

- Within the agriculture industry, gypsum is used for its' sulfur nutrient value. Behind nitrogen, phosphorous and potassium (NPK), sulfur is the fourth most necessary nutrient for higher crop yields. Power plant gypsum has a very high purity of calcium sulfate compared to most natural gypsum mined products therefore brings superior value to the agriculture applications as well as to the wallboard manufacturing industry. The value of this market is included in the $3-$5 billion products value listed above.

- Investment Scale - The markets discussed above are currently achievable market potentials at today's prices. Investments in beneficiation equipment at some sites will be required to grow the market penetration to higher ratios. These investments can be $25M-$100M per site, and as many as 20 facilities will need beneficiation installed, for a total of up to $2.5 billion.

- Deployment Cycle - The deployment of beneficiation investments for CCP product expansions can occur very quickly. To develop and install a new project requires approximately 24 months to design, permit and construct the required facilities. Introduction of the new products can take an additional 12-24 months after startup.

- Regulatory Attributes - Each beneficiation facility requires permits to construct and operate including air permits, water use and discharge permits and building/construction permits. In many cases the beneficiation equipment will be installed at CCR disposal units which are being reclaimed for the mineral CCPs. This activity is usually permitted by the solid waste permit related to the existing CCR disposal activity or a new reclamation permit.

Coal to Building Products – Emerging Coal Composite Technologies

In addition to the more established uses of coal combustion residuals in building products, several emerging technologies are seeking to use the coal itself as a feedstock for building applications. For example, coal core composites are being developed for use in roofing tiles and fire-resistant panels, and coal plastic composites are being developed as an alternative to the wood plastic composites commonly used in decking applications. These products show potential for being disruptive by offering certain cost and performance advantages (e.g., flexure strength, moisture resistance, and fire resistance) relative to currently-used materials, and do not require combustion or conversion of the coal, resulting in very low emissions.

Coal to Carbon Foam

Carbon foams made from coal also show potential for use in building material and structural applications, such as aggregate for lightweight concrete, proppants, non-combustible building materials, and components used in transportation and military defense items, which have the potential to grow to meaningful volumes. Currently, coal-derived carbon foam is being used commercially in small-volume, high-value applications with stringent performance requirements, including as a tooling material in the production of carbon-fiber composites for aerospace, military, and commercial goods

Graphitic carbon foam has a highly-oriented, low density graphite foam structure. Its main benefits include high performance attributes such as extremely high thermal conductivity, high compressive strength, high electrical conductivity, near-zero coefficient of thermal expansion and extreme lightweight properties.

The U.S. is the main consumption region (>90% of global consumption), dominated by demand from aviation, automotive and electronics sectors in which an increasing number of applications are requiring more efficient lightweight thermal management such as in high-density electronics, hybrid diesel-electric vehicles, communication satellites and advanced aircraft.

The market for carbon foam is estimated at $23M in 2017 and growing at CAGR rate of 6%, expected to reach $37M by 2025. Price of current carbon foams are relatively high, up to 500 $/kg. At the time of this writing, annual consumption volumes were not known; a simple estimation based on market and price per kg would indicate a relatively small volume of about 151 tons, likely used in specialty aerospace and defense applications.

Coal to Carbon Black

Carbon black is used to improve certain properties of the materials to which it is added, primarily for abrasion resistance in rubber tires and other rubber products; as a black pigment in coatings, printing inks, and plastics; and for conductive properties in some polymers and resins.

Production economics are very dependent on the specific feedstock for carbon black manufacturing. Coal-based feedstocks in China are supplied from massive metallurgical coking operations, typically enjoying a lower cost position than petroleum-derived carbon black feedstocks. The growth of carbon black is closely tied to the automotive industry and the production of tires. With the global automobile industry moving east to China, India, and Central and Eastern Europe, the tire industry has followed, and with it the carbon black producers.

Coal to Carbon Black – Market Attributes

- Market - The global carbon black market is expected to surpass $25 billion by 2020, growing at a CAGR of over 4%.

- Industry Supply - The total global capacity of carbon black stood at ~16 million tonnes in 2017, with China as the largest producer accounting for ~43% of the global capacity with more than 100 plants running. China is also the largest global consumer at 35%. China has experienced strong growth in the export volumes of carbon black, ~52% CAGR, during the period of 2010-14. China produces nearly 7 million tonnes per year of carbon black from wholly coal-derived feedstock.

  The global carbon black industry is concentrated in nature, with the top 10 players controlling ~ ⅔ of global capacity. The industry as a whole, exhibits relatively
  1. High capital intensity
  2. Project deployment cycle time (~2 years)
  3. Customer qualification timelines, due to stringent quality requirements (18-24 months)

- U.S. Competitiveness - The major proponent of growth for Chinese exports of carbon black has been the distinct cost advantage over global peers, which emerged as a result of the use of coal tar oil as the raw material feed. Coal tar is available in large quantities in China because it is a by-product of coking processes. China's carbon black exports grew rapidly starting in 2011 and then stabilized to around 640 thousand tonnes per year after 2014. This led to the capture of significant volume share by Chinese manufacturers. This phenomenal rise in the Chinese exports for carbon black also resulted in a situation of excess supply in the global industry.

  In theory, the opportunity exists for U.S. coal to play a similar role in the carbon black market. In practice however, the U.S. metallurgical coal coking industry is relatively small in comparison to China's; and much of today's coking capacity in the U.S. does not recover the coal tars, instead consuming these directly for integrated on-site heating purposes. New specialized on-purpose coal to coal tar technologies would need to be developed and commercialized.

- China Coal Tar Industry and Implications - As it relates to carbon black, a closer look at China's coal tar sector is illustrative, especially considering the upward of 20 million tons of coal-derived products that result from the coal tar industrial sector. High-temperature coal tar from the metallurgical coking industry, holds a dominant position in the Chinese market. In 2016, 16 million tons of high-temperature coal tar (from coking operations) and 4 million tons of medium-temperature coal tar (from pyrolysis processes) were produced. High-temperature coal tar from metallurgical coal coking operations were primarily used in high-value-added chemicals while medium-temperature coal tar was used in the fuel oil field, it is expected the former will grow faster than the latter.

China currently holds a position as the world's leader in metallurgical coke production. China's coke output has remained fairly stable over the past few years at ~420 million tons a year, accounting for 69% of the total global volume. Similarly, China's coal tar output, a byproduct of coking operations, kept pace at around 16 million tonnes per year (~4% of coke output). In 2017, the majority of this output was consumed by two large sectors, also shown below in Figure Appendix A-7:

1. Coal tar distillate products (pitch, anthracene, naphthalene), comprising about 12 million tonnes (74%)
2. Direct feedstock to carbon black at 3.5 million tonnes (21%) direct consumption, noting that carbon black processes can also consumes other coal tar distillate derivatives

Key Highlights

- China retains a very large scale and robust coal tar industrial segment.
- The supply chains have evolved along the lines of both specialty and commodity product lines, which compete directly with petroleum derived products.
- Market sectors which are growing include graphite materials for electrodes and anodes, carbon black and phthalic anhydride. All enjoy relatively high margins in large part due to the low price of coal, buoyed by the relatively high price of crude oil, which is customarily used as the key feedstock for competing products on the market.
- In China, it is also reported that coal tar serves as raw material for pharmaceuticals, agricultural chemicals, dyes, and synthetic fibers. At the time of this writing it was not known to what extent China is producing these specific specialty products from coal tar.
- These and other questions about China's coal-to-products industry are relevant to U.S. strategic interests and would be worthy of further analysis.

<table>
<tr><td rowspan="15">Matallurgical Coke Output
415 Mio tonnes</td><td rowspan="15">Coal Tar Liquid Output
16.45 Mio tonnes
(4% of coke)</td><td rowspan="13">Coal Tar Distillation
12.21 Mio tonnes
(74% of CTL)</td><td rowspan="5">Coal Tar Pitch
5.5Mio tonnes</td><td>Prebaked Al Anodes
EAF Steel Electrodes
Needle Coke</td><td>3.26</td></tr>
<tr><td>Export</td><td>0.62</td></tr>
<tr><td>Fuel oil</td><td>0.1</td></tr>
<tr><td>Other</td><td>0.35</td></tr>
<tr><td>Carbon Black</td><td>1.20</td></tr>
<tr><td rowspan="4">Anthracene Oil
2.54 Mio tonnes</td><td>Carbon Black</td><td>2.21</td></tr>
<tr><td>Hydrogenation</td><td>0.14</td></tr>
<tr><td>other derivatives</td><td>0.075</td></tr>
<tr><td>Export</td><td>0.028</td></tr>
<tr><td rowspan="4">Naphthalene Oil
1.26 Mio tonnes</td><td>Phthalic anhydride</td><td>0.84</td></tr>
<tr><td>Water reducer (FDN)</td><td>0.24</td></tr>
<tr><td>Dyestuff intermediate</td><td>0.20</td></tr>
<tr><td>Export</td><td>0.00</td></tr>
<tr><td colspan="3">Carbon Black
3.45 Mio tonnes
(21% CTL)</td><td>3.45</td></tr>
<tr><td colspan="3">Fuel oil, hydrogenation, other</td><td></td></tr>
</table>

Figure Appendix A-7. China Coal Tar Industry Structure – 2017 Estimations [36, 37]

Coal Derived Rare Earth Elements and other Critical Minerals

REEs and other critical minerals (CMs) are used in end products in critical sectors of the U.S. economy that include health care, military, transportation, power generation, petroleum refining, and electronics. Specific REE applications include magnets for wind turbines, batteries and magnets for vehicles, and phosphors for lighting products. As of 2014, the use of these elements, as reported by the American Chemistry Council, was supportive in North America of over $329 billion of economic output, with an associated employment figure of over 618,000 people.[38] The most valuable of these are the heavy REEs.

REEs that are commercially produced include 14 different elements that occur in nature and are produced together. Various elements find uses in different applications and the markets for individual elements are complex.

[36] BAI INFO Report entitled "*China Coking Industry Overview - China Coal Tar Demand & Supply Analysis*" by ZHANG Mi, from July 2018 https://www.itaorg.com/conference-pdfs/presentation08-day1-Zhang.pdf
[37] The accuracy of the BAI INFO report has not been further tested or validated. Some of the numbers may not be consistent with other sources, for example, this report does not appear to take into account the low temperature coal pyrolysis market in China is estimated to be about 4 million tonnes/year
[38] American Chemical Council, The Economic Benefit of the North American Rare Earths Industry, Economics & Statistics Department, American Chemistry Council, April 2014.

In May 2018, the Department of the Interior (DOI) published its "Final List of 35 Minerals Deemed Critical to U.S. National Security and the Economy"[39] which was compiled in response to White House Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals." Some items on the Critical Minerals list, such as vanadium and germanium and other REEs, have been commercially extracted directly from coal products. In other cases, coal is used as a reagent in the extractive metallurgy processes used to produce these commodities.

However, the U.S. is virtually 100% import-dependent for the raw materials for its REE-based manufacturing sector. Restarting production of rare earth commodities from U.S. mineral deposits can improve national security and help assure that the related manufacturing base and supply remains secure within the U.S. and grows.

REE extraction from U.S. coal and coal byproducts can have numerous advantages, including the development of domestic REE sources, use of the existing supply chains and labor force in U.S. coal-producing regions, and providing for economic improvements in those regions.

A proportion of coal deposits are naturally rich in rare earth elements (REE). The extraction of REE from raw coal or coal by-products (tailings, ash and aqueous effluent) holds real promise as an important method to secure the industrial supply of critical elements. A number of different groups are pursuing various technical paths that will result in viable options for commercial domestic production of REE oxides. Coal as a source of minerals has a history dating back to the 1940s when uranium was first extracted from coal seams. For this new REE-coal initiative the presence of a pre-existing mine operation and material handling systems may make the industry more competitive. Continued support at the federal level will be critical as these options move from bench to pilot-scale and finally commercial demonstration.

Coal Derived Rare Earth Elements and other Critical Minerals – Market Attributes

- U.S. Competitiveness – Currently the U.S. imports 100% of the REE from China. Due to the strategic importance of these materials, the U.S. needs to identify domestic sources for REE. In addition to the economic benefit to the U.S. provided in the overview above, a significant amount of the total U.S. consumption supports the U.S. military. For example, the U.S. Airforce and U.S. Navy both use sizeable amounts of RREs to produce advanced aircraft and naval vessels.

- Current Gross Market Rev Size - The global Rare Earth Elements market in 2015 was estimated to ~$5B (130,000 metric tonnes/yr)[40]. The major producers include China – 105,000 tonnes per year, Australia – 20,000 tonnes per year, Russia – 3,000 tonnes per year. Only minor amounts were mined in Brazil, India, Malaysia, Thailand, and Vietnam. Mine production from RRE ore was zero in US. Neither have REE's been commercially derived from coal or coal byproducts at the time of this writing.

[39] Final List of 35 Minerals Deemed Critical to U.S. National Security and the Economy https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018
[40] https://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/myb1-2015-raree.pdf

- Required Investment Scale - REE could be recovered either from coal or from coal by-products. For REE recovered from lignite coal, it is estimated that the minimum size for a commercial facility would be 50 ton/hour and would result in salable product of either upgraded coal or activated carbon. For either tailing from a bituminous coal cleaning facility or acid mine drainage, the expected size for a commercial operation is not known at present.

- Value Chain opportunities that could be realized using REE domestically produced from coal or coal by-products shown below in Figure Appendix A-8.

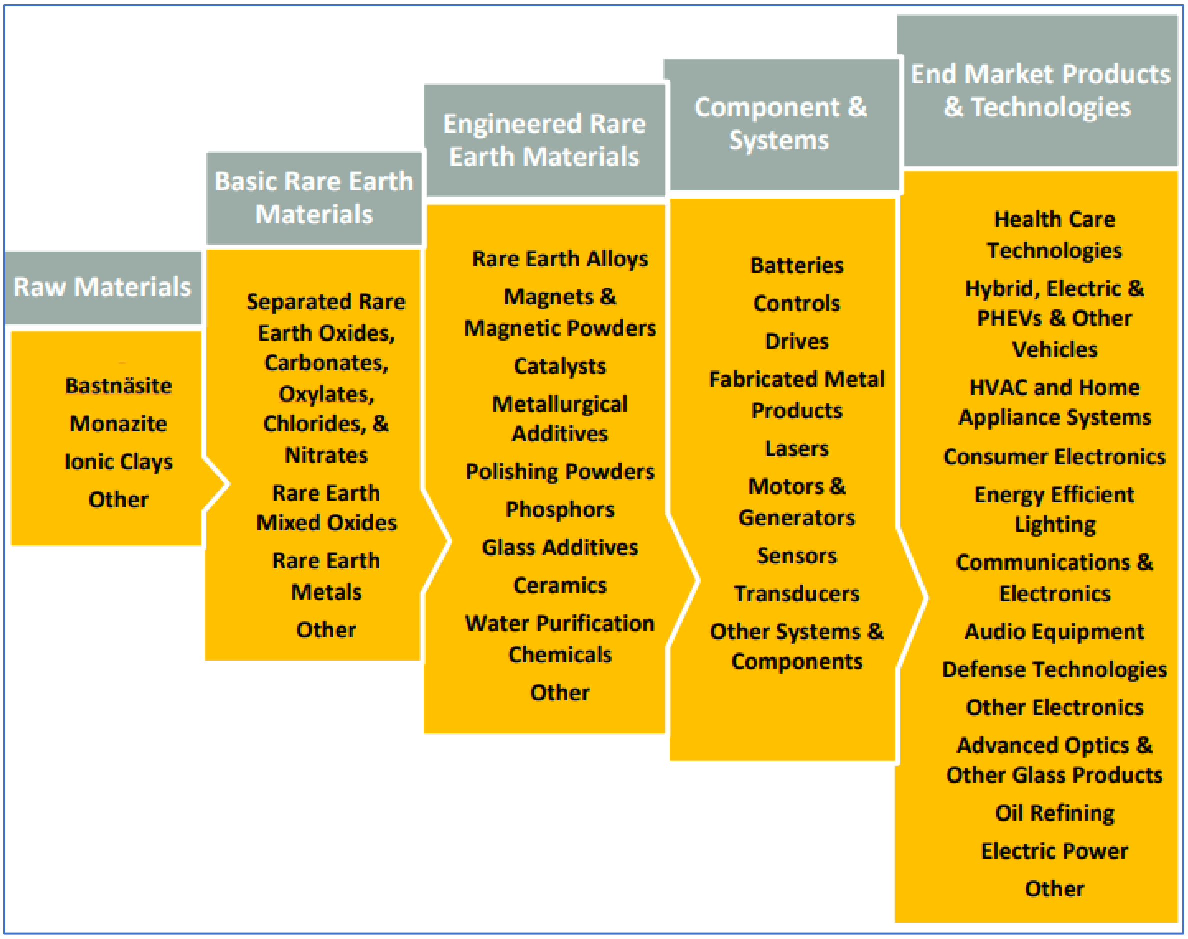

Figure Appendix A-8. The Rare Earth Value Chain [41]

[41] http://www.rareearthtechalliance.com/Resources/The-Economic-Benefits-of-the-North-American-Rare-Earths-Industry.pdf

Life Sciences and Medical

The history of coal in the chemical and pharmaceutical industry can be traced to the discovery and development of synthetic dyes from coal tar – a byproduct of town gas and the steel industry. In 1856, the first synthetic aniline purple dye was extracted from coal tar. During this period of history, the synthetic dye industry was the "high-tech" industry.

Modern pharmaceuticals have their origins in apothecaries (e.g. Merck, Schering, Hoffman-La Roche, Abbott, Eli Lilly, and Burroughs-Wellcome) that commenced to produce and sell drugs extracted from flora and fauna as well as in the organic chemical companies – especially dyestuffs[42] – (e.g. Bayer, Sandoz, Pfizer, and Hoechst) that moved from manufacturing dyes through extraction from coal tar to other organic chemicals, using the organic building blocks extracted from coal and coal byproducts. The development of pharmaceutical and medicinal chemistry, as well as pharmacology, as areas of rigorous research was the inflection point of apothecaries and the organic chemistry companies becoming blended into a recognizable pharmaceutical industry.[43, 44, 45]

- Graphene Medical Potential - Graphene's unique physical structure, as well as its chemical and electrical properties, make it ideal for use in sensor technologies. In the past years, novel sensing platforms[46] have been proposed around graphene. Several of these platforms were used to immobilize biomolecules, such as antibodies, Deoxyribonucleic acid (DNA), and enzymes to create highly sensitive and selective biosensors. The main reason for researchers to use this detection approach is that it is simple, rapid and presents good sensitivity. These coal-based biosensors can be particularly useful in life sciences and medicine, since biosensors with high sensitivity and specificity can significantly enhance patient care, accurate early diagnosis of diseases and pathogen detection in clinical practice.
- The markets for bio-sensors are both large in terms of near term revenues and at growth rates well above global GDP. Some examples of near term project revenues and growth: Rapid diagnostics ($38B, 7.6% CAGR), Cancer detection ($232B, 19.6% CAGR), Sequencing ($18B, 8.0% CAGR), Environmental and lab sensor ($20B, 7.7% CAGR).

BioTech and Agricultural Uses

Lignite coal has a history of use as a fertilizer; it is currently being assessed as a large-scale solution to help counter the problem of desertification with remediation. If upgraded lignite coal performs as an effective agricultural additive, then this could be a significant alternate high-volume use of a valuable resource.

[42] Chemical and Engineering News, Emergence of pharmaceutical science and industry: 1870 – 1930.
[43] *Understaning technology adoption in the German pharmaceutical industry.* Lacasa, Iciar Dominguez. January 16-18 , Karlsruhe, Germany : DRUID Academy Winter 2003 Ph.D. Conference, 2003.
[44] CEN. Emergence of pharmaceutical science and industry: 1870 - 1930. *Chemical & Engineering News*
[45] *Early drug discovery and the rise of pharmaceutical chemistry.* Jones, Alan Wayne. Historical , s.l. : Wiley Online Library, 2011, Vol. Drug Testing and Analysis.
[46] *Creating a Standardized Approach for Developing Medical Grade 2D Materials.* Nichols, GP. 1, Oak Ridge, TN : Trends in Nanotechnology & Material Science (Exceytics Publishers), April 4, 2016, Vol. 1.

Lignite contains natural organic compounds known as humate, which are from the decomposition of plants and are found in soil, peat, as well as lignite[47]. Application of humates to soils is beneficial, promoting increased water retention, growth of beneficial micro-organisms, root growth, and plant yield serving as a source of natural nutrients and replacement of lost top soil. The environmental applications include removal of toxic metals, organics and radionuclides by adsorption of acidic water streams and reduction of harmful metal species. Organic fertilizer made from lignite coal is increasingly in use to improve soil fertility, improve efficiency of mineral fertilizers and overcome drought and salinity impacts.

Humate and humic acid products could play an important role in counteracting the deterioration of fertile land, a challenge caused by intensive farming, erosion and drought.

By one estimate, up to 50 million acres of agricultural land in North America would benefit from the application of humic acid products. As an illustration of the future potential, if 10 ton/acre were applied to 1 million acres annually, this would equate to 10 million ton per year of humate product usage.

The economic value of the industry depends on the adoption of humate technology to replace and, to a certain extent, supplement chemical fertilizers. The value of the humates industry will depend on demonstration of proven long-term fertility benefits, water retention and NPK fertilizer retention benefits.

[47] *Review: Commercial Humates in Agriculture: Real Substances or Smoke, and Mirrors?* Grapham Lyons, and Yusuf Genc. s.l.: Agronomy, 2016, Vol. October 2016

APPENDIX B

TECHNOLOGY COMPENDIUM

A stakeholder survey was conducted to gather information on activities to develop technologies for producing fuels, chemicals, rare earth elements, and carbon-products from coal. Stakeholders provide their own assessment of technology maturity and market potential against 13 metrics shown in the following three tables. Stakeholders self-ranked the maturity and market potential using a scale from 1 to 9 with 9 being the highest rating.

PLEASE NOTE: NCC has included information in this appendix on an “as submitted” basis based on submissions by survey respondents; NCC has not verified any of the information submitted and is not responsible for the accuracy of the information submitted.

Table Append B-1. Technology Maturity and Market Opportunity Matrix

Technology	Technology Stage	Scale Demonstrated	Timing of Prototype	Timing of Pilot	Timing of Full-scale	Timing of commercial deployment	Economics Stage	Investment Stage	Potential U.S. coal utilization	Price comparison	Competitiveness	Environmental Impacts	National Security
Carbon Fibers													
Green Coal Solutions	9	9	9	9	9	9	9	9	4	9	9	9	9
Penncara Synpitch	5	4	4	N/A	5	5	6	N/A	3	6	9	9	9
Wave Liquefaction Carbon Fiber - H-Quest	1	1	5	5	5	6	4	3	6	9	9	9	9
Rare Earth Elements													
CCR-to-CCP Rare Earth Elements - RamRock	1	1	1	1	2	2	7	3	2	9	9	9	9
CTC Foundation Coal derived REE	6	3	6	7	7	7	5	4	6	8	9	9	9
Microbeam Technologies Recovery of REE	3	3	1	2	5	5	2	3	3	5	5	9	9
Remedial Coal Solutions - CBA Environmental	7	5	9	9	7	7	9	9	9	9	9	9	9
Southern Illinois University - Hybrid Nanofibers	x	x	x	x	x	x	x	x	x	x	x	x	x
Southern Illinois University - REE & Transition Metals	x	x	x	x	x	x	x	x	x	x	x	x	x
Building Materials													
CCR-to-CCP Flowable Fill - RamRock	9	5	9	9	9	7	9	9	4	9	9	9	1
CCR-to-CCP Concrete - RamRock	9	9	9	9	9	7	9	3	9	9	9	9	1
CFOAM Carbon Foam Products	4	4	5	5	5	5	5	5	8	5	9	9	9
CO2 Concrete, LLC	4	4	9	7	5	5	5	3	9	5	9	9	5
CTC Foundation Fly Ash & CCR to Building Products	6	4	6	6	5	5	7	5	6	6	8	9	4
Green Coal Solutions	9	9	9	9	9	9	9	9	4	9	9	9	9
Ohio University Coal Plastics Composites	4	4	9	7	5	5	7	5	2	9	9	9	1

Table Append B-1. Technology Maturity and Market Opportunity Matrix (continued)

Technology	Technology Stage	Scale Demonstrated	Timing of Prototype	Timing of Pilot	Timing of Full-scale	Timing of commercial deployment	Economics Stage	Investment Stage	Potential U.S. coal utilization	Price comparison	Competitiveness	Environmental Impacts	National Security
Life Science Applications													
NOVIHUM - Novihum Technologies	8	7	9	9	9	5	6	9	4	5	9	9	5
Transportation Fuels													
Beneplus - LP Amina	6	5	9	9	7	7	5	5	8	8	8	8	8
Carbide - LP Amina	3	3	7	5	3	2	5	1	8	8	8	7	7
CTC Foundation Coal to Syngas	8	4	6	7	6	6	6	4	7	7	8	9	8
DryFining - Great River Energy	x	x	x	x	x	x	x	x	x	x	x	x	x
Gen2, LLC - Gen Tech PTD, LLD	4	4	9	5	5	5	7	5	6	7	9	9	9
H-Coal - Axens North America	7	7	9	9	9	7	9	7	8	7	9	9	9
Riverview Energy	x	x	x	x	x	x	x	x	x	x	x	x	x
Southern Illinois University - Coal to Liquid Fuels	x	x	x	x	x	x	x	x	x	x	x	x	x
Synfuels Americas Fischer-Tropsch Synthesis	9	9	9	9	9	9	7	4	9	4	9	5	9
Synfuels Americas Stepwise Liquefaction	5	4	1	5	2	4	5	5	9	5	9	5	9
Wave Liquefaction Transportation Fuels - H-Quest	6	4	9	6	4	4	5	3	9	9	9	9	9
Other - Activated Carbon													
CCR-to-CCP Activated Carbon- [RamRock	1	2	5	5	5	7	7	3	4	9	9	9	1
Other - Coal Beneficiation													
DryFining - Great River Energy	x	x	x	x	x	x	x	x	x	x	x	x	x
Wave Liquefaction Coal Beneficiation - H-Quest	6	4	9	6	4	4	5	3	9	9	9	9	1

Table Append B-1. Technology Maturity and Market Opportunity Matrix (continued)

Technology	Technology Stage	Scale Demonstrated	Timing of Prototype	Timing of Pilot	Timing of Full-scale	Timing of commercial deployment	Economics Stage	Investment Stage	Potential U.S. coal utilization	Price comparison	Competitiveness	Environmental Impacts	National Security
Other - Chemicals & Petrochemicals													
H-Coal - Axens North America	7	7	9	9	9	7	9	7	8	7	9	9	9
Synfuels Americas Stepwise Liquefaction	5	4	1	5	2	4	5	5	9	5	9	5	9
Wave Liquefaction Chemicals - H-Quest	6	4	9	5	5	4	5	3	6	7	9	9	9
Other - Graphite													
Penncara Synpitch	5	4	4	N/A	5	5	6	N/A	3	6	9	9	9
Wave Liquefaction Graphite - H-Quest	1	1	5	5	5	6	4	3	6	9	9	9	9
Other - Nanoparticles & Nanotubes													
CTC Foundation Nanoparticles	4	3	5	7	5	5	7	5	4	8	8	9	8
Southern Illinois University - Carbon Nanotubes	x	x	x	x	x	x	x	x	x	x	x	x	x
Other - Hydrocarbons													
Beneplus - LP Amina	6	5	9	9	7	7	5	5	8	8	8	8	8
Other - Soil Amendments													
CCR-to-CCP Soil Amendment - RamRock	4	5	9	9	9	7	9	3	4	9	9	9	1
Other - Compounds													
CCR-to-CCP Magnesia - RamRock	1	2	1	3	2	5	7	3	4	9	9	9	1
Southern Illinois University - Silicon Carbide-Alumina	x	x	x	x	x	x	x	x	x	x	x	x	x
Other - Mineral Fiber-Paper Pulp													
Green Coal Solutions	9	9	9	9	9	9	9	9	4	9	9	9	9

The stakeholder survey criteria are shown in Table Appendix B-2. Each stakeholder survey response is provided after this table.

Table Appendix B-2. Technology Maturity and Market Opportunity Survey Criteria

		Matrix Entry								
	Topic	1	2	3	4	5	6	7	8	9
Development phase	Technology Stage	Concept / White paper			Feasibility confirmed; commercial case promising			Investment ready		Commercial
	Scale Demonstrated	None	Lab	Bench	Small Pilot (<10% of full scale)	Large Pilot (>10% of full-scale)		Demo/FOAK		Commercial
	Timing of Prototype	> 1 year				<6 mo				Complete
	Timing of Pilot	unknown	>3 year	2-3 year		1-2 year		<1 year		Complete
	Timing of Full-scale demonstration (FOAK)	unknown	>5 year			1-2 year		<1 year		Complete
	Timing of commercial deployment	unknown	>10 year			3-5 year		1 year		Complete
	Economics Stage (Cost accuracy range, e.g. +/- 30%)	unknown	unknow n			+/-50%		+/-30%		+/-10%
	Investment Stage	unknown		Govt Grant		Other Gov't support needed (describe in survey)				Investment Grade Financeable
Business Case	Potential U.S. coal utilization, magnitude (MMton/yr)	<1	>1	>5 MM	>10		25-50		50-100	>100 MM
	Price comparison - cost-competitive advantage over alternative	More expensive				Neutral		10% less		>20% less
	Competitiveness (benefits other than price)	None				1 key benefit				2+ key benefits
	Environmental Impacts	net increase				Neutral				net benefit
	National Security	Neutral				1 benefit				2+ benefits

"Investment Stage": refers to ability to access investment financing to deploy the technology
"Comptetitiveness" key benefits include: Jobs, better utilization of resources, environmental, national security
"National Security" benefits include: reducing import dependency, providing redundancy of sourcing, improving trade
"FOAK": First of a kind

H-Coal®

Axens North America | John Duddy
650 College Road East, Princeton NJ 08540 | 609-987-3027 | john.duddy@axens.net

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☒ Other: Petrochemicals (BTX)

The H-Coal Process licensed by Axens is an advanced direct coal liquefaction technology that is fully developed and is ready for commercial application. The coal liquefaction technology, uses the same technology as the commercial H-Oil® Process for heavy oil upgrading, has been tested at the bench unit scale (50 lb coal /day), Process Development Unit scale (3 Ton coal /day), and the Demonstration Plant scale (200 Ton coal/day). Axens prepared the design and startup of the first commercial scale direct coal liquefaction plant (6,000 Metric T coal/day producing 20,000 BPSD of liquid fuels) for Shenhua in Inner Mongolia, China which started operations in 2008. The H-Coal Process has been successfully applied to a wide range of coals including bituminous, sub-bituminous, and lignite. The H- Coal Process produces high yields of distillate liquid products from coal. These coal liquids are upgraded using Axens' commercial refining technologies to make on-specification transportation fuels. A large size single train H-Coal Plant process about 2.5 MMTPA of coal and produces 10-Million barrels per year of transportation fuels and LPG. Alternatively, the product upgrading can produce petrochemicals production with high selectivity to paraxylene.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☒25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

The basic process flow scheme, ebullated-bed reactor, pilot units and development path is the same as that used in the commercial H-Oil Process. Axens was selected by Shenhua to provide Basic Engineering Design and technical support services for DCL plant based on the extensive experience with heavy oil conversion and coal liquefaction.

TIMING

Full commercial availability is feasible within:
☒1 year ☐3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ____

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☐ Other: ____

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

- Reduction of net imports of crude oil and petroleum products.
- Utilize existing/idle coal production capacity.
- Revitalize economy in coal producing regions impacted by mine closings.
- Opportunity to utilize existing and idle coal processing facilities.
- Jobs creation for operation, maintenance and management of coal liquefaction facilities (approximately 500 per facility) plus associated indirect jobs creation.
- Jobs creation for facility construction. Peak construction jobs creation is typically more than 1000 skilled laborers.
- Clean coal technology. Produces completely fungible liquid transportation fuels with low emissions compared to coal combustion.
- Opportunity to synergistically utilize abundant and low cost coal and natural gas resources. Natural gas can be efficiently utilized to provide a low-cost source of hydrogen for direct coal liquefaction. Synergy readily exploitable in hard-hit Appalachian coal production which growing shale gas production.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Capital investment requirement is approximately $100,000/BPD of capacity. Consider a minimum economically viable production capacity to be 10,000 BPB, with capital investment of $1-Billion.

What is the magnitude and type of investment needed to take this technology commercial?

Technology is fully developed and commercially available.

What major hurdles or barriers to next steps of development need to be addressed?

Full-scale commercial development efforts in the U.S. have historically been hampered by oil price volatility. This has made project financing difficult.

Remedial Coal Solutions (RCS)

CBA Environmental Services, Inc. | Bruce L. Bruso
57 Park Lane, Hegins, PA 17938 USA | 570-682-8742 | bbruso@cbaenvironmental.com

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☒Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: Improving the Competitiveness of U.S. Coal, reduction of CO2 & all GHG's, and increased reliability of base-load power plants through gains in efficiency & reduced cost of generation while recovering REE's

The RCS process is a modular and scalable pre-combustion coal enhancement process utilizing proprietary chemistry and standard mineral & aggregate processing equipment to improve ROM thermal coal resulting in better power plant heat rates and efficiencies while significantly reducing CO2 and other GHG's. The process reduces costs of generation and O&M of emission controls.

The RCS process while improving moisture and calorific value, can reduce other pollutants without having to pulverize or briquette the coal. RCS coal will not spontaneously combust, reabsorb moisture or increase friability during transportation, handling or storage.

RCS refined coal creates a dual benefit in that RCS treated coal provides multiple benefits to the US-base load coal-fired generation fleet, while also increasing the export market value of U.S. coal, while providing a major contribution to U.S. Energy Dominance.

The RCS process also can improve the quality of off-spec and waste metallurgic coking coals by removing oxidation, increased transmittance, fluidity & reactivity promoting the reuse of millions of tons of thermal and coking coal impoundments by re-entry into applicable markets at current benchmark values.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☒Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

CBA operated a large pilot plant for 4 years at CBA's corporate facility. Today, through an external equipment manufacturer, a 500-lb per hour full flow-through unit is available for client demonstrations and preparation of reasonable volumes of refined coal in order to carry out independent combustion testing and analysis.

TIMING

Full commercial availability is feasible within:
☒1 year ☐3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade

☒Provides redundancy of sourcing ☒ Other: Substantial contribution to increasing the competitiveness of U.S. coal and the desire to be energy dominant.

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☒ Other: Reduction of power generation costs across the chain, and increased efficiency and reliability of base-load coal-fired power generation. Economic diversification and creation of commodity arbitrage that can hedge against market swing.

OTHER ☒Environmental improvement ☒Improved resource utilization

☒ Other: Significant reduction of CO_2 and CO_2-e - qualified carbon oxides as well as other GHG's. Increased power plant efficiency, base-load reliability and reduced derates.

Expand on the indicated benefits of this technology in 200 words or less (for example, quantify number of manufacturing jobs created at a specified scale if "job creation" is checked):

Creation and preservation of up to 60-100 jobs per RCS facility deployed including direct and indirect jobs. Increase the competitiveness of U.S. coal. Substantial contribution to U.S. - energy dominance status. Reduced cost of power generation across the entire power generation chain. Reduction of as much as 50% - 60% CO_2 and CO_2-e as well as Greenhouse Gasses (GHG's). The RCS process is a near-Zero-emission process that also produces strategic metals and REE's from the process providing for a positive, dual cost-benefit-analysis that improves the value of the coal while optimizing the fuel for the power plant, and recovers strategic metals and REE's with one single-train processing application and cost. Creation of coal export arbitrage.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

$20-million. A Government-Industry joint investment should be taken into consideration.

What is the magnitude and type of investment needed to take this technology commercial?

$20-million.

What major hurdles or barriers to next steps of development need to be addressed?

Investment. The technology owner and industry participants have advanced this technology to commercial-ready status with investment of over $15-million to date with no investment from the U.S. government.

CFOAM® Carbon Foam Products

CFOAM® LLC - Rudolph Olson III, PhD
The Millennium Center - 1142 Middle Creek Rd., Triadelphia, WV 26059
Office: 304-907-2501 - Cell: 828-489-4531 - rolson@cfoam.com

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents ☒Building materials ☐Life science applications ☐Transportation fuels
☒ Other: ______________________________

CFOAM® Carbon Foam is a strong, machinable, non-combustible, and lightweight material enabling a host of next-generation technologies. The first large-scale CFOAM® commercial product is a tooling material used in the production of carbon-fiber composites for aerospace, military, and commercial goods. CFOAM® tools have been used to build components for rockets, aircraft, satellite dishes, and naval ships. We expect the carbon-fiber composite market to continue to expand rapidly as their use is further integrated into society. Several other CFOAM® products having much larger markets are being considered today, including high-temperature kiln components, aggregates for high-temperature refractories and lightweight concrete, proppants, non-combustible building materials, and components used in large military defense items. We believe these markets could use over 50 million tons of coal. Currently the product line is supported by 27 patents with more in the works generated by an active R&D program. Lastly, CFOAM® carbon foam is considered to be a very green material relative to coal, as most of the coal becomes sequestered as an amorphous, inert carbon. In the future, further green refinements are possible through recycling of process scrap back into the product and using volatiles to support thermal processing steps.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☒Commercial

CFOAM® LLC supports the aerospace composites market with a capacity of 25,000 ft^3. CFOAM is growing rapidly and scalable to capacities which could utilize >50-million tons. CFOAM is used in many DOD platforms and the business focus is on high-value applications, but the technology is scalable to a huge platform.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing

☒ Other: New technologies that enhance the ability of the U.S. to protect itself.

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☒ Other: Added value over existing products.

CFOAM® carbon foam has grown 300% in 24 months making a coal-based product used by virtually all U.S. aerospace companies and we have already created about 50 jobs. It has been deployed in Iraq to absorb radar, built parts which have flown on aircraft in Afghanistan, and has built rocket nozzles for U.S. rockets. CFOAM, Ltd has been focused on high value, small market CFOAM® carbon foam applications. This technology is a great, high value job creator – adding an order of magnitude of labor per ton of coal; the coal grows in value as it becomes an advanced material.

By adding an additional business strategy – focusing on very large applications – such as aggregate for lightweight concrete or proppants (>50 million tons in North America in 2017), we could also maximize the use of coal. The base CFOAM® technology that was originally funded through SBIR programs from the Navy, Air Force, and Department of Energy is solid and proven at scale. The ultra large volume applications will need some research funding to make them a reality quickly. CFOAM® carbon foam holds the promise of a large-scale, environmentally friendly industry that sequesters carbon and could produce energy as a by-product.

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Tripling capacity will cost about $23 million and this can be done at our current location along I-70 just outside Wheeling, WV. Expanding this plant will add about 185 new jobs with both this plant and its largest customer located in the same industrial park.

What is the magnitude and type of investment needed to take this technology commercial?

To achieve large coal volume processing means entering new markets with a less-expensive and much larger scale processing facility. This would require about $3.8 million in R&D costs and a new plant with a cost of $37 million. These large-scale plants would likely be located on coal mine properties.

What major hurdles or barriers to next steps of development need to be addressed?

CFOAM, Ltd. and its largest customer, Touchstone Advanced Composites, are both growing rapidly, but are constrained by a lack of sufficient capital. Achieving meaningful sales in high volume, lower cost markets will require significant R&D ($3.8 million) to elevate the process from a batch mode to a continuous mode.

Turning CO_2 Emissions into CO_2Concrete

CO_2Concrete, LLC - Gaurav Sant, Ph.D.
520 Broadway, 6th Floor, Santa Monica CA 90404 - (404) 775-6527 - gsant@co2concrete.com

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents ☒Building materials ☐Life science applications ☐Transportation fuels
☐ Other: ____________________

This technology uses CO_2 within flue gases to produce prefabricated concrete building materials and products. Unlike other approaches to CO_2 utilization, this technology can directly use flue gas streams with dilute CO_2 concentrations typical of emissions from coal-fired power plants and does not require an additional CO_2 capture or enrichment system. Further, the process requires little extrinsic heat inputs, as it can make use of low-grade heat in the flue gas. These key advantages enable unparalleled energy and CO_2 uptake efficiencies, and low CAPEX/OPEX relative to similar technologies for CO_2 utilization within construction materials. The process's use of abundant and economical material inputs, including hydrated lime and off-spec coal combustion wastes, ensures that it can produce construction products with price-equivalence to traditional concrete. The process can be used to produce prefabricated/precast concrete construction products (e.g., concrete blocks, bricks, beams, slabs) etc., which have large global markets. Today's global concrete industry has a market size of $1 T with a projected growth rate of 5 – 6 % annually (over 20% of which is prefabricated concrete products). A majority of the market may be readily replaced by products that utilize CO_2. This potential market is projected to reach $400 B by 2030.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

To date, the largest scale demonstration has been a small pilot production facility located at the University of California, Los Angeles (UCLA). This system demonstrated the utilization of 200 kg CO_2 per day from simulated coal flue gas to produce concrete produces. The system operated in over 10 production trials.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☒Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ____

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ____

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

The technology has the potential to have a positive impact on three industrial sectors within our economy: (1) retain jobs within the coal industry by offering end user (power industry) the ability to utilize coal-fired generation and greatly reduce CO_2 emissions, (2) utilize traditionally off-specification coal combustion residual, reducing corporate liabilities related to their management; (3) allow both utilities and independent power producers to meet their CO_2 emissions reduction targets and allows for the option to maintain their coal-fired generation; and, (4) create additional manufacturing jobs in the precast concrete industry through the integration of precast concrete plants with existing or new coal-fired generation.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Approximately $10.0M is required to take the technology from its current small pilot scale to a large pilot scale and demonstration level operations. The current strategy for demonstration projects includes integration and pilot operation at coal plants, which will begin in 2020 and carry on through 2022.

What is the magnitude and type of investment needed to take this technology commercial?

Taking the technology from multiple proven demonstrations at coal-fired power stations to full commercial operations will take approximately $3.0M - $5.0M for the core support activities required to achieve s strong commercial presence. This investment would cover technical support staff, marketing, sales and product development.

What major hurdles or barriers to next steps of development need to be addressed?

Taking into account the success of the technology at the small pilot scale, the major hurdle is obtaining the level of investment required to conduct a minimum of two large scale demonstrations of the technology. Design work for the next level of activity is already underway.

Technology Overview

Coal Fly Ash and CCR to Building Products

CTC Foundation | Howard McClintic

2711 Jefferson Davis Hwy, Suite 620, Arlington, VA 22202 | (202) 689-4586 | McClintH@CTC.com

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements

☐Sorbents ☒Building materials ☐Life science applications ☐Transportation fuels

☐ Other: ____

The Technologies International Corporation (TIC) high temperature process is very well suited for converting coal fly ash into salable rock wool fibers, used in making insulation, and the recovery of iron found in the ash. Unlike current manufacturers that use older cupola technology for melting, which is unsuitable for the high velocities of coal fly ash, the low gas velocities in the TIC furnace reactor minimize the amount of fly ash that could blow out of the furnace.

The rock wool market is a multibillion dollar one. The main raw materials for current rock wool manufacturers comes from blast furnace operations, which are closing.

Technologies International Corporation (TIC) uses an electric arc furnace (EAF) to achieve high temperatures, to transform waste streams (coal fly ash, e-waste, etc.) into useful, salable products.

TIC has been in existence for 10 years and holds 18 related patents. Organic materials are transformed into clean syngas. Inorganic materials turn to slag and float on top of recovered metals. Nearly $9 million invested in TIC, including funding from NETL.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:

☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot

☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Tests have been done a number of times using a small pilot plant.

TIMING

Full commercial availability is feasible within:

☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☒Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ______________________________

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ______________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ______________________________

The technology allows for the conversion of coal ash into rock wood fibers a valuable product for insulation, agriculture (for commercial seed growing and aquaponics) and fibers that have application in high strength concrete. The process will also recover the iron found in the ash while remediating a potential environmental issue due to leaching from the ash ponds. The process will allow existing power plants with a new disposal alternative for excess fly ash and thus provide work for coal miners and power plant employees. The treatment facility employment will depend on size but in a commercial system the plant employment will be between 100 to 200 workers per plant.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

The next stage is a pilot plant that can generate larger amounts of rock wool fiber that can be supplied to potential users for testing. The cost for this pilot will be $7.4 million

What is the magnitude and type of investment needed to take this technology commercial?

The commercial sized plant cost will depend on the size of the unit. A system capable of processing about 20 tons per hour of coal ash will cost about $45.7 million dollars.

What major hurdles or barriers to next steps of development need to be addressed? (50 words)

Acceptance of a new technology is the first barrier. Funding leadership is a second barrier. Narrow “vision” or sense of mission is a third barrier as utilities are reluctant to take risks even though the risks are advantageous for reducing an environmental issue and generating a revenue from what is currently an expense.

Technology Overview

Coal to Fullerenes and Nanotubes

CTC Foundation | Howard McClintic
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: ___Carbon nanoparticles

A novel method for the formation of fullerenes and carbon nanotubes is to convert CO2 in a very high temperature vessel. Technologies International Corporation (TIC) described this process in a U.S. Patent Office submission entitled "Method and Apparatus for Precipitation of Nano-structured Carbon Solids". The process described included the introduction of CO2 into an AC plasma environment wherein the carbon becomes ionized and reforms into nano particles, mainly fullerenes and nanotubes. The particles are rapidly quenched to stabilize them. This process for making nano-particles is suitable in the formation of "Bucky paper".

TIC uses an electric arc furnace (EAF) to achieve high temperatures, to transform waste streams (coal fly ash, e-waste, etc.) into useful, salable products. TIC has been in existence for 10 years and holds 18 related patents. Organic materials are transformed into clean syngas. Inorganic materials turn to slag and float on top of recovered metals. TIC is the only thermal technology for extracting rare earth elements (REEs). Conventionally, chemicals are used. The system has zero air emissions. Nearly $9 million invested in TIC, including funding from NETL.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Tests have been done a number of times using a 500 kW AC plasma system

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☒ Other: Military and Aerospace

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ________________

OTHER ☒Environmental improvement ☐Improved resource utilization

☐ Other: ________________

The technology allows for the conversion of CO_2 into fullerenes and nanotubes in large quantities at a very reduced cost. The system may also work for the formation of graphene, but work has not been done to confirm that carbon configuration. This process will convert CO_2 into desirable products that have many applications and are needed for research into new fields

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

The next stage is a pilot plant that can generate larger amounts of nanoparticles that can be supplied to potential users for testing. The cost for this pilot will be $5.8 million

What is the magnitude and type of investment needed to take this technology commercial?

The commercial sized plant cost will depend on the size of the unit. Due to the unusual products being generated with this technology, a versatile system capable of producing nanoparticles in commercial quantities will cost about $8 million dollars.

What major hurdles or barriers to next steps of development need to be addressed?

Acceptance of a new technology is the first barrier. Funding leadership is a second barrier. This technology is of great interest to other researchers that are investigating further applications of these products. Some of the national labs, like Oak Ridge, have expressed interest.

Coal derived rare earth elements

CTC Foundation | Howard McClintic
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☒Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☐ Other: ____

A novel method for the recovery of REEs from coal or coal ash uses a modified arc furnace where the organics and inorganics in the coal and coal ash are reduced in a carbothermic process prior to being tapped leaving behind a misch metal containing the metals and REEs. These metals can then be conventionally processed or the metals can be recovered individually by sequential distillation and condensation. This process of carbothermic reduction was demonstrated to NETL in a prior contract and was found to be a success.

Technologies International Corporation (TIC) uses an electric arc furnace (EAF) to achieve high temperatures, to transform waste streams (coal fly ash, e-waste, etc.) into useful, salable products.

TIC has been in existence for 10 years and holds 18 related patents. Organic materials are transformed into clean syngas. Inorganic materials turn to slag and float on top of recovered metals. TIC is the only thermal technology for extracting rare earth elements (REEs). Conventionally, chemicals are used. The system has zero air emissions. Nearly $9 million invested in TIC, including funding from NETL.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Tests were conducted in a bench scale for a NETL project to confirm the process which was deemed to be a success. Small pilot is being considered next.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ___________________________

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ___________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ___________________________

The technology allows for the recovery of REEs from existing coal ash ponds from power plants and from new coal sources. The main sources of REEs currently are from China and this process will allow the U.S. to be self-sufficient and less reliant on foreign imports. The process will provide work for miners if new coal is being used and can remediate the environmental issues with current coal ash ponds that are leaching into the ground water table. The treatment facility employment will depend on size and whether it uses coal or an ash source, but in a commercial system the plant employment will be between 100 to 200 workers per plant. In addition, current coal mining employment can be maintained to supply the needed coal or coal ash. The recovered non-metallic slag will be non-leaching and pass TCLP tests.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

The next stage is a pilot plant that fully recovers individual REE's and fine tunes the process. The cost for this pilot will be $6.5 million

What is the magnitude and type of investment needed to take this technology commercial?

The commercial sized plant cost will depend on the size of the unit. A system capable of processing about 20 tons per hour of coal ash will cost about $45.7 million dollars.

What major hurdles or barriers to next steps of development need to be addressed?

Acceptance of a new technology is the first barrier. Funding leadership is a second barrier. Narrow "vision" or sense of mission is a third barrier as utilities are reluctant to take risks even though the risks are advantageous for national security by not relying on imported REEs

Technology Overview

Coal to Syngas for liquid fuels

CTC Foundation | Howard McClintic
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ___ ____

Technologies International Corporation (TIC) uses an electric arc in a modified electric arc furnace (EAF), operating at 1760°C (3200°F), to gasify coal and create a syngas. This novel method has a very favorably energy mass balance as coal is completely converted into usable syngas — there are NO inherent losses. Conventional gasifiers combust a portion of the syngas ton generate the reaction. This unique EAF process produces an unusually pure syngas with minimum contaminants and thus is ideal for liquid fuel formation. The system allows for steam reformation within the furnace to increase the amount of hydrogen.

TIC use of an electric arc furnace (EAF) to achieve high temperatures transforms diverse waste streams (coal fly ash, e-waste, MSW, etc.) into useful, salable products. TIC has been in existence for 10 years and holds 18 related patents. Organic materials are transformed into clean syngas. Inorganic materials turn to slag and float on top of recovered metals. TIC is the only thermal technology for extracting rare earth elements (REEs). Conventionally, chemicals are used. The system has zero air emissions. Nearly $9 million invested in TIC, including funding from NETL.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Tests have been done a number of times using different types of coal. The process allowed the use of high sulfur coal and tests were done with lignite, metallurgical coal and anthracite. All except the lignite had steam injection to get the right syngas chemistry.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ____________________

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ____________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____________________

The technology allows for the conversion of coal into a very clean syngas that has multiple applications, from liquid fuels to chemicals. The ability to steam reform in the reactor/furnace as the coal is being gasified provides an increase level of control while reducing capital costs. This is a flexible gasifier where the system controls can adapt and accept coals with different characteristics without requiring equipment modifications. The coal does not have to be pulverized.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

The next stage is a pilot plant that can generate larger amounts of syngas that can be tested for different applications, both and chemicals supplied to potential users for testing. The cost for this pilot will be $6.4 million

What is the magnitude and type of investment needed to take this technology commercial?

The commercial sized plant cost will depend on the size of the unit. A typical plant gasifying 20 tons per hour of coal will cost about $42 Million.

What major hurdles or barriers to next steps of development need to be addressed?

Acceptance of a new technology is the first barrier. Funding leadership is a second barrier. The reduced cost of natural gas oil at this time has diminished investors' interest in this technology even though the costs are still below market.

Pyrolysis of coal

Gen2, LLC - Gen Tech PTD, LLC - Kim Johnson
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ______________________________

The technology within this sector includes several processes which fall broadly into liquefaction and gasification followed by an additional process to convert the liquid or syngas to a fuel or chemical. .
Liquefaction may be direct liquefaction where a liquid is made in a single step through either pyrolysis, carbonisation, or direct hydrogen liquefaction. In addition to the process listed below, the direct liquid can be converted to diesel, naphtha and heavy fuel oil via high pressure hydrocraking and distillation.
Indirect liquefaction includes processes whereby a synthetic gas is made in one process followed by conversion of this syngas into synthetic crude through: Fischer Tropes and further refining into fuels, methanol production, dimethyl ether production, and/or subsequent gasoline production. Other process options include the conversion of the formed syngas into a methane rich gas or SNG, or to separate the Hydrogen from the Carbon monoxide and other gases by means of membrane separation technology.
Market size:
The market size for direct liquefaction of bituminous coal to coal tar and subsequent diesel production could be as high as 146.33 million bbl/year (6145 million Gal/year) based on 46 % of U.S. coal production being attributed to bituminous coal and a coal to tar conversion of 10% and a conversion of coal tar to diesel of 60 %.
The technology can also be used to convert coal fines or waste coal to fuels.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Testing has been done on a small scale unit of 5 kg/hr in a Technotherm, an owner of Gen Tech PTD, pilot reactor in S. Africa. Upgrading of coal tars to diesel can be done in traditional hydrocracking processes which have widespread commercial use. FT of syngas produced from coal pyrolysis can be done using various FT processes available on the market.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ____

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☐ Other: ____

OTHER ☐Environmental improvement ☐Improved resource utilization

☐ Other: ____

The U.S. imports 10.14 million bbl/day of petroleum (crude and other hydrocarbons) conversion of coal to liquids could replace these imports.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

To go from a lab scale to a small pilot system, the technology required to convert bituminous coal to coal tar would be 1.8 million U.S.$ for a 1.102 U.S. ton/hour facility which would output 0.1102 U.S. ton/hour of coal tar. The same investment of 1.8 million US$ would be required for a facility processing 1.102 U.S. ton/hour of coal to 0.55 U.S. ton/hour of syngas.

The refinery required to convert the coal tar to diesel, naphtha and residue would be similar to a traditional hydrotreating circuit involving hydrodemetalation, hydro-desulphurisation, hydrocracking followed by distillation of the products. A 3 reactor setup will cost around 9 million US$ for 1000 BPD throughput of coal tar.

The investment required for the FT route is estimated at 1.16 million US$ using 0.55 U.S. ton/hour syngas based off of 10 MBTU syngas/bbl syncrude and 65 000 US$/Daily barrel. This will output 17.5 bbl/day syncrude, of which 12.5 bbl/day is diesel, and 5.35 bbl/day is Naphtha.

What is the magnitude and type of investment needed to take this technology commercial?

Commercial stage for the technology require to convert bituminous coal to coal tar would be 3 million U.S.$ for a 1.102 U.S. ton/hour facility which would output 0.1102 U.S. ton/hour of coal tar.

The refinery required to convert the coal tar to diesel, naphtha and residue would be similar to a traditional hydrotreating circuit involving hydrodemetalation, hydrodesulfurisation, hydrocracking followed by distillation of the products.

What major hurdles or barriers to next steps of development need to be addressed?

Extended testing needs to be done on bituminous coals specific to the U.S. and of consistent quality to give further proof of concept. This can be done by continuous pilot operation in the U.S. or by sending samples abroad for testing. Laboratory and pilot testing needs to be done on coal tar hydrotreating to diesel although this has been demonstrated at lab and pilot scale abroad.

Technology Overview

DryFining™

Great River Energy | Sandra Broekema
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☒ Other: Coal Beneficiation - Lignite and Sub-bituminous

Simultaneous drying and density separation of sulfur and mercury compounds in a pre-combustion or gasification process; 55 Mt of coal beneficiated since 2009.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☒Commercial

1,000 ton/hr at a 1200 MW electric generating station since late 2009.
DOE CCPI project for Prototype in 2007

TIMING

Full commercial availability is feasible within:
☒1 year ☐3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☒Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other:

ECONOMIC ☐Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other:

OTHER ☒Environmental improvement ☒Improved resource utilization

☒ Other: ___Plant efficiency improvement____

3% to 5% Plant efficiency improvement potential. SO2, NOx, Hg and CO2 reduction potentials dependent on fuel and thermal head availability

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

NA

What is the magnitude and type of investment needed to take this technology commercial?

What major hurdles or barriers to next steps of development need to be addressed?

Likely $1 to $2 in overall cost per ton for the benefits enjoyed

Technology is commercial

Coal Ash to Mineral Fiber

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MARKET SECTOR AND SIZE

☒Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☒Building materials ☐Life science applications ☐Transportation fuels
☒ Other: Mineral Fiber, Paper Pulp, Insulation fibers, Textiles, Coal Emissions Capture Technology

Ability to convert all types of coal ash into a non-toxic, non-cancerous mineral fiber for use in multiple end-products that include:

MARKET SECTOR	GLOBAL MARKET SIZE IN USD 2016/2017
• Paper & Paper Products	~81.8 Billion
• Ceramic Fiber / Construction & Machine Insulation	~41 Billion
• Textiles	~1.237 Trillion
• Carbon Fiber Pre-Curser	~2.859 Billion
• Plastics	~321.4 Billion
• Rubber	~18.1 Trillion

As we consume coal in our recycling/manufacturing technology we utilize a secondary emissions capture technology that is capable of capturing 96-98% of coal power plant emissions (CO_2, SO_2, N_2O, mercury (HG)). Additionally, capable resulting from the emissions capture process of converting emissions into Synthetic Natural Gas.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☒25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☒First-of-a-kind demonstration at full scale ☐Commercial

24,000 tons/year capacity mineral fiber plant successfully demonstrates the conversion of coal ash into high grade mineral fiber. Independent lab confirmed product safety and quality properties.
Each production plant is scalable to convert/recycle up to 1 million tons of coal ash per year while directly employing over 200 personnel per factory.
Consumption of nearly 15K Tons of Coal Ash

TIMING

Full commercial availability is feasible within:
☒1 year ☐3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☐Provides redundancy of sourcing ☐ Other: ____________________

ECONOMIC ☒Job creation ☒Economic support to regionin downturn ☒Price advantage over alternative ☐ Other: ____________________

OTHER ☒Environmental improvement ☒Improved resource utilization

NATIONAL SECURITY:

- Establishes the U.S. as the #1 producer of mineral fiber in the world
- Increase exports and ability to meet market demands for mineral fiber insulation and other downstream products manufactured from mineral or wood fiber.

ECONOMIC

- Over 200 direct jobs per a standard 1 MM Ton/year capacity facility & unspecified downstream jobs
- Downstream market stimulation – Textiles, Carbon Fiber, Plastics, Rubber, Construction, Cement & Piping industries, Friction Materials, Aviation & Space, Sound Proofing, Automotive
- Flexible production capability to respond to economic fluctuations and product demands by producing any one of ten product lines
- Significantly lower cost of production over fiberglass and other mineral fiber (Rockwool Fibers)

OTHER:

- Increased regional economic activity through the consumption of other materials
- Ecologically sound alternative for the production of paper, plastics, rubber, and construction materials
- Above industry standards in the reduction of greenhouse gases generated by the usage of coal fuel
- Provide affordable composite / carbon fiber production material for the marine, automotive, and aerospace industries to be used in commercial and defense applications
- Eliminate the need for long-term coal ash storage by power plants and state/local governments
- Comprehensive / scalable / permanent solution to clean up existing coal ash ponds/landfills

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Between 22 to 44 acres of industrial zoned land, 25-60 megawatts of power, access to rail, and close proximity to coal ash (Power Generation Plant) or Coal Ash deposits. Ability to utilize existing industrial facilities (brownfields) as production plants, where available.

What is the magnitude and type of investment needed to take this technology commercial?

Between $21-$155M investment needed to stand a up a full scale facilities that can recycle a range of 100,000 tons to 1M tons of coal ash per year into equal amounts of top-grade mineral fiber. With adequate funding, a single factory takes 8-14 months to get operational depending on site needs.

What major hurdles or barriers to next steps of development need to be addressed?

Availability of investment capital.

Wave Liquefaction™

H Quest Vanguard, Inc. | George Skoptsov
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: Battery-grade and industrial graphite

Wave Liquefaction™ technology (WL™) is an enhanced direct coal-to-liquids (DCL) process that uses non-thermal electromagnetic discharge to directly convert coal and methane into refinable oil (~10 API). Development of the technology targets a wide range of applications and scales of deployment. In particular, the process has been shown to produce coal liquids analogous to coal tar – aromatic liquids that are a by-product of coking – at 10x yields of conventional coking and with significant reduction of scale and capital cost requirements. Coal tar is an established source of chemicals and carbon materials, for example needle coke and battery-grade and electrode graphite. However, as the legacy coking plants are closing, the sources of coal tar continue to decrease world-wide.

From 30 M to 125 M electric vehicles are predicted to be sold by 2030. As much as 50kg-100kg of graphite is required per electric vehicle battery, translating into demand of 1.5M to 12.5M tons of graphite for the electric vehicles alone. Assuming 5% yield of battery graphite from a ton of coal, 30M to 250M tons of coal could be utilized as a source of this strategic material over the next decade.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☒25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Wave Liquefaction™ has been demonstrated in a continuous laboratory-scale pilot system, capable of converting 3 kg/hour with a wide range of coals. The resulting liquids have undergone extensive characterization including GC/MS, elemental, NMR-13C analysis, and simulated distillation, which indicate low impurities, (especially quinoline insolubles), and high suitability for coking and graphitization.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

Technology Benefits

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☒Provides redundancy of sourcing☒ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ______________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

Growth in U.S. sales of electric vehicles has been hindered by the high cost of the lithium-ion batteries used to power many electric vehicles (more than 50% of the vehicle cost). Currently, synthetic graphite is used in the anode of most lithium-ion batteries. Companies prefer using it because the consistency, quality, and properties of high-end synthetic graphite can be controlled during the manufacturing process, despite its cost being 2–10 times that of natural graphite. Natural flake graphite may serve only to supplement synthetic graphite and is limited in quantity and occurrence: China dominates production with 68% of the world's output, while there are no operational mines in the United States.

Wave Liquefaction™ may open nation's vast coal resources as a new source of graphite. It will secure supply of this strategic material, create new demand for coal, benefit environment through supporting electrification of mass transport and provide a cleaner and cheaper method of synthetic graphite production. A single 1,500 – 15,000 ton/year synthetic graphite plant would create a new demand for 30-300 thousand tons of coal. Situated in coal regions impacted by the downturn in coal production, each plant would create ~50 permanent, high-skilled jobs where they are needed most, and 4-5 times as many indirect jobs.

Investment and Barriers

What is the magnitude and type of investment needed to take this technology to the next stage?

To advance to a pilot plant stage, the current lab-scale system must be upgraded to support continuous conversion of coal at the rate of 10-20 kg/hour, to demonstrate viability of the technology. The resulting liquids will be graphitized using conventional methods. Resulting graphite will be evaluated in the final applications such as Li-ion battery. The full cost of a 3-year effort culminating in a standalone commercial plant producing 1500 tons of synthetic graphite per year ($30M/year revenue) would be $30M dollars.

What is the magnitude and type of investment needed to take this technology commercial?

Once the process has been proven at pilot scale, scale-up by unit replication will allow fast deployment at commercial scale. Assuming 5% yield of graphite (battery-grade or needle coke for electrodes) from raw coal, a single full-scale reactor plant would support production of 1500 tons of graphite per year ($30M in revenue) consuming 30,000 tons of coal. A single-reactor fully commercial plant could be deployed within 3 years for ~$30M. A $300M revenue plant (10 reactors) could be deployed for only $50M.

What major hurdles or barriers to next steps of development need to be addressed?

Major development hurdles are reactor scale-up and testing with adequate balance of plant system. One-step scale-up minimizes costs and risk: once reactor operation is proven at the next (industrial) scale, further scale-up will be accomplished only through unit replication. Graphite would be produced via conventional, well-established methods, and would be confirmed as acceptable to industrial consumers early in the program.

Wave Liquefaction™

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MARKET SECTOR AND SIZE

☒Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels

Wave Liquefaction™ technology (WL™) is an enhanced direct coal-to-liquids (DCL) process that uses non-thermal electromagnetic discharge to directly convert coal and methane into refinable oil (~10 API). Development of the technology targets a wide range of applications and scales of deployment. In particular, the process has been shown to produce coal liquids analogous to coal tar – aromatic liquids that are a by-product of coking – at 10x yields of conventional coking and with significant reduction of scale and capital cost requirements. Coal tar is an established source of chemicals and carbon materials, for example high-stiffness graphitic carbon fiber. However, as the legacy coking plants are closing, the sources of coal tar continue to decrease world-wide.

Pitch-based carbon fibers have exceptional properties compared to the commonly used PAN-fibers. They are distinguished by high mechanical stiffness (high modulus), have high heat and electric conductivity, have near zero coefficient of thermal expansion, and a high degree of dimensional stability. These carbon fibers have been widely used in Japan for seismic reinforcement and repair of concrete structures, and have been piloted in the United States for non-disruptive reinforcement of concrete overpasses. Reduction of cost for the high modulus fibers would spur explosive growth of use in construction and civil engineering, allowing reduction in use of steel and concrete for new construction, and non-intrusive repairs in reinforcement projects. As the carbon fiber does not corrode, cost-effective carbon laminate reinforcement would be an attractive alternative to costly capital repairs or bridge replacement. Chopped fibers are widely used as an additive to plastics to improve their thermal conductivity and, at a lower price point, would be an attractive addition to thermoset plastics with applications in vehicle lightweighting.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☒25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Wave Liquefaction™ has been demonstrated in a continuous laboratory-scale pilot system, capable of converting 3 kg/hour with a wide range of coals. The resulting liquids have undergone extensive characterization including GC/MS, elemental, NMR-13C analysis, and simulated distillation, which indicate low impurities, (especially quinoline insolubles), and high suitability for pitch processing, spinning, and graphitization.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☒Provides redundancy of sourcing ☒ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ______________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

The main hurdle to pervasive adoption of carbon fiber and carbon-based composites in construction and automotive industries is the high cost of production. Cost of precursor (polyacrylonitrile accounts for more than 90% of carbon fiber produced worldwide) exceeds $3/kg and accounts for as much as 50% of the lowest grade carbon fiber manufacturing costs.

Coal tar pitch is an attractive alternative feedstock for carbon fiber production. Pitch-based carbon fibers generally have higher stiffness and thermal conductivities, which make them particularly useful in thermal management application and for uses demanding high dimensional stability. Pitch-based carbon fibers are a lot less common, with price levels one to two orders of magnitude higher than for regular (PAN-based) carbon fiber. They have traditionally been used for the most demanding applications, such as satellite structures and space radiators, but they have also gained acceptance in high-end sports and industrial applications in spite of their high cost.

Wave Liquefaction™ may open nation's vast coal resources as a new source of graphitic carbon fiber. It will significantly lower the costs of this material, opening vast vehicle light weighting and construction markets, hence resulting in new demand for coal. It would benefit environment through reduction in GHG and energy-intensive cement and steel production, and provide a cleaner and cheaper source of carbon fiber precursor. Situated in coal regions impacted by the downturn in coal production, each 1,000 m.t./year plant would create 60-80 permanent, high-skilled jobs where they are needed most, 4-5 times as many indirect jobs.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

To advance to a pilot plant stage, the current lab-scale system must be upgraded to support continuous conversion of coal into liquids at the rate of 10-20 kg/hr, to demonstrate viability of the technology. The resulting liquids will be processed, spun, and graphitized using conventional methods, targeting stiff short fiber. Resulting fiber will be evaluated in the final applications such as thermoset plastics and concrete reinforcement. The full cost of a 3-year effort culminating in a standalone pilot processing 1.5 tons coal per hour would be $25M dollars.

What is the magnitude and type of investment needed to take this technology commercial?

Once the process has been proven at pilot scale, scale-up by unit replication will allow fast deployment at commercial scale (12,000 m.t. / year nameplate capacity). A 10 reactor plant could be deployed for $50M-$85M, depending on complexity and cost of the carbon fiber manufacturing equipment.

Major development hurdles are reactor scale-up and testing with adequate balance of plant system. One-step scale-up minimizes costs and risk: once reactor operation is proven at the next (industrial) scale, further scale-up will be accomplished only through unit replication. Carbon fiber would be produced via conventional, well-established methods, and would be confirmed as acceptable to industrial consumers early in the program through a partnership with Oak Ridge National Lab.

What major hurdles or barriers to next steps of development need to be addressed?

Wave Liquefaction™

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications Transportation fuels
☒ Other: Industrial Chemicals

Today, benzene and other monoaromatics (BTEX) are the crude oil-derived platform chemicals at the base of many important industrial supply chains: plastics, rubbers, fabrics, solvents, detergents, dyes, and pharmaceuticals. Benzene market for chemical use alone is 50 million tons worldwide. However, the domestic benzene deficit is expected to grow from 1.8 million tons in 2014 to 4.4 million tons by 2023, due to impact of the shale revolution on domestic BTEX sources.

A viable alternative method for production of coal-derived platform chemicals is direct, thermal conversion (pyrolysis) of coal. Destructive distillation of coal yields hydrocarbon gases, liquids (monoaromatics and coal tar), and coke. Until 1950s, the coke ovens were responsible for virtually 100% of the domestic benzene supply.

H Quest has developed and demonstrated a novel coal conversion process that avoids heat transfer and scale requirements limitations of conventional coal conversion technologies, and is well-suited for small-scale, distributed production of chemicals and material precursors from coal. Rapid (< 1 sec) pyrolysis of coal releases liquid products and intermediates into the relatively cool process gas, where immediate quenching prevents secondary cracking reactions. The result are the high yields of the relatively high-value liquids (50-60wt%, d.a.f), with a large BTEX fraction, and minimal yields of the low-value gases < 5wt%).

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☒50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Wave Liquefaction™ has been demonstrated in a continuous laboratory-scale pilot system, capable of converting 3 kg/hour. The resulting liquids have undergone extensive characterization including GC/MS, elemental, NMR-13C analysis, and simulated distillation, which indicate higher API, lower aromaticity, low asphaltene, higher paraffinic, and higher hydrogen contents than conventional coal liquids. In particular, monoaromatics can range in the 10%-30% of the liquid product.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☒Provides redundancy of sourcing ☒ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other:

OTHER ☒Environmental improvement ☒Improved resource utilization

Producing 5 million tons of coal-derived BTEX per year would require production of 25M-50M tons of coal-derived oil per year and create new demand for 50M-100M tons of coal per year. This scale require deployment of a 40-80 small 100K bpd Wave Liquefaction™ plants across the nation's coal basins, each creating ~80 permanent, high-skilled jobs where they are needed most and contributing to creation of at least 300 indirect jobs. Coal-derived oil and chemicals produced with up to 80% lower lifecycle GHG emissions than the conventional petroleum refining would not only improve energy security by reducing reliance on foreign oil, but would also strongly contribute to the nation's net oil exports and improve competitiveness of the domestic chemical industry through lower prices and higher availability of the petrochemical feedstocks.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

To advance to a pilot plant stage, a project delivering gallon/barrel quantities of fuels, techno-economic and life-cycle analyses, and a detailed system design package is needed. The full cost of a 3-year effort culminating in a standalone pilot plant is $20M dollars.

What is the magnitude and type of investment needed to take this technology commercial?

Once the process has been proven at pilot scale, scale-up by unit replication will allow fast deployment at commercial scale (within 5-7 years). A 100 kbpd fuels plant co-producing 125-250 thousand tons of BTEX per year would cost $150M-$200M depending on the type of coal and final product requirements.

What major hurdles or barriers to next steps of development need to be addressed?

Major development hurdles are reactor scale-up and testing with adequate balance of plant system. One-step scale-up minimizes costs and risk: once reactor operation is proven at the next (industrial) scale, further scale-up will be accomplished only through unit replication. Yields of products and energy requirements have to be demonstrated at scale for each addressed coal.

Technology Overview

Wave Liquefaction™

H Quest Vanguard, Inc. | George Skoptsov
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: Coal Beneficiation

Wave Liquefaction™ technology (WL™) is an enhanced direct coal-to-liquids (DCL) process that uses non-thermal electromagnetic discharge to directly convert coal and methane into refinable oil (~10 API). Originally developed under a DARPA JP8-from-coal study at the Pacific Northwest National Laboratory, the technology has been under development by H Quest Vanguard, Inc. in Pittsburgh, PA. Continuous oil production has been demonstrated on a wide range of coals, including Illinois #6 and Wyodak. Energy requirements reached as low as 350 kWh per barrel, liquid yields >60%, and gas yields <5% (weight, dry ash-free basis).

Coal beneficiation is a free side-effect of the liquefaction process, with yields of solid char starting at ~40% (wt%, d.a.f). The carbon-rich char product shows complete removal of moisture, translating into significant increase of heat contents compared to high-moisture parent coals such as Wyodak. Depending on specific configuration of the process, char can be completely devolatilized, further improving quality of the char as fuel. Alternatively, heavier liquid compounds may be retained in the char serving as intrinsic binder to ease pelletization and suppressing pyrophoricity of reactive coals such as Wyodak, hence improving their export profile (10% reduction in weight decreasing transportation costs and correspondingly higher heating value). U.S. exports 120 million tons of coal per year. For sulfur-rich coals such as Il#6 (~60Mt/year), Wave Liquefaction™ has been shown to decrease sulfur contents from 3%-6% in parent coal to < 1% in the char. Application of Wave Liquefaction at broad scales would double production of coal and while improving the solid fuel properties essentially free of charge.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☒<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Wave Liquefaction™ has been demonstrated in a continuous laboratory-scale pilot system, capable of converting 3 kg/hour with a wide range of coals. The chars have undergone extensive characterization including elemental and proximate analyses, SEM, TEM and optical photography, which indicate decrease in S%, elimination of moisture, high porosity in raw char, and potential for retention of coal pitch as intrinsic binder agent and pyrophoricity suppressor.

TIMING

Full commercial availability is feasible within:

☐1 year ☐3 years ☐5 years ☒10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☒Provides redundancy of sourcing ☐ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn ☒Price advantage over alternative ☐ Other:

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

Producing 10M barrels/day of coal-derived oil would require deployment of a 100 small 100K bpd Wave Liquefaction™ plants across the nation's coal basins, each creating ~80 permanent, high-skilled jobs where they are needed most and contributing to creation of at least 300 indirect jobs. These plants would create a new demand for 120M tons of coal per year while offering 50M-60M tons of cleaner burning beneficiated coal product with reduced sulfur, moisture, and volatile contents for domestic and export markets. Elimination of moisture would directly improve the electricity generation efficiency and environmental profile of the high-moisture coals such as Wyodak (> 165 billion recoverable tons), improve their export attractiveness, and reduce railroad transportation costs (48% of delivered cost of coal according to EIA) as well as its environmental impact.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

To advance to a pilot plant stage, a project delivering gallon/barrel quantities of fuels, techno-economic and life-cycle analyses, and a detailed system design package is needed. The full cost of a 3-year effort culminating in a standalone pilot plant processing 30-50 tons of coal per day is $20M dollars.

What is the magnitude and type of investment needed to take this technology commercial?

Once the process has been proven at pilot scale, scale-up by unit replication will allow fast deployment at commercial scale (within 5-7 years) – 100 kbpd plant costing $150M-$200M depending on the type of coal and final product requirements.

What major hurdles or barriers to next steps of development need to be addressed? (50 words)

Major development hurdles are reactor scale-up and testing with adequate balance of plant system. One-step scale-up minimizes costs and risk: once reactor operation is proven at the next (industrial) scale, further scale-up will be accomplished only through unit replication. Value of the solid char product and suitability for coal replacement / augmentation will need to be established in collaboration with a coal power plant and coal vendors. Transportation safety of beneficiated (dried) coal with will need to be established.

Wave Liquefaction™

H Quest Vanguard, Inc. | George Skoptsov
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ____________________

Wave Liquefaction™ technology (WL™) is an enhanced direct coal-to-liquids (DCL) process that uses non-thermal electromagnetic discharge to directly convert coal and methane into refinable oil (~10 API). Originally developed under a DARPA JP8-from-coal study at the Pacific Northwest National Laboratory, the technology has been under development by H Quest Vanguard, Inc. in Pittsburgh, PA. Continuous oil production has been demonstrated on a wide range of coals, with energy requirements reached as low as 350 kWh per barrel, liquid yields >60%, and gas yields <5% (weight, dry ash-free basis). The projected costs to produce JP-8 from Illinois #6 coal and methane (70% coal on HHV basis) are 25% lower than conventional petroleum production. CO_2 emissions and water consumption are estimated to be 80% lower than competing technologies, meeting or exceeding EISA 2007 §526 lifecycle greenhouse gas emissions requirements.

In 2014, the crude oil market worldwide exceeded $3 trillion. Worldwide demand for petroleum is in excess of 90 million barrels/day and is projected (EIA 2016) to grow by 1.0% a year through 2040, mostly in the non-OECD countries. Outside of the Middle East, the new oil plays are primarily in unconventional oil: deep water, shale, tar sands, and gas/coal-to-liquids).

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Wave Liquefaction™ has been demonstrated in a continuous laboratory-scale pilot system, capable of converting 3 kg/hour. The resulting liquids have undergone extensive characterization including GC/MS, elemental, NMR-13C analysis, and simulated distillation, which indicate higher API, lower aromaticity, low asphaltene, higher paraffinic, and higher hydrogen contents than conventional coal liquids.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☐5 years ☒10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☒Provides redundancy of sourcing ☐ Other:

ECONOMIC ☒Job creation ☒Economic support to region in downturn ☒Price advantage over alternative ☐ Other

OTHER ☒Environmental improvement ☒Improved resource utilization

☒ Other: ____

Established unconventional oil sources, such as deep-water drilling, heavy oil sands, and shale oil, are capital intensive, have high costs of production ($40-$100 / barrel), and have a grave environmental impact. This opens an attractive window of opportunity for the nation's large, long-term coal reserves to be a new, dependable source of crude petroleum and fuels, which will not be hampered by well depletion or a requirement to continually invest in exploration and drilling.

Coal-derived oil produced with up to 80% lower lifecycle GHG emissions than the conventional petroleum would not only improve energy security by displacing 10M barrels/day imports of foreign oil, but also strongly contribute to oil exports, creating jobs across the United States, and strengthening the nation's coal industry. Producing 10M barrels/day would require deployment of a 100 small 100K bpd plants across the nation's coal basins, each creating ~80 permanent, high-skilled jobs where they are needed most and contributing to creation of at least 300 indirect jobs. These plants would create a new demand for 120M tons of coal per year.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

To advance to a pilot plant stage, a project delivering gallon/barrel quantities of fuels, techno-economic and life-cycle analyses, and a detailed system design package is needed. The full cost of a 3-year effort culminating in a standalone pilot plant producing 100 barrel/day of fuels or refinable oil is $20M dollars.

What is the magnitude and type of investment needed to take this technology commercial?

Once the process has been proven at pilot scale, scale-up by unit replication will allow fast deployment at commercial scale (within 5-7 years). 100 kbpd plant would cost $150M-$200M depending on the type of coal and final product requirements -- an order of magnitude lower than conventional processes thanks to high throughout, mild conditions, and elimination of additional hydrogen (SMR) units.

What major hurdles or barriers to next steps of development need to be addressed?

Major development hurdles are reactor scale-up and testing with adequate balance of plant system. One-step scale-up minimizes costs and risk: once reactor operation is proven at the next (industrial) scale, further scale-up will be accomplished only through unit replication. Liquid products will be confirmed as acceptable transportation fuels early in the development program.

Beneplus

LP Amina - William Latta, Founder and Director
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Market Sector and Size

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☒ Other: __High value hydrocarbons and power generation______________________________________

BenePlus is a unique coal processing technology that upgrades coal and, in parallel, produces clean streams of high-value hydrocarbons, including a fuel gas, NGLs and Aromatics (Benzene, Toluene, Xylene). Simply put, BenePlus is to coal what oil refining is to crude oil, where it fractionates feedstock into various high-value products. The technology works on a wide range of coals including lignite, sub-bituminous and bituminous coals. Capital requirements for the technology are relatively modest, and multiple high-value outputs result in a projected simple payback of less than 3 years.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

Largest Scale Demonstrated

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

BenePlus was developed in partnership with Bayer Technology Services and the Southwest Research Institute over the past 5 years. A pilot plant was constructed and operated at SwRI since 2015. Based on pilot plant results, the technology is ready for development to commercial scale.

Timing

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ________________________________

ECONOMIC ☐Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ________________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ________________________________

Technology Highlights

BenePlus is a revolutionary proprietary technology that converts raw coal into three value-added products

1. upgraded coal, PCI, carbon fiber / foam, activated carbon, etc. with various high value applications
2. liquid aromatics (Benzene, Toluene, Xylene (BTX) for petrochemical feedstock and/or gasolin octane boosting
3. fuel gas to improve power generation efficiency by 50%

BenePlus also[1]:

- reduces greenhouse gases
- removes 80% of mercury and 75% of sulfur from raw coal
- reduces up to 85% of power plant SOx air pollutants
- removes 95% of water from raw coal
- produces clean water for industrial use or potable use with additional purification
- improves power generation efficiency by 50% (using fuel gas produced)
- captures CO_2 for enhanced oil recovery or other applications

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

$35M for large pilot.

What is the magnitude and type of investment needed to take this technology commercial?

$100m for demonstration / semi-commercial

What major hurdles or barriers to next steps of development need to be addressed?

Funding.

Technology Overview

Carbide

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ______________________________

Alkali Carbides from coal is a disruptive coal technology for both chemical production and power generation by providing an easy route to commercially competitive acetylene production. Acetylene is a valuable intermediate compound used in the production of dozens of light and medium molecular weight organic compounds. Alkali carbides are stable solids that readily form acetylene when added to water. An example is calcium carbide:

Figure 1: Calcium Carbide Reaction

1) $CaO + 3C \rightarrow CaC_2 + CO$
2) $CaC_2 + H_2O \rightarrow Ca(OH)_2 + C_2H_2$

Rxn 1 is carried out at high temperatures (1800C) and forms the marketable product. The CO can also be used for power generation or chemical production. The CaC_2 produces acetylene, which is formed by hydrating the CaC_2 using Rxn 2. The lime can be used in Portland cement or recycled. The current state of the technology utilizes an electric arc furnace to achieve the high temperature conversion. LP Amina's development effort is to eliminate the need for the electric arc furnace through a carbothermic process or using an alternative alkali carbide reaction. The market size could be enormous at over 500m tons/year of coal utilization.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot

In a joint US-China collaboration, a consortium of partners modified an existing 50 MWel tangential pulverized coal-fired boiler and retrofitted it based on the carbothermic process. The testing was not completed due to funding constraints.

☒Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☐5 years ☒10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other:

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

1. Reduce Oil Dependence: Nearly 3 million barrels of crude per day, or approximately 15% of U.S. oil consumption, is utilized by the chemical industry. Even a partial transition to domestic coal feedstock will significantly reduce U.S. dependency on foreign oil.

2. Improve Energy Efficiency: By combining chemical production with power generation, LP Amina's process is 50% more energy efficient than the conventional carbide process.

3. Create Jobs: The industry transition is poised to create tens of thousands of jobs across the value chain, from additional employment in engineering, to equipment manufacturing, construction, research and development, logistics, plant operations, etc. Companies and communities that adapt to this transition early will have the unique opportunity to build knowledge clusters and excellence centers to serve the rest of the industry.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Grant funding of $5m to develop a bench and small pilot in the US.

What is the magnitude and type of investment needed to take this technology commercial?

$100M to develop a FOAK facility

What major hurdles or barriers to next steps of development need to be addressed?

In the large pilot demonstration, material issues were encountered that need to be resolved. A consortium would work to resolving these issues and build a new FOAK facility. An initial investment of $5M USD is required to resolve the issues encountered in the FOAK facility.

Recovery of Rare Earth Elements (REE) from Coal

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Market Sector and Size

☐Carbon fibers ☐Carbon resins ☒Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☐ Other: ____

Today the U.S. consumes about 16,000 tons/year of REE and is 100% dependent on imports for these important materials. Lignite from SW North Dakota has been shown to have significant amounts of weakly bound REE. A team led by the Institute for Energy Studies at UND has developed a process that is environmentally benign involving multiple extractions that results in a stream containing high levels of the valuable REE suitable for industrially proven processing methods that are extremely simple –resulting in fast time to market and low scale-up risks. For a single seam of lignite, the resource of recoverable REE is estimated to be between 1.8 and 3.7 million tons or enough to provide 100 to 200 years of U.S. supply. Multiple REE-rich seams exist. As an added benefit, the resulting coal product has been upgraded resulting in a "premium" boiler fuel. The development team led by the Institute for Energy Studies at UND includes Microbeam Technologies Inc., Barr Engineering, PNNL, and MLJ Consulting with funding support from the DOE's NETL, North Dakota Industrial Commission, Great River Energy, North American Coal Company, Minnkota Power Cooperative, and Great Northern Properties. Collaborators include the North Dakota Geological Survey, ND University System, and Valley City State University.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

Largest Scale Demonstrated

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

The REE recovery process is environmentally benign and produces a REE-rich stream and a high purity lignite that can be utilized for power (as is currently occurring), chemicals, and other products. The process has been scaled up from a laboratory to a bench-scale. The bench-scale processes 5 to 10 kg/hr of coal. The next scale up will be at 0.25 to 0.5 ton/hour coal pilot plant.

Timing

Please check one. Full commercial availability is feasible within:
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ____________________

ECONOMIC ☐Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☐ Other: ____________________

OTHER ☐Environmental improvement ☒Improved resource utilization

☐ Other: ____________________

The REE recovery from lignite upstream of a 120 MW plant could produce up to 500 tons/year of REE. REE produced from a 120 MW plant for coals ranging from 300 to 600 ppm (dry coal basis) has the potential to $180 to 360 million per year. The value of the REE is determined using average data from the U.S. DOE used in estimating REE value for coal (U.S. DOE, NETL – FOA, 2017). This does not include the cost of processing to separate and produce the pure individual REE.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

The pilot-scale at about 0.25-0.5 tph coal feed would require $8 to 10 million. The investment would be from the U.S. Department of Energy and industry.

What is the magnitude and type of investment needed to take this technology commercial?

A small commercial demo at about 5-10 tph coal feed that would be ready for additional and larger (i.e. 50 tph) commercial projects would cost on the order of about $20-25 Million. The source of investment would be from industry and U.S. DOE.

What major hurdles or barriers to next steps of development need to be addressed?

Funding for detailed characterization/mapping of the REE resource – drill coring in ND to obtain samples for analysis coordinated with the ND Geological Survey and building on considerable data already available.

Funding for scale-up, determination of overall economics, and opportunities to develop addition industries associated with REE (value chain from ore to products).

NOVIHUM®

Novihum Technologies Inc.| Andre Moreira, CEO
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☒Life science applications ☐Transportation fuels
☐ Other: ____

NOVIHUM® is produced by chemically modifying lignite to make a stable humus concentrate. Humus is the natural reservoir of high-grade stable organic matter that is the source of long-lasting fertility in naturally productive soils. It plays a critical role in soil function and health and takes many years to form under natural conditions.

Novihum Technologies has developed a chemical process that accelerates nature's work to produce top-quality humus in hours, using lignite as a raw material. When lignite is formed from decomposing plant material it undergoes chemical and biological processes that are very similar to those by which humus is formed. That makes it a rich source of the molecular building blocks of stable humus. However, over millions of years underground it loses critical elements – most especially nitrogen – and becomes less useful for plants. That is where Novihum Technologies steps in, with a new patented process that restores lignite's lost chemistry, transforming it into a concentrated carbon-rich granulate that is indistinguishable from the organic matter reservoirs found in nature's best soils.

Novihum Technologies estimates that between 25 and 50 million acres of agricultural land in North America would benefit from the application of NOVIHUM.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☒10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☒First-of-a-kind demonstration at full scale ☐Commercial

NOVIHUM is currently produced at a demonstration plant (1,000 metric tons/year capacity) located in Dortmund, Germany and is sold directly to farmers and through specialty distributors in USA, Spain and Germany. Novihum Technologies plans to set up large-scale manufacturing capabilities in the USA within the next five years.

TIMING

Full commercial availability is feasible within: *please see NB below*
☐1 year ☐3 years ☒5 years ☐10 years ☐>10 years
NB: Novihum Technologies is already registered and commercially available in some states (CA, AZ). The next stage is to build a manufacturing site in the USA (first step: ca. 30,000 tons/year).

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☒ Other: *increased soil health and long-term food security*

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☐ Other: ______________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ______________________________

National Security: under current agricultural practices, soils often lose fertility and become less productive over time. With an increasing population and demand for high-value foods, it is paramount to protect access to good soils that can support food production now and for the long term.

Job creation & Economic support to region in downturn: Novihum Technologies' facility in the USA will be close to lignite-producing areas that are today economically depressed. A 30,000 tons production plant will create 20 long-term jobs and protect many more jobs in agriculture.

Environmental improvement: NOVIHUM greatly increases the health of soils and the plants that grow in them. It also contributes to CO2 emission reduction in agriculture (fertile soils require fewer inputs and produce more biomass).

Improved resource utilization: NOVIHUM unlocks the true value of lignite, transforming it into a high-value material for agriculture that enables farmers worldwide to grow better crops or even grow food in areas that were not previously suitable for agriculture.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

We expect to need investment of 15 to 20 million USD in order to build and operate a large-scale manufacturing site in the USA, starting with a plant size of ~30,000 tons/year.

What is the magnitude and type of investment needed to take this technology commercial?

The technology is already commercialized.

What major hurdles or barriers to next steps of development need to be addressed?

Low awareness of soil health. NOVIHUM is a new product in the market and is still convincing farmers and investors both that it works and that soil health solutions are worth investing in. There is a growing awareness among farmers and industry of the importance of soil health, and it is important for NOVIHUM that this trend continues.

Coal Plastic Composites

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☒Building materials ☐Life science applications ☐Transportation fuels
☐ Other: ____

Coal plastic composite (CPC) materials are manufactured by mixing pulverized coal with thermoplastic resins and formed to various profiles based upon application. CPCs are an alternative to wood plastic composite (WPC) materials which have a host of applications in the construction, automotive, and electrical sectors. The first commercial CPC application being considered is decking materials. The composite decking sector is projected to undergo significant growth with 6 million tons per year of new demand by 2023.

CPC manufacturing requires minimal coal processing (pulverizing and drying), generates nearly zero emissions, and has been shown to possess better properties than WPC decking (flexure strength, fire properties, water absorption, lower costs). If successful, CPC manufacturing would create an additional 3 million tons per year of new coal demand.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

To date, CPC materials are being manufactured using commercial pilot plant equipment.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ___

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ___

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ___

Benefits associated with CPC materials include: 1) coal product with minimal to no emissions, 2) lower cost decking product in comparison to WPCs, and 3) CPCs possess better burn properties, greater flexure strength, lower water absorption, and equivalent thermal expansion coefficients as WPCs allowing existing building methods to be used. Further, the team estimates that if CPCs would create 3 million tons per year of new coal demand this new industry would generate 2,000 new manufacturing jobs.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

Approximately $250,000 in additional investment is necessary to conduct pilot-scale manufacturing of CPC boards and complete fire rating tests. Successful completion of these tests will demonstrate ability of CPCs to be used in decking applications.

What is the magnitude and type of investment needed to take this technology commercial?

Between $1 to $2 million in additional investment is necessary to scale and optimize CPC manufacturing and manufacture sufficient CPC boards to complete commercial qualification testing and offer initial CPC boards sales.

What major hurdles or barriers to next steps of development need to be addressed?

The next step in CPC development is to complete pilot-scale testing to manufacture sufficient quantity of boards to allow completion of fire testing. If CPC fire ratings are sufficient, the final steps to commercialization include optimizing CPC formulation and manufacturing processes and successfully completing qualification testing to allow commercial sale of CPC decking.

Penncara Synpitch

Penncara Energy | James Swistock, President

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MARKET SECTOR AND SIZE

☒Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: _Produces feedstock for carbon fibers and specialty graphite products, graphite furnace electrodes, needle and anode coke, and carbon electrodes for the silicon metal, aluminum, and ferroalloy production markets.

Pitch is the required feedstock for a variety of carbon products, and U.S. production of pitch derived from coal has been steadily disappearing. The Penncara Synpitch technology produces pitch from coal, using a direct extraction process, avoiding environmental issues associated with production from coal tar.

The U.S. currently produces less than 3% of global pitch production, and U.S. producers of carbon products are reliant on imports. Penncara Energy is developing U.S. production capacity, located in the U.S. coal fields, to supply a domestically-produced pitch with superior properties.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

The technology was developed in the laboratory, tested at small pilot scale, and elements have been tested at large pilot scale.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐<10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☒ Other: Notably, reduction of import dependence for suppliers of carbon materials in the Department of Defense industrial base.

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☐Price advantage over alternative ☒ Other: Reduced feedstock requirements (over alternatives) for producers of carbon materials.

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other:

The number of new manufacturing jobs related to this technology is in the range of 35 per plant installation. The availability of the materials will also help secure existing jobs in the U.S. mining and carbon materials manufacturing sectors.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

$10 million, R&D investment

What is the magnitude and type of investment needed to take this technology commercial?
$50 million, private placement(s)

What major hurdles or barriers to next steps of development need to be addressed?
Securing the required R&D funds, which will buy down risk associated with the first commercial installation.

Technology Overview

CCR-to-CCP

RamRock Building Systems, LLC | David White
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Market Sector and Size

☐Carbon fibers ☐Carbon resins X Rare earth elements
☐Sorbents X Building materials ☐Life science applications ☐Transportation fuels
X Other: Activated carbon

The disposal of coal ash — properly, coal-combustion residuals (CCR) — has been ongoing for decades and has now reached some 2-3 billion tons contained in over 1,100 impoundments and landfills nationwide. In addition, over 100 million tons is produced annually and represent a large mineral resource and/or industrial waste stream.
RamRock uses proprietary, highly advanced, quantum computational chemistry and support processes to turn CCR into the line of CCR-based products (CCP).
High range estimates suggest the cleanup by the U.S. electric utility industry *may* cost it billions of dollars. Beyond the U.S., the rest of the world has hundreds of coal plants that are planned or already under construction.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 X >100

Largest Scale Demonstrated

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale X Commercial

Our foreign technology partner has commercialized advanced CCR utilization in projects including poured concrete buildings and foundations for wind farms, while proving out a line of related products from high-strength flowable fill for building and road bases to the roads themselves, along with consumer products like floor tiles, roof tiles, and pavers.

Timing

Full commercial availability is feasible within:
☐1 year X 3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY X Reduction of import dependence X Enhancement to international trade

X Provides redundancy of sourcing X Note: Rare earth elements only

ECONOMIC X Job creation X Economic support to region in downturn

X Price advantage over alternative ☐ Other: ________________________________

OTHER X Environmental improvement X Improved resource utilization

X Other: Automation

We intend to turn conventional, single-purpose, coal-based power plants into large-scale, cutting-edge, eco-industrial parks, whereby coal isn't used solely for power generation but to manufacture commercial-grade products for sale into a wide variety of markets, thus having vastly more economic development impacts than they otherwise would, with vastly less environmental impact.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

We need $2.5 million, over a three-year period, to conduct an at-scale demonstration project at one or another coal-fired power plant at one or another electric utility, supported by offsite laboratory R&D.

What major hurdles or barriers to next steps of development need to be addressed? (50 words)

Simple: finding an electric utility that has the vision to see what coal has to offer the world in the context described herein and the willingness to move mountains (of CCR) in order to make it happen.

Direct Coal Hydrogenation Using the Veba-Combi Cracking Technology

Riverview Energy | Gregory Merle
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203-979-3993 | greg.merle@riverviewenergy.com

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents ☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ______________________________

To-date three commercial scale VCC Technology plants are operating – 2 in China and 1 in Russia. The first U.S. operating plant facility developed by Riverview Energy will utilize approximately 1.6 million metric tons per year of high sulfur coal.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☒Commercial

The Direct Coal Hydrogenation process allows to transform coal into valuable and ultra-low sulfur transportation fuels. It is a chemical process that relies exclusively on temperature and pressure. The coal is neither burned or gasified insuring a carbon foot print much lower than coal gasification and Fisher-Tropsch processes. All by-products are marketable and there is no landfilling of ash. Both feedstocks – coal and natural gas – are abundant and cheap in the U.S. Including debt service, the break-even point is about $47 per barrel of crude oil equivalent.

TIMING

Please check one. Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other: ____________________

ECONOMIC ☒Job creation ☐Economic support to regionin downturn

☒Price advantage over alternative ☒ Other: Ultra-low sulfur diesel fuel

OTHER ☒Environmental improvement ☒Improved resource utilization

☒ Other: Production of low sulfur Naphtha as an additive for gasoline productions.

During the peak construction period, Riverview Energy will hire 2,500 construction work force. To operate the plant, it will require approximately 300 permanent employees.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

What is the magnitude and type of investment needed to take this technology commercial?

This selected VCC Technology based proposed plant will invest approximately $2.5 billion to take it to operation.

What major hurdles or barriers to next steps of development need to be addressed?

Technology Overview

Coal to Liquid Fuels in Supercritical CO_2

Southern Illinois University Advanced Coal and Energy Research Center | William Hoback
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618-453-7322| william.hoback@siu.edu

MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☐ Other: ____

Uses Fischer Tropsch Synthesis technology, but improves carbon utilization by nearly 3 fold and reduces GHG emissions by nearly 45 %. No refining required and can alter grade by blending with different fractions produced. Can compete with diesel and gasoline in end user markets.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☒25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Have produced liquid fuels up to 160 mL/day in a 150 mL reactor.

TIMING

Full commercial availability is feasible within:
☐1 year ☐3 years ☐5 years ☒10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ____

ECONOMIC ☒Job creation ☐Economic support to regionin downturn

☐Price advantage over alternative ☐ Other: ____

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

Uses coal to produce petroleum based products.
Will create new jobs in coal rich regions.
Reduces GHG emissions by 45 % compared to traditional coal to liquid methods
Increases carbon utilization by 3 fold compared to traditional coal to liquid methods

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

$600,000 to take it to produce 1 gal/day.

What is the magnitude and type of investment needed to take this technology commercial?

1.5 million to produce 30 gal/day.

What major hurdles or barriers to next steps of development need to be addressed?

Sensitivity of investment to oil prices is the major hurdle.

Technology Overview

Hybrid Nanofibers for Supercapacitors

Southern Illinois University Advanced Coal and Energy Research Center | William Hoback
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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☒Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: _____________Silicon Carbide, Alumina
____

Hybrid nanofiber containing heterogeneous mixed carbon nanofibers derived from coal, can be used to improve specific capacitance in a supercapacitor.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial
Clarify the scale in up to 50 words:

Concept has been proven and tested in a button cell.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☐Reduction of import dependence ☒Enhancement to international trade

☐Provides redundancy of sourcing ☒ Other: _Low cost high capacity storage_____________

ECONOMIC ☒Job creation ☐Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ____

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

Low cost materials with a higher specific capacitance produced. No environmental impact due to material degradation and supports renewable energy goals.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

$1M and 3 years of research funding to take it to a pilot scale level.

What is the magnitude and type of investment needed to take this technology commercial?

Uncertain due to the nature of scale up of prototype. However, initial estimates suggest about 5-10 mil for commercializing this technology.

What major hurdles or barriers to next steps of development need to be addressed?

This technology needs high quality carbon nanofibers that can be generated from coal. The major hurdle is to be able to produce these nanotubes at a lower cost than what is currently available in the market.

Technology Overview

REE and Transition Metals from AMD sludge

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☒Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: _____________Silicon Carbide, Alumina
____

Process produces separate streams of highly concentrated stream of rare earth elements and individual transition elements from acid mine drainage sludge.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☒10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☒None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Concept has been devised and methods of extraction proven to work.

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

Technology Benefits

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ______________________________

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ______________________________

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ______________________________

China dominates the world market in REE's. In 2017 alone, USA imported 150 million worth of rare earth compounds and metals, up from 118 million in 2016. Rare earths were not mined in 2017 in the United States. With Chinese tariffs of up to 25% on refined REE's, this import amount will be significantly higher in 2019.

Cost of extraction of REE's internally in the country, is expected to be lower than that from traditional sources since the fly ash and AMD sludge contain relatively high concentrations of REEs and certain transition metals of value. The treatment of the AMD sludge will reduce environmental and ecological issues associated with existing AMD ponds as well as create new sources of revenue.

Investment and Barriers

What is the magnitude and type of investment needed to take this technology to the next stage?

$500,000 and 1 year of research funding

What is the magnitude and type of investment needed to take this technology commercial?

Government regulations and permit issues.
Success to form partners/obtain investment or other funding for initial resource evaluation.

What major hurdles or barriers to next steps of development need to be addressed?

Refining processes would utilize commercially available equipment. Process will need investors/partners in the form of raw material suppliers and venture capitalists along with matching government support.

Technology Overview

Coal to Carbon Nanotubes

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☐Transportation fuels
☒ Other: _______Carbon Nanotubes____

The carbon nanotubes market is estimated to grow from USD 3.95 billion in 2017 to USD 9.84 billion by 2023, at a [CAGR of 16.70%] during the forecast period. Please refer to https://www.marketsandmarkets.com/Market-Reports/carbon-nanotubes-139.html

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☒1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☐>100

LARGEST SCALE DEMONSTRATED

☐None ☒Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

TIMING

Full commercial availability is feasible within:
☐1 year ☒3 years ☐5 years ☐10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade

☐Provides redundancy of sourcing ☐ Other: ____

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other: ____

OTHER ☒Environmental improvement ☒Improved resource utilization

☐ Other: ____

This technology once viable will allow very large scale production of carbon nanotubes (CNTs). CNTs already show a large application in several fields including high strength composite fillers, super capacitor battery materials, sorbents etc. So, it is anticipated that this will create large number of manufacturing jobs etc.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next stage?

A proper cost assessment needs to be done and the final output needs to be analyzed before answering this question.

What is the magnitude and type of investment needed to take this technology commercial?

Financial support for building large scale infrastructure as well as for recruiting expert man power for market/tech. analysis/risk assessment/ for production.

What major hurdles or barriers to next steps of development need to be addressed?

Inadequate financial support, appropriate collaboration with other (natural) industry partners/stake holders lacking,

Synfuels Americas
Fischer-Tropsch Synthesis Technology

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels

Synfuels Americas' parent company, Synfuels China Technology Company, Ltd. has developed and commercialized Fischer–Tropsch Synthesis technology for the production of liquid fuels and chemicals from coal. The technology is supported by Synfuels China's proprietary catalysts which are customized for each plant by the extensive Synfuels China team of scientists working in multiple hi tech laboratories throughout the globe. **The market for these products is substantial, and commercial adoption in the U.S. can result in a larger new market for U.S. coal.**

Indicate the potential U.S. coal utilization from this technology, million tons/yr:
☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☐Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☒Commercial

TIMING

Full commercial availability is feasible within:
☒1 year ☐3 years ☐5 years ☐10 years ☐>10 years

Technology Benefits

NATIONAL SECURITY ☒Reduction of import dependence ☒Enhancement to international trade ☐Provides redundancy of sourcing ☐ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn ☒Price advantage over alternative ☐ Other:

OTHER ☐Environmental improvement ☒Improved resource utilization ☐ Other: ____

The Chinese CTL plants use Synfuels China's proprietary Fischer-Tropsch synthesis process with medium temperature slurry-bed reactors as the process produces three times more C3+ hydrocarbon products per ton of catalyst than the industry average for conventional slurry-bed processes.
Synfuels China Engineering Company, Ltd. has leveraged the technology even further through enhanced integration with the world's best gasification technologies.
Under the leadership of Professor Yong Wang Li, Synfuels China has built up world-class R&D facilities thought China and beyond, adopting extensive chemical engineering research capabilities covering the full gamut of high throughput experimentation. The approach extends beyond deployment of commercial technology and delves into science and innovation, especially in catalyst development, in ways that are different from other Chinese companies.
Due to its breakthrough in indirect coal-to-liquids commercial technology, Synfuels China has won several awards, including the Outstanding Technological Achievement Award from Chinese Academy of Sciences, and the First Prize of National Energy Technological Advancement from National Energy Administration.
While this technology is commercial, one key to adaptation to the U.S. market is modularization. This can result in cost reductions and widespread use.

Investment and Barriers

What is the magnitude and type of investment needed to take this technology to the next stage?

$20 million, for R&D, engineering, and reduced-scale prototype production, which has not been a focus to date as the current target markets (in China and other developing countries) have been addressing the challenge to scale up.

What is the magnitude and type of investment needed to take this technology commercial?

This technology is commercial. The next stage is modularization of the process, which would require approximately $20 million.

What major hurdles or barriers to next steps of development need to be addressed?

R&D is required to adapt the process design to modularization, moving more of the construction of technology components from the field to the fabrication shop.

Synfuels Americas
Stepwise Liquefaction Technology

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MARKET SECTOR AND SIZE

☐Carbon fibers ☐Carbon resins ☐Rare earth elements
☐Sorbents☐Building materials ☐Life science applications ☒Transportation fuels
☒ Other: Chemicals

A novel stepwise liquefaction technology has been developed by Synfuels China to improve the efficiency of liquefaction for various feedstocks such as low-rank coal, heavy oil, coal tar, and biomass. Stepwise Liquefaction utilizes both Direct Coal Liquefaction (DCL) and Indirect Coal liquefaction (IDCL) technology.

Synfuels China has carried out comprehensive R&D work on DCL catalysis. Using a Chinese brown coal, the DCL process can convert 85-88% of the feedstock with an oil yield of up to 60%.

- The overall energy conversion efficiency could be increased from 44-47% to 50-55%
- The reaction conditions of the hydrogenation process are comparable with other processes.
- The oil product produced from stepwise liquefaction technology is easy to be refined and blended, and is suitable for the production of high-quality gasoline and diesel

In addition to brown coal, heavy oil and coal tar can also be used as feedstocks for Stepwise Liquefaction.

The scope of the market includes gasoline, diesel, jet fuel, kerosene, and chemicals. The products would be direct, coal-derived replacements for commodities currently produced from petroleum feedstocks.

Indicate the potential U.S. coal utilization from this technology, million tons/yr:

☐<1 ☐1 to 10 ☐10 to 25 ☐25 to 50 ☐50 to 100 ☒>100

LARGEST SCALE DEMONSTRATED

☐None ☐Laboratory or bench formulation ☒Small pilot
☐Large pilot ☐First-of-a-kind demonstration at full scale ☐Commercial

Tested with low rank coal

TIMING

Full commercial availability is feasible within:

☒1 year ☐3 years ☐5 years ☒10 years ☐>10 years

TECHNOLOGY BENEFITS

NATIONAL SECURITY ☒Reduction of import dependence ☐Enhancement to international trade

☒Provides redundancy of sourcing ☐ Other:

ECONOMIC ☒Job creation ☒Economic support to regionin downturn

☒Price advantage over alternative ☐ Other:

OTHER ☐Environmental improvement ☒Improved resource utilization

☐ Other: ____

This technology is being adapted for modularization, which would provide for production employment in a geographically diverse set of U.S. coal fields. Employment requirements per plant would be in the range of 50, not counting mining and support jobs. Commercialization would lead to the development and operation of numerous modular plants.

INVESTMENT AND BARRIERS

What is the magnitude and type of investment needed to take this technology to the next

The investment required would include additional laboratory-scale R&D for testing new concepts that are envisioned for the process, and additional pilot testing before moving to a large scale pilot. This cost is envisioned to be approximately $20 million.

stage?

What is the magnitude and type of investment needed to take this technology commercial?

Getting through a large-scale (modular) pilot will require approximately $150 million (total),

What major hurdles or barriers to next steps of development need to be addressed?

The major hurdles to the next step (large pilot) are:

- Modeling and laboratory process work to optimize the process for selected U.S. low rank coals.
- Development of a modular large scale pilot design
- Securing all of the required financing for a large scale pilot.

APPENDIX C

Acronyms

^oC – Degree Centigrade
^oF – Degree Fahrenheit
% – Percent
$ – Dollar
3D – Three dimensional
ACCP – Advanced coal conversion process
Al – Aluminum
AMCA – American Coal Ash Association
AMD – Acid mine drainage
AMO – Advanced Manufacturing Office
AVS – Antelope Valley Station
BACT – Best available control technology
bbl – barrel
BOF – Basic oxygen furnace
BOM – Bureau of Mines
BPD – Barrels per day
BDY – Barrels per year
BTU – British thermal unit
BTX – Benzene, toluene and xylene isomers
C2P – Coal-to-products
CAGR – Compound annual growth rate
CAPEX – Capital expense
CBTL – Coal/biomass to liquids
CCPI – Clean coal power initiative
CCPs – Coal combustion products
CCR – Coal combustion residuals
CCT – Clean coal technology
CCUS – Carbon capture, utilization and storage
CDL – Coal-derived liquids
CM – Critical material
CO – Carbon monoxide
CO_2 – Carbon dioxide
COTC – Crude oil to chemicals
CPCPC – Consortium for Premium Carbon Products from Coal
CTC – Coal-to-chemicals
CTL – Coal-to-liquids
Dakota Gas – Dakota Gasification Company
DCL – Direct coal liquefaction
DBP – Disinfectant byproduct
DHS – Department of Homeland Security
DME – Dimethyl ether
DOD – Department of Defense
DOE – Department of Energy
DOI – Department of the Interior
DOL – Department of Labor
DOT – Department of Transportation
DRB – Demonstrated reserve base
EAF – Electric arc furnace
EAR – Export Administration Regulations
ECA – Electrically calcined anthracite
EDA – Economic Development Administration
EERE – Energy Efficiency and Renewable Energy
EIA – Energy Information Administration
EOR – Enhance Oil Recovery
EPA – Environmental Protection Agency
ERDA – Energy Research and Development Administration
ESA – Energy Security Act
EV – Electric vehicle
Fe – Iron
FE – Office of Fossil Energy
FEED – Front-end engineering and design
FOA – Funding opportunity announcement
FOAK – First of a kind
FT – Fischer-Tropsch
FY – Fiscal year
GDP – Gross domestic product
H – Hydrogen
H_2 – Hydrogen
H_2S – Hydrogen disulfide
Hg – Mercury
HCCM – High-conductive carbon material
HM/UHM – high modulus and ultra-high modulus
iCAM – Carbon Advanced Materials Center
ICL – Indirect coal liquefaction
IEA – International Energy Agency
IGCC – Integrated gasification combined cycle
iPark – Industrial Innovation and Invention Park
ITC – International Trade Commission
Kg – Kilogram
kWh – Kilowatt-hour
KY – Kentucky
LA – Louisiana
LCA – Life cycle analysis
LD – Linz-Donawitz
LFC – Liquids from coal
LNG – Liquefied natural gas
LPG – Liquid propane gas
LPMEOH – Liquid-phase methanol
m – meter
MATS – Mercury air toxics standards
MedTech – Medical technology
MD – Maryland
mm – Millimeter
MO – Missouri
MMBTU – Million metric British thermal units
MMlb – Million pounds
MMst – Million short tons
MTPY – Million tons per year
MMTPY – Million metric tons per year
MRC – Micronized refined coal

MRL – Manufacturing Readiness Level
MS – Mississippi
MTA – Methanol to aromatics
MTG – Methanol-to-gasoline
MTO – Methanol to olefins
MTP – Methanol to propylene
MTPD – Million tons per day
MW – Megawatt
N – Nitrogen
NASA – National Aeronautics and Space Administration
NCC – National Coal Council
NEPA – National Environmental Policy Act
NETL – National Energy Technology Laboratory
NextGen – Next generation
NGLs – Natural gas liquids
NH_3 – Ammonia
Ni – Nickel
NIH – National Institute of Health
NIST – National Institute of Science and Technology
NOx – Nitric oxides
NPK – Nitrogen, phosphorous and potassium
O – Oxygen
OK – Oklahoma
OSTP – Office of Science and Technology Policy
PA – Pennsylvania
PAHs – Polycyclic aromatic hydrocarbons
PAN – Polyacrylonitrile
PDF – Process-Derived Fuel
PET – Polyethylene terephthalate
ppm – parts per million
PPT – Pounds per ton
PRB – Powder River Basin
prep – Preparation
PSI – Physical Sciences, Inc.
PVC – Polyvinyl chloride
QIT – Quebec Iron and Titanium
R&D – Research and development
RCRA – Resource Conservation and Recovery Act
REE – Rare earth elements
REMS – Radically engineered modular systems
REOs – Rare earth oxides
ROM – Rough order of magnitude
RF – Radio frequency
ROI – Return on investment
S – Sulfur
SASOL – South African Synthetic Oil Liquids
SCF – Standard cubic feet
SFC – Synthetic Fuels Corporation
SiC – Silicon carbon
SNG – Synthetic natural gas
SOTA – State-of-the-art
SOx – Sulfur oxides
stons – short tons
Synfuels Plant – Great Plains Synfuels Plant
Syngas – Synthetic gas
Ti – Titanium
TN – Tennessee
TPD – Tons per day
TPH – Tons per hour
TRL – Technology Readiness Level
TPY – Tons per year
TX – Texas
UHM – Ultra-high modulus
UHP – Ultra-high power
U.S. – United States
USA – United States of America
USD – United States dollar
USDA – United States Department of Agriculture
USGS – United States Geological Survey
V – Vanadium
VOCs – Volatile organic compounds
VLCTL – Very large coal to liquid
Vs. – Versus
wt% – weight percent
WV – West Virginia
WVU – West Virginia University
WY – Wyoming

APPENDIX D
Supplemental Comments

Submitted by Fred Palmer, Senior Fellow, The Heartland Institute

May 17, 2019

H Quest Vanguard is identified in the Report under the New Technology (pages 54-55) discussion. Coal refining technology advances are, of course, key for coal's full potential to be reached as set forth in this superb report. The H Quest Wave Liquefaction approach, non-thermal plasma based, I believe will prove key to realizing the Report Vision. The technology is the ultimate realization of Beneficial Electrification and at scale will also create additional electric demand for the Nation's coal-based power plants.

Because of the importance of this technology, a more fulsome description is submitted below and I ask this comment be seriously considered. I do believe at the end of the day the H Quest technology will be identified as the emissions free, cost effective and most energy efficient process for refining coal into precursors for manufacturing high value products. I also believe that through the H Quest technology approach the far reaching Vision of the Report can be realized.

Existing description (Page 55 in Main Report)

"***H Quest Vanguard, Inc.'s Wave Liquefaction™ Process - This thermochemical process involves use of microwave/radio frequency (RF) plasma to enable rapid pyrolysis (carbonization) of coal and natural gas in a modular reactor to produce value-added liquid products and a char that can be used as fuel or for carbon product applications."***

Revised description

"***H Quest Vanguard, Inc.'s Wave Liquefaction™ Process - This electrically driven, thermochemical process involves use of microwave/radio frequency (RF) plasma to enable rapid pyrolysis (carbonization) of coal and natural gas in a modular reactor to produce value-added coal tars as the source for liquid fuels and chemicals, carbon fiber, needle coke, graphite, graphene and a char all of which meet the needs of New Carbon Age product applications."***