CHARFUEL® Coal Refining
Environmentally Responsible Energy Solutions

Carbon Fuels LLC

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OVERVIEW OF CARBON FUELS, LLC CHARFUEL® COAL REFINING PROCESS

A PARADIGM SHIFT IN THE UTILIZATION OF COAL

A New Paradigm: Industry Affects & Market Benefits

Coal and Crude Oil are Both Raw Hydrocarbons

Coal is refined in the same manner as crude oil is refined

- Produce **transportation/heating** fuels and **petrochemicals** that are the same (and sometimes better-higher molecular weight than those produced from crude oil.
- **Remove the pollutants** from coal prior to combustion (sweetener) or gasification for electrical generation (IGCC)
- **Economical CCS** by conventional methods for CO_2 capture oxy-fuels and oxygen blown IGCC

The CharFuel® Process Refines Coal Like Oil Refineries Refine Crude Oil

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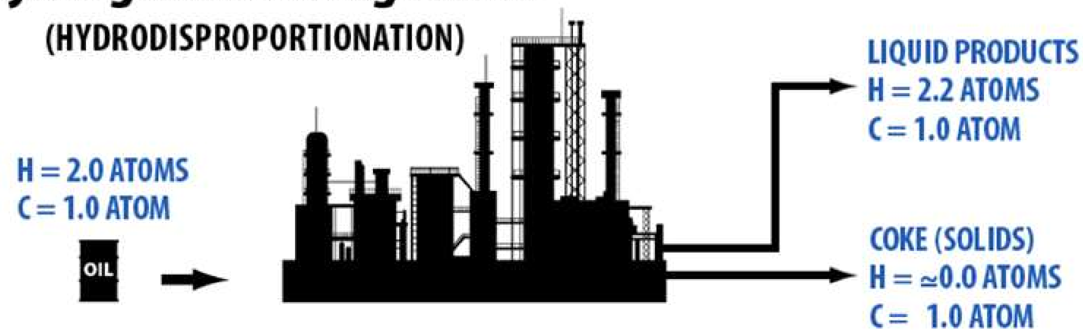
Oil Refining Process: Hyrdogen Rearrangement

(HYDRODISPROPORTIONATION)



Charfuel® Refining Process: Hyrdogen Rearrangement

(HYDRODISPROPORTIONATION)

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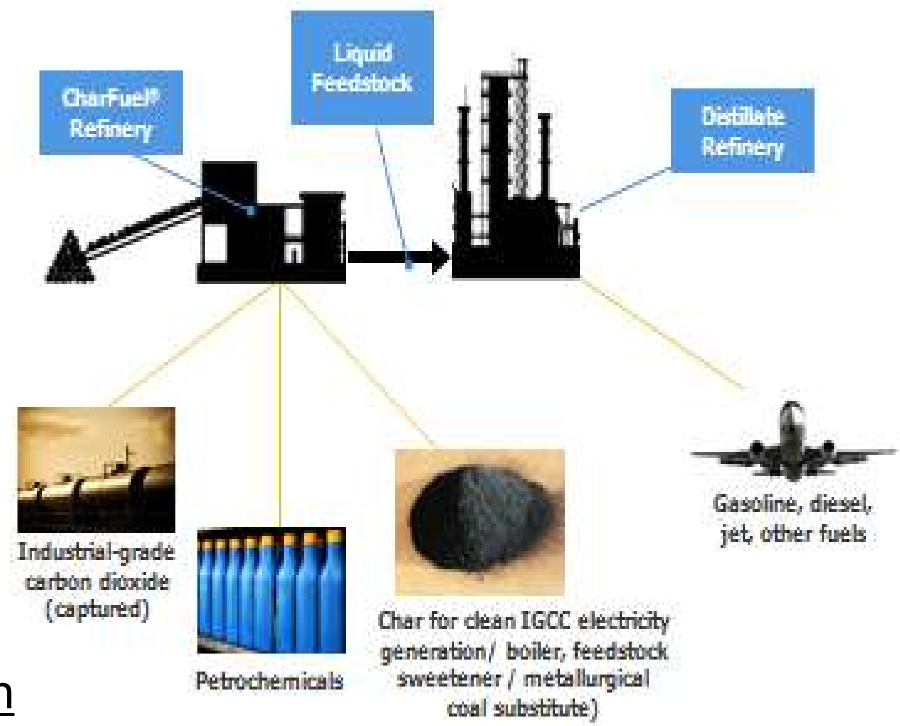
COAL: AMERICA'S MOST ABUNDANT NATURAL RESOURCE

COAL IS TOO VALUABLE TO BURN!

Treating raw coal as a refinery feedstock, rather than a fuel, overcomes numerous negatives traditionally associated with the use of this inexpensive, abundant, domestic resource.

The CharFuel® process meets the criteria for near-term US energy independence, as well as the environmentally compliant generation of abundant, cheap electricity with economical CCS using existing power distribution infrastructure.



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DOE OBJECTIVE - ENVIRONMENTAL COMPLIANCE

Hydro-cracking coal produces minimal carbon dioxide

- **Requires no process water:**
  (ethanol, for example, which requires 4+ gallons of water for every gallon of liquid fuel. Fisher-Tropsch coal gasification process requires 3+ gallons of water for every gallon of liquid fuel. High water consumption processes are undesirable in arid regions, e.g. Wyoming and Montana.
- **Removes pollutants** such as sulfur, nitrogen, and mercury from the raw coal feedstock and turns them into co-products that, along with captured carbon dioxide, are valuable industrial commodities.
- **Char is a clean, inexpensive, high BTU feedstock** for an environmentally compliant, "sweetener" or an efficient electricity generation (IGCC) feedstock for inexpensive CCS.

The CharFuel® Process Is Environmentally Compliant

0% emissions	0% water	0% carbon
Removes pollutants – sulfur, nitrogen, chlorine and mercury	Uses only raw coal and air– No external process water	No greenhouse gas emissions

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COAL VOLATILIZATION REACTION RATES

VOLATILIZATION

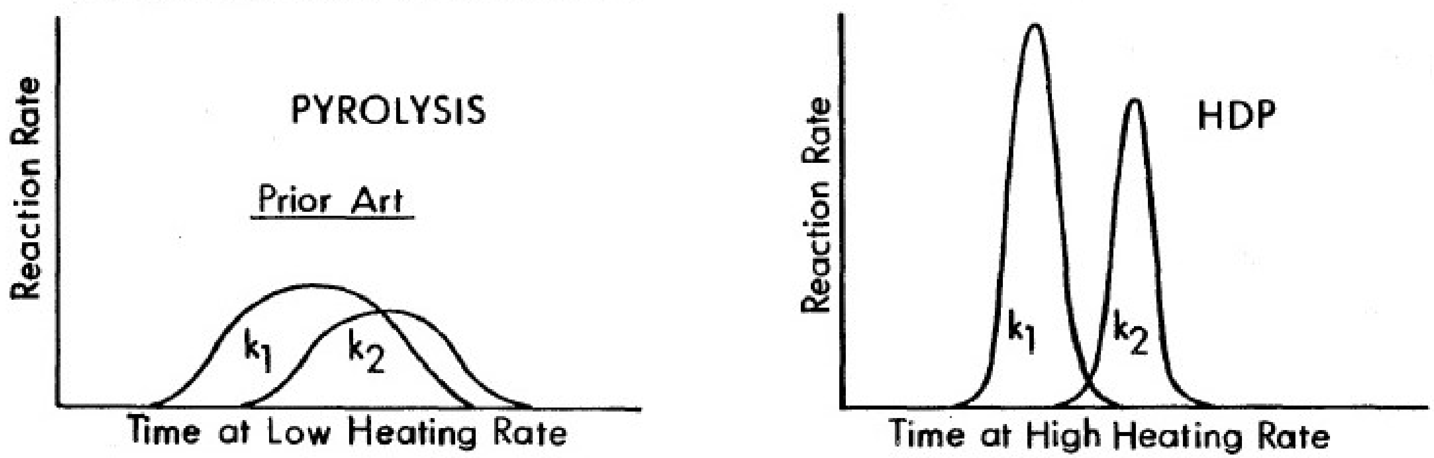
Solid Organic

$\downarrow K_1$ (Reaction Rate)

Decomposition Products (Outside Particle)

$-H_2$, k_2 (Reaction Rate) → Carbon (Solid) + Dehydrogenated Hydrocarbons

$+H_2$, k_3 (Reaction Rate) → Hydrogenated Hydrocarbons



COMPATIBLE WITH EXISTING DISTRIBUTION & UTILIZATION INFRASTRUCTURE

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The CharFuel® Coal Refining Process yields much the same fuels as petroleum, including gasoline, Jet-A, green diesel, and fuel oil, as well as aromatic petrochemicals including benzene, toluene, and xylene; and Ammonia.

- Use existing pipelines, tankers, and trains, as well as fuel for existing engines with no modification.
- Char is a clean, inexpensive, high BTU feedstock for efficient IGCC generation which can connect directly to the grid. Enhances CCS making CCS economically viable

CharFuel® is a glove-fit with existing infrastructure

CharFuel® Coal Refining Process utilizes existing refineries, distribution networks, engines, and electrical distribution systems.

Existing Transmission Lines

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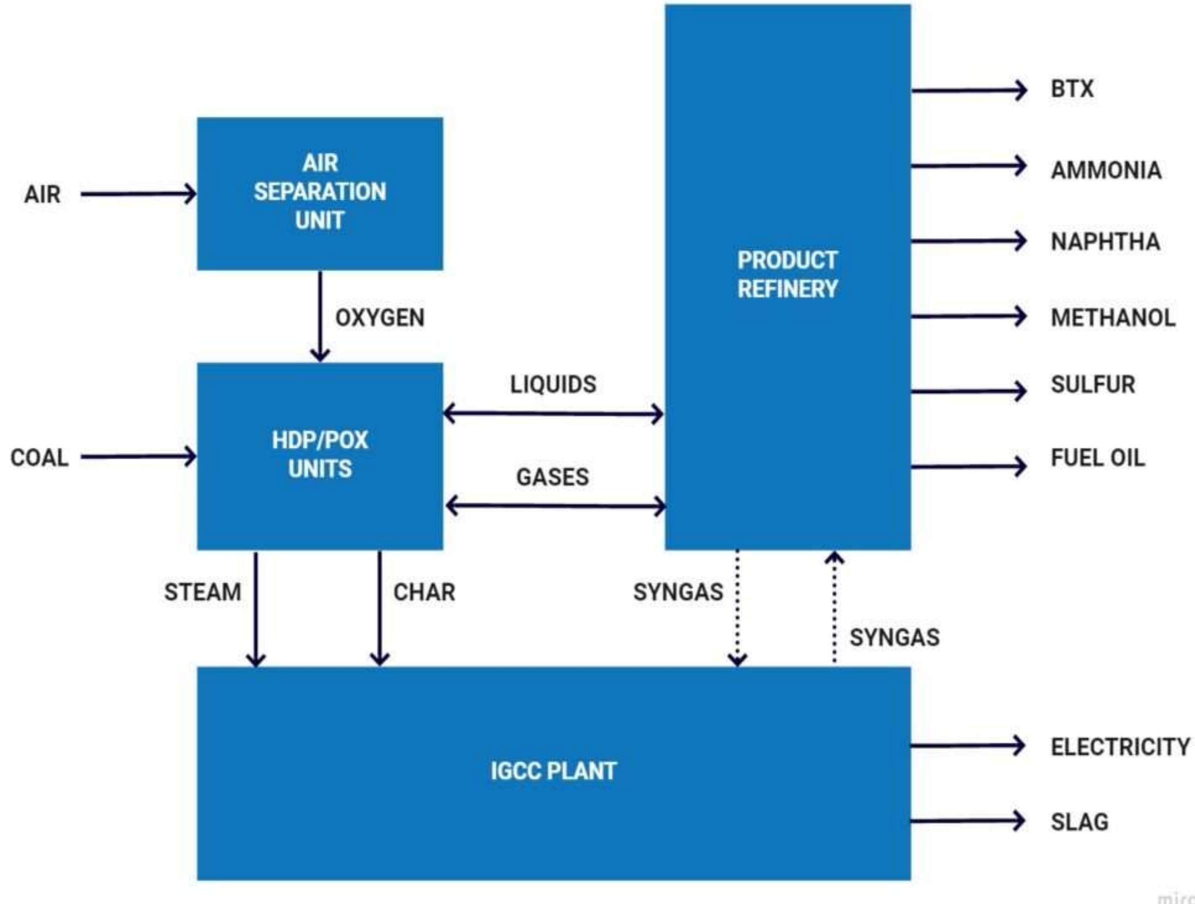
NEW INDUSTRY - INTEGRATED CHARFUEL® /IGCC PLANT-CCS

Small generation capacity e.g. 300MW-combined cycle

Load following capability-CH_4 to turbine or chemicals

Pure CO_2 in methane stream, like natural gas-CO_2 separation



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CARBON CAPTURE & STORAGE (OXYGEN-BLOWN IGCC)

Table 1. Cost Analysis and Comparison

Attribute	SOA Value[1]	Coal Refinary Integrated Plant	Description / Justification
Power generator type	IGCC	Oxy-combustion char gasification	Oxygen blown char gasifier will generate clean process ga with little CO and high partial pressure of CO_2 for cost-effective CCS
CCS plant technology	46 $/ton	<36 $/ton	Dry feed, removed pollutants, and increased CO_2 concentration (PP) results in estimated 25%-45% reduction in cost of conventional CO_2 capture and storage
Capital cost (TACS)	$8,810 $/kW (IGCC)	7,084 $/kW (Oxy-comb.)	CCS equipment adds about 11% to IGCC capital costs. Using char generated by CharFuel® process will reduce capital costs by >25%
Fixed O&M cost	223.62 $/Kw	<15O .0$/kWh	Reduction in cost of CCS plant results in lower O&M costs
Variable O&M cost	17.28 $/kWh	<10.00 $/kWh	Reduction in cost of CCS plant results in lower Var. O&M costs
Power generator heat rate	10,497/BTU/kWh (w CCS)	<8,840 BTU/kWh (w CCS)	Saving upstream (preparation) and downstream (no pollutant removal i.e. acid gas; system simplicity and greater CO_2, separation efficiency.)
Capture rate	<80%	>90%	Char/oxygen IGCC/CCS will meet or exceed CO_2 capture rate of coal/oxygen IGCC/CCS

[1] 14 (NETL) – "COST AND PERFORMANCE BASELINE FOR FOSSIL ENERGY PLANTS VOLUME 1: BITUMINOUS COAL AND NATURAL GAS TO ELECTRICITY".

THE CHARFUEL® PROCESS: A PARADIGM SHIFT IN COAL

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- Coal Feedstock – long-term, price stable supply agreements, high density, tnsportable.
- Economiclly and competitively produces hydrocarbon-based aromatic chemicals, chemical feed stock, "Green” diesel and jet fuels.
- Produces clean char for high heat rate combined cycle low emission electricity generation on brownfield sites.
- Uses existing infrastructure: refineries, pipelines and distribution networks.
- No process emissions - environmentally compliant.
- Facilitates inexpensive CCS, making electricity generation with coal (char) economically competitive and environmentally compliant.
- No process water

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Novel Charfuel® Coal Refining Process
18 TPD Pilot Plant Project for Co-Producing an Upgraded Coal Product,
And Commercially Valuable Co-Products

PROJECT GOALS AND OBJECTIVES

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PROJECT GOALS AND OBJECTIVES

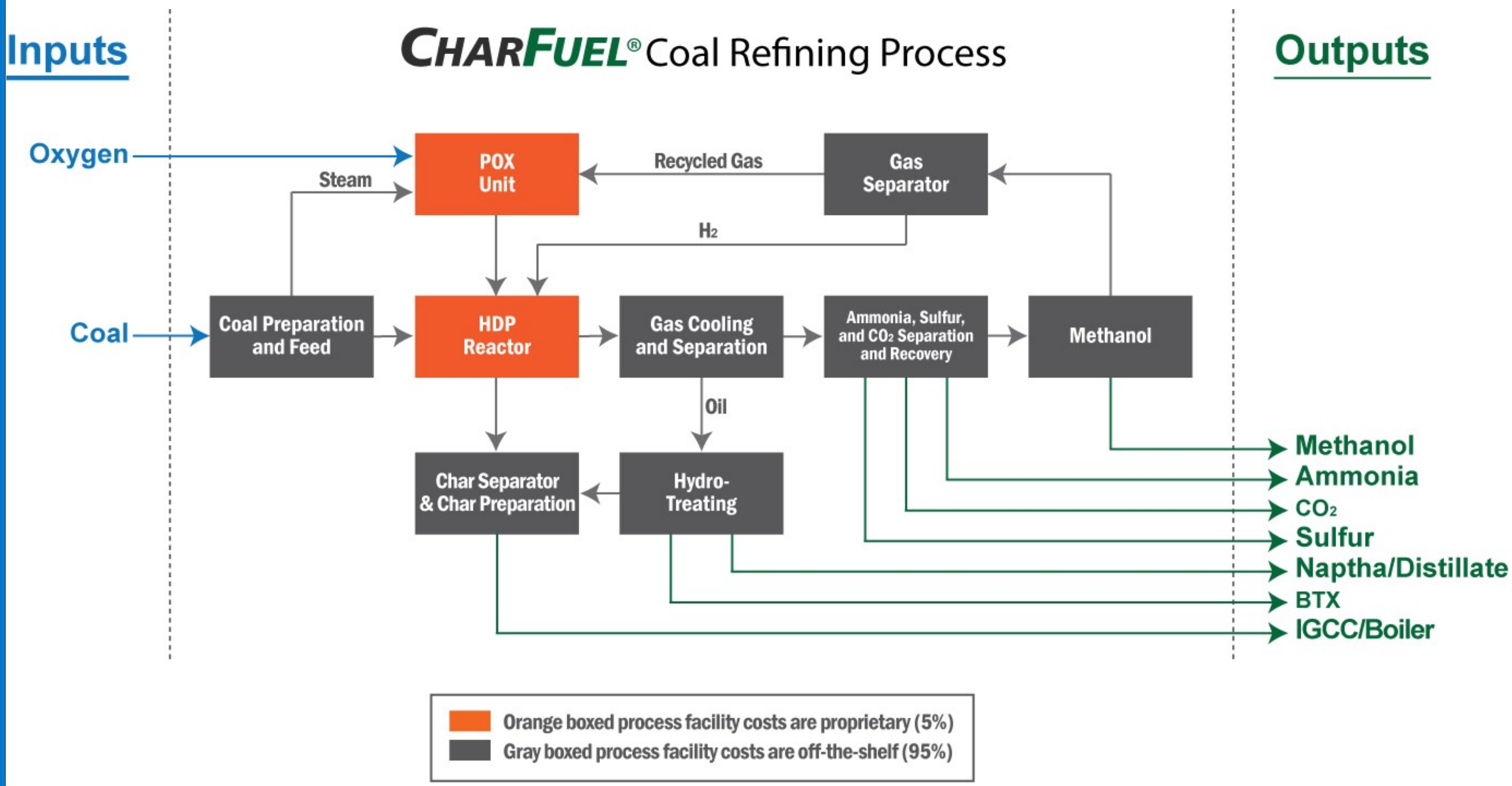
Novel Charfuel® Coal Refining Process

18 TPD Pilot Plant Project for Co-Producing an Upgraded Coal Product And Commercially Valuable Co-Products

The overall goals of this project are to operate Carbon Fuels, LLC's existing, permitted 18 ton per day ("tpd") pilot plant located in Golden, Colorado using two individually ranked (ASTM D 388) coal types (two campaigns), employing the novel Charfuel® Coal Refining Process to produce an upgraded coal product and a number of high-valued commercial organic and inorganic coproducts in order to produce engineering and product data which will then be utilized toward the design of a commercial scale integrated facility (Pre-front end engineering design ("Pre-FEED") document).

CharFuel® Coal Refining Process: A New Paradigm

The CharFuel® Coal Refining Process Combines Established and Proprietary Technologies



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CharFuel® Coal Refining Process Project for DOE

Proprietary components of the CharFuel® process (5% of Plant Cost)

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DE-FE0031708 PROJECT OBJECTIVES

- Take Technology Readiness Level ("TRL") from **TRL-7** to a **TRL 8 -** high fidelity prototype in an operational environment at operating conditions and quantities sufficient to scale to commercial size plant;
- Operation of the integrated 18 tpd pilot plant, using two coal types (ranks);
- Demonstration of process flexibility in being able to produce different products (gas, liquid, and char), as well as determination of operating parameters for identifying scale-up criteria for two coal types (ranks);
- Generation of engineering and design information (process specifications) for use in designing a commercial scale plant (scale-up);
- Determination of important environmental issues surrounding the process and the products, such as fate of trace elements (mercury and other heavy metals) and distributions of SO_2, NOx, and CO_2 by analysis of effluent streams;
- Sampling of product mix to generate data for commercial economic evaluation of both the refined coal product and the coproducts; and,
- Assessment of longer-term reliability of unit operations.

TECHNOLOGICAL CHALLENGES

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- 18 TPD Pilot Plant was built operated using a single coal on a shorter runtime basis.
- The reactor, residence time is in tenths of a second, greatly increasing the quantity of material to be processed as well, as storage capacity for product for longer project campaigns.
- The modifications required to handle two coals and substantially increase runtime was not completely understood e.g. atritor train.
- To meet the project requirements while generating the quality, quantity of data to support and generate pre-feed documentation, including variations of reaction parameters, the Pilot Plant had to be reconfigured presenting technological challenges the extent of which were not anticipated.
- Further, the coal feed system used to grind and dry the coal feedstock was inadequate for handling bituminous coal, such as Illinois #6
- Modification of the coal drying and grinding system which could be varied depending upon the moisture content and rank of coal.

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TECHNOLOGICAL CHALLENGES CONT'D

- The technology required to measure the coal flow into the reactor available at the time the 18 TPD Pilot Plant was built and operated, comprised load cells mounted on the "coal feed vessel" which is pressurized and depressurized cyclically.
- The difficulty in calibrating this device, as well as deviations caused by operating condition, made this device inaccurate.
- One of the objectives of this Project is to determine heat and material balances to determine the commercial feasibility of Charfuel® Coal Refining Process using two coals of different rank
- A <u>new technology incorporating inline measurement of coal in dense phase</u> (as used by the Charfuel ® Coal Refining Process) has been developed with accuracies in the +/- 1% to 3% range and was not known to be available when the Project was proposed.
- This technology improves the accuracy of the material balance by almost an order of magnitude The coal feed train required substantial modification to incorporate this device upstream of the reactor to get maximum accuracy, which caused some delay.

CONCLUSION

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- The Charfuel® Coal Refining Process, which produces an upgraded coal product and a number of high-valued commercial organic and inorganic coproducts, is an economic clean paradigm shift in the utilization of coal.
- The concept of "refining" coal by hydrodisproportionation (moving hydrogens around on the carbon molecules) opens-up the myriad of possibilities for clean coal utilization
- Refining coal allows pollutants present in raw coal to be removed to form valuable coproducts without degradation of the heating value or utility of the refined product.
- This process not only meets the requirements set out in the proposal, but a number of the other DOE 2020 – 2024 objectives, including efficient inexpensive CCS, contributing to this country's energy independence, and providing high-value hydrocarbon products as well as ammonia for fertilization, all <u>without process water or CO2 emissions</u>.