

CHARFUEL® Coal Refining

Environmentally Responsible Energy Solutions



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CARBON FUELS, LLC CHARFUEL® COAL REFINING PROCESS

**A PARADIGM SHIFT IN THE
ENVIRONMENTAL UTILIZATION OF
COAL IS A SOCIETAL NECESSITY**



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CARBON – A DIRTY WORD

WITHOUT CARBON

NO LIFE WITHOUT CARBON -- NO WORLD AS WE KNOW IT
OUR WORLD IS BUILT ON CARBON, AS ARE WE

- Krebs Cycle-Powers us
- DNA and RNA-our structure
- Photosynthesis-feeds us
- Lubricants fuels-moves us & keeps us warm/cool
- Diamonds-keeps the society procreating
- Soil Rejuvenation-feeds us
- Products and materials-infrastructure



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CARBON DIOXIDE (CO₂) - A DIRTY WORD

WITHOUT CARBON DIOXIDE -- NO LIFE
WITHOUT CARBON DIOXIDE -- WORLD UNINHABITABLE

- Photosynthesis requires CO₂ - no food
- Sun energy capture of heat-oceans would freeze



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ENERGY - A NECESSITY OF LIFE & CIVILIZATION

- NATIONAL SECURITY
- SOCIETAL AND TECHNOLOGICAL DEVELOPMENT
- QUALITY OF LIFE



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ENERGY - THE LAWS OF THERMODYNAMICS

NO FREE LUNCH

FIRST LAW-ENERGY CAN'T BE CREATED OR DESTROYED

“ENERGY DENSITY” e.g., wind and solar vs. carbon

SECOND LAW-CONVERSION OF ENERGY FORM ALWAYS RESULTS IN LOSS OF ENERGY, e.g., electrical to chemical (“a battery”).



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ENERGY DENSITIES COMPARED

“ENERGY DENSITY” of gasoline v. wind (1054 joules-1 BTU-first law

- 1 gallon of gas = 110 MM Joules of energy.
- 1 cubic meter = 260 US gallons.
- 1 cubic meter of gasoline has 28,600,000,000 (billion) Joules of energy.

What is the energy density of wind (and solar) on earth? For example, a cubic meter of wind at 20 mph (all that an electric turbine can handle) has an energy density of 65 Joules.

Therefore, gasoline has over a *BILLION* times the energy density of a 20 mph wind!

Thus, it would take one billion cubic meters of air blowing at 20 mph to equal the energy contained in just one cubic meter of gasoline.

- **However, a cubic meter of char (pure carbon) has energy density of 48 Billion Joules.**



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WHAT HAVE WE LEARNED

- The Earth (as we know it) cannot do without carbon dioxide,
- Life on earth cannot do without carbon and carbon dioxide.
- Solar and wind do not have sufficient energy density to sustain our quality of life.

WHAT IS THE ANSWER?

**CARBON FUELS, LLC CHARFUEL®
COAL REFINING PROCESS**

***A PARADIGM SHIFT IN THE ENVIRONMENTALLY FRIENDLY
UTILIZATION OF COAL OUR MOST VALUABLE NATURAL
RESOURCE***



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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 CO₂ capture oxy-fuels and oxygen blown IGCC



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

Oil Refining Process: Hydrogen Rearrangement (HYDRODISPROPORTIONATION)

H = 2.0 ATOMS
C = 1.0 ATOM

OIL



LIQUID PRODUCTS
H = 2.2 ATOMS
C = 1.0 ATOM

COKE (SOLIDS)
H = ≈ 0.0 ATOMS
C = 1.0 ATOM

Charfuel® Refining Process: Hydrogen Rearrangement (HYDRODISPROPORTIONATION)

H = 1.0 ATOM
C = 1.0 ATOM



CHARFUEL® PROCESS



LIQUID PRODUCTS
H = 2.0 ATOMS
C = 1.0 ATOM

CHAR (SOLIDS)
H = ≈ 0.0 ATOMS
C = 1.0 ATOM



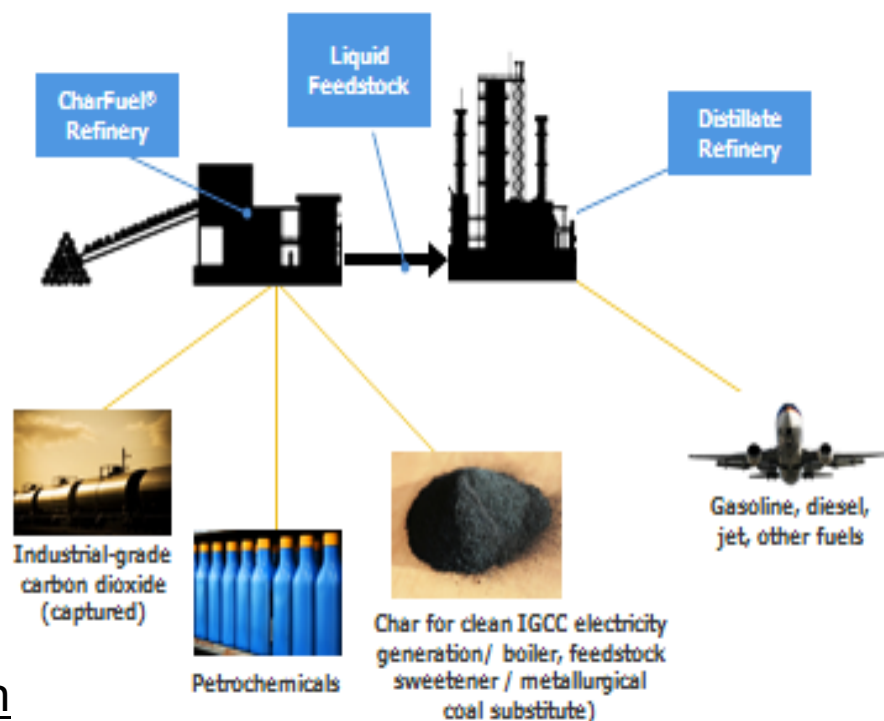
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COAL: AMERICA'S MOST ABUNDANT NATURAL RESOURCE

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

Removes pollutants –
sulfur, nitrogen, chlorine
and mercury

0%

water

Uses only raw coal and air –
No external process water

0%

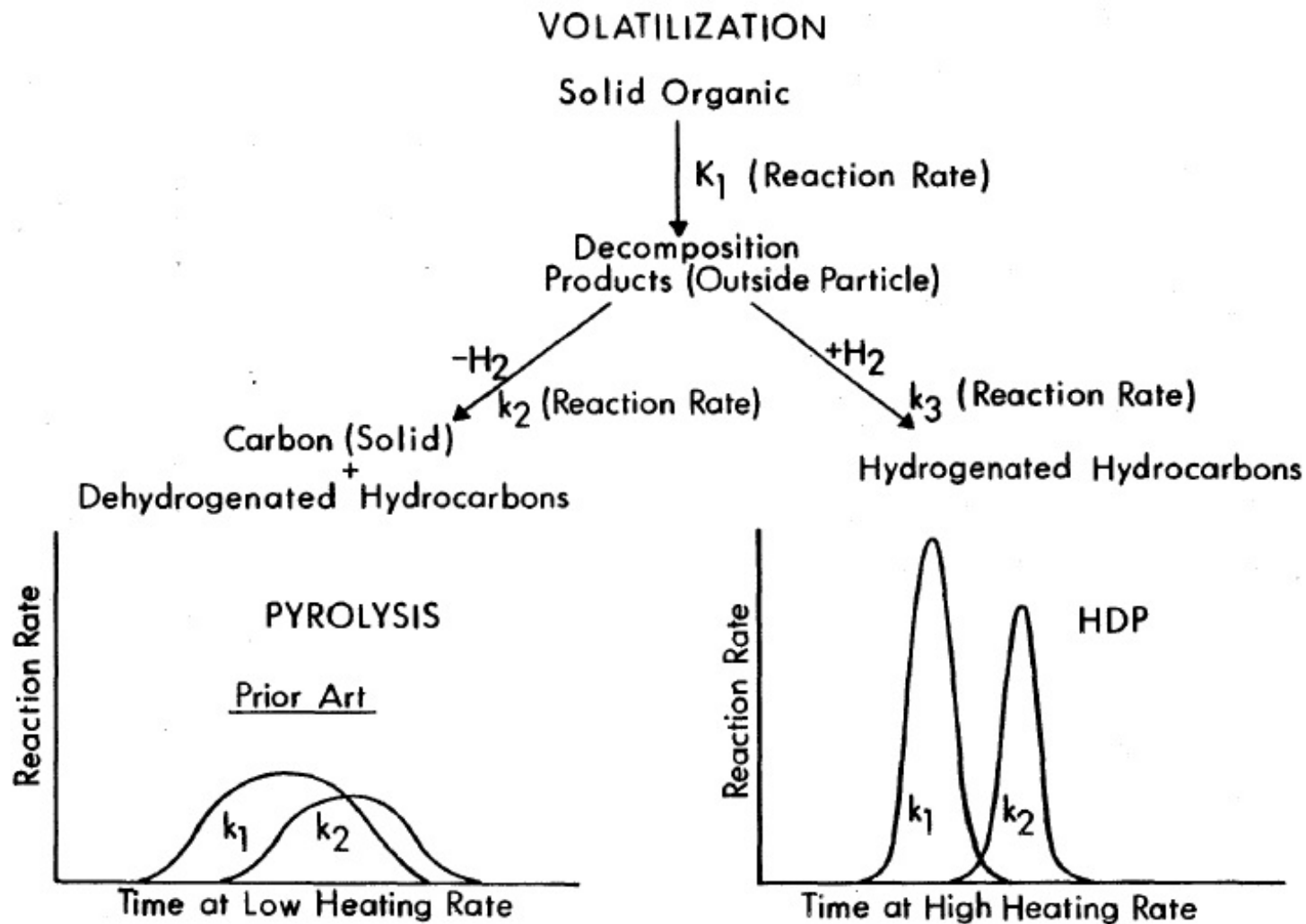
carbon

No greenhouse gas
emissions



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COAL VOLATILIZATION REACTION RATES





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COMPATIBLE WITH EXISTING DISTRIBUTION & UTILIZATION INFRASTRUCTURE

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



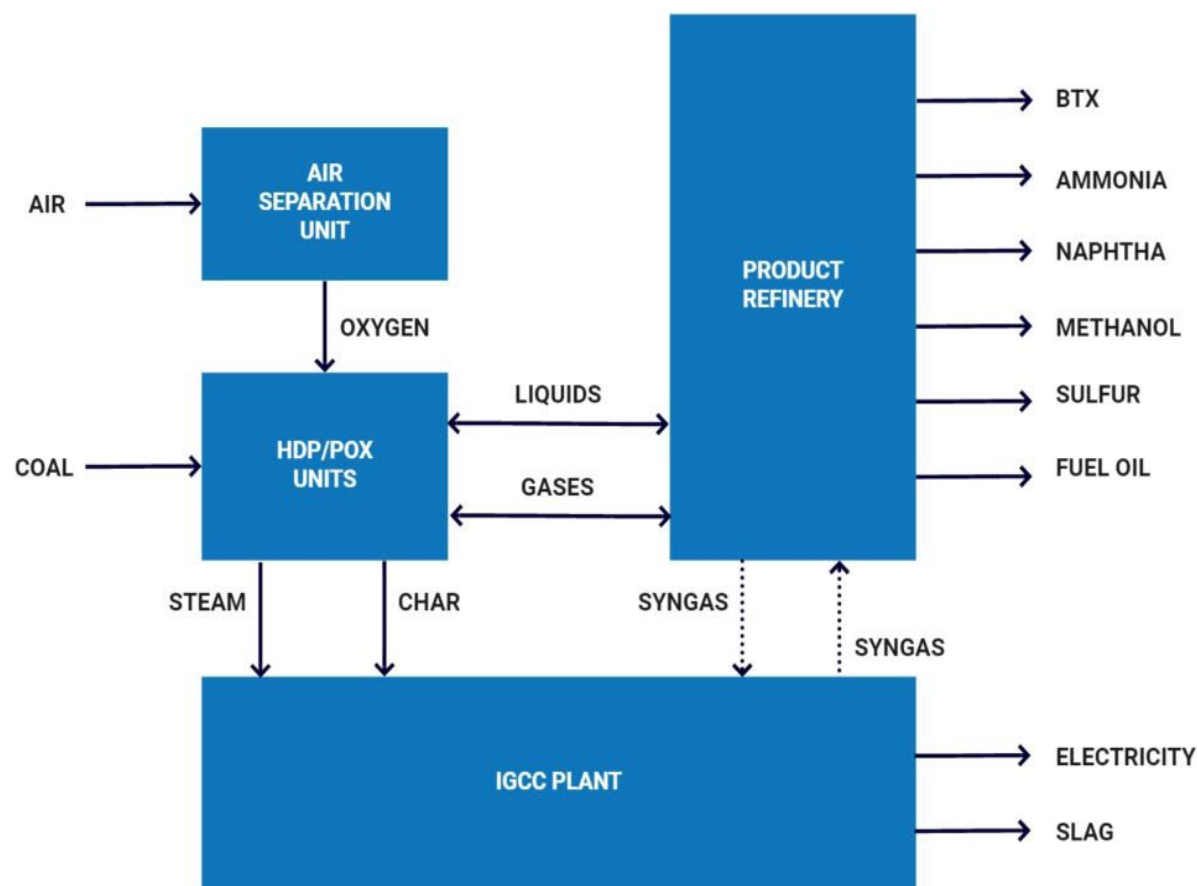
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NEW INDUSTRY - INTEGRATED CHARFUEL® /IGCC PLANT-CCS

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

Load following capability-CH₄ to turbine or chemicals

Pure CO₂ in methane stream, like natural gas-CO₂ separation





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CARBON CAPTURE & STORAGE (OXYGEN-BLOWN IGCC)

Table 1. Cost Analysis and Comparison

Attribute	SOA Value ¹	Coal Refinery Integrated Plant	Description / Justification
Power generator type	IGCC	Oxy-combustion char gasification	Oxygen blown char gasifier will generate clean process gas 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 <u>cost</u> 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	<150 .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”.



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THE CHARFUEL® PROCESS: A PARADIGM SHIFT IN COAL

- Coal Feedstock – long-term, price stable supply agreements, high density, transportable.
- Economically 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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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).

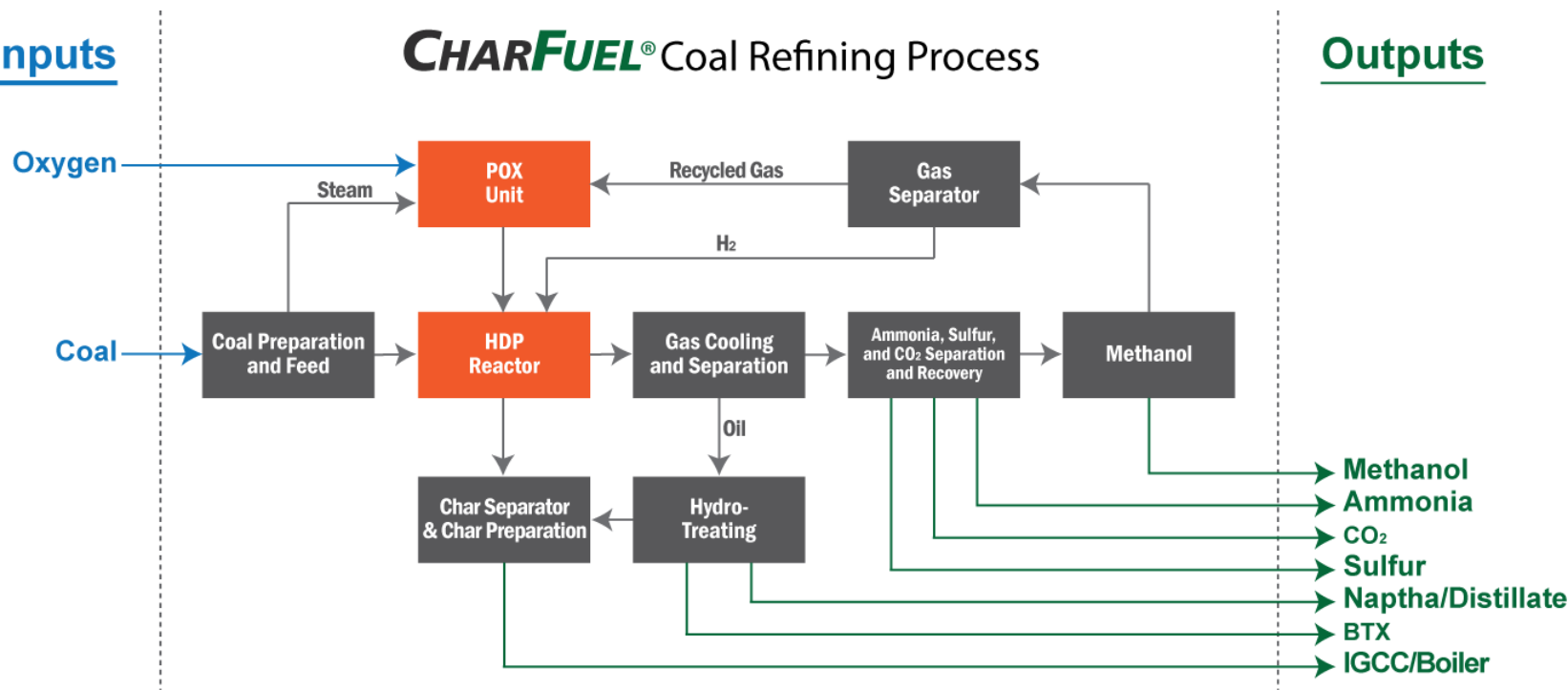


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CharFuel® Coal Refining Process: A New Paradigm

The CharFuel® Coal Refining Process Combines Established and Proprietary Technologies

Inputs



Outputs



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CharFuel® Coal Refining Process Project for DOE

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



Coal Feed

POX Unit

HDP Reactor



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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 SO₂, NO_x, and CO₂ 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.



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DELAYS AND MITIGATION

- Loss of Project Manager in October 2019 due to health issues.
- Mandated shutdown of project in March of 2020 for approximately 4 month due to Covid-19;
- Subsequent to Covid-19 shutdown, manufactures' and vendors' inability to timely provide goods and/or services;
- Approximately 4 months delay in Project Timeline;

MITIGATION OF DELAYS:

CF has modified the Project Timeline to account for the above delays resulting in failure to complete the Project by February1, 2021. It is anticipated that an additional 4 month extension will be required to complete all the tasks.



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TECHNOLOGICAL CHALLENGES

- 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. attritor 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 new technology incorporating inline measurement of coal in dense phase (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.



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SUBAWARDEE ISSUES

- CF's 18 TPD Pilot Unit is situated at Subawardee's facility in Golden, Colorado where it was successfully operated previously.
- Loss of Subawardee project manager and Covid-19 caused project delays and overruns.
- CF has attempted to mitigate this situation by hiring third party vendors to complete certain tasks.
- CF believes that this will mitigate the issues with Subawardee without 1) reducing the scope of the Project, 2) substantially increasing the cost of the Project, or 3) substantially increasing the time to completion over and above the COVID-19- and supply chain related delays.



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CONCLUSION

- 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 without process water or CO2 emissions.