Wave Liquefaction™
The Novel Coal-Biomass to Liquids Process

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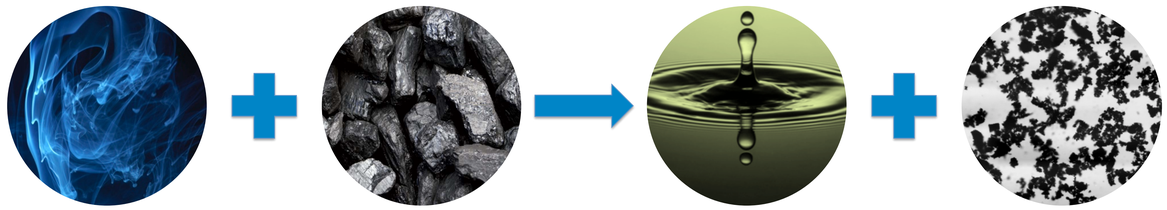
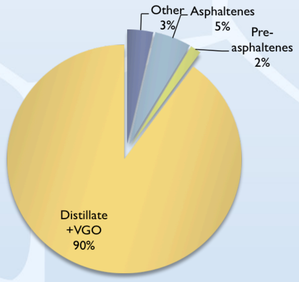
Wave Liquefaction™ combines gaseous and solid hydrocarbons to cleanly and efficiently produce liquid fuels or chemicals and carbon char.



With only 15% biomass feed and no CCS, lifecycle CO_2 emissions are 22% less than for transportation fuels from conventional oil refining.

SYNCRUDE COMPOSITION

Wave Liquefaction™ syncrude yields are 50%-65% wt (on dry, ash-free basis). Liquid product flows at room temperature, has API > 10, and < 50% aromaticity. Low asphaltene content reduces requirements for downstream hydrotreating needed to produce finished fuels.



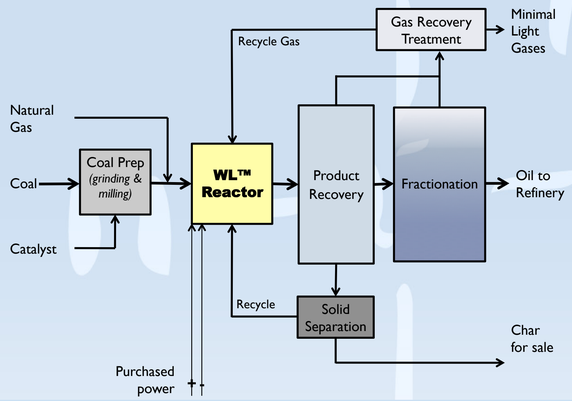
COALS TESTED

More than a dozen coals ranging from lignite to low-volatile bituminous as well as a pine/coal mixture were shown to have high liquid yields with Wave Liquefaction™. Selected results are shown below:

Feedstock Type	Coal Seam	Liquid yield with hydrogen (% wt)	Liquid yield with methane (% wt)
low-volatile bituminous	Pocahontas #3 (VA)	67%	53%
high-volatile bituminous	Pittsburgh #8 (PA)	56%	65%
	H Quest #1 (Russia)	66%	71%
	Blind Canyon (UT)	68%	60%
	Illinois #6 (IL)	72%	61%
subbituminous	Wyodak (WY)	67%	61%
	Wyodak, *dry* (WY)	57%	43%
lignite	*Beulah (ND)*	*29%*	*30%*
	Victoria Brown (Aus.)	76%	52%
biomass-coal blend	Blind Canyon (UT) / Pine	52%	45%

PROCESS DIAGRAM

Wave Liquefaction™ converts coal and natural gas in a simple, continuous process into synthetic crude and an added-value char product. No coal preparation apart from sizing is needed.



BACKGROUND

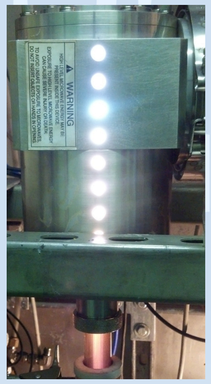
Wave Liquefaction™ process was originally developed with the specific goal of establishing the vast US coal resources as an alternative, cost-effective domestic source of military jet fuel with the lifecycle greenhouse gas emissions below those of a conventional crude oil refining process. Blending coal with 15% biomass by weight will decrease lifecycle CO_2 emissions by more than 20% relative to conventional gasoline production without use of any carbon capture or sequestration solutions.

Wave Liquefaction™ is a rapid, efficient, continuous process, with a compact footprint, high feedstock flexibility, and liquid yields exceeding 50% wt (d.a.f.) for most coals tested. It has a low environmental impact, with little to no CO_2 emissions or water consumption. Production costs of synthetic crude with the current coal, natural gas and electricity prices are estimated to be as low as $30 per barrel.

With natural gas co-feed, methane is activated and converted into hydrogen within the reactor without use of steam-methane reforming or other GHG-intensive solutions. Excess hydrogen can be produced for downstream processing of synthetic crude into finished products. The process rejects carbon in the form of a solid, added-value char, which has a wide range of potential applications.

HOW IT WORKS

Wave Liquefaction™ combines low-energy gas ionization and rapid microwave pyrolysis in a novel direct coal liquefaction process.



- Solid hydrocarbon particles are rapidly and selectively heated to pyrolytic temperatures (over 1000°C within 100 milliseconds).
- Pyrolysis products (liquids) are immediately hydrogenated in-situ with ionized and activated hydrogen-rich transport gases.
- Hydrogenated liquids are quenched by cool (< 300°C) transport gases, stopping further reactions, preventing gas production and maximizing yields of high value products.
- High thermal efficiencies (~80%) and material throughputs dramatically reduce reactor footprint and energy requirements.
- High liquid yields enable conversion of 1 ton of coal into 3-4 barrels of synthetic crude oil or finished fuel products.
- Excess hydrogen production enables downstream oil upgrading to finished fuel products with dramatically reduced GHG emissions.

With no intrinsic CO_2 output or water use, Wave Liquefaction™ can efficiently convert a blend of coal and biomass into cost-competitive net carbon-neutral or carbon-negative transportation fuels.

TECHNOLOGY VERSATILITY

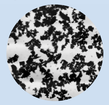
Properties of the Wave Liquefaction™ liquid product (aromaticity, density, H:C ratio) can be widely varied by adjusting energy input, feedstock and gas composition. The product aromaticity can be made close to 100%, with as much as 20% of the liquid yield consisting of the BTEX fraction. Industrial non-fuel uses for these liquid and solid products include:

Carbon pitch for production of aluminum smelting anodes: e.g. ALCOA needs worldwide are >500,000 metric tons/year

Creosote for wood preservation (railroad ties, poles)
Pavement sealants and roof coatings.
Carbon black, graphite and anthracene oil.

Napthalene and other chemicals and precursors.
BTEX (single-ring aromatics) for the plastics industry.

Activated carbon applications (e.g. mercury removal)
Electric arc furnace and PCI applications.



LOW GREENHOUSE GAS EMISSIONS

Wave Liquefaction™ produces little to no CO_2 emissions from both the conversion and from the excess hydrogen production. When deployed with a non-fossil source of electricity, both process and lifecycle emissions are significantly lower than for conventional oil refining processes.

	Current State of the Art Technologies			Wave Liquefaction™		
	Conventional Petroleum	Indirect Coal Liquefaction	Direct Coal Liquefaction (CMSL)	Purchased Power	Integrated Power from Natural Gas	Integrated Power from Char
Operating Pressure		10-60 bar	170 bar	1 bar		
Fungible Oil Cost ($/bbl)	>$80/bbl	~$61/bbl	>$52/bbl	<$41/bbl		
Capital Cost ($K/bpd capacity)	$14-18K	~$80K	$50-56K	$15K	$29K	
Liquid Yield (bbl/ton$_{coal, daf}$)		2.4	3.0	3-4		
Thermal Efficiency	>86%	48%	60%	80%		
Water Consumption (gal/gal$_{fuel}$)	2.5 (est.)	7	0.8	< 0.65		
CO_2 Process Emissions [kg$_{CO2}$/bbl]	33	706	434	13	<90	180
Well-to-Wheels CO_2 [gCO2eq/MJ]	88	195	157	80	94	111
Technology Readiness	9	7-8	6-7	3-4		

Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels, R. W. Stratton, H.M. Wong, J. I. Hileman, 2010

Wave Liquefaction™ can enable not only production of liquid transportation fuels with 22% less lifecycle CO_2 emissions than conventional oil refining, but also clean, sustainable production of chemical feedstocks and solid carbon materials, which can significantly improve sustainability and emissions metrics of the downstream processes and industries.