

Headwaters has developed a direct coal liquefaction (DCL) process used for converting coal into clean transportation fuels. Headwaters CTL, LLC is licensing this technology internationally. The first commercial plant started up December 30, 2008 in China. This is a 20,000 barrel per day plant owned by the Shenhua Group, the largest coal mining company in the world. The installed capital cost of this plant is \$1.5 billion (2007 dollars). The estimated break even cost is \$35 – 40 per barrel selling price (Q. Sun, US-China Energy Center, WVU, Unconventional Fuel Forum 2008, presentation).



DCL Plant, Erdos, Inner Mongolia, China

The advantages of direct coal liquefaction technology compared to indirect coal liquefaction technology (based on coal gasification plus Fisher-Tropsch technology) are:

1. 30 percent lower capital cost for a comparably sized plant (verbal communication with Shenhua)
2. Up to 50 percent more liquid product per ton of coal
3. Up to 50 percent less plant generated CO₂ (almost all of which can be captured for enhanced oil recovery)
4. Half the water consumption
5. 25 percent higher thermal efficiency
6. Balanced power – no need to generate excess power

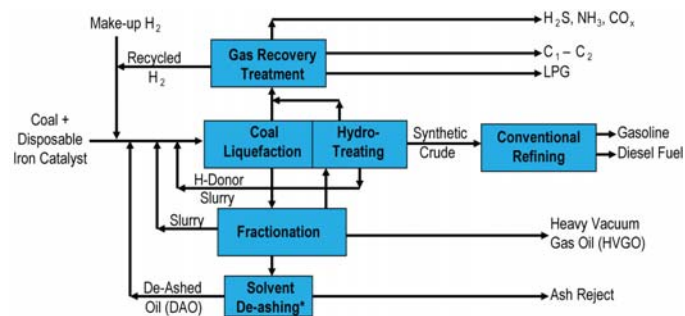
The direct coal liquefaction process operates on low-ash bituminous coal or sub-bituminous coal. A typical bituminous coal can yield 3 barrels of ultra-clean liquid fuel products (diesel and gasoline) per tonne of coal compared to 2 to 2.4 barrels per tonne of coal for indirect coal liquefaction. The thermal efficiency (energy in products divided by energy in coal x 100%) is approximately 60% compared to 48% for indirect coal liquefaction.

Coal is a solid organic material made up of large, complex molecules containing carbon, oxygen, hydrogen, sulfur and nitrogen. The aim of direct coal liquefaction is to: (1) break down the complex coal molecules into smaller component molecules, (2) add hydrogen, and (3) removing oxygen, sulfur and nitrogen.

The end product is high-quality synthetic crude which can be further refined into ultra clean transportation fuels using conventional refining technology.

The Headwaters DCL Process features:

- Headwaters' proprietary GelCat™ Catalyst (dispersed, nano-scale, iron-based catalyst)
- Two-stage, back-mixed, slurry-phase reactors
- Solvent de-ashing to remove ash and unconverted coal and recover residual oils for recycling
- Mild hydrogenation to replenish the hydrogen content of the recycle solvent and to stabilize the raw distillate products
- Resid recycle to enhance net coal conversion



*Omitted for low-ash and/or high-reactivity coal

Headwaters DCL Process

In the Headwaters DCL Process, dry pulverized coal is mixed with recycled process liquid and hydrocracked at 435 to 460°C in the presence of high-pressure hydrogen (about 170 bars). Most of the coal structure is broken down in the first-stage reactor. Liquefaction is completed in the second-stage reactor. The proprietary GelCat Catalyst is dispersed in the slurry for both stages. The intermediate coal liquids from the mild hydrogenation step can be further upgraded using conventional refining techniques to produce gasoline, jet and diesel fuels that will meet or exceed existing and future fuel specifications.

For more information, please contact Headwaters directly.

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