



Alternative Fuels - Technologies and Commercial Status

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Presentation Outline

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 - Fischer-Tropsch Synthesis
 - Methanol-to-Gasoline & Diesel

• Existing Plants

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 - Chemicals
- Announced Projects
- Economics of Alternative Fuels

U.S. Liquid Fuels Supply

million barrels per day

Source: Sieminski, Energy Information Administration, AEO2013 Early Release Rollout Presentation, Paul H. Nitze School of Advanced International Studies, Johns Hopkins University, December 5, 2012, Washington, D.C.

GTL (Diesel) Role in U.S. Transportation

U.S. natural gas consumption quadrillion Btu

Source: Adam Sieminski, U.S. Energy Information Administration, Status and outlook for shale gas and tight oil development in the U.S, CERAWEEK2013, North American Energy, March 06, 2013, Houston, TX

What are Alternate Fuels

- Conventional Fuels from New Sources (e.g., coal, natural gas, & biomass)
 - Gasoline
 - Diesel fuel
 - Kerosene
 - Jet fuels

• Different Fuels from New Sources

- Hydrogen
- Methane (CNG, LNG)
- Dimethyl Ether
- Methanol
- Ethanol (cellulosic)
- Methyl tertiary butyl ether (MTBE)
- Propane (LPG)
- Bio-diesel & Bio-oil

Products From Coal and Natural Gas

Alternative Fuels from Coal

Source: An Alternative Route for Coal To Liquid Fuel, applying the ExxonMobil Methanol to Gasoline (MTG) Process, ExxonMobil Research and Engineering, 2008 Gasification Technologies Conference, Oct 5-8, 2008, Washington, DC

Fuels Hydrogen-to-Carbon (H/C) Atomic Ratios

- To make liquid fuels from coal, either
 - add hydrogen to the feedstock, or
 - reject carbon from the feedstock
- To make liquid fuels from natural gas, either
 - reject hydrogen from the feedstock
 - add carbon to the feedstock

Two Chemical Routes to Alternative Fuels

• Direct Coal Liquefaction

- Hydrogen addition via elemental H₂ or H₂ donor compound
- High temperature and pressure operation (400 to 450 °C, 1,500 to 3000 psig)
- Single or two-stage reaction process
- Maximum theoretical efficiency 70-75%
- Indirect Liquefaction (Coal and Natural Gas)
 - Carbon rejection as carbon dioxide
 - Gasification of feedstock to CO and H₂ (1,000 to 1,500 °C, up to 1,200 psig)
 - Fuel synthesis occurs 250 to 350 $^{\rm o}{\rm C}$ and 300 to 1000 psig
 - Maximum theoretical efficiency 60-65%

Direct Coal Liquefaction

- Originally developed in Germany in 1917
- Used to produce aviation fuel in WWII
- US spent \$3.6 billion on DCL from 1975-2000
- Headwaters Technology licensed to China in 2002

Lawrenceville, NJ 3 TPD (30 bpd)

Catlettsburg, KY 250 – 600 TPD (1,800 bpd)

Inner Mongolia, China 6,000 TPD (20,000 bpd)

Direct Coal Liquefaction Chemistry

Generic Direct Coal Liquefaction Process

Indirect Liquefaction Chemistry

Synthesis Gas Formation

Steam Methane Reforming (SMR) $CH_4 + H_20$ $\frac{Catalyst}{Cot}$ $CO + 3 H_2$ Autothermal Reforming (ATR) $4CH_4 + O_2 + 2 H_2O$ $\frac{Catalyst}{Cot}$ $4 CO + 10 H_2$ Partial Oxidation (POX) $CH_n + O_2$ $\frac{Catalyst}{2}$ $\frac{1}{2}$ $n H_2 + CO$

Fuel Synthesis

Fischer-Tropsch $2n H_2 + CO$ $\xrightarrow{Catalyst}$ $(CH_2-)n - + H_2$ Methanol $CO + 2 H_2$ $\xrightarrow{Catalyst}$ CH_3OH Dimethyl Ether (DME) $2 CH_3OH$ $\xrightarrow{Catalyst}$ $H_3C-O-CH_3 + H_2O$ Methanol-to-Gasoline (MTG) $H_3C-O-CH_3$ $\xrightarrow{Catalyst}$ Gasoline

Indirect Liquefaction Process

Anderson-Schulz-Flory Distribution Wn=2(1- α)² α ⁿ⁻¹ where n=carbon number

Fischer-Tropsch Distribution

Comparison of Direct & Indirect Liquefaction

Direct Liquefaction

- Higher thermal efficiency
- Less complex process
- Applicable to wide range of coals
- Higher liquid yield per ton of coal
- Primary products contain higher concentration of contaminants (S, N, O, metals)
- High octane, low sulfur gasoline (high aromatic content)
- Poor quality diesel/jet fuel (low paraffinic content)
- Maybe better carbon footprint
- May have higher operating expenses

Indirect Liquefaction

- Lower thermal efficiency
- More complex process, but more advanced
- Zero sulfur
- Minimal refining required
- Well suited for C capture
- More complex process
- F-T Process
 - Low octane gasoline ; high cetane diesel (low aromatic, high paraffinic content)
 - Naphtha excellent chemical feedstock
 - Wax high value
- MTG Process
 - High octane gasoline

Commercialization Challenges for Alternative Fuels

- Uncertainty of world oil prices, must stay above \$80/bbl
- High capital costs, \$ billions
- Investment risk in unproven technologies, investors prefer serial #100, not #1
- Limited commercial experience, especially with new, advanced technologies capable of lowering capital and O&M costs
- Very long project development, several years to get to construction
- High water usage
- Uncertainty in regulations for CO₂ and other criteria pollutants

Direct Coal Liquefaction Commercial Projects

Shenhua Direct Coal Liquefaction Project

- Ordos, Inner Mongolia
- Based on HTI two-stage coal liquefaction technology
- Coal feed: 6,000 tpd
- 20,000 bbl/d liquid product
- Project cost: 10 billion yuan (~\$1.6 billion today)
- Construction start: Aug. 2004
- Start-up: Dec 30, 2008

- Operation; 445-455°C , 2,600 psig.
 45/55 dry coal/solvent mass ratio
- First stage slurry catalyst
 - Catalyst: 1 wt% Fe/dry coal
 - Suflur addition: S/Fe=2 (mol ratio)
- Products: 70% diesel, remainder naphtha and liquefied natural gas

Indirect Coal Liquefaction Commercial Projects

SASOL I Sasolburg, South Africa

Plant startup in 1955

- 17 Sasol-Lurgi Fixed Bed Dry Bottom (FBDB) gasifiers
- 100% Sub-bituminous coal feedstock
- Fisher-Tropsch process for Liquid Chemicals production

Supplies syngas to

- Sasol Wax to produce
 - Fischer-Tropsch hard waxes
- Sasol Solvents to produce
 - methanol and butanol
- Sasol Nitro to produce
 - ammonia

• 2004 plant converted from coal gasification to natural gas reforming

- Gasifiers decommissioned 2005
- Replaced with 2 natural gas autothermal reformers

SASOL II & III Secunda, South Africa

- Fisher-Tropsch process for Liquid Fuels & Chemicals production
- Plant startup in 1974
- 155,000 bbl/d production levels achieved in 2004

Photo: Courtesy Sasol

- Sub-bituminous coal feedstock, supplemented with natural gas
- 80 Sasol-Lurgi Fixed Bed Dry Bottom (FBDB) gasifiers

Gas-to-Liquids Commercial Projects

Motunui MTG Project

- New Plymouth, New Zealand (North Island)
- Ownership: 25% ExxonMobil, 75% New Zealand Govt
- Plant Cost: \$1.4 billion
- NG from offshore Maui and Onshore Kapuni gas fields
- Syngas generation: Steam Methane Reformer (SMR)
- NG to Snygas to DME to Gasoline
- Two train, Fixed-bed, ZSM-5 catalyst for MTG process
- Capacity: 14,500 bbl/d gasoline
- Operations: Oct 17,1985 first methanol
- Plant shutdown in Mar 1997 for economic reasons: MTG unit demolished 2003/20044

•Methanol production continued to Nov 2004; shutdown due to natural gas shortage; restarted in 2008

Mossgas GTL Project

- Mossel Bay, South Africa
- Sasol, Petro SA
- Feed: Natural Gas from offshore E-M and F-A fields
- Syngas generation: SMR
- Capacity: 36,000 bbl/d liquids
- Project cost: \$2.5 billion
- Syngas generation: Autothermal Reformer (ATR)

- High Temperature Fischer-Tropsch 3 Synthol high temperature F-T reactor
- Construction started: early 1988
- Operations: 1992
- Continues in operation with new natural gas supply

Bintulu GTL Plant

- Bintulu, Malaysia
- Ownership: Shell 60%, Petronas 10%, Sarawak State 10%, Mitsubishi 20%,
- Project cost: \$850 million; > \$1 billion now
- Feed: 110 million SCFD natural gas
- Syngas generation: Partial Oxidation (POX)

- Shell SMDS process: Tubular fixed-bed reactors; Cobalt catalyst
- Capacity: 14,700 bbl/d liquids
 - Originally 12,500 bbl/d
 - Capacity increased following 1997 ASU explosion
- Construction Initiated: 1989; Operations: 1993

Sasol Oryx Project

- Joint Venture Sasol (49%) & Qatar Petroleum (51%)
- Ras Laffan Industrial City
- Feed: 325 million SCFD natural gas from Qatar's North Field
- Syngas generation: Autothermal Reformer (ATR)
- Sasol slurry reactor; Co catalyst
- Capacity: 34,000 bbl/d liquids
 - 24,000 bbl/d diesel
 - 9,000 bbl/d naphtha
 - 1,000 bbl/d LPG
- Construction started: 2003; Operations: Jan 2007

Pearl GTL Project

- Ras Laffan Industrial City, Qatar
- \$18-19 billion (100% Shell)
 - Includes development of two offshore resources
- Feed: 1.6 billion SCFD natural gas from Qatar's North Field
- Syngas generation: Partial Oxidation (POX)
- Shell SMDS process: Tubular fixed-bed reactors; Cobalt catalyst
- >40,000 workers from >50 countries
- Capacity: 140,000 bbl/d liquids; 120,000 boe/d NGL + ethane
- Construction: Feb 2007
- Start-up: early 2011 (first product export June 2011)

Escravos GTL Project

- 100 km SE of Lagos, Nigeria
- Owners: Chevron 75%, Sasol 10%, National Nigerian Petroleum Co. 15%
- Project Cost: \$8.4 billion
- Feed: 325 million SCFD natural gas from CNL Escravos gas plant
- Syngas generation: ATR
- Sasol slurry reactor, Co catalyst
- Capacity: 33,000 bbl/d liquids
- Construction started: Apr 2005
- Operations: September 2013

Coal to Substitute Natural Gas Commercial Projects

Dakota Gasification Company Buelah, ND

- Part of Basin Electric Power Coop.
- Plant startup 1984
- Coal consumption >18,000 tons/day
- Produces more than ~150 million standard cubic feet of SNG per day
 - also produces fertilizers, cresylic acid, phenol, carbon dioxide, krypton, Xenon, naphtha, tar oil, and liquid nitrogen
- 200 mmscfd CO₂ capacity
- >25 MM tons CO₂ sequestered Feb 2013
- EnCana injecting 7,000 tonnes/day; increasing oil production by 18,000 bbl/d
- Apache injecting 1,800 tonnes/day

CO₂ captured, pressurized, and piped 205 mi. to Saskatchewan for EOR by EnCana and Apache Canada

POSCO SNG Project

- POSCO Gwangyang Steel Works
- Feed: 5,500 tpd subbituminous coal, up to 20% petcoke blend
- 17.6 million SCFD Substitute Natural Gas (SNG)
- Syngas Generation: E-Gas gasification
- Methanation: Haldor Topsoe TREMP[™]
- Construction Started: June 7, 2011
- Start-up: December 2013

Coal to Chemicals and Fertilizers Commercial Projects

Eastman Chemical Company Kingsport, TN

- "Coal-to-Chemicals" Facility
- Plant startup 1983
- Texaco gasifiers
- Gasifies 1,200 tons/day Central Appalachian medium sulfur coal
- Sulfur compounds and ash are removed from the syngas
- Syngas is used to make methanol, acetic acid, acetic anhydride, methyl acetate...

Courtesy: Eastman Chemical Co.

Coffeyville Resources Nitrogen Fertilizers Coffeyville, KS

- Plant converted from natural gas to petcoke to reduce costs by adding GE Energy gasifier
- Produces syngas with CO and H₂
- Syngas shifted to CO₂ and H₂
- CO₂ removed, leaving concentrated H₂ stream
- H₂ used to make ammonia for fertilizer
- 326,663 short tons ammonia in 2007

Economics of Alternative Fuels

Economics of Bituminous Coal Liquefaction

	F-T (1)	F-T Poly (1)	CBTL (1)	DCL	MTG (2)	GTL
F-T Liquid Fuels					32,000 BPD	
(bbl/day)	50,000	50,000	50,000	na	gasoline	34,000
Total Overnight Cost (\$MM)	6,781	7,561	7,061	na	6,063	na
Coal (MM \$/yr)	283	318	255	na	176	na
Required Selling Price (\$/bbl COE)	\$95	\$98	\$104	@\$90 - \$100+	\$ 114	\$89

1. Production of Zero Sulfur Diesel Fuel from Domestic Coal: Configurational Options to Reduce Environmental Impact, NETL, Revision 1, September 2012

2. Internal C-MTG report, William Summers, e-mail, 3-15-2013

3. Viability of GTL for the North American Gas Market, Hydrocarbon Processing, January 2013. Asuumes \$5.60/MMBtu gas, CAPEX of \$100,000 per bpd capacity.

4. Broad estimate based on reported costs in: Robinson, K.K. Reaction engineering of direct coal liquefaction. Energies 2009, 2, 976-1006

Proposed Alternative Fuels Projects

Proposed Gas-to-Liquids Projects

PROJECTNAME	DEVELOPER	STATE	ΤΥΡΕ	SIZE (BBL/D)	COST	STATUS
LaPlace Methanol Facility	Zero Emissions Energy Plants (ZEEP)	LA	GTL	5,000 TPD methanol	\$1 billion	Active
Methanex GTL	Methanex	LA	GTL	1 million TPY methanol	\$550 million	Active
Ohio River GTL Project	Ohio River Clean Fuels, LLC	ОН	GTL	53,000 BPD/diesel and jet fuels	\$3.5 billion	Active
Calumet GTL Plant	Calumet Specialty Product Partners/Oxford Catalysts	ΡΑ	GTL	1,000 bpd Fischer- Tropsch products	TBD	Active
Marcellus GTL	Marcellus GTL & ABCD Corp	PA	GTL	2250 bbl/day	250 Mil	Active
Shell GTL	Shell	LA or TX	GTL	TBD	>\$10 billion	Other
Louisiana GTL	Sasol	LA	GTL	96,000 bpd	\$11 - \$14	2018
Lake Charles Gas-to-gasoline	G2X Energy	LA	GTL	12,500 bpd	\$1.3	
EmberClear Natchez Site	EmberClear	MS	GTL	14,000 bbl/day gasoline	TBD	Other
Celanese GTL	Celanese	тх	GTL	1.3 million metric TPY of methanol	TBD	Other
Carbon Sciences GTL	Carbon Sciences, Inc.	Undecided	GTL	TBD Gasoline	TBD	Other
Primus GTL	Primus Green Energy	Undecided	GTL	25 million GPY gasoline	\$20 million	Other
Sweetwater NGC GTL	Nerd Gas Company (NGC)	WY	GTL	10,000-15,000 bpd gasoline	\$900 Million	Other
Pampa Fuels Phase I	G2X Energy	ТХ		65,000 tonnes		2014
	Sasol/ Ptronas/ Uzbneftegaz	Uzbekistan	GTL	36,000 to 40,000		
	Sasol/ Talisman	W Canada	GTL	TBD		
	Syntroleum	New Guinea	GTL	50,000		

* "Other" is defined as a project that has been announced, but for which limited data is available

Proposed Substitute Natural Gas Projects

PROJECTNAME	DEVELOPER	CITY OR COUNTY	STATE	TYPE	SIZE	COST \$ Billion	STATUS
CPI Yinan	CPI Yinan	Yili City, Xinjiang Province	China,	SNG	6 bill Nm3/a SNG	TBD	Active
Indiana Gasification SNG	Indiana Gasification, LLC, (Leucadia National Corp.)	Rockport	Indiana	SNG	47 million mmBtu per year of SNG/ 134 MW	3.65	Active
POSCO Gwangyang SNG	POSCO Gwangyang SNG	POSCO	Korea, Gwangyang	SNG	500 KTA of SNG	TBD	Active
Lake Charles Clean Energy	Leucadia National	Port of Lake Charles	Louisiana	SNG	120 MMSCFD	2.5	Active
Demonstration "Bluegas"	GreatPoint Energy	Grand Forks	North Dakota	SNG	Biomass fuel	TBD	TBD
Gaz Ukrainy a subsidiary of Naftogaz	Gaz Ukrainy a subsidiary of Naftogaz	PJSC Severodonetsk NIIKHIMMASH	Ukraine, Severodonetsk, Horlivka and Odesa	SNG	TBD	TBD	TBD

* "Other" is defined as a project that has been announced, but for which limited data is available

Proposed North America Coal-to-Liquids Projects

PROJECTNAME	DEVELOPER	STATE	TYPE	SIZE	COST	STATUS
FEDC Healy CTL	Fairbanks Economic Development Corp.	AK	CTL/ GTL	~40,000 BPD /110MW	\$7 billion	Active
Alaska Accelergy CTL Project	Accelergy	AK	CBTL	60,000 bpd /200-400 MW	TBD	Other
Sturgeon Refinery (formerly Redwater Heavy Crude Upgrader)	Canadian Natural, North West Upgrading (NWU)	Alberta	CTL	50,000 BPD	US\$5.704	Active
Future Fuels Kentucky CTL	Future Fuels, Kentucky River Properties	KY	CTL	Undefined	\$1.5 billion	Active
Many Stars CTL	Australian-American Energy Co.	МТ	CTL	8,000 BPD	\$1 billion	Active
Utah Coal and Biomass Fueled Pilot Plant	Viresco Energy LLC	UT	CBTL	40 BPD	\$3 million	Active
Adams Fork Energy - TransGas WV CTL	TransGas Development Systems (TGDS)	WV	CTL	18,300 BPD	\$4 billion	Active
Medicine Bow Fuel and Power Project	DKRW Advanced Fuels	WY	CTL	10,600 BPD	\$2.7 billion	Active
Freedom Energy Diesel CTL	Freedom Energy Diesel LLC	TN	CTL	Undefined	\$405 million	Other

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