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GLOBAL PROSPECTS OF SYNTHETIC DIESEL FUEL PRODUCED FROM HYDROCARBON RESOURCES IN OIL&GAS EXPORTING COUNTRIES

PERSPEKTIVE PROIZVODNJE SINTETIČKOG DIZELSKOG GORIVA IZ UGLJIKOVODIČNIH RESURSA U ZEMLJAMA IZVOZNICAMA NAFTE I PLINA

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Ključne riječi: GTL, Fisher-Tropsh proces, sintetičko gorivo, fosilni dizel, prirodni plin

Abstract

Production of synthetic diesel fuel through Fischer-Tropsch process is a well known technology which dates from II World War, when Germany was producing transport fuel from coal. This process has been further improved in the South Africa due to period of international isolation. Today, with high crude oil market cost and increased demand of energy from China and India, as well as global ecological awareness and need to improve air quality in urban surroundings, many projects are being planned regarding production of synthetic diesel fuel, known as GTL (Gas To Liquid). Most of the future GTL plants are planned in oil exporting countries, such are Qatar and Nigeria, where natural gas as by-product of oil production is being flared, losing in that way precious energy and profit. In that way, otherwise flared natural gas, will be transformed into synthetic diesel fuel which can be directly used in all modern diesel engines. Furthermore, fossil fuel transportation and distribution technology grid can be used without any significant changes. According to lower emissions of harmful gasses during combustion than fossil diesel, this fuel could in the future play a significant part of EU efforts to reach 23% of alternative fuel share till 2020., which are now mostly relied on biodiesel, LPG (liquefied petroleum gas) and CNG (compressed natural gas).

Sažetak

Tehnologija proizvodnje sintetičkog dizel goriva pomoću Fischer-Tropsh procesa datira još od razdoblja 2. svjetskog rata, kada je Njemačka proizvodila dizelsko gorivo iz ugljena. Proces je nadalje usavršen u Južnoj Africi za vrijeme perioda međunarodne izolacije i nestašice goriva. Danas, uslijed visokih cijena sirove nafte na svjetskom tržištu te povećane potražnje energije iz Kine i Indije, kao i zbog globalne ekološke osviještenosti i potrebe za poboljšanjem kvalitete zraka, planira se veći broj projekata proizvodnje sintetičkog goriva, poznatijeg kao GTL. Većina budućih projekata planirana je u zemljama izvoznicama nafte kao što su na primjer Katar i Nigerija, gdje se prirodni plin, kao nus-produkt proizvodnje nafte, najčešće spaljuje. U tom slučaju, gorivi prirodni plin bi mogao biti transformiran u sintetičko dizelsko gorivo i primijenjen u svim modernim dizelskim motorima. Također, trenutna transportna, distribucijska i skladišna opskrbna mreža dizelskim gorivom može biti upotrijebljena bez većih modifikacija. Zbog manjeg udjela štetnih plinova u ispušnom plinu nego li kod fosilnog dizela. GTL gorivo bi moglo znatno doprinijeti cilju Europske Unije od 23% udjela alternativnih goriva u transportnom sektoru, uz postojeća goriva kao što su biodizel, ukapljeni naftni plin i stlačeni prirodni plin.

1. Introduction

Today world production of crude oil is just below 80 million barrels per day and such large emissions of GHG (greenhouse gases) and harmful gases into the atmosphere, caused by oil utilization, have led to increased introduction of alternative fuels because of rigorous air quality regulations regarding climate change fears. Many oil companies believe that the world's oil producing regions have reached sustainable production limit and that the natural gas must be exploited to produce transportation fuels. Increased demand from China and India soon will influence the world's ability to supply crude oil-based products which will further increase crude oil prices. In

2006, the transport sector consumed almost 1 600 Mtoe of energy worldwide [2] and over the next thirty years, the most rapid increase in energy demand is expected to come from this sector (+2.1%/yr versus 1.7%/yr for total demand). Today, transport relies almost entirely on petroleum products, what causes rise in dependence upon oil import and increase in emissions of harmful and greenhouse gases. Alternative motor fuels such are natural gas for vehicles (NGV), liquefied petroleum gas (LPG) and biofuels, represent about 40 Mtoe what is less than 3% of the total fuel consumption.

In the early 20[th] century Germany started to develop process known as Fischer-Tropsch (F-T) which produced transport fuels from coal, resulting in numerous large scale plants built during the 1938 to 1943 era. Afterwards, the conversion process has improved in South Africa, country with plentiful coal and low domestic oil and natural gas resources. Key driver for implementation of alternative fuels are environmental regulations concerning fossil diesel and the fact that supply in future will not be able to meet demand, especially in EU countries with negligible oil resources. Beside present alternative fuels, Gas to Liquid synthetic fuels derived from wide variety of carbon-based feedstock, such are natural gas, coal, biomass and oil sands can reduce petroleum dependency, ensuring security of energy supply and improving air quality. In last five years oil prices has become quiet politically influenced which led to the almost highest price per barrel on world markets ever. Due to political unstable world environment it is predicted that price of oil will never reach a level at the end of the 20[th] century again. Therefore, most of major oil companies have started further R&D of Fischer-Tropsch fuel conversion technology and construction of GTL production facilities.

2. Conversion Process Of Carbon-Based Feedstock Into Synthetic Hydrocarbon Liquid

Fischer-Tropsch is the process of chemical converting natural gas into liquids (GTL), coal to liquids (CTL), biomass to liquids (BTL) or bitumen from oil sands to liquids (OTL). All four processes, usually known as Gas-to-Liquids, consist of three technological separate sections. In the first step carbon feedstock is reacting with oxygen and steam inside of gasifier/reformer generating mixture of hydrogen and carbon monoxide (H_2 + CO) called syngas. This syngas generation can be used in many processes like fertilizer, methanol and specialty chemical production. In addition, generated waste heat could produce steam-derived electricity in IGCC power plants as side-product of the GTL process what could increase the overall energy efficiency, thereby helping to offset the large cost of the equipment. After that, syngas undergoes high pressure with presence of a catalyst inside F-T synthesis reactor and forms long chain carbon-hydrogen molecules, named F-T wax or paraffin. The third step splits these long chain molecules into shorter-length hydrocarbon molecules (diesel, naphtha, kerosene, LPG) in a hydrocracking stage that is almost identical to crude oil refining. The F-T process offers the potential to produce variety range of products such are middle distillates fuels, as well as lubricants and waxes. The complete Fischer-Tropsch process input and outputs as well as is illustrated in picture 2-1.

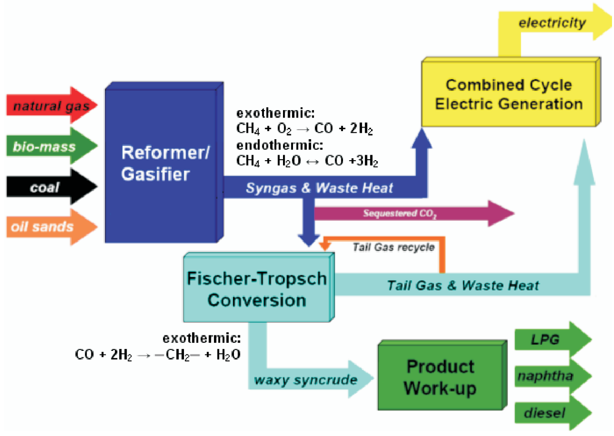

Figure 2-1 Gas to Liquid technological process with Fischer-Tropsch synthesis reactor

Slika 2-1. *GTL tehnološki proces s Fischer-Tropsch sintetskim reaktorom*

Because F-T synthetic fuels are made from natural gas, coal, bitumen or biomass through a chemical process, they have none of the impurities like crude oil derived products such are sulphur, heavy metals and carcinogenic compounds such as benzene. During Gas to Liquid technological process CO_2 becomes significantly problematic as by-product. However, CO_2 gas is in a concentrated stream and therefore is easily sequestered as long as there is a disposal or utilization possibility near the GTL production site. Biomass synthetic fuel (BTL) is considered as CO_2 neutral transport fuel when evaluated on a full life cycle basis what could contribute to greenhouse gasses (GHG) emissions reducement. Efficient combining of all three steps and process integration, is a major challenge for F-T technology developers. Advances and improvements in the first two steps will result in lowering of production costs due to enhanced carbon conversion, thermal and process efficiencies.

The economy of the plant strongly depends upon the chosen feedstock as carbon source. The choice whether GTL plant will use natural gas, coal or biomass in conversion process also depends on feedstock availability for specific region. Many projects with natural gas based GTL plant are planned in Middle East region because of numerous gas and oil fields as well as stranded gas resources. In North America, with large conventional fuel consumption and increment tendency, taking into account dependence upon imported oil and natural gas and substantial domestic coal resources, few large-scale production projects regarding coal and biomass feedstock are considered. Because of different feedstock properties, like carbon content and specific calorific value, the infrastructure of GTL plant should be properly sized concerning feedstock quantity transportation needed for designed fuel output of the plant.

If coal is considered as feedstock for production of GTL fuel (CTL) it should be taking into account widespread calorific value for different sorts of coal (coal, coke, charcoal, carbon). It varies approximately from 10 to 30 MJ/kg of carbon source. For example, assuming conversion process gross plant energy efficiency of 45% [3] the amount of coal feedstock needed could be calculated as follows:

$$f = \frac{E_{fuel}}{(H_d)_{feedstock} \cdot \eta} \qquad (1)$$

where is:

f - feedstock needed for production of 1 bbl CTL, kg

E_{fuel} - calorific value of 1 bbl CTL (5 331 MJ)

$(H_d)_{feedstock}$ - lower calorific value of coal (10 – 30), MJ/kg

η - gross plant energy efficiency (45%)

For production of 1 bbl CTL and 20 MJ/kg coal calorific value it is needed:

$$f_{coal} = \frac{E_{CTL}}{(H_d)_{coal} \cdot \eta} = \frac{5331}{20 \cdot 0{,}45} \approx 590\,kg$$

Analogue to that, if biomass as feedstock is considered (≈ 15 MJ/kg), for production of 1 bbl BTL it is needed:

$$f_{biomass} = \frac{E_{BTL}}{(H_d)_{biomass} \cdot \eta} = \frac{5331}{15 \cdot 0{,}45} \approx 790\,kg$$

Natural gas is the most available and economically favourable of all of these three investigated feedstock. Although, there were some investigations made concerning underground coal gasification which significantly reduces capital and operative costs, natural gas is still primarily used in worldwide existing production facilities. In GTL refinery, for production of 1 bbl GTL and average natural gas calorific value of 33 MJ/m^3, it is needed:

$$f_{natural\,gas} = \frac{E_{GTL}}{(H_d)_{natural\,gas} \cdot \eta} = \frac{5331}{33 \cdot 0{,}45} \approx 360\,m^3$$

3. World Gas To Liquid Production Activities and Future Prospects

Total world gas reserves are estimated to be 176 billion m^3, equivalent to 1,10 BOE (148,7 million m^{3}oe) which is almost equal to the proven world oil reserves of 1,15 billion barrels (155,4 m^{3}OE) [9]. Most of the natural gas world reserves are located in Former Soviet Union (32.1%) while in the Middle East natural gas reserves accounted for 40.8% and crude oil reserves of 63.3%. Initial development and future activities regarding construction of the GTL facilities are related to locations of hydrocarbons reserves in the world. Exception is South Africa's coal based GTL plant which was built due to oil embargo. Today there are totally five synthetic fuel production plants, of which two are pilot-plants, located in Japan (GTL) and Germany (BTL). Commercial sized plants that are in operational stage have been developed on coal based feedstock (South Africa) and natural gas (Qatar, Malaysia). All production and proposed synthetic fuel projects are shown in picture 3-1 in view of proven natural gas reserves and project characteristics are presented in table 3-1.

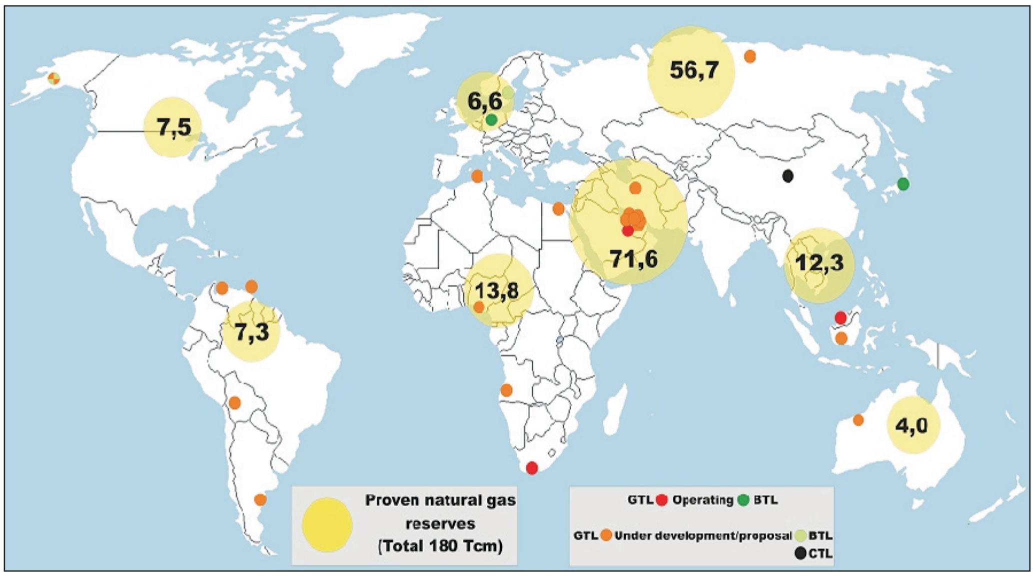

Figure 3-1 World wide synthetic fuel projects in view of proven natural gas reserves [6]

Slika 3-1 *Svjetski projekti proizvodnje sintetičkog goriva uz prikaz zaliha prirodnog plina [6]*

The main companies started to develop GTL plant projects near the large natural gas and oil fields, mainly in Russia, Qatar, Iran and the FSU. There are two main reasons; GTL processes are using natural gas as the feedstock and in this locations they could be commercialized at large production scales projects (>100,000 barrels/d), especially where natural gas is abundant or gas flared associated with oil production. Gas flaring is estimated at 108 billion cubic meters per year what is equivalent of approximately 700 million barrels of oil (BOE) per year [7]. In some countries, particularly Nigeria, flaring will bring economic penalties such that the natural gas resource will have negative values, what improves the economics of most GTL projects. The second reason is associated with production of CO_2 as GTL technological process by-product.

Sequestration of carbon dioxide could be utilized in view of enhanced oil recovery projects which offer further GTL production cost effectiveness and increased oil yield.

Table 3-1 Worldwide GTL production facilities and future prospects [1], [8]

Tablica 3-1. *Svjetska postrojenja za proizvodnju GTL-a i budući planovi [1], [8]*

Facilities	***Investor***	***Production capacity (10^3 bbl/d)***	***Production start -up***
Existing			
Sasol II & III	Sasol	150,0	1974/1979
Mossel Bay, South Africa	PetroSA	22,5	1992
Bintulu, Malaysia	Shell	12,5	1993
Ras Laffan, Oryx I, Qatar	Sasol, QP	34,0	2006
Under construction			
Escavros, Nigeria	Chevron, NNPC	34,0	2008
Planned			
Ras Laffan, OryxII, Qatar	Sasol, QP	32,0	2009 +
Ras Laffan, Qatar	Shell, QP	70,0 + 70,0	2010 +
Qatar	ExxonMobil, QP	166,0	2010 +
Qatar	Sasol, QP	130,0	2010 +
Qatar	ConocoPhillips, QP	80,0 + 80,0	2010 +
Australia	Sasol Chevron	45,0	2012 +
Arzew, Alger	Shell, Statoil,PetroSA	36,0	2010 +
Project proposal			
USA, China, Russia, Iran, Venezuela, Argentina, Bolivia, Angola, Trinidad & Tobago			

4. Energy And Environmental Advantages of GTL Fuel Over Conventional Fossil Diesel

The trend of world growth in diesel consumption will continue in the future, what is caused by increment in number of diesel engine vehicles from 750 mil. in 2005. to predicted 1.10 bil. in 2020. Such growth represents a major problem of ecologically sustainable development.

Today, various transport fuels are taken into consideration as one of the alternatives to the conventional fossil fuels. GTL seems to be available in significant quantities in the near future what could lead to the further reduction of emissions into the atmosphere, necessary to meet future air-quality regulations. The influence of GTL fuel and GTL blends on emissions and engine performance has been researched by numerous oil companies.

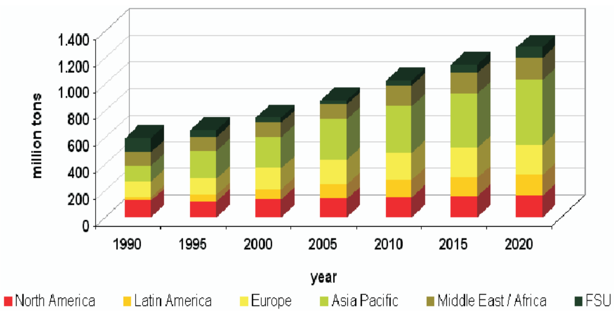

Figure 4-1 Diesel fuel consumption growth by world regions and future predictions [7]

Slika 4-1. *Porast potrošnje dizelskog goriva po svjetskim regijama i buduće procjene [7]*

GTL is extremely clean fuel with low sulphur and aromatics content and has cetane number larger than 70, what is advantageous during cold start and low temperature engine operation, as seen on table 4-1. Higher cetane number yields in reduced ignition delay and reduced fuel evaporation before ignition. Furthermore, GTL demonstrated a slightly longer combustion duration and more uniform heat release rate than the fossil diesel. Density is 8% lower than conventional diesel, but with 1,8% larger heating value and the properties of the blends change roughly proportionally to the blending ratio. Only disadvantage in physical-chemical properties of GTL fuel is that the total GHG emission during combustion, when observing complete life cycle of the fuel, is higher as much as 15% than those for conventional technologies.

Compared to regular diesel fuels over various conditions tested taking into account both heavy-duty and light-duty vehicles, FT fuel reduce particulate emissions substantially around 20% and HC 10%. NO_x emission reduction using the FT fuel is approximately 20% while carbon monoxide CO emission is reduced for 10%. Average savings in harmful exhaust emission for various blends of GTL and biodiesel is shown on picture 4-1.

Table 4-1 Comparison of GTL fuel properties with conventional diesel and biodiesel [6], [4]

Tablica 4-1. *Usporedba GTL goriva sa konvencionalnim dizelom i biodizelom [6], [4]*

Fuel properties	***GTL***	***Low sulphur EU 2005 Diesel***	***Biodiesel (RME)***	***Blend 60% DF 20% GTL 20% RME***	***Blend 95%GTL 5%RME***
Lower calorific value, MJ/kg (MJ/L)	*43,8 (33,53)*	*42,7 (35,44)*	*37,8 (33,3)*	*41,94 (34,68)*	*43,5 (33,52)*
Density, kg/dm^3	0,765	0,83	0,88	0,827	*0,771*
Cetane number	*≈ 70*	*45 - 50*	*50 -60*	*53*	*69*
Kinematic viscosity, cSt (mm^2/s)	*≈ 2,0*	*2,5 – 4,0*	*≈ 7,0*	*3,75*	*2,25*
Total sulphur, ppm	*< 1,0*	*8,0*	*0*	*5*	*0,95*
GHG emission due to production process, kg eq.CO_2 /MJ	*0,0336*	*0,0191*	*0,0240*	*0,0230*	*0,0331*
GHG emission due to combustion process, kg eq.CO_2/MJ	*0,0667*	*0,0639*	*0**	*0,0517*	*0,0634*
Total life cycle GHG emission, kg	0,1003	0,0830	0,0240	0,0747	*0,0965*

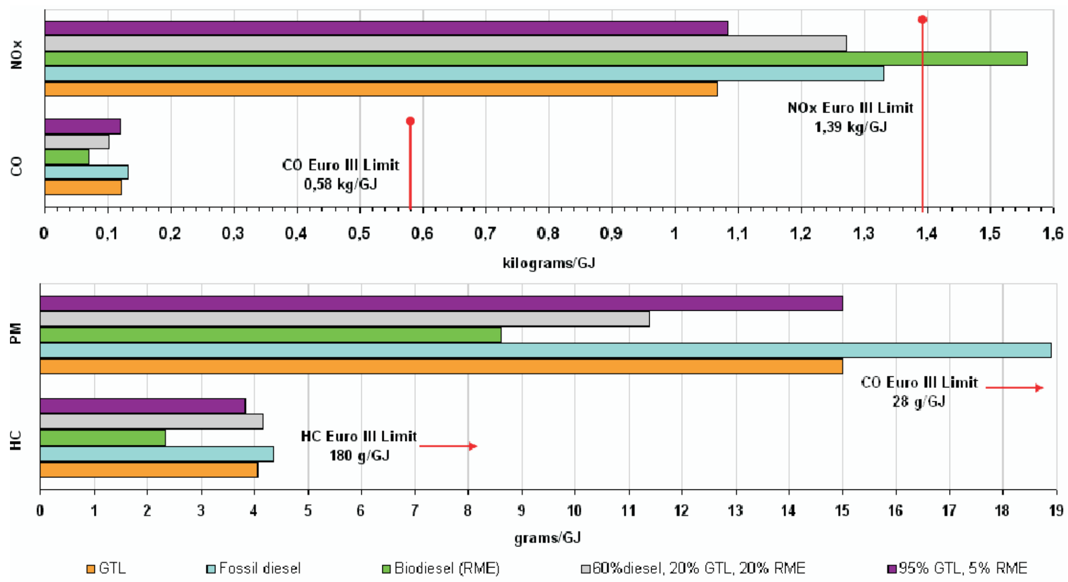

Figure 4-2 Comparison of GTL emissions with various types of fuel [5], [7]

Slika 4-2. *Usporedba emisija različitih goriva uslijed izgaranja [5], [7]*

5. Gas To Liquid Production Economy

Major OPEC exporters willing to sustain and support crude prices certainly in the $40bbl to $60/bbl range. The tendency in the GTL industry is to improve plant economics and reduce operating costs. As plant size increases, natural gas feedstock required to support the operation increase with total costs of the complex (from small scale of $2 million to large facilities of $5 billion investment), eliminating all but the largest oil companies and State-run oil companies from developing new projects. Today, majority of technological R&D advances are directed to the large-scale GTL projects. The economics of modern F-T plants is determined with six individual factors; the cost of capital investments, construction costs; feedstock costs (coal, natural gas or biomass); the gross conversion/thermal plant efficiency; operating costs and the value of the finished products. Plant capital expenses various from $30.000 /bbl/d to $60.000 /bbl/d, depending upon location and type of plant, feedstock and output fuel transportation infrastructure and energy efficiency of the plant [2]. The future intention is to reach $15.000 /bbl/d threshold with implementation of next generation reactor where GTL projects could compete with new crude-oil refineries. Picture 5-1 presents production capacity unit costs trend line and future cost index with share of investments in overall GTL production refinery.

Typically F-T fuel plants require big investments in utility and offsite support systems which can account for 40%–50% of the total cost of a plant. These costs are usually included in each of three basic F-T steps; synthetic gas generation, F-T wax conversion and product workup. Typical cost allocation is 50% to 55% of the total cost for syn-gas generation, 25% to 30% to the F-T conversion and 15% to 25% to product upgrading.

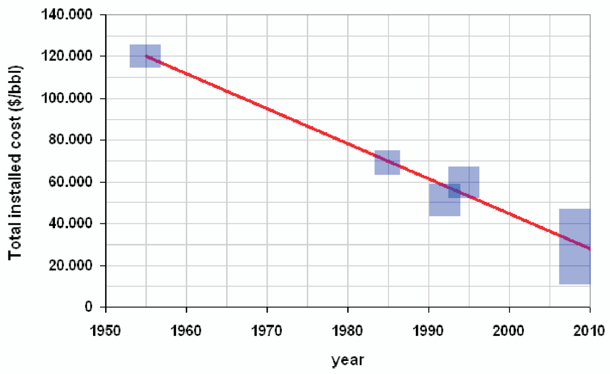

Figure 5-1 Total investment cost depending upon operational capacity of GTL refinery [2]

Slika 5-1. *Ukupni troškovi ulaganja u ovisnosti o kapacitetu GTL rafinerije [2]*

Table 5-1 Synthetic fuel production costs from the different carbon source types for power plant's gross energy efficiency of 33%

Tablica 5-1. *Troškovi proizvodnje sintetičkog goriva iz različitih izvora ugljika te uz stupanj iskorištenja elektrane od 33%*

Production costs	**Natural gas**	**Crude Oil**	**Biomass**	**Coal**
Lower calorific value	33 MJ/m^3	42 MJ/kg	15 MJ/kg	20 MJ/kg
Feedstock price, $/GJ (2007.)	3,46	9,4 (60$/bbl)	4,0	3,0 (60 $/ton)
Fuel price, $/GJ	7,70	-	8,0	6,66
Fuel logistics, $/GJ	1,0	-	3,0	1,0
Production syngas from fuel, $/GJ	3,5	-	3,8	3,8
Production diesel from syngas, $/GJ	1,8	-	1,8	1,8
Diesel total costs, $/GJ	**14,00**	**11,85**	**16,60**	**13,26**
Diesel total costs, $ per litre	0,47	0,42	0,56	0,44

Technologies for a large scale F-T plant have a common infrastructure requirement which includes need for large amount of energy for air separation processes, the preheater for the syngas generation step, waste heat recovery from syngas and its effective utilization, medium/low grade heat generation by the F-T process, hydrogen provision for the hydrocracker and optimum product recovery. GTL projects are around 60% thermal efficient, with around 45% of gross plant efficiency, resulting in around 40% heat rejection [3]. Research in this sector will provide greater utilization of this latent heat on economical basis. The element of market risk is particularly significant due to the massive scale at which the refineries are planned. With expected cash flows of over $1 billion per year from the sale of products, unexpected down time can doom a project. On a smaller scale, installation costs of GTL/CTL/BTL F-T plants rise rapidly, soon exceeding $80,000 per daily barrel of capacity. Most major F-T technology companies are seeking large gas fields to support large-scale projects.

As seen on table 5-1 GTL fuel has greater costs than CTL fuel production technology. Nevertheless, natural gas is often flared during oil production because of lack in transportation and utilization infrastructure grid which results in CO_2 emissions penalties. Oil produced from such reservoirs, especially Nigeria and Middle East, could have poor economical balance. Possibility of the GTL projects development near such fields would have economical advantage and environmental significance over similar projects. CTL projects are of special interest for countries that poses significant coal deposits. World coal reserves, which can ensure production for more than 200 years at the present rate of utilization, are mainly concentrated in countries like China and India. High world oil prices and traditionally low-cost coal mined in these regions, assure economical competitiveness of future CTL projects. As seen on table 5-1 BTL synthetic fuel has the greatest production costs and future prospects are related only as fuel extender (adding coal to biomass feedstock) [9]. Table values have been derived according to calorific value for each feedstock, taking into account assumed power plant's gross energy efficiency of 33% and up-to-date feedstock world market prices.

6. Conclusion

In the time of high oil prices and their instability on world market there is a trend of increased research and development in the field of alternative fuels. Aside that, drivers that contributed to greater implementation of alternative sources of energy, are high level of harmful and greenhouse gasses emissions into the atmosphere, especially in highly populated regions, strong global demand for liquid fuel supply, geopolitical uncertainty of oil supply and principles of sustainable development. Due to life standard increment, especially in developing countries, there is accretion in demand for transportation fuel what will soon lead to problems in supply chain. Gas to liquid technology could supplement share of conventional fossil fuels, resulting in that way with lower dependency upon oil, as well as some ecological and energetic advantages. Transportation and distribution of synthetic fuels could be carried out without significant investments, using existing infrastructure. Future GTL projects are planned near large oil and gas fields, as well as substantial coal deposits, making in that way projects more economically feasible. Regarding existence of CO_2 as by-product of the F-T production process, sequestration could be accomplished by injection of carbon dioxide into the oil reservoirs as part of tertiary methods of recovery. In this way GTL fuel could lower overall greenhouse gasses emissions, as well as make economic benefits to oil production. Moreover, locations of special interest for GTL projects could be oil fields without natural gas transportation grid, where gas is flared making in that way production of oil economically burdened because of enormous CO_2 emissions. Further research of synthetic fuel production technologies will lower investment costs, making it in that way more economically competitive with conventional fuels. On EU example, continued world GTL technology development would not be dependent upon world oil market price because of directives and regulations concerning ecology, implementation of alternative sources of energy and diversification of fuel supply.

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References

[1] California Energy Commission: *GTL Working Group Analysis*, Sacramento, CA, USA, October, 2004, pp.21

[2] Cornitius, T.: *The Impact of Synfuels (GTL,CTL,BTL,OTL) On World Petroleum Supply*, Zeus Development Co, 14th Annual EIA Energy Outlook and Modeling Conference, March 2006., pp.16

[3] Department of Energy National Energy Technology Laboratory: *Gilberton Coal-to-Clean Fuels and Power Co-Product Project*, DOE, 2004, pp.2

[4] Fiato R.; Sibal P.: *ExxonMobil's Advanced Gas-to-Liquids Technology - AGC21*, Presentation at the 2005 Middle East Oil & Gas Show and Conference, March 2005, Kingdom of Bahrain, pp.16

[5] Munack A.; Schröder O.; Ruschel Y.; Herbst L.; A. Kaufmann: *Comparison of Shell Middle Distillate, Premium Diesel Fuel and Fossil Diesel Fuel with Rapeseed Oil Methyl Ester*, Institute of Technology and Biosystems Engineering, April, 2006., pp.43

[6] Schaberg P.; Botha J.; Schnell M.; Maly R.; Pelz N.; Herrmann H.: *Effect of GTL Diesel Fuels on Emissions and Engine Performance*, Proceedings of the 2004 DEER Conference: 2004 Diesel Engine Emission Reduction, Coronado, USA, August, 2004., pp.5

[7] Shell International Gas Limited Technical Report: *Shell Middle Distillate Synthesis (SMDS) Update of a Life Cycle Approach to*

Assess the Environmental Inputs and Outputs, and Associated Environmental Impacts, of Production and Use of Distillates from a Complex Refinery and SMDS Route, PricewaterhouseCoopers Co., May 2003, pp.171

[8] Sichinga J.; Jordaan N.; Govender M.; Van de Venter E.: *Sasol Coal-to-Liquids Developments*, Presentation to the Gasification Technologies Council Conference, 10-12 October 2005, San Francisco, USA, pp.43

[9] Van Ree, R.; Van der Drift B.; Zwart R.; Boerrigter, H.: *Market competitive Fischer-Tropsch diesel production*, 1st International Biorefinery Workshop, Washington, 20-21 July 2005, pp.22