Journal of the Society of Korea Industrial and Systems Engineering
Vol. 35, No. 1, pp.32－38, March 2012.

몽골에서의 석탄액화플랜트 건설에 대한 경제성평가

바트볼트*・김재곤**†

*서울대학교 에너지자원공학과
**인천대학교 산업경영공학과

Cost-Benefit Analysis of Coal-to-Liquids Plant Construction in Mongolia

Batbold Dagvadorj*・Jae-Gon Kim**†

*Department of Energy Resources Engineering, Seoul National University
**Department of Industrial and Management Engineering, University of Incheon

몽골은 석탄 매장량이 매우 풍부하고 석유연료를 전적으로 수입에 의존하기 때문에, 석탄액화플랜트 건설에 필요한 충분한 여건을 갖추고 있다. 본 연구에서는 몽골에 하루 10,000배럴의 석유연료를 생산할 수 있는 석탄액화플랜트를 건설할 경우에 대한 경제성분석을 수행한다. 먼저 기존에 있는 산업계의 석탄액화플랜트 프로젝트 데이터와 학계의 연구결과를 토대로 몽골 석탄액화플랜트 건설에 필요한 비용과 기대수명, 그리고 예상 수명기간 동안 운영했을 때 발생하는 운영비용과 소득을 추정한다. 추정된 비용과 소득을 이용하여 네 가지 시나리오(기본, 악화 1, 악화 2, 매우 악화) 하에서의 경제성 분석을 실시한다. 분석결과 투자수익률이 기본 시나리오에서는 45%에 가까우며, 가장 나쁜 시나리오에서도 5%보다 컸다. 이는 몽골 석탄액화플랜트 건설이 경제적으로 충분히 타당성이 있음을 나타낸다.

Keywords : Coal-to-Liquid Plant, Cost-Benefit Analysis, Mongolia

1. Introduction

During past several years, world petroleum prices reached record highs, even after adjusting for inflation. Concerns about current and potentially higher future petroleum costs for imported oil and petroleum products have renewed an interest in finding ways to use unconventional fossil-based energy resources to displace petroleum-derived gasoline and diesel fuels. Oil shale, tar sands, biomass, and coal can all be used to produce liquid fuels. Of these, coal appears to show the greatest promise considering both production potential and commercial readiness. It is the world's most abundant fossil fuel. Coal-to-Liquids (CTL) is a technology that converts dry coal into liquid fuels to replace gasoline, diesel and jet fuel. CTL technology is ready for existing commercial projects and has applications in some countries [4].

Mongolia is landlocked country in central east Asia with the average population of 2.6 million. It borders Russia to the north and China to the south, east, and west. There is the extraction of crude oil in Mongolia, but so far the country has no domestic

논문접수일 : 2011년 09월 05일　　논문수정일 : 2011년 11월 26일　　게재확정일 : 2011년 11월 30일
† 교신저자 jaegkim@incheon.ac.kr
※ 이 논문은 인천대학교 2010년도 자체연구비 지원에 의하여 연구되었음.

downstream oil industry and almost all crude is exported to China. Consequently, all petroleum products must be imported. The present consumption of oil products in Mongolia is relatively low and the country has a total dependency on imported oil products. However, with growing urbanization and industrialization, as well as an increasing number of cars, there is a growing demand for fuels such as diesel, gasoline and gas.

Currently, coal is the only fossil fuel explored and extracted to any large extent in Mongolia. Mongolia has estimated coal reserves of about 150 billion tons, located in more than 200 coal deposits in 15 major coal basins [1]. The proven reserve of coal is around 20 billion tons. In 2007, over nine million tons of coal was extracted in Mongolia. Government proposals are that this amount is to be increased to 40 million by 2012 and 70 million by 2020 (www.mmre.gov.mn). Domestically, the majority of the coal is used as fuel for the country's thermal power plants and fuel for heating homes, which becomes a main reason for air pollution in Mongolia.

The above Mongolia's energy situation has caused a push for alternative energy technologies with low CO_2 emissions which can replace coal fuel power plants and imported oil products. Among the many energy technologies, the CTL is considered as one of the most promising technologies in Mongolia because Mongolia has no downstream oil industry but abundant coal. So this paper focuses on the cost-benefit analysis of construction of a CTL plant in Mongolia which produces fuels such as diesel and LPG, and electricity from domestic coal resources.

The CTL process (generally termed coal liquefaction) consists of three major steps: coal feeding, gasification to produce a synthesis gas and conversion of the gas to liquid fuels. There are two types of coal liquefaction schemes in principle: direct coal liquefaction and indirect coal liquefaction [7]. Direct coal liquefaction is accomplished by converting the organic matter in coal directly to a liquid by hydrogenation which is a process of breaking up the solid matrix of coal, bringing it into solution (in a process solvent) and effecting further reduction in molecular size to produce distillate products [5]. On the other hand, indirect coal liquefaction first converts the coal to a synthesis gas (primarily hydrogen and carbon monoxide) via coal gasification, and then making synthetic fuels from the syngas in a catalytic process either in the Fischer-Tropsch (FT) process or in the Methanol-to-Gasoline (MTG) process [6]. The FT process first converts the syngas to liquid hydrocarbons, and then refines them to obtain diesel, naphtha and LPG, while the MTG process first makes methanol from the syngas, and then converts methanol to gasoline and LPG. The MTG process is not in commercial production any more, although it was practiced for a brief period in New Zealand.

With respect to CTL technologies, at present time, indirect liquefaction by FT synthesis appears to be the preferred route because of its greater commercial experience, lower capital cost, flexibility in coal feed, plant efficiency, environmental performance, and higher product quality for the end-use fuels and chemicals [5]. The remainder of this paper addresses CTL processes based on the indirect liquefaction approach via FT synthesis.

After Fischer and Tropsch invented the conversion of synthesis gas to liquid products, the German company Ruhrchemie commercialized the process and built the first FT CTL plants in 1936 in Germany. Indirect coal liquefaction plants were subsequently constructed and operated in South Africa, including the Sasol I plant (1955) and two additional plants at Secunda (1980's) [7]. Numerous feasibility studies are currently under way for construction of FT CTL plants in various countries, including the USA, China, India and South Africa. Some recent cost benefit analyses for FT CTL plants are briefly summarized as below.

Comolli et al. [4] conduct a feasibility study on constructing a 25,000 barrels per day (bpd) FT CTL plant in Shenhua, China. The total plant cost is estimated $1.52 billion, with annual revenues and operating costs of $796 million and $693 million, respectively, and 18.5% rate of return. In 2007, National Energy Technology Laboratory (NETL) of the USA examines an economic feasibility of a commercial 50,000 bpd FT CTL plant construction in the Illinois coal basin and 14,640 bpd FT CTL plant construction in Alaska [2, 3]. As a result, the rate of returns are 19.8% for the Illinois FT CTL plant and 12% for the Alaska one, respectively. In 2008, Science Applications International Corporation of the USA conducts an economic feasibility study on constructing an 6,099 bpd FT CTL plant in the State of Indiana, USA and shows the project gives a 18% internal rate of return and 11 year payback. Vallentin [12] analyses and discusses policy drivers and barriers for CTL technologies in the United States. For an extensive survey on the CTL plants, refer to the Zeus global gasification database [14] which offers CTL project statistics, news, and analysis on over 300 CTL plants worldwide.

In this research, we conduct a cost-benefit analysis of the potential construction of an FT CTL plant associated with Tavan Tolgoi coal resource in southern Mongolia. Tavan Tolgoi coal baisn is one of the world's largest unexploited reserves of bituminous coking coal and it is estimated to contain five billion tons.

The rest of this paper is organized as follows. Costs and benefits of constructing and operating a 10,000 bpd CTL plant in Mongolia are investigated in sections 2 and 3, respectively. Cost-benefit analysis for the Mongolia CTL plant project is presented in section 4. Section 5 gives discussions on the results and draws a conclusion for the study.

2. Costs of the Mongolia CTL Project

According to Energy Research and Development Center of Mongolia, the total demand of liquid fuel (FT synthesis) in Mongolia is estimated to be 780 thousand ton in 2009 and is projected to reach nearly 1.4 million ton by 2020. So we set the capacity of the proposed CTL plant to 10,000 bpd (coal feed is 5,500 ton/day) - approximately 450~470 thousand tons per year. Note that the 10,000 bpd CTL plant is a relatively small-sized plant compared to CTL plants projected or operating in other countries but can supply 50~65% of liquid fuel consumption of Mongolia in 2010.

The proposed CTL plant adopts Integrated Gas Combined Cycle technology (IGCC) to produce electricity as well as FT synthesis from syngas. Recently it is commonly recognized that IGCC technology offers opportunities for significantly increasing overall production efficiency while reducing operation costs [7, 10]. Readers are suggested to see Yamashita and Barreto [13] for more details on IGCC. Based on the data from previous literature [2, 3, 9], we can predict the 10,000 bpd CTL plant produces 70 MW electricity per hour. <Table 1> summarizes the parameters related to the capacity of the CTL plant.

<Table 1> The Capacity of the Proposed CTL Plant

Parameter	Value
Coal feed	5,500 ton/day
FT synthesis	10,000 bpd
Net power	70 MW/hour

There are two kinds of costs regarding the Mongolia CTL project: capital costs and operating costs. Capital costs are costs needed to bring a project to a commercially operable status. Capital costs include the cost of the plant's construction, the cost for purchasing equipment needed to run the plant, the cost of financing, permitting and legal costs, and the project and process contingency costs. Capital costs are one-time expenses, although payment may be spread out over many years in financial reports and tax returns. Capital costs can be considered as fixed costs and they are therefore independent of the level of output. Unlike capital costs, operating costs is recurring expenses which are related to the operation of a plant. Operating costs include labor, maintenance materials, engineering and construction management, chemicals, and waste disposal.

In this paper, we collected data for all costs from other recent international projects, the best available commercial sources, research papers, and data from the Internet. For the collected cost data, we estimated costs under the average cost method and added inflation to the all cost estimates from 2007 to match 2010 values as accurately as possible using the web site ‘www.usinflationcalculator.com’.

The proposed IGCC CTL plant contains many equipments for coal gasification, synthetic gas cleaning, air separation, electricity generation. <Table 2> summarizes the capital equipment costs for the CTL plant. The balance of plant includes product tank, instrumentation, controls, site improvements, and buildings and structures. In <Table 2>, the total capital equipment cost is $785.482 million. Note that the total cost includes CO_2 capture, but not compression and storage.

<Table 2> CTL Plant Capital Equipment Costs

No	Description	Cost(1,000$)
1	Coal and sorbent handling	20,365
2	Coal-water slurry prep and feed	34,620
3	Feedwater and misc bop systems	26,474
4	Gasifier and accessories	155,792
5	Gas cleanup	115,062
6	Air separation and compression	86,551
7	CO_2 compression	11,200
8	FT systems	98,770
9	Combustion turbine generator	25,456
10	Ducting and stack	36,693
11	Steam turbine generator	51,930
12	Cooling water system	27,492
13	Ash/spent sorbent handling sys	26,855
14	Accessory electric plant	29,529
15	Instrumentation and control	14,255
16	Improvements to site	12,219
17	Land and buildings and structures	12,219
Total capital equipment cost		785,482

<Table 3> Additional Capital Cost

No	Description	Cost(1,000$)
1	Home office	64,149
2	Licence fee	12,320
3	Financing fee	11,412
4	Project and process contingency	58,911
5	Non-depreciable capital	27,180
Total additional capital cost		173,972

<Table 3> summarizes the additional capital requirements for this plant. This includes home office mostly front end engineering and design, process and project contingency, and license, financing and legal fees. Project and process contingency was estimated at 7.5 percent of the total capital equipment cost as was done in [5, 9]. The total additional capital cost amounts to $173.972 million. By adding the total addition capital cost to the total capital equipment cost, the total capital cost of the CTL plant comes to $959.454 million.

<Table 4> summarizes the annual operating costs for the CTL plant. Fixed operating costs include operating labor and overhead, administrative labor, coal feed, chemical catalysis, waste disposal and maintenance materials. The coal cost is estimated $14.6/ton at the current Mongolian average price.

<Table 4> Operating Costs

No	Description	Cost(1,000$)
1	Fixed operating costs	
1.1	Operating labor	16,460
1.2	Maintenance labor	8,120
1.3	Administrative and support labor	6,920
2	Variable operating costs	
2.1	Maintenance materials	12,120
3	Consumables	
3.1	Chemicals/Catalysts	800
3.2	Waste disposal	20
3.3	Coal cost	29,333
Total annual operating cost		73,773

3. Benefits of the Mongolia CTL Project

We look at both direct and indirect benefits of the CTL project. Direct benefits are the output products of the CTL plant and indirect benefits are socioeconomic benefits. Direct benefits is possible to quantify in money terms while indirect benefits is difficult to quantify.

3.1 Direct Benefits

As can be seen in <Table 1>, the proposed CTL plant produces 10,000 barrels of liquid fuels per day accompanying some kinds of chemical by-products and 70 MW of electricity per year. Since the CTL plant is able to produce certain finished fuel products that are ready for retail distribution, it would increase the overall petroleum supply chain resiliency in Mongolia. <Table 5> summarizes estimated CTL plant incomes from the sale of fuels, electric power and by-products such sulfur, slag and as carbon dioxide captured. All market prices of products are estimated at the exchange rate of 1,350 Mongolian Tugrik (MNT) to the U.S. dollar. Naphtha and distillate's prices are taken from the web sites 'www.yarnsandfibers.com' and 'www.eia.doe.gov,' respectively. Net power price is estimated from the average price in Mongolia over the past two years, i.e. 58 MNT/KW. Carbon dioxide, sulfur and slag prices are from the web sites 'news.alibaba.com' and 'www.saic.com.' It is assumed that only 25% of carbon dioxide can be sold considering the market demand.

<Table 5> Estimated CTL Plant Revenue

Product	Market Price $	Plant Output	Daily Revenue $
Naphtha	1.82/gal	4,300 bpd	328,692
Distillate	2.37/gal	5,700 bpd	567,378
Net power	44/MW	70 MW/hour	52,800
Carbon dioxide	4/ton	5,000 tons/day	5,000 (25% sold)
Sulfur	95/ton	120 tons/day	11,400
Slag	9/ton	350 tons/day	3,150
Total daily revenue			968,420

The CTL plant is expected to run at a 85% capacity utilization rate based on the data from the existing CTL plants [14]. From <Table 5>, the total annual revenue of the CTL plant is estimated $300,452,305(= 968,420×365×0.85).

3.2 Indirect Benefits

3.2.1 Decreased Air Pollution

For several decades, air quality in Ulaanbaatar, the capital of Mongolia, is deteriorating rapidly. Major sources of air pollution are 5.7 million tons of coal and 160 million cubic meters of wood that are used for energy generation every year [11].

The CTL plant is one of the decisions to decrease the air pollution of Mongolia's capital city. For example, the CTL plant can supply electricity and high standard fuels which can replace a huge amount of coal consumption for home heating.

3.2.2 National Security Benefit

Today Mongolia's petroleum consumption is increasing due to economy growth but the Mongolia energy sector does not produce final petroleum products and depends entirely on imports from Russia and China. All fuels prices are determined by prices of exporting countries and are influenced by the world petroleum price. Mongolia needs its own fuel production plants to avoid this outside influence on the price of energy. The CTL plant would be a great domestic energy source in Mongolia.

In 2009 and 2010, Mongolia imported about $1.6 billion of oil products which accounts for 24% of total imports (www.ecustom.mn). If Mongolia constructs a 10,000 bpd CTL plant, the country can save $750 to $850 million per year in imports, which is 50% to 55% of current imports.

3.2.3 Employment

The development of a domestic CTL industry will create new jobs both during CTL plant construction and its operation. Compared to other construction projects of Industrial Corporation Mongolia (www.icm.mn), we can estimate 7,000~9,000 jobs will be created during the construction period and 8,000~9,000 jobs will be created when the CTL plant is in operation.

4. Cost-Benefit Analysis

<Table 6> shows parameters and assumptions used for the cost-benefit analysis. All parameter values were estimated by comparison with other CTL projects [2, 3, 9, 14]. In the table, the project time is 3 years during which 5% of the total capital cost is incurred and the construction period is 3 years incurring 15%, 50% and 30% of the total capital cost in the 1st, 2nd and 3rd year of the construction, respectively. The yield rate of the CTL plant is expected to start at 50% in the 1st year of operation and improve up to 70% and 85% in the 2nd and the remaining years, respectively. The inflation rate was estimated at the average rate from 2007 to 2010 in Mongolia. The tax rate is estimated 15% considering Mongolia Government grant preferential policies given to SOC projects with foreign investment and the Mongolia legislation on gasoline and diesel fuel tax [8].

<Table 6> Parameters and Assumptions

Parameter/Assumption	Value
Project time, construction cost %	3 years, 5%
Construction Period	3 years
year 1 construction cost %	15%
year 2 construction cost %	50%
year 3 construction cost %	30%
Oper year 1 output %	50%
Oper year 2 output %	70%
Oper year 3 and beyond output %	85%
Plant lifetime	30 years
Interest rate	10%
Inflation rate	4.2%
Tax rate	15%

We conduct a cost-benefit analysis subject to four scenarios: a base case (scenario 1), two worse cases (scenarios 2 and 3) and the worst case (scenario 4). In the base case, we use the cost and benefit data given in <Table 4> and <Table 5> under the situation given in <Table 6>. Two worse cases, scenarios 2 and 3, consider negative effects each on the cost and the benefit, respectively. In scenario 2, the plant construction cost increases 20% higher than that in the base case due to possible social and economic crisis in construction time. In scenario 3, the production of FT diesel and naphtha declines 20% from the base case possibly due to engineering problems, with no other changes. Scenario 4 assumes both 20% higher construction cost and 20% lower productivity.

<Table 7> shows calculation of costs and incomes of the CTL project over 36 years in the base case. The construction cost occurs through year 1 to year 6 and the operating cost and the income begin to occur at year 7 and it is generated until year 36. We use the following notation to calculate the construction cost, the operation cost and the income at each year.

CC_t : construction cost at year t for $1 \le t \le 6$
OC_t : operation cost at year t for $7 \le t \le 36$
I_t : income at year t for $7 \le t \le 36$
TCC : total capital cost (= $959.454 million)
AOC : annual operating cost (= $73.773 million)
AI : annual income (= $300.452 million)
IR : interest rate (= 0.10)
IFR : inflation rate (= 0.042)
TR : tax rate (= 0.15)

<Table 7> Calculation of Costs and Incomes of the CTL Project in the Base Case

(Unit : Million $)

Time period	Project period(3 years)			Construction period(3 years)			Operation period(30 years)				
Year	1	2	3	4	5	6	7	8	9	17	36
Operating cost	0.0	0.0	0.0	0.0	0.0	0.0	53.3	50.5	47.8	31.0	11.1
Construction cost	16.0	15.1	14.3	122.3	386.3	219.5	0.0	0.0	0.0	0.0	0.0
Cumulative cost	16.0	31.1	45.4	167.7	554.0	773.5	826.8	877.3	925.1	1227.4	1585.5
Income	0.0	0.0	0.0	0.0	0.0	0.0	92.3	122.4	140.7	96.3	32.6
Cumulative income	0.0	0.0	0.0	0.0	0.0	0.0	92.3	214.7	355.4	1244.5	2298.1
Net revenue	-16.0	-15.1	-14.3	-122.3	-386.3	-219.5	39.0	71.9	92.9	65.3	21.5
Cumulative net revenue	-16.0	-31.1	-45.4	-167.7	-554.0	-773.5	-734.5	-662.6	-569.7	17.1	712.6

<Table 8> Economic Sensitivity Analysis

Scenario	Payback period	IRR	ROI
Scenario 1(Base case)	17 years	16.3%	44.9%
Scenario 2(Worse case 1 : construction cost +20%)	20 years	14.3%	32.1%
Scenario 3(Worse case 2 : productivity -20%)	24 years	12.5%	16.0%
Scenario 4(Worst case : construction cost +20% and productivity -20%)	30 years	10.9%	5.65%

γ_t : construction-cost ratio at year t (= 0.05/3 for t = 1, 2, 3; 0.15 for t = 4; 0.5 for t = 5; 0.3 for t = 6)

ρ_t : output ratio at year t (= 0.5 for t = 7; 0.7 for t = 8; 0.85 for $t \geq 9$)

In the table, the construction cost is calculated using equation (1).

$$CC_t = TCC \times \gamma_t \times \left(\frac{1+IFR}{1+IR}\right)^{t-1} \quad \text{for } 1 \leq t \leq 6 \qquad (1)$$

On the other hand, the operating cost and the income are calculated using equations (2) and (3), respectively.

$$OC_t = AOC \times \left(\frac{1+IFR}{1+IR}\right)^{t-1} \quad \text{for } 7 \leq t \leq 36 \qquad (2)$$

$$I_t = AI \times \rho_t \times (1-TR) \times \left(\frac{1+IFR}{1+IR}\right)^{t-1} \quad \text{for } 7 \leq t \leq 36 \qquad (3)$$

<Table 8> shows results of the cost-benefit analysis subject to different economic and technical situations. In the base case, the payback period is 17 years, the internal rate of return (IRR) is 16.3% and the return on investment (ROI) is 44.9%. Note that IRR larger than the interest rate (10% in this study) or ROI larger than 0 means the project is profitable. Even the worst scenario gives a positive ROI (5.65%), which means the CTL project is profitable enough. Furthermore, considering that the indirect benefits of the CTL project were not taken into account in the cost-benefit analysis in this study, the real economic value of the CTL project would be much higher than assessed by the cost-benefit analysis.

5. Conclusion

In this paper, we investigated an economic feasibility of constructing a 10,000 bpd FT CTL plant in Mongolia. We estimated construction and operating costs and direct and indirect benefits from the CTL plant. The cost-benefit analysis shows that the plant's direct benefits outweighs the costs leaving the indirect benefits asides, which means the proposed CTL plant is economically feasible in Mongolia. Thus, Mongolia Government is strongly suggested to understand the benefits and strategic significance of the CTL industry and attract foreign investment to construct a CTL plant in Mongolia for the country's future development.

References

[1] Bayarsakhan, B.; "The coal development and utilization in Mongolia and need for coal conversion technology," The 4th U.S.-Mongolia Business Forum, Washington, D.C., USA, 2009.

[2] Bibber, L. V., Shuster, E., Haslbeck, J., Rutkowski, M., Olson, S., and Kramer, S.; "Baseline technical and economic assessment of a commercial scale Fischer-Tropsch liquies facility," *National Energy Technology Laboratory*, USA, 2007.

[3] Bibber, L. V., Thomas, C., and Chaney, R.; "Alaska coal gasification feasibility studies-healy coal-to-liquids plant," National Energy Technology Laboratory, USA, 2007.

[4] Comolli, A. G., Lee, T. L. K., Popper, G. A., and Zhou, P.; "The Shenhua coal direct liquefaction plant," *Fuel Processing Technology*, 59(2-3) : 207-215, 1999.

[5] Gray, D., Challman, D., Geertsema, A., Drake, D., and Andrews, R.; "Technologies for producing transportation fuels, chemicals, synthetic natural gas and electricity from the gasification of Kentucky coal," HB299 Report on CTL and SNG Technologies, University of Kentucky, USA, 2007.

[6] Larson, E. D. and Tingjin, R.; "Synthetic fuel production by indirect coal liquefaction," *Energy for Sustainable Development*, 7(4) : 79-102, 2003.

[7] Liu, Z.; "Clean coal technology : direct and indirect coal-to-liquid technologies," The InterAcademy Council, 2005.

[8] PricewaterhouseCoopers; "Mongolia doing business guide," 2010.

[9] Science Applications International Corporation; "Coal gasification and liquid fuel-an opportunity for Indiana," *Indiana Center for Coal Technology Research*, 2008.

[10] Sudiro, M., Bertucco, A., Ruggeri, F., and Fontana, M.; "Improving process performances in coal gasification for power and synfuel production," *Energy Fuels*, 22(6) : 3894-3901, 2008.

[11] The World Bank; "Mongolia environment monitor 2004 : environmental challenges of urban development," 2004.

[12] Vallentin, D.; "Policy drivers and barriers for coal-to-liquids (CtL) technologies in the United States," *Energy Policy*, 36(8) : 3198-3211, 2008.

[13] Yamashita, K. and Barreto, L.; "Energyplexes for the 21st century : coal gasification for co-producing hydrogen, electricity and liquid fuels," Energy, 30(13) : 2453-2473, 2005.

[14] Zeus Global Gasification Database : www.ZeusLibrary.com/Gasification.