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Business Model for the Commercialisation of Compressed Bio-methane Gas by Substituting Conventional Fossil Fuels in the Thai Industrial Sector

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Thailand has modified various anaerobic digestion technologies on a commercial scale since the start of biogas promotion campaigns in the late 1990's. These include biogas from livestock farms, agro-factories and waste. Compressed Bio-methane Gas (CBG), which is considered the second-generation of biogas development, is deemed appropriate for the promotion scheme in the long-term operation. Through a technical field survey from 350 various types of factories, it was found that CBG reliability, price, and less boiler/engine modification are the most important factors for fuel substitution from the factory point of view. This study aimed to investigate the appropriate Renewable Heat Incentive (RHI) to encourage CBG projects in the Thai market based on the fuel switching concept from fuel oil, natural gas and Liquefied Petroleum Gas (LPG) to CBG in the industry sector. This was calculated by applying investment cost, fuel cost, operation and maintenance cost, and depreciation along with engineering approaches. A rate of return from 10 to 15 % was expected. It was found that the replacement of LPG by CBG required the most support, with 5.50 THB/kg of CBG. Natural gas required less support with 1.28 THB/kg of CBG. Policies and barriers to the implementation of the CBG subsidisation programme have also been presented and discussed.

1. Introduction

Thailand has the potential to produce biogas from the livestock, industrial and community sectors. In 2016, the country could produce 1,170 Mm3/y of biogas for and supply to all parts of Thailand (ERDI, 2013). Biogas can be upgraded to Compressed Bio-methane Gas (CBG), which can replace fossil fuels for heating applications and power generation, providing a solution to current and future environmental problems as well as the global challenge of energy security (Pellegrini et al., 2015). CBG is a source of renewable energy with significant potential for further development. It is necessary to promote CBG in the country more efficiently.

According to the Department of Alternative Energy Development and Efficiency (DEDE), the Ministry of Energy has defined the Alternative Energy Development Plan (AEDP) with a target to produce about 1,200 t/d of CBG by 2021 (Department of Alternative Energy Development and Efficiency, 2012) and increase up to 4,800 t/d or about 2,000 ktoe by 2036 (Department of Alternative Energy Development and Efficiency, 2016a). From the DEDE database, Thailand produced more than 95 million MJ/d of biogas between 2015 and 2016, which was used for the supply side, as analysed in this paper. Analysis of the demand side will require a survey from the industrial group. Biogas is often upgraded (Gamba and Pellegrini, 2013) to bio-methane that can be: (1) injected into the national gas grid instead of natural gas or (2) compressed in 200 - 250 barg to be used as vehicle fuel (Niesner et al., 2013) instead of Natural Gas for Vehicle (NGV). It can also (3) be applied

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in household and industrial applications as a substitute for LPG to be used as fuel in the production process. Figure 1 presents guidelines for the utilisation of CBG.
In this study, the fuel consumption from LPG, fuel oil and natural gas in Thailand's industrial sector which can be replaced by CBG was studied and the appropriate supporting mechanism for the implementation of CBG in Thailand was presented.

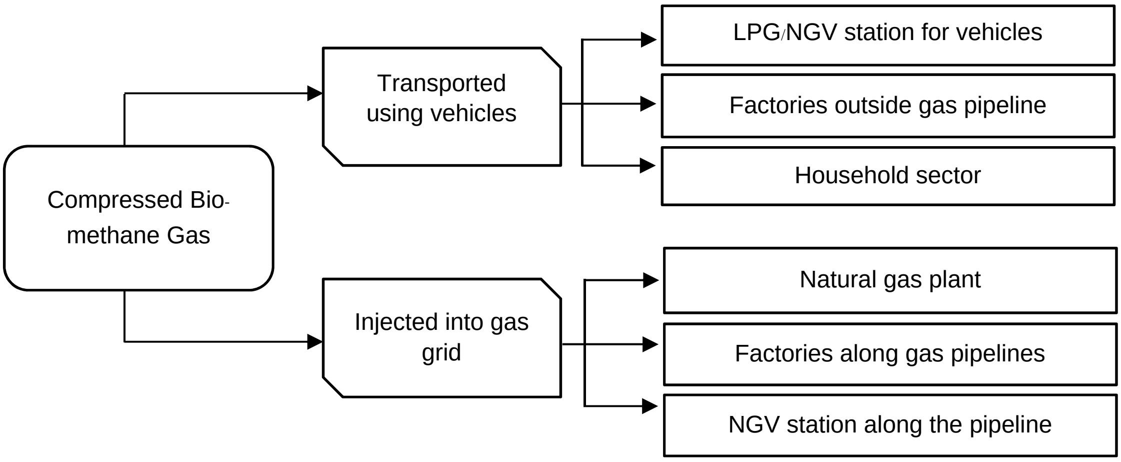

Figure 1: Compressed bio-methane gas utilisation (ERI, 2015)

Although the country has been promoting biogas and bio-methane, the production is only 7.2 t/d due to the problems and obstacles as shown in Table 1.

Table 1: The problems and obstacles of the various factors that influence the CBG in Thailand (Department of Alternative Energy Development and Efficiency, 2016b)

Factor	Obstacles
Society and people involved	The people are not confident to use CBG
Economic	The fallen of petroleum product price
Technological	Biogas upgrading technology to be imported from abroad.
Environmental	Strict enforcement of pollution control of waste water and industrial waste is low.
	No security standards the production and storage of biogas.
Policy	No policy to support the purchase price alternative fuel in the form of CBG
Regulation	Fuel registration.
	No support for security standards.

2. Survey

2.1 Details of the survey in the Thai industrial sector

Study of the demand for fossil fuels in various industrial sub-sectors has the potential to promote biogas and CBG as renewable energy across the country. Three types of energy including LPG, fuel oil and natural gas have been surveyed. It was found that the major factors affecting the substitution of CBG for existing fuels and promoting the use of renewable energy are thermal industrial-oriented demand and supply. Data on economic costs, the possibility of fuel substitution, logistics and planning were collected to promote the use of CBG with supportive measures from the government.
The survey showed a wide variety of industrial groups using LPG and fuel oil for production throughout all regions of Thailand, likely due to the ease of transportation, storage and applicability.
In contrast, industrial groups using natural gas were found mostly in the central region. The fuel must be passed through a gas pipeline, but only industrial plants existing around the gas pipeline have such accessibility.

2.2 Required information from the survey

The survey was constructed based on the CBG demand side. There were 350 factories. Among these, 140 factories primarily used LPG, while 150 factories used fuel oil and 60 factories used natural gas. On the CBG supply side, the focus was on those industries that could produce biogas or CBG, such as food factories, sugar mills, flour mill, etc. The CBG supply side was extracted from the DEDE database, which is a database consisting of reported biogas production between 2015 and 2016. Table 2 presents the survey structure and required information from the demand-side.

Table 2: The survey structure and information from factory demand side for CBG

Part	Details
Part 1 General information	Factory information
	Type of industry
	Operation hours
Part 2 Information on using fossil fuels and biogas	Monthly consumption of fossil fuels
	Fuel consumption in main equipment and machinery
	Fuel quality specifications or fuel requirements
	Fuel processing include logistic and in vehicle
	The proportion of fuel consumption by product types
Part 3 Production quantity	Production volume, by each product
Part 4 The fuel substitution trend	Expansion of production plans
	The decision to change the existing fuel to biogas, CBG
	Concerns in changing the original fuel to a bio-methane
	Interested about bio-methane
	Readiness assessment to improve the factory to switch to bio-methane

2.3 Result and analysis of survey

Information for the industry sector, fuel consumption, fuel prices and attitudes and trends of entrepreneurs is shown in Table 3. It was found that the unit price for natural gas was the lowest, while the LPG price had the highest fuel consumption. In this section, it was found that the attitudes and trends of enterprises were mainly focused on fuel price as it is the most important and influential factor in decisions on investments.

Table 3: Survey results of the fuel consumption in the industry sector (data survey on January to May 2017)

Fuel type	Amount	Consumption (MJ/y)	LHV (kJ/Unit)	Price (THB/MJ)`	Attitude and Trend (%)		
					Price	Fuel quality	Machine adjustment
LPG	140	$3,661.83 \times 10^6$	50,220	0.39	65.08	17.46	17.46
Fuel oil	150	$5,043.17 \times 10^6$	38,174	0.29	71.31	17.21	11.48
Natural gas	60	$25,239.38 \times 10^6$	36,694	0.21	57.15	32.14	10.71

Note: Unit of LPG, fuel oil and natural gas are kg, L and Nm^3.

3. Economic model

The basis/justification for the assumptions used in the economic model includes the biogas system operators that are already required to receive compensation from CBG production, with an internal rate of return (FIRR) not less than electricity production with the feed-in tariff (FIT), which is not less than 15 %. Due to the normal rate of renewable energy promotion in Thailand, which requires the FIRR to be not less than 15 %, the government must provide material and financial support if the FIRR is higher. Biogas technology is used in the assessment. The plug flow digester has a biogas production at a capacity of 1.5, 3, 6 and 12 t/d, which is the proper size in the country. The membrane separation technique is popular for upgrading to CBG. The form of distribution is subjected to the manufacturer of CBG. They are responsible for the production costs as well as transportation from the gas stations to distributors with a project duration of 20 y. From Figure 2, it was discovered that smaller CBG production size resulted in higher, cost per unit. As a result, production must be in a large enough quantity to meet the investment potential. The highest production quantity is 12 t/d with a production cost of 9.6 THB/kg. Thus, entrepreneurs gain more benefits from higher levels of CBG production.

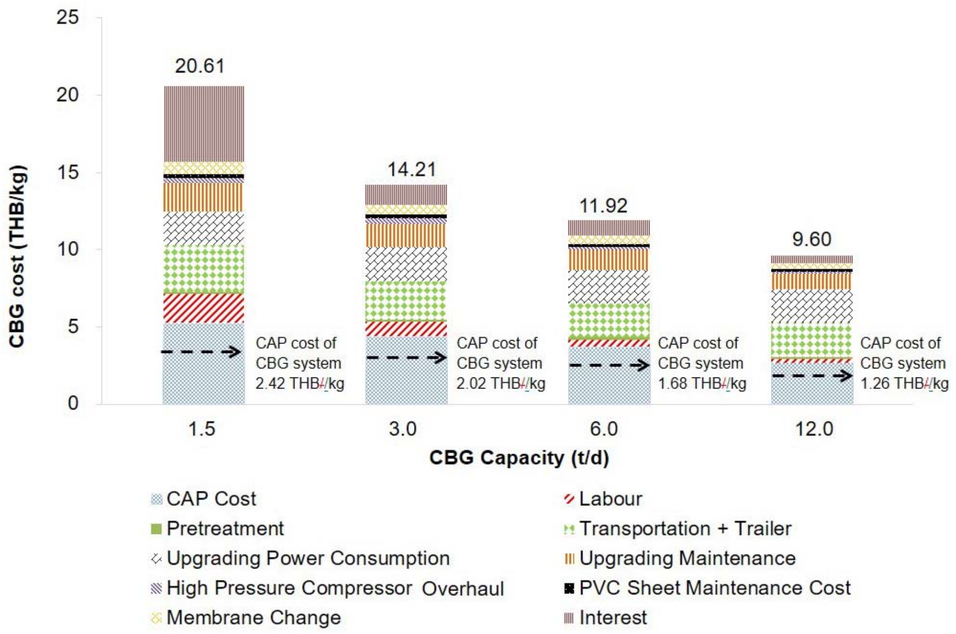

Figure 2: Compressed bio-methane gas cost structure. Note: CAP cost is included biogas and CBG systems

3.1 Fuel cost

It was found that fuel oil and natural gas prices were lower than LPG in monetary unit per MJ. As shown in Table 4, CBG price was not able to compete in the market due to the fact that factories that used fuel oil and natural gas were able to obtain fuel at a cheaper price. CBG should be considered as a substitute for LPG, indicating LPG will be replaced by CBG with the support from the government. It is likely that the replacement with CBG as a substitute for LPG is possible.

Table 4: The fuel cost in Thailand's industrial sector

Fuel type	Unit	Fuel cost	
		THB/Unit	THB/MJ
LPG	kilogram (kg)	19.12	0.39
Fuel oil	litre (L)	11.66	0.29
Natural gas	standard cubic metre (Sm^3)	0.006154	0.005944
CBG	kilogram (kg)	9.60 to 20.61	0.22 to 0.46

Remark: Low Heating Value (LHV) of LPG, Fuel oil, Natural gas and CBG (CH_4 89 vol%) are 62.26MJ/L (54.0kg-LPG/L), 77.39MJ/L, 36.74 MJ/Sm^3 and 44.5 MJ/kg)

3.2 Business model

CBG is mainly supported on the research and lab scale, which is of non-commercial application. This is because the cost per unit of CBG remains high, which is the main factor making operators focus on more than 50% of all fuels. The government plays a major part in the expansion and stimulation of CBG market. The business model is shown in Figure 3, which describes the potential and feasibility of upgrading biogas production plants for CBG through quality improvement processes. The monitoring and verification of CBG quantity have been set by using two meters on both the supply and demand sides for checks and balances. Transport by truck, at a maximum distance of 70 km, where the purchased CBG, which is used in the production of heating, is already supported. Subsequent to this is the measurement of CBG volume at the destination in order to correspond with the "before CBG" through the second meter installed at the factory destination. This ensures that operators receive support from the government and take such support for the available CBG to meet the objectives.

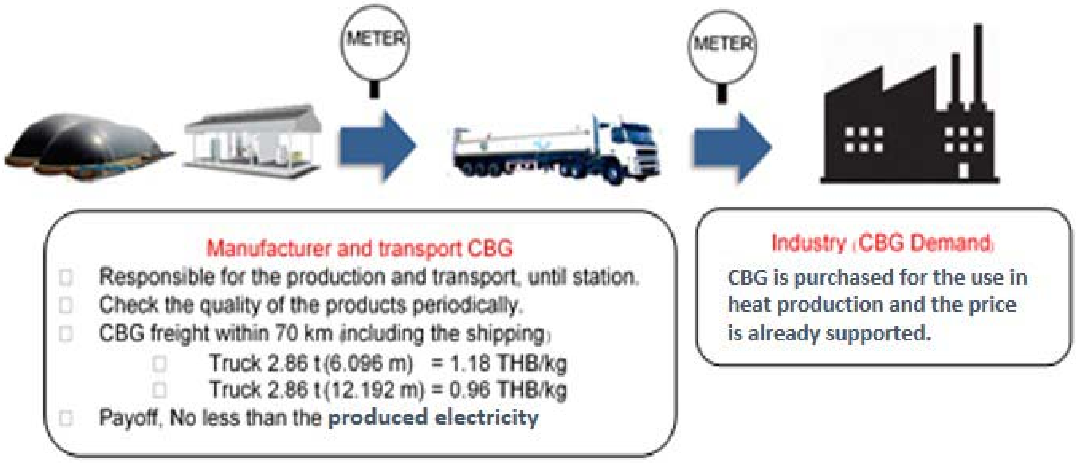

Figure 3: CBG transport from supply to demand and monitoring concept

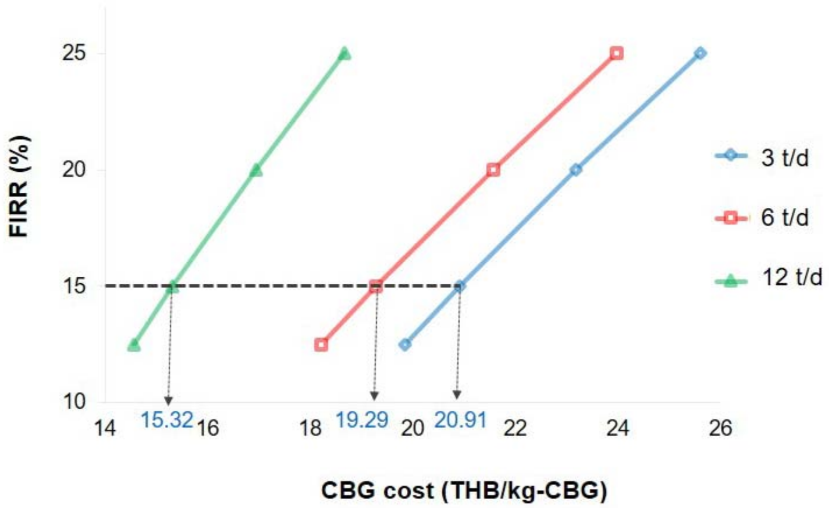

Figure 4: CBG cost on FIRR with incentive

With CBG production capacity of 1.5 t/d, it is not feasible to stimulate motivation for CBG investment. Due to small capacity, accompanied with high cost per unit, it is not worth the investment when compared to the larger size. When FIRR increased, the profit enterprises will be increased. This will cause the government to spend money to support CBG. Therefore, FIRR at 15% is appropriate for CBG with capacities of 3, 6 and 12 t/d.

3.3 Economic model summary and support mechanism

From Table 5, the cost of appropriate CBG production capacity should start from 3, 6 and 12 t/d. When comparing the capacity between 3 t/d with 6 t/d, it was found that more support was required for the latter due to the larger size system. No support from the government was needed for CBG production with the largest capacity of 12 t/d. Production of this size allows competitive advantage under the market mechanism. The government must have the financial support in using CBG as a substitute for LPG and end the support programme when the LPG price is higher than 22 THB/kg. This is due to CBG price being competitive with LPG price under the free market mechanism. It was found that every capacity has a Payback period (PB) of less than 6 y and is not much different.

Table 5: Economic model of CBG Production on FIRR 15 %

Production capacity of CBG (t/d)	Payback period (y)	Part of the state support		
		THB/MJ-CBG	THB/kg-CBG	THB/y
3	5.63	0.123	5.475	5,995,025
6	5.72	0.087	3.851	8,433,690
12	5.66	-0.003	-0.120	-525,999

4. Conclusions

This paper presents a CBG business model for replacing fossil fuels in the Thai industrial sector for thermal utilisation. The model compared three fossil fuel types including (i) liquid petroleum gas, (ii) fuel oil and (iii) natural gas, with CBG price per unit of fuel for comparison. The fossil fuels cost that can compete with CBG is LPG, which cost 0.39 THB/MJ, while fuel oil and natural gas are cheaper or equal to CBG price, making it difficult for CBG to compete with them. As for appropriate CBG production, government support mechanisms for CBG are strongly recommended with 15 % FIRR incentives for CBG supply and demand side in fuel switching. CBG should be generated from the biogas produced from the sewage or waste water, not energy crops, for long-term cost effectiveness. Capacity development concerning CBG characteristics and benefit should be developed and initiated from the possible CBG demand side.

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