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Market and Economic Assessment of Using Methanol for Power Generation in the Caribbean Region

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Abstract: *The cost of electricity is an important factor for sustainable development of countries in the Caribbean region. Due to current reliance on oil derivatives (diesel and fuel oil), these economies are susceptible to high prices and volatility. It is proposed here that methanol, traditionally a feedstock for petrochemicals, is an alternative fuel for power generation, requiring only minor modifications to existing infrastructure (such as plant, storage, import facilities and shipping). Modifications would address the particular fuel properties of methanol in terms of its relatively low heating value, low lubricity and high inflammability. In order to assess its overall economic viability, an integrated economic model of the entire methanol to power (MtP) chain is developed in this paper. Based on preliminary cost estimates, it is shown that the use of methanol in new gas turbine installations or retrofitted turbines and reciprocating engines may be cheaper than conventional fuels due in part to the lower market price on an energy equivalent basis. This is found to be the case especially in smaller markets which currently use fossil fuels only in reciprocating engines. However, certain countries, typically the larger ones, obtain discounted prices for diesel, which makes MtP less favorable. The extent to which renewable energy forms part of a country's energy mix also impacts MtP's competitiveness. Nonetheless, a reduction of up to about 10 US cents per KWh can be realised, with a potential regional MtP power market size of about 6000 MW or 16.2 billion kWh of electricity generated annually. Hypothetically, this would result in an incremental methanol market of roughly 7.1 millions tonnes per annum requiring 626 MMscfd of natural gas.*

Keywords: *Methanol; alternative fuel, gas turbine; Caribbean power market*

Nomenclature

A_m	Discount factor
COx	Oxides of carbon
CNG	Compressed natural gas
FFB	Fossil fuel based
G_P	Country replaceable generating capacity
H.R.	Machine heat rate
H.V.	Fuel heating value
I_L	Labor cost index
I_P	Power generation cost index
I_R	Retrofitting cost index
I_S	Shipping cost index
I_T	Storage tank cost index
LNG	Liquefied natural gas
MtP	Methanol to power
NOx	Oxides of nitrogen
P_m	Methanol market price
P_{Opex}	Power plant operational expenditure
P_R	Cost of retrofitting
P_S	Shipping costs
P_{Capex}	Power plant capital expenditure
$_r$	subscript refers to reference data
α_P	Power plant scaling factor
α_T	Storage tank scaling factor

1. Introduction

Methanol is primarily known for its use as a chemical feedstock, for instance in the production of formaldehyde and acetic acid. It can also be used to produce olefins and other longer chain hydrocarbons such as proteins and gasoline (Olah et al., 2006), although these applications are not as extensive. However, as these markets develop, there are significant implications in the light of potentially peaking global crude oil production (Campbell, 2002). Methanol's use is not restricted to chemical production. One such example is that methanol has been proposed as a solution to addressing stranded gas fields; the key advantages being increased safety and a potentially more economic means of transportation than LNG (Olah et al., 2006). As such, much work is being done to reduce methanol's cost of production. Traditionally produced by the breakdown of organic matter, methanol is today almost entirely produced by the synthesis gas route. However, it is possible for methanol to be produced by the direct oxidation of methane (Cheng et al., 2006), and from the hydrogenative reduction of CO_2. Both of these methods have tremendous potential, and at present there is much effort directed to their development.

Even using the conventional production route, methanol is being considered in fuel applications. With an excellent octane number, methanol has been used in spark ignition engines in various ways, including as a simple additive to improve engine performance, and in the development of special methanol blends for use in racing applications with modified engines (Burns, 2008). In particular, methanol's use soared in the late 1990's when MTBE, a derivative of methanol, was used as a common additive for gasoline engines. Several other tests were carried out by different US State agencies to examine the technical feasibility of using methanol and di-methyl ether (DME), which is another derivative, in compression ignition diesel engines for transport purposes (Olah et al., 2006). However, most of these projects came to a halt at the end of the testing stage.

More recently, methanol is finding new fuel applications, namely in fuel cells (Sangtongkitcharoen et al., 2008). It can be catalytically reformed to produce hydrogen gas (H_2) for use in fuel cells, or reacted with air in direct methanol fuel cells (DMFC).

In general, methanol's use as a fuel is becoming more attractive. This is significantly being influenced by recent trends in the global energy market. Firstly, prices of oil and its related products have been at a record high recently. This has been partly attributed to the rapid growth of Far East and Asian markets, which placed higher demands on limited oil resources. This has prompted consideration of other alternative energy sources that are not oil dependent. A second key issue has been growing global concern for the environment and emphasis being placed on the use of fuels having lower COx and NOx emissions. Methanol offers these advantages, being a derivative of natural gas which is partly de-linked from oil, and is a clean burning fuel.

This is of key significance to countries of the Caribbean region, given that almost all are net importers of fossil fuels, which have been negatively affected by recent fluctuations in crude oil prices. As such, there is a keen interest in sourcing cheaper and cleaner fuel alternatives. Consequently, this work investigates the potential for methanol as such an alternative for the Caribbean region. It presents both a qualitative assessment of MtP relative to other potential natural gas transportation technologies, and a quantitative comparison to the present fossil fuel-based power generation technologies in the Caribbean.

The paper first gives an overview of some of the key technical considerations of the MtP (i.e., Section 2), and outlines important characteristics of the Caribbean power market (i.e., Section 3). In Section 4, factors affecting MtP's feasibility relative to other means of supplying energy to the region are considered. A description of the economic model of the MtP value chain is presented in Section 5, and results are discussed in Section 6. The paper concludes by highlighting some of the key findings on the suitability of MtP to the Caribbean region, and identifies future work on technical as well as commercial aspects of the technology.

2. Technical Considerations of Methanol as a Fuel

The use of methanol as a fuel for stationary engines has previously been investigated (General Electric, 2001). The overall result was that methanol can be used successfully, with only minor modification of the standard machinery to account for the main differences in the fuel characteristics of methanol as compared to those of other liquid fuels. For comparison, Table 1 shows some of the fuel properties of methanol and other fuels used for power generation (Martinez, 2007), along with a summary of key considerations on methanol's use in a gas turbine engine.

Firstly, methanol has a significantly lower calorific value, which for example, is approximately half that of diesel. This is generally compensated for by a concomitant increase in the volumetric flow rate of methanol which can be achieved without significant difficulty or deviation from usual operating conditions. Special nozzles can be used for high fuel distribution with low pressure drop

(Beukenberg and Reiss, 2006).

Table 1. Comparison of Fuel Properties and Resulting GTE considerations

Fuel property	Methanol	DME	Natural gas	Diesel	Issues of MtP using a Gas Turbine
Density (kg/m^3)	790	1.8	0.68 – 0.70	820 – 860	Liquid fuel versus gaseous
Viscosity Coefficient	0.59	0.086 – 0.14	0.01 – 0.012	2.6 – 4.1	Lubrication and fuel-delivery issues
Flash point (K)	285	232	85	330	Safety issues requiring special handling, control and monitoring
Heating value (MJ/kg)	22.7	30	54	45	Increased fuel flow rate requirements

Secondly, the lubricity of methanol is relatively low. This poses problems with standard fuel-delivery systems, such as those involving the use of valves for flow rate control, and in situations where the fuel comes into contact with other moving parts within the engine. There are generally two approaches to addressing this. If preserving the chemical integrity and consistency of the methanol is not a major requirement, then the use of suitable lubricant additives may be employed, with a consequent alteration in combustion emissions. This may also impact the rate of wear and residue build-up on other engine components. Alternatively, an appropriate pump (e.g. screw type) with effective coatings may be used. The third factor concerns methanol's combustibility and flammability, which consequently requires specific handling, controls and monitoring.

Despite the foregoing issues, previous work has confirmed that the use of methanol as a fuel for power generation is indeed possible. However, this has been mostly limited to an experimental scale on gas turbines. In addition, Seko and Kuroda (1998) showed that methanol's use in compression-ignition engines is not only possible, but can be more efficient than using diesel. It also yields lower NOx emissions, with a lower brake specific energy consumption at medium load conditions. The major requirements here are similar to those when methanol is used in gas turbine engines. More specifically, the key issue is increasing the auto-ignition ability of methanol, given that its auto-ignition temperature is higher than that of diesel. This can be achieved chemically by the addition of combustion enhancers. Several mechanical methods have also been developed. Two of the more common include exhaust gas scavenging techniques (Tachiki, 2007) and flash-boiling the fuel (Seko and Kuroda, 2001). Currently, research into the development of other methods is ongoing.

3. Caribbean Market Assessment

Although the compatibility of methanol as a fuel for use in power generation equipment is important, it is not the sole factor in determining its use in the region. An assessment of Caribbean power markets is also a preliminary step in order to determine trends and key details that were unique to the Caribbean context and would influence the implementation of MtP in the region. The information extracted includes the size of power demand in each country, different energy sources (oil-derivatives, natural gas or renewable), power generation equipment being used (reciprocating engines or gas turbine), cost of electricity and cost of fuel. As noted later on in this section and in section 5, this information is useful in determining the market potential for MtP and also feeds into the economic model.

The market assessment was conducted by gathering data related to energy usage and arrangements in twenty-six countries. This data was obtained from the United States Energy Information Administration (EIA), Caribbean Energy Information Systems (CEIS), Organisación Latinoamericana de Energía (OLADE) and the websites of national power authorities. Table 2 shows some of the main power market data for the countries.

Based on the market assessment, some defining characteristics of Caribbean power markets have been identified:

- *Size classification of markets*. It was found that the island markets could be differentiated on the basis of size. In general, generation capacities for the countries were either significantly below or above 100MW; there were only three islands with capacities close to 100MW. As such, markets were classed as either small (below 100MW) or large (above 100MW).
- *Technology classification of markets*. Another basis for differentiation between markets was the type of power generation technology used. For some islands, power is generated solely by thermal processes using turbines or reciprocating engines. However for others,

power is generated using a mix of renewable energy technologies and thermal technologies. Countries with mixed technologies usually had lower yearly electricity prices than those without. Accordingly, power markets can also be divided into two other categories: single and mixed technologies.

- *Turbine and engine market share*. The two main types of machinery used for thermal processes are gas turbines and reciprocating engines. However, it was found that their distribution is correlated to the market size of the country. Generally, those with smaller market sizes tended to use reciprocating engines more, while larger markets used gas turbines.

In addition, the assessment revealed that most countries increase their installed generating capacity by 15% to 45% every 4 to 6 years. Consideration of these factors points to different motivations and configurations for the implementation of MtP in a country. For example, MtP may be implemented via the installation of new turbines to replace existing infrastructure. Alternatively, it may be implemented as a means of satisfying new demand. It is also possible to modify existing turbine and reciprocating engines to burn methanol, as was noted earlier. These options are explored in greater detail in Sections 5 and 6.

Table 2: Installed Electricity-Generating Capacity in the Caribbean Region (2005)

Country	Total Installed Capacity (MW)	Installed FFB Capacity (MW) / (% of total installed capacity)	Renewables & Other installed capacities (MW)	Primary FFB Power Generation Technology
Antigua & Barbuda	27	27 (100%)	0	Possibly reciprocating
Aruba	150	150 (100%)	0	Mixed: Diesel reciprocating and gas turbines
The Bahamas	401	401 (100%)	0	Reciprocating
Barbados	210	210 (100%)	0	Gas turbines
Belize	52	27 (52%)	25 (48%)	Data not found
Virgin Islands (UK)	10	10 (100%)	0	Possibly reciprocating
Cayman Islands	115	115 (100%)	0	Reciprocating
Cuba	3958	3901 (99%)	57 (1%)	Data not found
Dominica	22	14 (64%)	8 (36%)	Reciprocating
Dominican Republic	5530	4988 (90%)	542 (10%)	Primarily reciprocating, and gas turbines
French Guiana	140	140 (100%)	0	Data not found
Grenada	32	32 (100%)	0	Reciprocating
Guadeloupe	423	411 (97%)	12 (3%)	Primarily reciprocating, and gas turbines
Guyana	313	308 (98%)	5 (2%)	Primarily reciprocating
Haiti	244	181 (74%)	63 (26%)	Reciprocating
Jamaica	1469	1325 (90%)	144 (10%)	Primarily reciprocating
Martinique	396	396 (100%)	0	Primarily reciprocating, and gas turbines
Montserrat	2	2 (100%)	0	Reciprocating
Netherland Antilles	210	210 (100%)	0	Data not found
Puerto Rico	5358	5258 (100%)	100 (2%)	Primarily reciprocating, and gas turbines
St. Kitts & Nevis	20	20 (100%)	0	Reciprocating
St. Lucia	57	57 (100%)	0	Reciprocating
St. Vincent/ Grenadines	24	18 (75%)	6 (25%)	Reciprocating
Trinidad & Tobago	1416	1416 (100%)	0	Gas turbines
Turks/Caicos Islands	4	4 (100%)	0	Data not found
Virgin Islands (US)	323	323 (100%)	0	Data not found

4. Factors Affecting MtP's Feasibility

Present global concerns surrounding energy security and environmental impact have crafted a space for the emergence of a new type of fuel which can satisfy increasing energy demand in a sustainable and cost competitive manner. For countries of the Caribbean region, natural gas is one of the most promising fuel sources because of its relative abundance, cleaner combustion emissions and proximity to supply, Trinidad and Tobago being the primary one. This section presents a qualitative assessment of various means of transporting natural gas including via methanol.

The main options previously considered, for instance in Kromah et al. (2003), are gas pipeline, gas to hydrate, gas to wire (GtW), gas to liquid (GtL), and the more familiar LNG and compressed natural gas (CNG). However, given the fact that the proponents of each of these technologies assume the use of the same natural gas source and with markets being small, these technologies cannot be jointly implemented. It follows therefore that these are all competing technologies for the utilisation of natural gas in the region. Aside from natural gas, it is worth mentioning that the increasing global use of bio-fuels has sparked some level of consideration in the region. Bio-diesel and bio-ethanol have already found use in some countries, but in most instances they have only been explored on a small scale. Consequently, the major focus here is on MtP's comparison to some of the aforementioned technologies for natural gas utilisation within the region. Table 3 summarises the main factors.

Table 3. Comparison of Natural Gas Transportation Technologies

Considerations	**Pipelines**	**CNG/LNG**	**MtP**
Shipping	None	1. May require multiple vessels, partial loading/ offloading depending on inventory 2. Special alloy materials needed	May require multiple vessels, partial loading offloading depending on inventory
Harbor	None	Development of deep water harbor and compressors/ LNG offloading facilities	Use of existing harbor
Storage and other infrastructure	Compressors, metering, *etc.*	New storage infrastructure; re-gasification plants	Use of existing fuel import facility with relatively minor modification
Speed of implementation	Long (> 3 years)	CNG (Medium, 2-3 years); LNG (Long, > 3 years)	Short (< 2 years)
Supply flexibility (multiple suppliers, increase in market size, *etc.*)	Low	Medium	High
Typical initial capital investment per country (millions US$)	Medium (> 10)	High (> 100)	Low - Medium (<100 depending on option for implementation)

4.1 Shipping/Transportation

Shipping of methanol uses no specialised containment or materials, methanol being relatively non-corrosive, and a liquid at room temperature and atmospheric pressure. In contrast, LNG and CNG require cryogenic alloy materials (and in most cases double containment), and materials capable of high pressure respectively.

4.2 Infrastructure (Harbor and Import Facilities)

Methanol ships consist of a wide range of sizes, so smaller ones may be available which would not require harbors as deep as those for LNG and CNG vessels. Being a liquid fuel, storage and handling equipment at the import terminal would be essentially the same as that of other oil-based liquid fuels, which are already in existence in regional markets. However, compressors would be required for a pipeline, a regasification facility for LNG, and high pressure storage and compression facilities for CNG.

4.3 Implementation Time and Supply Flexibility

Unlike other gas transportation technologies, MtP can be implemented in a relatively short space of time given that methanol is a widely traded commodity with significant production from T&T. As such, there is flexibility in supply in terms of the number of countries in the Atlantic Basin region, and the ability to access incremental volumes on a spot trade basis. As mentioned above, no specialised equipment is required which also reduces the time to implement and expand facilities compared to pipeline, LNG and CNG.

4.4 Initial Capital Investment

LNG has proven to be economic only for long distances and large volumes, which are not characteristic of regional markets. CNG has been considered for closer and smaller markets but this has not yet been proven economic for this region. An OECS report estimates a construction cost of approximately 5 to 10 million US dollars per island for pipeline transmission (Hertzmark, 2006), which is relatively small. However, consideration has been given to a single main transmission pipeline, with spurs to each market, since building separate pipelines for each country is not a feasible option. As such, the capital cost, and commercial, legal and political hurdles for such a project may be prohibitive.

Overall, the comparison of different natural gas transportation technologies suggests that MtP has certain distinct advantages particularly for the unique Caribbean power market. Of the competing technologies, it is the most flexible and easily implementable, while potentially being the least costly. As mentioned earlier, MtP can be implemented using gas turbines or by retrofitting reciprocating engines which is the most common power generation technology being used. Consequently, a more detailed economic analysis is required for determining the best solution for MtP's application.

5. Economic Model of MtP Value Chain

5.1 Integrated Value Chain Model

A schematic of a generic value chain was developed to encompass key elements of the MtP process and to allow for a more holistic economic evaluation, see Figure 1. The MtP value chain comprises four key economic activities.

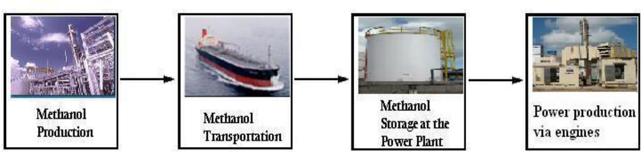

Figure 1: Schematic of Generic MtP Value Chain

1) Methanol production – For the purposes of this study, the market price of methanol is used as the cost of methanol, obtained from Chemical Marketing Associates Inc. (CMAI). This allows for a fair market-based comparison since it avoids issues such as rates of return and natural gas pricing in determining the cost of methanol production.
2) Methanol transportation – This approach considers the cost for the shipping of methanol to the various markets using standard vessels.
3) Methanol storage – Here, it is assumed that inventory at the import terminal would be large enough for thirty days of power generation demand. The cost involves the capital for construction of the necessary storage facilities.
4) Power generation – This element of the chain covers the cost of generating power from methanol using either gas turbine engines or reciprocating engines. Both the initial capital outlay and the subsequent operational expenses are considered here.

In order to quantitatively assess MtP's feasibility, an integrated economic model comprising these activities was developed. The model sought to capture the contributions of each of these four activities to the overall unit cost of generating power for a given year, C_{MtP}, as given by:

$$C_{MtP}= C_m + C_P + C_S + C_T \quad (1)$$

where all costs, C, are of units US\$/kWh. C_m represents the cost associated with purchasing methanol fuel required to generate one unit (kWh) of power; this is computed by:

$$C_m = (P_m) * (H.R./H.V.) \quad (2)$$

where P_m is a variable that represents the market price of methanol for a given year in US\$/tonne, H.R. is the heat rate (MJ/KWh) for the gas turbine (or reciprocating engine), and H.V. is the heating value of the fuel (MJ/t).

C_P represents the unit amortized capital costs plus the unit annual operating cost associated with the power plant. This can be for the installation of a new power plant or the retrofitting of an existing plant. For a new installation C_P is given by (3a), and for a retrofitted plant by (3b):

$$C_P = A_m[P_{Capex} * (I_{P,y}/I_{P,r})] * [(G_P/ G_{P,r})^{\alpha_P}] + [P_{Opex} * (I_{L,y}/I_{L,r})] \quad (3a)$$

$$C_P = A_m[P_R * (I_{R,y}/I_{R,r})] * [(G_P/ G_{P,r})^{\alpha_P}] + [P_{Opex} * (I_{L,y}/I_{L,r})] \quad (3b)$$

The terms $(I_{P,y}/I_{P,r})$ and $(I_{L,y}/I_{L,r})$ in (3a) and (3b) are inflation correction terms for the respective year *y* relative to the reference year *r*, and for power plant cost (I_P) and operating cost (I_L) respectively. A_m is the discount factor which adjusts the capital cost (P_{Capex} or P_R for new or retrofitted plants respectively) given in million USD to an annual figure. P_{Opex} is the annual operating cost. These costs are for a plant of power generating capacity GP (MW). The term $[(G_P/ G_{P,r})^{\alpha_P}]$ is a scaling factor adjuster, which alters the capital cost of the reference plant capacity $G_{P,r}$ to the plant capacity G_P that will be used for MtP, in the specific island. This accounts for economies of scale. C_S represents the unit cost associated with shipping methanol:

$$C_S = P_S * (I_{S,y}/I_{S,r}) * (H.R./H.V.) \quad (4)$$

with corrections, as before, for inflation and converting the total cost P_S given in US$/tonne to US$/kWh.

Finally, C_T represents the unit amortised cost for a storage tank, given by:

$$C_T = A_m[P_T * (I_{T,y}/I_{T,r})] * [(V_G/V_{G,r})^{\alpha_T}] \quad (5)$$

The usual adjustments for inflation and capacity requirements for the particular country are made to the capital cost of the tank P_T as given in million USD, which is based on a volume of $V_{G,r}$.

These economic model equations were used to compute the overall cost of power generation for the following scenarios, which arose from the market assessment (cf. Section 3):

- Scenario A – New turbine installation
- Scenario B – Retrofit of an existing gas turbine to use methanol
- Scenario C – Retrofit of an existing reciprocating engine to use methanol.

The model treated each scenario differently by altering the input parameters. It determines the power generation cost using methanol for each country, in a specific year, based on a particular scenario. For example, assuming the island of Grenada selected to retrofit reciprocating engines (Scenario C) in the year 2000, the model determined the unit cost of power generation in US cents per kilowatt-hour (kWh) for Grenada using reciprocating engines in that year.

5.2 Model Inputs and Assumptions

The main inputs are shown in Table 4, comprising plant costs, scaling factors and inflation indices. The market assessment provided the countries replaceable generating capacity, G_P, which is essentially the portion of the total installed power generation capacity that is derived from fossil fuels.

Table 4. Main Input Parameters for Cost Estimation

Parameter	Value	Unit
Power Plant cost, P_{Capex}	10	Million US \$ per 8.5MW capacity ($G_{P,r}$)
Plant operational expenses, P_{Opex}	0.025	\$/kWh
Storage Tank costs, P_T	10	Million US \$
Cost of retrofitting (mainly for fuel delivery system), P_R	0.065	Million US \$
Shipping costs, P_S	20	US \$/tonne
Methanol heating value, $H.V.$	22.7	MJ/kg
Country replaceable generating capacity, G_P	Island specific	MW
Power plant scaling factor, α_P	0.6	NA
Storage tank scaling factor, α_T	0.57	NA
Turbine heat rate, $H.R._{Turbine}$	12.77	MJ/kWh
Reciprocating engine heat rate, $H.R._{Recip}$	10	MJ/kWh
Methanol market price (Source: CMAI), P_m	Year specific	US \$/gallon
Electric Power Generation index (US Bureau of Labor statistics), I_P	Year specific	NA
Metal tanks and vessels custom fabricated and field erected index (US Bureau of Labor Statistics), I_T	Year specific	NA
Utilities: Unit labor cost index _ Nat gas distribution (US Bureau of Labor Statistics), I_L	Year specific	NA
Deep sea freight transportation index (US Bureau of Labor Statistics), I_S	Year specific	NA
Pump and pumping equipment manufacturing except hydraulic (US Bureau of Labor Statistics), I_R	Year specific	NA

The following outlines the cost estimation techniques and key economic assumptions.

1) The model estimates cost on a nominal US dollar basis. All capital investments are amortised over the economic lifespan of twenty years at a discount rate of 8%, used to calculate the discount factor A_m in Equations (3) and (5).
2) For the new installation scenarios, the cost of electricity from MtP in any given year was derived by assuming that all the relevant MtP infrastructure capital cost were expended in that particular year.
3) It was found that trends for historical diesel fuel market prices and historical electricity prices for the various countries exhibited a

high level of correlation (greater than 0.9). This was calculated using MATLAB 6.5 and a sample plot illustrating this relationship is shown in Figure 2. As a result, forecasted data for the fuel market prices were used to project the respective electricity prices with an expected reasonable degree of accuracy.

4) Given the data for an 8.5MW gas turbine engine (Breeze, 2005), similar capital cost estimates for machines of higher generating capacities were obtained using a factored estimate with the relevant scaling exponents as listed in Table 4 (Peters and Timmerhaus, 1991), cf. Equations 3 and 5. It was assumed that this estimation technique was applicable up to a plant capacity of 100MW.

The economic model was used to determine the yearly power generation cost for a country, for each scenario, over the period 1996 to 2006. It should be noted that of the twenty-six countries in the region a sample of eight (see Table 5) was considered for the more detailed economic analysis. These countries are representative of a wide range of power market sizes and mix of power generation technologies.

Also, projections for the generation costs in future years were also determined for each country and each scenario, using a correlation between historical methanol market prices and MtP power generation cost, similar to that outlined in assumption (3). As such, forecasted trend data for methanol prices (CMAI) was used to produce projections for the power generation costs over the period of 2007 to 2012.

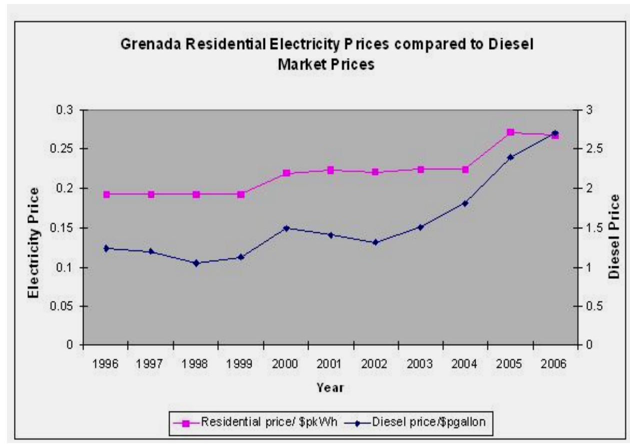

Figure 2: Correlation between Electricity Price and Diesel Market Price

Table 5: MtP Cost Difference under Different Scenarios for Selected Islands

Country	Total Installed capacity (MW)	Fossil fuel based installed capacity	MtP and FFB cost difference in 2010 (Scenario A)	MtP and FFB cost difference in 2010 (Scenario B)	MtP and FFB cost difference in 2010 (Scenario C)
Bahamas	401	100%	-2¢/kWh	-1¢/kWh	+4¢/kWh
Barbados	210	100%	-2¢/kWh	-1¢/kWh	+4¢/kWh
Belize	52	52%	-4¢/kWh	-3¢/kWh	+1¢/kWh
Cayman Islands	115	100%	-6¢/kWh	-5¢/kWh	0¢/kWh
Dominica	22	64%	-2¢/kWh	-1¢/kWh	+4¢/kWh
Grenada	32	100%	+2¢/kWh	+3¢/kWh	+7¢/kWh
Jamaica	1469	91%	-1¢/kWh	0¢/kWh	+5¢/kWh
St. Lucia	57	100%	+4¢/kWh	+5¢/kWh	+9.7¢/kWh

Remarks: +ve values = MtP savings

6. Economic Comparison

This section examines the cost of power generation via MtP, as calculated by the economic model described above. The relative cost under the different scenarios is essentially the same for the forecast period. Thus, for comparison purposes, the year 2010 was chosen as a reference, this being a likely timeframe taking into account actual implementation time. The projected power generation cost for each of the three MtP scenarios was compared to the projected fossil fuel-based (FFB) power generation cost in that year. Table 5 summarises the results of this comparison for several countries, where a positive cost difference indicates that the MtP option is cheaper than the FFB one (i.e. a savings), and *vice versa*. These are discussed below:

1) MtP is economic using turbines in certain markets

As can be seen from Table 5, islands with relatively small markets and that are 100% dependent on fossil fuels stand to save by switching to MtP. Specifically, the cost of power generation in Grenada and St. Lucia is cheaper (i.e., 2 to 5 US cents per kWh) using MtP either as a new gas turbine facility installation (i.e., Scenario A) or retrofit of an existing one (i.e., Scenario B).

2) MtP is most economical with the use of reciprocating engines

As can be seen from Table 5, Scenario C yields the cheapest MtP electricity generation cost. Thus, retrofitting reciprocating engines is the best option for employing methanol as a fuel compared to retrofitting gas turbines (i.e., Scenario B) and installing new turbines (i.e., Scenario A) in all countries. It therefore follows that countries which employ reciprocating engines as the primary power generation technology are most amenable to switching to MtP. The main reason for this lies in the fact that reciprocating engines are generally more efficient power conversion devices than turbines, as can be seen by the difference in heat rate values of Table 4; the average heat rates are 12.77 and 10 MJ/kWh for turbine and reciprocating engines respectively. Additionally, the value used for a reciprocating engine heat rate is in fact on the higher end of the spectrum for diesel operation, and some research has shown that it is possible for methanol's use in reciprocating engines to be more efficient than conventional diesel (Seko and Kuroda, 2001). A more efficient process would mean an even lower cost of MtP electricity generation.

3) MtP is most economical in smaller markets

Another key result is that the MtP initiative is cheaper in countries having a relatively small installed capacity (i.e. below 100 MW) and close to 100% fossil fuel dependence, namely for Dominica, Grenada and St. Lucia. The highest savings (achieved under Scenario C) for these three islands are US cents per kilowatt-hour (kWh) 4, 7 and 9.7, respectively (see Table 5). This amounts to a potential saving of US$ million 9, 30.4 and 82.6 respectively over the period 2010 to 2012, as shown in Table 6. These numbers were derived from the product of MtP Scenario C unit cost savings (taken from last column of Table 5) and annual power consumption. A likely reason for the greater savings in these smaller islands is that the cost of diesel appears to be consistently higher than that for other countries, as shown in Table 7. Hence, the residential cost of electricity is higher, making the differential with respect to MtP greater.

4) MtP is less economical in larger markets

Conversely, larger markets benefit less from switching to MtP, for instance in the case of Cayman Islands, Barbados and Bahamas. In addition to the reason proffered above, this may also be attributed to differences in efficiency of the primary power generation technologies, particularly in the case of comparing residential prices to MtP via turbines. Additionally, in some islands, the fossil fuel-based power generation is derived from the use of both diesel and the cheaper fuel oil (see Figure 3). The cumulative effect of this is a decrease in the island's overall generation costs and hence residential prices, consequently leading to a less competitive MtP price.

5) Impact of renewable energy in energy mix on MtP's competitiveness

A fifth noticeable result was that MtP also tended to be less competitive in countries whose energy consumption needs are partially met by renewable resources, namely Dominica, Belize and Jamaica. Table 5 shows that of the eight countries, Belize has one of the lowest MtP savings and one of the highest renewable energy components (i.e., 48%).

Table 6. Potential MtP Savings for Selected Caribbean Markets

Country	Island Power Consumption in 2005/billion kWh	Cost Savings in 2010/ cents/kWh	Cost Savings in 2011/ cents/kWh	Cost Savings in 2012/ cents/kWh	Total Savings over the Period 2010-2012/ million US$
Bahamas	1.76	3.5	4.2	3.8	202.4
Barbados	0.89	3.4	4.1	3.7	99.7
Belize	0.16	1.2	1.9	1.5	7.4
Dominica	0.07	4.0	4.7	4.2	9.0
Grenada	0.14	7.0	7.6	7.1	30.4
Jamaica	6.13	4.3	5.0	4.5	845.9
St. Lucia	0.28	9.7	10.2	9.6	82.6

Table 7. Price Paid by Countries for Diesel

Country	Fuel Purchase Cost 2001 (US $/gallon)	Fuel Purchase Cost 2002 (US $/gallon)	Fuel Purchase Cost 2003 (US $/gallon)	Fuel Purchase Cost 2004 (US $/gallon)
Bahamas	0.680	0.690	0.907	1.082
Barbados	0.804	0.790	0.536	0.583
Belize	0.935	0.775	1.267	1.353
Dominica	0.870	0.836	0.977	1.130
Grenada	0.808	0.825	0.548	1.186
Jamaica	0.686	0.746	0.867	1.186
St. Lucia	0.867	0.832	1.067	1.100
US Gulf Coast Market Price	0.708	0.675	0.822	1.116

Source: Statistics Based on CEIS

In all these cases, the primary renewable energy generation source is hydro-electricity, which is generated by well-established plants and can be expected to be somewhat cheaper than FFB power generation. Consequently, the overall price of electricity in these countries is considerably lower than that of a country with similar installed capacity. This is well demonstrated if one were to compare Belize and St. Lucia (see Table 5). Another example is Dominica relative to Grenada. It should be noted however that the price of such a country's residential electricity is in most instances more of a weighted average or overall price and therefore does not reflect the true cost of FFB generation alone. It is possible therefore that a switch to MtP for the FFB component of the country's capacity could lead to an overall lower cost of electricity.

6) Impact of fuel market price differential

Figure 3 illustrates the historical as well as projected market prices (up to 2012) for both diesel and methanol on an energy equivalent basis. As can be seen, the difference in price between the two fuels widens significantly during certain prolonged historical and projected periods. This difference increases the savings by switching to MtP under Scenario C, and may also improve the chances of savings under Scenarios A and B.

7) Overall MtP potential in entire Caribbean region

Given the foregoing, in order to quantify the total potential for MtP in all twenty-six countries of the region, it is hypothetically assumed that MtP can replace diesel in all reciprocating power generation plants with only minor retrofit. This amounts to over 6000MW of installed capacity and represents about 16 billion kWh of power consumption. This would require approximately 7.1 millions tonnes of methanol yearly, which is just over the total current methanol production capacity in T&T. The quantity of natural gas required to meet such a market is 626 million standard cubic feet per day (MMscfd), replacing around 5.2 million tonnes of diesel per annum. This market share can be further increased given that turbine-based MtP generation is also cheaper in some instances, thus representing a lower limit for MtP's potential.

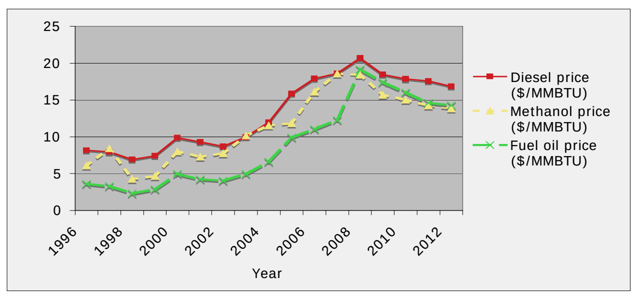

Figure 3. Comparison of Market Price for Different Fuels

However, this criterion does not represent the sole basis on which some countries make such decisions; there may be other strategic advantages to another approach that is not considered by this model, such as financing constraints, bilateral trade arrangements involving fuel and other commodities and market penetration incentives which can be lobbied. Nonetheless, to give an idea of the significance of MtP's potential, an average of just 1 US cent per kWh reduction in electricity prices for the entire region is roughly equivalent to US$ million 200 per annum in savings. As shown previously in Tables 5 and 6, given that some countries may have significant unit cost savings (up to an order of magnitude of 10 US cents per kWh), this figure is not unrealistic, but is subject to more detailed assessment of each of the countries in the region.

7. Conclusion

Energy security and affordability are important ingredients to achieving sustainable development. In this regard, it is important for the Caribbean region to move decisively away from its dependence on oil and its derivatives in order to reduce the overall power generation cost and high volatility of electricity prices. As noted here, methanol prices on an energy equivalent basis have been historically competitive with diesel. Relative to other fuels and means of transporting natural gas, advantages also include lower capital cost, minimal infrastructure requirements, use of standard equipment and materials, and ease of shipping. LNG for instance requires large capital investments for ships and storage tanks with cryogenic materials and regasification import terminals. Furthermore, because methanol can be shipped cost effectively in smaller quantities, MtP can be economic for small niche power markets such as in the Caribbean. The legal and commercial hurdles of supplying gas to the region via pipeline from Trinidad and Tobago do not arise with a MtP solution. Additionally, it is a cleaner burning fuel. Methanol is an attractive alternative fuel for meeting the energy needs of niche markets in an economic and environmentally sustainable manner, utilising existing or new power generation infrastructure in the Caribbean.

In order to further assess MtP's potential, an integrated economic model of the MtP chain has been presented here, taking into account methanol production, shipping, importation and power generation. It is found that MtP proves to be cheaper in smaller islands which tend to pay slightly more for diesel and due to the lower economies of scale and efficiency of power generation at smaller capacities. Retrofitting reciprocating engines, which is the most prominent technology being used in the region, gives the highest savings for MtP, of up to about 10 US cents per kWh. As one would expect, as the gap between the market prices of methanol and diesel widens in favor of methanol, as is expected in the projections obtained and reported here, MtP's economic advantage improves further. Based on these preliminary findings, there is a potential for MtP to replace at least 6000MW, or put another way 16.2 billion kWh per annum of power generation in the Caribbean region. This will require approximately 7.1 millions tonnes of methanol per annum (or 626 MMscfd of natural gas), thus providing a large new market for methanol, and hence for natural gas. Of course, there are several factors to consider in implementing a change-out of technology in any one island, including capital outlay and financing, project viability based on detailed engineering and economic evaluation, payback period, commercial arrangement and ownership structures comprising the various stakeholders in the MtP chain, and risk distribution.

One consideration which is important but difficult to gauge is the level of subsidy for electricity provided by governments in the region. This subsidy varies from country to country and for different categories of consumers (e.g. residential versus commercial). As such, the actual data of electricity prices used here, which are known to be subsidised, do not provide a fair reference for MtP's viability. Therefore, the savings reported are likely underestimates since pure market prices were used for computing the overall power generation cost for MtP. Furthermore, in scenarios where current fuels and technologies showed to be better, MtP may ultimately lead to savings if these subsidies were removed, thereby relieving governments of the economic burden and even provide lower prices to customers. It is estimated that with just an average 1 US cent per kWh reduction in electricity prices via MtP, a total saving of roughly US$ 200 million can be realised per annum in the region. This highlights the potential impact of a cheaper power generation option, and makes MtP worthy of further consideration.

Future work may improve on the accuracy of the cost estimates used in the economic evaluation. A probabilistic approach can be adopted to account for uncertainty and in determining the level of risk in switching to MtP. The issue of regional natural gas pricing was not specifically considered, as well as possible incentives for MtP, both of which are crucial matters at the governmental level. The price structure of natural gas for methanol production would have implications on the fuel price volatility issue which is currently a major concern for countries in the region. The viability of MtP for distant and larger markets was not the focus here, but worth evaluating. Finally, the technical feasibility of MtP needs to be assessed, i.e. equipment efficiency, reliability, availability and maintenance programme. This work is currently being undertaken by The University of Trinidad and Tobago along with Methanol Holdings Trinidad Limited which is overseeing the operation of a demonstration power plant on the Point Lisas Industrial Estate, Trinidad (Furlonge and Chandool, 2007).

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