Prospects and Analysis of Potential CNG Vehicle Implementation in China

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Abstract:

China is currently heavily dependent upon foreign oil imports from the Middle East in an effort to support its growing economy. This puts China in a politically compromising position, forcing it to be dependent on volatile oil prices and on the unstable political environment of the Middle East. Considering that energy independence has been a long term goal for China, a logical governmental goal is to decrease use of oil and increase use of domestically produced energy sources. China has large coal deposits and about 70% of its energy consumption is driven by coal. This implies that coal bed methane is also a highly available resource in China. Coal bed methane has the potential to add to the limited natural gas reserves of China by 10%. The increase in natural gas serves as the ideal springboard from which compressed natural gas vehicles can gain economic viability in China. Adopting compressed natural gas vehicles in China would improve national political and environmental standing. First, increased use of compressed natural gas vehicles will lower demand for foreign petroleum. Second, compressed natural gas vehicles exude fewer pollutants than traditional petroleum based vehicles. Consequentially, CNG vehicles will decrease pollution emitted into the air, which is a strong motivator as the current air quality in China is poor, particularly in Beijing wherein pollution levels are 23 times those of New York City. Therefore, CNG vehicles will greatly contribute to the air pollution issue.

We chose Beijing as a case study for our social cost-benefit analysis because it has an established infrastructure favoring CNG vehicle implementation. The city has access to four pipelines that carry natural gas to the city, as well as a raging pollution issue which presupposes that CNG use will produce tangible results there. The paper runs a social and consumer cost-benefit analysis examining the upsides of a mass introduction of CNG vehicles within China. The social cost-benefit analysis takes Beijing as a case-study, and concludes that CNG implementation will result in a benefit to society in the form of decreased pollution levels, which will spell great societal savings considering the amount of vehicles present in Beijing.

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1. Introduction:

Global economic growth has slowed throughout 2008, consequentially bringing global energy consumption growth down with it. Energy pricing and consumption followed market trends exceptionally closely over the last 12 months, therefore "primary energy consumption growth slowed in 2008, as did growth for each of the fossil fuels. All the net growth in energy consumption came from the rapidly industrializing non-OECD economies, with China alone accounting for nearly three-quarters of global growth."[1] Figure 1 displays market trends for the year to date, highlighting crude oil prices in dark blue and natural gas prices in orange. Oil prices have increased to record highs over the last 12 months, and this, in tandem with extreme overall price volatility having to do with major oil suppliers' policies, leaves countries no choice but to actively seek alternative energy strategies.

Production growth has exceeded consumption for all fossil fuels leaving plenty of viable options. "Expanded OPEC production drove increases in world oil supply, even as consumption declined. The cost-effective development of unconventional gas, enabled by technological innovation, drove the largest-ever increase in US natural gas supply, and for coal, strong growth in China was once again a key driver."[2] Recently, China has gravitated toward opening up new sources for obtaining natural gas, implying the emergence of a political agenda geared towards making natural gas a more significant portion of its energy use landscape. We will argue that the best option for China in its goal to diminish dependence upon foreign oil is to capitalize upon its many investments in the area (pipelines) and to increase use of natural gas as a substitute for petroleum products. By extension, we will argue that a significant portion of increased natural

[1]Energy Academy and Centre for Economic Reform and Transformation, *BP Statistical Review of World Energy, June 2009,* Heriot-Watt University.
[2]Energy Academy and Centre for Economic Reform and Transformation.

gas usage should come through utilizing compressed gas vehicles, and that it is both feasible and logical for the Chinese government to subsidize such vehicles on a national scale. Although there are political constraints and other obstacles (infrastructure) which have stalled possibilities of a shift away from petroleum geared transportation to CNG, we will argue that this is a feasible option with potential societal benefits, and a possible step on the way to China's increased energy independence.

Figure 1: Oil Prices vs. Natural Gas Prices over the Last Twelve Months.[3]

1.1 China's Energy Outlook

China's energy production and consumption is largely dominated by coal due to its low price. China has shown an increase in oil demand as the economy has developed and become more complex. China is a leader in exporting oil but since international oil prices are so volatile, China faces a dependence on imported oil prices which affects, among other issues, national energy security. "In [the] long term, however, with the large-scale development and utilization of China's rich CBM resource, coal and oil are expected to be partially substituted by CBM to some

[3] Commodities Section, *The Wall Street Journal*, December 7, 2009.

extent."[4] In relying less upon oil and substituting CBM, China hopes to reduce their excessive reliance on coal and oil and improve its consumption mix alongside its national energy security situation. Figure 2 below[5] displays the evident disparity in energy consumption in China, and highlights the overt popularity of coal. Although it is logical that a rapidly developing economy would implement the cheapest and most effective means of providing energy (which is China's case happens to be coal as a result of its availability and price advantages), nonetheless such a strong bias in one direction brings disadvantages – for example China's rampant pollution which will be discussed further below.

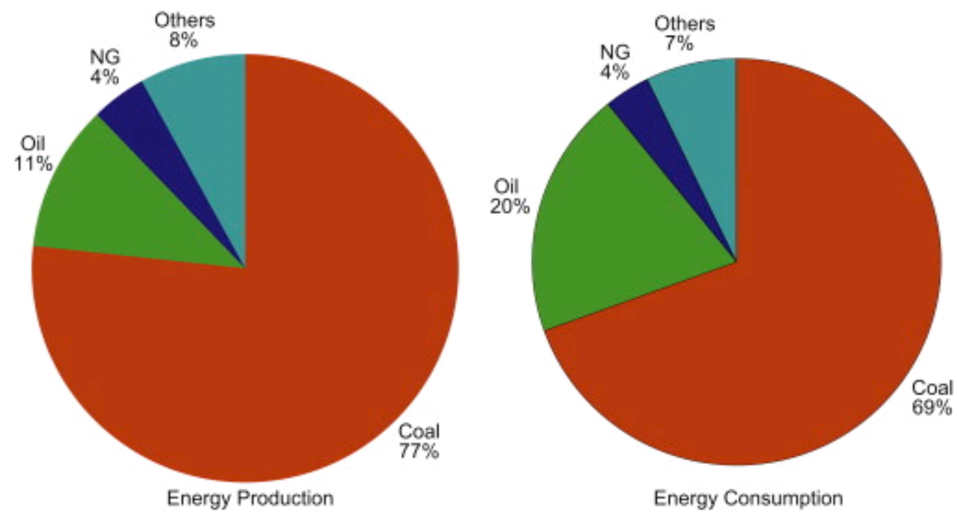

Figure 2: China's Energy Consumption Allocation for 2009.

[4] Dai, Youjin and Dongkun Luo, "Economic Evaluation of Coalbed Methane Production in in China," *Energy Policy* Vol 37 Issue 10, October 2009, 3883-3889.
[5] Dai Youjin and Dongkun Luo.

1.2 Coal Bed Methane Overview

We will examine the implications of increased coal bed methane (CBM) production in light of technologies utilizing natural gas as exemplified by compressed natural gas vehicles within our analysis. We chose CBM in particular because China has coal reserves that are the third largest in the world, and since coal bed methane is extracted from the coal sites it follows that there is a large domestic natural gas reserve which would make CBM a viable long-term alternative to petroleum based fuels. Energy independence is of great importance to China as evidenced by their 11th Five Year Plan[6] – thus CBM is a very significant source of energy politically.

Coal bed methane is a natural gas formed during the coalification process that can be extracted from coal bed seams. CBM is generated either from a biological process as a result of microbial action or from a thermal process as a result of increasing heat correlated with the depth of the coal. Since coal has a large internal surface area, it can store large volumes of methane rich gas – about 6 to 7 times the amount of gas at conventional natural gas reservoirs with equal rock volume. A large portion of the coal, and thus the methane, are found at shallow depths, thus it is easy to drill and inexpensive to obtain. Exploration costs for coal bed methane are low, and wells are cost effective to drill.

To get an idea of the scope of CBM in China, we list certain key statistics. In general, China aims to increase use of natural gas from 4% to 10% of the overall energy mix by 2010. Natural gas consumption is projected to rise rapidly, growing by 5.2 percent per year, on average,

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[6] Kuijs, Louis, *Mid-Tern Evaluation of China's 11th Five Year Plan (Report No. 46355-CN),* Development Planning Department of China's National Development and Reform Commission (NDRC), December 18, 2008.

from 2006 to 2030.[7] CBM is an integral part of this overall goal since it is a reliable source of competitively priced natural gas. China has removed 3.24 billion cubic meters of CBM, and is further planning to produce up to 10 billion cubic meters by 2010 (as stated in China's 11th Five Year Plan). 35.5% of the CBM that has been removed was used as an energy source – this is equivalent to 1.152 billion meters of CBM having been implemented. Further, the Five Year Plan maintains that China intends to consume 10 billion cubic meters of CBM by 2010.[8]

One of the reasons we believe that CBM will be an important energy source for China is that the price structure in China favors use of CBM over natural gas. CBM is subsidized by 0.2 Yuan/cubic meter.[9] To put this in perspective, since China is planning to produce 10 billion cubic meters of CBM by 2010, this is equivalent to a 2 billion Yuan (292 million US dollars) subsidy. In addition, relative to the average price of natural gas for industrial users (1.9 Yuan/ cubic meter), the CBM subsidy makes natural gas 10.5% cheaper.

In addition to economic feasibility of CBM development, China also has an established infrastructure for CBM. China established the CBM Engineering Research Center to further the national goal of increasing the significance of CBM as a natural gas contributor. There are both public and private investments in CBM which indicate the increasing degree of seriousness and dedication to CBM development. In the public sector, as stated above, CBM was included in China's 11th Five Year Energy Development Plan. In addition, the Chinese government spent 375 million US dollars to build 2 pipelines for CBM transmission.[10] In the private sector, PetroChina, which is one of the largest oil companies in China with a market cap of $26.9 billion,

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[7] International Energy Outlook 2009, Chapter 3, Report No: DOE/EIA-0484(2009), *Energy Information Administration*, May 27, 2009.
[8] Dai Youjin and Dongkun Luo.
[9] Ibid.
[10] Chi-Chu Tschang, "China Looks to Coal Bed Methane," *Business Week*, January 3, 2008.

plans to expand its natural gas pipeline network by connecting 3 existing pipelines (West-East Gas Pipeline, Shaan-Jing Pipeline, and Zhongxian-Wuhan) with a planned Sichuan-Shanghai Pipeline. The bottom line is that China shows an increasing degree of commitment to CBM development considering the large investments already made.[11]

CBM is used in power generation, feedstock for the chemicals industry, and natural gas fueled vehicles. We have chosen to focus on the impact of the potential injection of an increased quantity of natural gas upon the usage and implementation of CNG vehicles in Beijing.

1.3 Compressed Natural Gas Vehicles Overview

Compressed natural gas (CNG) is created through compressing methane to less than 1% of its volume under standard atmospheric pressure. It is an odorless, tasteless gas that is obtained from gas wells or in tandem with oil products.[12] CNG has been used widely as an alternative source of fuel for the automotives industry. A vehicle can be converted to run on CNG technology through a simple process of internal alteration, and within our analysis below we examine the costs and benefits of this conversion process, including its effects upon the general well-being of the population as linked to pollution levels.

This shift toward CNG vehicles is justified by two emerging macro patterns – the overt dependence of automotives upon foreign-based and price-volatile petroleum, and also the growing issue of pollution.[13] Statistics as of May 2009 indicate that 80 cities in 30 provinces of

[11] *"11th Five-Year Plan" for Development and Utilization of Coalbed Methane and Coal Mine Methane,* http://www.methanetomarkets.org/m2m2009/documents/coal_cap_china.pdf.
[12] "Clean Alternative Fuels, Compressed Natural Gas" (Part of Series), United States Environmental Protection Agency, Transportation and Air Quality/Transportation and Regional Programs Division, Report No: EPA420-F-00-033, March 2002.
[13] "China CNG (compressed natural gas) Filling Machine Market Analysis," http://www.reportbuyer.com/energy_utilities/oil_gas/natural_gas/china_cng_compressed_natural_gas_filling_machine_market_analysis.html, May 2009.

China support and promote the use of natural gas vehicles, and most of these "are concentrated in places close to natural gas fields like Sichuan province, Chongqing, Urumchi, Xi'an, and Lanzhou. In these places, gas sources are close and gas price is low (only about 40 percent to 50 percent of oil price). These favorable conditions constitute the major force that drives the development of CNG vehicles in these places."[14] On a macro scale, it was pointed out above that China is seeking to increase the proportion of its overall energy use that is provided through natural gas. As stated, coal bed methane technology is being subsidized heavily by the central government in an effort to decrease domestic dependence upon foreign oil.[15] Therefore, China sees natural gas technology as a viable long-term solution to its energy needs. As a result, we argue that CNG vehicles should be subsidized upon a national scale (as opposed to regionally/based upon geographic access), as such support would diminish dependence upon petroleum fuels and increase the subset of natural gas use in China.

Within our analysis we also make it a point to quantify the social benefits derived from decreased pollution. Although the detailed explanation of our analysis will appear below, it is important to point out that China's pollution levels are dangerously high relative to other large cities. According to the New York Times, "only 1 percent of the country's 560 million city dwellers breathe air considered safe by the European Union […] Experts once thought China might

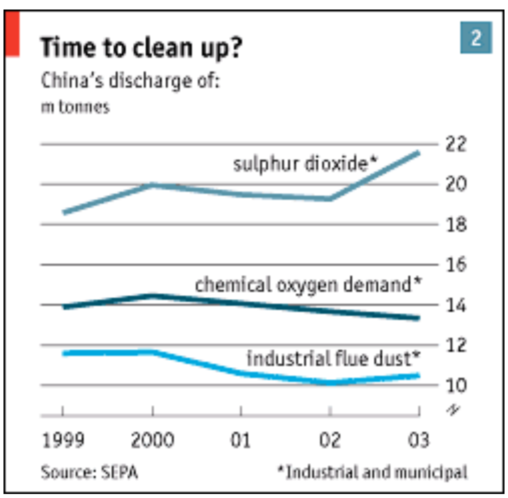

Figure 3: China's Pollution Discharge Broken Down by Chemical Components.

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[14]Ibid.

[15] Kuijs, Louis.

overtake the United States as the world's leading producer of greenhouse gases by 2010, possibly later. Now, the International Energy Agency has said China could become the emissions leader by the end of this year [published in 2007], and the Netherlands Environment Assessment Agency said China had already passed that level."[16] Figure 3[17] displays the levels of pollutant particles in China. China's horizons are shrouded in what is referred to as particulate matter – "a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles."[18] The automotive industry in large cities such as Beijing (our analysis case study) contributes to a great extent to the poor air quality of such locations.

We seek to claim that use of CNG vehicles would contribute to reducing pollution levels in Beijing as a case study, and by inference throughout China generally. Within their 2009 publication *Life Cycle Analysis of Energy Use and Greenhouse Gas Emissions for Road Transportation Fuels in China*, Xiaoyu Yan and Roy J. Crookes "attempt to identify the most reliable results to date and possible ranges of life cycle fossil fuel use, petroleum use and greenhouse gas emissions […] Fuels reviewed include conventional gasoline, conventional diesel, liquefied petroleum gas, compressed natural gas, wheat-derived ethanol, corn-derived ethanol, cassava-derived ethanol, sugarcane-derived ethanol, rapeseed-derived biodiesel and soybean-derived biodiesel."[19] Among their results is the below chart, which indicates that CNG is significantly lower in life cycle greenhouse gas emissions than conventional gasoline (CG) or conventional diesel (CD), which are the two most popular fuels used in China.

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[16]Kahn, Joseph, and Jim Yardley, "As China Roars, Pollution Reaches Deadly Extremes," *The New York Times*, August 26, 2007.
[17]Joseph Kahn and Jim Yardley.
[18]"Particulate Matter," US Environmental Protection Agency, http://www.epa.gov/oar/particlepollution/.
[19] Renewable and Sustainable Energy Reviews, 13, (2009) 2505–2514.

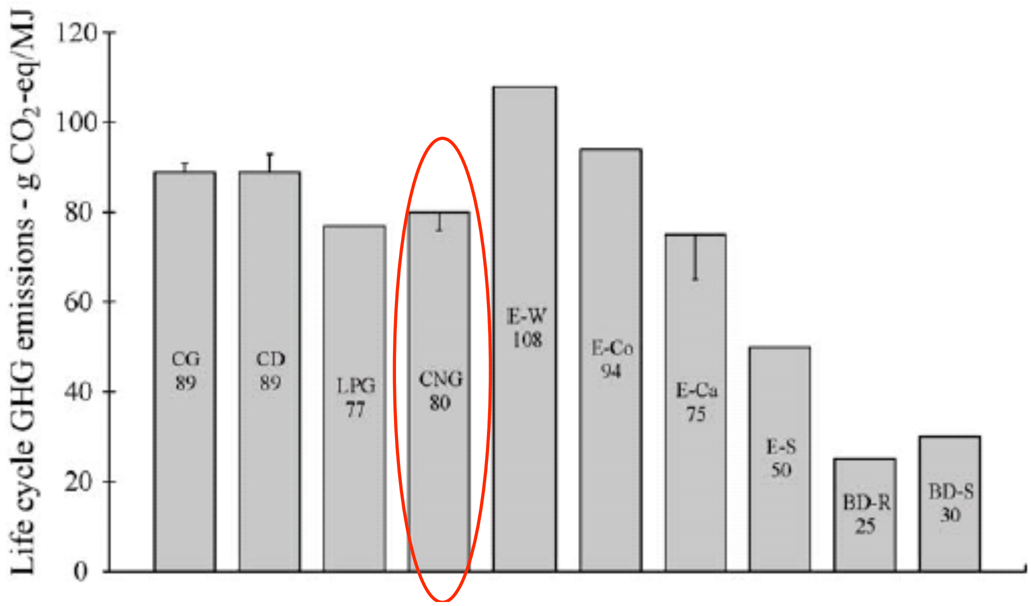

Figure 4: Life Cycle GHG Emissions for Each Fuel in China.

Although our analysis will further examine the question of pollution in terms of the costs it imposes upon society, suffice it to note that CNG has the potential to create lower emissions in comparison to the more basic petroleum-based fuels, and therefore subsidizing and increasing the use of CNG vehicles has the potential to become a vital part of reducing China's GHG emissions.

1.4 CNG Vehicle Implementation in Other Countries

Before proceeding with our analysis and explanation, we would also like to briefly touch upon the success stories of other countries which have invested into and implemented CNG technology within their borders. One of the fastest growing users of CNG technology is Pakistan. Although for a very long time Brazil and Argentina were world leaders in utilizing CNG technology, Pakistan overtook Brazil in 2006 and Argentina in 2008 to become the largest user of CNG with 2 million vehicles and 2,941 refueling stations.[20] The technology thrived due to

[20] Mughal, Owais, "Pakistan Has Highest Number of CNG Vehicles in the World," *All Things Pakistan*, December 7, 2009.

Pakistan's extremely high gas prices, as well as an abundance of natural gas on its territory.[21] In part, the wide-scale implementation of CNG in Pakistan has been possible due to the government's support and proactive policies. Among these are the following:

- Strong Government commitment to promote CNG use
- Liberal policy to provide license for CNG retailing
- Deregulated market consumer price of CNG
- Natural gas tariff for CNG linked to petrol
- Priority of natural gas connection to CNG stations
- Exemption of import duty and sales tax on import of machinery and equipment, CNG kits and cylinders[22]

Likewise, Thailand has been active in promoting CNG use within its borders. Volatility and increases in oil prices, as well as the high amount of oil consumption in Thailand has driven an active search for alternative energy resources. In order to diversify its energy consumption sources, Thailand has offered incentives geared to promote the use of compressed natural gas. For example, it has instituted discounts for those who converted their engines to be CNG-driven. It has also fixed the price of CNG in order to ensure that it will be lower than the price of gasoline. Thailand's hope, over time, is to replace many petroleum driven vehicles with compressed natural gas, which would both stimulate the economy and help reduce damages to the environment. According to a Wall Street Journal article, "In Thailand, drivers have converted or purchased more than 40,000 natural-gas-burning cars and trucks in the past six months."[23] This number is predicted to triple by 2012. The relatively lower price of natural gas

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[21] Mughal, Owais.
[22] Hydrocarbon Development Institute of Petroleum, Ministry of Petroleum, http://www.hdip.com.pk/hydrocarFSUB.htm, December 7, 2009.
[23] Barta, Patrick, "Thais Lead Drive to Natural-Gas Cars," *The Wall Street Journal*, October 21, 2008.

as compared to gasoline has led to big savings, especially for those who travel a substantial amount. A similar trend has begun and continues in China and across the developing world. Governments see the potential environmental benefits as well as the economic effects of an increase in demand for natural gas.[24]

Proved reserves

	At end 1988 Trillion cubic metres	At end 1998 Trillion cubic metres	At end 2007 Trillion cubic metres	At end 2008 Trillion cubic feet	At end 2008 Trillion cubic metres	At end 2008 Share of total	At end 2008 R/P ratio
Thailand	0.20	0.42	0.32	**10.7**	**0.30**	0.2%	10.5
Vietnam	n/a	0.17	0.48	**19.7**	**0.56**	0.3%	70.1
Other Asia Pacific	0.27	0.51	0.40	**13.9**	**0.39**	0.2%	22.1
Total Asia Pacific	8.86	11.39	14.80	**543.5**	**15.39**	8.3%	37.4
Total World	**109.72**	**148.01**	**177.05**	**6534.0**	**185.02**	**100.0%**	**60.4**

Production*

Billion cubic metres	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**2008**	Change 2008 over 2007	2008 share of total
Thailand	17.5	19.2	20.2	19.6	20.5	21.8	22.4	23.7	24.3	26.0	**28.9**	10.7%	0.9%
Vietnam	0.9	1.3	1.6	2.0	2.4	2.4	4.2	6.9	6.8	7.1	**7.9**	11.9%	0.3%
Other Asia Pacific	3.3	3.3	3.3	3.6	5.3	6.4	6.2	7.0	10.5	13.0	**14.1**	8.5%	0.5%
Total Asia Pacific	245.7	262.6	272.1	282.4	300.6	322.3	336.8	362.6	378.5	396.3	**411.2**	3.5%	13.4%
Total World	**2273.0**	**2330.9**	**2412.4**	**2477.4**	**2519.4**	**2615.5**	**2694.1**	**2777.8**	**2876.1**	**2945.3**	**3065.6**	**3.8%**	**100.0%**

Consumption

Billion cubic metres	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**2008**	Change 2008 over 2007	2008 share of total
Thailand	17.6	19.2	22.0	24.8	26.9	28.8	29.9	32.5	33.3	35.4	**37.4**	5.6%	1.2%
Other Asia Pacific	4.5	4.9	5.5	5.8	6.0	6.5	8.7	12.1	12.3	13.0	**13.6**	4.3%	0.4%
Total Asia Pacific	255.8	272.2	294.9	314.9	329.5	355.6	372.3	402.2	427.8	456.8	**485.3**	5.9%	16.0%
Total World	**2268.2**	**2322.8**	**2424.8**	**2453.3**	**2529.7**	**2595.5**	**2683.9**	**2769.8**	**2842.7**	**2938.0**	**3018.7**	**2.5%**	**100.0%**

Figure 5: Natural Gas Reserves, Production, and Consumption Statistics for Thailand.[25]

The tables above summarize Thailand's proved reserves as of 2008 (.2% of world share), as well as its total production (0.9%). These numbers combine to almost fulfill their consumption amount (1.2%), thereby indicating that Thailand has a high degree of domestic access to natural gas relative to the amount it uses. It appears that one of the pre-requisites to successfully implementing CNG vehicle technology is relatively cheap access to natural gas, and this characteristic may limit many countries in regard to the technology. However, China's large amount of coal fields which makes CBM extraction possible is one of the reasons that we believe CNG vehicle implementation is feasible and potentially profitable for China. Likewise, the suck

[24] Barta, Patrick.
[25] *BP StatisticalReview of World Energy Use June 2009.* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf

costs of investing into a natural gas infrastructure (pipelines and filling stations for CNG vehicles) imply that the government is serious in increasing access to and use of natural gas domestically, and by extension should look favorably upon CNG technology.

The two graphs below display the consumption and production patterns for natural gas across the world. It is evident that limitations in access are one of the largest factors in the potential success of implementing CNG vehicles, and therefore China's potential use of CBM is a highly important factor, given that natural gas reserves in China are fairly limited if CBM technology is not considered. That said, natural gas use and production remain very close for the overall Asia Pacific region, further enforcing the view that the natural gas they use is largely produced domestically, as to avoid price vacillations and foreign dependence.

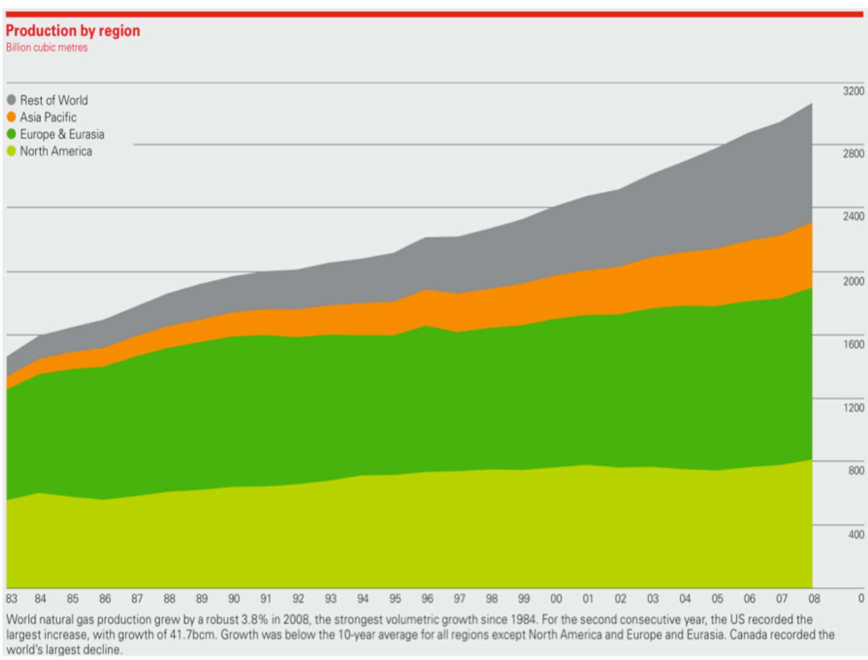

Figure 6: Production of Natural Gas by Region.[26]

[26] *BP StatisticalReview of World Energy Use June 2009.* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf

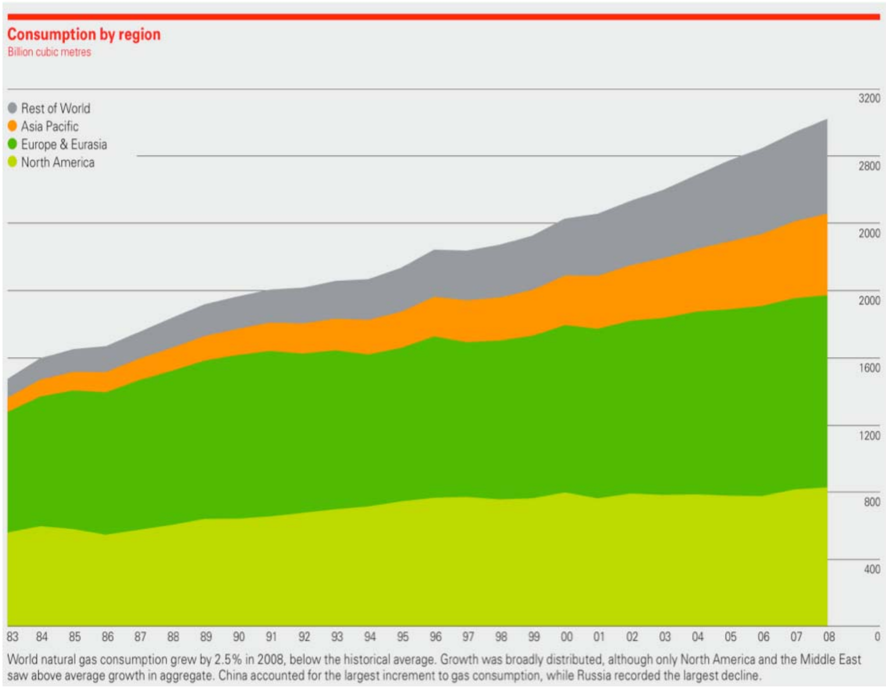

Figure 7: Consumption of Natural Gas by Region.[27]

Due to the unstable and rising price of gasoline, the easy access to natural gas, and incentives promoting both consumer subsidies and environmental safety, many developing countries are or have already had movements to replace gasoline with natural gas.

2. Methodology:

Assumptions and Formulas:

Assumptions are in blue. Formulas are in red

1. Discount Rate and Inflation Rate to calculate the Real Discount Rate.
2. The lifetime, kilometers traveled per year, and the retail price of the car (retail price based on WV Jetta).
3. Conversion cost to CNG is 5000 Yuan.

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[27] *BP StatisticalReview of World Energy Use June 2009.* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.pdf

4. We used Brent Oil Futures spot prices from Dec 1st 2009 to predict oil prices for next 10 yrs. The last two years are repeated because the curve only extends to 8 yrs.

5. The exchange rate between dollars and Yuan is assumed to be 8.0 and fixed at that rate for 10 years.

6. Transportation costs for fuel are not included in either Gasoline or CNG prices.

7. We use an Australia to China LNG deal price to estimate LNG price in China. Then we use an energy conversion to find the price of CNG in China. Also, we don't take into account how prices will decrease as China develops their CBM Natural Gas reserves.

8. Miles per equivalent gallon of a CNG vehicle is assumed to be the same as the miles per gallon of a gasoline vehicle.

9. Green House Gas prices are fixed at $18.3/ tCO2 (present trading value in the European Climate Exchange), and is assumed to be the same over the lifecycle of the car.

10. The health costs are taken to be the purchasing power parity corrected price from that of United Kingdom.

11. The emissions from the vehicle does not deteriorate over 10 years.

12. We assume that Volkswagen would not penalize people for changing the fuel system of a new car.

The methodology below calculates the Life Cycle Costs for a mid-sized passenger “Volkswagen Jetta” car with the following characteristics:
1. Manual Transmission
2. Lifetime of the vehicle: 10yrs
3. Kilometers traveled per year: 20,000km
Total kilometers traveled: 200,000km
Value of Yuan: 8 Yuan/Dollar

Note: These formulas are only indicative of the general approach of our analysis. However, the step by step analysis done in Excel, is far more complex, and takes into account more variables. Refer to Appendix for in depth analysis.

Assumptions for Calculation of the Vehicle Initial Costs (relative to the baseline gasoline vehicle):
Retail price of the baseline gasoline vehicle: 100,000 Yuan
Excise tax for a gasoline vehicle (2L): 0.05
Value added tax in China: VAT 0.17

First costs of a gasoline car without tax:
Retail Price of Gasoline Vehicle/ ((1 + VAT) (1 + Excise Tax))

Calculation of the first costs of a CNG vehicle without tax:
First vehicle cost gasoline + Conversion Cost = Price of CNG vehicle without tax

Calculation of the vehicle operation costs (relative to the baseline gasoline vehicle):
Fuel price of gasoline (with tax): 6.43 Yuan/liter
Fuel price of CNG: 2.35 Yuan/meters cubed

Fuel price of gasoline (without tax): Gas Price= 4.64 Yuan/liter
Gas Tax = .17 VAT and +1 Yuan
(Gas price - 1)/(1 + VAT)

Fuel price of CNG (without tax): CNG Price = 2.08 Yuan/m^3
CNG Tax = .13
CNG Price/(1+ CNG Tax) = 1.80 Yuan/liter gasoline equivalent

Life Cycle Operational Costs:
7.6 liters/100 km (Assume same for CNG)
Total kms/year=20,000 km
(Total kms/year) * (Liters/km) = Liters of fuel used/year
CNG price =1.80 Yuan/liter gasoline equivalent
Gasoline price= 4.64 Yuan/liter

Total fuel costs = (Liters of fuel used/year) * CNG or Gas price per liter

CNG vehicle: 2736 Yuan/year
Gasoline vehicle: 7053 Yuan/year

Real Discount Rate (RDR) = ((1+DR)/(1+Inflation)) - 1
Inflation = .07
DR = .10
RDR = .028

DPV = ((1+RDR)^t) - 1)/(RDR * (1+RDR)^t))
PV=A*DPV
A = average annual costs

PV Gas = Life Cycle Operational Cost
PV CNG = Life Cycle Operational Cost

Relative Fuel Costs of CNG = PV CNG – PV Gas

Cost of polluting
NO_x 22.8 Yuan/kg
CO 0.124 Yuan/kg (GHG price)

PM 76 Yuan/kg
NMOG 11.4 Yuan/kg

Emissions from VW Jetta (2010)
NO_x 0.07 g/mile
CO 4.2 g/mile
NMOG 0.09 g/mile
PM 0.01g/mile
GHG 390 g/mile
Total cost of polluting per year= 653.3 Yuan
PV Gasoline = (Total cost of polluting/yr)*(sum of emissions in g/mile) = Lifecycle gasoline pollution cost

Two scenarios of reduction of emissions from CNGV
CO 90 to 97%
NO_x 35 to 60%
NMOG 50 to 75%
PM 90%
GHG 330 g/mile
Total cost of polluting per year=532.5 Yuan and 523.83 Yuan
PV CNG= total cost of polluting per year *(sum of emissions g/mile)

Societal Life Cycle Costs
Societal Life Cycle Costs= Sum of all costs without tax relative to the baseline gasoline vehicle
Costs:
Additional vehicle first costs without tax
Additional operation costs without tax
Additional pollution damage costs: ** PV CNG (pollution) - PV Gasoline (pollution)

Consumer Life Cycle Costs
Consumer Life Cycle Costs = Sum of all costs without external costs or tax (relative to the baseline vehicle):

3. Social Cost-Benefit Analysis:

3.1 Lifecycle Assessment

The consumer cost takes into account the cost of the vehicle and the operation cost. For our analysis, we have taken into consideration the cost of pollution to calculate the social cost. A complete life cycle calculation for both gasoline and CNG vehicles would require the calculation of pollution arising from the following:

1. Vehicle production
2. Fuel production
3. Vehicle operation and maintenance
4. Vehicle disposal

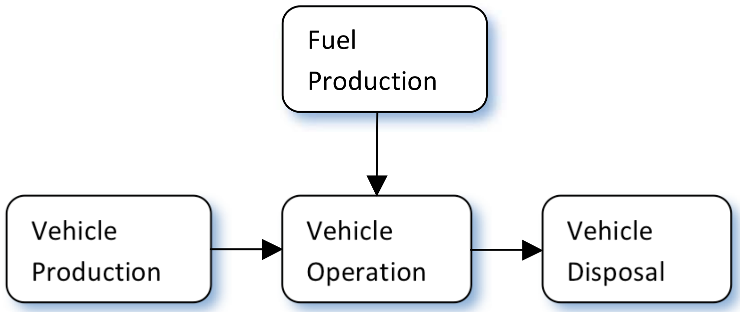

Figure 8: Life Cycle of a Vehicle.

The vehicle lifecycle begins with the production of the vehicles. This can be broken down further into materials acquisition, part production, assembly and transport to dealership. Further complexities can be added to this by taking into account the lifecycle costs from the dealership. The fuel life cycle can also be broken down into fuel extraction, conversion and distribution. This has not been attempted in this report, partly due to the complexity of such an analysis.

In our report, we assume that the customer buys a gasoline car, be it with or without the modification for CNG capability. As has been mentioned earlier, the gasoline car is set as the baseline. The additional contribution to the vehicle lifecycle cost arises from the manufacturing of the components required to change the gasoline car to a CNG vehicle. This has not been considered in our assessment. The complexity of the calculation of the fuel life cycle costs prevents us from attempting it in this report. The cost of vehicle disposal is assumed to be the same for the CNGV and the gasoline car. The cost considered in our lifecycle analysis arises from the operation of the vehicle.

3.2 Cost of Pollution

The operation of a vehicle has negative externalities that should be considered in calculating the cost to society. The burning of the fuel gives the much required energy for the functioning of a car, but it also leads to emissions that give rise to air pollution. The emissions from cars are as follows:

1. Carbon Monoxide (CO)

   As per EPA, the main source of CO in air arises from burning fuels in automobiles. Carbon monoxide, when inhaled, reduces the delivery of oxygen to the vital organs. The maximum impact of CO pollution is on people with preexisting heart and respiratory conditions.

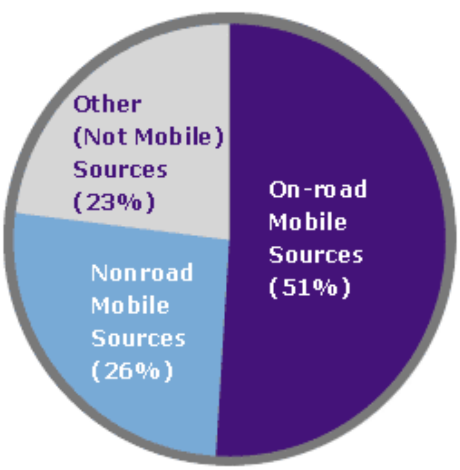

Figure 9: 1999 National Emissions by Source in the US: Carbon Monoxide[28]

[28] US Environmental Protection Agency, http://www.epa.gov/oms/invntory/overview/pollutants/carbonmon.htm#onroad, December 7, 2009.

2. Hydrocarbons

   The incomplete combustion of fuels leads to the emission of hydrocarbons. The hydrocarbons combined with NO_x lead to ozone and smog production, especially in cities that have a high density of cars.

3. Nitrogen Oxides (NO_x)

   Nitrogen Oxides are formed within the combustion engine as a result of the high temperature inside. These combine with other chemicals in the air to produce particulate matter. This matter is one of the key precursors for ozone and smog. The NO_x can also travel across large distances, thus affecting people who live far away from places with high vehicular densities.

4. Particulate Matter

   Particulate matter is solid matter dispersed in the air. The size of the particles is in the range of a few microns. They are associated with serious health effects. The small particles can get accumulated within the lungs, leading to respiratory problems like asthma and bronchitis.

5. Greenhouse Gas

   The biggest contribution of vehicular emissions comes in the form of green house gases like CO_2. It is well known by now that green house gases are responsible for global warming leading to climate change.

To calculate the cost of externalities for a gasoline vehicle, one needs its emission profile. This has been listed on the US EPA green vehicle guide. It is assumed that the emission profile of the 2009 Jetta in Beijing is the same as that in Illinois.

Pollutant	Gasoline Car Emissions (g/mi)
NO_x	0.070
CO	4.200
PM	0.090
NMOG	0.010
GHG	390.000

Figure 10: Emissions per mile for a 2010 Volkswagen Jetta.[29]

The emissions from a CNGV are considerably reduced. The two biggest changes are in the NO_x and particulate matter emissions. Both show a reduction of more than 90%. The hydrocarbons are also reduced by 75%, and the GHG by ~10%.[30] A recent study on buses in Washington by the National Renewable Energy Laboratories shows further reductions of emissions from CNG vehicles as compared to diesel buses.[31]

[29] *US EPA Green Vehicle Guide*, http://www.epa.gov/greenvehicles/Index.do.
[30] US Department of Energy, http://www.afdc.energy.gov/afdc/vehicles/natural_gas_emissions.html
[31] "Emission Testing of Washington Metropolitan Area Transit Authority (WMATA) Natural Gas and Diesel Transit Buses, M. Melendez" J. Taylor, and J. Zuboy, *Technical Report* NREL/TP-540-36355, December 2005.

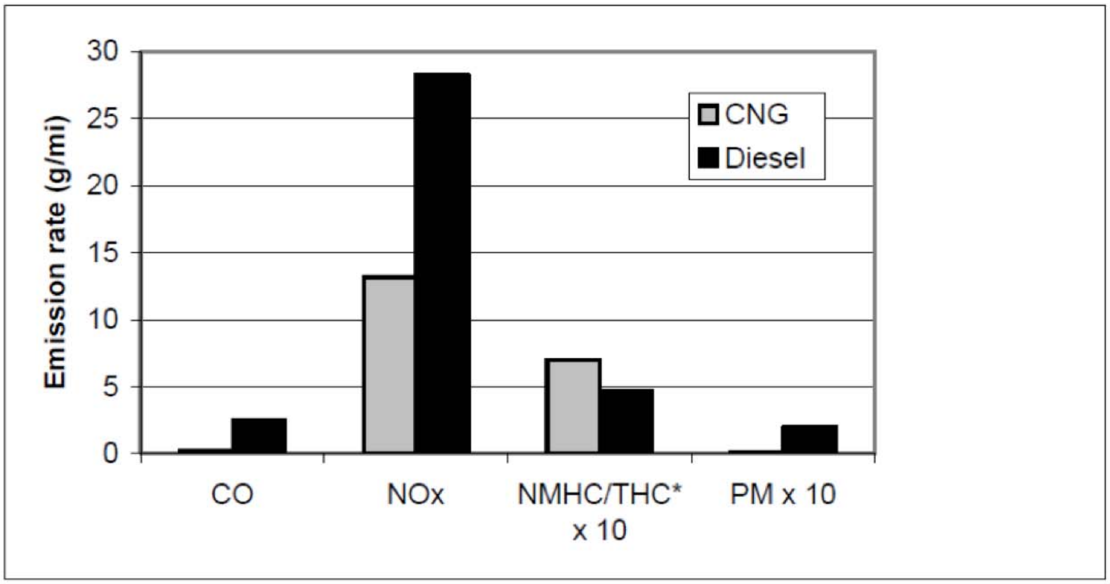

Figure 11: Comparison of emissions for diesel and CNG buses.[32]

The cost of polluting is the trickiest step in the lifecycle analysis. For greenhouse gas emissions, the price was fixed at the current trading price of carbon at the European Carbon Exchange. It is important to point out here that this price is the price of mitigation, and ideally the cost of GHG should be the marginal cost of pollution leading to global warming. We have been unable to find the marginal price of polluting in the literature, and were therefore led to assume that the cost of mitigation is the same as the cost of pollution. The literature was also found to be lacking on the report of calculation of health cost of air pollution for China. Instead the report on a similar study on the UK was used.[33] The costs were purchasing power parity corrected for China.[34] A noteworthy point is that the health costs calculated in this fashion might not be exact. The costs not only depend on the country, but also on the population density.[35]

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[32] Ibid.

[33] Mike Holland and Paul Watkiss, Estimates of the marginal external costs of air pollution in Europe, Version E1.02a.

[34] Link to PPP Data, *International Monetary Fund*, www.imf.org/external/pubs/ft/survey/so/2008/RES018A.htm, January 8, 2008.

The annual cost of polluting was finally calculated by taking the product of the cost of emissions per gram and the total emissions from the car in the first year. The total cost was computed by adding the discounted present value of the additional cost of polluting from the lifecycle of the CNGV.

Pollutant	Pollution Costs (Yuan/kg)	Gasoline Car Emissions (g/mi)	CNG Emissions (g/mi)	Additional CNG Pollution(Yuan)
NO_x	22.800	0.070	0.002	-166.738
CO	0.124	4.200	1.680	-33.655
PM	76.000	0.090	0.009	-663.023
NMOG	11.400	0.010	0.003	-9.209
GHG	0.124	390.000	360.360	-395.849

Figure 12: Additional Pollution from CNG vehicle with a 2010 Volkswagen Jetta as the baseline.

As shown in Figure 11, the cost of pollution from a CNGV in the first year is -396 Yuan. In other words, the benefit of using the CNGV for the first year is 396 Yuan. Using the same discount value as that for the consumer cost calculations, the lifecycle benefit of pollution for a CNG vehicle is 1268 Yuan per car.

Due to the limited scope of the present work, not all the externalities (positive as well as negative) were quantified. The development of the technology to extract coal bed methane has increased the supply of natural gas in China. It has also made various previously uneconomical gas reserves viable for development. Natural gas will be an important energy source for China in the future years. The benefits of relying on domestic energy sources and increasing energy

[35] Gheewala, Shabbir and Goedeckeb, Martin and Therdthianwonga, Supaporn, Life Cycle Costs Analysis of Alternative Vehicles and Fuels in Thailand, Energy Policy 35, 3236–3246, 2007.

independence have not been quantified. These not only have direct economic but also political impact on China's future. The setting up of CNG filling stations has also not been considered in our work. The CNG vehicles can be refilled either from a CNG pumping station or by buying domestic compressors. But this can be a topic of further research. Another key assumption made here is that the emission profile of both vehicles does not change over the course of 10 years.

The estimate of the price of externalities calculated should be considered to be a conservative one. We are comparing a CNG vehicle with a 2010 VW Jetta (petrol) which is amongst the lower polluting vehicles. If the diesel vehicles, especially from a few years ago, are taken into consideration the social benefits would be far greater, as their pollution levels are extremely high.

3.3 Summary of Results

For our case study of Beijing, the Volswagen Jetta 2009 was used as the baseline. The cost of converting this car to a CNG vehicle is 5000 Yuan. With the lifecycle mileage of this car at 200,000 kilometers and the annual miles driven at 20,000 kilometers, the fuel and emission costs for both cases were calculated. The costs were calculated for the consumer and the society, with the gasoline car as our baseline. The consumer cost is the sum of the cost of conversion of the vehicle and the additional cost of fuel over the lifecycle of the car. The social cost is the sum of the cost to the consumer and the cost of the externalities. The costs were calculated in 2009 Yuan, and converted to 2009 USD with the exchange rate of 6.8 Yuan per USD.

From our analysis it appears that through converting a gasoline vehicle to CNG the consumer saves USD 3,167. T he cost of the externalities is found to be USD 187, bringing out the benefit to the society consisting of USD 3,354. Thus, the conversion of the regular gasoline vehicle is beneficial to the consumer as well as the society as a whole.

4. Consumer Cost-Benefit Analysis:

For the consumer cost benefit analysis, we essentially calculated the consumer lifetime cycle cost of a CNG vehicle using the lifetime cycle cost of a gasoline vehicle as a baseline. We defined the consumer lifetime cycle cost as the initial purchase price of a gasoline vehicle plus the operating costs. Considering that a consumer would need to own a car before being able to convert it to a CNG vehicle (ownership costs are implicit), we focused on accurately calculating the operating costs of a CNG vehicle vs. a gasoline vehicle.

We used the Volkswagon Jetta as the model car for our Beijing case study for two reasons. Firstly, the Volkswagon Jetta is the 1st most commonly bought car in China.[36] Secondly, as mentioned within the introduction, Beijing has 3 established natural gas pipelines and one that is presently under construction, so the infrastructure is already in place for natural gas distribution to CNG vehicles.

Initially we calculated the operating costs of a gasoline vehicle (which we assume consist of the amount paid for gasoline) for the next 10 years. These turned out to be 46,874 Yuan in present value terms. It is to be noted that we did not include taxation within the analysis. The step by step analysis process is as follows:

- We used the Brent Futures Curve starting with an initial value of the floating price as of November 30th, 2009 to calculate the price of oil over the next 10 years (please note the

[36] Best selling cars in January 2008, China Car Times, http://www.chinacartimes.com/2008/02/25/best-selling-cars-in-january-2008.

last two years are equivalent to the 8th year since the Brent futures curve only goes out for 8 years).

- We added 50 cents for Dubai (due at a fixed rate per barrel) and a multiple of (1 + interest paid to refineries) to the Brent futures curve. This figure depends on the dollar amount per barrel. The interest paid to refineries in China is determined by the Chinese government; consequentially 5% interest is paid if the price of oil is less than $80, less than 5% (not specified) if the price of oil is between $80 and $130, and 0% if the price of oil is over $130.
- We converted dollars per barrel to Yuan per liter by using the current Yuan-Dollar exchange rate of $1 = 6.8 Yuan. Since the exchange rate is determined politically as well as pegged to the dollar, it is impossible to predict with high precision. We assumed the exchange rate to be fixed for the next 10 years.
- From this, we calculated the gasoline cost per month and discounted it to the present value.
- After summing up the present value of the gas cost per month over the next 10 years, we received the gasoline lifetime operation costs, determined to be 46,874 Yuan.

After determining the operating costs of a gasoline vehicle, we turned to calculating the lifetime operating costs for a CNG vehicle (which we assumed was the amount paid for compressed natural gas used to fuel the car), which turned out to be 20,337 Yuan. Before we begin explaining this aspect of the analysis, it is noteworthy to point out that compressed natural gas is not a traded commodity, thus the price for CNG is determined indirectly via examining the pricing of LNG (liquid natural gas). Note: We did not include transportation costs or taxes. The step by step analysis is as follows:

1.) Implementing the diagram below, we used the ex-ship (excluding the prices of shipment) prices to get the LNG futures prices from Australia to China. We decided to use this approach as a result of learning about the "PetroChina deal worth up to US $37 billion with Woodside Petroleum Ltd on 9-6-2007 to buy liquefied natural gas from offshore Western Australia."[37]

Australia

	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11
Netbacks																		
NE Gateway/Canaport	5.46	5.34	4.01	3.48	3.50	3.60	3.85	3.91	3.72	3.78	4.42	5.26	6.59	6.43	5.03	4.27	4.21	4.27
Cove Point	3.46	3.40	3.37	3.35	3.37	3.48	3.50	3.57	3.51	3.56	4.02	4.41	4.59	4.58	4.42	4.11	4.08	4.09
Elba Island	3.16	3.10	3.06	3.06	3.14	3.26	3.37	3.44	3.48	3.50	3.83	4.21	4.42	4.39	4.22	3.83	3.85	3.91
Sabine Pass/Cameron	2.98	2.91	2.89	2.88	2.97	3.08	3.16	3.22	3.27	3.30	3.62	3.98	4.14	4.13	3.97	3.62	3.64	3.70
Lake Charles (NGL)	3.86	3.76	3.69	3.63	3.65	3.73	3.77	3.80	3.83	3.84	4.09	4.38	4.51	4.51	4.38	4.09	4.09	4.14
Freeport	2.93	2.87	2.86	2.88	2.98	3.11	3.19	3.25	3.25	3.27	3.54	3.90	4.07	4.05	3.96	3.56	3.62	3.70
Costa Azul	3.85	3.82	3.78	3.72	3.75	3.91	4.16	4.20	4.15	4.05	4.24	4.82	5.12	5.13	4.88	4.43	4.42	4.45
UK	3.17	3.27	3.15	2.86	2.83	2.84	2.81	2.99	3.00	3.63	4.73	5.47	5.72	5.62	5.42	4.46	4.50	4.50
Atlantic Arbitrage																		
US - UK	2.28	2.07	0.86	0.85	0.92	1.08	1.35	1.22	1.15	0.42	(0.31)	(0.22)	0.88	0.81	(0.39)	(0.02)	(0.09)	(0.05)
Onshore US - UK	0.69	0.55	0.63	0.85	0.92	1.08	1.35	1.22	1.15	0.42	(0.49)	(0.65)	(0.60)	(0.49)	(0.54)	(0.02)	(0.09)	(0.05)
Competitive ex-ship price																		
Spain	7.14	7.11	5.80	5.51	5.52	5.66	5.92	5.97	5.92	5.89	6.61	7.40	8.56	8.40	7.39	6.39	6.40	6.40
Japan/Korea	6.11	6.03	4.71	4.42	4.45	4.59	4.85	4.89	4.84	4.78	5.48	6.24	7.38	7.22	6.21	5.23	5.26	5.26
India	6.13	6.06	4.75	4.45	4.48	4.62	4.88	4.92	4.87	4.81	5.51	6.27	7.42	7.25	6.25	5.26	5.29	5.29
China	5.99	5.91	4.59	4.30	4.32	4.47	4.73	4.77	4.72	4.65	5.35	6.11	7.25	7.08	6.07	5.09	5.13	5.12

Figure 13: LNG Price Curve, Australia.[38]

2.) The available LNG price list only covers 18 months, so we mathematically iterated the pattern and extrapolated over a 10 year span.

3.) The prices of LNG indicated above are in dollars per million BTUs. We converted these to dollars per million BTUs of CNG by multiplying by 42% since CNG contains 42% of the energy of LNG, which is the energy conversion methodology used by traders.

4.) The price of CNG in dollars per million BTUs was then converted to Yuan/meters cubed and then to Yuan/liter gasoline equivalent, which is how much Yuan a consumer would have to pay for the CNG to get the equivalent energy effect of one liter of gasoline.

[37] Shanghai Daily, China, Australia ink US $37 b natural gas deal, http://english.sina.com/business/1/2007/0906/124305.html], September 6, 2007.

[38] DeBaz, Peter, Louis Dreyfus Highbridge Energy research material.

5.) We calculated the CNG cost per month, discounted to present value, and summed it up over 10 years to come up with 20,337 Yuan as the lifetime CNG cycle cost.

Thus if we subtract the lifetime gasoline costs from the lifetime CNG cycle costs, we get a consumer lifecycle cost of 21,536 Yuan of savings relative to the baseline gasoline vehicles. It would take 27 months to break even, meaning to recoup the initial conversion cost of switching the vehicle to CNG technology.

We also performed a sensitivity analysis (See Figure 14), taking the inflation rate from a low of 0.92% to a high of 8.91% and determined that in the former case the savings would be $3,555 and in the latter – $2,195.

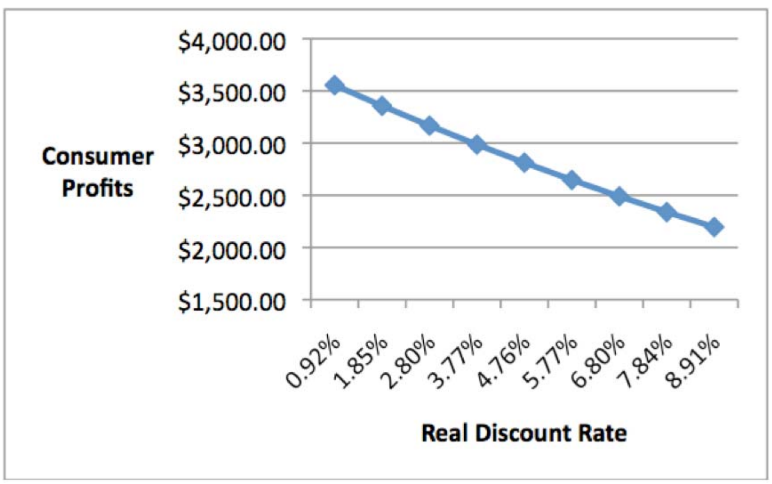

Figure 14: Sensitivity Analysis.

This implies that notwithstanding the degree of inflation or lack thereof, CNG vehicles still garner a significant amount of savings to the consumer. Since using CNG vehicles saves the consumer a significant amount, it seems as if CNG vehicle use should be heavily favored over gasoline vehicles, and consequentially the Chinese government should consider subsidizing the technology on a broad scale.

5. Conclusion:

From our cost benefit analysis, we conclude that not only do CNG vehicles' consumer benefits (24,536 Yuan) significantly outweigh those of gasoline based vehicles, but also that the conversion of gasoline vehicles brings $3,354 (22,901 Yuan) of benefits to the society as a whole. Thus, we recommend that China increase subsidies and/or tax incentives to encourage implementation of CNG vehicles for public and private transportation.

One may wonder, if CNG vehicles have such substantial benefits, why China has not yet implemented policies encouraging increased use of CNG vehicles. We will touch upon a few potential reasons, including consumer preferences and chemical properties of CNG technology that may act as limiting factors. Although these reasons cannot be solidified via quantitative analysis precisely, they do serve as a valid explanation of limited implementation of CNG despite its seemingly multiple benefits. Firstly, consumers that prefer a vehicle with fast acceleration capabilities will not be attracted to the CNG vehicle. Although CNG vehicles can reach the same maximum speed as a gasoline based vehicle, the acceleration leaves much to be desired, as a CNG operated car is unable to accelerate as quickly as the standard gas operated one.[39] In addition, CNG vehicles have less cargo space since CNG cylinders are stored in the trunk, which is the epitome of inconvenience. Many CNG vehicle users in Thailand have complained about this drawback. (See Figures 15 and 16.) The CNG cylinder weighs about 115 lbs, and frequently two cylinders are carried in the cargo space of a car.[40] This makes for about 230 additional pounds that the vehicle must lug around, which must decrease the car efficiency

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[39] Barta, Patrick.
[40] MCS International GmbH, CNG Cylinders, http://www.mcs-international-gmbh.de/downloads/mcs_cng01_engl.pdf.

by a significant factor. In fact, the heaviness of the CNG cylinders may explain why CNG vehicles are not able to accelerate quickly.

Figure 15: CNG Vehicle Trunk- Reduced Cargo Space.[41]

Figure 16: CNG Vehicle Trunk- Large size of CNG cylinders.[42]

It is also significant to touch upon the chemical limitations of CNG and its impact on CNG vehicle usage. One important downside is that the low volumetric density of CNG means that it is better suited for markets with a large gas supply. CNG's energy density is approximately 42% of LNG's and 25% of that of diesel.[43] This significantly limits the quantity of CNG that can be transported, for example LNG transports approximately 3 times the volume of gas per ship as

[41] AG CivicGX Trunk Picture, http://z.about.com/d/alternativefuels/1/0/b/N/-/-/ag_civicgx_trunk.jpg.

[42] Carroagas Picture, http://en.wikipedia.org/wiki/File:Carroagas.jpg.

[43] Deshpande, Asim and Economides, Michael, CNG: An Alternative Transport for Natural Gas Instead of LNG, http://www.spegcs.org/attachments/studygroups/6/CNG-An_Alternative_Transport_for_Natural_Gas.pdf.

CNG. As a result, while the majority of costs associated with LNG have to do with liquefaction and unloading, 89% of the costs of CNG production are derived from shipping.[44] The economics of CNG create a situation wherein it is only cheaper than LNG if the distance required to transport it is less than 2500 miles.[45] Over greater distances LNG becomes more attractive. This significantly limits the number of markets for CNG to only the areas that are within approximately 2500 miles of large gas resources. The conclusions about LNG in comparison to CNG can be extrapolated and applied to diesel versus CNG as both LNG and diesel are liquid, and thus both have significantly higher densities than CNG. CNG makes far more economic sense if a country has untapped local gas supplies such as in the case of Bangladesh.

Even with such potential drawbacks, we believe that with CBM being an increasingly attractive field for both foreign and domestic investors, and that more money will be funneled towards CBM development. Increased CBM development leads to greater amounts of natural gas supplied, and thus lower prices for natural gas. Lower prices for natural gas makes it an attractive alternative to diesel as a car fuel. Thus the demand for CNG vehicles should rise.

In light of the positive environmental impacts of CNG vehicles and positive social benefits, we highly recommend that the Chinese government take more proactive steps in subsidizing the CNG industry. Particularly helpful would be the subsidy of public transportation (ie buses) conversion to CNG as the first step in China's aim to embrace CNG – if they choose to do so.

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[44] Ibid.
[45] Ibid.

6. Appendix:

Sensitivity Analysis:

Base Case:

1. RDR = 2.8% (DR=.10, IR=.07)	Consumer Savings =	$3,167.17	-21536.76318
2. Volkswagen Jetta 2010	Societal Savings =	$170.56	-1159.811847
3. 1$ = 8.00 Yuen			

RDR	ConSavin
0.92%	$3,555.34
1.85%	$3,356.90
2.80%	$3,167.17
3.77%	$2,985.85
4.76%	$2,812.66
5.77%	$2,647.29
6.80%	$2,489.48
7.84%	$2,338.93
8.91%	$2,195.39

Calculation of Real Discount Rate	
DR =	0.1000
Inf =	0.0700
RDR =	0.0280
RDR_mon	0.0023

Lifetime of Vehicle	
Yrs	10.000
Km/yr	20000.000
Km Total	200000.000

First Costs of Gas Vehicle w/out Tax	
Retail Price	100000.000
Excise Tax	0.050
VAT	0.170
Gas_NoTax =	81400.081

First Costs of CNG Vehicle w/out Tax	
Cost of Conversion	5000.000
CNG_NoTax =	86400.081

Other Needed Variables	
Liters per 100km Driven	7.600
km driven each month	1666.667
liters of fuel used each month	126.667

Gasoline Price for Next 10 years

Gas_VAT	0.17	*Taxes not needed, but specified
Gas_Tax	1	
Premium to Dubai	0.5	
Dollar to Yen	8	

Lifetime Operational Costs Gas (Y) = 46874.230

Date	Brent	Ref. Prem	$/Bbl	$/Gal	Yuen/Gal	Yuen/L	Gas_Cost/ Month	PV of Gas_Cost
01-Jan-2010	78.470	0.050	82.919	1.974	15.794	4.172	382.611	382.611
01-Feb-2010	79.300	0.050	83.790	1.995	15.960	4.216	386.632	385.731
01-Mar-2010	80.110	0.050	84.632	2.015	16.120	4.259	390.515	388.697
01-Apr-2010	80.880	0.040	85.377	2.033	16.262	4.296	392.957	391.208

01-Jun-2010	82.230	0.048	86.682	2.064	16.511	4.362	399.977	395.336
01-Jul-2010	82.850	0.047	87.280	2.078	16.625	4.392	402.736	397.136
01-Aug-2010	83.450	0.047	87.858	2.092	16.735	4.421	405.402	398.833
01-Sep-2010	84.040	0.046	88.425	2.105	16.843	4.449	408.021	400.474
01-Oct-2010	84.610	0.045	88.973	2.118	16.947	4.477	410.548	402.015
01-Nov-2010	85.170	0.045	89.511	2.131	17.050	4.504	413.028	403.501
01-Dec-2010	85.740	0.044	90.057	2.144	17.154	4.532	415.550	405.018
01-Jan-2011	86.250	0.044	90.545	2.156	17.247	4.556	417.803	406.265
01-Feb-2011	86.700	0.043	90.976	2.166	17.329	4.578	419.789	407.245
01-Mar-2011	87.100	0.043	91.358	2.175	17.402	4.597	421.553	408.003
01-Apr-2011	87.460	0.043	91.702	2.183	17.467	4.614	423.139	408.583
01-May-2011	87.730	0.042	91.959	2.190	17.516	4.627	424.328	408.776
01-Jun-2011	87.990	0.042	92.207	2.195	17.563	4.640	425.473	408.923
01-Jul-2011	88.250	0.042	92.455	2.201	17.611	4.652	426.616	409.067
01-Aug-2011	88.480	0.042	92.674	2.207	17.652	4.663	427.627	409.080
01-Sep-2011	88.710	0.041	92.893	2.212	17.694	4.674	428.638	409.091
01-Oct-2011	88.930	0.041	93.103	2.217	17.734	4.685	429.604	409.058
01-Nov-2011	89.150	0.041	93.312	2.222	17.774	4.695	430.570	409.022
01-Dec-2011	89.370	0.041	93.521	2.227	17.814	4.706	431.536	408.983
01-Jan-2012	89.540	0.040	93.683	2.231	17.844	4.714	432.281	408.735
01-Feb-2012	89.710	0.040	93.845	2.234	17.875	4.722	433.027	408.485
01-Mar-2012	89.880	0.040	94.006	2.238	17.906	4.730	433.772	408.234
01-Apr-2012	90.220	0.040	94.329	2.246	17.967	4.746	435.261	408.681
01-May-2012	90.380	0.040	94.481	2.250	17.996	4.754	435.962	408.385
01-Jun-2012	90.540	0.039	94.632	2.253	18.025	4.762	436.662	408.088
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

01-Sep-2012	90.990	0.039	95.059	2.263	18.106	4.783	438.631	407.067
01-Oct-2012	91.140	0.039	95.201	2.267	18.134	4.790	439.286	406.725
01-Nov-2012	91.290	0.039	95.343	2.270	18.161	4.798	439.942	406.383
01-Dec-2012	91.440	0.039	95.485	2.273	18.188	4.805	440.597	406.040
01-Jan-2013	91.590	0.038	95.627	2.277	18.215	4.812	441.252	405.695
01-Feb-2013	91.740	0.038	95.769	2.280	18.242	4.819	441.907	405.350
01-Mar-2013	91.890	0.038	95.911	2.284	18.269	4.826	442.562	405.005
01-Apr-2013	92.040	0.038	96.053	2.287	18.296	4.833	443.216	404.658
01-May-2013	92.190	0.038	96.195	2.290	18.323	4.840	443.870	404.311
01-Jun-2013	92.340	0.038	96.336	2.294	18.350	4.847	444.525	403.963
01-Jul-2013	92.490	0.038	96.478	2.297	18.377	4.855	445.178	403.614
01-Aug-2013	92.640	0.037	96.620	2.300	18.404	4.862	445.832	403.264
01-Sep-2013	92.780	0.037	96.752	2.304	18.429	4.868	446.442	402.875
01-Oct-2013	92.920	0.037	96.884	2.307	18.454	4.875	447.052	402.484
01-Nov-2013	93.060	0.037	97.016	2.310	18.479	4.882	447.661	402.094
01-Dec-2013	93.230	0.037	97.176	2.314	18.510	4.890	448.401	401.819
01-Jan-2014	93.400	0.037	97.337	2.318	18.540	4.898	449.141	401.544
01-Feb-2014	93.570	0.036	97.497	2.321	18.571	4.906	449.880	401.268
01-Mar-2014	93.740	0.036	97.657	2.325	18.601	4.914	450.619	400.990
01-Apr-2014	93.910	0.036	97.817	2.329	18.632	4.922	451.358	400.711
01-May-2014	94.080	0.036	97.977	2.333	18.662	4.930	452.096	400.431
01-Jun-2014	94.250	0.036	98.137	2.337	18.693	4.938	452.835	400.150
01-Jul-2014	94.420	0.036	98.297	2.340	18.723	4.946	453.573	399.868
01-Aug-2014	94.590	0.035	98.457	2.344	18.754	4.954	454.310	399.585
01-Sep-2014	94.760	0.035	98.617	2.348	18.784	4.962	455.048	399.300

01-Dec-2014	95.270	0.035	99.096	2.359	18.875	4.986	457.259	398.441
01-Jan-2015	95.440	0.035	99.256	2.363	18.906	4.994	457.995	398.153
01-Feb-2015	95.610	0.034	99.415	2.367	18.936	5.002	458.731	397.863
01-Mar-2015	95.780	0.034	99.575	2.371	18.967	5.010	459.467	397.572
01-Apr-2015	95.950	0.034	99.734	2.375	18.997	5.018	460.203	397.281
01-May-2015	96.120	0.034	99.893	2.378	19.027	5.026	460.938	396.988
01-Jun-2015	96.290	0.034	100.053	2.382	19.058	5.035	461.673	396.694
01-Jul-2015	96.460	0.034	100.212	2.386	19.088	5.043	462.408	396.399
01-Aug-2015	96.620	0.033	100.362	2.390	19.117	5.050	463.099	396.067
01-Sep-2015	96.780	0.033	100.512	2.393	19.145	5.058	463.791	395.733
01-Oct-2015	96.940	0.033	100.661	2.397	19.174	5.065	464.481	395.399
01-Nov-2015	97.100	0.033	100.811	2.400	19.202	5.073	465.172	395.064
01-Dec-2015	97.100	0.033	100.811	2.400	19.202	5.073	465.172	394.143
01-Jan-2016	97.100	0.033	100.811	2.400	19.202	5.073	465.172	393.224
01-Feb-2016	97.100	0.033	100.811	2.400	19.202	5.073	465.172	392.307
01-Mar-2016	97.100	0.033	100.811	2.400	19.202	5.073	465.172	391.393
01-Apr-2016	97.100	0.033	100.811	2.400	19.202	5.073	465.172	390.481
01-May-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	393.541
01-Jun-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	392.624
01-Jul-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	391.709
01-Aug-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	390.796
01-Sep-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	389.885
01-Oct-2016	98.200	0.032	101.839	2.425	19.398	5.124	469.914	388.976
01-Nov-2016	99.300	0.031	102.864	2.449	19.593	5.176	474.644	391.976
01-Dec-2016	99.300	0.031	102.864	2.449	19.593	5.176	474.644	391.062
01-Jan-2017	99.300	0.031	102.864	2.449	19.593	5.176	474.644	390.151

01-Mar-2017	100.440	0.030	103.924	2.474	19.795	5.229	479.535	392.335
01-Apr-2017	94.420	0.036	98.297	2.340	18.723	4.946	453.573	370.229
01-May-2017	94.590	0.035	98.457	2.344	18.754	4.954	454.310	369.967
01-Jun-2017	94.760	0.035	98.617	2.348	18.784	4.962	455.048	369.704
01-Jul-2017	94.930	0.035	98.777	2.352	18.815	4.970	455.785	369.439
01-Aug-2017	95.100	0.035	98.936	2.356	18.845	4.978	456.522	369.174
01-Sep-2017	95.270	0.035	99.096	2.359	18.875	4.986	457.259	368.908
01-Oct-2017	95.440	0.035	99.256	2.363	18.906	4.994	457.995	368.641
01-Nov-2017	95.610	0.034	99.415	2.367	18.936	5.002	458.731	368.373
01-Dec-2017	95.780	0.034	99.575	2.371	18.967	5.010	459.467	368.103
01-Jan-2018	95.950	0.034	99.734	2.375	18.997	5.018	460.203	367.833
01-Feb-2018	96.120	0.034	99.893	2.378	19.027	5.026	460.938	367.562
01-Mar-2018	96.290	0.034	100.053	2.382	19.058	5.035	461.673	367.290
01-Apr-2018	96.460	0.034	100.212	2.386	19.088	5.043	462.408	367.017
01-May-2018	96.620	0.033	100.362	2.390	19.117	5.050	463.099	366.709
01-Jun-2018	96.780	0.033	100.512	2.393	19.145	5.058	463.791	366.400
01-Jul-2018	96.940	0.033	100.661	2.397	19.174	5.065	464.481	366.091
01-Aug-2018	97.100	0.033	100.811	2.400	19.202	5.073	465.172	365.781
01-Sep-2018	97.100	0.033	100.811	2.400	19.202	5.073	465.172	364.928
01-Oct-2018	97.100	0.033	100.811	2.400	19.202	5.073	465.172	364.077
01-Nov-2018	97.100	0.033	100.811	2.400	19.202	5.073	465.172	363.229
01-Dec-2018	97.100	0.033	100.811	2.400	19.202	5.073	465.172	362.382
01-Jan-2019	97.100	0.033	100.811	2.400	19.202	5.073	465.172	361.537
01-Feb-2019	98.200	0.032	101.839	2.425	19.398	5.124	469.914	364.371
01-Mar-2019	98.200	0.032	101.839	2.425	19.398	5.124	469.914	363.522
01-Apr-2019	98.200	0.032	101.839	2.425	19.398	5.124	469.914	362.675

01-Jun-2019	98.200	0.032	101.839	2.425	19.398	5.124	469.914	360.986
01-Jul-2019	98.200	0.032	101.839	2.425	19.398	5.124	469.914	360.144
01-Aug-2019	99.300	0.031	102.864	2.449	19.593	5.176	474.644	362.922
01-Sep-2019	99.300	0.031	102.864	2.449	19.593	5.176	474.644	362.076
01-Oct-2019	99.300	0.031	102.864	2.449	19.593	5.176	474.644	361.232
01-Nov-2019	100.370	0.030	103.859	2.473	19.783	5.226	479.235	363.876
01-Dec-2019	100.440	0.030	103.924	2.474	19.795	5.229	479.535	363.255

CNG Price for Next 10 Years

CNG_VAT	0.13	* Taxes not needed, but specified
EnerDen LNG to CNG	0.42	* Transportation costs not included
Dollar to Yen	8	

Lifetime Operational Costs CNG (Y) = 20337.467

	$/mmBTU of LNG	$/mmBTU of CNG	Yen/mmBTU of CNG	Yen/m^3 of CNG	Yen/LGas Equiv	CNG_Cost/ Month	PV CNG_Cost
01-Jan-2010	5.990	2.516	20.126	2.013	1.737	220.082	220.082
01-Feb-2010	5.910	2.482	19.858	1.986	1.714	217.143	216.637
01-Mar-2010	4.590	1.928	15.422	1.542	1.331	168.644	167.859
01-Apr-2010	4.300	1.806	14.448	1.445	1.247	157.989	156.887
01-May-2010	4.320	1.814	14.515	1.452	1.253	158.724	157.249

01-Jul-2010	4.730	1.987	15.893	1.589	1.372	173.788	171.371
01-Aug-2010	4.770	2.003	16.027	1.603	1.384	175.257	172.418
01-Sep-2010	4.720	1.982	15.859	1.586	1.369	173.420	170.213
01-Oct-2010	4.650	1.953	15.624	1.562	1.349	170.848	167.297
01-Nov-2010	5.350	2.247	17.976	1.798	1.552	196.568	192.033
01-Dec-2010	6.110	2.566	20.530	2.053	1.772	224.491	218.802
01-Jan-2011	7.250	3.045	24.360	2.436	2.103	266.377	259.020
01-Feb-2011	7.080	2.974	23.789	2.379	2.054	260.131	252.357
01-Mar-2011	6.070	2.549	20.395	2.040	1.761	223.022	215.853
01-Apr-2011	5.090	2.138	17.102	1.710	1.476	187.015	180.581
01-May-2011	5.130	2.155	17.237	1.724	1.488	188.484	181.576
01-Jun-2011	5.120	2.150	17.203	1.720	1.485	188.117	180.800
01-Jul-2011	5.990	2.516	20.126	2.013	1.737	220.082	211.029
01-Aug-2011	5.910	2.482	19.858	1.986	1.714	217.143	207.725
01-Sep-2011	4.590	1.928	15.422	1.542	1.331	168.644	160.953
01-Oct-2011	4.300	1.806	14.448	1.445	1.247	157.989	150.433
01-Nov-2011	4.320	1.814	14.515	1.452	1.253	158.724	150.780
01-Dec-2011	4.470	1.877	15.019	1.502	1.297	164.235	155.652
01-Jan-2012	4.730	1.987	15.893	1.589	1.372	173.788	164.322
01-Feb-2012	4.770	2.003	16.027	1.603	1.384	175.257	165.325
01-Mar-2012	4.720	1.982	15.859	1.586	1.369	173.420	163.211
01-Apr-2012	4.650	1.953	15.624	1.562	1.349	170.848	160.415
01-May-2012	5.350	2.247	17.976	1.798	1.552	196.568	184.134
01-Jun-2012	6.110	2.566	20.530	2.053	1.772	224.491	209.801
01-Jul-2012	7.250	3.045	24.360	2.436	2.103	266.377	248.365
01-Aug-2012	7.080	2.974	23.789	2.379	2.054	260.131	241.976

01-Oct-2012	5.090	2.138	17.102	1.710	1.476	187.015	173.153
01-Nov-2012	5.130	2.155	17.237	1.724	1.488	188.484	174.107
01-Dec-2012	5.120	2.150	17.203	1.720	1.485	188.117	173.362
01-Jan-2013	5.990	2.516	20.126	2.013	1.737	220.082	202.348
01-Feb-2013	5.910	2.482	19.858	1.986	1.714	217.143	199.180
01-Mar-2013	4.590	1.928	15.422	1.542	1.331	168.644	154.332
01-Apr-2013	4.300	1.806	14.448	1.445	1.247	157.989	144.244
01-May-2013	4.320	1.814	14.515	1.452	1.253	158.724	144.578
01-Jun-2013	4.470	1.877	15.019	1.502	1.297	164.235	149.249
01-Jul-2013	4.730	1.987	15.893	1.589	1.372	173.788	157.562
01-Aug-2013	4.770	2.003	16.027	1.603	1.384	175.257	158.524
01-Sep-2013	4.720	1.982	15.859	1.586	1.369	173.420	156.497
01-Oct-2013	4.650	1.953	15.624	1.562	1.349	170.848	153.816
01-Nov-2013	5.350	2.247	17.976	1.798	1.552	196.568	176.559
01-Dec-2013	6.110	2.566	20.530	2.053	1.772	224.491	201.170
01-Jan-2014	7.250	3.045	24.360	2.436	2.103	266.377	238.148
01-Feb-2014	7.080	2.974	23.789	2.379	2.054	260.131	232.022
01-Mar-2014	6.070	2.549	20.395	2.040	1.761	223.022	198.459
01-Apr-2014	5.090	2.138	17.102	1.710	1.476	187.015	166.030
01-May-2014	5.130	2.155	17.237	1.724	1.488	188.484	166.945
01-Jun-2014	5.120	2.150	17.203	1.720	1.485	188.117	166.231
01-Jul-2014	5.990	2.516	20.126	2.013	1.737	220.082	194.024
01-Aug-2014	5.910	2.482	19.858	1.986	1.714	217.143	190.986
01-Sep-2014	4.590	1.928	15.422	1.542	1.331	168.644	147.984
01-Oct-2014	4.300	1.806	14.448	1.445	1.247	157.989	138.311
01-Nov-2014	4.320	1.814	14.515	1.452	1.253	158.724	[illegible]

01-Jan-2015	4.730	1.987	15.893	1.589	1.372	173.788	151.080
01-Feb-2015	4.770	2.003	16.027	1.603	1.384	175.257	152.003
01-Mar-2015	4.720	1.982	15.859	1.586	1.369	173.420	150.059
01-Apr-2015	4.650	1.953	15.624	1.562	1.349	170.848	147.489
01-May-2015	5.350	2.247	17.976	1.798	1.552	196.568	169.296
01-Jun-2015	6.110	2.566	20.530	2.053	1.772	224.491	192.895
01-Jul-2015	7.250	3.045	24.360	2.436	2.103	266.377	228.351
01-Aug-2015	7.080	2.974	23.789	2.379	2.054	260.131	222.477
01-Sep-2015	6.070	2.549	20.395	2.040	1.761	223.022	190.295
01-Oct-2015	5.090	2.138	17.102	1.710	1.476	187.015	159.200
01-Nov-2015	5.130	2.155	17.237	1.724	1.488	188.484	160.077
01-Dec-2015	5.120	2.150	17.203	1.720	1.485	188.117	159.392
01-Jan-2016	5.990	2.516	20.126	2.013	1.737	220.082	186.042
01-Feb-2016	5.910	2.482	19.858	1.986	1.714	217.143	183.130
01-Mar-2016	4.590	1.928	15.422	1.542	1.331	168.644	141.896
01-Apr-2016	4.300	1.806	14.448	1.445	1.247	157.989	132.621
01-May-2016	4.320	1.814	14.515	1.452	1.253	158.724	132.927
01-Jun-2016	4.470	1.877	15.019	1.502	1.297	164.235	137.222
01-Jul-2016	4.730	1.987	15.893	1.589	1.372	173.788	144.865
01-Aug-2016	4.770	2.003	16.027	1.603	1.384	175.257	145.750
01-Sep-2016	4.720	1.982	15.859	1.586	1.369	173.420	143.886
01-Oct-2016	4.650	1.953	15.624	1.562	1.349	170.848	141.422
01-Nov-2016	5.350	2.247	17.976	1.798	1.552	196.568	162.332
01-Dec-2016	6.110	2.566	20.530	2.053	1.772	224.491	184.960
01-Jan-2017	7.250	3.045	24.360	2.436	2.103	266.377	218.958
01-Feb-2017	7.080	2.974	23.789	2.379	2.054	260.131	213.325

01-Apr-2017	5.090	2.138	17.102	1.710	1.476	187.015	152.651
01-May-2017	5.130	2.155	17.237	1.724	1.488	188.484	153.492
01-Jun-2017	5.120	2.150	17.203	1.720	1.485	188.117	152.836
01-Jul-2017	5.990	2.516	20.126	2.013	1.737	220.082	178.389
01-Aug-2017	5.910	2.482	19.858	1.986	1.714	217.143	175.596
01-Sep-2017	4.590	1.928	15.422	1.542	1.331	168.644	136.059
01-Oct-2017	4.300	1.806	14.448	1.445	1.247	157.989	127.165
01-Nov-2017	4.320	1.814	14.515	1.452	1.253	158.724	127.459
01-Dec-2017	4.470	1.877	15.019	1.502	1.297	164.235	131.577
01-Jan-2018	4.730	1.987	15.893	1.589	1.372	173.788	138.906
01-Feb-2018	4.770	2.003	16.027	1.603	1.384	175.257	139.754
01-Mar-2018	4.720	1.982	15.859	1.586	1.369	173.420	137.967
01-Apr-2018	4.650	1.953	15.624	1.562	1.349	170.848	135.604
01-May-2018	5.350	2.247	17.976	1.798	1.552	196.568	155.654
01-Jun-2018	6.110	2.566	20.530	2.053	1.772	224.491	177.351
01-Jul-2018	7.250	3.045	24.360	2.436	2.103	266.377	209.950
01-Aug-2018	7.080	2.974	23.789	2.379	2.054	260.131	204.550
01-Sep-2018	6.070	2.549	20.395	2.040	1.761	223.022	174.961
01-Oct-2018	5.090	2.138	17.102	1.710	1.476	187.015	146.371
01-Nov-2018	5.130	2.155	17.237	1.724	1.488	188.484	147.178
01-Dec-2018	5.120	2.150	17.203	1.720	1.485	188.117	146.548
01-Jan-2019	5.990	2.516	20.126	2.013	1.737	220.082	171.051
01-Feb-2019	5.910	2.482	19.858	1.986	1.714	217.143	168.373
01-Mar-2019	4.590	1.928	15.422	1.542	1.331	168.644	130.462
01-Apr-2019	4.300	1.806	14.448	1.445	1.247	157.989	121.934
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01-Jul-2019	4.730	1.987	15.893	1.589	1.372	173.788	133.192
01-Aug-2019	4.770	2.003	16.027	1.603	1.384	175.257	134.005
01-Sep-2019	4.720	1.982	15.859	1.586	1.369	173.420	132.291
01-Oct-2019	4.650	1.953	15.624	1.562	1.349	170.848	130.026
01-Nov-2019	5.350	2.247	17.976	1.798	1.552	196.568	149.251
01-Dec-2019	6.110	2.566	20.530	2.053	1.772	224.491	170.055

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