Report for Climate Action Secretariat – LCA GHG Emissions and Electricity Generation in China, Japan, Korea and Taiwan

I. Work Order

The contractor will provide an independent analysis of lifecycle GHG emissions from electricity generation in China, Japan, Korea and Taiwan using BC Liquefied Natural Gas and domestic or least cost thermal coal. This analysis will include the following:

- Literature review of existing research (academic, ENGO, industry, government)
- Develop a theoretical model for a typical coal fired and natural gas (LNG) fired electricity generation facility in each of China, Japan, Korea and Taiwan
  - Current generation facility design
  - Fuel type and source (assumption to include Horn River Basin shale gas, BC sourced PCI coal, other relevant coal sources such as Australia)
- Estimate lifecycle GHG emissions for each fuel source including exploration, development, production, and transportation to the plant gate for each generation facility type
- Estimate plant level GHG emissions from each generation facility type including total annual emissions, total design life emissions, emissions/KWh
- Estimate total GHG emissions/KWh for each fuel source and plant configuration

II. Spreadsheet Model

The attached spreadsheet (CAS_Model_Data.xlsx) contains a framework to analyze the impact of alternative coal- and natural gas-fired electricity generation facilities in China, Japan, Korea and Taiwan. The user can:

- Select from nine (9) recently constructed generation facilities for the technical specifications for an electricity generation facility.
- Modify default parameters to change the fuel types, caloric values, operating efficiency and average operating utilization to analyze the relationship between electricity output and corresponding fuel requirements.
- Modify default parameters to change the CO_2 emission factor, combustion efficiency and LNG transportation distance to analyze the relationship between input factors and the production of CO_2.

Based on analysis presented in Hondo (2005) for Japan, the model presents estimates of lifecycle CO_2 emissions for fuel combustion, construction, fuel extraction, processing, transportation and methane leakage. This analysis is based on extensive Input/Output models and at this point we have adopted the result parameters reported in Hondo (2005) rather than attempt to replicate the analysis within the current tight time frame.

The blue-shaded cells in Figure 1 are parameters that can be modified by the user either by using a drop-down menu (in the case of electrical generation facility or fuel type, for example) or by entering specific values (such as caloric value or efficiency rates).

Figure 1 – Presentation of Model

Power Plant Configuration: China - Wangqu 1 and 2 - Lean coal-fired, inland supercritical PCC plant

Modify Parameters in Blue-Shaded Cells

	Default		Over-ride	Value Used
Fuel Type	Chinese low volatile coal		BC Shale Gas	BC Shale Gas
Fuel Caloric Value - MJ/kg	1030 BTU / Cubic Foot	1030		1,030.0
Design Efficiency	41.4% (40% HHV)	41.4%		41.4%
Annual Operating Efficiency	Operating efficiency (LHV, sent out basis) 41.4	41.4%		41.4%
Capacity - Mwso	2 x 600 nominal	1,200.0		1,200.0

Operating at % of Capacity	70%		
Total Electricity Production	7,358	gWh	
	26,490,240	GJ - Output	
	63,986,087	GJ - Input	
Fuel Requirement	58.9	BCF @ 1030 BTU/mcf	
CO2 Emission Factor (KG/MJ)	0.0560		0.0560
Combustion Efficiency (%)	99.5%		99.5%
LNG Port of Origin	Prince Rupert Canada		
LNG Destination Port	Putian, Fujian Prov, CH		
% of CO2 in Raw Nat Gas	10.0%		10.0%
%Fuel Loss in Cdn Gas Transmission	2.0%		2.0%

BC Shale Gas

		g-CO2/kWh	%	
CO2 from Combustion		484.5	71.7%	
Construction	2.9		0.4%	
LNG Production - Fuel	68.5		10.1%	
LNG Production - CO2 in Crude NG	58.2		8.6%	<== Specific adjustment for BC Shale Gas
Transport	47.4		7.0%	<== Specific adjustment for BC Shale Gas
Refinery	0.0		0.0%	
Generation	4.6		0.7%	
Methane leakage	9.2		1.4%	
Subtotal		190.9	28.3%	
Total		675.4		

Non-combustion LCA CO2 factors Based on Hondo (2005)

Factors incorporated specifically to address issues related to BC shale gas include:

- Distance (straight line) between the LNG port of origin and destination port – this factor will adjust the base line numbers developed by Hondo (2005) based on the distance differential.
- Percentage of CO2 in raw natural gas – assumed to be vented to the atmosphere at source of extraction.
- Additional percentage fuel loss in Canadian pipelines from point of extraction to destination port.

The interior bold box presents the estimates of CO_2 emission factors (g CO_2 per kWh) for each of the stages of the lifecycle analysis.

III. Model Results

The attached spreadsheet model was simulated using the Wangqu 1 and 2 (China) coal fired plant for the key technical characteristics of the electricity generating facility. The model was then simulated using coal and natural gas as fuels to determine the volume of input fuel needed to generate the required electricity output.

The significant difference in the estimated impact of direct combustion is largely the impact of the result of the emission factors developed by the responsible agencies. The US EIA estimates coal CO_2 emissions ranging from 0.0883 kg CO2/MJ (bituminous) to 0.0978 (anthracite) while Natural Resources Canada estimates average coal CO_2 emissions at 0.0930 and natural gas CO_2 emissions at 0.0560. This accounts for the significant difference between the coal and natural gas combustion emissions in Table 1.

The Hondo (2005) LCA factors for construction, fuel extraction, processing, transportation and methane leakage for coal and LNG were then linked to the estimates of CO_2 from combustion to estimate the total volume of CO_2e emissions associated with the specified fuels. These are reported in Table 1.

Additional factors were incorporated specifically to address issues related to BC shale gas.

- Distance – The distance from Prince Rupert to China is significantly longer than the distance (straight line) between Indonesia (the LNG port of origin mentioned in Hondo (2005)) and a destination port in Japan. The Prince Rupert/China distance is used to adjust the estimate of LNG transportation emissions.
- Percentage of CO_2 in raw natural gas – We have assumed that the raw BC shale gas will have CO_2 content in the range of 10% (mol) which is higher than the amount that

Table 1 - Model Simulations Based on: China - Wangqu 1 and 2
Lean coal-fired, inland supercritical PCC plant

	International Bituminous Coal g-CO_2/kWh		Natural Gas/LNG g-CO_2/kWh		BC Shale Gas/LNG g-CO_2/kWh	
CO_2 from Combustion	752.5	90.9%	484.5	78.7%	484.5	71.7%
Construction	3.1	0.4%	2.9	0.5%	2.9	0.4%
LNG Production – Fuel	8.2	1.0%	68.5	11.1%	68.5	10.1%
LNG Production - CO_2 in Crude NG			26.6	4.3%	58.2	8.6%
Transport	13.2	1.6%	19.7	3.2%	47.4	7.0%
Refinery	0.0	0.0%	0.0	0.0%	0.0	0.0%
Generation	5.7	0.7%	4.6	0.7%	4.6	0.7%
Methane leakage	44.9	5.4%	9.2	1.5%	9.2	1.4%
Subtotal	75.1	9.1%	131.5	21.3%	190.9	28.3%
Total	827.6	100.0%	616.0	100.0%	675.4	100.0%

appears to be reported in Hondo (2005) of about 5% which is presumably based on a range of sourced LNG volumes.

- Additional percentage fuel loss in Canadian pipelines – We have assumed a 2% fuel use in transporting BC shale gas to Prince Rupert.

While these factors narrow the gap between the natural gas and coal CO_2 emissions somewhat (by about 28%) there is still a significant gap between the CO_2 emissions for LNG and BC shale gas/LNG (616 to 675 g-CO_2/kWh) and coal (828 g-CO_2/kWh).

We have not estimated any additional differential in the volume of fuel used in fracturing the subsurface in connection with well completions for BC shale gas. While this fuel use is presumably greater than would be realized in the jurisdictions that Hondo (2005) reviewed in estimating LCA emission factors (many of which likely sourced gas from conventional production in off- and on-shore settings):

- We do not have the information required to make an informed adjustment; and
- This adjustment would not be expected to significantly narrow the gap in CO_2 emissions between using coal and BC shale gas as the fuel for electricity generation in Asian nations. To close this gap would require fuel use in the field of about 30% of the energy content of the delivered gas. This would be extremely unlikely – and would require significant Carbon Tax payments on fuel consumed that would significantly adversely impact the profitability of developing the Horn River Basin, Cordova Embayment and Liard Basin.

Technology to Delivery Combustion for Electricity Generation	g-CO_2/kWh	% of Total Coal LCA CO_2 Emissions
Using Coal	828	
Using Natural Gas Delivered as LNG	616	74%
Using BC Shale Gas Delivered as LNG	675	82%

IV. Literature Review

Analysis for the preparation of this report has reviewed the literature presented below, grouped by topic. A more detailed analysis of the literature will be provided with the final delivery of this report.

A. Electric Power Sector – Generation

Report (A-01) sets out detailed information about the physical and operating characteristics of nine recently constructed (to 2007) electricity generating facilities with a range of fuels and technologies. Of particular interest to the current project are the emission design levels, fuel type, fuel caloric value and design efficiencies. This information is used in developing alternative scenarios for electrical generation inputs and outputs.

- Canada - Genesee 3 - Sub-bituminous coal-fired, inland supercritical plant
- China - Wangqu 1 and 2 - Lean coal-fired, inland supercritical PCC plant
- Denmark - Nordjyllandsværket 3 - Sea water cooled ultra-supercritical plant
- Germany - Niederaussem K - Lignite-fired, inland ultra-supercritical PCC plant
- India - Suratgarh - High ash bituminous coal-fired PCC plant
- Japan - Isogo New Unit 1 - Bituminous coal-fired, coastal ultra-supercritical plant
- S. Korea - Younghung Thermal Power Plant - Bituminous coal-fired, coastal supercritical PCC plant
- South Africa - Majuba - High-ash bituminous coal-fired PCC plant with dry and wet cooling
- United Kingdom - Enfield - Natural Gas Fired Plant

(A-01) International Energy Agency (2007). ”Fossil Fuel-Fired Power Generation: Case studies of Recently Constructed Coal- and Gas-Fired power plants:”.

B. Life Cycle GHG for Electric Power Sector

Each of these studies undertakes to estimate the life cycle analysis (LCA) of greenhouse gas (GHG) emissions associated with the operation of electrical generation facilities in each of the four study nations. While it appears that each study is following the methodology set out in ISO 14040 the level of detail provided varies widely. Hondo (2005) for Japan is the most comprehensive in providing estimates of GHG emission associated with each of the phases of activity – combustion, construction, operation (extraction, processing, transport, etc.) and methane leakage.

(B-01) Hondo, H. (2004). “Life cycle GHG emission analysis of power generation systems: Japanese case”. Energy 30 (2005) pp. 2042–2056

(B-02) Lee K-M, Lee S-Y & Hur T. (2004).Life cycle inventory analysis for electricity in Korea. Energy 29 (2004) 87–101

(B-03) Ou X, Yan, Xiaoyu, Y & Zhang, X (2011). “Life-cycle energy consumption and greenhouse gas emissions for electricity generation and supply in China”. Applied Energy 88 (2011) 289–297

(B-04) Yang Y-S, Lin S-J, Lewis C. “Life Cycle Assessment of Fuel Selection for Power Generation in Taiwan”. J. Air & Waste Manage. Assoc. 57:1387–1395

C. Energy Sector Overview

Each of the US Energy information Agency (EIA) brief provides analysis of the energy supply and demand situations affecting each of China, Japan, Korea and Taiwan. Of critical importance is the analysis of the fuels used in generating electricity in each nation.

(C-01) EIA, Country Analysis Briefs – China (2010)

(C-02) EIA, Country Analysis Briefs – Japan (2011)

(C-03) EIA, Country Analysis Briefs – Korea (2011)

(C-04) EIA, Country Analysis Briefs – Taiwan (2011)

D. Fuel Specific Analyses

The Li et al (2009) report presents a thoughtful review of the issues confronting expanded LNG consumption in the electricity generation and other sectors in China. The Heede (2006) report provides useful information in assessing the impact of distance on energy consumed in delivering LNG to market.

(D-01) Li, Y. & Bai F. (2009). “A policy study examining the use of imported LNG for gas-fired power generation on the southeast coast of China”. Energy Policy 38 (2010) pp. 896–901.

(D-02) Heede, R. (2006). “LNG Supply Chain Greenhouse Gas Emissions for the Cabrillo Deepwater Port: Natural Gas from Australia to California”. Climate Mitigation Services. 17 May 2006.

E. British Columbia Natural Gas

These reports are topical and present issues facing the development of the shale gas industry in British Columbia and the consistency with climate action objectives.

(E-01) Horne, M. (2011). ”Shale Gas in British Columbia: Risks to BC’s climate action objectives”. The Pembina Institute

(E-02) Jaccard, M. and Griffin B. (2010). ”Shale Gas and Climate Targets: Can They Be Reconciled?”. Pacific Institute for Climate Solutions

(E-03) Parfitt, B, (2011) ”Fracking up our water, hydro-power and climate: BC’s reckless pursuit of shale gas”. Canadian Centre for Policy Alternatives.

F. Shale Gas, Coal and Life Cycle GHG emissions

These reports compare LCA emissions from coal and shale gas and focus on an issue related to the possible escape of methane to the atmosphere – this appears to be a misunderstanding of the earlier report in which methane was reported to be captured.

(F-01) Hughes (2011). “Life Cycle Greenhouse Gas Emissions from Shale Gas Compared to Coal: An Analysis of Two Conflicting Studies”. Post Carbon Institute. July 2011.

(F-02) CERA (2011). “Mismeasuring Methane: Estimating Greenhouse GAS Emissions From Upstream Natural GAS Development”.

(F-03) Howarth RW, Santoro R & Ingraeffea A (2011) “Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations”.

G. Natural Gas and LNG vs Coal for power GHG LCA

These reports assess LNG and coal LCA GHG emissions primarily within the US context.

(G-01) Deutsche Bank Group (2011). “Comparing Life-Cycle Greenhouse Gas Emissions from Natural Gas and Coal”. August 2011

(G-02) DiPietro P (2010). “Life Cycle Analysis of Coal and Natural Gas-fired Power Plants”. US National Energy Technology Laboratory. July 2010.

(G-03) Jaramillo P., Griffin WM & Matthews HS (2005). ”Comparative Life Cycle Carbon Emissions of LNG Versus Coal and Gas for Electricity Generation”. Carnegie Mellon.

(G-04) PACE (2009). “Life Cycle Assessment of GHG Emissions from LNG and Coal Fired Generation Scenarios: Assumptions and Results”. Prepared for Center for Liquefied Natural Gas. February 2009.

(G-05) Sakmar (2010). “The Globalization and Environmental Sustainability of LNG: Is LNG a Fuel for the 21st Century?”. World Energy Congress (paper)