Open your mind. LUT.
Lappeenranta University of Technology
THE ECONOMICS OF LNG SUPPLY
BASED ON HYBRID PV-WIND
POWER PLANTS

First insights on economics of global PtG based LNG trading in 2030

Mahdi Fasihi and Christian Breyer
Neo-Carbon Energy 2nd Researchers’ Seminar
Lappeenranta, 16.03.2015
Agenda

- Motivation
- Methodology and Data
- Results
- Further Study
- Summary
Motivation

LNG is a solution for NG transportation in long distances

- RE-LNG
  - A non-diminishing reserve
  - Fixed cost
  - No Pollution
  - No Carbon emission cost
  - A step toward fuel security

Natural Gas proved reserves 2013
Data source: BP Statistical Review June 2014
Agenda

- Motivation
- Methodology and Data
- Results
- Further Study
- Summary
RE-LNG Value Chain

Hybrid PV-Wind → Methane Production → Methane Liquefaction → LNG Shipping → LNG Regasification
Data
Plants’ Location

1) Patagonia, Argentina:
   - Hybrid PV-Wind Power Plant
   - Electrolysis+Methanation Plant
   - Liquefaction Plant

2) Japan:
   - Regasification Plant

Data
Hybrid PV-Wind Power Plant

- 1-axis tracking PV plants
  - FLH: 2490 h
  - Capex: 550 €/kW
  - Irradiation: 3000 [kWh/m²/a]
  - PR: 0.83
  - LCOE: 19.9 €/MWh_{el}

- FLH: 3500 h
  - Capex: 800 €/kW
  - LCOE: 23 €/MWh_{el}

- Hybrid PV-Wind Power Plant
  - Place: Patagonia, Argentina
  - Capacity: 5 GW_{el} each
  - FLH: 5691 h
    - 5% overlap
  - Cost assumptions for year 2030
    - 7% WACC
    - LCOE: 22.84 €/MWh_{el}
**Data**

**Power to Gas (Electrolysis and Methanation)**

- **Electrolysis + Methanation**
  - Place: Argentina
  - Capacity: 5 GW\(_{el}\)
  - FLH: 5691 h
  - Lifetime: 30 y
  - Overall eff.: 64%

- **Electrolysis eff.: 78%**

- **Methanation eff.: 82%**

- **Cost assumptions for year 2030**
  - Capex: 500 €/kW\(_{el}\)
  - Water and CO\(_2\) with additional costs
Data
Liquefaction

- Conventional LNG is over 97% liquid methane (CH\textsubscript{4})
- Cooling Methane to -162 ºC.
- Volume decreases 600 times

Liquefaction Plant:
- Place: Patagonia, Argentina
- Volume: 1732.5 mcm/a Methane
- Lifetime: 25 y
- Efficiency: 96%
- Capex: 0.196 m€/mcm/a NG
- Opex: 3.5% of capex, annually

Pure Methane vs. NG
- Higher efficiency
- Simpler facilities
- Lower cost

Source: KBR Company; LNG Liquefaction - Not All Plants Are Created Equal
Data
LNG Shipping

- From: Patagonia, Argentina
- To: Japan, Yokohama
- Marine Distance: 17500 km

- Capacity: 138000 m³ LNG
- Speed: 20 knots
- Time on sea, one way: 20 days
- Boil-off gas: 0.1 %/d
- Efficiency: 99.9 %/d
- LNG ships required: 2.4
- Lifetime: 25 years
- Capex: 151 m€/unit
- Opex: 3.5% of capex, annually

LNG-powered ships use boil-off gas as the marine fuel.

Source: seasput.wordpress.com
Data
Regasification

- LNG is heated by sea water to be reconverted to NG
- Cold energy of regasification can be used for extracting liquid oxygen and nitrogen gas from air

Regasification Plant:
- Place: Japan, Yokohama
- Volume: 1630.7 mcm/a Methane
- Lifetime: 30 years
- Efficiency: 98.5%
- Capex: 0.074 m€/mcm/a NG
- Opex: 3.5% of capex, annually

Source: gastechnews.com
Agenda

- Motivation
- Methodology and Data
- Results
- Further Study
- Summary
Results
Cost Distribution in RE-LNG Value Chain

LCOE (7% WACC):
- 59.32 €/MWh\textsubscript{th}
- 23.21 USD/MBtu

LCOE (5% WACC):
- 49.88 €/MWh\textsubscript{th}
- 19.51 USD/MBtu

USD/€ = 1.35
Results
Market potential (2 scenarios)

The first breakeven can be expected for produced RE-SNG with a WACC of 5% and NG price with CO₂ emission cost of 50 €/t CO₂ and a crude oil price of 100 USD/bbl.

CO₂ emission cost:
- NG CO₂ emission: 56 t CO₂/TJ
- 0-50 €/tCO₂
- 0-4 USD/Mbtu
- USD/€ = 1.35

- LNG price in Japan: 88.6% of crude oil price.
- Regasification cost has been added
Agenda

- Motivation
- Methodology and Data
- Results
  - Further Study
- Summary
Further Study
Gas to Liquids (GtL)

GtL is a refinery process to convert natural gas or other gaseous hydrocarbons into longer-chain hydrocarbons.

Benefits:
- Lower shipping cost
- No special plant needed at destination
- Different types of products
- Higher efficiency: 65%

Fischer–Tropsch process

Air

Natural Gas

Air Separation

Gas Processing

Oxygen

Methane

Gas synthesis

CO

Fischer–Tropsch process

H₂

Liquid hydrocarbons

Cracking

Diesel
50-80%

Naphtha
15-25%

Paraffin
0-30%

Further Study

Power to Liquids (PtL)

- The idea is to transform water and CO$_2$ to high-purity synthetic fuels (petrol, diesel, kerosene) with the aid of renewable electricity.

Benefits:
- Integrated system
- Lower shipping cost
- No regasification plant at destination
- Different types of products
- Higher efficiency: 70%
Further Study
Different Possibilities’ Value Chain

- Methanol
  - Diesel
    - Kerosene
      - Wax
  - Diesel
    - Kerosene
      - Wax

- LNG
  - CH₄
  - Diesel
  - Kerosene
  - Wax

- Solar
  - CH₄
  - Diesel
  - Kerosene
  - Wax

- Wind
  - CH₄
  - Diesel
  - Kerosene
  - Wax

- Fossil Energy
  - CH₄
  - Diesel
  - Kerosene
  - Wax
Agenda

- Motivation
- Methodology and Data
- Results
- Further Study
- Summary
Summary

• The idea is to use hybrid PV-Wind power plants’ power to produce RE-SNG.

• Liquefaction plant, shipping and regasification plant are needed for delivering RE-SNG to far-off regions.

• RE-SNG is a non-diminishing carbon free fuel, which will insure both fuel security and environmental issues.

• The cost of delivered RE-SNG in Japan is 19.51 USD/MBTU (5% WACC).

• For crude oil price more than 100 USD/bbl and CO$_2$ emission cost of 50 €/t$_{CO2}$, RE-SNG is competitive to conventional NG price in Japan.

• This would be an upper limit for the conventional LNG price in the long-term.

• Substitution of fossil fuels by hybrid PV-Wind power plants could create a PV market potential in the order of several TWp.

• PtG-GtL and PtL are the other options which need more investigations.
Summary

Re-LNG Value Chain (an overview of all data and assumptions)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity: 5 [GW_{el,each}]</td>
<td>Capacity: 5 [GW_{el}]</td>
<td>Volume: 1732.5 [mcm/a Methane]</td>
<td>Marine Distance: 17500 [km] [10]</td>
<td>Volume: 1630.7 [mcm/a Methane]</td>
</tr>
<tr>
<td>3500 h Wind</td>
<td>Electrolysis eff.: 78%</td>
<td>Capex: 0.196 [m€/mcm/a NG] [2]</td>
<td>Ship size: 138000 [m^3 LNG] [11]</td>
<td>Capex: 0.074 [m€/mcm/a NG] [2]</td>
</tr>
<tr>
<td>2490 h PV</td>
<td>Methanation eff.: 82%</td>
<td>Opex: 3.5% [of capex, annually] [2]</td>
<td>Speed: 20 [knots] [8]</td>
<td>Opex: 3.5% [of capex, annually] [2]</td>
</tr>
<tr>
<td>FLH: 5691 (5% overlap)</td>
<td>FLH: 5691</td>
<td></td>
<td>Boil-off gas: 0.1 [%/day] [8]</td>
<td></td>
</tr>
<tr>
<td>PV, irradiation: 3000 [kWh/m2/a]</td>
<td></td>
<td></td>
<td>Efficiency: 99.9 [%/day]</td>
<td></td>
</tr>
<tr>
<td>PV, PR: 0.83</td>
<td>Capex (2030): 500 [€/kW]</td>
<td></td>
<td>LNG ships required: 2.4</td>
<td></td>
</tr>
<tr>
<td>Lifetime: PV: 40 [y], Wind 30 [y]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCOE(WACC 7%): 22.84 [€/MWh_{th}]</td>
<td>26.69 [€/MWh_{th}]</td>
<td>4.45 [€/MWh_{th}]</td>
<td>3.61 [€/MWh_{th}]</td>
<td>1.73 [€/MWh_{th}]</td>
</tr>
<tr>
<td>LCOE(WACC 5%): 19.04 [€/MWh_{th}]</td>
<td>22.41 [€/MWh_{th}]</td>
<td>3.83 [€/MWh_{th}]</td>
<td>3.12 [€/MWh_{th}]</td>
<td>1.48 [€/MWh_{th}]</td>
</tr>
</tbody>
</table>
NEO-CARBON Energy project is one of the Tekes strategy research openings and the project is carried out in cooperation with Technical Research Centre of Finland VTT Ltd, Lappeenranta University of Technology (LUT) and University of Turku, Finland Futures Research Centre.
References

- [4] Kotzot H., Durr Ch., Coyle D., Caswell, Ch. 2007. LNG liquefaction—not all plants are created equal, 15th International Conference & Exhibition on Liquefied Natural Gas (LNG 15), Barcelona, April 24-27
- [5] Breyer Ch., projections on current Tier1 PV industry cost, cost roadmaps and learning curve impact