Masterclass Natural Gas

Groningen, 3 October 2014

By Martien Visser ("prof. dr. Ir. B.M. Visser")

- Professor Energy Transition & Networks @ Hanze Univ. (25%)
- Manager Corporate Strategy Gasunie (70%)
- Fellow Clingendael International Energy Programme (5%)

Jobs in: Wind Energy, Electricity, Coal, Natural Gas

Physics, Research, Economics, Finance, Strategy
Masterclass: Natural Gas

Contents

1. The Energy Bill
2. Electricity & Gas
3. Gas Infrastructure
4. Flexibility & Storage
5. Geopolitics
6. LNG
7. Unconventional Gas (e.g. shale gas)
8. Joint Exercise (if time)
Gasunie transport grid
(The Netherlands and Northern Germany)

Volume ~125 bcm gas p/y
Length transport grid ~15,500 km
Compressor stations 22
Blending stations 19
Pressure regulating stations 93
Gas delivery stations 1,300
Export stations 14
LNG (incl peakshaver) 2
Nitrogen facility 2
Underground gas storage 1
Underground nitrogen storage 1
My Energy Bill in 2013: €2289

Gas:

- BTW:
- distributie E:
- distributie G:
Vastrecht:
Transport E:
Transport G:

Elektriciteit:

- Ecotax:
- BTW:
- Distributie E:
- Distributie G:
Vastrecht:
Transport E:
Transport G:
### My current energy Bill

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>4250 kWh</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1937 m³</td>
</tr>
</tbody>
</table>

\[ \text{Electricity} \times \text{Conversion Factor} = \text{Natural Gas} \times \text{Conversion Factor} = 19000 \text{ kWh (}>4x) \]

**Electricity Usage: day-night pattern**

**Gas Usage dependent on ambient temperature**

**Average Household Nethelrands:**
- 3500 kWh en 1500 m³ per annum
- Additional: 1200 liter benzine/diesel for transport

**Total Energy Demand per household:** about 30,000 kWh

This is the direct energy usage for a household
The Netherlands

Electricity consumption The Netherlands: 120 TWh
  6 million households x 3500 kWh = 20 TWh  (= 20%)

Natural Gas consumption Nederland: 45 bln m³ (450 TWh)
  6 million households x 1500 m³ = 9 bln m³  (=20%)

Total primary energy demand The Netherlands: 1000 TWh
  oil, gas, coal, etc…

Total final energy demand The Netherlands: 750 TWh
  including 120 TWh electricity (=16%)
Real Energy Usage

Total Energy Demand per household

Final energy usage per household (direct and indirect)

750 TWh/6 million = 125,000 kWh (!!)

(> 30 x 3,500 kWh)

Exclusive the energy usage for the Netherlands abroad, e.g. China
2. Gas en Electricity

Wholesale Gas Price : 25 €ct/m3
Wholesale Electricity Price : 6 €ct/kWh
Gas & Electricity

Volume Units

Gas is usually quoted in m³; Electricity is quoted in kWh

Energy value of Groningen gas: 35.17 MJ/m³ (HCV)
   Energy value of International Gas: 38 MJ/m³ (HCV)
   Groningen gas includes 14% N₂ (exceptional)

Your Bill: 1500 m³(n) 35.17 gas

   1 m³ gas = 35.17 x 1000 / 3600 ≈ 10 kWh

Gas is usually quoted in Higher Calorific Value! (“condensing equipment”)
   Groningen gas: 31.68 MJ/m³ LCV

Oil and Coal are always quoted in Lower Calorific Value

The efficiency of a gas-fired power station is 58% (HCV of LCV?)
   1 m³ gas => how much kWh?

LCV!
Capacity units

Capacity Matters!

My car has an average speed of 4 km/hr

Capacity Requirement determines infrastructure

Gas capacity is usually quoted as m3/hr
  “A house heating boiler has a capacity of 3 m3/hr”

Electricity Capacity is quoted in kW
  “A microwave has a capacity of 1 kW”

1 m3/hr ≈ 10 kW  (major trunk lines: 1 mln m3/hr = 10 GW)
Example: energy usage of city of Groningen (2012)

Exclusive mobility, exclusive big industrial users (data hotel etc.)

Gas demand = 4x electricity demand
Gas capacity = 7x electricity capacity   (very cold winter day: 10x)
Capacity for Heating is larger than electricity

The Netherlands (100% heat demand by gas)

Volume gas: 45 bcm (450 TWh)
Volume E: 120 TWh
### Main Elements

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Pressure</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production wells</td>
<td>200-300 bar</td>
<td>(“Siberia”)</td>
</tr>
<tr>
<td>Upstream pipelines*</td>
<td>80-150 bar</td>
<td>(“to Europe”)</td>
</tr>
<tr>
<td>Storages</td>
<td>100-300 bar</td>
<td>(“Norg”)</td>
</tr>
<tr>
<td>Downstream pipelines</td>
<td>40-80 bar</td>
<td>(“Gasunie”)</td>
</tr>
<tr>
<td>Distribution</td>
<td>1-8 bar</td>
<td>(“Enexis”)</td>
</tr>
<tr>
<td>Household</td>
<td>25 mbar</td>
<td>(“your house”)</td>
</tr>
</tbody>
</table>

*Alternative: Liquefaction – LNG vessel – LNG Terminal

Temperature of LNG = -162 °C  (1 m³ LNG = 600 m³ gas)
Physics of a (simple) pipeline system

Entry: 2.3 mln m³/hr

Capacity: 2.3 mln m³/hr

Exit: 2.3 mln m³/hr

65 bar

50 bar

100km & 42” pipeline

Available pressure drop = 15 bar

Flow and pressure drop: physics law of Bernoulli
Max gas velocity: 30-35 km/hr
Physics of a (simple) pipeline system

Entry: 2.1 mln m³/hr
Exit: 2.6 mln m³/hr
Capacity = 2.3 mln m³/hr

65 bar to 50 bar
100km & 42” pipeline

75 km & 25 km

gas field, storage or LNG terminal

0.5 mln m³/hr
Gas Infrastructure is rather cheap (per m3)

- 200 km pipeline + compression: € 500 mln
  - Dependent on size, geography, population density, river & road crossings, permitting requirements, access possibilities, construction market, steel prices, etc....

- The energy capacity of pipelines is huge
  - Typical 2 mln m3/hr (= 20 GW ≈ 20 power stations)

- Hence, although capital intensive, transport costs per m3 of gas are low
  - “1% of gas price per 100 km”
Typical investment process takes 5-7 yrs
In gas infrastructure, scale matters!

For 100 km @ 80% utilization. The current gas price is 25 €ct/m3

Gas Transportation costs are 10-20x less than Power Transmission costs

The Netherlands ⇔ United Kingdom

**Power-Britned**
260 km & € 600 mln

1 GW

230 € per kW/100 km

**Gas – BBL**
230 km & € 500 mln

20 GW

11 € per kW/100 km

10 power transmission lines are equal to 1 gas pipeline
Gas demand is rather unpredictable
thus: gas infrastructure is very flexible

Maxuurcapaciteit gasafzet Amsterdam (meetpunt 301257)

Effective Temperature
(including wind factor)
Energy Storages: be aware about the log-scales!!

Storage capacity of different storage types

1 kWh  10 kWh  100 kWh  1 MWh  10 MWh  100 MWh  1 GWh  10 GWh  100 GWh  1 TWh  10 TWh  100 TWh

Discharge time [h]

1 h  1 d  1 m  1 a

CAES Compressed air energy storage
PHS Pumped hydro storage
SNG Substitute natural gas
Large scale storage of electricity for seasonal purposes is (incredibly) expensive

- Car Battery: 1 kWh
- Norg Storage: 5 BCM (50.000.000.000 kWh)

**Investments**

- Costs of E-storage: car battery: € 100,- per kWh
- Costs of Gas-storage: “Norg” : € 00,10 per kWh (factor 1000!)

- A household in NL needs about 5000 kWh for a cold winter
Gas STORAGE IN UNDERGROUND SALT CAVERNS

- **Opening phase 1:** 27 January 2011 (4 caverns)
- **Completion phase 2:** 1 January 2014 (1 cavern)
- **Tubings per cavern:** 2
- **Working gas volume:** approx. 200 million m$^3$

(2014: approx. 300 million m$^3$)
- **Total withdrawal capacity:** 1.6 million m$^3$/h
- **Total injection capacity:** 0.8 million m$^3$/h
Gas Flexibility Options
The choice is a matter of economic optimization

<table>
<thead>
<tr>
<th>Flexibility Instrument</th>
<th>Annual</th>
<th>Seasonal</th>
<th>Weekly</th>
<th>Daily</th>
<th>Hourly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long distance production flexibility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Short distance production flexibility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Underground storage (fields &amp; aquifers)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Underground storage (caverns)</td>
<td>No</td>
<td>No(^a)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Interruptible contracts</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LNG storage (peak shaving)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Small scale local compressed gas</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Line pack</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: The European Market for Seasonal Storage; Clingendael, 2006
Gas has to be found (somewhere)

Electricity can be created (locally)

Gas is primary energy, Electricity is a mainly energy carrier ...

- Exceptions are solar-PV and wind

Main European gas producers:

- Netherlands, Norway, Algeria, Russia, UK, Qatar, ...

Gas has to be transported (and traded) internationally

For electricity, European countries are (almost) self supporting
Development of the European Gas Network: it started in The Netherlands ...

Most European gas pipelines are owned by private companies

Third Party Access and Regulation

Gas market was liberalized in 1995-2005
Gas in The Netherlands

Netherlands is a large gas producer

= natural gas fields

Groningen field (1959):
  Initial 3,000 billion m³ (GIIP)
  today: 800 billion m³

Approx. 100 other gas fields

Current production:
  Groningen: 40 BCM
  Other Gas Fields: 25 BCM
Natural gas production in Europe ≈300 BCM (50% of consumption)

- Gas production in UK, Denmark and Netherlands in decline
- More imports will be needed
- Dependency of Russia

Norway + Netherlands + UK = 80% of total production
New supplies for Europe

Norwegian gas reserves and supply to Europe in 2007
- Reserves: 3 tcm
- Export to Europe: 88 bcm

Russian gas reserves and supply to Europe in 2007
- Reserves: 44.7 tcm
- Export to Europe: 156 bcm

Azeri gas reserves and supply to Europe in 2007
- Reserves: 1.3 tcm
- Export to Europe: 6.6 bcm

Iranian gas reserves and supply to Europe in 2007
- Reserves: 27.8 tcm
- Export to Europe: 7 bcm

Libyan gas reserves and supply to Europe in 2007
- Reserves: 1.5 tcm
- Export to Europe: 8 bcm

Algerian gas reserves and supply to Europe in 2007
- Reserves: 4.5 tcm
- Export to Europe: 27 bcm

Sources: GasTerra; OME; BP; Gazprom; CIEP analysis

* The TransMed will be extended to 33.5 bcm/yr in 2008.
** The South Caucasus pipeline could be extended to 16 bcm/yr in 2012.
*** The Greenstream could be extended to 11 bcm/yr.
† Data from 2006; contract is not solid.
†† excluding LNG supply to Europe.
††† Converted to European bcm.
Why LNG

Cooling until -162 °C

Costly alternative for pipelines

- stranded gas fields – distance, politics, commercial, deep seas
- Middle East, Australia, Eastern Siberia, Cyprus, Mozambique, ..

Shipping to Europe, USA or Asia

Regasification in LNG terminals

Huge Scale Advantages

Gate: 12 BCM (>25% of Dutch gas demand)

(“8 million households”)
LNG is booming

Development of LNG terminals

- **EXISTING**
  - 22 LNG Terminals (195 bcm)

- **UNDER CONSTRUCTION / COMMITTED**
  - 7 LNG Terminals (35 bcm)

- **UNDER STUDY / PLANNED**
  - 31 LNG Terminals (>160 bcm)

Source: GLE LNG Map, May 2013


Legend:
- Existing
- Under Construction/Committed
- Planned/Under Study
- Dockside Regas Facility
- Small Scale (existing)
- Small Scale (planned)
Currently, ships use mainly heavy fuel oil; environmental legislation from 2015 onwards
LNG for Transport

Examples
Typology of natural gas resources

Conventional
- High quality reservoirs
- Low quality reservoirs

Unconventional
- Tight gas
- Coalbed methane
- Shale gas
- Gas hydrates

Volume

Higher concentrations
Easier to develop
More permeable

Larger volumes
More advanced technology needed

Sources: Masters (1979); Holditch (2006).

Source: IEA WEO 2009
### Types of Unconventional Gas
with commercial production

<table>
<thead>
<tr>
<th>Tight Gas</th>
<th>Shale Gas</th>
<th>Coalbed Methane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occurs in ‘tight’ sandstone</strong></td>
<td><strong>Natural gas trapped between layers of shale</strong></td>
<td><strong>Natural gas in coal</strong> (organic material converted to methane)</td>
</tr>
<tr>
<td><strong>Low porosity = Little pore space between the rock grains</strong></td>
<td><strong>Low porosity &amp; ultra-low permeability</strong></td>
<td><strong>Permeability low</strong></td>
</tr>
<tr>
<td><strong>Low permeability = gas does not move easily through the rock</strong></td>
<td><strong>Production via triggered fractures</strong></td>
<td><strong>Production via natural fractures (“cleats”) in coal</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Recovery rates low</strong></td>
</tr>
</tbody>
</table>
A guide to fracking:

Hydraulic fracturing is the process of extracting natural gas and oil from shale rock. A liquid mixture is pumped underground at high pressure to crack the rock and release gas or oil.

A pumper truck injects a mixture of sand, water and chemicals down a well and past a bend in the pipe. It is pushed into the shale rock under extreme pressure through holes at the end of the well pipe.

Pressure from the pumped fluid creates fissures that allow the natural gas or oil to escape from the shale and flow into the well.

The gas or oil then rises up the well to the surface, where it is collected.

Recovered gas or oil is stored in tanks, where it is then either pumped directly into a pipeline system or placed in trucks.

Note: Remaining water from the original pumping mixture is stored in a water pit and treated later.

Sources: ProPublica, U.S. Energy Information Administration, American Petroleum Institute, staff research

Shale drilling in the U.S.

Proponents say fracking:
- Increases development and use of domestic energy sources.
- Reduces U.S. dependence on foreign energy supplies.
- Can be used to extract more resources from existing sites, as well as open up new sites.
- Creates jobs in the oil and gas industries.

Critics say fracking:
- Uses excessive amounts of increasingly scarce fresh water.
- Pollutes the water used in the process with dangerous chemicals.
- Can introduce methane and other contaminants to groundwater. (The industry says this risk can be mitigated, but residents near some sites have been able to set fire to their tap water.)

Proefboringen in Polen, Denemarken en UK

Twijfels in Duitsland, Nederand, Frankrijk, ....
Literature

• CIEP: Clingendael International Energy Programme
  – Science
  – Policy makers
  – Industry

• Website: www.clingendaelenergy.com

• Some interesting papers on natural gas:
  – The European Market of Seasonal Storage (2006)
  – Crossing Borders in European Gas Networks (2009)
  – Seasonal Flexibility in the Northwest European Gas Market (2011)
  – Wind & Gas: Back-up or Back-out (2011)
International Gas Business – A case study

• Country A makes a large gas discovery (250 bln m3)
  – Development requires € 20 bln
• Country B needs gas
  – 5-10 bln m3 per year

• Connecting country A with B requires a pipeline of € 5 bln
  – Or a LNG system that costs € 7 bln

• How should we organize this?
• Timing, Gas Price, Finance, Risks, ....

• Examples: Cyprus, Mozambique, Tanzania