WP3-Gas for transport

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27-09-17
# WP3 activities and milestones

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<td>3.3.1 Results of applying modelling framework</td>
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Task 3.1.1 Literature study

• CNG/CRNG/LNG/LRNG infrastructure
• NGVs techno-economic performances in the existing and future markets
• Experts interview to polish the literature-based knowledge
• NGVs development in case study countries, Sweden, Italy, Germany, and Denmark

A state-of-the-art review on the development of CNG/LNG infrastructure and natural gas vehicles (NGVs)

Technical report
FutureGas project – WP3 Gas for transport
WP3 deliverable 3.1.1

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Task 3.1.2 Techno-economic study

- Identifying, on the basis of Task 3.1.1, potential fuel supply pathways for WTW evaluations
- WTW energy and GHGs and air pollutants emission evaluation
- WTT fuel production and conditioning costs
- Vehicle added cost- including sensitivity for price gap and driving distance
- Levelised cost of CNG/CRNG/LNG/LRNG distribution (LCOD) to filling and bunkering ports- including sensitivity for distance
- Social damage cost of air pollutants for each pathway
Selected WTT pathways (1)

• NGVs filling stations classed based on:
  — Filling stations configuration: time fill (T) vs fast fill (F) and mother stations (M)(grid-connected) vs daughter stations (off-grid)(D)

• Bunkering terminals
  — Truck-to-ship
  — Ship-to-ship

• Feedstocks
  — Domestic NG
  — Imported LNG
  — Manure (cattle/pig)
  — Organic municipal waste
### Selected WTT pathways (2)

<table>
<thead>
<tr>
<th>Pathway acronym</th>
<th>Final fuel</th>
<th>Pathway description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRA</td>
<td>CNG</td>
<td>Danish NG mix, distributed through transmission and distribution pipes to grid-connected households/industries. The home-filling facility, called vehicle refuelling appliance (VRA), is assumed to be supplied with a low-pressure grid (4 bar).</td>
</tr>
<tr>
<td>CNGMF, CNGMT</td>
<td>CNG</td>
<td>Danish NG mix, distributed through transmission and distribution pipes to grid-connected filling stations. The station could be either a fast-fill (CNGMF) or time-fill (CNGMT) station connected with a low-pressure grid.</td>
</tr>
<tr>
<td>CNGD</td>
<td>CNG</td>
<td>The same process description as CNGMF pathway, but it represents daughter stations. CNG supplied to the station is assumed to be filled at mother station and transported with truck/CNG trailer.</td>
</tr>
<tr>
<td>LNG</td>
<td>LNG</td>
<td>Remote LNG production, LNG sea transport to north-western Europe import terminals, distribution by truck/LNG trailer to skid-based LNG filling stations.</td>
</tr>
<tr>
<td>L-CNG</td>
<td>CNG/LNG</td>
<td>The same as LNG but at filling stations both LNG and CNG are available. Also, includes LNG vaporisation/compression to CNG at skid-based L-CNG.</td>
</tr>
<tr>
<td>LNG-STS</td>
<td>LNG</td>
<td>Remote LNG production, LNG sea transport to north western Europe import terminals, distributed by LNG bunkering vessel to bunkering facility at ports (storage tank); ship-to-storage (STS).</td>
</tr>
<tr>
<td>LNG-TTS</td>
<td>LNG</td>
<td>The same process description as LNG-STS, but LNG assumed to be distributed by truck/LNG trailer to bunkering facility at ports (storage tank); truck-to-storage (TTS).</td>
</tr>
<tr>
<td>CRNGD-manure, CRNGD-waste</td>
<td>CRNG</td>
<td>Raw biogas production from manure (CRNGD-manure) and municipal organic waste (CRNGD-waste), upgrading and compression to 200 bar, and truck/CNG trailer distribution to fast-fill CNG filling station.</td>
</tr>
<tr>
<td>CRNGP-manure, CRNGP-waste</td>
<td>CRNG</td>
<td>The same process description as (CRNGD-manure) and municipal organic waste (CRNGD-waste), but the gas is directly injected into the low-pressure grid (4 bar) through plastic pipes.</td>
</tr>
<tr>
<td>LRNG-waste</td>
<td>LRNG</td>
<td>Raw biogas production from waste, upgrading, liquefaction, and local distribution by truck/LNG trailer to LNG filling stations.</td>
</tr>
<tr>
<td>LRNG-manure</td>
<td>LRNG</td>
<td>Raw biogas production from manure, upgrading, liquefaction, and local distribution by truck/LNG trailer to LNG filling stations.</td>
</tr>
</tbody>
</table>
Selected TTW pathways

- Passenger car and LDV segments
  - PISI-gasoline, DICI-diesel
  - PISI-100% CNG, bi-fuel (two separate fuel systems, gasoline and CNG. Also, two fuel tanks, gasoline & CNG).
- HDV and passenger vessel segments
  - DICI-diesel
  - PIDF-40-60% diesel substitution is possible (diesel and CNG/LNG mixed at the injection port)
  - HPDI-90-95% diesel substitution is possible (high pressure LNG directly injected into the cylinder head)
  - PISI-100% diesel substitution or CNG/LNG dedicated (works on spark ignited engine or Otto cycle)
- Cycle thermal efficiency: 35% for PISI, 43% for DICI, PIDF, and HPDI engines
Meta-analysis on prior WTT evaluations

• Based on the assessment, special attention has been given to the assumptions involving the following activities:

  — Amount of flared NG at gas fields.
  — Assumed methane leakage and slip.
  — Long-range transportation distance: shipping, pipeline or truck/trailer.
  — Type of process energy (electricity/thermal) and auxiliary energy sources (renewable/fossil).
  — Process plant’s conversion efficiency (gas yield) and marginal substitutes of by-products (credit for digestate).
Methodology

• WTW energy and emissions evaluation

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\[
WTW [g CO_2 eq / km] = WTT [g CO_2 eq / MJ_{final/fuel}] - Credits [g CO_2 eq / MJ_{final/fuel}] * TTW [MJ_{final/fuel} / km] + TTW [g CO_2 eq / km] \quad (2)
\]

\[
WTW [kg_{CO,HC,N0x,PM} / km] = WTT [kg_{t} / MJ_{final/fuel}] * TTW [MJ_{final/fuel} / km] + TTW [kg_{t} / km] \quad (3)
\]

Pathway energy efficiency (%) = \frac{\text{final fuel (MJ)}}{\text{final fuel (MJ)} + \text{final fuel (MJ)} \cdot \text{process energy}_{WTW} (MJ / MJ_{final/fuel})} = \frac{1}{1 + TTW (MJ / MJ_{final/fuel})} \quad (4)
Assumptions-LCOD gas distribution

- Pipeline
  - Distance between nearby grid and filling station
  - Urban/rural share
  - Demand
- CNG swap body/trailer
  - Trip time (round way distance, truck speed, loading and unloading time..)
  - Swap body capacity-3*1500 Nm³
  - Demand
- LNG/LRNG trailer
  - Trip time (round way distance, truck speed, loading and unloading time..)
  - Trailer capacity-60m³
  - Demand
- LNG carrier
  - Carrier capacity-7500m³
  - Number of LNG terminals and vessels served, Carrier’s speed, round-way distance
  - Vessel daily demand
Assumptions- type approved and real-world emissions

- Type approved emission (Euro 6 and Euro VI) for conventional vehicles
- Chassis dynamometer measured data for gas vehicles (Source: Swedish gas center)
- MARPOL Annex VI NOx emission (Tier III, 2 g/kWh) and Sulfur limit (0.1%) for conventional vessels in emission control area (ECA), i.e. 0.5% as of 2020 in open sea.
- Field measurement data in ECA (NOx and CH\textsubscript{4} slip from Norwegian LNG vessels) (source: MARINTEK-Norwegian marine technology research institute)
Assumptions - social damage cost evaluation

- Social damage cost of air pollutants per exposure are externalities derived based on the willingness-to-pay for reducing or avoiding morbidity and the mortality rate
- Urban background (health effect near emission sources) and regional background (covers a relatively large area around emission sources and it has both direct and indirect environmental damage)
- Estimated for a typical Danish city with a total population of 20,000
- For GHGs, we have assumed the abatement cost from the Danish road transport sector to be 153 €/tonne of CO₂ (source: OECD)

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>Cost (€/kg-person)</th>
<th>Cost (€/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Local background</td>
<td>Regional background</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.21</td>
<td>9</td>
</tr>
<tr>
<td>SO₂</td>
<td>1.81</td>
<td>3.05</td>
</tr>
<tr>
<td>PM2.5</td>
<td>61.54</td>
<td>0</td>
</tr>
<tr>
<td>VOC</td>
<td>0.36</td>
<td>4.52</td>
</tr>
</tbody>
</table>

Source: SIKA - Swedish Institute for Transport and Communications Analysis
Main results (1)

- WTT energy and emissions evaluation

- Compared to gasoline, CNG pathways, on average, showed 50% lower energy and 79-81% lower GHG emissions, mainly due to the long-range crude oil transportation.

- CRNG-manure was found to be less energy intensive and more GHGs impact-avoiding than CRNG-waste due to better digestate quality and increased fertiliser substitution.
**Main results (2)**

- **WTW energy and GHG emissions-road transport**

- Compared to PISI-gasoline, PISI gas engines showed a 26%, 99%, and 195% GHG emissions reduction for passenger car and LDV segments (in the order of the Figure).

- In terms of energy, CNG pathways showed a 3% reduction while the CRNG pathways showed an increment of 108% and 62% for CRNG-waste and CRNG-manure, respectively.

- Compared to the DICl diesel engine, PISI: CNGMF showed a reduced 18% GHGs benefit, but again increased by 6% in PIDF: CNGMF; this is because the methane slip of the PIDF engine offsets the reduced CO₂ emission.
Main results (3)

- WTW energy and GHG emission-passenger vessel

- Compared to LS-HFO, on average, LNG-STS pathways showed a 14-36% reduction while LNG-TTS showed a 13-35% reduction; the effect is more pronounced in LRNG-manure, 110-172%.

- On average, in PISI gas engines, a 1%, 2.5%, and 5% methane slip results in 8%, 21%, and 43% increase in net GHG emissions, respectively.
Results (4)

- Breakeven vehicle added cost of passenger car & LDV; PISI-gasoline/DICI-diesel Vs bi-fuel CNG/gasoline

$1 \text{ kg CNG} = 1.37 \text{ L diesel}$

$1 \text{ kg CNG} = 1.5 \text{ L gasoline}$

Diesel price gap = $\text{diesel(€/L)} - (\text{CNG(€/kg)}/1.37$

Gasoline price gap = $\text{gasoline(€/L)} - (\text{CNG(€/kg)}/1.5$

For example, as of June 2017, the highest selling gas car in Sweden, the VW 1.4 TGI 110 BlueMotion, has an added cost of 1630 €

Current price gap, 0.33 €/L for gasoline and zero for diesel

Negative break-even added cost indicates a net loss
We assumed CNG to be used only in PISI, and LNG in PIDF and HPDI engines.

On average, the added cost for HD gas vehicles is reported to be between 10,600-16,450 €.

Current diesel price gap, 0.42 €/L for LNG and zero for CNG.
Results (6)

• LCOD of CNG and LNG to filling stations

  • Economies of scale were found to be more important than pipeline length and urban/rural share; doubling the filling capacity reduces the unit cost by 47-50% at the corresponding pipe length.

  • The saturation round-trip distance for the LNG trailer serving four stations was found to be 1,000km, for an even higher demand, one could expect a much shorter distance.
Thank you!