Proceedings of the NGV Global Technical Forum

Held in Conjunction with NGV Global 2014 Conference and Exhibition

Long Beach, California, May 5th 2014

Session 2 of 2

OBJECTIVE

The Technical Forum is open to all NGV Global members. The objective is to explore technical issues in a more detailed and informal forum than normal conference sessions allow. The focus is on critical issues requiring resolution which will help to define technical objectives and priorities for NGV Global to pursue.

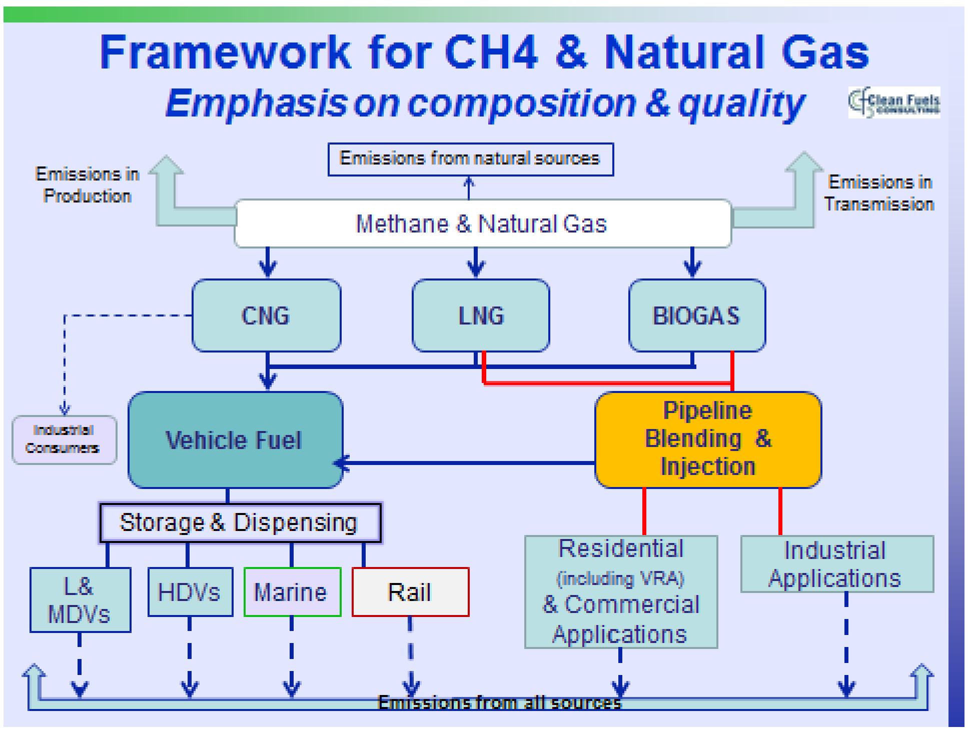
ATTENDANCE

Approximately 60 people participated in the Technical Forum 2014. A partial list of Attendees was captured and is appended to these proceedings.

AGENDA

Item	Description
1. Gas Composition and Quality	• The discussion will identify the separate issues associated with the composition of CNG, and biogas/biomethane, allowing the Technology Forum to consider what actions by NGV Global might be appropriate to add to the debate. (Dr Jeffrey Seisler)

GAS COMPOSITION AND QUALITY



General issues for natural gas composition & quality

- Methane content (level & methodology)
- Wobbe index: in broad terms, heating value at the 'burner tip'*
- Methane number: anti-knock value, i.e. octane (propensity not to self ignite) *(vehicle industry vs gas industry):*
- *The 'number' (lowest level)*
- *The methodology to determine MN*
- Water content
- Contaminants (H_2S, sulphur [incl.odorant])
- *Sulphur: foreseeable issue for gas industry*
- Other stuff: propane, H_2, oil, dust,

*MJ/per M³ (Btu/Scf) divided by the square root of the specific gravity

Other fuel composition issues

- **Biogas** (raw product before upgraded to biomethane)
  - Upgrading to *'pipeline quality'* biomethane
  - Bacteria (?) ('proven' not an issue)
  - Siloxanes, especially from landfill gas (detecting, measuring, and extricating)
- **LNG**
  - Ethane, especially over time in storage facilities (*weathering*)
  - Lack of odorant
  - Temperature/pressure (throughout vertically integrated transport-storage-end use)

Requirements (and potential) for gas composition is very different for different stakeholders

- Energy distribution companies
- *'pipeline quality'*
- Retailers of automotive methane fuels
- *No water or oil pass-through (or 'other stuff')*
- Needs of the vehicle manufacturers
- *Consistency, clean & 'high quality'*
- Driving customers
- *Hgas/Lgas = range concerns*

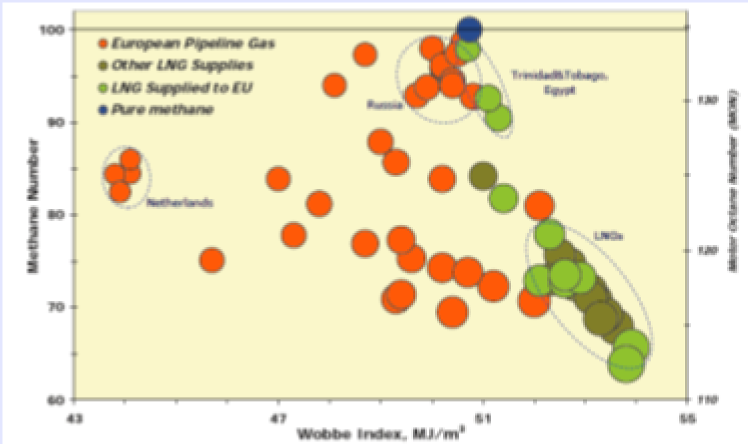
Components in natural gas can have a variety of effects on engines & compressors

Gross WI (MJ/m^3)	Power, fuel injection duration, OBD
Sulfur	Deterioration of exhaust emission treatment device, deposit. Use of odorants have been taken into account.
HC	Liquefaction
Methane Number	Anti-knock property
Water (dew point)	Water condensation under certain conditions of usage.
Lubricant contamination	Function deterioration caused by compressor oil
O_2, H_2, CO	Flammability, hydrogen embrittlement, attack on plastic and rubber, health effect
CO_2	Liquefaction, attack on plastic and rubber, lowered WI
Metal, Particulate Contaminants	Malfunction caused by metallic and particulate contaminant

Source: Masato Matsuki (Honda R&D Co.),'Study on Required CNG Qualities as an Automotive Fuel, as presented at ANGVA Conference, 28 November 2013

Engines using LNG sourced gas can rely on higher Wobbe # than from pipelines

Size of the bubbles expresses the variations in Gross Calorific Value [GCV]



Source: LNG for Europe: Some important considerations, Joint Research Center, European Commission, 2009.

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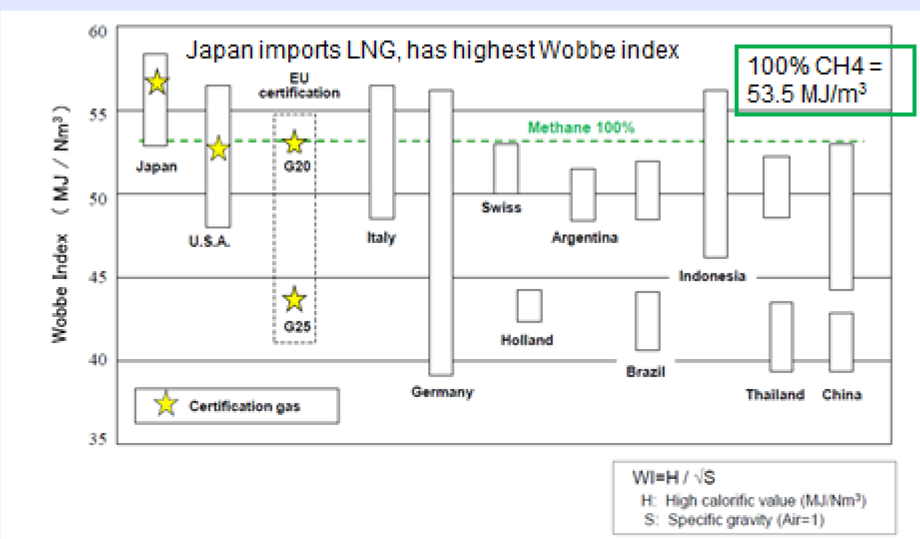
Wobbe index (i.e. energy value) will affect combustion & engine power.



Source: Masato Matsuki (Honda R&D Co.),'Study on Required CNG Qualities as an Automotive Fuel, as presented at ANGVA Conference, 28 November 2013

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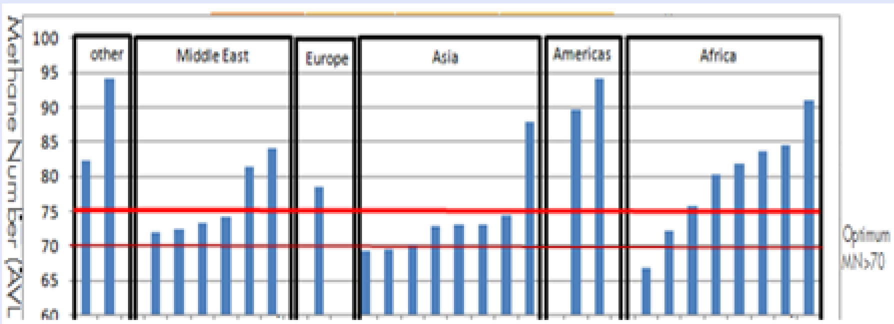
Methane Number of gas worldwide should be sufficient to meet the demands of regional NGVs: Americas are high



Source: *Gas Quality: Leadership as a Driver for LNG in Transport Markets*, Stuart McDonald, Shell International, as presented at Clean Fuels Consulting Poli-techs workshop, 27 March 2013, Brussels.

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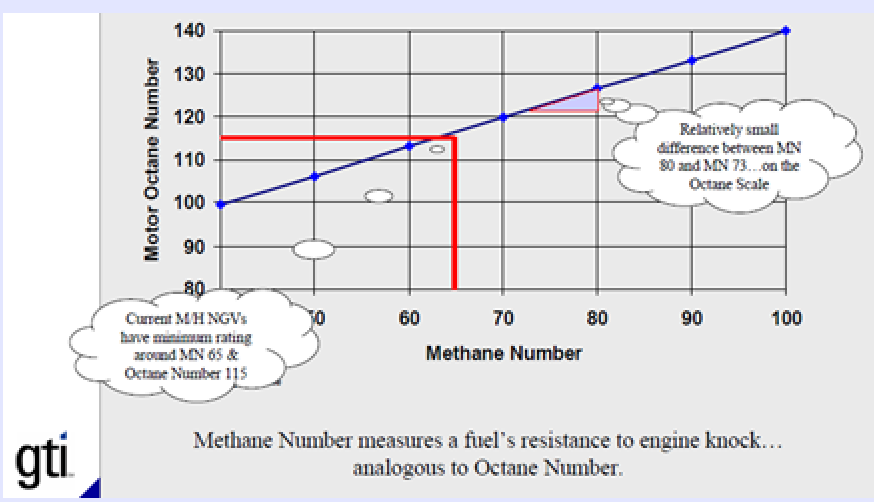
Natural gas has excellent knock resistance



Source: Bill Liss, Natural Gas Composition for NGVs, Gas Technology Institute.

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Samples of natural gas specifications show different requirements and realities in different world regions

① USA EPA (Federal)

Item		ASTM test method No.	Value
Methane	min. mole pct.	D1945	89.0
Ethane	max. mole pct.	D1945	4.5
C_3 and higher	max. mole pct.	D1945	2.3
C_6 and higher	max. mole pct.	D1945	0.2
Oxygen	max. mole pct.	D1945	0.6
Inert gases:			
Sum of CO_2 and N_2.	max. mole pct.	D1945	4.0
Odorant [1]			

② USA CARB

Specification	Limit
Compressed Natural Gas Certification Test Fuel	
Methane	90.0 ± 1.0 mole percent
Ethane	4.0 ± 0.5 mole percent
C_3 and higher hydrocarbon content	2.0 ± 0.3 mole percent
Oxygen	0.5 mole percent maximum
Inert gases (CO_2 + N_2)	3.5 ± 0.5 vol. percent

③ Japan

Methane	(% mole)	85.0 over
Ethane	(% mole)	10.0 under
Propane	(% mole)	6.0 under
Butane	(% mole)	4.0 under
C_3 + C_4	(% mole)	8.0 under
C_5 upper	(% mole)	0.1 under
Others	(% mole)	1.0 under
High heating value	(Kcal/Nm³)	10410～11050
Wobbe Index	(Kcal/Nm³)	13260～13730
Sulfur	(mg/m³)	10.0 under

④ Europe ※1 CH4 cert fuel = 86-100%

Characteristics	Units	Basis	Limits minimum	Limits maximum
Reference fuel G20				
Composition:				
Methane	% mole	100	99	100
Balance (1)	% mole	—	—	1
N_2	% mole			
Sulphur content	mg/m³ (2)	—	—	10
Wobbe Index (net) ※2	MJ/m³ (3)	48.2	47.2	49.2

※1 G20 and G25(Methane86%, Nitrogen14%)

※2 Wobbe Index is calculated using low calorific value

Source: Masato Matsuki (Honda R&D Co.),'Study on Required CNG Qualities as an Automotive Fuel, as presented at ANGVA Conference, 28 November 2013

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Natural Gas Composition LNG main components

Component	Formula	MW (kg/kmol)	NBP (°C)	NFP (°C)
Nitrogen	N_2	28.013	- 195.5	- 209.9
Methane	CH_4	16.043	- 161.6	-182.5
Ethane	C_2H_6	30.07	-88.6	-183.3
Propane	C_3H_8	44.097	-42.0	-187.7
nButane	nC_4H_{10}	58.124	-0.5	-138.4
iButane	iC_4H_{10}	58.124	-11.8	-159.6
nPentane	C_5H_{12}	72.151	36.06	-129.8

One mol is defined as $6.022 \cdot 10^{23}$ atoms/molecules of a substance
The volume of one mol is 23.644 liters at standard conditions (15°C, 1 atm.)

MW=Molecular weight
NBP=Normal Boiling Point
NFP= Normal Freezing Point

Source: Statoil

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LNG compositions vary depending on it source

Properties at bubblepoint at normal pressure		LNG Example 1	LNG Example 2	LNG Example 3
Molar content (%)				
N_2	Nitrogen	0,5	1,79	0,36
CH_4	Methane	97,5	93,9	87,20
C_2H_6	Dimethyl Ether (Ethanol)	1,8	3,26	8,61
C_3H_8	Propane	0,2	0,69	2,74
i C_4H_{10}	Iso Butane	—	0,12	0,42
n C_4H_{10}	Butane	—	0,15	0,65
C_5H_{12}	Pentane	—	0,09	0,02
Molecular weight (kg/kmol)		16,41	17,07	18,52
Bubble point temperature (°C)		– 162,6	– 165,3	– 161,3
Density (kg/m^3)		431,6	448,8	468,7
Volume of gas measured at 0 °C and 101 325 Pa/volume of liquid (m^3/m^3)		590	590	568
Volume of gas measured at 0 °C and 101 325 Pa/mass of liquid (m^3/10^3 kg)		1 367	1 314	1 211

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Fuel Composition 'Decisions' from CEN TC 408* (Bio-&-NG Composition)

- **Methane Number:** discussed 80 for non-grid (i.e. vehicles); (65 for gas into the grid– TC 234)
- **Wobbe Index**: Proposed range from Volvo is 47.2 – 50.3 MJ/Nm3. Issue under discussion.
- **Sulphur limits**: Proposed limit in order to assure proper operation of NGVs should be 10 mg/Nm3 due to poisoning effect on the after-treatment equipment. (Values being discussed within CEN/TC 234 WG 11 for non-odorised and odorised gas).
- **H_2S + COS** (carbonyl sulfide)**:** proposed limit for is 5 mg/Nm3

*CEN TC 408 communication: Expert Group discussion 2013,

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Fuel Composition 'Decisions' from CEN TC 408* (Bio-&-NG Composition)

- **Siloxanes**: CEN TC/408 discussing various preliminary limits:
  - <0,1mg/Nm3 (also *0,06 mgSi/kg) for the vehicle fuel application*
  - *2 mgSi/m3; for pipeline injection*
- **Other contaminants**: filter out the rest of the 'nasties' (1 micron filter for dust; coalescing filters in fuel stream, etc.)

*CEN TC 408 communication: Expert Group discussion, 2013,

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Fuel Composition Lessons *being* learned

(The jury is still out)

- Gas composition should be identified: all applications
- Natural gas fuel composition *standards* must allow for *natural* and regional variations while achieving levels of energy content and combustion characteristics to satisfy the needs of regional gas consuming technologies.
- Regulations on sulfur could cause a re-think of gas odorization (big change for a small market)
- LNG standard challenging: *pipeline quality* needed
- Biomethane (upgraded from biogas) = *pipeline quality*, with potential for high methane content
- Compressor stations (public/private/VRAs) should have gas dryers on inlet side & filters (oil/dirt/metallics) on outlet side

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Which is best?

Reduce fuel variation to enable optimized engines?

or….

Adapt engines to fuel variation?

The answer is: Yes!

- In areas where fuel composition is widely varied, adaptive engine technology would be useful.
- In areas with a relatively stable and high quality gas, engines can be optimized for local conditions (and so long as they are not driving into areas with lower quality gas).

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