



Estimation of gas quality from sound speed measurements

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cmr

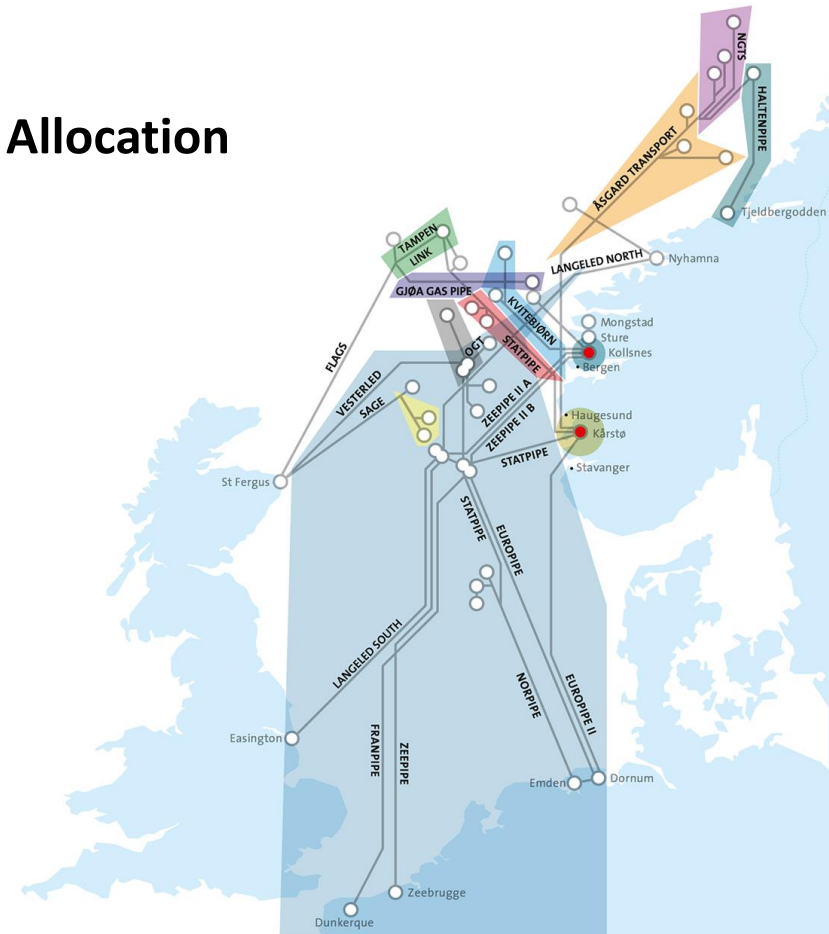
Christian Michelsen Research

Quality of natural gas

- Composition
- Density
- Calorific Value
- Wobbe Index
- Water content
- Hydrogen sulphide content
- Sulphur content
- Oxygen content
- Hydrocarbon Dewpoint
- Cricondenbar pressure
- Cricondenthem temperature
- Methane number (Knock)
- Water Dewpoint
- Incomplete Combustion Factor (ICF)
- Sooting Index
- Relative density
- Carbon number
- ...



Allocation



Calorific Value

- Energy released by combustion, and return to ref. temperature
 - Net (Inferior/Lower)
 - Gross (Superior/Upper)
- Reported per
 - mass unit
 - standard volume unit
 - mole
- Here: Gross Calorific Value (GCV) per kg at reference combustion temperature 25 °C
- $H_{S,m}$



Flow rates

USM
measures
volumetric
flow rate at
line
conditions:

$$q_v$$

Quality
parameters

Mass flow rate:

$$q_m = \rho q_v$$

Energy flow rate:

$$q_e = H_{s,m} \rho q_v$$

Conventional method

1. Measure composition



On-line GC

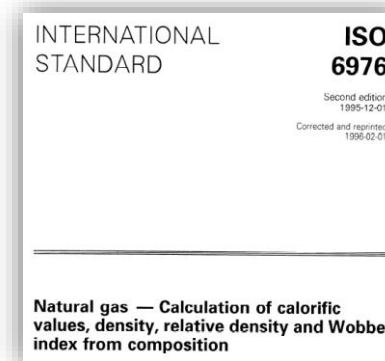
or



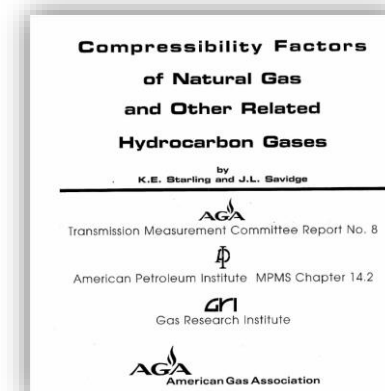
sampling

2. Calculate quality parameters using relevant standards e.g.

ISO 6976



AGA 8



and line pressure and temperature



Alternative methods

- Renewed interest in connection to processing in subsea factories
 - Conventional methods may not be feasible
- Measure physical parameters
 - Exploit correlation to infer gas quality indirectly
- May require additional instrumentation
- Research on the topic since the 90's
 - Gasunie
 - Ruhrgas
 - Instromet
 - Advantica
 - Flow Comp
 - RMG
 - Honeywell
 - CMR

Alternative methods

- Many different approaches, e.g.
 - Speed of sound (SOS)
 - Relative permittivity
 - Infrared absorption
 - Isobaric heat capacity
 - Heat conductivity
 - Dynamic viscosity
 - Density
 - CO₂ and N₂ molar fractions
- Typically a combination of three input parameters

CMR method – from Sound Speed

- Initial version developed from 97
- Presented at NSFMW 05 and 06
- New implementation

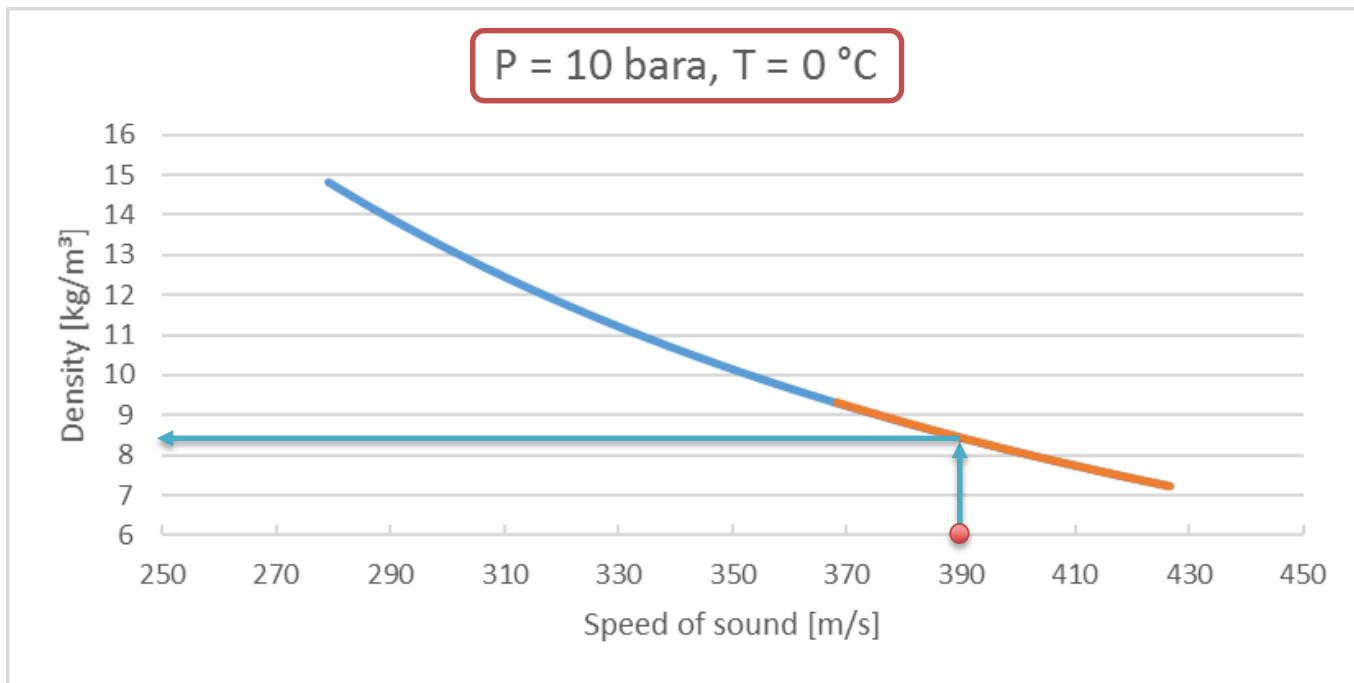
- USM installed, with P and T measurement
 - No additional instrumentation needed

CMR method – from Sound Speed

- Input:
 - Measured speed of sound, pressure and temperature at line conditions
 - Composition assumptions
 - Nitrogen mole fraction known
 - Carbon dioxide mole fraction known
 - Assumes negligible amount of water etc.
 - Typical hydrocarbon distribution
- Calc/Output:
 - Finds «equivalent» composition
 - Calculates gas parameters in accordance with AGA 8, AGA 10 and ISO 6976
 - Here: **Density** and GCV

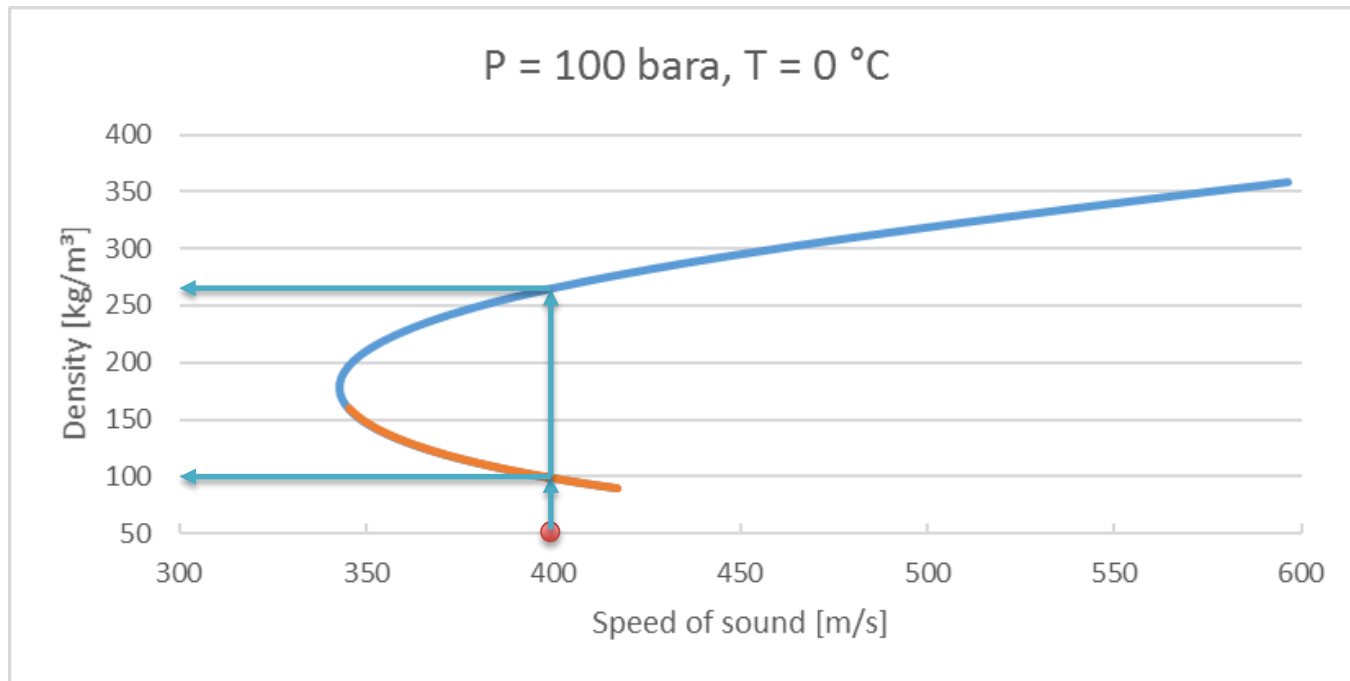
Methodology

- Method exploits the relation between density and speed of sound
- Example:
 - Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
 - Density vs SOS from AGA 8 / AGA 10
 - One sound speed corresponds to one density



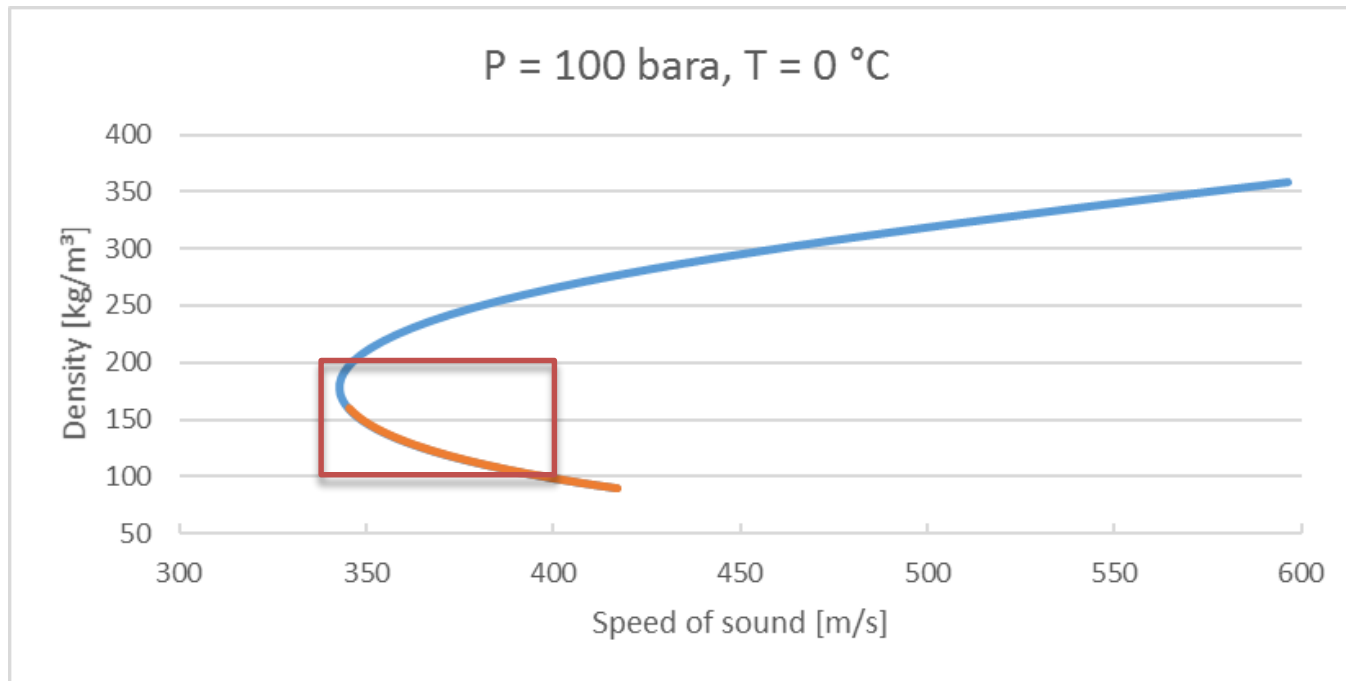
Ambiguity

- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
- Increased pressure and low temperature
- Existence of «turning point»
- One sound speed may correspond to two densities



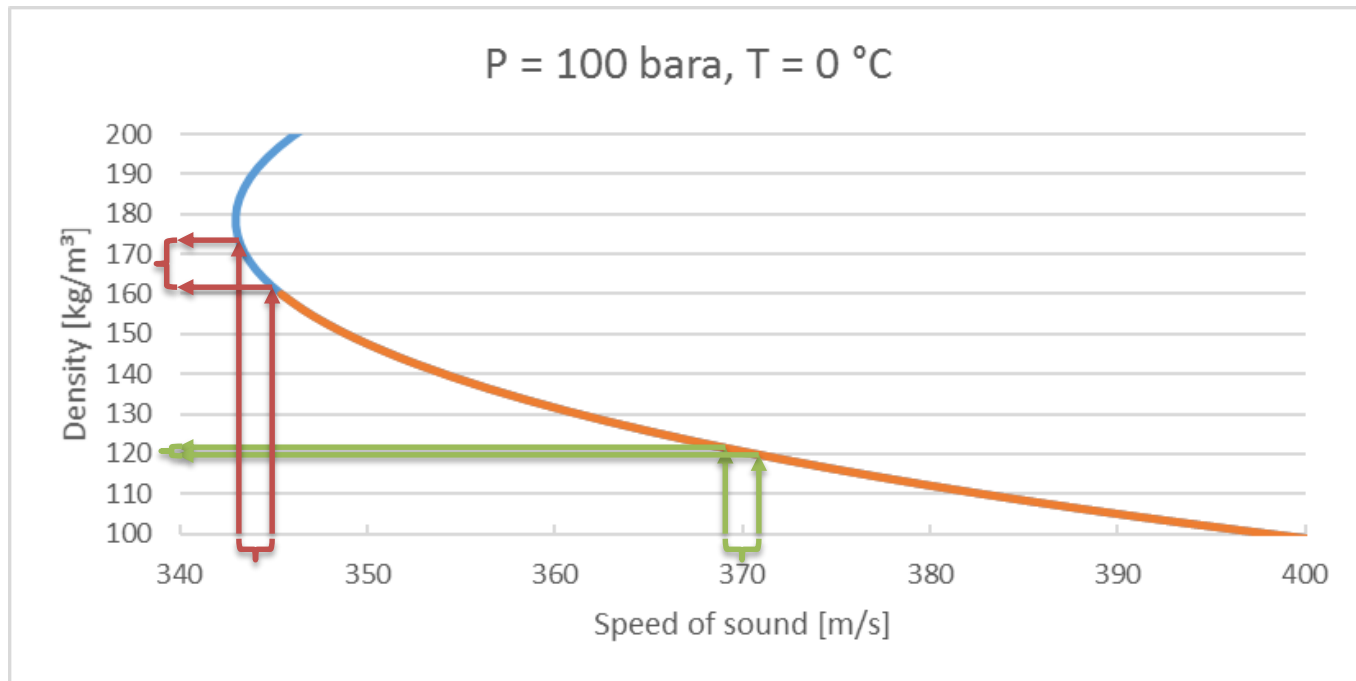
Ambiguity

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Sensitivity

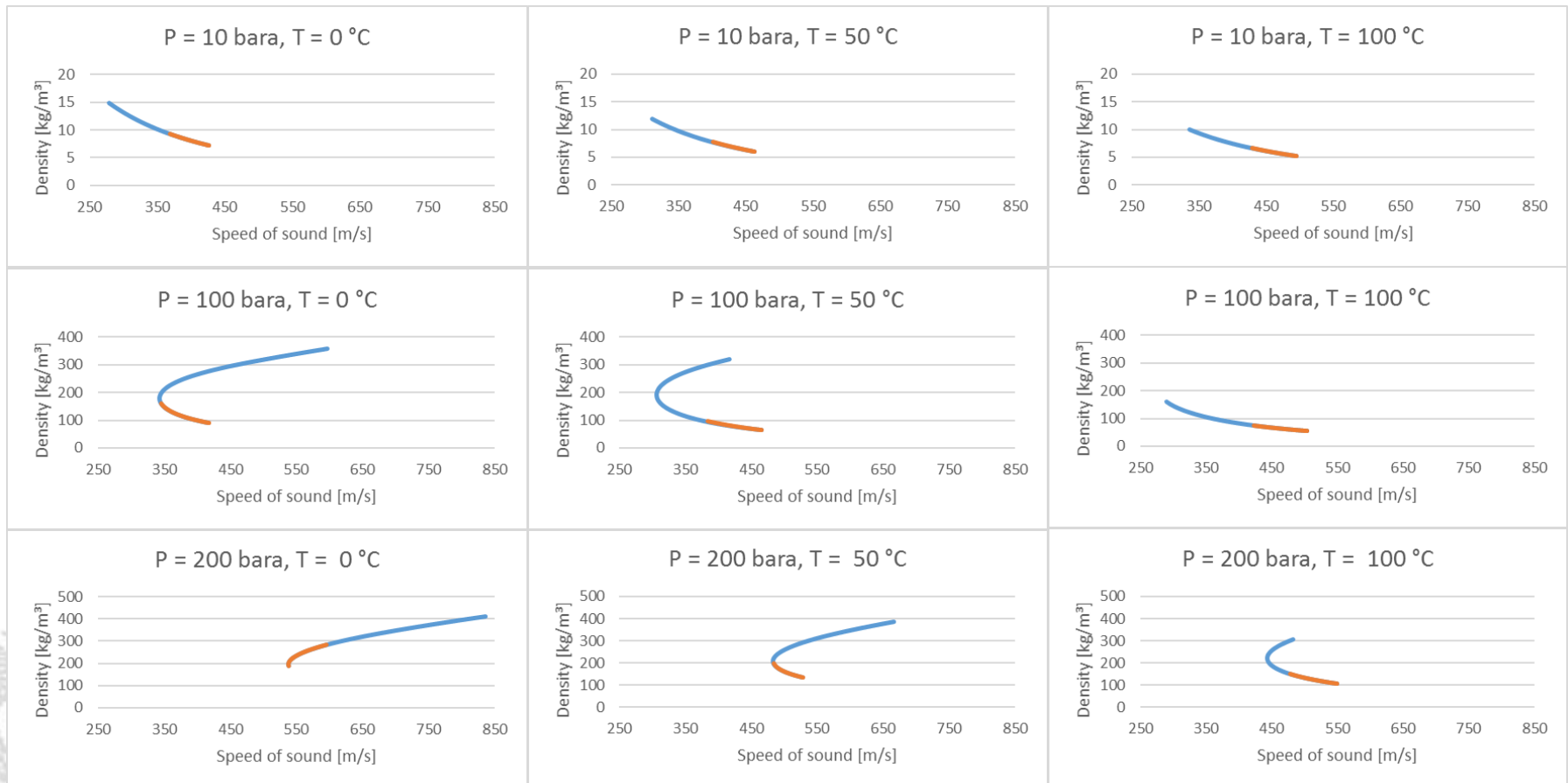
- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
- Sensitivity of sound speed measurement increases near turning point
 - Same ΔSOS gives higher $\Delta\rho$



Pressure and temperature dependence

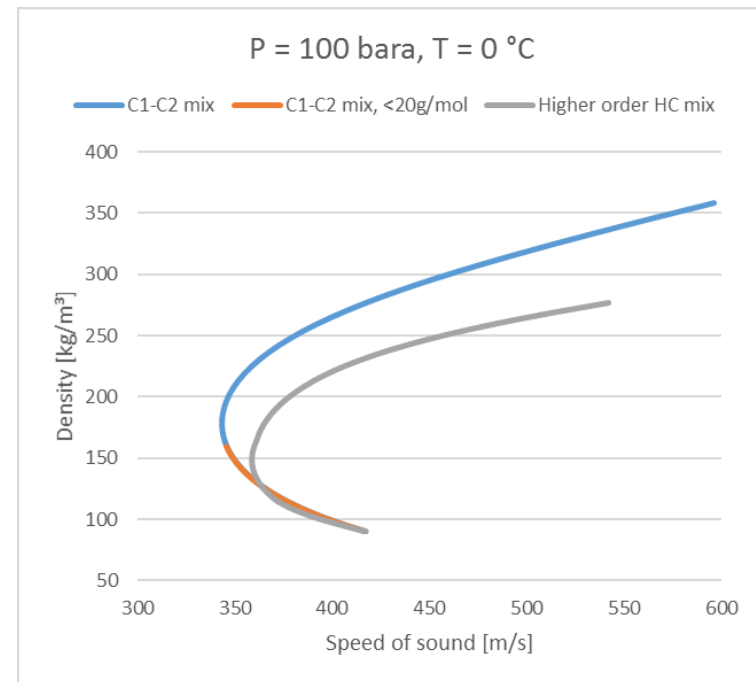
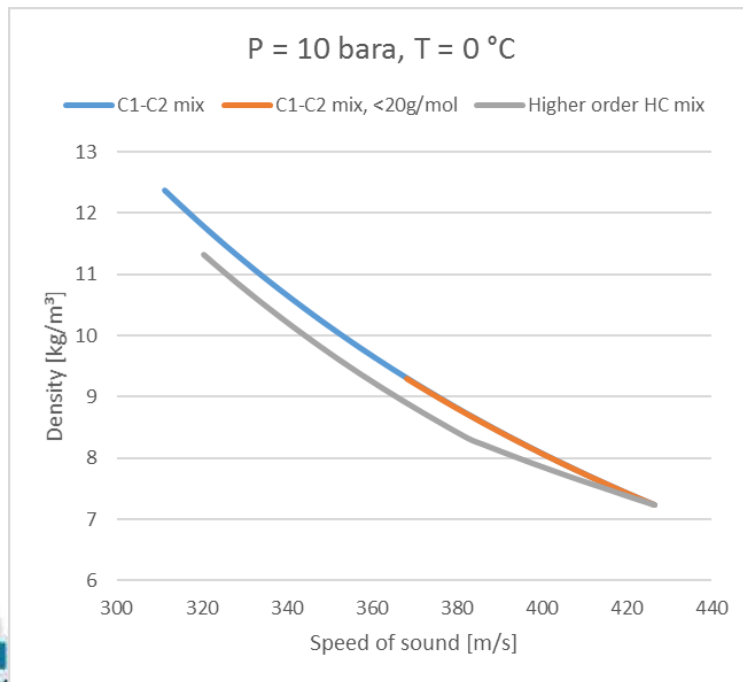
- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
- Change in P and T changes the position of the turning point
 - i.e. the turning point affects different compositions

Temperature →



Heavier hydrocarbons

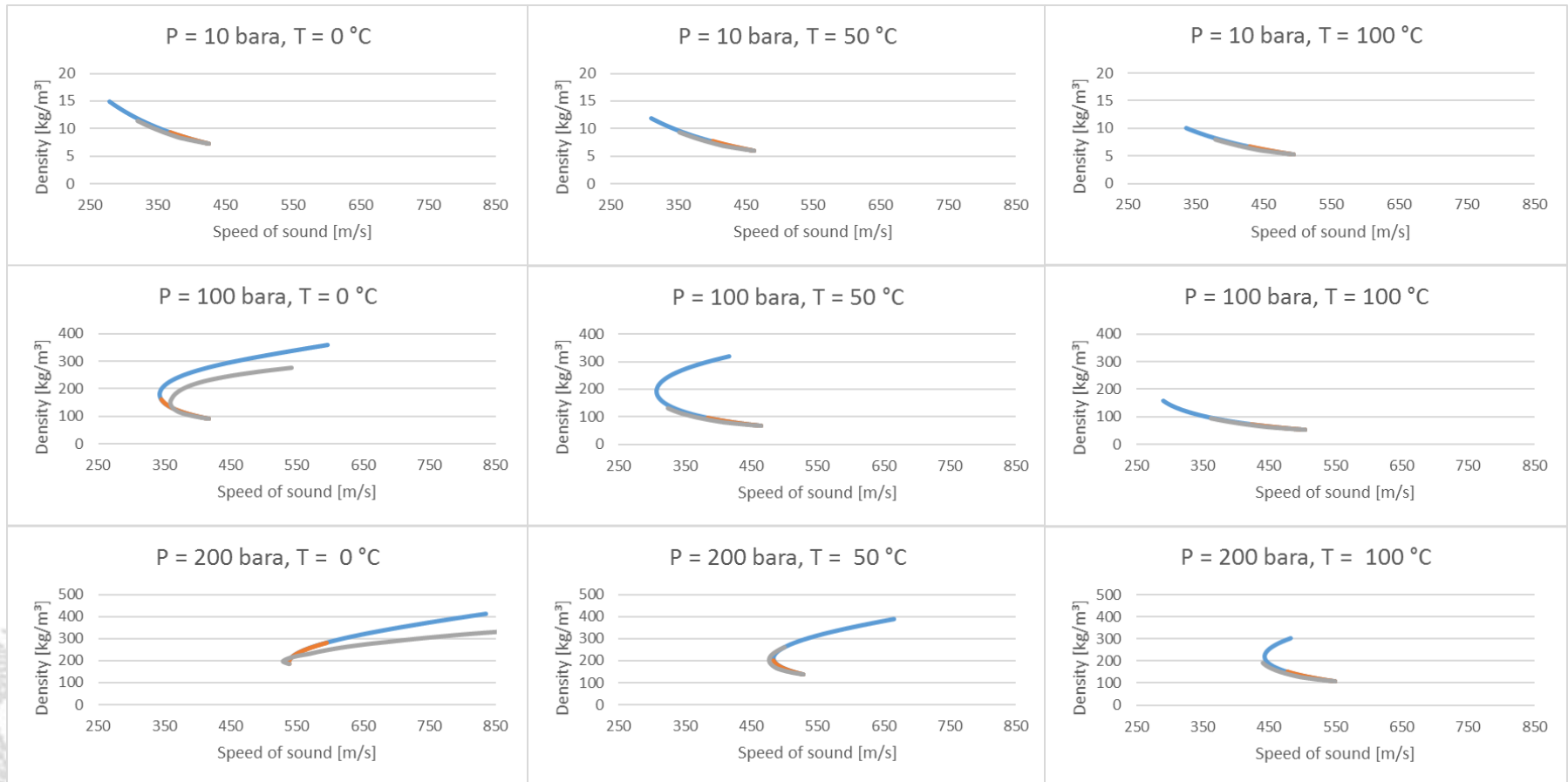
- Until now only considered binary C1-C2 mixture
- Including heavier hydrocarbons creates more ambiguity
- Needs typical composition as input to decrease uncertainty
- Include «worst case» HC mix in plots (C1 and C6, C5, C4, C3)



Pressure and temperature dependence

- Include heavier hydrocarbons
- Largest deviation at low temperatures and high pressures

Temperature →

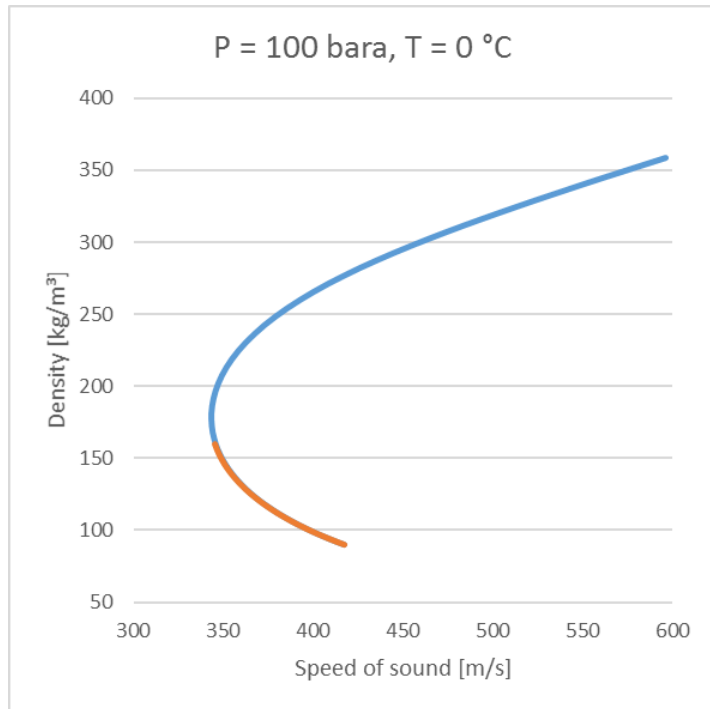


Pressure →

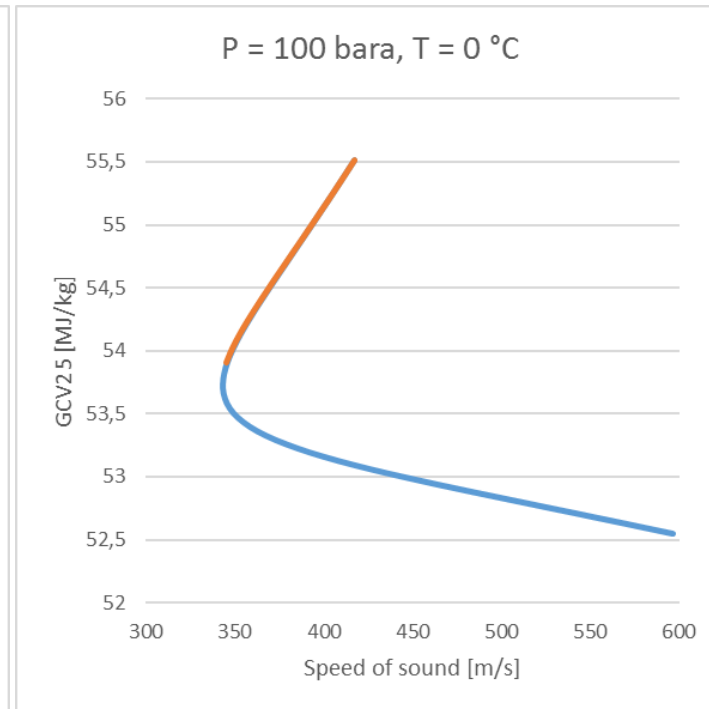
Gross Calorific Value

- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
- Similar behavior for density and GCV
 - but inverted with respect to composition (molar mass)

Density



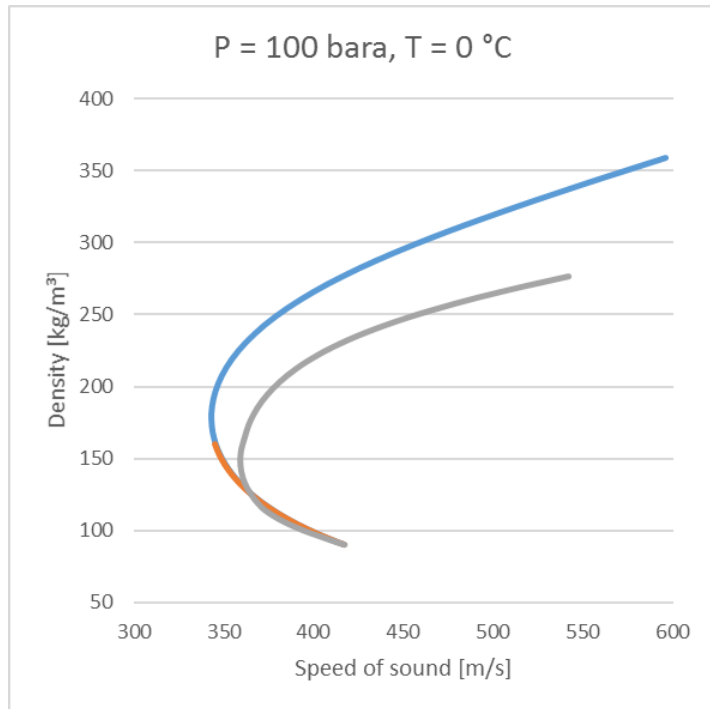
GCV



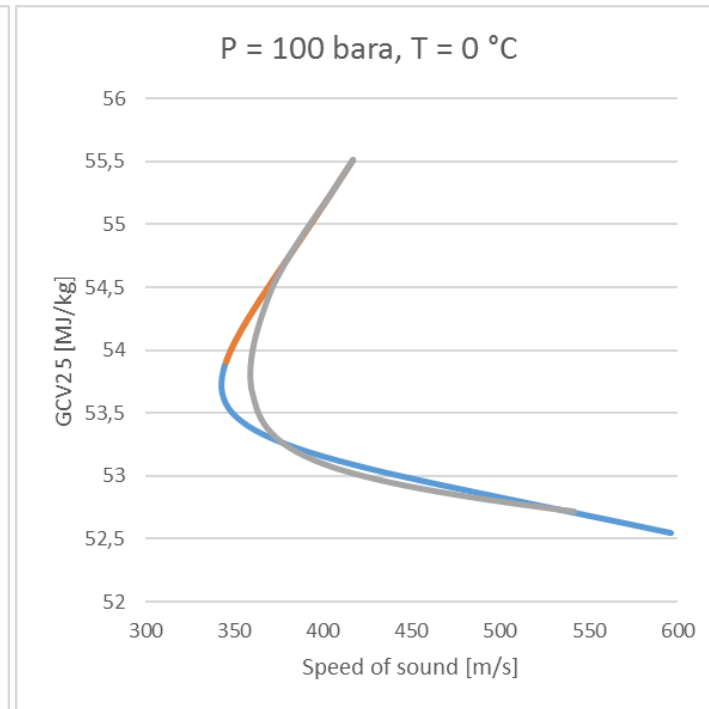
Gross Calorific Value

- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
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Density



GCV



Uncertainty examples

- Uncertainties are calculated for the output parameters
 - Density
 - GCV at 25 °C reference combustion temperature, in MJ/kg
 - Mass flow rate
 - Energy flow rate
- Using input uncertainties and numerical sensitivity coefficients
 - In accordance with ISO GUM
- Example: One gas composition, two PT combinations
 - (Relatively) Bad case
 - Good case

Algorithm input and uncertainties

Example composition: 19.1 g/mol, 412.7 m/s @ 110 bara / 50 degC

Volume flow uncertainty (k=2): 0.5 %

Composition

	Molar fraction	Uncertainty (k=2)
Component	mol%	mol%
C1	86	5
C2	7	1
C3	3	0.5
iC4	0.4	0.1
nC4	0.4	0.1
iC5	0.2	0.1
nC5	0.2	0.1
C6	0.3	0.1
N2	1.5	0.3
CO2	1	0.3

Estimated from comp. variation

P&T

	Uncertainty (k=2)
Pressure	0.3 %
Temperature	0.3 °C

Measurement regulations

Sound Speed

	Uncertainty (k=2)
Speed of Sound	1 m/s

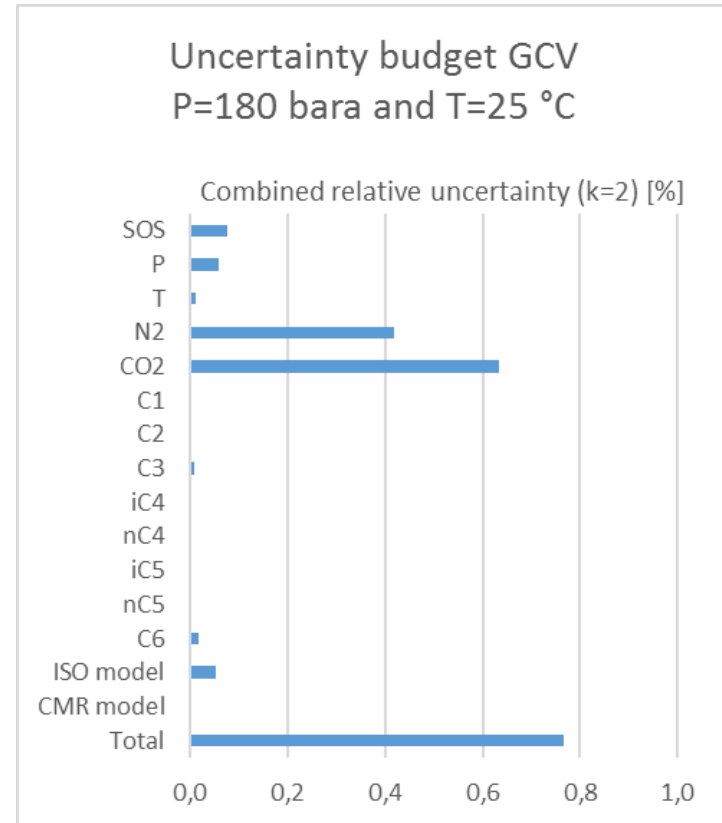
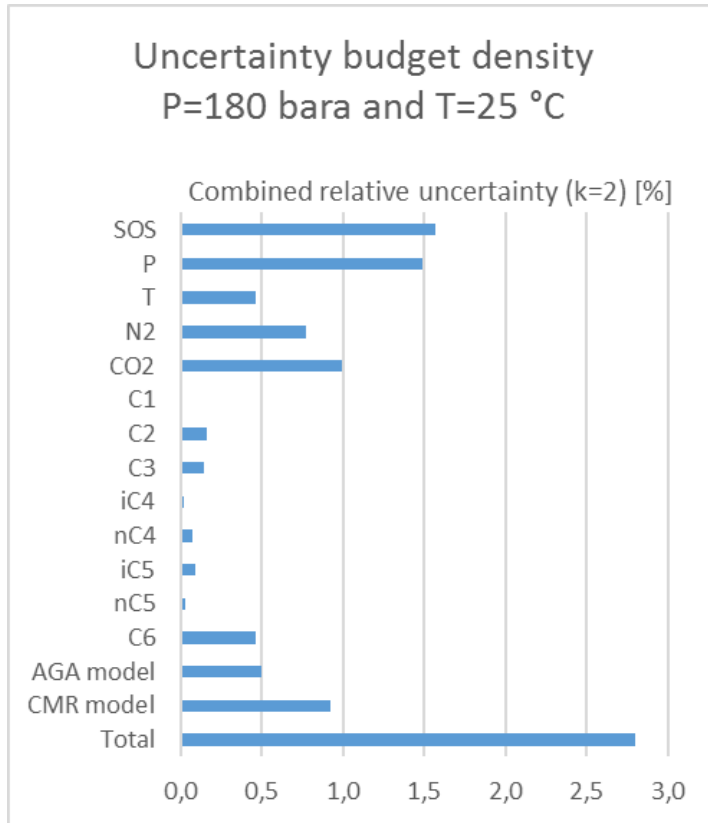
Estimated

Models

	Uncertainty (k=2)
AGA 8/10	0.1 to 0.5 % + ?
ISO 6976	0.052 %
CMR (C6+)	Dynamic

Uncertainty in estimated parameters

Example: Challenging P&T



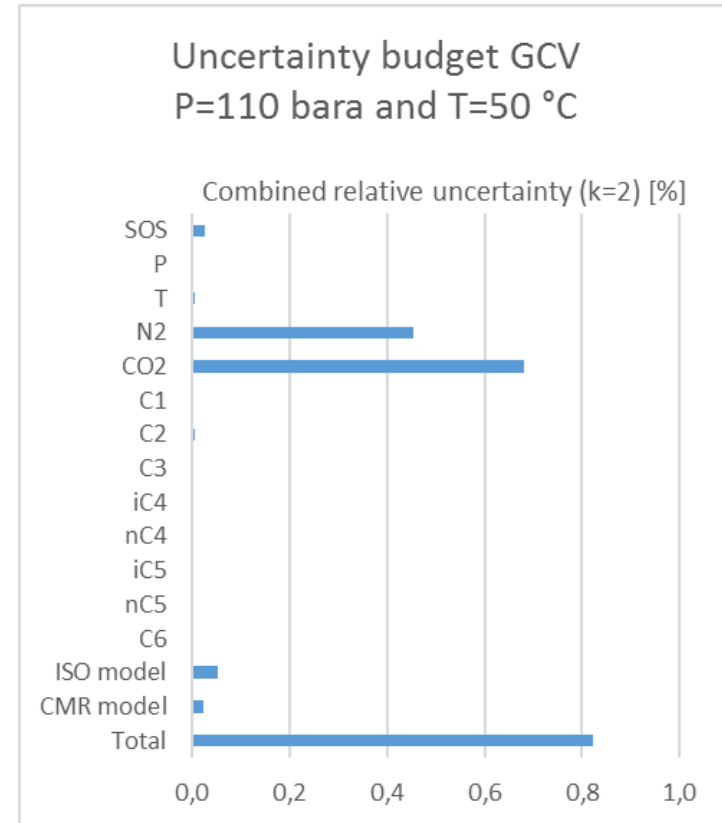
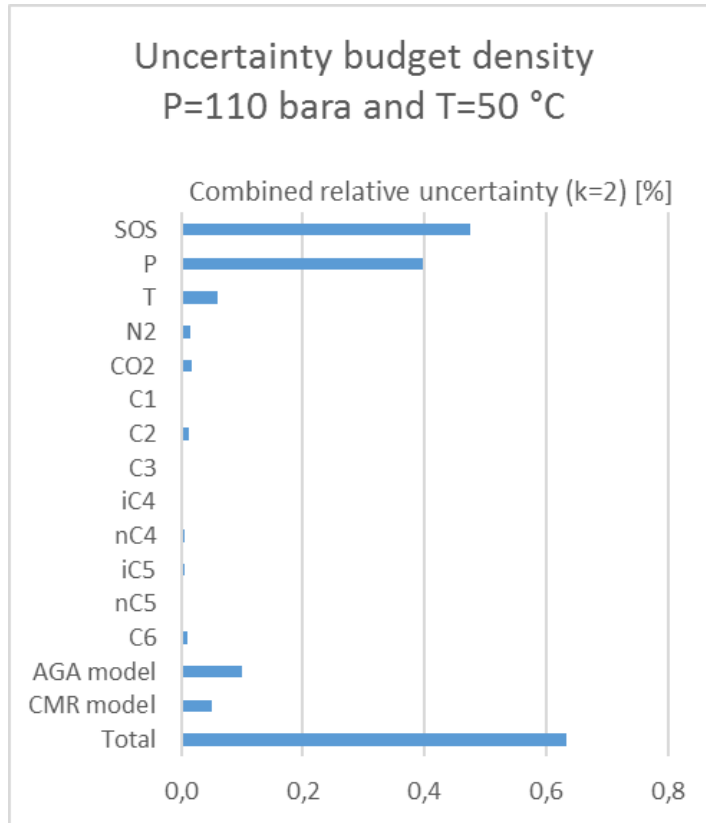
Total expanded uncertainty

Mass flow rate: 2.8 %

Energy flow rate: 3.2 %

Uncertainty in estimated parameters

Example: Favourable P&T



Total expanded uncertainty

Mass flow rate: 0.8 %

Energy flow rate: 1.1 %

Summary

- Uncertainties around 1 % for mass and energy flow rate
 - For certain P, T and composition combinations
 - And given input uncertainties
- Main uncertainty contributors
 - Speed of sound (Density)
 - Pressure (Density)
 - Inert component fractions (GCV)
- Possible improvements
 - Routinely update input composition after sampling (drift)
 - Reservoir/well modelling
 - Traceability in sound speed measurements

Acknowledgements

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Thank you!

Questions?



Christian Michelsen Research