Estimation of gas quality from sound speed measurements

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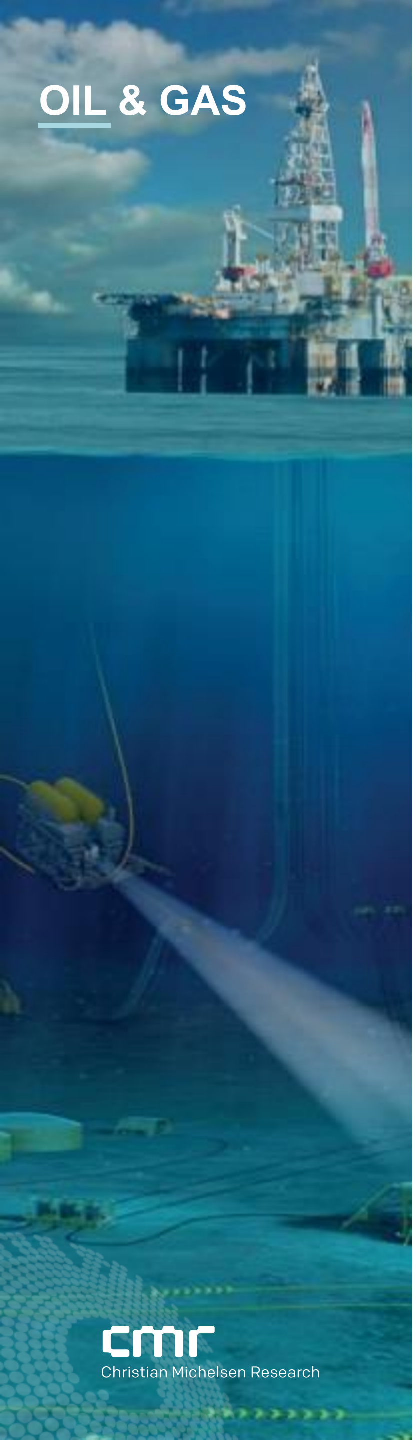
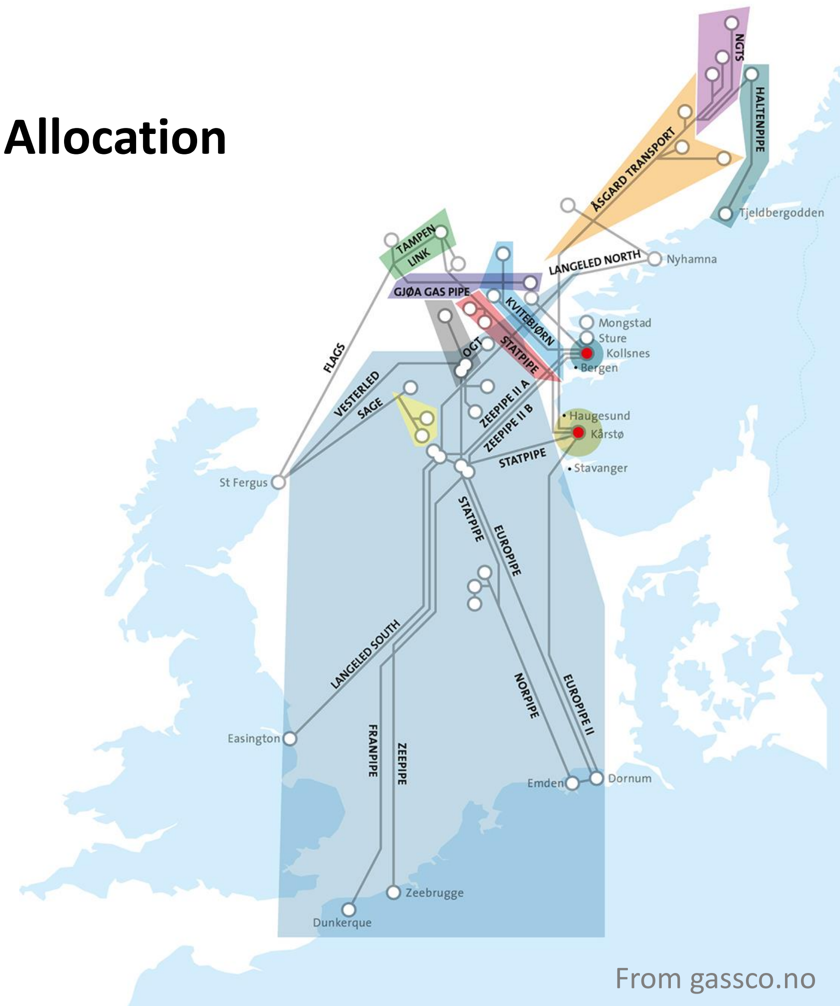


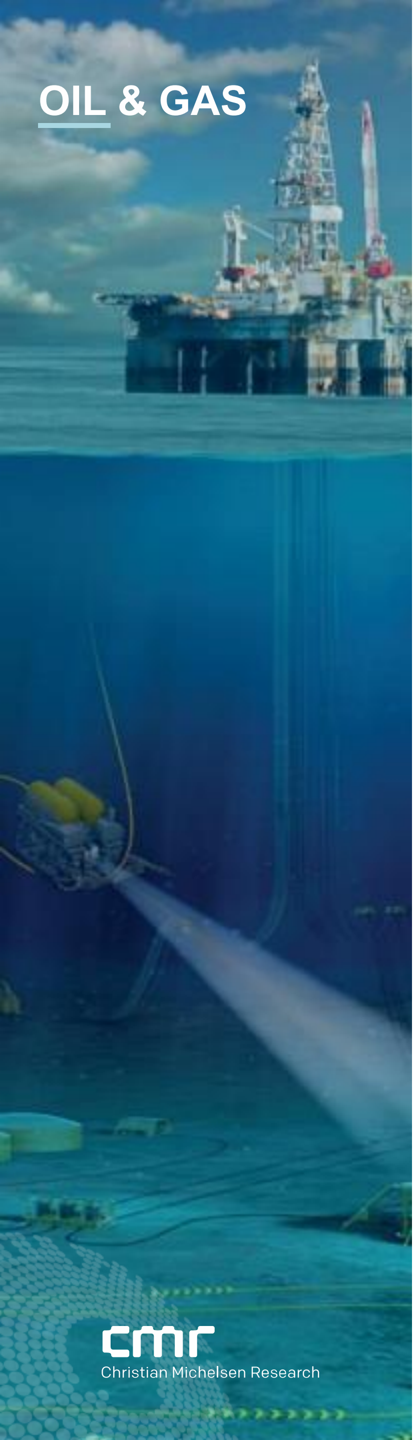
Quality of natural gas

- 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
- …

Density and Calorific Value → **Allocation**



From gassco.no



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

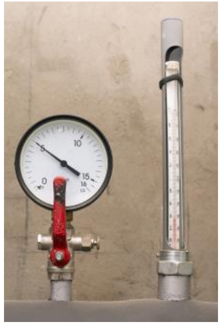
1. Measure composition

Siemens.com

Swagelok.com

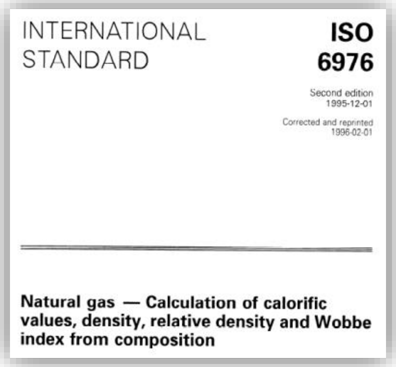
On-line GC or sampling

and line pressure and temperature



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

ISO 6976



INTERNATIONAL STANDARD

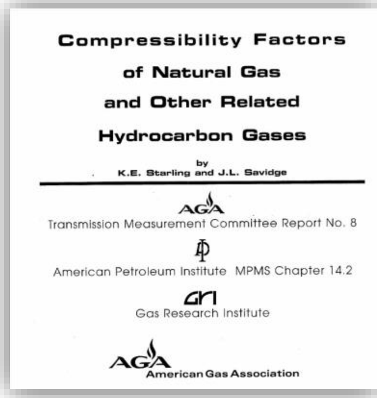
ISO 6976

Second edition 1995-12-01

Corrected and reprinted 1996-02-01

Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition

AGA 8



Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases

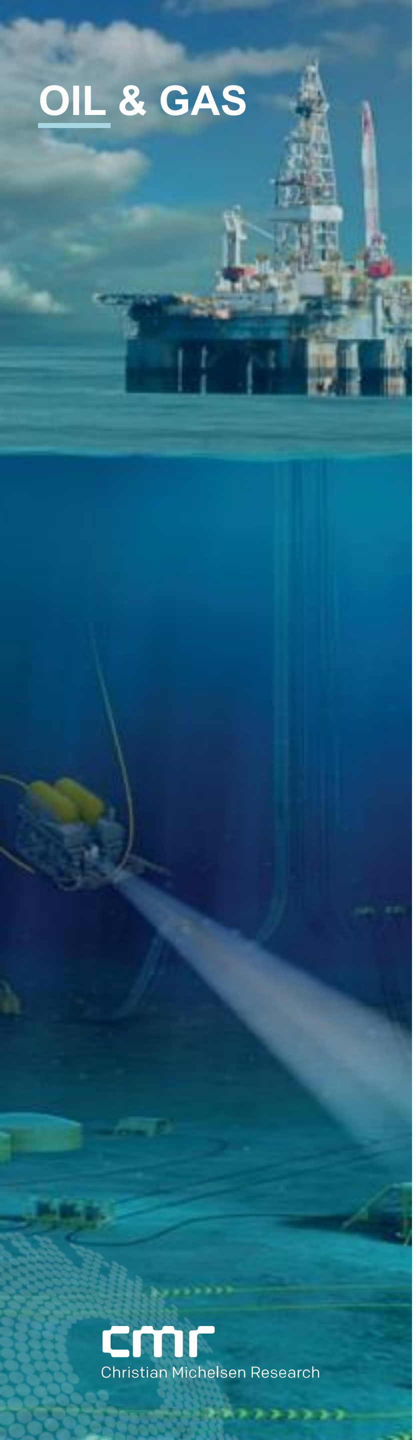
by K.E. Starling and J.L. Savidge

AGA Transmission Measurement Committee Report No. 8

American Petroleum Institute MPMS Chapter 14.2

GRI Gas Research Institute

AGA American Gas Association

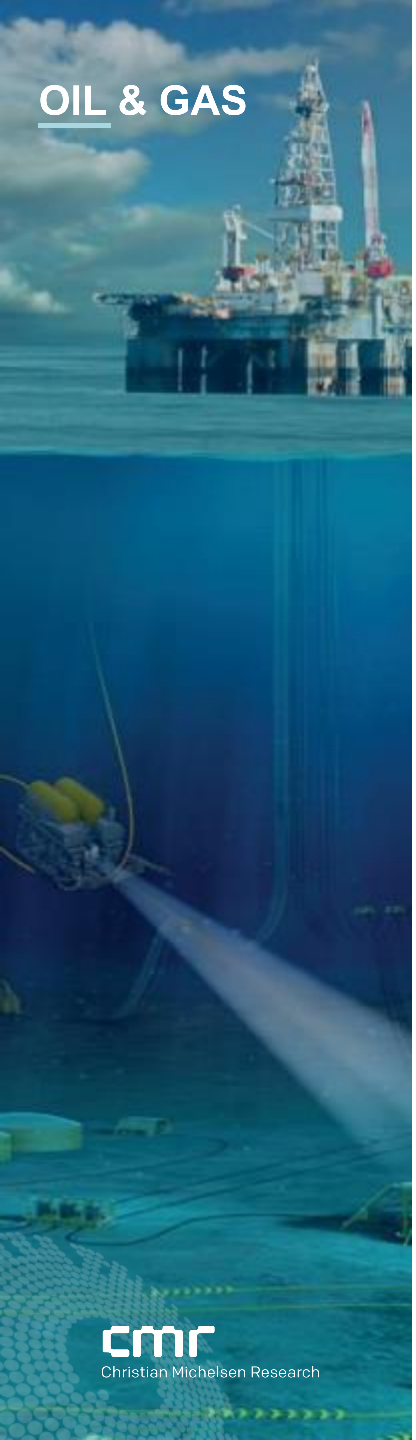


Alternative methods

- 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

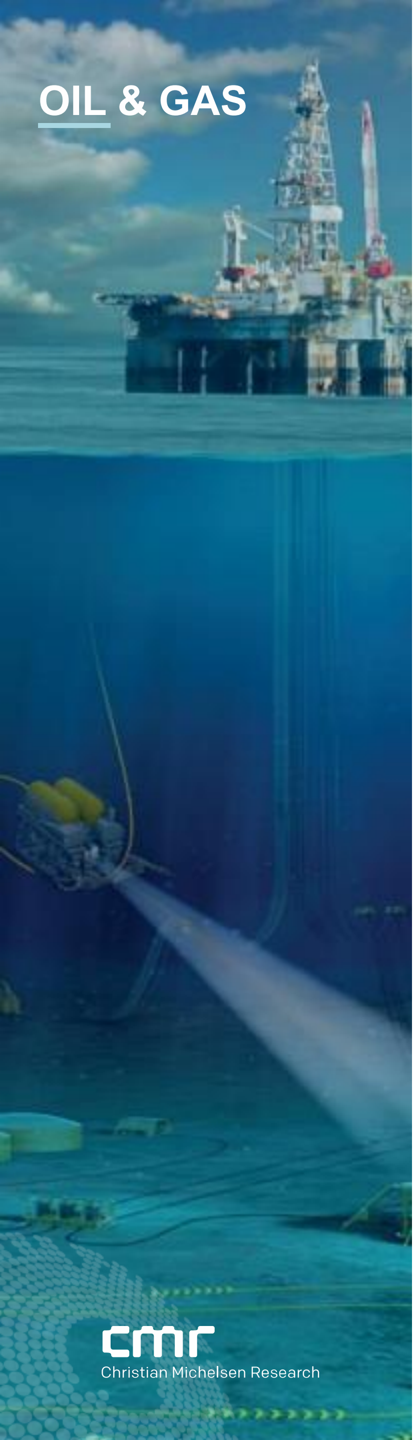
- Research on the topic since the 90's
  - Gasunie
  - Ruhrgas
  - Instromet
  - Advantica
  - Flow Comp
  - RMG
  - Honeywell
  - CMR



Alternative methods

- Many different approaches, e.g.
  - Speed of sound (SOS)
  - Relative permittivity
  - Infrared absorption
  - Isobaric heat capacity
  - Heat conductivity
  - Dynamic viscosity
  - Density
  - CO_2 and N_2 molar fractions

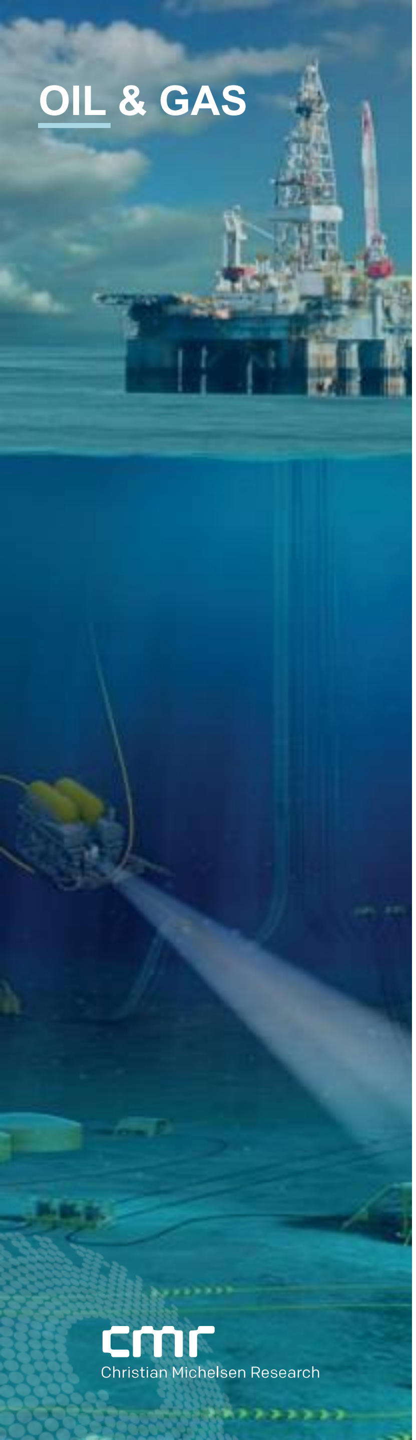
- Typically a combination of three input parameters



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

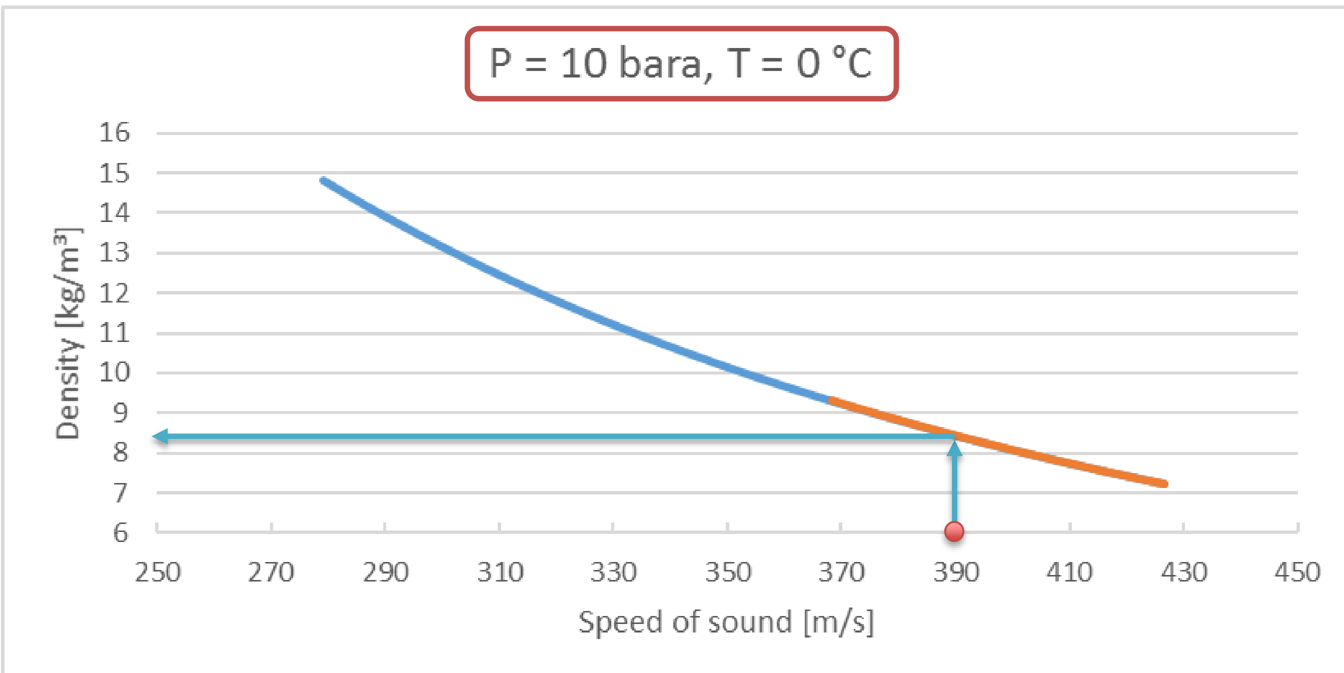


CMR method – from Sound Speed

- 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



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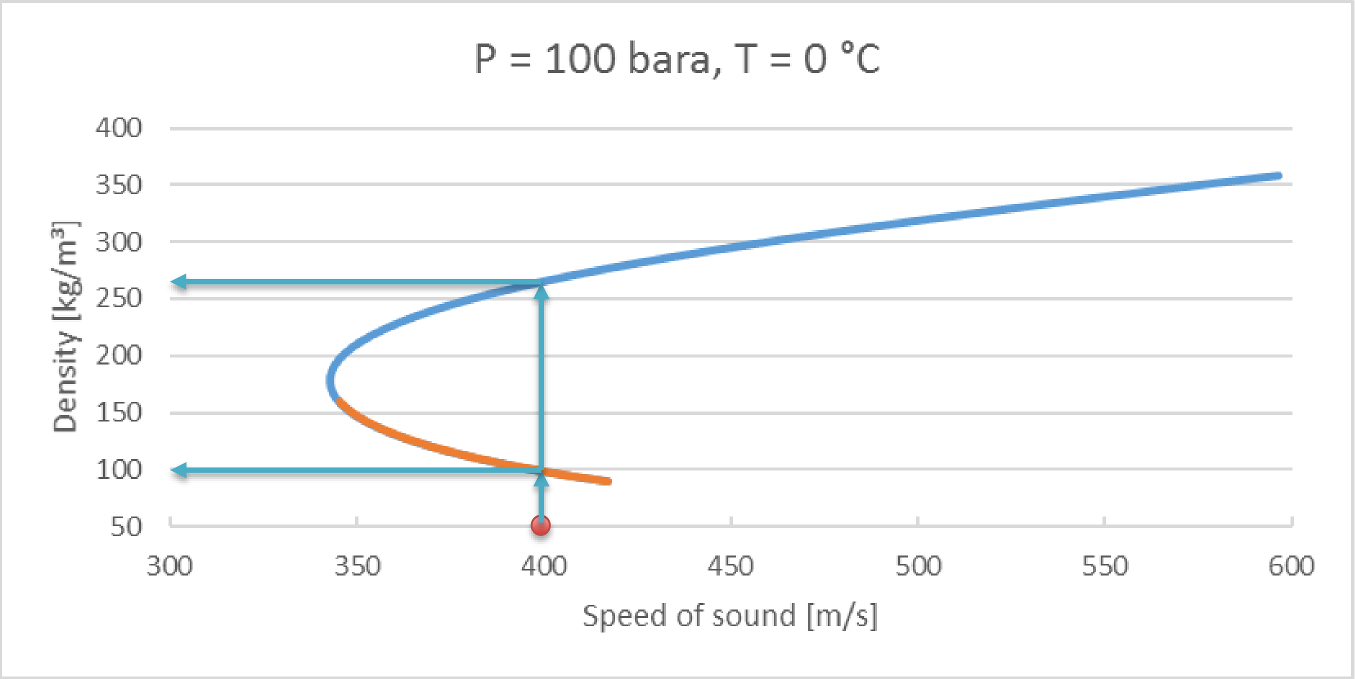
Ambiguity

- 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



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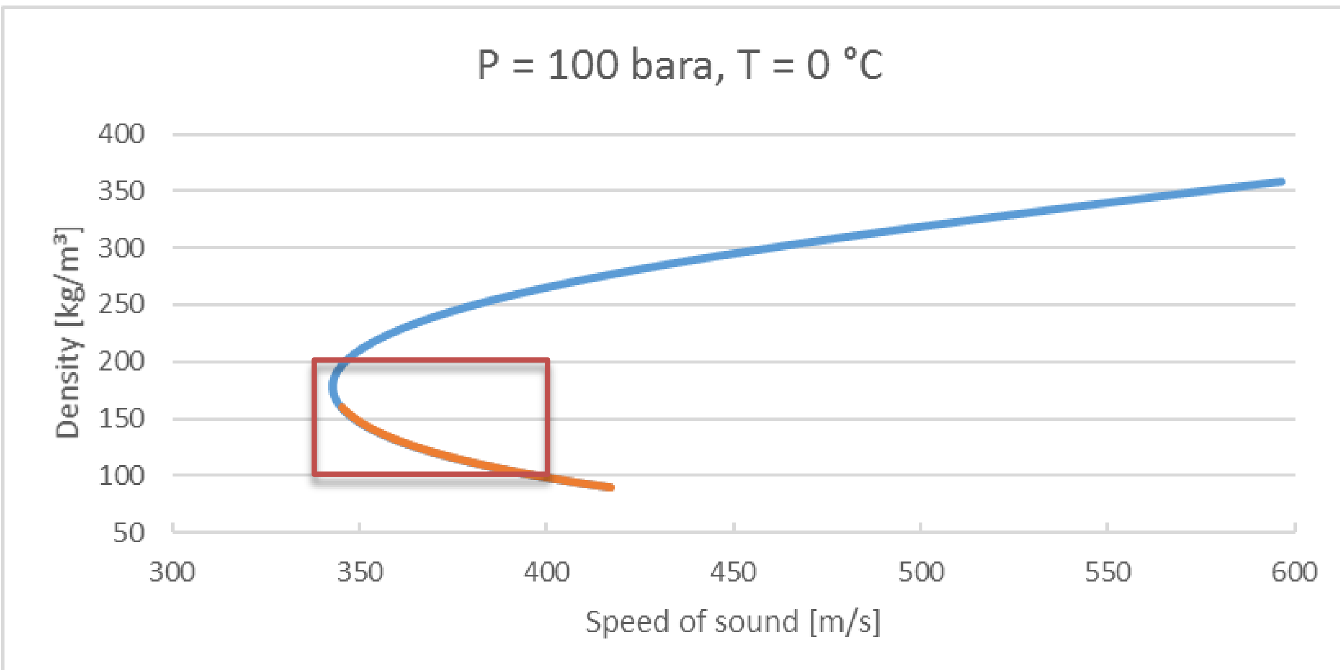

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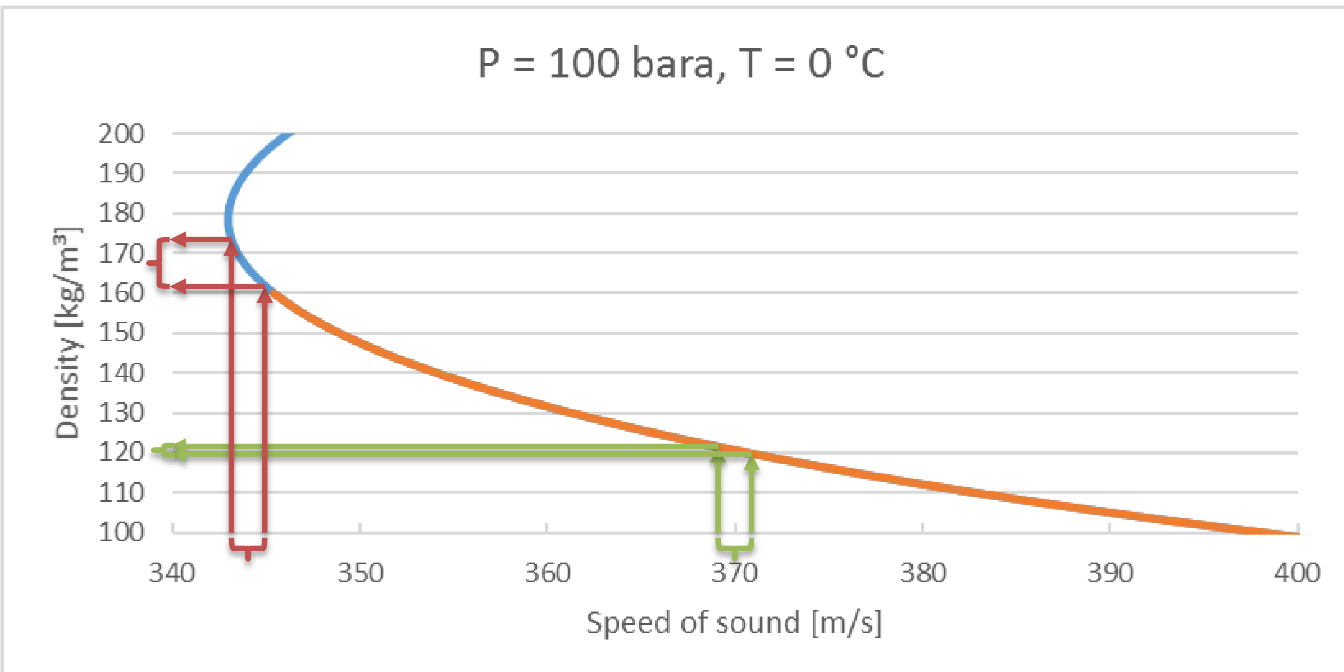
Sensitivity

- 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 $\Delta \rho$



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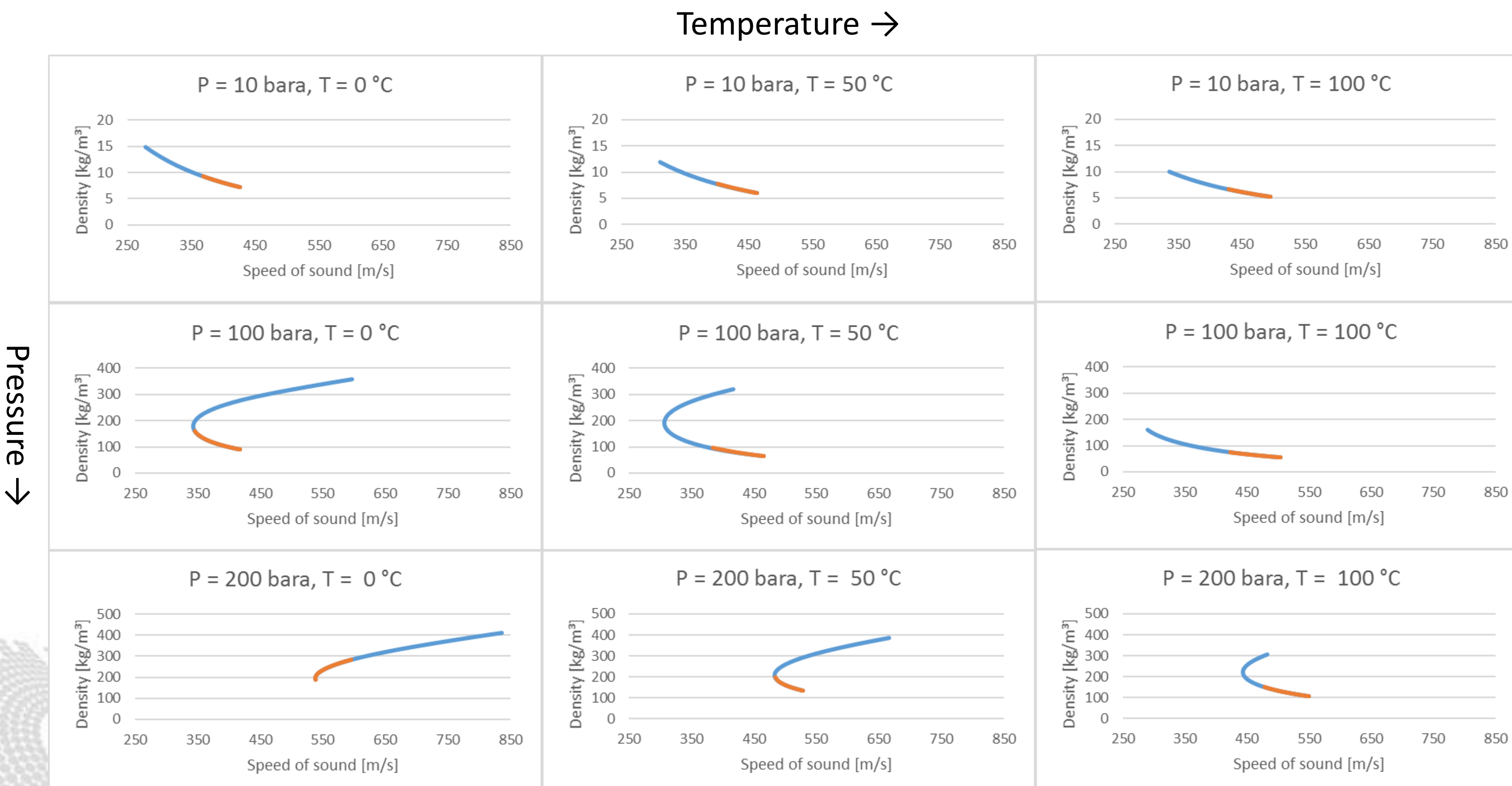
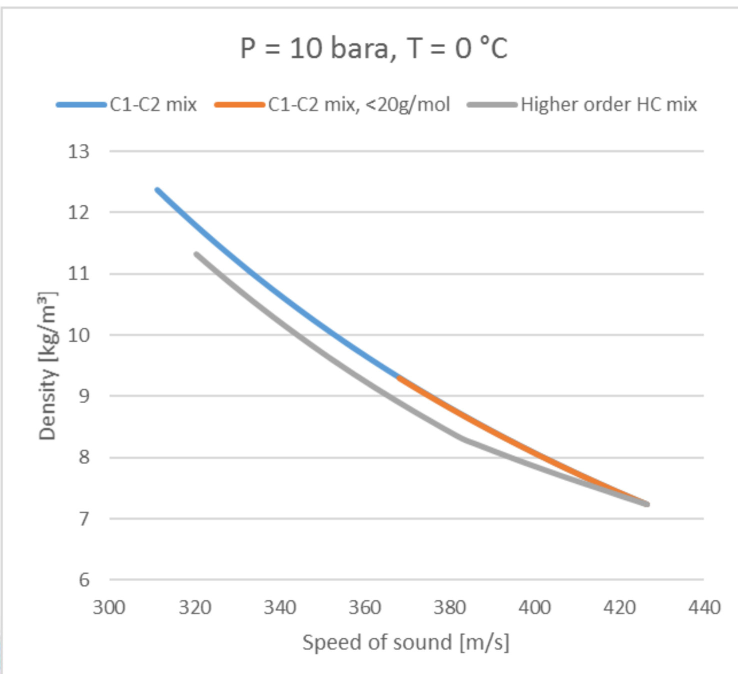
Pressure and temperature dependence

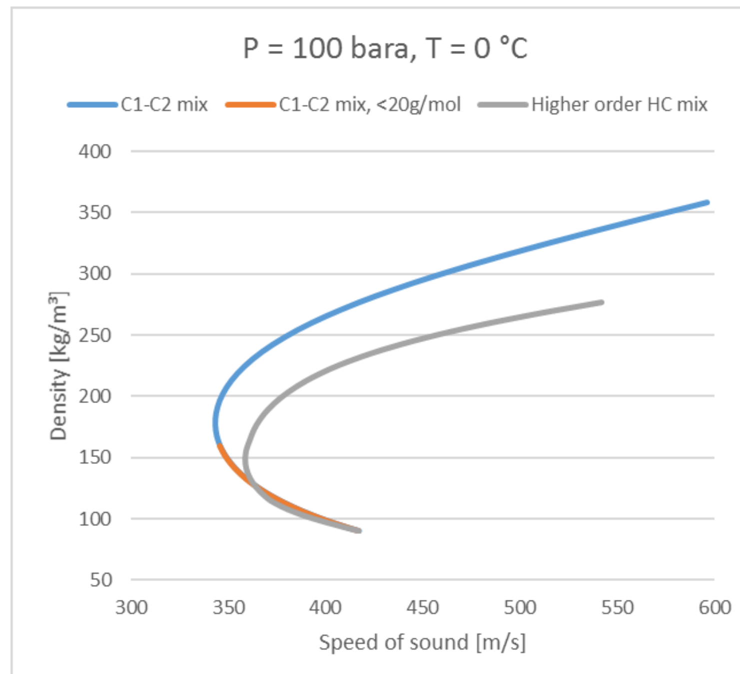
- Binary HC-mix of C1 and C2 (~16-20 g/mol in orange)
- Change in P and T changes the position of the turning point
  - i.e. the turning point affects different compositions



Heavier hydrocarbons

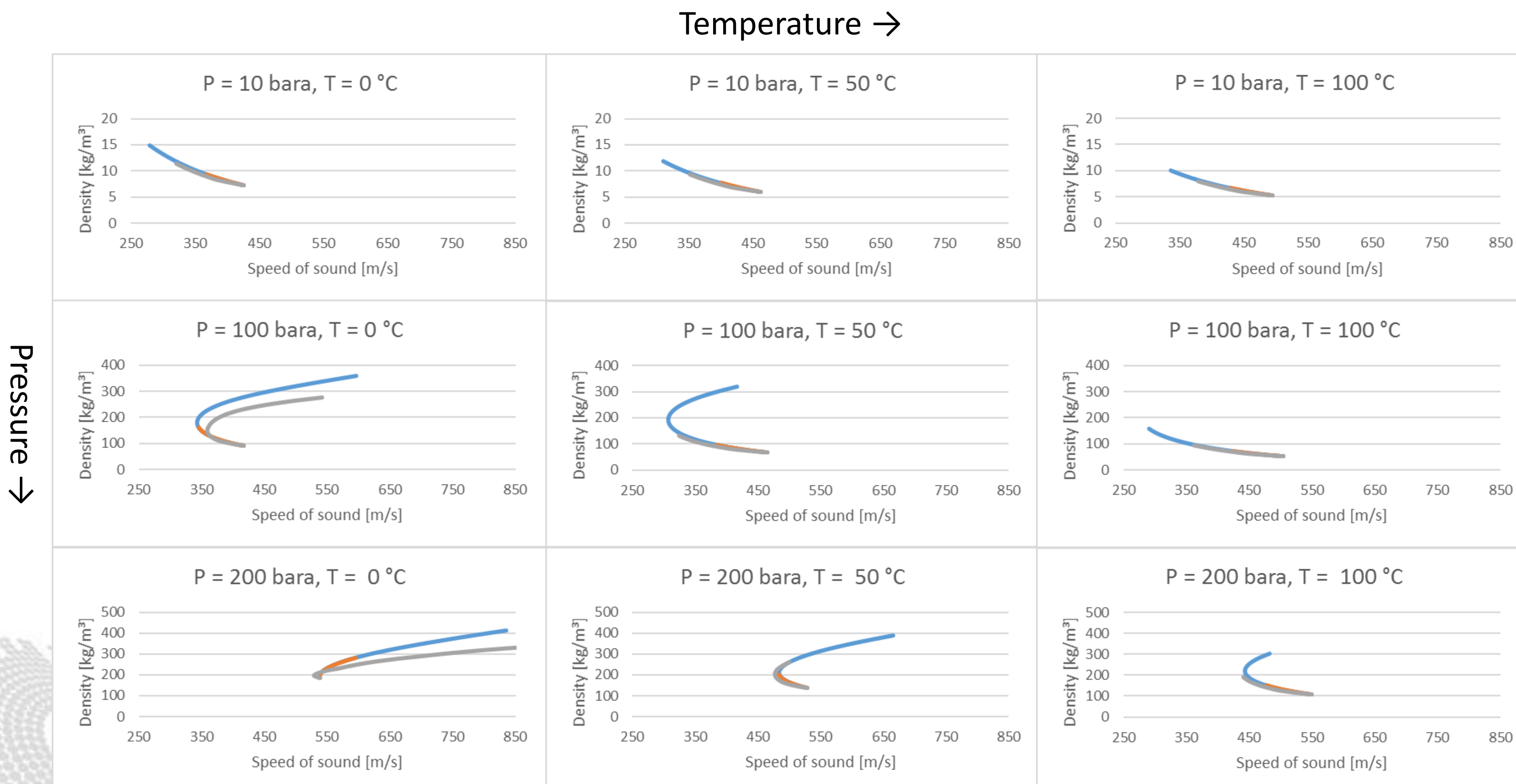
- Until now only considered binary C1-C2 mixture
- Including heavier hydrocarbons creates more ambiguity
- Needs typical composition as input to decrease uncertainty
- Include «worst case» HC mix in plots (C1 and C6, C5, C4, C3)





Pressure and temperature dependence

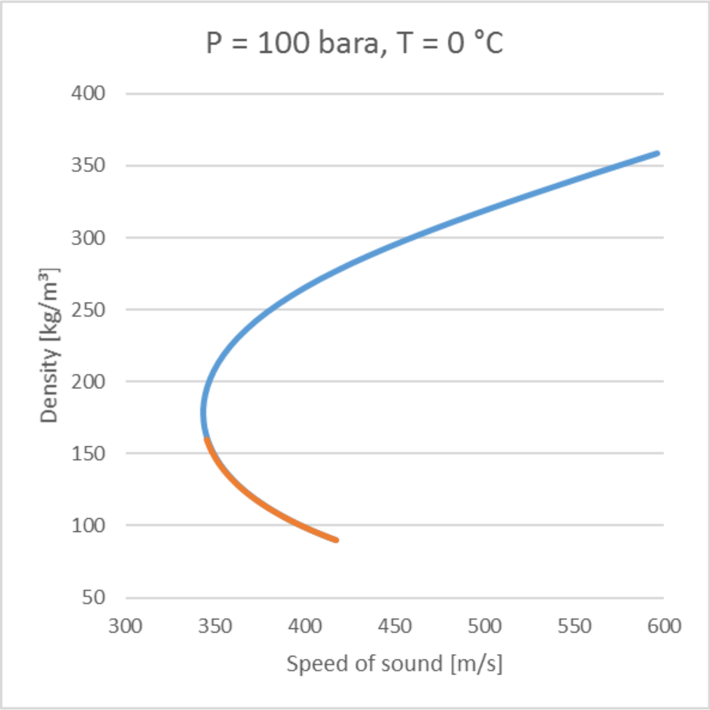
- Include heavier hydrocarbons
- Largest deviation at low temperatures and high pressures



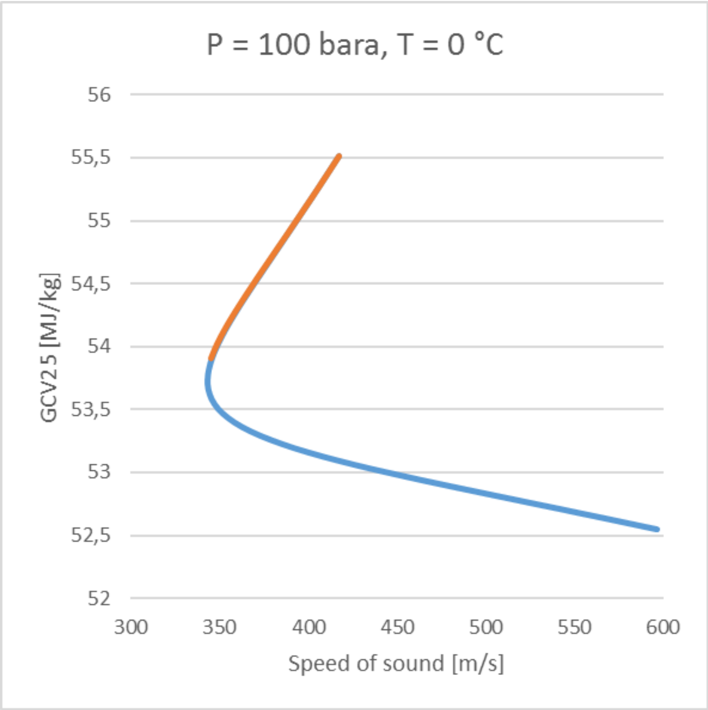
Gross Calorific Value

- 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



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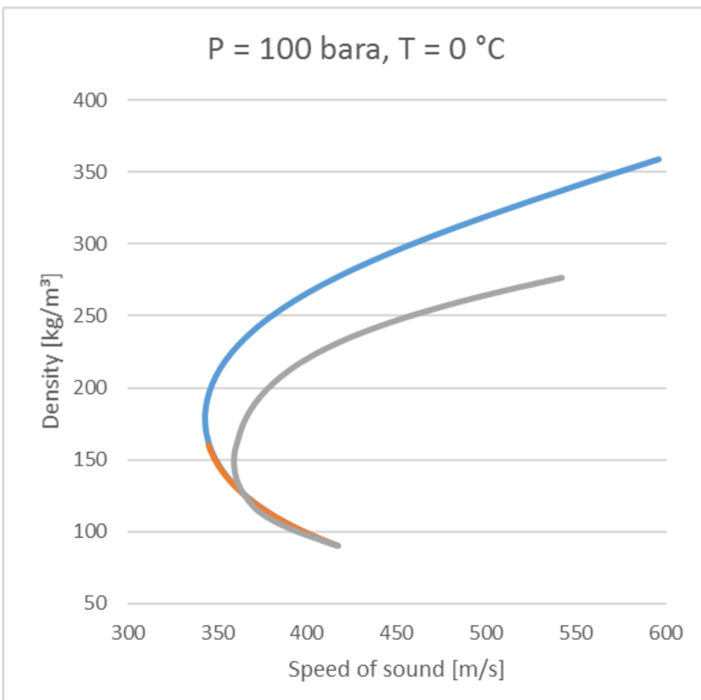
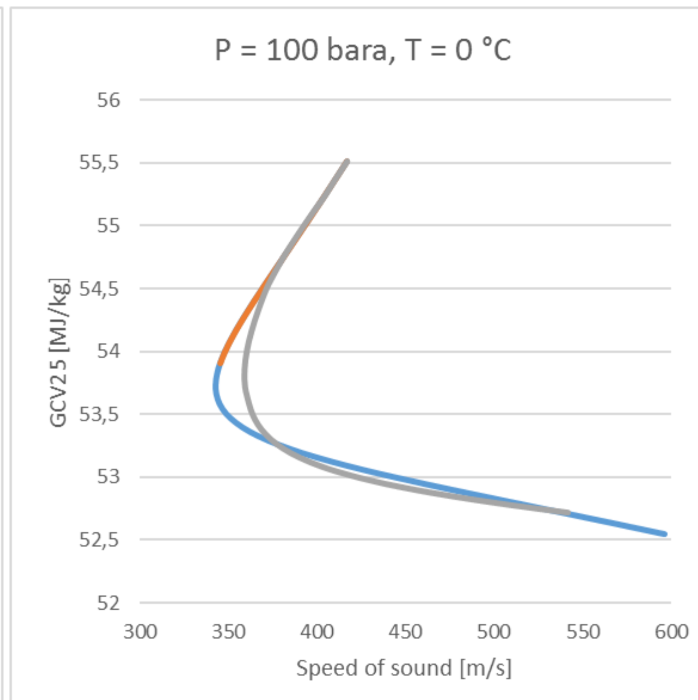


GCV



Uncertainty examples

- Uncertainties are calculated for the output parameters
  - Density
  - GCV at 25 ^{o}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

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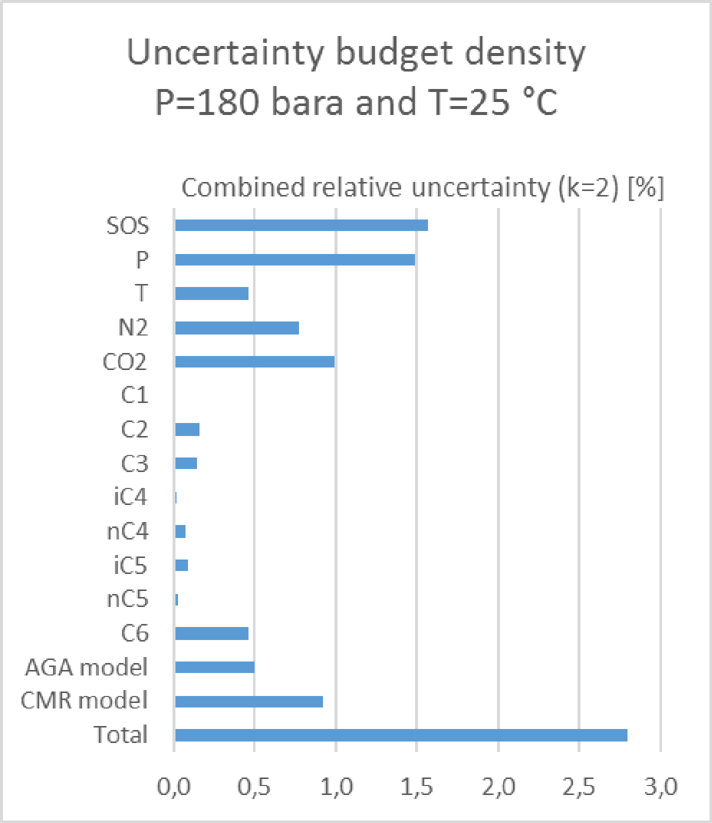
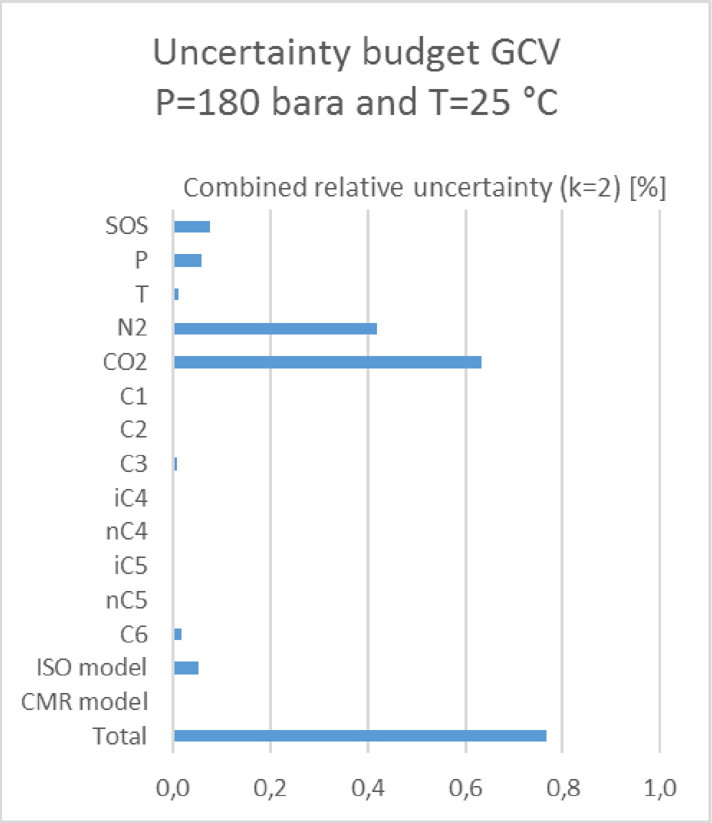
Uncertainty in estimated parameters

Example: Challenging P&T





$$q_m = \rho q_v$$

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

Total expanded uncertainty

Mass flow rate: 2.8 %

Energy flow rate: 3.2 %

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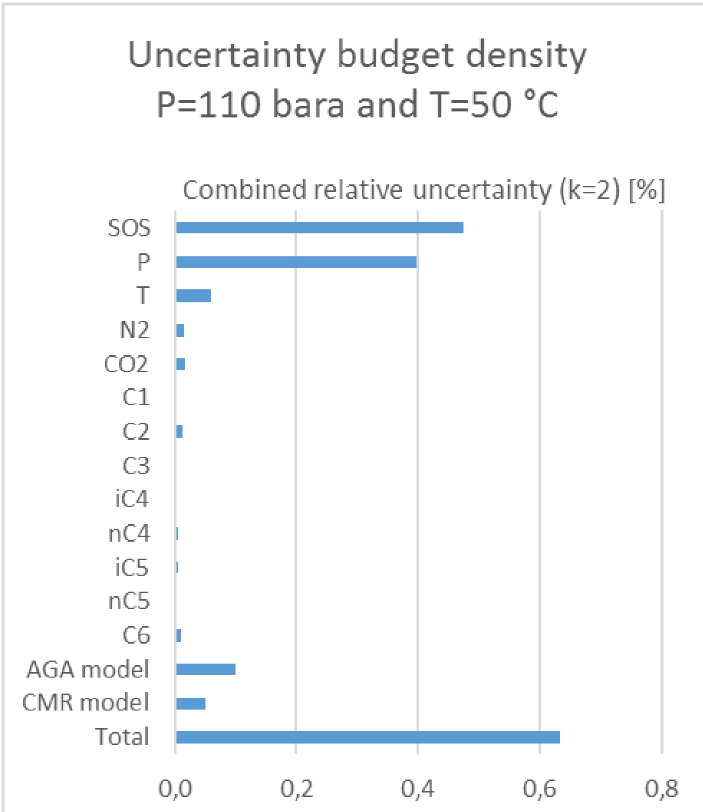
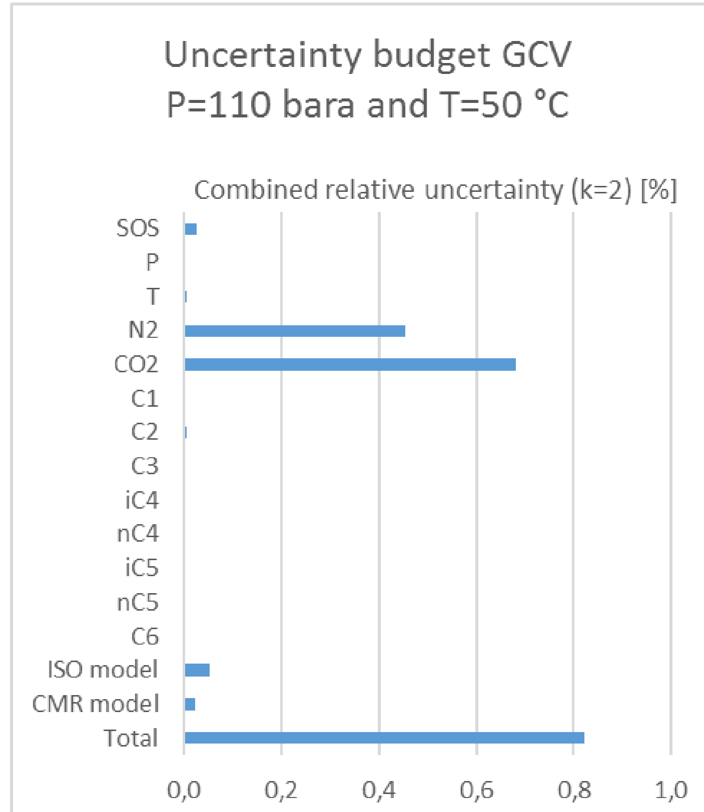
Uncertainty in estimated parameters

Example: Favourable P&T





$$q_m = \rho q_v$$

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

Total expanded uncertainty

Mass flow rate: 0.8 %

Energy flow rate: 1.1 %

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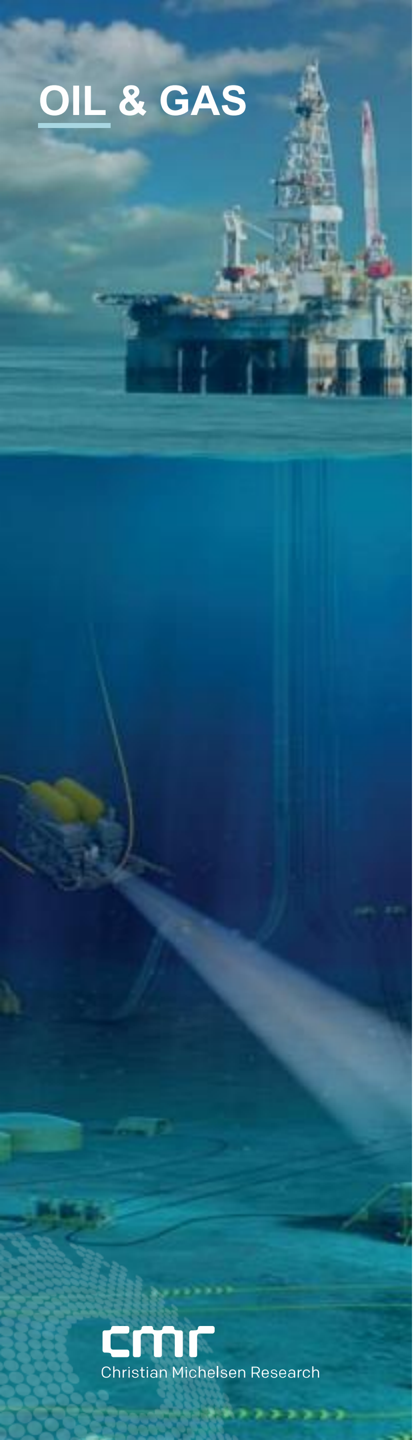
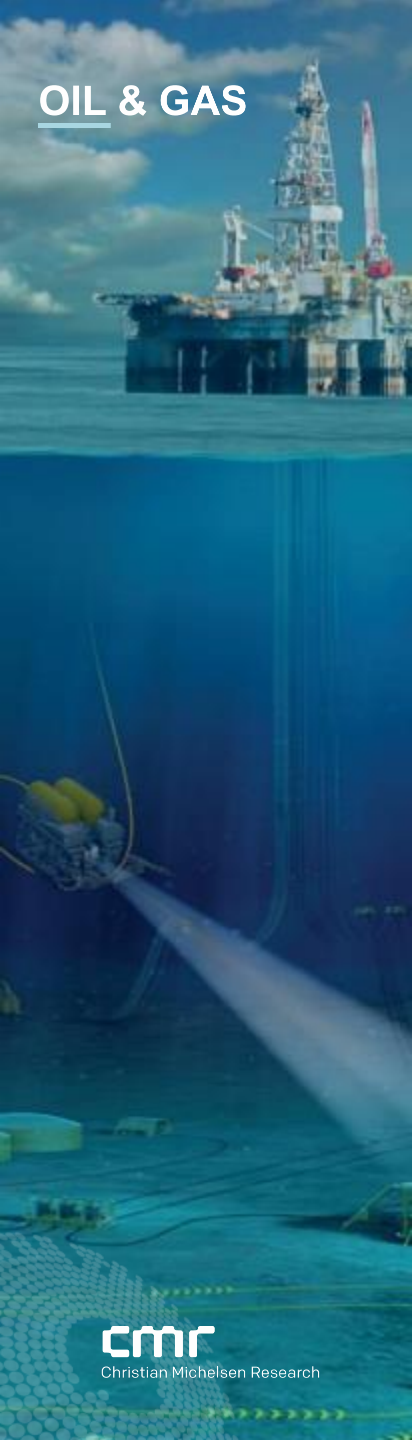


Summary

- 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?

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