



Department for
Science, Innovation
& Technology



Density determination of LNG for accurate custody transfer

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**Add value.
Inspire trust.**

What is LNG?



Liquified Natural Gas

- **Cryogenic Condition:**
Typical LNG temperature:
approximately -162°C / $\sim 115\text{ K}$

- **Multicomponent mixture**

Mainly CH_4

C_2H_6

C_3H_8

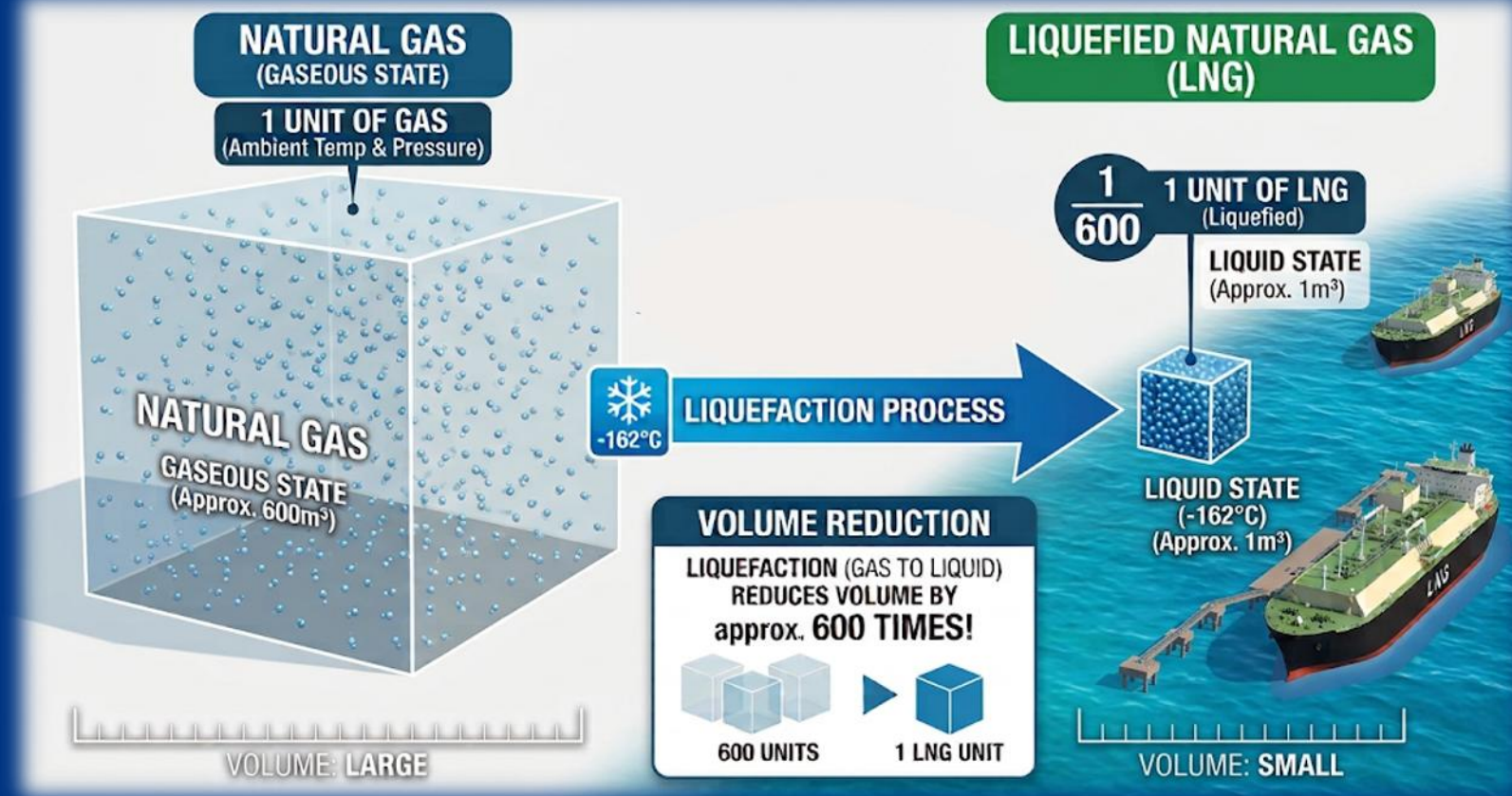
C_4H_{10}

C_5H_{12}

N_2

H_2

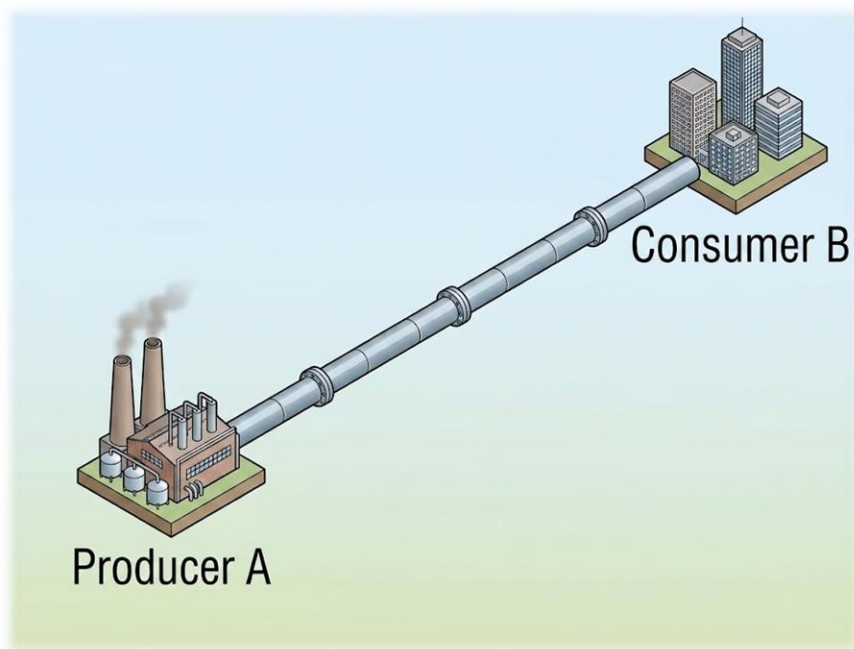
O_2



Natural Gas Transportation

Option A – Compress the gas

- Compressed Natural Gas (CNG)



- A pipeline creates a relatively fixed connection

Option B – Liquefy it

- Natural Gas* $\xrightarrow{\text{Cryogenic Cooling}}$ *LNG*
- When pipelines are technically, geographically, or economically unsuitable.



- Transporting over a long distance or across an ocean.
- Flexibility in delivering to multiple destinations.

LNG Custody Transfer

- What is actually being measured/calculated?

how much energy has been transferred.

$$E = (V_{LNG} \times \rho_{LNG} \times GCV_{LNG}) - E_{gas\ displaced}$$

Volume +
Temperature +
Pressure +
Composition

Density + Heating
Value

Transferred Energy

E = The total energy transferred

V_{LNG} = the volume of LNG loaded or unloaded in m³.

ρ_{LNG} = the density of LNG loaded or unloaded in kg/m³.

GCV_{LNG} = the gross calorific value of the LNG loaded or unloaded in MMBTU/kg.

$E_{gas\ displaced}$ = the net energy of the displaced, also in MMBTU.

Why Energy Rather Than Simply Volume?



- **Two LNG cargoes can have:**

- The same components,
- Different mole fraction,
- Different densities,
- Different heating values,
- The same volume

Components	Mixture 1	Mixture 2	Heating (BTU/mol)
Methane	0.91798	0.81564	843,445
Ethane	0.05698	0.13374	1,478,595
Propane	0.01303	0.03679	2,103,754
Butane	0.00396	0.00688	2,726,374
Nitrogen	0.00805	0.00695	0



different amounts of chemical energy.

- **The commodity being traded is effectively energy, not simply LNG volume.**

Input Parameters

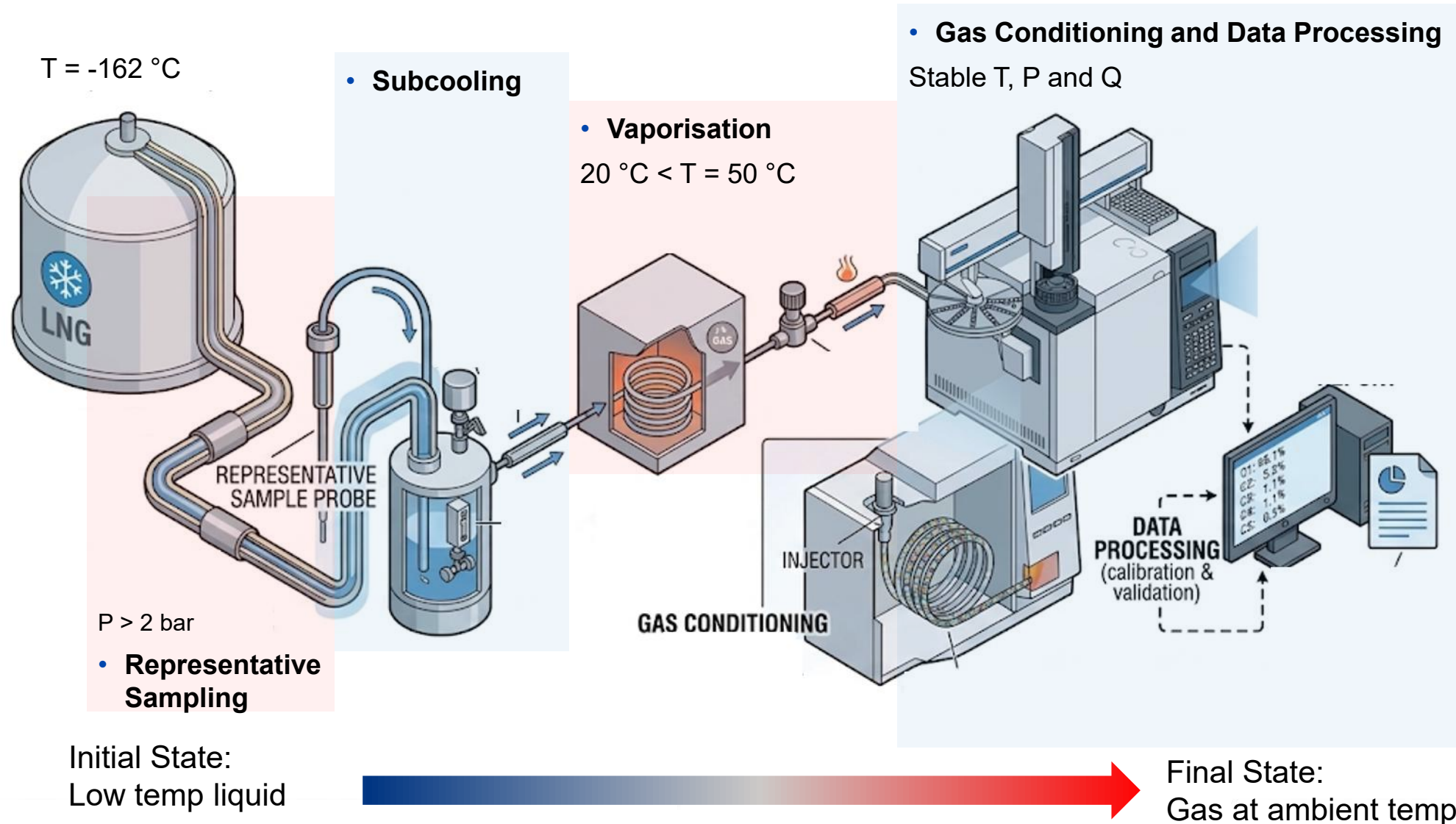
Volume

Temperature

Pressure

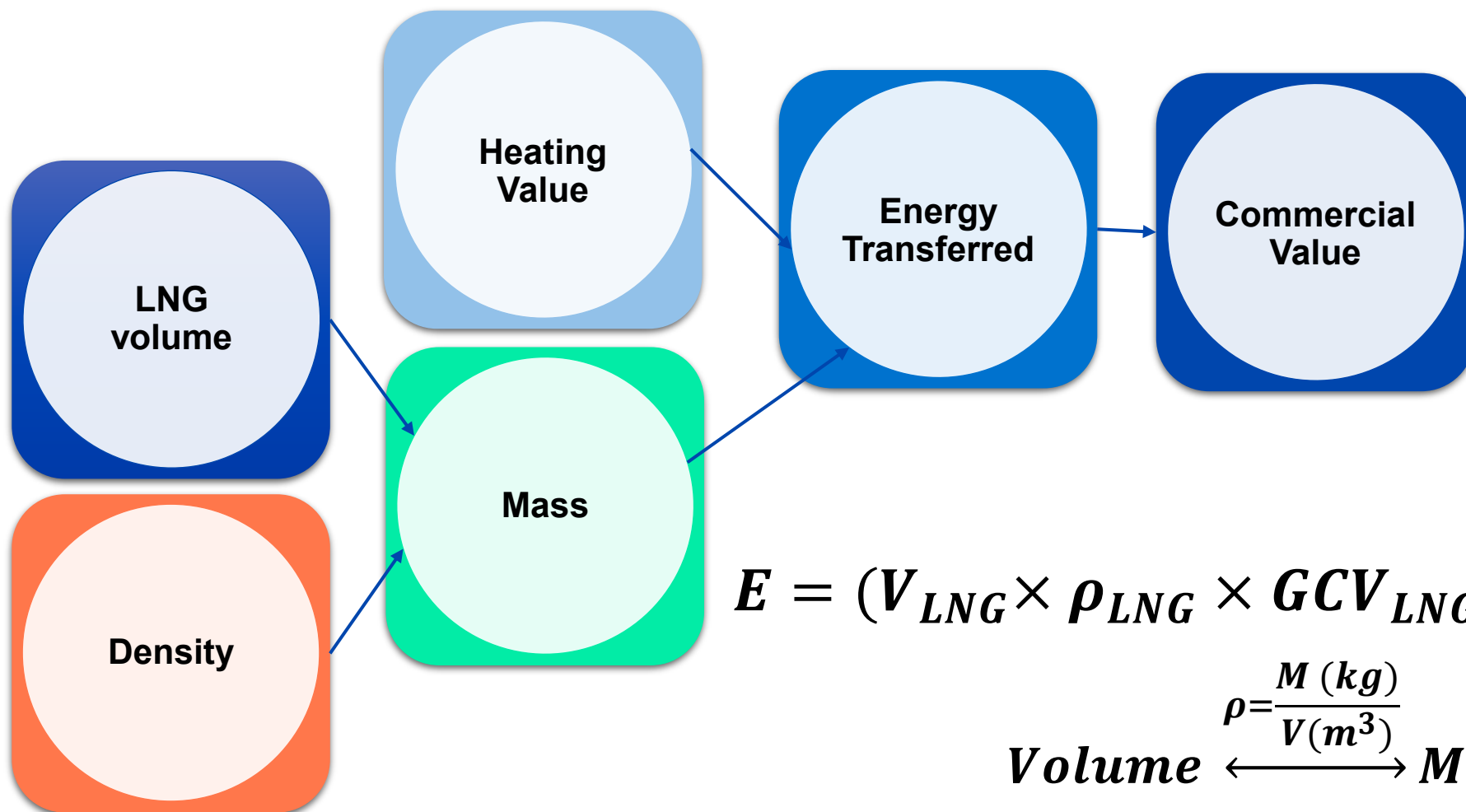
Composition

LNG Compositional Analysis



Density Determination

Where does density enter custody transfer?



$$E = (V_{LNG} \times \rho_{LNG} \times GCV_{LNG}) - E_{gas\ displaced}$$

$$\rho = \frac{M\ (kg)}{V\ (m^3)}$$

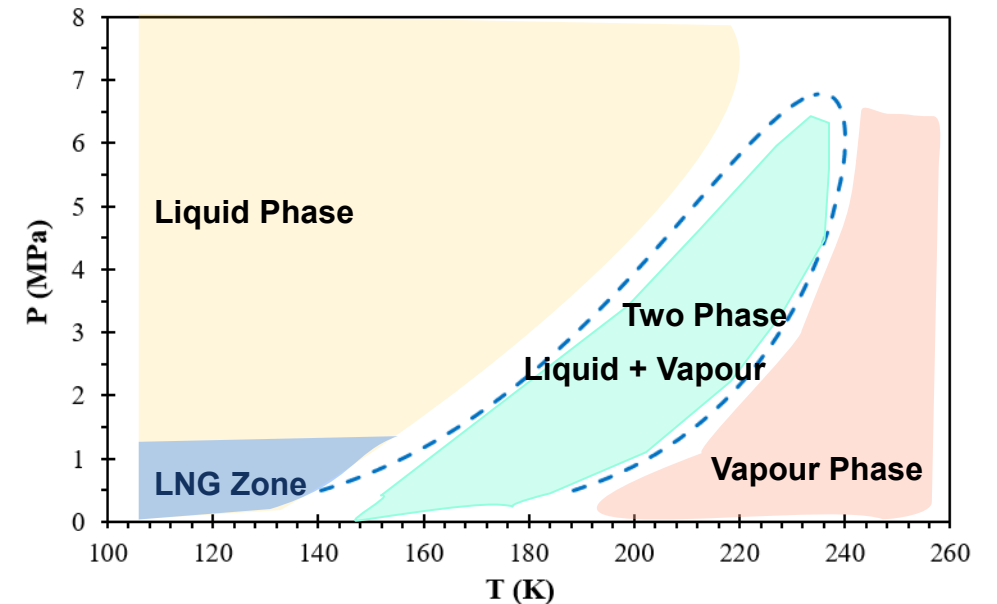
Volume $\longleftrightarrow$ *Mass*

$$U_{Density} \rightarrow U_{Mass} \rightarrow U_{Energy} \rightarrow \text{financial uncertainty}$$

Why is LNG density challenging?

1. Closeness to liquid – vapour phase boundary

- LNG is normally maintained as a liquid.
- The liquid–vapour boundary defines where phase change begins.
- Near the boundary, small changes in T, P or composition can affect phase behaviour.
- EOS predictions become particularly important in this region.



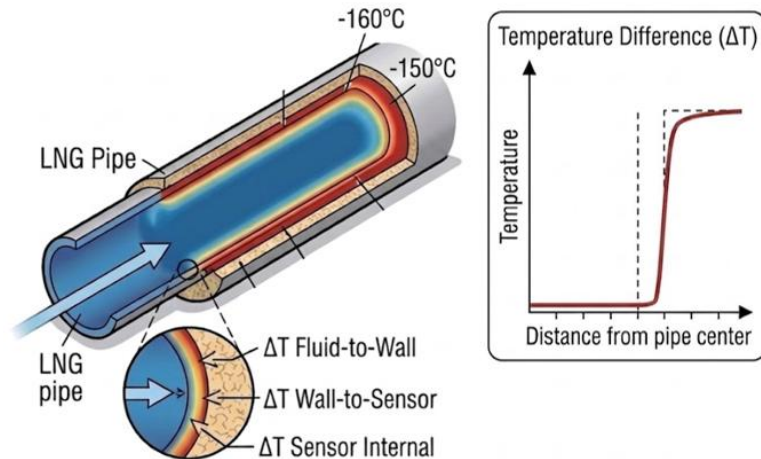
P–T phase envelope for an LNG mixture

Why is LNG density challenging?

2. Temperature

Cryogenic temperatures

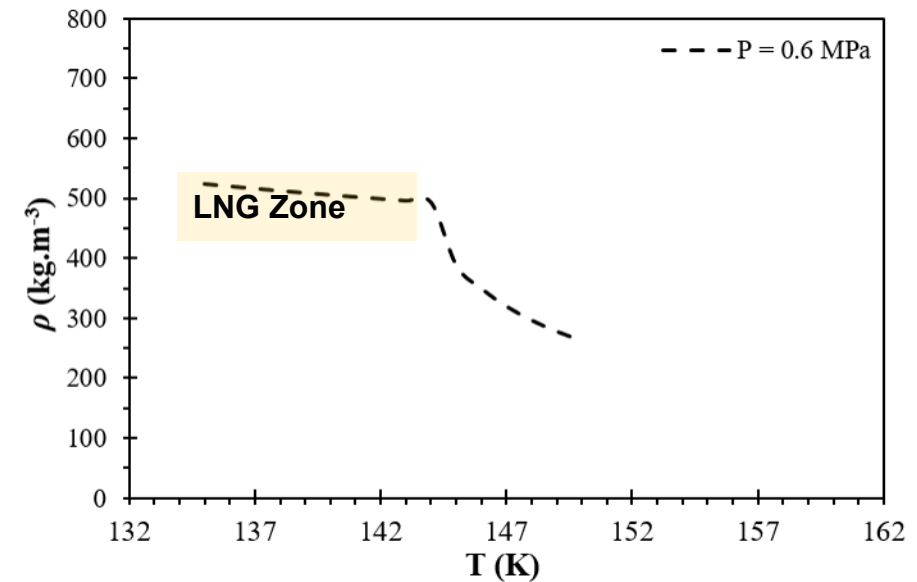
- Maintaining stable temperature
- Temperature differences between fluid, pipe wall and temperature sensor reading



- Uncertainty in temperature measurement and accordingly density determination

High sensitivity to temperature

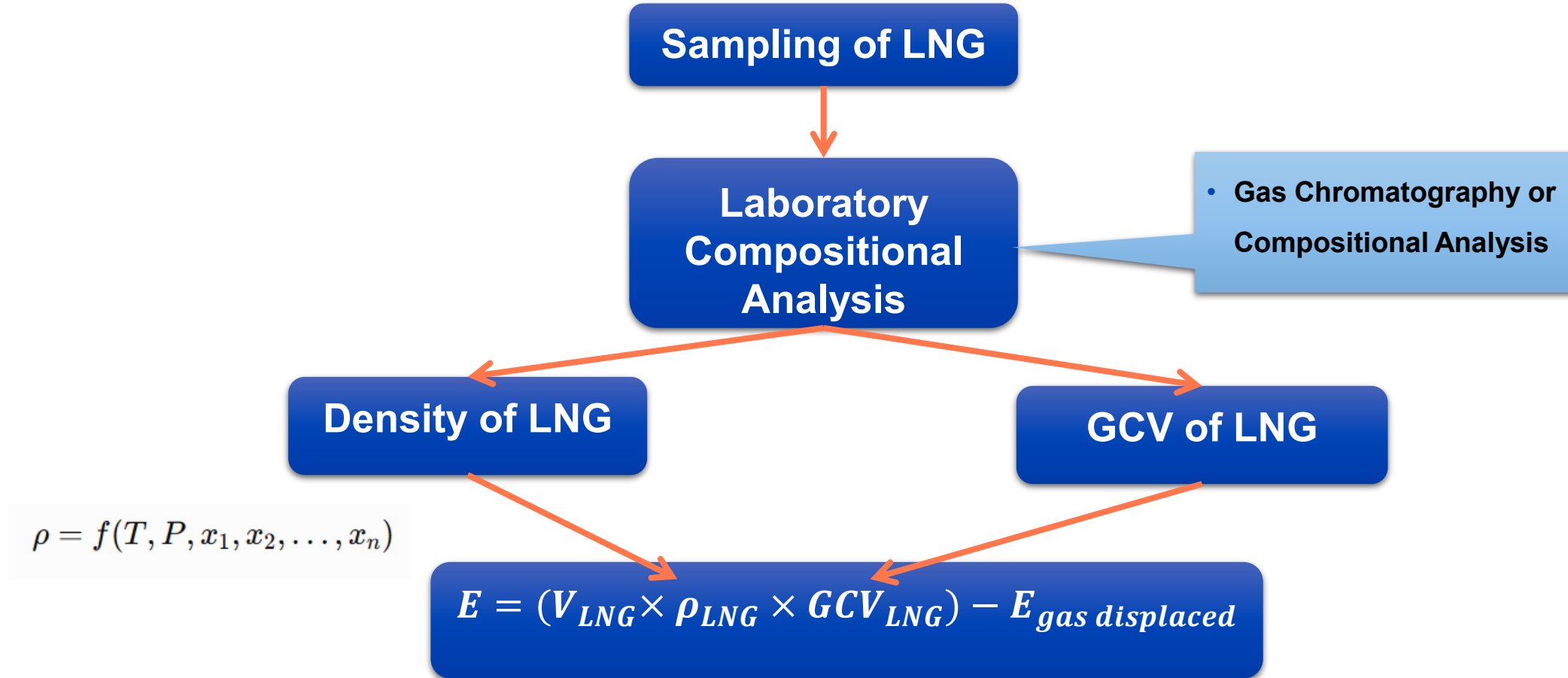
- Close to saturation condition



Small $\Delta T \rightarrow \text{Significant } \Delta \rho$

Why is LNG density challenging?

3. Difficulty in Compositional Analysis



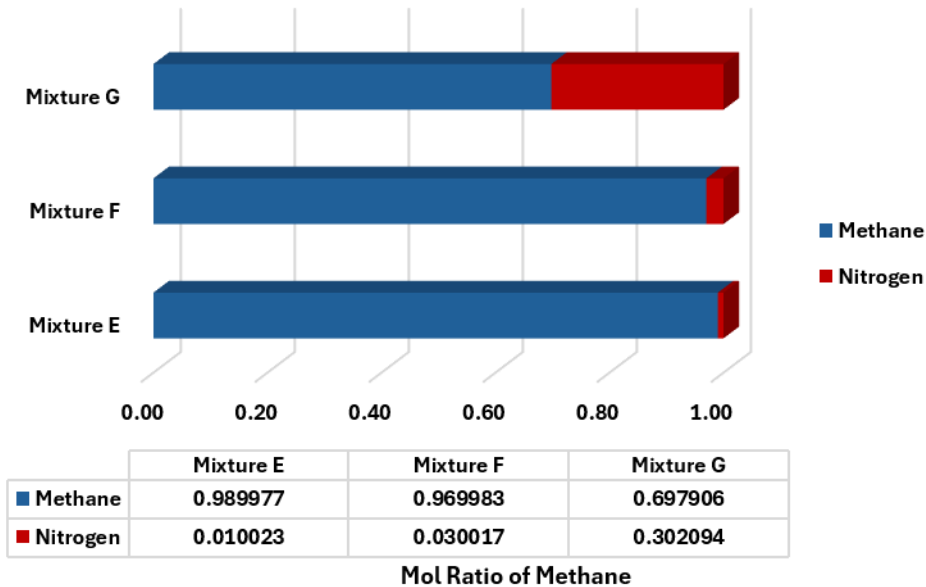
GCV_{LNG} = the gross calorific value of the LNG

Reference: GIIGNL - LNG CUSTODY TRANSFER HANDBOOK

Why is LNG density challenging?

4. Composition Dependency

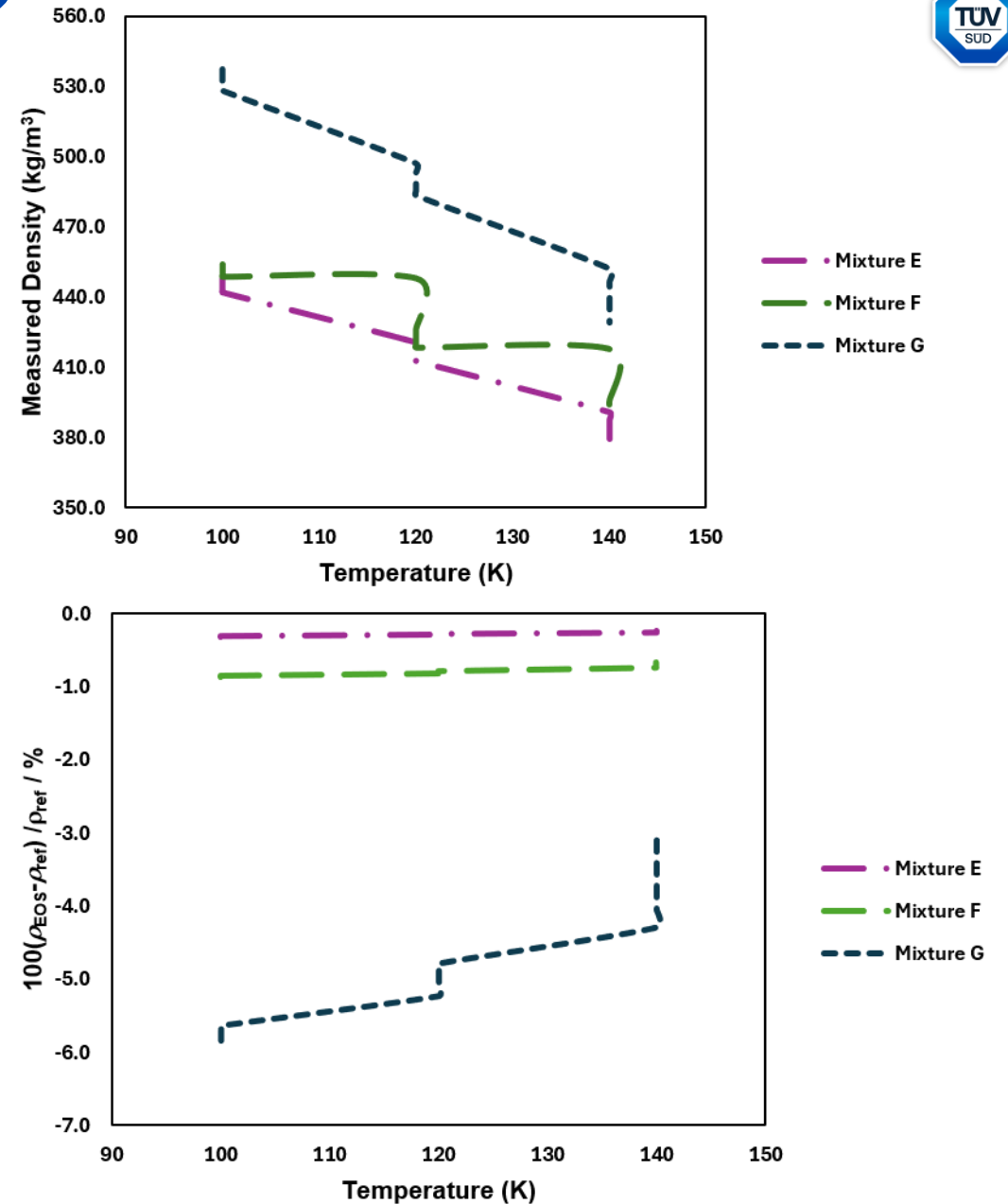
- Binary LNG mixtures ($\text{CH}_4 + \text{N}_2$)



ρ_{EOS} : Density determined using GERG equation of state

ρ_{ref} : Density measured at cryogenic condition

Reference: Data extracted from Table 5-Lentner et al., 2020. ($U(\rho)/\rho \approx 0.016-0.019\%$).



CryoMet Project

The project (24GRD07 CryoMet) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.



CryoMet

EUROPEAN PARTNERSHIP



METROLOGY
PARTNERSHIP



WP1: Liquefied energy gases flow metering reliability.



Endress+Hauser

WP2: (Bio-)LNG composition and density measurement reliability.



EffecTech



TÜBITAK



National Metrology Institute



Institute for
Energy Technology

IMPERIAL



EMERSON

WP3: SI-traceable liquefied energy gases temperature measurements.



Endress+Hauser



fsb

Sveučilište u Zagrebu
Fakultet strojarstva
i brodogradnje



UNIVERZA
V LJUBLJANI

WP4: Develop a reliable way to calibrate measurement systems.



National Metrology Institute



Endress+Hauser



National Physical Laboratory



EMERSON

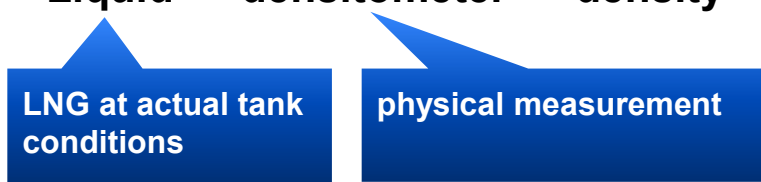


IMPERIAL

How can LNG density be determined?



Direct Measurement

- Using a densitometer
 - **Liquid** → **densitometer** → **density**
- 
- LNG at actual tank conditions
- physical measurement
- No appropriate densitometer is available currently to provide reliable measurement at LNG operating condition¹.

[1] GIIGNL - LNG CUSTODY TRANSFER HANDBOOK

Indirect Empirical Correlations

- **Revised Klosek–McKinley (RKM)**
- **COSTALD**
- **Pros:**
 - Fast
 - Simple
 - Widely used
- **Cons:**
 - Restricted validity ranges
 - Empirical nature
 - Limited ability to describe general thermodynamic behaviour
 - Different applicability to saturated/homogeneous liquid conditions

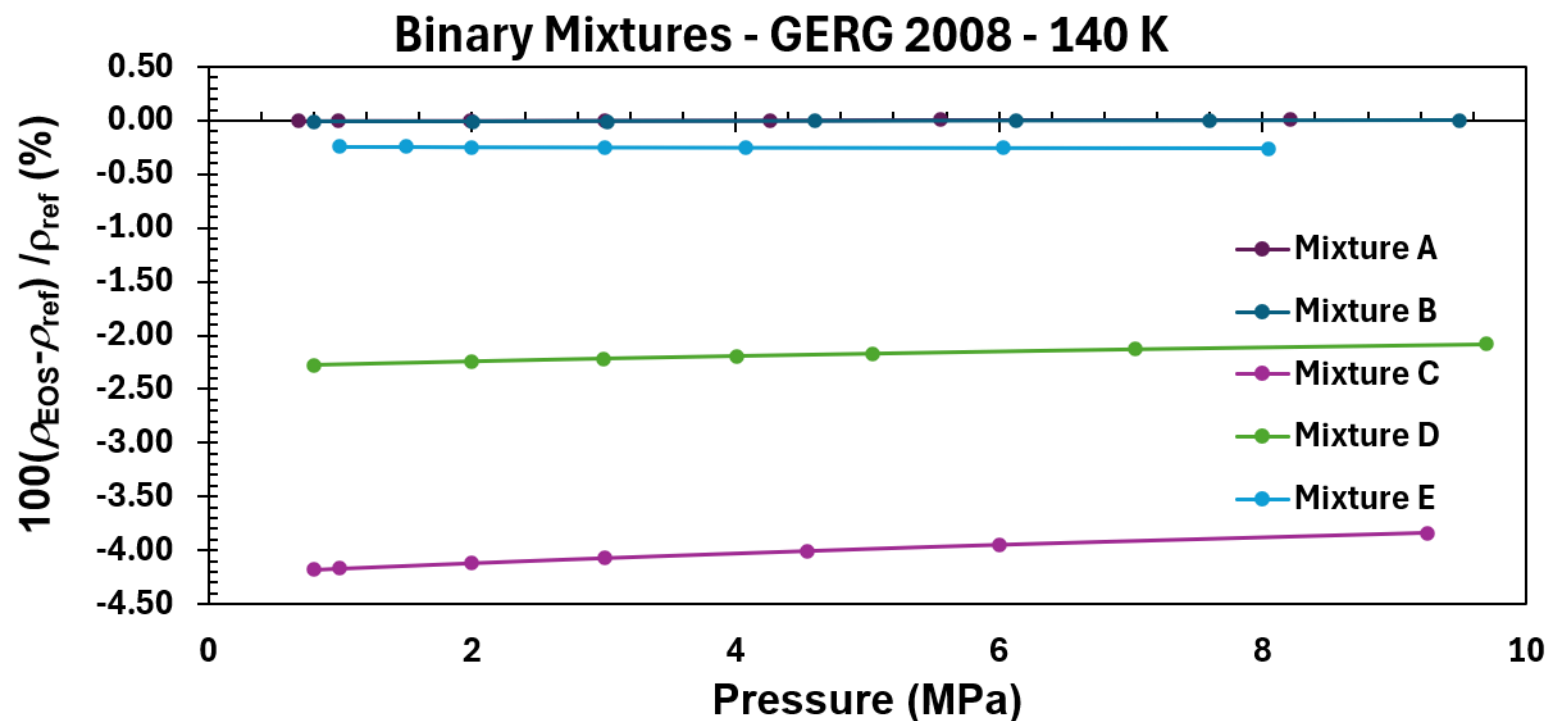
Indirect Thermodynamics Models

- **Cubic EOS**
 - Peng–Robinson
- **Molecular/statistical approaches**
 - PC-SAFT
- **Multiparameter Helmholtz EOS**
 - GERG-2008 / EOS-LNG
- Try to model the complex thermodynamic behaviour of LNG mixtures.

EoSs/Correlations Performance

- Different Components
- Different Concentrations
- Different Temperatures

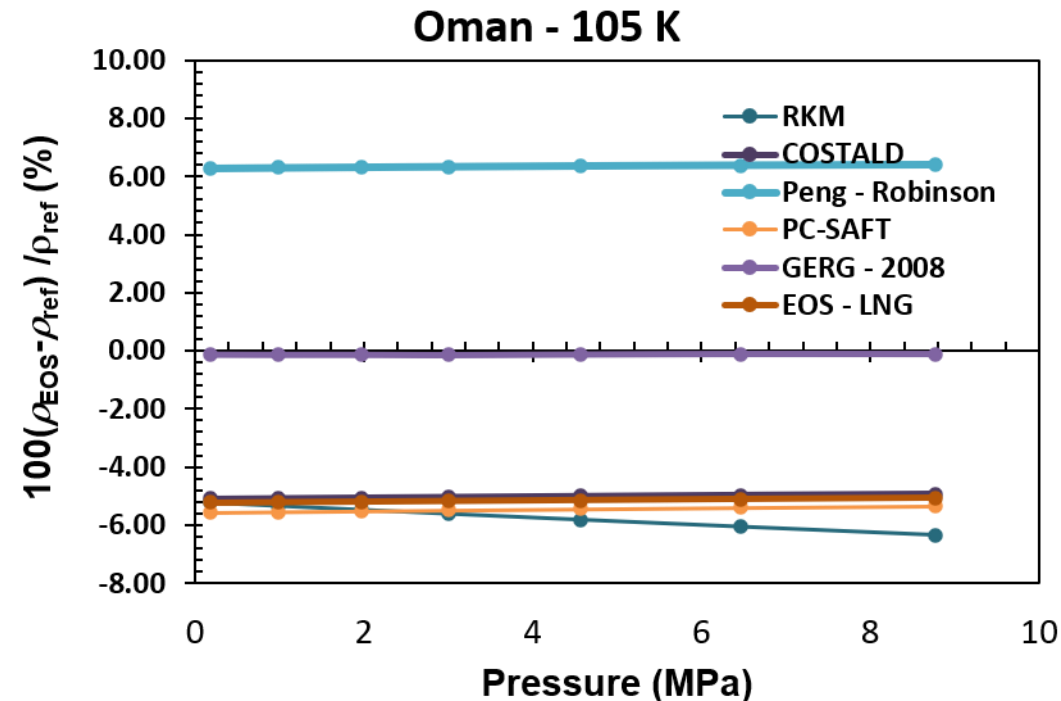
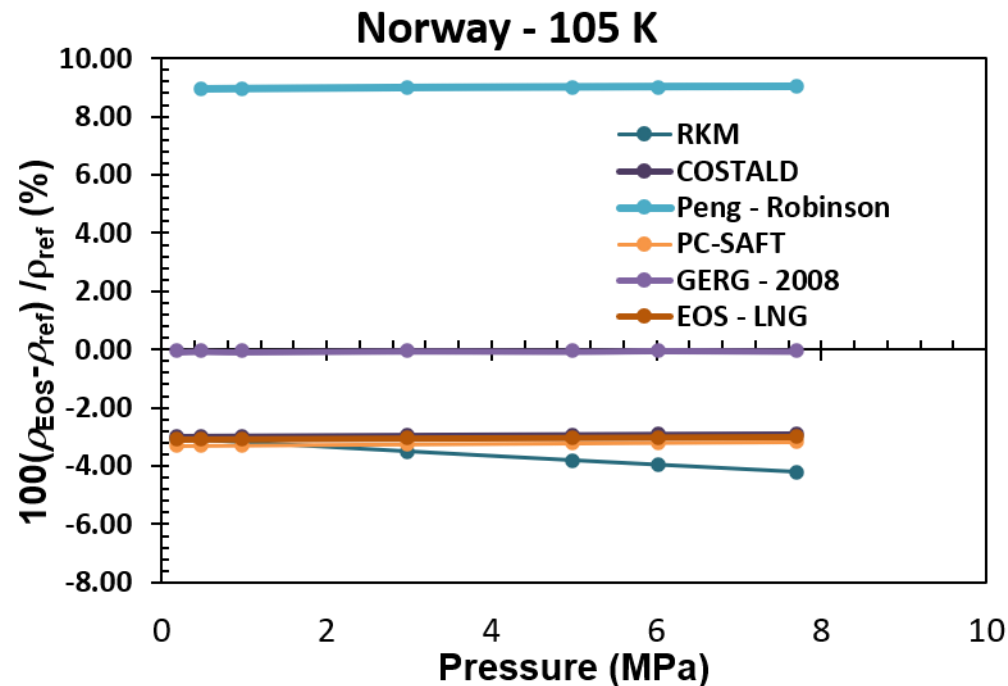
Effect of Components' type on Indirect Density Determination



Mixture A	Mixture B	Mixture C	Mixture D	Mixture E
Methane: 0.7504	Methane: 0.8803	Methane: 0.97007	Methane: 0.990136	Methane: 0.989977
Ethane 0.2496	Propane: 0.1197	Isobutane: 0.02993	Pentane: 0.009864	Nitrogen: 0.010023

Reference: Lentner et al., J. Chem. Thermodynamics 142 (2020)

Effect of Components' Concentration on Indirect Density Determination

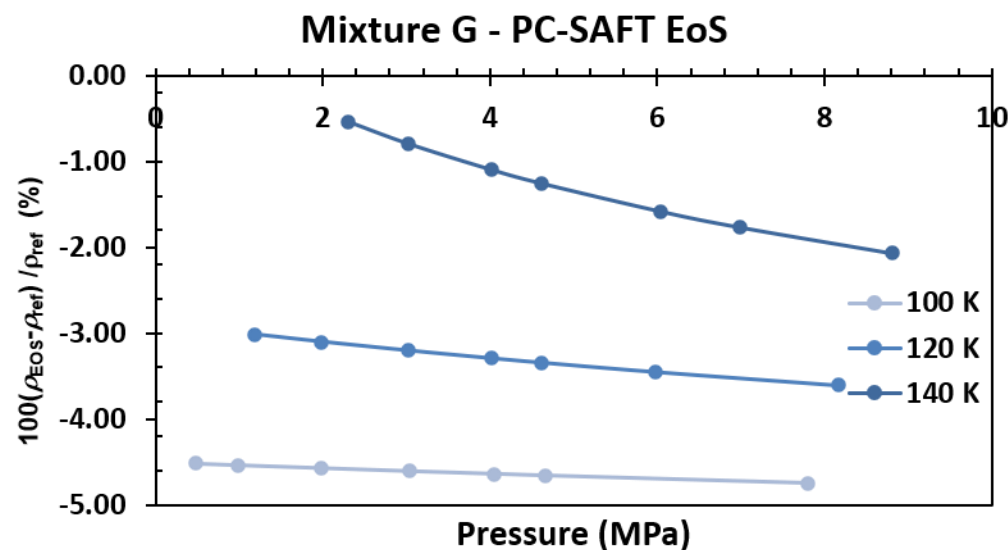
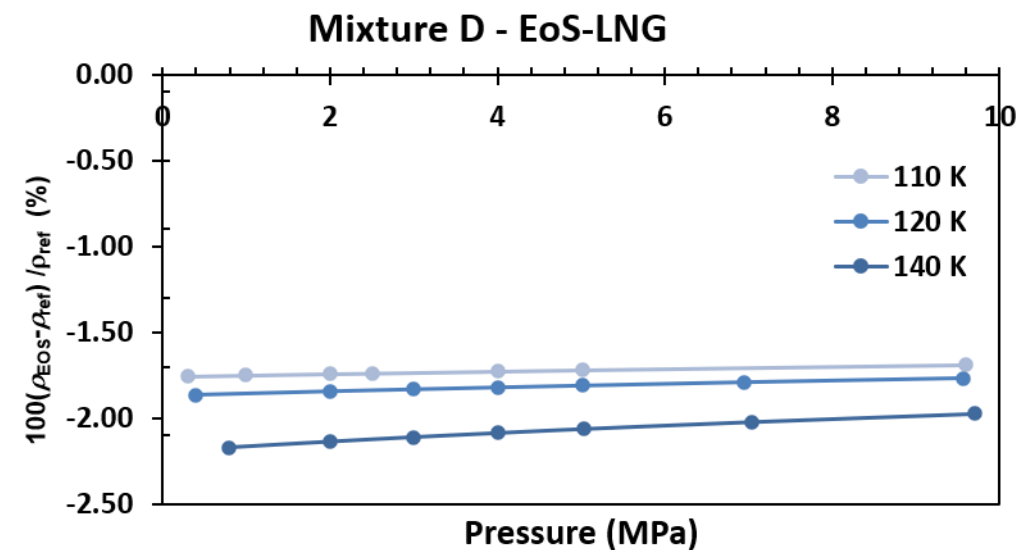
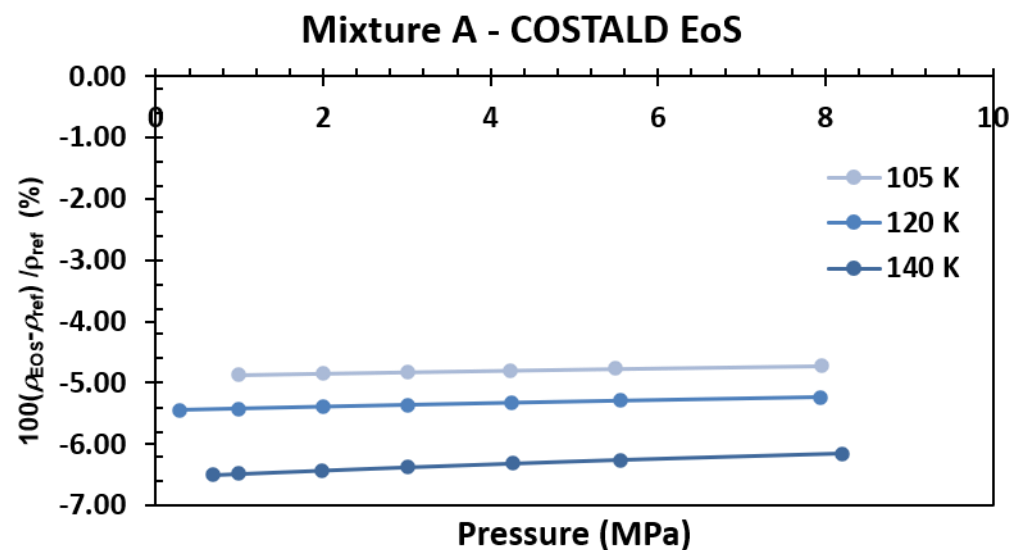


Mixture	Methane	Ethane	Propane	Butane	Nitrogen
Norway ¹	0.91798	0.05698	0.01303	0.00396	0.00805
Oman ²	0.87885	0.07274	0.02926	0.01565	0.0035

1. Richter et al., J. Chem. Thermodynamics 93 (2016)

2. Lentner et al., J. Chem. Thermodynamics 112 (2017)

Effect of Temperature on Indirect Density Determination



Mixture A	Mixture D	Mixture G
Methane: 0.7504	Methane: 0.990136	Methane: 0.697906
Ethane 0.2496	Pentane: 0.009864	Nitrogen: 0.302094

Reference: Lentner et al., J. Chem. Thermodynamics 142 (2020)

Conclusion



- **Why LNG?**

LNG enables efficient long-distance transport of natural gas by significantly reducing its volume.

- **How is LNG custody transfer determined?**

LNG custody transfer is primarily determined on an energy basis, requiring accurate measurement of the quantity and energy content of the LNG.

- **What parameters are required?**

Accurate custody transfer requires reliable measurements of LNG composition, temperature, pressure, volume and density.

- **How are the measurement challenges addressed?**

Cryogenic conditions introduce significant measurement challenges; the CryoMet project addresses these through improved measurement methods, reference data, calibration and uncertainty assessment.

- **What does the density modelling show?**

Indirect density determination is strongly dependent on composition, component concentrations, temperature and pressure; selecting the appropriate correlation or EoS for the specific conditions is therefore essential to minimise uncertainty.



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Thanks for your attention

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