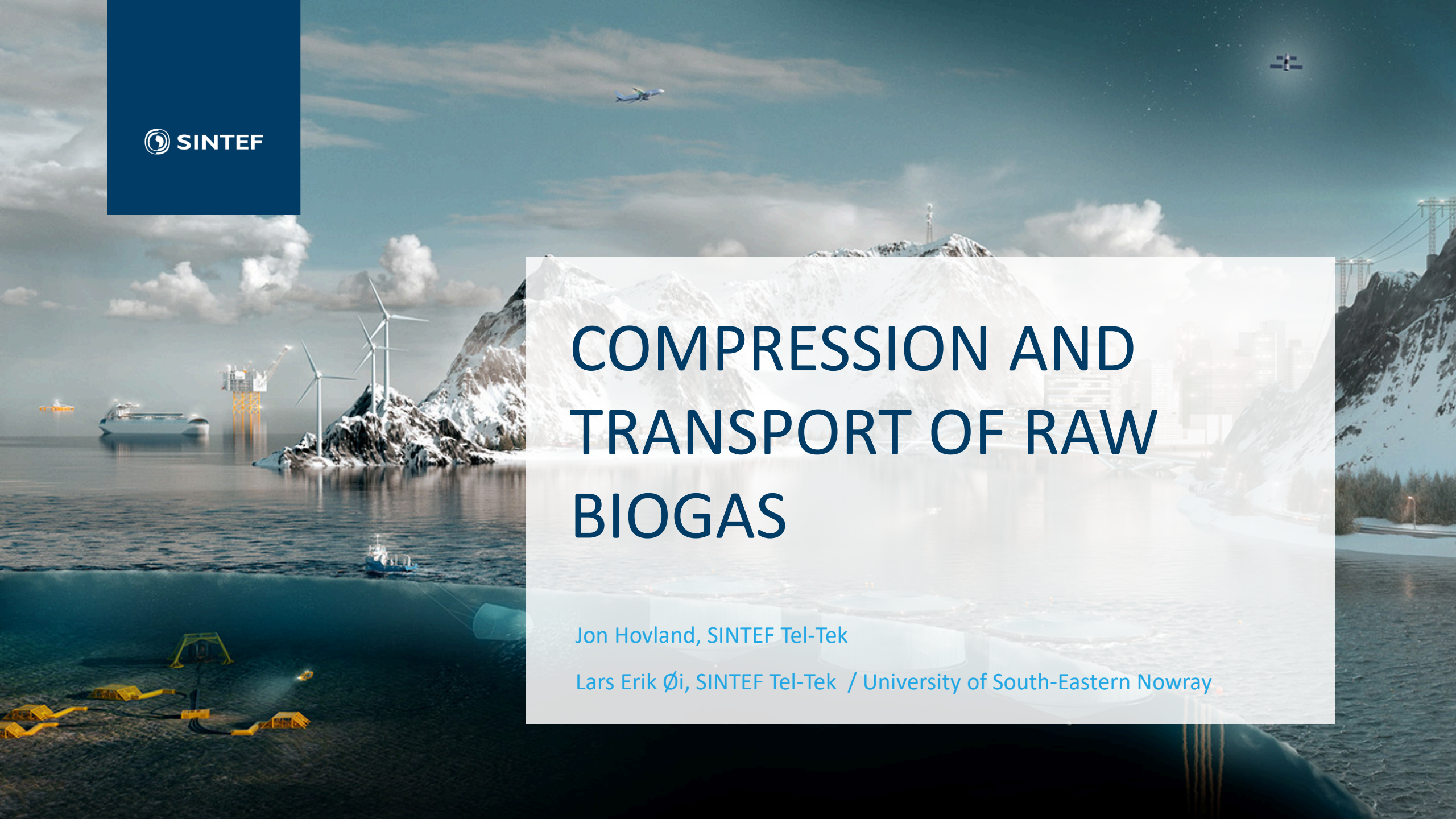

COMPRESSION AND TRANSPORT OF RAW BIOGAS

Jon Hovland, SINTEF Tel-Tek

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One of Europe’s largest independent research organisations

NOK 3.2 billion
Revenues

NOK 450 MILL
International sales

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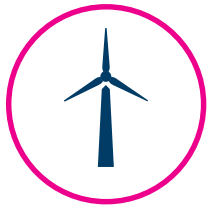
Applied research, technology and innovation

Expertise from ocean space to outer space:


Renewable energy


Ocean space


Industry


Buildings and infrastructure


Materials


Micro-, nano- and biotechnology


Climate and environment


Oil and gas


Health and welfare


Society


Digitalization


Transport

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This presentation:

- Background – why am I interested in compression of raw biogas
  - Including the Norwegian framework
- Why is there a technical issue?
- How to solve it

Why biogas?

Biogas from waste is a good option for:

- Treating organic waste
- Produce renewable energy
- Recycling of nutrients like nitrogen, phosphorus, and potassium back into food production

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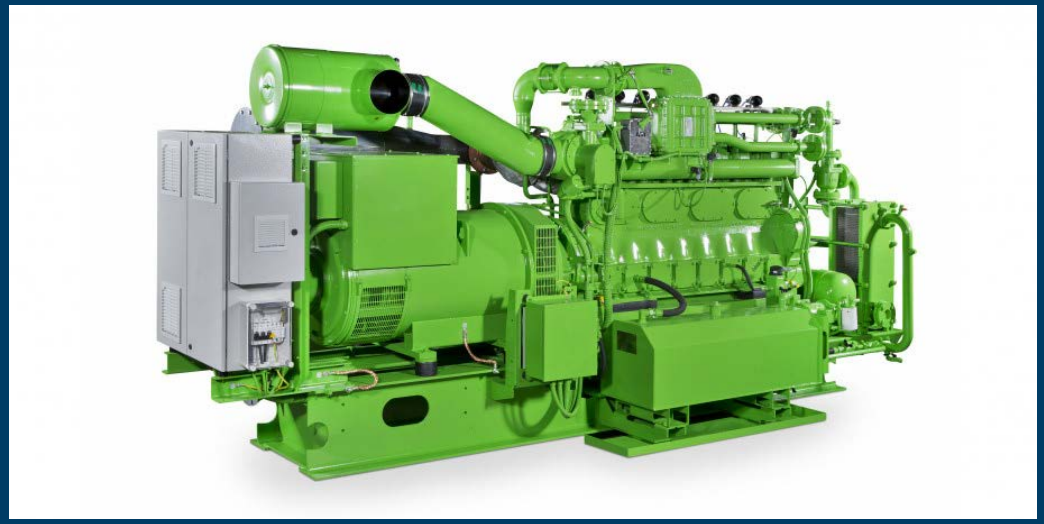
Biogas or biomethane?

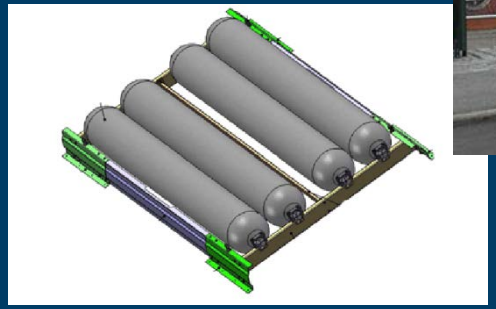
- Biogas (containing CO_2) can be used for stationary applications, heat or combined heat and power (CHP)
  - Normally the gas will need cleaning, removal of H_2S, water vapour, ammonia, siloxanes, etc before use
  - There are several other options for renewable energy in stationary applications, wood fuels, waste incineration, renewable electricity, heat pumps.



Jenbacher gas engine with generator for CHP

Biomethane or biogas?

- Biomethane (cleaned and upgraded biogas, approx. 97% methane) can be used as a vehicle fuel or injected in natural gas pipelines, replacing fossil fuels
- CO_2 has to be removed in addition to cleaning
- Biomethane European standard EN 16723



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In Norway, the best use of biogas is for transportation

- In the Nordic countries, especially Norway, there is a high share of renewables in the electric power mix

- Biomethane (upgraded biogas) should be used for transportation (vehicles, trains, ships)

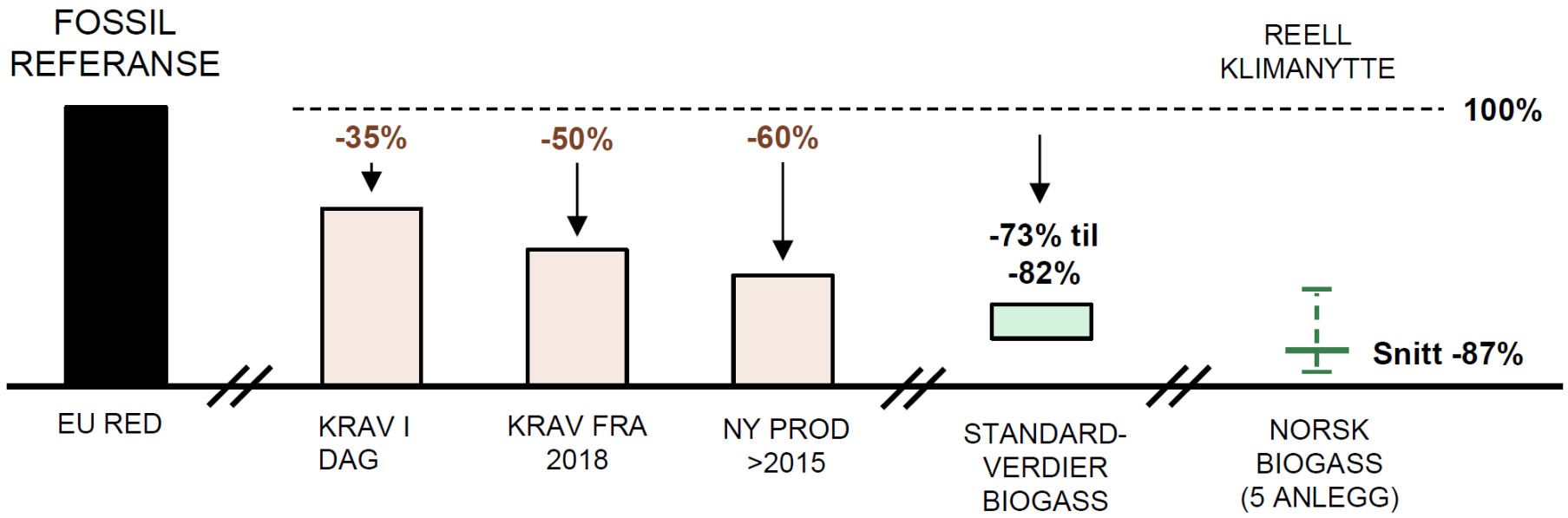
Government regulations in Norway

- No road use tax for the use of methane (bio and NG) as vehicle fuel
  - For gasoline 5.17 NOK/litre = 0.60 €
  - Favours the use of biomethane for road transport over trains and ships

- CO_2 tax
  - None on biomethane
  - CO_2 tax on natural gas, 1 NOK/Sm^3 = 0.10 €

Greenhouse gas – According to RED

Figur 2 Reell klimanytte for norskprodusert biogass, beregnet i henhold til metodikk i Produktforskriften



→ Klimanytten kan forbedres, og kan overstige 100% ved lagring eller utnyttelse av «grønn» CO_2

Figure from A. Pederstad – report for Avfall Norge

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Sustainability – Life Cycle Analysis

Figur 9 Totale klimavirkninger knyttet til verdikjeder for biogass sammenlignet med beregninger ihht. Produktforskriften

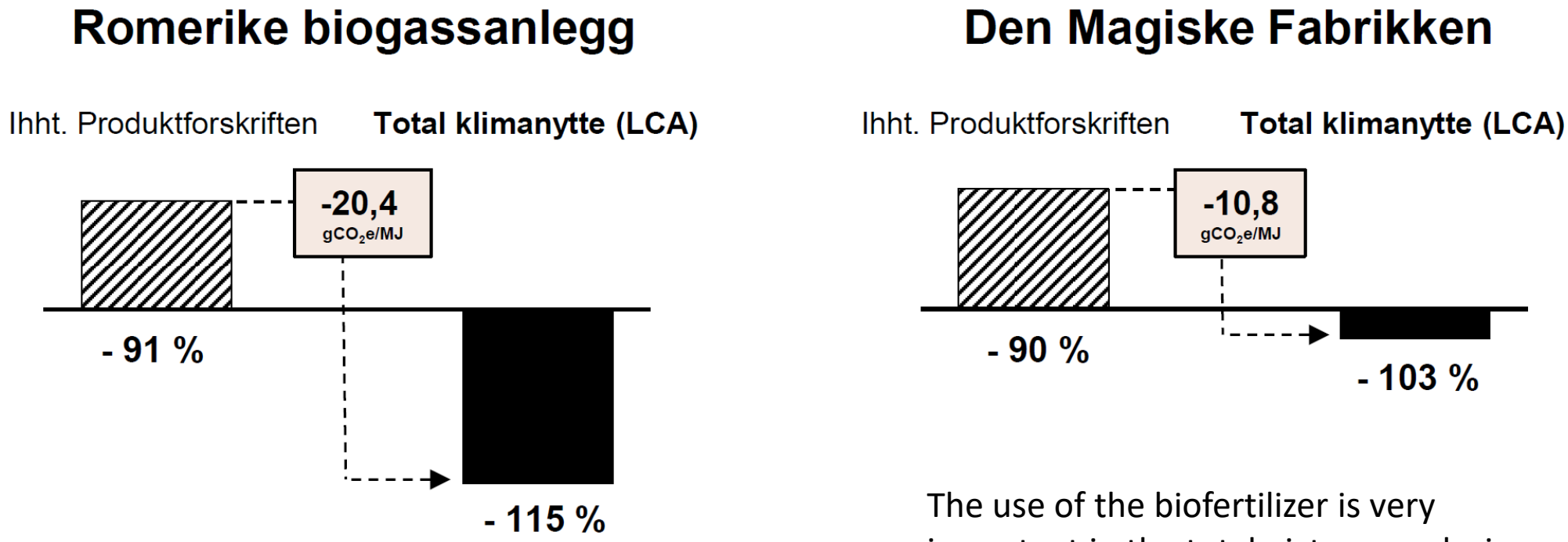

Figure from A. Pederstad – report for Avfall Norge

The use of the biofertilizer is very important in the total picture, replacing N in mineral fertiliser with recycled N, and returning carbon to soil

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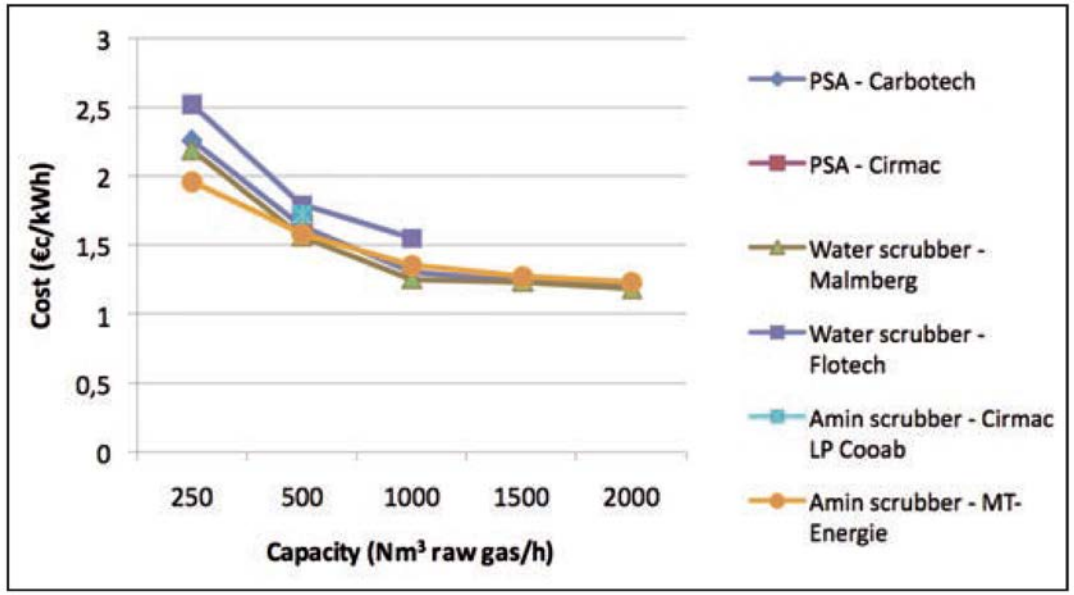
Conclusion:

- We should upgrade as much biogas as possible!
- What are the technical and economic barriers?

Upgrading - cost

- Upgrading of small volumes of biogas is costly
- Lower limit for profitable upgrading is around 100 Nm^3 raw biogas/hour – 800 000 Nm^3/yr
  - For biogas with 60 % methane this is 4.8 GWh/yr
  - At present membranes may be the cost-efficient option for small volumes



"Biogas upgrading technologies – development and innovations" IEA Bioenergy report 2009

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Transport of compressed biomethane (CBG)

- By pipeline
  - Very limited in Norway
- CBG: Biomethane is transported in cylinders at approx. 230 bar
- Cylinders are connected in parallel in a container skip
- Transported with a skip loader truck

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Concept: From medium sized plant to upgrading

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Transport of raw biogas

- Can compressed raw biogas be transported from a production site to an upgrading plant, like one do for CBG?

- Challenges:
  - Water vapour
  - Hydrogen sulphide (H_2S) and other contaminants
  - Corrosion
  - Dry ice formation (solid CO_2)
  - Formation of liquid phase (mixed CO_2 and methane)

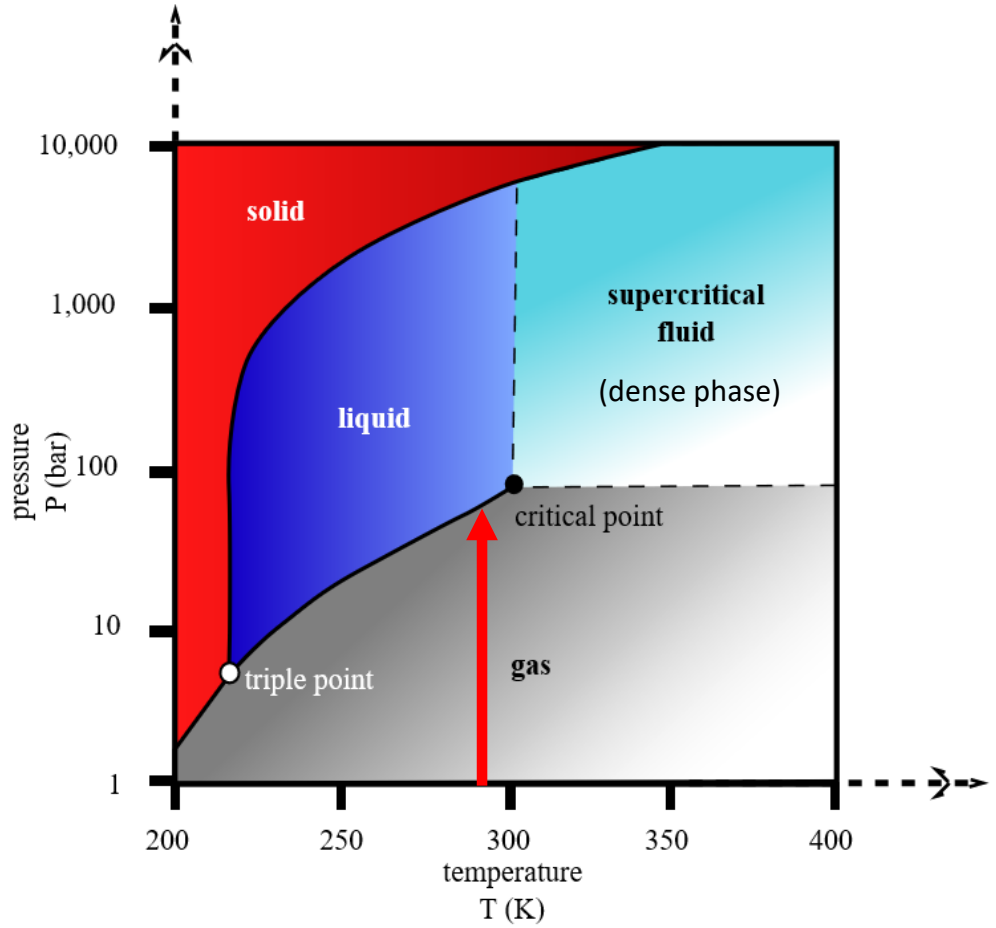
Is it possible?

- In a Norwegian report from 2014 it is claimed based on advice from a major gas supply company that it is not possible to compress raw biogas to more than 120 bar, and thus the concept would be too expensive

- Discussions with colleagues and other gas supply companies led us to believe that this statement needed checking.

First – the properties of CO_2

- Is a gas at ambient temperature
- At cooling forms solid – dry ice – at -78.5 °C (atmospheric pressure)
- Forms liquid when pressurised, e.g. 20 °C / 57 bar
- At temperatures above the critical point (31 °C) gas changes directly to supercritical fluid, also called dense phase, when compressed



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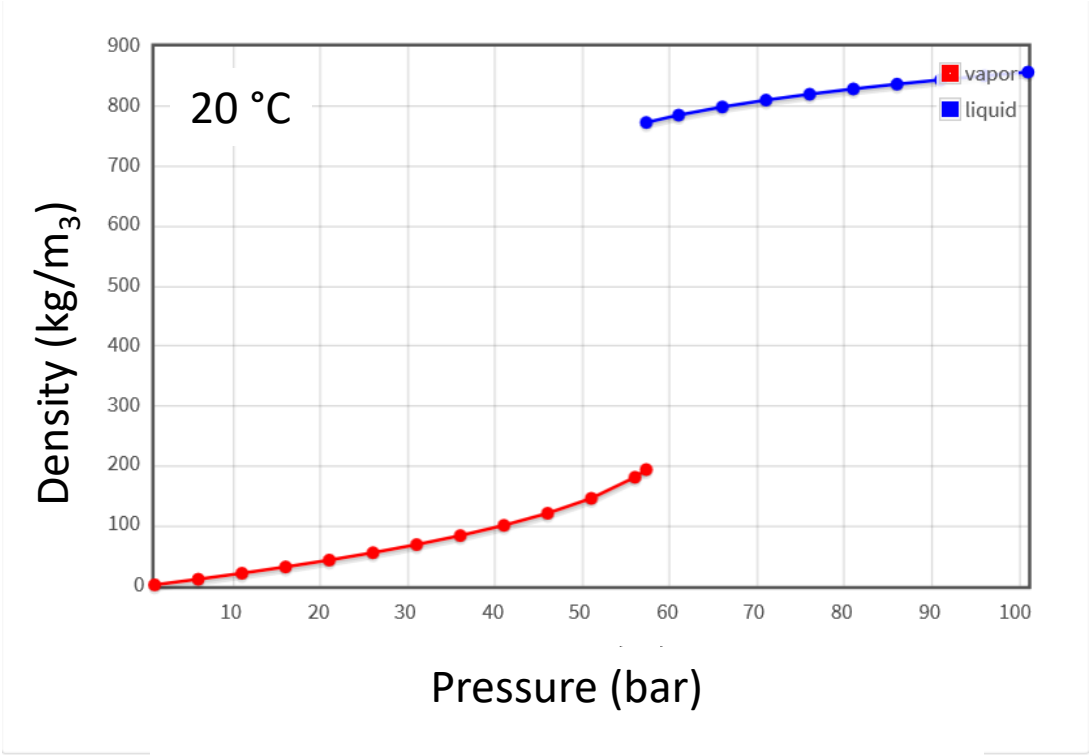
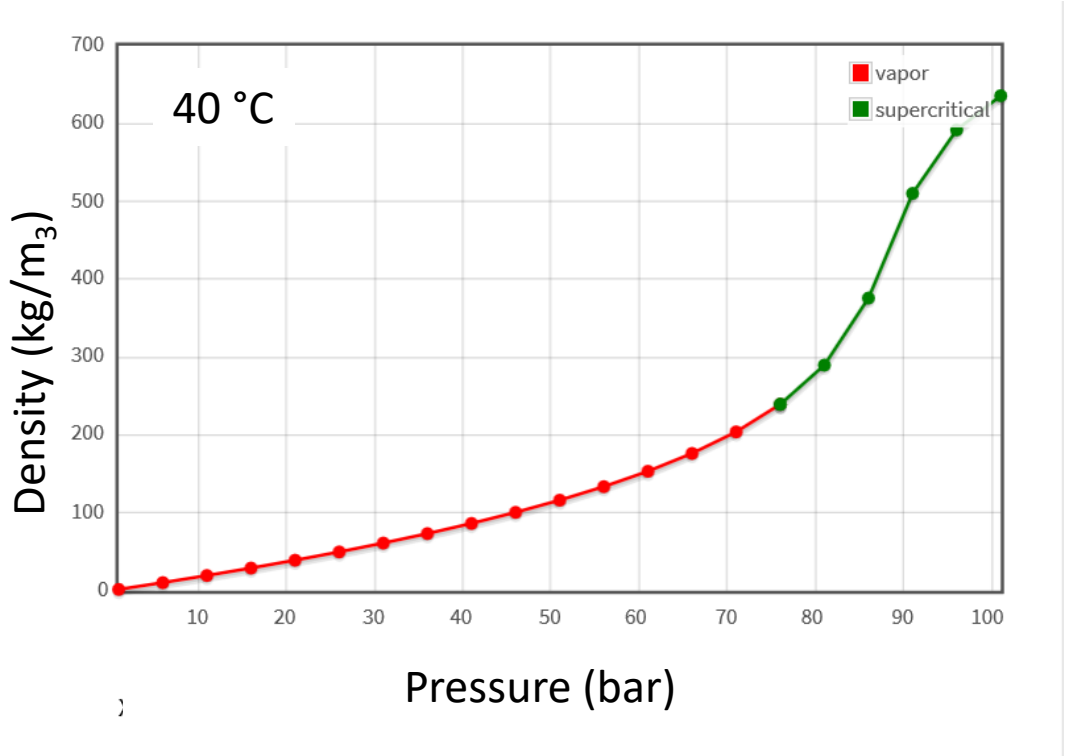
Liquid vs supercritical CO_2





From: https://webbook.nist.gov/chemistry/fluid/

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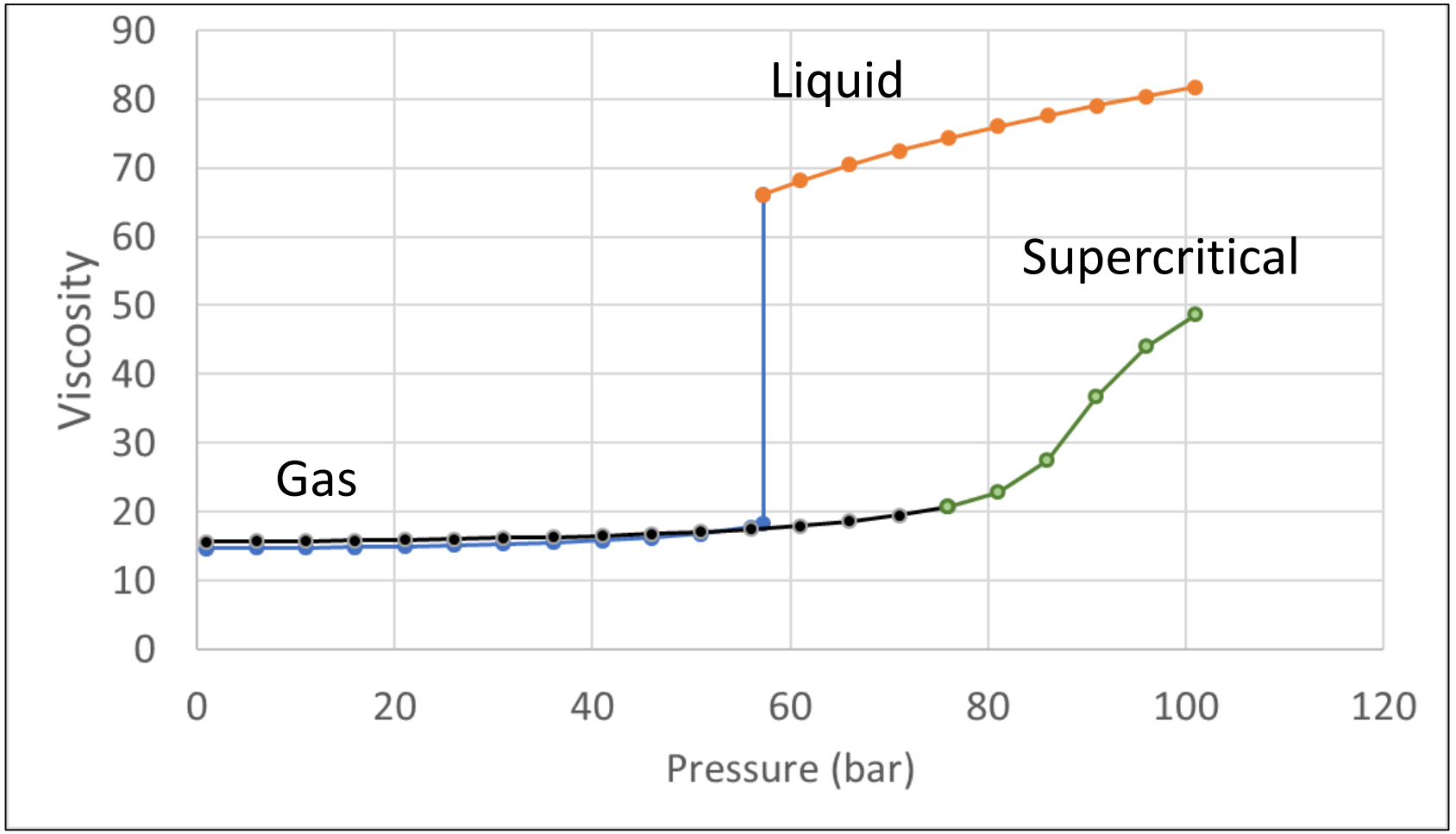
Viscosity of CO_2



From: https://webbook.nist.gov/chemistry/fluid/

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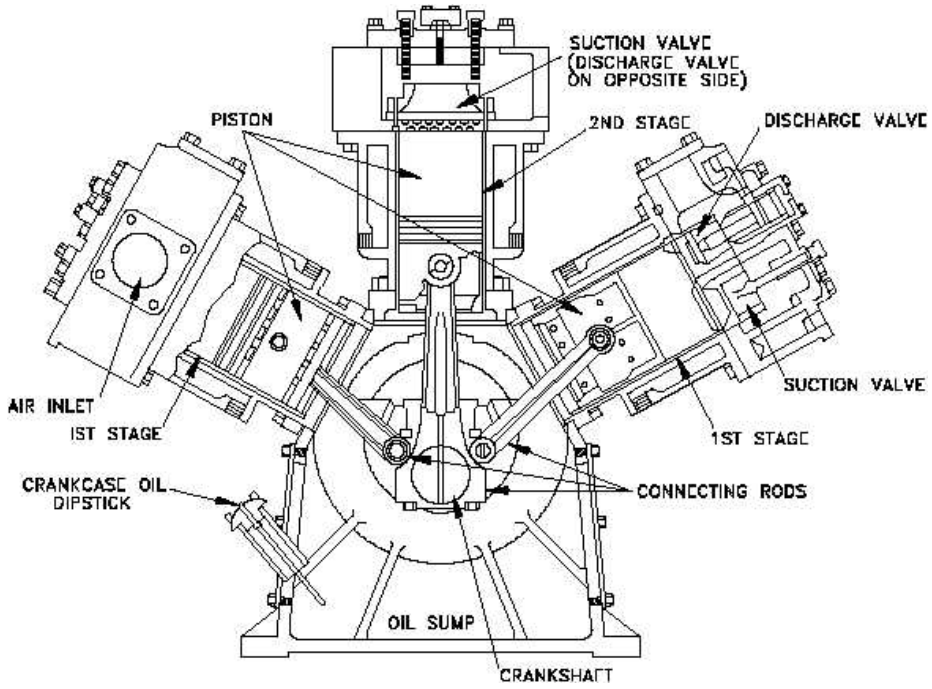
For compression – go supercritical

- Piston compressor cannot handle formation of liquid CO_2
- So, stay in the supercritical range
- Water vapour and H_2S must be kept sufficiently low



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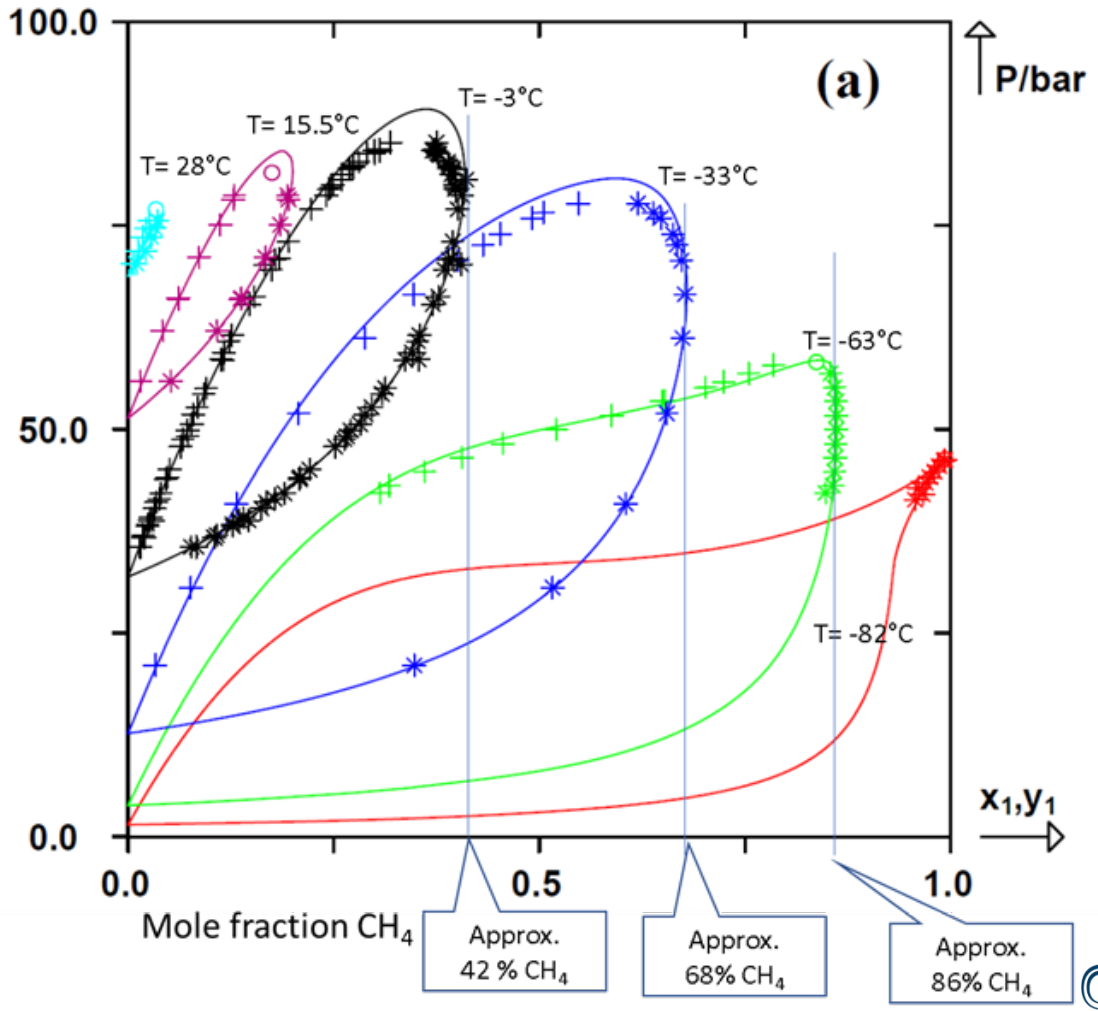
The phase diagram is our guide

- Inside the loops, we have two phases, gas and liquid
- Phase diagrams can be made based on experimental work and mathematical model tools
- There are a number of commercial data programs



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Phase diagram CH_4 / CO_2 at -23 °C

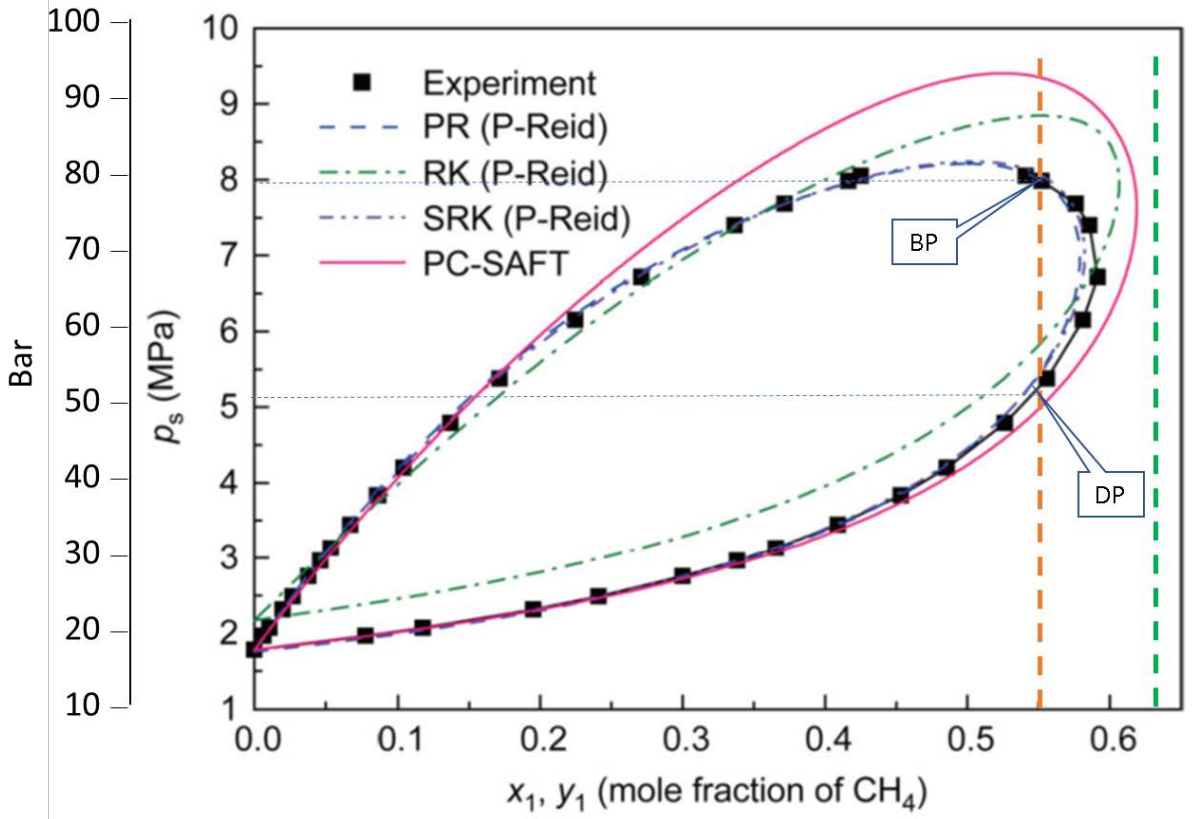

Figure 6 (Color online) 250 K, mole fractions of CH_4 in both phases calculated by different EoS models were compared with the experiment.

Yang, Z.; Gong, M.; Zhou, Y.; Dong, X.; Li, X.; Li, H.; Wu, J., Vapor-liquid equilibria of CH4, CO2 and their binary system CH4 + CO2: A comparison between the molecular simulation and equation of state. *Science China Technological Sciences* **2015,** *58* (4), 650-658.

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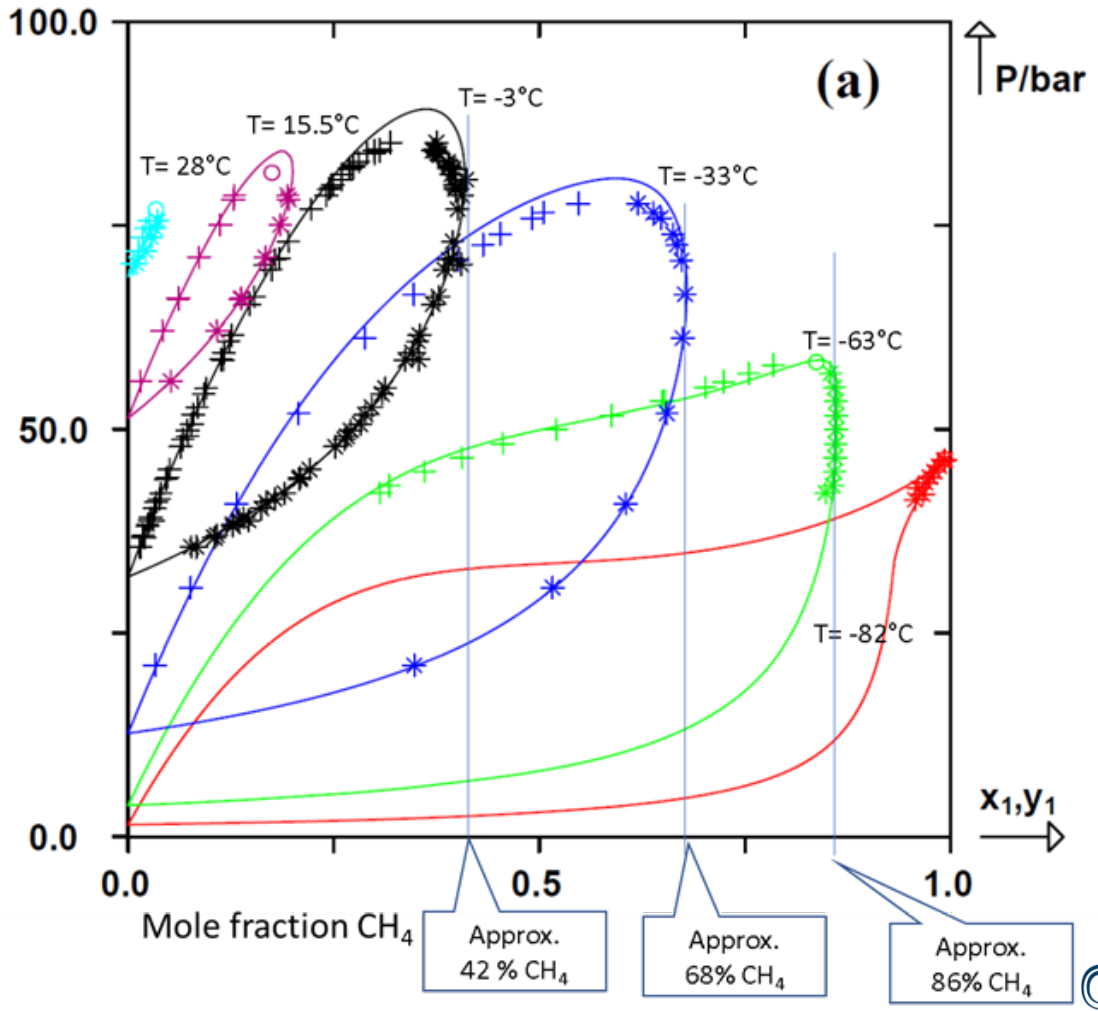

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Both phases contain CO_2 and CH_4

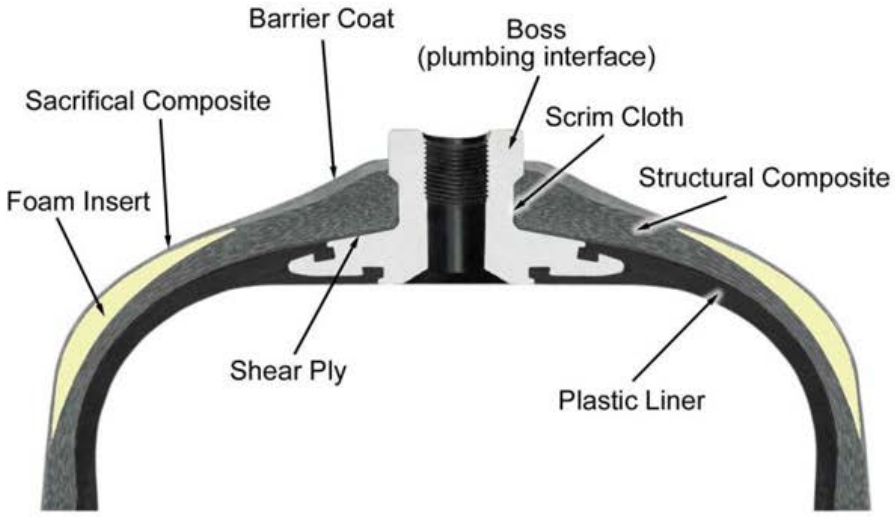
- Compression to form two phases (liquid and gas) and separating the liquid from the gas cannot in practice be used as a method to separate CO_2 and methane
- Both phases still contain both compounds
- The commercial available technologies for upgrading are better with regard to energy efficiency and cost

Decompression at upgrading facility

- At the upgrading plant the cylinders must be emptied – decompression
- When you decompress the gas is cooled – the Joule-Thomson effect
- Can in worst case lead to formation of solid dry ice – plugging valves and tubes
- Solution: ensure correct temperature
  - Heating valves and tubes
  - Control pressure drop

Gas cylinders

- Use composite cylinders, type 4
- Steel cylinders cannot be used due to possible corrosion by CO_2



US Patents: 5429845 – Boss/ Liner Interface, 5476189 - TUFFSHELL ® Layer

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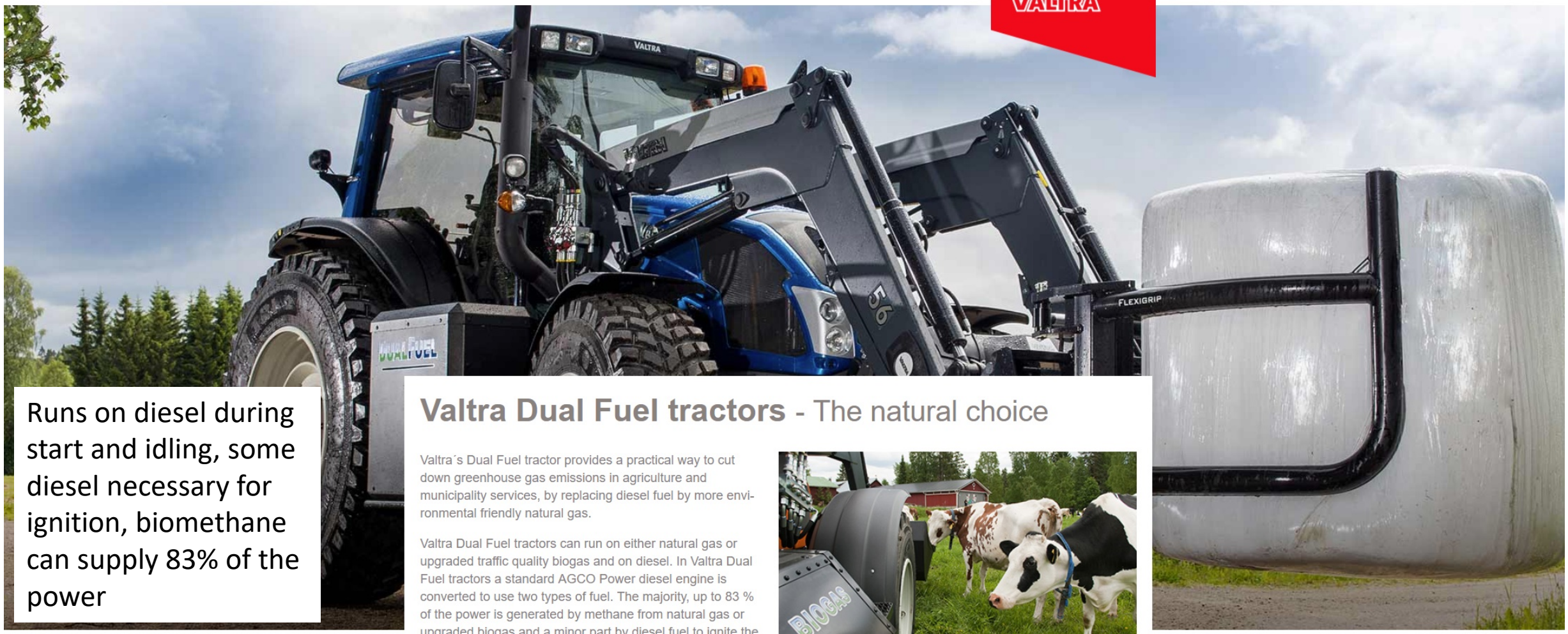
Transport of compressed raw biogas is technically possible

- We don't now the economics – yet
- An estimate is need for the cost – and then we can build a demo

Use of partially upgraded biogas

- It is normal to upgrade biogas to at least 97 % methane, but it is not necessary for the engine
- Pure methane saves tank space

- Are there situations for the use of cleaned and partially upgraded biogas?



Runs on diesel during start and idling, some diesel necessary for ignition, biomethane can supply 83% of the power

Valtra Dual Fuel tractors - The natural choice

Valtra´s Dual Fuel tractor provides a practical way to cut down greenhouse gas emissions in agriculture and municipality services, by replacing diesel fuel by more environmental friendly natural gas.

Valtra Dual Fuel tractors can run on either natural gas or upgraded traffic quality biogas and on diesel. In Valtra Dual Fuel tractors a standard AGCO Power diesel engine is converted to use two types of fuel. The majority, up to 83 % of the power is generated by methane from natural gas or upgraded biogas and a minor part by diesel fuel to ignite the gas- air mixture according to the diesel process.

Valtra Duel Fuel is available with Valtra N Series HiTech and HiTech 5 models N103.4, N113 and N123.

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Can the farmer produce fuel for his tractor?

- All the elements are available in the market – never been put together for this purpose
  - Even at home filling station for gas
- 80% methane is sufficient to avoid liquid phase formation at – 50 °C
  - Avoiding liquid phase when pressure in the tank drops during use
- What does it cost?
- A pilot is necessary!

Connie Jones with her 2003 natural gas powered Honda Civic and natural gas home refueling station located on the garage wall of her home in Chandler, Arizona, October 3, 2013. REUTERS/Ralph D. Freso

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Teknologi for et bedre samfunn