Bio-LNG Improves your Carbon Footprint

Dr. Mattias Svensson

Swedish Gas Technology Centre

3rd Small Scale LNG Forum 2014

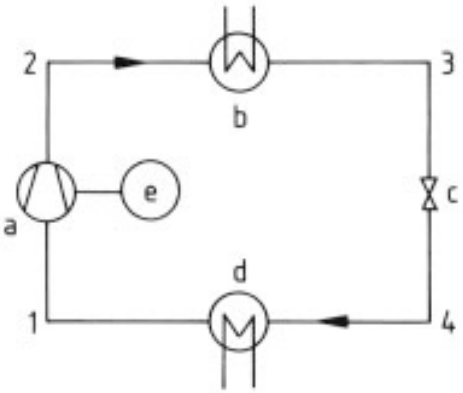
SGC Svenskt Gastekniskt CenterAB

The technology and economy of liquefied biomethane production

1. Cryogenic upgrading followed by liquefaction (or not)

Basics of liquefaction

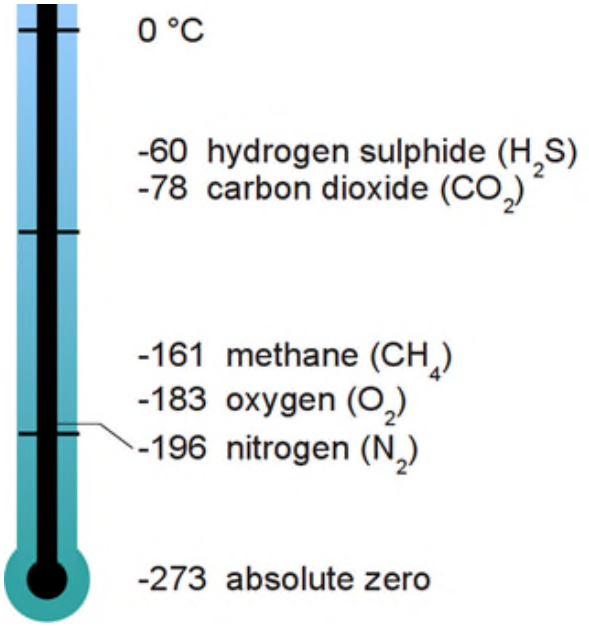
N2 expansion process: a) compressor b) condensor c) expansion valve d) evaporator

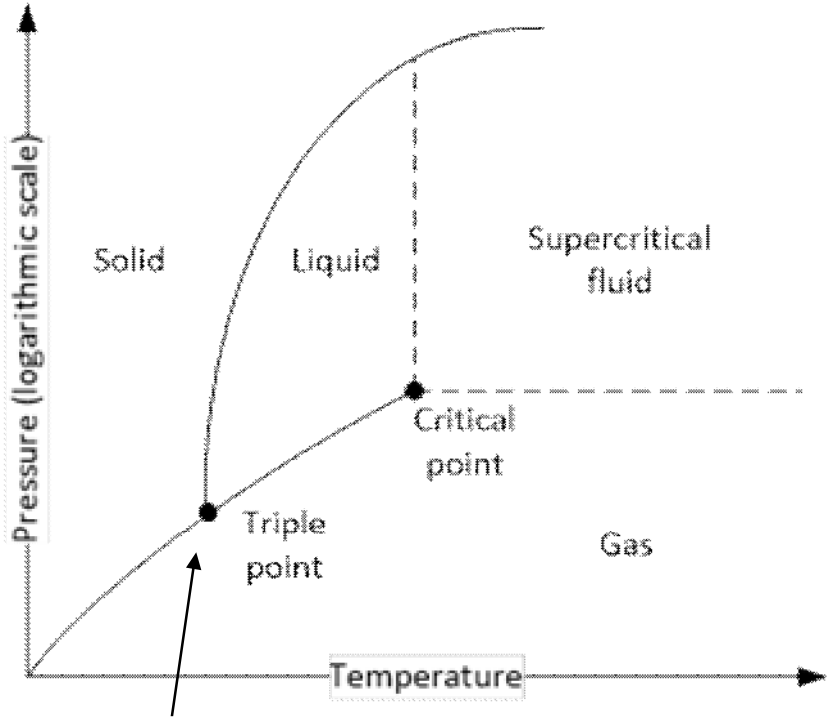


- **Direct or indirect cooling**
  - Refrigerant and upgraded biogas cooled directly through compression and expansion
  - Incoming biogas cooled indirectly through heat exchange with the refrigerant or other cool product streams
- **Energy efficiency and good economy is the challenge**
  - Multi-stage cycles (reverse nitrogen Brayton cycle) – easy to design but have inherent efficiency limitations
  - Mixed refrigerant cycles more energy efficient but choice of refrigerant boiling point characteristics need to be adjusted to fit each application (makeup of the raw biogas)

Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

Cryogenic upgrading





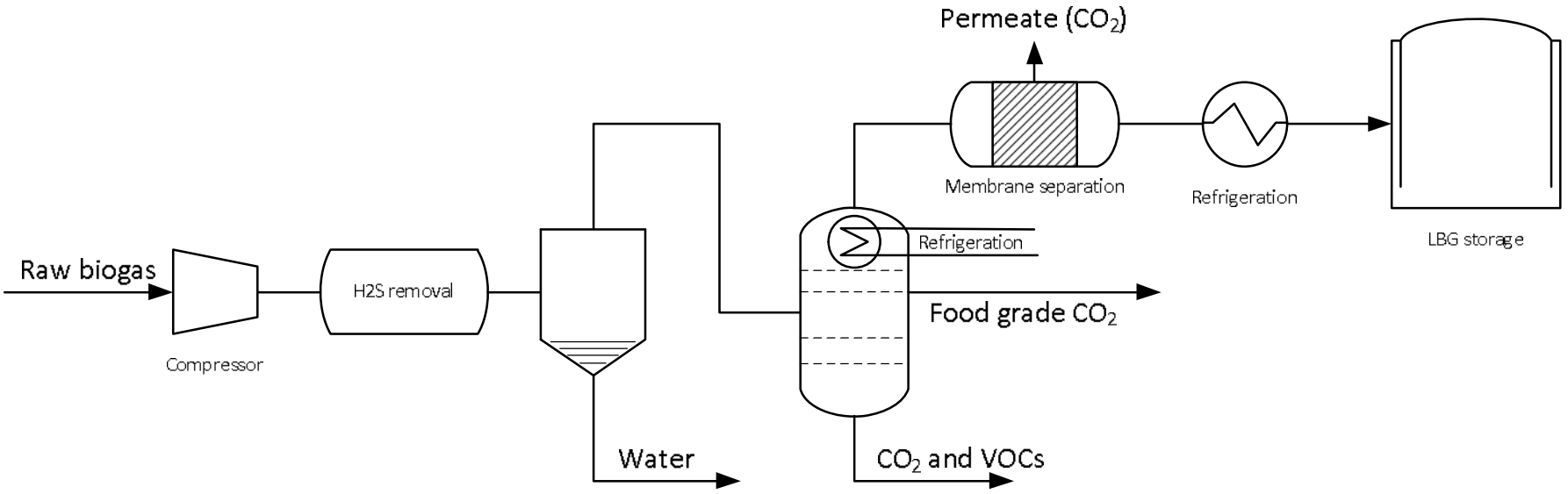
-56.6°C and 5.2 bar(a).

- **CO2 removal the most challenging**
  - Sublimates to solid and/or condense to liquid when chilled

Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

CO2 wash ® cryogenic upgrading

- **Acrion/Firmgreen, CBG licence passed to Terracastus***
- **0.76 kWh/Nm³ raw gas (15 % energy loss)**
- **Sites close to completion, on hold (?):**
  - Novo Gramacho landfill, Rio de Janeiro (Firmgreen)
  - NSR, Helsingborg SWE (Terracastus)



*Business activities suspended due to owner (Volvo) wanting to sell the company

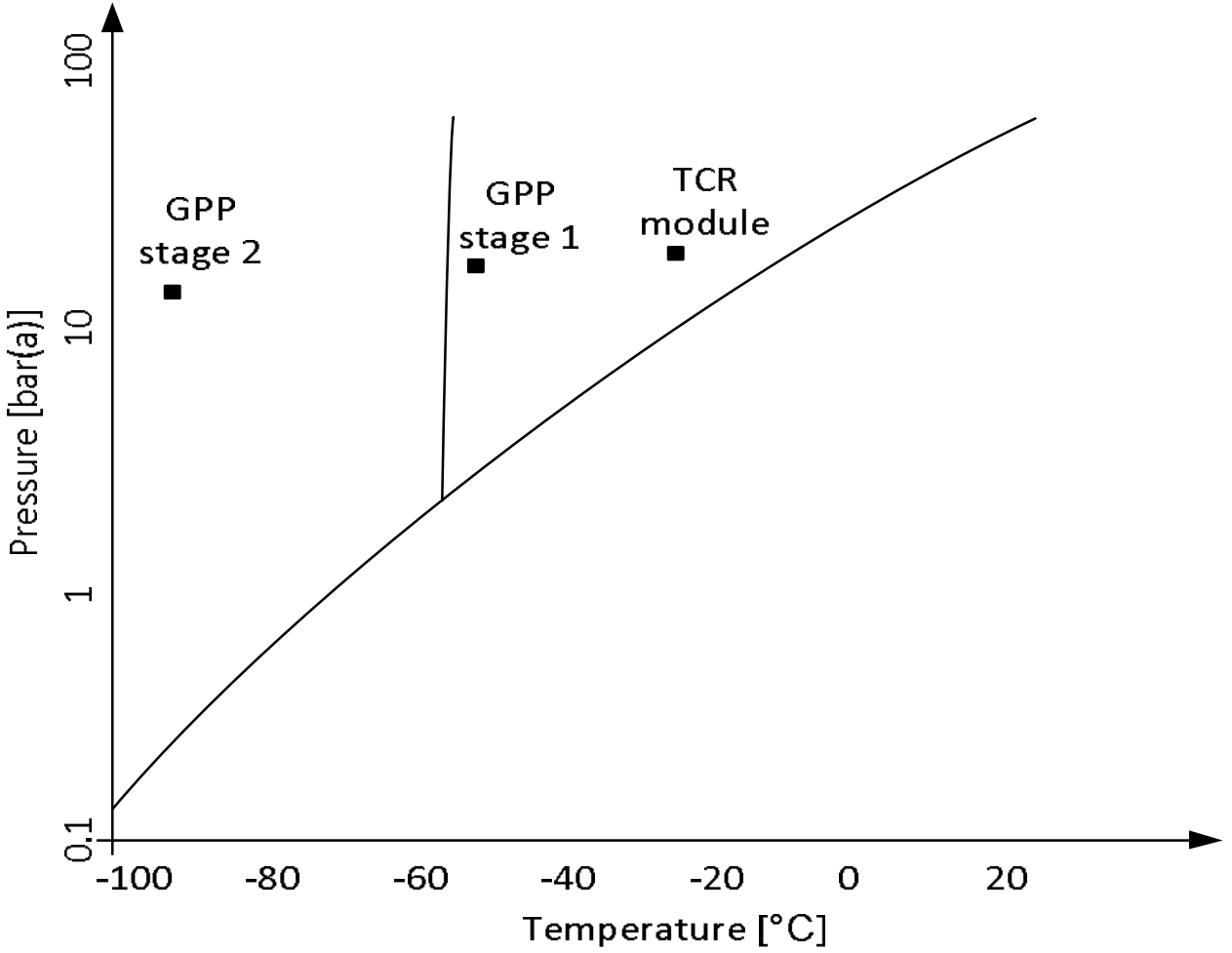
Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

GtS modular cryogenic upgrading

GPP+: Compression and flashing produces LBG

Upgrading energy requirement dependent on CBG and LCO2 streams used for cooling or not

Only existing cryogenic upgrading facility in operation? – Schoteroog landfill + Rijnland WWTP, Haarlem NL



Footnote? 1990-2006 in the US, Prometheus Energy (5 TPD,1,54kWh/Nm3 product gas)

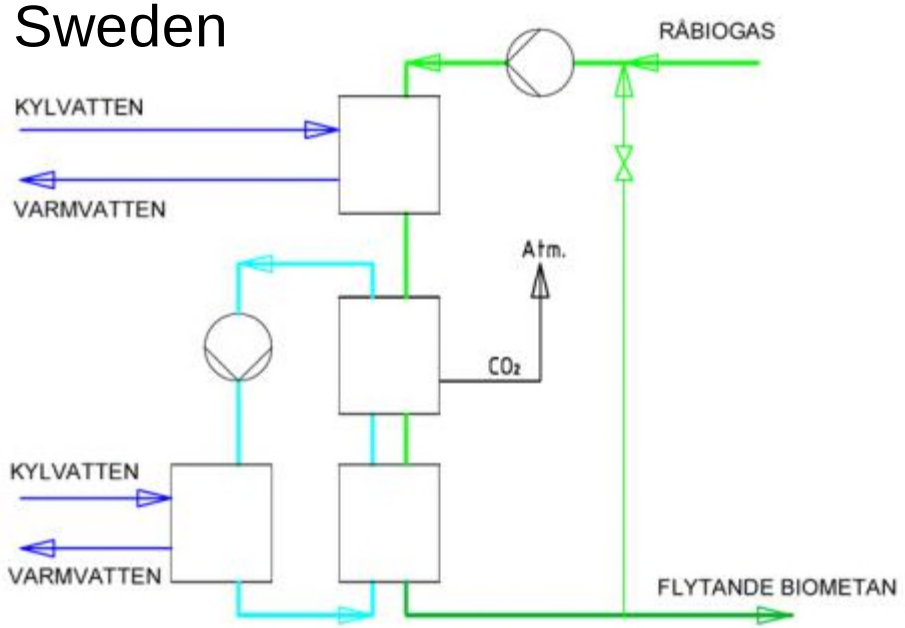
Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

TCR = Total Contaminant Removal; GPP = Gas Treatment Power Package

LBG from farm based biogas?

- **Really small scale cryogenic upgrading – is it feasible?**
  - Using standard equipment, module based
  - 35 Nm3/h raw biogas flow <-> 360 kg LBG/day
  - 10-15% energy loss; 35 kW heat (60 degr) and CO2 for greenhouse utilisation
  - Pilot plant in Borås, Sweden

BIOfrigas



Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

The technology and economy of liquefied biomethane production

2. Normal biogas upgrading followed by small-scale liquefaction

Small scale liquefaction after normal biogas upgrading

- **Purity requirements for the liquefaction of biomethane**

Compound	Limit for liquefaction
Water, H_2O	0.5 ppm
Hydrogen sulphide, H_2S	3.5 ppm
Carbon dioxide, CO_2	50 – 125 ppm

Source: SGC Rapport 270 http://www.sgc.se/en/?pg=1445651)

Small scale liquefaction – Air Liquide

- **Polishing + liquefaction of 60 GWh biogas plant**
  - Reverse nitrogen Brayton cycle
  - 1.56 kWh/kg LBG (1.12 kWh/Nm3 CH4)
  - -163 bar at 1.5 bar(a) product stream
  - 1MW at 45 degr waste heat stream
  - 84 MSEK CAPEX (10 MEUR)

The Lidköping plant, liquefaction supplied by Air Liquide (source: Göteborg Energi)

Small scale liquefaction – Wärtsilä

- **Polishing + liquefaction of 40 GWh biogas plant**
  - Mixed refrigerant cycle
  - 0.5-0.6 kWh/kg LBG (estimated)
  - 3-25 TPD capacity (170 - 1,440 Nm3 CH4/h)
  - -160 bar at 2 bar(a) product stream
  - Oslo plant:
    4.5 MEUR CAPEX,
    600 Nm3 CH4/h
    (10TPD)

The EGE (Oslo) plant, liquefaction supplied by Wärtsilä

Source: Wärtsilä

Small scale liquefaction – GTI

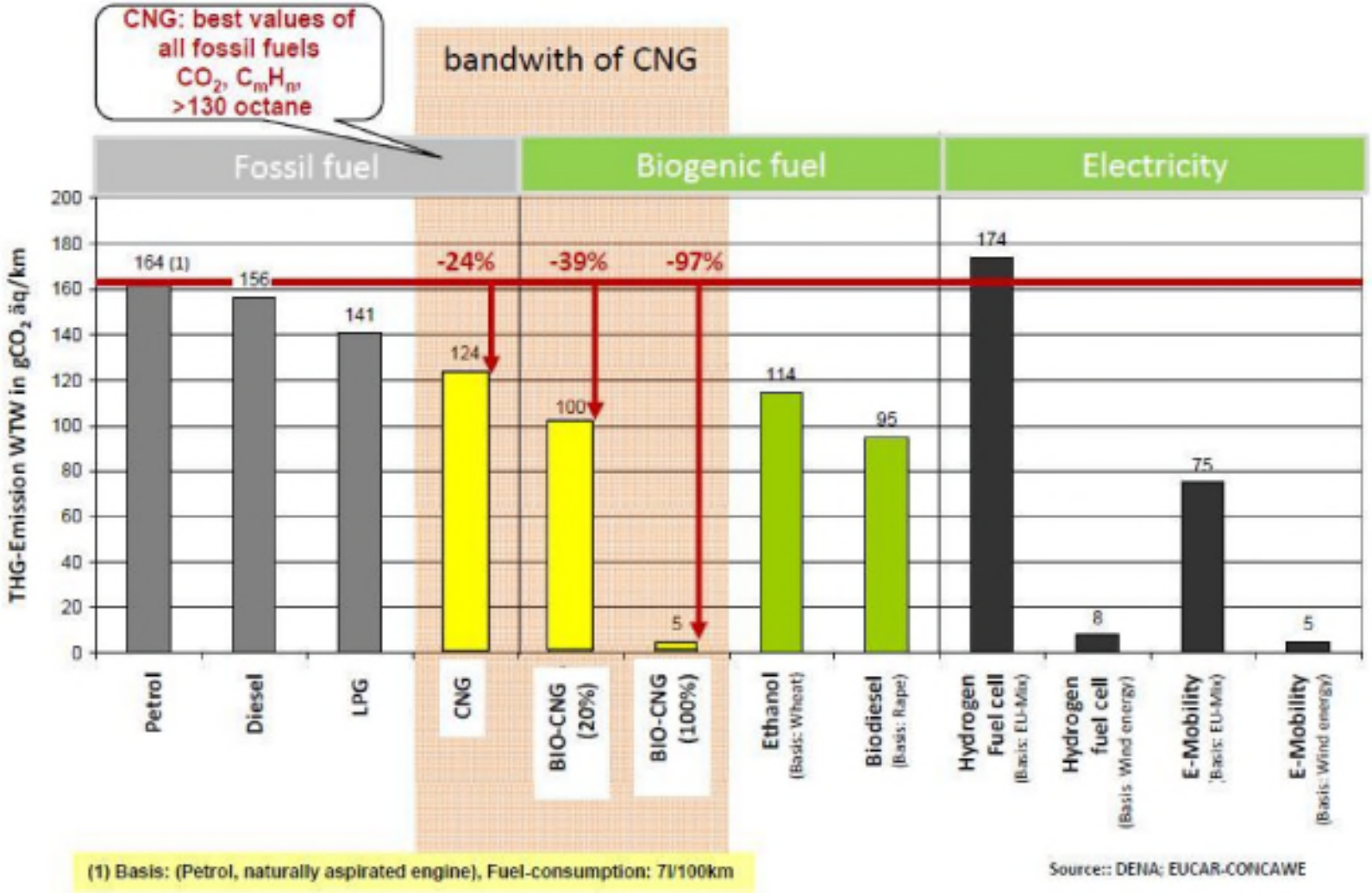
- **Linde Gas/GTI process**
  - Mixed refrigerant cycle
  - Larger scale, down to 30 TPD (1,700 Nm3 CH4/h)
  - 29.3 kWh/MMBtu (1.0 kWh/Nm3 CH4)
- **Known sites**
  - USA, 3 landfill sites (Waste Management)
  - GasRec, Albury landfill

Bild: Waste Management


Bild: Waste Management

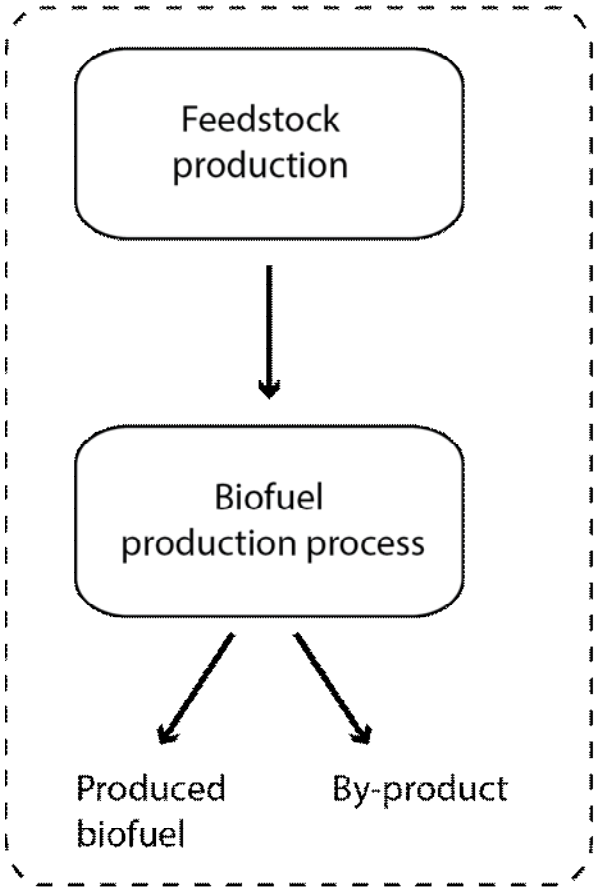
Carbon footprint of biomethane

GHG performance biofuels



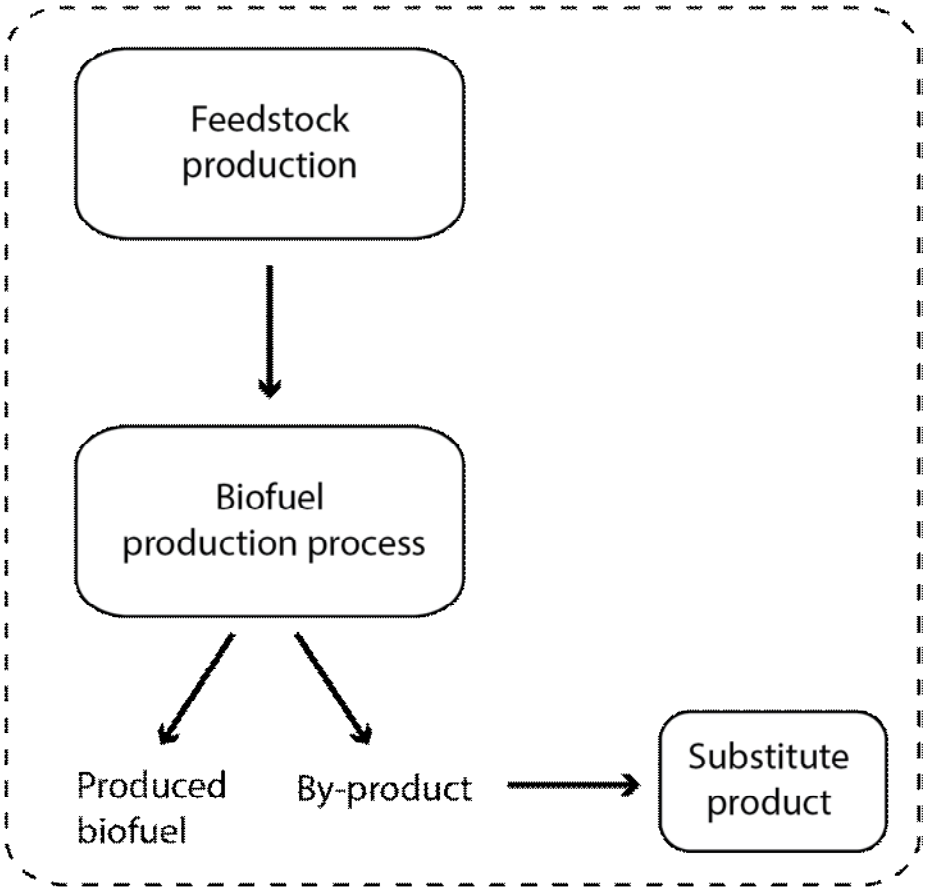
GHG calc. methodology differences

a) System boundary RED



Allocation based onthe energy content of products

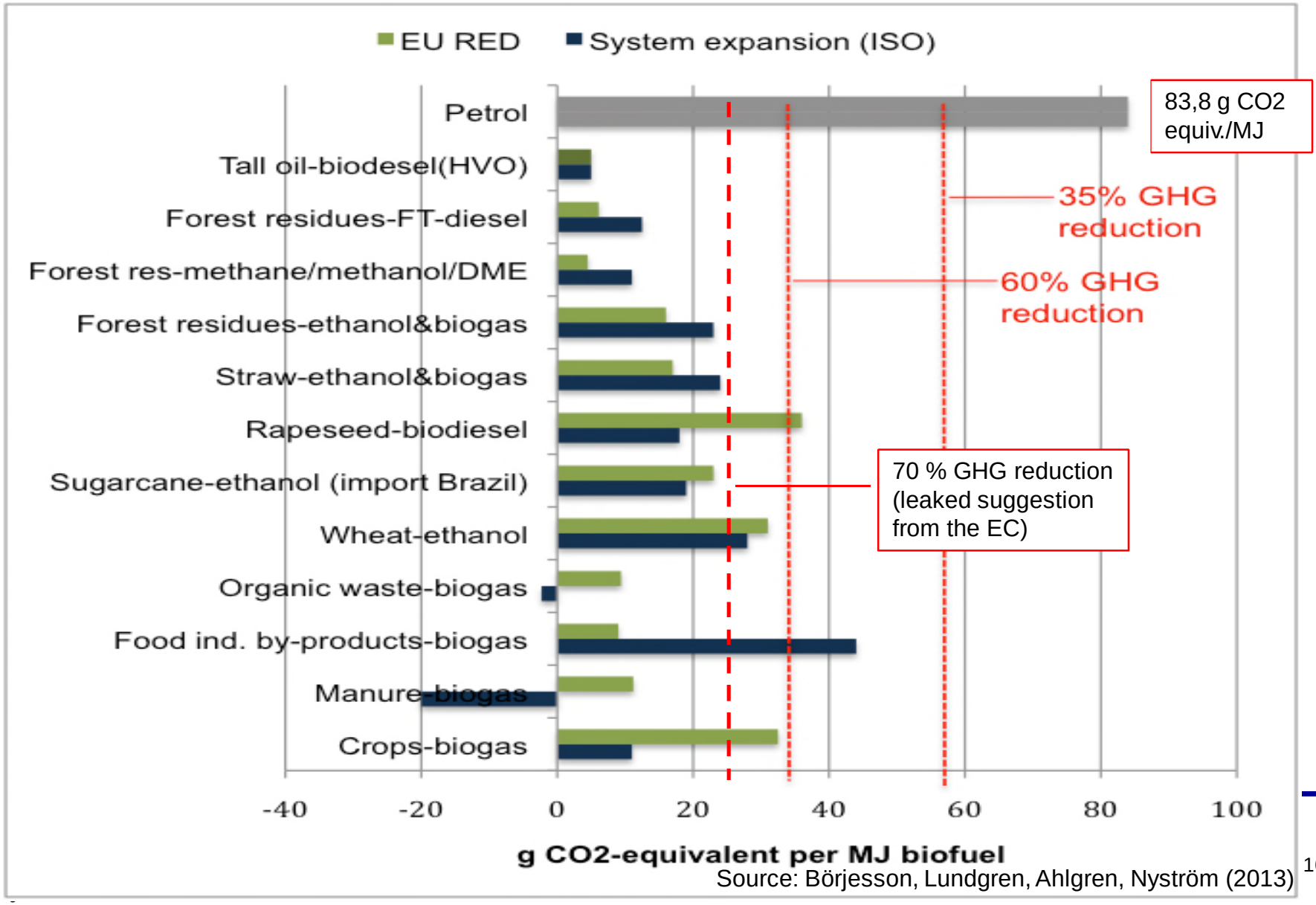
b) System expansion (ISO 140 44)



Including indirect benefits due to replacement of alternative product *(e.g. digestate as fertiliser)*

Source: Pål Börjesson

GHG performance biofuels (SWE)

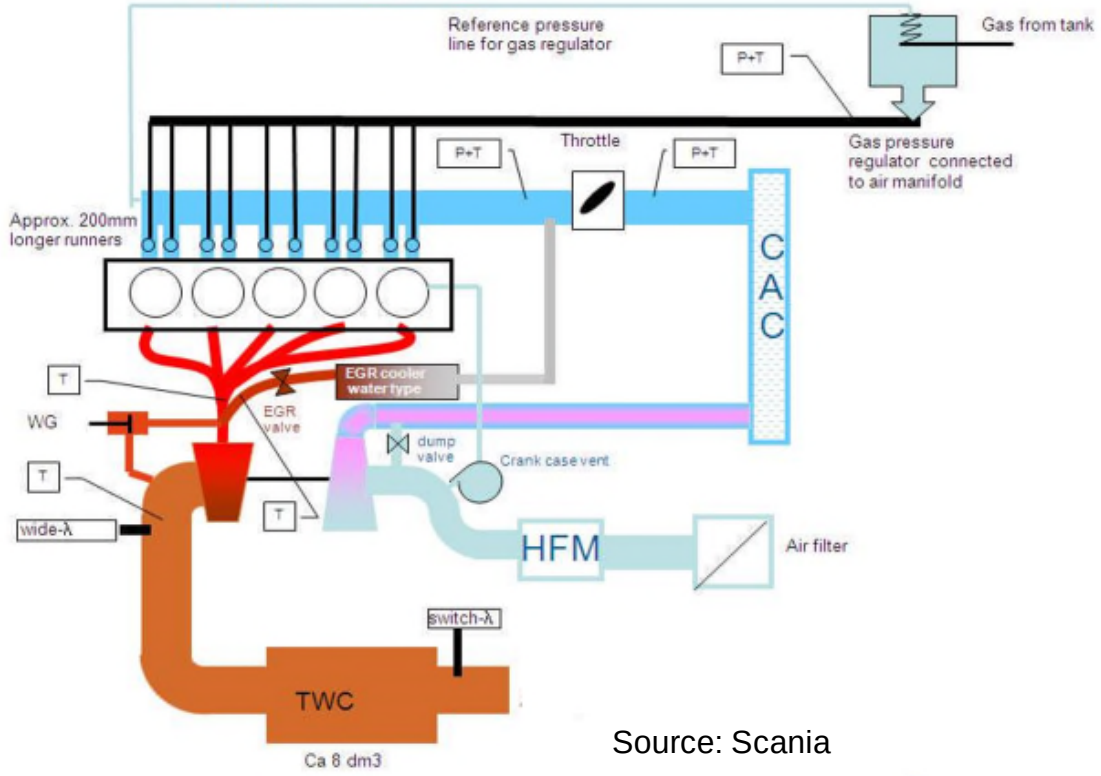


Source: Börjesson, Lundgren, Ahlgren, Nyström (2013)

Overview, LNG powered truck engine technologies

Engine technology options

- **Spark ignited gas engines**
  - Stoichometric (air/fuel ratio lambda = 1) preferred to leanburn (lambda >>1) due to emissions of Nox
  - Typically 30 % higher fuel consumption compared to diesel
  - Limit regarding engine size (< 400 hp)



Source: Scania

Dual fuel engine technologies

Diesel = liquid spark plug

- **Port injected engines**
  - similar in combustion characteristics to dedicated gas engines → knocking limitation at high load
  - 50-90 % substitution rate (load dependent), 100 % diesel also
- **High pressure direct injection engines**
  - Truer diesel process characteristics
  - Only 5 % diesel needed
  - Drawback: Only limphome mode possible on pure diesel

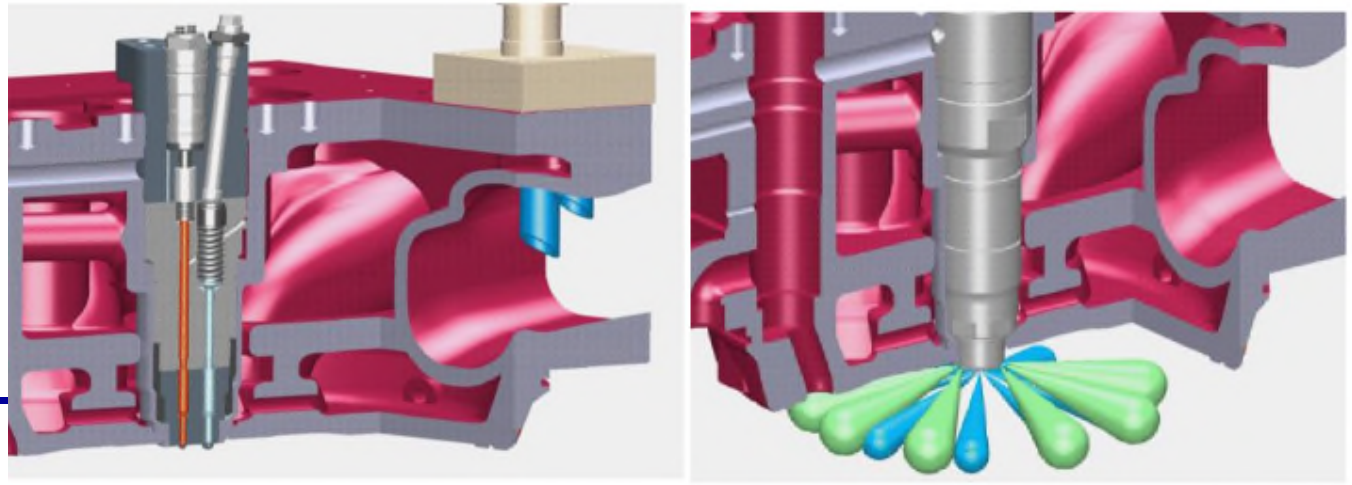


Figure 3. Port injected methane (left)and direct injected (DI) methane (Source: Wärtsilä)

Available trucks with LNG capability

Iveco Stralis - 2014

Scania P-serie - 2014

Spark ignited stoichometric gas engine (280-340 hp)
New Scania only 7% fuel consumption penalty mixed driving!

Mercedes Econic, 2015

Volvo FE CNG, 2015

MAN TGM - 2016

Source: LNG24 presentation

Available trucks with LNG capability

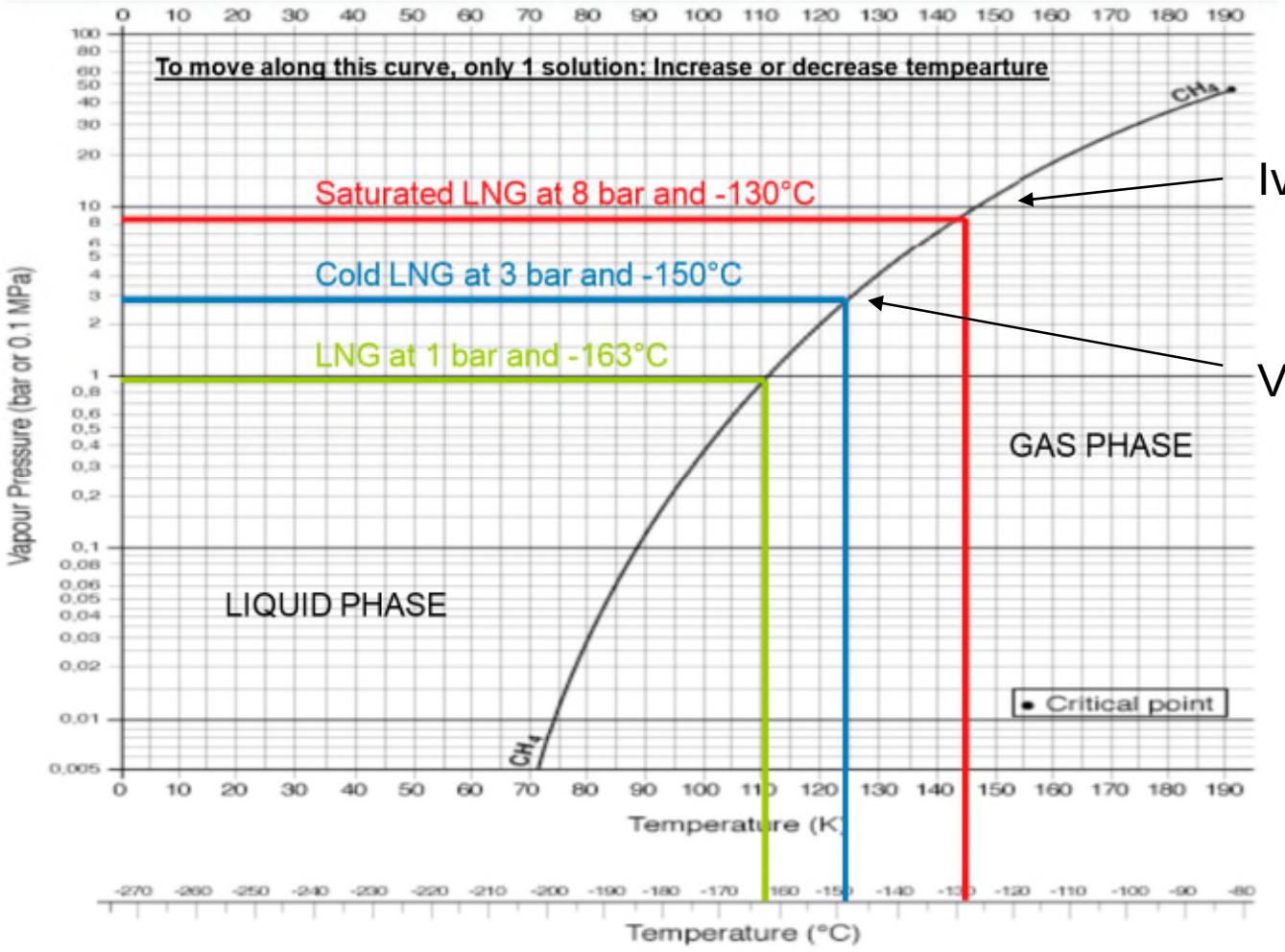
Dual fuel options: Close to diesel like performance (torque, horsepower)

Hardstaff Mercedes Benz Actros
(Euro V)

Volvo FM/FH Euro V
Euro VI next year (HPDI techn.)

Source: LNG24 presentation

Storage pressure: trend towards cold



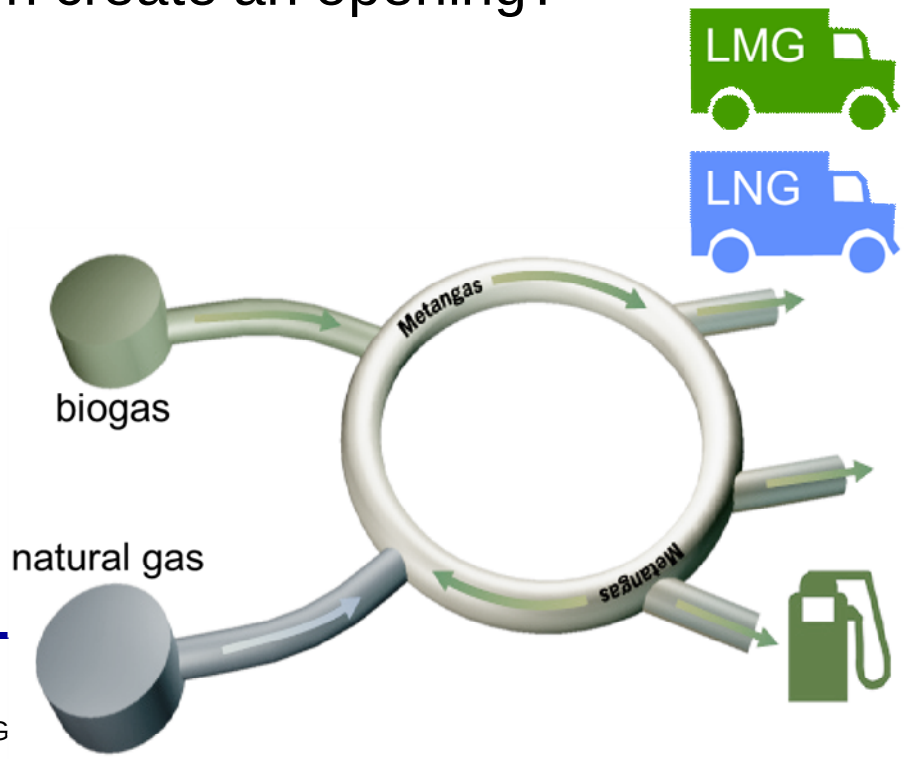
Iveco, Daimler (8-9 bars)

Volvo, Scania (3-4 bars)

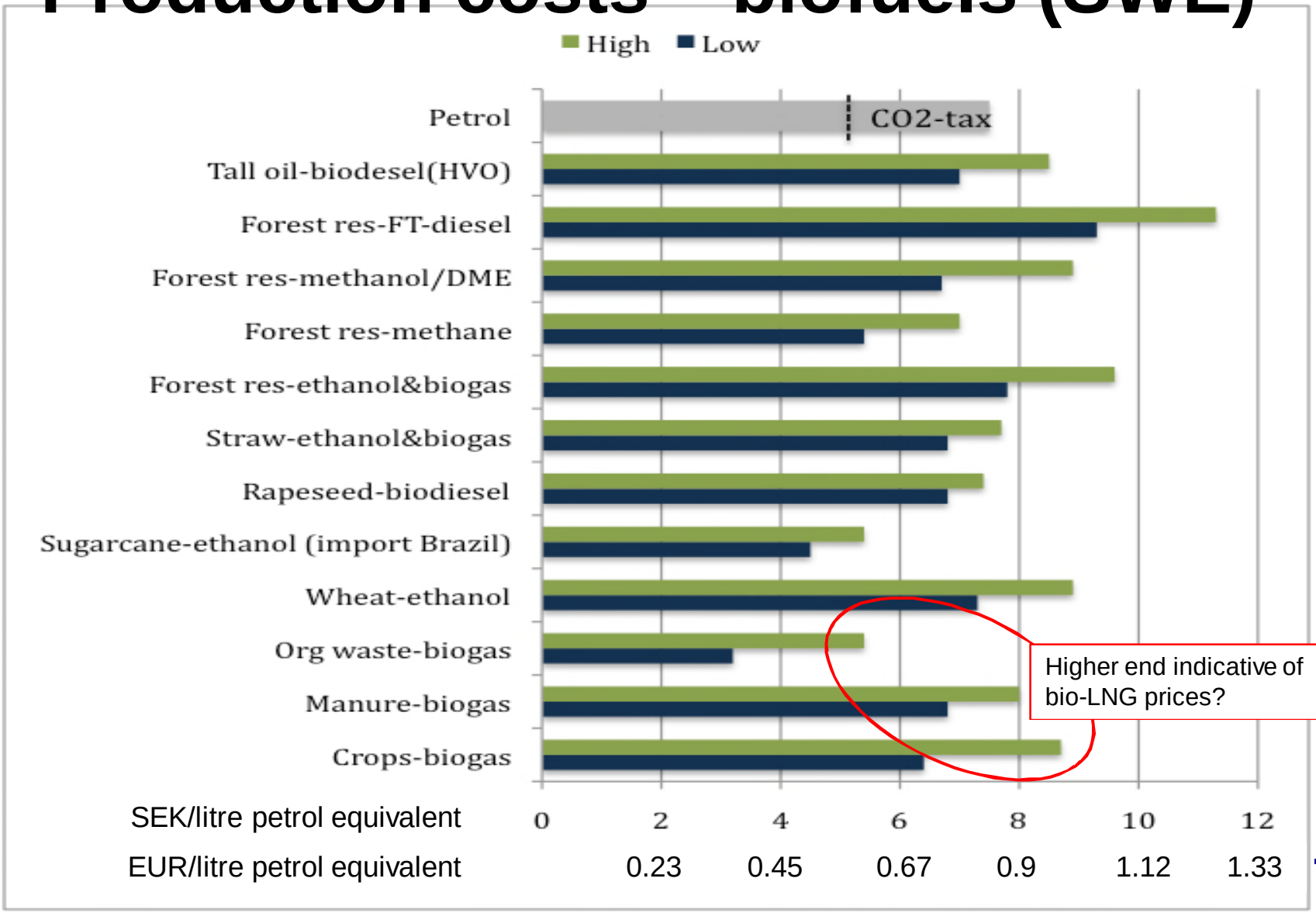
Source: Philippe Heisch, Cryostar

Bio-LNG use in maritime transport?

- **Depends on the customers and the market conditions**
  - LNG is already a big environmental improvement
  - IMO regulations on CO2 a future possible market driver
  - Higher prices in Baltic region create an opening?
  - Green gas principle increase LBG market size!
  - But: RED creates barrier to free cross border trading (mass balance requirement on national level for the grid)



Production costs – biofuels (SWE)



Source: Börjesson, Lundgren, Ahlgren, Nyström (2013)

Bio-LNG Improves your Carbon Footprint

Thank you for your attention!

Any questions?

mattias.svensson@sgc.se

Örnsköldsvik

150323-150325

www.greengasresearch.se

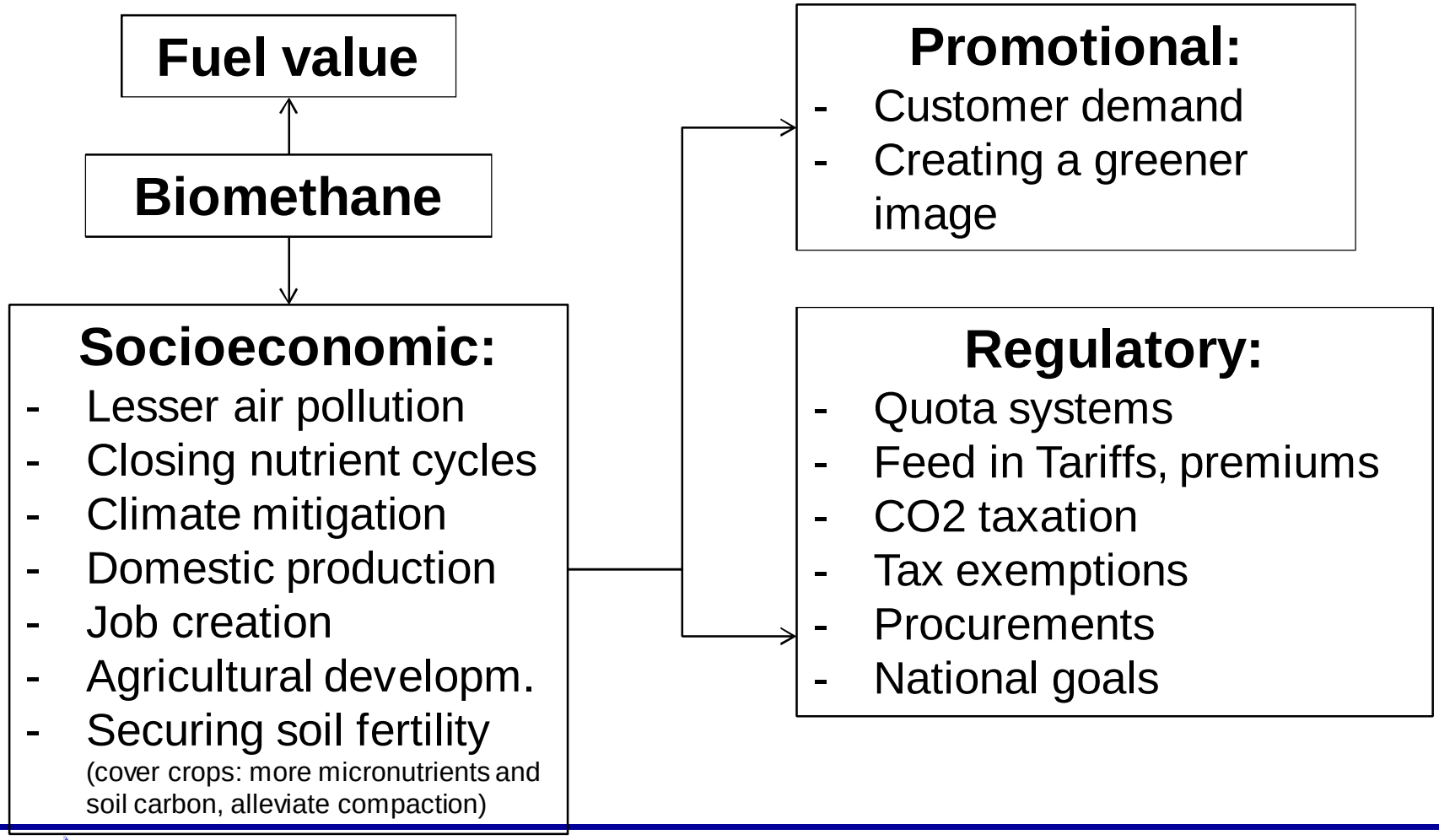
Why biomethane in transports?

Most oil dependent sector in Europe (95-100%)

- **Full utilization of energy with solutions available now**
  - Inevitable heat losses in CHP utilization, wind & sun better alt.
  - Commercially available solutions for oil dependent transports of all types (LDV, MDV, HDV, short, medium and long-distant)
  - Natural gas and biomethane: freely intermixed and interchangeable
  - Evident co-distribution and backup synergies (backup for market fluctuations, process failure)
- **Promotional value compensates for added costs**
  - Steadily increasing the renewable share gives true greening

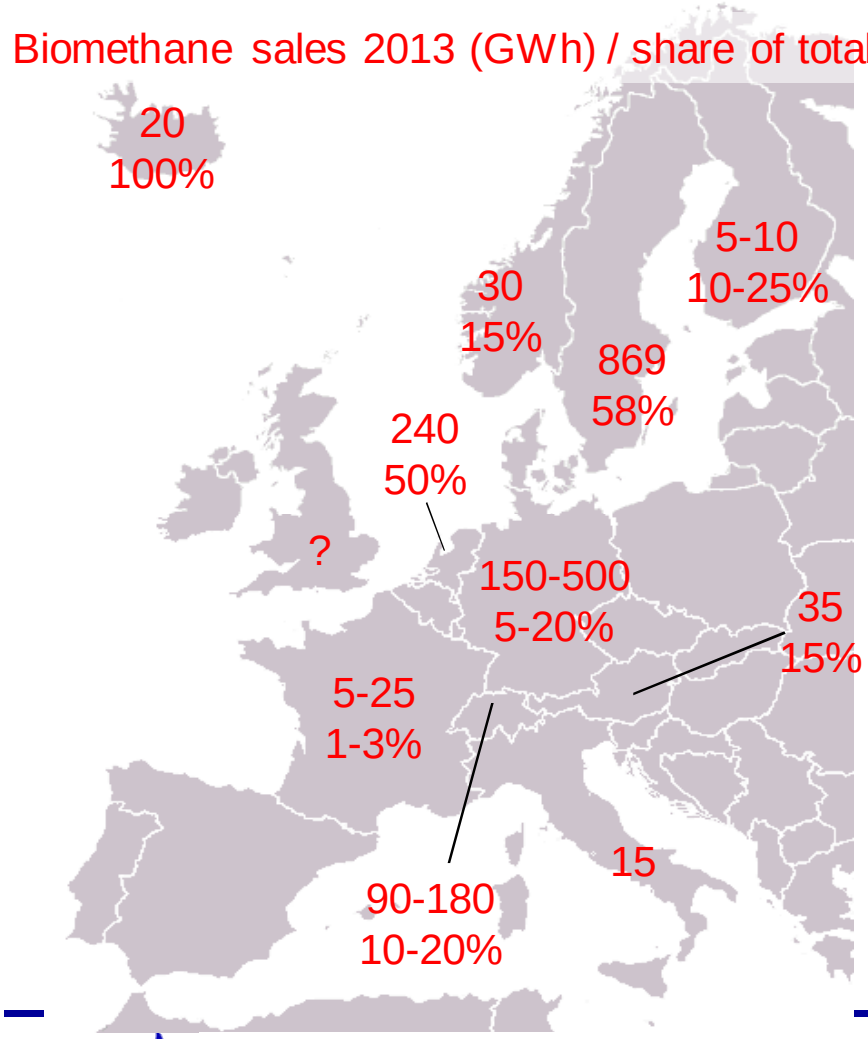
Drivers spelled out

Putting a value on the positive externalities of biomethane



Biomethane in road transport

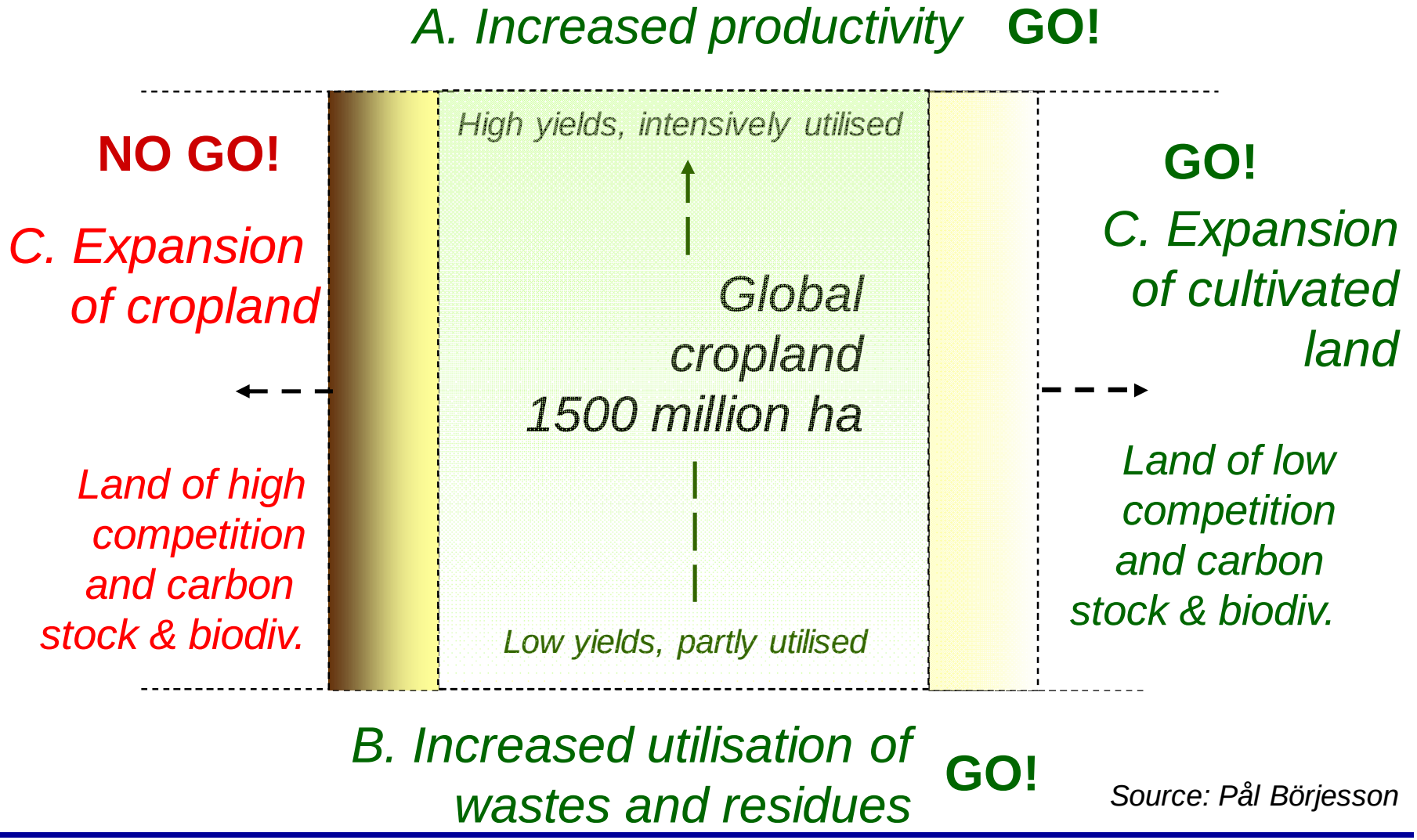
Most common in Europe, Sweden forerunner country



- **Big fleet operations outside Europe; US future no.1?**
  - USA, maybe 1TWh (2014: 3,9TWh expected!)
- **New projects happening**
  - India, Canada, Thailand, Estonia, China, New Zealand, South Korea, South Africa, Brazil
- **Small but growing market**
  - Guesstimate: 3TWh (2014: 6 due to US development)

Sources: European Biogas Assoc., NGVA Europe, newsletters

“Low indirect impact biofuels”
(minimizing risks of indirect land use changes - iLUC)



Source: Pål Börjesson