Liquified Carbon Dioxide – CO2(liq)

Improvement of the carbon footprint and GHG

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TOC

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CO_2 usage

Chemical industry
- Urea production
- Manufacture of drugs / pharmaceutical products
- Methanation (Power-to-Gas)
- Formaldehyde
- Extracting agents

Food & beverage industry
- Carbon dioxide
- Alcohol fermentation (production of beers and sparkling wines)
- Inert gases in foodstuffs
- Cooling and refrigerant agents
- Decaffeinating of coffee

Plastics
- Polyurethane foam
- Polycarbonate (substitute glass)
- Others in development

Building and construction materials
- Concrete and cement
- Asphalt
- Hardwood

Dry ice and cooling
- Dry ice
- Cleaning with dry ice / CO_2
- Refrigerant gases in cooling systems

Industrial gases & liquids
- Oil production (tertiary recovery)
- Cleaning of oil deposits
- Water upgrading
- Cleaning fluids for semiconductor industry
- Cellulose and paper processing

Fuels
- Fuel production
- Renewable methanol production
- Algae based fuel

Others
- Growing/culturing (Greenhouses, cultivation of algae)
- Pressure gas applications
- Welding technologies (steel industry)

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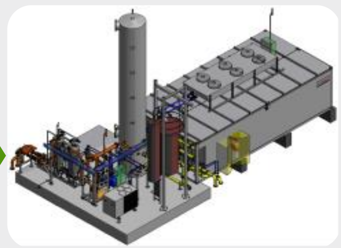
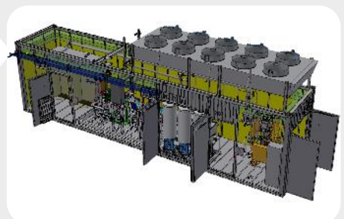
CO_2(liq) from AD plant – biogenic CO_2(liq)

Biogas Plant

CH_4
CO_2



CO_2



CO_2

CH4

e.g. gas grid

Upgrading Plant

- 55% Methane
- 45% CO_2

Liquefaction Plant

- Compression
- Cooling system
- Drying
- Liquefying

Storage Tank

- !! < 31°C

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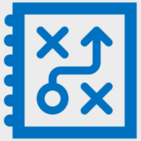
CO_2 sources and comparison

	Agricultural biogas	Biogas from bio-waste	Flue gases
Description	Fermentation of corn, beets, other agricultural products	Food waste; organic waste from agricultural; organic waste from industries	Flue gas from burning wood, coal, oil or gas
Flow CO2	50 – 1000 m³/h	50 – 1000 m³/h	50 – 10.000 m³/h
Contamitants	Small amount of VOC- mostly Ketones Sulfur (H2S)	Huge amount of VOC (Ketones, Terpenes, Alcohols) Sulfur (H2S)	Acetaldehyde; Formaldehyde; light hydrocarbons; NOx; SO2; Air



The sources of the inlet gas will challenge the production costs of the CO_2

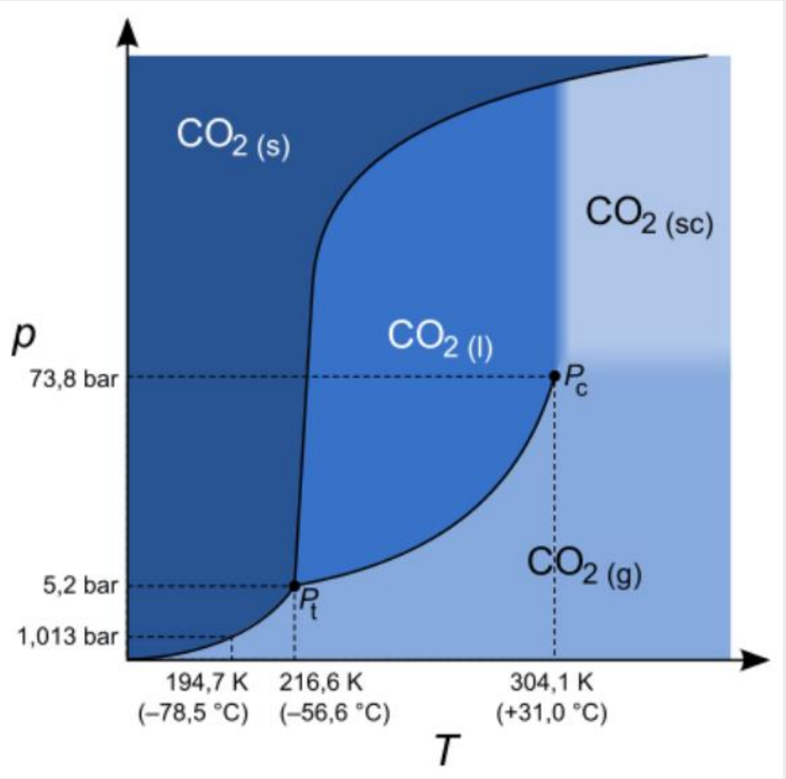
CO_2(liq)

Liquefaction pressure > 5 bar(a)

- ★ compression required
- ★ temperature rises

Liquefaction Temperature Range:

- ★ -56,6° C up to +31° C
- ★ cooling necessary



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CO_2 Liquefaction – Costs view

2) Logistics

1) Production

30 - 65 €/t

Petrochemical industry

50 – 130 €/t

Biogas plants

Production costs

2.1) Filling | 2.2) Transport

a) Road tanker

10-40 €/100km

b) Bottling

Small scale, detailed examination necessary

c) Dry ice

Not relevant

Conditioning and transport costs

3) Demand

Gas provider/ Key account

Gas provider / Key account, whole sale, retail sale

Whole sale, retail sale

Distribution costs

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CO_2(liq) – Costs view

1) Production

30 - 65 €/t

Petrochemical industry

50 – 130 €/t

Biogas plants

Production costs

EIGA / ISBT standards

Specific analytical equipment

3) Quality

The required quality of the CO_2 is the key factor for the production costs

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Guideline for required CO_2(liq) purities

component	beverage grade (ISBT standard)	dry ice	Medical and pharmaceutical
CO_2 purity	≥ 99.9 %		
moisture	≤ 20 ppm		
O_2	≤ 30 ppm		
CO	≤ 10 ppm	In case of utilisation in food industry -> EIGA/ISBT standard.	
NH_3	≤ 2.5 ppm		
NO/NO_2	≤ 2.5 ppm each		
non-volatile residue	≤ 10 ppm (wt)		Niche market with even higher standards
non-volatile organic residue	≤ 5.0 ppm (wt)		
Phosphine (PH_3)	≤ 0.3 ppm		
total volatile HC	≤ 50 ppm		
Acetaldehyde	≤ 0.2 ppm	Different applications similar or lower in comparison to EIGA/ISBT	
aromatic HC	≤ 0.02 ppm		
total sulfur (H_2S/COS)	≤ 0.1 ppm		
SO_2	≤ 1.0 ppm		
specials	no color or turbidity in water		
	no odor; no taste in water		

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CO_2(liq) – Uplift for GHG

$$E = \sum_{1}^{n} S_n \cdot (e_{ec,n} + e_{td,feedstock,n} + e_{l,n} - e_{sca,n}) + e_p + e_{td,product} + e_u - e_{ccs} - e_{ccr}$$

Field Emissions Food Crops

e_{ec}: Field emissions e.g., due to use of fertilizer
e_{ln}: Improved agrigulture practice
e_{td}: transport of substrate
e_{sca}: savings from improved agricultural managemen

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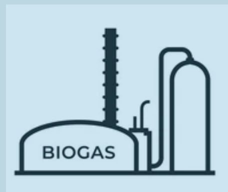
Processing



e_{p1}: Biogas production
e_{p2}: Methan upgrading
e_{p3}: Liquefaction

e_{ccr}: Carbon Capture and Replacement)

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Distribution

e_{td}: Distribution of LBG

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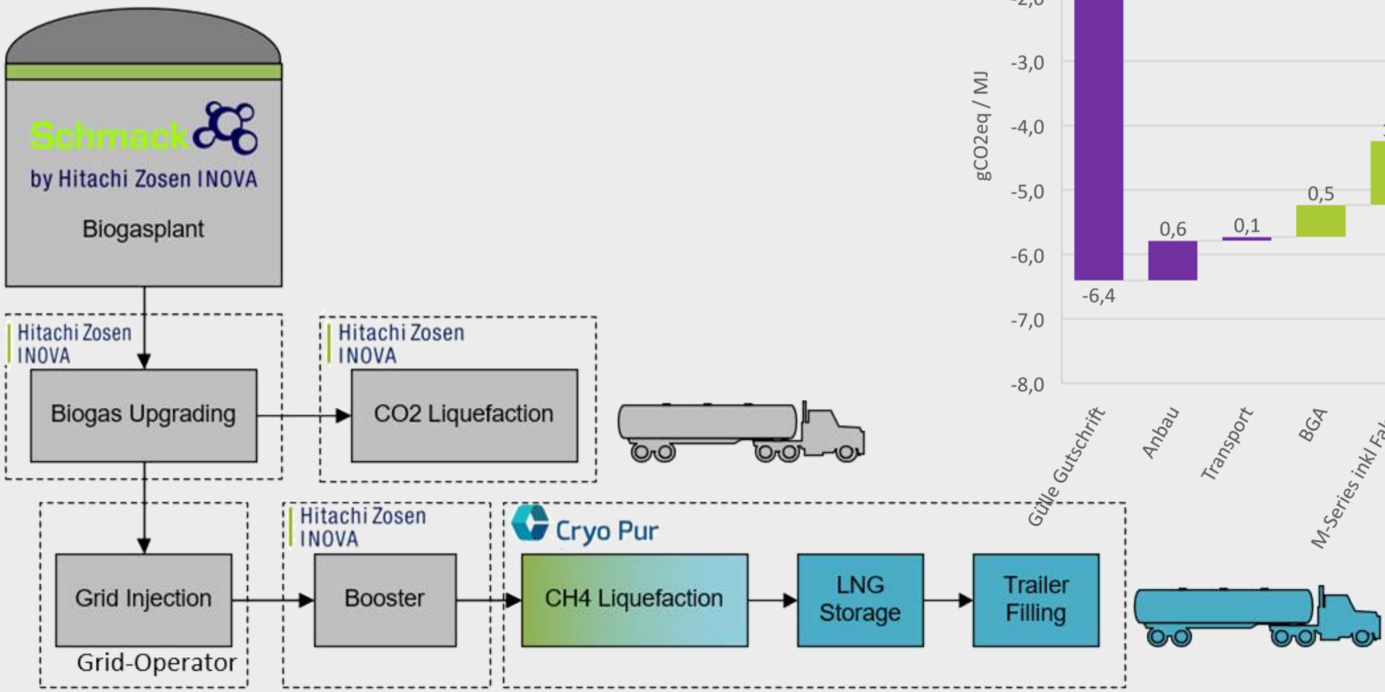
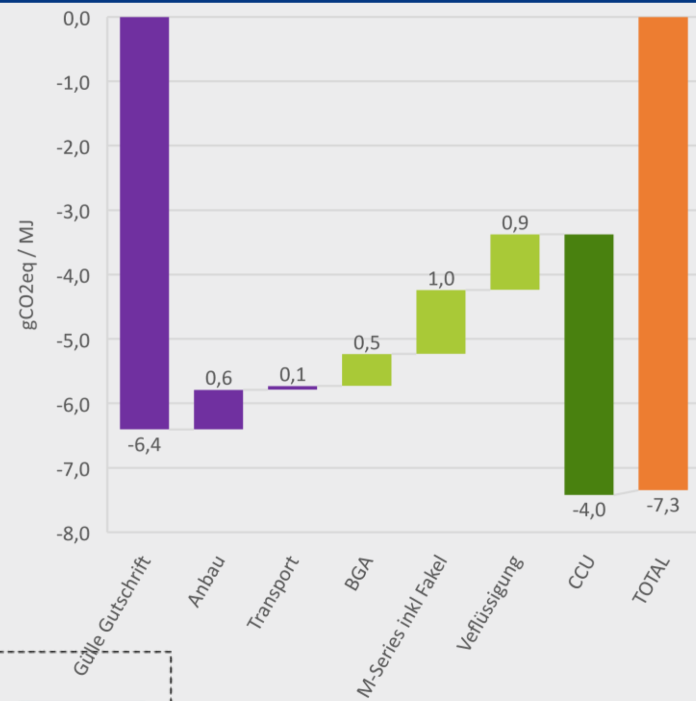
CO_2(liq) – Uplift for GHG





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CO_2(liq) – Uplift for GHG

20%

80%

33 GWh

BIOGAS

- Update Marketprice for Biomethane

Ltd Quota price	350	Euro/tCo2eq
Gasprice TTF	40	Euro/MWh
Fixprice	120	Euro/MWh
Power	0.2	cents/kWh
Heat	0.05	cents/kWh
Biogas	0.12	cents/kWh

IRR -1%

NPV –1’657’510 €

Current Deal

IRR 21%

NPV 5’913’183 €

Ltd Quota price	350
Gasprice TTF	40
Fixprice	120
Power	0.2
Heat	0.05
Biogas	0.09

Full Quota price	350
Gasprice TTF	40
GHG	120
Power	0.2
Heat	0.05
Biogas	0.12
CO2-Price	80

IRR 27%

NPV 11’948’821 €

- Update Marketprice for Biomethane
- regular TTF Offtake LNG
- Full Selling GHG Quota
- CO2 Offtake

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HZI Models CO_2(liq)

Type	Model S	Model M
Plant Output (kg_{CO2}/h)	300-500	600-1000
Plant Input (Nm^3-CO2/h	130-250	260-500
Design	Single Container Design + BOP	tbd
Capture Rate CO2	85-95%	85-95%
Power Demand	210-250 kWh_e/t_{CO2}	< 250 kWhe/tCO2
Main dimensions (L x B x H)	13 x 16 x 11 m	tbd
Gas Quality	Off-gas Upgrader	Off-gas Upgrader
CO2 Grade	EIGA / ISBT	EIGA / ISBT
Business Model	EPC / BOO	EPC / BOO
CAPEX	2’m€	tbd
Technical Availability	97%	95%
PAC	NTP + 13 Months	NTP + 13 Months

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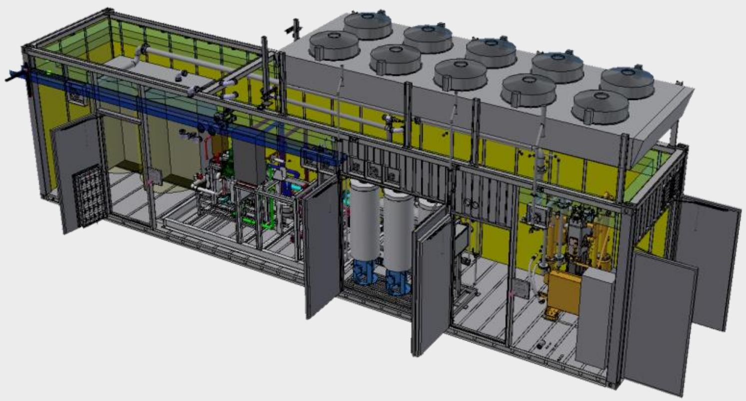
Nesselnbach – CO2(liq) Model S500



Containerised modular system assembled in Germany

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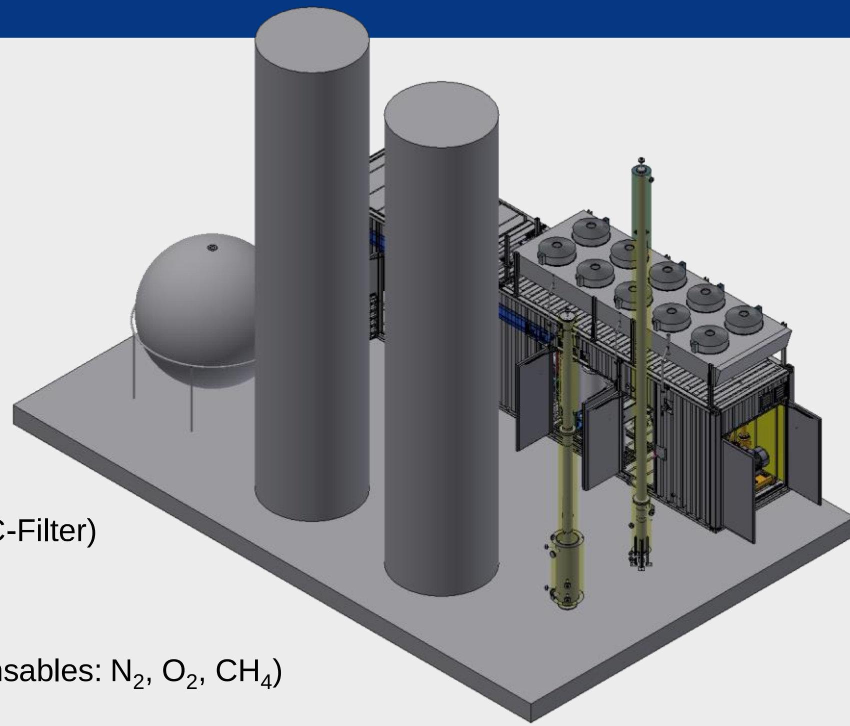
Process Description



Operating Pressure: ~ 18 bar(g)

→ Liquefaction @ ~ -35 ℃

Process steps:

1. Compression
2. Drying (water removal)
3. Contaminant removal (DCC + AC-Filter)
4. Liquefying (condensing CO_2)
5. Stripping (removal of non condensables: N_2, O_2, CH_4)
6. Storage

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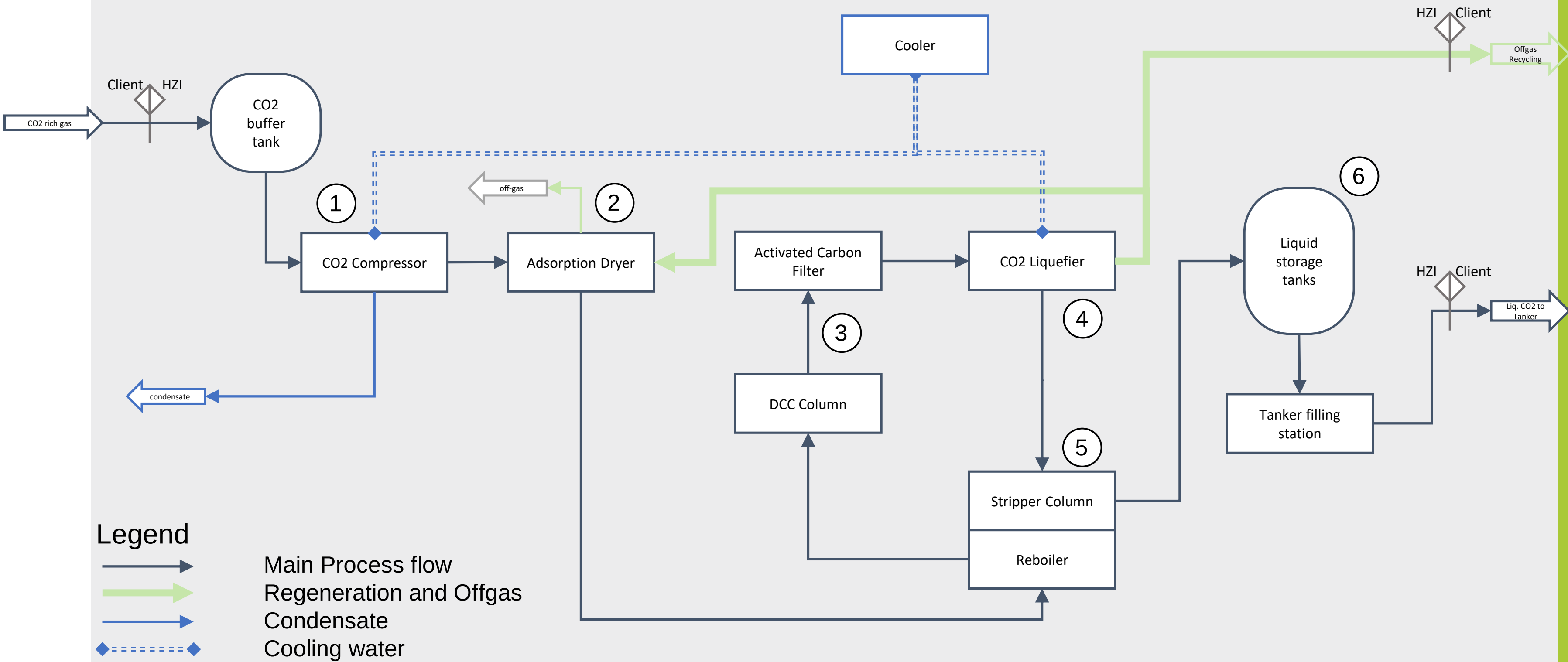
Process Description



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Process Description – Compression and Drying

Oil-free compressor

- 2-stage compressor
- Water-cooled
- Condensate removal

Adsorption-dryer

- Dew point -40℃
- 2 vessels for batch operation
- Regeneration with off-gas (non condensables)

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Process Description – Contaminant removal

DCC-Column ← Required due to VOC

- First stage cleaning
- for higher contaminations
- Counter flow with liquid CO_2
- Lower yield of liquid CO_2 (reduced by ~10%)
- No problems with contaminants that impact the product quality

Activated Carbon

- Second stage cleaning
- For low contaminations

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Process Description – Liquefying

Pre-cooling the CO_2 with column reboiler (stripping)

- U-tube bundle design
- Heat supply for stripping column

Refrigeration Unit for cooling

- R449A based (other refrigerants upon request)

Liquefying

- Cooling with plate heat exchanger
- Collecting vessel for purging non condensables

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Process Description – Stripping

Stripping Column

- Stripping gas: boiling CO_2 (heat supply: reboiler)
- Liquid CO_2 flows from top to bottom
- Dissolved gases (CH_4, O_2, N_2) removed

Product with high purity

- According to ISBT & EIGA

Offgas containing CO_2 and non condensables

- Can be recycled before the upgrader, depending on quality of inlet gas

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Process Description – Storage

Vacuum-insulated Storage Tanks

– vertical or horizontal

Minimum 2-tank system to achieve batch production (mandatory for ISBT)

– Optimum: > three tanks

Pressure to be kept in vessels > 5,2 bar(a)

– Risk of dry ice
– Possible damage or downtime

Thank you