Webinar 2
Deep decarbonisation for refineries starts in Ireland: introducing the REALISE pilot campaigns

REALISE CCUS

23 November 2021

Welcome and Introduction

Peter van Os

23 November 2021

Agenda

- Welcome, introduction & REALISCE CCUS project overview – Peter van Os, TNO
- Solvent testing in a real-life refinery setting: introduction – Juliana Monteiro, TNO
- Demonstration at Irving Oil Whitegate Refinery: video premiere and insights – Eirini Skylogianni, TNO
- Demonstration goals at SINTEF's Tiller CO_2 labs – Thor Mejdell, SINTEF
- Panel Q&A

Demonstrating a refinery-adapted cluster-integrated strategy to enable full-chain CCUS implementation

REALISE CCUS

Webinar #2 GoToWebinar 2021-11-23

REALISE project (05.2021-10.2023)

CO_2 capture with 2nd gen. solvents

- Mobile pilot on-site refinery
- Stationary pilot

Solvent management technologies

- Avoid solvent loss
- Emissions control

CO_2 transport, conversion and storage

- CO_2 liquefaction
- CO_2 conversion
- CO_2 storage

Socio-political context

- EPE program
- CCUS readiness

CCUS business cases: Irland, China, S. Korea

Dissemination and knowledge sharing

Partners

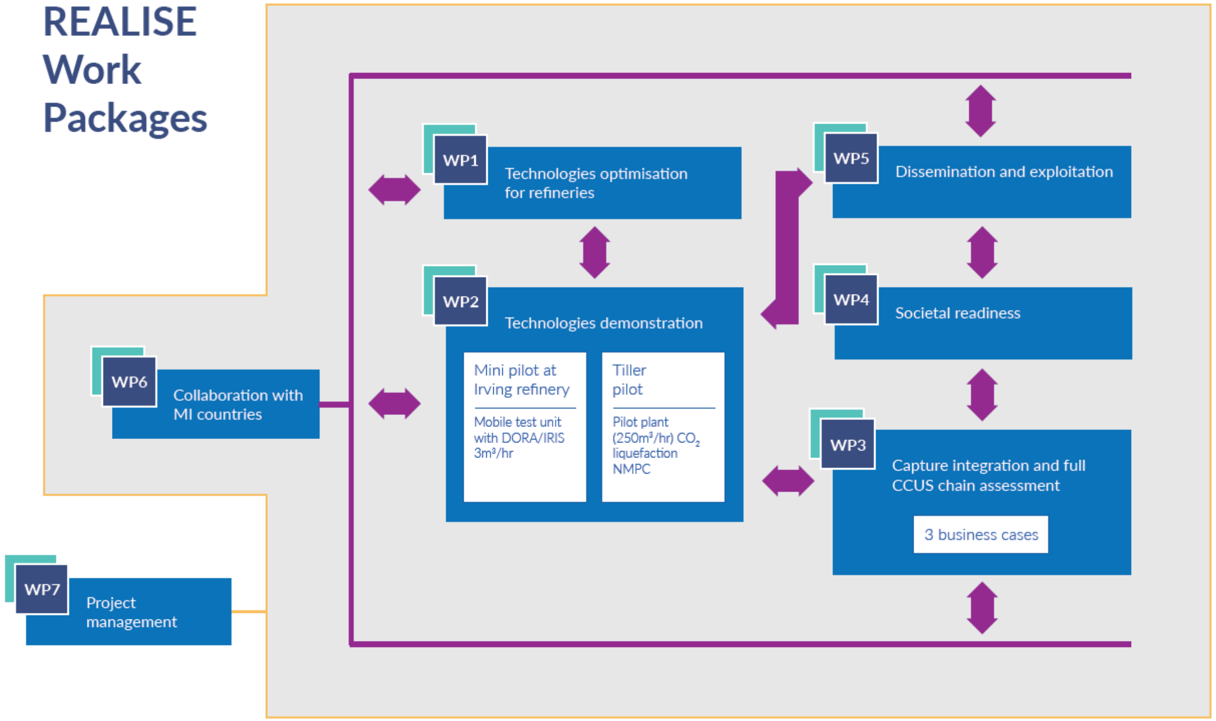
biobe Expertise in plastics, Bord Gáis Energy, CYBERNETICA, equinor, 敦华石油 DUNHUA OIL, IRVING, NTNU, PENTAIR UNION ENGINEERING, POLITECNICO MILANO 1863, SCCS, ervia, ESB Energy for generations, UCC, SINTEF, TNO innovation for life, SK innovation

Advisory Board

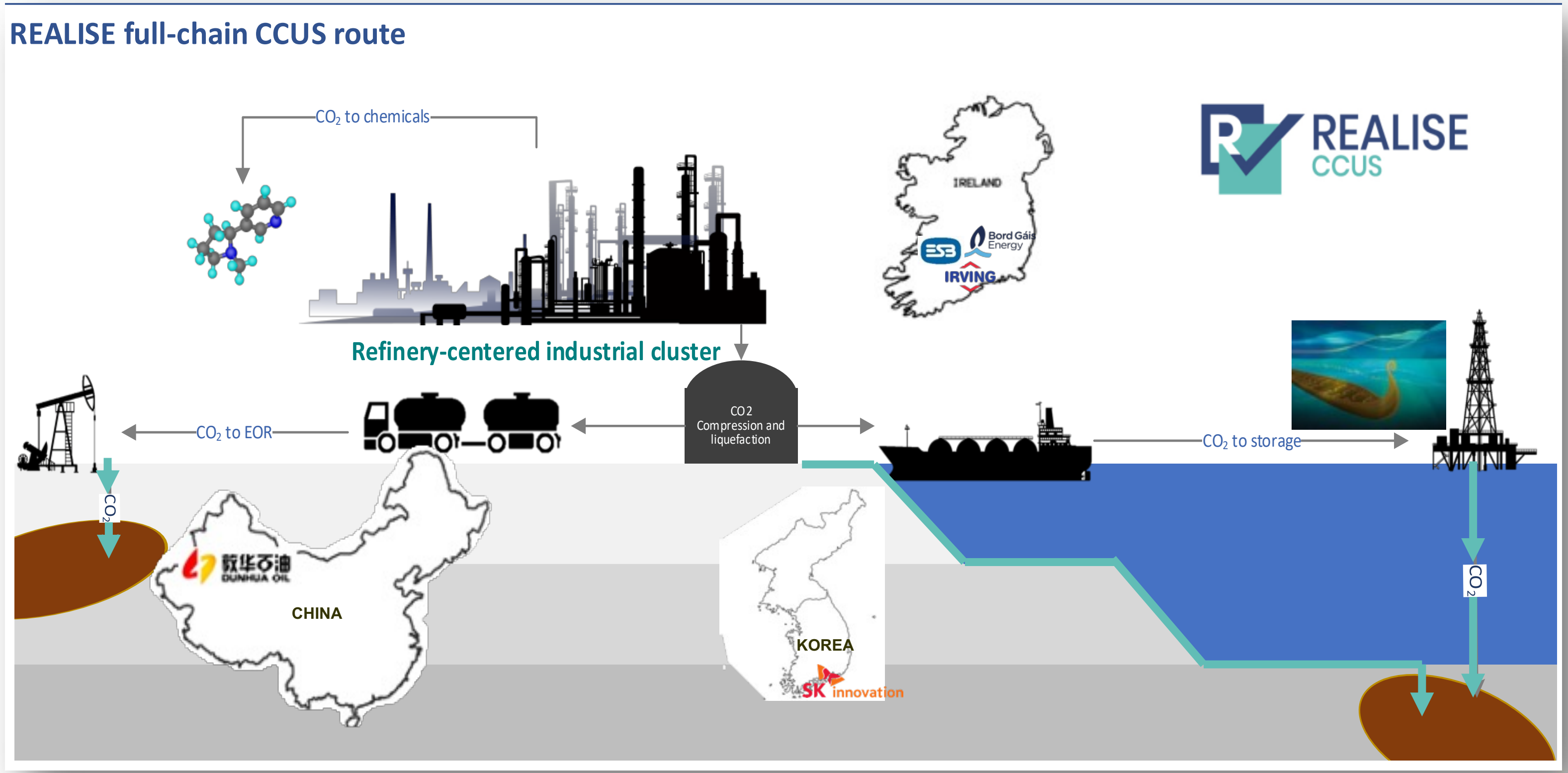
Concawe, petroineos REFINING AND TRADING, GLOBAL CCS INSTITUTE, CO2 TECHNOLOGY CENTRE MONGSTAD, SARAS, Science Foundation Ireland sfi For what's next

REALISE Objectives

- ✓ Decrease energy demand of CO_2 capture by 30%
- ✓ Maximize use of solvent by reducing losses of solvent components by 80%
- ✓ Decrease Capex by 15% using plastics
- ✓ Lower capture cost by at least 30% by coupling of the facilities with the power sector
- ✓ Provide guidance for the choice of CO_2 capture scenarios at different refineries using an open-access simulation tool



Case studies in REALISE



Solvent testing in a real-life refinery setting

Juliana Monteiro, TNO

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Solvent testing in a real-life refinery setting

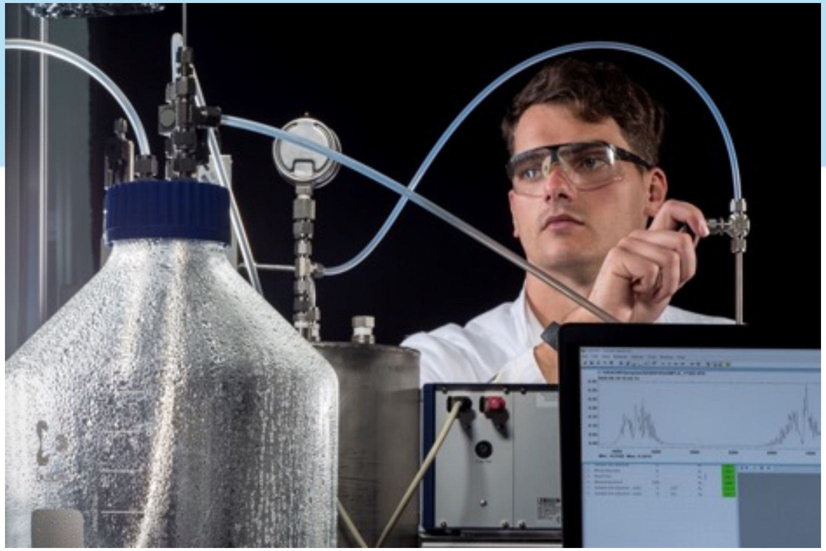
Introduction

- Why perform solvent testing?
- Why perform solvent tests at a refinery?

Demonstration at Irving Oil Whitegate Refinery in Cork → Eirini Skylogianni

WHY PERFORM SOLVENT TESTING?

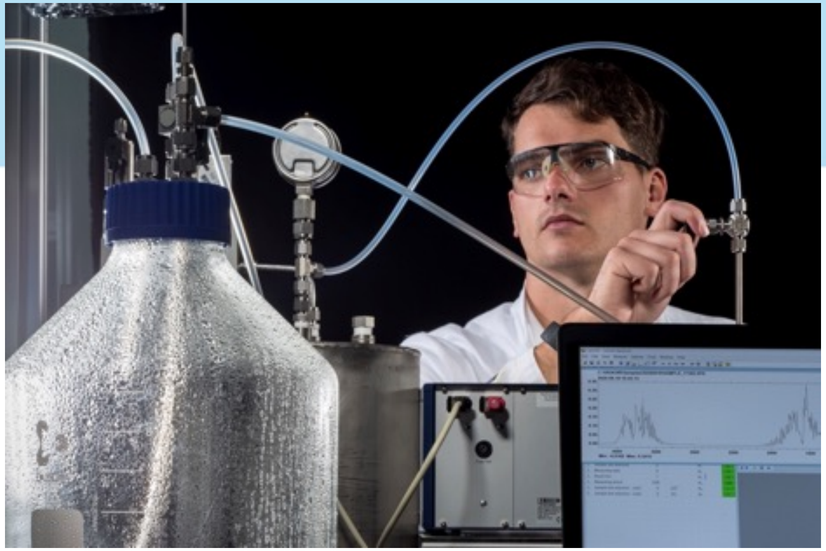
Why perform solvent testing?



Solvent-based CO_2 capture

- Relatively mature technology
- 10+ technology providers in the market; proprietary solvents
- Open solvents
  - 30wt% monoethanolamine → MEA
  - 3M 2-Amino-2-methylpropan-1-ol + 1.5M piperazine → CESAR1

Why perform solvent testing?



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  - 3M 2-Amino-2-methylpropan-1-ol + 1.5M piperazine → CESAR1
  - 40wt% 1-(2-Hydroxyethyl)pyrrolidine (HEP) + 15wt% 3-amino-1-propanol (3A1P) → HS-3

There's room for improvement

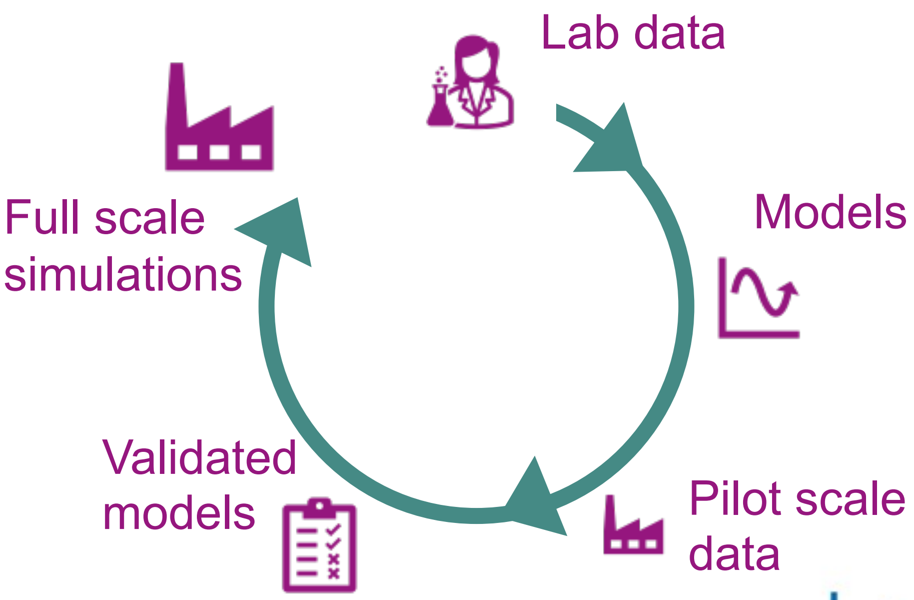
- MEA (1st generation)
  - Relatively high energy demand 3.2 – 3.6 GJ/ton CO_2 (heat at ca. 120ºC)
  - Amine consumption: 0.3 to 1.5 kg/ton CO_2 (degradation + emissions)

- CESAR1 (2nd generation)
  - Lower energy demand 2.5 – 3.0 GJ/ton CO_2 (heat at ca. 120ºC)
  - Amine consumption: lower than MEA (under evaluation at the LAUNCH project)
  - Contains piperazine → not ideal from an HSE perspective

- HS-3 → targets: low energy demand and amine consumption, improved HSE aspects

Why perform solvent testing?

- Energy demand
- Emissions
- Solvent degradation



WHY PERFORM SOLVENT TESTS AT A REFINERY?

Why perform solvent tests at a refinery?

- Multiple stacks with varying gas composition (CO_2 and impurities)

- Exposing the solvent to the impurities in long-term tests allows to:

  Evaluate degradation (identify and quantify products formed)

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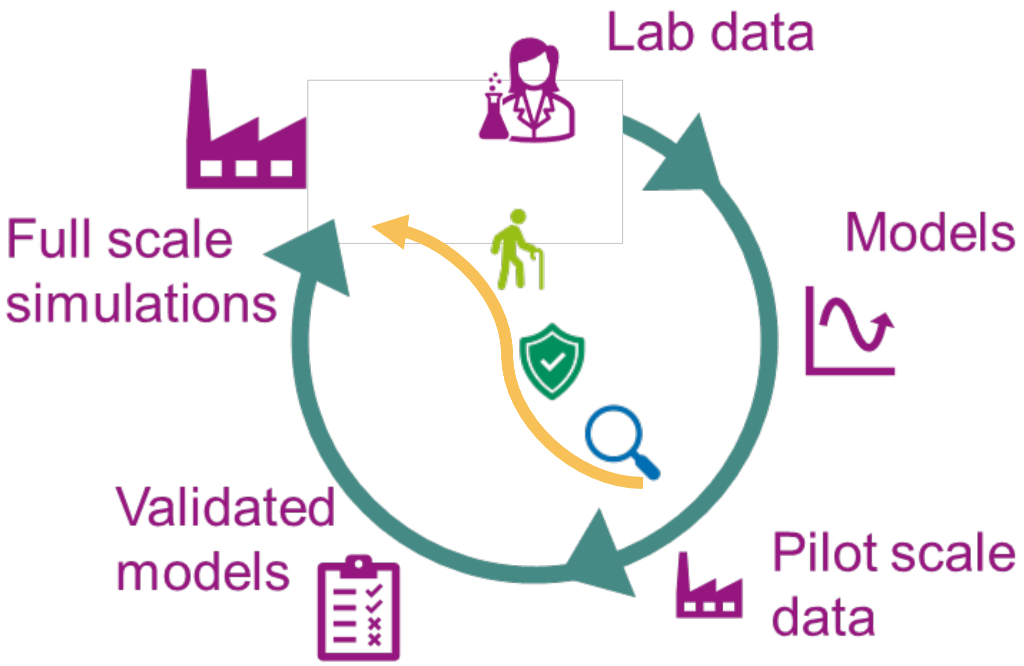
  - Test degradation counter-measures

Why perform solvent tests at a refinery?

- Multiple stacks with varying gas composition (CO_2 and impurities)

- Exposing the solvent to the impurities in long-term tests allows to:
  - Evaluate degradation (identify and quantify products formed)
  - Test degradation counter-measures
  - Verify the impact of aging over solvent behaviour (emissions, viscosity, etc.)

Why perform solvent tests at a refinery?



- ✓ Increased confidence in model results
- ✓ Improved cost estimates
- ✓ De-risked scale-up

Demonstration at Irving Oil Whitegate Refinery - video premiere and insights

Eirini Skylogianni, Research Scientist in TNO

Webinar **Online** **23 November 2021**

Objectives

Objective

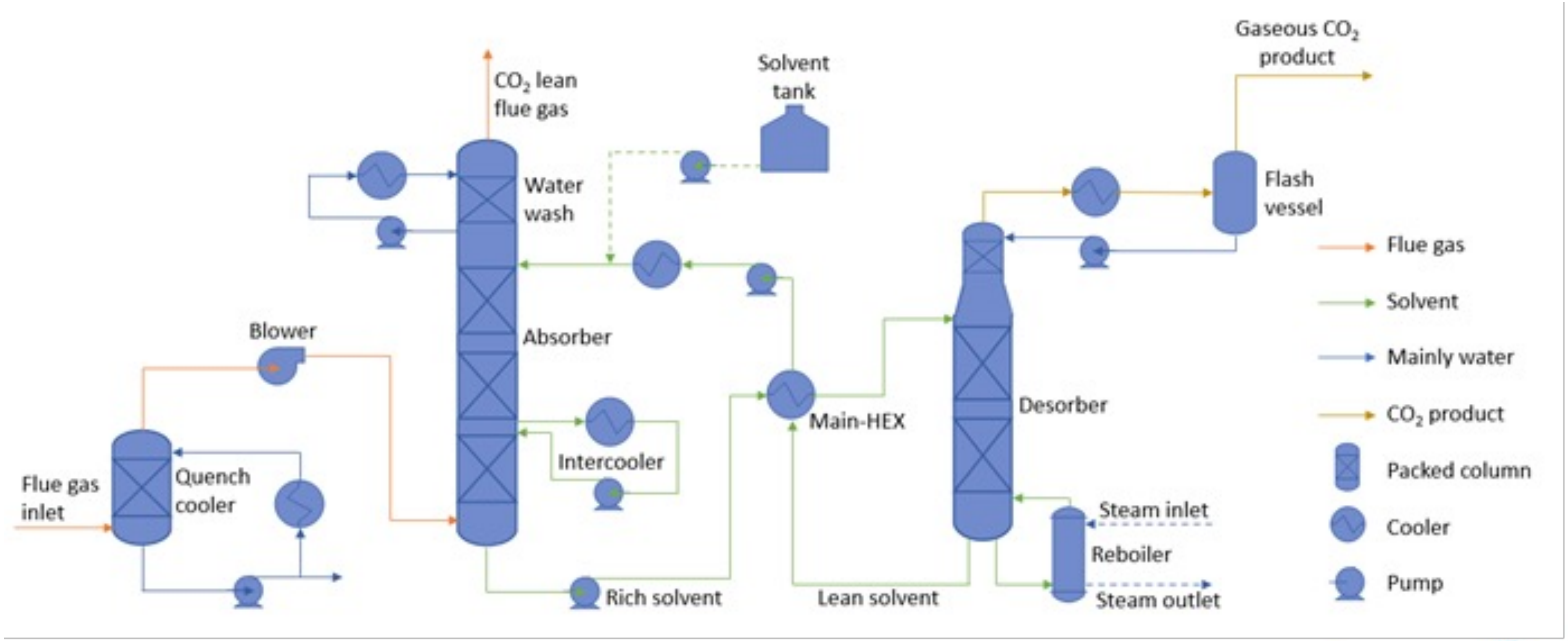
Demonstration of CO_2 capture from **Irving Oil Whitegate Refinery stacks** using the **HS-3 solvent** formulation as optimized within REALISE.

Sub-objectives

- Modify TNO's miniplant for operations in a refinery
- Test the performance of HS-3 solvent with focus on solvent stability and emission mitigation
- Demonstrate solvent management technologies for oxygen and iron removal

TNO’s miniplant

- Capture capacity of 25 kg CO_2/day
- Continuous cyclic operation
- Improved automation for 24/7 operation
- Emission control: water wash technology and online monitoring
- Artificial and industrial flue gases


CO2 lean flue gas
Solvent tank
Gaseous CO2 product
Water wash
Flash vessel
Flue gas
Solvent
Mainly water
CO2 product
Packed column
Cooler
Pump
Blower
Absorber
Main-HEX
Desorber
Intercooler
Quench cooler
Flue gas inlet
Steam inlet
Reboiler
Steam outlet
Rich solvent
Lean solvent

ATEX-compliance

- The areas where flammable and hazardous materials are processed (like in a refinery), are considered potentially explosive atmospheres.
- For safety, all equipment and rigs must be ATEX-compliant.
- ATmosphere EXplosible (ATEX) is a European Union directive relating to the risk of fire and explosion arising from flammable substances stored or used in the workplace.
- The miniplant can be operated at hazardous environments by being installed in an ATEX container.
- Clean air is blown inside the container, creating overpressure and thus ensuring a safe atmosphere inside the container.

Preparations at Irving Oil Whitegate Refinery

- Choice of miniplant position
- Civil, mechanical and electrical work for miniplant's accommodations
    - Wind loads investigation
    - Foundation and scaffolding
    - Utility supply
    - Telecommunications

Flue gas characterization

- 15 emission points in the refinery

- Measurement of particles and gas components:
  - Particulate matter → can form aerosols, thus increasing emissions
  - SOx → can form heat stable salts (HSS), which deactivate the solvent and accumulate in the system, thus decreasing solvent performance
  - NOx → can form HSS, which deactivate the solvent and accumulate in the system, thus decreasing solvent performance
  - CO_2 → the most important gas to be removed; the goal of REALISE

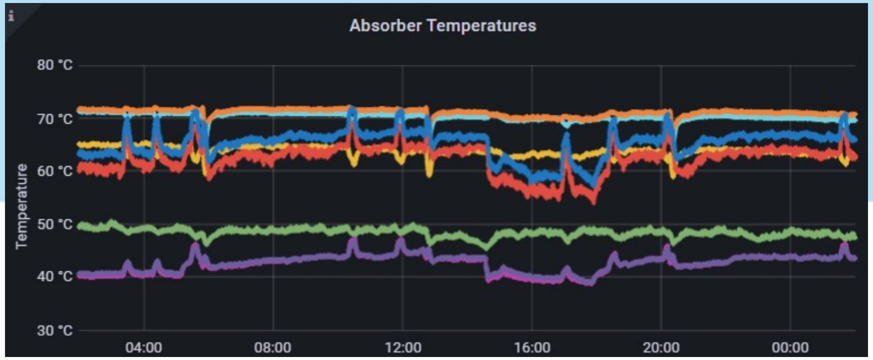
Criteria for emission point selection

Three main criteria were used for the selection of the flue gases from which CO2 will be captured:

1. **CO_2 content** → Flue gases with highest CO_2 flowrates have the highest impact
2. **Impurities** → The solvent should be exposed to various impurities, in order to increase our knowledge regarding its stability and performance in the presence of impurities
3. **Distance from miniplant location** → It must be practically feasible to connect the emission source with the miniplant. Emission points located further than 200m from the miniplant's location were excluded due to high pressure drop and requirements of additional blowers.

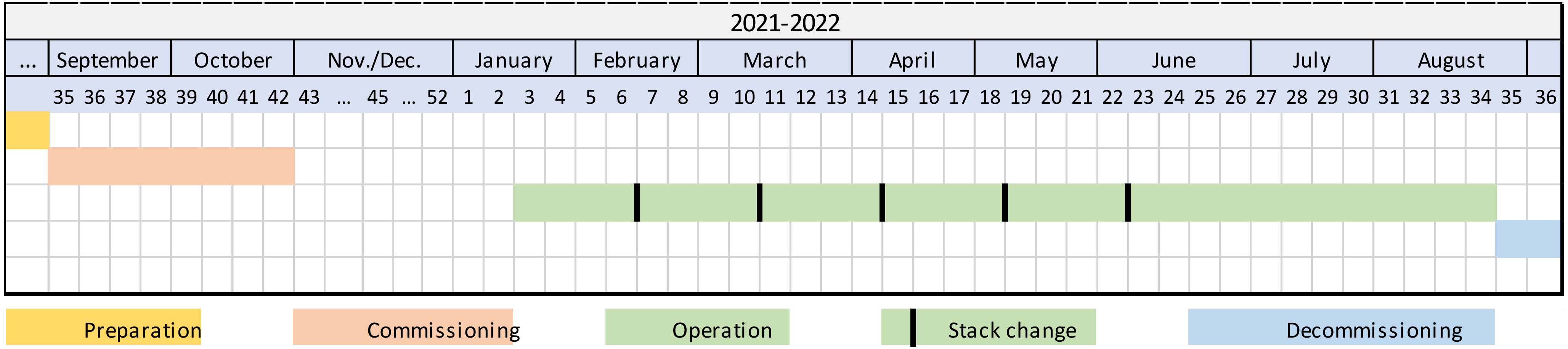
Six stacks were selected, whose emissions combined account for 84% of the total CO_2 emissions of the refinery

HS-3 testing



- Based on the flue gas characterization of the selected stacks, the testing program of the HS-3 solvent, was drafted.
- Different parameters and settings were used in order to gain insights on the miniplant operation with this solvent:
  - Synthetic gas was used
  - Two campaigns were conducted: one with low CO_2 content (4.5vol%) and one with high CO_2 content (10.5vol%) of flue gas
  - In each campaign, the L/G ratio and stripping pressure was varied and its effect on the operation was studied (capture rates, solvent loading, temperature profiles in absorber and stripper, emissions)

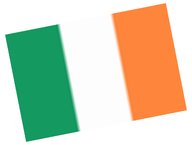
Demonstration program



Partners' collaboration

During the demonstrations:

TNO: will continuously monitor and remotely operate the miniplant. Sporadic visits will be performed for maintenance or if needed.



Irving Oil Whitegate Refinery: will provide the operators and system engineers to perform daily and weekly checks

SINTEF: will analyze solvent and water wash samples in a weekly basis

Reach TRL 6-7

Validate process **models**

Provide input for **OPEX and CAPEX** estimations for full-scale CO_2 capture with HS-3 solvent

Thank you for your attention!

Demonstration campaigns at Tiller CO2 pilot plant

REALISE CCUS

Thor Mejdell, Senior Research Scientist at SINTEF Industry

Webinar **Online** **23 November 2021**

Objectives

Main objective

Demonstrate the benefits of using the HS-3 solvent formulation as optimized within REALISE.

Sub-objectives

- Add a CO_2 compression and liquefaction unit (CCLU) to the Tiller pilot plant.
- Test the performance of HS-3 solvent with focus on specific reboiler duty (MJ/kg CO_2 captured), solvent degradation, emissions to air and impurities in the liquefied CO_2.
- Demonstrate nonlinear model predictive control to minimize the energy consumption under fast changing operating conditions.

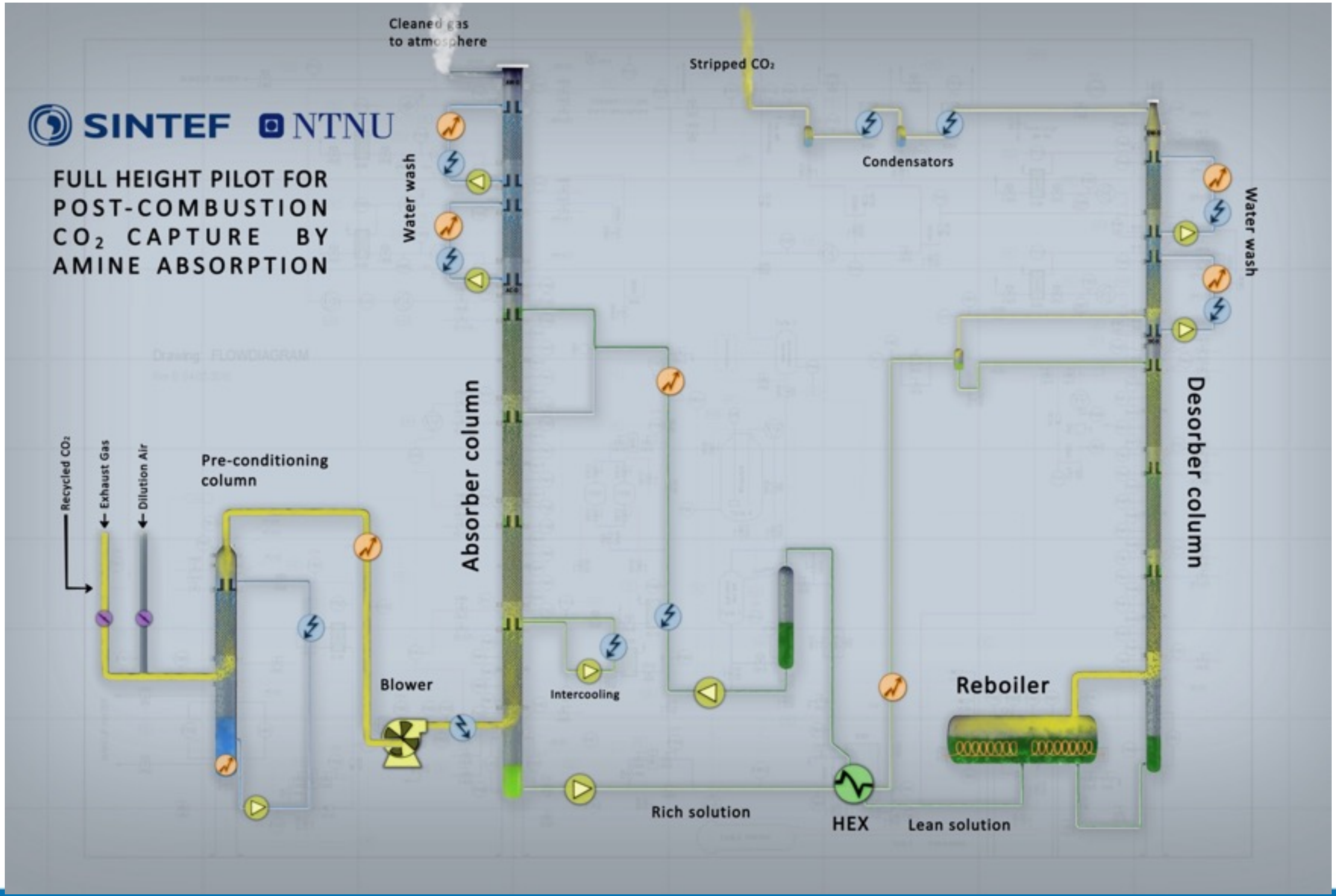
Tiller CO2Lab, Trondheim Norway

- 10 km from Trondheim city
- 30m (11 floors) high building
- Completed in November 2009

CO_2 post combustion plant (Completed February 2010)

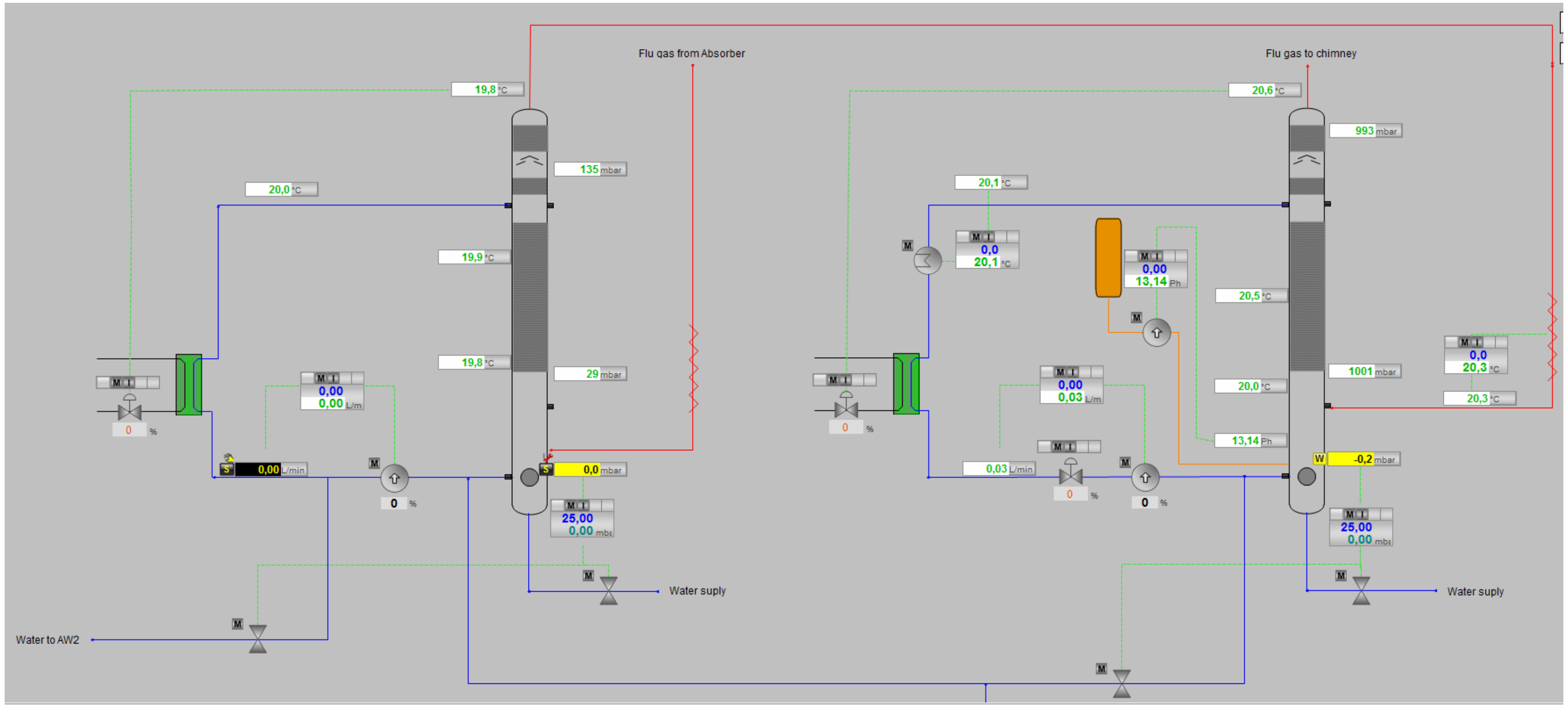
- Flue gas flow 100-350 m3/h
- Liquid flow – 20 kg/min
- Reboiler duty 60 kW
- CO_2 up to 30-40 kg/h
- 160 temperatures
- 110 process tags
  - Pressures
  - Flows
  - Analysers
  - etc

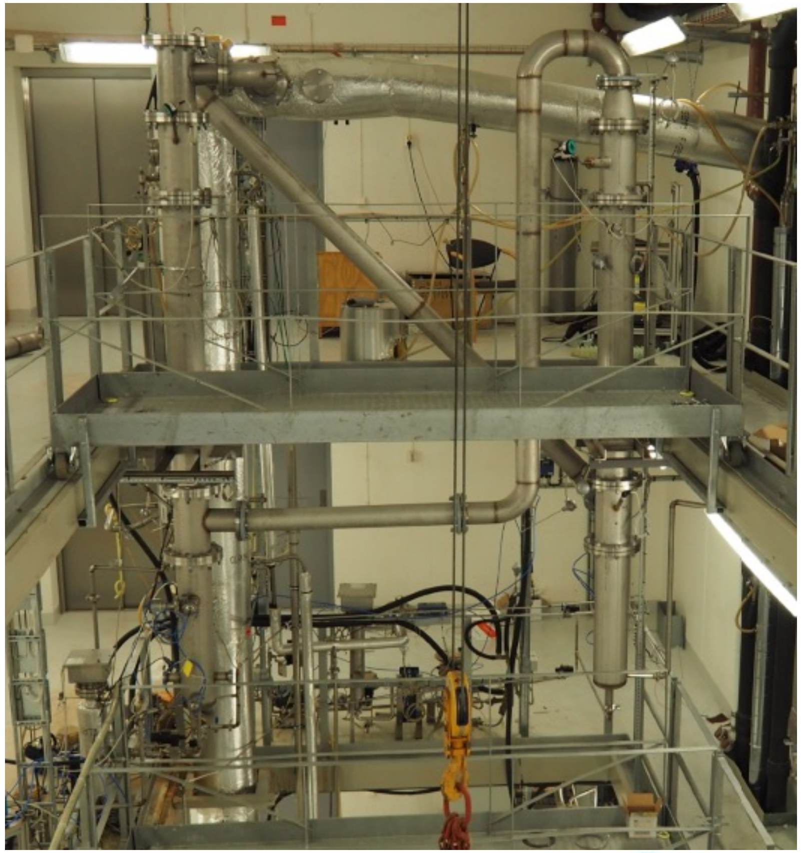
Tiller simplified flow diagram 2010



- Absorber
  - D= 0.2m
  - 4 sections, totally 20m of structural packing
  - Intercooling between sections
  - 2 water wash sections on top
- Desorber
  - D= 0.2m
  - 3 sections, totally 15 m of structural packing
  - Interheating between sections
  - 2 water wash sections on top
- Lean/rich HEX giving 3-6 °C approach on cold side

Additional two water wash sections are installed



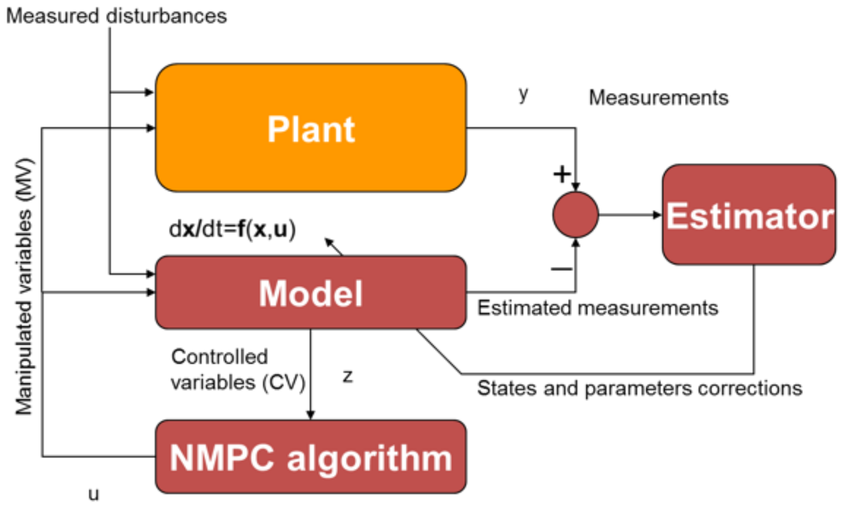


Demonstration of the benefits of the HS-3 solvent

- 12 weeks campaign starting in September 2022
- Mimic partly reclaimed solvent: 20 L from Irving + 600 L fresh solvent
- Find minimum specific reboiler duty MJ/kgCO_2 by changing L/G
- Compare with results from an earlier MEA campaign.
- Measure emissions of solvent and solvent degradation product to air for
  - Various process conditions
  - Number of water washes (up to four)
  - Using FTIR and manual gas sampling
- Measure impurities in the CO_2 product
  - Various process conditions including water washes

Demonstrate Nonlinear Model Predictive Control (NMPC) of the pilot with the HS-3 solvent

- Dynamic step response data will be generated fin the beginning of the campaign for validating the dynamic model
- In the last part of the campaign the Nonlinear Model Predictive Controller (NMPC) will be tested online in closed loop
    - Demonstrate the capability of NMPC to minimize the energy consumption under fast changing operating conditions.
    - Provide valuable data for WP3.



Preparation for the campaign:

Construction of a CO2 compression and liquefaction unit (CCLU)

- Will use the CO_2 flow directly from the desorber top (~99%)
- Measure impurities in knock out water and CO_2 liquid.
- Impact of amine, degradation products, desorber water washes, etc
- In terms of impurities be similar to large scale processes
- Realise: Transportation for ships, 16 bar, -27C
- Will store CO_2 temporarily,

Preparation for the campaign:

Construction of a CO2 compression and liquefaction unit (CCLU)

Background:

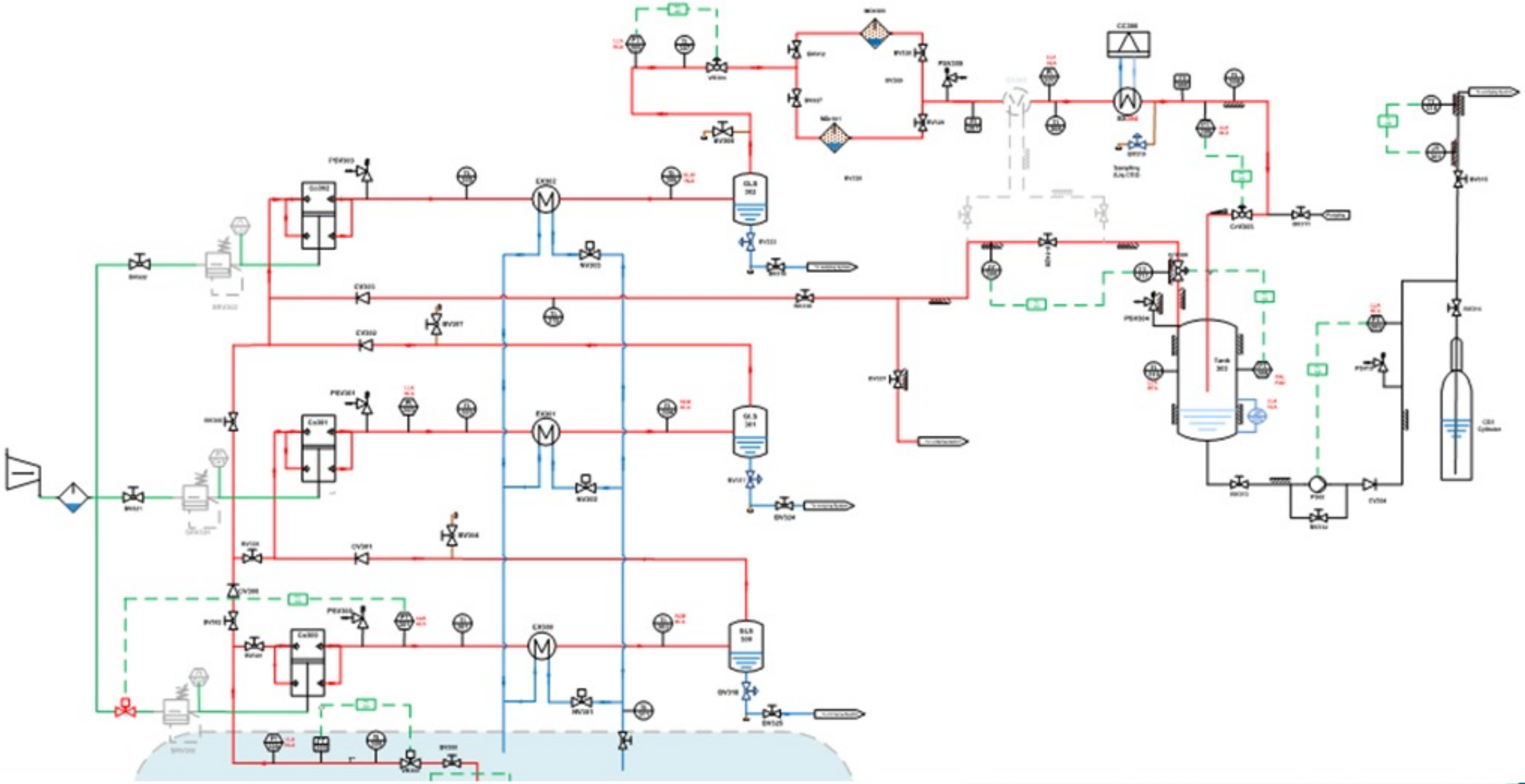
- Purity requirement of compressed CO_2
  - CO_2 transport by ship
  - CO_2 transport by pipe
  - EOR
  - Food industry
  - Chemical for CCU (methanol synthesis etc)
- The compounds found in the exhaust gas leaving the absorber are also present to some extent in the CO_2 stream out of the desorber.
- These includes the amines and degradation products

EIGA LIMITING CHARACTERISTICS

FOR CARBON DIOXIDE TO BE USED IN BEVERAGES FOR SOURCE SPECIFICATION[3]

Component	Concentration
Assay	99.9% v/v min.
Moisture	20 ppm v/v max
Ammonia	2.5 ppm v/v max.
Oxygen	30 ppm v/v max.
Oxides of nitrogen (NO/NO2)	2.5 ppm v/v max. each
Non-volatile residue(particulates)	10 ppm w/w max.
Non-volatile organic residue (oil and grease)	5 ppm w/w max.
Phosphine ***	0.3 ppm v/v max
Total volatile hydrocarbons (calculated as methane)	50 ppm v/v max. of which 20 ppm v/v max non-methane hydrocarbons.
Acetaldehyde	0.2 ppm v/v max.
Aromatic hydrocarbon	0.02 ppm v/v max.
Carbon monoxide	10 ppm v/v max.
Methanol	10 ppm v/v max.
Hydrogen cyanide*	0.5 ppm v/v max
Total sulfur (as S) **	0.1 ppm v/v max.
Taste and odour in water	No foreign taste or odour
Appearance in water	No colour or turbidity
Odour and appearance of solid CO2 (snow)	No foreign odour or appearance

PI&D compression and liquefaction unit



Construction ongoing

SINTEF investments:

- 3 Haskel gas boosters
- Lauda Integral IN 250XTW for cooling
- CO2 storage tank (Carbo-Mizer 450 from Linde).

Unit will be commissioned with MEA

Thank you for your attention!

Thank you for listening

Presenters

Juliana Monteiro, TNO

Eirini Skylogianni, TNO

Thor Mejdell, SINTEF

Project

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