E-fuel – final report

16/04/2024 VTT – beyond the obvious

BUSINESS FINLAND

VTT

Basics and some numbers

eFuel

Parallel company projects

ANDRITZ, convion, Fuel cell technology elcogen, NESTE

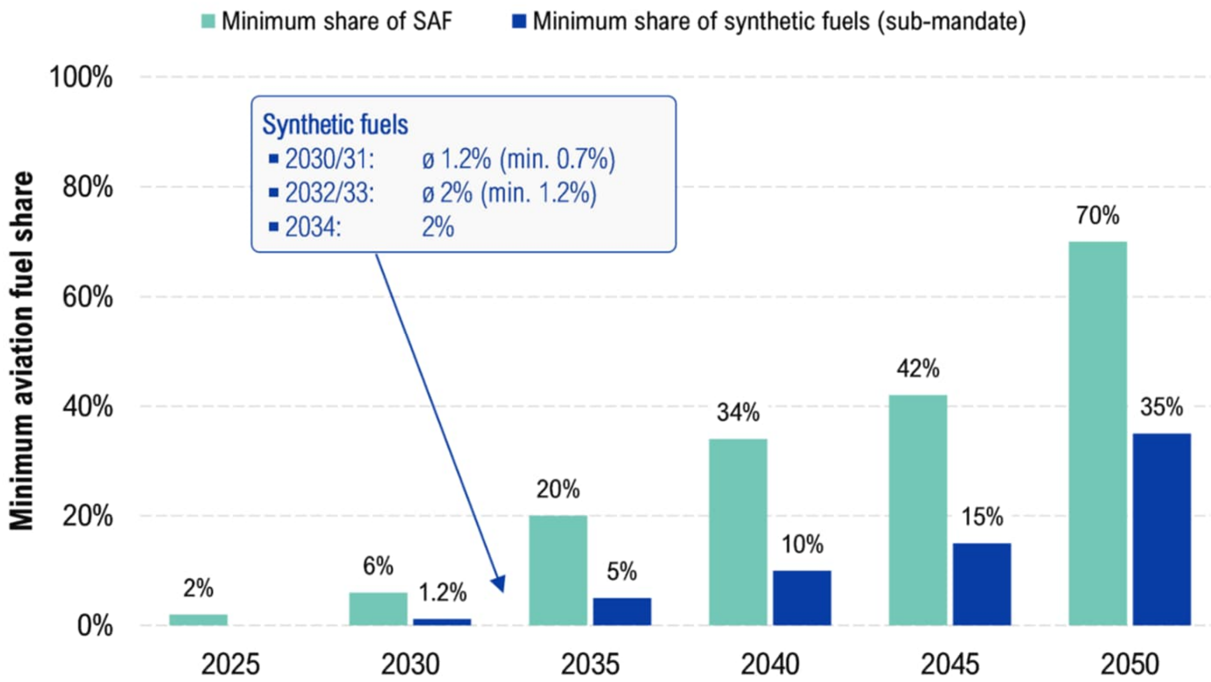
Companies supporting the public project

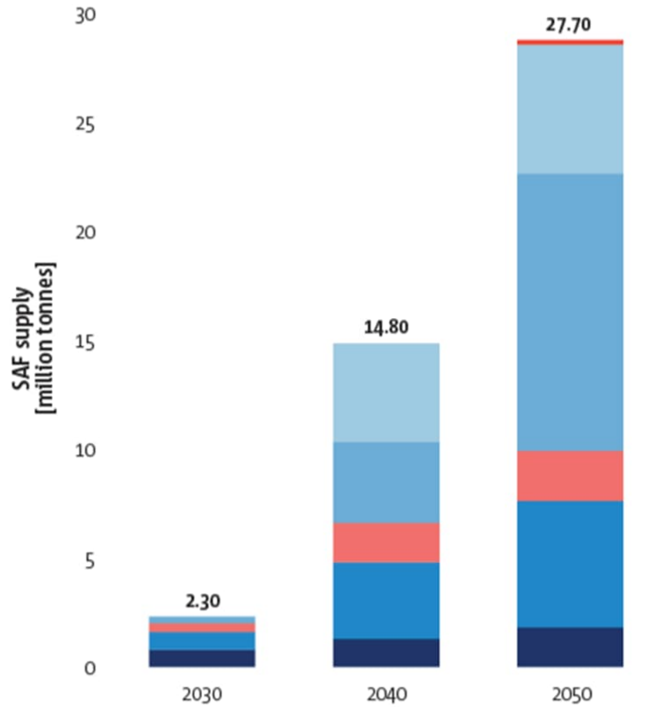
ABB, AGCO POWER, AW-ENERGY OY, HELEN, CarbonReUse, ESL Shipping, INERATEC, KLEENER POWER SOLUTIONS, MERIAURA, PROVENTIA

- Business Finland's co-innovation project (part of Neste Veturi)
- 14 partner companies, VTT as research organisation
- Duration 3 years (1.1.2021-31.12.2023)
- VTT's budget 3.7 M€ (about 30 000 work hours), total budget ~ 7 M€
- In addition, VTT's projects with companies ~700 k€
  - Neste's project for demonstration at Bioruukki
  - Convion & Elcogen projects for SOE development and
  - Andritz CO_2 capture development

Motivation and objectives of E-fuel

ReFuel EU Aviation



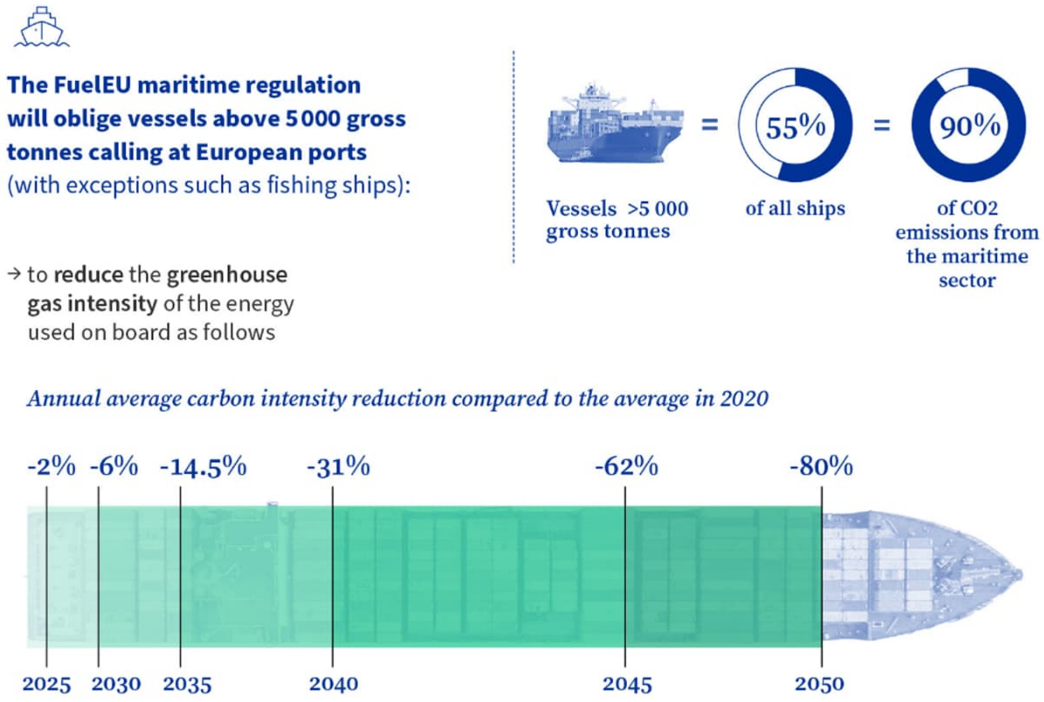


	2030	2040	2050
Electricity	0.00	0.00	0.20
Gasification+FT	0.00	4.50	5.90
PtL	0.30	3.70	12.70
Imports	0.40	1.80	2.30
ATJ	0.80	3.50	5.80
HEFA	0.80	1.30	1.80

Synthetic fuels = e-fuels

ReFuelEU aviation - (sustainable-aviation.net)
Current landscape and future of SAF industry | EASA Eco (europa.eu)

FuelEU Maritime

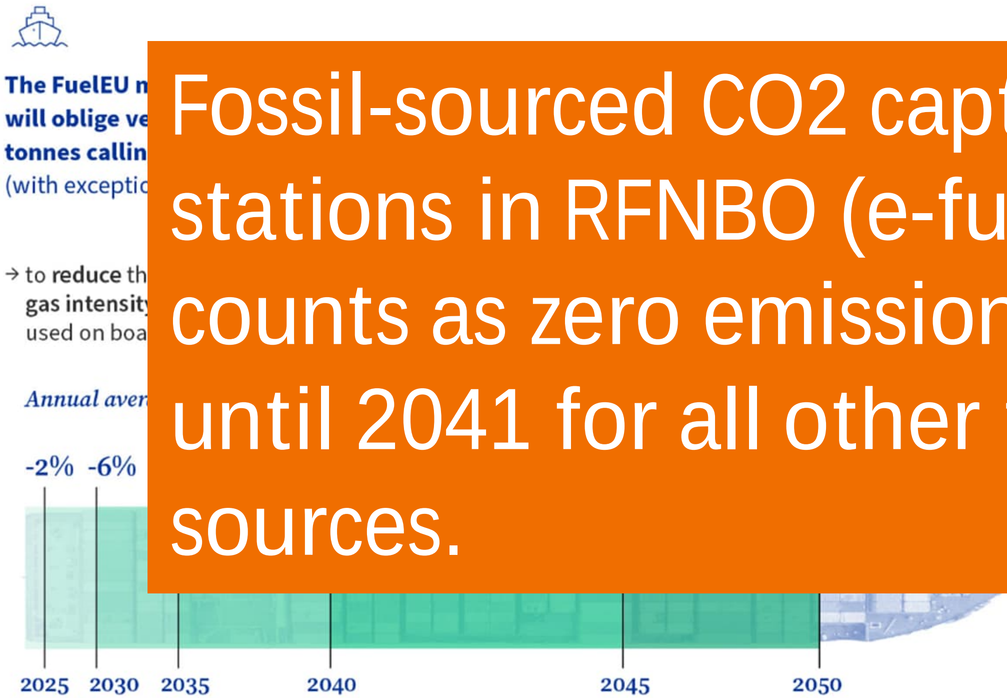


E-fuels needed for marine transport to reduce carbon intensity:

- Methanol
- Ammonia
- E-diesel

Special reward (double counting) for e-fuels in 2025 - 2033

FuelEU Maritime



Fossil-sourced CO2 captured from power stations in RFNBO (e-fuel) production counts as zero emissions until 2036, and until 2041 for all other fossil industrial sources.

transport

unting)

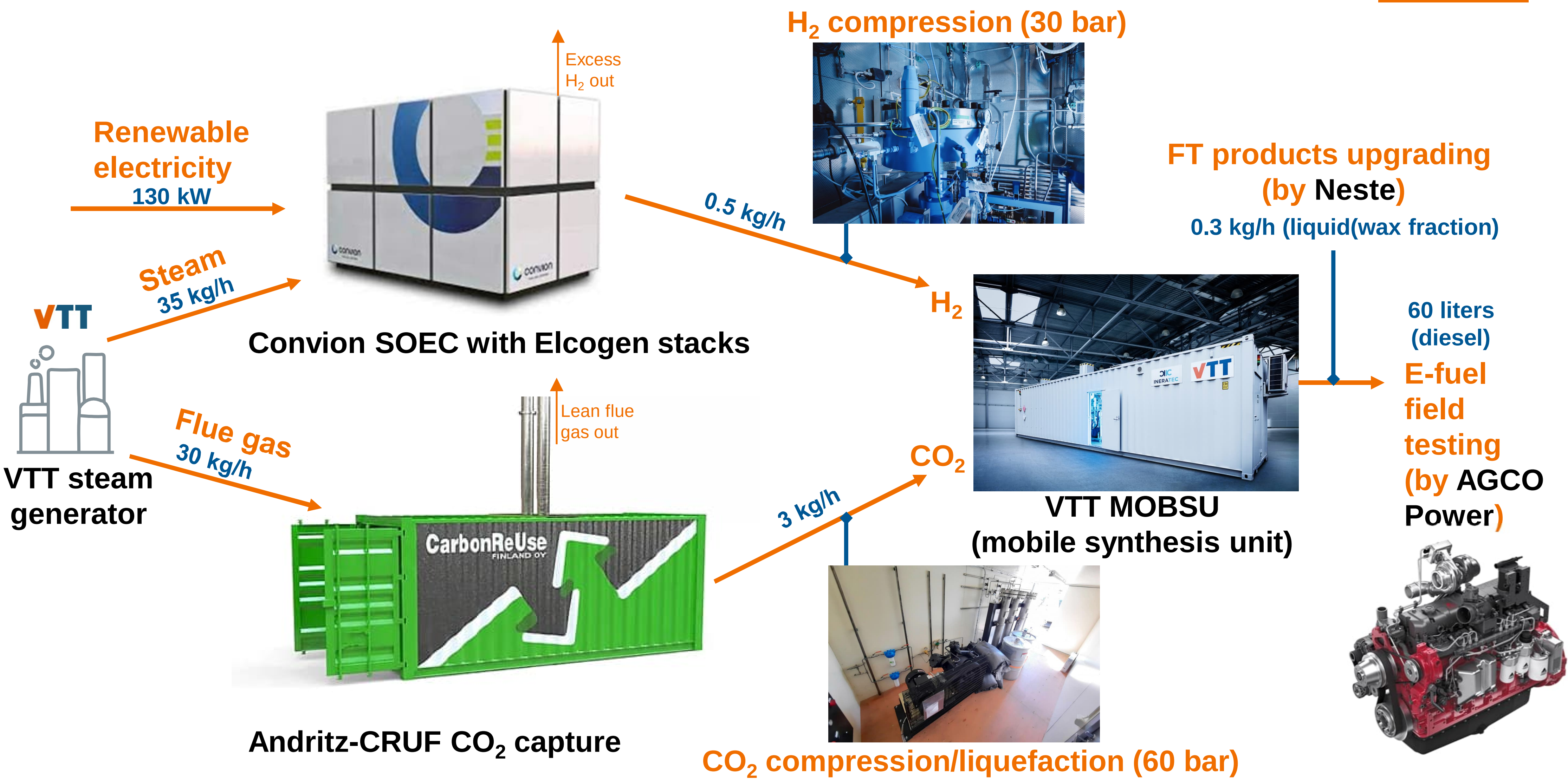
The main objectives

1) To demonstrate production of drop-in paraffinic e-fuels in bench scale with high efficiency by combining and integrating high temperature electrolysis and Fischer-Tropsch synthesis

2) A readiness to scale up the concept after 2-year project to a production scale of 10 kton/a

E-fuel highlights

E-fuel demonstration and e-diesel field tests



Highlights 1/2

- WP1 Novel high temperature electrolysis:
  - A 10 kW size Solid Oxide Electrolyser (SOEC) system with Elcogen E3000 stack was designed, built and tested at VTT.
- WP2 CO_2 capture:
  - High potential and feasible ways to produce pure CO_2 to synthesis.
- WP3 Synthesis:
  - Improved MOBSU-scale CPOX/rWGS + FT-process and catalyst that allowed successful demo tests at WP4.
- WP4 Process integration and demonstration
  - E-fuel concept successfully demonstrated in Bioruukki by the integration of 6 units resulting in the production of 300 kg of FT crude product.

Highlights 2/2

- WP5 E-fuel usability:
  - The end-use performance of high-quality, high-cetane number, aromatics-free and sulphur-free e-diesel proved to be excellent in a small-scale field demonstration with a tractor powered by AGCO Power diesel engine and in comprehensive emission studies.
- WP6 Energy systems and climate impact analysis:
  - The EU regulations for RNFBO GHG criteria were clarified during the project and GHG balances according to the criteria could be studied.
- WP7 Business case evaluation:
  - Optimization tool of RFNBO-eKerosene FT-plant for dimensioning and operation strategy; tool showed clearly (1) the importance of optimization for production costs, (2) emission reduction targets for SAF can be reached
- WP8 Management, collaboration and dissemination
  - Excellent collaboration with companies, high visibility in media by 5 press releases and 3 main events.

E-fuel main results

WP1 Novel high temperature electrolysis

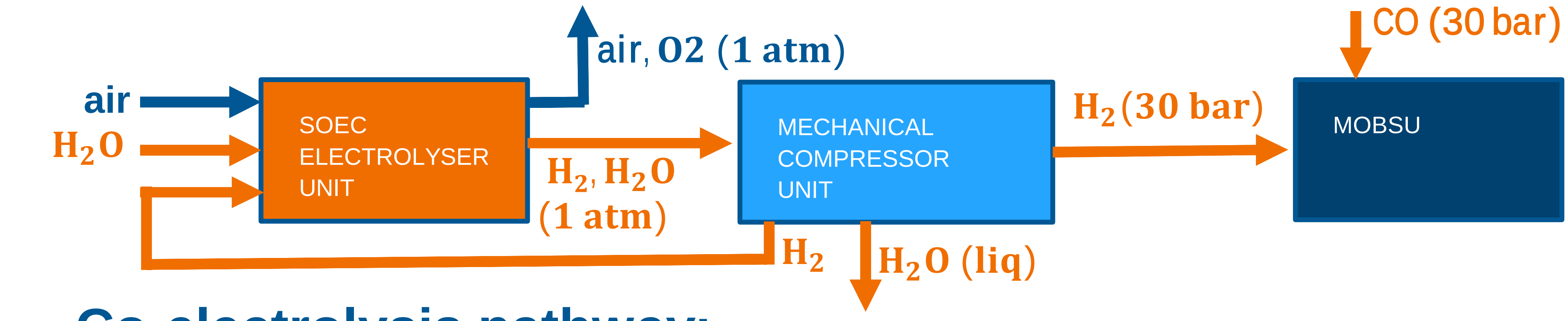
Ville Saarinen
VTT Hydrogen Production

E-fuel WP1 Novel high temperature electrolysis

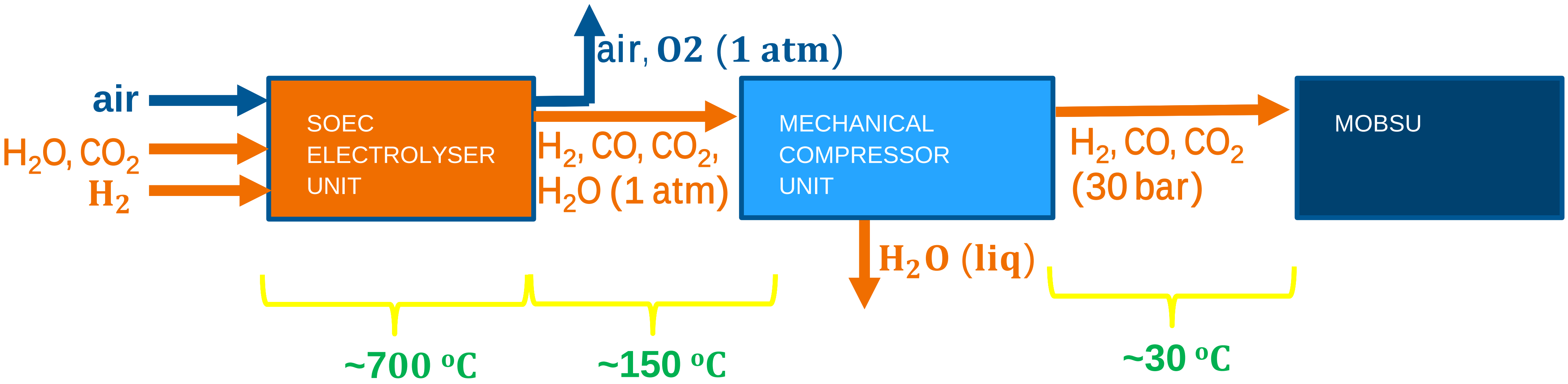
- **Main Objectives:**
  - Development and validation of the operation 10 kW size SOEC system
  - Development of interface between hydrogen production and compression system

- **WP1 is divided in 4 separate tasks with corresponding deliverables:**
  - T1.1 SOEC system proof of concept and operation validation
  - T1.2 SOEC downstream process development
  - T1.3 SOEC system modelling and heat integration
  - T1.4 SOEC stack characterization and degradation tests

Electrolysis pathway:



Co-electrolysis pathway:



WP1 Main research questions and goals

1. Building VTT's 10 kW size SOEC system with in-house developed technical solutions (e.g. super heaters, component placements, insulation etc.) *(T1.1, T1.3)*
2. Validation of the system operation and transitions between selected nominal points *(T1.1)*
3. Demonstrate highly instrumented SOEC system to investigate enthalpy and heat fluxes through the system and BoP components *(T1.1, T1.3)*
4. Investigate specific scientific questions like temperature distribution of the stack and system in different operation points and to develop low and high temperature heat recovery/utilization methods & heat integration *(T1.1, T1.3)*
5. Investigate and develop the interface between hydrogen production and compression system (automation, control and safety systems) *(T1.2)*
6. Develop system model "Digital Twin" for BoP components & electrolyser-compression system *(T1.3, WP7)*
7. Performing stack characterization and degradation tests to validate and estimate stack performance values *(T1.4)*

WP1 Novel high temperature electrolysis

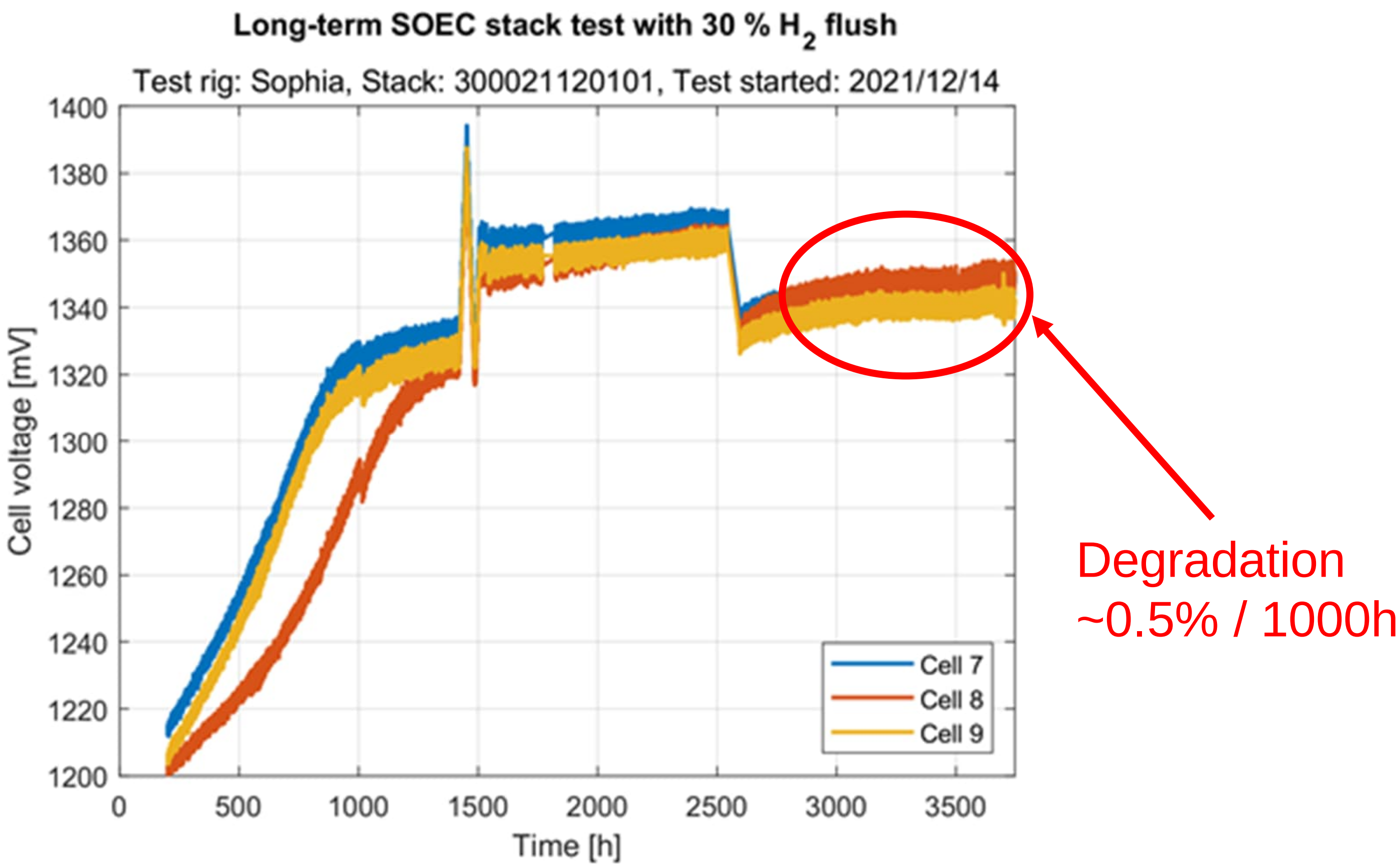
T1.4 SOEC stack characterization and degradation tests

- All planned 3 tests were completed as planned.
  1. 3000 h+ long-term tests with Elcogen's E350 (15 cells) stack
  2. 3000 h+ long-term tests with Elcogen's E350 (15 cells) stack
  3. 3000 h+ test with Elcogen's E3000 (119 cells) stack
- Nominal long-term test conditions: 0.5 A cm^{-2}, RU: 40 %, Fuel side H_2 flush: 10-30 %, T=700 ^{O}C
- First E350 stack test (2 current collection points) started 25.5.2021 and lasted 3690 hours
- Second E350 stack test (8 current collection points) started 14.12.2021 and lasted 4008 hours
- Third test run for E3000 stack started with test station building and long-term test started 11.4.2022 and lasted 3245 hours

WP1 Novel high temperature electrolysis

T1.4 SOE Stack testing at VTT

- 2 long-term 3500h+ performance tests with Elcogen 15 cell stack were done
- 15 cell stack tests together with later E3000 stack (119 cells) tests were giving valuable information of stack performance to be utilized later with VTT's SOE system «Ressu» and Convion's demonstration unit

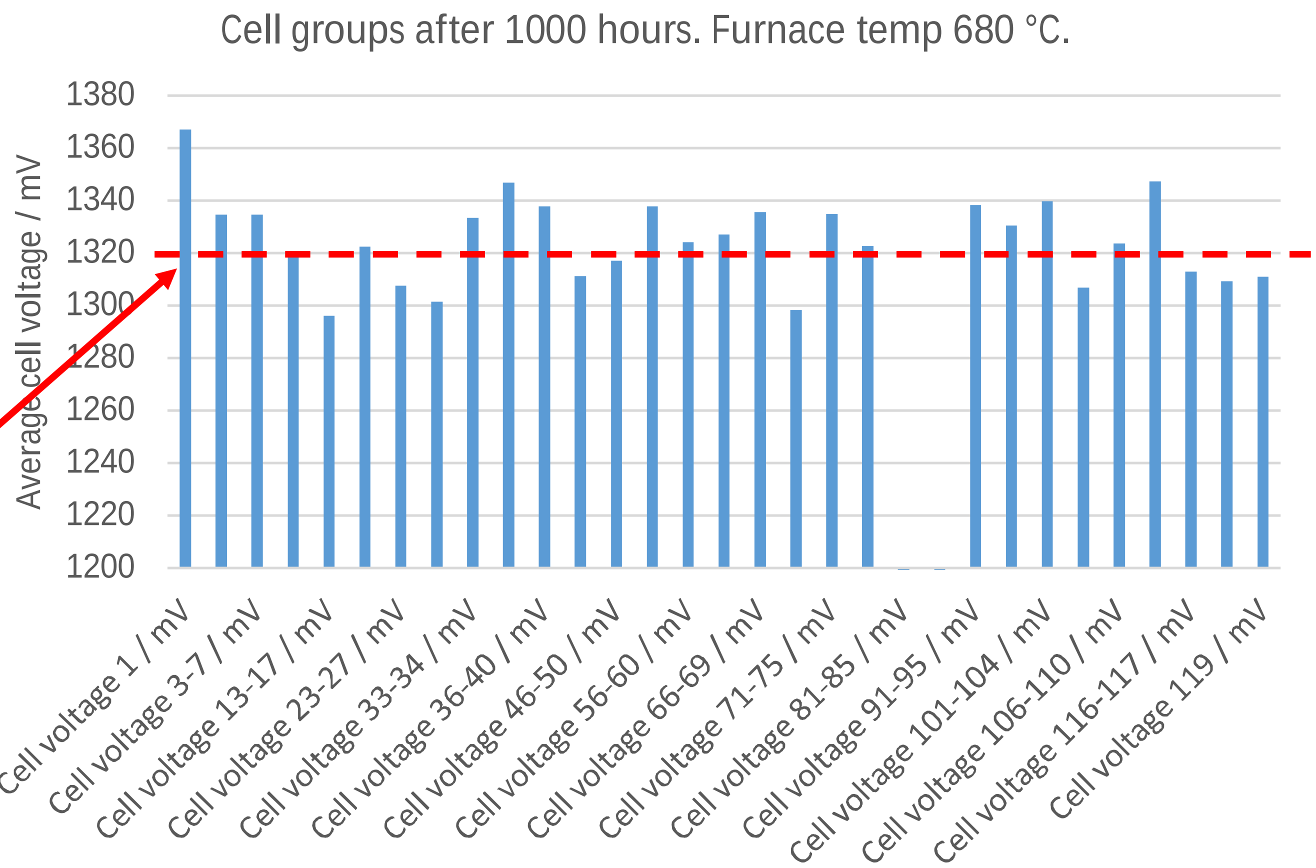


WP1 Novel high temperature electrolysis

T1.4 SOE Stack testing at VTT

- Test station for Elcogen E3000 stack (119 cells) was built and 3000h+ long-term-test was finished Q3/2022
- @1000h: relative even cell voltage and temperature distribution, ΔT_{max} ~20 ^{O}C

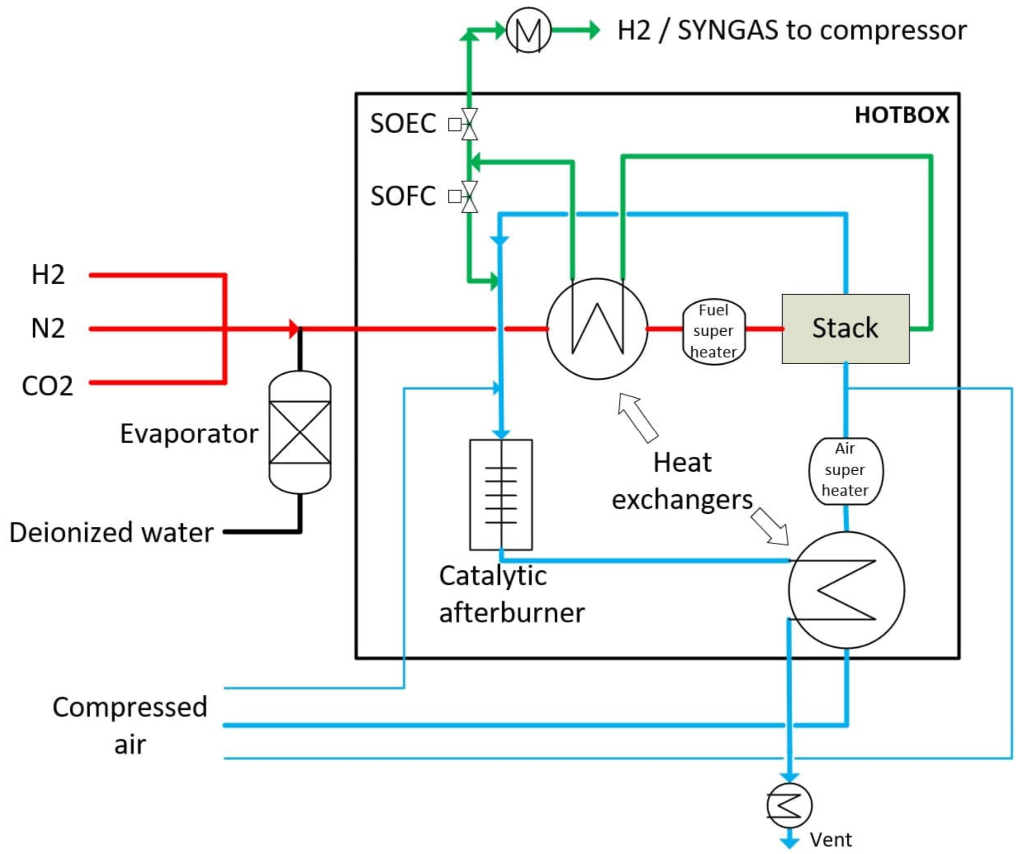
Average cell voltage ~1320mV @1000h



WP1 Novel high temperature electrolysis

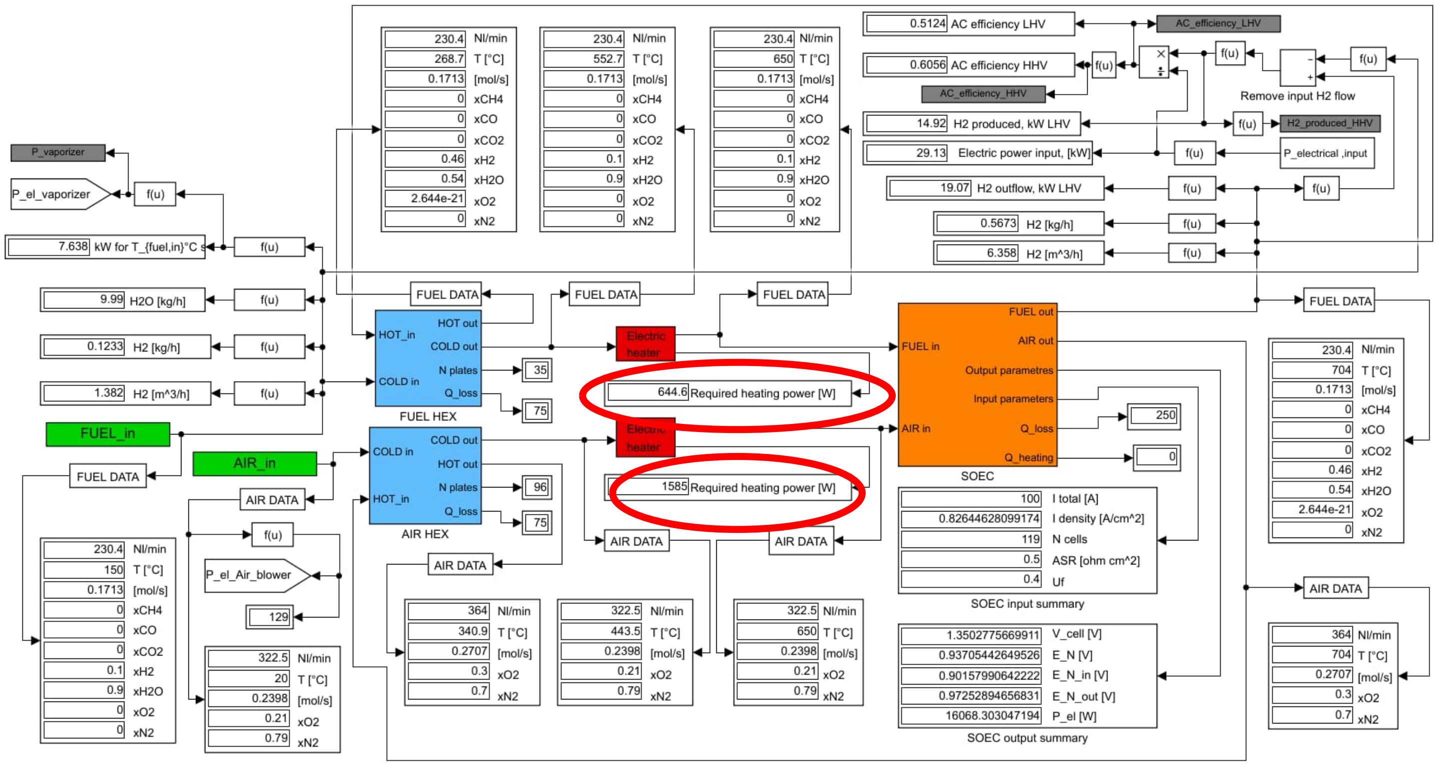
T1.1 SOEC System proof and operation validation

Simplifieds PI-diagram of VTT's highly instrumented Reversible SOC System Unit "RESSU"



WP1 Novel high temperature electrolysis

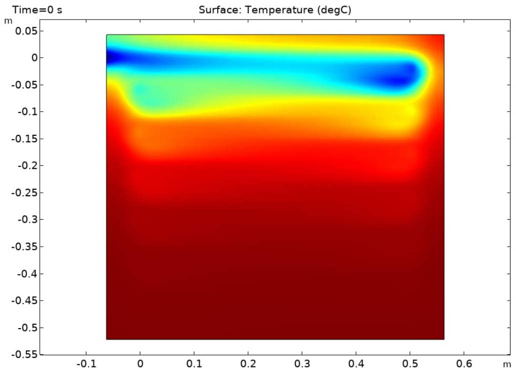
T1.3 SOEC system modelling and heat integration

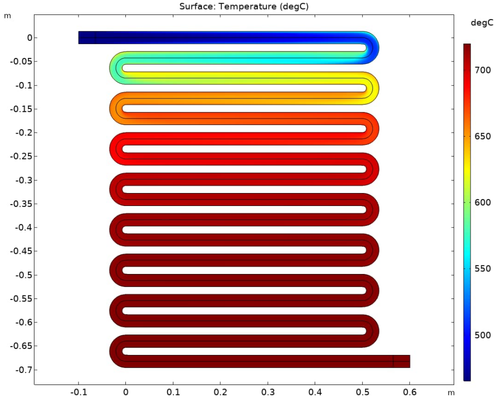


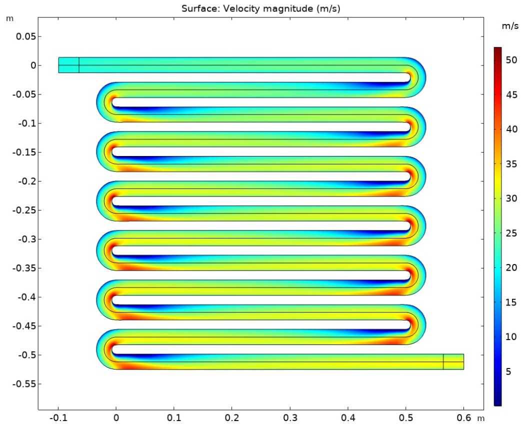
Example of Simulink system model (stack current 100A BOL, evaporator max. steam flow 10kg/h, RU 40%), giving e.g. estimations for required heating powers for superheaters: Fuel SH 645W and Air SH 1585W (at that operation point)

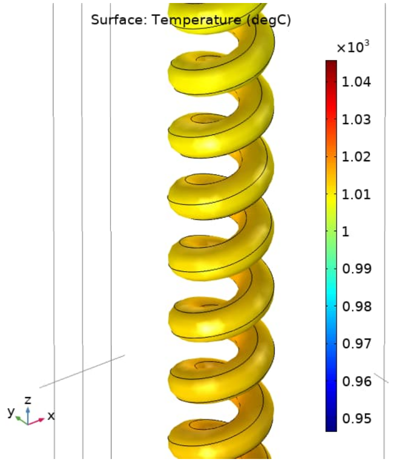
WP1 Novel high temperature electrolysis

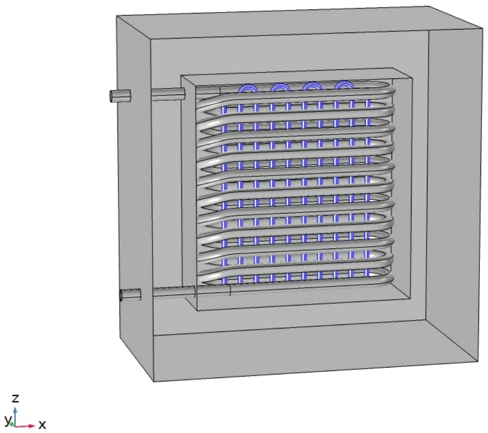
T1.3 SOEC system modelling and heat integration



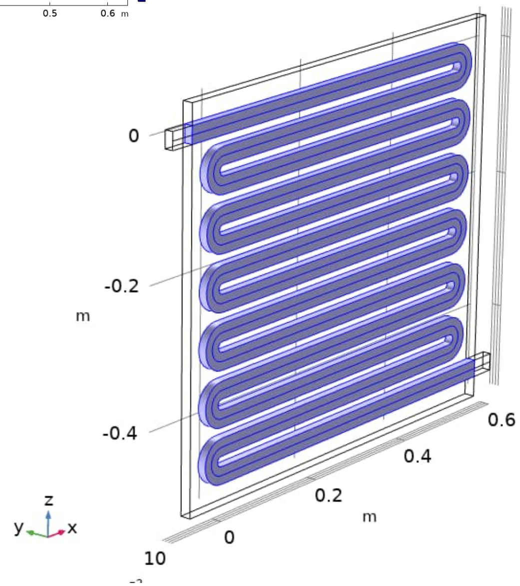








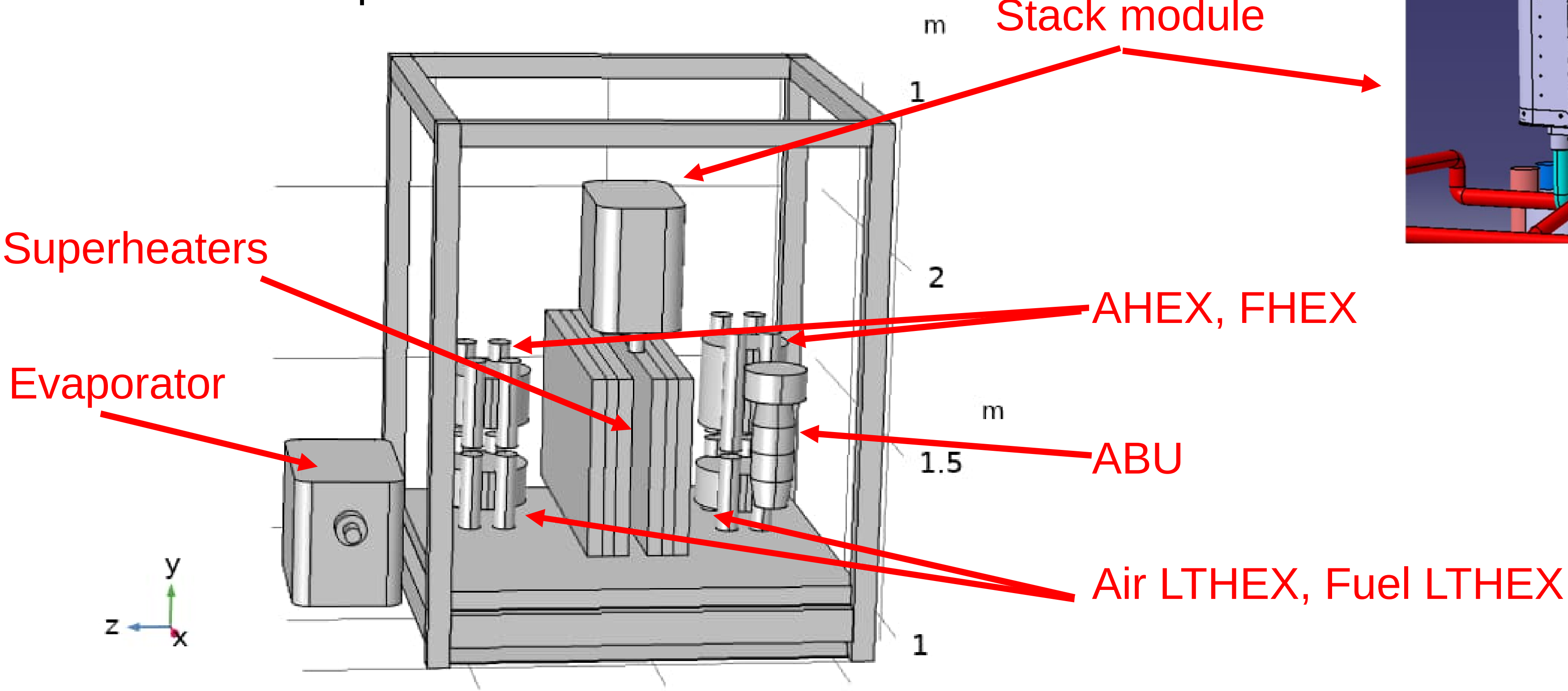
Modeling superheater properties (sizing, geometry, needed heating elements, heating power)

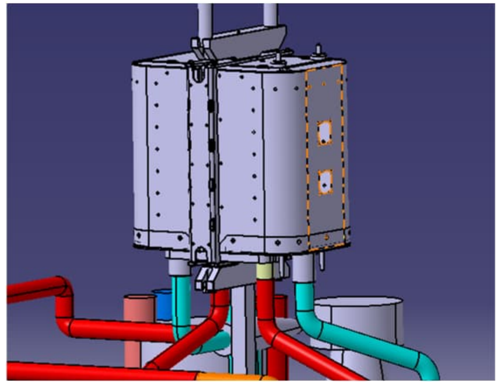


WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration

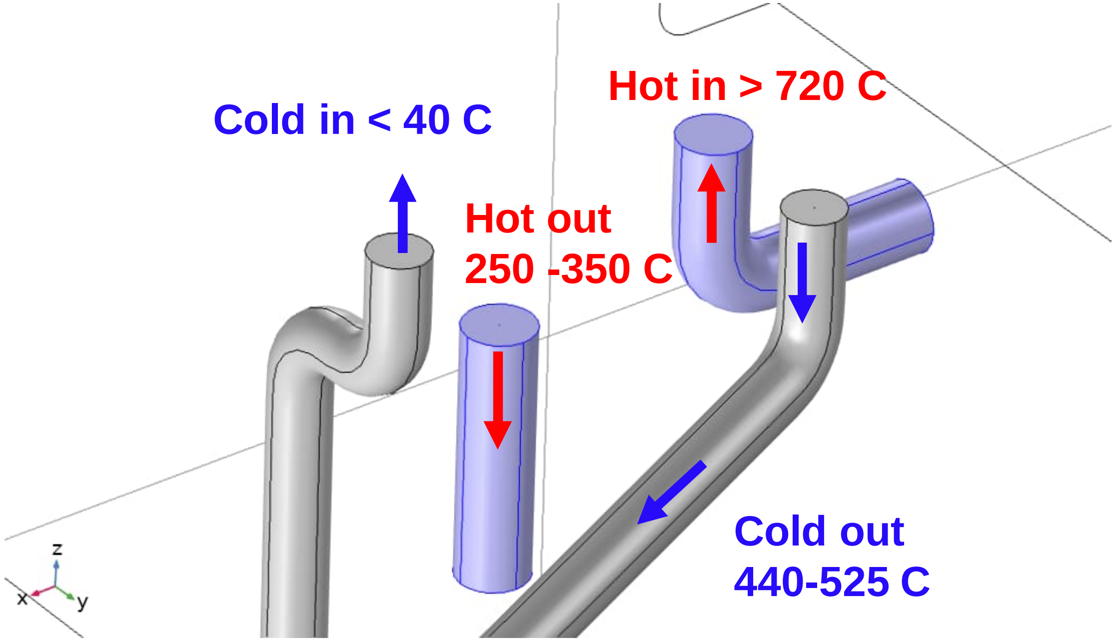
Main hotbox components and stack module



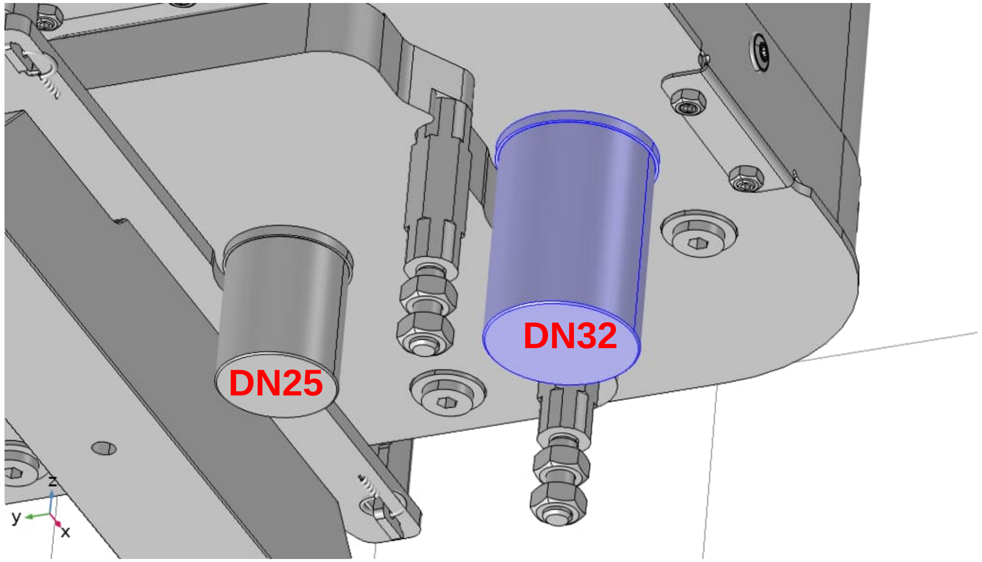


WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration



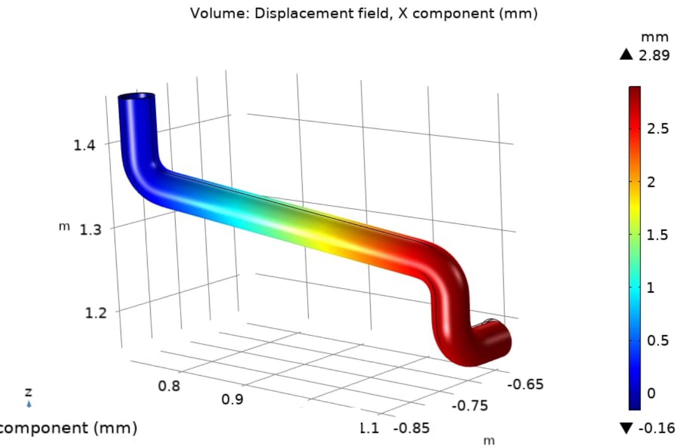
Temperatures of DN32 and DN40 tubes from the bottom of AHEX

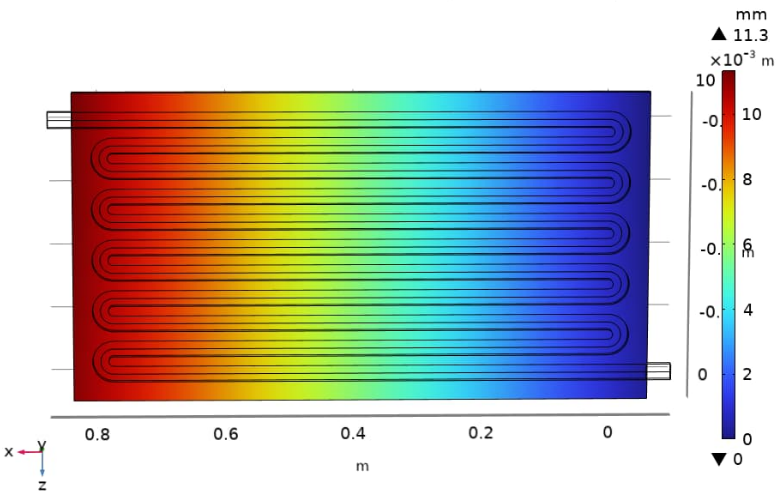


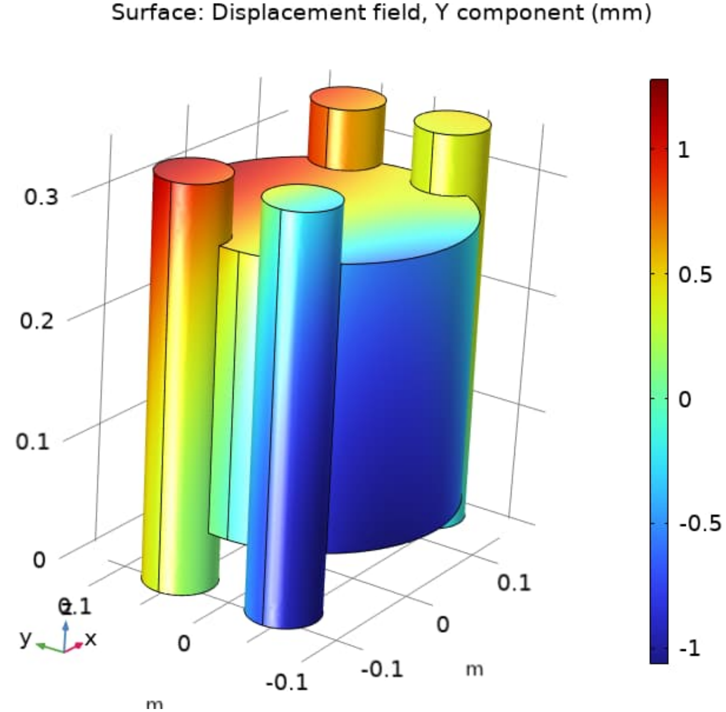
Tubings in the bottom of the stack module: Stack air in (DN25) from superheater and Stack air out (DN32) to ABU in

WP1 Novel high temperature electrolysis

T1.3 SOEC system modelling and heat integration



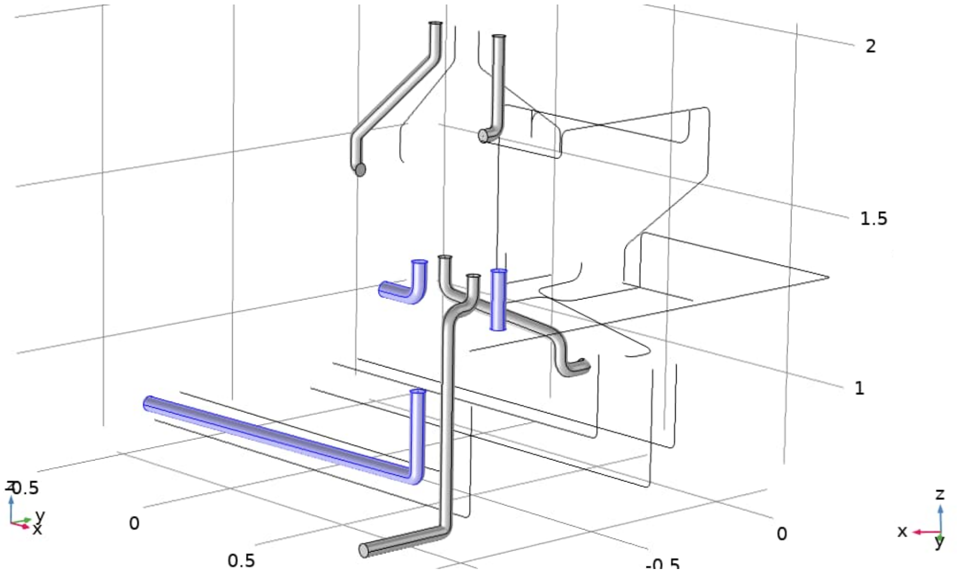




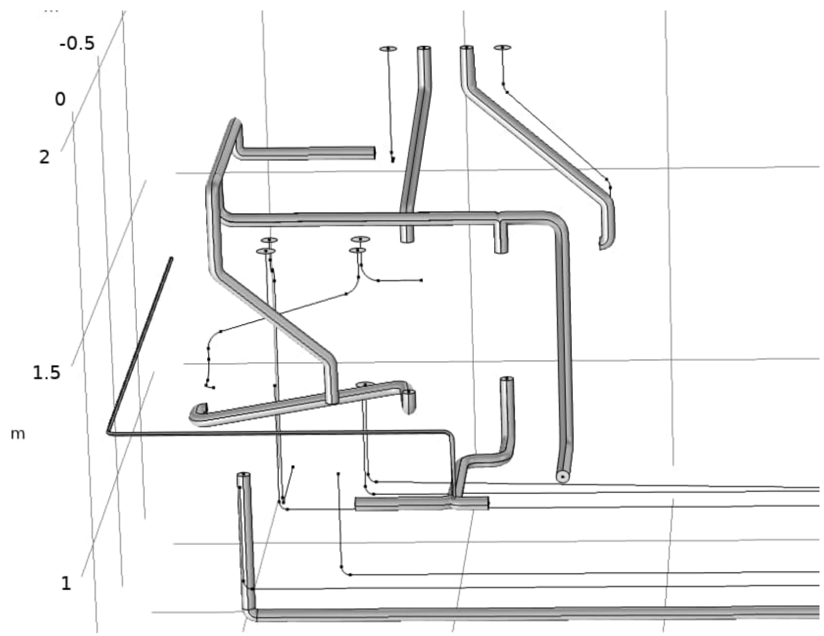
Modeling thermal expansion of Air superheater, AHEX and the tubes between (20^{O}C → 750 ^{O}C)

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation
T1.3 SOEC System modelling and heat integration



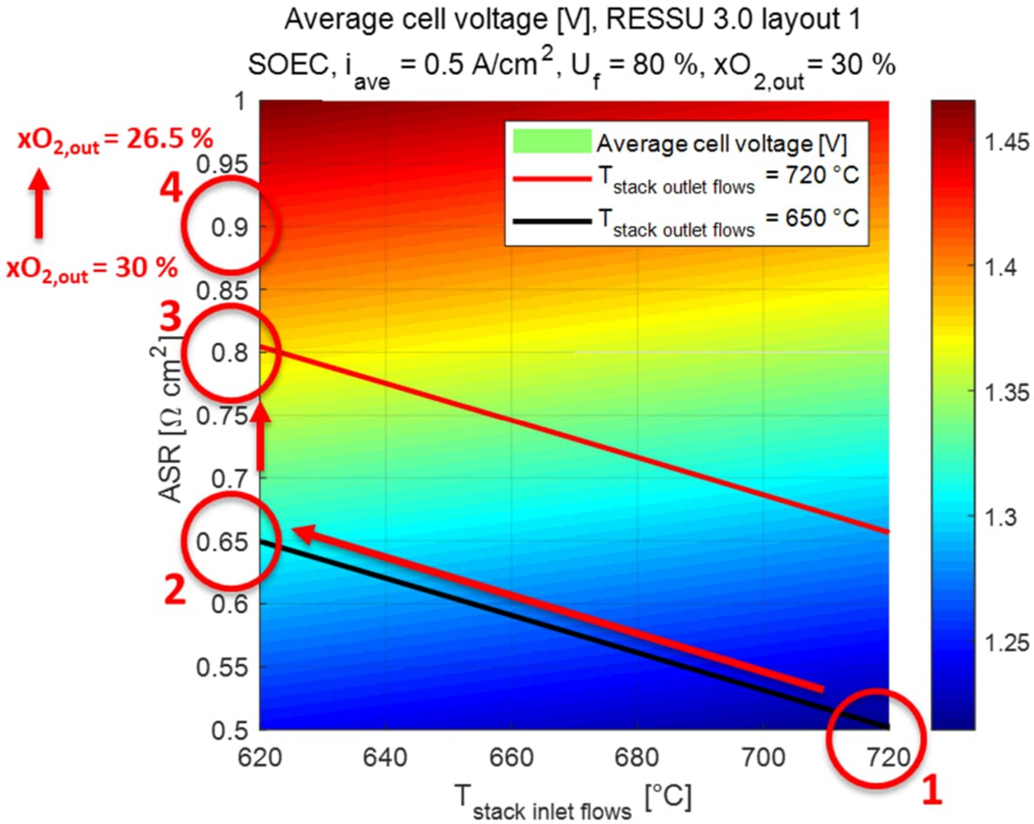
Air side main pipings with DN35 and DN40 tubes



Fuel side main pipings with DN25 and other pipings with 10 mm inner diameter tube

WP1 Novel high temperature electrolysis

T1.3 SOEC system modelling and heat integration

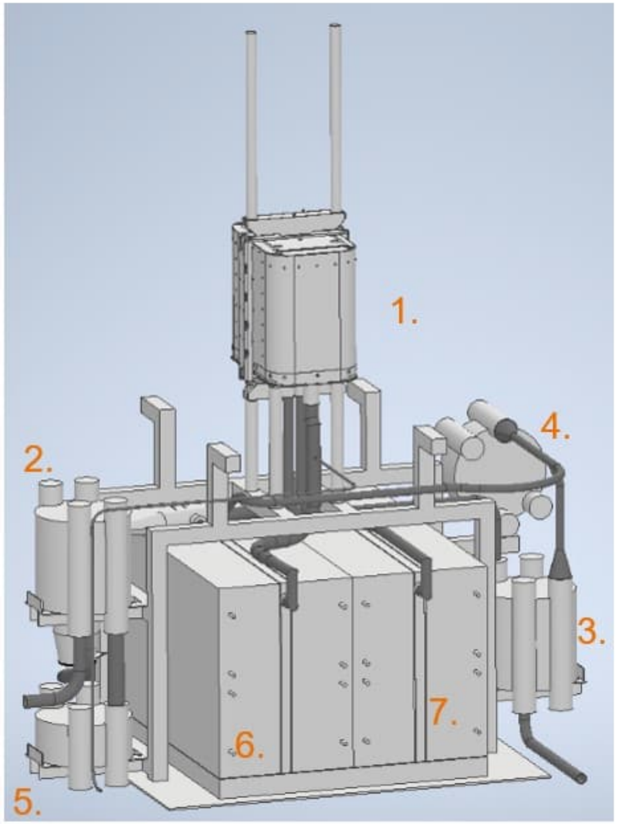


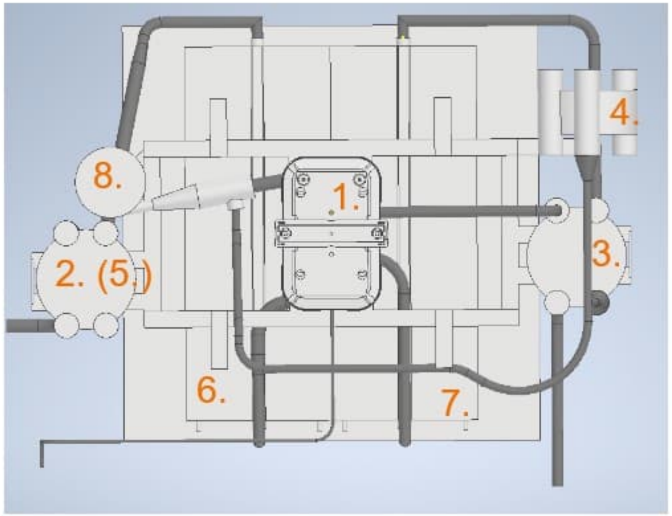
	AC → H_2 HHV (%) (H_2 at 1 atm) (AC → DC, 84 %)	AC → H_2 (kWh/kg) (H_2 at 1 atm) (AC → DC, 84 %)	AC → H_2 (kWh/kg) (H_2 at 1 atm) (AC → DC, 84 %) (Free 150 C steam)	DC → H_2 (kWh/kg) (H_2 at 1 atm)	DC → H_2 HHV (%) (H_2 at 1 atm)
1	73.9	53.8	45.2	32.5	122.0
2	73.2	54.2	45.6	35.1	113.1
3	72.0	55.2	46.6	36.9	107.7
4	65.5	60.7	52.0	38.2	104.4

A method by which the E3000 SOE stack could be operated with a constant current in VTT's SOEC system throughout its full life cycle and calculated SOEC system efficiency values.

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation



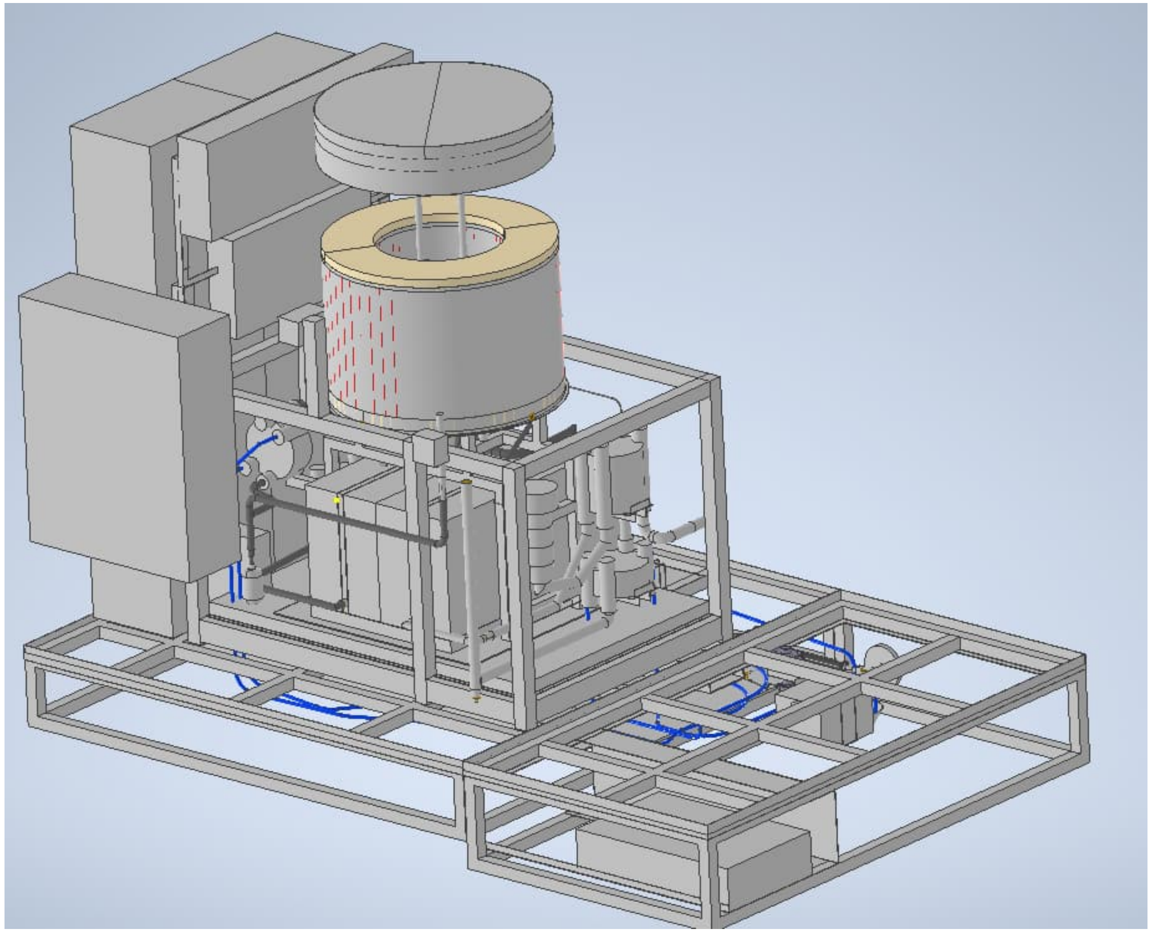


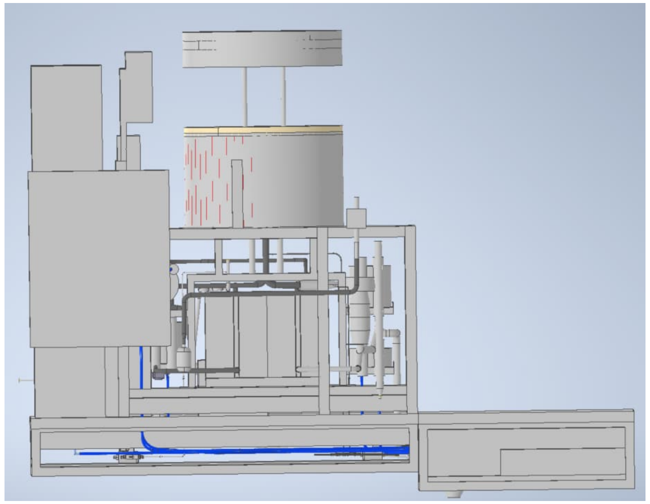
1. Stack module
2. Air HEX
3. Fuel HEX
4. Fuel cooler HEX
5. Air cooler HEX
6. Air Superheater
7. Fuel Superheater
8. Afterburner (ABU)

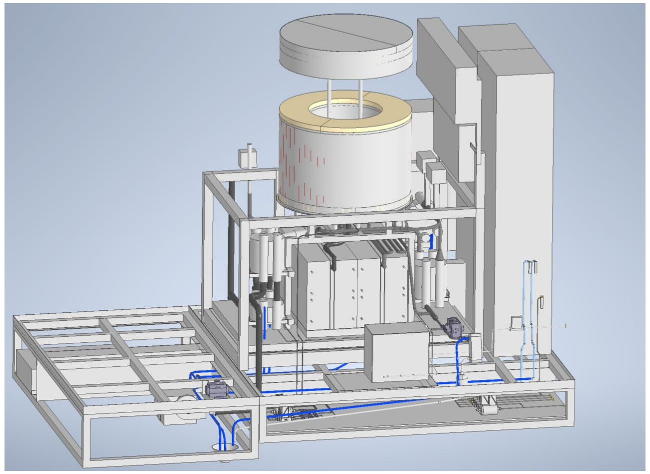
Detailed component placements in the final design of VTT's SOEC system

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation







AutoCAD images of the VTT's SOEC system

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation

A steel and aluminium frame of the SOEC system and preliminary fitting of superheaters.

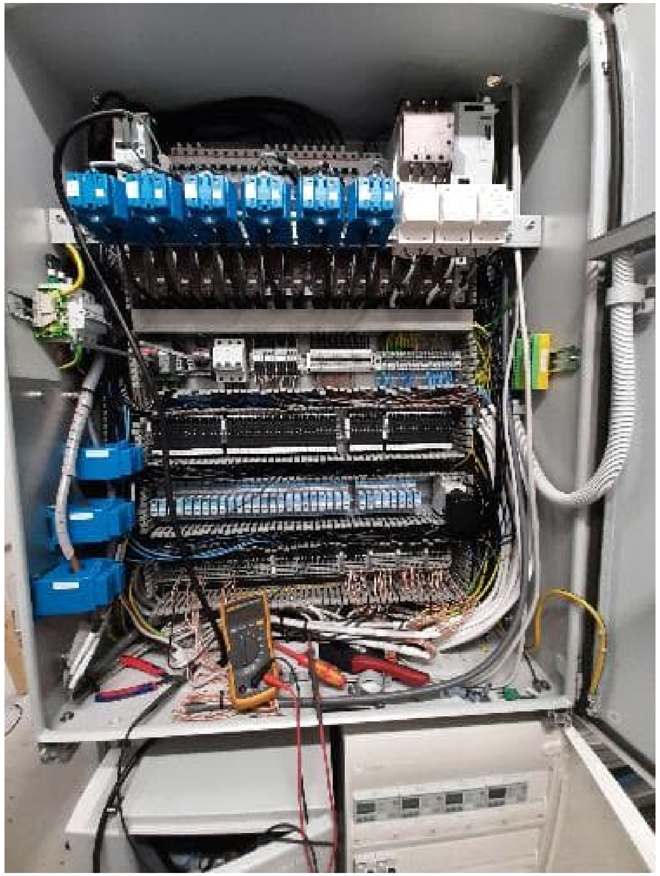
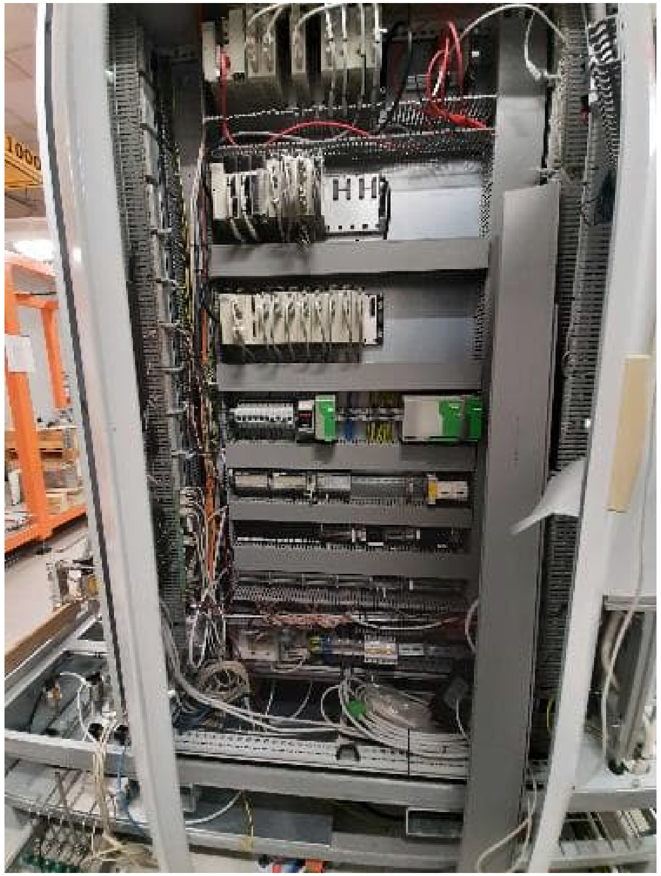
WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation

Installing superheaters and heat exchangers

WP1 Novel high temperature electrolysis

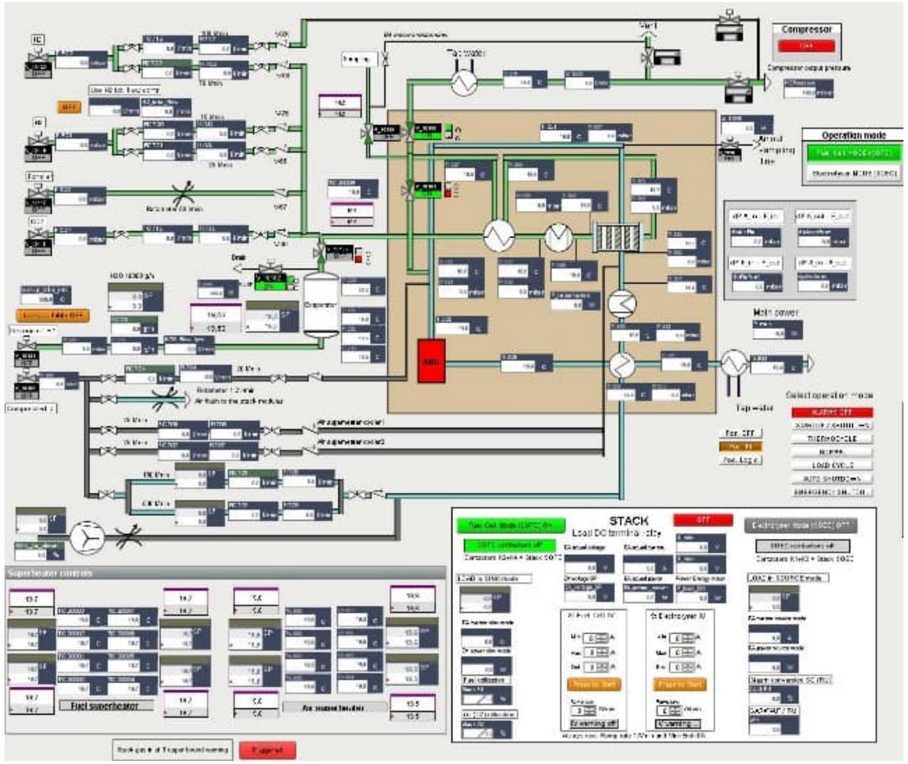
T1.1 SOEC System proof and operation validation

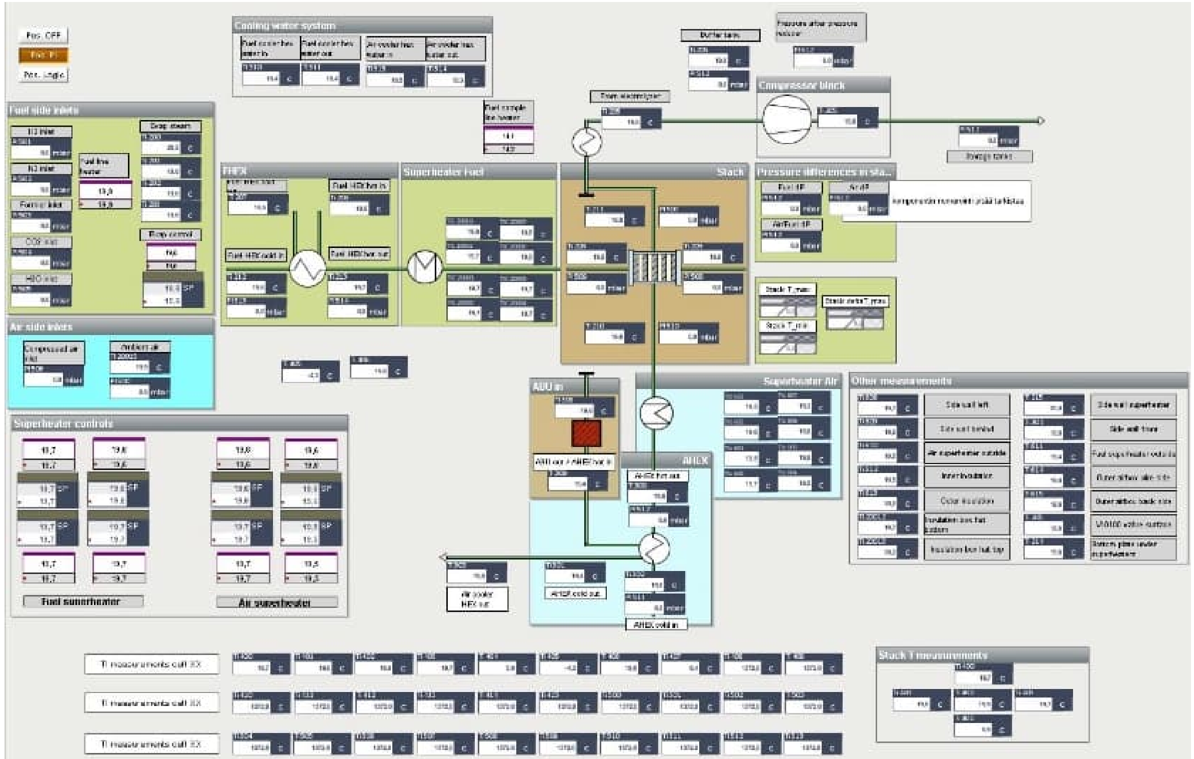




Automation control cupboards installed to SOEC system

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation





Developed automation control system and HMI.

WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation

The installation of cylinder-shaped insulation dome over the stack module.

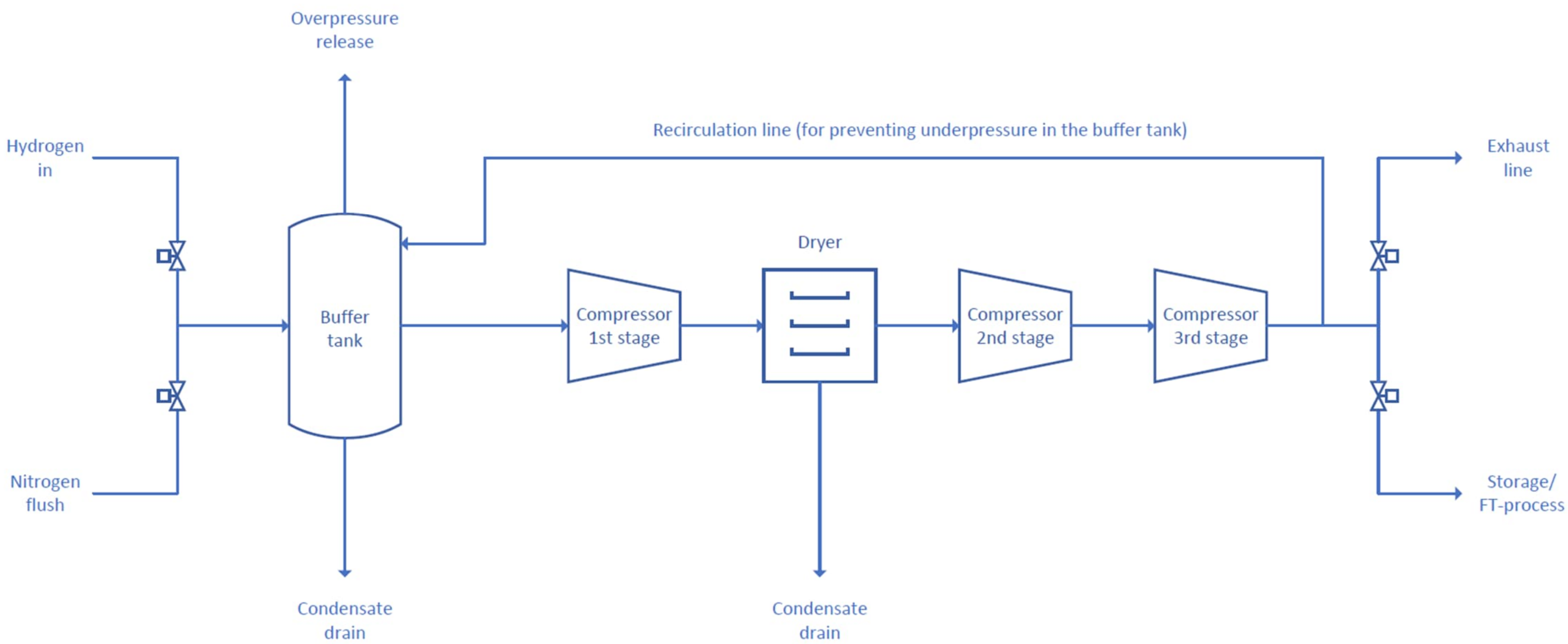
WP1 Novel high temperature electrolysis

T1.1 SOEC System proof and operation validation

The BoP hotbox module was filled with granule sealing material and cylinder-shaped insulation dome was installed over the stack module.

WP1 Novel high temperature electrolysis

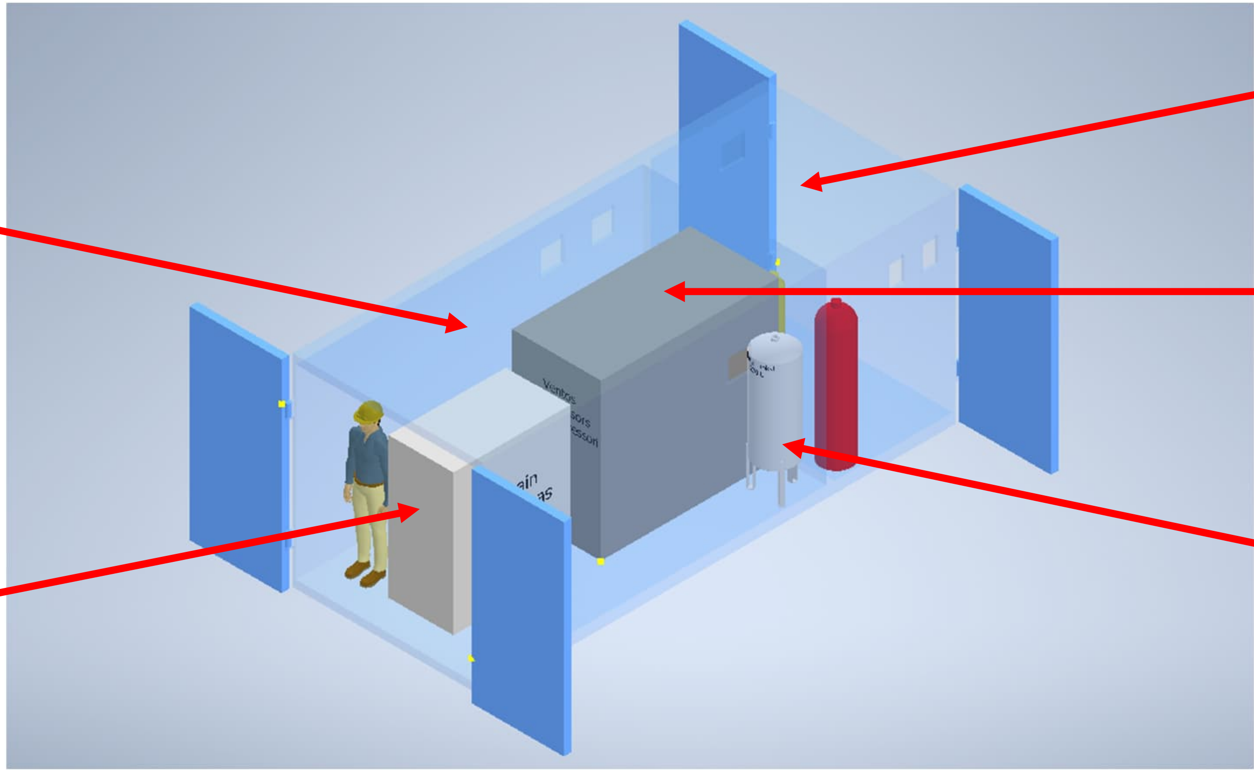
T1.2 SOEC downstream process development



Process flow diagram of the compressor system including the main process components.

WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development



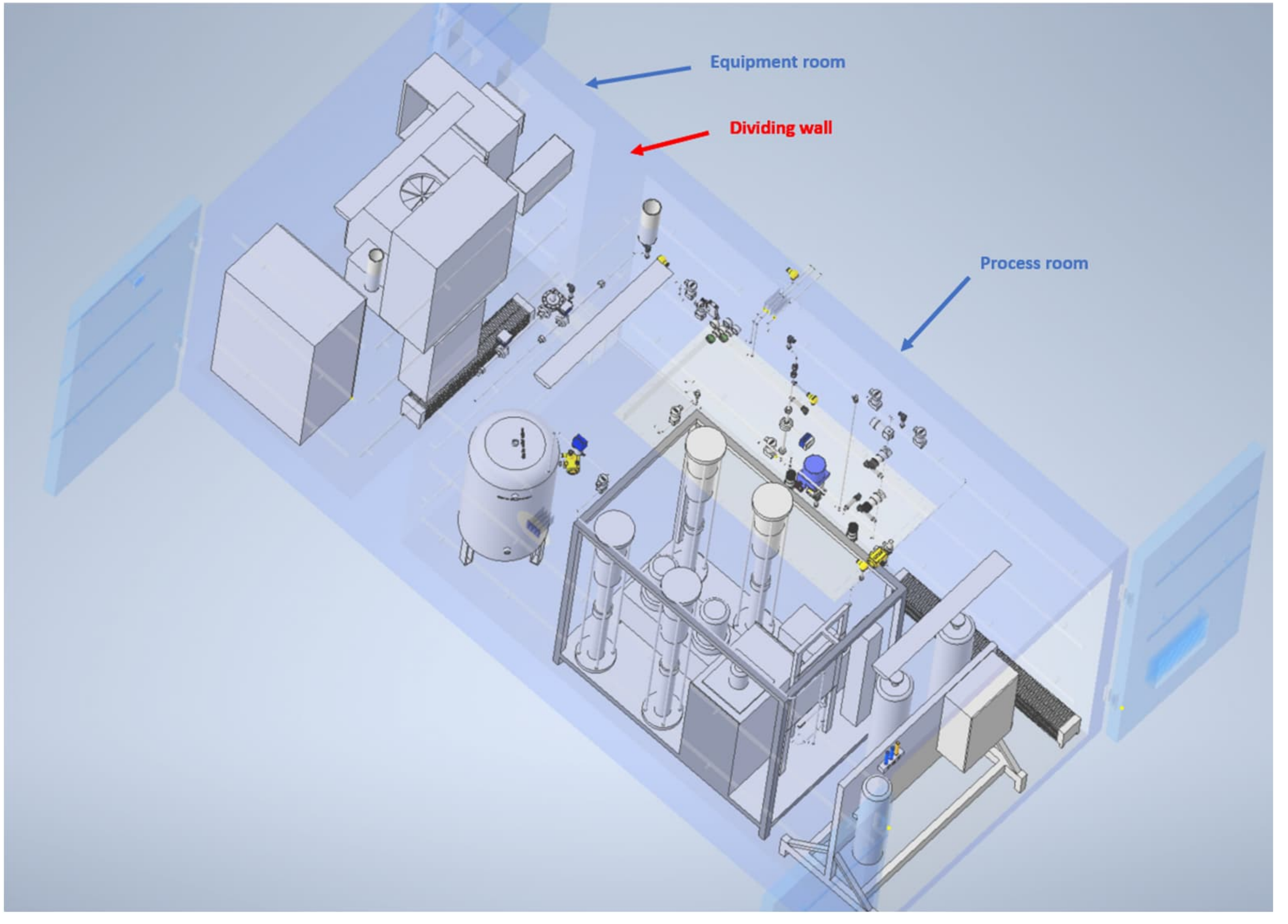
WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development

Process room (ATEX zone 2)	Equipment room
Hydrogen compressor	Main switchboard
Hydrogen gas dryer	Automation center (main)
Inlet buffer tank	Automation center (compressor)
Piping	Automation center (dryer)
Valves	Indoor air blower
Process sensors	Indoor air gas sensors (2x H_2 + O_2)
Indoor air blower	Room heater (2 kW) + thermostat
Indoor air gas sensors (2x H_2 + O_2)	Gas control panel
Room heater (3 kW) + thermostat	Dryer’s chiller unit
	Gas chromatograph

WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development



WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development

20ft container where the hydrogen compression system is being built.

WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development

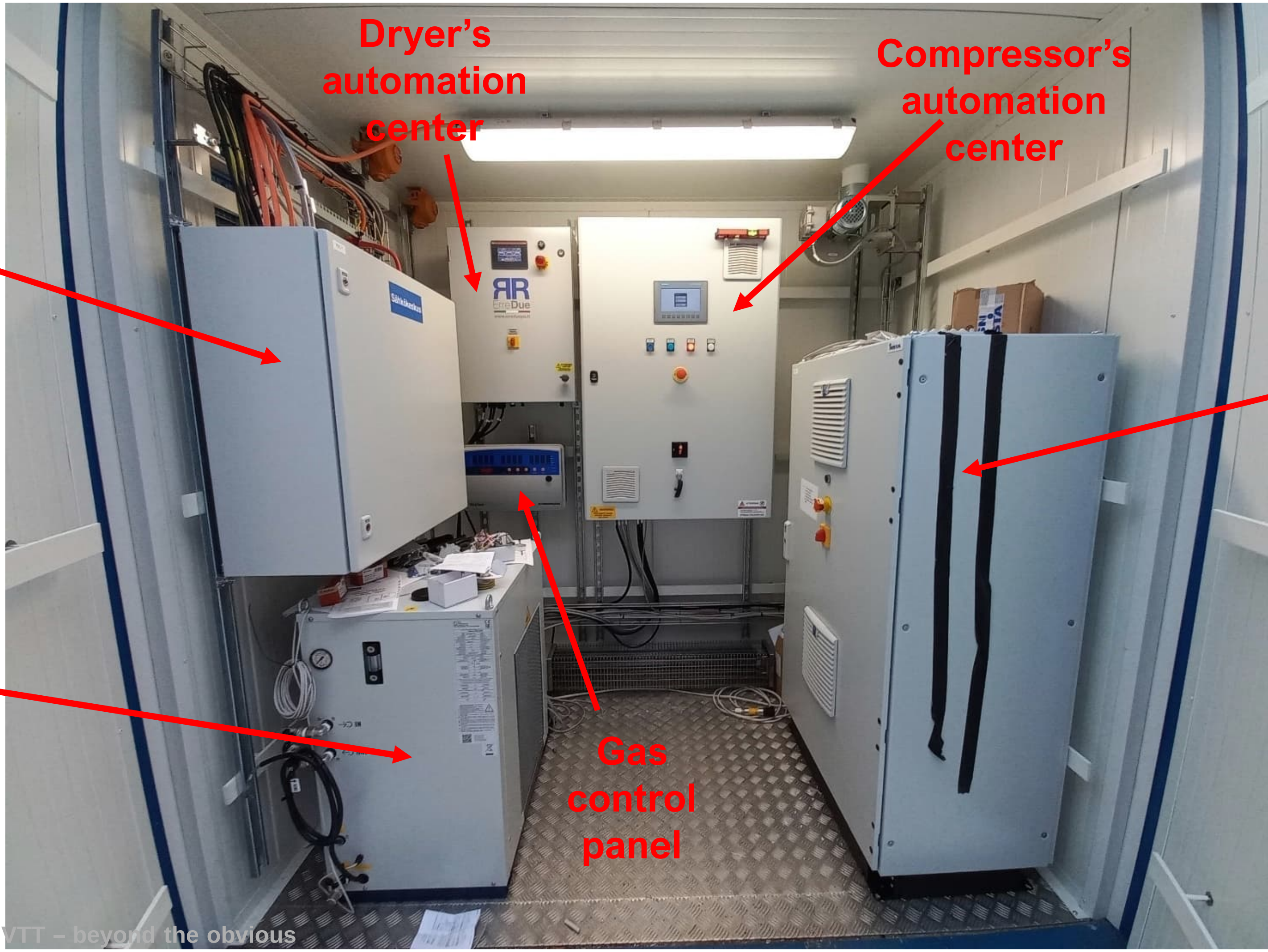
Hydrogen gas dryer

Hydrogen gas compressor (3 stage)

Buffer tank (Compressor inlet)

WP1 Novel high temperature electrolysis

T1.2 SOEC downstream process development



WP1 Summary

- ***T1.1 and T1.3:*** A 10kW size Solid Oxide Electrolyser (SOEC) system with Elcogen E3000 stack was designed, built and tested at VTT. The preliminary testing showed that the performance values were very similar compared to the stack performance results. Also control and safety systems, automation and Human Machine Interface (HMI) for VTT's SOEC system were built and tested successfully.
- ***T1.2:*** Hydrogen compressor and auxiliary components were designed and built and HAZOP analysis was done – the automation system building is still in progress. Elcogen's mechanical compressor testing was completed at VTT's premises
- ***T1.4:*** All tests were finished successfully: two 3000h+ long-term tests with Elcogen's 15 cell stack and one 3000h+ test with Elcogen's E3000 (119 cells) SOEC stack

→ more details in deliverables *D1.1-D1.4*

Any questions?

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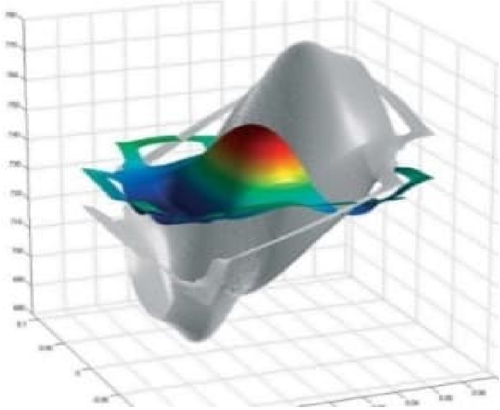
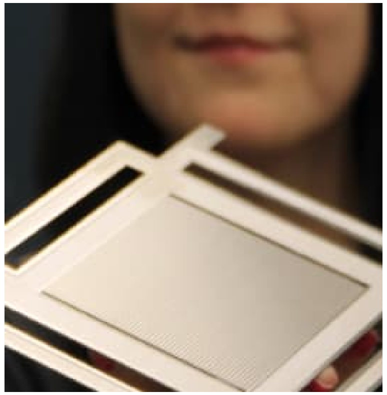
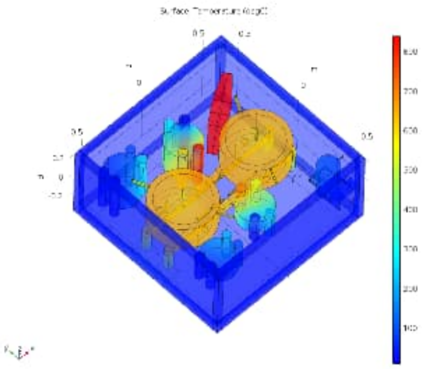






WP2
CO_2 capture

E-Fuel project
Tuula Kajolinna

CO_2 capture / One slide overview

Tasks

- T2.1 State-of-the-art review and evaluation of suitable CO_2 capture technologies for E-fuel concept
- T2.2 Enhanced soda scrubbing technology development
- T2.3 CO_2 capture & purification pre-testing for the e-fuel concept

Deliverables and dissemination

- D2.1 “State-of-the-art review and evaluation” Available
- D2.2 “Pre-tests of VTT carbon capture units and indicative concept integration designs” Draft on Teams
- D2.3 “Mass Transfer Efficiency for CO_2 Capture Using Soda Solutions” Available
- Blog text on E-fuel webpage
- Conference presentation and article at GHGT-16 Available
- *Extra:* Article1 on concept of VTT carbonate-based CO_2 capture process Submitted
- *Extra:* Article2 on TEA of VTT carbonate-based CO_2 capture process Under work

Company and other collaboration

- Andritz, CarbonReUse Finland, Kleener Power Solutions, LUT University

T2.1 State-of-the-art review and evaluation of suitable technologies for e-fuel concept

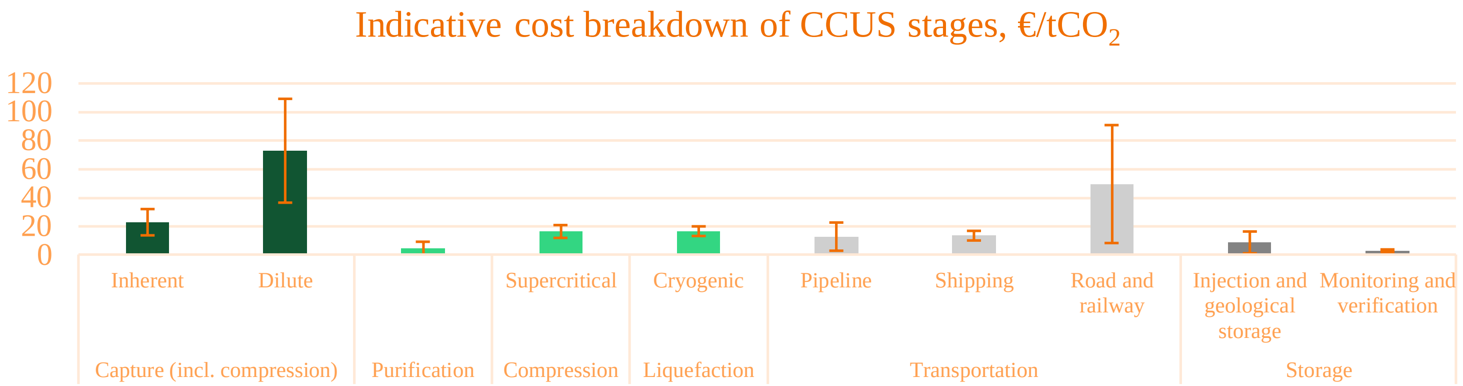
Report title: Industrial CO_2 supply pathways for CCU-based electrofuel production in Finland

Available at
www.e-fuel.fi/publications/

- Focus on point source capture over DAC due to high maturity and more favorable economics
- Objectives of the study
  - Gain a *holistic understanding on technical requirements* and economics of CCUS stages
  - *Map potential carbon capture technology options* for industrial point source capture
  - *Identify industrial emission point sources* with high potential for carbon capture implementation

Conclusions of Task 2.1 (1/2)

- CCUS consists of several, *case-specific* stages that yield a
  - total cost ranging around 42–161 €/tCO_2, with the cost depending primarily on a) CO_2 concentration / partial pressure, b) scale of operation and c) required stages of logistics



- Several technology options for point source carbon capture are available
  - *Amines* are a proven option with a *low risk* of implementation.
  - *Alternative technologies* like carbonate salt solvents have emerged to TRL 8–9 and become reasonable to consider alongside amines.
  - Several other *emerging technologies* like solid sorbents, membranes, and fuel cell systems are on the brink of commercialization.

Conclusions of Task 2.1 (2/2)

- *Carbon capture potential* of forest industry, petroleum refining and biorefining in Finland

	Pulp and paper mills		Petroleum refineries (excl. SMR)		Steam methane reforming		Ethanol fermentation		Hydrotreated vegetable oils	
Annual CO2 emissions of the industry in Finland	2	20.6 Mtpa (2020)	1	2.9 Mtpa (2020)	1	Estimated based on facilities in Finland	0	18 ktpa (2017)	0	97.5 ktpa (est.)
Onsite CO2 emissions of an average Finnish facility/complex	2	1 Mtpa average of facilities reported in E-PRTR	2	2.7 Mtpa (Neste Kilpilahti)	1	192 ktpa Linde Kilpilahti	0		0	
Industry trend in Finland by 2030	2	Capacity to grow, e.g., Metsä Fibre Kemi bioproduct mill	1	Capacity expected to remain similar	1	Capacity expected to remain similar	2	Capacity expected to grow, e.g., Bioenergo Pori and NordFuel Haapavesi	1	Capacity expected to remain similar
Average CO2 concentration of the emission point source(s)	0	12–13 % (recovery and power boiler) 20 % (lime kiln)	0	8–10 % (heaters) 3–5 % (utilities) 10–20 % (FCC)	1	30–45 % (PSA exhaust stream)	2	>90 %	2	>90 % (best case scenario: decarboxylation)
Degree of carbon capture implementation	2	Commercial: e.g., Saipem at Resolute's kraft pulp mill in Quebec, Canada (TRL 8)	2	Commercial: e.g., Sinopec at Qilu refinery, China	2	Commercial: e.g., Air Products Port Arthur and Linde Kilpilahti	2	Commercial: widely used in the US to provide CO_2 for enhanced oil recovery	0	
System integration challenges (e.g., equipment size limitations, energy integration, utility and waste streams)	1	Requires post-combustion capture retrofit. Steam supply may be inadequate, and an auxiliary boiler may be required if the recovery boiler is targeted.	1	Several point sources of CO2, often limited space available, unique site configurations for which it is difficult to create a standard solution for CO2 capture.	1	Requires PSA-based capture or solvent-based CO2 scrubbing	2	Straightforward integration, requiring only dehydration and purification of the exhaust stream.	2	Straightforward integration expected if the exhaust stream is not mixed with other streams, requiring only dehydration and purification.
Natural origin of CO2	1	>90 % biogenic	0	Fossil	0	Fossil	1	Biogenic	1	Biogenic
Total score (max. 13)	**10**		**7**		**7**		**9**		**6**	

- Indicators:
  - Annual CO_2 emissions
  - Industry trend by 2030
  - CO_2 source concentration
  - Implementation status
  - Integration challenges
  - Origin of CO_2 (biogenic/fossil)

- Industrial CO_2 emissions in Finland provide high potential for bio-CCUS
  - *Pulp mills* have the most appeal *for large-scale* implementation
  - *Biorefinery processes* like fermentation and *HVO* yield potential for low capture cost and simple carbon capture implementation at *small scale*

T2.2 Enhanced soda scrubbing technology development

- VTT's carbonate-based CO_2 capture process
  - In freight container, easily transportable pilot-scale process
  - Modifications of process are easy
  - No need of steam, all temperature requirements < 80°C
  - Low pumping energy demand
- Study and developed further capture & energy efficiency
  - D2.3: Master Thesis "Mass transfer efficiency for CO_2 capture using soda solutions"
- VTT's carbon capture units and indicative concept –review, D2.2
  - CO_2 capture process and it's techno-economic scaling possibilities
  - Production concepts of Formate and Formic acid from bicarbonates
  - Electric Lime Kiln concept to produce pure CO_2 from lime calcination

Link at www.e-fuel.fi/publications/

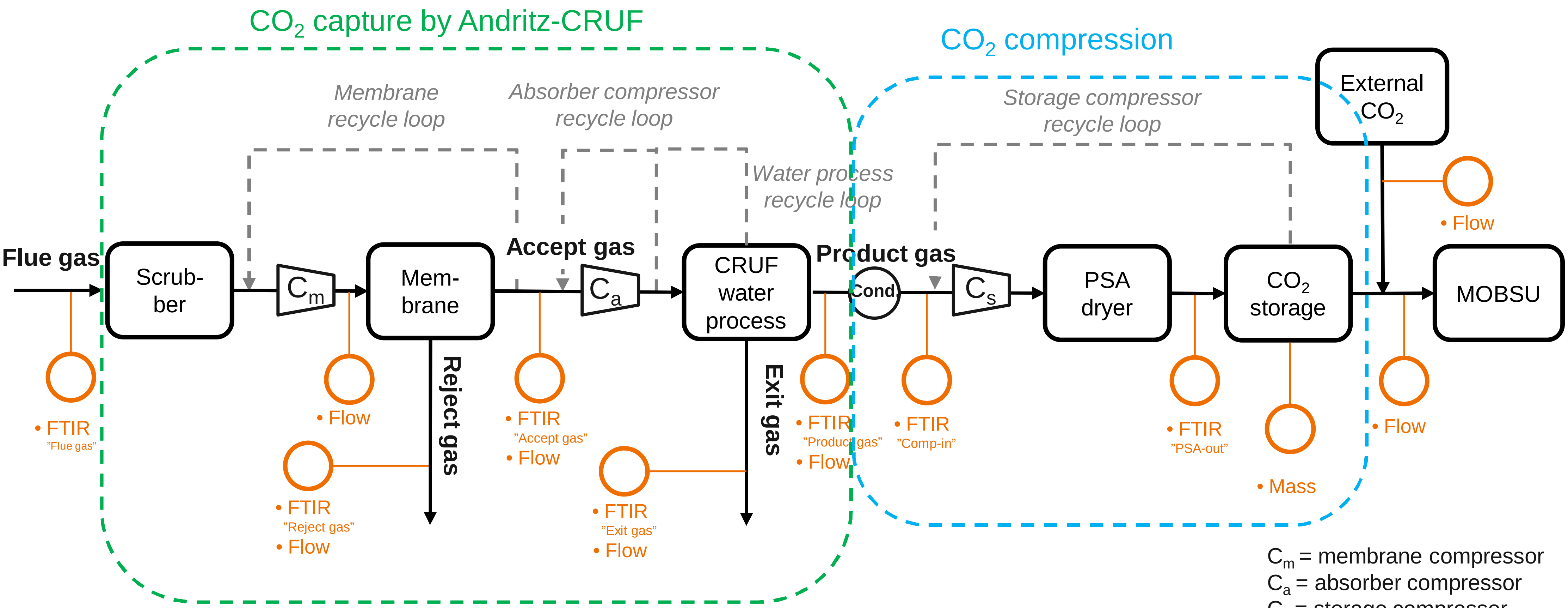
Report on Teams

T2.3 CO_2 capture & purification pre-testing for the e-fuel concept

Presentation on Teams

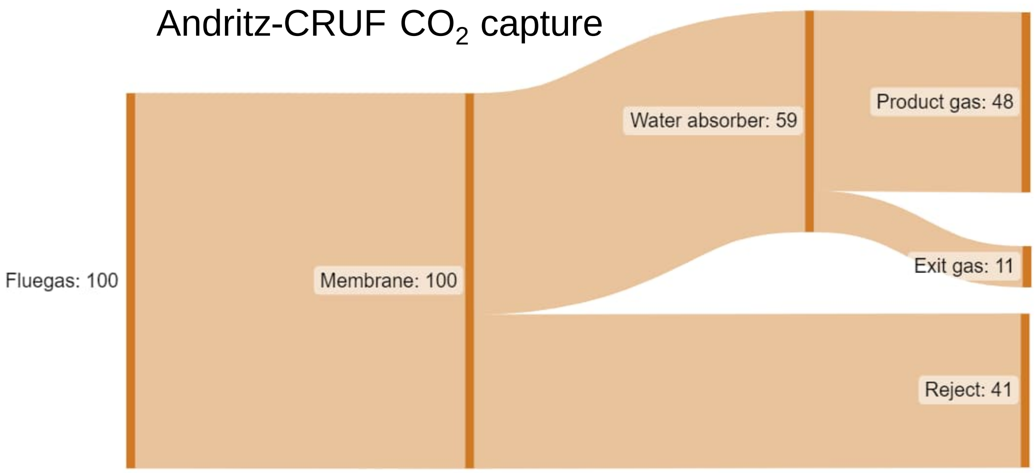
- During WP4 Demonstration tests at Bioruukki 6/2023
- Aim to study CO_2 capture, purification and compression performances during Demo
  - Gas concentrations
    - Removal rates of each process
  - Energy consumptions
- CO_2 capture by Andritz-Carbon ReUse Finland (Andritz-CRUF)
- CO_2 compression by VTT

T2.3, Process and measurement flowchart



C_m = membrane compressor
C_a = absorber compressor
C_s = storage compressor
Cond. = condenser

T2.3, CO_2 flows and concentrations



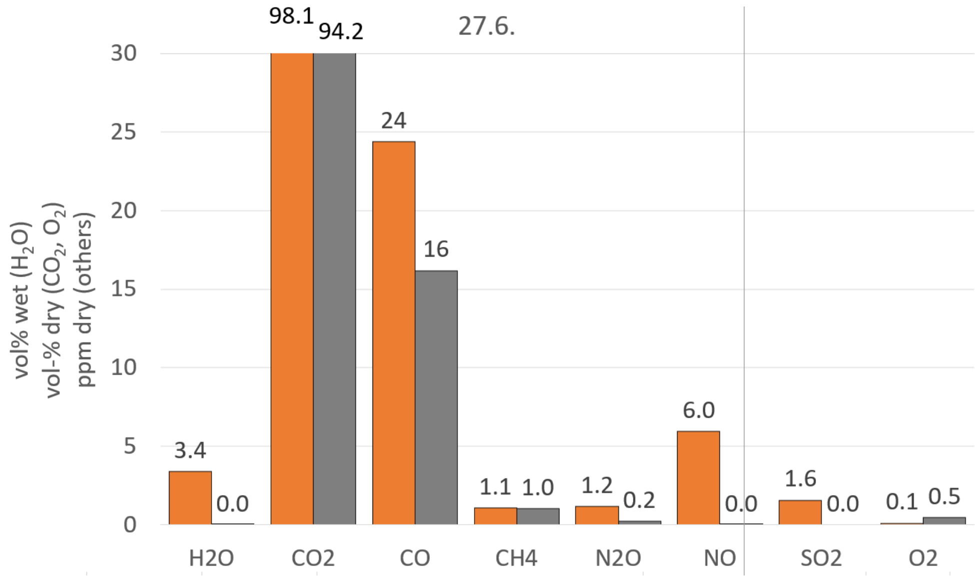
- Total CO_2 capture rate was ~48%
  - The main aim was to achieve a high CO_2 concentration in product gas – NOT a high capture rate
- Capture rates of membrane and water absorption processes were ~60% and ~80%, respectively

- Product gas
  - CO_2 up to 99 vol% (dry)
  - O_2 0.1 – 0.2 vol% (dry)

T2.3 Summary and conclusions

- CO_2 capture using a hybrid membrane-water absorption process and subsequent gas drying and compression was successfully demonstrated
- Up to 99 vol% CO_2 content in dry gas after capture process was achieved
- Very low amounts of harmful impurities (NO, SO_2) in the product gas
- Electricity consumption of the process was very high but not representative of an actual commercial processes

Concentrations before and after the PSA dryer & storage compressor



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WP3 Synthesis

Pekka Simell, Christian Frilund, Niko Heikkinen

16/04/2024 VTT – beyond the obvious

Objectives WP3

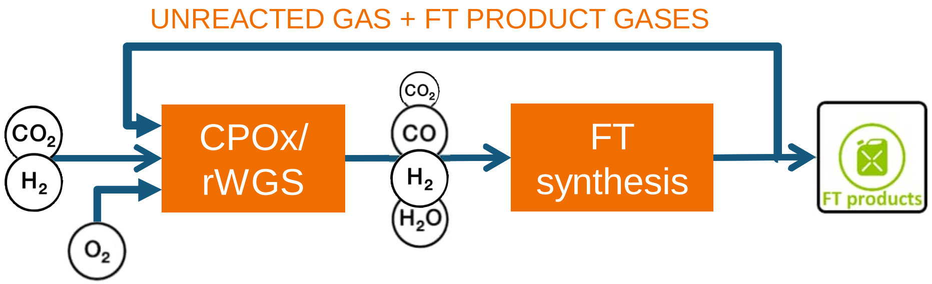
- **T3.1 RWGS/CPOX**

- A) CPOX/rWGS technology long term piloting, TRL5, **Christian Frilund**
  - ensure correct reactor design and dimensioning of the equipment for large scale process design
  - determine feasible circulation ratio of the off-gases to ensure operation conditions that allow long term coking free runs
- B) e-reactor concept development for rWGS, TRL3, **Pekka Simell**
  - PoC at lab scale

- **T3.2 Fischer-Tropsch synthesis (FT), Niko Heikkinen**

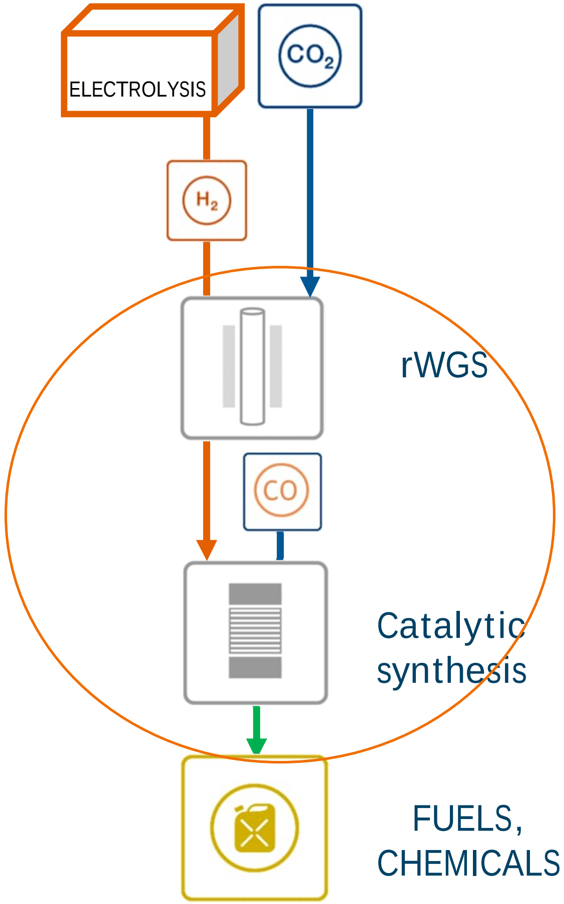
  - find out the role of water concentration on catalyst activity and selectivity
  - to make sure that adequate catalyst stability can be achieved

T3.1 MOBSU CPOx/rWGS Process

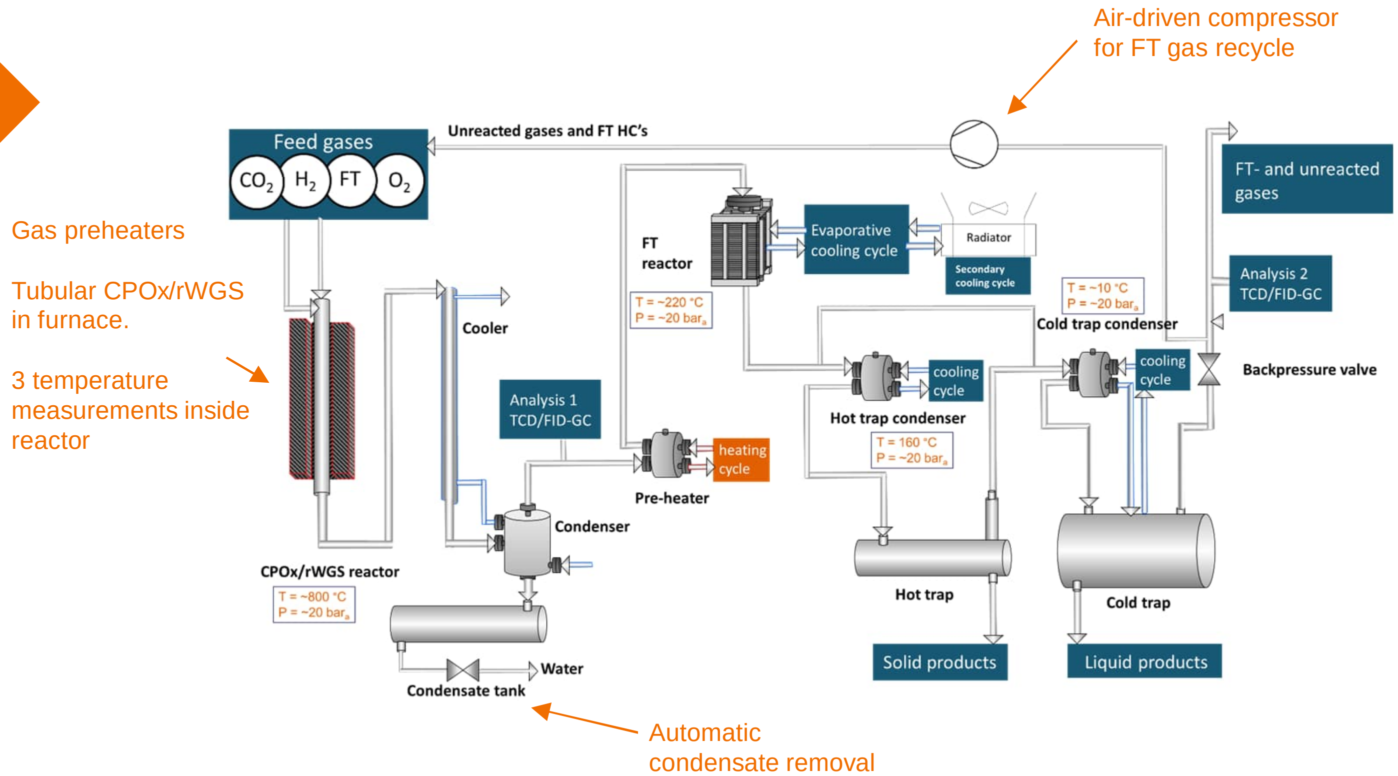


- Converts CO_2+H_2 gas feeds to syngas (H_2,CO,CO_2,CH_4, H_2O)
  - $rWGS: CO_2 + H_2 + Heat \rightarrow CO + H_2O$
  - *Methanation:* $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + Heat$
  - *Catalytic partial oxidation (CPOx) or reforming of hydrocarbons*
  - *Combustion e.g.* $2H_2 + O_2 \rightarrow Heat + 2H_2O$
- CPOx mode allows for **improved recycling of FT gas streams** and provides in-situ heat generation
- **High-throughput** catalytic reactor
  - In-house developed concept and reactor design with catalyst
    - Patent granted WO2019/175476 A1

EFUEL concept



MOBSU bench-scale implementation



EFUEL results for CPOx/rWGS

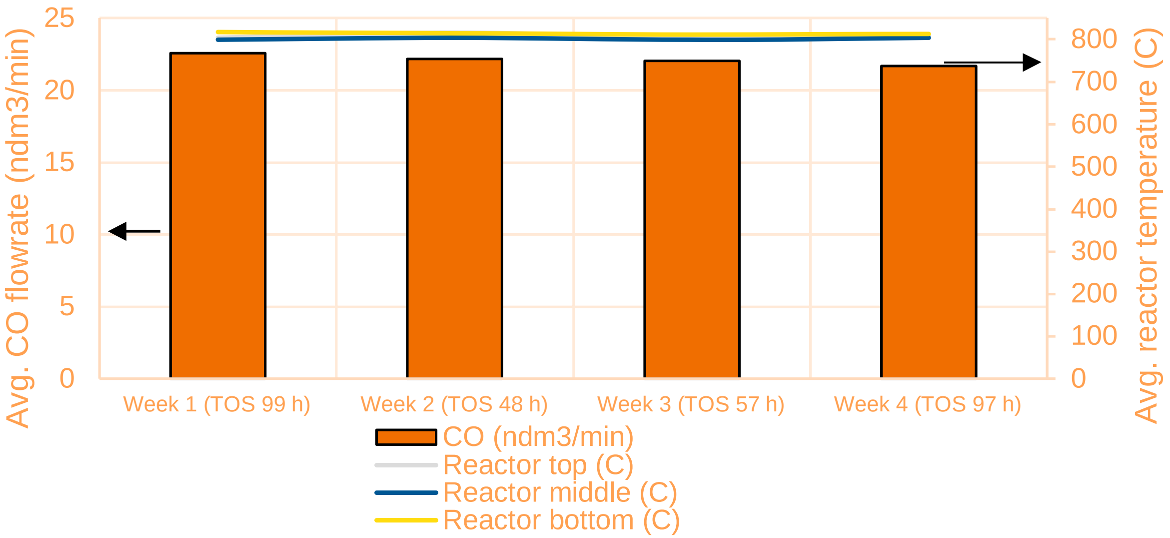
- The CPOx/rWGS process (version 2.0) was integrated in bench-scale inside the MOBSU container at TRL 4/5

- The main unknowns of the CPOx/rWGS process studied for further development:
  - Validation of the reactor design & dimensioning
  - The effect of FT recycle gases on solid carbon formation
  - Longer-term performance (stability) of the catalyst

- Improved bench-scale (MOBSU) system:
  - Operation with high FT-off gas recycle
  - Unmanned operation of CPOx/rWGS in preparation for EFUEL demo (WP4)

Extended duration CPOx/rWGS testing
With recycle

- **4 test weeks** at (semi)fixed conditions (300 h)
  - 38 ndm^3/min fresh CO_2 feed rate at H_2/CO_2 ratio of 2.3. Recycle ratio ca. 0.2. Slight variations in recycle gas composition depending on FT performance.
  - Ca. 800 C and 19 bar reaction conditions
  - No solid carbon removal (oxidation) performed
- Higher CO production rate at lower fresh gas feed rate than in tests without recycle
  - **Higher carbon-efficiency** achieved
- **Slight deactivation** detected (replicates)
  - Regeneration afterwards restores activity

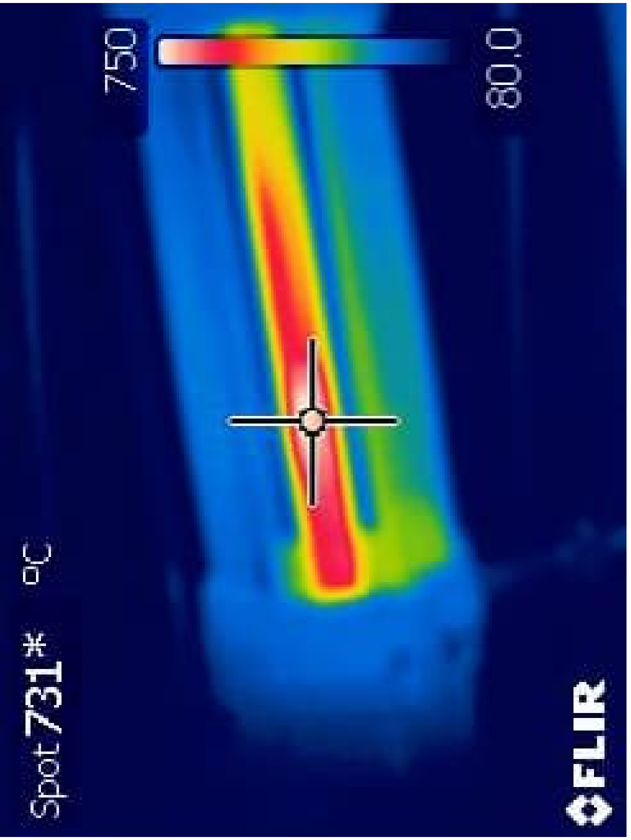


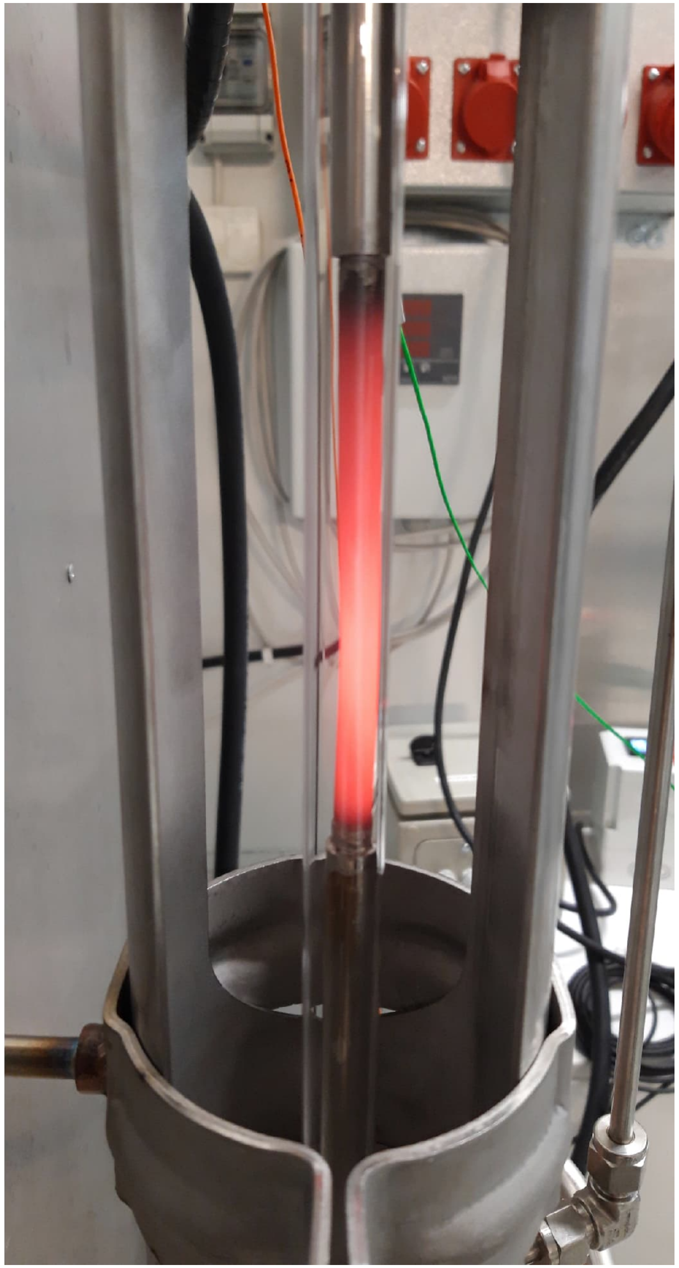
Replicate setpoint (40 ndm^3/min CO_2 at H_2/CO_2 ratio 2.2, without recycle):
(Combined TOS ~320 h including 5 startups/shutdowns)

	Before	After
Process conditions		
CPOx/rWGS Tavg (C)	809	809
P (bar)	19.9	19.4
Results (gas GC)		
Specific CO activity (mmol CO /cm$^3_{cat}$*h)	320	303
Carbon balance (IN/OUT)	1.00	0.985

T.3.1 e-rwgs reactor

- **Porous Kanthal tube that is heated resistively**
  - Ni-catalyst coating
  - Gases flow through porous layer
    = radial flow type reactor
  - Porous tube inserted in a quartz tube to N2-flush gases out of reactor
- Total gas flow ca. 27 l/min
  - 9 l/min CO2, 18 l/min H2
  - Flush 5 l/min N2
- Temperature range 800-850C, atmospheric pressure

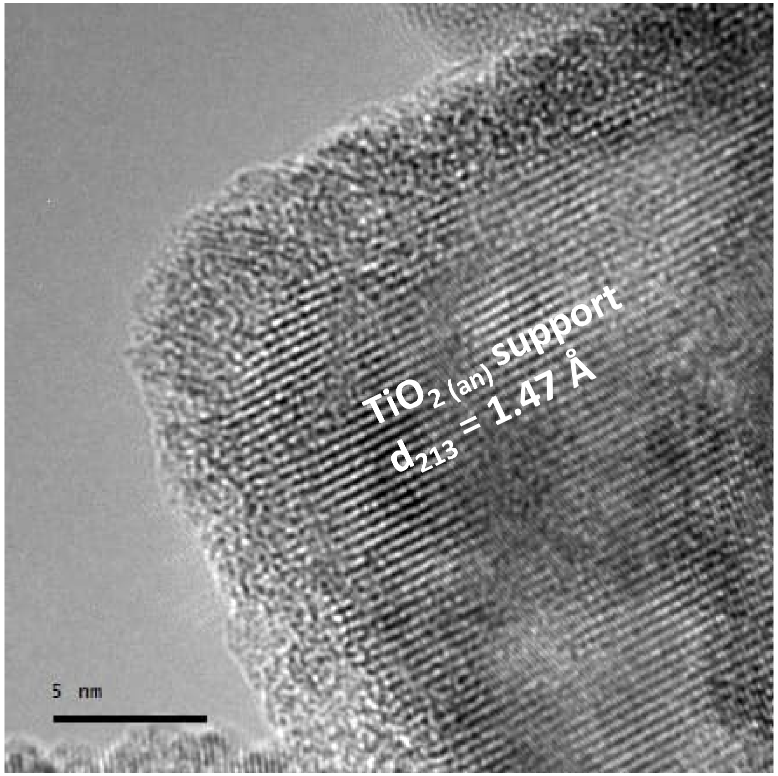

750
80.0
Spot 731*
°C



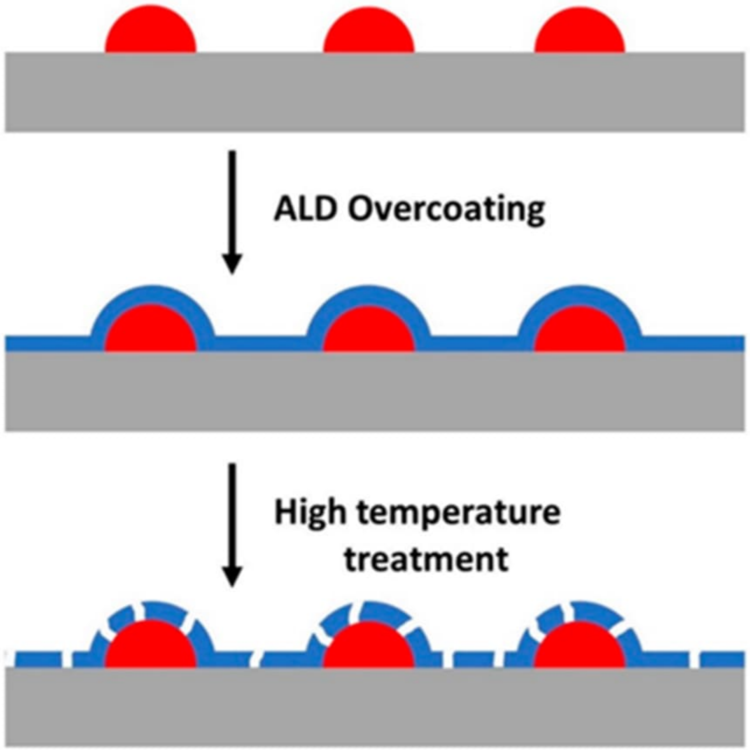
Bench scale e-reactor testing

- First reaction tests carried out in MOBSU
  - 32 l/min flow rate, temperature at approximately 800-850 °C
- **CO_2 conversion 61%, equilibrium 65%** at this temperature
- **No carbon deposition** on the porous reactor!
- However, the reactor is fragile and cannot handle the thermal expansion => new design
- Temperature control and measurement challenging
  - Indirect temperature measurement by gas composition (measured vs equilibrium)
- Work continued in a follow-up project

T.3.2 Overcoating deposition and reformation into a porous structure



30 deposition cycles, **no** thermal treatment



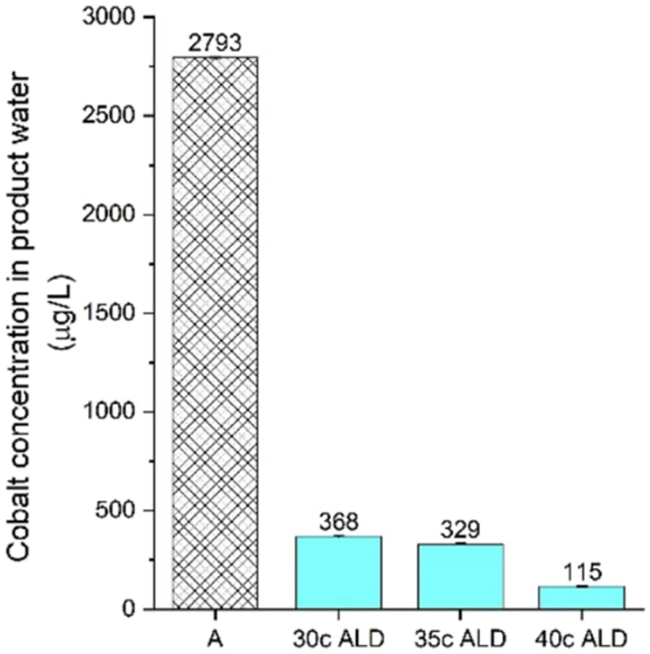
Overcoating after deposition

Porous overcoating

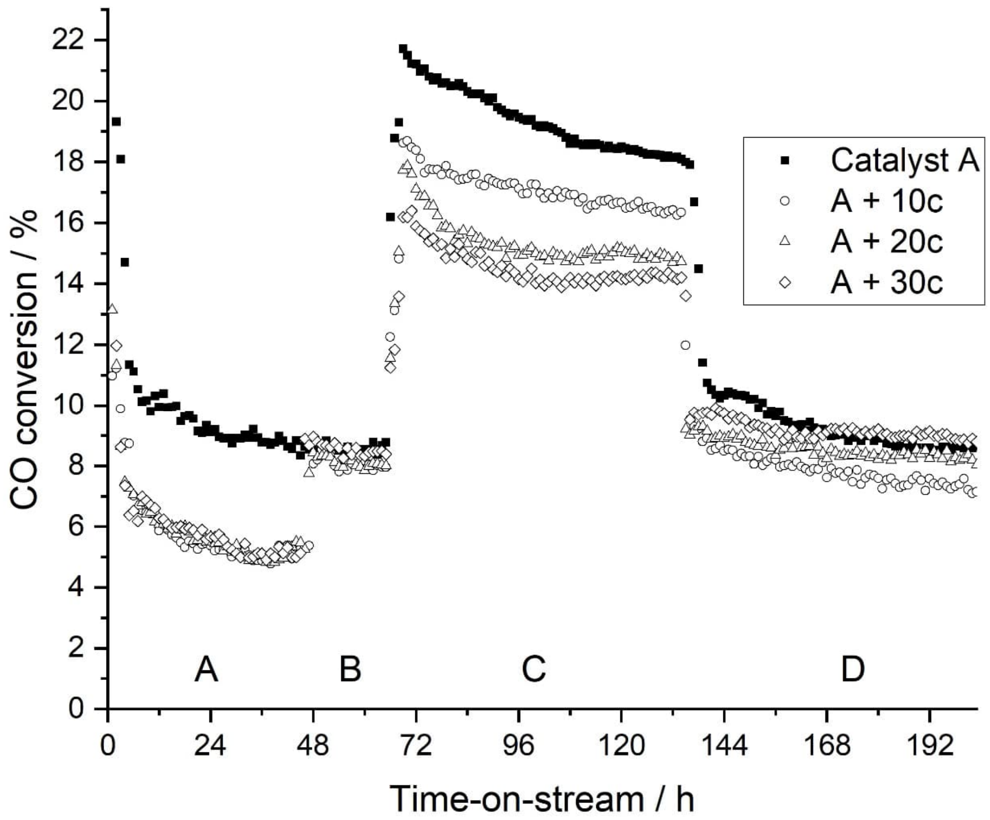
Sarnello et al., ACS Catal. 2021, 11, 2605−2619
https://dx.doi.org/10.1021/acscatal.0c05099

Catalyst reaction performance

Cobalt (active metal) leaching



ICP−MS analysis results from produced water samples



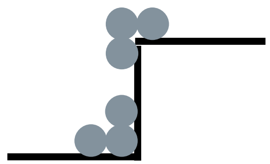
Fischer-Tropsch reaction overall activity as carbon monoxide conversion versus time-on-stream. Catalyst A non-overcoated sample and three samples with 10, 20, and 30 cycle ALD overcoating. Reaction steps A (initial activity), B (conversion adjusted to ~9%), C (added water conditions, simulated conversion level ~70%) and D (back to step B conditions, no added water to reactor inlet).

T3.2 Conclusions

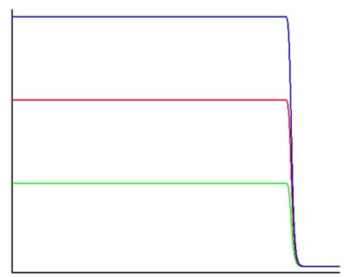
- Catalyst active sites are covered due to ALD overcoating
  - Thermal treatment is required to induce porosity into the overcoating

- The total amount of active sites decrease due to overcoating application
  - Some active sites are permanently covered
  - However, **re-opened active sites are protected against deactivation** ”anchored to the support”

- ALD overcoating (TMA/H_2O) process seems to prefer low coordination site for initial deposition cycles
  - Fischer-Tropsch activity and hydrocarbon chain growth is mainly dependent on defect sites, kinks and corners with low coordination number



- Diffusion-reaction model can be used to estimate penetration depth and to design ALD process on porous catalyst structures



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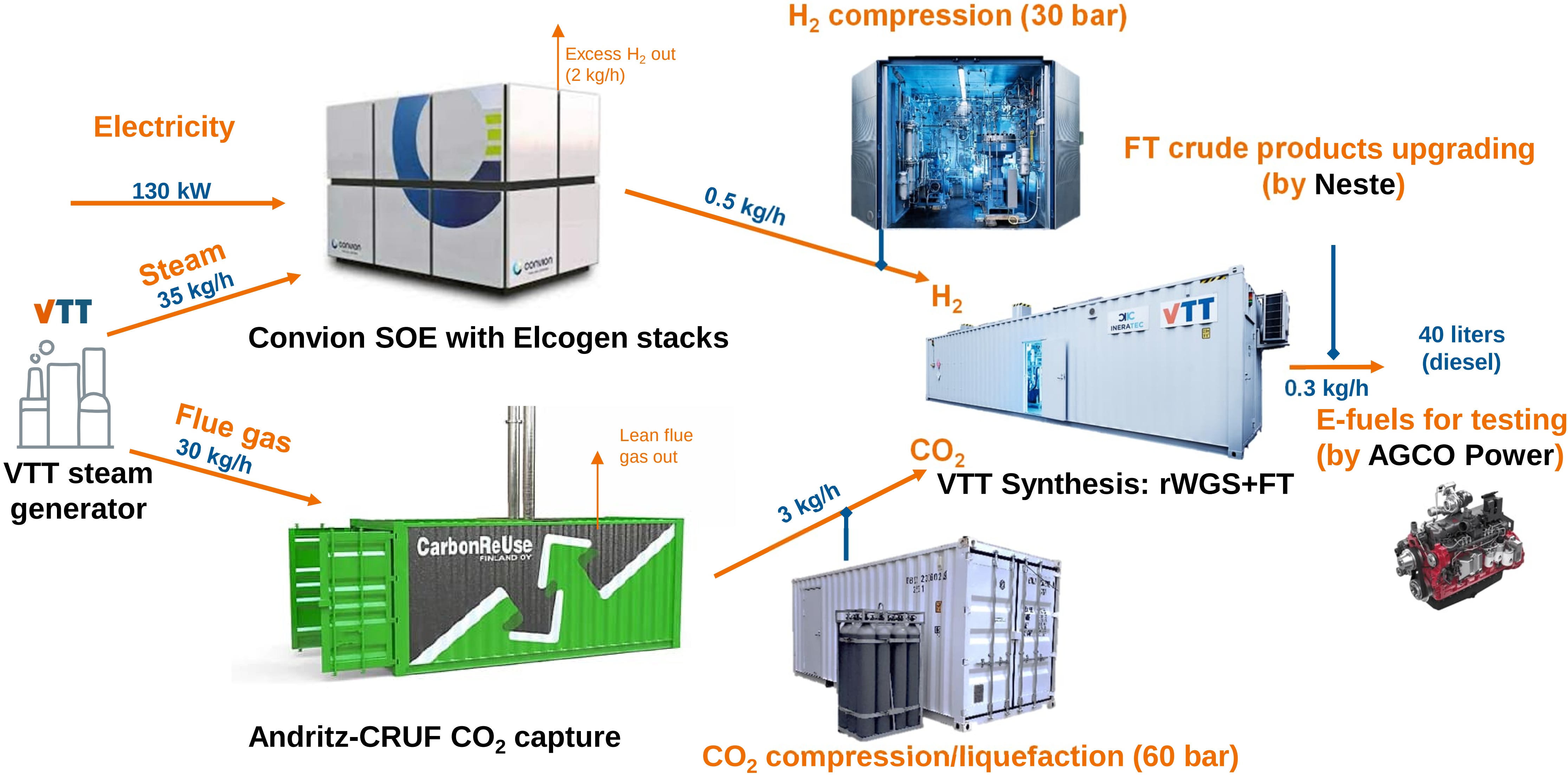
WP4
Process integration & demonstration

Christian Frilund & Juha Lehtonen

WP4 Process integration & demonstration

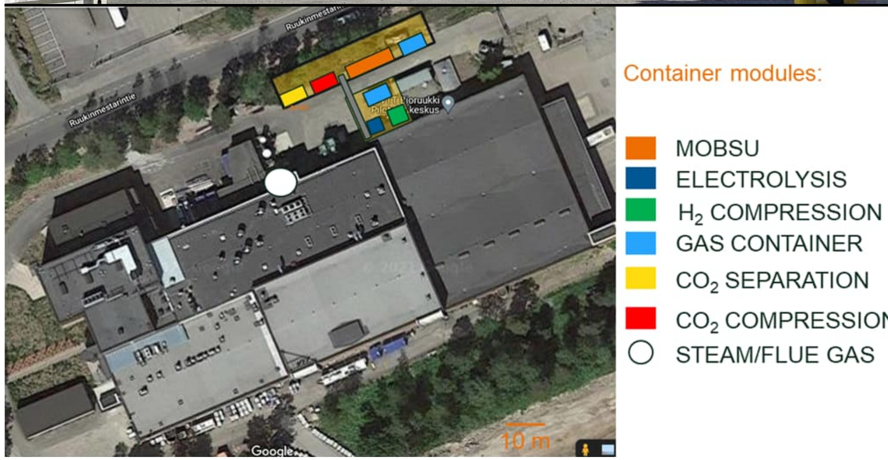
- **Objective:** Power-to-X demonstrator of integrated E-fuel concept at industrially relevant site
- **Timeline:** Summer 2023
- **Location:** After extensive discussions with project partners about the site choice, VTT Bioruukki was chosen as the most suitable E-FUEL demonstration site

E-fuel demonstration – Integration of 6 units



Bioruukki demo preparations

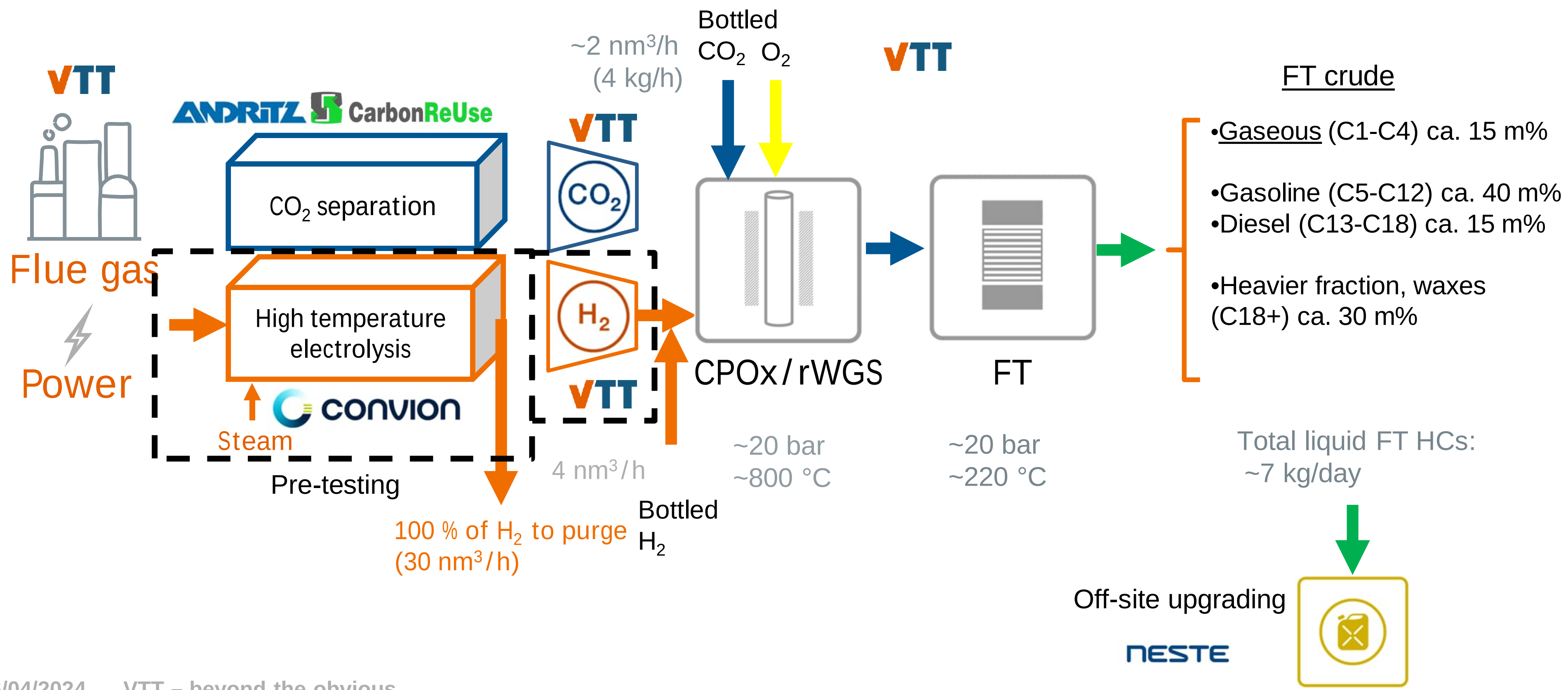
- **Infrastructure preparations**
  - New process area to Bioruukki north side
- **Bioruukki steam generator upgrades**
- **Risk analysis** with unit suppliers (interface HAZOP)
- **Unit integrations** to infrastructure
- **Unit testing and plant commissioning**



EFUEL demo area

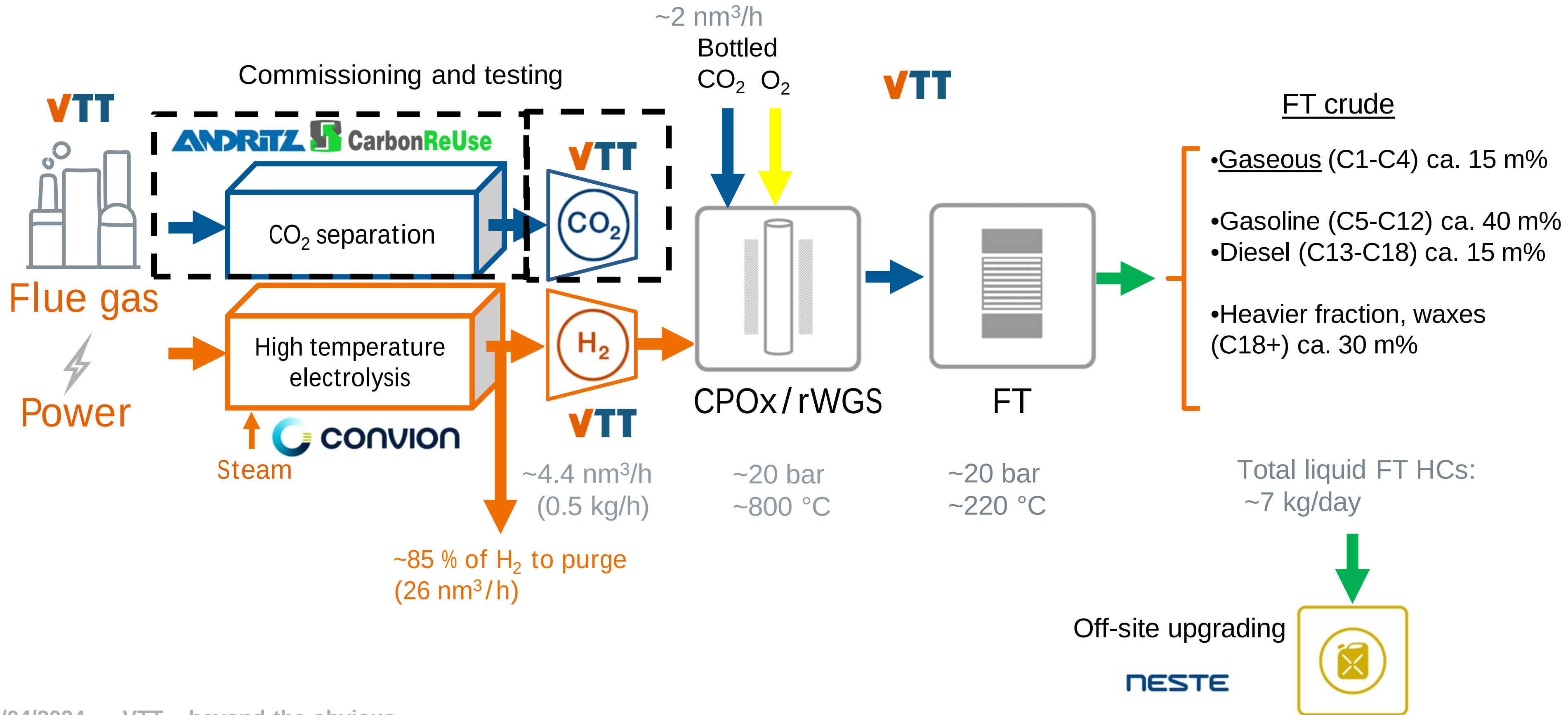
EFUEL demonstration

MOBSU start with bottled gases: End of May 2023



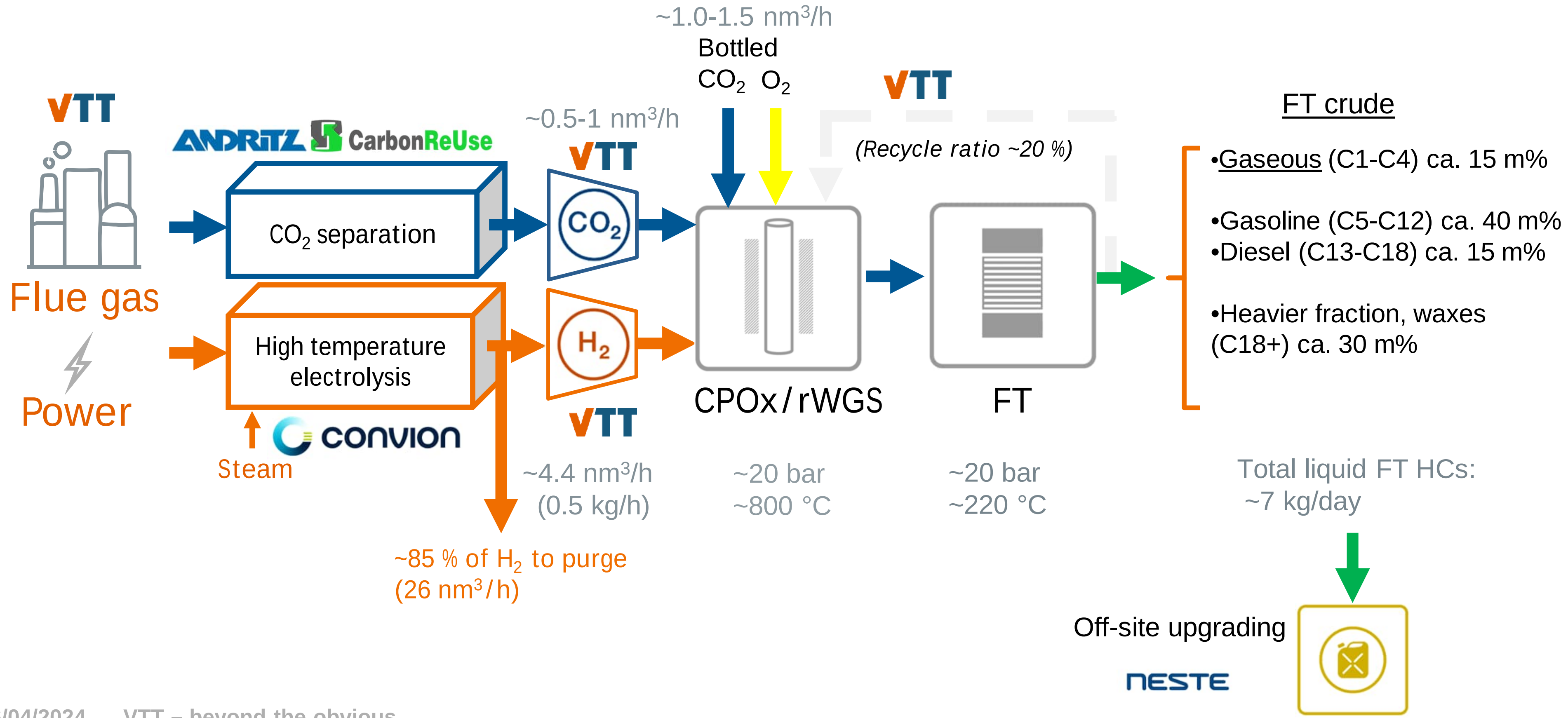
EFUEL demonstration

Coupling of Convion to MOBSU: Mid June



EFUEL demonstration

Fully coupled process Late June to Early July



Steam and flue gas supply

- Flue gas contained some excess O2, with CO2 content ca. 12 vol% (dry)
- Steam quality deemed sufficient for feeding to SOE, though large variances in analysis results was observed.
- During the EFUEL demo a few steam generator issues persisted, which occasionally caused a shutdown of the system

Steam generator flue gas (dry) analysis results 29.6.2023

		Flue gas (29.6)*
H_2O	% wet	4.5
CO_2	% dry	12.7
O_2	% dry	1.9
CO	ppm, dry	524
CH_4		9
N_2O		0
NO		33
NO_2		5.5
SO_2		0.1

*FTIR analysis

Steam analysis results

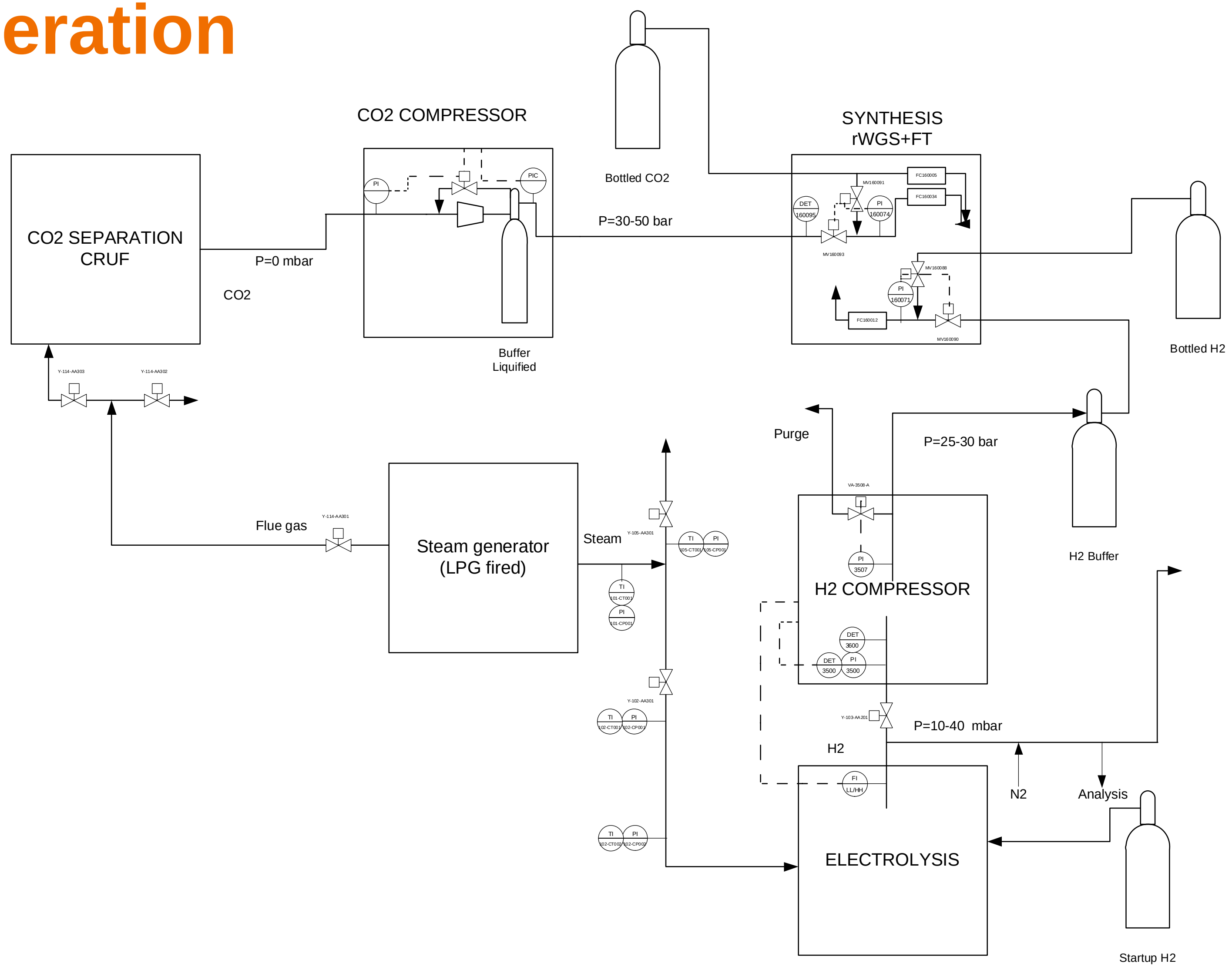
	Steam 2 14.6	**Steam 2 11.7**
pH	9.8	5.6
Conductivity [µS/cm]	18	1.4
Silicates [µg/l]	39	25

Coupled unit operation

MOBSU was modified to allow backup bottled gas feeding if the upstream process is not running.

H2 compressor process monitored O2 in the SOE product gas and MOBSU monitored O2 concentration in process CO2

SOE monitored feed steam pressure. Compressor container monitored SOE status.



Convion SOE product gas

Gas composition (ABB online analyzer)

	H2 (vol%, dry)	N2 (vol%, dry)	O2 (vol%, dry)
20.6.2023 14:00	96.6	3.2	0.2
4.7.2023 21:00	94.3	5.3	0.4
6.7.2023 21:00	94.9	4.9	0.2
10.7.2023 11:00	96.8	3.0	0.2
12.7.2023 11:00	96.6	3.3	0.1

GC: HP3000. Calibration gas H2 N50 (99.999 vol%). Results normalized to 100% for H2/N2/O2.
ABB online analyzer calibration gas H2 51 vol% in N2

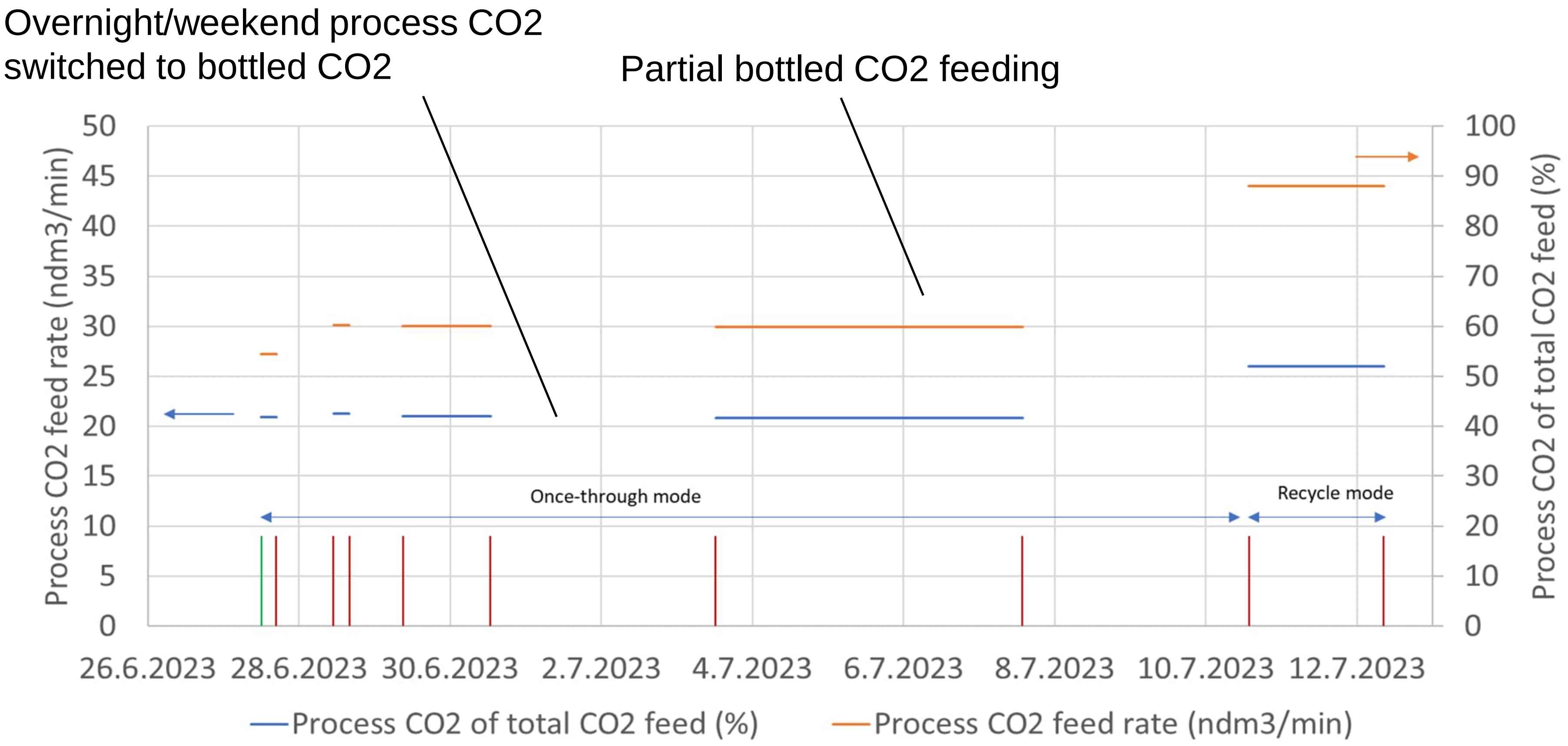
Product gas flowrate analysis

	Flowrate (ndm3/h, dry)
12.7.2023 14:00	480

*by N2 injection through +- 5 % accuracy rotameter

Synthesis results

Process CO2 feeding to MOBSU



*During this period Convion H2 was the only hydrogen source

rWGS results

Feed H2/CO2 ratio = 2.2-2.4

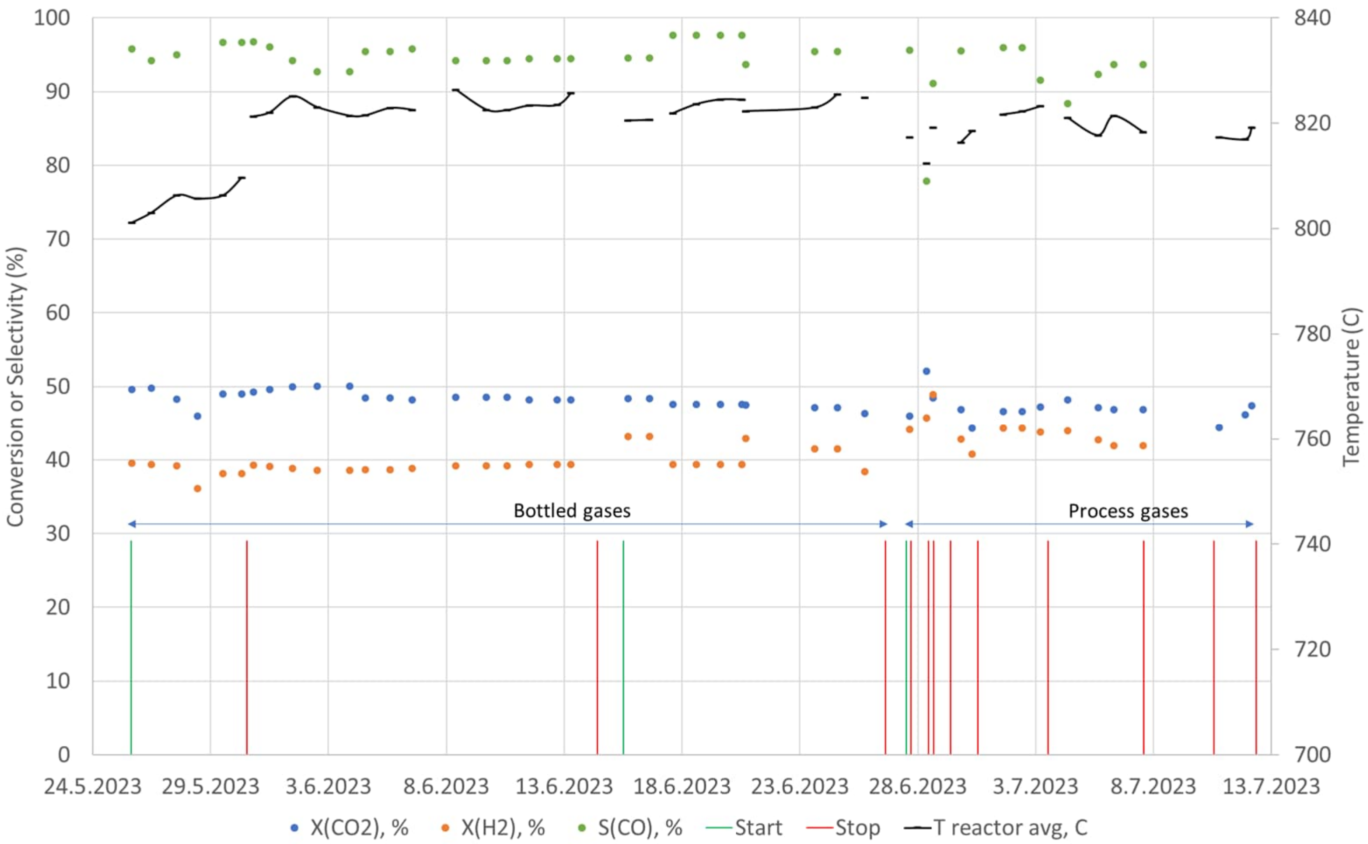
Gas feedrate = 110-115 ndm3/min

rWGS T = 800 to 830 C

X(H2) = 40 %

X(CO2) = 45-50 %

S(CO) = 95 %



X =conversion
S = selectivity

FT results

Feed H2/CO ratio = 2.6-2.9

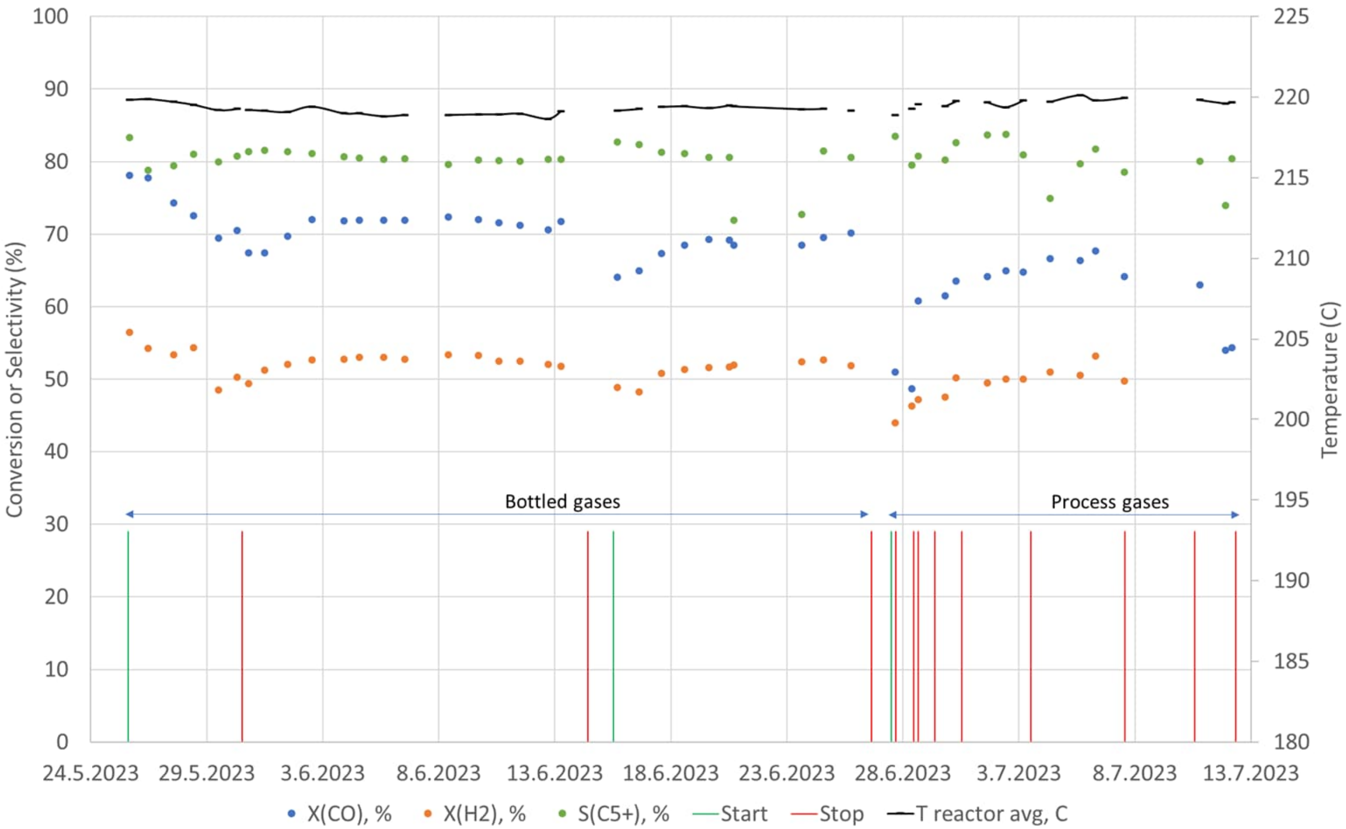
Gas feedrate = 75-85 ndm3/min

FT T = 219 -220 C

X(H2) = 50-55 %

X(CO) = 60-72 %

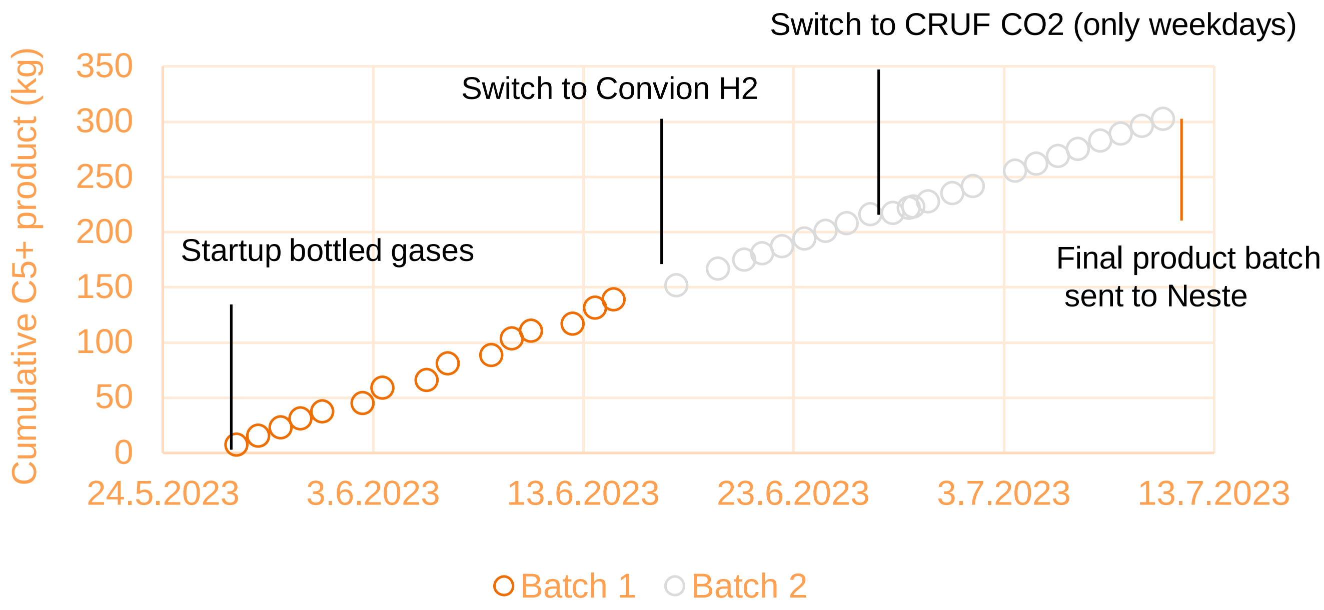
S(C5+) = 80-83 %



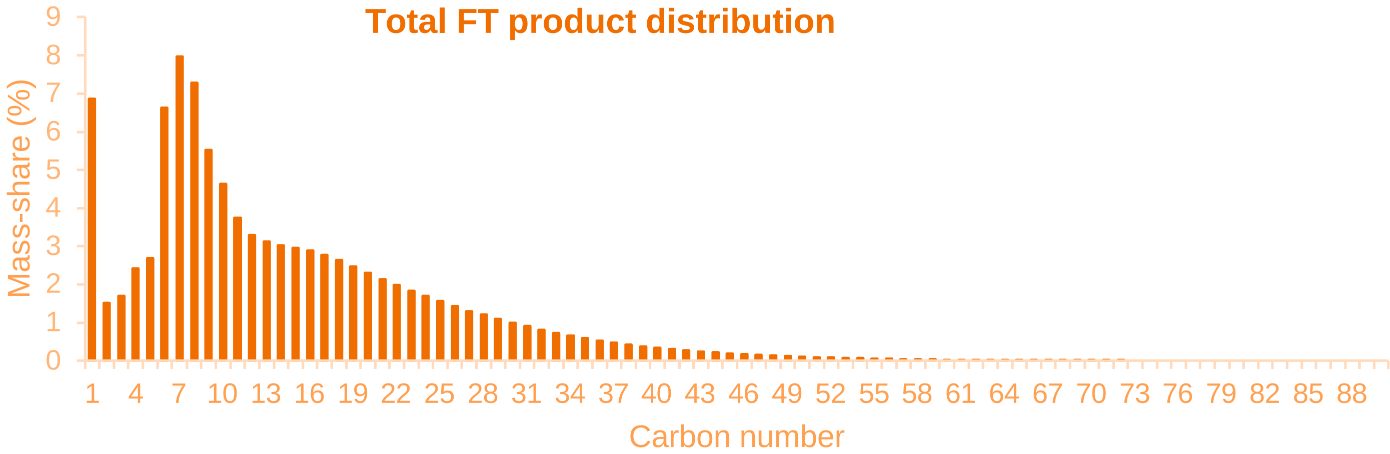
MOBSU FT crude production

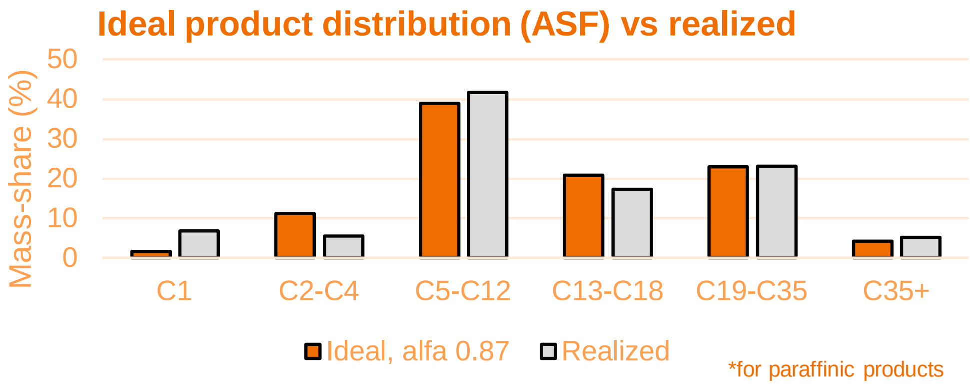
MOBSU operation using:		TOS (h)
Convion H2	**CRUF CO2**	
No	No	607
Yes	No	333
Yes	Yes	184
		1124

*TOS=time-on-stream



MOBSU product analysis





*for paraffinic products
Sample: 06.07.2023 with
Convion H2 and CRUF CO2

FT crude (oil+wax) product analysis

	Batch 1
Alfa (wax C30-C45)	0.87
Mass (kg)	143
Oil to total (C5+) product	0.45
C5+ productivity (g/h)	304
Share of paraffins in oil (%)	87

	Batch 2
Alfa (wax C30-C45)	0.87
Mass (kg)	157
Oil to total (C5+) product	0.44
C5+ productivity (g/h)	297
Share of paraffins in oil (%)	88
Convion H2 share (%)	81
CRUF CO2 share (%)	24

MOBSU results summary

- Stepwise integration of process gases to MOBSU (start with bottled gases, then Convion H2 feeding and finally combined Convion H2 and CRUF CO2 feeding)
- Productivity remained stable for the entire duration at ca. 300 g/h of C5+
- No significant deactivating effect of either Convion H2 or CRUF CO2 was detected. However, the diluting effect of N2 present in the Convion H2 (3-5 vol% N2) and CRUF CO2 (4-10 vol% N2) possibly affected system productivity negatively.
- Process gas included O2 which was observed to increase the rWGS reactor temperatures. Fortunately, O2 concentration was low (<0.5 vol%) and thus was not an issue.

rWGS repeat test

rWGS setpoint	SPA2 31.5.2023	SPA2 13.7.2023
TOS (h)	130	1130
Tavg (C)	823	821
P (bar)	19.5	19.5
V (O2) (ndm3/min)	3.4	3.4
X(H2) %	49.6	47.4
X(CO2) %	39.1	42.1
S(CO) %	96.1	95.2
Specific activity (mmol CO /cm3cat*h)	250	246
Carbon balance (IN/OUT)	0.996	0.995

EFUEL demo conclusion
WP4 T4.1/4.2

Objectives	Outcome
Planning and preparation the integration of SOE, CO_2 capture and MOBSU units	MOBSU, SOE, CO_2 capture and auxiliary processes successfully integrated to Bioruukki infra
Demonstration of integrated operation at least 1000 hrs	MOBSU operated for >1100 h (incl. with bottled gases) SOE&MOBSU coupled operation >500 h Total integrated operation 185 h
Gather data for the development of the final optimized concept	Achieved
Produce at least 300 kg FT hydrocarbons for upgrading	300 kg C5+ FT crude sent to Neste in July 2023

beyond
the obvious

Christian Frilund

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E-fuel usability (WP5)

P Aakko-Saksa, A Järvinen, H Kuutti

16/04/2024 VTT – beyond the obvious

Task 5.1 E-Fuel with oxygenate component
Task 5.2 Durability of particle filters
Task 5.3 Demonstration

End-use set requirements on the quality of fuels.
→ **Compatibility** of fuels with exhaust after-treatment systems and materials to support long-term durability.
→ **Capability of fuels to provide low exhaust emissions** to avoid local pollution and adverse health effects.

WT5.1 Task 5.1 E-Fuel with oxygenate: set-up

VTT

Fuels

- Conventional EN590
- Paraffinic HVO mimics e-diesel
- OME3-5 as a 10% blend with paraffinic fuel.

Engine, cycle

- Modern heavy-duty diesel engine, AGCO 44HD, without aftertreatment.
- RMC-C1 cycle (ramped mode) developed for non-road machinery and industrial equipment

Partners: VTT, FMI, TAU

Property	Unit	OME3-5	EN590	Paraf
Density 15 °C	kg/m^3	1067.1	825.1	780.7
Flash point	°C	69	60	69
Kin. Viscosity 40 °C	mm^2/s	1.2	2.0	3.0
HFRR	µm	410	380	294
Cetane Number / IQT		73.2/-	-/53.4	-/71.2
Sulfur content	mg/kg	<0.5	6.3	<1
Total aromatics	wt%	-	16.1	0.4
CFPP	°C	-24		-40
Lower Heating Value	MJ/kg	19.2	43.0	43.7
Carbon content	%(m/m)	43.8	86.1	84.8
Hydrogen content	%(m/m)	8.68	13.9	15.2
Oxygen content	%(m/m)	42.6	-	-

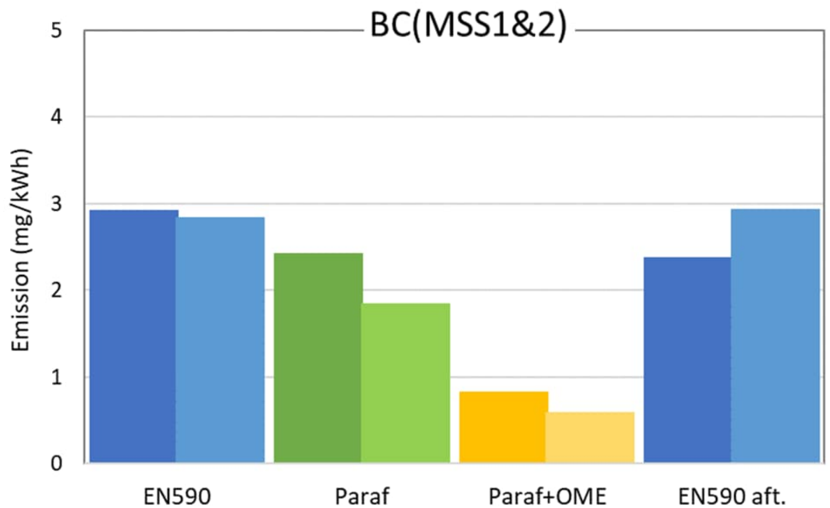
OME3-5 has diesel-like fuel properties

$CH_3O(CH_2O)_nCH_3$

WT5.1 Results

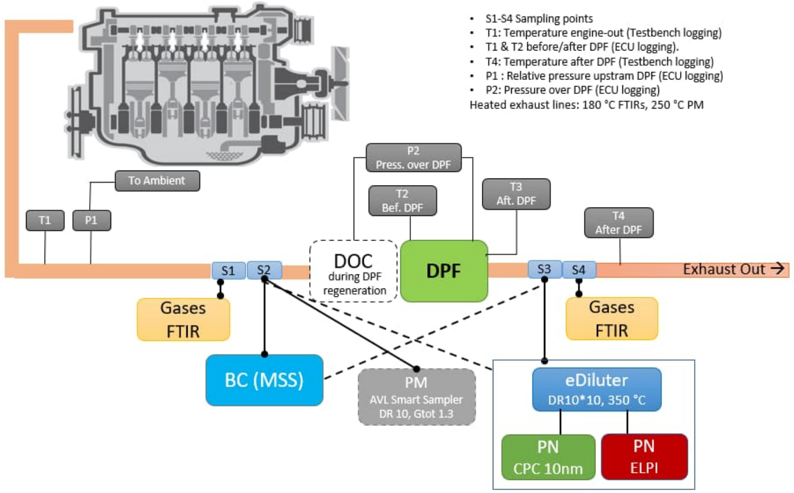
- **Very low black carbon emission** was observed for 10% OME3-5 blend. **PAH emissions were lower** for OME3-5 blend and paraff. than for EN590, and so were **number of non-volatile particles** (nvPN23 and nvPN10). These fuels showed **lower potential to form secondary organic aerosols** than EN590.
- For gaseous emissions, paraffinic fuel **reduced the engine-out NOx** compared with EN590. EN590 induced the highest **aromatic emissions**, while **formaldehyde emissions were high** for OME3-5 blend (oxidation catalyst needed).

E-diesel type paraffinic fuel reduced the exhaust emissions substantially, and black carbon emission further reduced with OME3-5 blend.



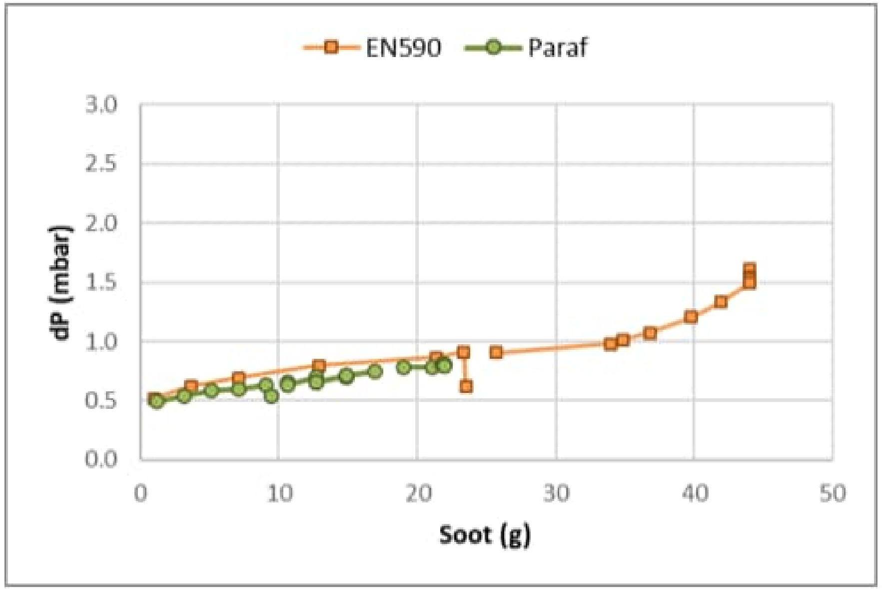
WT5.2 Durability of diesel particle filters (DPF)

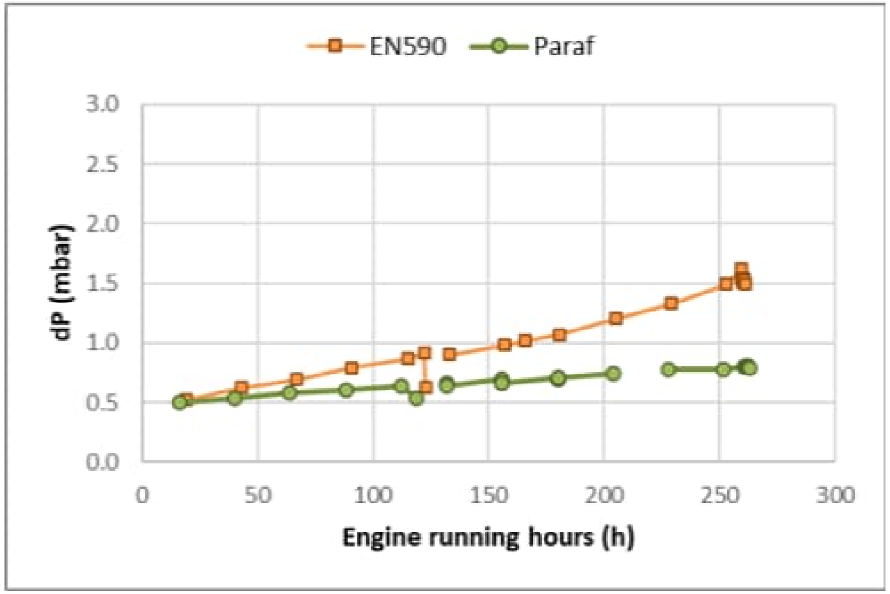
- DPF efficiently reduces particle emissions by collecting soot, which is removable by regeneration. Ash accumulated in the DPF requires an external cleaning.
- The effect of fuel on DPF was studied by using EN590 and paraffinic HVO mimicking e-diesel.
- AGCO 44HD Stage V engine was used in the study, however, without other exhaust aftertreatment than DPF.
- Testing of 250 hours/fuel, idle and load cycle.
- EN590 and paraffinic (HVO) fuels from Neste, DPF from AGCO, DPF cleaning Proventia.



WT5.2 Results

Soot and ash accumulated in the DPF was only half with paraffinic fuel of that with EN590, and so was the dP increase. Paraffinic e-diesel type fuel is expected to improve the lifetime of DPF due to less soot and ash accumulated and fewer regenerations needed when compared to EN590.





WT5.3 Small-scale demonstration of e-diesel with tractor.

Tractor. location: Valtra T235D, AGCO Power, Linnavuori, Nokia

Cycles: PTO 5-mode cycle, Real driving cycle

Four fuels: EN590, HVO (NesteMY), e-Diesel, EN590/e-diesel blend

Emissions measured a) engine-out b) tailpipe

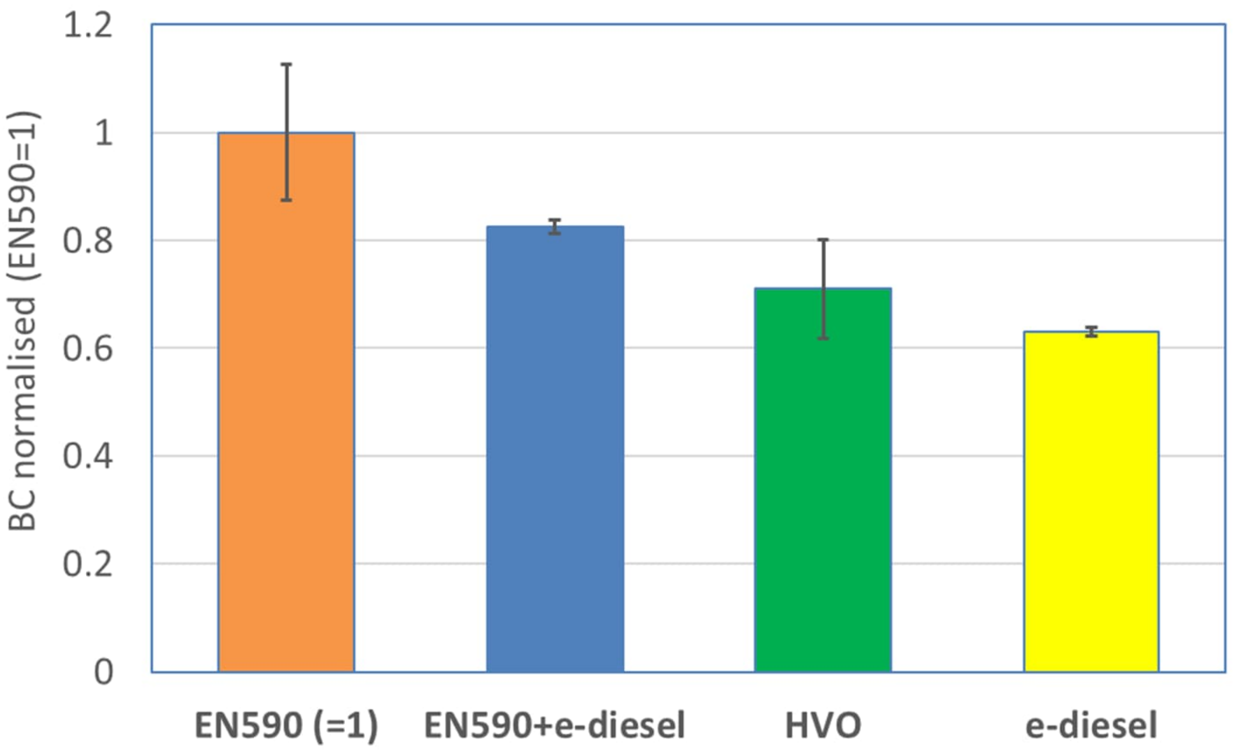
- Gaseous emissions
- Black carbon (soot)
- Non-volatile particles (PN23)

Portable measurement system for heavy-duty applications' field testing.

Organised by VTT, AGCO Power and Neste

WT5.3 Results

- For conventional diesel fuel (EN590), black carbon concentrations were at the highest level
- Black carbon concentrations were **even lower for e-diesel** than for HVO.
- Other emissions in progress.



Calculated from concentrations.

SAE paper (peer-review) presented: 16th International Conference on Engines & Vehicles for Sustainable Transport, 10th - 14th September, 2023. Naples, Italy. www.ice2023.info
Poster presented in ETH 20-22.6.2023, Switzerland, https://www.nanoparticles.ch/

VTT

Reduced particle emissions from paraffinic diesel blended with polyoxymethylene dimethyl ether

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[3] Atmospheric Composition Research, Finnish Meteorological Institute, P.O.Box 503, 00101 Helsinki, Finland

Introduction

New synthetic electrofuels, mimicked here by a renewable-based paraffinic and an oxygenate component, are potential methods to reduce engine emissions. In previous studies, polyoxymethylene dimethyl ether (OME) as a blend component has been observed to reduce particle emissions of a single cylinder test engine [1, 2].

Methods

Three different diesel fuels were tested: fossil EN 590 diesel, HVO-type paraffinic diesel and HVO-type paraffinic diesel blended with 10.6 vol-% of OME.

Engine-out emissions were measured from a modern 4.4 L turbocharged common-rail non-road diesel engine, which was used in this study without any aftertreatment system. The engine was run according to the RMC-C1 cycle and additional 5 static loads were also tested. The engine speed and torque was set to the same values for all the fuels.

Gaseous emissions were measured with an FTIR (Gasmet DX-4000) and an exhaust analyzer (Horiba PG-250). Particulate matter (PM) emission were measured with ISO 8178 type sampling system. Elemental and organic carbon (EC/OC) analysis were conducted from quartz filter samples. Particle number emissions (Non-volatile PN23) were measured with a dilution system (Dekati eDiluter followed by DEED) and a 23 nm CPC (Airmodus A23).

Results

Fuel type affected gaseous emissions. CO emissions were reduced with paraffinic diesel and even further with OME-blend. Paraffinic diesel produced the lowest THC emissions (measured with FTIR) . OME-blend resulted in similar THC with EN 590 and larger than with paraffinic. Formaldeldehyde emissions from OME-blend were high compared to other fuels. NO_x emissions were relatively similar with all fuels.

OME-blend resulted in large decrease in non-volatile PN23. Paraffinic and OME-blend produced lower PM emissions than EN 590. EC emissions from paraffinic diesel were lower than from EN 590. OME-blend produced clearly the lowest EC emissions. The reduction in EC but not in PM with OME-blend may be related to relatively high THC emissions with the OME-blend.

[1] Ahmad Omari, Benedict Heuser, Stefan Pischinger, Christoph Rüdinger, Applied Energy, 2019, 239, 1242-1249.
[2] Matteo Parravicini, Christophe Barro, Konstantinos Boulouchos, Fuel, 2021, 292, 120177.

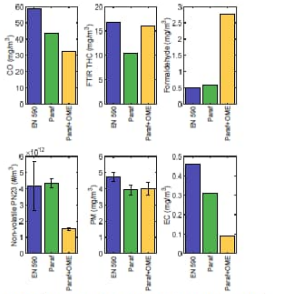

Figure 1. Average engine-out (no aftertreatment) CO, FTIR THC, formaldehyde, non-volatile PN23, PM and EC emissions with different fuels for RMC-C1 cycle. Errorbars shown represent the standard deviation.

Conclusion

- **OME blending significantly reduced engine-out emissions of black/elemental carbon and non-volatile particle number but not PM.**
- **OME blending increased emissions of hydrocarbons compared to paraffinic diesel and formaldehyde compared to paraffinic and EN 590 diesels.**
- **Further study is needed to evaluate emissions with OME when engine is equipped with exhaust aftertreatment**

Acknowledgements

This study was a part of the E-fuel-project funded by Business Finland (43287/31/2020). Authors thank Neste for providing the diesel fuels and AGCO Power for providing the engine for the study.

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SAE INTERNATIONAL

Electrofuel Concept of Diesel and Oxygenate Fuels Reduces Engine-Out Emissions

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Sami Harni, Minna Aurela, and Hilkka Timonen Finnish Meteorological Institute

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Abstract

Electrofuels produced from renewable hydrogen (H_2) and captured carbon dioxide (CO_2) can be sustainable and carbon-neutral. Paraffinic electrodiesel (e-diesel) can be produced via Fischer-Tropsch synthesis with fuel properties resembling hydrotreated vegetable oils. Electrofuels can be also oxygenated compounds, such as oxymethylene dimethyl ethers (OMEn), having different chain lengths. We studied emissions using paraffinic diesel mimicking e-diesel and its blend with 10% of OME3-5, which has diesel-type fuel properties, in comparison with normal EN590 diesel fuel. An intensive measurement campaign was performed with a modern diesel engine without exhaust aftertreatment to study the effect of fuel on the engine-out emissions. Measurements with the RMC-C1 cycle included detailed characterization of gaseous, particle and polyaromatic hydrocarbon (PAH) emissions having adverse effects on health and the environment. In these tests without a diesel particulate filter, the fuel containing the OME3-5 component reduced the black carbon (BC) emissions substantially in comparison with EN590. PM and PAH emissions, as well as the number of non-volatile particle numbers (nvPN), were lower for paraffinic fuel than for the EN590 fuel, and particularly for the OME3-5 blend. As regards gaseous emissions, paraffinic fuel showed lower engine-out NO_x emissions than the EN590 fuel, however, OME3-5 oxygenate did not further increase this NO_x reduction. Higher formaldehyde concentration in the exhaust was found for OME3-5 containing fuel than for the hydrocarbon-only fuels, which can be tackled with an inexpensive oxidation catalyst. In summary, e-diesel type paraffinic fuel reduced the engine-out exhaust emissions from a modern diesel engine substantially, and OME3-5 addition further reduced the most harmful emission species even at a 10% blending level.

News on demonstration

Press day 21.11.2023,

- https://yle.fi/a/74-20061418
- https://www.hs.fi/talous/art-2000010005216.html
- https://www.is.fi/autot/art-2000010008164.html
- https://www.tekniikkatalous.fi/uutiset/suomalaista-sahkopolttoainetta-testataan-ensimmaista-kertaa-trakto historiallista-dieselia-varten-tuotettiin-satoja-kiloja-synte hiilivetyja/c2d94a8a-cd74-40da-b4c0-c158ced82d9c
- https://www.koneviesti.fi/uutiset/5fb206dc-b95f-4fee-b367-1d1b7ad18793
- https://www.agcopower.com/fi/vihreasta-vedysta-ja-hiilidioksidista-sahkopolttoainetta-suoraan-tankkiin-agco-powerin-ja-vttn-e-fuel-hanke-etenee-ainutlaatuiseen-testausvaiheeseen/
- https://www.vttresearch.com/fi/uutiset-ja-tarinat/vihreasta-vedysta-ja-hiilidioksidista-kehitettya-sahkopolttoainetta-testataan


HELSINGIN SANOMAT Uutiset Lehdet Tilaa

Etusivu HS Ytimessä HS Visio News in Russian Uusimmat Vaalikone Kaupunki

Nokia −0,40% Nordea Bank −1,42% Sampo −0,37% Nasdaq Composite +0,31%

PÄIVÄN TIMANTTI: Kaksi Aku Hirviniemen uutta ohjelmaa hyllytettiin ensi keväältä

BLACK WEEKEND: HS Digi+ 5,95 €/kk vielä tänään. Tilaa nyt!

Talous | Energia

Suomalaista sähköpolttoainetta kokeillaan ensimmäistä kertaa traktorissa

Nokialla tehdään tiistaina testiajo dieselmoottorilla varustetulla traktorilla, johon tankataan sähköpolttoainetta.


Viikko 46/2023

ENERGIA

Suomalaista sähköpolttoainetta testataan ensimmäistä kertaa traktorissa – historiallista dieseliä varten tuotettiin satoja kiloja synteettisiä hiilivetyjä

Uusien menetelmien ansiosta vihreän vedyn tuotannosta saatiin huomattavasti aiempaa tehokkaampaa. Polttoaineella voidaan korvata fossiilinen dieselpolttoaine muun muassa vaikeasti sähköistettävissä kohteissa, kuten raskaassa tieliikenteessä ja laivaliikenteessä sekä työkoneissa.

Litra löpöä 120 000 eurolla – hinta on mieletön, mutta lopulta kyse on ihan jostain muusta

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Thank you

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The end-use performance of high-quality, high-cetane number, aromatics-free and sulphur-free e-diesel proved to be excellent in a small-scale field demonstration with a tractor powered by AGCO Power diesel engine.

E-diesel type paraffinic fuel substantially reduced emissions, especially black carbon and particle emissions as blended with oxygenated fuel component.

In long-term study, e-diesel type fuel accumulated low amount of soot and ash in the diesel particulate filter (DPF), which is significant for DPF's durability.

WP6

E-fuel climate impacts and the EU criteria

Kati Koponen, VTT

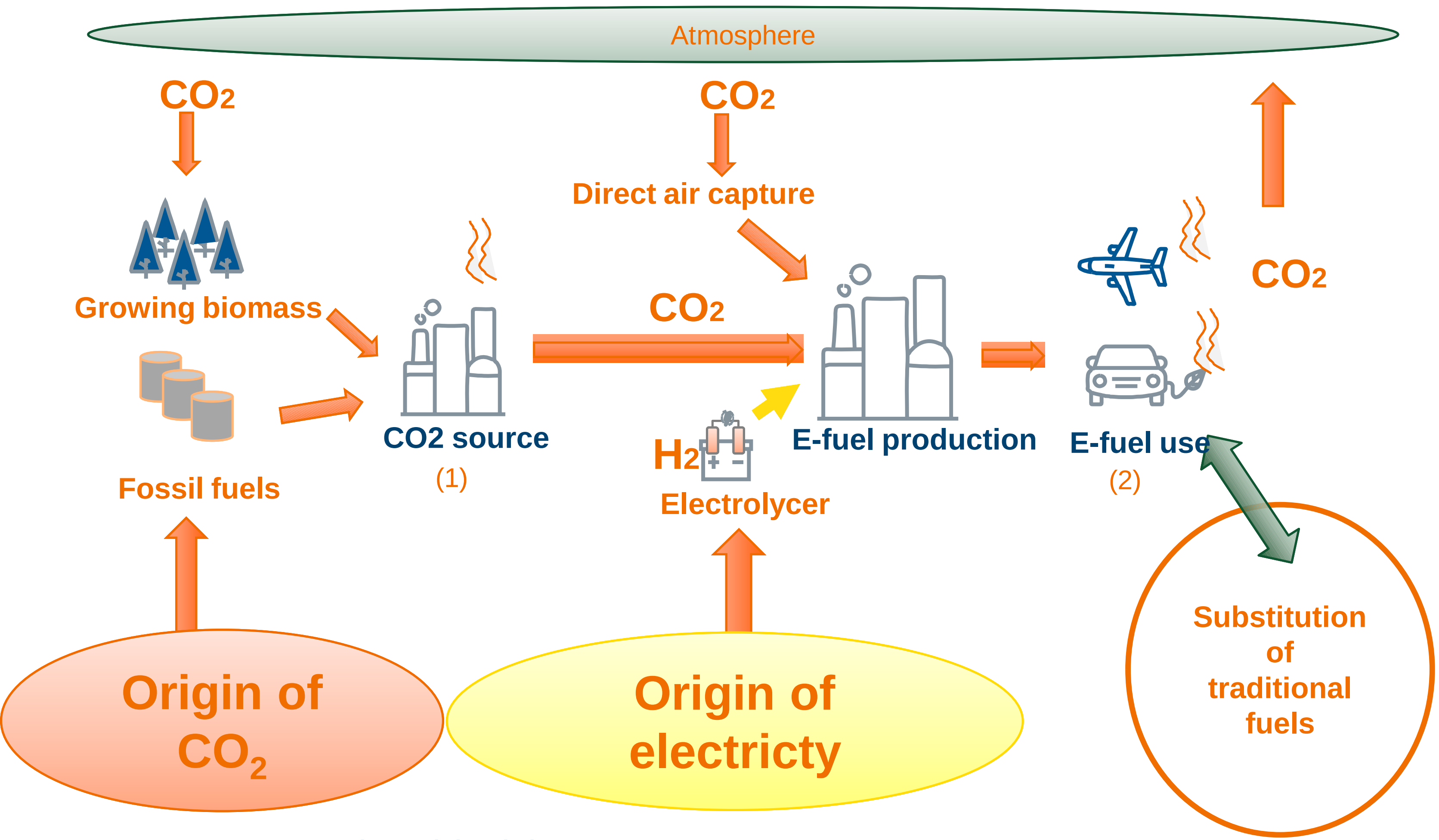
Content

1. EU regulation: definitions, targets & criteria
2. Key issues in GHG accounting for e-fuels & EU calculation rules
3. GHG balances for the e-SAF concepts studied in the project
4. E-fuel market model

Several EU regulations regarding e-fuels were accepted during the project

- **RED3**
  - Definition of RNFBO = “renewable fuels of non-biological origin”
  - Targets & double counting rules: Share of RNFBOs at least 1 % by 2030 / Share of RFNBOs in maritime transport sector is at least 1.2 %
  - Double counting allowed for RNFBOs, 1.5 x counting for aviation & maritime fuels
- **Refuel EU aviation** (”synthetic low-carbon aviation fuels”)
  - Targets for aviation:
    - 2030-2031: 6% SAF of which 0.7%/year e-fuels
    - 2035: 20% SAF of which 5% e-fuels
    - 2050: 70% SAF of which 35% e-fuels
- **Delegated acts** (2023/1184, 2023/1185):
  - Definition of the 70% emission saving reduction & GHG calculation rules for e-fuels
  - Definition of fully renewable electricity

Key issues in GHG accounting for e-fuels:



In case of e-fuels, the CO_2 emission to atmosphere is delayed, not cancelled:

- For fossil CO_2 the emission needs to be fully accounted for either at point (1) or (2).
- For biogenic CO2 and CO_2 captured by DAC, the cycle is carbon neutral.
- Emission reductions if e-fuels replace traditional fuels with higher life cycle emissions.
- However, this **does not make the concept "carbon negative".**

EU criteria for the origin of the CO_2 (EU 2023/1185)

- **CO_2 from e-fuel combustion is fully accounted despite the origin of the CO_2.**

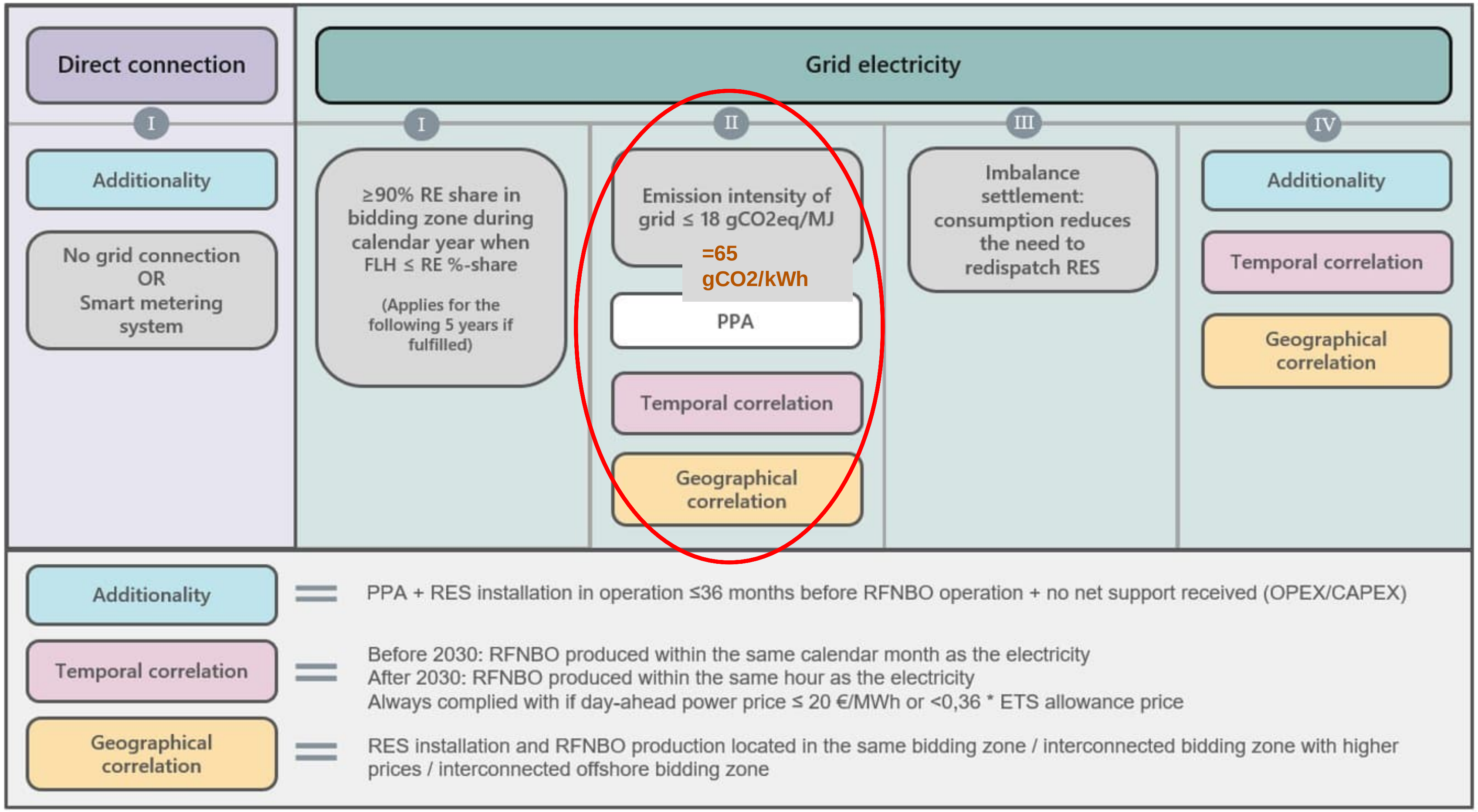
- **However, captured CO_2** incorporated in the chemical composition of the e-fuel can be considered as **“avoided emission”** when the origin of the CO_2 is one of the following:

  - **Until 2035: Fossil** CO_2 which has been captured from **electricity production** under ETS
  - **Until 2040: Fossil** CO_2 which has been captured from **other source** under ETS

  - CO_2 captured from the **air**
  - CO_2 from production of bioenergy complying with the EU **sustainability and GHG criteria**
  - CO_2 captured from the **combustion of RNFBOs** complying with the EU **GHG criteria**

→ Emissions from the capture process need to be included.

Electricity: Fully renewable electricity (EU 2023/1184)



Summary by Aleksandra Saarikoski VTT

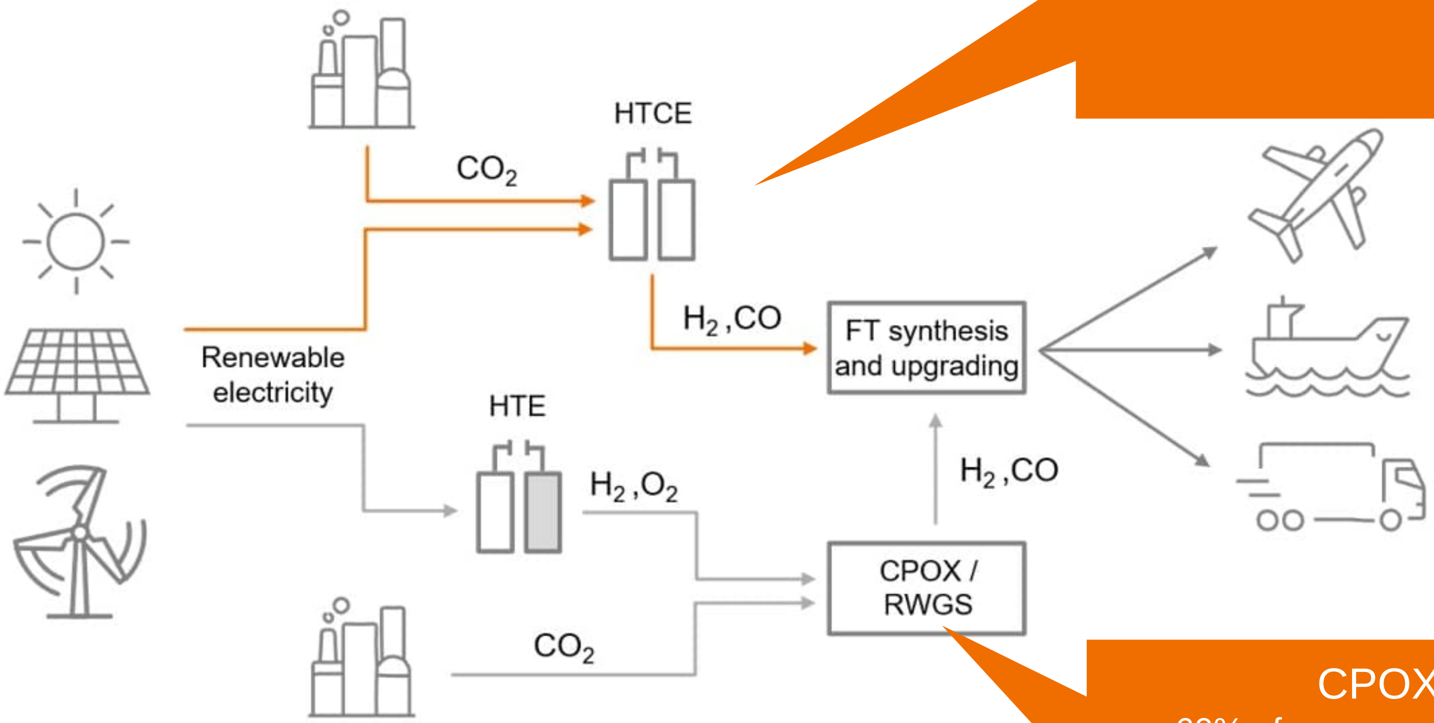
Electricity not defined as fully renewable (EU 2023/1185)

- Three methods to define emissions for electricity which does not qualify as fully renewable
  1) Method given in Delegated act (2023/1185) Annex part C to define country / bidding zone emission intensity (Table A emission for Finland 82 gCO_2/kWh).
  2) Full load hours of RNFBO production ≤ hours in which the marginal price of electricity is set by renewable / nuclear installations.
  3) The GHG emission value of the marginal unit generating electricity at the time of the production of the RNFBO in the bidding zone.
     - (Information for 2&3 is not publicly available by Fingrid / Nordpool)

E-fuel concepts studied

VTT

Co-SOEL
60% of purge gas recycled



Products:

- Jet fuel (C9-C16)
- Gasoline (C5-C8)
- Purge gas

CPOX
60% of purge gas recycled
(90% of purge gas recycled)

eRWGS
60% of purge gas recycled
(90% of purge gas recycled)

Reference concepts:
H_2 production by AEL

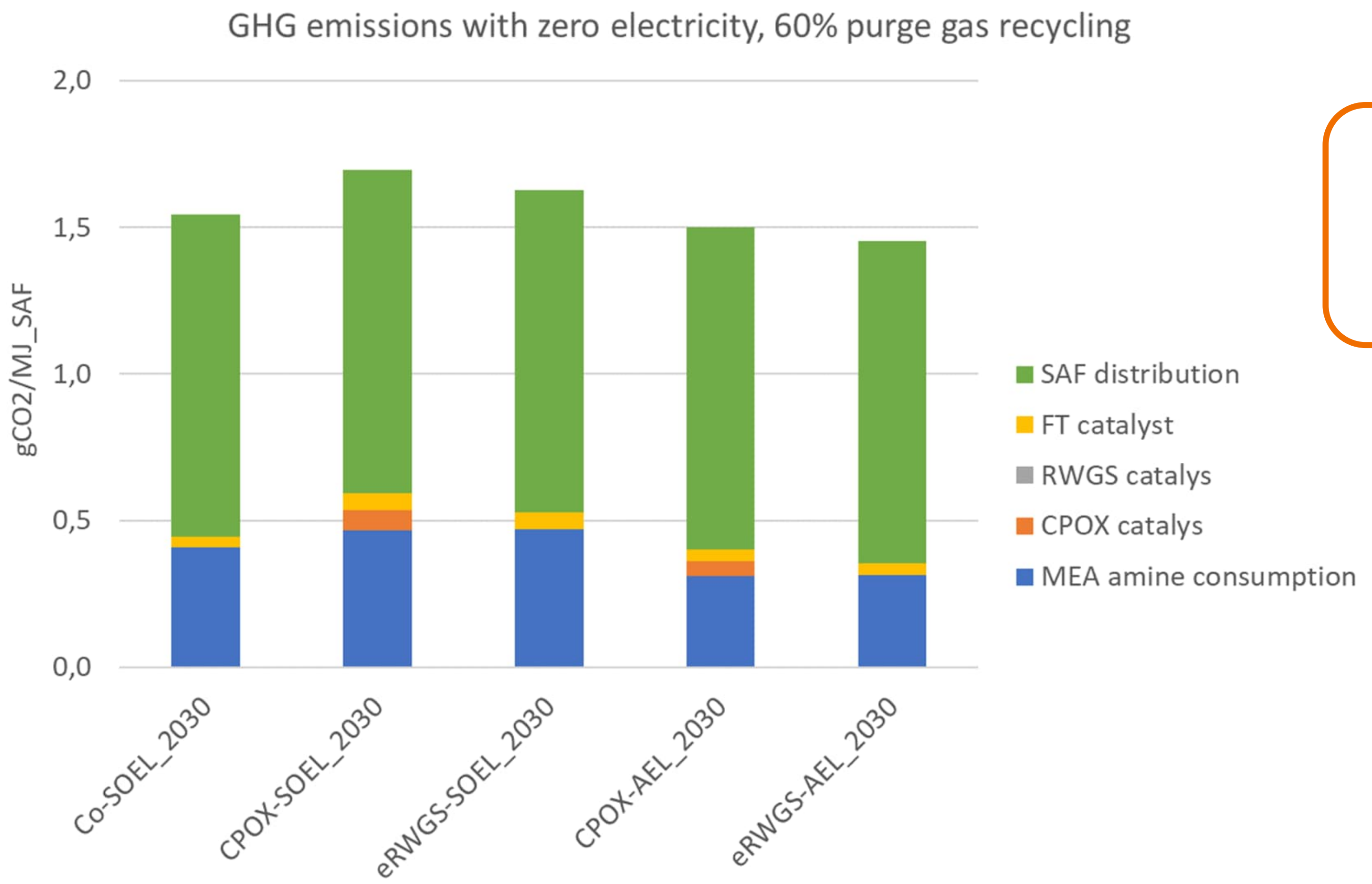
Abbreviations:

Co-SOEL	Co-solid oxide electrolyser
CPOX	Catalytic partial oxidation
eRWGS	electrically heated reverse water gas shift reactor
AEL	Alkaline electrolyser
FT	Fischer-Tropsch

Calculation principles used

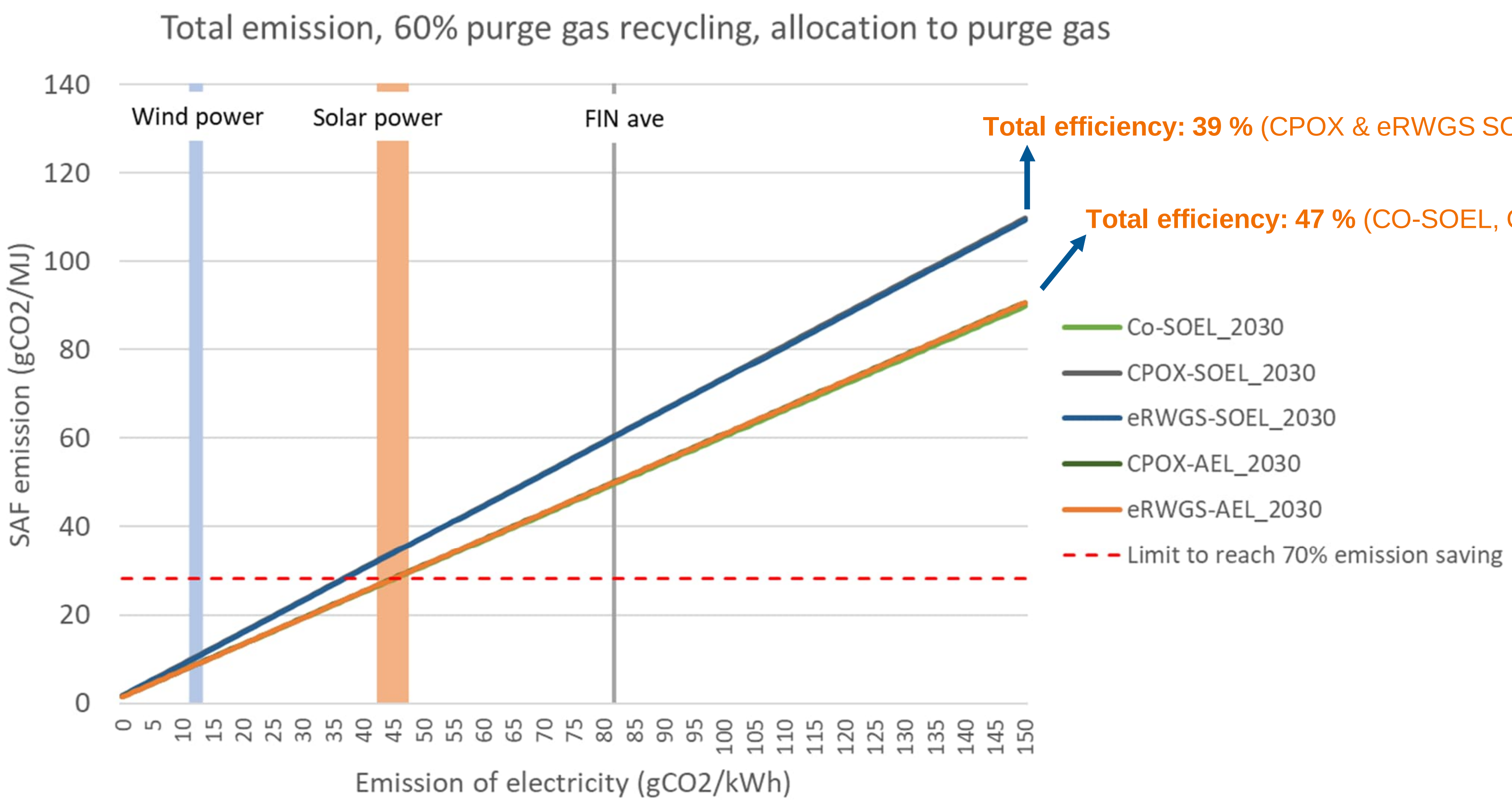
- The CO_2 input for the process is considered as “avoided emission” according to the EU criteria → balances the emission of e-fuel combustion.
  - Also the CO_2 emission from purge gas combustion in the process is considered as avoided emission.
- Emission of electricity production for electrolyser is varied from 0-150 gCO_2/kWh to show the impact on the e-fuel emissions.
  - According to the EU criteria, emission of electricity is zero, if defined as fully renewable.
- Process data represents 2030 case and 60% recycling of purge gas in the process.
- Hydrogen & energy needs for the refining phase of SAF are covered by the process.
- Emissions by catalyst application and fuel distribution are included.
- Emissions are allocated between main product (SAF) and co-products (gasoline and purge gas). Energy allocation (LHV) is applied according to the EU criteria.

GHG results when zero emission used for electricity



Fossil comparator emission $94gCO_2/MJ$

GHG results when emission of electricity is varied



Total efficiency: 39 % (CPOX & eRWGS SOEL)

Total efficiency: 47 % (CO-SOEL, CPOX & eRWGS AEL)

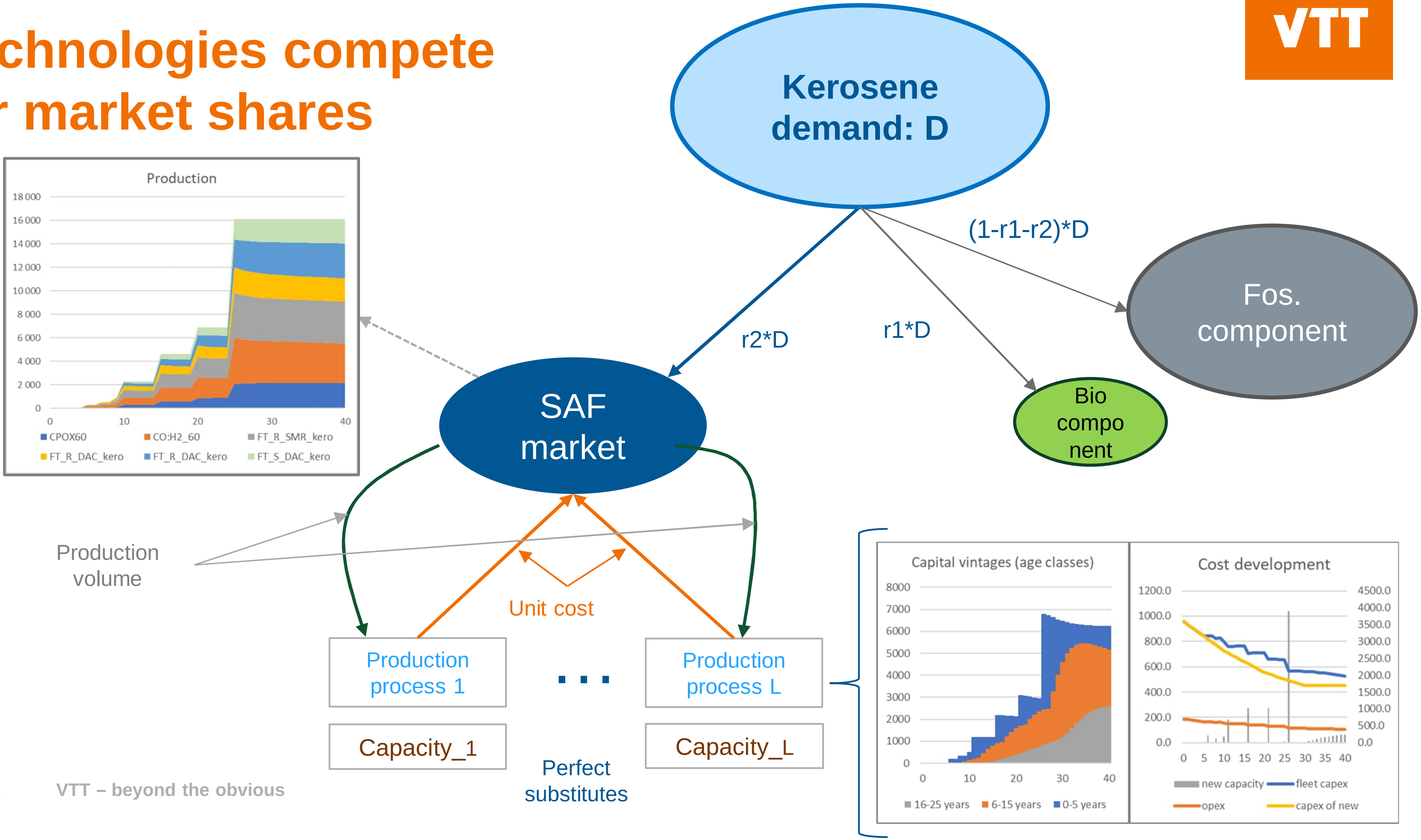
Conclusions from the GHG calculation

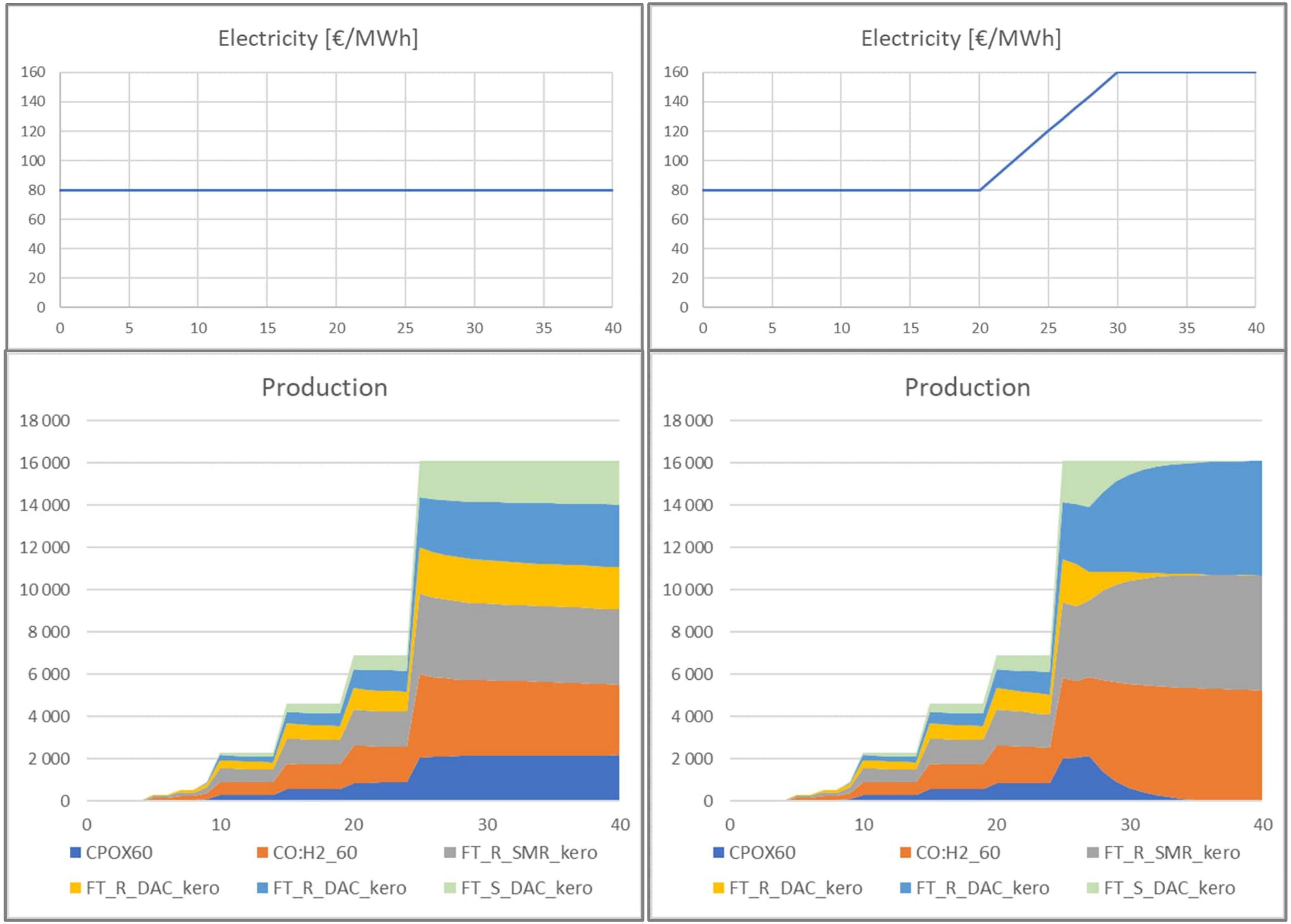
- When zero emission for electricity is used and CO_2 input considered as “avoided emissions”, emission saving for the studied concepts is 98%.
- Grid electricity emission should be under 34-44 gCO_2/kWh to for the concepts to reach emission savings over 70%. (However, not all grid electricity is renewable.)
- The origin of the CO_2 is important in future and needs to be under Emission Trading Sector (or equivalent pricing mechanism) already now.

Task 2: E-fuel market model

Juha Forsström VTT

Technologies compete for market shares





Production inputs for a production plant

- CAPEX(t)
- OPEX(t)
- Efficiency(t)
- Prices of feedstocks

Thank you!

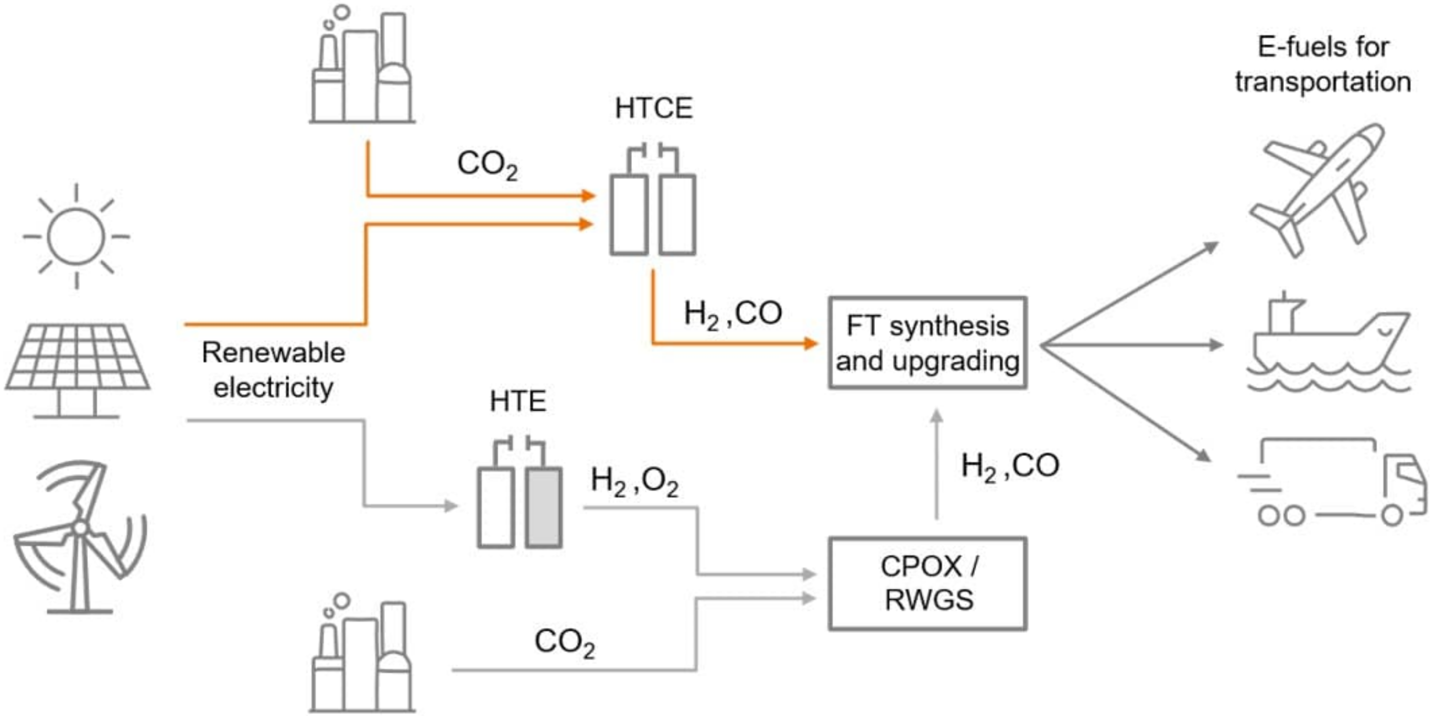
Contact:
Kati.koponen@vtt.fi

Efuel WP7:
Business case evaluation

Techno-economic assessment

Robert Weiss, Marjut Suomalainen

eFUEL WP7: Techno-economical evaluation



Objectives and methods

Efuel –target products

- **Main product: Jet fuel C9-C16**
  - **SAF: RFNBO-kerosene** according to EU Delegated Act 2/2023
  - Non-RFNBO-kerosene assumed to be priced as fossil kerosene (600 €/t)

- By-products

1) Light paraffinic hydrocarbons C5-C9 (compared to gasoline)
   - **RFNBO-gasoline** according to EU Delegated Act 2/2023. Assumed sales price 2400 €/t
   - Non-RFNBO-gasoline assumed to be priced as fossil gasilene (600 €/t)

2) District heat,
   - supply temperature 85C, assumed sales price 25€/MWh
   - heat sources:
     i. electrolyser Cooling Load
     ii. downstream units' Cooling Load, using High-Performance Heat Pumps
     iii. remaining Purge Gas (prioritizing internal use such as steam needs)

Optimization of RFNBO-eKerosene FT-plant for dimensioning and operation strategy

To meet EU-rules and definitions for RFNBO and green H2 (Delegated act 2/2023)

Example site Finland, using Finnish power system and land-based wind power

Results presented here are based on

1) Aspen petrochemical plant steady-state simulations for the Hydrocarbon related processes
2) Power System Forecasts 2025-30 for North Europe Power system, using Finland price area
3) Wind power forecasts 2025-30 for Finland price area
4) VTT’s optimization tools for dynamic Power-2-X Optimization
   - Results from (1) – (3) above are used by the optimization model

- Cost estimates range from 2400 – 9 600 €/ton RFNBO-eKerosene, depend on
  - optimal unit dimensioning of the plant (electrolysers, H_2 storage, compressors etc)
  - optimal long term contracting of renewable power
  - optimal long term and intraday power trading strategy

- Specific GHG-emissions 9-12 gCO_2eqv/MJ RFNBO-eKerosene
  - which is a reduction of 87-90% in GHG-emissions

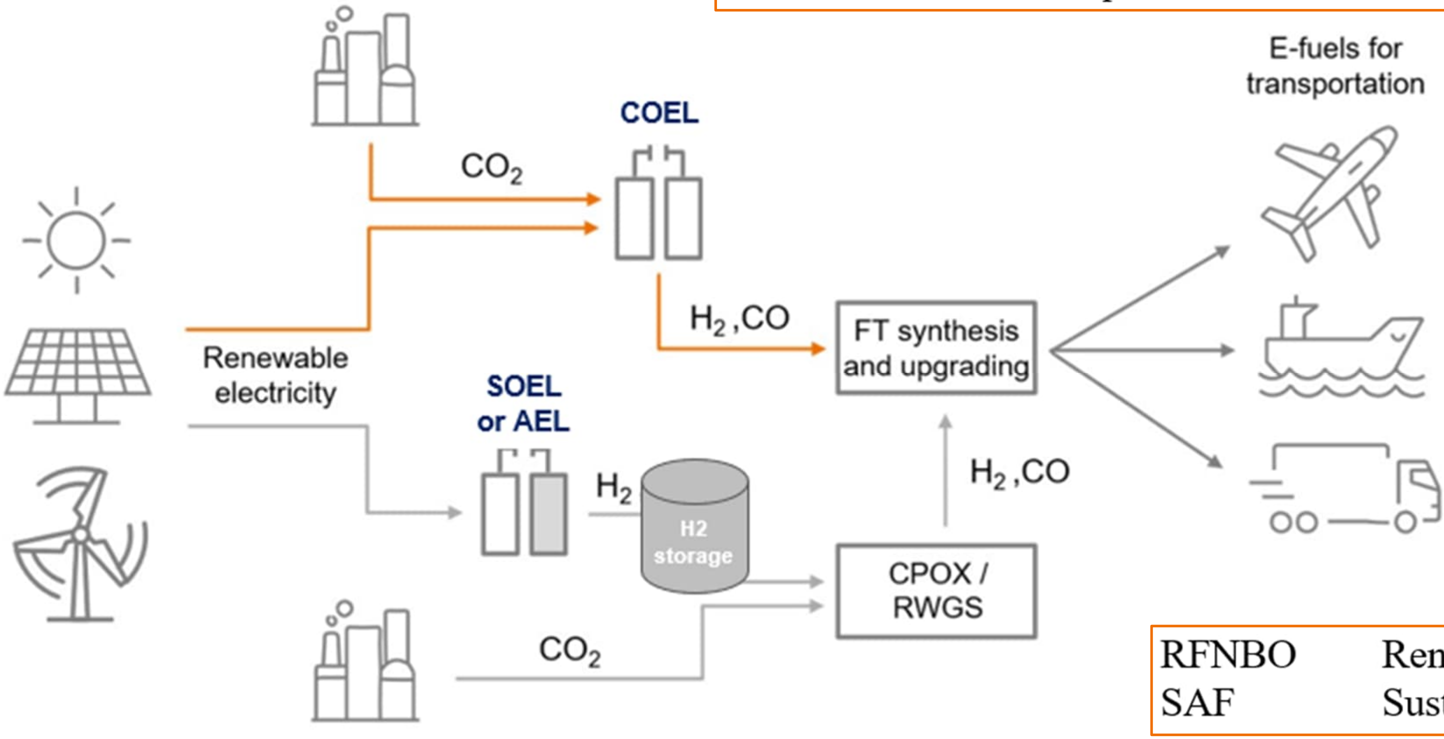
(fossil kerosene is ~94 gCO_2eqv/MJ)

Concepts to be evaluated

PLANT Concepts

Abbreviations

SOEL	Solid Oxide electrolyzer, *produces H_2* from steam and power
COEL	Co-electrolyser, *produces syngas (H_2 and CO),* from CO_2 , steam, and power
AEL	Alkaline electrolyzer, *produces H2 and O2* from water and power
ASU	Air Separation Unit, *produces O2 and N2*
CPOX	Catalytic partial oxidation, *produces syngas (H_2 and CO)*
eRWGS	electrically heated reverse water gas shift reactor, *produces syngas (H_2 and CO)*
FT	Fischer-Tropsch

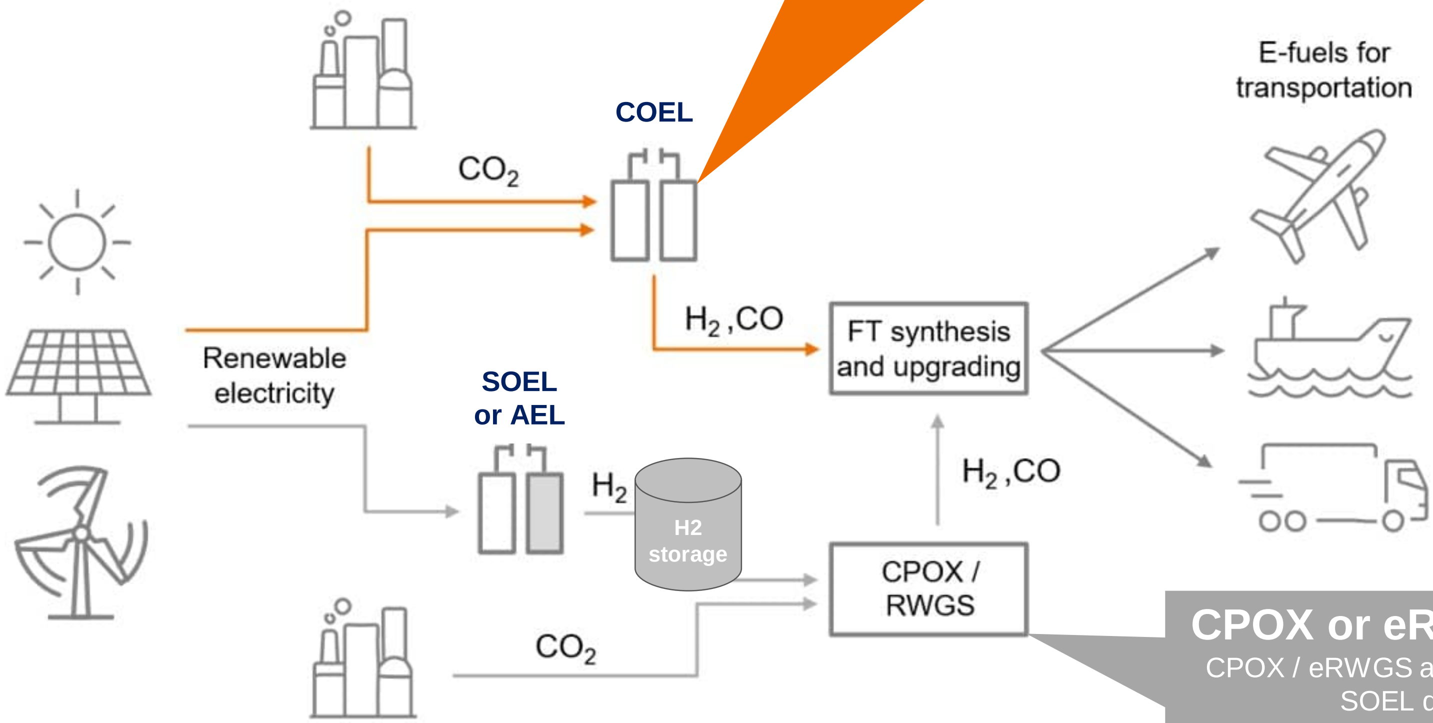


RFNBO	Renewable fuel(s) of non-biological origin
SAF	Sustainable Aviation Fuel

PLS	Pipeline H2 gas storage
PPA	Power purchase agreement (here for wind power)

PLANT Concepts to be evaluated

COEL + water SOEL (hybrid)
COEL and FT synthesis in steady-state
SOEL dynamically operated
60% of purge gas recycled



CPOX or eRWGS + water SOEL
CPOX / eRWGS and FT synthesis in steady-state
SOEL dynamically operated

60% of purge gas recycled
OR
90% of purge gas recycled

Comparison to reference concepts:
H_2 production by AEL

Flowsheet of the baseline concept

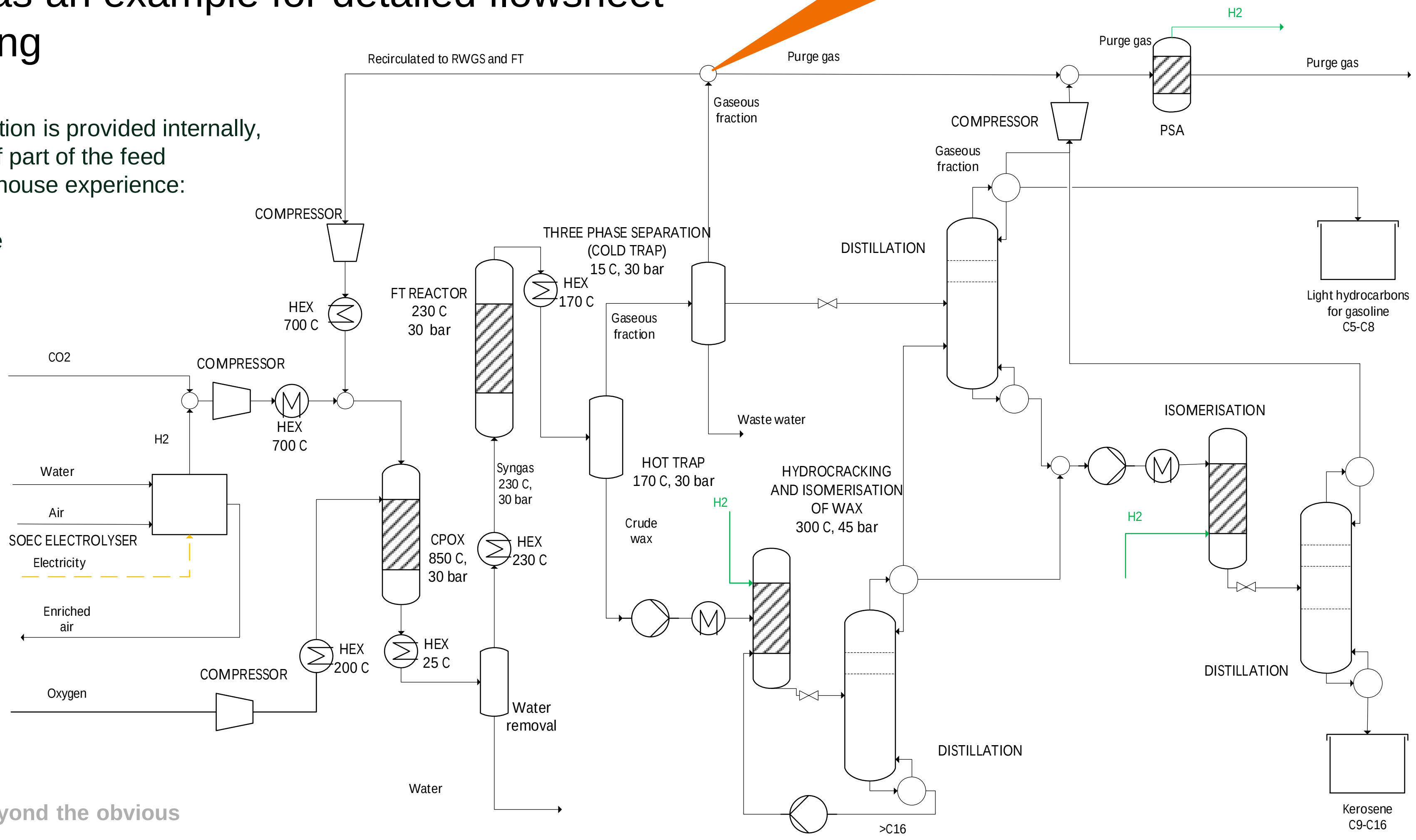
Gas recycling ratio: either 60% or 90%

VTT

- CPOX concept as an example for detailed flowsheet for FT and refining

CPOX model:

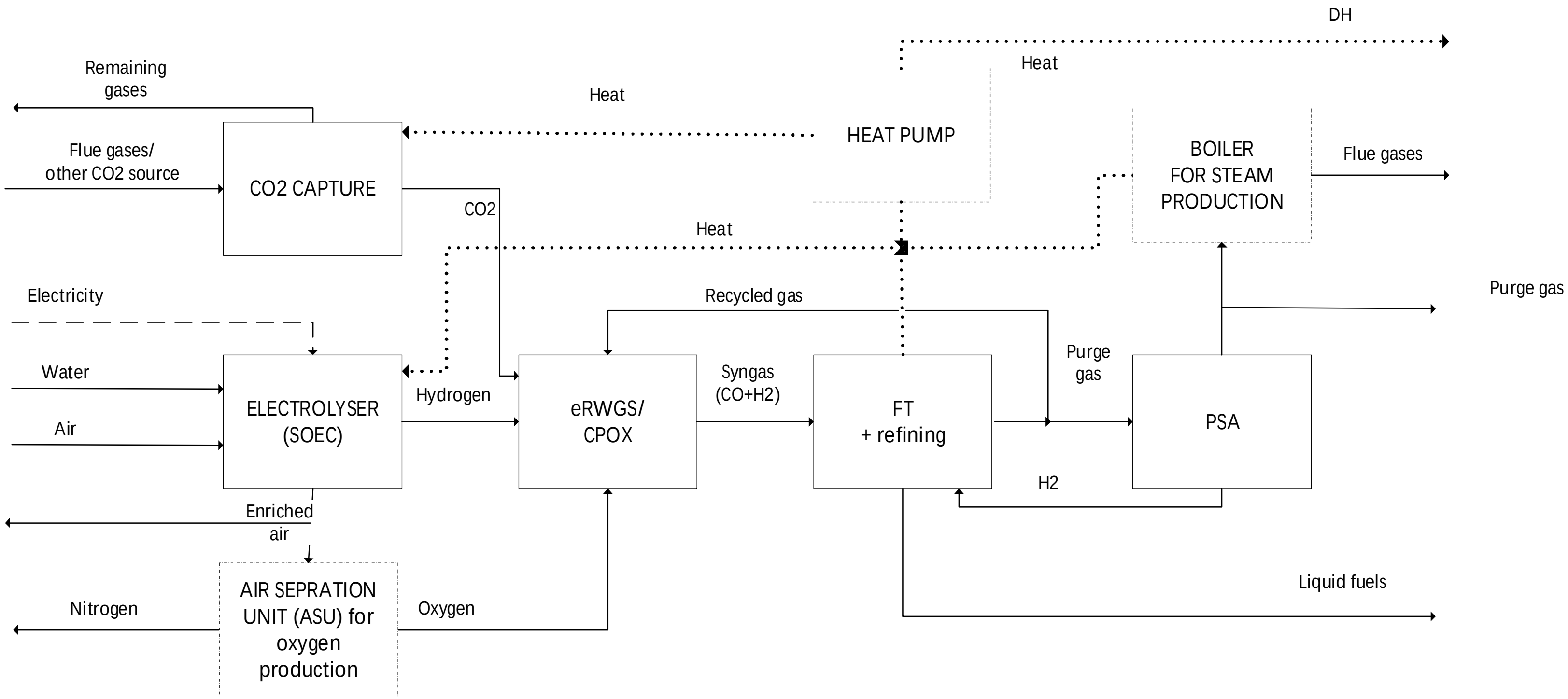
- Heat required for RWGS reaction is provided internally, by catalytic partial oxidation of part of the feed
- Modelling based on VTT's in-house experience:
  - Rgibbs reactor in Aspen
  - Operation in isothermic mode
  - Equilibrium assumed
  - Operation temperature 850 C
  - Operation pressure 30 bar



Fischer-Tropsch standalone plant and optional units

Optional units depending on the concept are

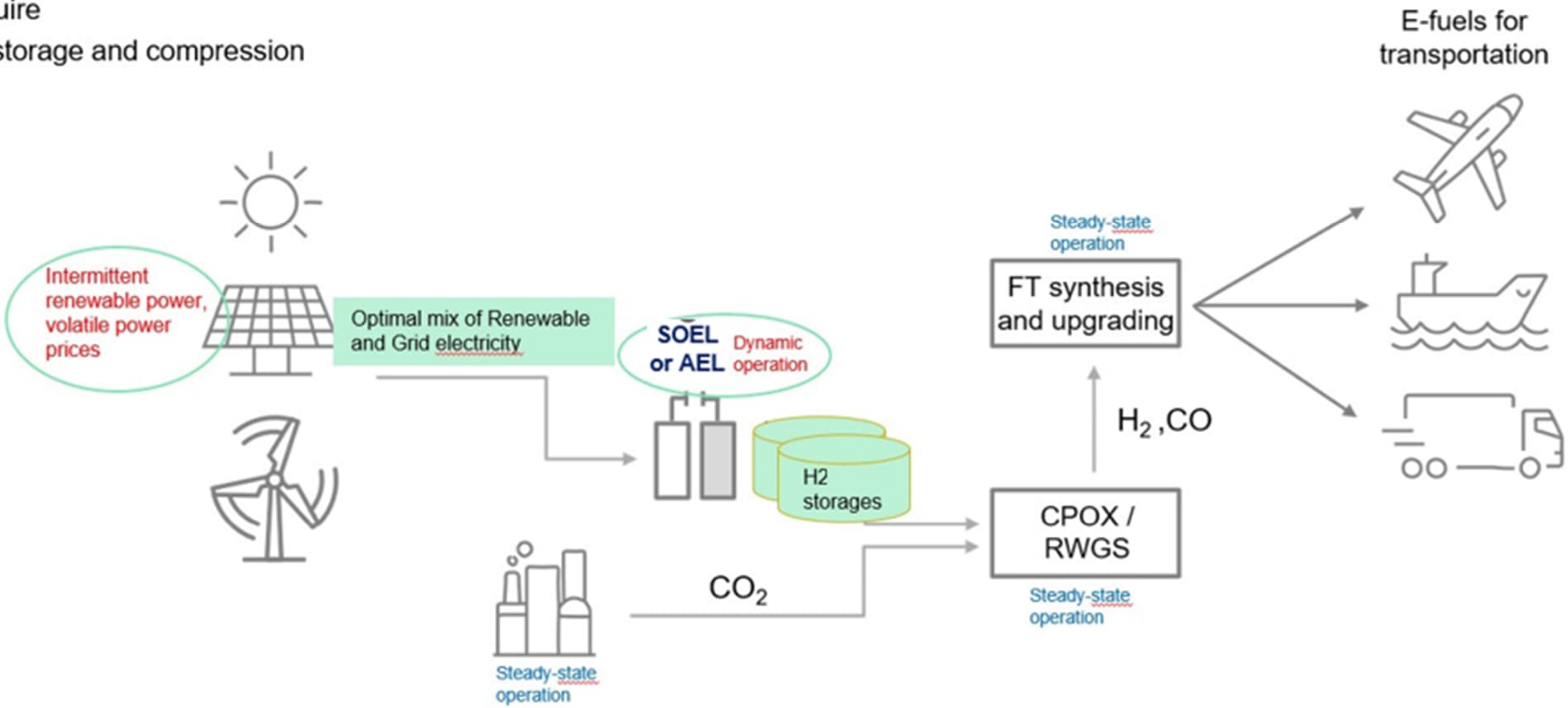
- *Power: Wholesale market power operations, Wind Power Purchase agreement (PPA)*
- Water electrolysis for H_2: AEL or SOEL
- Syngas: CoEL / eRWGS / CPOX
- ASU or AEL for needed O_2
- Heat Pump (cooling load / MEA upgrade / DH supply)
- Steam Boiler (purge gas)



Main operational principles for the Water-Electrolysis routes

Dynamical operation of Water electrolysis
will require

- H_2 storage and compression



Reference concepts: H_2 production by AEL

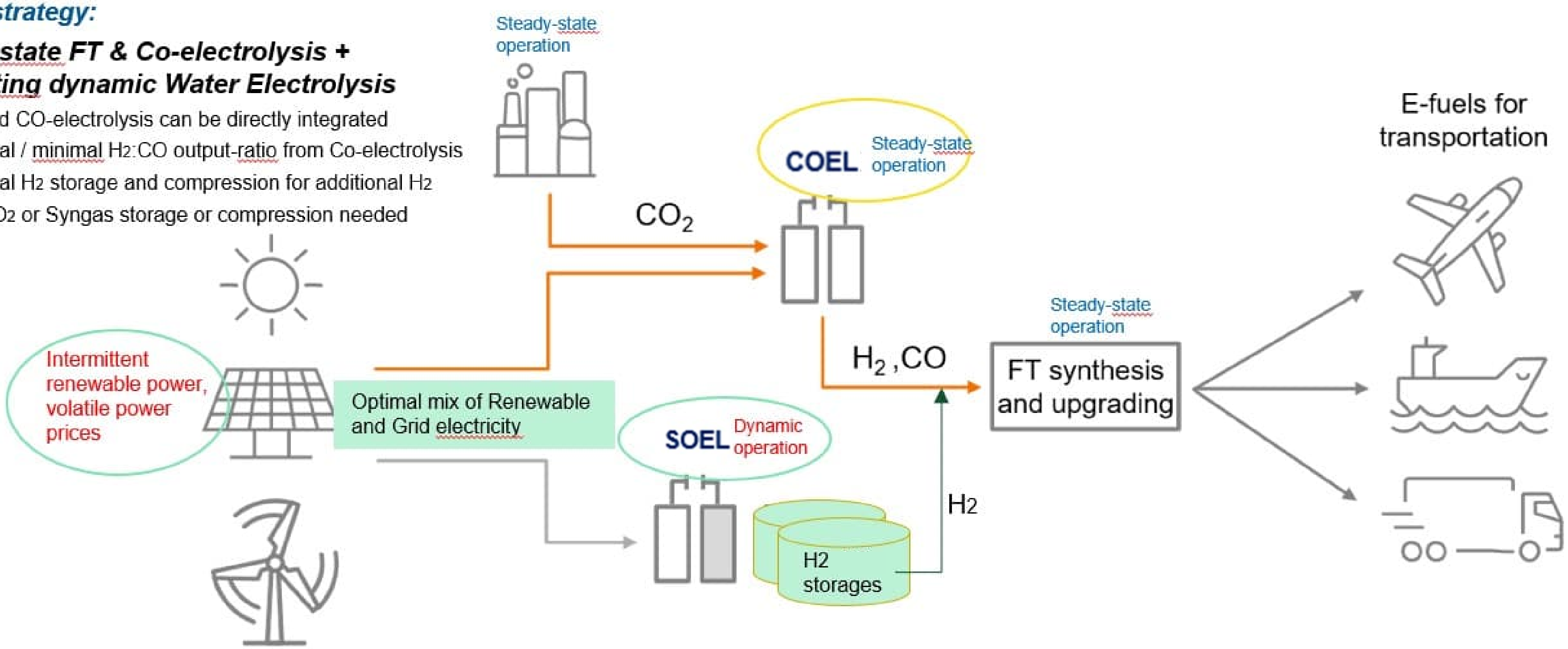
Main operational principles for the Co-Electrolysis route

VTT

Hybrid strategy:

Steady-state FT & Co-electrolysis + supporting dynamic Water Electrolysis

- FT and CO-electrolysis can be directly integrated
- Optimal / minimal H_2:CO output-ratio from Co-electrolysis
- Optimal H_2 storage and compression for additional H_2
- No CO_2 or Syngas storage or compression needed



Assessed concepts

	CPOX 60%			eRWGS 60%		Co-SOEL + water SOEL	CPOX 90%			eRWGS 90%	
	AEL	SOEL O2asu	SOEL O2ael	AEL	SOEL	(small) SOEL	AEL	SOEL O2asu	SOEL O2ael	AEL	SOEL
CPOX	X	X	X				X	X	X		
ASU for O2		X						X			
(small) AEL for O2 and H2			X						X		
eRWGs				X	X					X	X
Co-SOEL						X					
Boiler	X	X	X	X	X	X	X	X	X	X	X
Heat pump	X	X	X	X	X	X	X	X	X	X	X

Economic assessment using VTT's generalized P2X-optimization model

For P2X-site and plant level
optimal dimensioning of units and renewable power long term contracting

Renewable Power (direct or PPA)

Power Market

P2X Optimal Operation and Dimensioning

- Multiple, often conflicting targets
- **GHG (CO_2) emissions & cost of grid** (market) power
- Demand and market price for (green) end products and intermediate products
- **Intermittency and Cost** of renewable power, PPA
- Sales of surplus renewable power, balancing purchases
- **"Green" definition** requirements:
  - CO_2/GHG emissions: direct and indirect
  - Minimum needed share of renewable power
- **Optimal dimensions** of P2X plant dimensions and unit processes, dimensioning of wind power PPA

PtX green products

- Steels
- Fuels
- Chemicals
- Reduction Agents

Side products
Oxygen
Heat
(Steam)

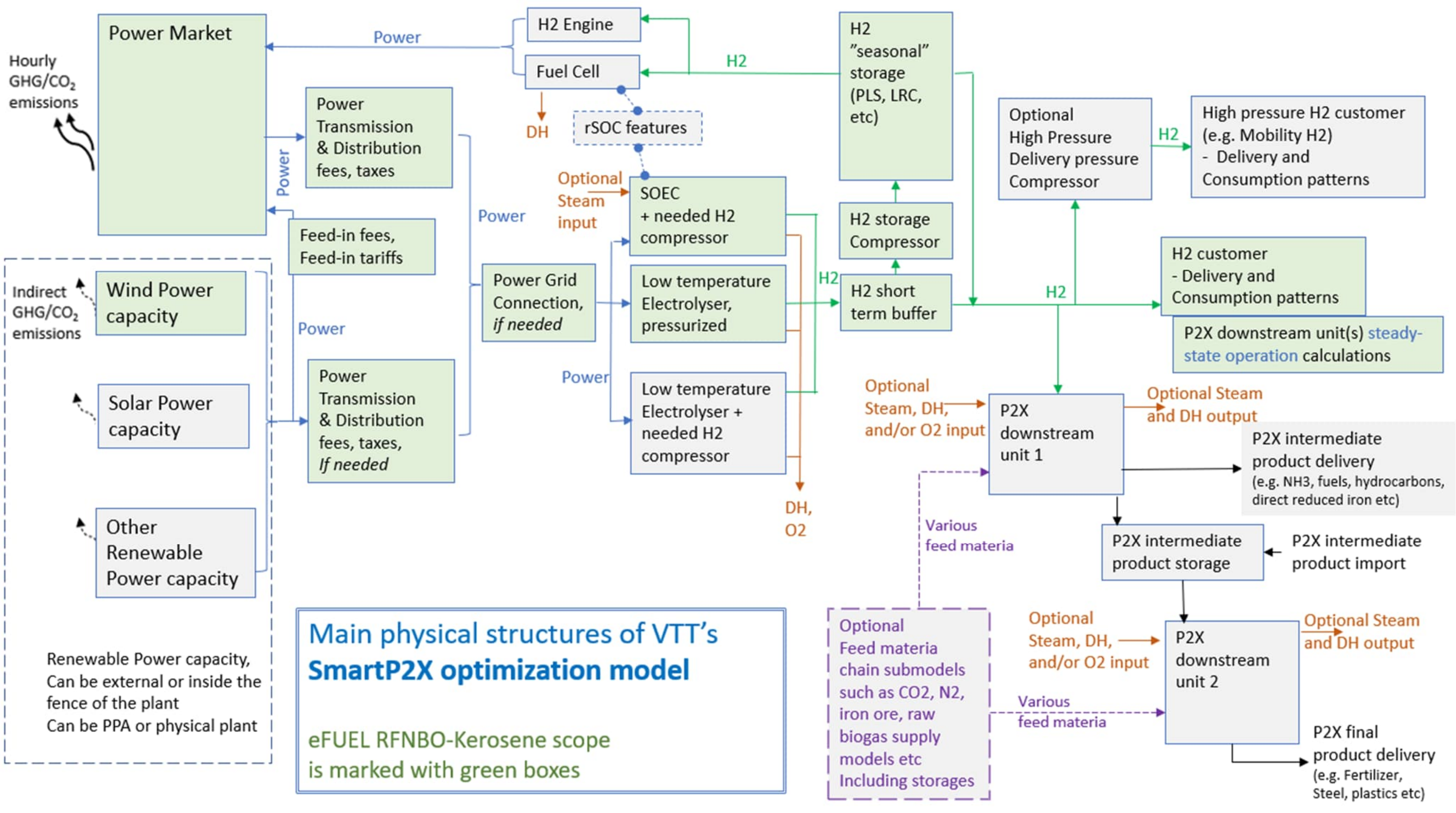
Projects:

Past 2015-2021
- SmartP2G2 (EIT Digital)
- Neocarbon (BF)
- R3water (FP7 – future WWTP developments)
- Feasibiltiy studies
- PLANET (H2020 – interaction between power, heat and gas grids)

Ongoing 2021-:
- eFUEL (BF) – Sustainable Aviation Fuel
- FFS (BF) – green steel
- Customer feasibility study
- Hydrogen mobility
- *FinH2 (BF, 2023-2024)*

Main structures of VTT's P2X-optimization model

Detailed model and equations are presented in scientific papers



Market and Wind power forecast

Market power and Wind power: Forecast scenarios

VTT

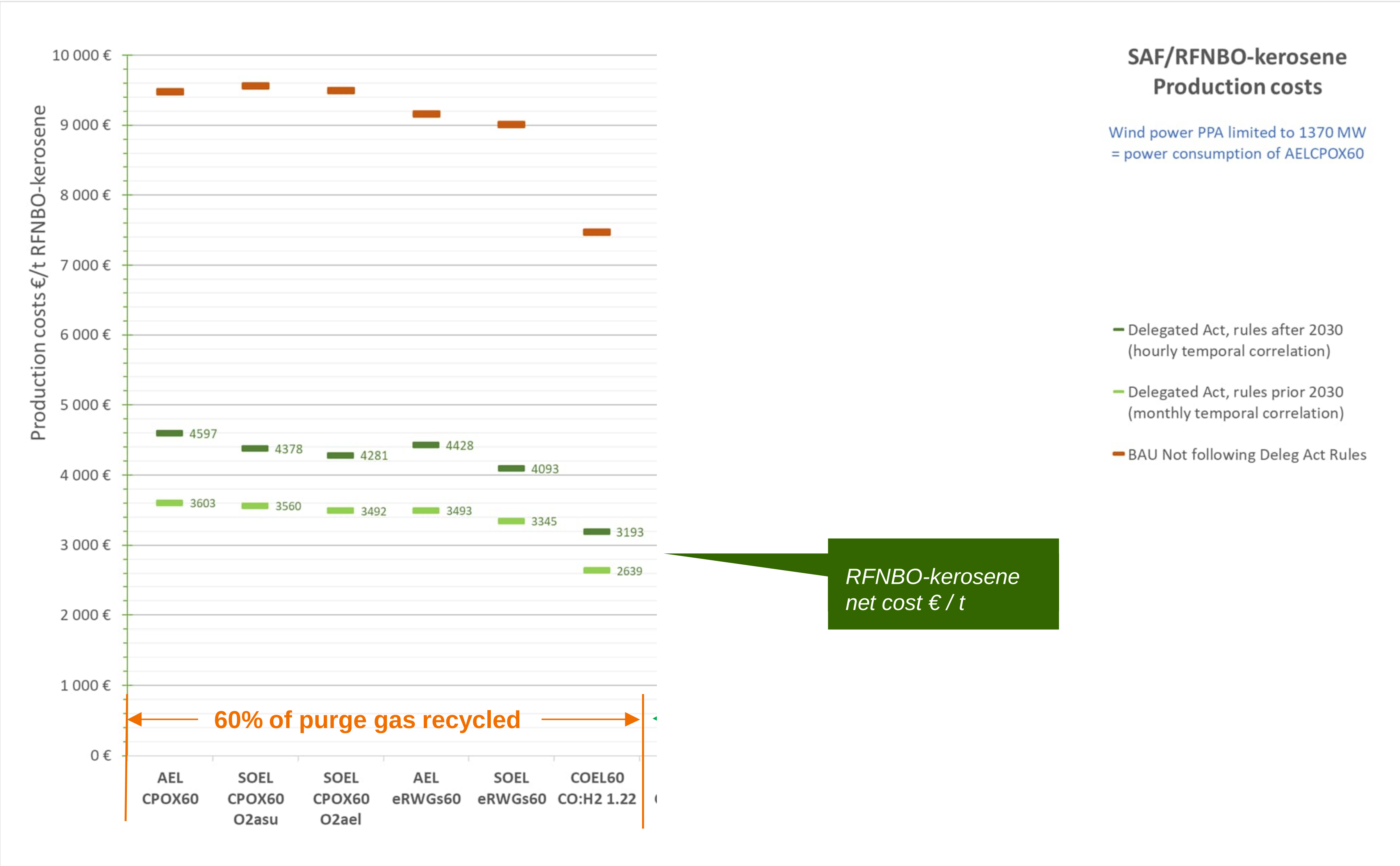
Forecast scenario 2025-30
using power market and wind data from North European power market model

		Forecast Scenario 2030 year with				Measured Data	
		Low gas price		High gas price			
		Average wind	Low wind	Average wind	Low wind	2020	2021
Power Grid CO_2 emissions							
average	gCO_2/MWh	15	20	14	17	72	91
max	gCO_2/MWh	84	137	93	134	162	176
Wholesale power, ELSPOT FI							
average	€/MWh	30	46	36	60	28	72
max	€/MWh	183	380	217	368	254	1000
min	€/MWh	2	2	2	2	-2	-1
std dev	€/MWh	20	24	30	34	21	66
Wind power capacity factor							
average	%	43	40	43	40	38	36
std dev	%	27	27	27	27	25	26
Wind power cost and value							
PPA cost**	€/MWh	39	42	39	42		38
ELSPOT value	€/MWh	21	33	25	43	24	64
correlation coefficient		-0.63	-0.67	-0.54	-0.62	-0.26	-0.17

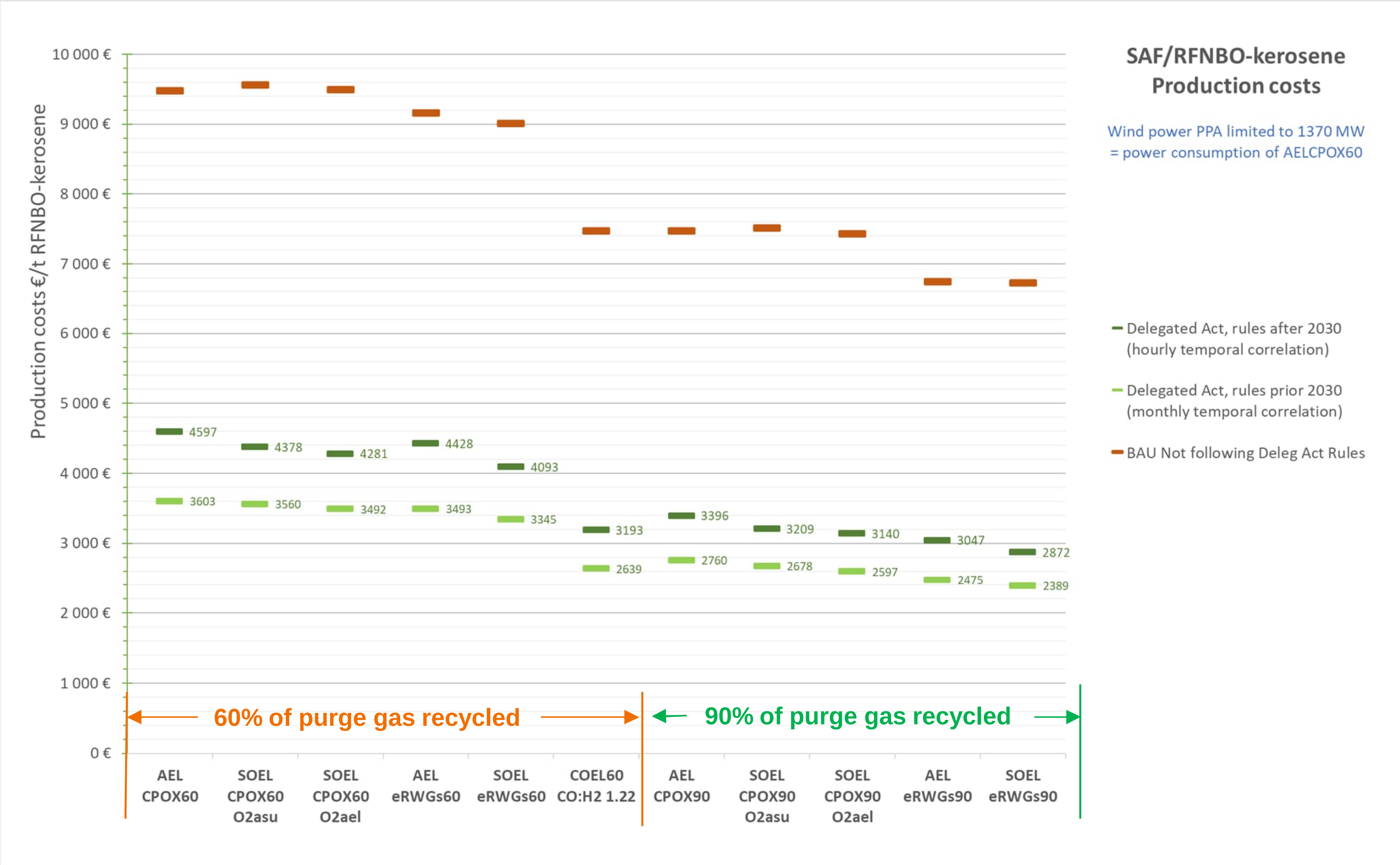
Forecasted PPA price ***40 €/MWh,*** *adjusted with the yearly capacity factor*

Results

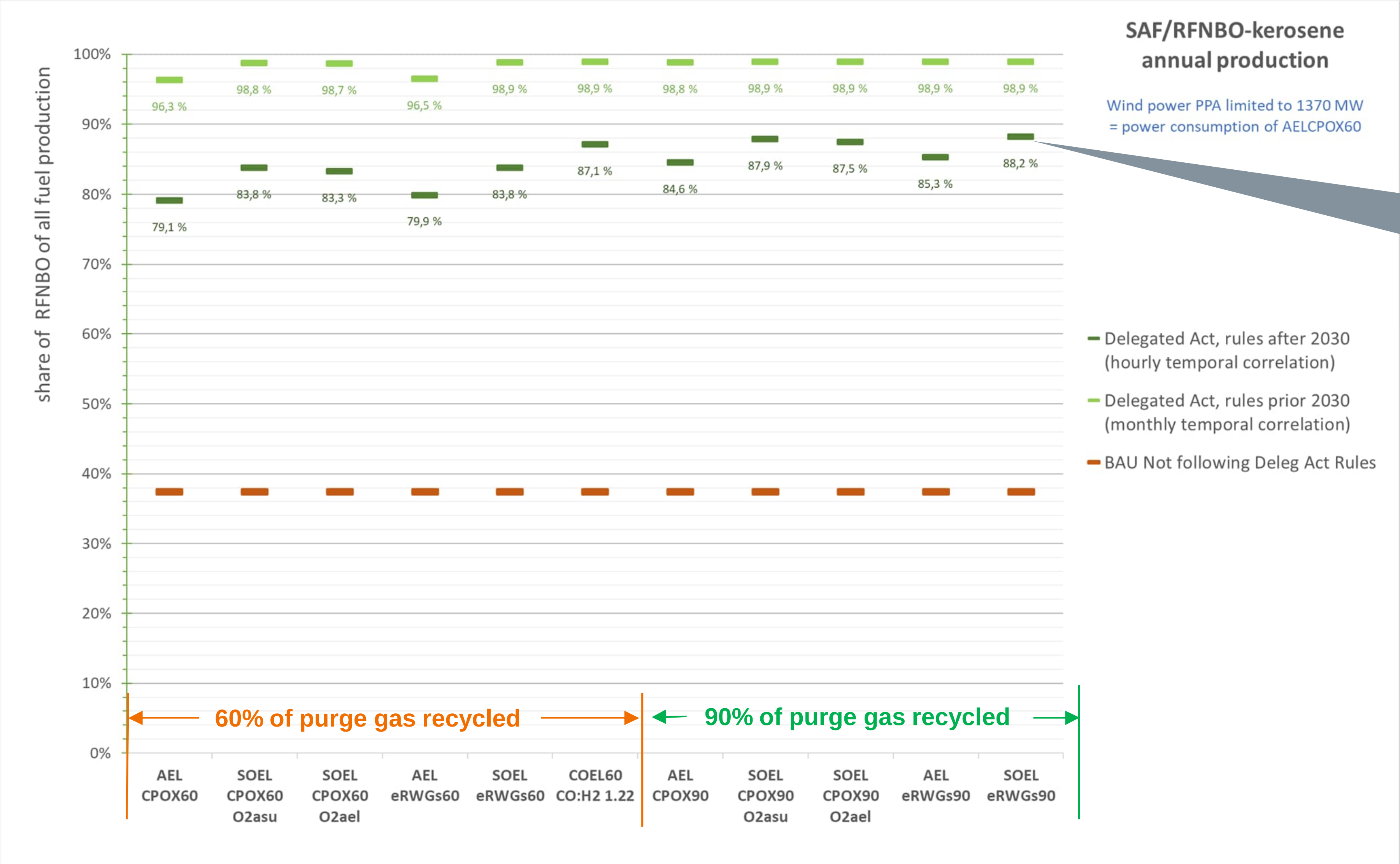
SAF Production costs *vs impact of RFNBO-rules*



SAF Production costs *vs impact of RFNBO-rules*

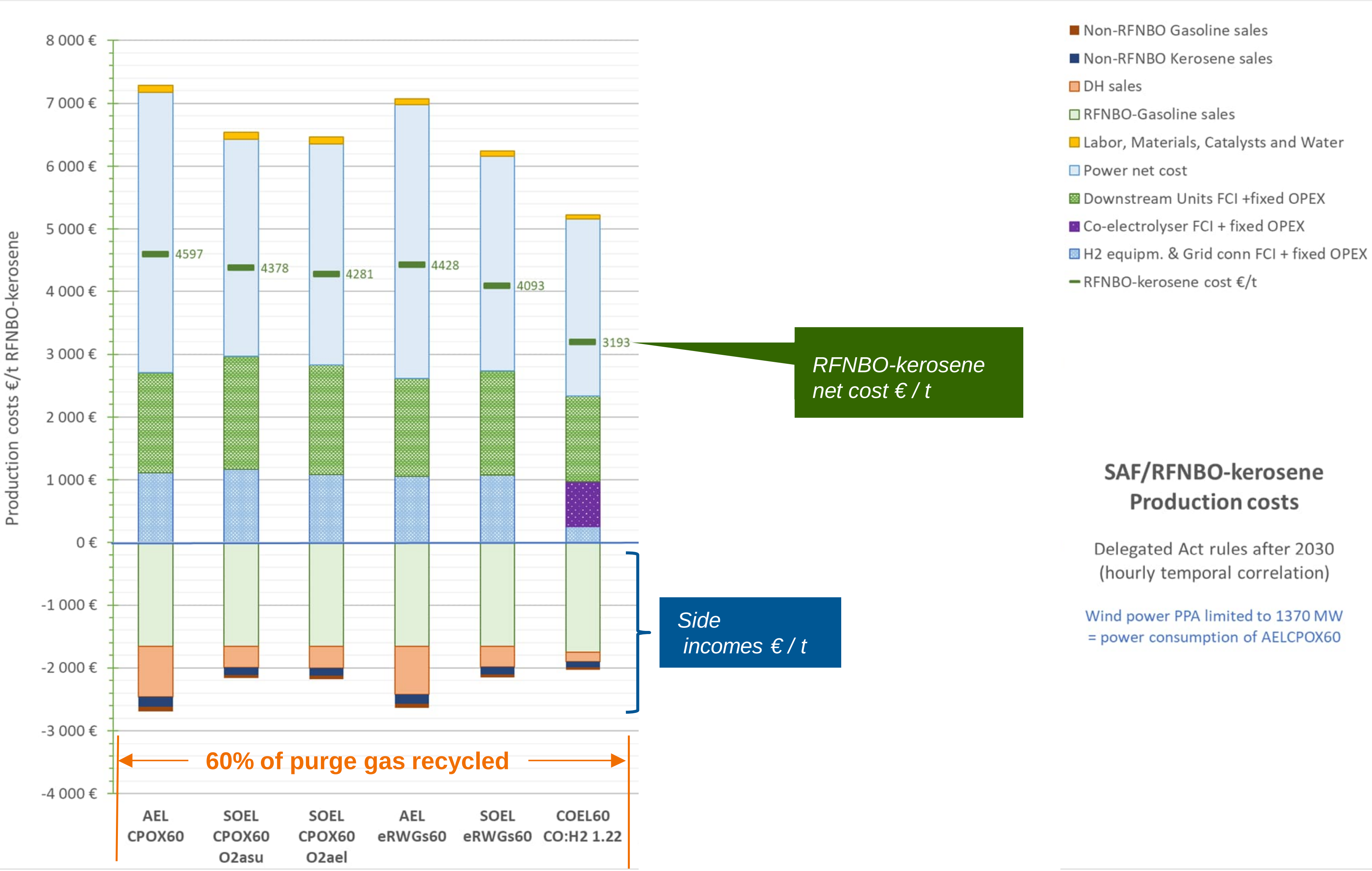


RFNBO production share – impact of RFNBO-rules



Higher RFNBO-production levels, up to 99.5%, can only be achieved with more plant flexibility or a large-scale H_2-storage

SAF Production cost structures – 2030 and beyond

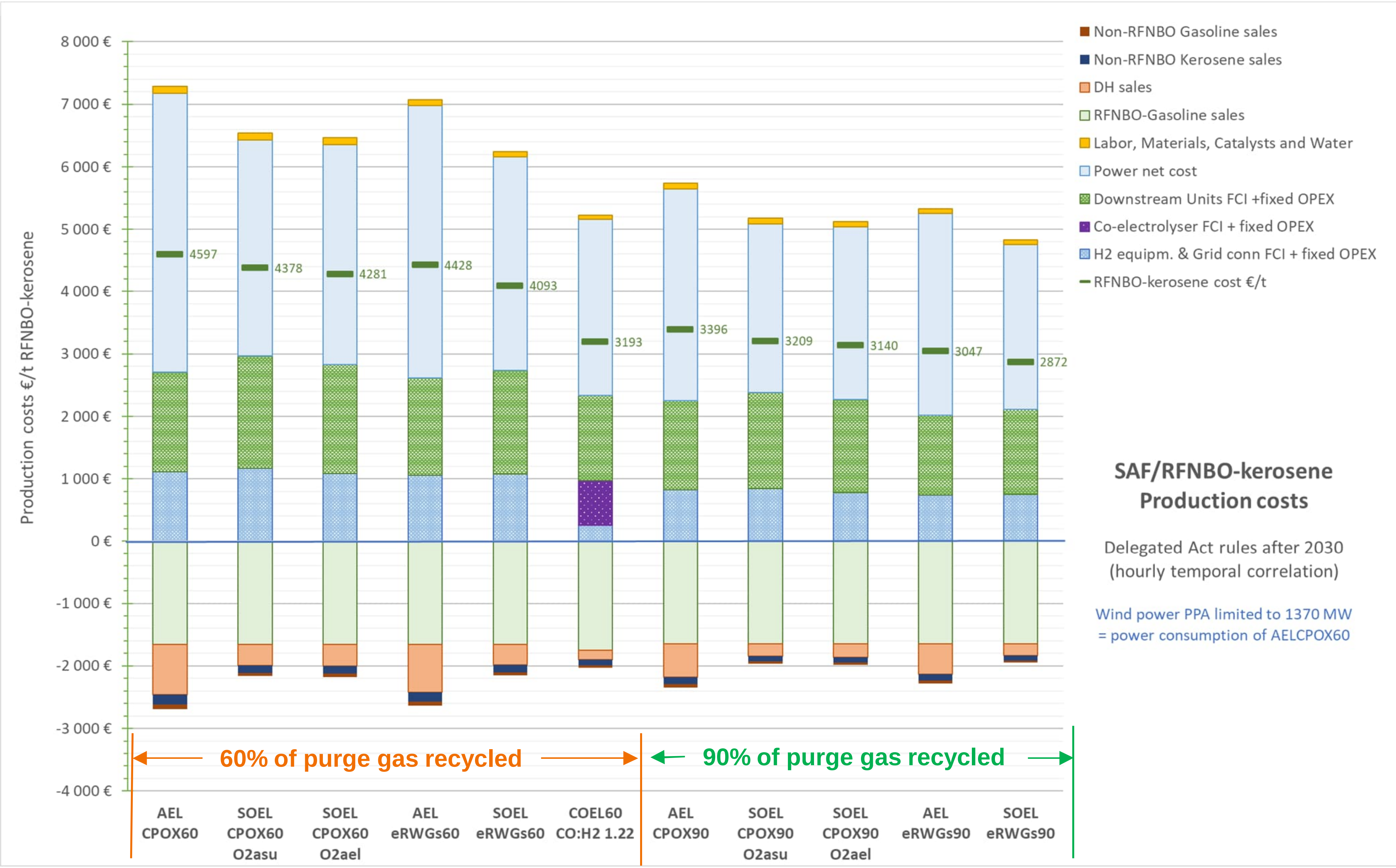


SAF/RFNBO-kerosene Production costs

Delegated Act rules after 2030 (hourly temporal correlation)

Wind power PPA limited to 1370 MW = power consumption of AELCPOX60

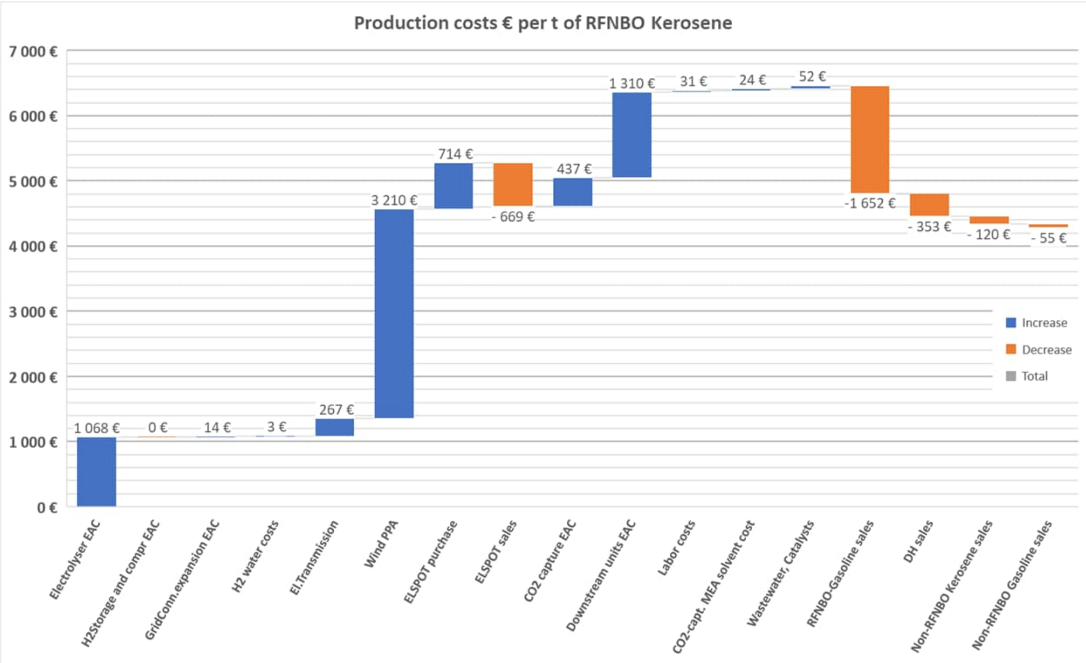
SAF Production cost structures - 2030 and beyond



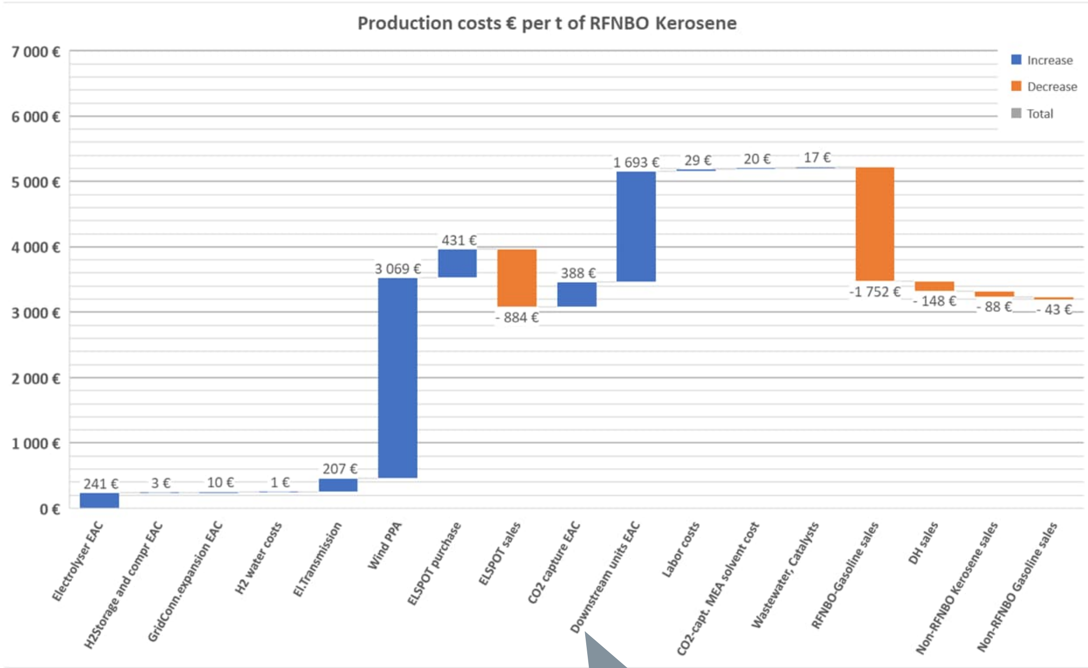
SAF Production cost distribution examples

60%-recycling level of purge gas

case SOEL CPOX60 -O2 from AEL



case COEL60 CO:H2 1.22

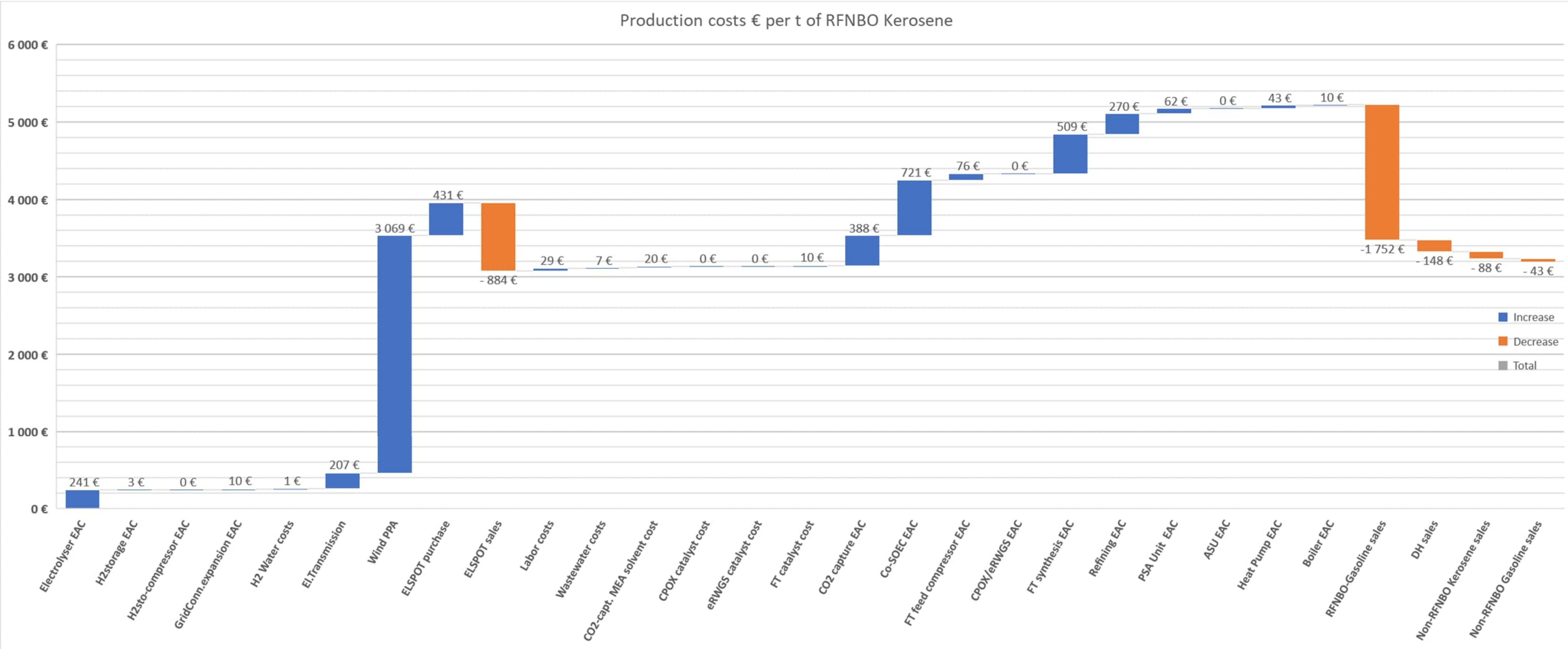


Downstream units EAC+OPEX include the COEL unit

SAF Production cost distribution example detailed

60%-recycling level of purge gas

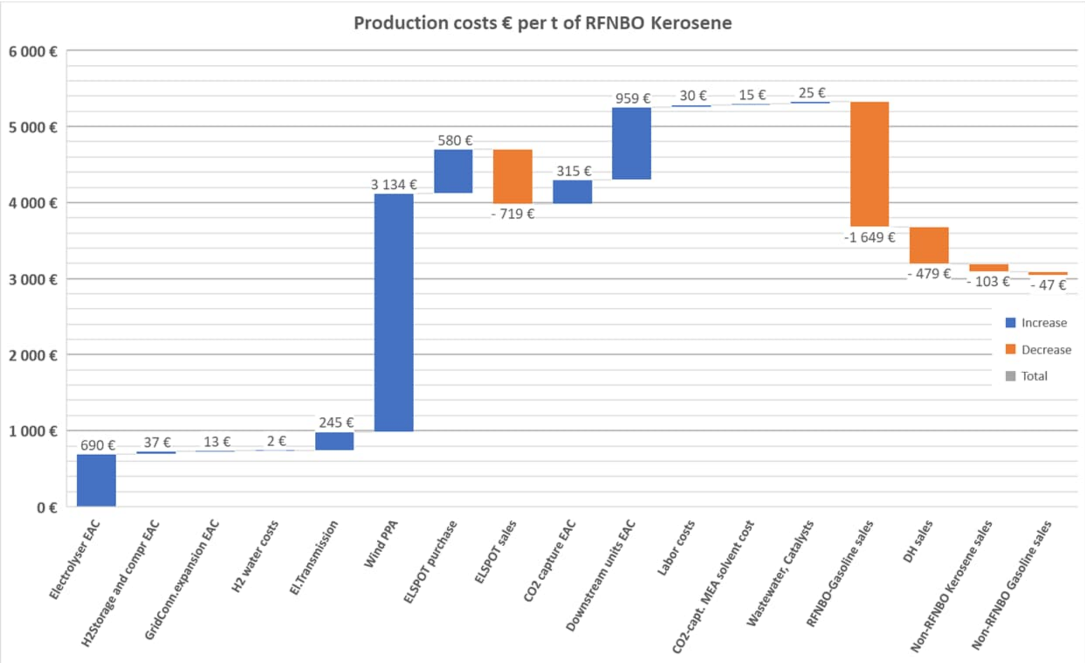
case COEL60 CO:H2 1.22 (remaining H_2 need from SOEL)



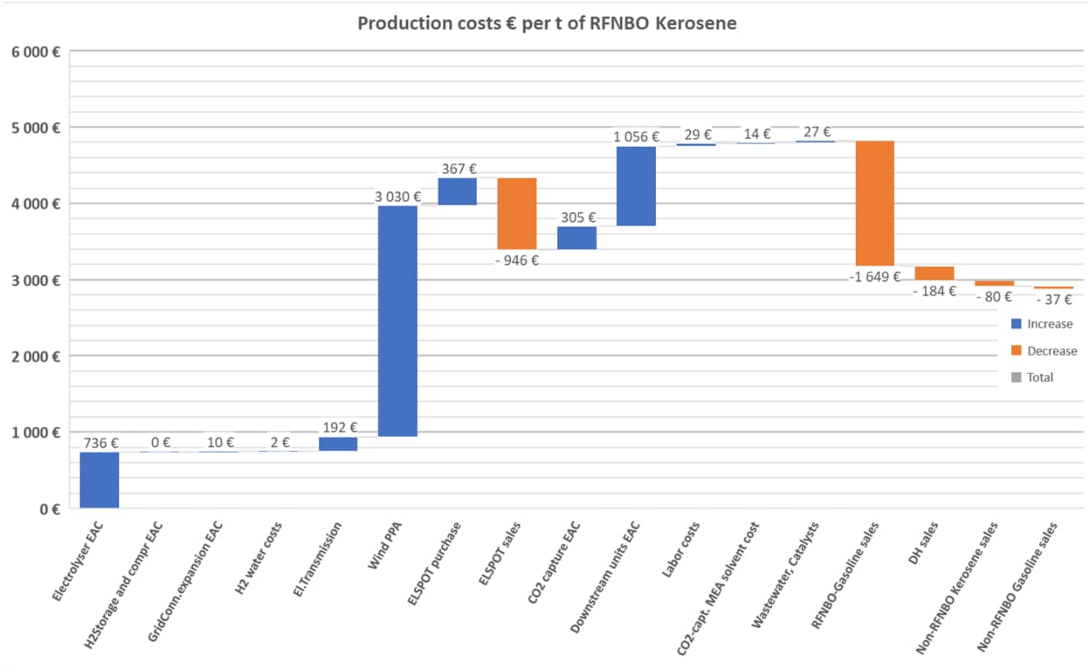
SAF Production cost distribution examples

90%-recycling level of purge gas

case AEL eRWGs90



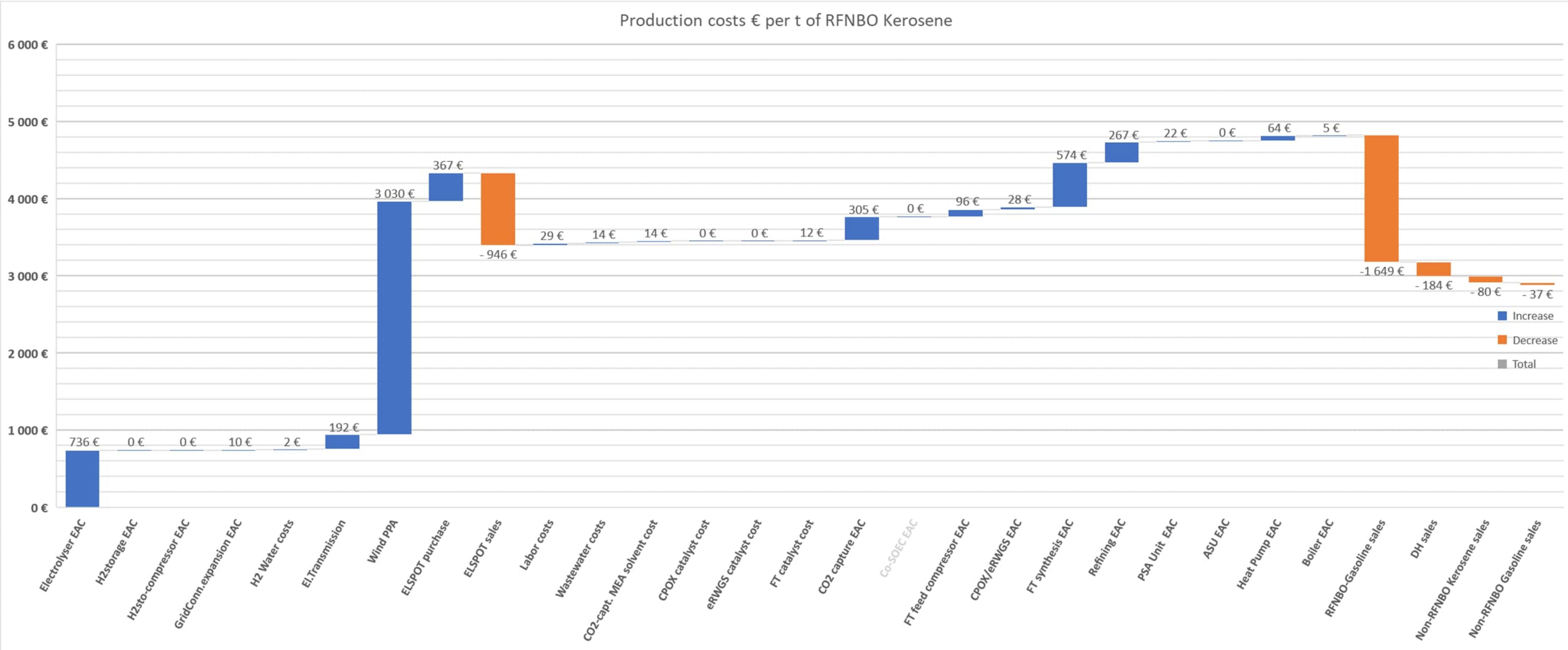
case SOEL eRWGs90



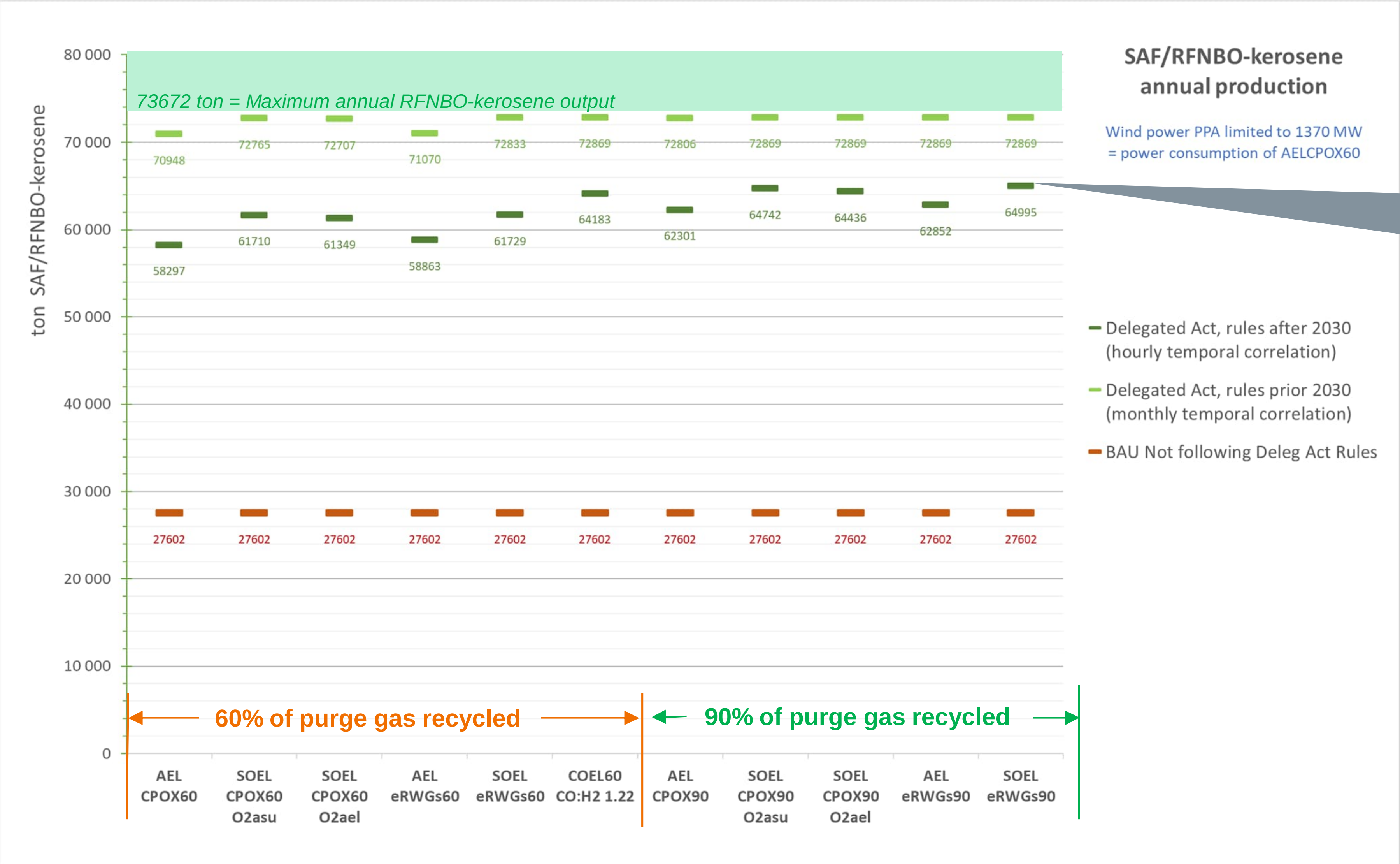
SAF Production cost distribution example detailed

90%-recycling level of purge gas

case SOEL eRWGs90



SAF Production levels – impact of RFNBO-rules



Higher RFNBO-production levels, up to 99.5%, can only be achieved with more plant flexibility or a large-scale H_2-storage

Dimensions and yearly balances – 2030 and beyond

VTT

	Recirculation rate 60%						Recirculation rate 90%				
	AEL CPOX60	SOEL CPOX60 O2asu	SOEL CPOX60 O2ael	AEL eRWGs60	SOEL eRWGS60	COEL60+ H2:CO 1.22 +small SOEL	AEL CPOX90	SOEL CPOX90 O2asu	SOEL CPOX90 O2ael	AEL eRWGS90	SOEL eRWGS90
WP size [MW]	1370	1370	1370	1370	1370	1370	1370	1370	1370	1370	1370
Grid Connection need [MW]	600	470	470	600	460	370	480	370	370	460	360
for electrolysers [MW]	590	440	410	560	410	100	460	340	310	410	300
Electrolyser size @StackAverageAge [MW]	570	420	400	540	400	(245+) 95	450	330	290	400	290
Electrolyser max capacity [tonH2/hour]	11,5	11,4	10,8	11,1	10,7	2,5	9,1	8,8	7,9	8,1	7,9
Electrolyser oversize [tonH2/h]	0,3	0,1	0,0	0,4	0,0	0,0	0,3	0,0	0,0	0,3	0,0
Electrolyser oversize %	2,3 %	0,8 %	0,0 %	3,6 %	0,3 %	0,7 %	3,1 %	0,2 %	0,3 %	3,5 %	0,0 %
H2 Storage size [ton]	50	50	0	50	9	4	50	7	23	50	0
H2 Storage potential limit [ton]	50	50	50	50	50	50	50	50	50	50	50
WP production, yearly average [GWh]	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900
WP sold, yearly average [GWh]	1 200	1 700	1 700	1 200	1 800	2 200	1 700	2 300	2 200	1 800	2 300
WP own use, yearly average [GWh]	3 700	3 200	3 200	3 700	3 100	2 700	3 200	2 600	2 700	3 100	2 600
Spot power bought, yearly average [GWh]	1 200	700	800	1 200	700	500	700	400	500	600	400
Power consumed, yearly average [GWh]	4 900	3 900	4 000	4 800	3 900	3 200	3 900	3 100	3 200	3 700	3 000
used in downstream units [GWh]	100	300	500	300	400	2 400	100	200	600	400	500
used in electrolyser H2 production [GWh]	4 800	3 600	3 500	4 500	3 400	800	3 700	2 800	2 600	3 400	2 500
H2 used in downstream units [ton]	97 000	97 000	92 000	92 000	92 000	22 000	76 000	76 000	68 000	68 000	68 000
H2 production specific power consumption [kWh/kg]	49,6	37,5	37,5	49,6	37,4	38,5	49,6	37,4	37,5	49,6	37,4
Purified water consumed for H2 [ton]	1 060 000	1 060 000	1 020 000	1 010 000	1 010 000	510 000	830 000	830 000	750 000	740 000	740 000
Waste water from downstream units [ton]	570 000	670 000	670 000	570 000	660 000	230 000	460 000	540 000	540 000	390 000	470 000
CO2 used [ton]	790 000	790 000	790 000	790 000	790 000	690 000	500 000	500 000	500 000	500 000	500 000
- CO2 captured from Purge gas combustion [ton]**	350 000	360 000	360 000	350 000	350 000	260 000	90 000	90 000	90 000	90 000	90 000
CO2 net need [ton]	440 000	430 000	430 000	440 000	430 000	430 000	400 000	400 000	400 000	400 000	400 000
CPOX catalyst (0.5% Rh) [ton]	0,96	0,96	0,96				0,88	0,88	0,88		
eRWGS catalyst (Ni based) [ton]				0,39	0,39					0,34	0,34
FT catalyst [ton]	26	26	26	26	26	21	26	26	26	26	26
O2 produced in ASU [ton]		34 000						61 000			
O2 produced in AEL [ton]	774 000		34 000	733 000			605 000		61 000	540 000	
- O2 used in CPOX [ton]	34 000	34 000	34 000				61 000	61 000	61 000		
Surplus O2 [ton]	740 000	0	0	733 000	0	0	544 000	0	0	540 000	0
Product output											
Kerosene [ton]	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700
of which RFNBO-kerosene [ton]	58 300	61 700	61 300	58 900	61 700	64 200	62 300	64 700	64 400	62 900	65 000
Gasoline [ton]	50 700	50 700	50 700	50 800	50 800	53 800	50 600	50 600	50 600	50 600	50 600
of which RFNBO-gasoline [t]	40 100	42 500	42 200	40 600	42 600	46 900	42 800	44 500	44 300	43 200	44 700
Steam 150C from downstream unit [GWh], used in SOEL	*0*	*780*	*780*	*0*	*740*	*180*	*0*	*610*	*610*	*0*	*540*
DH 85C from downstream units [GWh]	1 290	500	530	1 240	410	300	860	240	300	790	240
DH 70-80C from water electrolyser [GWh]	750	430	410	710	440	100	580	340	300	520	300

Larger electrolyser (over)capacities would require larger H2 storage or plant flexibility

Higher RFNBO share requires

(1) larger electrolyser (over)capacities and

(2) more H2-storage or FT-process flexibility

Dimensions and yearly balances – 2030 and beyond *….focused*

	Recirculation rate 60%					Recirculation rate 90%			
	AEL CPOX60	SOEL CPOX60 O2ael	AEL eRWGs60	SOEL eRWGS60	COEL60+ H2:CO 1.22 +small SOEL	AEL CPOX90	SOEL CPOX90 O2ael	AEL eRWGS90	SOEL eRWGS90
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Electrolyser size @StackAverageAge [MW]	570	400	540	400	*(245+)* 95	450	290	400	290
Electrolyser max capacity [tonH2/hour]	11,5	10,8	11,1	10,7	2,5	9,1	7,9	8,1	7,9
Electrolyser oversize %	2,3 %	0,0 %	3,6 %	0,3 %	0,7 %	3,1 %	0,3 %	3,5 %	0,0 %
H2 Storage size [ton]	50	0	50	9	4	50	23	50	0
H2 Storage potential limit [ton]	50	50	50	50	50	50	50	50	50
WP production, yearly average [GWh]	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900	4 900
WP sold, yearly average [GWh]	1 200	1 700	1 200	1 800	2 200	1 700	2 200	1 800	2 300
WP own use, yearly average [GWh]	3 700	3 200	3 700	3 100	2 700	3 200	2 700	3 100	2 600
Spot power bought, yearly average [GWh]	1 200	800	1 200	700	500	700	500	600	400
Power consumed, yearly average [GWh]	4 900	4 000	4 800	3 900	3 200	3 900	3 200	3 700	3 000
used in downstream units [GWh]	100	500	300	400	2 400	100	600	400	500
used in electrolyser H2 production [GWh]	4 800	3 500	4 500	3 400	800	3 700	2 600	3 400	2 500
H2 used in downstream units [ton]	97 000	92 000	92 000	92 000	22 000	76 000	68 000	68 000	68 000
H2 production specific power consumption [kWh/kg]	49,6	37,5	49,6	37,4	38,5	49,6	37,5	49,6	37,4
Purified water consumed for H2 [ton]	1 060 000	1 020 000	1 010 000	1 010 000	510 000	830 000	750 000	740 000	740 000
Waste water from downstream units [ton]	570 000	670 000	570 000	660 000	230 000	460 000	540 000	390 000	470 000
CO2 used [ton]	790 000	790 000	790 000	790 000	690 000	500 000	500 000	500 000	500 000
- CO2 captured from Purge gas combustion [ton]**	350 000	360 000	350 000	350 000	260 000	90 000	90 000	90 000	90 000
CO2 net need [ton]	440 000	430 000	440 000	430 000	430 000	400 000	400 000	400 000	400 000
Product output									
Kerosene [ton]	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700	73 700
of which RFNBO-kerosene [ton]	58 300	61 300	58 900	61 700	64 200	62 300	64 400	62 900	65 000
Gasoline [ton]	50 700	50 700	50 800	50 800	53 800	50 600	50 600	50 600	50 600
of which RFNBO-gasoline [t]	40 100	42 200	40 600	42 600	46 900	42 800	44 300	43 200	44 700
Steam 150C from downstream unit [GWh], used in SOEL	*0*	*780*	*0*	*740*	*180*	*0*	*610*	*0*	*540*
DH 85C from downstream units [GWh]	1 290	530	1 240	410	300	860	300	790	240
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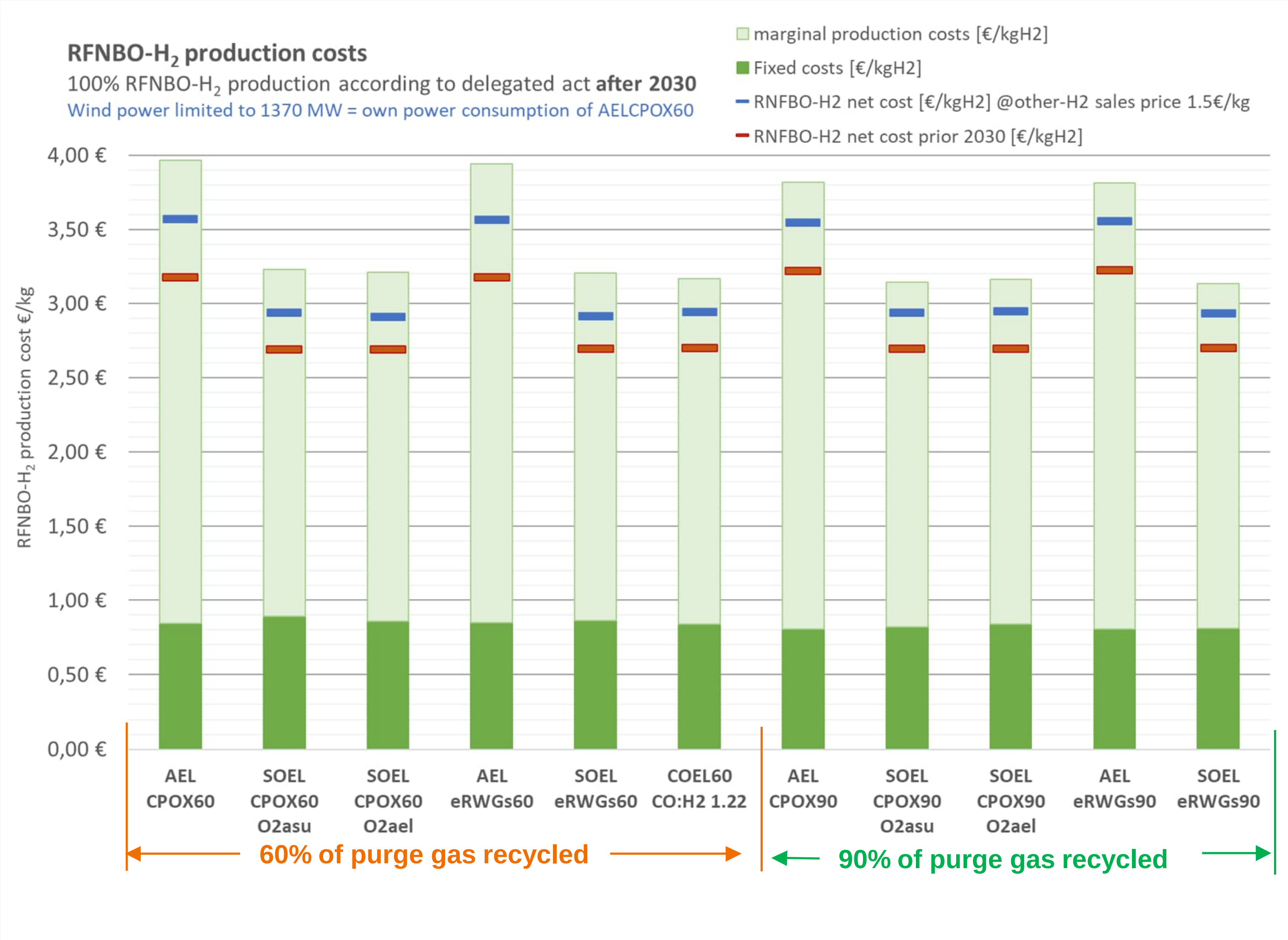
Larger electrolyser (over)capacities would require larger H2 storage or plant flexibility

Higher RFNBO share requires

(1) larger electrolyser (over)capacities and

(2) more H2-storage or FT-process flexibility

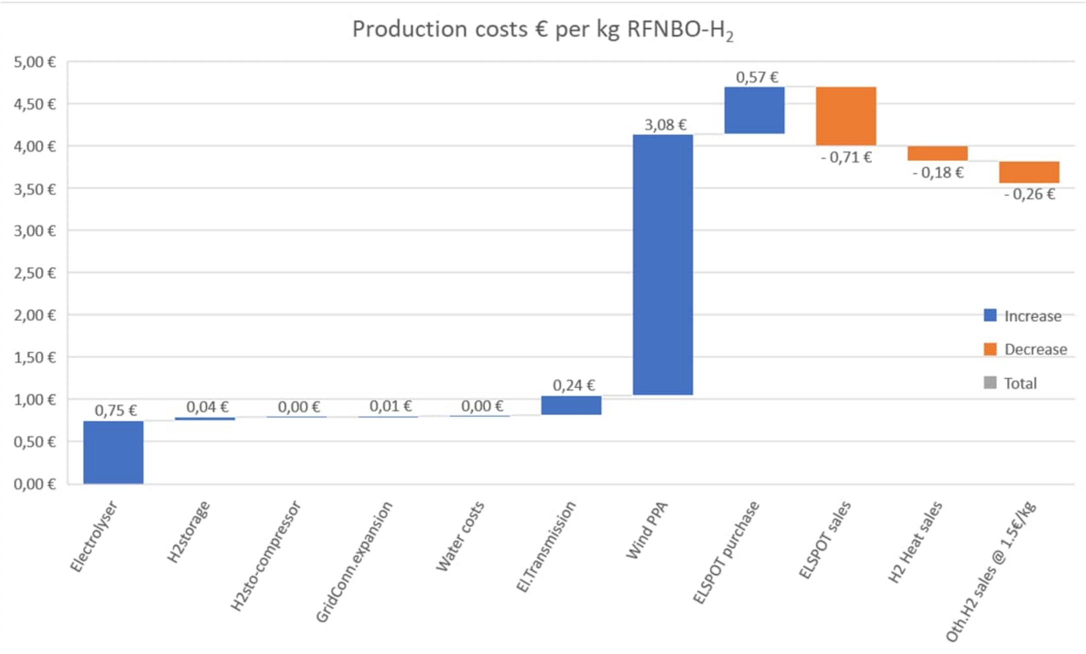
Production costs: RFNBO-H2



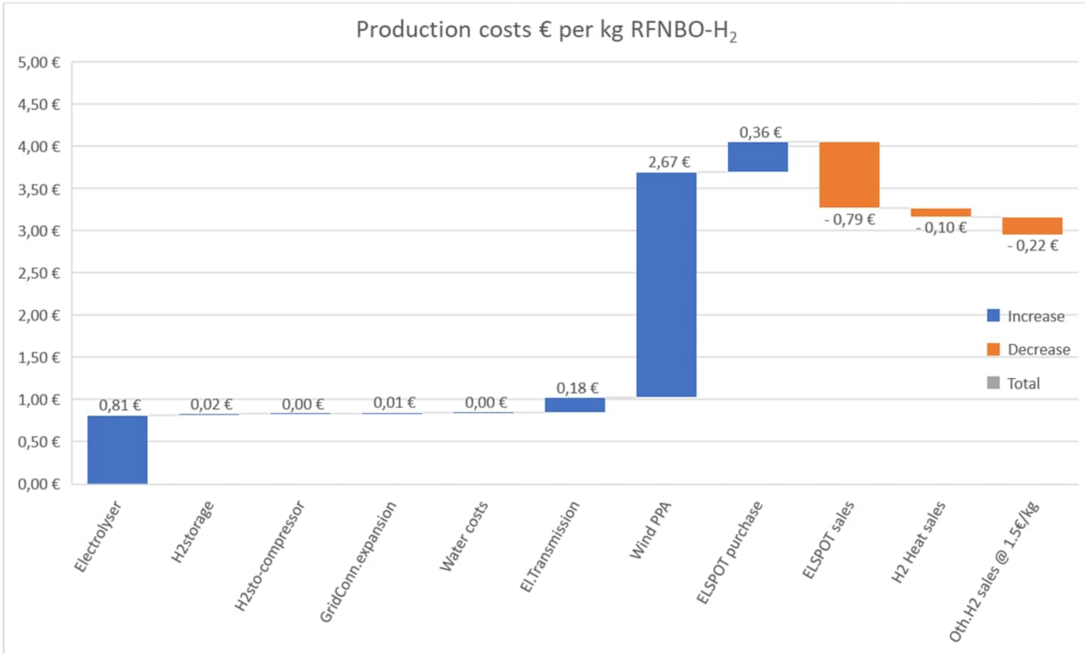
H2 Production cost distribution examples

VTT

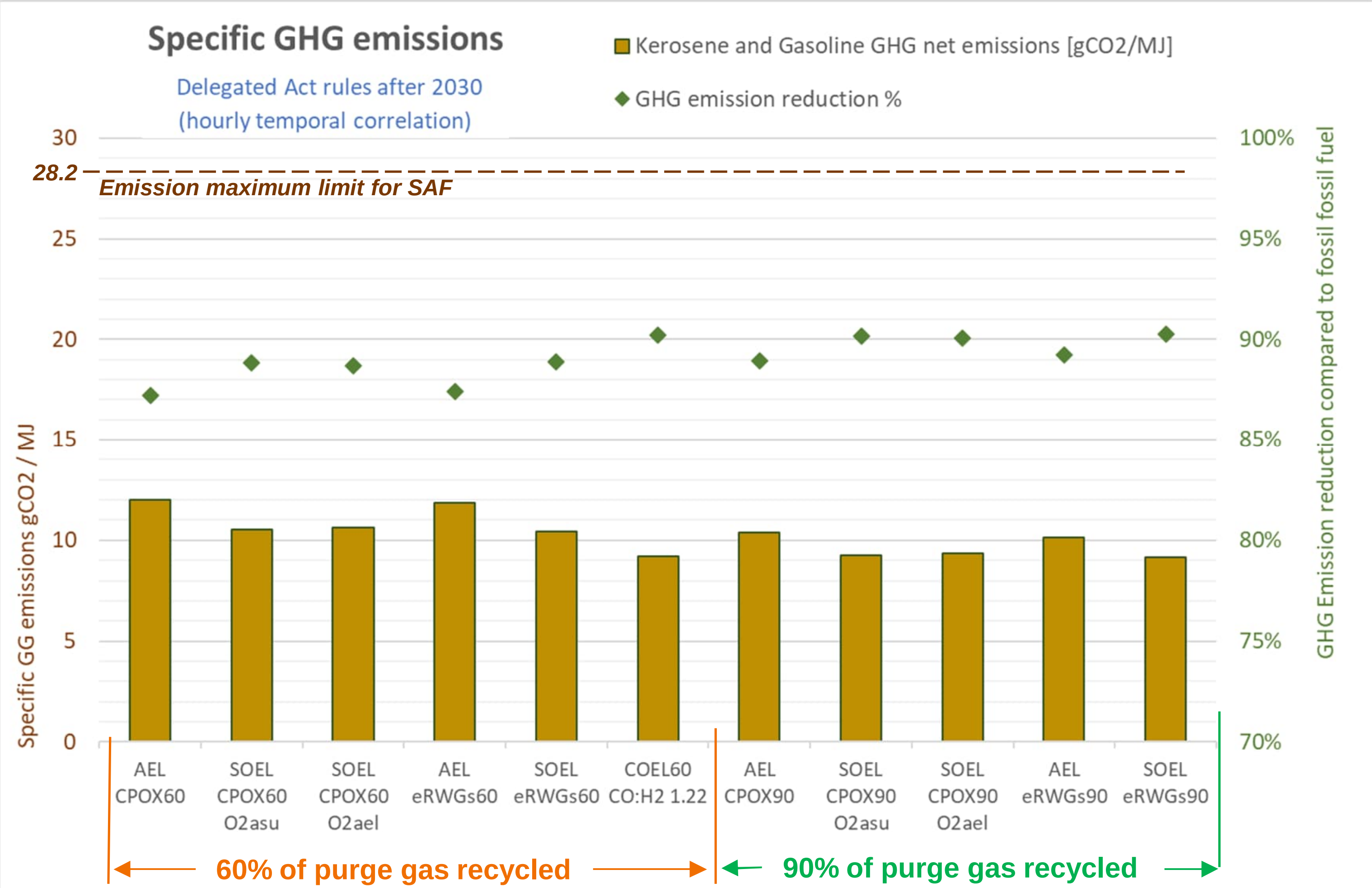
case AEL eRWGs90



case SOEL eRWGs90



SAF Specific GHG Emissions



Approximately same specific emissions and emission reduction, regardless applying Delegated Act rules prior 2030 or after 2030

Summary and conclusions

EU-rules and definitions for RFNBO and green H2 (Delegated act 2/2023) can be met both for rules prior and after 2030.

Example site Finland was presented, using Finnish power system and land-based wind power

Results based on hydrocarbon related processes Aspen steady-state simulations, VTT's optimization tools for Power-2-X Optimization and Power System Forecasts 2025-30:

- Cost estimates range from 2400 – 9 600 €/ton RFNBO-eKerosene, depend on
  - optimal unit dimensioning of the plant (electrolysers, H_2 storage, compressors etc)
  - optimal long term contracting of renewable power
  - optimal long term and intraday power trading strategy
  - Rules applied from the Delegated 2/2023: prior 2030 (montly correlation to RE) or after 2030 (hourly correlation to RE) .

- Specific GHG-emissions 9-12 gCO_2eqv/MJ RFNBO-eKerosene
  - which is a **reduction of 87-90% in GHG-emissions**

(fossil kerosene is ~94 gCO_2eqv/MJ)

E-fuel WP8: Management, collaboration and dissemination

Toni Pikkarainen

Dissemination 2021 – main activities

In chronological order

- 8.2.2021 Press release: VTT, Neste and their partners seek breakthrough in Finnish e-fuel technology
- 04/2021 Dissemination plan and up-dated throughout the project.
- 7.4.2021 blog by Taneli Fabritius and Janne Kärki: Electrofuels and P2Chemicals are emerging – How to renew the world's oil refineries and petrochemical industry?
- 26.4.2021 blog by Juha Lehtonen and Janne Kärki: New products from carbon dioxide and hydrogen – when and how?
- 27.4.2021 E-fuel project webinar, promoted in Transdigi network and in social media.
- 6.5.2021 Leevi Levo B.Eng Thesis "Hiilivetyjen reformointi sähköreaktorissa".
- 08/2021 article in Baltic Transport Journal 3-4/21: SUSTAINABILITY – One piece at a time. Renewing the world's oil refineries and petrochemical industry with electrofuels and P2Chemicals
- 14.9.2021 conference presentation at Future Energy Solutions by Juha Lehtonen (VTT) and Ville Saarinen (VTT): Production of synthetic fuels with FT-synthesis and high temperature electrolysis
- 11/2021 MSc Thesis by Mohankumar Narayanasamy: Mass transfer efficiency for CO_2 capture using soda solutions

Dissemination 2022 – main activities

In chronological order

- 10.-11.2.2022 KEROGREEN Winter School, organized together with KEROGREEN, BECCU and EERA Joint Programme Energy Storage
- 15.6.2022 E-Fuel mid-term workshop and launch of E-Fuel concept video for dissemination purposes
- 22.6.2022 Press release: VTT ja Neste rakentavat power-to-liquids -demonstraatioympäristön hiilidioksidin talteenottoon sekä vihreän vedyn ja sähköpolttoaineiden tuotantoon
- 06/2022 participation in Advanced Motor Fuels Technology Collaboration Programme AMF TCP
- 11.8.2022 article in Physical Chemistry Chemical Physics: Modelling atomic layer deposition overcoating formation on a porous heterogeneous catalyst
- 22.9.2022 Collaboration with Technology Collaboration Programme on Advanced Motor Fuels (AMF TCP) was started and the 1st Workshop included presentation by Juha Lehtonen about E-fuel
- 6.10.2022 blog by Tuula Kajolinna: Novel, eco-friendly technology to capture CO_2
- 6.10.2022 "Change journey" event with Neste Veturi, E-fuel present with roll-up and slides
- 15.11.2022 participation in Neste Innovation Fair Veturi Stands, E-fuel present with roll-up and slides

Dissemination 2023 – main activities

In chronological order

- 30.1.2023 VTT News by Päivi Aakko-Saksa: Reducing greenhouse gas and other emissions from ship engines: Current trends and future options
- 1.3.2023 article in HS Tiede: Synteettiset polttoaineet etenevät – myös Suomi voi kohta tehdä bensiiniä ja dieseliä vihreällä sähköllä
- 04/2023 article in ECS Transactions: Integration of Reversible Solid Oxide Electrolysis (rSOC) to Wastewater Treatment Plants for Sustainable Green Gas Production and Balancing of Green Power
- 25.5.2023 Press release: Production of electrofuels from green hydrogen and captured carbon is demonstrated at VTT Bioruukki
- 25.5.2023 E-fuel demonstration opening event with about 50 invited participants and media
- 28.6.2023 article in SAE Technical Paper: Electrofuel Concept of Diesel and Oxygenate Fuels Reduces Engine-Out Emissions
- 21.11.2023 E-fuel test campaign media event
- 21.11.2023 Press release: Electrofuel developed from green hydrogen and carbon dioxide to be tested in practice for the first time
  - Editorial media total hits 62, total reach 15.1 M, international hits 31 and international reach 12.1 M
- 17.1.2024 E-fuel final seminar, about 50 invited participants, launch of 2nd E-fuel promotion video

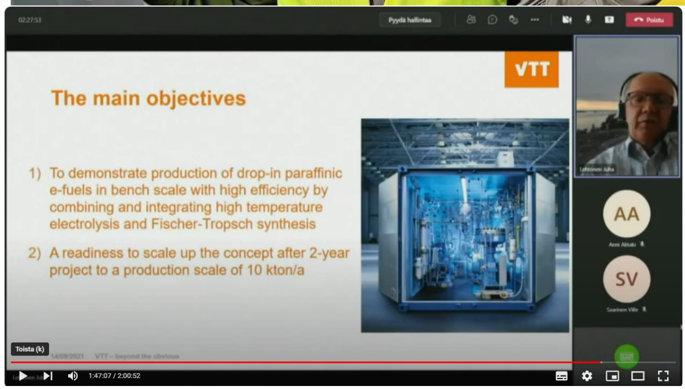
Dissemination after end of project

- "FT crude production from CO_2 using a bench-scale two-step CPOx/rWGS-FT process" to be presented in 15th European Congress on Catalysis
- "Electrofuel concept of diesel and oxygenate fuels reduces engine-out emissions" to be presented in 16th International Conference on Engines & Vehicles for Sustainable Transport
- "Integration of Reversible Solid Oxide Electrolysis (rSOC) to Wastewater Treatment Plants for Sustainable Green Gas Production and Balancing" to be presented in 243rd ECS Meeting, with the 18th International Symposium on Solid Oxide Fuel Cells
- "Reduced particle emissions from paraffinic diesel blended with polyoxymethylene dimethyl ether" to be presented in 26th ETH Nanoparticles Conference
- "Development and Demonstration of Efficient Fischer-Tropsch E-fuel Concept" to be presented in 20th International Conference on Carbon Dioxide Utilization.

Some media/dissemination examples

Electrofuel developed from green hydrogen and carbon dioxide to be tested in practice for the first time

News, Press release 21.11.2023 09:00 EET



Synteettiset polttoaineet etenevät – myös Suomi voi kohta tehdä bensiiniä ja dieseliä vihreällä sähköllä

Saksalainen autovalmistaja Porsche on jo kokeillut tekemäänsä polttoainetta Chilessä. Suomessa on suunnitteilla synteettisten polttoaineiden tuotantolaitoksia.

Teknologian tutkimuskeskus VTT:n tutkija Christian Frilund koelaitteiden kimpussa

AUTOT

Litra löpöä 120 000 eurolla – hinta on mieletön, mutta kyse on lopulta ihan jostain muusta

Suomessa kehitettyä sähköpolttoainetta kokeiltiin ensi kertaa traktorissa. Bensaversio tulossa henkilöautoihin jo tällä vuosikymmenellä.

Kolmen vuoden projekti on maalissa. On siis hyvä syy kokoontua ryhmäkuvaan. KUVA: KALLE PARKKINEN

Press releases, articles and blogs

Press releases, blogs, presentations and webinars

- https://www.vttresearch.com/en/news-and-ideas/vtt-neste-and-their-partners-seek-breakthrough-finnish-e-fuel-technology
- https://www.youtube.com/watch?v=8HETEwGbHd8
- https://www.vttresearch.com/en/news-and-ideas/electrofuels-and-p2chemicals-are-emerging-how-renew-worlds-oil-refineries-and
- https://www.vttresearch.com/en/news-and-ideas/new-products-carbon-dioxide-and-hydrogen-when-and-how
- https://www.vttresearch.com/fi/uutiset-ja-tarinat/vtt-ja-neste-rakentavat-power-liquids-demonstraatioympariston-hiilidioksidin
- https://www.vttresearch.com/en/news-and-ideas/novel-eco-friendly-technology-capture-co2
- https://www.vttresearch.com/en/news-and-ideas/reducing-greenhouse-gas-and-other-emissions-ship-engines-current-trends-and-future
- https://www.vttresearch.com/en/news-and-ideas/production-electrofuels-green-hydrogen-and-captured-carbon-demonstrated-vtt
- https://www.vttresearch.com/en/news-and-ideas/electrofuel-developed-green-hydrogen-and-carbon-dioxide-be-tested-practice-first

Articles and theses

- https://baltictransportjournal.com/index.php?id=1827
- https://www.theseus.fi/handle/10024/496560
- https://lutpub.lut.fi/handle/10024/163424
- https://pubs.rsc.org/en/content/articlelanding/2022/CP/D2CP02491H
- https://www.hs.fi/tiede/art-2000009314878.html
- https://iopscience.iop.org/article/10.1149/11106.1639ecst
- https://www.sae.org/publications/technical-papers/content/2023-24-0090/

Thank you for reading E-fuel final report!

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the obvious

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