FUEL FOR THE FUTURE

The vision of CESTAP is to transform the aviation and power generation sectors to run continuous combustion engines on 100% sustainable turbine fuels by 2045.

ANNUAL REPORT 2024

CESTAP

Competence cEnter in Sustainable Turbine fuels for Aviation and Power

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CESTAP (Kompetenscentrum för hållbara turbinbränslen för luftfart och kraft-produktion)	
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Nyckelord: 5-7 st Biofuel; gas turbine; jet engine; sustainable aviation fuels; lignocellulose; sus-tainability analysis, experiments, numerical simulations	

Preface

In its third year, the CESTAP initiative is accelerating efforts to transform the aviation and power generation sectors by enabling jet engines and gas turbines to run on sustainable fuels. PhD students involved in the program are now two years into their research and have successfully achieved key milestones in their projects. Progress is further driven by close collaboration with other projects.

This report provides a brief overview of key activities and outcomes from the technical Work Packages (WP) during 2024. For a more detailed account, refer to the main section of this report, titled “Progress and Results”, as well as the published reports and publications listed at the end of this report. In general, 2024 has been a very productive year for CESTAP with several important milstones reached and several key publications in print, accepted, and submitted.

The combined virtual and physical pre-certification combustion test bed developed in WP1 have reached production status. All but one test rig (the DESS combustion rig which is expected to be commissioned during 2025) is operational and experimental data for fuels are generated. The numerical combustion modeling is operational, and fuels tested here are typically characterized by their liquid properties and

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chemical composition. Modeling of chemical kinetics has during 2024 become sufficiently mature to deal with most fuel compositions, with only some fine-tuning to perform and fuel typologies remaining to be tested.

The development of turbine fuels from sustainable lignocellulosic residue feedstocks in WP2 advanced significantly in 2024. The first fuel sample made entirely from wood residues via pyrolysis and slurry hydrotreatment was delivered in liter quantities. Organosolv lignin, produced through an optimized solvent-based extraction process using renewable gamma-valerolactone (GVL), is now available for CESTAP project partners to use as a starting material. This lignin will be used to manufacture fuel samples in liter quantities during 2025 as part of collaborations within WP2. Regarding fuel production from pyrolysis oil and lignin via slurry hydroprocessing, the first SAF sample is ready for testing, with three to five additional samples planned for 2025 and 2026. Work on a novel process and catalyst for converting alcohols to turbine fuel components focuses on redesigning the zeolite catalyst to achieve a complete jet fuel molecular composition. Catalyst design and characterization efforts – covering both hydrotreatment and zeolite catalysts – continue to understand their operation, robustness for continuous use, and catalytic reaction mechanisms.

The work on mutual adaptation of turbine fuel and engine technology in WP3 is progressing with further insights being obtained into the combustion process of both stationary and aviation gas turbines. Detailed numerical fuel and combustor studies have been made that will provide insights into possible ways of modifying combustor components in order to improve their fuel flexibility.

WP4 Material science focuses on fuel lubrication, fuel soft material interaction and deposits and corrosion possibly caused by fuel combustion. The lubrication task is delayed but is planned to catch up during 2025-2026. The soft material interaction test is progressing well with a number of important test results presented during the first half of 2024. Improved testing methodology to rapidly and cost-effectively characterize engine system soft material (gaskets etc.) fuel interactions is in place, and will be used routinely going forward to test candidate fuels produced inside and outside CESTAP. The deposits and corrosion task is also delayed and the focus has, in dialogue with key CESTAP partner organizations, shifted towards long time storage property characterization.

The work on holistic techno-economic and sustainability analysis in WP5 is generally on track and has during 2024 delivered a review manuscript characterizing the techno-economic performance for a number of different routes/processes for the manufacture of SAF from different starting materials. Ongoing techno-economic studies are purposely aligned with the case studies being progressed in WP2, using lignin, pyrolysis oil from lignocellulosic forestry residues and methanol as starting materials. The sustainability studies of biofuel production and use are on track and partly relying on data from tests in WP1. Finally, the studies of holistic analysis of biofuel alternatives are also on track with partners delivering information about infrastructural and logistics around turbine fuel manufacture, transport/distribution and use at e.g. airports.

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Introduction and background

The world is now experiencing the effects of global warming, with temperatures exceeding pre-industrial levels by approximately 1.6°C as of 2024[1]. As the climate continues to warm, the likelihood and severity of extreme weather events are expected to increase, driven by human activities. The combustion of fossil fuels – coal, oil, and gas – remains the largest contributor to global climate change, accounting for nearly 90% of all carbon dioxide emissions and over 75% of global greenhouse gas emissions. Sectors heavily dependent on fossil fuels, such as aviation, maritime transport, and power and electricity generation, are under increasing pressure to contribute to the United Nations' Sustainable Development Goal SDG 13[2], and the Paris Agreement[3] from 2015 that commits countries to limit global warming to well below 2°C, with efforts to keep it below 1.5°C. These international frameworks emphasize the need for transformative actions across all sectors to achieve a climate-resilient development pathway.

The International Civil Aviation Organization (ICAO) has set a long-term global goal for international aviation to achieve net-zero carbon emissions by 2050[4]. While continuing to rely on hydrocarbon-based jet fuels, ICAO's approach includes pathways for progressively reducing greenhouse gas emissions through the use of Sustainable Aviation Fuels (SAF) and in the future possibly also hydrogen. The IATA Aircraft Technology Roadmap[5] outlines that SAF is essential for achieving net-zero carbon emissions by 2050. It emphasizes the need for advancements in feedstock collection, refining, and blending technologies to support the large-scale production and integration of SAF into existing and future aircraft systems. Furthermore, the destination 2050 roadmap[6] predicts a European SAF demand of 37 million tons in 2050, compared to a global production of only 1 million tons in 2024. Similarly, the International Energy Agency (IEA) has set a comprehensive roadmap to achieve net-zero emissions by 2050 for the energy sector[7]. For the power end electricity sub-sectors this includes (i) Increasing the share of renewable energy sources like solar, wind, and hydroelectric power in the energy mix; (ii) Replace the use of fossil fuels with alternatives such as ammonia, hydrogen, Hydrogenated Vegetable Oil (HVO), Rapeseed Methyl Ester (RME), and possibly also metals[8]; (iii) Implementing technologies and practices to enhance the efficiency of power plants and reduce energy losses during distribution; (iv) Upgrading the electricity grid and integrate smart grid technologies; (v) Develop and deploy energy storage systems, such as batteries, to store excess renewable energy and ensure a stable power supply; and (v) Investing in Carbon Capture and Storage (CCS): technologies to capture carbon emissions from fossil fuel-based power plants and store them underground.

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[1] https://climate.copernicus.eu/global-climate-highlights-2024
[2] https://www.un.org/en/climatechange/17-goals-to-transform-our-world
[3] Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104
[4] ICAO, 2022, "Long term global aspirational goal (LTAG) for international aviation". Available (2024-0318) https://www.icao.int/environmental-protection/Pages/LTAG.aspx.
[5] https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/aircraft-technology-net-zero-roadmap.pdf
[6] https://www.destination2050.eu/roadmap/
[7] https://www.iea.org/reports/net-zero-by-2050
[8] Bergthorson J.M. *et al*.; 2017, Applied Energy, 186, p 13.

Nationally produced fuels, derived from regionally available feedstocks, play a crucial role in enhancing local energy security and economic stability besides reducing greenhouse gas emissions. Using local feedstocks such as agricultural residues, forest biomass, and organic waste reduces dependence on imported fossil fuels, thus mitigating the risks associated with global supply chain disruptions and geopolitical tensions[9]. This localized approach to fuel production ensures a more reliable and resilient energy supply, capable of withstanding external shocks. Moreover, the development of alternative fuels from regional feedstocks stimulates local economies in the agriculture, processing, and distribution sectors[10]. It fosters innovation and investment, promoting sustainable economic growth. The circular economy model, where waste products are converted into valuable fuels, enhances resource efficiency, and reduces environmental impact[11]. By leveraging locally available feedstocks, communities can achieve greater energy independence, reduce greenhouse gas emissions, and support local economies. This strategy not only aligns with global climate goals but also strengthens the resilience of energy systems and economic structures in an increasingly uncertain world[12].

The production of SAF, HVO, RME and other sustainable turbine fuels faces significant challenges across feedstocks, production, infrastructure, and supply chains. Securing a consistent and sustainable supply of feedstocks like vegetable oils, animal fats, and waste oils is difficult due to limited availability and high costs. Technological barriers, such as the complexity and expense of chemical and biological conversion processes, hinder large-scale production. Additionally, the energy intensity of some of these process pathways can offset environmental benefits. Existing infrastructure for fuel storage, transportation, and distribution is primarily designed for conventional fuels, necessitating adaptations. Regulatory hurdles further complicate the process, particularly for SAF as it must meet very stringent aviation standards. Supply chain logistics, including the collection, transportation, and processing of diverse feedstocks, are complex and vulnerable to disruptions from geopolitical events and natural disasters. Market volatility in feedstock prices also impacts the economic viability of sustainable turbine fuels production.

Jet engines and gas turbines are essential components in the aviation and power generation sectors, both relying on the Brayton cycle[13]. This cycle involves four key processes: intake, compression, combustion, and exhaust. In both engine types, air is compressed by a rotating gas compressor, mixed with fuel in the combustor, ignited to produce high-temperature, high-pressure gases, and then expanded through a turbine to produce mechanical power[14]. Jet engines, primarily used for aircraft propulsion, generate thrust by expelling exhaust gases at high speed. They typically operate on kerosene-grade fuels like Jet A, JP5, and JP8, which are optimized for high performance and safety. Gas turbines, used in power generation and

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[9] Varalakksmi V. et al.; 2024, 2024, "Sustainable Utilization of Biomass Resources", In: Kumar S., *et al* (eds) Clean Energy Transition-via-Biomass Resource Utilization. Green Energy and Technology. Springer, Singapore.
[10] El-Araby R.; 2024, Biotechnol. Biofuels, 17, p 129.
[11] Elroi H.; et al., 2023, Front. Environ. Sci., 11, p 2023.
[12] IEA 2022, Climate Resilience for Energy Security, OECD Publishing, Paris.
[13] Cengel Y.A. & Boles M.A.; 2002, "Thermodynamics: An Engineering Approach", McGraw-Hill.
[14] Lefebvre A.H.; 1983, Gas Turbine Combustion, Hemisphere Pub. Corp., Washington, USA.

mechan-ical drive systems, produce mechanical power rather than thrust and are optimized for fuels such as natural gas, diesel, or heavier distillates. Despite their similarities, jet engines and gas turbines differ in design and application. Jet engines include turbojets, turbofans, turboprops, and turboshafts, each tailored for specific flight conditions. Gas turbines are categorized into industrial, aeroderivative, and microturbines, designed for various power outputs and operational environments.

Both engine types are sensitive to fuel variations, which can impact performance, efficiency, and emissions. Key factors include: (i) *Combustion characteristics*: Variations in the molecular composition of the fuel influences the density, viscosity, surface tension, lower heating value, volatility, laminar flame speed, flame temperature, and ignition delay time, which in turn affect the combustion stability and emission profile. Fuels with unusual combustion properties can lead to incomplete combustion, higher emissions, and reduced engine performance[15]. (ii) *Ignition and lean blowout*: The ability of an engine to ignite and maintain stable combustion is affected by the fuel properties. Fuels with atypical ignition characteristics can affect the ability of the engine to start and operate under lean conditions, potentially leading to lean blowout where the flame extinguishes[16]. (iii) *Material Compatibility*: Alternative fuels may interact differently with the engine materials, potentially causing issues such as corrosion, deposits, or material degradation. This necessitates careful selection and testing of materials to ensure long-term engine reliability[17]. (iv) *Emissions*: Fuel variations can significantly impact the levels of pollutants such as NO_X, CO_2, CO, and particulate matter[18].

As of July 2023, there are ten American Society for Testing and Materials (ASTM) approved pathways for the production of jet engine SAF[19], Table 1.

Table 1. Approved pathways for the production of SAF.

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM D7566 Annex A1	Fischer-Tropsch hydroprocessed Synthesized Paraffinic Kerosene	FT-SPK	Coal, natural gas, biomass	50%
ASTM D7566 Annex A4	Fischer-Tropsch hydroprocessed Synthesized Paraffinic Kerosene with Aromatics	FT-SKA	Coal, natural gas, biomass	50%
ASTM D1655 Annex A1	Co-Hydroprocessed Fischer-Tropsch hydrocarbons in a petroleum refinery	CO-FT-SPK	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D7566 Annex A2	Hydroprocessed Esters and Fatty Acids Synthesized Paraffinic Kerosene	HEFA-SPK	Vegetable oils, animal fats, used cooking oils	50%
ASTM D1655 Annex A1	Co-Hydroprocessed Esters and Fatty Acids in a conventional petroleum refinery	CO-HEFA-SPK	HEFA hydrocarbons co-processed with petroleum	5%
ASTM D7566 Annex A3	Hydroprocessed Fermented Sugars to Synthetic Iso-Paraffins	HFS-SIP	Sugars from biomass	10%
ASTM D7566 Annex A5	Alcohol to jet Synthetic Paraffinic Kerosene	ATJ-SPK	Ethanol, iso-butanol and iso-butene from biomass	50%
ASTM D7566 Annex A8	Synthetic Paraffinic Kerosene with Aromatics	ATJ-SKA	C2-C5 alcohols from biomass'	

[15] Burns D. & Camou A.; 2019, J. Eng. Gas Turb. Power, 141, 101006-1.
[16] Esclapez L. *et al*., 2017, Comb. Flame, 181, p 82.
[17] Mosier S.A., Pratt & Whitney, West Palm Beach FL, USA.
[18] Di Sabatino *et al*., 2025, AIAA 2025-0162.
[19] https://www.icao.int/environmental-protection/GFAAF/Pages/conversion-processes.aspx.

ASTM D7566 Annex A6	Catalytic Hydrothermolysis Synthesized Kerosene	CH-SK	Vegetable oils, animal fats, used cooking oils	50%
ASTM D7566 Annex A7	Hydrocarbon-Hydroprocessed Esters and Fatty Acids Synthesized Kerosene	HC-HEFA-SPK	Algae	10%

In addition to these ten approved pathways, there are several other pathways under evaluation[18] and development. For gas turbines, alternative fuels comprise a wider span including hydrogen[20], ammonia[21], alcohol[22], bio-syngas[23], bio-methanol[23], pyrolysis oil[24], dimethyl ether (DME)[25], and HVO[26]. Potential future fuels may also include electro fuels from CO_2 or industrial residual gases, water, and renewable electricity. Figure 1 shows schematically how the different feedstocks are converted to neat SAF for the pathways described in Table 1 before being blended with conventional Jet A to result in the drop-in SAF used. Figure 1 also includes the process pathways for HVO and RME conveniently employed for power and electricity generating gas turbines.

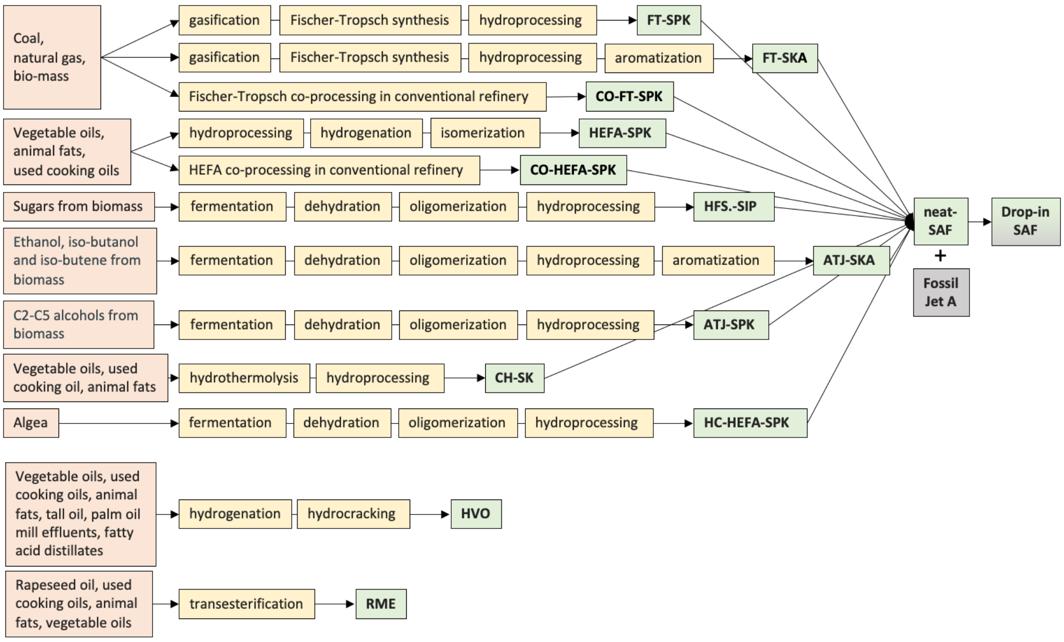


Figure 1. Schematic of fossil and alternative turbine fuel production pathways.

Alternative turbine fuels usually differ in composition compared to the fossil fuels they are to replace as they are synthetically produced. This difference in carbon chain length and chemical structure (i.e. n-, iso- and cyclo-paraffins as well as aromatics) may affect (i) materials compatibility throughout the whole fuel system, (ii) fuels miscibility, (iii) fuels toxicology, (iv) combustion stability and flame anchoring, (v) combustor liner heat loads, (vi) emissions (such as CO, CO_2, NO_X, and soot), and (vi) environmental footprint and overall climate impact. As alternative fuels are synthetically produced, the selection of the feedstock and the production

[20] Gobbato P., *et al*.; 2011, Int. J. Hydrogen Energy, 36, p 7993.
[21] Valera-Medina A., *et al*.; 2019, Int. J. Hydrogen Energy, 44, Issue 16, p 8615.
[22] Moliere M., *et al*., 2009, ASME GT2009-59047.
[23] Gupta K. K. *et al*., 2010, Renewable and Sustainable Energy Reviews, 14, 2946,
[24] Sallevelt J.L.H.P., *et al*.; 2016, Energy Conversion and Management, 127, p 504.
[25] Glaude P., *et al*., 2012, GT2011-46238, p. 649.
[26] Hui X., *et al*; 2012, Fuel, 98, p 176.

pathways becomes more complex. The first row in Figure 2 illustrates the difference in composition between Jet A and JP5 and between these fossil fuels and some selected neat SAF's, ATJ-C1 from Gevo and FT-SKA from Sasol, and a HEFA-based drop-in fuel with 34% SAF contribution. The second row in Figure 2 shows surrogate models for the fuels in first row, which are used to develop chemical reaction mechanisms using for simulating the combustion dynamics. The third row in Figure 2 shows how selected thermophysical properties, specific heat capacity, C_P, dynamic viscosity, μ, vapor pressure, p_v, and the heat of vaporization, h_v-h_l, vary with temperature, T, for selected fuels. The fourth row in Figure 2 shows how different chemical reaction mechanism families, CRECK, HyChem and ZXX, represent the laminar flame speed s_u and ignition delay time, τ_{ign}. Here, the CRECK mechanism is the most detailed, whereas the HyChem and ZXX mechanisms are appropriate for use in simulations[27].

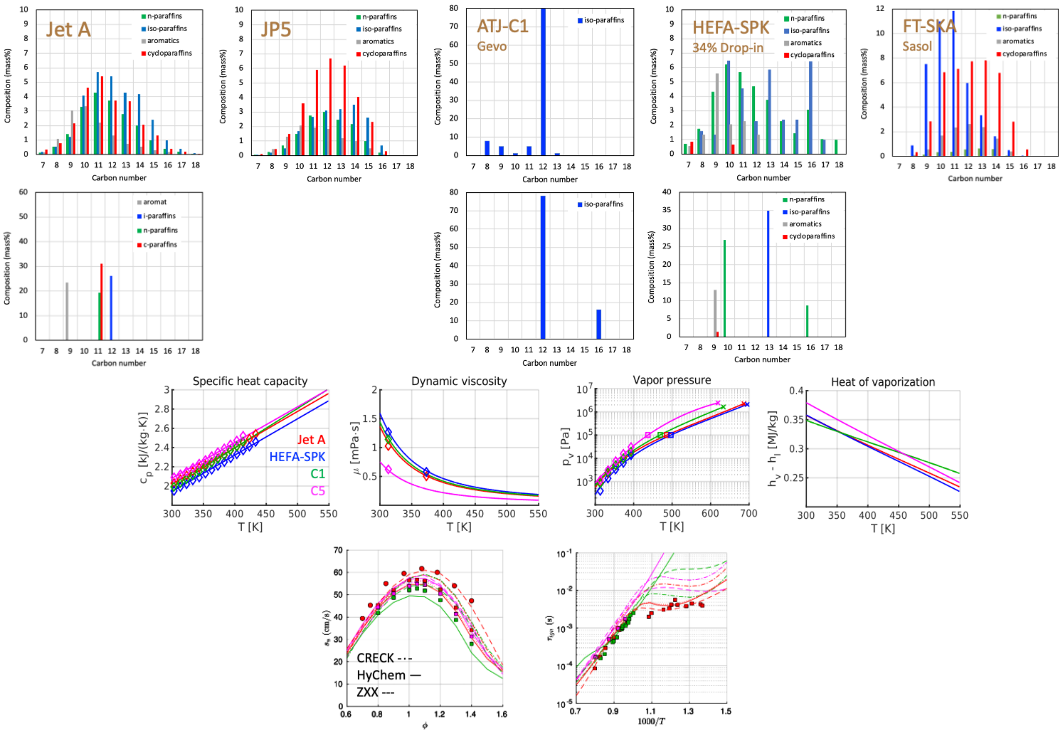


Figure 2. First row: Samples of carbon distribution plots from Jet A, JP5, ATJ-C1 (from Gevo), 34% drop-in HEFA-SPK (from a commercial manufacturer), and FT-SKA (from Sasol). Second row: Surrogate models for the fuels in the upper row. Third row: Thermophysical properties of selected liquids, and Fourth row: Combustion properties (laminar flame speed $\mathbf{s_u}$ and ignition delay time, $\boldsymbol{\tau_{ign}}$) of selected fuels.

CESTAP (Competence cEntre in Sustainable Turbine fuels for Aviation and Power) is a competence centre jointly funded by the Swedish Energy Agency, industry, and academia promoting the production and use of sustainable fuels for stationary gas turbines and aviation jet engines. The academic partners include the coordinator, Lund University (LU), Luleå Technical University (LTU), and Research Institutes of Sweden (RISE). The overall objective is to promote the development, use, and function of biofuels for gas turbines and aviation, through research in (i) biofuel development, (ii) physical and virtual testing of the biofuels, (iii) mutual adaptation

[27] Fureby C. & Hedberg M.; 2024, ISABE-2024-072, ISABE, Toulouse, France, 22-27 Sept.

of biofuel and relevant continuous combustion engine technologies, (iv) materials sciences, and (v) techno-economical and life-cycle studies.

Implementation

To meet the needs of aviation and power production industries, the aim of CESTAP is to develop knowledge and technologies for efficient, sustainable, and cost-effective turbine fuels. Figure 3 present the roadmap of CESTAP, towards our vision:

> *To transform the aviation and power generation sectors to run continuous combustion engines on 100% sustainable turbine fuels. In addition, the focus is on sustainable turbine fuels from raw material readily available in Sweden, to achieve security of supply.*

In 2024 research and development made significant strides across all five technical work packages (WP's), with detailed activities and outcomes presented in the "Progress and Results" section of this report. As anticipated, during 2024 there was a notable transition from the establishment phase to a production phase, characterized by the generation of data, fuels, results, and analysis.

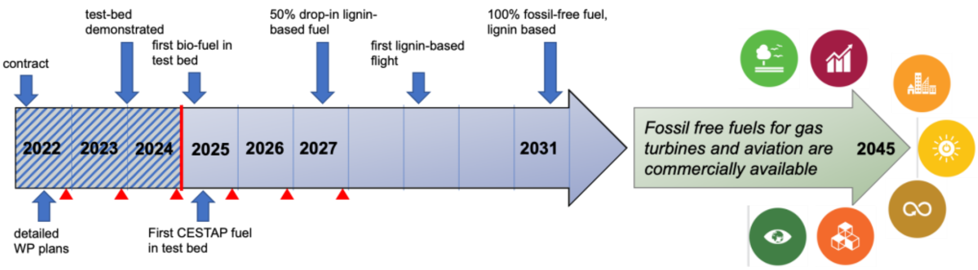


Figure 3. Schematic illustration of the roadmap and vision of CESTAP. The red line across timeline symbolizes how far into the projects we are at the writing of this report.

In its third year, CESTAP has refined its organizational structure, facilitating progress in research activities through close collaboration with industrial partners. WP leaders have consistently organized meetings with academic researchers and interested industrial partners. Approximately every two months, WP leaders convene to align activities and report progress. All CESTAP partners have gathered twice for full-day meetings featuring WP reports and presentations by selected industrial partners. The Summer Meeting focused technically on WP2, inviting all partners, while the Annual Meeting in late November covered a broader scope. As the PhD students affiliated to CESTAP has now made significant progress in their projects, they have taking leading roles in presenting research both at the internal meetings and at scientific and technical conferences. For more details on the Centre meetings see the section on WP7, Communication and Outreach. Additionally, the CESTAP Program Council met four times throughout the year to discuss organizational issues and strategic matters crucial to the Centre.

During 2023 Valmet Technologies Oy applied to join CESTAP as new partner as was informed during the GA meeting on Feb. 9 2024. A GA information/discussion meeting was set up on April 29 2024 where Valmet Technologies Oy's contribution to CESTAP was scrutinized. Following this review, a *per capsulam* voting process was arranged whereby Valmet Technologies Oy was approved as partner of CESTAP. In 2024 also the company Ecopar AB formally became a member after having been accepted by the 2023 General Assembly. During 2024 UGI International LLC have decided to leave CESTAP since they have shifted their business focus to areas outside of those of interest to CESTAP.

Progress and Results

All Work Packages (WPs) have delivered more data than during 2023 as a result of more intense research efforts during 2024. In general progress has therefore been catching up and CESTAP activities are overall well in line with the original plans for the Centre. Examples of key achievements mentioned already here are that the first internally produced fuel sample have been manufactured from pure wood residues via pyrolysis and hydrotreatment upgrading, and that key technical issues with WP1 test equipment have been resolved, achieving a powerful test bed infrastructure during 2024, for which there is significant also external interest. More details on the progress and results follow below for each respective WP.

WP1 Development and maintenance of the pre-certification test bed

Three PhD students are also during 2024 active specifically in this work-package, with the task of establishing, maintaining and operating the pre-certification test-bed. Task progression is briefly summarized in Table 2.

Table 2. Progression of tasks WP1.

Tasks of WP1	Progression (%)	Comments
Task 1: Simulation models.	90%	On track. Methodology is validated and ready for use.
Task 2: Experimental pre-certification test bed.	90%	On track except for the DESS high-pressure test rig which is planned to be operational during 2025.
Task 3: Full scale jet engine test bed.	95%	On track. Ljungbyhed jet engine lab is finalized and a few test runs have been performed on selected larger donated fuel samples.

Since the previous annual report, the following activities have been conducted.

Experimental research

Within CESTAP there is, since October 2022, one dedicated PhD student working with the experimental tasks in WP1. In addition to this, there are now several related projects on similar topics running in parallel. Since January 2024 the experimental capability in the field of sustainable aviation fuels, include one additional PhD student and one Postdoc. In July, 2024, yet one more PhD student joined the SAF activities. As a result, this brings critical mass to the experimental efforts, and all contributing researchers and projects are expected to benefit from the synergetic effects associated by these collaborations. In addition to skillful personnel, the experimental investigations require some highly unique infrastructure. A brief update on the most critical apparatus and the associated research performed, can be found in the following paragraphs.

Refurbishment of the high-pressure rig

The work on bringing the large high-pressure combustion facility back in operation has seen some great progress in 2024. The electric air pre-heater has returned from the manufacturer where it has undergone thorough refurbishment. It is currently awaiting instrumentation and some electrical installations before being ready to be reinstalled in the pressure containing vessel, that can be seen protruding through the roof of the test facility. The need for replacing the damaged air compressor in combination with the requirement of eliminating the risk of future disturbances caused by oil in the system, resulted in a decision to go for an oil-free solution. An order for three new air compressors was placed early in 2024. Just before Christmas these compressors where delivered to the site and brought into the renovated compressor hall on the ground floor. Next step will be to conduct the installation of all the auxiliary systems. The repairs of the switchgear central are also close to being finished. This includes a new shielding wall of aluminum towards the compressor hall and a new electrical transformer that matches the compressors. In summary, the work is currently progressing in a good pace. It should be mentioned though, that although there has been great progress so far, this is the most complex collection of equipment used within the Competence Center, and there might still be hidden problems emerging as the refurbishment progress. If everything proceeds according to plan, the re-commissioning is scheduled to take place in the summer of 2025.

Figure 4. To the left the new oil-free compressors can be seen. The door to the right connects the compressor room with the switchgear. To reduce electrical interferences, the separating wall is made of seam-welded, 5 mm thick aluminum.

Laboratory-scale pressurized burner

Early in 2024 the pressurized burner, Figure 5, was run for the first time with the re-designed fuel system that allowed for pre-vaporization of liquid fuels. Essentially, these tests turned out fine. Some issues with cold-traps were identified though. Since this could potentially cause condensation of high boiling point components, the work of mitigating this problem was urgently addressed. By re-routing some of the pipe work and applying more thermal insulation in critical areas, these issues could be solved. Currently, the fuel supply system is capable of metering, vaporizing, mixing and transporting the fuel/oxidizer/buffer -gases at a preset temperature up to 230 C. This successful implementation meant that the target of commissioning the laboratory-scale HP-burner for use with aviation like fuels was now accomplished. Optical diagnostics for flame speed measurements were performed on reference fuels, starting with ethanol and n-heptane. During this work is was noticed that the frequent flame-out events that occurred when approaching the flame stability limits needed some attention. The build-in system for remote controlled ignition worked as intended, but proved to be too slow for practical operation when experiencing frequent flame-outs. The solution was to build a new burner that featured a continuously burning pilot flame.

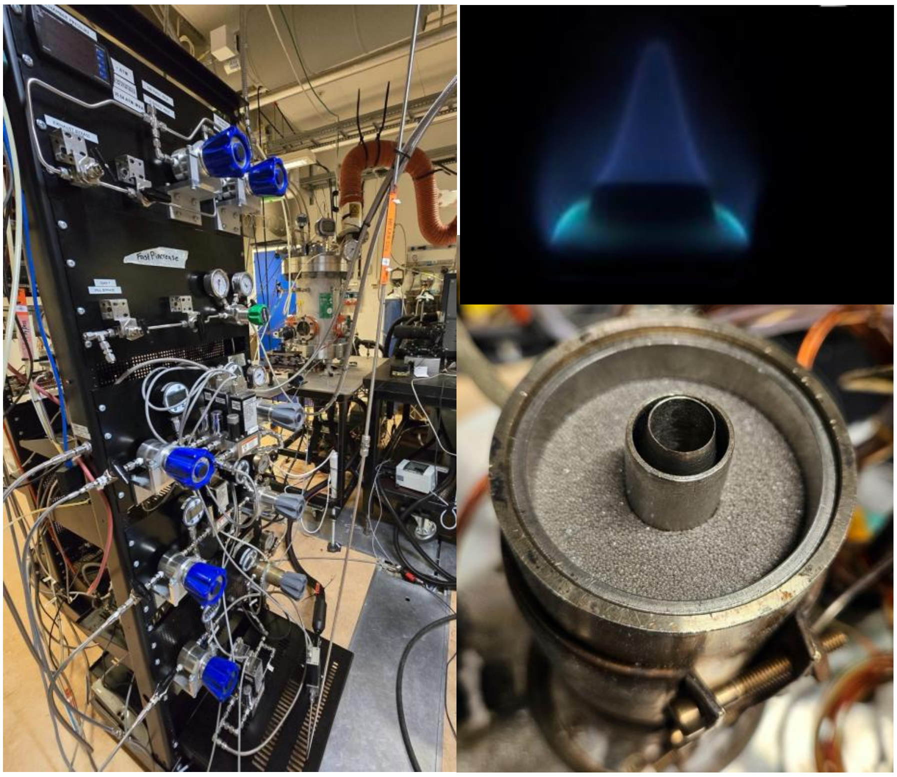


Figure 5. To the left, the laboratory-scale high-pressure vessel seen together with some of the pressure governing units. The lower right picture shows the new burner design that features a continuously burning pilot-flame. The bi-annular pipes in the center holds the conical flame used for measurements and the surrounding pilot-flame, whereas the sintered large-diameter plug provides a protective co-flow. In the upper right corner, is a picture showing the conical flame and the pilot-flame.

After these additional modifications, the lab-scale HP-burner is now operational. Flame speed measurements based on flame cone angle determination from chemiluminescence imaging have been successfully performed for reference fuels, including Jet-A1. Examples of measured flame speeds can be seen in Figure 6. Recently the measurement technique was changed to planar laser induced fluorescence imaging of OH-radicals. Measurements on novel sustainable turbine fuel candidates, using this more precis method, are now ongoing.

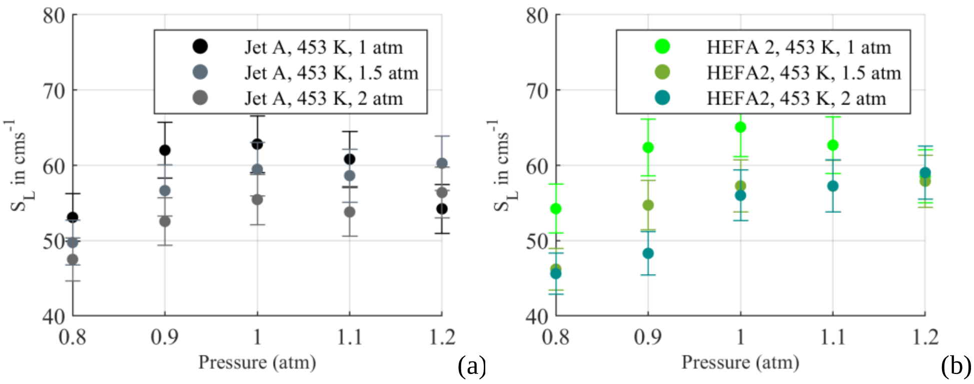


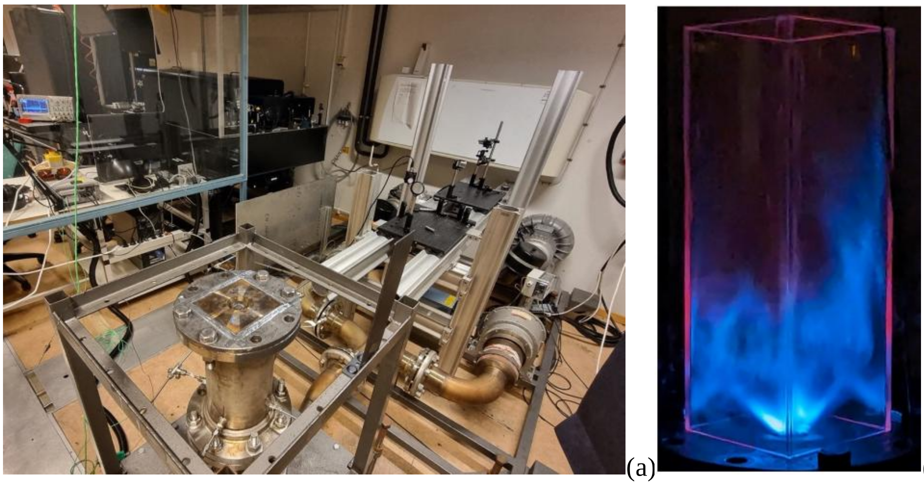
Figure 6. Plots showing measured laminar flame speed, S_L, for Jet-A1 together with a neat HEFA-based SAF supplied by Tosoe A/S at different pressures.

Atmospheric combustion test facility

The third experimental facility is the atmospheric combustion rig, Figure 7. A system with low pressure compressors and electric heaters is configured to provide pre-heated air (~800 K) to the burner section. In CESTAP, two different burner configurations can be employed. One is the CECOST burner which is designed to replicate the flow and flame structures in a Siemens Dry Low Emission (DLE) combustor. The other configuration is the Triple Annular Research (TARS) burner which is designed to mimic an aviation jet engine fuel combustor. Both combustors have been used before, but only with gaseous fuels.

The work of establishing a liquid fuel supply system was initiated at an early stage and the first iteration of this system was tested during the spring of 2024. These tests indicated problems with oscillating and unstable heat-release rate. The origin of the oscillations was tracked back to the high-pressure dosing pump. After consulting both the supplier and the manufacturer, it was concluded that the stringent requirement for a pulsation free fuel supply, made it infeasible to proceed with this pump technology. A new fuel system with separate pressurization and metering was designed, put together and tested. This new approach proved to have mitigated the oscillation problems. During the downtime, overall improvements to the test facility, such as installing rigid optical table tops around the burner and adding a stable platform for housing of laser equipment, was realized in parallel.

In conclusion, also the atmospheric combustion test facility is now operational and ready for fuel characterization experiments. Exhaust gas emission measurements and high-speed chemiluminescence imaging of the flame structures, when operating on a SAF candidate and reference fuel, are scheduled for early 2025.



(a) (b)

Figure 7. Panel (a) shows the air supply system with compressors and heaters, that is used to feed the CECOST-burner or the TARS-burner with pre-heated air. In the background the laser system for exciting OH radicals can be seen. Panel (b) shows a chemiluminescence image of the TARS-flame when operating on ethanol in a full quartz optical liner.

Jet-engine test facility

The work of setting up the jet engine test facility at the school of aviation in Ljungbyhed started from scratch when CESTAP was initiated. 2023 was very productive in establishing the main infrastructure. In this phase, the engine got installed in a bespoke frame, a bellmouth was manufactured and mounted. Linkage between the engine and the control room was arranged and a fuel tank/supply system was put in place. The lab building was purpose built for testing aviation engines while being mounted in the aircraft. This meant that necessary infrastructure such as air intake and exhaust ports were already in place. Altogether, this resulted in a swift establishment and a successful start-up and test run in early 2024. The last year (2024) has been spent addressing aspects related to legal and safety requirements. A new fire alarm system has been installed along with a warning system for combustible gases. The pre-existing fixed installation, foam based, fire suppression system has been complemented with mobile units. New emergency exit doors have been added. Heaters for keeping the room temperature at reasonable levels from a working environment perspective was also installed. Approved and certified steel containers, for outdoor fuel storage, have been acquired and installed. Safety regulations called for modification of the fuel storage and supply system. The previous design where the fuel was gravity fed to the engine had to be replaced. A new fire-proof storage unit, with room for two different fuels, was built close to the engine. A low-pressure fuel feeding pump has been installed between the tank and the engine mounted pump. The earlier exhaust evacuation pipe has recently been replaced by a larger diameter pipe, typically three times the diameter of the engine outlet nozzle.

Figure 8. The turbo-fan engine mounted in the test rig. On the left wall the new gas supply system for calibrations gases can be seen. The exhaust pipe dimeter has been significantly increased compared to the first iteration.

To provide the required measurement capabilities, the following areas have been addressed. To assure accurate emission measurements, the gas sampling equipment was thoroughly serviced on site by the manufacturer. Safe storage for the calibration gas bottles was arranged outdoors. Since there are more than ten different gases needed for the operation of the emission measurements system, an extensive pipe arrangement, guiding the gases from the outdoor storage to the instruments, had to be installed, Figure 8. Apparatus for measuring particulate matter was added to the setup. The engine frame is designed to measure thrust through two load cells, one on each side of the frame. These load cells were calibrated by an external company before the first operational engine test was initiated. To facilitate probing of the total airflow through the engine, the bellmouth was equipped with pressure bleed-off holes at four locations.

In December of 2024, Jet-A1 and neat HEFA-based SAF from St1 was delivered to Ljungbyhed, Figure 9. In January the first operational engine test runs were successfully performed. The neat SAF component delivered was approved as an aviation fuel for blends up to 50% with Jet-A1. Since these tests were performed in an aviation jet engine mounted in a test stand, it was decided to test three blends; 100% Jet-A1, 50% Jet-A1 and 50% neat HEFA-based SAF, and 25% Jet-A1 and 75% neat HEFA-based SAF, the latter composition outside of the certification range. As for all experimental activities, the first operational test was not expected to be without some technical issues. Still, the measurements of the gaseous exhaust emissions turned out to be very stable and repeatable in this first run. For the particulate matter probing there was some issues with exceeding the maximum sampling pressure that needs to be addressed before the next test, planned early 2025.

(a) (b) (c)

Figure 9. Panel (a) shows the new fire proofed storage for the fuel used during testing. In the picture, mixing of Jet-A1 and a HEFA-based neat SAF from St1 is ongoing. Panel (b) shows he outdoor fuel storage containers. Panel (c) shows fuel delivery from St1. Both the reference Jet-A1 fuel and the neat HEFA-based SAF was delivered in December 2024, just before the first operational engine test run and emission measurements.

As an example from the jet engine testing Figure 10 shows emission indices, $EI_X = m_X\ [g]/m_{fuel}\ [kg]$, where m_X is the mass of species and m_{fuel} and is the mass of fuel, of CO and NO_X from the three fuel blends with increasing neat SAF fractions, i.e. 100% Jet-A1, 50% Jet-A1 and 50% HEFA-based SAF, and 25% Jet-A1 and 75% HEFA-based SAF, at four different engine loads 'Idle', 'Climb', 'Cruise' and 'Take-off' conditions. The emission results follow the expected pattern with decreasing $EI_{CO}$and increasing EI_{NOX} for increasing engine power, with the low EI_{CO} and high EI_{NOX} at 'Take-off' suggesting almost complete combustion at full load. We also find very similar EI_{CO} and EI_{NOX} values for the three fuel blends, suggesting that the HEFA-based fuel from St1 is very close to being "fossil identical", i.e.

having the same combustion performance as the fossil fuel it is intended to replace. The slightly lower EI_{NOX} at ‘Take-off’ condiditions for the HEFA-blends may suggest a marginally lower flame temperature.

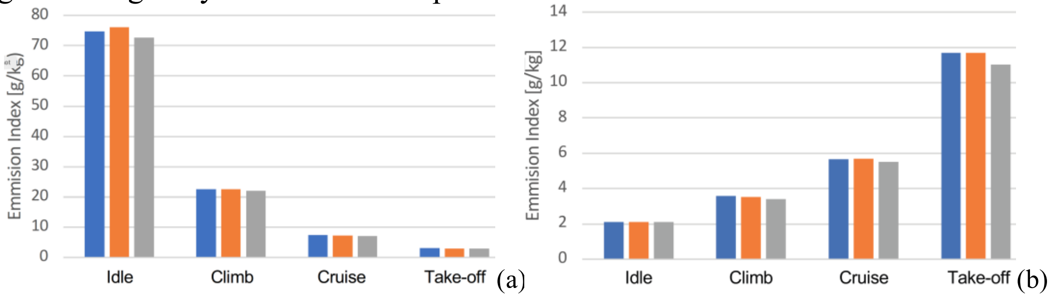


Figure 10. (a) CO and (b) NO_X emission indicies (g/kg fuel) from the jet engine testing for ‘Idle’, ‘Climb’, ‘Cruise’ and ‘Take-off’ conditions for three fuel blends with increasing neat SAF fractions, i.e. 100% Jet-A1 (—), 50% Jet-A1 and 50% HEFA (—), and 25% Jet-A1 and 75% HEFA (—).

In summary, the jet-engine test facility is up and running. Emission data has successfully been collected under various engine loads. The next step will include the following upgrades: Improvement of the thrust measurements, through new load sensors. Addition of a precise fuel flow metering system. Adding a dedicated system for the intake air flow/pressure measurements.

Spray test facility

The high-pressure spray rig at RISE in Piteå, is operational, Figure 11. The diagnostics used for spray characterization will include laser-based measurement techniques. The test rig operates with an atmosphere of pressurized nitrogen gas. The available ambient pressure range is 0 to 10 bar, while the fuel injection pressure can reach around 150 bar. The first fuel spray characterization on SAF, using laser diagnostics, is scheduled for early 2025. In this study, Phase Doppler Anemometry (PDA) will be combined with Structured Laser Illumination Planar Imaging (SLIPI) to investigate droplet break-up and size distribution for different fuels, nozzles and operating conditions.

Figure 11. Inside view of the pressurized spray chamber at RISE in Piteå. The green light originates from a horizontal laser sheet (PDA measurements).

Chemical kinetics studies

Reduced chemical kinetic mechanisms are crucial for computational fluid dynamics (CFD) simulations of continuous combustion engine combustion. While full chemical models provide high accuracy, their complexity makes them computationally expensive. Reduced mechanisms simplify these models by minimizing the number of species and reactions while maintaining key combustion characteristics such as ignition delay and flame speed. This balance between efficiency and fidelity enables CFD to support engine design and optimization.

The work on chemical kinetics is performed in collaboration between researchers at Combustion Physics (LTH) and Niklas Zettervall at FOI, in close connection to the CFD group at Department of Energy Sciences (LTH). The CESTAP funded work is performed in close collaboration with the project "Combustion characteristics of aviation biofuels" funded by the Swedish Energy Agency 2020-2025.

An outline of the research methodology in the performed and ongoing work is given in Figure 12. The left-hand side of the figure represent the early stages with collection of data and reference simulations, while the right-hand side represent the current phase of development of compact chemical mechanisms. The middle "Analys" part of the figure represent continuously ongoing fundamental studies that provide the scientific foundation for accurate mechanism development and validation.

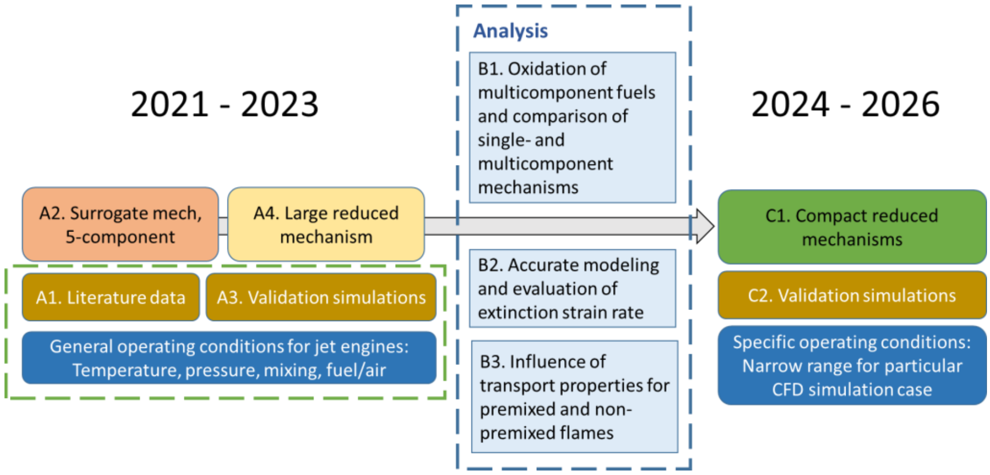


Figure 12. Outline of the mechanism development strategy and research targets. A, B and C represent sub-projects.

The fuels targeted in CESTAP are heavy biofuels for jet engine and gas turbine combustion, but must also include the fossil fuels since their properties are the target properties for the novel fuels. Heavy fuel combustion kinetics are particularly complex due to the variety and size of hydrocarbon molecules. Reduced mechanisms often rely on single-component surrogate fuels, such as HyChem[28] and Zettervall's compact single-component mechanisms[29], which approximate the overall combustion behavior of jet fuel. These mechanisms capture global combustion properties well and have been implemented in the majority of the CFD simulations in CESTAP, with excellent results. However, they may fail to reproduce the distributed reaction sequences of multi-component fuel mixtures, especially those containing both fast-reacting n-alkanes and slower-reacting aromatics. Therefore, an important work is to develop and validate compact multi-component mechanisms for heavy fuels.

To improve flame structure accuracy, multi-component mechanisms incorporating n- and iso-alkanes, cycloalkanes, and aromatics are advantageous. A milestone in CESTAP in 2024, addressing target C in Figure 12, was the introduction of a highly compact multi-component mechanism, including seven fuel components and only 153 reactions, offering a balance between detailed chemistry and computational efficiency.[30] Following this work the research group has started a sub-project on the

[28] https://web.stanford.edu/group/haiwanglab/HyChem/pages/Home.html
[29] Methodology for developing reduced reaction mechanisms, and their use in combustion simulations, N. Zettervall, Lund University PhD thesis 2021
[30] Zettervall N. and Nilsson E.J.K., under review for publication in ACS Omega.

detailed analysis and validation of multi-component mechanisms in relation to single-component mechanisms, target B1 in Figure 12.

In 2024 the research has progressed significantly on targets B2 and B3 on analysis of the chemistry and transport properties of relevance for extinction strain rate. There are two main goals with this work, to get accurate transport properties for use in detailed chemistry, and to understand which chemistry is needed in the reduced representations. Regarding transport properties an in-depth analysis has been performed for the smaller hydrocarbon n-heptane[31], and based on that work on dodecane and several cyclic compounds have been initiated.

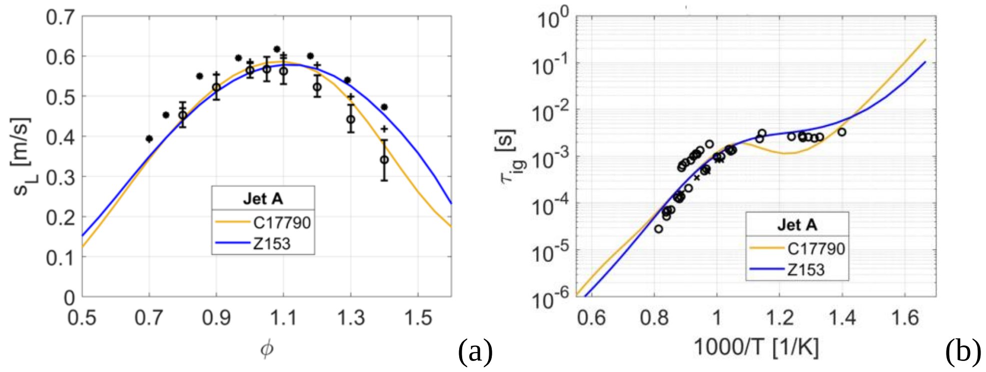


Figure 13. Laminar flame speed (a) and (b) ignition delay time for Jet A simulated with the CESTAP heavy fuel reduced mechanism Z153 and the complex CRECK mechanism.

Computational Fluid Dynamics (CFD) studies

Computational Fluid Dynamics (CFD) is crucial in studying combustion processes in gas turbine engines, allowing for the simulation and analysis of complex fluid flows and chemical reactions. CFD provides detailed insights into the spray distribution, including droplet size distribution, evaporation rates, and fuel-air mixing, which are essential for understanding how the liquid properties of the fuel influence the spray and hence the downstream combustion events. It also enables the simulation of flame stabilization mechanisms, such as swirl-induced recirculation zones and bluff-body stabilization, helping to identify optimal conditions for stable flame anchoring and preventing issues like flame blowout or flashback. Additionally, it also determines the heat load of various combustor components as well as the flow split between the core flow and the cooling flows. CFD models turbulent combustion by incorporating advanced turbulence, turbulence chemistry interaction and radiation models, allowing us to study the effects of fuel properties on flame structure, heat release rates, and pollutant formation. A key enabler for successful combustion CFD is to use sufficiently accurate chemical kinetics reaction mechanisms as previously elaborated on. The ability to simulate and analyze combustion in a virtual environment allows researchers to gain insights that are often difficult or impossible to obtain through experimental methods alone.

Previously in CESTAP we have worked on validating a high-fidelity Large Eddy Simulation (LES) model and understanding how different pre-vaporized fuels such as ethanol (C_2H_5OH), n-heptane (C_7H_{16}), Jet A ($C_{11}H_{22}$), JP5 ($C_{12}H_{23}$), a typical Alcohol-to-Jet fuel C1 ($C_{13}H_{28}$)[32], and a laboratory test fuel with flat boiling curve

[31] Passad M. and Nilsson E.J.K, under review for publication in Combustion and Flame.
[32] Edwards J.T.; 2017, AIAA 2017-0146.

C5 ($C_{10}H_{19}$) anchor and burn downstream of an axisymmetric bluff-body in the Cam-bridge burner[33,34]. Very good agreement between the experimental data[33] and the LES predictions[34] were obtained, indicating that both the LES model and the different chemical reaction mechanisms are reliable, and work as intended. Both reaction mechanisms from the HyChem[35-36], and Zettervall *et al.*[37-38], families of reaction mechanisms were successfully tested. The same LES methodology and chemical reaction mechanism were then used to simulate Jet A combustion in the single cup TIMECOP combustor[39-40], for which experimental data is available for Jet A combustion at ‘idle’ and ‘cruise’ conditions. This work provides further validation of the LES model and the HyChem and Zettervall *et al* families of reaction mechanisms for Jet A, and provide detailed information about how the spray distribution, flame stabilization and thermoacoustics are influenced by the fuel combustion.

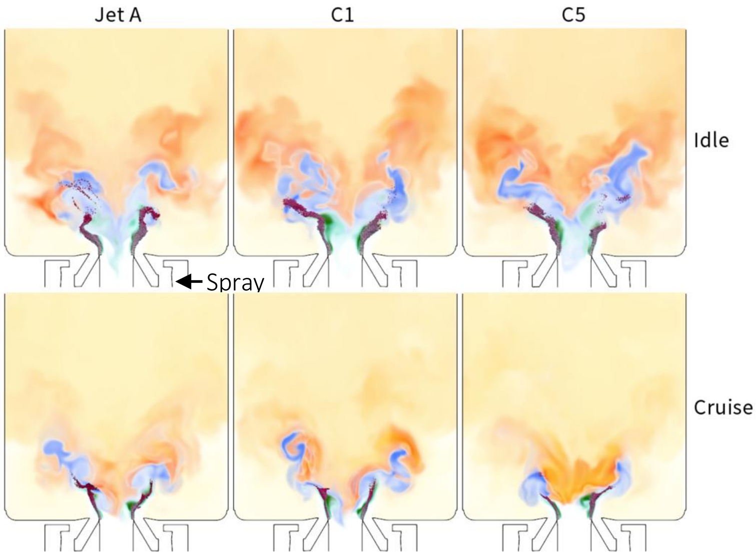


Figure 14. Instantaneous cross sections of the spray (magenta, colored by the droplet temperature) and important gaseous species including the fuel species (green), decomposition products ethylene and iso-butene (blue), OH (red), and CO_2 (yellow).

During 2024 we have continued investigating the single cup TIMECOP combustor[39] with the objectives of understanding the influence of the fuel on the spray distribution, vaporization process, and on the subsequent turbulent combustion process[41], figure 1. We found that at idle conditions, all fuels show similar spray and flame structures. At cruise conditions, Jet A produced a more lifted flame due to its liquid thermodynamic properties, while C5 atomized and vaporized easier. C5 produces the most ethylene, a soot precursor, followed by Jet A, with C1 producing the least. C1 decomposes into iso-butene, leading to different chemical pathways and more OH in the post-flame zone. C5 generates slightly less NO_X due to its slightly

[33] Pathania R.S., Skiba A.W. & Mastorakos E.; 2021, Comb. Flame, 227, p. 428.
[34] Åkerblom A. & Fureby C.; 2025, Comb. Flame, 272, p 113895
[35] Xu R., *et al.*; 2018, Comb. Flame, 193, p. 520.
[36] Wang K., *et al.*.; 2018, Comb. Flame, 198, p 477.
[37] Zettervall, N., Fureby C. & Nilsson E.J.K, 2016, Energy & Fuels, 30, p 9801.
[38] Åkerblom A., Zettervall N. & Fureby C.; 2024, AIAA 2024-0179.
[39] Meier U., Heinze J., Freitag S. & Hassa, C.; 2011, J. Eng. Gas Turbines Power, 134, 031503.
[40] Åkerblom A. & Fureby C.; 2024, Flow, Turb. Comb., 112, p 557.
[41] Åkerblom A. & Fureby C.; 2024, Accepted for publication in Flow, Turb. Comb.

lower heat of combustion, while Jet A produces significantly less NO_X at cruise due to its large spray penetration depth and flame lift. All fuels exhibit similar pressure oscillations at idle, but C1 and C5 show stronger longitudinal oscillations at cruise due to higher vaporization rates.

During 2024 we have also worked with the TARS (Triple Annual Research Swirl) combustor being composed of the TARS burner, Figure 15, attached to a rectilinear combustion chamber with optical access, Figure 16. The TARS burner is a jet engine type of fuel injector, based on a design by General Electrics Aerospace Engines and Goodrich Aerospace, typically used in industrial dry low emission combustors[42]. As observed in Figure 15, this fuel injector is equipped with three concentric swirlers with adjustable vanes angles: the inner and intermediate swirlers are axial while the outer swirler is radial. The outer diameter of the TARS at the nozzle is D=50.8 mm. The TARS burner relies on a concept of variable geometry, meaning that each swirler can be mounted with different vane number, angle, and orientation: clockwise (CW) or counterclockwise (CCW). This implies that various intensities and flow directions through the different channels can be obtained. Regarding the fuel injection, the burner has eight eight ports in the outer (main) and four fuel ports in the intermediate (pilot) swirl channels. Each of the twelve fuel injection ports of the TARS burner have the same diameter d_{inj}=0.76 mm. The TARS burner has previously been successfully employed by Gutmark *et al.*[43-44] to investigate spray combustion of both ethanol and Jet A.

Figure 15. The TARS burner.

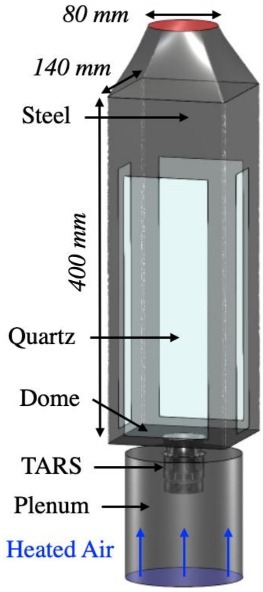


Figure 16. The TARS combustor.

Building on previous work in CESTAP and parallel work in the EU H2020 projects MORE & LESS[45], MYTHOS[46], and CIRCULAR FUELS[47] a standard Finite Rate Chemistry (FRC) Large Eddy Simulation (LES) model has been developed to meet the demands for high accuracy and versatility. In this FRC-LES model the gas phase is treated using Eulerian methods, while the spray droplets are tracked using Lagrangian particle tracking methods. Droplet dynamics include drag, evaporation, and break-up, modeled by point-parcels. Chemical reactions follow Arrhenius laws, and turbulence and turbulent combustion are captured using the Localized Dynamic K-equation Model (LDKM) and the Partially Stirred Reactor (PaSR) model, respectively. Radiative heat transfer is calculated for a gray medium using either the P1 spherical-harmonics or Discrete Ordinates Model (DOM). Skeletal or small comprehensive reaction mechanisms are required, and we often use the HyChem[35-36] or

[42] Grinstein F.F., Young T.R., Gutmark E.J., Li G., Hsiao G. & Mongia H.C.; 2002, J.Turb., 3,
[43] Li G. & Gutmark E.J.; 2004, ASME GT2004-53674.
[44] Li G. & Gutmark E.J.; 2005, Proc. Comb. Inst., 30, p 2893.
[45] https://cordis.europa.eu/project/id/101006856/results
[46] https://mythos.ruhr-uni-bochum.de/the-project/
[47] https://circularfuels.eu/

Zettervall[37-38] reaction mechanisms combined with a separate NO_X mechanism[48]. The FRC-LES model equations are solved using a semi-implicit finite-volume code based on OpenFOAM, with high-order reconstruction and a PISO scheme for pressure-velocity-density coupling. Stability is maintained with compact stencils and a Courant number below approximately 0.5.

A number of LES computations have been performed on this configuration, corresponding to the experimental investigations of the TARS combustor in the atmospheric combustion laboratory[49]. The purpose of these simulations has primarily been to investigate the effects of different fuels with respect to Jet A and the experimental data. As an example of the FRC-LES results obtained the annotated Figure 17 show instantaneous axial velocity (v_x), spray droplets colored by droplet temperature (T_d), gaseous temperature (T), and time-averaged heat release (Q) for LES of Jet A, C1, and C5 combustion using the Zettervall *et al*. Z79 chemical reaction mechanism[37-38] together with a 20 step NO_X reaction mechanism[48].

In all cases, the spray discharges from the twelve injection ports, and the droplets are rapidly entrained by the co-rotating crossflows of the intermediate and outer swirlers. The droplets follow the shear layer between the swirling air jets, forming a truncated diverging cone, wrinkled and fragmented by Kelvin-Helmholtz (KH) instabilities and shear-layer turbulence. The pre-heated air causes the spray to evaporate, creating a combustible gaseous fuel-air cloud surrounding the downstream part of the spray. The droplets appear similar for the first burner diameter, after which they gradually diminish, and the concentration of gaseous fuel increases. The axial velocity (vx) shows how the concentric swirling air jets, enclosing the spray and the gaseous fuel cloud, discharge into the combustor and break up, creating low-speed jets that discharge along the combustor wall, a Central Recirculation Zone (CRZ), an annular Outer Recirculation Zone (ORZ), and a Precessing Vortex Core (PVC). These flow features anchor the flame. The temperature (T) shows an annular, wrinkled, M-shaped flame, the inner part of which almost penetrates into the TARS burner. The flame front also coincides with the KH shear layers. Further downstream, T is homogeneous, influenced by large-scale flow dynamics and turbulence. The time-averaged heat release (Q) reveals the M-shaped flame and distinguishes between the flames from Jet A, C1, and C5.

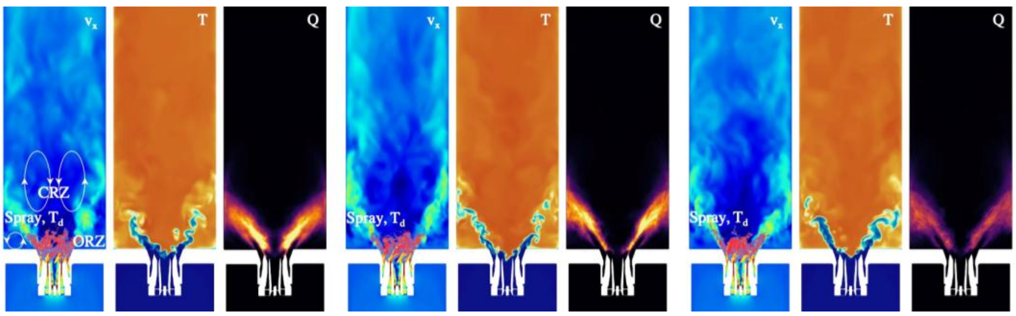


Figure 17. Instantaneous axial velocity, v_x, spray droplets colored by the droplet temperature, T_d, gaseous temperature, T, and time-averaged heat release, $\langle Q \rangle$, for LES of Jet A, C1, and C5 combustion using the Z79 chemical reaction mechanism and the 20 step NO_X mechanism.

48 Yoshikawa T. & Reitz R.D.; 2009, SAE Int. J. Engines, 1, p 1105

49 Vauquelin P., Cakir B.O., Sanned D., Prakash M., Hannappel J.-P., Subash A.A., Richter M., Bai X.-S. & Fureby C., 2025, AIAA 2025-0163.

Figure 18 presents time-averaged experimental OH chemiluminescence images for Jet A compared with LES predictions of the spray droplets colored by the droplet temperature, T_d, superimposed on the chemical heat release, Q, for Jet A, C1 and C5 using the Z79 reaction mechanism. Included are also preliminary results from a more advanced multi-species mechanism, Z153[50], for Jet A and C1. The droplet distributions highlight the temperature gradients and interactions with the heat release zones while the Q distributions illustrate the spatial and intensity variations of thermal activity across the cases. Jet A seems to have a more uniform spray distribution with cooler droplets, while C1 exhibits clustered droplets with a wider temperature range, indicating higher thermal interaction. C5 displays a dispersed spray with significant temperature variations, suggesting a more dynamic behavior. In terms of Q, Jet A has concentrated regions with moderate intensity, C1 shows broader and more intense heat release, whereas C5 presents highly variable heat release, indicating complex interactions and possibly unstable conditions. Compared to the experimental OH chemiluminescence image for Jet A the FRC-LES results show more details and flame wrinkling. The difference in spray characterizes and Q can be tied to the lower ignition delay time of C1 and the higher volatility of C5 compared to Jet A. The preliminary results for the Z153 reaction mechanism seem promising, and will facilitate a more streamlined modeling of new fuels.

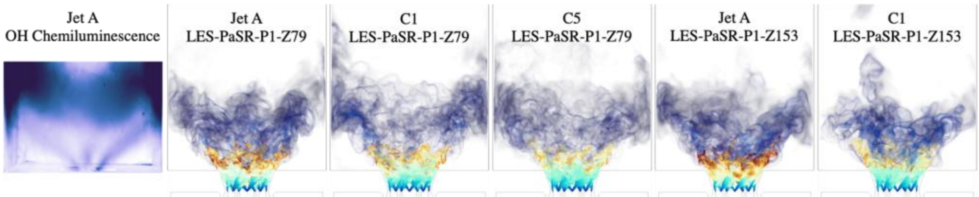
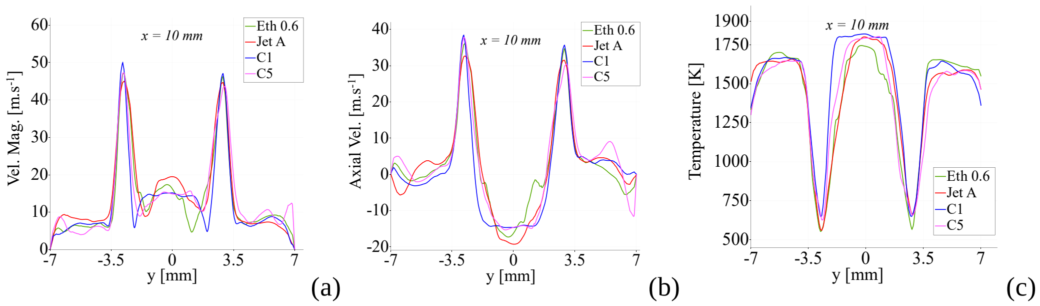


Figure 18. Time-averaged OH chemiluminescence for Jet A together with instantaneous spray droplets colored by the droplet temperature, T_d, and superimposed on the chemical heat release, Q, from the FRC-LES computations for Jet A, C1 and C5 using the Z79 reaction mechanism, and preliminary results from a more advanced multi-species mechanism Z153 for Jet A and C1.

Figure 19 helps to quantify some of the previous observations with line profiles of time-averaged velocity magnitude, $\langle|\mathbf{v}|\rangle$, axial velocity, $\langle v_x\rangle$, and temperature, $\langle T\rangle$, at x=10 mm for ethanol, Jet A, C1 and C5. In regions of low velocity, the largest time scales that are implied result in less smoothen time statistics compared to higher flow speed regions. The antisymmetric behavior could also be surpassed by enhanced temporal averaging. However, it is confirmed through 19a and 19b that ethanol and Jet A present higher absolute values of negative $\langle v_x\rangle$ in the CRZ close to the TARS nozzle in comparison to ethanol, C1 and C5. Also, the peaks of $\langle|\mathbf{v}|\rangle$ for



50 Zettervall N. & Nilsson E.J.K., under review for publication in ACSOmega.

Figure 19. Line profiles of time-averaged velocity magnitude (a), axial velocity (b) and temperature (c) at x=10 mm. Legend: Jet A (—), C1 (—), C5 (—) and ethanol (—) with the Z79 mechanism.

C1 appear as the thinnest ones relatively the y direction and reach higher values than for ethanol, Jet A and C5. This seems to correlate with a larger CRZ at the core for C1, just downstream of the TARS nozzle and it is similarly observed in figure 19b, where the high ⟨T⟩ area, i.e. the CRZ, is broader for C1 at this location.

Vauquelin *et al*[49], have also investigated the difference in pollutant formation (CO, CO_2, and NO_X) from ethanol, Jet A, C1 and C5 based on the Zettervall *et al* Z79 mechanisms[37-38] together with the 20-step NO_X mechanism[48]. Figure 20a shows similar CO trends for different fuels, with CO primarily found along the inner shear layer of the V-shaped flame, not in the ORZ. As the distance from the TARS nozzle increases, CO concentrations rise along the main flame cone and are gradually consumed further into the combustion chamber. Jet A has the lowest CO mass fractions, ethanol the highest, with C1 and C5 in between. The CO levels from C1 are closer to Jet A, while those of C5 are more similar to ethanol. Figure 20b shows that CO_2 levels start high due to hot gases from the ORC but drop as unburned air enters. The CRZ, with the highest temperatures, expands with distance from the nozzle, leading to increased CO_2-formation until around x≈0.1m, where temperatures level off. Ethanol has the lowest CO_2 proportion compared to jet fuels. Within the CRZ, Jet A has the highest CO_2 content, while C5 shows higher CO_2 concentrations downstream. C1 follows that of Jet A after x≈0.8m, with slightly lower CO_2 mass fractions. Figure 20c shows NO distributions. Ethanol displays the lowest NO values, while Jet A and C1 are at the upper end, with C5 in between. In the downstream region, Jet A has slightly higher NO values than C1. Close to the TARS nozzle, the higher NO content of C1 is likely due to higher temperatures within the CRZ. However, Jet A's similar NO levels despite slightly lower temperatures suggest that prompt NO plays a role.

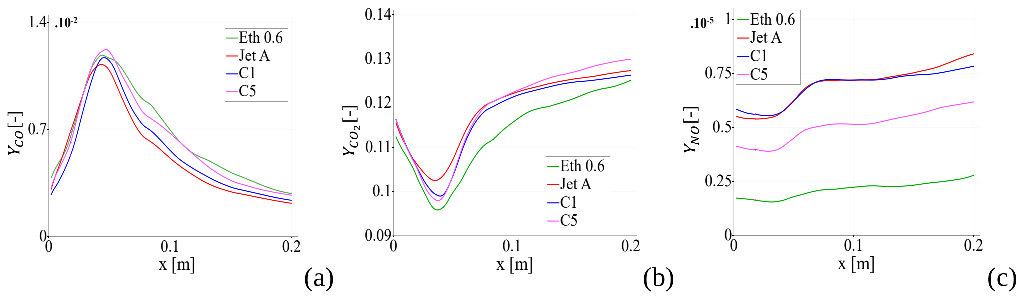


Figure 20. Planar integrations of the time-averaged mass fractions of CO_2 (a), CO (b) and NO (c) along the x axis for ethanol, Jet A, C1 and C5.

In addition, numerical simulations of an afterburner-like geometry[51,52,53], are being performed with both gaseous and liquid fuels to understand the flame stabilization mechanisms and how these change with different fuels. This work is primarily carried out in another project[54] but have significant relevance to the understanding of

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[51] Sjunnesson A., Henriksson R. & Löfström C.; 1992, AIAA -1992-3650.
[52] Paxton B.T., Fugger C.A., Tomlin A.S. & Caswell A.W., AIAA 2020-0174.
[53] Jarfors B. & Fureby C.; 2025, AIAA 2025-2488.
[54] https://defence-industry-space.ec.europa.eu/system/files/2023-01/Factsheet_EDF21_NEUMANN_0.pdf

how different jet fuels perform under different operating conditions. More specifically, based on varying the turbulence intensity and the equivalence ratio, thermo-acoustic instabilities can be observed both in the experiments and in the corresponding FRC-LES computations.

WP2 Development of turbine fuels from sustainable feedstocks including lignocellulose

WP2 is divided into four subtasks, with one PhD student affiliated with each task: Medya Hatun Tanis (Lund University, Faculty of Engineering (LTH)) to Task 2.1, Niklas Bergvall (RISE/LTH) to Task 2.2, Judith Hernandez Cabello (LTU) to Task 2.3, and Jonas Elmroth Nordlander (LTH) to Task 2.4. There is also a large industry group which currently engages actively at least 15 of the companies and other organizations of the Centre in the research and development activities. The overall progression of tasks in WP2 is presented in Table 3.

Table 3. Progression of Tasks in WP2.

Tasks WP2	Progression (%)	Comments
Task 1: Lignin abstraction and separation.	90%	On track. Gamma-valerolactone (GVL) Organosolv lignin is available for characterization and use by project partners.
Task 2: Development of a process for turbine fuel production from pyrolysis oil and lignin via slurry hydroprocessing.	65%	On track after a productive year with first samples of candidate SAF-components produced. Another important milestone is that the analytical chemistry package for sample characterization has been defined.
Task 3: Development of a novel process and catalyst for direct conversion of alcohols to turbine fuel components.	80%	On track. Further development of the zeolite catalyst and optimizing the process is ongoing.
Task 4: Catalyst characterization.	60%	The task proceeds according to plan with regards to characterization of catalysts. The plan for *in situ*-monitoring of hydroprocessing catalysts has been modified.

The different routes from lignocellulose and from methanol to candidate SAF which are the subject of research and development in WP2 of CESTAP are schematically illustrated in Figure 21. These routes can be comparted also to the classical approved routes for SAF development illustrated in Figure 1.

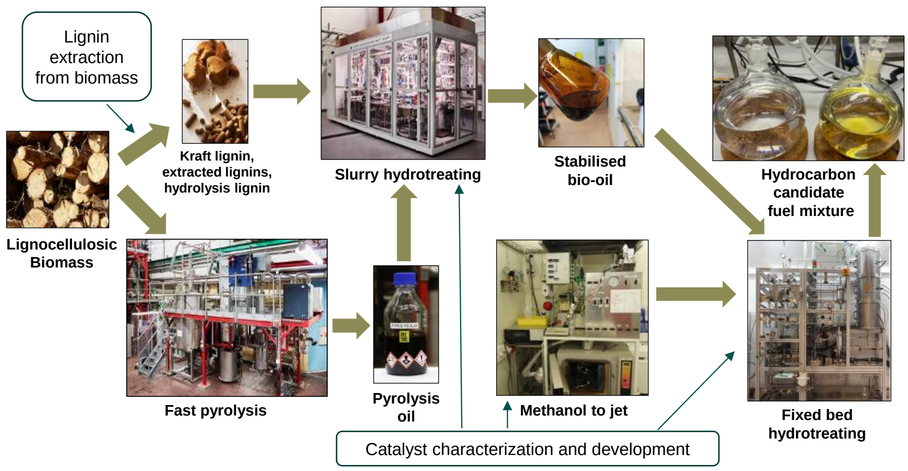

Figure 21. Schematic illustration of the different manufacturing routes from biomass and from

methanol to candidate SAF which are the subject of research and development activities in CESTAP WP2, cf. figure 1.

Task 2.1 Lignin abstraction and separation

The research performed in Task 2.1 will contribute to the area of high-purity lignins for value-added applications not "only" related to the manufacture of SAF. The research is focused on the so called Organosolv fractionation method. Organosolv-lignin is recognized for its high quality indicated by a high fraction of internal β-O-4 linkages, a low sulfur content (if performed without sulfur-containing catalysts), a relatively low molecular weight distribution, and significant amounts of phenolic and aliphatic hydroxyl groups. All these properties make organosolv lignin more suitable for high(er)-value applications. Organosolv-processes using gamma-valerolactone (GVL), a solvent manufactured from natural carbohydrates including cellulose,[55] open a new venue for fractionating lignocellulose while avoiding more traditional high-pressure Organosolv methods.

A starting point for this research is a review article[56] which provides a detailed understanding of available fractionation techniques and their effects on lignin recovery. As a continuation, two-step fractionation of Norway spruce using steam pretreatment (210 °C for 5 min) followed by GVL organosolv was investigated. An important finding was that steam pretreatment did not positively affect lignin recovery. A single step fractionation process, as shown in Figure 22, was therefore developed. The process starts with lignin extraction using GVL-organosolv, leaving a cellulose-rich residue. The results of this work show that GVL pulping is a promising method for recovering lignin from Norway spruce and are detailed in a completed manuscript titled "Lignin recovery from Norway spruce: an evaluation of different extraction conditions by GVL-organosolv".

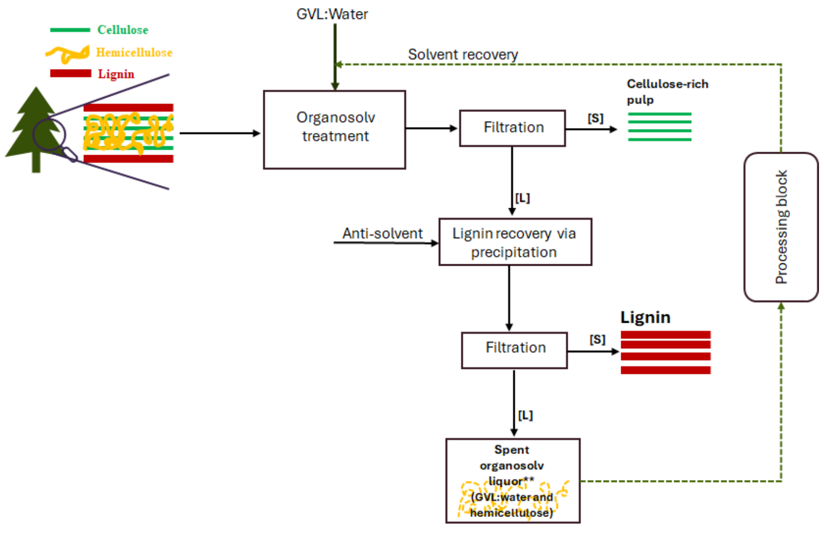

Figure 22. Schematic overview of the fractionation of Norway spruce using GVL-organosolv (**further processing of spent organosolv liquor will be experimentally investigated.).

In collaboration with RenFuel K2B AB, lignin qualities produced using the new

55 Alonso D.M., Gallo J.M.R., Mellmer M.A., Wettstein S.G. & Dumesic J.A.; 2013, Catal. Sci. Technol., 3, p 927.
56 Tanis M. H., Wallberg O., Galbe M. & Al-Rudainy B.; 2024, Molecules, 29, p 98.

process are currently being investigated as a feedstock for the Lignol® process.[57] Evaluation of the GVL lignin quality for hydroprocessing to mixed hydrocarbons will be performed in lab scale during 2025-26. Upcoming work includes a techno-economic analysis of the lignin-first biorefinery concept for lignin valorization using GVL organosolv.

Task 2.2 Development of a process for turbine fuel production from pyrolysis oil and lignin via slurry hydroprocessing

Task 2.2 is managed by RISE and focuses on the production of hydrocarbon-based candidate SAF-components from pyrolysis oil manufactured from lignocellulosic waste streams from forestry or agriculture, or from different types of lignin as schematically illustrated above in Figure 21. The activities are performed in close collaboration with members of the WP Industry Group like Topsoe, Hulteberg Chemistry and Engineering, SkyNRG, RenFuel, AlfaLaval, Preem, St1, Envigas, Cortus, Valmet Technologies Oy and Ecopar, as well as with the other WPs. During 2024, significant progress in both these areas has been made, as summarized below:

- Pyrolysis oil (produced in the pilot plant at RISE) has been stabilized by partial hydrodeoxygenation (HDO) and hydrogenation of thermally sensitive components like ketones in the slurry hydroprocessing pilot plant at RISE (lower second route from lignocellulosic biomass in Figure 21). Obtained products have been shipped to both Topsoe A/S and Hulteberg Chemistry and Engineering AB for further processing using a combination of at least fixed bed plug flow continuous hydrotreatment in standard refinery type processes as well as fractionation by distillation to set desired boiling point ranges and to achieve sufficient quality in general as candidate fuel component samples for aviation/turbine fuel use.
- Pyrolysis oil (supplied by Preem) has been processed in the slurry hydroprocessing pilot plant at RISE (another example of the lower second route from lignocellulosic biomass in Figure 21). The obtained products were then further processed in a fixed bed hydrotreater at RISE. This resulted in the first (so far) aviation fuel fractions produced from lignocellulosic pyrolysis oil within CESTAP. This fraction is currently being characterized analytically to assess compliance with the existing specifications, and the plan is also to perform combustion tests in the small high pressure laminar flame speed test facility in collaboration with WP1. A technoeconomic assessment based on the obtained experimental data is also underway in collaboration with WP5.
- Kraft lignin (30 wt.%) has been processed in the slurry hydroprocessing pilot plant at RISE in two continuous mode experimental campaigns (see first upper route in Figure 21). Vacuum gas oil (supplied by Preem) was used as carrier oil in order to render the solid lignin to a pumpable slurry. The first hydroprocessing experiment identified suitable operating conditions. For this run, only fresh catalyst was used. Figure 23 shows the visual appearance of the heavy products obtained from each set of operating conditions. In the second experimental campaign, a part of the heavy product stream (containing

[57] For information around RenFuels technology for Lignol® see https://renfuel.se/biofuels/technology

all catalyst) was recirculated and used as carrier for fresh lignin. This recycling procedure for the heavy products and catalyst was repeated several times, during which only new Kraft lignin was added to the process. This led to a gradual replacement of the vacuum gas oil carrier initially in the feed with liquid lignin products. Evaluation of the analytical results is ongoing for the obtained lignin oil intermediate.

Figure 23. Heavy products obtained from continuous mode hydroprocessing of Kraft lignin slurry. In the bottle to the left some sticky lignin residue can be observed, indicating insufficient conversion at these conditions. The three bottles to the right (obtained at more severe conditions) practically contain only catalyst particles, indicating near complete lignin conversion to non-solid products.

Upcoming work in 2025-26 includes more experimental work targeting the production of at least another three candidate SAF component test batches for testing in the various test equipment in WP1, including comprehensive analytical testing for key properties as well as molecular compositions. In addition to this further analytical characterization of thermal surrogate and fuels supplied from CESTAP partners are examples of planned deliveries, preparing for in silico modelling, material science as well as techno-economic assessments etc. in WP1, WP 4 and WP5. Focus will also be put into summarizing all the work and the results into manuscripts for submission to peer review journals.

Task 2.3 Development of a novel process and catalyst for direct conversion of alcohols to turbine fuel components

Task 2.3 is managed and executed mostly by LTU. This WP focuses on the process development and zeolite catalyst synthesis for direct conversion of methanol to hydrocarbon-based turbine fuel components using a methanol to jet-type process concept (route from methanol schematically illustrated in Figure 21)[58].

After production and analysis of liter quantities of produced hydrocarbon mixtures intended for use as jet fuel components, performed in collaboration with RISE, the work has during 2024 been focused on improvement of the zeolite-based catalyst targeting higher yields of also heavier hydrocarbons fraction. During the first half of 2024, the efforts were focused on design and synthesis of the novel optimized

[58] The research at LTU builds on previously published efforts, e.g. Grahn M., Faisal A., Öhrman O.G.V., Zhoua M., Signorilec M., Crocellàc V., Nabavia M.S. & Hedlund J.; 2020, Catalysis Today, 345, p. 36.

catalyst. Since then, the catalyst has been evaluated under different reaction conditions. As shown in Figure 24, improved performance results were indeed obtained observing a substantial yield increase of SAF-range hydrocarbons formed in the process compared with earlier catalyst types (>50% increase in jet fuel components yield, see Figure 24).

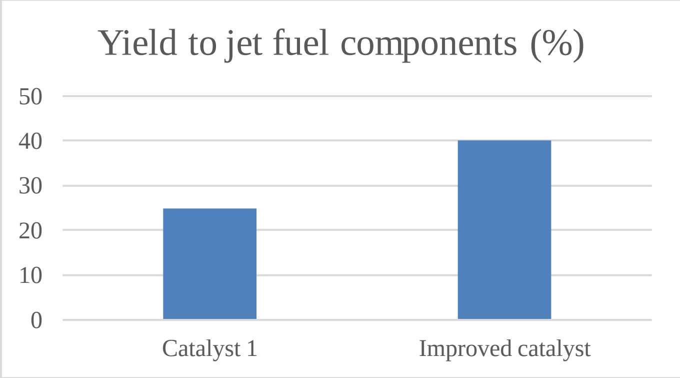

Figure 24. Yield to jet fuel components for both synthesized catalysts.

A thorough chemical analysis of the synthesized hydrocarbon mixtures shows that both catalysts are selectively producing aromatic hydrocarbons. This brings the potentially interesting opportunity to use the synthesized product as a blending component to other SAF that might be rich in aliphatic content and are lacking the essential aromatic fractions.

Efforts during 2025-2026 include development of methods more suitable for industrial production of zeolite catalysts with equally good or better performance than the current catalysts followed by demonstration tests to produce new mixed hydrocarbons which may depending on the molecular composition be subjected to further upgrading by for instance catalytic fixed bed hydrotreatment.

Task 2.4 Catalyst characterization

During 2024, the work with characterizing unsupported MoS_2 hydrotreatment/hydrodeoxygenation (HDO) catalyst nanoparticles has continued. In February a beamtime session was completed at MAX IV's NanoMAX beamline, yielding insights into the size distribution of the nanoparticles.

Further electron microscopy and powder X-ray diffraction work has also been carried out, indicating that the feedstock in which the particles are generated has a large impact on both particle structure and morphology. Figure 25 shows transmission electron micrographs of nanoparticles: generated in a fast pyrolysis bio-oil (FPBO) feed (a) and in hydrocarbons (b). The nanoparticles generated in FBPO show a much more loose, "urchin"-like structure compared to those generated in hydrocarbons. Additional differences can be observed via powder X-ray diffraction, with Rietveld refinement indicating a higher average stacking order for hydrocarbon-MoS_2 as compared to FPBO-MoS_2. As the stacking order is known to control the ratio of HDO to ring hydrogenation[59], this represents an interesting avenue for further research.

[59] Daage M. & Chianelli R.R; 1994. Journal of Catalysis 1994, 149, p 414.

Due to issues with feasibility, the original plan to build a lab-scale HDO reactor with optical access for Raman-spectroscopy has been discontinued. The current focus is instead to build a capillary reactor cell with Raman access. On the positive side a lab-scale reactor cell with online MS and GC analysis for evaluating HDO of lignin model compounds, Figure 26, as well as an ex-situ Raman spectroscopy set-up have successfully been installed during 2024.

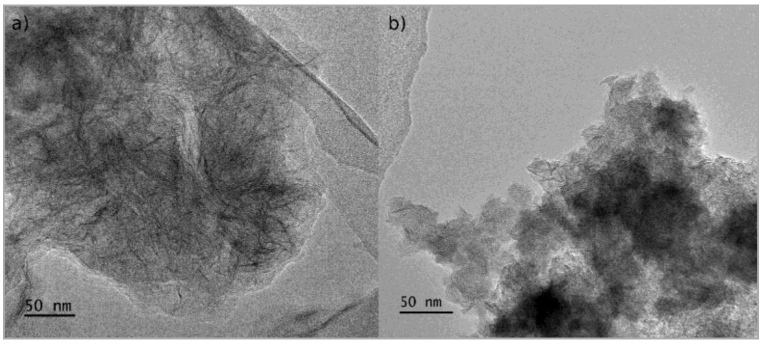

Figure 25. **(**a) TEM micrograph of FPBO-MoS_2 nanoparticle. (b) TEM micrograph of hydrocarbon-MoS_2 nanoparticle.

Figure 26. Continuous reactor system for HDO of lignin model compounds.

WP3 Mutual adaptation of turbine fuel and engine technology

The aim of this work package is to study different combustion chamber concepts that may be suitable for aviation and stationary gas turbines, that may fulfill the requirements of the future concerning robustness, that may use different green liquid fuels and that may achieve low emissions. One PhD student has been connected to this work package from the beginning of the project that initially will set baselines to identify needed improvements, improve modeling capability and quantify fuel effect on spray and flame kinetics together with WP1. Then the aim is to perform numerical studies of improved concepts and down select the most promising concepts for testing. During 2024 also an industrial PhD student from Uniper, Rania Torabi Aysf, has started within the project. Apart from regular project meetings, there is quarterly WP3 status meetings with all partners that are interested to participate (Lund Uni., RISE, Siemens Energy, GKN, Uniper, Göteborg Energi, SAAB, SKYNRG). The progression of tasks are shown in Table 4, where the tasks have been adjusted to better reflect more relevant goals for WP3.

Table 4. Progression of tasks WP3.

Tasks of WP3	Progression (%)	Comments

Task 1: Investigation of spray characteristics vs fuel flexibility	30%	On track and in line with project plan. Spray tests to be performed spring 2025.
Task 2: Investigate combustion technology relevant for stationary GTs	50%	On track and in line with project plan using the CECOST burner.
Task 3: Investigate combustion technology relevant for aviation GTs	40%	On track and in line with project plan using the TARS burner.
Task 4: Investigate high pressure effect	10%	On track and in line with project plan.

The following activities have been conducted during 2024.

Baseline cases for stationery Gas Turbine (GT) combustion systems

The CECOST burner[60] has been investigated in this part of WP3. It has been selected because it is relevant to the burners used in modern power generation gas turbin-es, and since it is suitable in size for both atmospheric testing and for the high-pressure rig at Lund University. More specifically, the CECOST burner, is a downscal-ed similar version of the type of burners used in Siemens Energy gas turbines SGT-600, SGT-700 and SGT-800. Figure 27a shows the impression of the flame structure from the reacting Large Eddy Simulation, together with the variety of turbulent structures in the mixing tube set to interact with it. Figure 27b shows a detail of the axial swirler, included in the computational domain. Firstly, focus has been on the baseline cases, where improved CFD modeling has been performed to confirm the prediction accuracy as compared to the measurement data that were obtained within the CECOST program. More specifically, the study helped in eval-

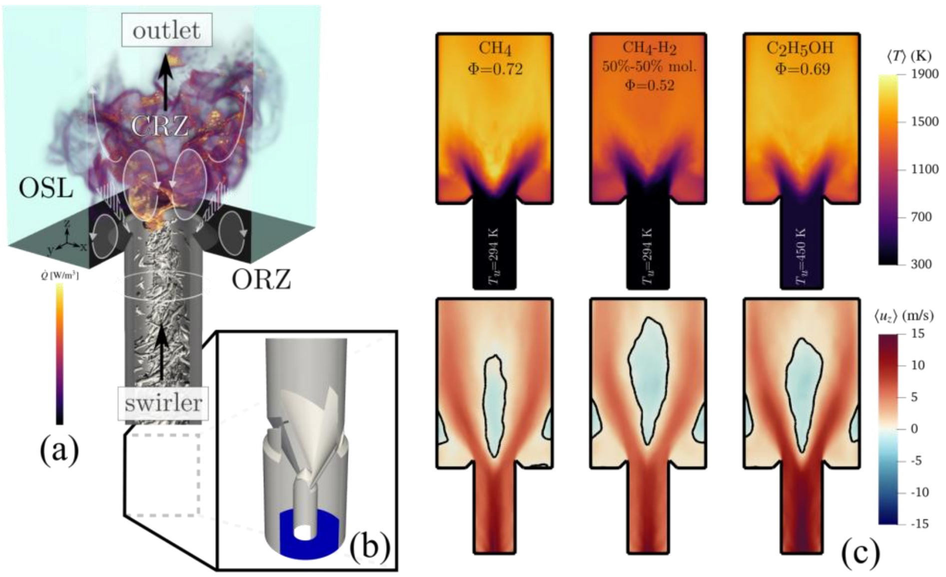

Figure 27. (a): Volume rendering of heat release, showing the reaction region in the quartz combustion chamber. The flame is stabilized thanks to the presence of the Central Recirculation Region (CRZ), the Outer Recirculation Region (ORC), and the Outer Shear Layer (OSL). (b) Detail of the axial swirler. (c) Time-averaged temperature and axial velocity for the stable CH_4 flame, a lean CH_4-

[60] https://www.lth.se/cecost/

H_2 flame, and a stable pre-vaporized, premixed C_2H_5OH flame. The black contour in the axial velocity field outlines the recirculation zone induced by vortex breakdown of the swirling flow.

uating the sensitivity of the simulation results to the turbulent combustion model and to the thermal boundary conditions. The outcome of the campaign was the selection of a baseline modeling methodology for the ensuing simulation campaigns, which focuses on the effects of alternative (or green) fuels, both gaseous and liquid. Figure 27c compares recent time-averaged results for the baseline methane case, a lean methane-hydrogen flame, and a lean, pre-vaporized, premixed ethanol flame. The first two cases have been experimentally tested during the CECOST program, while data is expected to be available for the third case as part of the outcome of future experimental campaigns in CESTAP WP1. As can be noticed in the figure, hydrogen addition (center) can sustain stable flames at temperatures way below the blow-off limit of pure methane, thus enhancing operational flexibility and potentially reducing idle emissions. For the ethanol case (right), the liquid fuel is considered vaporized and premixed at the inlet of the computational domain, where temperature is set to 450 K. The mass flow, as well as the flame temperature, matches the baseline methane case. With this set of constraints, the increase in flow velocity is compensated by a larger flame speed, resulting in a similar combustion regime and in a stable, predictable flame with interesting implications for the design of future experiments.

As input to the baseline cases, Siemens Energy have performed high pressure combustion tests using alternative green liquid fuels to quantify the fuel effect intended to be compared to the laboratory tests. During 2023 Siemens Energy high pressure combustion rig in Berlin was modified to easier exchange between alternative liquid fuels and then SGT-800 burners were tested using RME and methanol. Further, as complement to the previously performed SGT-800 engine tests using HVO at the Göteborg Energi Rya site, at Stockholm Exergi and at Siemens Energy Finspång, during 2024 HVO engine tests were performed for SGT-700 and SGT-750.

Furthermore, Sydkraft Thermal Power AB/Uniper, has during 2024 performed further testing and implementation of green fuels across their gas turbine sites in Sweden. In June 2024, an HVO trial was successfully conducted on an aeroderivative gas turbine at the Barsebäck (BVT) OCGT site, and the HVO conversion process for the BVT G13/G14 units is underway[61]. In December 2024, the HVO conversion and commissioning of the Karlshamn (KVT) G13 OCGT unit was completed[62]. At Öresundsverket, the first 12-month period of HVO operation was completed on the G24/G25 OCGT units. Further HVO conversions and commissioning are planned for 2025, and any learnings or further research questions that are developed from the increased operational experience is to be shared and explored with CESTAP. The plan is to support these full-scale tests with more fundamental studies, using laboratory facilities and numerical simulations, to provide more detailed understanding, supporting further full-scale tests and optimization.

[61] https://www.linkedin.com/posts/uniper-se_aemverbelastningshantering-activity-7283039429542236160-hwas/?utm_source=share&utm_medium=member_desktop&rcm=ACoAAB8DPUoBVvCRnqKATAeDRdz4_lYuGFvc2o4
[62] https://www.linkedin.com/posts/uniper-se_nu-har-ocks%C3%A5-gasturbinen-i-karlshamn-konverterats-activity-7273247596217839616-aTQH/?utm_source=share&utm_medium=member_desktop&rcm=ACoAAB8DPUoBVvCRnqKATAeDRdz4_lYuGFvc2o4

Baseline cases for aviation gas turbine (GT) combustion systems

A literature study was performed to evaluate baseline options and to investigate potential complementing baselines. A medium size jet engine combustor was identified as suitable for tests to quantify the effect of different fuels on global level. For detailed experi-mental and numerical studies in laboratory scale, the TARS (Tripple Annular Research Swirler) burner is identified as the best available option. The selected options have been approved with the partners that attend the WP3 status meetings. Experimental and simulation work of the TARS burner using liquid fuels have been initiated in collaboration with the EU Horizon Europe projects MORE&LESS[63], MYTHOS[64] and CIRCULR FUELS[65].

The initial focus of WP3 on the TARS burner has been on extending the simulation database for Sustainable Aviation Fuels (SAFs) beyond the compact, pathway-centric reaction mechanisms of the Z79 family[37-38]. To achieve this goal, conventional Jet-A and two SAF variants, C1 and C5 are simulated using the skeletal HyChem chemical kinetics[35-36]. The simulations are performed in cooperation with the Circular Fuels project, on the setup inherited from the MYTHOS project. The methodology includes finite-rate chemistry (FRC) and Lagrangian Particle Tracking (LPT) to model the spray combustion process. Figure 28 reports instantaneous snapshots from the three different cases, for some quantities of interest. Noteworthily, C1 and C5 show different tendencies in forming high temperature hot-spots in the vicinity of the flame front, which in turns affects the predictions of NO_x and CO emissions.

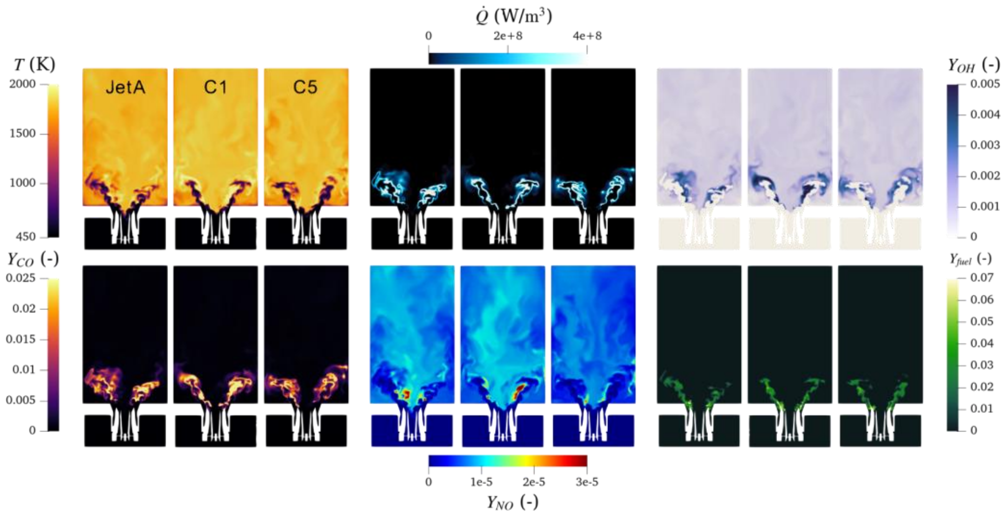

Figure 28. Comparison of instantaneous results from the HyChem FRC-LES, for conventional Jet A (left), C1 (center), and C5 (right). Top row, left to right: temperature, volumetric heat release, OH radical mass fraction. Bottom row, left to right: CO mass fraction, NO mass fraction, vaporized fuel mass fraction.

In addition to the impact of chemical kinetics, the impact of the fuels' liquid properties is also under investigation. The different physical properties of the SAF candidates, e.g., density, surface tension, viscosity, boiling point, etc. are expected to

[63] https://archivio-poliflash.polito.it/en/research_innovation/moreandless_towards_the_future_of_civil_supersonic_aviation
[64] https://mythos.ruhr-uni-bochum.de/
[65] https://circularfuels.eu/

play a crucial role in the modeled breakup and evaporation processes prior to mixing and combustion. This involves analyzing the lagrangian phase data for the different fuels both qualitatively and quantitatively, using a statistical approach.

Furthermore, initial numerical simulations of the TARS burner as set up at Lund University were performed by GKN Aerospace. The simulations were done with LES WALE turbulence model and the FGM combustion model with either Kinetic Rate or Turbulent Flame Speed Closure models. The HyChem Jet-A detailed mechanism with 119 species and 841 reactions was used for the flamelet table generation.

In addition, GKN Aerospace Engine Systems AB and Lund University of Technology supervised a M.Sc. thesis work[66] with two students: Måns Larsen and David Attoff during spring 2024. The students numerically studied a premixed flame behind conical bluff-body that was experimentally studied by Pathania *et al.*[33]. The studied fuels were Jet A and an Alcohol-to-Jet biofuel C1. The simulations were performed using the Star-CCM+ software with EDC, TFM and FGM combustion models using both RANS and LES modelling. Two reaction mechanisms were used the skeletal HyChem Jet A mechanism[35] and the Zettervall Z79[37]. The two combustion models that show the best agreement are the Finite Rate Chemistry models EDC and TFM, the former for RANS and the latter for LES. The Z79 mechanism had better agreement with experiments when compared to HyChem, in both the OH distribution and the diameter of the flame.

Spray tests to evaluate fuel nozzle performance

One of the main parameters concerning the effect of different fuels is the spray characteristics when liquid fuel is to be mixed with air upstream the flame, which has a great effect on the downstream flame. Therefore, WP3 will include spray tests at the high-pressure spray rig at RISE, with complementary laser measurements in collaboration with WP1. During 2023/2024 similar spray tests were performed in this rig within the competence center program TECH4H2[67]. During 2024 the preparations for the WP3 measurements have been performed and the tests are to be initiated during spring 2025. The down-selection and priority lists of what conditions, nozzles and fuels that will be included in this study has been approved by the partners attending the WP3 status meetings.

WP4 Material Sciences

The aim of the work package is, with knowledge about the full certification process and needs, to define and use a set of cost-effective and facile test methods for the characterization of lubricating properties, effects on elastomer materials present in the engine system as well as any corrosive effects of candidate fuels tested against reference as part of the pre-certification test package of CESTAP. Stabilities for storage and transportation of fuel candidates are also part of the scope for this WP. The overall progression of WP4 tasks are shown in Table 5.

Table 5. Progression of tasks WP4.

Tasks of WP4	Progression (%)	Comments (%)
Task 1: Lubricati-	15%	This task is delayed. The plan is to catch up 2025-

[66] Larsen M & Attoff D.; 2024, "Validation of Combustion Models Using Sustainable Aviation Fuels", MSc Thesis Project, Dept. Energy Sciences, Lund University, Lund, Sweden.
[67] https://www.chalmers.se/en/centres/techforh2/

on		2026. A literature study is planned as a start summarizing best practice in the field.
Task 2: Soft material interactions.	70%	This task is on track. A published method for rapid evaluation of SAF-candidates polymer compatibility has been set up and used. Swelling performance on new and old samples and preferred material for low aromatic fuels are to be further investigated.
Task 3: Deposits and corrosion	20%	This task is delayed. The plan is to catch up during 2025-2026. Storage properties of biofuel will be the main focus during 2025-2026. Recruitment of a Post Doc and Master students started Q4 2024.

Task 1 Lubrication

The impact of having different fuel properties such as viscosity and assessing potential negative implications on pumps and valves in the fuel system will be investigated going forward. The correlation between lubricity and chemical composition as determined within the activities of WP2 and other physical properties will be further investigated. Fuel samples produced outside and inside CESTAP will be investigated, and possible remedies will be sought as part of this work if there is a need for improved lubrication. Standard test methods measuring lubricity, e.g ASTM D5001 and Brugger test (DIN 51347-1/2) will be used to assess lubricity sending samples for analysis to either partners in CESTAP or to contract labs.

Task 2 Soft material interactions

In Task 2, fuel - soft material interactions are, will be and have been investigated for selected fuel samples produced outside and inside CESTAP. The Master Student Thesis from CESTAP WP4 published in Q1 2024 presents a rapid and efficient evaluation method for characterizing compatibility of alternative jet fuels with elastomer seals. The conclusion from the Master thesis are as follows.

- Volume swell is a one of the most important properties in sealants.
- Volume change equilibrium seems to be obtained in a short amount of time for conventional fuels or already during the first 24 hours.
- Ageing of elastomer samples to be studied is important to simulate elastomers that have been in service for extended periods of time.
- Optical dilatometry[68] is a useful way of testing elastomers. Using advanced image processing software, the analysis of changes in sample volumes can be quickly executed, Figure 29.

[68] Graham J.L., Striebich R.C., Myers K.J., Minus D.K. & Harrison W.E.; 2006, Energy Fuels, 20, p 759.

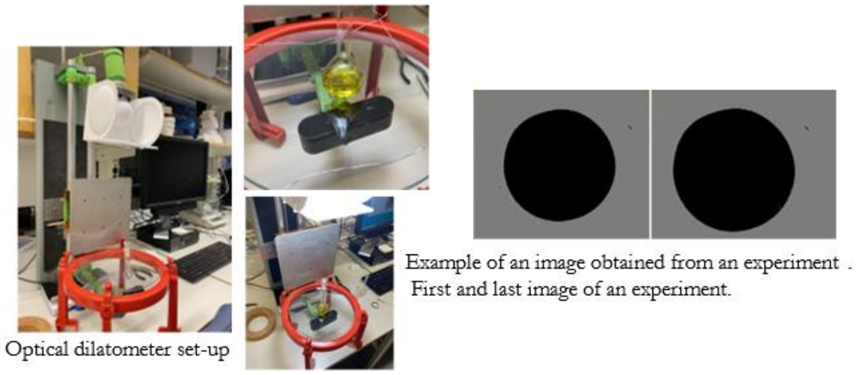

Figure 29. Optical dilatometry set up and sample images.

- Data from optical dilatometry in combination with the data from WP2 on the molecular compositions of (candidate) fuel samples will create better understanding around fuel specification criteria and potential flexibility.
- Further work will concern using the set up method to test new (candidate) fuels on both new and "used" elastomers belonging to traditionally used polymer classes and well as on more modern materials. In addition, tests will be expanded to test higher temperatures during contact between the elastomer materials and the (candidate) fuel samples to achieve faster collection of data.

Task 3 Deposits and corrosion

Biofuel introduces new feedstocks, processes and molecules that may require new test methods not used for fossil fuels. High- and low temperature corrosion, chemical stability and deposits will during 2025-26 be assessed for selected test fuels. Deposits resulting from the combustion of fuels are related to presence of trace metals in the fuel, something which will be carefully analyzed as part of the analytical package in WP2, where the default scenario is that trace element contents of candidate renewable fuel samples should be very low (typically < 10 ppm). Still, specific metals atoms/ions can work as catalysts causing decomposition of fuel molecules into more reactive components, at lower temperature present during storage, causing a FOD/filter problem and at high temperatures causing deposits in nozzles and regulator valves (as worst cases). Cost-effective standard methods used also to analyze standard fossil jet fuels will be used to assess tendencies to form deposits like coke, represented by ASTM D7111, D8110-17 and UOP 389 as well as the so-called Jet Fuel Thermal Oxidation Test (JFTOT, ASTM D3241). Corrosion will be evaluated by microstructural evaluation of material samples soaked in test fuel at elevated temperatures (ASTM D4054 "Standard Practice for Qualification and Approval of New. Aviation Turbine Fuels and Fuel Additives"). Storage shelf life evaluation of selected samples of candidate SAF will be characterized through accelerated stability studies, analyzing also changes in molecular composition (compound classes) and any changes in key physical properties happening during storage at elevated temperatures.

Meetings have been held with the WP4 WP Industry group during 2024 and the most active organizations involved in WP4 activities during 2024 have been LTH, RISE, Saab, GKN, Siemens Energy, Topsoe and Svensk Kraftreserv.

WP5 Holistic techno-economic and sustainability analysis

WP5 focuses on a comprehensive analysis of sustainable turbine fuels from a system perspective, highlighting their advantages and trade-offs. The evaluation includes factors such as production potential, economic feasibility, and environmental impact. Overall progression of tasks of this WP during 2024 is briefly described in Table 6.

Table 6. Progression of tasks WP5.

Tasks of WP5	Progression (%)	Comments
Task 1: Techno-economics of biofuel production	70%	Significant progress has been made compared with 2023 and activities are again aligned with case studies in WP2 (see below).
Task 2: Sustainability of biofuel production and use	40%	On track and this task is partly dependent of emissions data from tests in WP1. During 2024 in silico tools have been developed providing a good starting point as soon as emissions data from WP1 are available.
Task 3: Holistic analysis of biofuel alternatives	50%	On track and for instance Swedavia contributed with a report on system aspects of SAF from an infrastructural and logistics perspective during 2024.

As outlined in the overall research plan, the activities stated for the first three years of the project include:

1. Literature study on production sustainable aviation fuels (submitted for journal publication)
2. Case study for methanol-to-jet (MTJ) SAF production (awaiting data confirmation)
3. Case study for SAF production from slurry hydrotreatment of pyrolysis oils and lignin (ongoing)
4. Engine emissions and high-altitude effects (ongoing)
    a. Based on experimental emissions from other WPs and modelled (non-CO_2) impacts
    b. Estimation of non-GHG climate impact

Additionally, an overview of the current status and short-term plans for SAF production at both Nordic and global levels is provided.

Current and projected SAF production until 2030

Figure **30** presents the projected growth of SAF production capacity in the Nordic region from 2018 to 2030, categorized by technology type. Initially, HEFA dominates the region's SAF production, maintaining a steady contribution until 2026. However, from 2027 onwards, there is a significant diversification with co-processing (Co) and PtL-J technologies becoming major contributors to the total capacity. The rapid increase in capacity after 2026 suggests a strategic push towards

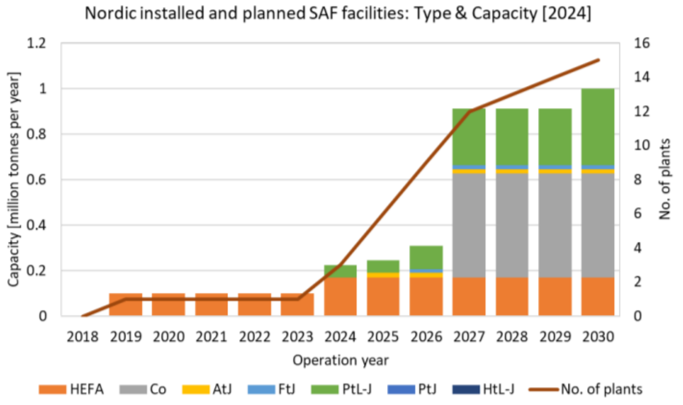

Figure 30. Nordic installed and planned SAF facilities between 2018 and 2030. *HEFA – Hydroprocessed Esters and Fatty Acids, Co – Co-processing, AtJ – Alcohol-to-jet (including methanol), FtJ – Fischer-Tropsch to jet, PtL-J – Power-to-Liquid to jet, PtJ – Pyrolysis-to-jet, HtL-J – Hydrothermal liquefaction to jet.*

advanced SAF technologies to meet sustainability targets and reduce dependency on traditional bio-based feedstocks. The forecasted SAF capacity approaches 1 million tonnes per year by 2030, reflecting a strong commitment to decarbonizing aviation in the Nordic region through a mix of mature and emerging SAF pathways.

Figure 31 illustrates the growth of SAF production capacity and the number of SAF facilities globally from 2018 to 2030. Both capacity (in million tonnes per year) and the number of plants show exponential growth, with significant acceleration from 2024 onwards. The data suggests that the industry is ramping up production capacity in response to increasing demand and regulatory pressure for sustainable aviation solutions. By 2030, SAF production capacity is projected to reach nearly 30 million tonnes per year, with over 200 facilities globally, highlighting a strong commitment to scaling up SAF deployment.

Figure 31 also provides a breakdown of SAF production capacity by technology type, highlighting the dominance of HEFA technology, which constitutes the majority of installed and planned capacity through 2030. Other SAF production pathways, such as AtJ, FtJ, and PtL-J, gradually increase their share, especially from 2025 onwards. The diversification of SAF technologies indicates ongoing efforts to enhance feedstock flexibility and reduce reliance on limited resources like waste oils and fats, positioning the industry for long-term sustainability and scalability.

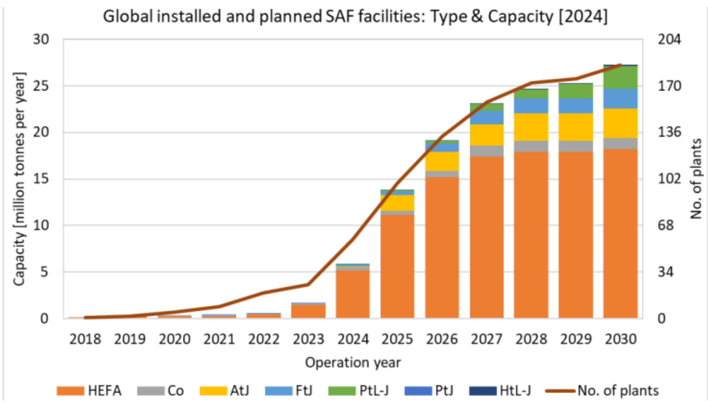

Figure 31. Global installed and planned SAF facilities between 2018 and 2030. *HEFA – Hydroprocessed Esters and Fatty Acids, Co – Co-processing, AtJ – Alcohol-to-jet (including methanol), FtJ*

– Fischer-Tropsch to jet, PtL-J – Power-to-Liquid to jet, PtJ – Pyrolysis-to-jet, HtL-J – Hydrothermal liquefaction to jet.

Activities in WP5

Activity 1: Zeenat Farooq, a PhD student at LTU, has conducted a comprehensive literature review evaluating the technoeconomic performance of commercially available SAF production routes in the short to medium terms. These routes are based on sustainable and cost-effective feedstocks. A manuscript containing the literature review and a meta-data analysis results of the data reported in them is submitted for publication in Q4 2024. In her research, Zeenat examined 52 greenfield and 42 integrated process configurations. High production costs remain a major obstacle to the large-scale adoption of SAF. Economic viability assessments of SAF pathways often rely on the Minimum Jet Fuel Selling Price (MJSP) as a key performance indicator, but comparisons across pathways and studies are complicated by differing technoeconomic assumptions and methodologies. A comprehensive meta-analysis and variable harmonization of techno-economic assessment (TEA) studies for high-technology readiness level SAF pathways utilizing non-food feedstocks addresses these challenges. Based on MJSP rankings, Hydroprocessed Esters and Fatty Acids (HEFA) pathways outperform others, followed by Pyrolysis-to-Jet (PTJ), Alcohols-to-Jet (ATJ), and Fischer-Tropsch (FT), although rankings depend heavily on underlying parameters and context-specific assumptions. PTJ and FT pathways, especially when using non-food feedstocks, show improved economic outcomes when integrated with existing biorefineries or industrial plants. Variability in TEA results is influenced by factors such as by-product credit treatment, process design, capital cost estimation, and financial assumptions. Regression analysis reveals that the impact of TEA input variables on MJSP variance is route-specific, while harmonization analysis highlights the critical role of by-product credits and feedstock costs, as well as their interactions with other variables. These insights offer strategic opportunities to enhance the technoeconomic performance of SAF pathways. A summary of SAF production cost reported in the literature and reproduced in this study is shown in Figure 32.

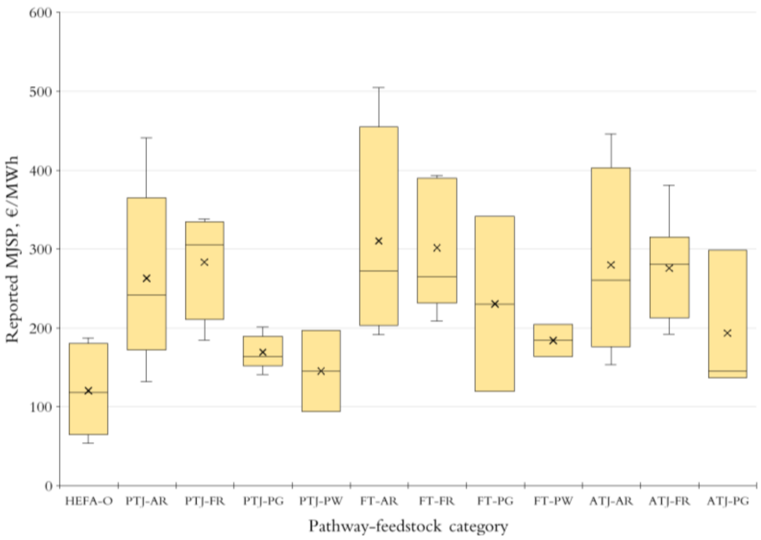

Figure 32. Summary of reported and reproduced SAF production cost, Farooq et al. (2024, manuscript submitted). *AR – agricultural residues, FR – forest residues, O – oil feedstock, PW – process*

waste, ATJ – alcohols-to-jet, PTJ – pyrolysis-to-jet, FT – gasification + Fischer-Tropsch, HEFA – hydroprocessed esters & fatty acids.

Activity 2: The work on a methanol-to-jet track was initiated in 2022 and further developed in 2023 to include upstream (renewable methanol production) and downstream (catalytic conversion and hydrotreatment). A simplified process model for the methanol-to-finished distillate process chain was established by integrating results from methanol-to-jet project along with data from the open literature. The model facilitated the derivation of mass and energy balances, which were subsequently employed for estimating production costs. The carbon, mass and energy balance results derived from the model implemented in Aspen Plus® is shown in Figure 33. The model assumed the recirculation of unreacted methanol, incrementally adding the methanol-to-product yield to100%. The gases (C_2-C_4) produced were assumed to substitute fossil gas in the integrated refinery, while the light liquid fraction (C_5-C_7) was considered for sale as a feedstock for renewable gasoline (naphtha). It is noteworthy that the gas, although theoretically convertible into a liquid product by recirculation to the reactor with the zeolite ZSM-5 catalyst was not considered in this context due to time constraints. Further catalyst development and the impact of recirculation on the performance of the catalyst will be studied under CESTAP WP2. Regarding excess heat generated from the process, an assumption was made that it is comparable to that in the methanol-to-gasoline process, and it can replace steam produced from fossil gas in the refinery.

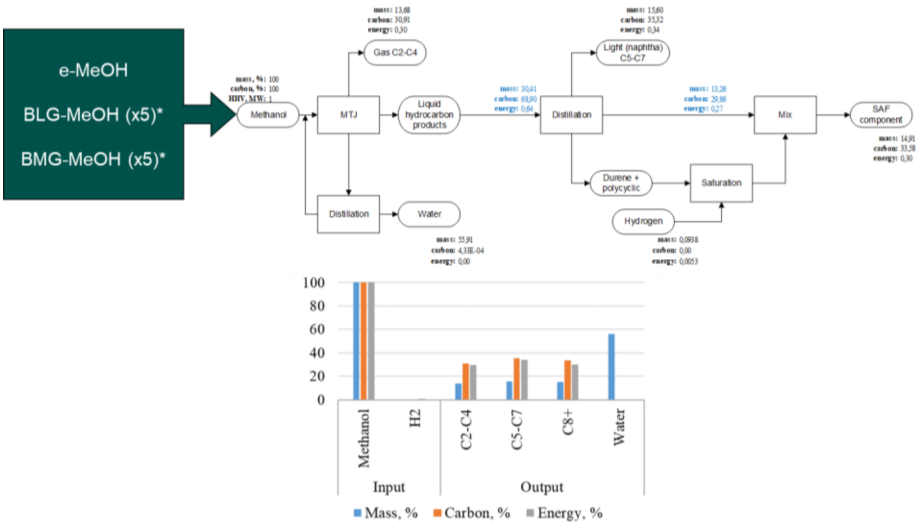

Figure 33. Schematics for SAF production via methanol-to-jet track used for technoeconomic evaluation. *e-MeOH – captured CO_2 based methanol (via a reverse water-gas-shift process), BLG-MeOH – Black liquor gasification-based methanol, BMG-MeOH – Biomass gasification-based methanol.*

Production cost or Minimum Fuel Selling Price (MFSP) was evaluated as economic indicator, with adjustments made to raw material costs and CAPEX to align with 2021 levels, Figure 34. Two allocation methods were employed: (1) MFSP was calculated for all liquid fuel products (bio-distillate/jet fuel intermediate plus naphtha), and (2) naphtha was treated as a saleable by-product of the bio-distillate. The cost assessment of biojet fuel focused solely on the distillate component derived from methanol, excluding the isomerized HEFA component. The resulting production costs were benchmarked against reported costs from various renewable jet fuel production routes from the literature review in Figure 32.

Figure 34 illustrates the resulting production costs (MFSP), depicting the distribution among various cost components. The figure highlights that the majority of the production cost for the final product stems from the expenses associated with renewable methanol production, with the costs of converting methanol into renewable hydrocarbons being relatively modest. The methanol cost is, in turn, dominated by capital cost (CAPEX) and raw material cost (biomass and/or electricity). The figure assumes an electricity price of €59/MWh and a biomass price of €17.5/MWh. Methanol concepts with low electricity usage, such as black liquor and biomass gasification without electrolysis, yield the lowest total cost. At an electricity price of €40/MWh combined with a biomass price of €25/MWh, hybrid concepts become comparable to pure gasification cases.

As shown in Figure 33, a significant portion of the formed renewable hydrocarbons comprises lighter fractions (gas or naphtha). Treating these as by-products to the distillate fraction in the economic analysis can result in a misleading production cost (right graph). Therefore, considering the MFSP for all liquid fuel products (left graph) provides a more accurate indication of actual production costs, especially considering considerable market demand for renewable hydrocarbons, including renewable naphtha/gasoline.

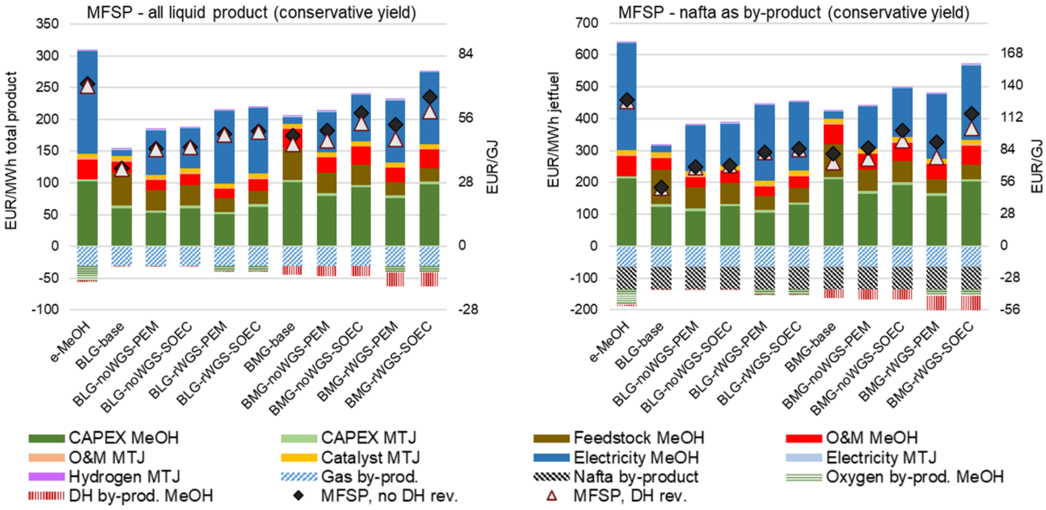

Figure 34. Resulting cost distribution and cost of production (MFSP) for the analyzed scenarios, with different production concepts for renewable methanol. Left: MFSP calculated for all liquid products; Right: MFSP for only bio-distillates with naphtha as a by-product.

Figure 35 summarizes reported renewable jet fuel production costs for comparable production pathways, relative to the economic findings from this study (shaded area). The publication costs exhibit a considerable range within most production routes. Similarly, the MFSP spread for the studied concept in this project is largely influenced by variations in methanol production costs. Nonetheless, the resulting cost is comparable or superior to the most relevant Sustainable Aviation Fuel (SAF) production concepts, such as FT-FR and PTJ-FR.

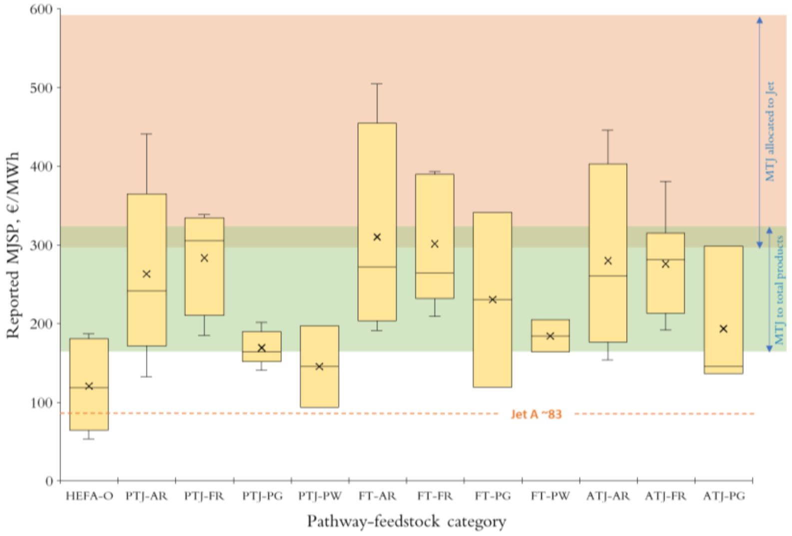

Figure 35. Compilation of reported MJSP for comparable SAF production pathways. The shaded area represents the range of production costs for MTJ tracks evaluated in this project (light green: MFSP allocated to all liquid fuel products and light red: MFSP allocated to jet fraction). *AR – agricultural residues, FR – forest residues, O – oil feedstock, PW – process waste, ATJ – alcohols-to-jet, PTJ – pyrolysis-to-jet, FT – Fischer-Tropsch, HEFA – hydroprocessed esters & fatty acids.*

Optimizing process conditions or polymerizing the C2-C4 fraction to achieve a higher yield to liquid hydrocarbons could likely further enhance the MFSP of this project's concept. However, additional process step costs have not been considered here, and the yield from the C2-C4 fraction to >C8 has not been experimentally studied yet.

Activity 3: Based on the results of Activity 1, direct liquefaction via the pyrolysis-to-jet (PtJ) pathway demonstrates strong economic competitiveness, making it a viable option for leveraging Swedish forests in sustainable aviation fuel (SAF) production. Ongoing evaluations of the pyrolysis oil and lignin hydrotreatment tracks are being conducted in collaboration with experimental work in WP2. The findings from Activity 3 will be presented at SDEWES 2025, the 20th Conference on Sustainable Development of Energy, Water, and Environment Systems, held on October 5–10, 2025, in Dubrovnik, Croatia. A summary of the current results follows.

PtJ fuel production pathways based on sustainable feedstocks offer a promising short-term alternative to fossil-based jet fuel. However, upgrading bio-oil—an intermediate product of fast pyrolysis with high oxygen content—presents technical challenges, contributing to uncertainties in techno-economic feasibility. To address this, the performance of a two-step Slurry Hydroprocessing (SHP) technique, which combines slurry- and fixed-bed hydroprocessing, is being assessed for upgrading bio-oil from low-cost sawmill residues into jet fuel. This approach integrates decentralized bio-oil production with centralized refinery upgrading. The bio-oil upgrading process is modeled using experimental data and Aspen Plus® simulations, covering the entire production chain. The two-step hydroprocessing method reduces the oxygen content in bio-oil to 0.5%, meeting fossil refinery standards while yielding jet fuel as the primary product and naphtha as a co-product.

A preliminary techno-economic analysis indicates that the MJSP is highly sensitive to factors such as hydrogen production methods, catalyst costs, bio-oil transportation, and by-product credits. Onsite energy requirements are met by combusting char and gaseous by-products from fast pyrolysis, while sawmill residues serve as a low-cost feedstock. This synergy enhances both the economic viability and greenhouse gas (GHG) performance of SAF production.

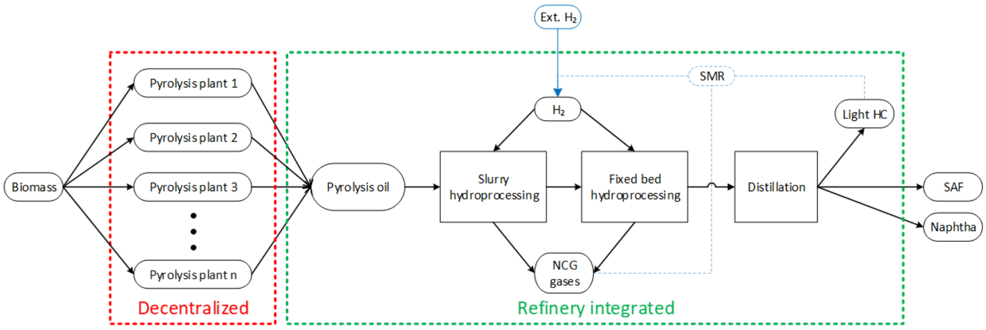

Figure 36. Schematic process flow diagram and system boundaries considered for technoeconomic and GHG performance evaluation of PtJ pathway.

Figure 36 provides a systemic overview of the conceptual PtJ track used for techno-economic evaluation. Multiple pyrolysis plants supply pyrolysis oil to an SHP unit integrated into a refinery, enabling independent scaling and leveraging economies of scale for commercially relevant throughput. Pyrolysis and subsequent hydrotreatment produce light hydrocarbons (C_1–C_4), which can be reformed to supply up to 79% of the hydrogen required for hydrotreatment, provided process localization maximizes utilization. Alternatively, these by-products can be sold for additional revenue, with hydrogen sourced from electrolysis or natural gas reforming.

The operating cost of PtJ tracks is analyzed under different shares of externally sourced hydrogen from water electrolysis or natural gas reforming. Figure 37 illustrates the contribution of operating costs to SAF production costs, excluding CAPEX and fixed O&M. By omitting CAPEX, the analysis minimizes the impact of economies of scale, allowing a clearer comparison of case studies based on specific OPEX and product yield. OPEX includes costs for feedstock procurement, hydrogen, labor, overhead, catalysts, and pyrolysis oil transport relative to SAF production. The results in Figure 37 assume feedstock, electricity, and natural gas prices of 20, 40, and 45 €/MWh, respectively.

To put the PtJ operating cost into perspective, the results are compared to the operating costs of other PtJ configurations reproduced from the literature, Figure 38. Literature values vary widely, indicating the influence of different assumptions and methodologies. Some values are lower than the CESTAP cases, while others are higher, indicating variability in assumptions such as feedstock costs, hydrogen sourcing, and process efficiencies. The lower ends of the literature values benefit from combination of cheap feedstock and internal hydrogen production.

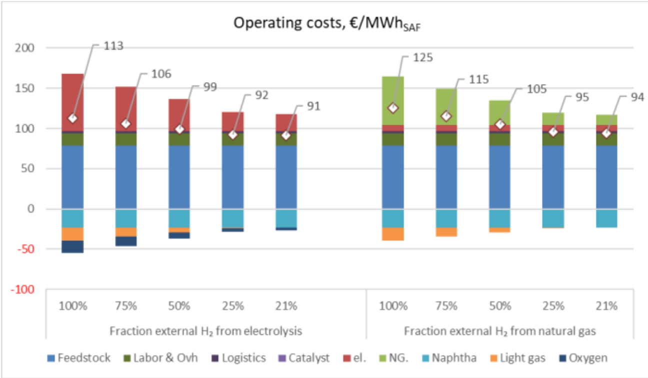

Figure 37. PtJ operating cost build-up under different shares of externally sourced hydrogen.

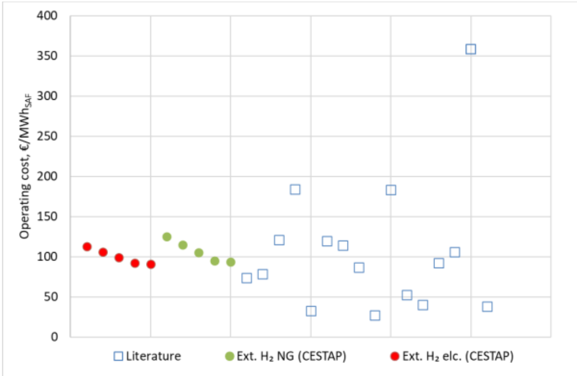

Figure 38. Operating cost of PtJ value chains – comparison with literature.

WP6 Exploitation and Implementation Plan

Work Package 6 (WP 6) has during 2024 focused on Intellectual Property Rights (IPR) assessment within CESTAP. Key achievements include a draft of a sustainable business plan for the CESTAP candidate jet fuel pre-certification test bed in collaboration with WP1 as well as strategic discussions with LU Innovation. The pre-certification test bed plan is still in progress, but the framework for a comprehensive and sustainable business plan has been laid. The plan will be further developed and fine-tuned in parallel with the developments from the experimental work in the pre-certification test bed during 2025-2026.

WP 6 collaborates with Universities and RISE to identify and address potential patent opportunities, ensuring future commercial rights. In our regular meetings, the Work Package leaders report on a comprehensive overview of outcomes achieved within their respective packages and the identification of potential patentable results. The aim is to ensure that all valuable research findings are appropriately protected in terms of IPR-rights, contributing to the long-term commercial success of innovations from CESTAP.

WP7 Dissemination and Outreach

WP7 is the work package for communication and dissemination, within CESTAP as well as to stakeholders outside the Centre. As stated in the Program Description for CESTAP, WP7 includes activities that ensure that the project results are collected and disseminated, including attendance at major scientific dissemination events; disseminate the knowledge developed during the course of the project; promote the results to the wider international community and arranging a strong and fruitful collaboration with other relevant projects.

Examples of routine activities performed in WP7 is the sharing of information through the internal CESTAP Sharepoint site. A quarterly Newsletter is sent by email to all involved personnel in the partner organizations, informing about recent and upcoming activities.

External outreach has mainly been through the website (http://cestap.se) where the project is described, partners presented and publications shared. Also, news related to CESTAP activiteis are regularly shared on the LinkedIn page.

During 2024 an online seminar series has been delivered for all Centre partners. The purpose of the seminars was to share knowledge between partners in CESTAP, without going too deep into technical details, making the knowledge more accessible also to non-experts. The seminars were generally held online on Friday afternoons at 13.30, with about 45 minutes talk followed by questions and discussions. The seminars were popular with more than 40 attendants every time.

Seminar series held during the spring 2024:

- How to communicate research, Susanne Sävenfalk, Fly Green Fund
- Jet Fuel Specifications, Per-Johan Tolf, SAAB Aerospace
- Heterogeneous catalysis - the workhorse of the chemical industry, Dr Christian Hulteberg, Hulteberg Chemistry and Engineering AB

Seminar series held during the spring 2024:

- Potential feedstocks for biofuel production, Prof. Pål Börjesson, Department of Technology and Society, LTH
- Transportation fuels from fossil and renewable feedstock, Dr Jens Anders Hansen, TOPSOE
- Systems perspective on SAF, Dr Sennai Asmelash Mesfun, RISE

In addition to the seminar series a seminar by Prof. Effie Gutmark (University of Cincinnati) on 8th of April 2024 was made available for all CESTAP partners to attend online. Prof. Gutmark has a close connection to the the work in CESTAP WP1 with his particular expertise concerning the so-called TARS-burner.

Two physical all partner CESTAP meetings have been arranged during 2024:

- The 2024 CESTAP Summer Meeting was held at Luleå Technical University on May 21-22, with a focus mostly on R&D-activities in WP2. The meeting included a visit to the labs at LTU, and to RISE pilot scale labs in Piteå. The meeting had 22 attendants from 12 partner organizations.
- The 3rd CESTAP Annual Meeting was hosted by Siemens Energy in Finspång on November 20th 2024, with 47 participants from 17 partner organizations. Three industrial partners presented their work on biofuels. Several PhD students reported on scientific progress in 2024 and the WP leaders highlighted the overall status in relation to the goals of CESTAP.

Doctoral Degrees

Bora O. Cakir 2024 “Optical Diagnostics with Background Oriented Schlieren – A practical perspective on reactive and non-reactive flow scenarios”, Lund University, Dept. of Energy Sciences, 2024-10-25.

List of Publications

Journal Publications

Åkerblom A., Pignatelli F. & Fureby C.; 2022, “Numerical Simulations of Spray Combustion in Jet Engines”, Aerospace, **9**, p 838.

Cakir B.O., Lavagnoli S., Saracoglu B.H. & Fureby C.; 2023, “Assessment and Application of Optical Flow in Background-oriented Schlieren for Compressible Flows”, Exp. Fluids, **64**, p 11.

Åkerblom A., Zettervall N., Passad M., Ercole A., Nilsson E. & Fureby C.; 2024, “Numerical Modeling of Chemical Kinetics, Spray Dynamics, and Turbulent Combustion towards Sustainable Aviation”, Aerospace, **11**, p 31.

Åkerblom A. & Fureby C.; 2024, “LES Spray Combustion Modeling of the DLR Generic Single Cup Combustor”, Flow, Turb. Comb., **112**, p 557.

Hatun Tanis M., Wallberg O., Galbe M. & Al-Rudainy B.; 2024, “Lignin Extraction by using Two-Step Fractionation: A Review”, Molecules, **29**, p 98.

Cakir B.O., Lavagnoli S., Saracoglu B.H. & Fureby C.; 2024, “Sensitivity and Resolution Response of Optical Flow based Background Oriented Schlieren to Speckle Patterns”, Meas. Sci. Tech., **35**, 075201.

Åkerblom A. & Fureby C.; 2025, “LES Modeling of Sustainable and Conventional Aviation Fuel in the Cambridge Premixed Bluff-body Burner”, Comb. Flame, **272**, p 113895.

Cakir B., Sanned D., Prakash M., Brackmann, C. Richter M. & Fureby C.; 2025, “Application and Assessment of Background Oriented Schlieren for Laminar Burning Velocity Measurements”, Exp. Thermal and Fluid Sci., **163**, p 111357.

Ercole A., Lörstad D. & Fureby C.; 2024, “Large Eddy Simulations of Turbulent Premixed Swirling Flame using Finite Rate Chemistry and Different Combustion Models”. Accepted for publication in Flow, Turb. Comb.

Farooq Z., Wetterlund E., Mesfun S. & Furusjö E.; 2024, “Uncovering the economic potential of sustainable aviation fuel production pathways A meta-analysis of techno-economic studies”. Submitted for publication in peer reviewed journal.

Åkerblom A., Zettervall N. & Fureby C; 2024, “Comparing Chemical Reaction Mechanisms for Jet Fuel in Turbulent Premixed Combustion Simulations”, Accepted for publication in AIAA.J.

Åkerblom A. & Fureby C.; 2024, “LES Modeling of the DLR Generic Single-Cup Spray Combustor: Comparison of Exploratory Category C Jet Fuels”, Accepted for publication in Flow, Turb. Comb.

Tanis, M. H.; Al-Rudainy, B. and Wallberg, O., “Lignin Extraction from Norway Spruce using Steam Pretreatment and Hydrotropic Extraction”, Submitted to J. Biomass & Bioenergy.

Hatun Tanis M. et al. 2024, “Lignin Recovery from Norway Spruce: an Evaluation of Different Extraction Conditions by GVL-Organosolv”, Manuscript in preparation.

Passad, M. & Nilsson, E.J.K. 2024, “Impact of Transport Data on Extinction Strain Rate of n-heptane Flames”. Under review for publication in Comb. Flame

Zettervall N. & Nilsson, E.J.K. 2024, “A Compact Chemical Kinetic Mechanism for Heavy Fuel Surrogates with n-, iso- and Cyclo-Alkanes, and Aromatic Compounds”, Under review for publication in ACS Omega

Zettervall N. & Nilsson, E.J.K.; 2024 “Evaluation of Single Component Kinetic Mechanisms for Aviation Fuels Combustion”, in preparation for submission to Comb. Sci. Tech.

Conference Publications/Presentations

Åkerblom A.; 2022, “The Impact of Reaction Mechanism Complexity in LES Modeling of Liquid Kerosene Combustion”, 33rd Congress. of the Int. Council of the Aeronautical Sciences, 4-9 Sept., Stockholm, Sweden.

Fureby C.; 2022, “Paving the Route Towards Green Aviation with Hydrogen and Biojet-fuels – A Numerical Study using OpenFOAM”, OpenFOAM and combustion Webinar 2022-11-25, SNU, Singapore.

Farooq Z., Wetterlund E., Mesfun S. & Furusjö E.; 2023 “Techno-economic Assessment of Methanol-to-Jet (MTJ) pathway”. Poster presentation at EUBCE 2023.

Åkerblom A., Zettervall N. & Fureby C.; 2024. “Comparing Chemical Reaction Mechanisms for Jet Fuel Combustion in Simulations of a Turbulent Premixed Bluff-Body Burner”, AIAA 2024-0179.

Fureby C. & Hedberg M.; 2024, “Sustainable Turbine Fuels for Aviation and Power”, ISABE-2024-072, ISABE, Toulouse, France, 22-27 Sept.

Pignatelli F., Subash A.A., Richter M., Sanned D. & Fureby C.; 2024, “Experimental and Numerical Investigation of Sustainable Aviation Fuels on a Helicopter Combustion Chamber”, ISABE-2024-174, ISABE, Toulouse, France, 22-27 Sept.

Cakir B.O., Sanned D., Vauquelin P., Prakash M., Hannappel J.-P., Subash A., Richter M., Bai X.-S. & Fureby C.; 2024, “Experimental and Numerical Investigations of a Swirl Stabilized Jet Engine Combustor”, 34th Congress of the Int. Council of the Aeronautical Sci. (ICAS), Florence, Sept. 9-13.

Ercole A. Lörstad D. & Fureby C; 2024, “Turbulent Combustion Model Sensitivity in LES of a Gas Turbine Combustor”, 19th Int Conf. on Num. Comb. Kyoto, Japan.

Vauquelin P., Cakir B.O., Fureby C., Bai X.-S., Richter M., Subash A.A., Prakash M. & Sanned D.; 2024, “Numerical Investigation of the Fuel Flexibility of a Typical Aero Engine Swirl Stabilized Flame”, 19th Int Conf. on Num. Comb. Kyoto, Japan.

Cakir B.O., Vauquelin P., Sanned D., Prakash M., Subash A.A., Richter M. & Fureby C.; 2024, “Numerical Investigation of the Fuel Flexibility of a Typical Aero Engine Swirl Stabilized Flame”, 19th Int Conf. on Num. Comb. Kyoto, Japan.

Vauquelin P., Cakir B.O., Sanned D., Prakash M., Hannappel J.-P., Subash A.A., Richter M., Bai X.-S. & Fureby C., 2025, “Large Eddy Simulation of a Model Jet-Engine Swirl-Stabilized Flame Using Sustainable Aviation Fuels”, AIAA 2025-0163.

Vauquelin P., Zhou Y., Åkerblom A., Fureby C. & Bai X.-S.; 2025, “Multidimensional Chemistry Coordinate Mapping for Large Eddy Simulations of a Turbulent Premixed Bluff-Body Burner”, AIAA 2025-2485.

Hatun Tanis M. et al., "Lignin recovery from Norway spruce by two-step fractionation", International Conference on Renewable Resources & Biorefineries (RRB), 5-7 June 2024, Brussels, Belgium. Oral presentation.

Hatun Tanis M. et al., "Lignin recovery from Norway spruce into value-added components", Nordic Wood Biorefinery Conference (NWBC), 15-17 October 2024, Örnsköldsvik, Sweden. Oral presentation.

Farooq Z., Wetterlund E., Mesfun S., Bergvall N. & Ma C.; 2025, “Techno-economic analysis of biomass fast pyrolysis with ex-situ slurry hydroprocessing of bio-oil to jet fuel”, To be presented at SDEWES, 20th conference on sustainable development of energy, water and environment systems, Oct 05-10, 2025, Dubrovnik, Croatia.

Mesfun S., Farooq Z., Ma C., Hed E., & Wetterlund E.; 2025, “Carbon, cost and climate performance screening of bio-electrofuel value chains relevant for unlocking SAF production in the Nordic context”, Abstract submitted for ICSAR 2025, 1st conference on sustainable aviation research, July 9-11, 2025, Dublin, Ireland.

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