FIT4MICRO SOLUTION FOR A MICROCHCP HYBRID HEATING SYSTEM RUNNING ON BIOFUELS

Delanaye, M.[1]; Rehman, D.[1]; Løkke, S.[2]; van de Beld, B.[3]; Korteweg, H.[4]; Tudoroiu, A.[4]; De Paepe, W.[5]; Gaitanis, A.[5]; Füldner, G.[6]; Velte-Schäfer, A.[6]; Harboe-Minwegen, S.[7]; Ramaswamy, S.[7]; Capaccioli, S.[8]; Grassi, A.[8];
[1]MITIS, Liege, Belgium
[2]Aalborg University, Aalborg, Denmark
[3]BTG – Biomass Technology Group, Enschede, The Netherlands
[4]COGEN Europe, Bruxelles, Belgium
[5]Univerisity of Mons, Mons, Belgium
[6]Fraunhofer Institut for Solar Energy Systems ISE, Freiburg, Germany
[7]OWI Science for Fuels GMBH, Herzogenrath, Germany
[8]ETA – Florence Renewable Energies, Florence, Italy

ABSTRACT: The main aim of the Horizon Europe Fit4Micro Project is to develop a micro-combined heat cooling and power (microCHCP) unit running on sustainable liquid biofuels. The application of this unit is foreseen at multi-family houses and at remote or off-grid locations. This technology will lead to very high electrical efficiencies (>40%) and a flexible heat/power ratio. Moreover, the usage of a truly advanced and RED III compliant biofuel will guarantee a high GHG emission reduction. The technology developed in Fit4Micro is based on a hybrid heating system. This flexible hybrid energy system is based on a double-shaft micro gas turbine (mGT) combined with a novel humidification unit, and will be able to provide renewable heating, cooling and power production, mainly for domestic usage. These systems have several advantages compared to pure electrically driven ones: they can supply heat at a similar temperature to gas or oil boilers, with little impact on efficiency. For this reason, they are particularly attractive in the retrofit market for hard-to-treat homes. The Fit4Micro solution contributes to make Europe the first enabled circular, climate-neutral and sustainable economy.
Keywords: biofuel, biomass, combined heat and power generation (CHP), microturbine, renewable energies, cooling

1 FIT4MICRO PROJECT WITHIN THE EU CONTEXT

The overall objective of the Horizon Europe Fit4Micro Project is to implement a microCHCP hybrid heating and cooling system running on sustainable liquid biofuels for domestic usage, in order to increase environmental sustainability of the building sector.
Today, the current renovation rate of existing buildings is low, risking substantial delays to achieving the EU's CO_2 reduction targets. Moreover, the energy demand in the European building sector is very diverse, and the differences in seasonal demand and local energy infrastructure are an additional obstacle to the transition towards a sustainable building sector.

As highlighted in the Renovation Wave Strategy of the European Green Deal, renovating buildings is fundamental to reach the EGD objectives: it presents an opportunity in terms of decarbonisation, improving energy efficiency, empowering consumers and boosting the local economy. Decarbonisation of heat is a major challenge for the EU: the modification of millions of individual homes to improve energy efficiency would present significant challenges. In this regard, a hybrid microCHCP system can significantly increase the socioeconomic and environmental sustainability at household level: the Fit4Micro solution aims at increasing the share of renewables at consumer level and the socioeconomic and environmental sustainability of these renewables.

2 FIT4MICRO PROJECT FEATURES

Fit4Micro is a Horizon Europe Research and Innovation Action, with title "Clean and efficient microCHCP by micro turbine-based hybrid systems".

The project consortium has put together 8 partners from 5 countries with long-term expertise in renewable energy applications, from technologies development to the market implementation.

Fit4Micro Project is coordinated by MITIS (Belgium). Partners include:
- two universities: University of Mons (Belgium) and University of Aalborg (Denmark);
- two research institutions: Fraunhofer ISE (Germany) and OWI Aachen (Germany);
- one industry partner: MITIS (Belgium);
- two SMEs: BTG Biomass Technology Group (The Netherlands) and ETA Florence Renewable Energies (Italy);
- one European Association: COGEN Europe (Belgium).

3 SCIENTIFIC INNOVATION AND RELEVANCE

The technology developed in Fit4Micro is based on a hybrid heating system, see Fig. 1.

These systems have several advantages compared to pure electrically driven ones: they can supply heat at a similar temperature to gas or oil boilers, with little impact on efficiency. For this reason, they are particularly attractive in the retrofit market for hard-to-treat homes.

In order to implement the Fit4Micro solution, the research's starting point is the innovative Intercooled Regenerative Reheating Gas Turbine (IRRGT) prototype from MITIS, which works with flameless combustors that can achieve very low emissions and high fuel flexibility. During the project implementation, it was the aim to improve its original design efficiency from 29.6% to 40%. Then, a prototype combustor has been developed and built, to advance flameless combustion with liquid biofuels for use in the turbine.

Finally, for enabling the use of biomass-based fuels at off-grid locations, Fit4Micro has widen the feedstock base to allow a widespread implementation of biomass fuelled microCHCP systems.

The Fit4Micro project investigates those systems in which the solution provides an improvement to the climate performance. These results will assist decisionmakers in implementing the technology to obtain the highest emission reductions.

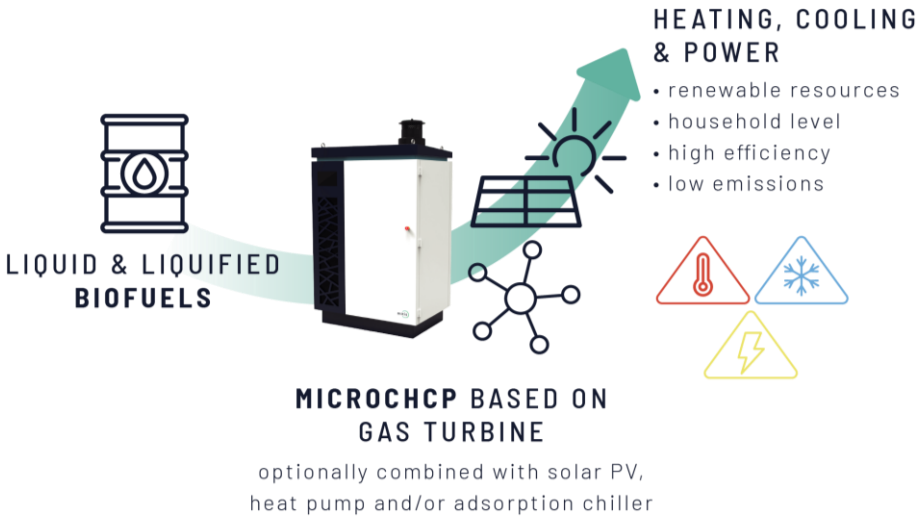

Figure 1: The Fit4Micro technology.

Analysis and activities of Fit4Micro are comprising:

- biofuel production starting from feedstocks, biomass residues and organic waste, firstly converted into Fast Pyrolysis Bio-Oil (FPBO), a liquid bioenergy carrier, then to hydrotreated pyrolysis oil (HPO);
- combustion properties of Hydrotreated Pyrolysis Oil (HPO) within the MITIS combustion chamber: development of optimized liquid fuel atomizers and flameless combustors for the use of liquid biofuels;
- humidification impact on the performance improvement of a novel two-shaft micro gas turbine from MITIS, with the supply of the liquid biofuels to the combustors for the test bench;
- Integration of hybrid trigeneration system in four selected use cases;
- Sustainability assessment (Life Cycle Assessment) and socio-economic analysis;
- Policy, market assessment, and business development;
- Dissemination and exploitation.

The development of this hybrid heating system significantly increases the socioeconomic and environmental sustainability in household sector, replacing fossil fuels with biofuels. Moreover, activities in Fit4Micro contribute to increase the share of renewables at consumer level: one of the main outcomes of the project concerns the production of low-cost biofuel with good technical characteristics. [11]

4 BIOFUEL PRODUCTION AND SUPPLY

In the long run, one of the main expected outcomes is the availability of renewable fuels for domestic usage. Ideally, a renewable fuel should have a high energy density to limit storage volumes and optimize distribution. For flexible operation, either a gaseous or liquid form is preferred to rapidly control the combustion process. In terms of sustainability and availability, it is important that a wide and diverse feedstock base, preferably consisting of residues, can be utilized. In Fit4Micro, the ambition is to produce a liquid biofuel with high energy density from Renewable Energy Directive III (RED-III) compliant resources. These resources will be converted into a liquid biofuel suitable for domestic heating, cooling and power system through processing in two stages: i) fast pyrolysis and ii) hydrotreatment. The final product obtained from processing is referred to as 'Hydrotreated Pyrolysis Oil', abbreviated to HPO.

In the first stage (the fast pyrolysis process) the solid residue is converted into a liquid bioenergy carrier referred to as 'Fast Pyrolysis Bio-Oil' or FPBO in short. One of the goals in the Fit4Micro project is to obtain a HPO product with suitable quality for micro gas turbine usage, at the lowest possible operational costs. This is targeted by i) reducing the biomass feedstock costs by targeting residual streams and ii) limiting the hydrogen consumption in the hydrotreatment process. Experimental activities are employed within the project on both approaches. For the Fit4Micro project, three different resources were selected already in the proposal stage, i.e. forest/woody residues (bark), contaminated wood and wheat straw. HPO has been successfully produced from the three feedstocks It must be noted here that the HPO can also be considered for other applications, and possible by-products could be used as well in the micro gas turbine.

The conversion by fast pyrolysis is self-sustaining and no external energy input is required. Fast pyrolysis of biomass is a thermochemical conversion technology, where the biomass is rapidly heated in the absence of oxygen to form an organic vapour, non-condensable gas and a solid by-product (char). The organic vapour is rapidly quenched to form the FPBO, the non-condensable gas and char are both combusted in the process to generate the heat for the pyrolysis process as well as a surplus for external usage. Excess heat can be used to dry the biomass before the process and/or be sold as renewable heat or power. FPBO is already produced on a

commercial scale in Europe.

For small scale heat and power generation, improving the FPBO fuel properties before usage is desirable. Various options to improve fuel properties have been investigated, both by the beneficiary in Fit4Micro consortium BTG and other companies and institutes. One of the most promising ways to improve fuel property is through hydrotreatment. By hydrotreating the FPBO, oxygen is removed from the fuel, increasing the heating value and ultimately a hydrocarbon fuel chemically similar to conventional fossil fuels can be obtained.

The hydrotreatment of FPBO involves reacting the FPBO with hydrogen gas at high pressure, elevated temperature and in the presence of a catalyst. The hydrotreatment technology is already applied in fossil fuel refineries, where hydrotreatment primarily aims to remove heteroatoms such as nitrogen and sulfur from the oil. Hydrotreatment of FPBO requires some adjustments as the FPBO is very reactive due to the large number of chemical components. Over the last twenty years BTG established an efficient upgrading process which involves two stages, an initial stabilization of the FPBO, followed by hydrotreatment. During the stabilization process the most reactive components in the FPBO are converted first while suppressing polymerization and cracking reactions. The liquid product is referred to as Stabilized Pyrolysis Oil (SPO). For the production of SPO, BTG developed a proprietary catalyst “PiculaTM”. In the second stage, the SPO is reacted over a conventional hydrotreatment catalyst such as CoMo or NiMo, the product from this stage is referred to as Hydrotreated Pyrolysis oil (HPO). HPO is a mixture of hydrocarbons, which can be already used as a fuel, or it can be separated by distillation to obtain various fuel qualities. If desired a low boiling fraction referred to as ‘HPO-Naphtha’ or ‘lights’ can be separated from the HPO. This can be done for example to increase the flashpoint of the other fraction ‘HPO-Diesel’ in order to comply with existing fuel (safety) standards.

The product properties of HPO can be controlled by adjusting the process conditions (severity) in the hydrogenation stage.

Various quantities of HPO of different qualities have been produced in the bench-scale systems during the project to select the most convenient ‘reference-HPO’ to be successfully used as Fit4Micro fuel in the microturbine. [1]

5 FLAMELESS COMBUSTION FOR LIQUID FUELS DEVELOPMENT

Fit4Micro aims to develop a flexible hybrid energy system, able to provide renewable heating, cooling and power production for demand-driven domestic (multifamily) usage. The core of the micro-CHCP (Combined Heating, Cooling and Power) unit is a novel, high-efficiency micro gas turbine (mGT).

By implementing an Intercooled Regenerative Reheat Gas Turbine Cycle (IRRGT) with a double shaft turbogenerator system and cycle humidification option, waste heat is recovered leading to increased electric efficiency while providing a flexible heat and power output. Flameless combustion further ensures minimum pollutant emissions and high fuel flexibility to allow the use of various liquid biofuels.

The Fit4Micro system is based on the recuperated Brayton cycle and consists of an assembly of a compressor, combustion chamber, turbine, recuperator and generator. The IRRGT cycle is characterized by two stages of compression separated by intercooling and two stages of turbines with a reheat (second combustor) between the LP and HP stages. Combustors have been designed to operate using renewable fuels (HPO in this case) and for two pressure levels, 3 bar (LP) and 5 – 6 bar (HP). Both in the case of HP and LP combustion chambers, the gas supply will be air. [2]

6 HIGH TEMPERATURE MATERIAL ASSESSMENT

Regarding the material resistance of combustor and turbine components, the design and development of a mGT system, including its heat exchanger and combustion chamber, for operation with biomass-derived liquid fuels necessitates careful consideration of material degradation phenomena. The operational lifespan of metallic components in such environments is often influenced by a complex interplay of corrosion, creep, and fatigue mechanisms. Moreover, the chemical composition of biomass-based fuels can result in corrosive flue gas atmospheres, and cycle humidification may further intensify corrosion processes under high-temperature conditions.

Based on a preselection of promising material candidates, a comprehensive test campaign was conducted to evaluate their performance under conditions representative of actual mGT operation - including high temperatures, corrosive combustion gases, and mechanical loads. The objective of these investigations was to identify materials capable of ensuring long-term durability and minimizing the risk of premature failure or rapid degradation. [3]

7 HUMIDIFIED MICRO GAS TURBINE

As discussed before, (the Fit4Micro MITIS system is based on the recuperated Brayton cycle and consists of an assembly of a compressor, combustion chamber, turbine, recuperator and generator. The Intercooled Regenerative Reheat Gas Turbine (IRRGT) Cycle is characterized by two stages of compression separated by intercooling and two stages of turbines with a reheat (second combustor) between the LP (low pressure) and HP (high pressure) stages, see Fig. 2.

The classical issue within such MicroCHP systems, like the Mitis M10 is the fixed heat-to-power ratio, limiting the operating range of microCHP. This often leads to system shutdown in the absence of a heat demand, despite significant electrical power demand, given the lower electrical efficiency. Cycle humidification, allowing to reintroduce waste heat in the cycle, and by doing so, improving the electrical efficiency in periods with low demand, is an interesting route for enhanced operating flexibility, as it allows to partially decouple heat and power production. This option for cycle humidification is investigated within Fit4micro.

Cycle humidification can be performed under different forms, ranging from steam or heated liquid water injection, down to the introduction of a saturation tower for evaporative humidification. At this stage, the

main developed technology further consists in the development of the HAT micro Humid Air Turbine cycle for IRRGT, and more specifically the saturation tower. Using and in-house developed 2nd law analysis tool [4], the HAT cycle was found to have the highest performance combined with ease of implementation and reduced number of cycle alterations as well as the optimal use of original components [5].

A new saturation tower was developed, constructed, and is currently tested.

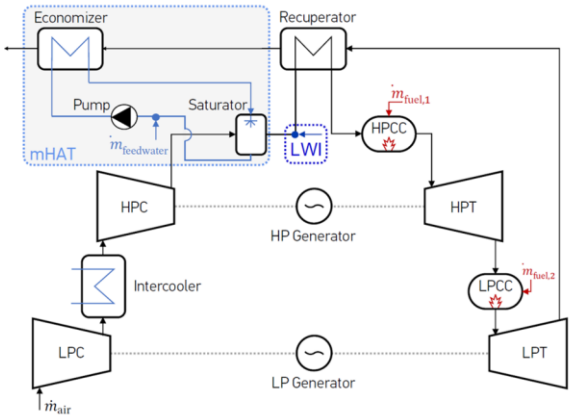

Figure 2: Advanced humidified cycle configuration.

Besides the HAT concept, cycle humidification by simple water injection was also studied and tested. Although only limited performance improvement can be expected, this technology requires the lowest amount of cycle modification (no), while it leaves a significant amount of thermal power available in the flue gases to be valorised for heat and cooling and allowing to tune this heat flow. By doing so, it responds to the demand for increased flexibility. [6]

8 BUILDINGS SUITABLE FOR THE PROJECT'S TECHNOLOGY

Project "Report on 4 use case definitions for system development and evaluations" describes the identification of promising heating and cooling applications for the mGT systems under development in Fit4Micro. Simulated load profiles of five different building applications are evaluated in terms of achievable full load hours. The objective of this report is the identification of use cases (applications) in which the implementation of a mGT – possibly in combination with an electric heat pump, a thermally driven chiller (TDC, in this case an adsorption chiller) and/or photovoltaics – seems generally promising in terms of system layout, economics and ecological aspects. To meet the objective described above, the applications were split into two major groups which were studied separately in the following:

- buildings and their respective heating and/or cooling demand, to be studied for all variants of mGT system configurations;
- industrial/commercial (manufacturing) processes which require cooling as potential applications for the combination of a mGT with a TDC.

In residential and office buildings the mGT seems promising for large buildings as a base load supplier of heat (dimensioning typically to <15% of maximum load). In office buildings in southern climates with an extended cooling demand, the combination with a TDC may be feasible.

Non-residential buildings with high occupancy and significant DHW demand such as hospitals and lodging buildings can be regarded as auspicious for mGT systems as well. Due to a more constant load, the mGT can cover a higher share of the required load. A dimensioning to up to 30% of the peak demand can be feasible. The simulated average electricity consumption indicates that a high share of the electricity produced by the mGT can be consumed in the building itself.

The integration of mGT-TDC combinations in processes for cooling depends highly on the demand hours and the required temperature. [7]

9 LIFE CYCLE ASSESSMENT (LCA)

In Fit4Micro a first Life Cycle Assessment (LCA) has been conducted with the aim of facilitating decision support in technology development and support sustainable implementation of the technology [8]. The primary objective of this study is to assess the environmental impact of the mGT system when fuelled with hydrogenated pyrolysis oil (HPO) in various use case scenarios and with different feedstock sources for the biofuel production process. Scenario development encompasses 18 different potential applications of the mGT, spanning various building types, locations, and building standards.

The preliminary LCA results demonstrate that the environmental performance of the mGT system is highly dependent on the choice and treatment of biofuel feedstock. Using a consequential modelling approach, the study shows that climate impact is influenced not only by emissions from combustion and operation, but also by the alternative use of the feedstock and the substitution effects when it is diverted from conventional applications. For example, forest residues (Scenario A1) and contaminated wood (Scenario A2) yield net negative GWP100 (Global warming potential) values, though via different mechanisms—biogenic carbon uptake in A1 and avoided incineration emissions in A2. In contrast, wheat straw (Scenario A3), when sourced from regions with fossil-intensive heat substitution, results in net positive GWP100, underscoring the importance of regional energy contexts.

According to the carried out LCA, the variation across building types, standards, and geographic locations confirms that use-case-specific modelling is essential. The mGT system's performance depends not only on feedstock but also on the local energy grid and heating supply, reinforcing the need for nuanced scenario development. This furthermore implies that the mGT system if implemented in an off-grid context likely will perform better if alternatives are based on more emission heavy technologies, which often are seen in off grid applications.

These findings emphasize that biofuel production must be evaluated within its broader system context—considering regional energy mixes, building energy demands, and substitution technologies. The model will be improved and in the following final versions, we will expand the scope to include a full range of use scenarios, each linked to specific future business-as-usual

alternatives for heating, cooling, and hot water.

10 POLICY AND MARKET ASSESSMENT

EU buildings are responsible for 40% of energy demand, of which 80% is represented by heating, cooling and hot water. Most energy consumed in buildings is produced by inefficient stand-alone boilers running on fossil fuels. Rural and remote communities, home to more than 130 million EU citizens residing in approximately 50 million households, experience further challenges related to poor grids connectivity and an ageing building stock. Moreover, buildings are at the intersection of energy infrastructure – electricity, gas, district heating – which must also evolve as energy sources diversify and decarbonise. Responding to these challenges, EU and national policies are prioritising building renovations, including higher shares of electrification, increase integration of renewable electricity, the uptake of renewable fuels and boosting energy efficiency.

Against the background of the ambitious buildings policies across the EU, a range of clean buildings solutions are available to improve the energy performance of buildings, increase renewable energy use and mitigate increasing energy costs to European households and businesses.

The Fit4Micro solution, combining energy efficient micro-CCHP with renewable fuels, PV and electrification, provides multiple benefits aligned with EU's objectives on energy, climate and competitiveness, see Fig. 3.

As a highly efficient hybrid system, the Fit4Micro package can deliver an all-year round zero-emissions energy for buildings with limited access to energy grids, at lowest possible cost for the consumer and the energy system as a whole. Depending on the local circumstances, consumer needs and regulatory environment, different configurations can be achieved to optimise and smartly combine an innovative micro-CHP with heat pumps, storage and PV, as well the integration of a range of sustainable biofuels.

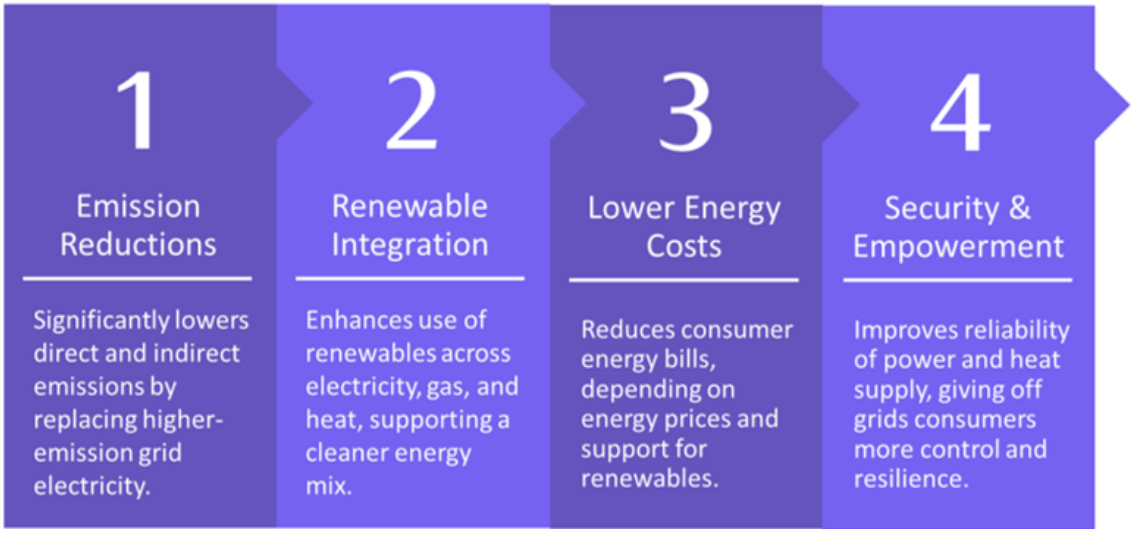

Figure 3: Benefits of highly efficient hybrid buildings.

The Fit4Micro solution responds to major challenges identified for EU's building stock, with a special focus on ensuring affordable supply of clean energy in remote and off-grids buildings. Combining micro-CHP with different renewable technologies helps meet both the high-level objectives and targets set at EU and national levels. Yet certain policy measures and regulatory provisions fall short of fully capturing the benefits of the Fit4Micro solution. [9] [10]

11 CONCLUSIONS

Fit4Micro is developing a hybrid microCHP unit running on sustainable liquid biofuels. Application is foreseen at multi-family houses, and more specifically at remote and/or off-grid locations. The innovative system is based on a double shaft micro gas turbine (mGT) combined with a novel humidification unit. This unique combination leads to increase the electrical efficiencies as well as to obtain a very flexible heat:power ratio. Low emissions are achieved by the application of flameless combustion, and a high GHG emission reduction is obtained by using advanced biofuel.

The integrated hybrid system demonstrator plant was built for the evaluation of a microCHCP trigeneration system based on a humidified microturbine cycle, with also a smart control system developed to enable optimal performance at all times.

Many of the project deliverables are designated as "Public", and those already finalised are available in dedicated sections of the project website, demonstrating the commitment of the consortium on open science practices. Project publications, papers and articles form partners are stored in the Zenodo related community.

In addition, Fit4Micro project in cooperation with other European partners organised events that examined the role of micro-combined heat cooling and power (microCHCP) technologies and their integration with heat pumps in supporting Europe's decarbonisation and energy transition objectives.

Stakeholder engagement is a key aspect of this approach, thus a database of target stakeholders related to the topics of the project has been defined, currently managed, and regularly updated.

Single or grouped stakeholders from any sector being

linked to industry, research and innovation in the field of the clean energy and sustainable and efficient heating systems, and who are interested in sharing and receiving information about Fit4Micro, best practices regarding market implementation, commercialization and deployment of new technologies and processes, are therefore invited to register themselves to the dedicated platforms and events.

12 REFERENCES

[1] Evert Leijenhorst & Bert van de Beld, Deliverable 2.1 Production report of 200 L reference-quality HPO, 01.12.2023

[2] Sangeetha Ramaswamy, Dirk Möntmann, Siri Harboe-Minwegen, Danish Rehman, Deliverable 3.1 Operating parameters combustor, 31.12.2022

[3] Siri Harboe-Minwegen, Deliverable 3.2. Material resistance of combustor and turbine components, report on testing, 30.09.2024

[4] Ward De Paepe, Marina Montero Carrero, Svend Bram, Francesco Contino, Alessandro Parente, Waste heat recovery optimization in micro gas turbine applications using advanced humidified gas turbine cycle concepts, Elsevier, Applied Energy, Volume 207, 1 December 2017, Pages 218-229

[5] Aggelos Gaitanis, Francesco Contino, Ward De Paepe, Optimal waste heat recovery through humidification in 2-spool micro gas turbines: A comparative study of advanced humidified cycles, Elsevier, Energy, Volume 332, 30 September 2025, 136976

[6] Ward De Paepe, Ali Baghernejead, Nicolas Dewaersegger, Deliverable 4.3 Analysis of Humidification techniques for the IRRGT cycle, 31.03.2023

[7] Fraunhofer ISE, Factsheet #2: The Fit4Micro solution and its applications: buildings suitable for the project's technology, 13.12.2023

[8] Søren Løkke, Giovanni Codotto, Emily Greve Somerset, Deliverable 6.1 Technical report on Life Cycle Assessment 1, 30.11.2025

[9] Hans Korteweg, Alexandra Tudoroiu-Lakavice, Dominika, Lange, Deliverable 7.1 Paper on Policy and Regulatory Framework and Recommendations, 19.01.2026

[10] Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU https://data.europa.eu/doi/10.2833/14675

[11] Fit4Micro project website, homepage, https://www.fit4micro.eu/

[12] Cordis, Fit4Micro webpage, https://cordis.europa.eu/project/id/101083536

13 ACKNOWLEDGEMENTS

Funded by the European Union

Fit4Micro Project has received funding under European Union's Horizon Europe programme, Grant Agreement n. 101083536.

14 LOGO SPACE