Centre for Energy and Environmental Technologies – Explorer (CEETe): Advanced Scientific Perspectives and Applications

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Abstract: The Centre for Energy and Environmental Technologies – Explorer (CEETe) is a research platform combining research and development of cross-sectoral cooperation in sustainable energy, aiming to transfer innovative technologies to ensure energy self-sufficiency and raw material independence in the European context. Its interdisciplinary approach enables the efficient decarbonisation of industrial processes, the optimisation of the use of renewable energy sources and the implementation of circular economic models. CEETe's research activities include advanced energy technologies and environmental processes, with key areas being combustion modelling, hydrogen technology development and energy storage. The Centre is actively involved in international research projects and technology transfer to industry. This article provides an overview of the key research areas, current projects and future directions of CEETe's scientific activities, emphasising the integration of advanced technological solutions for sustainable energy and environmental management.

1 INTRODUCTION

The Centre for Energy and Environmental Technologies – Explorer (CEETe) is an interdisciplinary research platform within the VSB-Technical University of Ostrava (VSB-TUO). The primary research focuses on advanced technologies in energy and environmental processes, emphasizing the development of innovative and sustainable solutions for the decarbonizing industry and the efficient utilization of renewable energy sources. The Centre addresses global challenges related to transforming energy systems, promoting a circular economy, and optimizing water and material management. The primary research focuses on advanced technologies in energy and environmental processes, emphasizing the development of innovative and sustainable solutions for the decarbonizing industry and the efficient utilization of renewable energy sources. The Centre addresses global challenges related to transforming energy systems, promoting a circular economy, and optimizing water and material management. The foundation stone of the CEETe polygon was laid on 18 February 2022. After a year and a half of intensive work, the polygon was launched in October 2023.(Misak Stanislav et al., 2024)

In line with the principles of technological innovation and environmental sustainability, the CEETe research platform formulates the following scientific objectives:

- Advanced development of energy systems: - optimisation of technologies for efficient energy conversion, storage and distribution
- Minimisation of environmental externalities - implementation of innovative methods to reduce industrial emissions and ecological impacts.
- Renewable energy integration - modelling and simulation of energy networks with a high share of renewable technologies.
- Industrial cooperation and technology transfer - application of research outputs in industrial sectors to decarbonise production processes.

The CEETe research platform was designed using a digital twin, enabling precise modelling, simulation,

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and optimisation of its energy systems before physical implementation. This approach allowed for detailed analysis of energy flows, component interactions, and operational scenarios, ensuring optimal integration of renewable energy sources, battery storage, and microgrid systems. Figure 1 and Figure 2 show CEETe's digital twin.

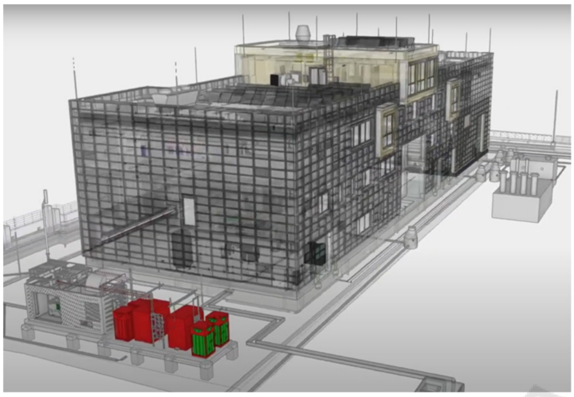

Figure 1: CEETe's Digital Twin.

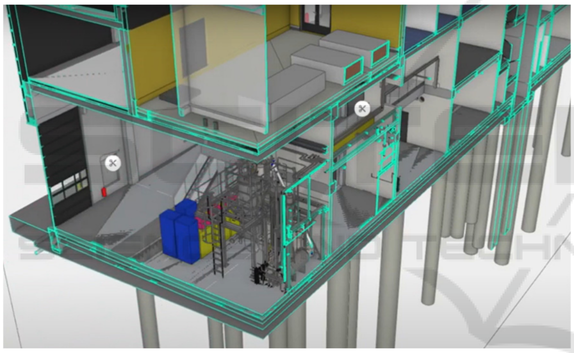

Figure 2: Detail of CEETe's Digital Twin.

CEETe provides an environment for experimental validation of power management and generation models under realistic conditions. Within this platform, the following key elements have been implemented and tested:

- Renewable Energy Integration - CEETe includes the operation of photovoltaic power plants (PV) and other decentralised sources that are key to testing models for energy production and consumption management.
- Energy Resource Flexibility Analysis—The platform simulates various operational scenarios, including controlled charging and discharging of battery storage and real-time prediction of its availability.
- EV charging optimisation - Telematics data and predictive models allow efficient charging cycle management to maximise the use of PV energy and minimise grid draw.
- Dynamic energy flow management—The developed analytical tools monitor and optimise energy flows between generation sources, storage, and consumption in real-time.
- Testing of decision-making algorithms - CEETe serves as a testbed for implementing and validating the developed models for community energy management and their integration into real energy systems.

The early first results achieved within the CEETe research platform confirm the potential of community energy for efficiently managing distributed energy systems. Combining renewables, storage, and intelligent consumption management is key to achieving higher energy self-sufficiency and reduced operating costs.

In the future, CEETe is envisaged as an active energy component of the VSB-TUO campus. It will optimise energy flows within the university infrastructure, including managing individual building consumption and integrating the electric vehicle fleet. This approach will enable more efficient use of renewable resources, reduce the campus carbon footprint, and create a model environment for the future development of decentralised energy communities.

VSB-TUO has seven faculties and two research centres. The campus houses the Rector's Office building, where laboratories and classrooms are located. In the central part of the campus are laboratory facilities, a library, a canteen, CEETe and a kindergarten. This part is connected to the sports facilities and the student dormitory buildings close to the complex. The campus has many modern research centres, and several buildings have won awards. The university campus thus offers maximum comfort, the complex is also close to public transport, has plenty of parking space, and is connected to the forest park. The total area of the campus is 39.7 hectares, and the total electricity consumption is 2 GW·h. A photo of the campus of the VSB-TUO can be seen in Figure 3.

Figure 3: Campus VSB-TUO.

The CEETe project's next phase will extend the test platform with new functionalities, including developing decentralised energy communities, advanced management of peer-to-peer energy transactions and implementing blockchain technologies to ensure transparency and security of energy distributions. The outputs of this phase will contribute to developing a scalable and replicable community energy model with direct application in industrial practice and urban energy systems—a photo of the CEETe is show in Figure 4.

Figure 4: CEETe (CEET Website, 2025).

The article's primary goal is to introduce the potential of CEETe, like technological infrastructure and its role in developing and advancing microgrid management, renewable energy integration, and intelligent energy storage. Furthermore, CEETe can optimise energy flows, enhance grid resilience, and reduce carbon footprint through advanced control algorithms and real-time energy management. Additionally, the article explores future applications of CEETe within the VSB-TUO campus, positioning it as a model for decentralised energy systems and smart community energy management. (Blažek, 2024)

2 ENERGY INFRASTRUCTURE OF CEETe BUILDING

CEETe energy management is based on modified Schneider Electric's comprehensive EcoStruxure™ Microgrid Advisor (EMA) system, which enables advanced real-time control of electricity generation, storage and consumption. This system significantly reduces operating costs and carbon dioxide emissions by optimising energy use from local sources and minimising the demand on the grid. A key feature is the ability to operate autonomously and 'start from dark', so if the external grid fails, the building can immediately switch to off-grid mode and provide a stable electricity supply for key technologies.

The system covers smooth transitions between parallel and off-grid operation, regulating both voltage and frequency so that the operation does not suffer outages or performance degradation at any stage. The power solution also includes a peak load management mechanism that continuously evaluates current demand and renewable resource availability and balances any imbalances between generation and consumption through battery storage. These features ensure high power reliability while ensuring efficient energy management.

The basis of the local electricity generation is a photovoltaic system comprising 473 panels (type JAM60S21-370/MR from JA Solar Holdings Co., Ltd.) with a total area of 883.7 m², which are placed on the roof and facades of the building in the east, south and west directions. Optimisers have been installed to maximise efficiency. The resulting system has a projected annual specific energy gain of 516.3 $kW \cdot h \cdot kWp^{-1}$ and an annual production of approximately 90.505 MW·h. The complex also includes a 500-kW·h battery storage facility with a 250 kVA Schneider Electric inverter and batteries from Pylontech. This allows surplus PV to accumulate energy and be used later, for example, for peak shaving or off-grid. Pylontech batteries are shown in Figure 5.(CEET Website, 2025)

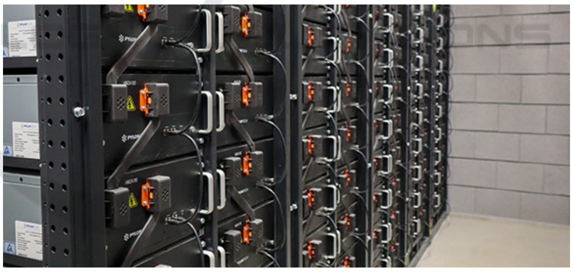

Figure 5: Pylontech Batteries.

3 HYDROGEN INFRASTRUCTURE

The hydrogen technology laboratory is equipped with technological equipment for the electrolytic production of hydrogen and equipment for its reverse conversion into electricity using fuel cells. Fuel cells produce DC electricity and heat by directly converting hydrogen fuel and oxidant to electrical energy in a catalytic process that uses a non-explosive and non-flammable fusion reaction. Pure hydrogen gas with defined purity and parameters is used as the fuel, and air is used as the oxidant. The fuel cell modules or fuel cell 'stacks' shall use chemical and physical processes consistent with polymer proton exchange membrane technology, and the individual fuel cell 'stacks' shall be designed for this technology.

According to established international nomenclature, the laboratory has installed low-temperature fuel cell modules classified as Proton Exchange Membrane Fuel Cells, commonly called PEM or PEMFC fuel cells. The laboratory is designing the distribution and metering systems for industrial gases to enable the connection of fuel cells with an installed power of approximately 100 kWe. The envisaged installation, serving the research purposes of CEETe, consists of 5 modules ("stacks") in a primarily series electrical connection, with a total installed output power of 50 kW, used to generate electricity (and heat) from the supplied hydrogen gas with defined parameters. (CEET Website, 2025)

The electrical power is connected via a coupling power converter in the hydrogen laboratory control room to an AC bus at a 3 x 230/400 V for other CEETe process units. The heat produced (up to 80 CEET Web (2025)kWt) is mainly dissipated through a water-cooling circuit with demineralised water, with a temperature gradient of 65/60 °C, which will be divided into two parts by a heat exchanger, with the secondary part already being part of the waste heat recovery system for building purposes. As a matter of interest, we have added Figure 6 which shows the hydrogen laboratory's digital design, and Figure 7 shows an actual photo of the hydrogen laboratory.(CEET Website, 2025).

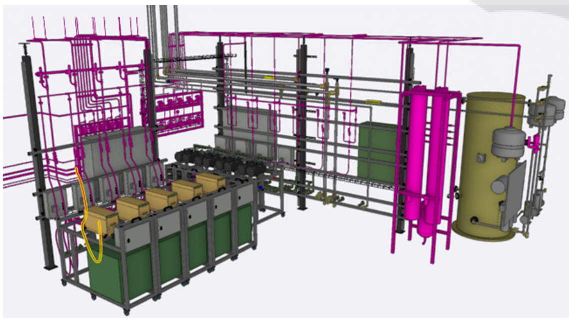

Figure 6: Digital Model of Hydrogen Laboratory.

The input media for the fuel cells will be:

- humidified reaction air (up to 5 · 500 $N\cdot l\cdot^{-1}$), supplied from the reaction air supply system by blowers (compressors),
- hydrogen gas (up to 5 · 200 $N\cdot l\cdot min^{-1}$) stored in the outdoor hydrogen filling station.

The inerting of the fuel cells will be carried out using nitrogen gas.

Figure 7: Hydrogen Laboratory.

The electrolysers produce hydrogen gas with defined parameters and quality per the specifications below. They are principally based on water electrolysis or a suitable aqueous electrolytic solution utilising solid ion polymer membrane technology. Furthermore, industrial gas distribution and metering systems in the laboratory are designed to connect two types of electrolysers with an installed max power of 85 kWe.(CEET Website, 2025)

The AEM-type electrolysers are installed in several freestanding modular carts. The hydrogen gas produced will be extracted from the individual production units via separate pressure hoses containing the required number of hydrogen production equivalents, i.e., 4 $N\cdot m^3\cdot block^{-1}$. The operating hydrogen production by these electrolysers is assumed to be at least 1 $N\cdot m^3\cdot h^{-1}$ (max. 8 $N\cdot m^3\cdot h^{-1}$) at a pressure of 30 bar, with a system of treating the physical parameters of hydrogen—separation of residual moisture—incorporated into the pipeline route of the produced hydrogen. The medium (electrolyte) for hydrogen production is a demineralised water solution with 1% K2CO3+ KHCO3. (CEET Website, 2025)

The electrolyte circuit, which serves the purpose of both cooling and supplying reaction water, will be automatically replenished during the operation of the AEM electrolysers in the amount of 4 $l\cdot h^{-1}$ for each production unit, i.e., up to 8 $l\cdot h^{-1}$ in total. The electrolyte circuit removes heat from the electrolyser units with a value of 12 kWt while maintaining a temperature gradient of 45/40 °C. In the supply branch of this circuit, primarily located one floor above (the room of the air handling plant), the heat exchanger will be connected to the central cooling water source of CEETe. The return line (from the electrolyser outlet), containing not only the electrolyte but also the gaseous oxygen produced by electrolysis in a quantity of at least 2 $Nm^3\cdot h^{-1}$ (max. 4

$N \cdot m^3 \cdot h^{-1}$), will be discharged into a non-pressurised expansion tank from which the accumulated oxygen and the water mist produced in the tank will be actively vented outside the building by a fan. The vessel will also incorporate electrical heating for the start-up phase of the electrolysers. Their inerting will be carried out with nitrogen gas. As a matter of interest, we have added Figure 8, which shows the outdoor hydrogen filling station during refuelling for the hydrogen vehicle.(CEET Website, 2025)

Figure 8: Hydrogen Refuelling for the Vehicle.

4 THE THERMOCHEMICAL CONVERSION LABORATORY

The Thermochemical Conversion Laboratory focuses on research into advanced technologies for the thermo-chemical conversion of waste materials, with plasma gasification being a key activity area. This innovative technology is a highly efficient and environmentally friendly method of converting waste into energy-using products, overcoming the limits of traditional incineration and standard gasification processes. The extremely high temperatures of up to 2000 °C in the plasmatron result in near-perfect decomposition of the feedstock and minimise unwanted emissions or solid residues.

The entire plasma gasification process consists of several stages. The first step is the pre-treatment and dosing of the raw materials, which are then fed into the plasma reactor, where they are gassed under intense thermal radiation. The resulting synthesis gas (syngas) is then subjected to a multi-stage purification process, where unwanted components are removed, and the individual fractions are separated. This treated gas can then be used in various energy applications, for example, for the production of synthetic hydrocarbon fuels, for the cogeneration of electricity and heat, or for the production of hydrogen, which, after separation and purification, can be used in fuel cells.

The laboratory is equipped with a state-of-the-art 150 kW plasmatron, part of a complex technological system including a superheated steam generator, cooling circuit, raw material transport system, oxidation medium supply and waste management. Synthesis gas purification is carried out in several stages using high-temperature filtration, wet and alkaline scrubbing and advanced membrane separation, which allows selective extraction of key gases, including hydrogen.

One of the main advantages of plasma gasification is that it is environmentally friendly, as the process generates minimal harmful emissions and allows efficient use of the energy potential of the waste. Dioxins and nitrogen oxide emissions are significantly reduced compared to conventional incineration technologies. At the same time, residual inorganic components are converted into inert glassy slag that can be further used, for example, in the construction industry. Another advantage is the high flexibility of the process, which allows the treatment of a wide range of materials, including biomass, plastics, industrial waste and hazardous substances.

The laboratory currently focuses on optimising the hydrogen separation process for its subsequent use in fuel cells and the efficient production of synthetic hydrocarbon fuels. An important research direction is linking plasma gasification technology with hydrogen management and its potential integration into decentralised energy systems.

The thermochemical conversion laboratory is thus creating a unique platform for developing and testing advanced technologies for converting waste into clean energy products, hence contributing to the development of the circular economy and sustainable energy solutions. The research results have potential for industrial applications and wide deployment in municipal and local energy systems, which can contribute significantly to minimising negative environmental impacts and increasing energy self-sufficiency. As a matter of interest, we have added Figure 9, which shows the digital model of the thermochemical conversion laboratory digital design, and Figure 10, which shows an actual photo of the thermochemical conversion laboratory.

The thermochemical conversion laboratory is thus creating a platform for developing and testing advanced technologies for converting waste into clean energy products, contributing to the development of the circular economy and sustainable energy solutions. The results have the potential for industrial applications and wider deployment in municipal and local regional energy systems, which can significantly minimise negative environmental impacts and increase energy self-sufficiency.(CEET Website, 2025)

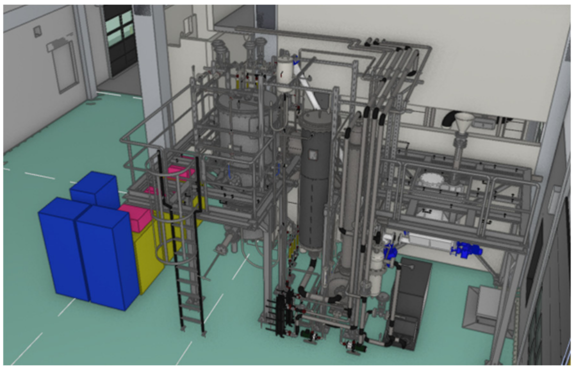

Figure 9: Digital Model of Thermochemical Conversion Laboratory.

Figure 10: Thermochemical Conversion Laboratory.

5 CONCLUSIONS

CEETe is a key element of modern research and development in sustainable energy and environmental technologies. Its interdisciplinary approach enables the efficient integration of renewable resources, the development of hydrogen technologies, the optimisation of microgrid management, and the implementation of circular economic models. Advanced digital simulation and the digital twin concept have created a unique platform that allows experimental validation, predictive control, and optimisation of energy flows in real-time.

The results obtained so far confirm the high potential of decentralised energy communities and the importance of efficient management of distributed energy systems. The combination of photovoltaics, battery storage, hydrogen infrastructure and intelligent control algorithms allows for achieving higher energy self-sufficiency, optimising consumption and reducing operating costs. Thus, CEETe becomes a reference model for applying advanced technologies in academic settings, industrial practice, and urban energy systems. A full schematic of the CEETe technology is attached for completeness. Not everything could be described in the article. The article would be substantially extensive. The article serves as a basic description of the technology platform.

In the future, the CEETe testbed is envisaged to be extended with new features, including developing decentralized energy communities, advanced peer-to-peer energy transaction management, and blockchain technologies to ensure transparency and security of energy trading. Future directions of the project will include deeper integration of renewable energy sources into the university infrastructure to create a smart and adaptive energy system for the VSB-TUO campus that will serve as a model for future decentralized energy systems.

The results achieved within the CEETe research platform thus represent a significant contribution to innovation in sustainable energy and environmental management. Their application will enable more efficient use of energy resources, carbon footprint reduction, and energy independence development within the European context.

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APPENDIX

The technical diagram of the CEETe research platform is attached on the next page. The diagram describes the interaction of the different technologies. (Blažek, 2024).