NATIONAL
CENTRE
FOR ENERGY

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NATIONAL CENTRE FOR ENERGY II

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CONTENT

1 EXECUTIVE SUMMARY

This Policy Brief has been prepared as a joint output of two strategic projects: the National Centre for Energy II (NCE II)[1] and the Centre for Advanced Nuclear Technologies II (CANUT II)[2]. Drawing on an analysis of scientific findings from leading European institutes, the document provides a synthesis of the latest technological trends, research insights and strategic recommendations for the development of the Czech energy sector up to 2035. Attention is paid to strengthening the link between research and public policymaking (*knowledge-to-policy*). The Policy Brief aims to initiate a discussion on the need to establish an independent institute in the field of energy which would serve as a highly specialized advisory body to the Government of the Czech Republic.

NCE II and CANUT II represent complementary pillars of the Czech Republic's energy transition. Together they create an integrated knowledge base that connects research, development, innovation and strategic advisory services for public administration and industrial partners. Through their cooperation, a unique expert platform is emerging, capable of providing government and institutions with independent recommendations, foresight analyses and proposals for measures that reflect technological developments, European legislation and the needs of Czech industry. The shared ambition of both projects is that the country should not merely be a recipient of global trends, but an active shaper and innovation hub in the field of low-carbon energy – both non-nuclear and nuclear. Hence, this first Policy Brief presents:

- an overview of the main technological directions in the energy sector,
- the economic, research and societal implications of deploying these technologies,
- recommendations for public policymaking that make effective use of research potential.

The document also proposes an implementation structure for knowledge-to-policy designed to link the outputs and results of NCE II and CANUT II with decision-making practice in public administration through four instruments: **Foresight Briefs, Policy Options Papers, Rapid Response Notes and Implementation Audits**. The dissemination of the essential findings to the target group of stakeholders and political decision-makers in selected ministries will, unlike in many other Policy briefs[3], be carried out in a transparent manner. The sustainable energy in the context of the circular economy is currently not the subject of any existing Policy Briefs, nor has such a body yet been established at EU level.[4]

[1] NCE II focuses on low-carbon and modern energy technologies – in particular hydrogen technologies, renewable energy sources, energy storage, flexibility, intelligent grid control, waste heat utilization and the circular economy. Its objective is to connect excellent research with industrial practice and to support the transformation of the Czech economy towards decarbonization, energy self-sufficiency and technological competitiveness.

[2] CANUT II is oriented towards the development of advanced nuclear technologies as an essential component of low-emission energy systems. The project is devoted to research and development aimed at enhancing safety, extending service life and increasing the reliability and efficiency of existing nuclear power plants, as well as to the development of advanced nuclear technologies and small modular reactors (SMRs) in the areas of materials engineering, technologies, safety systems and the integration of nuclear sources into hybrid energy systems combining nuclear with renewable energy sources and other modern technologies (such as energy storage). At the same time, it analyses the social, economic and legislative aspects of the development of nuclear energy in the Czech Republic and at the level of the European Union, with emphasis on safety, sustainability, competitiveness and public acceptability.

[3] Policy Briefing Papers and INSPIRE Policy Briefs of the London School of Economics and Political Science are published on the SSRN preprint server; the University of Cambridge pursues dissemination primarily through its own Corporate Leaders Groups; the University of Oxford, in turn, curates Reports & Policy Briefs produced by other academies.

[4] The Council for Research, Development and Innovation is established by Act No. 130/2002 Coll., on the support of research, experimental development and innovation from public funds and on the amendment of certain related acts (the Act on the Support of Research, Experimental Development and Innovation), and by Government Regulation No. 397/2009 Coll., on the information system for research, experimental development and innovation. From the perspective of the energy sector, however, we see scope for an independent advisory body with a dedicated specialization in this field (see Section 2.2).

2 MAIN TECHNOLOGICAL DIRECTIONS AND THE ECO-SOCIAL DIMENSION

2.1. MAIN TECHNOLOGICAL TRENDS AND LINKS TO THE ACTIVITIES OF NCE II & CANUT II

A global megatrend in energy and industry is decarbonization[5], i.e. the transition to low-emission energy sources with the aim of achieving climate neutrality by 2050. Technological innovation is directed towards meeting the objectives of the Paris Agreement and the European Green Deal, while at the same time responding to new European legislative initiatives (such as Fit for 55, REPowerEU, the Net-Zero Industry Act and the Critical Raw Materials Act). In this context, several major technological directions – megatrends – are emerging, which at the same time represent the main pillars of the research carried out within the NCE II and CANUT II projects.

2.1.1. ALTERNATIVE FUELS (TA1: SYNTHETIC FUELS, ADVANCED BIOFUELS AND HYDROGEN)

The substitution of fossil fuels in transport and industry with synthetic fuels, advanced biofuels and renewable or low-carbon hydrogen is developing rapidly worldwide. Synthetic fuels and biofuels are already in the demonstration phase (technology readiness level TRL ~7), and their large-scale deployment is expected around 2030–2035, when their cost could approach that of fossil fuels. Hydrogen produced by electrolysis (or via fossil-based routes with carbon capture) represents another crucial area – projections indicate that by 2030 global demand for hydrogen could exceed supply by approximately 13 million tons per year. This underlines the need to expand production capacities and to develop new technologies for the production, storage and distribution of H_2. In addition, the EU has set criteria for renewable hydrogen (RFNBO) in its delegated acts (EU 2023/1184 and 2023/1185) – the Czech national support and certification scheme needs to be aligned with these regulations.

NCE II is developing advanced CO_2-to-X processes, the production of e-fuels and green hydrogen from renewable energy sources, while CANUT II is linking nuclear heat sources (SMR, HTR) with electrolysis and fuel synthesis.[6] Together, the two projects thus contribute to the megatrend TA1 – Alternative fuels, and thereby to the development of the hydrogen economy and the substitution of fossil fuels in the Czech market.[7] Emphasis is placed on the development of low-carbon hydrogen in line with European RFNBO requirements and on its integration with the planned hydrogen pipeline network in the Czech Republic.

INTERLINKAGES: **TA1 →** DEVELOPMENT OF E-FUELS AND CO_2-TO-X PROCESSES (NCE II); INTEGRATION OF HEAT FROM SMRS AND HTRS FOR HIGH-TEMPERATURE ELECTROLYSIS AND FUEL SYNTHESIS IN HYBRID NUCLEAR–RES SYSTEMS (CANUT II).
HYDROGEN → RESEARCH ON PEM AND AEM ELECTROLYSIS, LOCAL H_2 HUBS AND HYDROGEN NETWORK MODELS (NCE II); STABLE NUCLEAR SOURCES OF HEAT AND ELECTRICITY FOR LARGE-SCALE H_2 PRODUCTION (CANUT II).

[5] (Awijen et al., 2022); (Fan et al., 2023); (Pauliuk et al., 2021); (Rissman et al., 2020); (Valera-Medina et al., 2021);
[6] (Kober et al., 2020); (Ruhnau et al., 2023); (Slamersak et al., 2022); (Yalew et al., 2020);
[7] (Baeyens et al., 2020); (Ines et al., 2020); (Lebrouhi et al., 2022); (Odenweller et al., 2022);

INFRASTRUCTURE → PREPARATION FOR FUTURE HYDROGEN PIPELINES, SAFETY ANALYSES AND H_2-RESISTANT MATERIALS (NCE II + CANUT II). **REGULATORY FRAMEWORK →** ALIGNMENT OF CZECH PRACTICE WITH EU RFNBO REQUIREMENTS (2023/1184 AND 2023/1185) AND THE IMPLICATIONS FOR CERTIFICATION OF E-FUEL AND HYDROGEN PRODUCTION PLANTS IN THE CZECH REPUBLIC.

2.1.2. CIRCULAR ECONOMY AND ENERGY RECOVERY FROM WASTE (TA2)

Technologies for converting waste into energy and for the advanced recycling of raw materials are growing in importance. **Thermochemical waste conversion** (e.g. pyrolysis, thermolysis) is an attractive method which, after 2030, could be deployed more extensively for the production of hydrogen, synthetic fuels and heat (TRL 7–9). A related trend is advanced material recycling, for example of plastics – at present, only about 38% of plastic waste is recycled in the EU. The EU is therefore moving towards **a ban on landfilling recoverable waste by 2030**, which requires making existing recycling technologies (TRL 8–9) more efficient and developing new ones. Another crucial area for the future is the recycling of lithium-ion batteries from electric vehicles: a much greater need will emerge after **2035**, when the first generation of batteries reaches end of life, which is why it is already necessary to invest in the development of recycling processes (currently TRL ~4–5) to recover valuable materials. Effective battery recycling may represent substantial economic potential in the future.

The field of the circular economy also includes research into the reprocessing of spent nuclear fuel. **Advanced reprocessing methods** make it possible to utilize the residual energy potential of the fuel and to reduce the volume of long-term stored radioactive waste. These technologies are already used to a limited extent on an industrial scale; in the medium term, the deployment of advanced reprocessing technologies based on pyrochemical processes is envisaged (currently at TRL ~4–5). For the Czech Republic, the use of mixed nuclear fuels based on MOX, which are already routinely applied worldwide, is likewise relevant.

NCE II addresses thermochemical processes for the energy recovery of waste, plastics recycling and the recovery of critical raw materials from batteries.[8] **CANUT II builds on this through research into advanced materials for nuclear technologies, which can also be used in facilities for the treatment and disposal of radioactive waste and spent nuclear fuel, including technologies for a closed fuel cycle.**[9] Together, these two lines of research embody the principles of the circular economy – transforming waste into sources of energy and materials.

INTERLINKAGES: **TA3** → THERMOCHEMICAL CONVERSION IN PILOT LINES AT VSB-TUO; **TA4–TA5** → HYDRO- AND PYRO-RECYCLING OF LI-ION BATTERIES, CANUT II PROVIDES MATERIAL MODELS FOR RESISTANT MATERIALS AND TECHNOLOGIES FOR THE TREATMENT OF RADIOACTIVE WASTE; **TA6** → UTILISATION OF WASTE HEAT AND INTEGRATION INTO LOW-TEMPERATURE NETWORKS CONTROLLED BY AI.

2.1.3. RENEWABLE ENERGY SOURCES AND ENERGY EFFICIENCY (TA3)

Renewable energy sources (RES) – particularly, solar, wind, hydropower and geothermal energy – are now mature and widely deployed technologies (TRL 9) and will continue to grow significantly. For the

[8] (Frith et al., 2023); (Kohse-Hoeinghaus, 2023); (Lebrouhi et al., 2021); (Roy et al., 2024); (Zhu et al., 2022);

[9] (Breyer et al., 2022); (Ruhnau et al., 2023); (Alavi et al., 2021);

period 2023–2031, the global RES market is projected to grow on average by around **12% per year**. For the Czech Republic, this creates pressure to make better use of its domestic potential: for example, wind power currently covers only about **1%** of electricity consumption in the country, even though the conditions (e.g. in South Moravia or in the border mountain regions) are comparable to areas where wind energy is far more developed.

An integral part of this trend is the **utilization of waste heat and the improvement of energy efficiency**. Technologies for waste heat recovery – such as heat exchangers, recuperation units or ORC (Organic Rankine Cycle) systems – are commercially available and rapidly expanding (the market for these technologies is expected to grow from around USD 56 billion to USD 108 billion between 2023 and 2031). The priority is to further increase the efficiency of these systems, including new applications (for example, the deployment of ORC microturbines to utilize low-grade heat).

NCE II advances the development of solar, wind and geothermal technologies, including hybrid RES + storage installations. CANUT II develops models of hybrid energy systems that combine SMRs with RES and storage, enabling flexible production of electricity, heat and hydrogen. In this way, the megatrend **TA3 – RES and efficiency** – is translated into practice, creating a highly efficient low-carbon energy system adapted to the conditions of the Czech Republic.

INTERLINKAGES: NCE II → PILOT PROJECTS OF SOLAR + BATTERY SYSTEMS IN COMMUNITY ENERGY; CANUT II → UTILISATION OF HEAT FROM SMRS IN DISTRICT HEATING AND INDUSTRY, ANALYSIS OF THE EFFICIENCY OF INTEGRATING SMRS INTO SMART-GRID REGIONS.

2.1.4. SMART GRIDS AND ENERGY COMMUNITIES (TB1–TB3)

The integration of large numbers of decentralized sources requires modern energy networks with advanced control. **Smart grid technologies** address grid fluctuations associated with a growing share of RES – they include, for example, semiconductor transformers, advanced controllers, high-voltage DC systems for data centers and sophisticated software for real-time management of supply and demand. These components have already reached a high level of technological maturity (TRL 7–9), and their wider deployment is expected around 2028, in parallel with the reinforcement of transmission and distribution infrastructure.

With the decentralization of the energy sector, **energy communities** are emerging that allow local producers and consumers to share energy within local networks. In the Czech Republic, a legislative framework for community energy (the so-called **Lex OZE II**) was introduced first, followed by **Lex OZE III** adopted in March 2025 – the latter expands the possibilities for aggregation, flexibility and storage. The implementation of secondary legislation and the commissioning of the energy data centre is taking place in 2025–2026. In advanced economies, energy communities already support the development of local grids, and it is expected that in the Czech Republic they will be fully operational after **2028**, actively contributing to the management of energy flows in low-voltage distribution networks.

New media and infrastructure for their distribution represent another trend: with the emergence of the hydrogen economy, dedicated **hydrogen pipelines** (H_2 pipeline networks) are being developed, along with the transport of liquid or liquefied hydrogen, the use of liquid organic hydrogen carriers (LOHC) and innovative hydride-based storage systems. These technologies require substantial infrastructure investment but are essential for future hydrogen supply. In the heating sector, the integration of RES into district heating systems and the transition to low-temperature district heating are taking place in parallel – pilot installations already employ solar thermal systems, large-scale heat pumps and geothermal sources (currently at TRL ~7–8).

NCE II is therefore developing intelligent control systems, predictive maintenance and energy data hubs (linked to Lex OZE III), while CANUT II deploys digital twins and AI-based diagnostics for the operation of large nuclear units as well as SMRs.[10] Together, they are creating the architecture of "**smart defense grids**" – secure and autonomous future networks interconnecting decentralized renewable energy sources and nuclear units.

INTERLINKAGES: **TB1** → ADVANCED CONTROL SYSTEMS FOR DECENTRALISED SOURCES; **TB2** → MODELS OF ENERGY COMMUNITIES AND ENERGY SHARING; **TB3** → TECHNOLOGIES FOR THE DISTRIBUTION OF HYDROGEN AND LOW-TEMPERATURE HEAT; (ORIGINAL TB4 → DIGITAL TWINS AND AI-BASED CONTROL FOR DISPATCH CENTRES AND NUCLEAR POWER PLANTS).

2.1.5. ENERGY STORAGE AND ENERGY FLEXIBILITY (TC1–TC4)

To balance supply and demand in a low-carbon energy system, efficient energy storage technologies are essential. Promising options include **new generations of batteries** – for example solid-state lithium-ion batteries with higher capacity and faster charging for electric vehicles. These batteries are under development (currently at TRL 5–6, with prototypes around 2025), and after **2030** they are expected to enable driving ranges of up to roughly **1,200 km** and full charging in about **10 minutes**. For large-scale stationary storage and grid stabilization, vanadium **redox flow batteries and Carnot batteries** are being tested – these technologies are still at an early stage (TRL ~4–5), and their wider deployment is likewise expected only after 2030.

Storing energy in the form of hydrogen represents another storage pathway: today, high-pressure tanks dominate (TRL 8–9), but development is moving towards safer and lighter vessels with pressures of up to around 1,000 bar using advanced steels and composites – their deployment is expected by the end of this decade (TRL 6–7). **Thermal energy storage** (TES) systems are also being developed – existing technologies (e.g. hot water tanks, molten salts or phase-change materials) are often already commercially available (TRL 8–9), and the thermal storage market is growing at around **10% per year**. After 2030, new options are expected to emerge, such as heat storage at temperatures above 1,000 °C for industrial applications. Equally important are energy-efficient systems and their control. Advanced **energy management systems** (EMS) use digital technologies for optimized control of energy consumption in industry, buildings and households.[11] These systems are already available (TRL 9), and their global market is expected to grow from around USD 63 billion to approximately USD 240 billion by 2030 (on average about 16% per year). The most dynamic development is anticipated in smart energy management software, which will enable advanced demand-side management and improvements in energy efficiency.

NCE II is developing new generations of batteries (solid-state, vanadium redox, Carnot batteries) as well as advanced thermal storage systems. CANUT II integrates energy storage into SMR models and

[10] (Cavus et al., 2025); (Gao & Liu, 2021); (Lebrouhi et al., 2022); (Rissman et al., 2020); (Stephens et al., 2022); (Vinuesa et al., 2020); (Zia et al., 2020);

[11] (Eshetu et al., 2021); (Lin et al., 2021); (Menye et al., 2025); (Tapia-Ruiz et al., 2021);

develops materials resistant to radiation, high temperatures and cyclic loading.[12] Together, they address **megatrends TC1–TC4** (storage of electricity, hydrogen and heat, and demand-side management), laying the foundations for flexible and resilient energy systems.

INTERLINKAGES: TC1 → BATTERY STORAGE SYSTEMS FOR ELECTROMOBILITY AND GRID STABILISATION (NCE II); TC2 → HYDROGEN ENERGY STORAGE IN COMPOSITE PRESSURE VESSELS AND HYDRIDE-BASED STORAGE SYSTEMS; **TC3** → HEAT STORAGE FROM INDUSTRIAL PROCESSES AND SMRS; **TC4** → AI-DRIVEN ENERGY MANAGEMENT OF BUILDINGS.

2.1.6. ADVANCED NUCLEAR TECHNOLOGIES (TA4)

Small modular reactors (SMRs) rank among the most important energy innovations of recent decades. Thanks to their modularity, lower upfront costs and enhanced safety, they enable flexible and decentralized energy production – not only in the power sector, but also for industry, district heating and hydrogen production. Several SMR concepts are currently undergoing licensing (e.g. GE BWRX-300, NuScale VOYGR, Rolls-Royce SMR), and the first commercial units could be in operation already during the 2030s. By 2030, SMR pilot projects are expected to be commissioned, confirming their technical and economic feasibility; by **2050**, a broad global fleet of SMRs is anticipated, including their deployment in hybrid energy systems together with RES – SMRs could thus form a substantial part of the decarbonized energy mix.

At the same time, research is underway on **advanced Generation IV reactors** – for example high-temperature gas-cooled reactors, sodium-cooled fast reactors or molten salt reactors – which will enable higher efficiency and the use of new materials and coolants. Demonstration deployment of these designs is envisaged after **2035**, as they are still at lower stages of technological readiness. Nuclear fusion also represents a highly significant prospect – the ITER project is a major milestone on the path towards the commercial use of fusion. **Fusion energy** could reach the demonstration phase around **2040**, which implies a realistic possibility of deployment in the period after 2035.

Safety remains a fundamental requirement in nuclear energy and in the energy sector. The trend is a shift towards **passive and inherent safety systems** (e.g. in SMRs and Generation IV reactors) and the use of advanced materials and accident-tolerant fuels **ATF** (ACCIDENT TOLERANT FUELS) that enhance operational safety. These developments reflect international frameworks (the Convention on Nuclear Safety and IAEA safety standards and guides). With increasing digitalization, greater emphasis is also being placed on the protection of control systems and infrastructure – by 2050, the cybersecurity of energy networks and nuclear facilities will form an integral part of their architecture. Autonomous AI systems capable of detecting and neutralizing cyberattacks in real time are also being developed.

CANUT II is developing small modular reactors (SMRs), new fuel cycles and materials with the aim of enhancing the safety, efficiency and reliability of nuclear energy. The project also explores options for using nuclear energy to support CO_2 capture and utilization (CCUS) processes as part of industrial decarbonization. At the same time, CANUT II is advancing digitalization and artificial intelligence – for

[12] (Bogachuk et al., 2020); (Khenkin et al., 2020); (Zampardi & La Mantia, 2022);

example predictive maintenance, autonomous reactor control and cybersecurity of critical infrastructure, drawing inspiration from other segments of the energy sector.[13]

INTERLINKAGES: **TD1** → SMRS AS A STABLE ENERGY SOURCE FOR CCU AND SYNTHETIC FUELS; **TAI** → AI ALGORITHMS FOR DIGITAL TWINS AND THE CONTROL OF COMPLEX ENERGY PROCESSES IN THE ENERGY SECTOR.

2.1.7. SECURITY AND RELIABILITY OF ENERGY SYSTEMS (TD1–TD3)

The **TD** megatrends reflect the growing need for a resilient and secure energy system. *TD1 – nuclear safety* – is moving towards the use of passive safety systems (especially in SMRs and Generation IV reactors) and accident-tolerant fuels (ATF); these technologies are broadly proven (**TRL 9**), and follow-up innovations are being pursued through testing. **TD2 – cybersecurity and infrastructure security** – responds to the digitalization of the energy sector: by 2030, European standards for the protection of control systems will be harmonized, and by 2050 cybersecurity will be fully integrated into the architecture of energy networks (also **TRL 9**). **TD3 – sensors and predictive diagnostics** – relies on advanced sensor networks, digital twins and AI for early fault detection; these technologies are available (**TRL 8**), but their large-scale integration is progressing gradually.

NCE II and CANUT II are putting the TD megatrends into practice through the development of digital twins, predictive diagnostics for SMRs, safety components and advanced systems for the control and protection of

INTERLINKAGES**: TD1** → DESIGN OF PASSIVE SAFETY SYSTEMS FOR SMRS, TESTING OF ATF FUELS, MODELLING OF ACCIDENT SCENARIOS (CANUT II); **TD2** → CYBERSECURITY OF DISTRIBUTION NETWORKS, DIGITALISATION OF THE CONTROL CENTRE, SECURING SMR CONTROL SYSTEMS; INTEGRATION INTO THE ENERGY DATA CENTRE (NCE II + CANUT II); **TD3** → PREDICTIVE DIAGNOSTICS OF TURBINES, HEAT EXCHANGERS, ELECTROLYSERS AND SMRS USING DIGITAL TWINS AND AI; SENSORS FOR MONITORING MATERIAL DEGRADATION IN NUCLEAR AND NON-NUCLEAR TECHNOLOGIES (NCE II + CANUT II).

2.1.8. SOCIETY, WASTE AND SUSTAINABILITY (TE1–TE3)

The **TE** megatrends broaden the technological perspective by including the long-term impacts on the environment and society. **TE1 – waste and decommissioning** – covers the safe management of energy-related waste (including radioactive waste), the development of a deep geological repository (in the Czech Republic, a decision on the site is to be taken by 2030) and research on closing the fuel cycle; the core processes are at **TRL 9**, while advanced pyrochemical methods and transmutation are at lower TRL levels. **TE2 – environmental impacts and sustainability** – addresses the reduction of the environmental footprint of RES, hydrogen and batteries through circular design and recycling; conventional recycling technologies are mature, but new materials (composites, solar panels, Li-ion batteries) require further development (**TRL 7**). **TE3 – social acceptance** – emphasizes transparent communication, participatory planning and the use of digital tools (AI-based visualization) in line with the Aarhus Convention; participation technologies are at **TRL 8**, but their systematic use remains a challenge.

[13] (Alam et al., 2022); (Cavus et al., 2025);

NCE II and CANUT II support the TE megatrends through research on battery recycling, the material cycle of nuclear energy, socio-economic analyses and participatory approaches in regions undergoing transformation.

INTERLINKAGES: **TE1** → RESEARCH ON RECYCLING AND REPROCESSING OF LI-ION BATTERIES (NCE II), ADVANCED METHODS FOR RADIOACTIVE WASTE MANAGEMENT, PYROPROCESSES AND CLOSING THE FUEL CYCLE (CANUT II); **TE2** → ASSESSMENT OF THE ENVIRONMENTAL IMPACTS OF RES, HYDROGEN TECHNOLOGIES AND BATTERY SOLUTIONS (NCE II); ANALYSIS OF THE SUSTAINABILITY OF NUCLEAR MATERIALS AND DECOMMISSIONING (CANUT II); **TE3** → SOCIO-ECONOMIC MODELS OF REGIONAL TRANSFORMATION, PUBLIC PARTICIPATION IN RES AND H_2 HUB PROJECTS (NCE II); COMMUNICATION OF SMR AND NUCLEAR TECHNOLOGY SAFETY TO THE PUBLIC (CANUT II).

2.1.9. INTERNATIONAL FRAMEWORKS AND RESEARCH OUTLOOK TOWARDS 2035

The technological megatrends described above represent a major challenge for the Czech Republic, but also an opportunity. They are closely interconnected with international climate and energy objectives and cannot be ignored. As an open economy, the Czech Republic must systematically monitor global developments and respond appropriately. **The activities of NCE II and CANUT II jointly cover the full set of megatrends TA1–TE3** and, in practice, help to deliver the objectives of decarbonization and energy sovereignty of the Czech Republic. While NCE II focuses on the non-nuclear part of low-carbon energy and infrastructure, CANUT II provides the nuclear and materials pillar. Together, the two platforms form an integrated ecosystem of excellence and knowledge transfer, linked to national and European frameworks (the updated State Energy Policy 2024, NECP 2030 and European initiatives such as NZIA, CRMA, etc.).

In shaping its policies, the Czech Republic relies on the Paris Agreement, the European Green Deal, the FIT FOR 55 package and the REPOWEREU plan. These frameworks define milestones such as the phase-out of coal in the energy sector, the development of electromobility by 2035 and improvements in energy efficiency by 2030. The technological trends mentioned – synthetic fuels, hydrogen, CCUS, AI, RES and energy storage – jointly support the achievement of these objectives. For research in the Czech Republic, this implies the following priorities: (i) focus on hydrogen technologies, new battery materials, digital twins and AI, recycling processes and advanced materials; (ii) align national strategies (State Energy Policy 2024, climate strategy, RIS3) with European initiatives (NZIA, CRMA, etc.); (iii) develop pilot plants (e-fuels, H_2 hubs, smart-grid regions, CO_2 geological storage); (iv) introduce regular technology foresight.

Detailed outlook towards 2035:

- **Synthetic fuels** enter large-scale deployment (after 2030; cost-competitive with fossil fuels).
- **Solid-state batteries** become standard in EVs (after 2030; ranges of around 1,200 km, ultra-fast charging of about 10 minutes).
- **Vanadium redox, Carnot and other long-duration batteries** are used for grid stabilization (after 2030; deployment in line with the growing share of RES).
- **Recycling of Li-ion batteries** becomes standard practice (after 2035; processing of large volumes of EV batteries).

- **The first SMRs** in Europe are in operation (during the 2030s); fusion energy reaches the demonstration phase (around 2040).
- **The operation of existing nuclear power plants** is extended beyond 60 years (gradual modernisation and lifetime extension of units is underway).
- **Community energy** in the Czech Republic is fully operational (after 2028); hydrogen infrastructure is in pilot operation (hydrogen pipelines, H_2 hubs).

2.2. THE MISSING ECO-SOCIO-ENVIRONMENTAL DIMENSION OF SCIENCE IN THE CZECH REPUBLIC

2.2.1. ECONOMY AND INDUSTRY

The technological trends described above represent significant **economic opportunities** for the Czech Republic. The global transition to clean energy is estimated to have a market potential of around **USD 27 trillion** in the period 2020–2040, signaling vast new markets in which Czech companies can also participate. For example, the development of the hydrogen economy could open up an entirely new industrial segment in the Czech Republic – from hydrogen production and distribution to its use in transport and the chemical industry. One expert study estimates that Czech nuclear sources could produce 200–300 thousand tons of hydrogen per year by 2050, which would markedly strengthen the industrial competitiveness of the country. The involvement of domestic enterprises in the production of synthetic fuels, battery manufacturing or recycling technologies can support exports and the creation of skilled jobs. The impact of innovation on the state's **energy security** is likewise significant – greater use of domestic RES, waste and new fuels can reduce dependence on imported fossil resources and help stabilize energy prices in the economy.

The **resilience and defence** dimension: energy infrastructure is becoming a strategic component of national security. Modern low-carbon and decentralized systems – hydrogen-based, battery-based and nuclear – increase resilience to cyber and physical threats, enable the operation of so-called island systems in crisis situations and ensure energy supplies for the defence, healthcare and security sectors. Research under NCE II and CANUT II therefore also focuses **on dual-use** technologies (civilian and defence) and on modelling crisis scenarios from the perspective of the state's energy security.

2.2.2. RESEARCH AND INNOVATION

The Czech research base has an opportunity to position itself in fields linked to the emerging energy transition. National projects such as NCE II and CANUT II already target topics such as **safe waste management, environmental technologies and the social acceptance of new energy sources** – in other words, areas that also cover the complementary megatrends TE1–TE3. This creates a knowledge base that can be further developed and utilized. Czech research institutions can become more actively involved in international research initiatives (Horizon Europe, the Clean Energy Transition Partnership, etc.) focused on hydrogen, batteries, smart grids, SMRs and other promising areas. An important opportunity for the Czech Republic lies in leveraging its traditional strengths – for example mechanical engineering and the chemical industry – for the development of RES components, CCUS technologies, modular nuclear reactors or software for energy management and AI. Strengthening the links between academic research and industry (clusters, innovation platforms) can accelerate the transfer of new knowledge into practice. The orientation of national innovation policy is also decisive: according to the updated RIS3 strategy, it is necessary to support high value-added sectors in line with global trends, so that research contributes to enhancing the competitiveness of the Czech Republic under changing international conditions.

2.2.3. SOCIETY AND THE ENVIRONMENT

The transition to new energy technologies has significant **social impacts** – it brings many benefits but also challenges. On the positive side, improvements in air quality and the environment can be expected (lower emissions, less waste thanks to recycling), which benefits public health and overall quality of life. Innovations in the energy sector can also support **regional development** – the deployment of RES and the expansion of community energy can generate income for municipalities and strengthen their energy self-sufficiency. In the Czech Republic, a legal framework has been adopted (Lex OZE II in 2023 and Lex OZE III in 2025) to support energy communities, enabling municipalities and citizens to become more actively involved in energy projects. In advanced economies, local energy sharing has proven successful and technical readiness is no longer a limiting factor – in the Czech Republic, full functionality of community projects is expected after 2028.

However, broad **social acceptance** of new solutions (wind farms, CO_2 storage facilities, nuclear sources, etc.) is essential, which requires transparent planning and communication with the public. There is a growing need to involve stakeholders early in the decision-making process – a megatrend in this regard is the use of participatory methods and digital tools (e.g. visualizations using AI-based simulations) to strengthen public trust. This principle is also embedded in the Aarhus Convention (1998), which guarantees the public's rights to information and participation in decision-making on environmental matters. An example is the need to take into account the views of local residents when developing, for instance, wind farms or deep geological repositories.

Equally important will be **preparing the workforce** for new qualifications: the transformation of the energy sector and industry will generate demand for experts in hydrogen technologies, data analysts, technicians for renewable energy systems, and related professions. It is therefore necessary to invest in education and retraining so that the transition is socially sensitive and does not create regional inequalities (for example in coal regions). The implementation of these trends is also essential for meeting the Czech Republic's international climate commitments – it brings broader societal benefits in the form of mitigating climate change and reducing environmental risks.

3 STRATEGIC RECOMMENDATIONS FOR POLICYMAKERS

I. **Target public support for research and innovation on priority decarbonization pathways.**
Adjust the priorities of national R&D&I programs and funding so that they reflect the trends outlined above. This includes research on alternative fuels and hydrogen (with the looming excess of H_2 demand over supply by 2030), new battery technologies and storage, CCUS, AI and advanced nuclear technologies including SMRs. Targeted programs can accelerate prototypes and pilot projects across these areas, including research on safety and digital control of nuclear facilities.

II. **Develop infrastructure for new energy carriers and modernize the legislative framework.**
Strategically plan and invest in hydrogen pipelines, the integration of charging stations, storage systems and the modernization of district heating networks. At the same time, adapt the legislative framework for the deployment of SMRs and their integration into energy systems, including the implementation of the principles of the Net-Zero Industry Act and the simplification of permitting procedures for new-generation nuclear facilities.

III. **Promote the implementation of the circular economy and waste reduction.**
Introduce a ban on landfilling recoverable waste by 2030 and create incentives for investment in recycling. In nuclear energy, support research on the material cycle, including robust composites and technologies for decontamination or reuse of structural materials, for example in SMRs and decontamination facilities.

IV. **Unlock the potential of RES and energy storage in the Czech Republic.**
Set more ambitious RES targets and remove administrative barriers. In parallel, develop hybrid RES–SMR systems to optimize flexible and reliable energy supplies, including support for thermal storage from nuclear sources and its integration into smart-grid solutions.

V. **Analyze new trends in industry (clean mobility, Industry 4.0).**
Prepare industry for new emissions and technology standards (AFIR, CBAM, ReFuelEU). Extend investment instruments to applications of low-carbon nuclear heat for industrial processes and support the use of SMRs, for example for hydrogen and synthetic fuel production, in line with European standards (RFNBO, RED III).

VI. **Ensure coherence with European policies and make use of EU funding.**
Exploit NZIA and CRMA to accelerate permitting and financing of projects – including SMR demonstrator units, fuel cycle development and related hybrid nuclear–RES solutions. Draw up an inter-ministerial plan for using the Modernization Fund and Innovation Fund also for these purposes.

VII. **Introduce systematic foresight and advisory mechanisms.**
Update the state's technology priorities every 2–3 years, including an assessment of readiness for SMR deployment under Czech conditions. Develop "research-for-policy" instruments linked to the outputs of NCE II and CANUT II – including expert support for decision-making processes in nuclear and hybrid energy.

VIII. **Strengthen the "defence" dimension – energy as a pillar of state resilience.**
Include SMRs among the essential elements of crisis infrastructure. Small modular reactors can serve as stable island power sources for healthcare, the armed forces, ICT and logistics. It is advisable to develop scenarios and emergency models for their deployment in extraordinary situations.

IX. **Create an expert working group NCE II – CANUT II – MIT – MoD – MoI.**
The group will coordinate the transfer of research and technologies (including nuclear) into the state's security, energy and industrial policies. CANUT II, as the guarantor of advanced nuclear solutions, will provide expert support for legislative proposals and SMR implementation scenarios.

X. **Strengthening education and skills for transforming energy sector.**
The transition will require new professional profiles – in addition to experts in RES, storage and data analytics, it is necessary to prepare a generation of engineers and technicians for the design, operation and maintenance of SMRs and other advanced nuclear technologies. The education system and retraining programs must anticipate and reflect this demand in a timely manner.

4 KNOWLEDGE-TO-POLICY: INDEPENDENT ADVISORY BODY

Purpose

To establish a permanent expert capacity for independent, science-based energy advisory services – linking low-carbon (NCE II) and nuclear (CANUT II) research with public policymaking in a transparent and open manner.

Core functions

- Quarterly Foresight Briefs: regular overview of trends (TRL, CAPEX, LCOE, EU regulatory developments)[14].
- Policy Options Papers: alternative policy recommendations for the Ministry of Industry and Trade / Ministry of the Environment (MPO/MŽP), including CBA and impact assessment.

Quality principles for transparent dissemination

- Open methodology, open peer review, transparent data sources.
- Independent governing body (representatives of academia, industry and regions).
- Public abstracts, FAIR data for public administration (in line with FAIR principles, data restricted only where necessary for state security or for the protection of intellectual property).[15]

Integration and governance

- Connection to the national energy data hub and government analytical portals.
- Joint working groups with ERÚ, ČEPS, DSOs, SFDI.

Benefits

- Faster knowledge transfer (from months → to weeks).
- Improved evidence base and legitimacy of strategic decisions.
- Strengthening the role of the Czech Republic as an innovation hub of the energy transition within the EU.

Period	**Key step**	**Output**	**Responsible entities**
Q1–Q2/2026	Memorandum of Cooperation between MPO–MZP–MO–MV	Agreement on mandate and governance	MPO, MZP, MO, MV, NCE II, CANUT II
Q2–Q3/2026	1st pilot Foresight Brief + first Policy Paper	Mapping of hydrogen infrastructure priorities for 2030	NCE II, MPO
Q3–Q4/2026	Connection to the energy data hub, launch of the Rapid Response service	Data interface, process manual	MPO, NCE II, ERU
Q1–Q2/2027	Implementation Audit SEK/NEKP 2025	Report to the Government of the Czech Republic	NCE II & CANUT II, TA CR

[14] The expert statements on TRL, growth dynamics and technology timing are based on the technology trends study and related sections (see references). Legislation and the current state of applicability are reflected in line with the existing EU/CZ framework: RED III (in force since 2023), AFIR (in force), CBAM (full regime from 2026), ReFuelEU Aviation (2024/25), FuelEU Maritime (2025), NZIA/CRMA (implementation in 2024/25), Lex OZE III (adopted in March 2025 – currently under implementation).

[15] The transparent open peer-review process, in compliance with the FAIR principles (*Findable–Accessible–Interoperable–Reusable*), will be implemented primarily through the Open Research Europe platform, which is among the recommended Open Science practices in the current *Horizon Europe* call. In addition, through discussion within the expert community, the Citizen Science dimension is fulfilled, as citizen science is likewise among the recommended approaches. The process of preparing the strategic documents is described in detail in the annex.

LIST OF ABBREVIATIONS

Abbreviation	Meaning / Explanation
AFIR	*Alternative Fuels Infrastructure Regulation – Regulation on the deployment of alternative fuels infrastructure (EU 2023/1804)*
AI	*Artificial Intelligence*
CANUT II	*Centre for Advanced Nuclear Technologies II – a National Competence Centre (NCK) project focused on the research and development of advanced nuclear technologies (SMRs, safety, materials)*
CBA	*Cost–Benefit Analysis*
CBAM	*Carbon Border Adjustment Mechanism – carbon border adjustment mechanism at the EU's external borders (EU 2023/956)*
CCUS	*Carbon Capture, Utilization and Storage*
CEET	*Centre for Energy and Environmental Technologies*
CZT	*District heating*
DAC	*Direct Air Capture*
DSO	*Distribution System Operator*
EMS	*Energy Management System*
ERÚ	*Energy Regulatory Office*
EU ETS	*European Union Emissions Trading System*
FIT for 55	*EU legislative package to reduce greenhouse gas emissions by 55% by 2030*
FuelEU Maritime	*FuelEU Maritime Regulation* (EU 2023/1805)
Gigafactory	*Large-scale battery cell manufacturing plant*
H_2	*Hydrogen*
IEA	*International Energy Agency*
ICE	*Internal Combustion Engine*
Implementation Audit	*Regular evaluation report on the implementation of the State Energy Policy (SEK) and the National Energy and Climate Plan (NEKP)*
LDES	*Long-Duration Energy Storage*
Lex OZE II / III	*National legislation for the development of renewable energy sources and community energy (Czech Republic, 2023 and 2025)*
LOHC	*Liquid Organic Hydrogen Carrier*
LCOE / LCOS	*Levelized Cost of Energy / Storage*

Abbreviation	Meaning / Explanation
MPO	*The Ministry of Industry and Trade of the Czech Republic*
MO	*Ministry of Defense & Armed Forces of the Czech Republic*
MV	*Ministry of the Interior of the Czech Republic*
MŽP	*Ministry of the Environment of the Czech Republic*
MYRRHA	*Multi-purpose Hybrid Research Reactor for High-tech Applications*
NCE II	*National Centre for Energy II – a National Competence Centre (NCK) project focused on research into low-carbon non-nuclear energy technologies (hydrogen, RES, storage, grids)*
NEKP	*National Energy and Climate Plan, CR*
NRIS3	*National Research and Innovation Strategy for Smart Specialization of the Czech Republic (RIS3)*
NZIA	*Net-Zero Industry Act* (EU 2024/1028)
RES	*Renewable energy sources*
ORC	*Organic Rankine Cycle*
Policy Options Paper	*Analytical document with alternative policy proposals based on scientific evidence*
QFB (Foresight Brief)	*Quarterly Foresight Brief*
RED III	*Renewable Energy Directive III* (2023/2413)
ReFuelEU Aviation	*ReFuelEU Aviation Regulation* (EU 2023/2405)
RFNBO	*Renewable Fuels of Non-Biological Origin*
RIS3	*Research and Innovation Strategy for Smart Specialization*
SFDI	*State Transport Infrastructure Fund*
SEP	*State Energy Policy*
SMR	*Small Modular Reactor*
TA ČR	*Technology Agency of the Czech Republic*
TES	*Thermal Energy Storage*
TRL	*Technology Readiness Level*
R&D&I	*Research, development and innovation*

LIST OF FULL NAMES AMONG THOSE MEGATRENDS

I. TA – Energy conversion

- TA1 – Alternative fuels (synthetic fuels, biofuels, hydrogen)
- TA2 – Circular economy and energy recovery from waste
- TA3 – Renewable energy sources and energy efficiency
- TA4 – Advanced nuclear technologies

II. TB – Transmission and distribution of energy

- TB1 – Smart grids and grid modernization
- TB2 – Decentralization and energy communities
- TB3 – New media and infrastructure for their distribution (hydrogen, low-temperature heat)

III. TC – Energy storage and use

- TC1 – New generations of batteries (for electromobility and grids)
- TC2 – Storage of energy in hydrogen
- TC3 – Thermal energy storage systems
- TC4 – Energy savings and demand-side management (EMS)

IV. TD – Safety

- TD1 – Nuclear safety and passive systems
- TD2 – Cybersecurity and infrastructure security
- TD3 – Sensors and predictive diagnostics

V. TE – Environmental and societal aspects

- TE1 – Waste management and decommissioning of facilities
- TE2 – Environmental impacts and sustainability
- TE3 – Social acceptance (public engagement)

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- NCK – Template for the mandatory output of a strategic sub-project, Technology Agency of the Czech Republic (2023).
- Notes on Policy Brief (TA CR 2023) – methodological guidance for application-oriented R&D outputs.
- Internal data of CEET / NCE II / CANUT II (2023–2025) – interim results of research work packages (WP 1–6).

EU legislative and strategic documents:

- European Green Deal – COM(2019) 640 final.
- Fit for 55 package – comprehensive set of EU legislative proposals (2021–2023, status as of October 2025).
- REPowerEU Plan – COM(2022) 230 final.
- Directive (EU) 2023/2413 – RED III on renewable energy (in force since 2023).
- Regulation (EU) 2023/1804 – AFIR (in force since 2024).
- Regulation (EU) 2023/956 – CBAM (transitional phase 2023–2025, full regime from 2026).
- Regulation (EU) 2023/2405 – ReFuelEU Aviation (in force since 2024, binding targets from 2025).
- Regulation (EU) 2023/1805 – FuelEU Maritime (in force since 2025).
- Delegated Regulations (EU) 2023/1184 & 1185 – criteria for RFNBOs and low-carbon hydrogen.
- Regulation (EU) 2024/1028 – Net-Zero Industry Act (NZIA) – adopted in 2024, implementation from 2025.
- Regulation (EU) 2024/1252 – Critical Raw Materials Act (CRMA) – adopted in 2024.
- Directive (EU) 2024/1275 – EPBD Recast (energy performance of buildings, revision of Directive 2010/31/EU).

National strategic documents of the Czech Republic:

- State Energy Policy of the Czech Republic (update 2024, Ministry of Industry and Trade – MPO).
- National Energy and Climate Plan (NECP) 2024–2030 – MPO & Ministry of the Environment (MŽP, draft version).
- Secondary Raw Materials Policy of the Czech Republic (2023) – MPO.
- Lex OZE II (Coll. 2023) and Lex OZE III (Coll. 2025) – acts on community energy and aggregation of flexibility.
- National RIS3 Strategy 2021+ (Ministry of Education, Youth and Sports / Council for RDI, 2021–2027).

Additional and specialized resources:

- IEA – GLOBAL HYDROGEN REVIEW (2023).
- IEA – ENERGY STORAGE REPORT (2024).
- OECD – SCIENCE, TECHNOLOGY AND INNOVATION OUTLOOK (2024).
- JRC – CLEAN ENERGY TECHNOLOGY OBSERVATORY (2023).
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APPENDIX

Table 1: Developing strategic documents via the transparent Open Research Europe pathway[16]

Step	Description	Implementation in ORE under Horizon Europe [17]
I. Definition of the target group	Identification of key stakeholders (government authorities, energy companies, non-governmental organizations).	At the beginning, always briefly specify who the output is specifically intended for.
II. Structure of the document	**Introduction** (context and objective) **Key findings** (concise summary of scientific results) **Policy recommendations** (concrete actions) **Scientific evidence and references** (citations of studies, data under a CC BY license) **Conclusion and outlook**	It is necessary to maintain a clear and concise format (max. 5 pages). The English text (mandatory for ORE) is accompanied by a Czech translation. Both files (English + Czech) must always be uploaded and marked as "language version". In this way, the drafting process becomes transparent from the perspective of discussion within the expert community. It must be borne in mind that the draft and data are made public immediately, and that the reviews, including the names of the reviewers, are subsequently public as well.
III. Open scientific outputs	All publications and data used must be available under a CC BY license.	When citing individual outputs, always include the DOI and a link to the ORE record where each output is stored.
IV. Preparation of open data	Raw data may consist of scientific datasets. Processed data may take the form of diagrams, visualizations, etc.	Raw data (in this case, articles) are made publicly accessible as soon as possible after publication and labelled with a CC BY license. Processed data are generated using analytical tools, for example within a closed AI and LLM system (e-infrastructure).
V. Metadata requirements	Each record (publication and dataset alike) must include: author(s), title, date, list of public grants, license, permanent identifier (DOI) and organization identifiers.	ORE automatically generates the required metadata; where appropriate, add information on the tools needed to validate the results. A list may be provided in .CSV or .TXT format.
VI. Licensing conditions	Use the latest version of the CC BY license (CC0 for metadata). For monographs and more extensive reports, CC BY-NC may be used.	When uploading a file to ORE, select the appropriate license; the chosen license forms part of the public record.
VII. Dissemination plan	Strategy for how the policy brief will be disseminated (webinars, social media, press releases).	Include a link to the ORE record in all communication materials; this ensures transparency and traceability. Not only the reviews, which are non-anonymous, are public – the discussion format also enables the wider expert community to express its views.
VIII. Review and approval	First an internal review (legal, institutional policy and ethical aspects), followed by an external review (stakeholders).	If an objection is raised (e.g. concerning the infringement of legitimate interests), it is necessary to ensure that the output is revised or restricted, in line with the protection of intellectual property, before it is submitted to ORE. The record cannot be deleted.

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