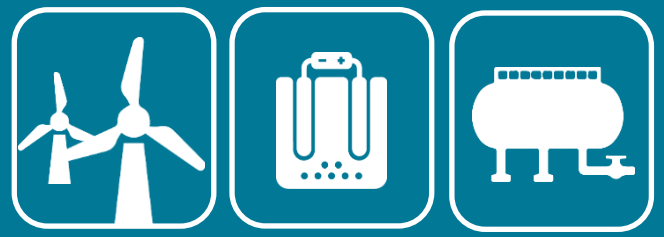
RDI Roadmaps for GreenE²

SYSTEMIC CHALLENGE: THE ENERGY TRANSITION

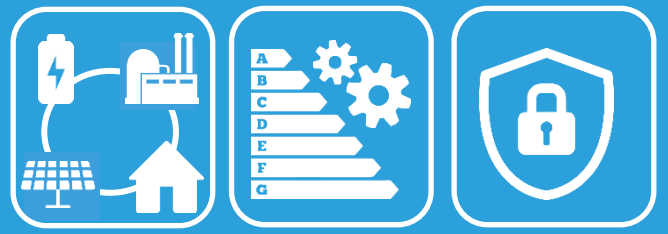
H_2 PRODUCTION, INFRASTRUCTURE AND UTILISATION



DEPLOYMENT OF P2X & CCU SOLUTIONS

SECTOR INTEGRATION TECHNOLOGIES AND VALUE CHAINS

ENHANCED SYSTEM LEVEL EFFICIENCY & SECURITY



GREEN H_2 PRODUCTION, INFRASTRUCTURE AND UTILISATION

GreenE²

GOALS

2025

- Properties of green H2 production technologies defined
- First green H2 production plants in use
- The role and most effective source streams of H2 defined and clearly presented in Finland
- Electrolyzer production started in Finland

2030

- Commercial engagement of the whole H2 value chain
- Sidestreams and H2 production from waste in use

2035

- Safe H2 logistics solutions in use, with connection to European gas grids.

	2025	2030	2035
Green H2 production processes and utilization	• Studies on the role and system-efficiency of hydrogen in transport, energy and industry sectors in Finland • System modelling to integrate power-to-x technologies • Large scale electrolysers tested and optimized • Process engineering know-how and experience in the steel, chemical and refinery sector • Integrated concepts for hydrogen production and mobility infrastructure	• Competitive H_2 price • First commercial large scale production and utilization plants in the operation	• The whole value chain in the operation
Cost-effective H2 production technologies	• Improvement of electrolysis technology to lower capital costs, to enhance lifetime and durability and to increase system efficiency • Off grid hydrogen production optimized and tested • Purification of side stream H2 • Hydrogen production even from small side streams • Circularity	• Production mix of large-scale centralized and smaller de-centralized plants possible • Photocatalytic production technology under development • Thermochemical and biological methods tested	• New production technologies tested and some of them already operating, • Thermochemical water splitting pilots
Reliable safety solutions for production, logistics and storage of H2	• Liquid organic hydrogen carriers (LOHC) solutions • System requirements from materials and safety perspective • Security development ongoing	• Logistics operating. • Material challenges of storages solutions solved. • H_2 pipelines under construction	• Fully commercial based solutions in use for production, logistics, storage and utilization.

DEPLOYMENT OF P2X & CCU SOLUTIONS

GreenE²

GOALS → 2025

- Clear national strategy for P2X & CCU
- Proof-of-concept P2X2P (e-fuels, gas or liquid, energy storage) pilot(s) with customers.
- Most effective source streams of carbon defined. Properties of CC technologies defined.
- Legal and regulatory directions in different markets.

→ 2030

- P2X2P, e-fuels and energy storage, commercial solutions.
- Business export (companies) and knowledge export (university research).
- Commercial-scale CCU demo - First Commercial Investment.

→ 2035

- First P2X2P export project delivered and in use. CCU and P2X -solutions are part of industry and gas infrastructure.
- Established Research and Knowledge Centers around CCU&P2X solutions.

P2X processes, economic feasibility and energy efficiency

- State-of-the-art survey on available and emerging technologies.
- Photo-electro-chemical (PEC) water splitting. Scalable demo reactor.
- Sustainability assessment of alternative routes from different carbon and hydrogen sources to different synthetic products.
- Flexible plants with multiple outputs (industrial transformation & integration).
- Modular plant solutions.
- Industrial demonstration of catalytic processes for examined synthesis routes to produce a wider variety of synthetic products (polymers, chemicals etc.).
- Catalyst development for new, less researched synthesis routes.
- Demonstration of new catalytic processes on industrial scale.

CCU (both CO2 and CH4) processes, cost and energy efficiency

- Study on different available sources of carbon for carbon capture
- Development of CCU road map for Finland and related regulatory framework to support CCU demonstration activities.
- Optimization models for different CCU end products taking lifecycle into consideration.
- Establishment of CCU ecosystem for Finland for utilizing the strengths of Universities, RI and companies.
- Commercial technologies to reduce CO2 content from the atmosphere.
- Solutions for direct air capture (DAC) of CO2.
- Development of material and cost efficiency of processes for solid carbon applications.

Infrastructure for integrated energy networks, incl. conversion and storage

- Process development to make e.g., H2 production a flexibility factor.
- Include storages and increase the flexibility of industrial processes.
- Combination of different types of storages: hybrid storages, batteries & compressed air, heat and electricity, bioenergy and synthetic fuels.
- Infrastructure for EV charging and V2G storage solutions.
- E-fuels in transport and power generation.
- Low-carbon concrete production
- CO2 hardening of concrete.
- Low-carbon steel production
- Hydrogen-enabled Direct Reduced Iron.
- Heat pumps and thermal energy storage dominate heating and cooling generation.
- Deployment of electro-mechanical storage in power grids with high share of renewables (RES).

SECTOR INTEGRATION TECHNOLOGIES AND VALUE CHAINS

GreenE²

GOALS

2025

- Sustainability criteria for all energy forms defined on EU level
- Systemic planning tools and mechanisms
- Pilots for system integration use cases
- New actors enter district heating value chains
- Energy communities and microgrids

2030

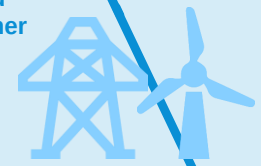
- Platforms and platform economy
- Regulatory sandboxes for experimenting, scaling solutions for future smart energy systems
- Piloting new market structures

2035

- System of systems management
- Flexible and integrated networks ready to be utilized in transportation, energy, industry and agriculture

System integrating value chains

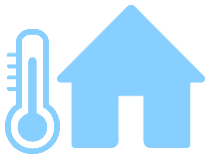
- Interfaces and system architectures for sector integration aligned with global markets.
- P2X2P value chain.
- Assets for power grid flexibility (P2X, heat pumps, storage, waste heat utilization).
- Multi-object optimization to support emerging decentralized decision making (AI)
- Smart integration of electricity system and electric traffic
- Integration of electricity and heating systems (DH + heating of buildings).
- Integration of different markets (energy, transport, chemicals, heat, gas, hydrogen).
- Building H2 production and consumption near each other
- Side stream O2 and waste heat utilization nearby.
- Development of control strategies for different energy systems and business models.



- Efficiency and further operation improvements of sector integration value chains.

Energy communities

- Citizen engagement and consumer preferences.
- Methods for considering storage already in the planning phase of the energy system.
- Sale of electricity by prosumers.
- Distributed systems for trading.

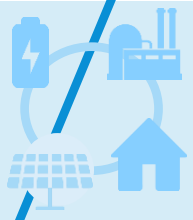


- Smart home, smart heating
- Role of aggregators.
- Logistics and business models of EV charging points and V2G solutions.
- EV battery as a storage.
- Digital platforms for energy trading between prosumers.
- Microgrids and RES integration.
- AI applications optimizing prosumer operations
- Combining modern decentralized solution architecture and old centralized systems
- Decentralized energy solutions.
- Integral DHC networks powered by heat pumps.

Flexibility services

- Business models for industrial flexibility with new actors.
- Design of the new services and business models for sustainable living that covers sector integration.
- New services for integration of transport, heating, industrial processes and biofuels.
- Energy and mobility as a flexibility service, e.g., V2G.

- Aggregators to include even smaller loads to provide flexibility in smaller scales.
- Innovative business models for energy systems integrated with digital solutions.



- Digitalization and AI for management of flexibility assets (storage, heat pumps, EV charging).

ENHANCED SYSTEM LEVEL EFFICIENCY, RESILIENCE & SECURITY

GreenE²

GOALS

2025

- Adoption of 6G and AI capabilities
- Communication infrastructure enabling big data applications
- Energy data space standards and framework
- Business models for emerging ICT solutions in energy systems
- Online energy cost used in production optimization: predictability, flexibility

2030

- Genuine alternatives exist in the energy system: different carriers to use in different markets
- Optimization pilots with different types of energy "communities“
- Cross-sectoral knowhow

2035

- Considerable efficiency improvements made in industrial processes
- Societal impacts of energy transitions are addressed

System modelling, optimization, monitoring forecasting & control

- APIs to existing electricity simulations model to enable digital twins
- Dynamic multi-energy system models
- Block chain to trace data on energy value chains
- Vertical integration to enable use of real time IoT-data and modelling
- 6G technical and practical use cases for energy Network level slicing and edge computing adaption
- Role of AI in demand prediction and optimized energy management
- Modelling overall efficiency of value chains
- Real time visualization of information
- AI for autonomous energy sub-systems, systems and system of systems.
- Optimization of resource use for different energy needs
- Local optimization in a system of systems
- Dynamic optimization of production and consumption

System-level resilience and sustainability, cyber security and data safety

- Theoretical and practical cyber security and use of war rooms for testing mechanisms
- Energy data spaces and data sovereignty
- Managing security of mixed energy system consisting of legacy systems and 6G systems
- Cyber security as part of process design
- Cyber physical systems and resilience
- Nearly carbon neutral energy systems, ensuring reliability and security of supply

Societal impact of energy transitions

- Difference in population density and effects of sector integration on population
- Access to affordable energy prices & addressing energ y poverty in EU
- Societal impacts of energy transition in terms of lost jobs and reskilling.
- Role of humans and AI when systems are automated
- Balancing urban / rural dichotomy in terms of access to energy, mobility and employment possibilities.