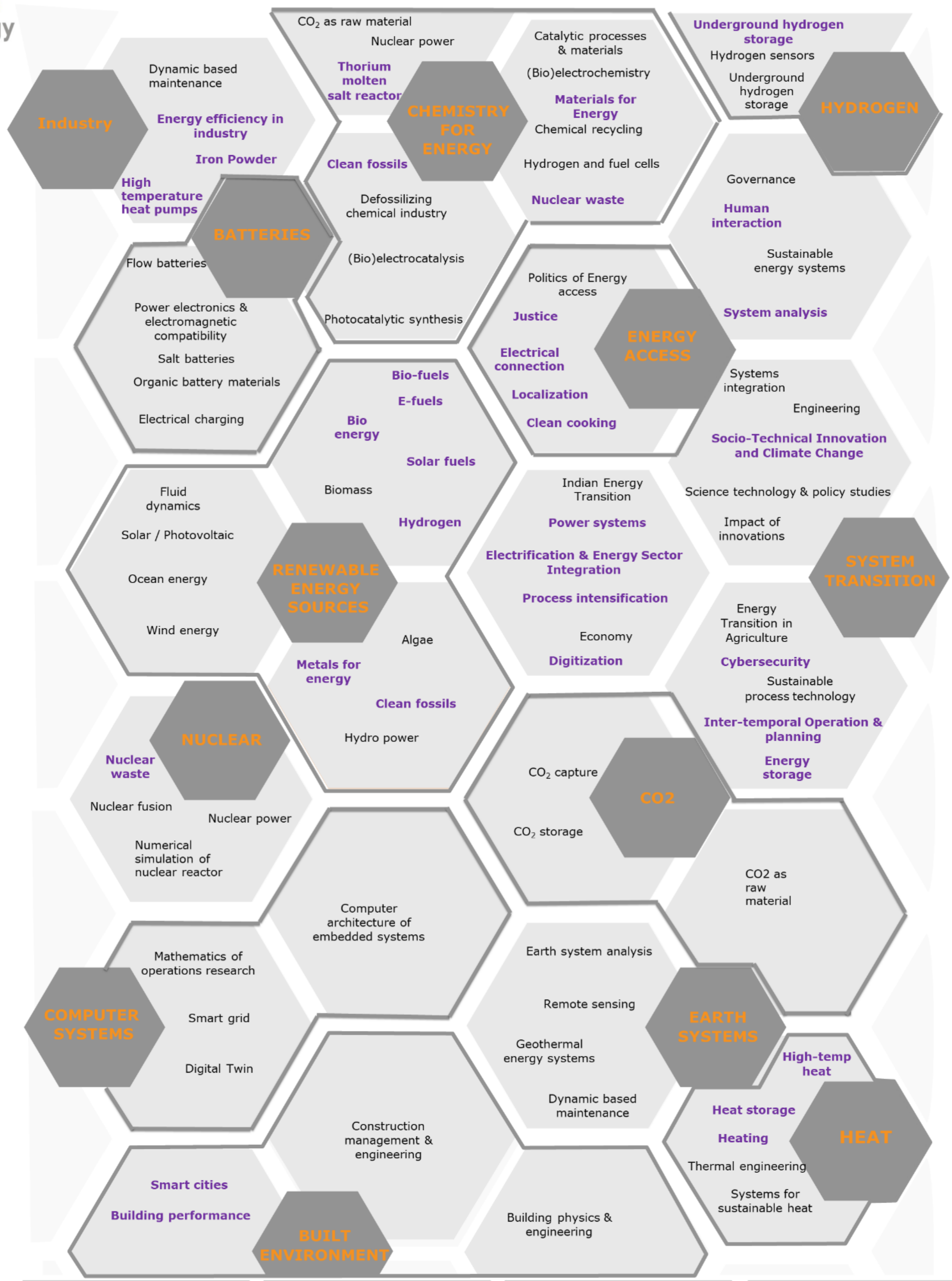
4TU.Energy Research Map

4TU .Energy



TU Delft Delft University of Technology | TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF TWENTE. | WAGENINGEN UNIVERSITY & RESEARCH

*Text in **purple** are newly added topics compared to version 2023;
*More info incl.topic introduction and researcher names is available on digital version on our website soon
*Feedback is very welcome via 4TU.Energy website > Research Map Input

4TU.

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Computer systems

Research into computer systems is necessary to manage the technologies utilised in the energy transition.

Smart grid

In a changing energy landscape, our energy grid must fulfill different requirements to those it was originally designed for. Renewable energy sources do not provide constant energy output, unlike fossil-based energy sources. Additionally, energy demand is also variable, resulting in frequent mismatches between energy demand and supply. Smart grids involve two-way communication between the energy producers and consumers by smart devices, resulting in more efficient energy usage. Smart grids can make use of excess energy supplied by renewables and flatten peak energy demand by shifting energy usage using smart devices to use power at times when demand is low by charging EVs or implementing energy storage techniques.

Digital twin

A digital twin is a virtual model of a system or object, intended to reproduce its real counterpart accurately. Digital twins have access to live data of the systems they represent allowing them to give highly accurate simulations. These simulations can then be used for much more efficient testing for optimal conditions or predicting outcomes without having to physically test every situation. This can be especially useful for large complex systems and systems where physical testing requires significant logistical effort or bears significant risks.

Mathematics of operations research

Operations research aims to develop and apply methods to analyze and improve decision making and efficiency. This is done by applying various mathematical concepts (e.g. statistical models, game theory, machine learning and stochastic models) to describe the system in question in order to improve understanding of the system and improve its efficiency. An example of this is investigating energy management in smart grids.

Computer architecture of embedded systems

This topic research goes around the engineering and design of computer systems to achieve specific performance goals. Computer architecture involves the careful organization and integration of hardware components, along with innovative mechanisms and software techniques.

Researchers working on Computer systems:

Name	University	Research group	Specialization
Guus Pemen	TUe	Electrical Energy systems	Smart grids, power grid components, power quality and EMC and pulsed power technology
Dujuan Yang		Information systems in the built environment	Digital twins, Travel behavior and energy effects using quantitative methods, Urban infrastructure management, Energy neutral city development, and Decision support system in the context of Smart Cities development
Phuong Nguyen		Electrical Energy Systems	Smart grids, Digital twins
Aayan Banerjee	UT	Catalytic Processes and Materials	Electro-catalysis, design, engineering, multi-scale modelling, digital twinning
Gerwin Hoogesteen		Energy management at UT collaboration - Energy in Twente | EWI - Energy (utwente.nl) Computer Architecture for Embedded Systems - CAES (utwente.nl) Mathematics of operations research - MOR | Mathematics of	Smart Grids, Cyber-physical systems, energy coordination algorithms, system integration and cyber system resilience

		Operations Research (utwente.nl)	
Elham Shirazi		Sustainable Products and Energy	Energy systems control, energy systems modelling
Johann Hurink		Mathematics of operations research	Operations research, Smart grids
Nataly Bañol Arias		Power Electronics group	• Modeling & optimization of modern distribution networks & microgrids • Energy management and control of inverter-based resources (IBRs) for seamless grid integration and support • Co-simulation of power systems and power electronics, interoperability of IBRs, and real-time hardware-in-the-loop applications for smart grids.
Peter Palensky	TuD	Intelligent electrical power grids	Digital Twins, Smart grids
Pedro Vergara Barrios		Intelligent Electrical Power Grids	Digital twins, distribution systems, machine learning, mathematical optimization, congestion, renewable energy, and storage integration

Nuclear

Nuclear fusion

Nuclear fusion reactions are reactions in which two light atomic nuclei merge to form a single heavier nucleus. Massive amounts of energy are released during fusion processes due to the difference in total mass between the two original nuclei and the single resulting nucleus ($\Delta E = \Delta mc^2$). Fuels/energy generated from nuclear fusion are clean (no CO_2 emissions) and can potentially complement other renewable energy sources.

Numerical simulation of nuclear reactor

The sun, and all other stars are powered by nuclear reactions. In the case of nuclear fusion, nuclei need to collide with each other at very high temperatures (over 10^6 °C) which gives the nuclei enough energy to overcome their mutual electrical repulsions. These extremely high temperatures pose safety risks involved in the operation of nuclear reactors. As such, numerical simulations provide a convenient method for optimizing nuclear reactions prior to large scale operation.

Nuclear power

Nuclear power holds a huge potential to mitigate emissions in energy production. Research on future reactor designs focuses on improved safety, efficiency and reduction of long-term radioactive waste generation.

Nuclear waste

With the production of nuclear energy and medical isotopes and their research analogues, radioactive waste is generated. The harmful nature of this waste can persist for millennia. Therefore, research and engineering into safe disposal facilities and strategies that can stand the test of time are crucial.

Researchers working on Nuclear:

Name	University	Research group	Specialization
Niek Lopes Cardozo	TU/e	Socio-economic aspects of the deployment of fusion energy; Science and Technology of Nuclear Fusion	Nuclear fusion
Guido Huijsmans	TU/e	Science and Technology of Nuclear Fusion	Numerical simulation of nuclear reactor
Jan Leen Kloosterman	TUDeflt	Reactor physics and nuclear materials	the analysis and development of nuclear reactors and fuel cycles that excel on safety and sustainability

Built environment (under construction with 4TU.Built Environment)

Smart cities integrate advanced technologies and data-driven solutions to improve the quality of life for residents, enhance urban services, and promote sustainability. Research in smart cities focuses on developing innovative approaches to urban planning, transportation, energy management, waste management, and public services. The aim is to create more livable, efficient, and environmentally friendly cities.

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Building performance

Building Performance research aims to produce a sustainable, energy-positive built environment, prioritizing indoor environmental quality for health, comfort, and productivity. This involves a multi-scale, multi-physics, and trans-disciplinary approach, integrating technological solutions for energy generation, storage, distribution, and demand reduction into building design, construction, and operation. Emphasizing performance-based perspectives, it enables informed decision-making in developing designs, products, and services that facilitate the transition to sustainability.

Construction management & engineering

Construction Management and Engineering involves preparing managers to navigate the complexities of modern construction projects. This field integrates engineering and organizational skills to tackle dynamic challenges in the construction industry. Emphasis is taken in process innovation, integral design concepts, and information management for smart cities and buildings. Key focuses include stakeholder participation, supply chain integration, and asset management. Experts in the field are equipped to address societal challenges like climate change and digital transformation, applying knowledge in areas such as procurement strategies, supply chain management, and industrialization.

Building engineering physics

The field of building engineering physics combines the existing professions of building services engineering, applied physics and building construction engineering into a single field designed to investigate the energy efficiency of old and new buildings. The application of building engineering physics allows the construction and renovation of high performance, energy efficient buildings, while minimizing their environmental impacts.

Building engineering physics addresses several different areas in building performance including: air movement, thermal performance, control of moisture, ambient energy, acoustics, light, climate and biology.[3] This field employs creative ways of manipulating these principal aspects of a building's indoor and outdoor environments so that a more eco-friendly standard of living is obtained. Building engineering physics is unique from other established applied sciences or engineering professions as it combines the sciences of architecture, engineering and human biology and physiology. Building engineering physics not only addresses energy efficiency and building sustainability, but also a building's internal environment conditions that affect the comfort and performance levels of its occupants.

Researchers working on Built environment:

Name	University	Research group	Specialization
Dujuan Yang	TuE	Information systems in the built environment	Energy neutral city development
Jos Brouwers		Building materials	Functional materials, eco building materials, resource materials
Jan Hensen		Building performance & simulation	Building and district energy optimization, energy and indoor enviroment, construction R&D support

Heat

Heat is the umbrella term for many subtopics, and includes many developing areas such as heat pumps, district heat networks and heat storage. In all heat-related topic, energy efficiency is key. Reducing heat losses and increasing energy efficiencies reduces the environmental impact.

Heat storage

The scientific field of heat storage involves the study of methods and materials for storing thermal energy efficiently. Heat storage systems are crucial for balancing the supply and demand of heat energy in various applications, including residential heating, industrial processes, and renewable energy systems. Understanding heat storage mechanisms and developing innovative storage technologies are essential for optimizing energy use, enhancing system flexibility, and promoting the integration of renewable energy sources into existing infrastructure

Heat transfer

Research in heat transfer explores the fundamental principles and applications of thermal energy transport in various systems. It entails the study of conduction, convection, and radiation processes to understand how heat flows within solids, fluids, and gases. Applications range from improving energy efficiency in industrial processes. The goal is to develop innovative heat transfer solutions for sustainable energy utilization, improved thermal comfort, and enhanced system performance across diverse fields

Ultra-high temperature thermal energy

Thermal energy is what we call energy that comes from the temperature of matter. The hotter the substance, the more its molecules vibrate, and therefore the higher its thermal energy. Ultra-High Temperature Thermal Energy Storage, Transfer and Conversion presents a comprehensive analysis of thermal energy storage systems operating at beyond 800°C.

Thermal engineering

Thermal Engineering research focuses on applying thermodynamics, fluid mechanics, and heat and mass transfer principles to industrial settings. Through theoretical analysis, numerical simulations, and experiments, researchers aim to advance knowledge for industrial design. The emphasis is on efficient energy use and reducing the environmental impact of future energy systems.

System for sustainable heat

Research in sustainable heat systems centers on thermochemical and phase change material storage concepts. It aims to design and characterize materials from molecular to reactor scale, integrating them into heat storage systems for domestic use. With over 65% of built environment energy consumed by low-temperature heating, thermal energy storage becomes essential. It addresses the disparity between thermal energy consumption and renewable production, making it a crucial component of future energy systems.

Researchers working on heat:

Researcher	University	Group	Specialization
Mina Shahi	UT	Thermal and Fluid Engineering	Heat conversion and Storage
Wilko Rohlfs			Convective Heat Transfer
Keerthivasan Rajamani			Magneto-caloric heat pump/refrigerator, liquid metal heat transfer fluid, ferrohydrodynamics, and waste heat to electricity conversion
Davoud Jafari		Advanced Manufacturing, Sustainable products & Energy systems	Heat transfer and thermal management, develop and control the thermal properties of functionally graded/composite/porous/multi-materials through additive manufacturing, tailoring material composition for specific (bidirectional) thermal conductivity, designing surfaces and interfaces for optimized heat dissipation.
Henk Huinink	TUe	Thermo Chemical Materials	Thermal energy storage, thermo-chemical materials
Philip de Goey		Power and Flow	High-temp. heat
David Smeulders		Energy Technology	Thermo chemical heat storage Heat storage
Olaf Adan		Transport in permeable media	Thermo chemical materials
Azahara Luna Triguero		Energy Technology	Sustainable blended refrigerants and (adsorption-based) thermochemical energy storage in porous materials.
Kamel Hooman	TUDelft	Heat Transformation Technology	Heat transfer, heat pump, heat exchanger, thermal energy storage, porous media flow, fluid mechanics, supercritical flow, thermal management, solar

			thermal, geothermal, renewable energy

Earth systems

The earth consists of a vast complex web of various interconnected systems. Understanding and analyzing the complicated relationships between the various earth systems helps us to grasp the implications of energy research.

Earth system analysis

Earth systems analysis is a scientific field that focuses on understanding the Earth as a complex system composed of interconnected components, including the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere (human activities). This interdisciplinary field draws upon principles from various branches of science, such as geology, meteorology, oceanography, ecology, geography, and social sciences, to study the interactions and feedback between Earth's subsystems.

Remote sensing

Remote sensing is based in the use, analysis and integration of geological and geophysical data to map fields of mineral resources and geothermal resources which are essential sources of clean renewable energy.

Geothermal energy systems

Geothermal energy systems focus on the utilization of the heat energy stored beneath earth's surface to produce electricity, heating, and cooling. Utilizing geothermal reservoirs and various technologies, such as wells and heat exchange systems, they produce sustainable energy with minimal greenhouse gas emissions. Geothermal power plants convert heat into electricity, while direct use applications provide heating and cooling for buildings. With minimal environmental impact and continuous innovation, geothermal energy systems offer a renewable and reliable energy source for diverse needs.

Dynamic based maintenance

Energy cycle in earth system is a dynamic process. Research in this topic looks at energy flow on macrolevel, and aims to increase energy efficiency by dynamic based maintenance.

Researchers working on Earth systems:

Researcher	University	Group	Specialization
Maja Rücker	TUe	Energy Technology	Sub-surface fluid reservoirs in rocks
Phil Vardon	TuD	Geoscience & Engineering	Coupled processes in geomaterials

CO_2

CO_2 capture, utilization and storage are a way to reduce emissions by removing CO_2. Additionally, it can be a renewable source of carbon for the chemical industry

CO_2 capture

CO_2 is a major contributor to anthropogenic climate change. To mitigate its effects as a greenhouse gas, CO_2 emissions must be drastically reduced. Some sources of emissions are difficult to replace by using renewable energy or by electrification. Additionally, any CO_2 already present in the atmosphere continues to have a warming effect. To this end CO_2 capture can be employed to remove CO_2 from the atmosphere.

CO_2 storage

Once CO_2 has been captured it must be stored to prevent it from re-entering the atmosphere. This can be done by pumping it underground where high pressures can form carbonate minerals with the CO_2

CO_2 as raw material

Captured CO_2 can be converted into useful chemicals using catalysis. In this way chemical building blocks can be synthesized from a renewable source instead. This can be done in several different ways: Electrochemical, Biochemical and Thermochemical. In all cases CO_2 must be reduced with a source of hydrogen to form products such as methanol, formic acid and methane.

Researchers working on CO2:

Name	University	Research group	Specialization
Harry Bitter	WUR	Biobased Chemistry and Technology	Catalysis, CO_2 capture and conversion
Annemiek ter Heijne	WUR	Environmental Technology	Microbial electrochemical technologies, microbial electrolysis for methane production from CO_2
Mar Pérez-Fortes	TuD	Engineering Systems and Services	Techno-economic assessments of CO_2 capture and utilization, bio-based processes, fuel cells
Azahara Luna Triguero	TUe	Energy Technology	CO2 capture and storage in porous crystalline materials

Renewable energy sources

Green/low-carbon energy can be harvested from naturally occurring renewable energy sources such as sunlight, wind, and biomass. This renewable energy can be engineered to power our world sustainably. As opposed to conventional finite fossil sources, renewable energy sources emit little to no greenhouse gas emissions and are replenished faster than they are consumed. Thus, renewable energy plays a major role in accelerating society's transition to a carbon neutral future.

Wind energy

Wind turbines convert the kinetic energy of air in motion to generate electricity. For the Netherlands in particular, harnessing offshore wind energy from the North Sea is favorable due to the suitable wind climate, relatively shallow waters, and the proximity of large ports and industrial energy consumers. Large wind farms are required to harness this vast amount of energy, which translates into significant computational work needed to understand the principles required to construct efficient, durable, and stable wind turbines.

Solar energy/ Photovoltaics

Radiation from sunlight can be harnessed as heat (thermal) or converted into electrical energy through solar/photovoltaic (PV) cells. These PV cells are usually made from semiconductor materials, the most common of which are silicon, cadmium telluride, copper indium gallium diselenide, and perovskites. The most important design concern for these PV cells is energy efficiency, which is dependent on band-gap energy.

Solar fuels

Solar energy can also be converted into chemical energy, thus producing synthetic chemical fuels called solar fuels. In principle, solar fuels are produced by combining common substances like CO_2 and H_2O using sunlight energy. A possible approach to their production is 'artificial photosynthesis'. Other options include hydrogen production by solar energy-powered H_2O electrolysis, or the production of less-conventional fuels like NH_3 and hydrazine through solar energy-powered nitrogen reduction.

Bio-fuels

Biofuels play a particularly important role in decarbonising transport by providing a low-carbon solution for existing technologies, such as light-duty vehicles in the near term and heavy-duty trucks, ships and aircraft with few alternative and cost-effective solutions in the long term.

e-fuels

eFuels are produced with electricity from renewable sources, water and CO2 and are a sustainable alternative to fossil fuels. eFuels can be used in existing infrastructure and thus decisively and affordably reduce CO2 emissions in the transport and heating market – all the way to climate neutrality.

eFuels can solve two challenges of the energy transition: the problems of storing and transporting renewable energies. Thanks to the high energy density of eFuels, and because they can be transported at room temperature and pressure, renewable energies can be generated easily and economically around the world and transported anywhere they are needed using existing technologies.

Fluid Dynamics

Fluid dynamics is important for optimizing energy conversion, storage, and distribution for renewable energy technologies, which are based on fluid flows. Computational Fluid Dynamics (CFD), which is a frequently used tool for renewable energy engineering research, as it can provide better understanding of the physical phenomena on which renewable energy technology is based. CFD can also be used to simulate designs and optimize equipment/machinery without having to build them.

Biomass

Biomass energy refers to the energy contained within plants, resulting from photosynthesis: the plants absorb solar energy and convert CO_2 and H_2O into carbohydrates. This energy can be transformed into usable energy through direct means (thermal conversion to generate heat or conversion into electricity), and indirect means (processing into biofuel). Algal biomass is also another source of renewable energy which has enormous potential. It takes up much less space than other biofuel crops and produces energy through photosynthesis at a quicker rate than other biofuel feedstocks. Sustainable management of these biomass energy sources is required to maintain their status as 'renewable energy sources'.

Bio energy

The energy produced from organic material (biomass) is referred to as bioenergy. Currently, modern bioenergy accounts for about 55% of renewable energy and over 6% of global energy supply, making it the largest source of renewable energy globally.

Clean fossils

The concept of clean fossils encompasses methods and technologies that are aimed at reducing the environmental impact of fossil fuel consumption. There are several pathways in research that potentially lower the impact of fossils, such as, carbon capture, increasing efficiency, utilizing fossil fuel options with lower emissions (such as natural gas) and co-firing fossil fuels with clean fuels.

Hydro power

Hydroelectric systems are a very important source of renewable energy. It plays a crucial role in the global energy supply and thus research on enhancing its efficiency and reliability, but also environmental sustainability is paramount. Key areas of research in this field are not only on harnessing hydro power but also how to address ecological concerns and future resilience to changes in water flow due to climate change.

Ocean energy

The ocean is potentially a vast and untapped source of energy. Various sources of potential energy, the most obvious source of energy lie within the tides and waves, which can be harnessed as a renewable source of energy. Furthermore, the saline water from the ocean can be combined with fresh water to harness energy. Finally, the water also contains potential thermal energy, as there are large temperature differences between the surface and the deeper layers.

Algae

Algae can be grown in the sea or on infertile soil and are thereby not in competition with the production of foods. Interestingly in algae, under stress conditions (depletion of nitrogen), the production of fats increases. This means it is a good potential source for biodiesel production. However, profitability and the design of a suitable production process remain challenging. An alternative would be to use algae in biorefineries and to produce several high-value products.

Metals for energy

The energy transition is in fact a material transition: from fossil fuels to metals. There are five to six core energy transition metals (ETM), them being lithium, cobalt, copper, aluminum, nickel, and rare earths. These metals are essential to the production of net-zero-supporting technologies.

Researchers working on Renewable energy sources:

Name	University	Research Group	Specialization
Simon Watson	TuD	TuD Wind Energy Institute (DUWIND)	Wind energy systems, wind climate and conditions, wind turbine design, wind turbine reliability and condition monitoring, Aeroacoustics
Olindo Isabella		Photovoltaic Materials and Devices	Crystalline silicon solar cells, thin film silicon solar cells, solar fuels, PV systems
Wiebren de Jong		Large-Scale Energy Storage	Electrocatalytic conversions, biomass gasification, energy storage
Luis Cutz IJchajchal		Large-Scale Energy Storage	Electrocatalytic conversions, biomass gasification, energy storage
George Lavidas		Marine Renewable Energies Lab	Ocean Energies
Kees Venner	UT	Engineering Fluid Dynamics	Aeroacoustics and aerodynamics, computational fluid dynamics, Wind tunnels, fluid mechanics in turbomachinery
Elham Shirazi		Sustainable Products and Energy Systems	Solar forecast, PV integration
Wilko Rohlfs		Thermal and Fluid Engineering	Solar energy, Energy systems integration, thermal conversion and storage

Barry Koren		Scientific Computing	Modeling, simulation, automatic design and optimization
Hamid Montazeri	TUe	Building Physics	Wind tunnels, computational fluid dynamics, numerical modeling
Yali Tang		Power and Flow	Computational Fluid Dynamics; particle-laden flows; metal electrolysis; direct iron reduction
Nico Dam		Group of Niels Deen	Optical Measurement techniques
Jeroen van Oijen		Power and Flow	Clean and efficient conversion of renewable fuels in combustion systems, including hydrogen, ammonia, e-fuels, and metal fuels
Erwin Kessels		Plasma and Materials Processing	ALD for energy, processing of nanomaterials
Richard van de Sanden		Plasma and Materials Processing for green chemical convertions	CO_2 neutral fuels, nanolayers for solar cells, plasma-based gas conversions, ALD for energy
Rene Janssen		Molecular Materials and Nanosystems	organic solar cells, perovskite solar cells, solar fuels
Maja Rücker		Energy Technology and Fluid Dynamics	Fluid-solid interactions, macroscopic flow phenomena
Herman Clercx		Fluids and Flows	Transport in turbulent flows
Niels Deen		Power & Flow	Computational and experimental fluid dynamics, multiphase flows

Hans Kuipers		Multi-Scale Modelling of Multi-Phase Flows for chemical reactors	Modeling of multiphase flow reactors, hydrodynamics
Michael D. Boot		Inorganic Materials & Catalysis	Catalysis for C1 chemistry, renewable energy storage, and bio-renewables
Bart Somers	TU/e	Power & Flow	advanced bio-fuels, e-fuels and H2 directly) in Heavy-Duty and marine applications. So principally in Internal Combustion Engines. (ICE)
Rob Bastiaans		Power and Flow	Biomass gasification
Bart Macco		Plasma and Materials Processing	Functional nanolayers for their application in crystalline silicon solar cells
Maike Baltussen		Multi-scale Modelling of Multi-phase Flows	Fluid Dynamics: Multiscale modelling of multiphase flows
Harry Bitter	WUR	Biobased Chemistry and Technology	Catalysis/conversion, biobased soft materials, synthesis
Maria Barbosa		Bioprocess engineering, AlgaePARC	Algae
Marcel Janssen		Bioprocess engineering, AlgaePARC	Algae

System Transition

System transition is a very broad topic, including everything involved in the transition of our energy system.

Energy storage

With the coming of new energy renewable resources, new energy storage methods must be developed. An illustrative example is the use of solar panels. As solar irradiance is not constant, e.g., day-night rhythm and seasonal variation and our electricity consumption is not aligned with solar electricity production, energy storage is required. Energy storage includes topics such as batteries and hydrogen.

Sustainable process technology

Sustainable process technology includes the development of new processes to convert biomass into biofuels and biochemicals. It included topics such as process design and catalyst development.

Energy transition in agriculture

The production of food costs a lot of energy. Therefore, agriculture is an important part of the energy transition. Fossil fuels are used for machinery but also in heating and drying. In addition, the production of fertilizers is an energy-costly process. Therefore, new technologies must be developed.

Economy

The energy transition is a complex problem. Besides the need for the development of new technologies, it is also a socio-economic problem. For example, when energy becomes more expensive, the production cost of goods and services will go up, affecting the population's purchasing power.

Process intensification

Process intensification has the goal to increase the efficiency of processes and can be studied on three different levels, namely unit operations, functional and phenomena level. A simple and commonly known example is the intensification of a batch process, by the development of a continuous system. Process intensification is important to develop sustainable processes which can compete with current commercial processes.

Power systems

An (electrical) power system is a network consisting of all electrical components which produce, transmit and consume the electricity within a grid. Such a system should be well designed, as efficiency and safety are essential in this application.

Indian energy transition

The energy transition is a crucial step in our futures. India is a great example of this. India is rapidly transforming, and the economic growth has been one of the highest. This also affects their CO_2 emissions. India now has the third highest CO_2 emissions in the world. However, India has set up ambitious targets and has made achievements in various sectors.

Systems Integration

System integration includes bringing together different components into one system. For the energy transition, system integration means the coordination of different energy carriers and sectors into one system, which is sustainable, safe and reliable.

Engineering

For the energy system transition, several challenges must be overcome. Here engineering will play a crucial role in developing novel systems to intensify processes and integrate systems.

Socio-technical innovation and climate change

Technical innovations will be crucial for the energy transition. However, besides these technical innovations, a transformation of the existing socio-technical systems is needed. An example is the transition needed in consumer behavior.

Science technology & policy studies

For the energy transition, technology is important. However, the problem is complex and besides new technologies, it also requires the cooperation of society through policy. Policy studies researches how scientific knowledge and innovation is influencing the policy making of modern society.

Impact of innovations

What is the impact of innovative technologies? Here, the impact of technology is studied on ecosystems and on different sectors.

Governance

Governance plays a crucial role in system transitions by policy-making and investments. Governance shapes the transition of countries, industries and communities.

Human interaction

How can individuals and communities contribute to energy transition? What effect has the energy transition on individuals and communities? How do these transitions within and across organizations go? This is all part of human interaction.

Sustainable energy systems

The current energy systems need to transform to more sustainable energy systems. It includes the switch to production and use of clean and sustainable energy and it includes a major transition of our current energy network.

System analysis

An important tool to improve our energy system is system analysis. This is a modelling tool to evaluate the opportunities and challenges within a system. The impact of different scenarios can be studied to explore potential future energy systems with zero emissions.

Digitalization

Digitalization – the increased use of digital technologies – is key to integrating renewables into electricity systems, improving the reliability of power grids and reducing the cost of access to electricity, therefore contributing to a more just and equitable energy transition.

Cybersecurity

Energy systems are deeply dependent on assets and infrastructure becoming more digitally connected to increase safety, bring down costs, increase efficiency, and enable greater renewable generation and electrification. However, the energy industry cannot reap the benefits of digital transformation without robust cybersecurity. While risks are increasing, there are significant benefits to those who invest, with greater security building confidence, enabling innovation, and increasing competitiveness. The energy transition relies on smart infrastructure, but smart is only good as long it isn't breached by a cyber-attack.

Inter-temporal operation & planning

To decarbonize the energy system, the share of renewable generation is expected to increase significantly, especially in the electricity sector. Some of these renewable energy sources, such as wind energy and solar photovoltaic (PV) energy, have an intermittent character, i.e., they are highly variable and have a limited predictability. Due to these characteristics, a large penetration of intermittent renewable energy sources (IRES) can have a significant impact on the operation of the electric power system.

Long-term energy-system planning models are frequently used in studies analyzing the transition towards a sustainable energy system. In these studies, intermittent renewable energy sources (IRES) are expected to be key contributors to this transition. However, their highly variable and stochastic nature poses challenges to long-term energy-system planning models, as these models typically use a low level of temporal and techno-economic operational detail.

Electrification & Energy Sector Integration

Sector integration means linking the various energy carriers - electricity, heat, cold, gas, solid and liquid fuels - with each other and with the end-use sectors, such as buildings, transport or industry.

Linking sectors will allow the optimization of the energy system as a whole, rather than decarbonizing and making separate efficiency gains in each sector independently.

The electrification of transport is a good example of the potential for integration. At present, we know that electric vehicles connect the transport and power sectors, but also buildings, where the charging points are often located. Currently there is only a very limited interface between these three sectors.

Researchers working on System Transition:

Name	University	Research Group	Specialization
Nihit Goyal	TuD	Multi-actor systems	Policy innovation and policy design
Jose Rueda Torres		Intelligent electrical power grids	physics-driven analysis of stability phenomena of HVDC-HVAC power systems, with emphasis on unravelling stability issues that can occur in time frames of micro- to mili-seconds. This involves large-scale modelling and dynamic equivalencing of HVDC-HVAC integrated power and energy systems. My research covers the development of new fundamentals and methods that intersect physics-driven analysis of stability phenomena with probability theory, fuzzy logic, and stochastic optimization. My methods bring the necessary tools for effective assessment and management of multi-systemic reliability and

			stability. Also, it brings breakthroughs concerning with adaptive, optimal, and resilient design of primary and secondary control systems.
Kenneth Bruninx		Engineering Systems & Services	Energy transition and industrial decarbonization
Abhigyan Singh		Design Conceptualization and Communication	Design Anthropology, Ethnography, Value Exchanges, Local Socioeconomic Transitions
Mar Pérez-Fortes		Engineering systems & services	Techno-economic assessment, emerging technologies
Nowella Anyango-van Zwieten	WUR	Forest and Nature Conservation Policy Group Wageningen Environmental Sciences Group	Environmental sociological perspective at the science-policy-society interface
Dujuan Yang	TUe	Information systems in the built environment	Travel behavior and energy effects
Rob Bastiaans		Power and Flow	Turbulent combustion modeling of any gaseous fuel
Phuong Nguyen		Electrical Energy Systems	Power systems
Canan Acar	UT	Thermal and Fluid Engineering	Hydrogen production, exergy,
Elham Shirazi		Sustainable Products and Energy systems	Systems integrations; sustainable

			energy systems. Specialization: Power systems operation and planning, energy systems integration

Energy access

Hundreds of millions of people do not have access to electricity and many more only have severely limited access. Improving energy access involves not only technological advancements, but also improvement in political, social and economic aspects. To facilitate cooperation in this field, the 4TU energy alliance on energy access was launched in 2023.

Politics of Energy access

The expansion of energy access comes with many political decisions. Politics decide who has power (both electrical and social) and who does not. Fair and inclusive increase of energy access thus requires important policy decisions.

Justice

A key factor in the improvement of energy access is ensuring inclusive procedures and striving for a fair and equitable distribution of the benefits that come with improved energy access. Introducing energy access to a community will lead to many opportunities in jobs and manufacturing that should be accessible to all.

Electrical connection

Connecting hundreds of millions of people to a grid will be a severe challenge. Various options such as local with or without solar power or connection to a bigger centralized grid need to be considered. The effect of policy and the needs of local communities are paramount.

Localization

It is important to focus on the needs of local communities when dealing with the electrification of their society. Empowering local communities to overcome external dependence and prevent extractivism is essential to achieve a just form of energy access. It is also important that the energy supply also matches the technological and social needs of the community.

Clean cooking

2.5 billion people still cook every day using biomass such as wood or dried cow dung. Combined with a high population density, this can lead to mass deforestation and air pollution. Not only does this way of cooking create health and environmental problems, but it is also much more time-consuming for the people involved, which are disproportionally women, inhibiting them from generating their own income or attending school. Developing and manufacturing affordable and accessible clean cooking devices is therefore of immense importance to improve the overall health and well-being of billions of people and lower environmental pollution.

Researchers working on Energy access:

Name	University	Research Group	Specialization
Nihit Goyal	TuD	Multi-actor systems	Policy innovation for sustainable future
Lui Cutz		Large scale energy storage	Thermochemical waste valorization
Kenneth Bruninx		Engineering systems and services	Energy market dynamics
Jelena Popovic	UT	Power electronics	Energy access and socio technical integration
Niek Moonen			Electromagnetic interference
Amalia Suryani			Energy access in Indonesia
Maarten Appelman			Modular battery packs
Ilman Sulaeman			Remote microgrids, electromagnetic interference
Nowella Anyango-van Zwieten	WUR	Forest and Nature Conservation Policy Group Wageningen Environmental Sciences Group	Environmental sociological perspective at the science-policy-society interface
Henny Romijn	TUe	Technology, Innovation & Society	Combatting poverty and fostering sustainable development
Jonas van der Staeten			Electric mobility transitions, history of electrification, urban infrastructure
Diego Quan Reyes		Power & Flow	Direct numerical simulations of hydrogen combustion, community-based

			research biomass reactors
Phuong Nguyen		Electrical Energy Systems	Electrical connection

Batteries

A major challenge within the energy transition lies in the storage of it. Batteries are used to store electrical energy, which can be released by chemical reactions that supply electrons, providing a mobile source of electricity.

Flow Batteries

Flow batteries are a type of battery where the electrolyte is stored in a reservoir and can be pumped into an electrochemical flow cell to be charged or generate electricity. Its advantage over a traditional battery is its capacity, which is determined by the volume of the electrolyte.

Power electronics & electromagnetic compatibility

Power electronics are ubiquitous in electrical devices. Understanding the interaction of power electronics and electric systems is key, ensuring that devices operate as intended without causing harm or interference to one another. Power quality and electromagnetic compatibility are challenges that are faced in the engineering of many electrical devices.

Salt batteries

A thermochemical battery, also known as a salt battery. They are different to a traditional battery in that it does not use electrodes or any type of electronic circuit, instead it uses the exothermic hydration of salts to generate energy. The idea is that a material, such as a metal carbonate, reacts with water to form a hydrate. This reaction releases energy which can be harnessed for a variety of means. To regenerate the battery only heat is needed, the water is then released regenerating the carbonate material.

Organic battery materials

Many state-of-the-art battery technologies rely on scarce and potentially harmful materials. Organic battery materials provide an alternative to metal-based materials and therefore mitigate the environmentally harmful effect of mining battery materials.

Electrical charging

Research in this field aims to improve charging efficiency, reduce charging time, and enhance the overall performance of battery systems for various applications.

Researchers working on Batteries:

Name	University	Research Group	Specialization
David Vermaas	TuD	Transport phenomena (TP)	Flow batteries
Swapna Ganapathy		Center for chemical energy storage	Li-O_2 battery systems, solid state batteries
Xuehang Wang		Storage of electrochemical energy (SEE)	Mechanistic studies, nanomaterials synthesis, interfacial engineering
Marnix Wagemaker			Improved Li-ion, Solid state, Li-air, Na/Zn aqueous batteries
Gerrit Brem	UT	Thermal engineering	Thermochemical heat storage
Henk Huinink	TUe	Thermo Chemical Materials	Thermal energy storage, thermo-chemical materials

Industry

Industry is one of the biggest consumers of energy in the world. As such there is great potential and opportunities for improvement in terms of efficiency.

Dynamic based maintenance

Systems and structures degrade over time due to use. Maintenance is needed to keep them functioning properly. Critical systems often undergo preventive maintenance, but determining the right timing for this maintenance is challenging. If done too frequently, it's costly; if delayed, it risks system failure with serious consequences. Technologies and methods are needed to accurately determine the optimal timing for maintenance, ensuring it occurs just when needed to maximize efficiency and avoid unnecessary costs or failures.

Energy efficiency in Industry

The field of industrial energy efficiency focuses on developing strategies and technologies to reduce energy consumption and improve energy utilization in industrial processes. It involves analyzing and optimizing various aspects of industrial operations, such as manufacturing processes, equipment efficiency, and energy management systems, to minimize energy waste and improve productivity. It explores innovative solutions for energy-efficient technologies, process optimization, waste heat recovery, and renewable energy integration tailored to specific industrial sectors. The goal is to promote sustainability, reduce greenhouse gas emissions, lower production costs, and enhance competitiveness in the global market.

High temperature heat pumps

In recent years the ability of heat pumps to deliver process heat as become more of interest for several industries under the aspect of energy efficiency, utilization of excess heat and reduction of climate gas emissions related to generated of process heat. High temperature heat pumps, or industrial heat pumps, can be defines as heat pumps being able to deliver heat. Current heat pump solutions are mostly limited to heat supply of around 70°C to 80°C, while industry process are quite often designed for heat supply temperature of around 100°C to 200°C. High temperature heat pumps can be used for everything from hot water production to upgrading waste energy to be used in other processes. One of the main challenges of high temperature heat pumps is the integrability into the production process industry and to match the available heat source to the required heat demand.

Iron powder

Metal fuels are powders which are used as energy carriers in a circular process. Iron Powder has an enormous potential for its contribution to the large-scale long-term storage and import of sustainable energy, complementary to hydrogen.
The advantages are:

- **Sustainable**
  No direct CO2-emissions, low NOx, fully recyclable and circular.
- **Safe**
  No health or environmental risks, and non toxic.
- **Highly efficient**
  high output temperature, high energy density and stable flame with high throughput
- **Competitive transport/storage**
  Efficiënt and cost effective methods for transport & storage of iron powder exist.

Defossilizing chemical industry

Due to the size of the industry and its use of fossil fuels and feedstocks, the chemical sector is responsible for approximately 6% of global greenhouse gas emissions.
The chemical industry cannot fully ‘decarbonise’ - as most chemicals inherently contain carbon atoms that are essential to the material’s structure. Decarbonisation measures such electrification and improved energy efficiency would help to reduce the chemical industry’s emissions.
Alongside decarbonisation measures, the chemical industry will also have to ‘defossilise’ – by replacing fossil feedstocks with alternative carbon sources to make chemicals.

Photocatalytic synthesis

Application of photocatalysis for synthesis of valuable organic chemicals appears an interesting approach. The use of a photocatalyst and light as the energy source can be considered as a green, sustainable alternative for other methods of fine chemicals production.
The research program aims at the development of innovative materials and concepts for photo- and electrocatalytic reactions with high efficiency.

Researchers working on Industry:

Name	University	Research group	Specialization
Mar Perez-Fortes	TuD	Engineering, Systems and Services	Techno-economic, environmental and social analysis of emerging technology
Congcong Sun	WUR	Agricultural Biosystems Engineering	Intelligent Control System for optimal, sustainable and autonomous agro-food production
Wilko Rohlfs	UT	Heat transfer and thermodynamics	Heat transfer, liquid film
Martin van Sint Annaland	TuE	Chemical process intensification	Integration of reaction and separation, integration of endothermic and exothermic reactions, Integration of heat exchange exploiting dynamic reactor operation.
Philip de Goey		Power and Flow	Iron powder

Chemistry for energy

Chemistry and energy are irrevocably intertwined. Chemical processes require or generate energy, by nature of thermodynamics. However, harnessing or reducing energy use requires fundamental understanding of underlying processes, and presents unique process design and engineering challenges.

CO_2 as raw material

Through CO_2 capture, storage, and utilization, CO_2 emissions can be turned from a problem into a solution. As such, rather than being seen as a waste product, CO_2 can be used as a reusable, sustainable raw material.

Catalytic processes & materials

Catalysis is the backbone of several industrial processes and is projected to play a central role in the energy transition. Catalysts function by lowering the energy barrier that must be overcome for a chemical reaction to occur (activation energy). As such, they facilitate chemical reactions and make them more energy efficient. Furthermore, through catalysis it is possible to increase the yield of desired products and reduce unwanted side-products. The scope of catalysis is broad, ranging from biofuel/bioenergy production to CO_2 capture and conversion, to H_2 production, electrocatalysis, etc. From this it is clear, that catalysis and catalytic processes play an enabling role, especially as humanity seeks to create a sustainable future and find new solutions to societal challenges.

(Bio) electrochemistry

In electrochemistry, the chemical energy contained within substances is converted to electrical energy or electrical energy is used to cause chemical reactions through electron transfer in redox reactions. Bioelectrochemistry is a branch of electrochemistry focused on electron transport involving enzymes and biomolecules. Both technologies play an integral role in the energy transition, as they can be used to foster defossilisation and decarbonization.

Chemical recycling

Chemical recycling involves converting polymeric waste into valuable feedstocks (monomers, oligomers, higher hydrocarbons) for the chemical industry. These feedstocks can be used to produce new high-quality plastics and other products. Pyrolysis, gasification, hydro-cracking, and depolymerization are the different technologies employed in chemical recycling.

Hydrogen and fuel cells

Hydrogen is an energy carrier which can be used to move, store, and deliver energy produced from other sources. As such, it plays a crucial role in the energy transition. The chemical energy contained within molecular hydrogen can be released, for example, by reacting it with oxygen in internal combustion engines or fuel cells to produce water. Fuel cells make use of electrochemical reactions for hydrogen conversion into energy/electricity, making them a clean, efficient, and reliable source of power. Unlike batteries which need periodic recharging, fuel cells can operate continually if a fuel source is present.

Thorium molten salt reactor

A molten salt reactor (MSR) is a nuclear reaction vessel that contains a hot liquid salt. This salt acts as both the fuel and reaction coolant, since it consists of the nuclear fuel and several other compounds which optimize reaction kinetics, heat transfer, and stability. Thorium molten salt reactors are superior in performance to other MSRs because thorium salts are abundant with relatively low nuclear waste production. Additionally, in its molten state, the salt has excellent heat transfer properties, allowing for optimal fuel utilization and high energy production.

Materials for Energy

The development and deployment of advanced materials for clean energy technologies: energy production, conversion, and storage. Research examples are:

- Advanced material characterization techniques
- Hydrocarbon conversion and storage
- Inorganic and organic photovoltaics
- Thermoelectric materials

Researchers working on Chemistry for energy:

Name	University	Research group	Specialization
Harry Bitter	WUR	Biobased Chemistry and Technology	Catalysis, CO_2 capture and conversion, electrochemistry
Guanna Li			Catalysis, computational chemistry, surface chemistry
Annemiek ter Heijne		Environmental Technology	Microbial electrochemical technologies, microbial electrolysis for methane production from CO_2
Akbar Asadi Tashvigh		Biobased Chemistry and Technology	Membranes, fuel cells, hydrogen
Mar Pérez-Fortes	TuD	Engineering Systems and Services	Techno-economic assessments of CO_2 capture and utilization, bio-based processes, fuel cells
Wiebren de Jong		Large-Scale Energy Storage	Electrocatalysis, electrochemical conversions of CO2
Luis Cutz IJchajchal		Large-Scale Energy Storage	Biomass, thermochemical processes, chemical recycling
Lars Bannenberg		Storage of Electrochemical Energy	Hydrogen sensors, thin metal film hydrides, neutron reflectometry
Hanieh Bazyar		Transport Phenomena	Membrane separation, smart membranes, microfluidics

Canan Acar	UT	Thermal and Fluid Engineering	Hydrogen production, exergy,
Aayan Banerjee		Catalytic Processes and Materials	electro-catalysis, design, engineering, multi-scale modelling, digital twinning
Davoud Jafari		Advanced Manufacturing, Sustainable products & Energy systems	Leveraging additive manufacturing to engineer functional surfaces for energy conversion reactions, controlling surface chemistry for efficient catalytic activity, optimizing material porosity and pore structure for enhanced mass transport, tailoring material composition for specific electrochemical reactions.
Emiel Hensen	TUe	Inorganic Materials & Catalysis	Catalysis, reaction kinetics
Diletta Giuntini		Mechanics of Materials	Ceramics manufacturing, sintering, additive manufacturing, ceramics for energy (membranes, SOFCs/SOECs, solid state batteries), hierarchically porous materials, manufacturing process

			modeling.
Marta Costa Figueiredo		Inorganic Materials & Catalysis	Electrochemistry, electrocatalytic synthesis
Thijs de Groot		Sustainable Process Engineering	Electrochemical process technology

Hydrogen

(Green) Hydrogen has a crucial role for the energy transition, due to its high energy density and its potentially clean production (e.g., water electrolysis with green electricity). It can be used to produce chemicals or as an energy carrier. Since hydrogen can be sustainably produced, it can be used to decarbonize a variety of sectors. The temporary storage of hydrogen can resolve the intermittency problems of the grid which are a result of renewable energy sources such as solar.

Hydrogen and fuel cells

Hydrogen is an energy carrier which can be used to move, store, and deliver energy produced from other sources. As such, it plays a crucial role in the energy transition. The chemical energy contained within molecular hydrogen can be released, for example, by reacting it with oxygen in internal combustion engines or fuel cells to produce water. Fuel cells make use of electrochemical reactions for hydrogen conversion into energy/electricity, making them a clean, efficient, and reliable source of power. Unlike batteries which need periodic recharging, fuel cells can operate continually as long as a fuel source is present.

Underground hydrogen storage

As the supply and consumption of energy (and hydrogen) is not constant, energy storage is required. A possibility would be to store hydrogen underground. An example is the storage of hydrogen in salt cavities near Zuidwending (The Netherlands). The safety of underground hydrogen storage is of great importance.

Hydrogen sensors

Hydrogen is a very small molecule, which is flammable (or even explosive). Since we want to use it in our gas pipes and on a large scale in industry, it is important to detect hydrogen leaks. Sensors are needed which are extremely sensitive, cheap, small and reliable.

Researchers working on Hydrogen:

Name	University	Research Group	Specialization
Lars Bannenberg	TuD	Storage of electrical energy	Hydrogen sensors, Hydrogen production, Hydrogen fuel cells
Canan Acar	UT	Thermal Engineering	Hydrogen Production
Guido Mul		Photocatalytic synthesis	Nanoparticle; water type; hydrogen production; electrode
Aayan Banerjee		Catalytic processes and materials	fundamental physico-chemical phenomena across multiple scales that govern the performance and life of next-gen (electro-)chemical devices e.g. hydrogen fuel cells, electrolysers, batteries
Akbar Asadi Tashvigh	WUR	Biobased chemistry & technology	Hydrogen proton exchange membrane fuel cells
Thijs de Groot	TUe	Sustainable Process Engineering	Hydrogen Production
Jeroen van Oijen		Power and Flow	Clean and efficient conversion of renewable fuels in combustion systems, including hydrogen, ammonia, e-fuels, and metal fuels
Azahara Luna Triguero		Energy Technology	Modified porous materials for hydrogen and hydrogen carrier storage
Antoni Forner Cuenca		Membrane Materials and Processes	multiple electrochemical technologies including but not

			limited to fuel cells, electrolyzers, and redox flow batteries