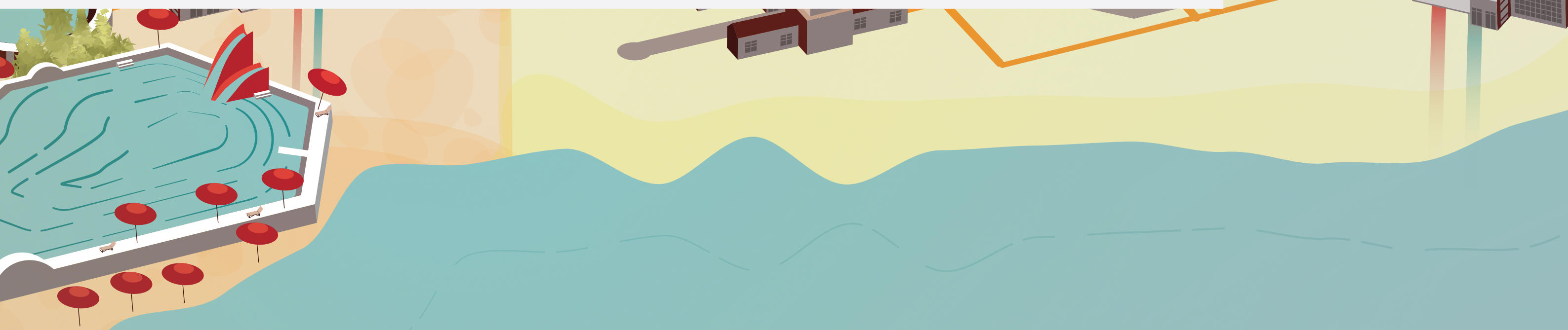
GEOTHERMAL HORIZONS

FROM CITIES TO REGIONS

ETIP Geothermal

etip-geothermal.eu



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This **ETIP Geothermal Vision** looks towards the future of geothermal energy development to achieve the European Union's climate-neutral milestone by 2050, and it highlights the great benefits of geothermal to decarbonise our economy. It is a unique solution to allow a sustainable energy transition with a paradigm shift for a circular economy.

Geothermal is a key enabler for energy system integration.

CONTENTS

PURPOSE AND SCOPE

Geothermal energy is a key form of renewable energy and plays a crucial role in the energy transition in Europe. Its benefits include heating and cooling supply, electricity generation, hot water provision, and thermal underground storage for short and seasonal periods. Moreover, geothermal energy has the unique ability to supply critical raw materials, such as lithium, in a sustainable way.

The European Technology & Innovation Platform on Geothermal (ETIP-Geothermal) is an open stakeholder group endorsed by the European Commission under the Strategic Energy Technology Plan (SET-Plan). Its overarching objective is to enable geothermal technology to proliferate and reach its full potential everywhere in Europe.

This vision is a progressive work that aims to serve as a cornerstone to achieve the EU climate-neutral milestone by 2050. Using the abundant geothermal resources spread across Europe, cities like Paris (France), Munich (Germany), Szeged (Hungary) and regions like Tuscany (Italy) are clear examples of the power of geothermal energy and its efficacy in reducing reliance on traditional fossil fuels and contributing to local economic development.

As members of ETIP, representatives from industry, academia, research centres, and sectoral associations support the development of geothermal research and innovation as a crucial part of the energy transition in Europe. The research agenda targets the development of novel geothermal applications, which must be tailored to meet the diverse energy needs of European citizens and industries. A crucial step is the integration of these applications into the European energy security scheme, particularly in regions vulnerable to external energy dependencies. By building "made in Europe" geothermal solutions, cities and regions can reduce their reliance on fossil fuel and materials imports, increasing their energy independence from external sources. Today geothermal technologies do not consume critical raw materials and are built using EU supply chains for equipment and components: steel, chemicals, and cement. Europe has a leadership role in geothermal technologies. Innovation must be supported to maintain the EU's leadership.

In summary, this vision for advancing geothermal technologies and innovations in Europe represents a breaking point and a unique opportunity to address the climate transition and secure Europe's energy supply in an affordable way.

GEOTHERMAL
IN EUROPE TODAY

Heating and cooling supply

Geothermal energy provides heating and cooling to more than 16 million inhabitants in Europe, and electricity to circa 11 million consumers.

More than 2.12 million geothermal heat pumps are installed in Europe. They largely consists of small-scale units of around 10 kWth capacity supplying heat, cold and hot water to single-family houses. The trend is towards larger systems of 50 kWth to 1 MWth to supply heating & cooling to residential and tertiary buildings, with closed- and open-loop systems. Geothermal systems also supply free cooling, especially to large consumers such as data centres.

395 geothermal district heating systems are in operation, with a total of 5,6 GWth installed capacity. They mainly supply heat to consumers in urban areas, such as residential buildings, but also for agriculture, in particular greenhouses. In a city like Paris, 1 million inhabitants are already heated by geothermal. More than 200 district heating projects are under development in Europe. Market trends are marked by an average size of systems of 10 MWth capacity to supply 10,000 heat consumers. Large-size projects, developed with project portfolio approaches, are now seen in the market. A trend is also to supply heat to industrial processes from low to high temperatures.

> "400 geothermal district heating systems are in operation, with 5.6 GWth installed capacity.

Technological innovation moves towards large heat pumps, new drilling design and technologies and novel business models are accelerating the deployment of geothermal district heating systems.

In terms of generation, geothermal supplies heat continuously (base load) and on-demand, being sizable and flexible. Its cost is competitive in several European markets, as shown in several lifecycle studies.

All heating and cooling sectors can be served by geothermal energy: building, industry, services and agriculture, etc.

Electricity

About 150 Geothermal power plants are installed in Europe, representing a capacity of 3.5 GWe. With the highest load factor of all energy technologies (typically > 80%), geothermal base-load electricity generates more than 22 TWh.

Geothermal electricity is one of the best answers to the challenges that Europe is facing today regarding renewable, local, competitive and secured electricity generation. Geothermal energy brings security of electricity supply with a high base load factor, flexibility with dispatchable solutions and resilience to the energy system.

For a cost competitiveness analysis, a full cost comparison must include levelized costs of electricity, system cost ands externalities with sustainability and resilience criteria. Lifetime is a key criterion: around 20 geothermal power plants are over 25 years old and ca. 50 are over 15 years old.

Geothermal power allows to save system costs and is a key competitive solution to decarbonize the electrical sector and to supply renewable electricity to the whole economy.

Thanks to innovation and development, the geothermal electricity market is now entering a new development phase, with 30+ power plants to be put into operation throughout the next 5 to 7 years.

Enel Green Power – Nuova San Martino Power Plant

Energy storage

Geothermal offers many storage options for energy systems integration.

The main technology in the market today is the Underground Thermal Energy Storage (UTES) in the low to medium temperature range (10-60°C) and shallow depth (typically 500 m). Innovation is opening the market to high-temperature (25-100°C) underground storage. UTES includes ATES (Aquifer Thermal Energy Storage) and BTES (Borehole Thermal Energy Storage).

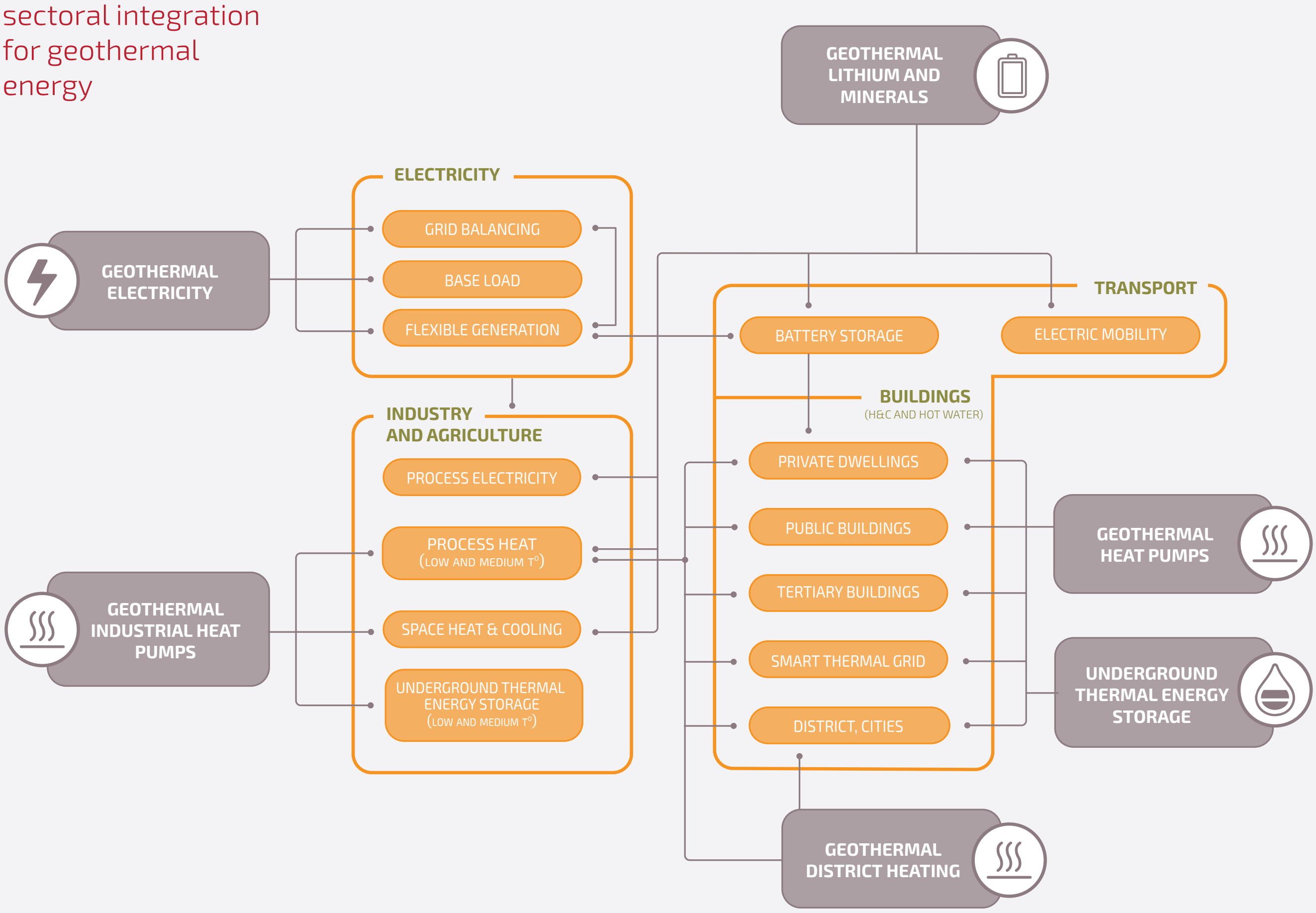
Other geothermal storage technologies include PTES (Pit Thermal Energy Storage), TTES (Tank Thermal Energy Storage), and MTES (Mine Thermal Energy Storage) systems.

These storage technologies are already today the cheapest solutions to store thermal energy.

Heating and cooling represent 50% of the European energy demand and require a lot of storage. Bridging the winter peak is essential, and thermal storage is the solution. Underground thermal storage can answer the challenge of large heat demand, as it provides large capacities with minimum land impact.

Geothermal electricity also provides a form of storage with its dispatchability and virtual storage with its load management. Geothermal resources also contribute to storing excess electricity by supplying minerals such as lithium for batteries, another key source of storage.

Visualising smart sectoral integration for geothermal energy



Eugeli Project Lithum

Minerals

Geothermal energy utilises the heat stored below the surface of the earth to provide permanent supplies of renewable heating, cooling and electricity, which is essential for the energy transition. Geothermal minerals are by-products of geothermal energy activities. The first kilograms of battery-grade lithium carbonate from geothermal has been produced in Europe in 2021, in France. Another milestone reached in 2023 is the Lithium Extraction Optimization Plant (LEOP) from geothermal in Germany.

The geothermal sector has been instrumental in designing and piloting methods to extract lithium from geothermal systems without hampering their energy generation activities. The first projects to scale up soon and exploration activities are already in process in Germany, France and Italy.

The potential of EU internal supply of critical raw materials can be increased with geothermal coproduction of minerals and critical raw materials. It passes through the recognition of strategic resources in Europe, such as supplies of domestically produced geothermal minerals.

This will help ensure the EU meets its core goals of energy and material independence.

Lithium is one of the foundation stone of a new shape of the energy system and our economy with digitalization and Artificial Intelligence.

KEY MESSAGES

1 EVERYWHERE IN EUROPE

Geothermal energy can be produced anywhere!

2 WHENEVER

Geothermal energy is always available to meet consumers' demands 24 hours a day, every day of the year.

3 ANYWHERE

Geothermal energy is the only renewable source that can contribute to the decarbonisation of electricity, heating and cooling, and transport sectors together. The geothermal role in balancing the grid and providing consistent baseload energy, or flexible generation is pivotal for a stable and reliable future energy system.

4 CHEAP RENEWABLE ENERGY IN THE LONG TERM

After initial installation investment, the operating costs are very low and predictable, and lifetime is long.

5 CUT GREENHOUSE GAS EMISSIONS

Geothermal energy can cut the EU's greenhouse gas emissions dramatically with zero emission energy supply.

7 EMPOWERING CLIMATE NEUTRALITY

Geothermal innovation is pivotal to achieving the EU's climate-neutral ambitions by 2050, catalysing a shift away from conventional fossil fuels in electricity, heating and cooling consumption.

6 ECONOMIC DEVELOPMENT HUB

Geothermal advancements contribute to economic growth, offering socio-economic benefits and foster the development of new industries across different European regions. By 2030, it could create 150,000 direct and indirect jobs.

8 VERSATILITY IN APPLICATIONS

Geothermal technology addresses power, heating & cooling, mineral extraction, and thermal storage needs, ensuring a holistic and sustainable energy approach. Geothermal is essentially invisible, with very low visual impact and land use.

9 EUROPEAN ENERGY INDEPENDENCE

Geothermal champions a future where Europe relies on its own resources, enhancing energy security and minimising dependence on external gas sources.

10 RESEARCH-DRIVEN RESILIENCE

Research and innovation within the geothermal sector help bolster Europe's resilience to climate change, ensuring a robust and adaptive energy infrastructure.

NOVEL TECHNOLOGIES
FOR GEOTHERMAL ENERGY

The Strategic Research and Innovation Agenda (SRIA) of ETIP launched in 2023 outlines relevant novel technologies required for the full and responsible deployment of geothermal energy. The SRIA is organized in four major disciplinary themes: **resource assessment, resource development, resource use and system integration,** as well as **resource sustainable use**, dealing with environmental and market issues. The novel technologies and methods to be developed apply to the four geothermal resources use domains (heating & cooling, electricity, UTES, and CRM).

Resource assessment

Resource assessment technologies seek to minimize the risks associated with pre-drill mining, extend the scope of available resources, and refine methods for identifying untapped potential. The initial focus centers on refining technologies to enhance resource prediction accuracy and mitigate uncertainty for the anticipated performance of the resource at depth:

- Cost-effective development and demonstration of geological, geochemical and geophysical exploration methods and technologies contributing to improve the imaging of geothermal reservoir structures (geometry and size), the prediction of its petrophysical properties and the chemical composition of bearing fluid;

- Reservoir characterization and performance assessment entails the implementation of cost-effective open, dynamic and transparent workflows by using advanced conceptual models and reservoir characterization methods;

- Sharing knowledge gained from productive reservoirs and geological analogs contributes to the creation of comprehensive rock property catalogues.

In addition, novel technologies deal with frontier resource development and identification:

- Medium-deep sedimentary reservoirs, geothermal heat pump systems and heat storage aim to explore geothermal resources at depths typically overlooked from ~300 to 2000m depth which are beyond ones covered by individual ground-source heat pumps;

- Deep sedimentary/basement reservoirs aim to unlock geothermal resources at depths between 2000- 6000m, which are marked by low natural permeability;

- Development of cutting edge reservoirs in high enthalpy resources, including super-critical geothermal systems, and offshore magmatic resources;

- Innovative geo-structures: development of technology for the integration of geothermal heat exchangers and heat and cold storage solutions into subsurface infrastructure elements that interface with the ground;

- Transformation of hydrocarbon assets entails the development of geothermal energy potential from abandoned or end of lifetime hydrocarbon reservoirs.

Finally, advanced methods are required for play-based portfolio exploration for heating & cooling. Taking advantage of shared geological (risk) factors in regional development and assessing resource potential entailing the development and demonstration of innovative approaches for a reliable estimate of geothermal resource potential resulting in a unified definition and harmonisation across Europe.

Resource development: drilling and subsurface engineering

Geothermal project expenses are heavily tied to drilling and subsurface engineering activities. These financial pressures are particularly evident during the early phases, even before productivity confirmation. This underscores the urgent need for strategies that reduce costs and introduce novel production concepts which can enhance productivity.

Novel technologies or drilling and well completion comprise for instance:

- Integration of robotic and AI-assisted drilling methods reduce drilling time and ensure reliable solution;
- Advanced drilling technologies, such as laser or thermal drilling, in order to radically optimize penetration rate;
- Novel drilling fluids and materials for casing, cementing, and completion are jointly key to enhancing well construction contributing to lower costs, enhanced performance and well integrity;
- Advances in monitoring and geosteering will significantly improve the result of the drilling processes;
- The inclusion of high-temperature electronics is crucial for sustained operations of high enthalpy systems.

Enhanced design and subsurface engineering, and technologies improving flow performance of wells include:

- Enhanced well architectures and stimulation, in order to improve the injectivity and productivity of wells;
- Shallow closed-loop technology (<500m) to lower cost and extend the effective deployment of geothermal heat pumps;

- Deep closed-loop technologies (>500m) to unlock extensive non-permeable resources;
- Enhanced production pumps to lower operational costs for fluid production (and reinjection).

Resource use and system integration

Efficient conversion of geothermal resources into usable energy, coupled with effective heat storage and co-production of minerals, holds the key to resource maximization, this entails:

- Advancing binary and power cycles and increasing overall energy efficiency;
- Flexibility in combined heat and power production further contributes to efficient resource utilization;
- Underground thermal energy storage at elevated temperatures demonstrates great potential;
- The extraction of valuable minerals, particularly lithium, enhances the economic viability of geothermal operations;
- The perspectives of chemicals production and other diversified applications of geothermal resources amplify their utility.

Enhancing the embedding of geothermal resource use in the energy system is of key importance for heating and cooling applications:

- Smart integration into different generations of district heating networks allows to exploit a larger range of resource temperatures and improve the load factor, extending the resource base perspective and lowering costs;
- The enhancement of resource management in dense installation environments results in most effective and sustainable use of subsurface space by indirect, direct and storage geothermal systems such UTES, ATES and BTES systems in dense urban areas;
- It also takes into account interaction between other urban users of the subsurface. Heating and cooling usage will be boosted by extending supply to the agri—food and industrial sector;
- Flagship projects for district heating networks in Metropolitan Heating & Cooling allow to exchange and concentrate experience and encourage other cities.

Resource Sustainable Management

This research and innovation activity is concerned with addressing environmental and market challenges through safe and sustainable resource management. The following aspects are considered vital components in the journey to achieve a sustainable geothermal future:

- Life Cycle Approach and Emission Footprint reduction assess and lower the environmental footprint of geothermal energy production, including lowering the carbon footprint. The environmental Life Cycle Assessment on all activities and solutions leading to a sustainable approach, including circularity, has to be developed. It includes a socio-economic lifecycle perspective.

- Circularity is enhanced by reuse of materials and recyclability;

- Water use management and Groundwater protection is improved to reduce water consumption and promote a sustainable water-use management;

- Sustainable reservoir management includes methods to enhance sustainable reservoir management, in particular in promoting tools for safe operations and associated potential environmental risks, including induced seismicity. Innovating with and for society sets the scene for a responsible development of both policies and projects that are aligned to social needs and expectations at different scales (from the local, to the global). New socio-scientific research on the desirability of geothermal energy, citizen and stakeholder engagement actions are key to build alliances among different actors towards common goals.

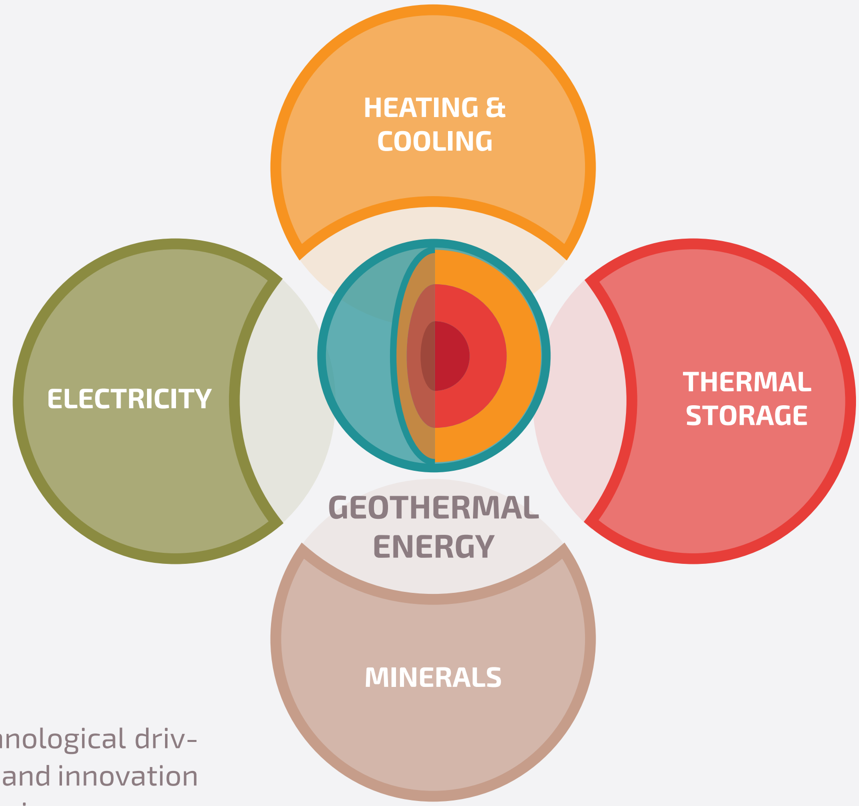
- Financing and risk mitigation develop the right financial support schemes for geothermal technologies facing subsurface uncertainty and system integration challenges.

- Policy and regulatory aims to set ambitious policies at the EU and national levels to allow the development of the geothermal market and the penetration of innovation in the sector. A sound financial and policy framework must be established to accelerate the deployment of innovative geothermal technologies, with adapted policies and better permitting regulations.

- Qualification and training ensures first-class skills and human resources to avoid shortcomings in skills development and lack of an adequate workforce, and consolidate the scientific base to educate the next generation of geothermal pioneers;

- Effective communication with the general public and increase awareness about benefits to use geothermal. Increasing dissemination, public awareness and engagement through the promotion of geothermal technologies is essential to the implementation and success of projects at the local level and the national level

Flagship developments



Key industrial and technological drivers can boost research and innovation in geothermal technologies:

I. Progress can be highly accelerated by technology transfers from the Oil & Gas industry. Existing tools and workflows have to be adapted to different kinds of resources such as water and heat, different geological settings e.g. basement and volcanic reservoirs and different environments as for temperatures, pressures and mineral content, with different ambitions and challenges in small and large scale projects and budgets. To this extent, it is interesting to note that major service companies now start to focus on geothermal energy, trying to define viable business models;

II. Artificial Intelligence (AI), Machine Learning (ML), high-performance computing and robotization are key enabling technologies to enhance resource assessment and resource development, lowering levelized cost of energy for operations and promoting safe and sustainable development. There is a wealth of subsurface data from geothermal resources exploration in the past, which serves as an important stepping stone for these technologies allowing to identify and unlock new resources

To conclude, a key message of the SRIA is that in order to implement this research program it is not only necessary to strengthen R&I private investments but also to increase the public funding budget for R&I projects at the European, national and regional levels.

GEOTHERMAL
CONTRIBUTION TO 2040

The **ETIP Geothermal Vision** for the geothermal contribution in future European energy consumption is based on the Implementation Plan of the Geothermal IWG, released in December 2023[1].

Where the Geothermal IWG geothermal presents the energy supply geothermal could provide by 2050 in order to achieve climate neutrality in Europe, the ETIP Geothermal believes that enhanced technological development and a new generation of technologies can allow a more ambitious share of geothermal already by 2040.

Implementing the Strategic Research and Innovation Agenda would support to have a large contribution of geothermal by 2040, in electricity, heating and cooling, but also through underground thermal storage, and in supply of sustainable minerals made in Europe such as lithium.

[1] SET Plan IWG Geothermal -Implementation Plan, version December 2023

Heating and cooling

Geothermal heat with district heating and cooling, supply to industry and agriculture and buildings with collective and individual heat pumps covers more than 30% of Europe's demand for heating and cooling of buildings, more than 20% in the agricultural sector and more than 5% in industrial and services sectors.

We have to keep in mind that about 50% of the energy used in Europe is in the form of heat, most of it is coming from fossil sources. To this extent, geothermal will be a strong lever to reduce greenhouse gases emissions in buildings and industrial processes. Unlocking this potential requires upscaling existing projects and designing assets to be more robust, reliable and efficient. The technical and industrial picture has to fit a social and environmental frame, which is evolving quickly and is now fully part of project management. These aspects are developed in detail throughout the SRIA as outlined in the previous section.

Electricity

Geothermal electricity covers more than 10% of the power consumption in Europe.

Each region in Europe must have a minimum geothermal power capacity to ensure its local security of supply. This will save costs for the decarbonisation of the power sector, and reduce systems costs especially for large grid infrastructures.

In all European regions, geothermal power plants will provide base load electricity and, when needed, flexible generation for the energy system integration.

Industrial performance for power production, which is not so much marked by local offtake conditions, is also a matter of business models and standards. The goal to reach has to be defined by asking key questions such as: what kind of wells does the industry need? What kind of projects do we want to run? At what cost? In other words: shall we develop tools and techniques for extremely deep reservoirs showing extremely high temperatures, if such targets remain exceptions? And where do we set the cursor for "extremely deep" and "extremely hot"? Industrialization and standardization require well established, benchmarked ranges which define what a "common geothermal well" should be, whether we talk about materials, tools, exploration or production operations.

Energy storage

Thermal underground storage (Underground Thermal Energy Storage: UTES) supports energy system integration with a UTES contribution to more than 10% of Europe's heating and cooling consumption, essentially coupled with district heating systems and industrial processes.

All thermal underground technologies will be deployed in Europe as the main source of energy storage. UTES applications cover a wide variety of opportunities: ATES (Aquifer Thermal Energy Storage), BTES (Borehole Thermal Energy Storage), PTES (Pit Thermal Energy Storage), TTES (Tank Thermal Energy Storage), and MTES (Mine Thermal Energy Storage) systems.

In addition, energy piles and PCM for (intra) day storage coupled to geothermal heat pumps, will enhance performance and avoid net congestion.

Sustainable production of minerals and critical raw materials

Sustainable extraction of minerals and critical raw materials (CRM) from geothermal, such as geothermal lithium, are contributing to EU targets of at least 10% of the EU's annual consumption for extraction of CRM.

Further exploration is necessary to identify the full potential of geothermal lithium across Europe. Ensuring 25% of 2040 lithium-ion batteries from indigenous geothermal lithium must be the target to provide an important foundation for the increased growth of this market. Other minerals such as silica or potassium will also be extracted sustainably from geothermal brines.

Made in Europe

In line with EU goals on resilience, and the IWG Geothermal Implementation Roadmap, to increase resilience of the geothermal energy supply chain, and to have 40% of the supply chain "Made in Europe" by 2030 and more than 60% by 2040.

A European Geothermal Industrial Strategy will pave the way to keep manufacturing of equipment and components for geothermal technologies made in Europe as today. The deployment of geothermal energy to become a mass market will create tension in the manufacturing markets and for the workforce. The aim of the Geothermal strategy is to plan this development and answer the challenges on the supply chain and skilled workforce in a time of exponential growth.

Geothermal Cities and Regions with Industrial Geothermal Valleys

Geothermal energy, a unique and resilient power local source, offers a versatile solution to Europe's energy needs. It has proven its ability to supply local electricity, heating, cooling, and hot water and allows for thermal underground storage and sustainable extraction of critical minerals, including lithium, in all regions of Europe.

It provides a renewable energy source for cities, industrial and rural areas, supports local economic and social development, and is at the heart of the first clean European value chain for batteries in electric vehicles. The following illustration showcases its versatility and competitiveness for the security of the energy supply from cities to regions.

Geothermal can be seamlessly integrated into the urban fabric, with buildings and houses powered by geothermal district heating and cooling. Surrounded by green areas, rural villages can also be equipped with geothermal heat pumps, showcasing geothermal energy efficiency and cost-effectiveness.

Agriculture is one of the largest and most essential sectors in the European Union. Geothermal energy provides local solutions for energy, climate, and food security. It has been increasingly used for the last 25 years in greenhouses, aquaculture, agro-industrial processes, and fish farming. Geothermal projects are installed locally and offer heating, cooling, and storage at competitive prices 24 hours a day.

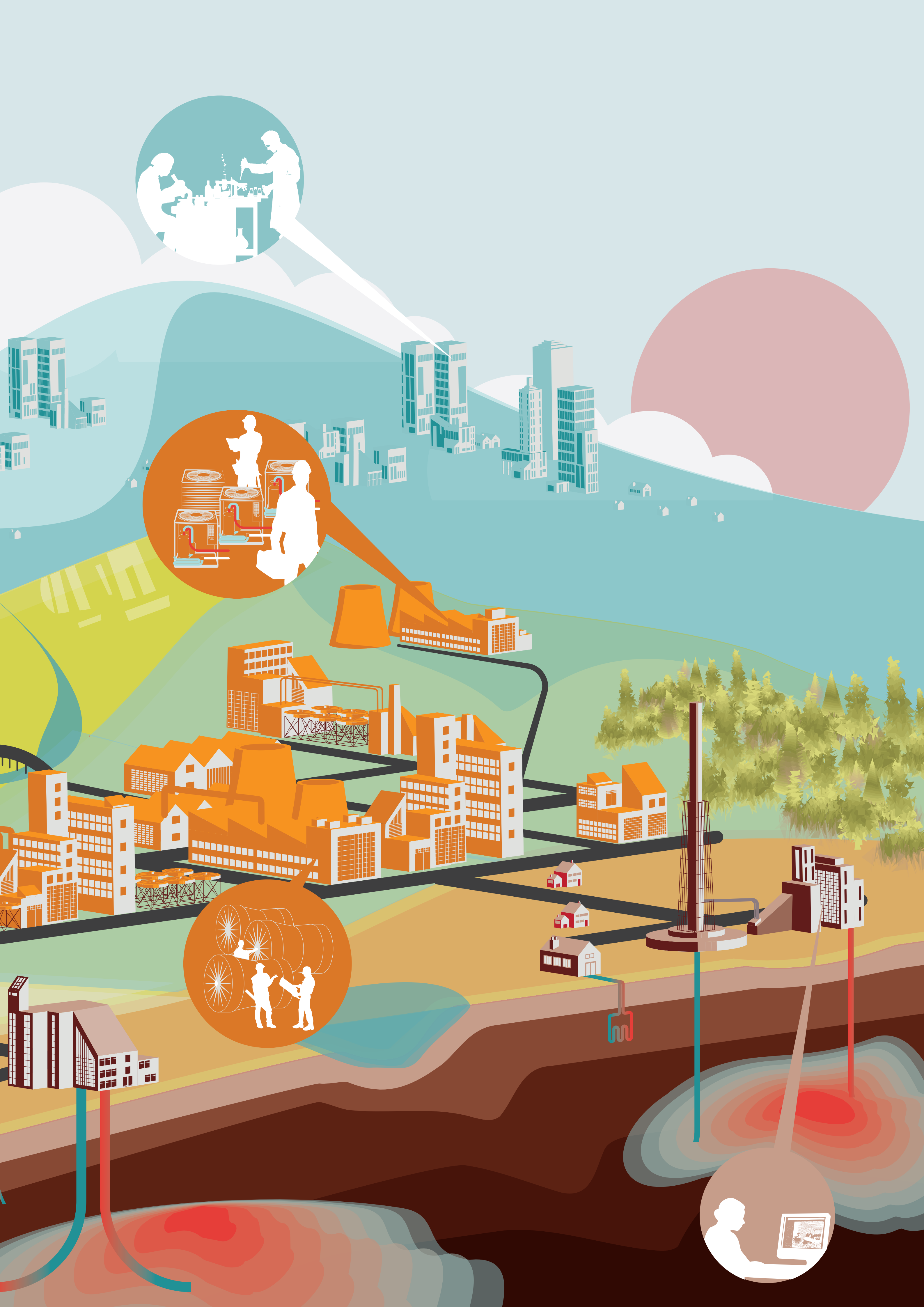
Geothermal industrial areas can guarantee Europe's energy independence and energy security. A single geothermal energy plant can produce electricity, heating, cooling, and raw materials, such as lithium, with a zero-carbon process. Lithium has become a key element in developing an independent European electric mobility and storage market. The geothermal industry can contribute significantly to the production of sustainable lithium in Europe.

Geothermal minerals differ from traditional critical raw materials mining because it has nearly zero environmental impacts and leave a marginal ground or water footprint. In geothermal plants, mineral brine is pumped to the surface from geothermal reservoirs, and the heat carried by the brine is used to produce renewable energy, and the brine is reinjected into the reservoir.

Geothermal industrial valleys represent a transformative concept poised to reshape Europe's economic landscapes. These systems aim to support the transition of regions from conventional energy sources to sustainable, self-reliant hubs for geothermal renewable energy to supply local energy generation, distribution, and consumption. Geothermal resource manufacturing of geothermal equipment is already made in Europe, allowing local supply of components and materials for geothermal technologies with European steel, cement, and chemicals.

GEOTHERMAL
CITIES AND REGIONS

INDUSTRIAL
GEOTHERMAL VALLEYS



INDUSTRIAL
GEOTHERMAL VALLEYS

AREA 1

- EXPLORATION TOOL & COMPONENTS FOR RESOURCE ASSESSMENT

AREA 2

- GEOTHERMAL RIGS FOR DRILLING AND SUBSURFACE ENGINEERING, FOR RESOURCE DEVELOPMENT

AREA 3

- MANUFACTURING EQUIPMENTS FOR GEOTHERMAL TECHNOLOGIES TO GENERATE ELECTRICITY, HEATING AND COOLING

AREA 4

- COMPONENTS AND RAW MATERIALS FOR GEOTHERMAL EQUIPMENTS

AREA 5

- RESEARCH AND INNOVATION INFRASTRUCTURES AND UNIVERSITIES
- INVESTORS, REGULATORS, LAWYERS, ENGINEERING

ETIP Geothermal
European Technology & Innovation Platform on Geothermal

The European Technology & Innovation Platform on Geothermal (ETIP-G) is an open stakeholder group, endorsed by the European Commission under the Strategic Energy Technology Plan (SET-Plan), with the overarching objective to enable deep geothermal technology to proliferate and reach its full potential everywhere in Europe.
The primary objective is overall cost reduction, including social, environmental, and technological costs.
The ETIP-G brings together representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal energy exploration, production, and utilization value chain.

For more information on its activities visit www.etip-geothermal.eu

Geothermal Horizons: from Cities to Regions

To obtain this publication visit: **www.etip-geothermal.eu**

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