This project has received funding from the **European Union's Horizon 2020 research and innovation programme.**
Grant agreement 818576

1/ Geothermal, an overlooked solution for global warming mitigation

Geothermal Energy

... The art of the strategic move

Geothermal stands as a sustainable energy source, derived from the Earth's subsurface heat. This deep-seated warmth is harnessed via cutting-edge technologies including **Organic Rankine Cycle (ORC)** geothermal power plants for electricity production initiating a smart residual heat valorization chain.

Geothermal has been generally **overlooked**. Yet, its benefits are extensive, spanning from the reduction of greenhouse gas emissions to the provision of an **unwavering energy supply**, available round the clock. The latter characteristic set this low-carbon energy source as a **serious baseload candidate** to fill in the gap faced by EU countries since the end of the Russian gas supply under the current geopolitical context. Additionally, the supply may also be adjusted to match intraday fluctuation energy demand, as tests run in German Geothermal plants have shown that output can be ramped up or down within seconds.

Capital expenditure investments often challenge geothermal projects. However, the unrivaled binary system power plant's flexibility can counterbalance this obstacle. Diversified applications enable projects' **financial de-risking** by **securing off-take agreements**, which enhances the attractiveness of geothermal initiatives. In this **factsheet**, we delve into the versatile spectrum of applications that geothermal plants with binary systems can serve.

Let's explore the key facets that makes geothermal a pivotal player to **decarbonize the industry** and address **climate change**.

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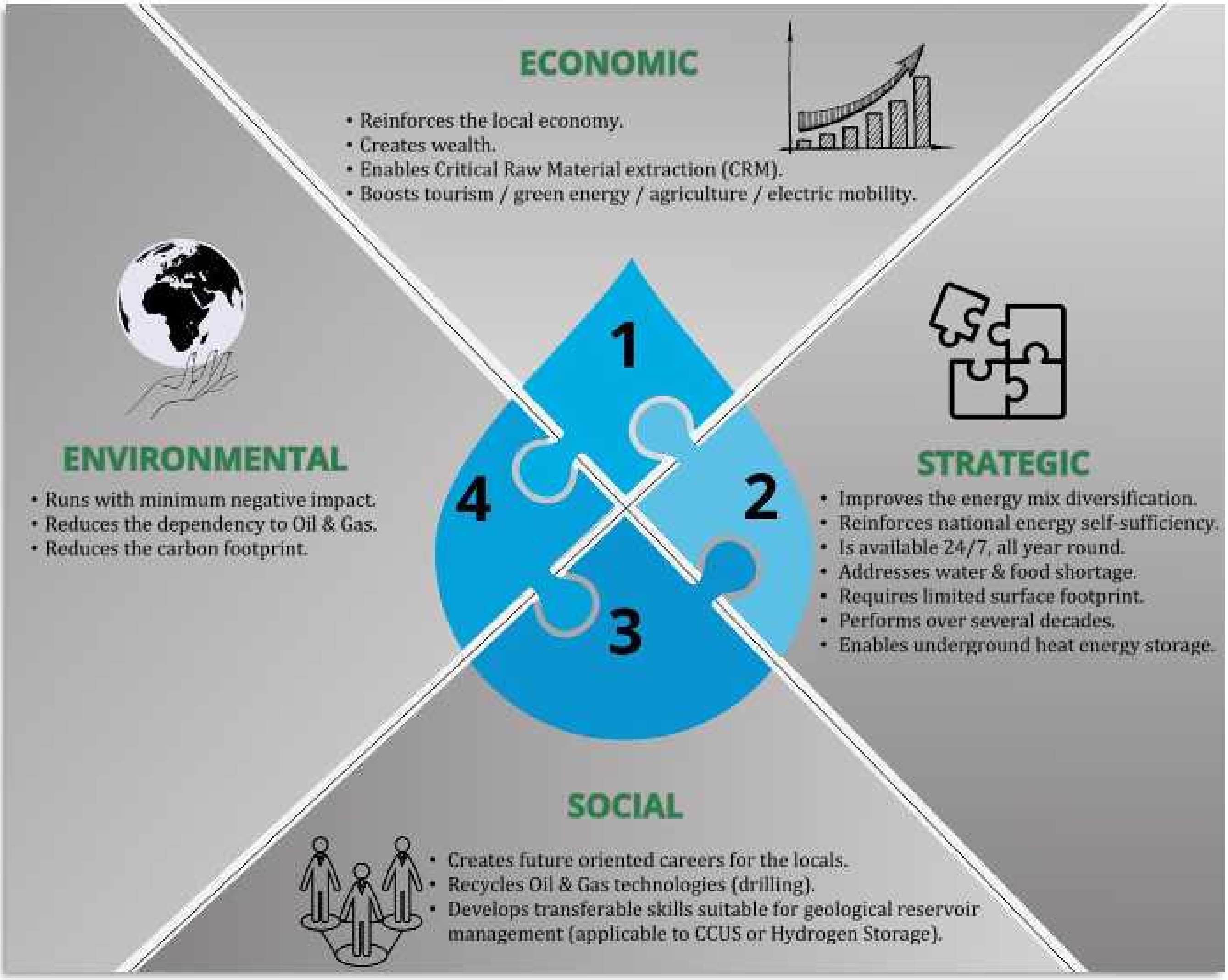
2/ Long list of benefits at different scales



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Geothermal energy depending on the local geology

1 Dry Steam Power Plants

Part of the first technologies applied in the geothermal industry. Exploiting naturally occurring underground high-pressure steam to run turbines that generate electricity.

2 Flash Steam Power Plants

Widely used across the globe. Extracting high-pressure hot water from the subsurface. The rapid steam expansion from the hot water is exploited to run the turbine to generate electricity.

3 Binary Cycle Plants / ORC Power Plants

For lower reservoir temperatures. Use of a working fluid with lower boiling point (e.g., organic fluid (pentane); CO_2 or N_2/water mixtures). The latter gets heated up in a Heat Exchanger by the geothermal brine. Past its boiling temperature point, the working fluid runs the turbine for power production.

Current technologies under development to support the power generation systems

Cutting-edge technologies: (EGS) Enhance Geothermal Systems; (AGS) Advance Geothermal Systems; Innovative drilling for Ultra-Deep Geothermal (UDG)

- **EGS** aiming at engineering an artificial reservoir in which water is injected and retrieved after being heated in the subsurface. Requires rock permeability enhancement (by the means of rock fracking or existing faults and fractures reopening via chemical dissolutions).

- **AGS** emerging technologies, aiming at engineering innovative systems such as closed-loops with no reservoir rock nor natural geothermal brine required.

- **UDG** reaching targets up to 5 times deeper than reservoirs regularly exploited in today's geothermal projects. It requires robust equipment able to withstand extreme conditions with high pressure (HP) & temperature (HT). A better understanding of risks, inherent to deep targets, is also needed (wellbore stability; corrosion; Normally Occurring Radioactive Material; induced seismicity). R&D remains crucial, not only to reduce drilling costs, but also to ensure safe and responsible technology deployment.

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4/ Binary geothermal plant using ORC

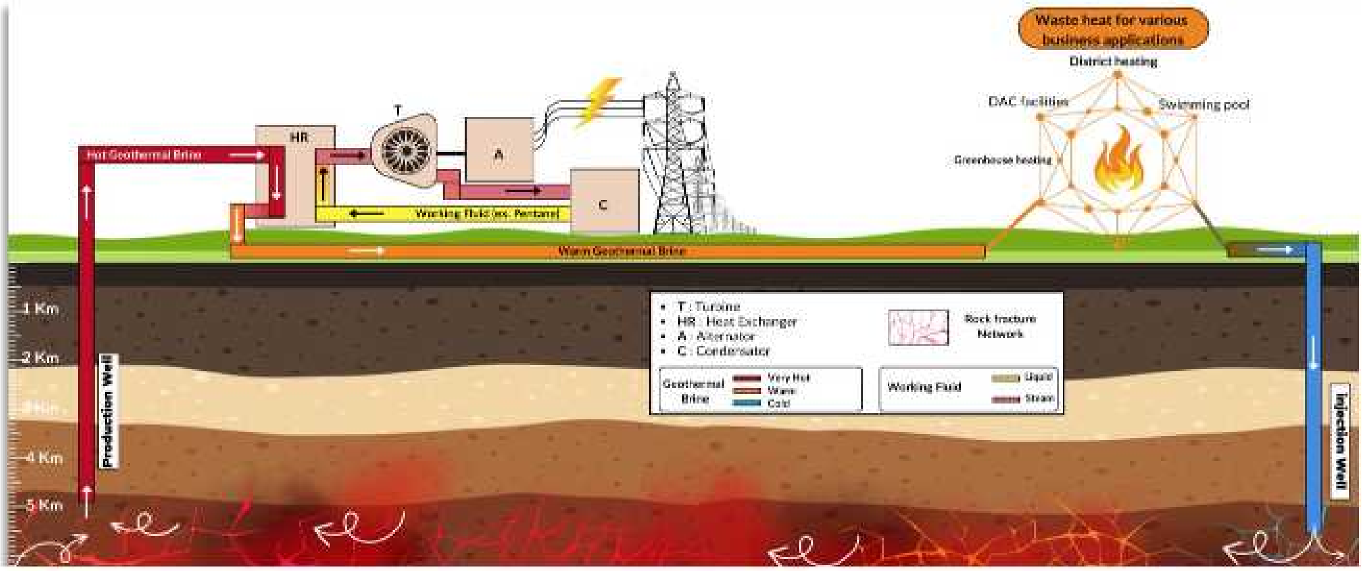
Why focusing on binary geothermal power plants?

- **Flexibility:** Different type of working fluids may be used according to the exploitable heat in place. Binary systems enable using the heat for electricity generation, while still being able to repurpose the waste heat for other business applications. For maximum heat exploitation, with the brine returning to the subsurface at lowest temperatures possible, solution must be implemented against mineral precipitation such as scale retention systems. The latter technology currently being developed by **Geosmart***. It is worth noting the inherent duality in these processes, as they necessitate not just technical feasibility but also economic viability.

- **Efficiency:** Lower subsurface temperature requirements for power generation. Thanks to its low boiling point, the working fluid can expand and drive a turbine for electricity production, even with temperatures around 100°C.

- **Scalability:** Unless located on a tectonic plate boundary with volcanic activity, most countries are not gifted with a high geothermal gradient. Most places present a geothermal gradient of ~30°C/Km. As being efficient at medium to low temperatures, binary systems are very scalable worldwide. Unlike Flash or Dry Steam technologies requiring specific contexts with high brine temperatures.

- **Sustainable:** Binary systems reduce the geothermal brine contact with the environment to a bare minimum. The environmental footprint is small, in comparison to other power plant systems inclined to release Carbone Dioxide. Binary plants are more inclined to preserve environments with a sensitive eco-system.



*Click here to access R&D on silica scaling
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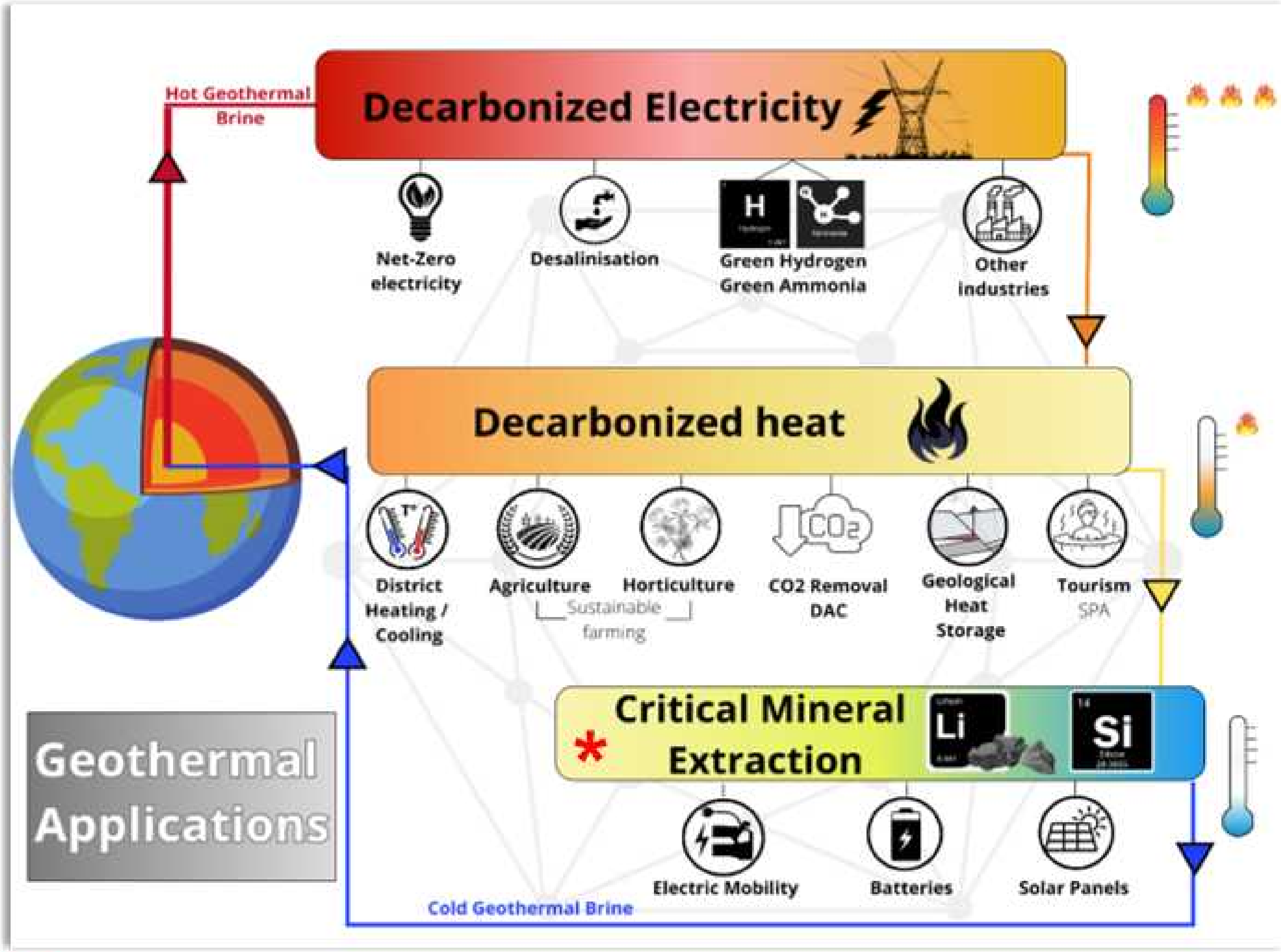
5/ Geothermal applications, cascade utilization



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Technologies are currently under development for brine critical mineral extraction (CME). The minerals can be extracted at different temperatures according to their inherent nature conditioning, their solubility or precipitation behavior. In other terms, CME can take place at different temperatures in the waste heat value chain – not per say at low temperatures.

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Geothermal energy, available **24/7**, offers a **versatile** and **sustainable** solution for building a cleaner, greener future. Its **diverse applications** and **adaptability** make it a crucial player in the transition to decarbonized energy sources.

Decarbonized Electricity

The **high-temperature** brine extracted from the subsurface can be harnessed to produce **electricity** using **ORC technologies** where the working fluid runs turbines. Such a low carbon power source can positively. impact various sectors targeting a net-zero supply chain (from **district** to **heavy industry electricity supply**) committed to combating climate change. It can also power water electrolysis for **Green Hydrogen** or **Ammonia production,** the latter being more inclined for transportation.

Decarbonized heat

Once the hot water is used for electricity generation, the residual heat can still be exploited for other applications. It can provide a **sustainable and efficient heat source** for residential, commercial, and industrial needs. For example, sectors like **agriculture**, **aquaculture**, and **horticulture** have heating requirements that need to be met. **Leisure activities**, such as **Spas**, can offer guests a relaxing experience thanks to the exploited brine, which brings Geothermal in the eco-tourism arena. Geothermal heat can support **carbon negative technologies** such as **Carbon Dioxide Removal (CDR)** via **Direct Air Capture (DAC) facilities**.

Critical Mineral Extraction

The brine, in some geological settings, can hold **silica** and **metallic minerals like Manganese, Zinc** or **Lithium.** The latter being essential for the energy transition, as it is a key feedstock serving the **booming electric mobility industry.** Albeit such valuable materials can be present in the scaling compound, the latter is a challenge for geothermal projects longevity. Scaling causes reduction in flow rates, and damages equipment such as pipes, pumps and heat exchangers leading to higher maintenance costs. Technologies are currently under development for brine critical mineral extraction (CME). The minerals can be extracted at different temperatures according to their inherent nature conditioning their solubility or precipitation behavior. In other terms, CME can take place at different temperatures in the waste heat value chain – not per say at low temperatures.

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6/ Challenges to overcome to achieve success

Flexibility

A booster to maximize interest for geothermal energy & ease the process!

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Right Geological Setting

Not all geological settings are suitable for conventional geothermal energy production systems. Tectonic plate boundaries with volcanic activity are generally sweet spots to find heat. Suitable reservoir structure and petrophysics (good porosity, permeability) are also required, as much as good thermal properties. The presence of a geothermal fluid (ideally confined aquifer) to circulate the heat to the surface is also preferable. Less suitable geological settings require cutting edge technologies for viable energy supply.

Technological Maturity

Technologies are currently being developed to exploit the heat from the subsurface, even in less favorable geological context. Among the innovative solutions, there are EGS, AGS including closed loop systems, or new adequate drilling practices for UDG. As such technologies evolve, they make geothermal energy exploitation possible in regions with low geothermal gradient.

Market Business Case

Can the geothermal plant provide different local businesses with energy all year round? The more the flexibility the more business opportunities can be secured. The geothermal plant must be designed according to both the geological context and the local energy demand. Is there a need for electricity and/or heating network? Is the geological setting suitable to meet the local demand? does an adequate funding system subsist to develop the technology required to meet the local demand? These are all question to address before launching a geothermal project.

Financial Support System

High initial expenses are a fundamental aspect of geothermal projects due to geological and technological complexities. Funding can be obtained from both national and international sources, including subsidies, supportive R&D investments, and insurance to counteract financial risks such as lower than expected well productivity. Flexibility can amplify the Return On Investment (ROI) of geothermal plants by supporting a variety of local businesses in reducing their carbon footprint. Government incentives to push private sector investments are also pivotal in advancing towards goals set by international climate agreements.

Oil Price Competition

The competition from established cheaper hydrocarbon technologies hinders emerging geothermal advancements. Yet, with policies promoting fossil fuel phase-out, geothermal shows promise in driving the industry towards a net-zero future.

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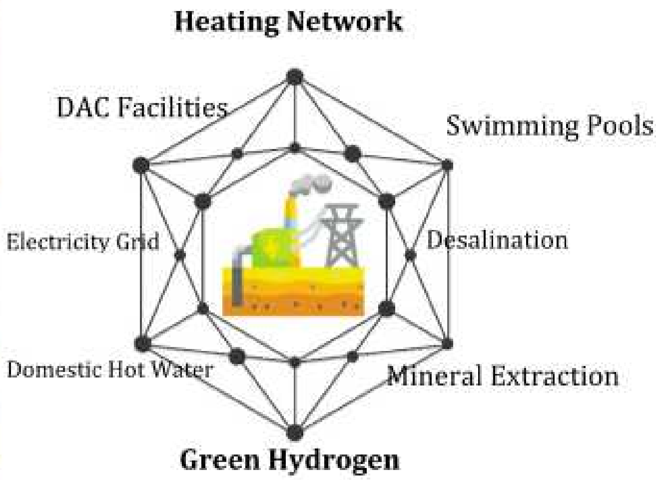
7/ Flexibility: geothermal to shape the local business eco-system

Business eco-system shaped by nature.
Geothermal: Use the geological settings to guide the development of the local region.

Combined geothermal heat & power represents a natural resource that can serve as a catalyst for local economic growth. It stands as a potential metric to drive the development of a business ecosystem, aligning with the specific challenges of the region. This versatile energy source can be harnessed to address a range of needs, from powering desalination plants to combat drought, to supplying heat for swimming pools and enhancing crop yields.



Business ecosystem driven by the geothermal potential available

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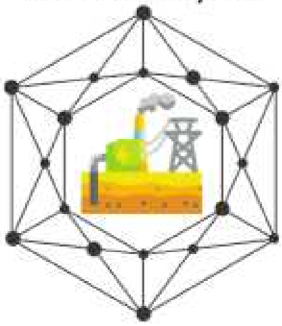
Example:
Location: European country, region with geothermal gradient of 32°C/km (no volcanic activity).
Power generation system: Binary power plant, engaging a working fluid.
Temperature, flow rate: brine temperature **(120 to 130°C)** with good production flow rate **(>300 m3/hr)**

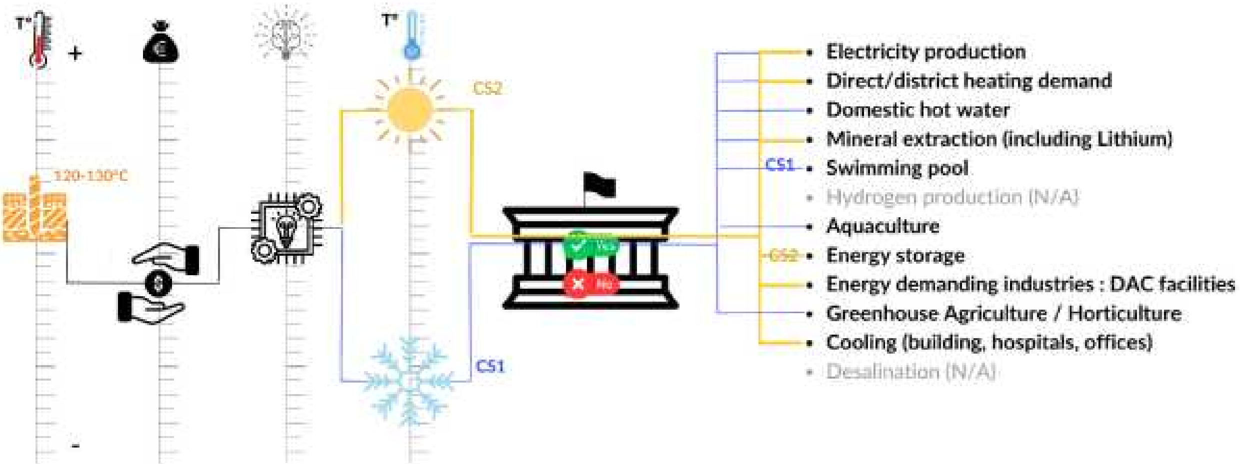
Business Eco-System



Case Scenario 1 (CS1) Vs Case Scenario 2 (CS2). Single variable applied: seasonal (Winter Vs Summer). Same geological context, CAPEX, used technology, validation by the authorities.

CS1: in the winter, the offtake is secured by:
Electricity and heat demand, mineral extraction, aquaculture, greenhouse agriculture, domestic hot water.

CS2: in the summer, off-take secured by:
Mineral extraction. The demand for direct heat is reduced but can still be stored or used for cooling.



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8/ Geothermal applications: flexibility in the Belgian context

Successful deep geothermal energy projects in Belgium send a resounding message to the global stage. Like most countries in the world located away from tectonic plates boundaries, Belgium has no volcanic activity, nor is it gifted with an above average geothermal gradient. Throughout the country, the geothermal gradient is about 32°C per kilometer depth. In Belgium, current deep geothermal projects are exploiting reservoirs at depths ranging from 2 to 4 kilometers (Dinantian, carboniferous limestone) with associated temperatures that could reach 140°C. If such thermal characteristics are relevant for some business applications, other criteria such as the presence of an aquifer, ideally confided in a reservoir rock with a good porosity network, is also required for standard doublet systems. Belgian deep geothermal projects are focusing on heat delivery, as the combination of the above-mentioned factors has not enabled the production of power yet.

The convergence of evolving policies promoting a transition away from fossil fuels and Belgium's current geopolitical situation, experiencing disruptions in the steady supply of Russian gas, highlights geothermal energy's role in heat delivery. This presents an opportunity to address the challenge while advancing toward a net-zero industry.

The below illustration shows the versatile role of geothermal energy in the current Belgian context. It presents a sequential usage of a single geothermal source, starting from the point of extraction until the brine gets reinjected into the subsurface reservoir where it came from. As the brine's temperature drops, the conveyed heat can serve different businesses. From district heating to swimming pools, greenhouses or simply to maintain an above zero temperature in warehouses in the winter. The baseload characteristics of this energy source not only helps companies to score better at their Environment Social & Governance scheme (ESG), but it also protects their economy from unpredictable gas price fluctuations.

Also, highlighted in the diagram is the pressing need for technological advancement, particularly to achieve higher temperatures to increase energy production (including electricity). UDG, or techniques like AGS, EGS could potentially elevate Belgium's geothermal capabilities to match the success of regions benefiting from volcanic activity. Finally, the social acceptance is also a crucial factor to consider.

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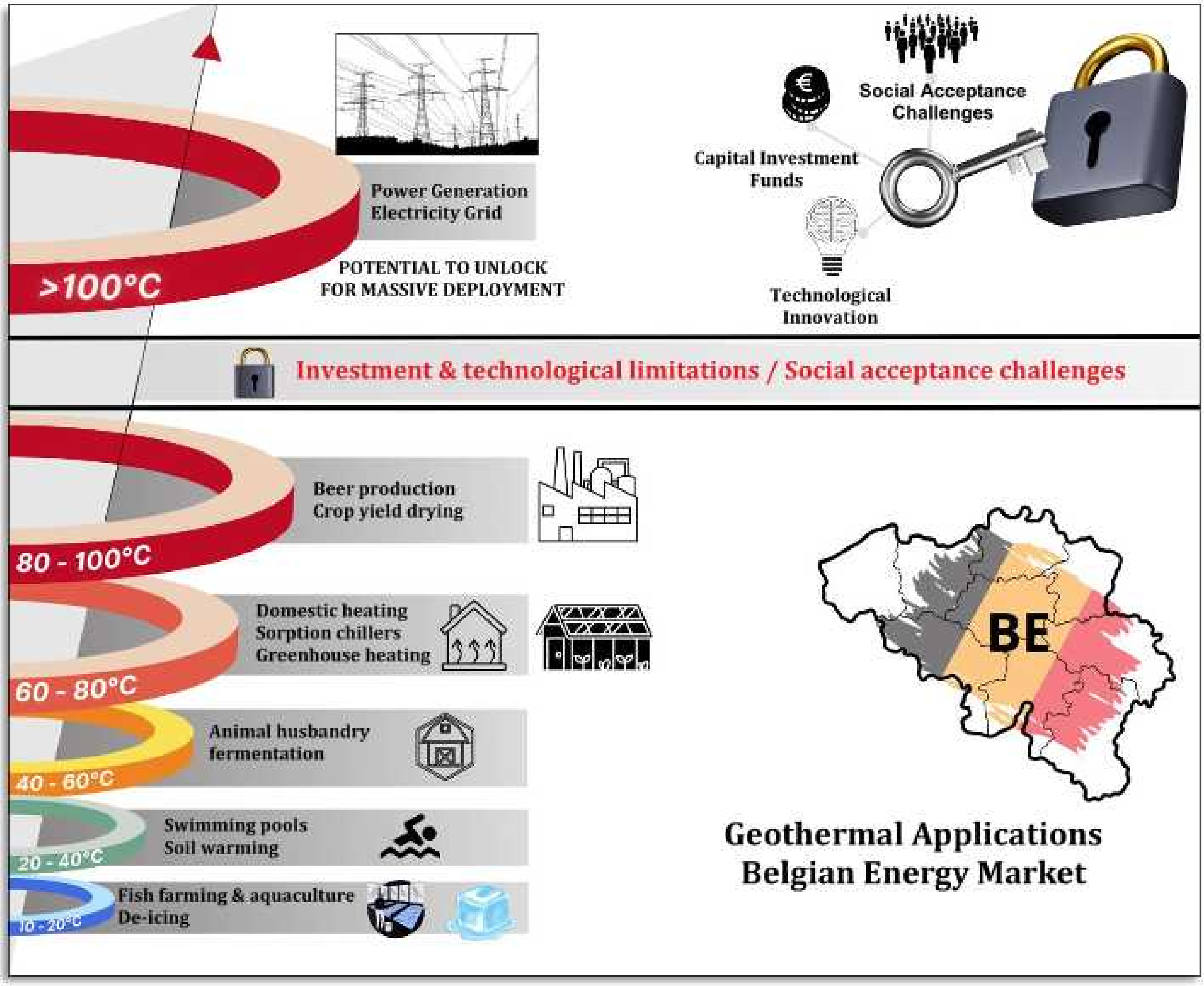

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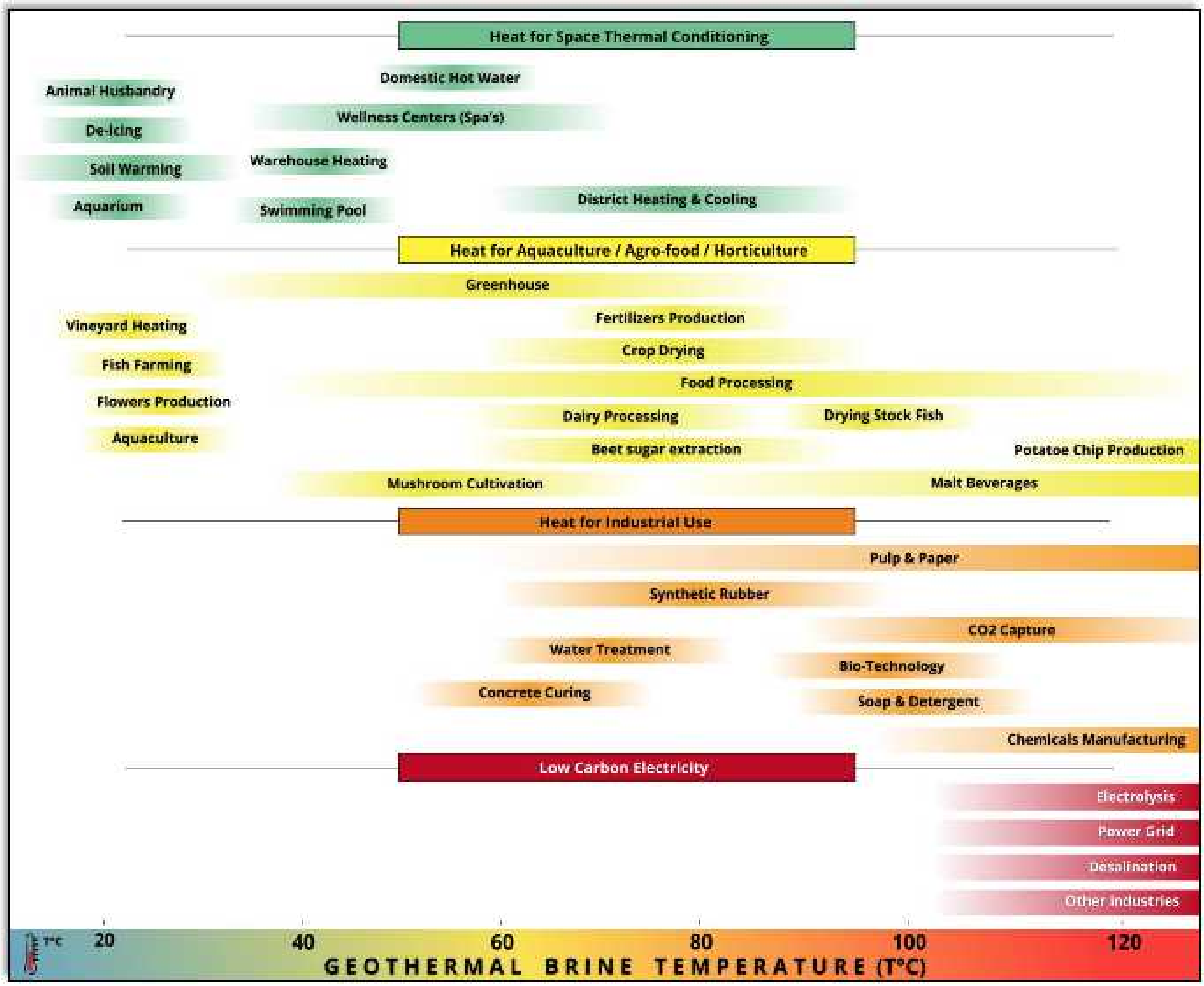
9/ Amongst the industries to decarbonize

Below is a comprehensive list of business applications that stand to gain from the utilization of geothermal energy (geothermal brine temperature below 130°C). The thermal energy extracted from the geothermal brine holds multifaceted advantages that extend beyond addressing power demands, catering to various industries.



References

Inspired by the Lindal's Diagram of geothermal production temperatures and direct uses (from Kurnai et al. 2022) & Jóhannesson, Th., Chatenay, C. "Industrial Applications of Geothermal Resources" (2014)