Integrated Geothermal System: What Are the Risks?*

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Abstract

Today, the development of the low-carbon energy mix is implemented in a context of growing environmental constraints and, most importantly, climate urgency. Hybrid energy systems are presently the most efficient and available integrated systems. For electricity production in remote areas, they combine wind, photovoltaics, generators and batteries, and are optimized systems capable to ensure energy service quality. The design of hybrid energy systems is fundamentally built around an energy buffer storage solution whose power capacity is used to dimension the extension of the system. In countries with large enough water stocks, hydroelectricity is used mainly as an energy buffer storage solution. This usage allows to stabilize the power distribution and to integrate all sources of power production. By offering a geological solution for energy storage and buffering, geothermal energy can become a high capacity storage solution that could enable an efficient hybridization at a large power grid scale. This solution is potentially achievable in almost all of the world's sedimentary basins, and unlike hydroelectricity, deep underground storage would not be dependent on local water stocks availability.

A risk analysis for two underground energy storage and buffering examples will illustrate the principles of a new application for geothermal energy called IGS (Integrated Geothermal Systems). Like a natural geological trap for hydrocarbons, IGS system requires deep, warm and sealed structure, with:

- An interesting storage capacity (reservoir),
- Reservoir characteristics allowing a good productivity,
- An effective energy carrier and phase change fluid, fit for large underground storage.

Unlike conventional geothermal exploitation, IGS will extract the energy and return it as a cooled fluid into a closed subsurface structure. This production and reinjection is performed into a sealed and constrained geological structure and will obviously require additional energy inputs to counterbalance the frequent and local energy outputs. The IGS process draws up rules for the dynamic management of an energy buffer

storage, where the natural weakness of the geothermal heat flow is compensated at the surface by the thermal storage of natural and free energies (e.g. solar thermal) and power generation surplus (e.g. ENR or nuclear electricity). This dynamic energy management based on determined withdrawals and modeled surface preheating of the energy carrier is the process integrated to the geothermal storage of the fluid. Known and discussed heat carrier fluids are LPG and super critical CO_2. According to the sum of the challenges represented by the energy transition, clean and balanced energy choices would have to be made, preferably having a system-based and sustainable vision. To date, most energy solutions have been put side by side and have been mainly based on the extraction (and the net degradation) of energy (whether fossil, mineral or poorly renewable, like biomass or conventional geothermal energy), as well as on the random capture of wind or solar energy. Based on well-operated deep geological structures, this article presents a new possibility for a clean and truly renewable energy solution, thanks to its integrated energy surface/subsurface management. We will also point out that IGS projects can offer a guarantee for clean, economic and sustainable energy services for the very long term.

Integrated Geothermal systems
what are the risks?

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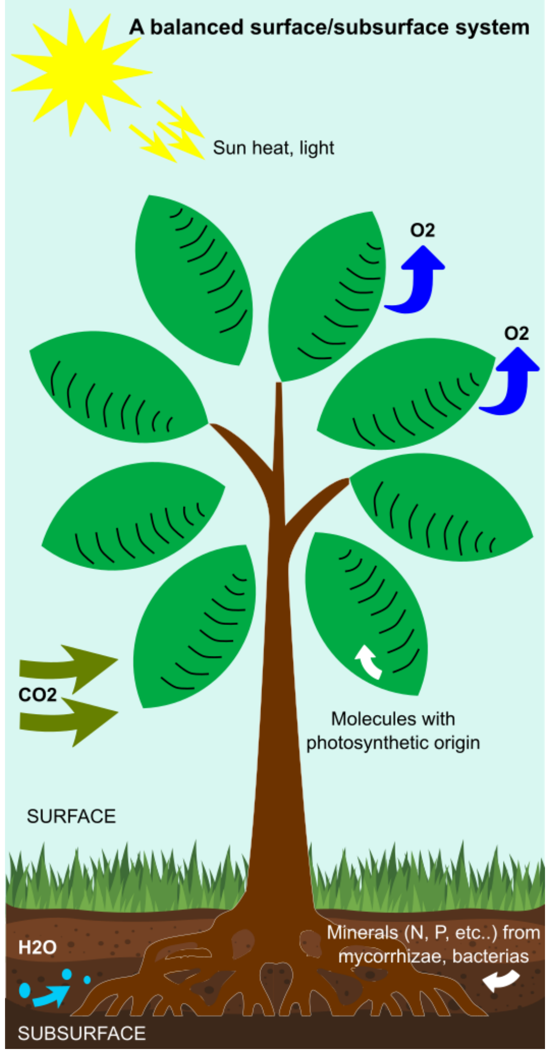
Integrated Geothermal Systems (IGS) are systems inspired by nature



ECOSYSTEMS

The 3 most important concepts conveyed by ecosystems are :

- **Integrated interactions,** i.e. exchanges for energy, information, material, nutrients. Theses interactions are balanced and integrated at a larger and lower scale.
- **Natural clock** for cycles, evolution.
- **Benefits for human kind**, in particular case of ecosystem domestication and proper maintenance.
  - Harvesting a part of ecosystem's production,
  - Other services, such as regulation, maintenance extended to other systems and also cultural services like complex systems pedagogy, even artistic inspiration.

Main risks are pathogens that will unbalance interactions, causing a degraded performance of the system, hence permanent disability or death

In this elementary level of an ecosystem (a tree) we appreciate the **productivity of the surface/subsurface interactions**

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Presenter's notes: To introduce this presentation, we can have a brief description of an ecosystem. The concepts conveyed by ecosystems are of great importance to humans. They are complex systems with a very high number of interactions, internal and external to the system. The particularity of these interactions is: to be always balanced. But also, they are scalable according to the needs (which can also vary over time). Such evolution introduces us to the notion of a “natural clock” made up of evolutionary cycles, which will allow the system to adapt to its age, its growth and also to environmental conditions change.

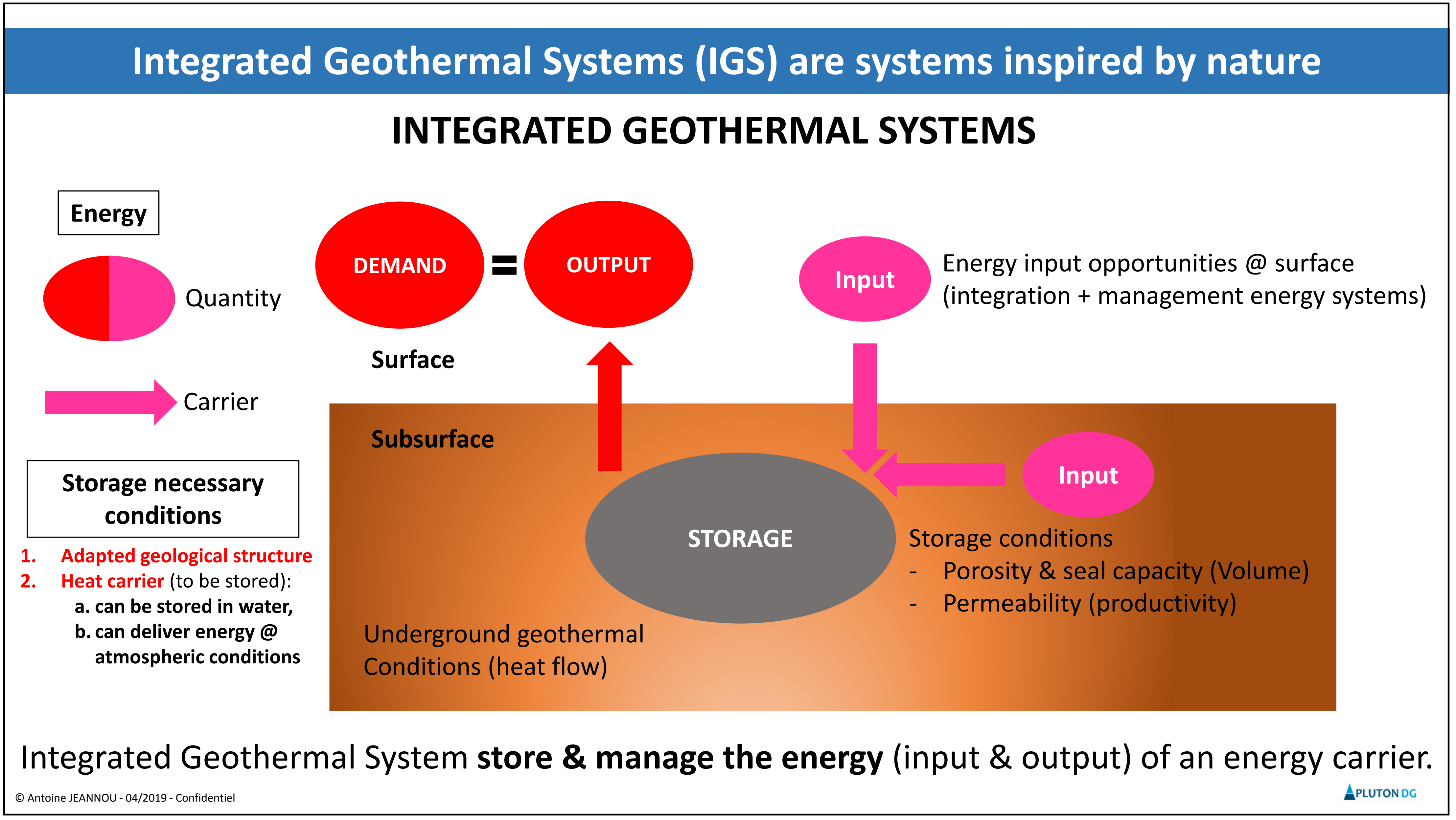
Ecosystems' interest for humans is vital, because they are our places of life and even of survival. Our evolution has allowed us to domesticate many of them and to benefit from them. In return, we are supposed to have understood our only constraint: to ensure their self-management.

But to properly manage an ecosystem, it is necessary to understand it first! *(Presenter’s notes continued on next slide)*

(Presenter’s notes continued from previous slide)

During this presentation, we will often talk about risks. For an ecosystem, the main risk is the pathogen that disrupts the balance of interactions. Today's human, through his demographic pressure and his very powerful technological means, has unfortunately demonstrated the extent of his pathogenic power.

Ecosystems can be defined at many scales. This tree illustrates an elementary ecosystem. We have chosen it because it is also a successful example of energy interactions between the underground and the surface. This successful model can be seen every day and has colonized almost all biotopes on land. The tree’s surface/subsurface balanced interactions are the inspirational source for Integrated Geothermal Systems.



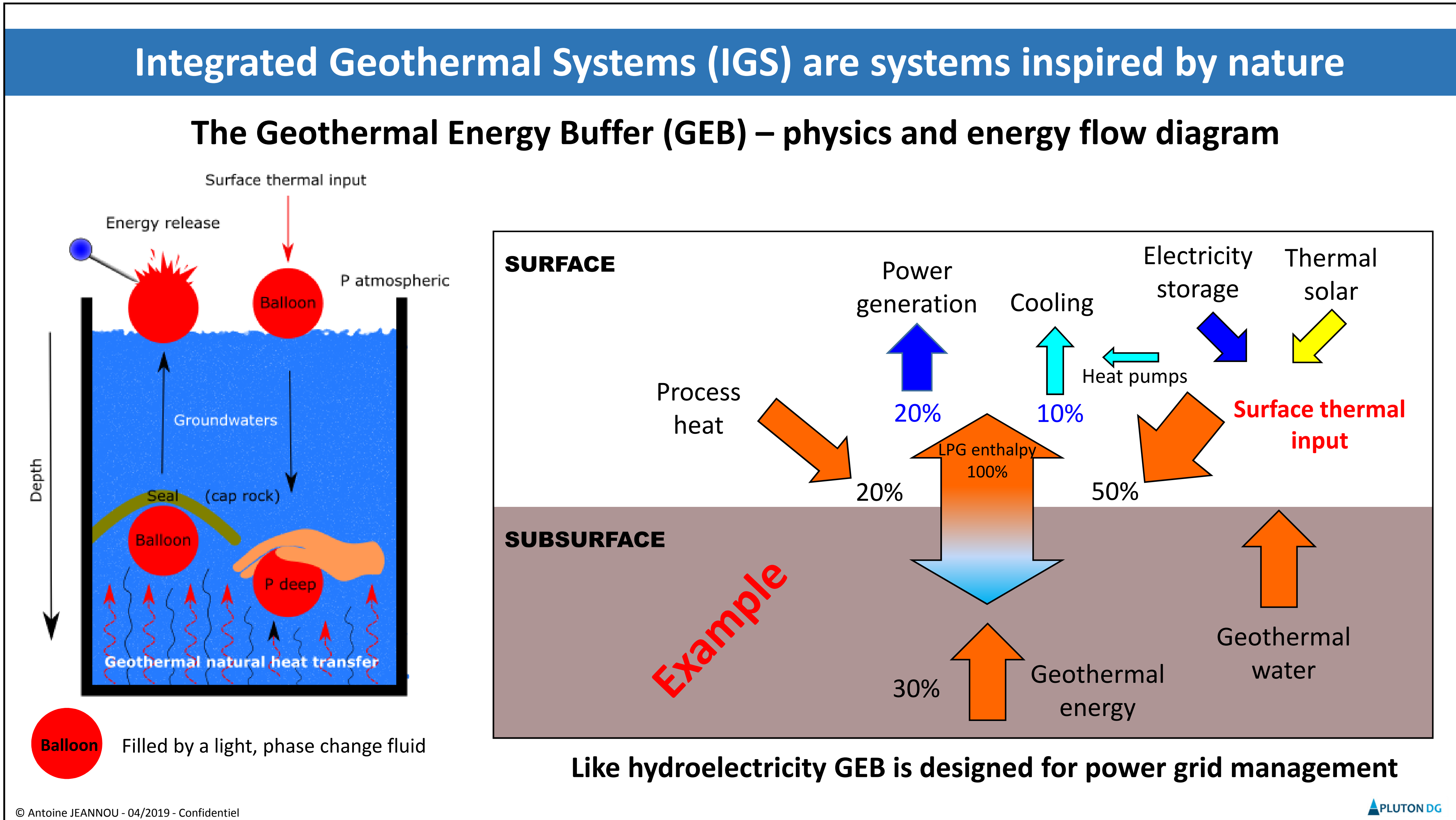
Presenter's notes: An IGS system is an energy storage system that combines balanced energy inputs and outputs between surface and subsurface. First of all, an IGS system will search the underground for a sealed and productive reservoir. Basically, this reservoir will be an aquifer and consequently stored products will have to be immiscible and lighter than water in order to be trapped and stored in this natural geological structure.

The stored element has to be an energy carrier whose unique function will be to stock and destock energy.

The core of the system is therefore the storage, i.e. the geological reservoir which will store and produce an energy carrier. This energy carrier will be stored of course in interesting energy conditions. *(Presenter's notes continued on next slide)*

(Presenter's notes continued from previous slide)

The remaining part of the system uses techniques and processes for reservoir management and energy conversion. Energy conversion processes in IGS would have to be balanced. The integration of surface and subsurface energy inputs modestly replicates the tree ecosystem mentioned above.



Presenter's notes: The GEB project (the "Geothermal Energy Buffer") is an application of IGS principles.

The diagram on the left shows the physical principle of GEB:

- A volume of liquefiable gas is preheated, moved deep and trapped in a volume containing a continuous column of water.
- Under deep conditions, this gas volume is liquid and buoyant, in other words, over-pressured compared to the in-situ hydrostatic pressure and exposed to the geothermal flow.

On the right, in the balanced energy flows example, produced LPG is hot and pressurized and is turbinated, but it generates also cold. Gas expanded after its energy conversion is preheated and re-injected hot by mixing it with the geothermal water superheated by various energies at the surface. As for a natural ecosystem, energy inputs and outputs are balanced, but in this case they are balanced by human action and control.

IGS and GEB are systems inspired by nature

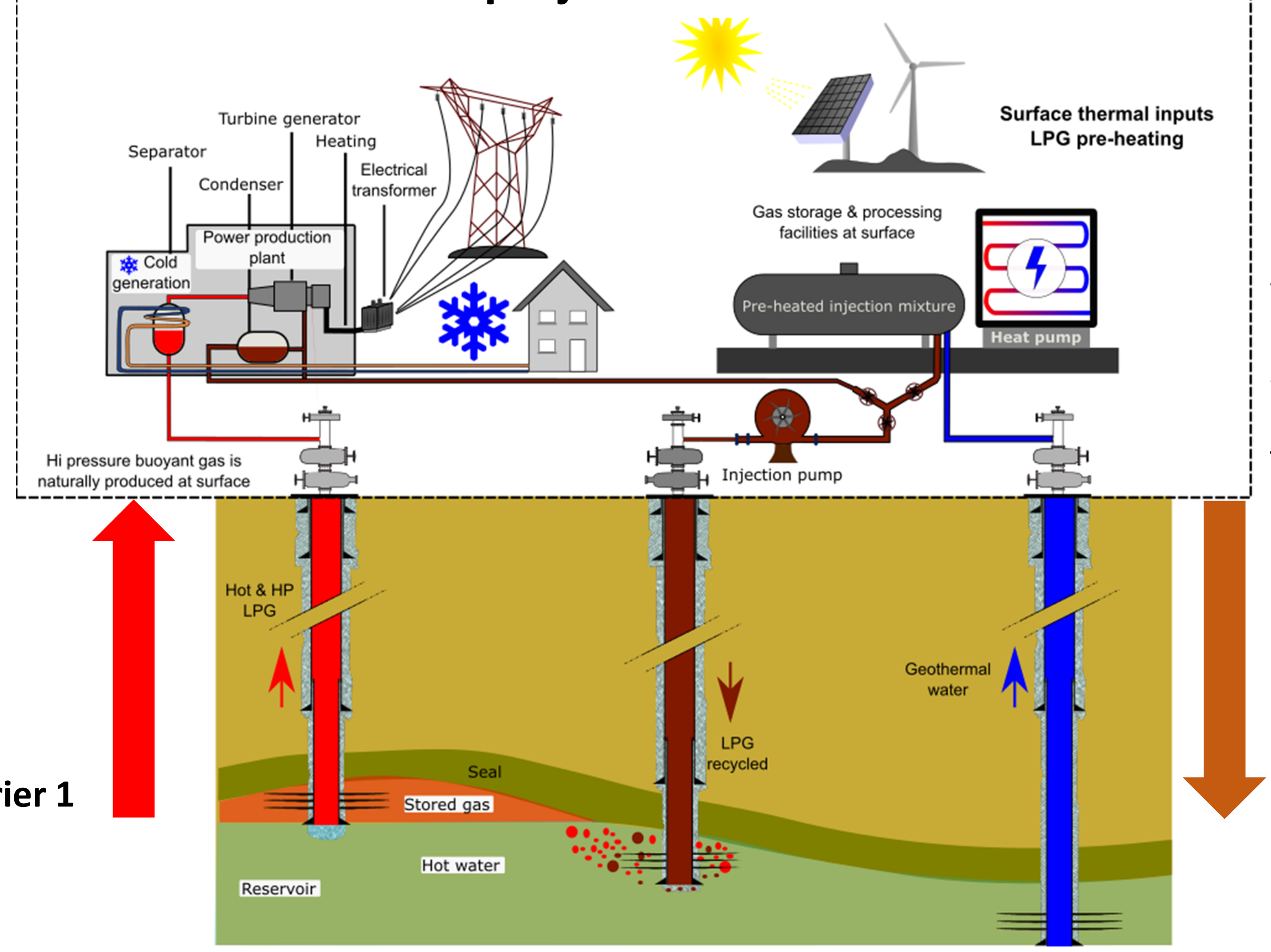
Oil & Gas fields are geological structures having trapped naturally hydrocarbons.

They are natural underground storage sites, for LPG

Two energy carriers (or vectors, or vehicles): LPG and hot water

energy carrier 1
LPG

GEB – project visualization



Main risks is the storage: we are looking for underground sealed structures including a productive reservoir formation

energy carrier 2
Geothermal water

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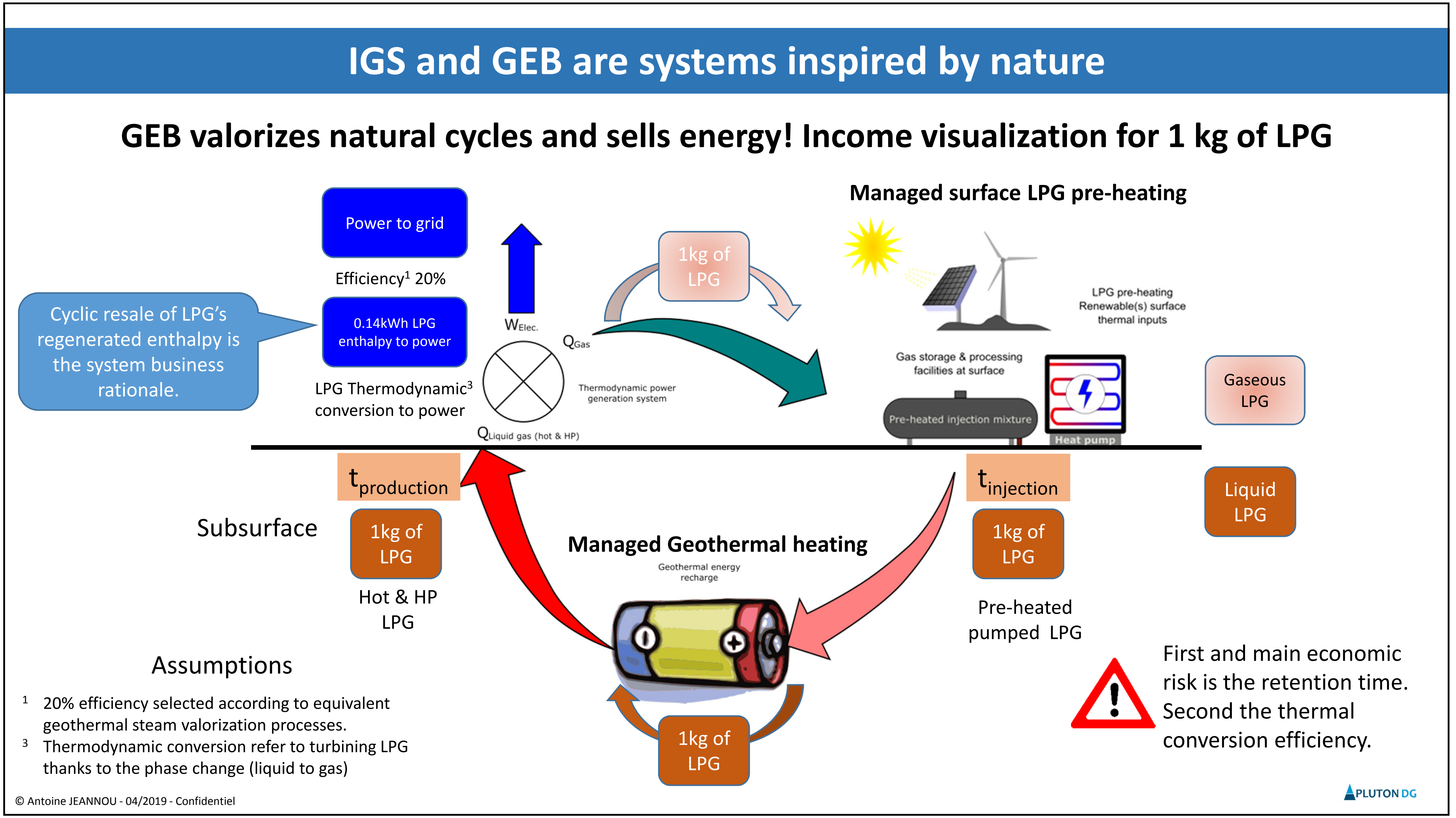
Presenter's notes: Oil and gas fields are natural sites for hydrocarbon storage. Over more than a century, exploration to improve the chance of discovery has characterized a geological optimum according to depth. This optimum has two main characteristics, the seal capacity of the cap rocks and the presence of a reasonable porosity. Porosity will allow an interesting storage volume and "sometimes" good permeability to ensure good production. These characteristics evolve differently according to depth. Positively for the shale sealing capacity, adversely for rock's porosity due to the increasing compaction of deep geological formations. Consequently, we will search for GEB (the "Geothermal Energy Buffer") the same geological optimum, in order to store, produce and deliver the maximum amount of LPG enthalpy which is the chosen energy carrier. De-risking a GEB site exploration is looking for good values of these two characteristics.

At the end of its life, a production site can very naturally become a storage place for a light and low-viscosity hydrocarbon such as LPG. Therefore, first GEB projects (without exploration) will be reconversion projects (as you can see it in the sketch above). *(Presenter's notes continued on next slide)*

(Presenter's notes continued from previous slide)

As a last comment, extracting thermal energy and reinjecting cool fluids into a closed structure would probably cool it, due to the energy in/out imbalance resulting from the weak geothermal heat flow, consequently we will have to input thermal energy to balance the extraction.

Electric storage is achieved by means of heat pumps that use fatal and excess electricity production as a thermal energy source. This thermal energy contributes to the overheating of a second energy carrier: the geothermal water, which will have the duty to preheat and to transfer the turbinated LPG into the deep reservoir.



Presenter's notes: This illustration shows the path for 1 kg of LPG. It allows us to visualize the enthalpy valorization for a single production cycle.

For profitability, economic rationale will imply maximizing the number of energy production cycles for a single kilogram of LPG, destocked and then restocked. In other words, the retention time in the buffer storage which will enable this kilogram of LPG to reach the required energy level should be as short as possible. Consequently, the quantity of surface energy recharge will have the greatest economic impact.

IGS and GEB are systems inspired by nature

A GEB project is an industrial application of technologies, known separately.

Managing complex innovation

Conception	Vision	Skills	Incentives	Resources	Action plan	**Success**
	Vision	Skills	Incentives	Resources	Action plan	**Failure**
Conception		Skills	Incentives	Resources	Action plan	**Confusion**
Conception	Vision		Incentives	Resources	Action plan	**Anxiety**
Conception	Vision	Skills		Resources	Action plan	**Resistance**
Conception	Vision	Skills	Incentives		Action plan	**Frustration**
Conception	Vision	Skills	Incentives	Resources		**False starts**

Antoine Jeannou (modified from Dr. Mary Lippitt (1987)

Risks are:

Project viability / sustainability issues

Project management issues

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Presenter's notes: A GEB project is not a research project with long term applications, it is an innovative application of existing know-how and technologies. GEB applications would have to be available in the short term.

The planning and coordination of different processes and technologies may be complicated. This generic risk matrix is used to sequence the main challenges that could affect the implementation of the project. We can analyze and separate them in two categories:

First, risk of project viability which is related to good or bad project design and also to the vision that underlies and justifies the project, e.g. is it useful, necessary or incidental?

And second, more conventional project management risks.

IGS and GEB are systems inspired by nature

GEB’s project viability / sustainability issues

Conception For the stored LPG, the formula defining the thermal conversion efficiency, gathers all GEB’s conception risks.

$$\eta\ (\%) = \frac{w}{m * h} * 100$$

- m is the expected mass flow rate: **Reservoir productivity** (we worked an example of 50 kg/s for a flow rate of 300 m3/h).
- h is the enthalpy at reservoir conditions: **Heat flow & Pressure** (our example the LPG mixture is @ 500kJ/kg).
- η is the thermal conversion efficiency: **Engineering**
- W is the power of the electricity production: **Engineering**

Vision GEB is designed to address the 3 main current energy challenges: energy security, equity (geographically) and sustainability.
Geothermal energy can become **THE** solution alternative to hydroelectricity, for high capacity energy storage.

GEB’s project management issues

- Skills
- Incentive
- Resources
- Action plan

Integration

- Gas field production
- Turboelectric generation
- LPG processing
- Surface thermal inputs
- Polyphasic injection

GEB’s social acceptance issues

The NIMBY syndrome
The legal frame for O&G production sites conversion?
(e.g. liabilities for hidden defects)

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Presenter's notes: This formula captures the design risks for GEB. First by recalling that LPG production flow rate is very important, hence the choice of a productive storage structure is decisive, but also the engineering work that will determine the performance of the power generation process. Although we have previously pointed out the economic importance of the short stock/destock cycles of the energy carrier, the thermal conversion efficiency is important too. This value will be compared to other energy solutions and should demonstrate its competitiveness and therefore its relevance.

Without major risk, GEB is proposed with an interesting vision. Vision is above all a message that gives a correct answer to a need. Globally, in a context of low carbon and intermittent renewable power generation, high power and dispatchable energy storage corresponds to recognized needs. In addition, in terms of sustainable development, GEB was designed in an exemplary way. *(Presenter’s notes continued on next slide)*

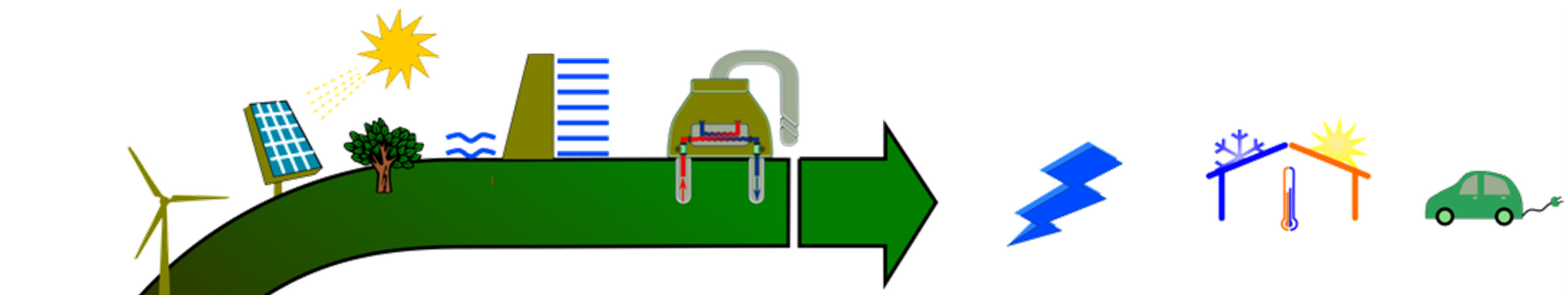
(Presenter's notes continued from previous slide)

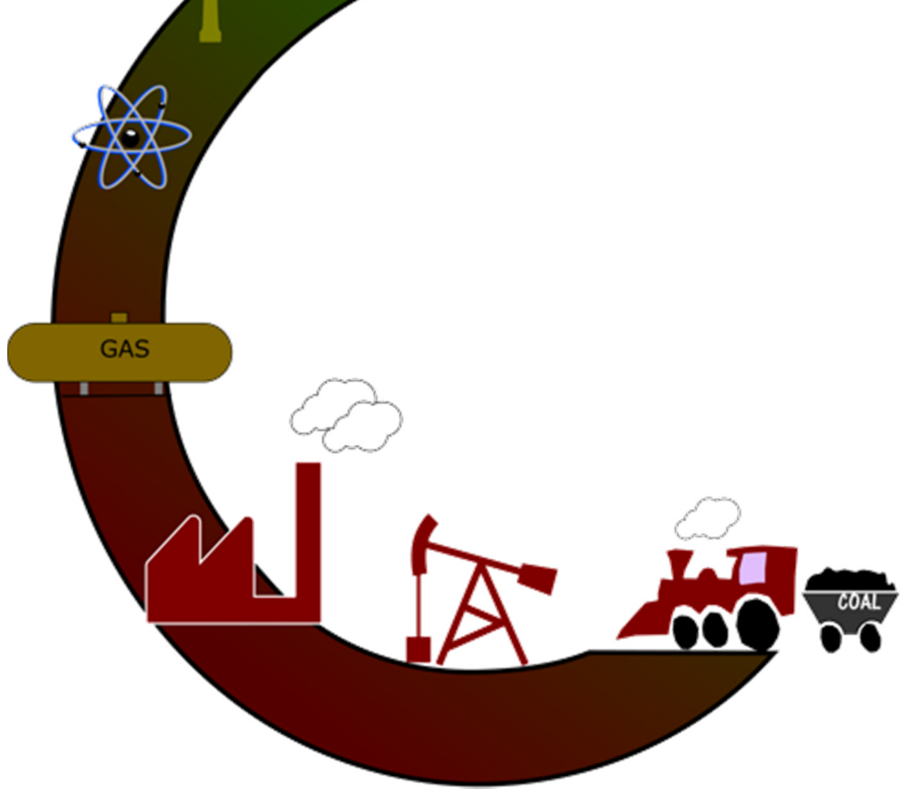
GEB is an innovative and multidisciplinary industrial project that will require the integration of different engineering departments. For project management risks, collaboration should be structured with a strong emphasis on complementarity.

Finally, like all "new" projects, a proposal such as GEB is likely to generate more or less rational public opposition. The consequences of the geothermal operation in the Basel region are now a part of the collective memory. However, the history of the past exploitation of the oil site and our good knowledge and experience of the drilling geological hazards may help us to answer effectively to the questions raised.

As a result of an often inadequate administrative framework, it will also be necessary to take into account the possibility of having to deal with some hassles.

The Geothermal Energy Buffer – GEB – is inspired by nature





Thanks, and …

to help us to make the energy transition a success, please, **support us!**

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GEB and PLUTON DG