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Synopsis of visualization exercises for the selection and operation of the Geothermal Energy Buffer (GEB)

Antoine Jeannou¹, Ahmadou Diaby², Brice Tréméac²

¹ PLUTON DG, Address

² Cnam Lafset, Address

antoine.jeannou@pluton-dg.com

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ABSTRACT

By storing a phase change hydrocarbon at depth, our innovation, the Geothermal Energy Buffer (GEB), stores underground thermal energy.

Liquid Petroleum Gas (LPG) thermodynamic characteristics, as a heat transfer fluid for thermal storage and as a phase change fluid for energy production, was studied. A model for daily balanced energy inputs and outputs was performed. First results allowed to demonstrate the energetic interest for this type of energy storage, in terms of power and dispatchability.

To achieve LPG's production and reinjection a set of wells has been determined and their capital expenditures (CAPEX) estimated. A technical-economic analysis exercise has been completed with marketed surface facilities technologies and energy data obtained from the modelling of the system energy inputs and outputs. The study conclusion resulting from the calculations showed that competitive economical results were reached and ways for GEB performance improvement identified.

1. INTRODUCTION

Our energy transition context reveals a critical need for energy storage solutions¹.

Energy storage is a means of energy management that has the decisive advantage of stabilizing and securing the energy supply. Furthermore, a greater storage capacity would allow a faster deployment of variable RNE, which would help us to reach more rapidly our CO₂ emission reduction targets.

The use or the reuse of deep geological structures, "trapping" naturally hydrocarbons, offers a solution to store energy in thermal form. Energy stored in the GEB system is the latent heat of a phase change organic fluid immiscible to water, the LPG.

Latent heat, also called the vaporization enthalpy (liquid-to-vapor phase change) is the amount of heat added to or removed from a fluid. Main favourable characteristic of the thermal storage of phase change

materials is its high energy density per mass and volume unit².

The versatility of a phase change fluid energy conversion allows a variable production of electricity and thermal energy. This possibility of energy conversion "à la carte" enables to meet various combined needs of cooling (and/or heating) and electricity, whether they are industrial or domestic. In this extended abstract, main results of the "Exercices de visualisations pour la sélection et la gestion du Geothermal Energy Buffer (GEB)"³ study are presented. They confirmed the relevance of GEB as an energy storage solution and helped to identify GEB project's areas for improvement.

2. GEB SYSTEM PRESENTATION

Expected performance of the GEB system as a thermal and geological storage for an organic phase change fluid, is to integrate and store energetically:

- Variable renewable energies.
- Thermal energy, direct and natural like solar, geothermal.
- Heat cogeneration from nearby industrial processes.

GEB system's objectives are to produce at variable capacities and durations the following energies:

- Cold and/or heat.
- Electricity.

To achieve these objectives, LPG is thermally stored into a suitable geological structure. The selection process will first focus on spent oil fields which will ensure proven storage and operating conditions.

Figure 1 below, shows an oil production site conversion example that would sustainably bring back LPG to its "natural habitat" and use it, as an energy carrier to stock and destock energy.

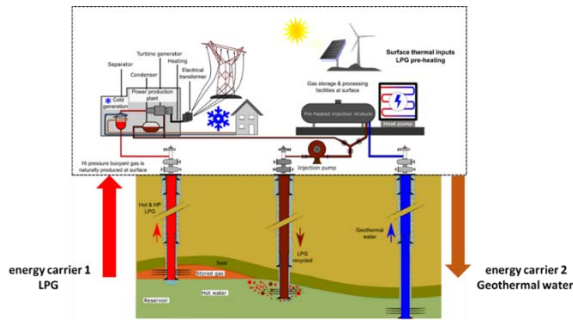


Figure 1: GEB system overview

Main criteria for a deep storage selection and for its exploitation were described in the above-mentioned report.

To summarise, criteria to be reviewed are:

- Storage's maximum volume and also pressure that can be hold by the geological structure,
- Storage structure's sealing, with a focus on the impermeable geological formation «capping".
- Storage structure's integrity, i.e., connections with neighbouring water table. Contamination risk having to be estimated as thoroughly as possible,
- Well's productivity and injectivity, production history will help to evaluate site capacity to store and restore LPG.

2.1 The importance of the LPG re-injection

GEB system use industry-proven expertise and techniques for LPG reinjection.

After assessing the thermodynamic model for the geothermal water and LPG mixture, we used a marketed software to model the reinjection. A sensitivity analysis for 66 cases was conducted based on variables listed in the table 1 below.

Table 1: Sensitivity analysis variable

Water ratio	0 to 50%
Top node pressure	70/87/...../187/200 bars
Permeability	50/100/150 mDarcy

Main results of the injection modelling are:

- Top node pressures from 87 bars and lower demonstrate the benefit of reinjection with a water ratio of 50% though at rather low LPG injection rates.
- The minimum pump injection pressure for the 100 mDarcy and 150 mDarcy cases is 87 bars, but with lower LPG injection rates.
- These results indicate that the number of injection wells should be adjusted to reinject LPG production.
- A good balance for the 100 mD case would be a top node pressure of 87 bars, a 50% water ratio for a 100 m³/h reinjection rate (table 2).
- Temperature wise there is low heating of LPG during the injection with hot water,

moreover higher injection rate tends to lower the thermal exchange.

Table 2: Modelling results for low injection pressure

Injection pressure	% LPG	Injection rate @ 100mD	Injection rate @ 150mD
87 bars	50	100 m ³ /h	140 m ³ /h
96 bars	50	120 m ³ /h	165 m ³ /h
109 bars	50	152 m ³ /h	202 m ³ /h

To conclude it was proved that it is feasible to lower the top node pressure to save injection pump energy. The trade-off being the adjustment of the number of injector wells to the LPG production. Consequently, a set of wells including one producer, two injectors and one geothermal well was used for the economic analysis.

3. MAIN RESULTS OF THE ENERGETIC ANALYSIS

In the referenced study, LPG's thermodynamic characteristics as a heat transfer fluid for thermal storage and as a phase change fluid for energy production were optimized as best as possible. The scope of requirements for the LPG production energy recovery required the identification of technical specifications from "off-the-shelf" technologies.

To compensate for a daily production of 6 hours x 300 m³/hour of LPG, conditions for energy balance were calculated using an electrical production process based on an existing 3.7 MW power turbine (or 22.2 MWh/day). Under the conditions shown in the Figure 3 below, the LPG daily energy recharge will have a power of 3.92 MW for thermal inputs, or 94 MWh cumulated over 24 hours.

3.1 Buffering LPG with GEB

To achieve the 1,800 m³ production of hot and pressurized LPG planned daily, passive geothermal input will require 7,354 m³ of LPG buffered at depth. This buffered volume (figure 2) will allow a sufficient time to LPG to complete its thermal recharge, by a simple exposure to the geothermal flux.

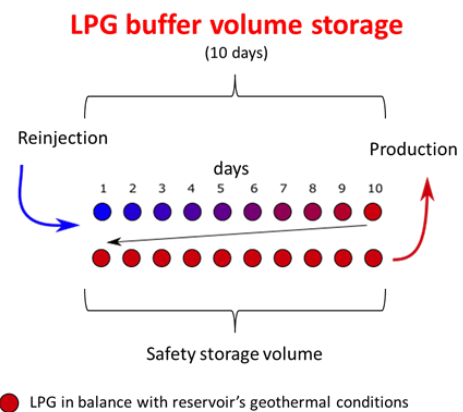


Figure 2: Example of GEB's buffered storage

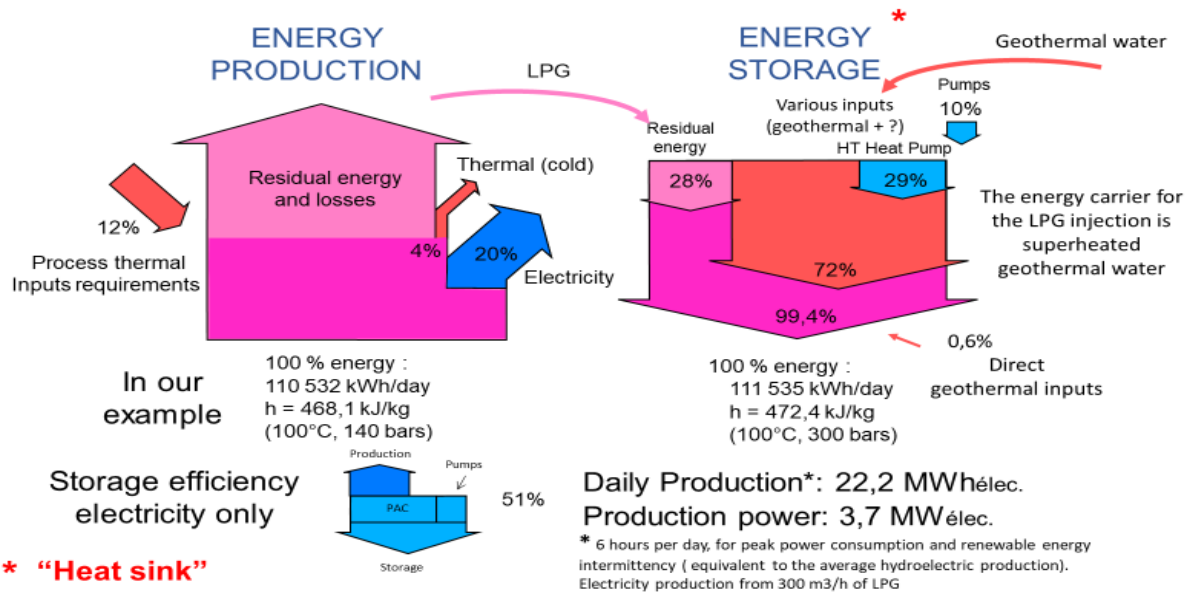


Figure 3: Overview of the main results for a 3.7 MW power production scenario

3.2 Geothermal energy contribution

In the balanced energy modelling of the GEB system, the main geothermal contribution to the thermal storage comes from geothermal water pumped out, in an adjacent well (Figure 1). This water is superheated and used as an energy carrier to reinject LPG to the deep storage. Direct geothermal contribution from simple exposure of the LPG to the geothermal heat flow represents only 0.6% of the total.

3.3 Electricity production potential at a field scale

According to different geological storage structures volumes, the buffer volume calculation (7 354 m³) allows to extrapolate the production potential at a field scale. Thus, for 80,000 tons of storage (169,409 m³ of LPG), a cumulative potential of 6,910 m³/h of production (or 23 wells at 300 m³/h) could be considered.

Using a 3.7 MW turbine per 300 m³/h of LPG production, this would generate a cumulative power of 85 MW (511 MWh for 6 hours) available and manageable as a hydroelectric resource (Table 3).

Table 3: Examples of 6 hours energy generation potential for several LPG storage volumes

Storage	tons	40 000	60 000	80 000	100 000
	m ³	84 705	127 057	169 409	211 762
LPG prod	m ³ /h	3 455	5 183	6 910	8 638
Prod. wells *		12	17	23	29
Power	MW	43	64	85	107
Energy	MWh	256	384	511	639

* if production per well is 300 m³/h

4. MAIN RESULTS OF THE TECHNICAL-ECONOMIC ANALYSIS

The technical-economic visualization was performed with conservative assumptions. GEB’s exploitation simulation used Pumped Storage Hydroelectricity’s

(PSH) storage and production method, i.e., to store thermally LPG, low-cost off-peak electric power is used to run injection pumps and during periods of high electrical demand, stored LPG is produced and released through turbines to produce electric power and heat or cold.

The goal of the technical-economic analysis of the results of the energy modelling of the GEB system allowed us to visualize:

- Best economic conditions for GEB’s system amortization in less than 40 years.
- GEB’s achievable energy prices.
- The identification of the most significant technological and economic improvements for the system.

4.1 GEB’s electricity price discussion

Figure 4 gathers GEB’s energy streams and our monetization assumptions.

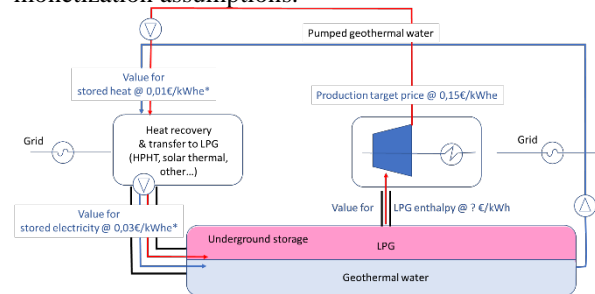


Figure 4: Monetization of energy streams for thermal storage and energy production

For direct thermal storage the selected economic value is 0,01 €/kWh. This value has for symbolic reference the current averaged energy cost of the coal. For the electricity storage, 0.03 €/kWh cost was determined from the literature^{4 5}.

In the system, LPG enthalpy or latent heat for the liquid-gas phase change is considered as a primary

energy sold to the electricity and heat/cold production unit. Consequently, we performed sensitivity calculations with a primary energy internal cost ranging from 0.02 €/kWh to 0.05 €/kWh.

Based on maximized investments (= 100% new wells), for a set of 4 wells (1 producer, 1 geothermal, 2 injectors,) and modelled energy inputs & outputs we estimated electricity selling prices.

Finally, several efficiency hypotheses of the phase change enthalpy energy conversion versus internal costs were tested in Table 4.

Table 4: GEB's electricity selling prices potential

Power prod. efficiency	Wellhead enthalpy max. 18,59 MW				Power
	Phase change enthalpy internal cost				
	0,05 €/kWh	0,04 €/kWh	0,03 €/kWh	0,02 €/kWh	
20%	0,27 €	0,22 €	0,17 €	0,12 €	3,72 MW
30%	0,19 €	0,15 €	0,12 €	0,09 €	5,58 MW
50%	0,12 €	0,10 €	0,08 €	0,06 €	9,29 MW
60%	0,10 €	0,09 €	0,07 €	0,05 €	11,15 MW
70%	0,09 €	0,08 €	0,06 €	0,05 €	13,01 MW

Green cells are the electricity selling process for GEB.

Next analysis was aimed to assess system's ability to be amortized in less than 40 years, at different selling prices and efficiencies of the power production (Figure 5).

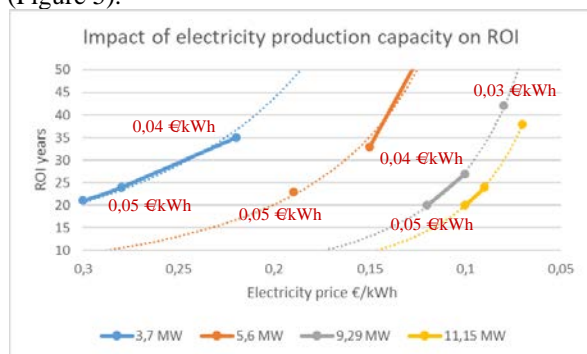


Figure 5: Return on investment according to 4 possible electrical outputs

In the diagram, red kWh costs are the internal transfer values of the LPG phase change enthalpy. Not surprisingly, the highest transfer values allow the fastest amortization for the complete system (around 20 years for a transfer at 0.05 €/kWh). Also, in case of a technological improvement, we can visualize the impact of the electrical production efficiency (grey and yellow curves) on the kWh selling price.

4.2 Technological ways of improvement

The energy production turbines that we have been able to study (and the processes derived from them) are not properly adapted to the high-pressure LPG production characteristics. Adapting conventional condensing steam turbines seems to be the most promising approach.

For electricity storage by thermal conversion, in the range of our required technical specifications, the appropriate high temperature heat pump could not be found. To be able to systematically add the electricity

storage capability to the current thermal storage opportunities for GEB, this way of improvement is very desirable.

4.3 Economical ways of improvement

We have established that energy recharge and discharge costs are mainly conditioned by the CAPEX control of storage site equipment. Particularly for an oil field conversion into a profitable energy storage site, main economic parameters to be addressed are the old wells rehabilitation and the drilling of new wells. In other words, the project to convert a hydrocarbon production site into a geological storage site for energy is a kind of architectural project which comprises an important renovation part.

5. CONCLUSION ET PERSPECTIVES

In our global context of energy transition, on top of the visualized economic interest for the development of this type of energy storage, we have demonstrated that GEB system offers carbon free solutions for electricity grid management comparable to PSH solutions (in terms of power and operating mode).

GEB also offers unprecedented abilities to work as a "heat sink" and to secure the electricity supply thanks to its deep and sheltered LPG storage.

Figure 6 illustrates its potential for the power grid hybridization and security.

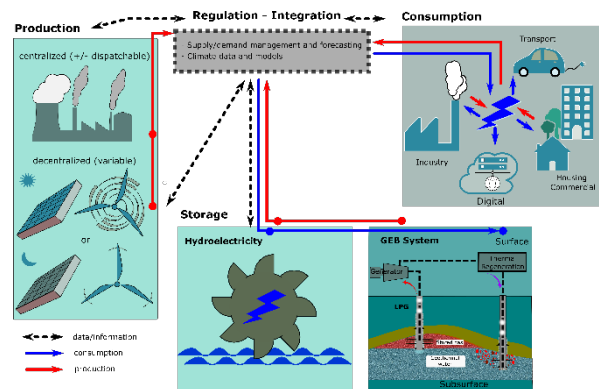


Figure 6: Grid hybridization example thanks to carbon free bulk energy storage solutions

Finally, the possibility to store multi-source energies and to generate a multi-energy production from LPG's phase change, gives to the GEB energy solution a flexibility which, if managed in an intelligent way ("smart grid"), makes it particularly adaptable to the complexity of the "new energy routes" presented in figure 5 below.

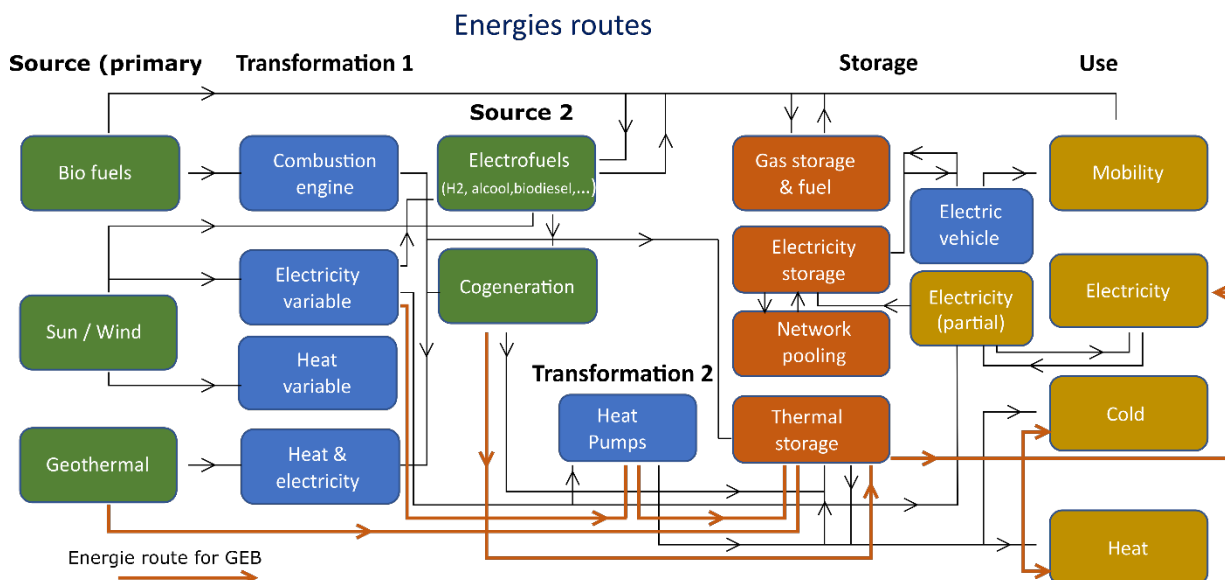


Figure 7: The new clean energy routes complexity (GEB route is in brown)

Practically, given the feasibility of GEB’s technological requirements and the existing "industrial" know-how that could be adapted to the innovation in the short or medium term, we can underline the "emerging industry" character of the Geothermal Energy Buffer (GEB) project.

Thanks to the granting of a European patent, the GEB project has passed the first stage : innovation securization and control.

The present quantified study for the visualization of GEB's selection and exploitation conditions represents the second stage.

Today, by presenting study's main results, we hope to create the suitable conditions to mobilize a collaboration, to facilitate the implementation of the third step: the pilot project.

The development of this geological energy storage solution will also have probably a positive impact on the emergence of new clean technologies like turbines and heat pumps. Finally, GEB projects could be beneficial for the preservation and even the development of subsurface activities.

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