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Geothermal Energy in Colombia: Beyond Electricity Supply; A Vision for Sustainable Development

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ABSTRACT

The present paper discusses how geothermal energy in Colombia could be versatile in several aspects to be more economically viable and hence encourage future geothermal projects to be more productive through different applications such as: reusing oil wells, using CO_2 as an alternative working fluid, water desalination, sustainable mining, recreational baths and hydrogen production. Many of these methods are still being researched. Nevertheless, appropriate investment and research in the following years could boost the development of these modern technologies and enhance geothermal projects. As a result, geothermal development and operation in Colombia could become more viable and more efficient.

1. INTRODUCTION

Facing the environmental impacts and the effects of climate change, Colombia has prioritized policies to promote efficient use of energy and the development of new renewable energy resources (ISAGEN, 2014). In this context, geothermal energy could potentially be an important resource for future energy production in Colombia.

Colombia has a complex tectonic setting favourable for development of geothermal projects due to the subduction of the Nazca plate under the South American plate. However, the country has reported problems in project evaluations attributed to the lack of incipient knowledge of the costs associated with this type of technology (Upme, 2017). Salazar et al. (2017) indicated that the country could face some inconveniences related to limited technical and scientific capabilities for resource exploration and development, unwillingness to make large investments given the high risks involved in exploration, and lack of regulatory frameworks. Hence, there are currently no geothermal power plants in Colombia. These problems can be solved with experimental studies and combining geothermal energy production with other resources. Depending on the application, geothermal projects could become more productive and the viability of exploration could improve. Additionally, geothermal operation and extraction could become more reliable for operators, which would make geothermal projects more attractive to investors. In this paper, greenhouse and district heating applications will not be mentioned since they are already well-known applications, though they could also be adapted and applied in the country.

1.1 Colombia geothermal energy context

As mentioned above, Colombia does not generate electricity commercially through geothermal energy. However, Salazar et al. (2017) indicated that by 2025 geothermal energy will account for 1.65% of electric power generation in the country through the Nevado del Ruiz and Cerro Negro-Chiles-Tufiño projects (Figure 1). The Nevado del Ruiz project which was scheduled to start in 2020 with an installed capacity projected to be 50 MWe but it was postponed. The project is led by ISAGEN S.A. E.S.P together with Toshiba Corporation, West Japan Engineering Consultants, Inc. (West JEC) and Schlumberger (ISAGEN, 2015). The bi-national project between Ecuador and Colombia known as the Negro-Chiles-Tufiño project is planned to start by 2025 with an installed capacity of 330 MW, of which 138 MW will be the part of Colombia (Mejía and Rayo, 2014; CELEC.EP., 2014). Despite this progress in sustainable energy development in Colombia, it is still short on its true potential. For example, studies by CORPOEMA (2010) indicate that Colombia has areas of geothermal interest which have a potential generation capacity of up to 1000 MW.

On the other hand, the Colombia Geological Survey (SGC by its acronym in Spanish) has carried out preliminary feasibility studies in geothermal areas such as the Azufral, Paipa and San Diego volcanoes (Alfaro, 2015). While other geological studies have been carried out (Moyano, 2012; Rojas, 2012; Rayo, 2012; Velez et al., 2018; Gómez-Diaz and Marin-Cerón, 2018) and some academic institutes are studying direct use options, such as agriculture, recreation, and district applications.



Figure 1. General scheme of the location of Nevado del Ruiz and Cerro Negro-Chiles geothermal projects.

2. VERSATILITY OF GEOTHERMAL ENERGY

The constant progress and innovation in the geothermal sector around the world can benefit and boost the geothermal development in Colombia, making not only the development of geothermal energy production more attractive, but also being of interest to the scientific community. In general terms, geothermal systems can be divided into two types based on utilization: the first type includes traditional geothermal (hydrothermal) systems, and the second type includes Enhanced Geothermal Systems (EGS) which involve harnessing geothermal energy in a system which lacks natural fluid convection due to a lack natural fluid, permeability or even both.

The integration of new technology has allowed a better evaluation of the viability of geothermal projects, such as the application of studies in abandoned wells using available data to determine the heat flow of the crust with depth or evaluate the application of the replacement of the working fluid, therefore, decreasing the cost of exploration. Another point to emphasize, is that with technological advances it is possible to improve the profitability or benefits of traditional geothermal systems by combining geothermal plants with additional beneficial coproduct, considering that heat flow and geothermal fluid are resources with potential economic advantages.

These extra benefits can be achieved in diverse manners. An example is the option of extracting resources from produced geothermal fluids. These fluids contain H_2O, CO_2, H_2S, NH_3, N_2, H_2 and CH_4 gases that are commonly present in geothermal discharges from wells and naturally occurring features (Nicholson, 1993). These gases can be useful for certain applications. For example, CO_2 can be re-injected or even used as a substitute for working fluid. Another example is the use of electrochemical reactions to get H_2 from H_2O as a fuel source. Additionally, N_2 and H_2 can be used to generate NH_3 as a commercial product. Nevertheless, those are not the only elements in the fluids. Sometimes, the geothermal fluids are saturated with various minerals and metals that could be saleable products, depending on the concentration of those minerals in the produced fluids. Another option is to remove various minerals or chemical species from the geothermal fluid to get usable water, which could be processed to create artificial pools where the condition of the water will be different from a typical thermal spring (such as the case of the Blue Lagoon in Iceland).

A brief explanation will be given on how these methods can be applied in future geothermal projects in Colombia, giving a general idea about how a geothermal plant could be a hybrid project (generating two revenues) or at least make it more economically viable for its development and operation. It should be noted that many factors that affect the economic viability a geothermal project depend on various factors such as prospecting technologies, drilling technologies, reservoir technologies, cost of energy in the region of interest, and resource assessments.

2.1 Reutilization of abandoned wells

As is well known, the high risk of drilling is one of the greatest concerns when starting a geothermal project. For example, in the case of the drilling wells for EGS projects, the cost of drilling accounts for about 42%–95% of total project expenses (Tester et al., 1994). This high percentage generates can deter exploration. A possible option for geothermal development, which may alleviate issues associated with the cost drilling exploration wells, is to use abandoned oil and gas wells. Databases of abandoned wells provide valuable information about the feasibility of geothermal energy surveys, reducing expenses and the high risks of failing. Caulk and Tomac (2017) showed using a mathematic modelling assessment that crustal heat flows can be suitable for the extraction and direct use of geothermal energy by means of EGS and borehole heat-exchangers. The data they used was obtained from a large number of abandoned oil and gas wells in California with thermal gradients ranging from 40 to 70°C/km (even up to 90°C).

Based on this, similar studies could be carried out in Colombia, applying similar methods to approach geothermal exploration. In 2008, the National Association of Hydrocarbons of Colombia (ANH by its acronym in Spanish), reported the thermal gradient distribution in 14 sedimentary basins measured in about 4600 wells, covering an area of about 50% of the country. There they estimated thermal gradients to be about 60–65°C/km in the Magdalena Valley, Caguan-Putumayo, Sinú San Jacinto and Llanos Orientales basins. The values of one point in the basins of Caguan-Putumayo, Llanos Orientales and Catatumbo are those with the highest geothermal gradient of around 29°C/km (Figure 2). Therefore, at first glance these basins may have abandoned wells with potential for direct-use, even production wells could be considered for geothermal production instead of plugging the wells, where this could be even more expensive than refurbishing it for thermal extraction (Sliwa and Kotyza, 2003). Even using coproduced hot water, which can be available in large quantities at temperatures up to 100°C or more from existing oil and gas operations, may be beneficial for oil companies. Panel (2006) described an example of this using a U.S. regional context where it is possible to generate up to 11,000 MWe with standard binary-cycle technology, increasing hydrocarbon production by partially offsetting parasitic losses consumed during production.

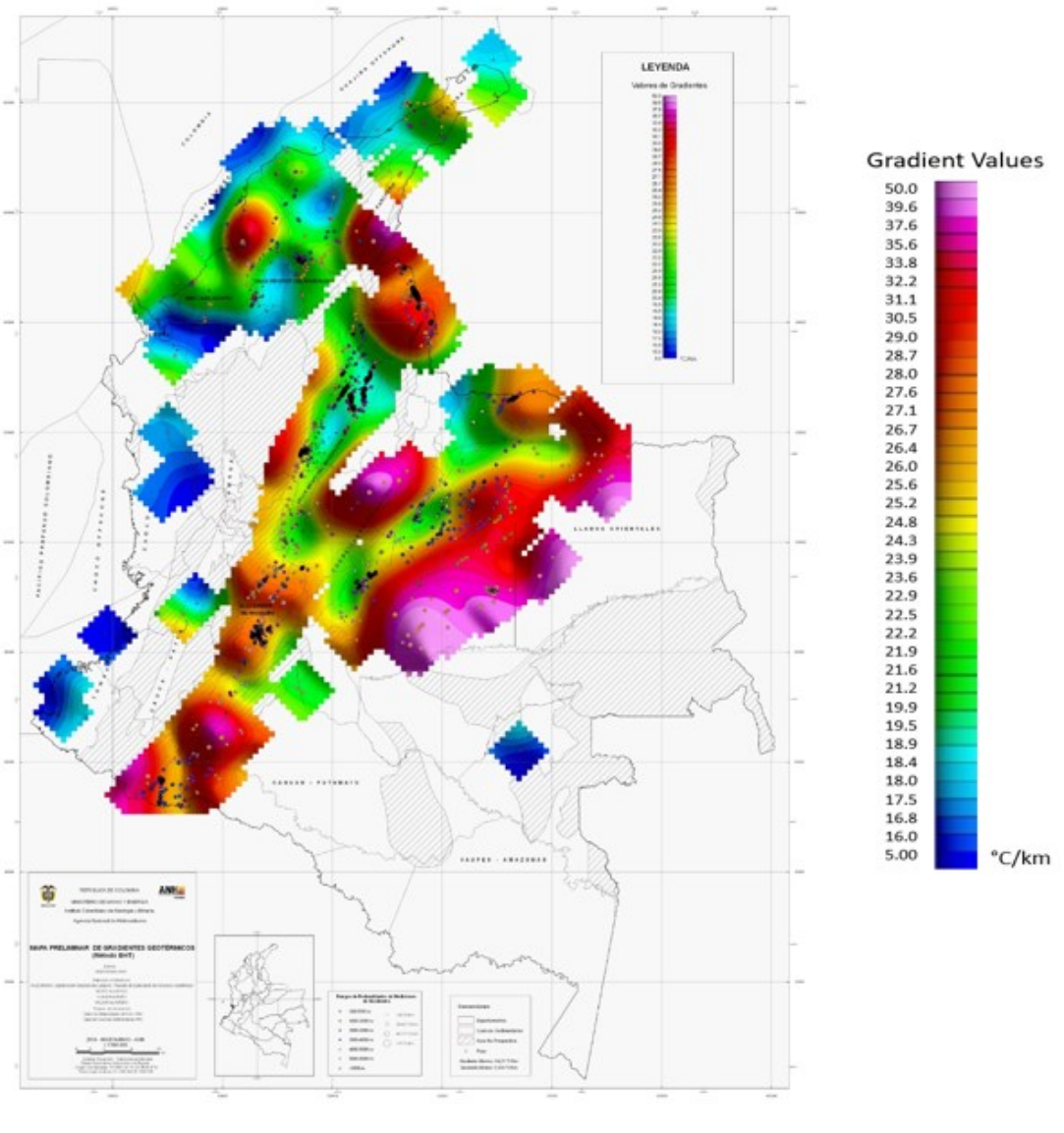


Figure 2. Preliminary geothermal gradient map of Colombia (scale 1:1500.00) through analysis and processing of temperature measurements recorded in 4,414 wells in different sedimentary basins in the country (ANH and INGEOMINAS, 2008).

2.2 Using CO_2 as a working fluid

Although Colombia is rich in underground water resources in most of areas, it could have some problems when it comes to deep sources due to the porosity and permeability of the reservoir rock where faults, lithology or other geological factors can affect the system. This may be of concern when it comes to geothermal projects. However, conventional fluids could be replaced by CO_2 as it is suggested in Ahmed and Javed (2014). Such studies are linked to modern advances in EGS providing new and efficient ways of increasing the potential in the case of hot dry rock systems. Additionally, Brown (2000) suggests a concept known as $SCCO_2$ which uses supercritical CO_2 ($SCCO_2$) as the fluid to transport heat. The heat contained in $SCCO_2$ is transferred to the secondary fluid which drives an expansion turbine in a binary cycle to produce power. Brown also remarked that the rate of geothermal energy production using supercritical CO_2 as a heat extraction fluid would be about 60% that of water-based system.

On the other hand, Pruess (2010) and Randolph & Saar (2011) have shown, through numerical analysis, that using CO_2 may give more favourable heat extraction rates than using water. Furthermore, Salimi and Wolf (2012) proposed that injecting a mixture of CO_2 combined with cooled production water into geothermal reservoirs has some advantages, thus improving reservoir characteristics (permeability and porosity heterogeneity) and the efficiency of heat extraction.

CO_2 can even be used in a two-stage energy recovery approach to sequestrate CO_2 and to produce geothermal energy. Buscheck et al. (2012) explain that brines acting as a heat extraction fluid can also provide pressure relief for CO_2 injection, where the produced brine is used for freshwater production through desalination or, alternatively, can be used as a working fluid for a neighbouring reservoir. The second step begins when CO_2 reaches the production well, where it is coproduced with brine and CO_2 acts as a working fluid. These procedures are still improving, and their implementation should be studied for the case of Colombia. However, it is a great alternative option not only to take advantage of the geothermal potential of a zone, but to reduce CO_2 emissions.

Applying these concepts can open new fields of research in Colombia that could be of interest, and for industries these ideas may help to reduce emissions and mitigate environmental impact. These concepts can even be considered to decrease costs of injection wells, using CO_2 instead of water as heat transfer fluid, hence lowering water consumption and saving on pump costs. In Figure 3, Barbosa et al. (2016) illustrate combining CCS (Carbon Capture and Storage) and EGS plants, where water is replaced by supercritical CO_2 that might then be stored permanently.

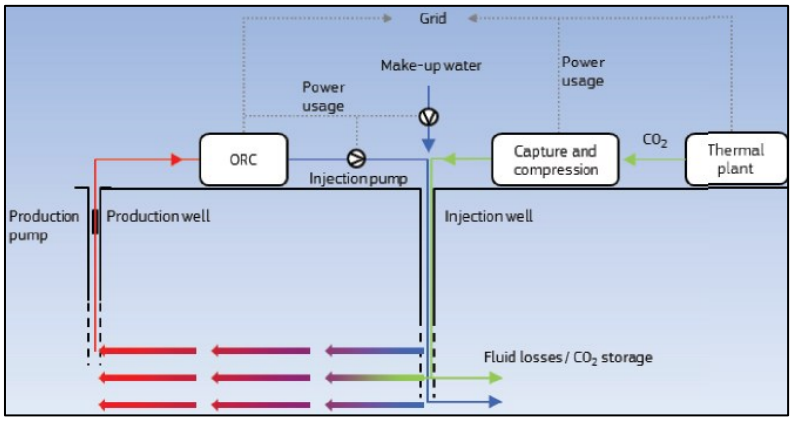


Figure 3. Schematic overview of an EGS power plant and how CO_2 (green lines) can replace water as the circulating fluid in the system. Figure taken from Barbosa et al. (2016).

2.3 Water desalination

Conventional desalination of seawater is an expensive procedure that requires high electricity and heat consumption. One of the solutions to make it affordable and financially beneficial is to use geothermal energy. Geothermal reservoirs can be applied as an excellent heat source for thermal desalination processes. Since thermal desalination processes require a lot of heat and energy, the geothermal energy represents a feasible, sustainable, and an environmentally friendly option. The advantage of geothermal energy is that it can act as a heat source and a storage medium for processing energy utilization (Gude, 2016). Gude shows numerous advantages of considering this alternative to obtain consumable water. In addition, the energy output of this supply is generally stable compared to other renewable resources such as solar and wind power (Sablani et al, 2003). Hence, this method may be used as an alternative solution for sectors affected by the lack of drinking water such as the case of the Colombian Caribbean coast where it could be possible to desalinate seawater using geothermal energy. This approach can even be extended to other regions, where the desalination of geothermal brine can be attempted.

A case in point is the desalination project carried out in Greece by Karytsas et al. (2004), where they looked at the technical feasibility of using low enthalpy geothermal energy in a multi-effect distillation unit (MED) for desalination. Furthermore, Goose et al. (2010) gave a critical overview concluding that geothermal sources could provide a viable source of energy to power both seawater and brackish water desalination plants. An example of this is mentioned by Gude (2016) through the experiment by Tomaszewska and Bodzek, (2013), where using a spiral wound DOWFILMTEC BW30HR-440i polyamide thin-film composite RO (Reverse Osmosis) membranes for making drinking water through of two-stage RO system with water reaction adjustment for the RO-2 stage. Thus, the geothermal water was split into two streams in the membrane process: a permeate stream (treated water), and a retentate stream that contained separated salts and dissolved mineral contents as shown in Figure 4.

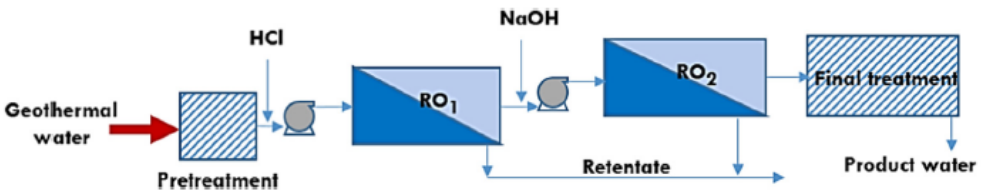


Figure 4. Schematic of a double stage RO process for recovering spent geothermal waters for drinking purposes in Poland. Figure taken from Gude (2016).

Although Colombia has important water sources, there are areas such as the Caribbean region where a lack of drinking water is a common problem. There is thermal spring activity and mud volcanoes reported by SGC, which is useful information in the exploration of geothermal heat sources. Otherwise, performing experiments using abandoned wells, as mentioned above, may avoid high costs of geothermal development and offer better details of the characteristics of the potential reservoir. Additionally, it is possible to consider areas with high geothermal potential for hybrid projects with high enthalpy systems for desalinizing brines and having higher reservoirs of consumable water in times of drought or to sustain demand in the future.

2.4 Sustainable mining and mining operation

High temperature geothermal reservoirs are associated with high concentrations of hydrothermal minerals, such as gold, copper and silver, due to the tendency of precious metals to precipitate and deposit in response to boiling and mixing of deep geothermal fluids (Simmons, 2000). In addition, geothermal reservoirs are associated with precipitations of other commercially useful minerals such as salt and silica. Thus, it would be an interesting target for exploration. The main problem of mining minerals from geothermal production fluids is whether the minerals have enough economic value to and are abundant enough to be mined profitably. These issues have been of interest in countries such as New Zealand and the United States with regards to extracting minerals from geothermal brines. Although there have been several barriers to implementation of commercially viable product recovery from geothermal sources (Bloomquist, 2006; Bloomquist and Povarov, 2008), new technologies and studies in recent years have provided ways to take advantage of the potential commercial opportunity for the recovery and sale of a range of materials, such as silica and lithium.

With adequate investment and studies, Colombia could take advantage of geothermal fluids from the moment geothermal plants are installed. For example, silica is a common component in geothermal fluids and its market is influenced mainly by chemicals, rubber for tires, dental products, cosmetics, paint industry, and the electronic market. Silica production can even generate revenues worth US$10-12M per year in a 50MW geothermal plant (Bloomquist, 2006), and according to Freedonia Group (2012), precipitated and colloidal silica produced from geothermal fluids are part of the specialty silica market, which is worth 1.3b US$ and is growing annual by 5%.

Additionally, rare metals may also be present in geothermal fluids as is the case for lithium (Li). According to the report of Research and Market (2017), the global lithium ion battery market was valued at 26.4 billion US$ in 2016 and is expected to grow at a CAGR (Compound annual growth rate) of 15.5% during the forecast period from 2017 to 2025. Although the amount of this resource in geothermal fluids is not always found in high enough concentrations to consider exploiting it, there are areas that due to the geological setting present high enough concentrations in the fluids to be an interesting target to study it more thoroughly. An example of this is the Salton Sea geothermal plant in USA, where extraction of lithium chloride from waste solutions generates 15000 tons of lithium carbonate or hydroxide salts annually (Lawagon et al., 2016).

A possible applicable experiment could be carried out in the Paipa geothermal zone in Colombia. This zone presents many hypersaline thermal waters related to saline deposits, where the spring waters contain relatively high amounts of lithium or up to 23 mg/l (Alfaro, 2002). At first glance it does not seem to be a significant amount but considering that lithium concentrations are usually below 5mg/l due to it being a very reactive element, then this is a significant amount and it is worth evaluating at the time of the implementation of future geothermal plant achieving the project not only of electricity generation, but a sustainable low-cost mining, compared to recovering lithium from hard-rock mining. Furthermore, a modern method of extraction proposed by Environ. Sci. Technol. (2017), demonstrates that it can achieve a recovery efficiency of about 91% through a sorbent of aluminium layered double hydroxide chloride, illustrating the efficiency of new technologies and research in this sector. Otherwise, the lithium is not the only element to that is extracted; in the same project it is possible to extract other elements such as silica (SiO_2), iron (Fe), manganese (Mn), zinc (Zn) and potassium (K) as long as these elements are worth extracting, as is the case at the Featherstone plant in Salton Sea where full-scale production yields an estimated 16,000 tons of lithium carbonate, along with 24,000 tons of electrolytic manganese dioxide, and 8,000 pounds of zinc metal (Harrison, 2010).

Additionally, mines are high energy consumers. In general, mines require energy to locate, extract, process and transport mineral resources to market. Hence, they require energy to sustain operations, provide safety and security, mediate environmental risks and to close a project at the end of its life cycle (Labrador and Newfoundland, 2012). Geothermal energy could be applied in remote mines which do not have access to the electric power grid in the country, providing an alternative supply energy for exploitation and improving efficiency.

2.5 Baths and spas

Examples of direct use in Colombia includes baths and spas located in the Andean zone (Alfaro, 2015). These baths and spas come from natural springs or shallow water wells which are perfect to save cost. However, the baths may be created from geothermal power plant biproducts as well. Such an approach can make the geothermal project more beneficial, as is the case for the Blue Lagoon in Iceland. The Blue Lagoon sources its water from geothermal water discharged from the Svartsengi power plant (Gudmundsdóttir et al., 2010). The characteristic color of this famous bath derives from silica, which starts to polymerize and precipitate as the fluid cools and at 37–39 °C it forms white silica mud on the bottom of the lagoon. In addition, the high amount of silica has dermatological benefits making it a popular attraction for local people and tourists.

Eventually, the geothermal spa at the Blue Lagoon has a market valuation of roughly $290 million according Journal of Business and Economic Affairs (2017). Whereas duplicating a project like that is complex because it involves many factors, such as cost development and the right chemical conditions of the water. Nevertheless, replicating similar bath attractions could be an advantage in planning future geothermal projects in Colombia.

2.6 Hydrogen production

In recent years, the market for hydrogen has grown remarkably due to new solutions for integrating clean energy and efficiency with new technologies. Hydrogen is a resource with a lot of interest in the technology market and is one of the competing green energy sources for transportation.

Hydrogen also has value in the chemical, metals, electronics, and space industries. As a result of innovate technologies, it is expected between 2017 and 2023 that the hydrogen market will grow at a CAGR of around 6.00% and generate revenue of around 183.34 billion USD by the end of 2023 according to a report by Global Hydrogen Market (2018). Although ways obtaining hydrogen through renewable energy technology is still being researched or developed, different studies (Jonnson et al., 1992; Yalmiz et al., 2011; Kanoglu et al., 2016) have showed the viability and feasibility of obtaining this resource using geothermal energy and how it may be beneficial in the economy. In Figure 5, Yilmaz et al. (2016) illustrate seven techniques to obtain hydrogen through electrolysis, liquefaction and/or high temperatures.

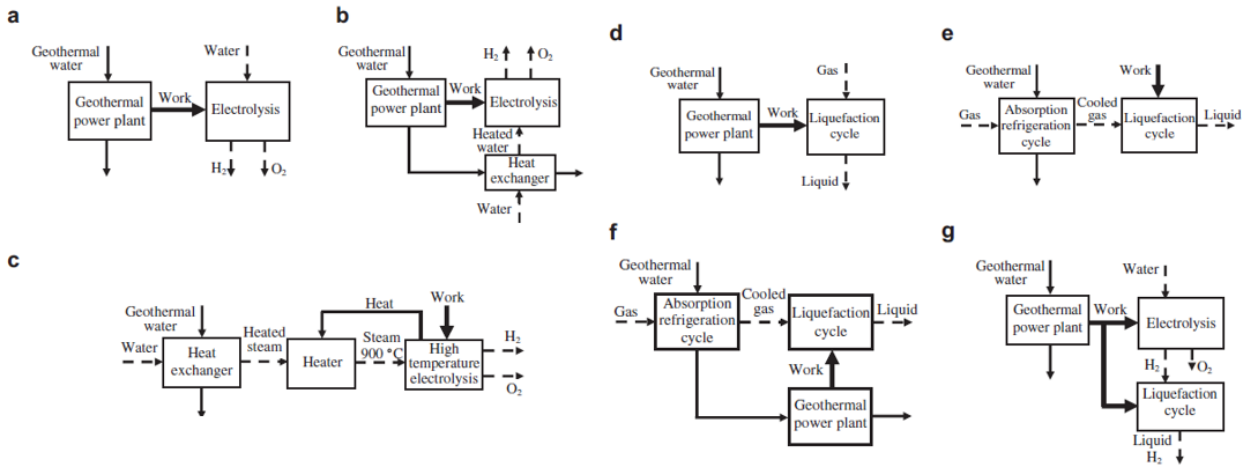


Figure 5. Illustration of Yilmaz et al., (2011) explaining seven cases considered for hydrogen production and liquefaction. (a) Case 1: Using geothermal work output as the work input for an electrolysis process. (b) Case 2: Using part of geothermal heat to produce work for an electrolysis process and the remaining heat to preheat the water for electrolysis. (c) Case 3: Using geothermal heat to preheat water in a high-temperature electrolysis process. (d) Case 4: Using geothermal work output as the work input for a liquefaction cycle. (e) Case 5: Using geothermal heat in an absorption refrigeration process to precool gas before its liquefaction. (f) Case 6: Using part of the geothermal heat for absorption refrigeration to precool gas and remaining heat to produce work in a liquefaction cycle. (g) Case 7: Using part of geothermal work for electrolysis and the remaining part for liquefaction.

Although, at the moment, giving an explanation in the context of how this resource could be produced in Colombia by geothermal energy is really difficult due to the lack of an active project in the country, it should still be considered. Colombia could contemplate this element as a new objective in the economic energy sector, including transport, power generation and portable energy systems, in order to become a leader in the region like Brazil is when it comes to the production of ethanol. The need of replacing conventional energy with clean resources in the next decades, and the confluence of events in sustainable development, will be the key to an important rise in the development of hydrogen production, where the country should not be left behind but rather promote and boost future renewable projects for the development of this resource. Furthermore, this element can also be produced by other renewable resources such as: solar, wind or biomass energy. Consequently, facilitating the growth and progress of this in the energy sector.

3. CONCLUSION

In general, extracting concrete data in each of these examples nowadays is very complicated without the appropriate infrastructure and development in the geothermal sector. However, these methods provide future possibilities that can clearly be applied indirectly along with geothermal utilization in Colombia. New technologies offer innovative ways to reduce risk in the development of geothermal power plants in Colombia. This may be the case when using abandoned wells and CO_2 as a working fluid, thus reducing high costs of exploration as well as providing new models of exploitation. On the other hand, it is important to consider geothermal resources as more than just an energy supply, as is discussed in this paper. Developing hybrid projects which combine geothermal power plants with other saleable resource generation methods may offer great advantages in new sustainable economic models. This may help to expand the geothermal market in Colombia by making it more attractive for investors as well as creating new opportunities for various industries. Finally, Colombia faces multiple challenges when it comes to implementing geothermal energy, but with knowledge from new fields its application will increase economic and political interest, making it more viable for a prosperous future.

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