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Sustainability-Investigating Compromises between Performance and Carbon Footprint – Drilling Fluid Applications for Enhanced Geothermal Systems: A Case Study

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Abstract— ***Energy transition is creating ways to replace our conventional power generation sources with more sustainable and environmental friendly alternatives. In order to meet net-zero emission target the countries are ramping up their energy transition projects and global economies will see a dramatic change in market distribution of current energy mix by 2030 (Rystad Energy,2022) .Geothermal market is a vital tool for countries and companies navigating the energy transition from fossil fuels to renewable resources. Deep low enthalpy reservoirs are creating new frontiers in geothermal energy with the development of enhanced geothermal systems (EGS). Drilling and completion fluids plays an integral part in the life cycle of building of geothermal energy. Geothermal wells emits around 38g CO_2 eq. per Kwh (IPCC, 2021).***

The paper uses output from a series of engineering tools to investigate if actively reducing the emission profile of a drilling fluid system designed for EGS operations impacts or compromises performance. The evaluation compares the operational lifecycle of a typical Water based mud (WBM) versus a High performance water based mud (HPWBM) for an EGS drilling program and the associated emissions profiles. Cradle to gate analysis helps in emission tracking, monitoring and product optimization of geothermal drilling fluids. The ESG engineering tool used in profiling the drilling fluid systems enables a rapid and simple estimate of the environmental performances of an EGS drilling and completion well operations. When coupled with a drilling fluid hydraulics engineering design tool, the paired outputs provide a clear an east to access evaluation for the stakeholders of the EGS sector and for decision & policy makers. The paper aims at contributing to the debate about engineering design and performance in this new emerging technology and its related environmental impacts.

Index Terms: Energy Transition, Environmental Impact, Geothermal Energy, Net-Zero Emissions.

I. INTRODUCTION

Geothermal energy is a sustainable source of energy that uses heat from the earth's core and emits one of the lowest levels of carbon dioxide (CO_2) emissions. Drilling down to hot water reservoirs up to a mile below the surface creates steam that rotates a turbine, which spins a generator to generate electricity. Geothermal is found along major tectonic plate boundaries where volcanoes are located. Because the Earth has an almost unlimited supply of heat generated by its core, and the water extracted from the reservoirs can be recycled via re-injection into the ground, it is a renewable energy source.

The three main types of geothermal power plants are:

1. Dry Steam
2. Flash Steam
3. Binary Steam

The six largest geothermal energy-producing countries (amount per year) in the world listed below as depicted in figure 1:

1. US – 3,639 megawatts (MW)
2. Indonesia – 1,948 MW
3. Philippines – 1,868 MW
4. Turkey – 1,347 MW
5. New Zealand – 1,005 MW
6. Mexico – 951 MW

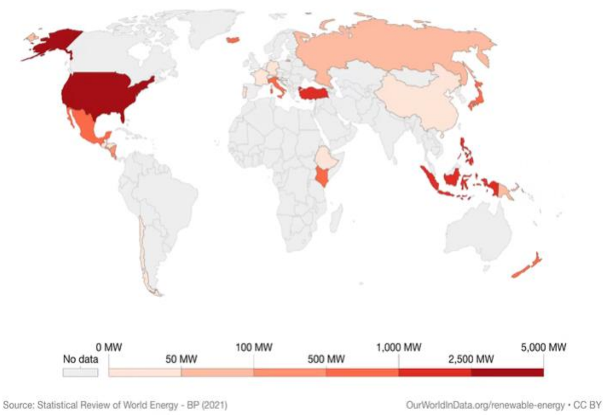

Figure 1. Six largest Geothermal Energy producing Countries shaded in color from lowest to highest shown through color intensity.

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On a life cycle basis, geothermal emits just a few grams of CO_2 equivalent per KWH of electricity produced as shown in figure 2. A median value of 38g of CO_2 equivalent/KWH been estimated closer to hydropower and almost lower than all types of solar. The majority of CO_2 emissions from the lifecycle of geothermal comes from the operations of geothermal plant generating electricity.

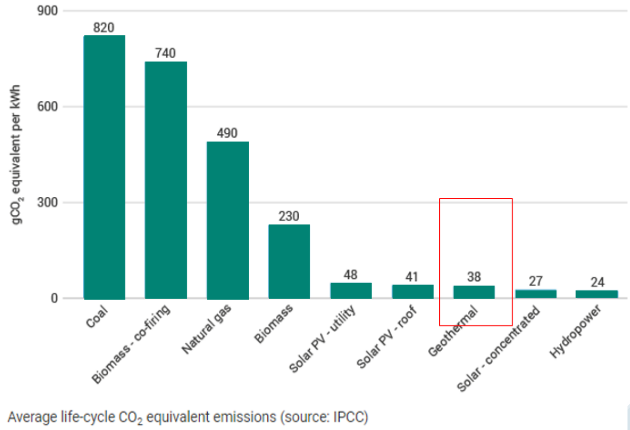

Figure 2. CO_2 equivalent emission per KWH of electricity produced.

II. METHODOLOGY

To understand the carbon footprint of geothermal energy, we must assess its life cycle and each stage's carbon footprint. This life-cycle assessment (LCA) is a method to evaluate the environmental impacts of products and materials. Over the years, companies has strategically used LCA to research and create more sustainable products.

Table 1. Stages of geothermal energy life cycle and description of its carbon footprint.

The life-cycle stages of geothermal energy	Each stage's carbon footprint
Building of geothermal energy	CO_2 emissions from drilling geothermal wells and construction of geothermal power plants
Operating of geothermal energy	CO_2 emissions from the operation of geothermal power plants
Building back of geothermal energy	Little to no CO_2 emissions or waste products

To estimate the carbon footprint performance of geothermal drilling fluid a geothermal life cycle assessment methodology been developed for geothermal drilling fluids using ISO14040 series of standards. LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

There are four phases in an LCA study:

- the goal and scope definition phase,
- the inventory analysis phase,
- The impact assessment phase, and
- The interpretation phase.

The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system been studied. It involves collection of the data necessary to meet the goals of the defined study.

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results to understand their environmental significance.

Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

The LCI analysis and modelling involves the data collection and implementation of calculation procedures to quantify relevant inputs and outputs of the product systems. Alternative types of approaches to conduct a life cycle inventory analysis (or modelling) summarized and compared in Table 2.

Table 2. Different approaches to life cycle inventory analysis (Modified from Shires et al., 2009).

Approach	Hierarchy
Published emission factors	Improved accuracy Additional data requirements Higher cost
Equipment manufacturer emission factors	
Engineering calculations	
Process simulation or other computer modelling	
Emissions monitoring over a range of conditions	
Periodic or continuous monitoring of emissions	

An engineering model build to estimate the emissions from drilling fluids operations of a geothermal resource. To assess the environmental burdens of geothermal well drilling fluids, a life cycle inventory (LCI) model created using the ISO 14040 standards and used to carry out the assessment. The system boundaries chosen follow a gate-to-gate approach, with the primary aim to find both the greenhouse gas emissions (GHG) and toxic emissions from geothermal well. The calculation of GWP (Global Warming Potential) is based on one hundred years using the IPCC AR5 accounting method (GWP 100 year for CH4 is 28) to allow comparison with other published studies.

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III. MODEL IMPLEMENTATION

The objective of the study is to quantify GHG and toxic emissions of an assumed geothermal well in APAC region. This assessment identifies the processes that have significant impacts on emissions, whereby providing the foundation for the development of policy and technology solutions that can then attempt to address these issues. The model also estimates the emissions involved in manufacturing and recycling from the decommissioned material and metal infrastructure.

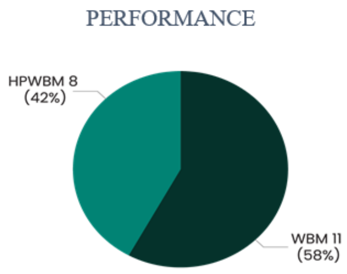
Each individual process in the geothermal well development from drilling fluid prospective associates upstream supply chain (energy, raw materials, product) and a downstream supply chain (emissions in air) that are included in this study to provide a full assessment of GHG and toxic emissions associated with geothermal well drilling. The sources of emissions considered in the LCA includes; emissions from the raw material extraction, manufacturing, lifting and transportation of chemicals and emissions from fuel consumption during onsite and offsite chemical mixing operations.

A sensitivity analysis carried out to enable the comparison of the two different drilling fluids given the uncertain nature of input parameters used in LCI modeling. Published data from the literature and realistic assumptions reported by the geothermal industry utilized in the model.

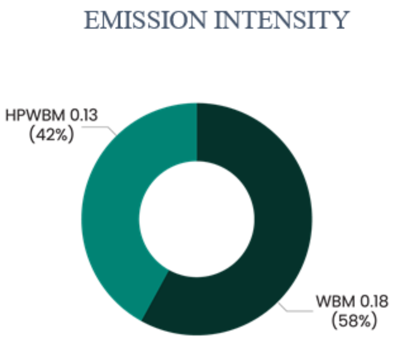
Once the level of detail and assumptions formalized, the LCI model coded in a PowerBI spreadsheet. Then all drilling fluid formulations modelled and emission rates were calculated. The sensitivity analysis allows assessing opportunities for change in chemical formulation and operational practices and the mode of transport used for delivering chemicals.

IV. RESULTS AND DISCUSSIONS

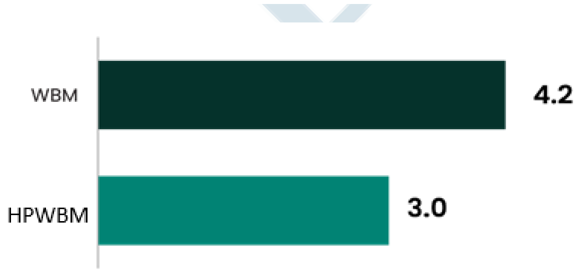
Selection of drilling fluid mainly depends on the type of formation and the borehole depth. The LCI model ran for the two drilling fluids systems used for drilling a geothermal well in same area with same customer. A life cycle perspective is important to assess the drilling fluid impacts on a geothermal reservoir development. The uncertainties may arise in estimated results mainly because of the variability of drilling fluids use by different well operators and the variability of rheological parameters.



Drilling days for 1,000 m



Kg CO_2 eq. /$



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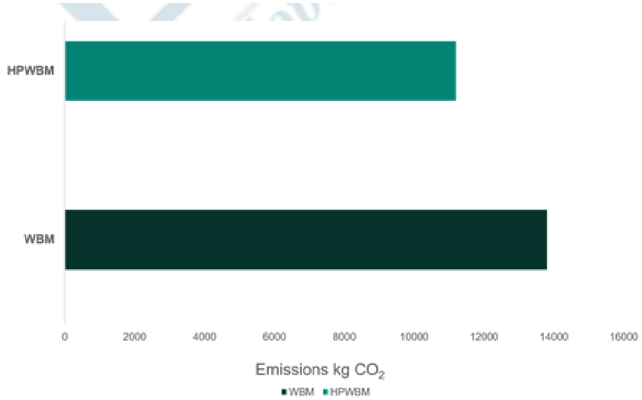

Water Based Mud (WBM):

The results indicates a carbon footprint of 13,800kg of CO_2 while drilling a geothermal well with WBM. The operator can benchmark other mud systems against WBM system for drilling the same formations with same drilling practices with an emission footprint of 14kg CO_2/bbl. WBM system built with 13 products, which helps the operator in reviewing the products against PCF (Product carbon footprints) and managing the inventory by reviewing the lead times. The specific formations were drilled in 11 days with WBM system and the project financial cost is 0.18kg CO_2/$. Fluids SME's along with sustainability leaders use the LCA to identify and manage the GHG protocol scope reduction areas.

High Performance Water Based Mud (HPWBM):

The results indicates a carbon footprint of 11,200kg of CO_2 while drilling a geothermal well with WBM. The operator can benchmark other mud systems against HPWBM system for drilling the same formations with same drilling practices with an emission footprint of 10kg CO_2/bbl. HPWBM system built with 09 products, which helps the operator in reviewing the products against PCF (Product carbon footprints) and managing the inventory by reviewing the lead times. The specific formations were drilled in 8 days with WBM system and the project financial cost is 0.13kg CO_2/$. Fluids SME's along with sustainability leaders use the LCA to identify and manage the GHG protocol scope reduction areas.

V. CONCLUSION

The above results shows that HPWBM is more environmental friendly as well has better drilling performance while drilling a geothermal well in APAC region. The results also indicates that the project cost is also minimized while drilling with HPWBM as emissions/$ value are significantly lower for HPWBM compared to WBM. The study also suggests that it helps the operators in optimizing their chemical supply chain as less chemicals utilized while drilling a geothermal well with HPWBM. This helps the customer in having an optimized inventory and helps them in maintaining their balance sheets.

Operators can use the results of these LCA's to identify emissions on basis of activity. The activity wise breakdown of the results guide the service delivery to make necessary strategic/operational changes to reduce the project carbon footprint in ongoing/future operations. The study suggests that Life cycle analysis of geothermal wells helps the operators in selecting the fluid on basis of carbon footprint and gives them an added criterion to select from range of fluids. This helps the operators to meet their sustainability goals and KPI's.

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