Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Development of an oil return system for Line Shaft Pump technology within the ANtLiA research project

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Keywords: artificial lift systems, line shaft pump, oil return system, electrical submersible pump

ABSTRACT

Line Shaft Pump (LSP) technology is used in harsh and high-temperature environments (Hettkamp et al. 2022) to artificially lift hot water or brine out of geothermal wells. LSPs are being installed down to depths of approximately 760 m, the shaft being driven by a hollow shaft motor at the wellhead at surface. The 2 3/16" diameter shaft rotates inside a 4" OD oil-filled tube for lubrication purposes. Currently, up to 20 liters of oil per day are being added at surface. At the wellhead, this shaft is being isolated from the atmosphere by a special dual cartridge seal, while at bottom in the well, just above the pump, this added and surplus oil is typically simply routed into the annulus between production and outer well casing through open ports.

Within the ANtLiA joint industry R&D project, a new seal is being developed to return all oil to surface within a closed loop. This will prevent water / brine contamination as well as further decrease oil consumption of LSP systems, ideally reducing it to near zero. This new seal will be developed incrementally, and the final, complete oil-return system will be tested and evaluated in a newly built test facility at Fraunhofer in Bochum, Germany in mid 2026. Furthermore, various oils will be examined to identify best and long-lasting solutions, also reducing oil consumption of LSP technology to near zero.

1 INTRODUCTION

Two artificial lift systems are commonly used to produce hot brine from geothermal wells: line shaft pumps (LSPs) and electrical submersible pumps (ESPs). In ESPs, the motor is installed downhole below the pump, and a high-voltage power cable must be run alongside the production casing to supply the motor. In contrast, an LSP uses a hollow-shaft motor installed at the wellhead to drive a solid shaft that rotates inside an oil-filled lubrication tube containing multiple bearings. The shaft can be up to 760 m long and is connected directly to the downhole pump. Although both pump types use comparable impeller designs, LSPs are limited in installation depth, more complex to install and more expensive to purchase. Nevertheless, LSPs are often the economically preferred solution because their overall efficiency and operational lifetime typically exceed those of ESPs.

In Germany, the installed downhole pumps are concentrated mainly in two regions. Two LSPs are operating in the Upper Rhine Graben in South West Germany (Landau and Insheim), complemented by three additional LSPs on the French side of the border (Rittershoffen, Soultz-sous-Forêts and Vendenheim). In contrast, approximately 25 ESPs are currently running in the Munich area within the Molasse Basin in southern Germany. Here, the static water level of the resource lies several hundred meters below ground, and ESPs are installed at depths of up to 900 m. The geothermal water produced in this region constitutes the area's potable water reserve for the year 3000 and is therefore strictly protected; contamination by lubricating oil must be avoided at all costs.

Since conventional LSPs rely on an open lubrication system – meaning the annulus between the well casing and the production casing becomes contaminated with oil during operation – they have not yet been installed in the Munich region, despite many wells where an LSP could operate more efficiently and more reliably than the currently installed ESPs. However, authorities in southern Germany are willing to permit LSP installations in the protected geothermal reservoir, provided that the lubrication oil is aromatic-free and the oil is recovered at the surface during pump operation. Therefore, within the ANtLiA research project, an oil return system and a downhole oil seal are being developed for LSP technology.

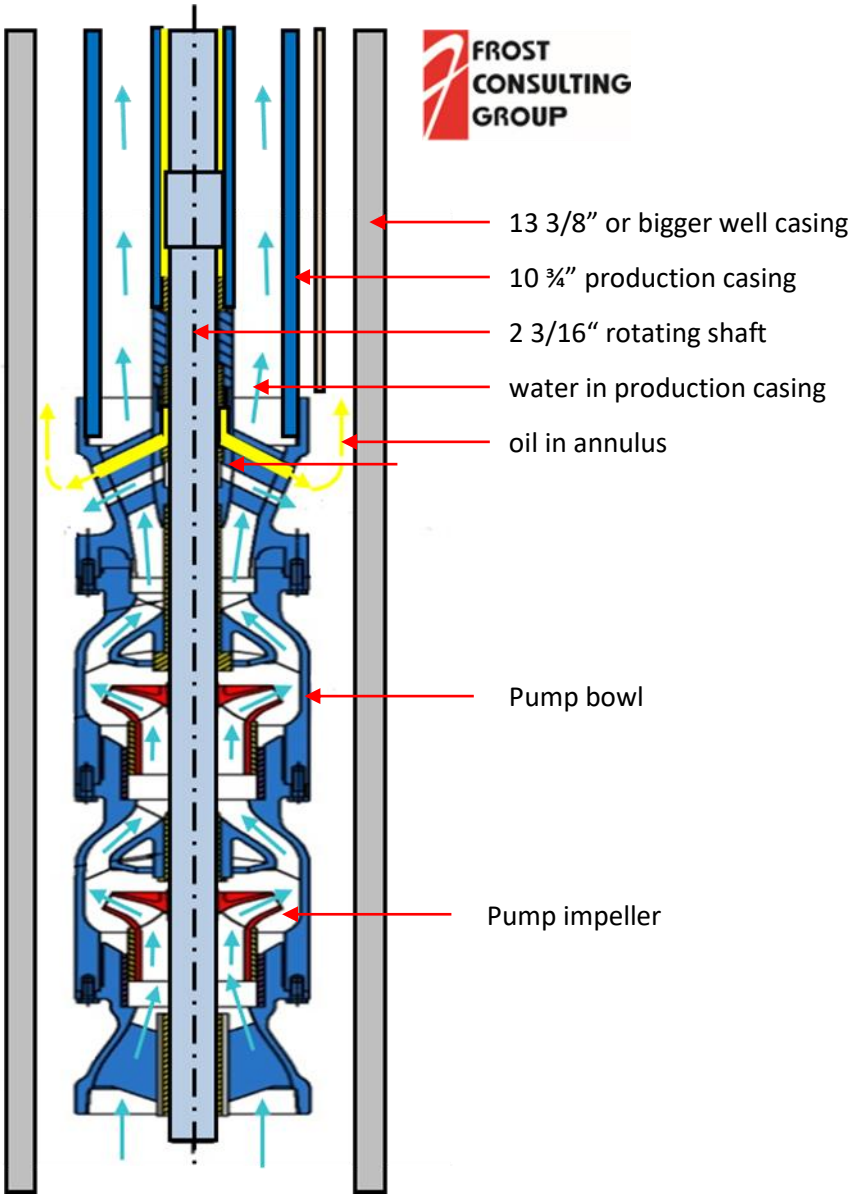


Figure 1: Oil and water / brine flow within a conventional LSP without oil return

Figure 1 illustrates a section of a conventional LSP with two pump stages and the production casing, along with the flow paths of the injected oil (yellow arrows) and the produced brine (blue arrows). The oil flows inside a 4" OD lubrication tube from the wellhead to the pump, lubricating the shaft down to the top pump bowl. With a tube volume of 3.33 liters per meter between the shaft and the tube wall, up to 20 liters of oil per day are injected. Above the pump bowls, the oil is diverted into the annulus between the well casing (13 3/8" or larger) and the production casing (10 ¾") via oil ports.

Inside the pump bowls, the shaft is lubricated by the produced brine. While most of the brine flow is lifted to the wellhead through the bowls and production casing, a small leakage flow is diverted into the annulus through a brine port, where it mixes with the lubrication oil. Because of its lower density, the oil separates from the brine in the annulus and accumulates on top, where it can be removed by artesian flow during extended pump shutdowns.

During continuous long-term pump operation, the downward oil flow rate of approximately 20 liters per day should prevent brine from entering the lubrication system, assisted by a labyrinth seal that restricts brine intrusion. However, since the oil and brine streams are not physically separated between the ports shown in Figure 1, fluid contact cannot be fully avoided. Depending on well hydraulics, pressure conditions and transient flow behavior during pump starts and stops, brine may enter the oil tube. Consequently, the amount of injected oil is typically increased after pump restarts to flush out any brine that may have entered the system.

To avoid any brine-oil contact in the annulus, a new seal system must be developed together with an oil return line. The standard annulus (13 3/8" to 10 ¾") provides sufficient space to install one or two such return lines to transport the required 20 liters per day without brine contact and without inducing friction losses. The new seal system must be installed between the two fluid ports shown in Figure 1. Both oil ports must be connected to the return line. The main sealing challenges are the vertical movement of the solid shaft (up to 4 ¾"), change in shaft length due to thermal expansion and the necessary radial clearance. Since an LSP typically operates for more than four years, the downhole seal system must achieve a comparable lifespan. Therefore, a simple, robust seal that allows minimal brine ingress and ensures long operational lifetime is preferable to a highly efficient but short-lived seal requiring frequent replacement.

2 ANTLIA RESEARCH PROJECT

The objectives of the ANtLiA research project are to identify the causes of pump failures, improve both LSP and ESP technologies, and evaluate newly developed solutions. Four partners are cooperating in this project: Fraunhofer IEG (a German research institute), BESTEC (a geothermal development company), SWM (the municipal utility of the city of Munich and operator of geothermal heat plants), and HM, Hochschule München (a university of applied sciences).

ANtLiA consists of two main research areas addressing both ESP and LSP technology. For the ESP-related work, all German geothermal operators are being contacted and existing failure documentation is collected to obtain a deeper understanding of the causes of pump failures to identify fields requiring further research. A monitoring system will be installed within the variable-speed drives of selected ESPs to gather performance data and to support the development of a digital twin. In addition, a new prototype motor will be developed.

The LSP-related research focuses on developing the oil return system and the new downhole seal, as well as assessing potential applications of LSPs in the Molasse Basin.

3 PROTOTYPE AND TEST FACILITY

A 10" LSP prototype has been ordered from ITT/Goulds, designed to deliver up to 30 l/s and having a total length of approximately 12 m. This six-stage test protype is shown in Figure 2. It will be equipped with an oil return system and a sealing section (highlighted in yellow in Figure 2; the return line is not shown). The test design enables the sealing section to be exchanged multiple times, allowing repeated testing with different sealing configurations.

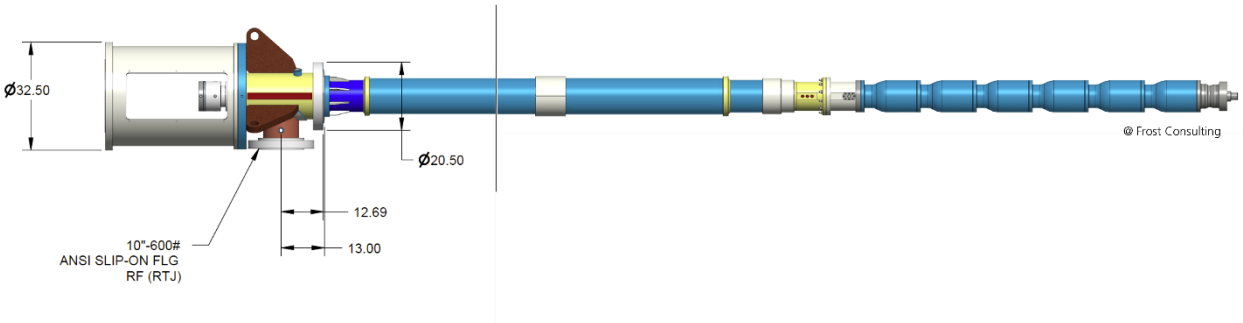


Figure 2: Six-stage LSP test prototype with an oil return system

The protype will be installed in the specially designed Fraunhofer test pump facility in Bochum (Figure 3), where several sealing concepts will be evaluated. The test facility will be approximately 18 m deep and equipped with a vacuum-insulated double-wall casing, allowing the circulation of heated production water. The prototype will be monitored closely, with particular attention to the seal tightness; injected and returned oil volumes will be compared to assess leakage. In addition, different aromatic-free lubrication oils will be applied and analyzed. While the standard LSP lubrication oil costs approximately 4 €/L, higher-quality oils are expected to be more expensive. Nevertheless, the operating costs with the new oil-return system are expected to be lower due to oil recycling.

The planned tests will help identify which sealing concepts and oil types minimize the leakage of produced fluid into the returned oil and how effectively the returned oil can be separated and recycled.

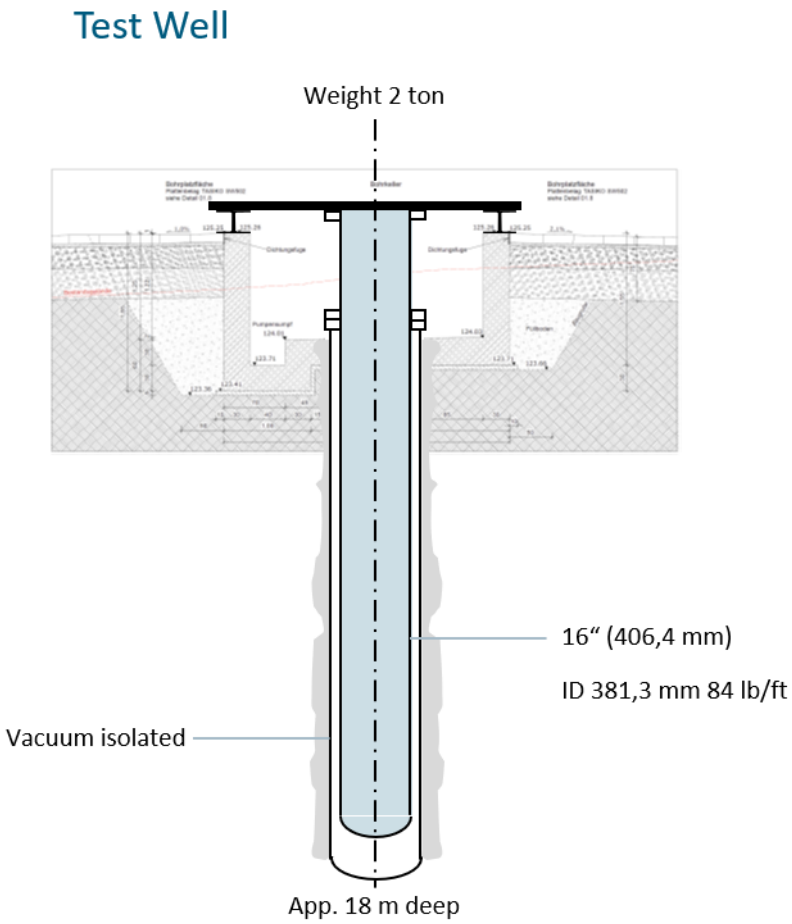


Figure 3: Pump testing facility, Fraunhofer Bochum; Germany

4 TIME SCHEDULE

The six-stage protype has already been ordered. In 2025, the sealing concept will be developed. The test pump facility will be drilled beginning of 2026, and the first tests of the initial sealing sections will be conducted in Q2 2026. A field test of the newly developed seal section and oil return system is optionally planned for the end of 2027.

5 CONCLUSIONS

An initial assessment of the installed pumps conducted by project partner SWM indicates that at least five to seven wells could be equipped with an LSP using an oil-return system that would be more cost-efficient than the ESPs currently in use. If the ANtLiA project succeeds in developing a reliable sealing and oil-return system, multiple LSP systems could potentially be installed in the Molasse Basin and Upper Rhine Valley in the near future.

ACKNOWLEDGEMENTS

The ANtLiA research project is funded by the German federal ministry for Economic Affairs and Energy under administrative reference number 03EE4067A, with a total budget of 3.2 million euros, from January 2025 to December 2027.

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