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A New Approach to Further Utilize Geothermal Energy Globally

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ABSTRACT

This project was established to deliver an economically viable solution for electrical power generation on a global scale, by maximizing energy conversion directly from downhole fluids produced in geothermal wells. Currently, geothermal power generation plants require a vast amount of sophisticated equipment to generate steam, and also need to treat the fluids with a cooling process after power generation. This approach requires a high volume of equipment and a large CAPEX which has, in fact, limited investments from the private sector.

GA R&D Ltd has been working for the past 5 years developing a new technological approach, which has resulted in creating a highly novel steam turbine design, with the potential to convert a much higher percentage of thermal energy into electricity. Theoretical analysis of this new type of turbine has given us the confidence to believe it will be successful and has led us into committing to develop a small-scale prototype application. This will demonstrate the substantial benefits of the technology and enable viable investment to be made in geothermal energy power generation. This technology, with much lower CAPEX and OPEX costs, could become the backbone of power generation for many geographical regions where finance is limited, such as countries in Africa, or geographic regions which have low enthalpy characteristics, such as Scotland.

1. INTRODUCTION

Environmental legislation aims to reduce greenhouse emissions, while introducing greener technologies to replace fossil fuels. Increasing energy demand has been on the global energy agenda, and alternative solutions must be developed to address this issue.

Various renewable energy technologies have been introduced in recent years to tackle this global challenge of replacing some of the current fossil fuel power generation solutions. For example, the European Union has established a multi-dimensional network in which different technologies, such as solar and wind, are installed to provide some of the required base load. However, none of these renewable energy sources can provide a sufficient and sustainable base load at all times, because they rely on variable weather conditions.

Power generation from geothermal energy has been known for a very long time and it has the ability to provide the sustainable base load that most communities require. The high cost of drilling operations and building of major infrastructure in different geological conditions has always discouraged investment in power generation from this source. Our novel technology however makes power generation from this source an economically and sustainable reality.

Various studies on current technologies associated with geothermal power plants have shown significant limitations on the steam turbine stage of the geothermal plant top side. In particular steam leaves the turbine at relatively high temperatures, requiring cooling, which involves additional infrastructure and cost. Our novel steam turbine technology extracts more energy from the steam and totally removes the need for expensive and costly to maintain cooling systems.

Globally most power generation plants, whether they be fossil fuel or nuclear, depend on steam turbine electricity generation at their core and this novel steam turbine technology will have application there as well as in the globally expanding and natural geothermal energy source.

2. BACKGROUND TECHNOLOGY CHALLENGES

Geothermal energy has been sourced in many regions of the world for many years and has shown significant growth in recent years, having the potential to replace other less environmentally friendly major energy resources, such as fossil fuels and nuclear power. All geothermal power generation plants are using steam turbine technology to convert thermal energy to mechanical, which is in common with most power generation stations powered by coal, gas, oil and nuclear.

Traditional steam turbine technology has been established for many years, and many improvements have been made to optimize turbine efficiency. Turbines are designed for a given inlet flow, in which they will operate at maximum design efficiency. However, maintaining sustainable and consistent inlet flow is an industry challenge and it is common that steam turbines operate at partial load capacity, which has a knock-on effect on the turbine efficiency and reduces the overall performance of the system (1). To mitigate this current limitation, a breakthrough game-changing technology with the ability to adjust its capacity based on the various inlet specifications, will be required.

Another great challenge related to current geothermal power plants is the need for large facilities to accommodate all of the equipment required, such as steam turbines, electric generators, cooling towers, steam processing equipment, heat exchangers etc. (2). The CAPEX and footprint costs required for these assets is relatively high and ongoing operational management and maintenance afterwards will introduce a large OPEX as well. Additionally, the overall efficiency of any system can be improved by simplifying the overall process, and hence reduce energy losses. This approach and philosophy have been taken in this study in which fewer components will be required to extract enthalpy from the given fluid and effectively convert it to electricity.

3. GARD C-GEN™ TECHNOLOGY

GA R&D Ltd has patented a modular system, GARD C-Gen™, which introduces a new approach to electricity power generation from steam. This technology has the advantage of incorporating in a single unit both electrical power generation and fluid cooling. This approach makes the energy conversion process much more efficient due to its simplicity.

3.1 Steam Turbine System description

Each GARD C-Gen™ system unit is designed to incorporate multiple stages in series within a flow line and with a unique compressible flow for each stage. This unique design was developed to allow adequate fluid compression within tapered stages as part of the operation. This method allows the fluid pressure to remain constant before the fluid enters each next stage. In current systems, when energy is converted at the first stage, there is a pressure drop as a function of energy conversion. The compression on this design for each stage will compensate for the pressure loss, and sustain the pressure magnitude to the next stage. This process will achieve nearly constant system pressure throughout the first two turbine zones and convert higher levels of thermal energy to mechanical energy. All of the stages are considered to be operating at high pressure with a back-pressure factor as a result of compression. Design optimization allows us to mitigate this to a relatively small value by adjusting the design length of the system to the input specifications of the application.

This design allows for the fluid to cool significantly and also condense during instantaneous power generation, with the result of maximizing the conversion of the available thermal energy to mechanical. This approach will therefore reduce the requirements to cool and condense the fluid exiting the turbine, allowing re-injection of the fluid to the original source, whether geothermal reservoir or any waste heat plant application. To achieve all these characteristics with a single design, the following zones are identified and analyzed to define the changes applied on the fluid conditions along the entire length of the turbine system. The following three zones are described below and shown in figure 1 below.

3.1.1 Steam **C**ompression (Zone A) – GARD C-Gen™ blade design to maintain inlet pressure through the turbine stages

This zone embraces the initial stages of steam compression with a low compression rate, to allow cooling of the fluid, while the fluid pressure is sustained at high values. While the mass flow rate will not change along the stages, the flow area will however reduce, and thus the fluid will accelerate and fluid velocity will increase.

3.1.2 Steam **C**ooling (Zone B) – Semi compressing blade design in which water droplets will be introduced

This zone will utilize the energy contained in the high-speed fluid from the previous zone to generate further torque on the rotor, without the need for re-heating the steam fluid between turbine stages. The high velocity flow achieved at the previous zone will be fed through this secondary zone blade design to produce additional torque. Normally fluid will accelerate when the flow area is reduced, however if at the same time there is cooling, less acceleration will occur through this process. When the temperature reduces, the volumetric density of the steam molecules will increase and will result in volumetric reduction. Balancing fluid compression and temperature drop in this zone is critical for the blade design, in order to provide an adequate inlet flow for the next zone.

3.1.3 Steam **C**ondensing (Zone C) – Condensing blade design for low enthalpy values.

This final zone will 'treat' the fluid volume, (%) not-condensed by further compression, in order to fully condense all the steam which has flowed through the turbine unit. This stage is very critical, and very novel in operation by achieving a significant technology milestone on the steam utilization process. Normally, cooling towers are required to accommodate this service, but the GARD C-Gen™ technology has been set to deliver a better solution in this very niche area of the steam power generation technology, rather than focusing only in design optimization of blade design and steam associated control technologies. Instead, a self-controlled environment of a set configuration, with different blade designs, will extract very high values of enthalpy in a single operation, providing a high velocity flow for the injection geothermal wells.

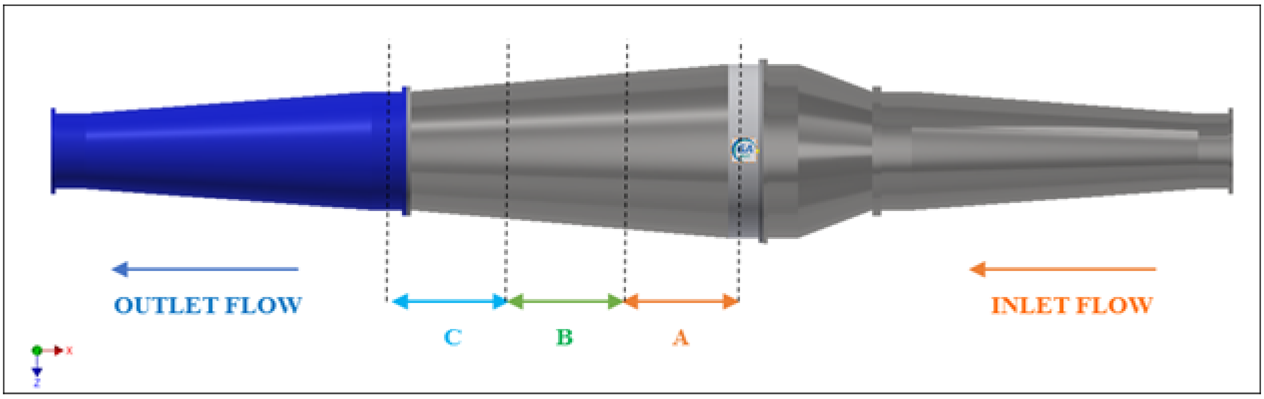

Figure 1: GARD C-Gen™ Module outlay with inlet and outlet sections (3)

3.2 Electrical generator system description

As described on section 3.1, the design of the turbine rotor, as detailed in figure 2 below, is combined with the electrical generator rotor to achieve system simplification and reduction of additional mechanical parts. To maximize electrical output, permanent magnet technology is used for the rotor design, removing the requirement for electrical brushes to be used and the complexity of having a sealed/oil filled environment in order to operate. This approach has led to a design of a magnetic levitated rotary system, which self-aligns with the respective stator by the use of electromagnetic force (emf). The design of the stator has proportional poles to interact with the permanent magnets allocated on the turbine rotor. The torque generated by the turbine rotor is directly converted to electrical power without any mechanical losses due to lack of powertrains or any other components, which differentiates GARD C-Gen™ technology from other traditional steam turbine systems. This design incorporates a common rotor structure for the turbine and the electrical generator.

Initially, a 12-pole permanent magnet generator will be considered for the design of this prototype system, with the capability to operate within a given speed range and accommodate variable baseload output in order to meet the power output demand. This generator design will be tested in a steam testing facility in July 2020, to measure its performance with variable fluid characteristics, such as system input temperature and pressure and then analyze the data obtained to compare and further optimize the CFD analysis of the given design, currently under development.

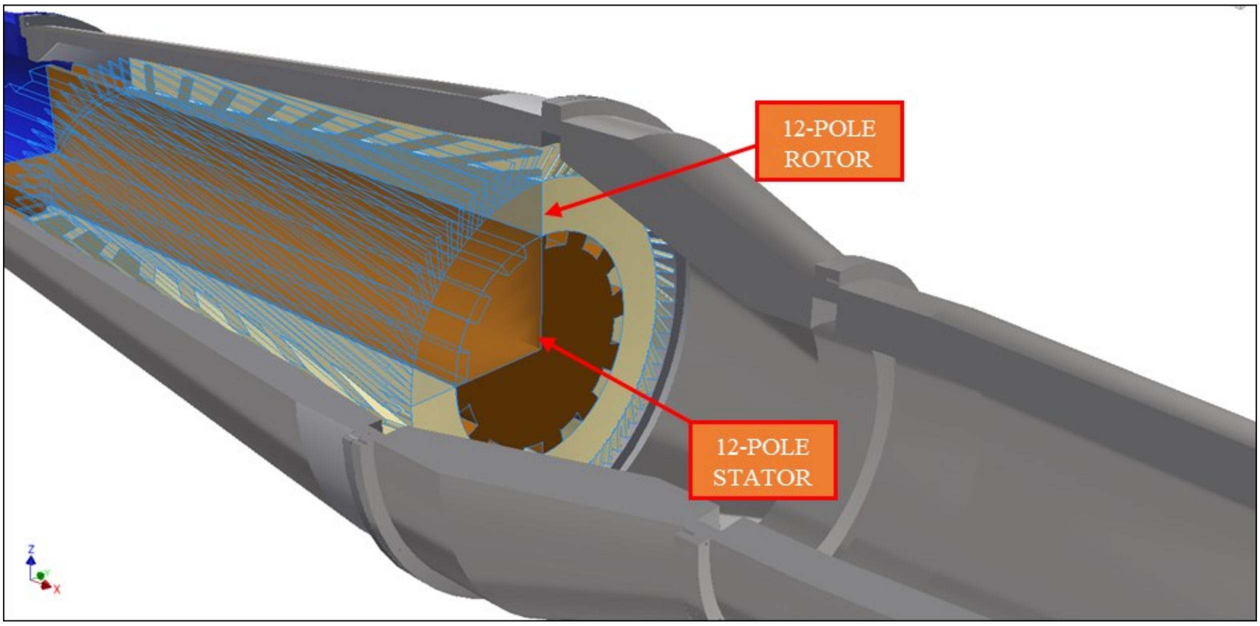

Figure 2: GARD C-Gen™ Module cross section view with turbine rotor and 12-pole electric generator (3)

3.3 Rotary system robustness

The research carried out during this project has enabled us to understand the critical design areas of traditional steam turbine systems, and has also helped us to develop better solutions in which we no longer face those critical challenges in design. The operation of this multi-functional module does not involve vulnerable components with critical failure mode such as mechanical seals, and the mechanical bearings are not operating at critical load capacities. The rotor is positioned inside the housing of the turbine and aligned with the stator, in which it will remain centralized due to the high magnetic forces interacting between the two. This technique will minimize load on retaining bearings, with a positive effect in maximizing lifetime of the mechanical components of the system.

3.3.1 Permanent Magnet Technology

Another challenge for geothermal applications was found to be solids from geothermal sources, entering the turbine and causing wear the mechanical seals. Having removed mechanical seals due to the use of permanent magnets on the rotor, the design will allow some fluid to pass between the stator and the rotor, which will effectively erode the surfaces. The surfaces of the rotor and the stator will be sealed (potted) and coated to control erosion and corrosion from the fluids. This design incorporates a number of operational conditions, such as controlled steam fluid with additives, or downhole fluids with solid particles, forming a three-dimensional fluid which the turbine design will withstand.

3.3.2 Additive Manufacturing Technology

Another area which will suffer from erosion and solids is the turbine rotor blade configuration, which will have to withstand the operating conditions, especially when operating with downhole fluids. GA R&D has designed a low cost, replaceable blade assembly, using additive manufacturing and other advanced forming techniques to produce a low-cost rotor assembly, which will allow frequent service on the turbine generators. This rotor design will be constructed from minimum components and will undergo balancing techniques to achieve a uniform and balanced assembly.

3.4 Downtime vs Maintenance

Most power plant systems are limited in offering alternative output when a major turbine is shut down for maintenance. This approach leads to additional cost from lost production which is effectively an overhead to the plant operator. GARD C-Gen™ technology modules allow maintenance routines to be performed without the requirement for shutting down the plant or major portions of it.

The illustration shown on figure 3, illustrates a configuration of multistage turbine units of the same capacity, installed in a parallel configuration, forming a total of 50 MWe output capacity. Each module can operate efficiently within a range of approximately 80-90% capacity of its maximum capability. This allows the generators to produce power by switching from 10 units at 80% output capacity, to 9 units at 90% output capacity. The inlet flow of the unit undergoing maintenance will be diverted to the other units and increase their output to sustain the baseload.

This methodology will allow sustainability of the baseload provided to the grid at all times. Routine maintenance can prevent failure of each unit and due to the system's modularity, units can be replaced in a very short period of time. All units are designed to be transported, in compliance with DNV rules for lifting in offshore vessels when transported internationally, by land or sea, and designed to plug & play.

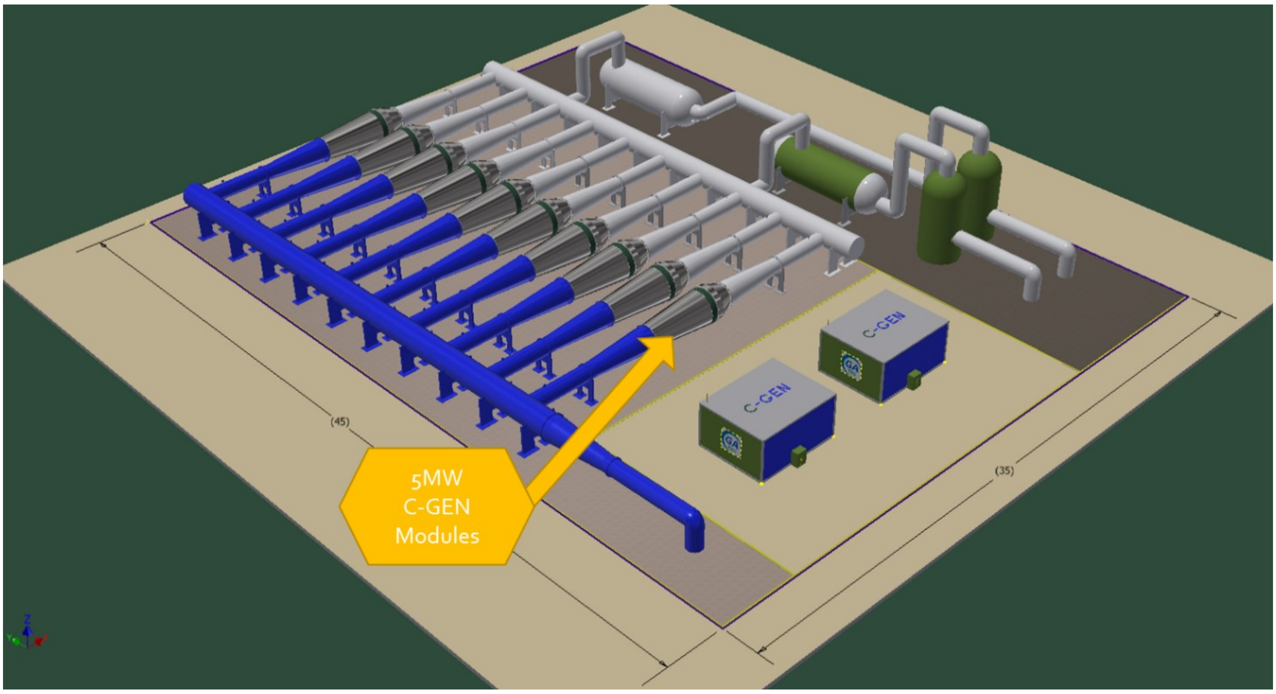

Figure 3: 50 MWe GARD C-Gen™ Power plant with 10 modules in a parallel configuration (3)

4. GLOBAL ECONOMIC BENEFITS

4.1 Global economic issues

As older and less environmentally friendly fossil fuel power generation is being replaced, new clean and sustainable energy solutions are urgently being sought to support growing global demand and to complement the emerging but more weather-dependent green technologies of wind, solar and wave. Securing energy resources and implementing them efficiently within a multi-dimensional network has always been a challenge, and in certain circumstances, implementation of new technologies requires major infrastructure changes.

Waste industrial heat and geothermal are both valuable and environmentally friendly energy sources of sustainable power through steam turbine power generation, but they currently remain largely untapped. Having again listened to the industry, learned of its challenges and understood the issues, GA R&D has developed a design solution which radically addresses the cost, efficiency and emission problems currently presented by existing steam turbine technology.

As illustrated in figure 4 below, between 2017 and 2018, electricity demand rose faster than overall global energy demand growth, in which 47% of the electricity is produced by Steam Turbine technology (4). Renewable technologies have shown the fastest growth with an increase of 449 TWh. Further on, the increased electricity demand has also caused an increase in electricity generated by coal and gas power stations to meet the demand. However, the oil power stations have shown a small drop with no much change and also being the only technology that did not respond to the increased demand.

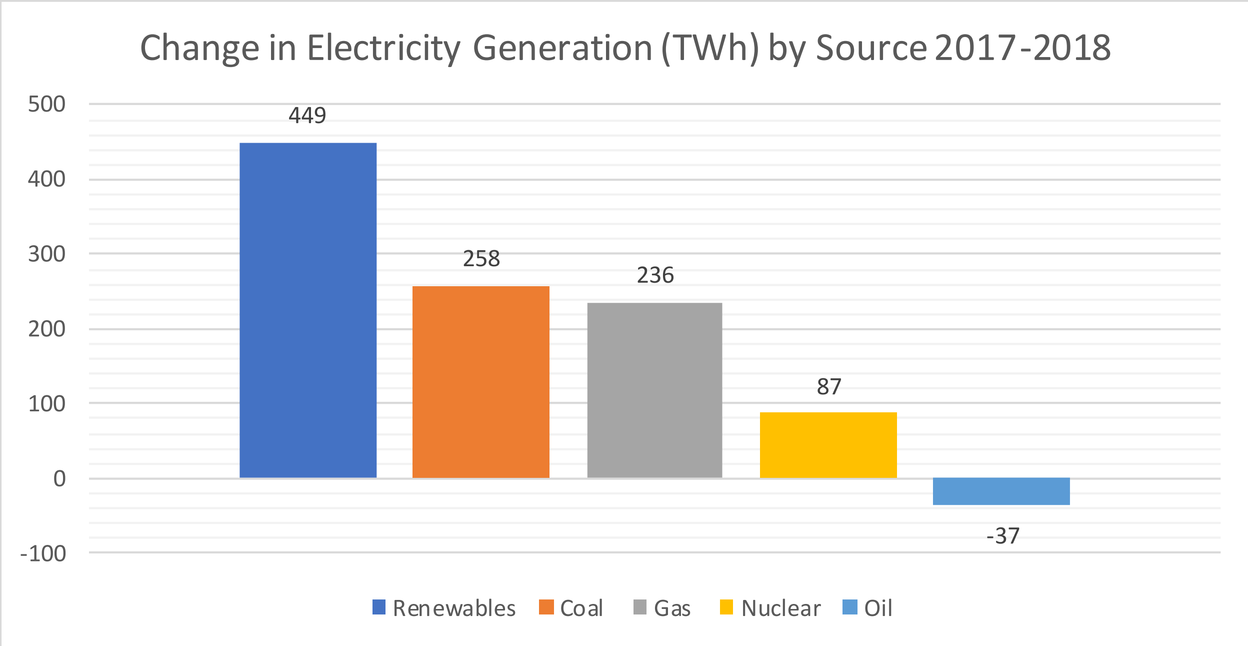

Figure 4: Change in electricity generation between 2017 and 2018 (4)

Figure 5, illustrates the overall electricity generation mix for 2018, in which it is noticeable that only the coal and nuclear power stations account to nearly half the power generated (48%), and both are mainly using steam turbine technology. It is therefore concluded that a more efficient steam turbine could address the need for continuous scale up within the power generation infrastructure globally, just by improving efficiency. Other applications for steam turbines which the C-Gen™ could be used for are gas, oil, and solar systems.

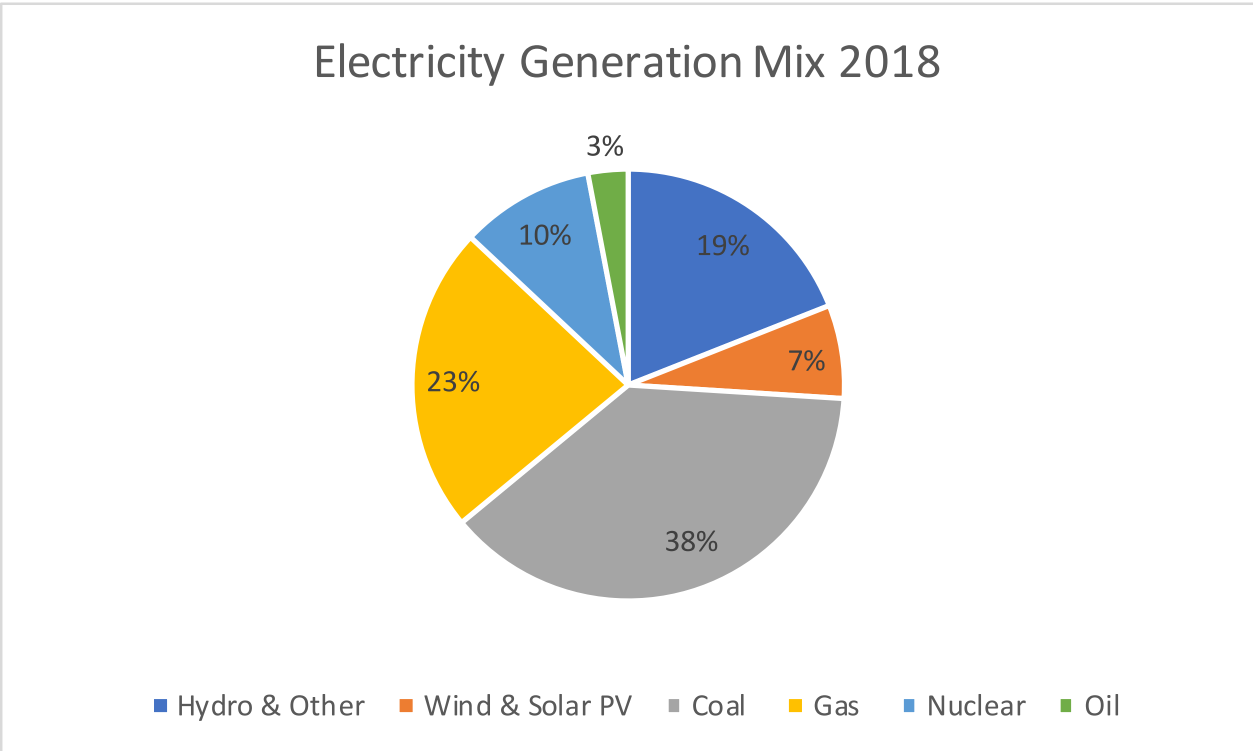

Figure 5: Electricity generation mix 2018 (4)

4.2 GARD C-Gen™ benefits

GARD C-Gen™ technology can be described as a sustainable energy technology with focus to tackle environmental emissions when implemented with current power generation technologies, including geothermal power generation plants. This technology can be implemented in a worldwide scale to deliver a less costly energy unit to the consumers by mitigating environmental emissions at the same time.

This fully patented highly novel modular steam turbine power generation design – GARD C-Gen™ cuts capital infrastructure and operational costs by more than half by removing the need for large cooling towers and eliminating the need for shutdowns. Designed to capture heat from industrial waste heat and geothermal, this compact modular design can be optimized to produce electricity locally, thus cutting down on the high loss normally suffered through lengthy distribution networks, where other renewables are dependent on location to maximize performance.

4.2.1 Less CAPEX to develop the power plants

Using direct downhole fluid is anticipated to reduce some of the complexity in the steam generation process, and introduce challenges on the robustness and reliability of some of the control and monitoring equipment. However, the proposed design can operate with different inlet fluids, such as steam with additives, providing sufficient temperature and pressure to operate the turbine with less energy resources.

The major reduction in CAPEX is s due to the fact that the steam passing through the turbine will cool sufficiently, hence removing the requirement for major cooling tower infrastructure. Additionally, the skid modular design for each power generation unit does not require to be installed within a building, but can simply be installed in the field, having the ability to directly plug & play when inlet flow is available

4.2.2 Less OPEX to operate the power plants

This approach of eliminating cooling requirements has a large positive impact on the operating cost required while using a GARD C-Gen power plant in comparison with existing plants. Additionally, the landscaping footprint required for installing cooling towers will be reduced.

5. CONCLUSIONS

Working towards meeting environmental legislation targets to reduce greenhouse emissions, whilst introducing greener technologies to replace fossil fuels and dealing with the increasing global energy demand, has been the challenge we have risen to.

Renewable energy technologies have been introduced in recent years to tackle this concern, with the aim of gradually replacing some of the fossil fuel power generation applications, while the European Union has established a multi-dimensional network in which different technologies address these challenges. Asset cost and infrastructure still require simplification to further improve energy production cost.

GARD C-Gen™ technology has the ability to make a substantial contribution towards addressing these challenges having incorporated in its design a number of established and proven technologies in a unique and patent protected configuration. This novel technology design for steam powered electrical generation (from existing power plants, waste steam and increasing geothermal sources) offers an economically viable, affordable and environmentally sustainable energy supply solution for our growing global demand.

Finally, making geothermal energy power plant applications feasible and viable on a global scale will offer a higher level of energy security both for countries in need of less costly energy production, and for countries which have yet to exploit the benefits of their geothermal energy resources.

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