Greenhouse Gas Emissions Reduction: Global Geothermal Catalogue Update 2024

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ABSTRACT

Geothermal power generation typically (but not always) results in greenhouse gas emissions as a result of these gases being naturally present in geothermal fluids. Globally, there is an increasing focus on reducing naturally occurring emissions from geothermal electricity generation to contribute to wider decarbonization goals and efforts. Several countries have already implemented carbon emissions pricing, generally as a carbon-dioxide equivalent (CO_2e) value, or are in the process of considering doing so. Three major factors will increase the focus of operators in reducing emissions: (1) increased direct costs due to carbon pricing, (2) societal pressure from the general public, and (3) investment funds or funding institutions with ESG targets that influence the pricing and availability of funding for both new and existing projects.

This paper provides an updated (to 31 December 2024) catalogue of global geothermal power plants that have meaningful greenhouse gas emissions reduction technologies in place, with details on the methods employed. Additionally geothermal power projects under development with emissions reduction technology, and existing plants undergoing retrofitting of emissions reduction technology are also included in this update.

The authors intend to republish this paper with an updated catalogue regularly, and we encourage feedback from readers to ensure this catalogue is updated accurately.

1. INTRODUCTION

Geothermal power generation is typically a low-emission, reliable and renewable source of electricity that is powered by earth's natural heat. Most geothermal power plants release a small amount (relative to fossil-fuelled power plants) of greenhouse gases – primarily carbon dioxide (CO_2) and methane (CH_4). These gases are not created in the geothermal power generation process. Still, they are contained naturally in the fluid from the geothermal reservoir and are then often released as a part of the power generation process. When pressure is reduced, the fluid from the reservoir boils, and due to Henry's law, these gases preferentially move into the steam phase, with minimal amounts retained within the separated geothermal water (also known as brine). The release of the gases from the power generation process is a result of the gases being non-condensable – such that when geothermal steam is condensed in a plant heat exchanger (typically a condenser in a flash plant and a vaporizer or pre-heater in a binary plant) the non-condensable gases remain as gases. In contrast, the steam is condensed into water. These non-condensable gases can interfere with the power generation process by restricting steam flow due to pressure build-up, so they must be removed from the process, and this typically results in them being released to the atmosphere (via a gas extraction system if the gases are at a pressure below atmospheric) and vented above a cooling tower or air cooled condenser to disperse the gases safely.

Several technologies are in use today to reduce gaseous emissions from geothermal power plants, and several drivers for emissions reduction from these power plants are described in last year's catalogue that was presented at the Geothermal Rising Conference (Richardson & Webbison, 2024).

1.1 Catalogue Details

The catalogue is built by each geothermal field rather than each power plant itself. All efforts have been made to ensure its accuracy, but we as authors welcome feedback, corrections or additions.

The field is listed as either Full or Partial for greenhouse gas emissions. This is at the field level, so if there are individual power plants that have full emissions reduction technology operating and other power plants that do not, then these are listed as Partial.

The technologies used for emissions reductions have been reviewed and after this we have identified that there are three ways for these to be categorized:

1. NCG Reinjection
2. Pumped Binary
3. Gas purification and reuse

The power plant technologies are categorized by the generation type, this being either Flash or Binary. The power plant technology that is listed is only the plant types that are actively reducing greenhouse gas emissions. An example to show is the Tauhara field in New Zealand, whereby the binary plant is undertaking full NCG reinjection, however the flash plant that has been recently commissioned is not currently employing greenhouse gas emissions reduction technology. Therefore the emissions at a field level are now Partial, and the Plant Type is Binary.

1.2 Rules for Introduction to Catalogue

This table is published with ownership and generation details as of 1 January 2025. This table excludes: temporary trials such as Umurlu, (Yucetas et al., 2018); plants that have

ceased greenhouse gas abatement processes (e.g. Coso); plants smaller than 5 MWe net in size; plants that are bottoming units or brine-only units; and, facilities that utilize geothermal CO_2 but do not generate electrical power (eg Haedarendi). This table is focused on greenhouse gas emissions abatement; for general emissions abatement from geothermal power plants Lenzi et al. (2021) provides a comprehensive overview.

2. DISCUSSION

Last year's catalogue (Richardson and Webbison, 2024) went into detail on each technology type and examples of each. This year's paper will not do so and will instead focus on highlighting key elements of the data from the catalogue.

2.1 Data

For the fields included in this catalogue, we see that there are 39 geothermal fields globally that are either fully or partially reducing greenhouse gas emissions. The breakdown of these are shown in Figure 1.

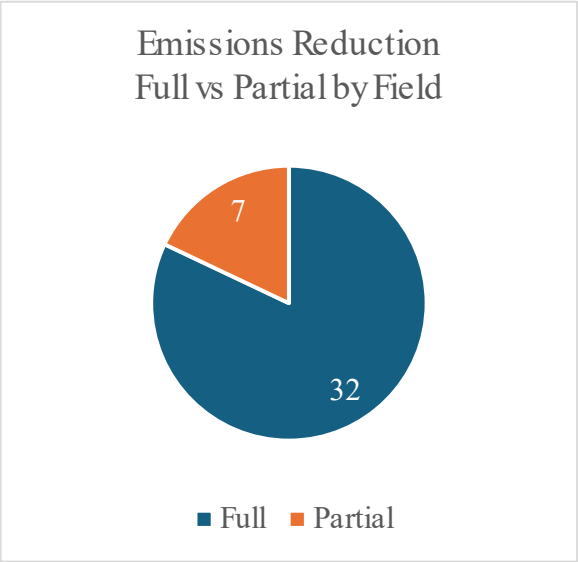

Figure 1: A comparison for 2024 of the number of geothermal fields with either Full emissions reduction or Partial

Figure 2 and Figure 3 show the breakdown of the catalogue by country. The United States of America significantly dominates the catalogue, primarily due to the significant number of lower temperature geothermal resources that have been developed with Pumped Binary as a technology approach due to the nature of the geothermal fields. As a result these plants are zero-emission when it comes to greenhouse gas emissions as a by-product of the application of the pumped binary technology.

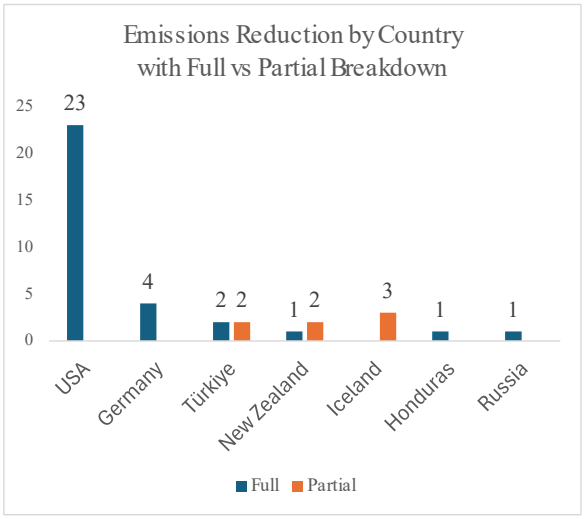

Figure 2: A comparison for 2024 of the number of geothermal fields with either Full emissions reduction or Partial by Country

Out of the 39 geothermal fields that have either partial or full emissions reduction in place, Ormat Technologies owns and operates 19 of these and all 19 are full emissions reduction. Cyrq and Stadtwerke München both have three facilities each.

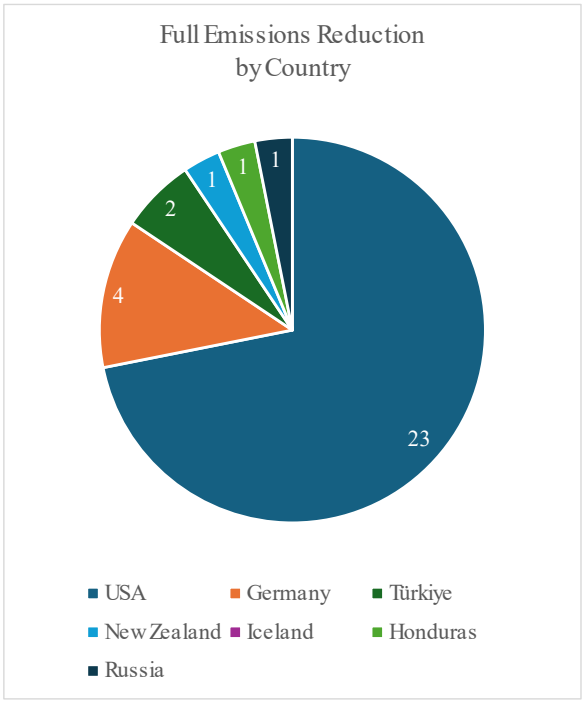

Figure 3: A comparison for 2024 of the number of geothermal fields with Full emissions reduction by Country

For the fields that have full emissions reduction, a breakdown of the power plant technology is shown in Figure 4. We see that Binary is dominant for full emissions reduction and this is seen with new additions to the catalogue.

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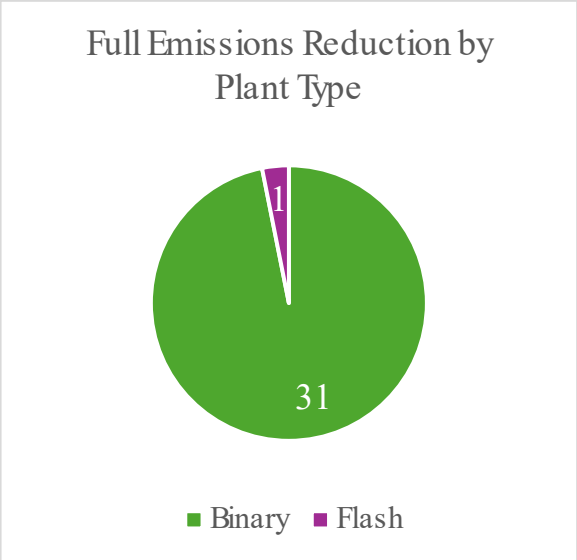

Figure 4: A comparison for 2024 of the fields with Full emissions reduction by power plant technology

In 2024 the only new facility added to the catalogue was the Beowawe project, located in Nevada USA. This project was a repower of an older facility, where pumps were added to the production wells that used to flow artesian, and an air-cooled binary was added (Wiggins et al., 2025).

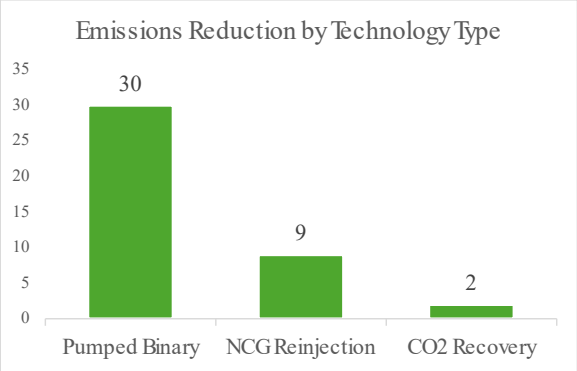

Figure 5: A comparison for 2024 of the Emissions Reduction (either Full or Partial) by Technology Type used. Please note that two fields use both Pumped Binary and NCG Reinjection.

Figure 5 breaks down the emissions reduction technology type utilized. Two fields globally make use of both Pumped Binary as well as NCG Reinjection, therefore the total count is 41 compared to the total number of fields as shown in Figure 1 being 39. We see that pumped binary dominates the technology utilized with NCG Reinjection coming in second. NCG Reinjection has historically been done on projects that often have environmental limits for hydrogen sulfide emissions, however in New Zealand with an emissions trading scheme for greenhouse gases (a price on carbon dioxide emissions) there has been a pick-up in recent years on the number of fields that are actively reducing their greenhouse gas emissions through NCG Reinjection.

2.2 Key updates and announcements for 2024

In New Zealand a number of binary plants are currently under construction. These plants are on high-temperature resources with 2-phase artesian well flow, but will enable NCG reinjection. On the Tauhara field there is Te Huka 3, which was undertaking NCG reinjection in 2024 during commissioning, however plant commissioning had not been completed as of January 1, 2025, so it is not listed in this year's catalogue. On the Nga Tamariki field Unit 5 is under construction, which is also planned for NCG reinjection, while NCG reinjection commenced on Unit 3 (in addition to Unit 4 reported in last year's catalogue). On the Kawerau field TOPP2 is currently under construction with NCG reinjection being specified for the plant. In late 2024 Contact Energy announced the commencement of the Te Mihi 2A project on the Wairakei field, with NCG reinjection being specified for the two binary units.

In the United States of America there have been continued announcements by Fervo about development of enhanced geothermal systems (EGS), with the first units due to come online in 2026 at Cape Station in Utah. EGS units such as the type from Fervo are expected to be zero greenhouse gas emissions facilities. The current catalogue is based on geothermal fields, so further refinement to the catalogue will be required when EGS projects come online.

Table 1: Details of facilities with Greenhouse gas emissions reduction practices in place as of 1 January 2025

Country	Field	Operator	MW	Emissions Reduction	Plant Type	Emissions Reduction Technology	Comments and References
USA	San Emidio	Ormat	39	Full	Binary	Pumped Binary	Includes San Emidio and North Valley plants
USA	Don A. Campbell	Ormat	28	Full	Binary	Pumped Binary	DAC1,2
USA	McGinness Hills	Ormat	146	Full	Binary	Pumped Binary	MGH1,2,3
USA	Steamboat	Ormat	79	Full	Binary	Pumped Binary and NCG Reinjection	Pumped Binary: Galena 1,3, Steamboat 2/3 and Steamboat Hills Repower Pumped binary and NCG Reinjection: Galena 2 has artesian well 24-5 as well as pumped wells
USA	Jersey Valley	Ormat	8	Full	Binary	Pumped Binary	
USA	Tuscarora	Ormat	17	Full	Binary	Pumped Binary	
USA	Tungsten	Ormat	41	Full	Binary	Pumped Binary	
USA	Raft River	Ormat	12	Full	Binary	Pumped Binary	
USA	Neal Hot Springs	Ormat	22	Full	Binary	Pumped Binary	
USA	Heber	Ormat	91	Full	Binary	Pumped Binary	Heber 1,2,South
USA	Ormesa	Ormat	36	Full	Binary	Pumped Binary	Field formerly known as East Mesa, consists of three separate plants: Ormesa 1,2,3
USA	Mammoth	Ormat	65	Full	Binary	Pumped Binary	G1,2,3, CD4
USA	Puna	Ormat	38	Full	Binary	NCG Reinjection	Conducted to prevent H_2S ambient discharge, Richard (1990)
USA	Stillwater	Ormat	12	Full	Binary	Pumped Binary	Acquired by Ormat in January 2024 - has some artesian wells but kept under pressure
USA	Salt Wells	Ormat	9	Full	Binary	Pumped Binary	Acquired by Ormat in January 2024
USA	Cove Fort	Ormat	18	Full	Binary	Pumped Binary	Acquired by Ormat in January 2024
USA	Beowawe	Ormat	20	Full	Binary	Pumped Binary	Repower project came online in Q2 2024 with a pumped binary setup, Wiggins et al. (2025)
USA	Blue Mountain	Ormat	20	Full	Binary	Pumped Binary	Acquired by Ormat in June 2025 with a declared capacity of 20 MW, Ormat (2025)
USA	Thermo	Cyrq	14.5	Full	Binary	Pumped Binary	
USA	Soda Lake	Cyrq	26.5	Full	Binary	Pumped Binary	
USA	Patua	Cyrq	48	Full	Binary	Pumped Binary	
USA	Lightning Dock	Zanskar	15.3	Full	Binary	Pumped Binary	Acquired by Zanskar in July 2024
USA	Star Peak	Open Mountain Energy	14	Full	Binary	Pumped Binary	

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Country	Field	Operator	MW	Emissions Reduction	Plant Type	Emissions Reduction Technology	Comments and References
Russia	Mutnovsky	Geotherm JSC (PJSC RusHydro)	12	Full	Flash	NCG Reinjection	Povarov and Nikolskiy (2005)
New Zealand	Tauhara	Contact Energy	199	Partial	Binary	NCG Reinjection	Te Huka 1(units 1&2) plant commenced NCG reinjection in November 2022, Richardson et al. (2023), Ruiz et al. (2021). Te Huka 1 is a 2 unit binary cycle power plant. Tauhara project came online in November 2024 at 174 MW. Tauhara is a triple-flash dual-steam turbine on a single shaft with a direct-contact condenser. Te Huka 3 plant has implemented NCG Reinjection and has commenced operation in 2025 at 51.4 MW. Te Huka 3 is a binary cycle power plant.
New Zealand	Nga Tamariki	Mercury	86	Partial	Binary	NCG Reinjection	NCG Reinjection commenced on one (OEC4) of four units, Ghafar et al. (2022). In 2024 an additional unit was commenced (OEC3). Declared MW of facility increased from 82/83 MW to 86 MW. An additional unit, OEC5, is under development and will add 48 MW to the facility.
New Zealand	Ngawha	Ngawha Generation (Top Energy)	57.5	Full	Binary	NCG Reinjection	NCG Reinjection commenced August 2022, Hanik (2024)
Iceland	Hellisheidi	ON Power (Reykjavik Energy)	303	Partial	Flash	NCG Reinjection	Carbfix, Gunnarsson et al. (2015), Juliusson et al. (2015)
Iceland	Nesjavellir	ON Power (Reykjavik Energy)	120	Partial	Flash	NCG Reinjection	Pilot plant, Carbfix (2024)
Iceland	Svartsengi	HS Orka	76	Partial	Flash	Gas purification and reuse: CO_2 Recovery	Methanol Production, Ragnarsson et al. (2023)
Türkiye	Babadere	MTN Energy	8	Full	Binary	Pumped Binary	
Türkiye	Kizildere	Zorlu	260	Partial	Flash	Gas purification and reuse: CO_2 Recovery	CO_2 utilized for commercial and industrial use, Simsek (2003), Layman (2017)
Türkiye	Salavatli	MEGE	18	Partial	Binary	Pumped Binary and NCG Reinjection	Asnük (2024)
Türkiye	Bukarkent	Limgaz	14	Full	Binary	Pumped Binary	Mertoglu and Basarir (2018)
Honduras	Platanares	Ormat	30	Full	Binary	Pumped Binary	
Germany	Dürrnhaar	Stadtwerke München	5.5	Full	Binary	Pumped Binary	
Germany	Kirchstockach	Stadtwerke München	5.5	Full	Binary	Pumped Binary	
Germany	Sauerlach	Stadtwerke München	5	Full	Binary	Pumped Binary	Bonafin (2021)
Germany	Traunreut	Equitix	5.5	Full	Binary	Pumped Binary	

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3. CONCLUSION

For the 2024 catalogue we conclude the following:

- There are relatively minor changes from the 2023 catalogue;
- The United States of America has a number of lower temperature geothermal fields in operation, and these make use of pumped binary as a function of the lower temperatures. As a result, there are a large number of zero greenhouse gas emissions fields;
- New Zealand activity is driven by a carbon price and is resulting in increasing use of NCG reinjection through time, with both retrofitted modifications and new plants being specified with NCG reinjection. If other markets introduce carbon pricing that is material, we would expect the same trends to occur;
- NCG reinjection is generally not occurring on fields that have formed large steam-caps;
- Carbon dioxide reuse from geothermal remains limited in use compared to the resource available, which is likely due to technology and cost issues;
- Binary plants remain the most common type of geothermal plant with reduced or zero greenhouse gas emissions technology by a significant margin;
- A number of announcements were made about enhanced geothermal systems in the year and these are expected to be zero greenhouse gas emission facilities. Future catalogues will need to factor in this different type of geothermal resource, with this expected to commence in 2026 with the commencement of operation of Fervo's Cape Station facility in Utah, USA;
- There is increasing interest in geothermal greenhouse gas emissions reductions from a number of countries and we expect to see further advancements in the years ahead.

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