2022 Annual Aotearoa New Zealand Geothermal Review

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ABSTRACT

During 2022 geothermal electricity generation increased by 1% to a new record of 8,060 GWh. This output supplied 18.5% of New Zealand's electricity. Due to the impact on hydro generation from favourable hydrologic conditions, total renewable generation increased to 87% of national electricity supply.

Net installed geothermal capacity remained steady at 1033 MWe for 20 stations on 8 fields. Over the next five years, geothermal electricity generation will likely increase by 24% to over 10 TWh per annum with the addition of new plants: Tauhara II (174 MWe) , Te Huka 2 (50 MWe) and Nga Tamariki (37 MWe).

The industry's weighted average CO_2e emissions rate remained steady at 63 tonnes of CO_2e per MWh. In response to global imperatives to decarbonise and steadily increasing carbon prices (peak of NZ $88.5/tonne in November 2022), power producers progressed pilot schemes for reinjecting CO_2, CH_4, and other non-condensable-gasses. These schemes at Nga Tamariki, Ngawha, and Te Huka power stations are able to reinject between 25% to 100% of emissions.

Although developers did not commission new high-temperature, direct-use facilities during the year, projects to increase heat use by (13 GWh) are in execution phase with commissioning expected in late 2023.

Operators drilled six deep conventional wells and five shallow wells during the year.

NZ Universities continued to support the industry. Enrolments at the NZ Geothermal Institute look set to bounce back from the COVID low of six in 2021.

1. INTRODUCTION

Our fourth annual New Zealand geothermal industry update aims to provide transparent summaries of geothermal activities during the 2022 calendar year. Key themes for the year include:

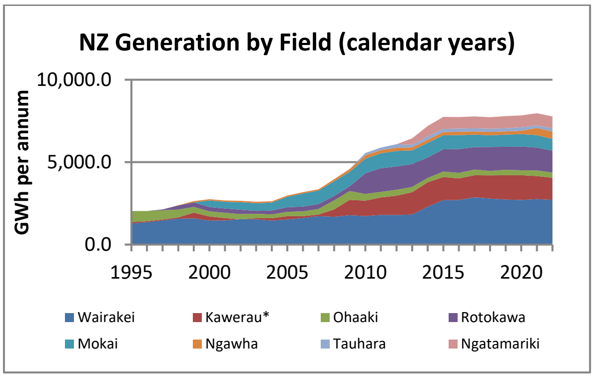
- Geothermal generation remained steady at around 8 TWh (increased 1.2%) and contributed 18.5% to national generation;
- NZ carbon emissions from electricity generation fell almost 30% during 2022 due to weather related increases in hydro generation, stable geothermal production, and additional wind capacity.
- Geothermal carbon emissions per kWh continue to fall with 100% NGC injection now taking place at some binary cycle power stations.
- Drilling and completions, testing, and workover activity continue at sustainable levels; and
- Producers are currently constructing 224 MWe of new geothermal capacity. Another 152 MWe are in development. Geothermal output looks to increase by 2 TWh before 2030.

We wish to acknowledge the efforts of plant and construction staff during 2022 who endured difficult weather conditions.

2. ENERGY SUPPLY

2.1 Electricity Generation

In 2022, geothermal electrical generation increased 1.2% to 8,060 GWh from 7,968 GWh in 2021.[1] Production was broadly consistent among all fields (Figure 2.1), with Kawerau and Ngawha up slightly.



[1] MBIE has revised the geothermal generation statistics upward by 2% to 3% over the last 10 years.

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Figure 2.1: Geothermal Power Generation in GWh by Field (Sources: New Zealand Electricity Authority, MBIE, company operating reports)

2.2 Contribution to New Zealand Power Supply

Geothermal comprised 18.5% of the nation's total power generation in 2022, on par with 2021 and steady since 2015 (Figure 2.2). Renewable generation surged to 87% of total generation due to favourable hydrological conditions and small increases in wind and solar generation.

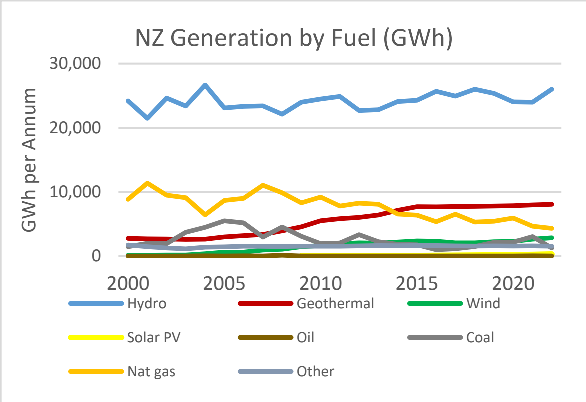

Figure 2.2: Annual New Zealand Power Generation by Fuel (Sources: MBIE)

2.3 Generation Capacity Changes

Operators did not commission any new plant during 2022. However, construction on the 174 MWe Tauhara 2 and the 50 MWe Te Huka 3 projects continued. Tauhara 2 is scheduled for commissioning in 2023 (Table 2.1) with up to 376 MWe of new capacity possibly coming online before 2030.

Table 2.1 Capacity under construction and delevoment

Project	Developer	Status	Capacity (MWe)	COD
Tauhara 2	Contact Energy Ltd.	Con	174 CST-TF	2023
Te Huka 2	Contact Energy Ltd.	Con	50 ORC	2024
Nga Tamariki 3	Mercury NZ Ltd.	Dev	37 ORC	2026?
TOPP2	Eastland Generation Ltd.	Dev	49 ORC	2026?
OEC5	Ngawha Generation Ltd.	Dev	30 ORC	2027?
Taheke	Eastland Generation	Dev	35 MWe ORC	2028?

2.4 Direct Use

According to MBIE's available statistics, direct use and losses have fallen 7% to 7.4 PJs from 2019 due to production suppression during Covid and the closure of paper/forestry capacity at Kawerau. Direct use will likely rejuvenate as new projects at Kawerau (Essity) and Tauhara (Tnue and the He Ahi Eco Business Park) Geo40) come online and wood pellet supply (Natures Flame) to the dairy industry ramps up in 2023.

3. CARBON EMISSIONS AND DISPLACEMENT

3.1 Annual Discharges and Trends

Table 3.1 shows the carbon emissions for calendar year 2022 for the geothermal power stations in New Zealand. CO_2-equivalent (CO_2e) values are calculated as a combination of CO_2 and methane (CH_4), using a multiplier of 25 for the methane as specified in the NZ ETS regulations (McLean and Richardson, 2019). Table 3.1 contains raw data - the total tonnes of steam, emissions factor (fraction of CO_2e in steam) and net generation for each power station, from the power station operators. Table 3.1 also contains calculated values – total tonnes of CO_2e, emissions rate in tonnes CO_2e per day, and then the operational and lifecycle emissions intensity in gCO_2/kWh (net), calculated as described in Mclean et al., 2021.

Operational emissions are those emitted directly from the power station during its daily operation. The lifecycle emissions account for emissions associated with materials manufacture and construction, maintenance, and decommissioning, as well as operational emissions. Lifecycle emissions for geothermal can be estimated by adding 10 gCO_2e/kWh to operational emissions (Fridriksson et al., 2017).

Table 3.1 Geothermal CO_2e emissions data for CY 2022

Station	Total Steam	Emissions Factor	Net Generation	Total CO_2e	Emissions Rate	Operational Emissions Intensity	Lifecycle Emissions Intensity
	Tonnes	t CO_2e/ t steam	GWh	Tonnes	t CO_2e/ day	gCO_2e/ kWh(net)	gCO_2e/ kWh(net)
Wairakei	8,575,775	0.0022	1013.1	18,867	52	19	29

Te Mihi	11,502,092	0.0044	1384.1	50,609	139	37	47
Poihipi	2,487,258	0.0049	317.1	12,188	33	38	48
Ohaaki	2,686,088	0.0333	317.2	89,447	245	282	292
Te Huka	1,331,899	0.0073	199.4	9,723	27	49	59
Rotokawa	1,161,833	0.0119	244	13,826	38	57	67
Nga Awa Purua	7,121,629	0.00871	1114	62,029	170	56	66
Mokai	4,716,085	0.00418	778	19,713	54	25	35
Ngatamariki	4,071,925	0.00728	735	29,644	81	40	50
Kawerau	6,679,817	0.0169	896	112,889	309	126	136
TOPP1	912,708	0.0102	126	9,310	25	74	84
TAOM	1,088,322	0.0106	194	11,536	32	60	70
GDL	304,734	0.0119	68	3,626	10	53	63
Ngawha OEC1-3[2]	697,890	0.0442	191	30,847	84	162	172
					MEDIAN	54	64
					25th PERCENTILE	39	49
					75th PERCENTILE	70	80
					MW WEIGHTED AV	63	73

The MW-weighted average emissions intensity is arguably the best indication of overall emissions for the geothermal industry, as it accounts for the size of the plant (using the net generation column as weights). This value is 63 gCO_2e/kWh (operational), and 73 gCO_2e/kWh (lifecycle). This is negligibly different to 64 gCO_2e/kWh(net) from the previous year. The exponential decline curve fit to this data for the past 8 years reveals a decline rate of 5.6 %/year (Figure 3.1).

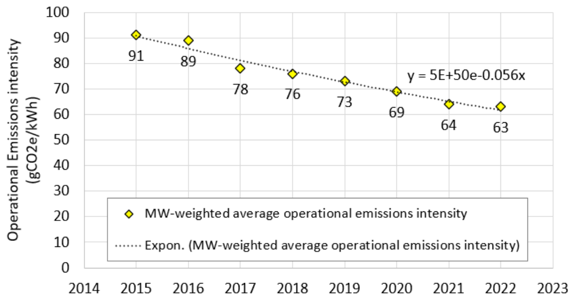

Figure 3.1: Exponential decline of MW-weighted average operational emissions intensity for 7 years from 2015 to 2022

Different energy sources are usually compared on the basis of the median rather than the weighted average. The median lifecycle emissions intensity value for New Zealand geothermal is 64 gCO_2e/kWh. Note this is different to the MW-weighted average lifecycle emissions intensity of 73 gCO_2e/kWh, a statistically different way of treating the dataset in Table 3.1. A comparison to other energy types used in Aotearoa is shown in Table 3.2 (McLean and Richardson, 2021):

Table 3.2: Comparison of lifecycle emissions intensity for different energy types.

Category	Energy type	Lifecycle emissions intensity gCO2/kWh (net)	Comments
Fossil fuels	Coal	980	Dominated by operational emissions.
	Natural gas – OCGT	670	Dominated by operational emissions.
	Natural gas – CCGT	450	Dominated by operational emissions.
Renewables	Wind	11	No operational emissions.

2 Top Energy reports that the results from OEC4 have not yet stabilised

	Hydro	19	No operational emissions.
	Solar – concentrating	28	No operational emissions.
	Solar - photovoltaics	44	No operational emissions.
	Geothermal – NZ 2022	64	Operational emissions outweigh other lifecycle emissions.

Fossil fuels have median lifecycle emissions intensities an order of magnitude higher (McLean and Richardson, 2021):

- 450 gCO_2e/kWh for natural gas combined cycle plants, and
- 980 gCO_2e/kWh for pulverised coal fired power plants.

3.2 Reducing CO_2 Emissions through Reinjection

It would be difficult to overestimate the importance of emerging geothermal sequestration technology in New Zealand. By steadily supressing carbon emissions, the geothermal industry is significantly increasing its value to the country in uniquely providing environmentally friendly, reliable, and affordable electricity. This may attract more international funding currently shy of geothermal investing due to carbon emissions.

The owners and operators of geothermal power stations in NZ have formed an Emissions Working Group, facilitated by the New Zealand Geothermal Association. This includes Mercury NZ Ltd, Contact Energy Ltd, Ngawha Generation, Eastland Generation, Tauhara North No.2 Trust and Ngati Tuwharetoa Geothermal Assets. These organisations represent 96% of geothermal power generation in NZ.

All group members have committed to trials to reduce emissions from their power stations. This is either by reinjecting the non-condensable gases (NCG - which includes CO_2, CH_4, and H_2S) back into the reservoir where they came from, rather than being released to the atmosphere[3], or through capture and utilisation of some of the gases for industrial or commercial purposes.

The first trials of CO_2 reinjection have been at binary power stations as the technical challenges are less for this plant type; however, the industry aims to include steam-flash power stations, which comprise the majority of geothermal emissions. Flash-type power stations usually have direct-contact condensers, which introduce oxygen into the NCG stream and therefore greatly increase corrosion risk. Flash-type plants also require compressors to increase NCG pressure from sub-atmospheric (when exiting condensers) to the pressure of the fluid in the reinjection line.

In binary power stations a fraction of the NCG which enters the power station in the separated geothermal fluid is never emitted to atmosphere – it exits the station dissolved in fluid and is reinjected under normal default operational conditions – a process called "passive reinjection". "Active reinjection" refers to modifications to power stations in order to increase and control the amount of NCG reinjection. All discussions of CO_2 reinjection trials/projects in NZ refer to active reinjection. To date, the industry has made significant progress.

Ngawha Generation has created the first zero-carbon geothermal power station in New Zealand, with 100% CO_2 reinjection at Station 1 (OEC1 and OEC2) since August 2022. This was followed by Station 2 (OEC3) with 100% CO_2 reinjection since January 2023. Station 3 (OEC4) has been at 70% reinjection since April 2023 and will transition to 100% later in 2023. This will make the entire Ngawha geothermal fleet zero-carbon, and any future plants will also be built with CO_2 reinjection.

The second zero-carbon geothermal power station in New Zealand is Contact Energy's 24 MWe (net) Te Huka power station, with 100% reinjection from the two OEC units since November 2022. A 50 MWe expansion of Te Huka power station is currently under construction and is being built for 100% CO_2 reinjection. Contact is now working on CO_2 reinjection at Poihipi power station, which would be the first steam-flash geothermal power station with reinjection in NZ. The shell and tube condenser type at Poihipi is more amenable to CO_2 reinjection than direct-contact condensors due to the lower oxygen concentration.

Mercury NZ conducted the first CO_2 reinjection pilot project in New Zealand (October 2021) at the 86 MWe (net) Nga Tamariki binary power plant. At Nga Tamariki 15% of the NCG which comes out of the reservoir via the wells is returned there by passive reinjection. Of the remaining 85%, which used to go to the atmosphere via four OEC units, one quarter (emissions from one unit) are actively reinjected into the northern reinjection wells. Mercury NZ has secured consents to expand Nga Tamariki (OEC5) and work is underway to expand active CO_2 reinjection at this plant.

Eastland Generation operates several binary power stations on the Kawerau geothermal field. A new binary power station, TOPP2, will be built with CO_2 reinjection. TOPP1 and Te Ahi O Maui power stations (24 and 26 MWe net) will transition to trials of CO_2 reinjection during the next 12-18 months, followed by the smaller GDL plant (8 MWe net).

To date, none of the operating companies have observed any negative impacts on plant performance or reinjection well performance resulting from CO_2 reinjection projects in NZ.

The regulatory framework for reporting CO_2 injection remains a work-in-progress and so national carbon emission

[3] More information on CO_2 reinjection can be found here in a two-page description from the NZGA: https://www.geothermalnextgeneration.com/knowledge/geothermal-co2-reinjection and here in an animation created by GNS Science in collaboration with the NZGA: https://www.youtube.com/watch?v=B-5s2LxnejQ

statistics may not fully account for actual reductions in emissions for facilities using injection.

As a country, New Zealand contrinues to reduce its energy carbon emissions. Since the high water mark of 5.2 million tonnes CO_2e in 2020, carbon emissions from electricity generation have fallen 38% to 3.2 million tonnes. New wind, solar, and geothermal projects in construction will add another 2.7 TWh to displace thermal generation in the coming years offering potential to reduce current electriicy emissions by 35%.

4. DRILLING AND COMPLETIONS ACTIVITY

4.1 Wells Drilled

To support new and existing capacity, field operators drilled five deep and five shallow wells in 2022 (Table 4.1). Deep activity was split between Kawerau and Tauhara Fields. MB Century drilled all six wells.

Table: 4.1 Calendar 2022 drilling statistics

Field	Deep				Shallow			Total
	APR	PRD	INJ	OBS	PRD	INJ	OBS	
Ngawha								0
Rotorua					1			1
Tauranga					3	1		4
Taheke								
Kawerau		2						2
Rotokawa								0
Mokai								0
Ngatamariki								0
Wairakei								0
Ohaaki								0
Tauhara		1	2					3
Totals	0	3	2	0	4	1	0	11

Sources: press reports, Environment Waikato, BOP Regional Council

4.2 Drilling Trends

Drilling activity has been steady but not spectacular after 2015 (Figure 4.1) to support new developments at Ngawha and Tauhara. Most of the current drilling focuses on Tauhara and Kawerau Fields.

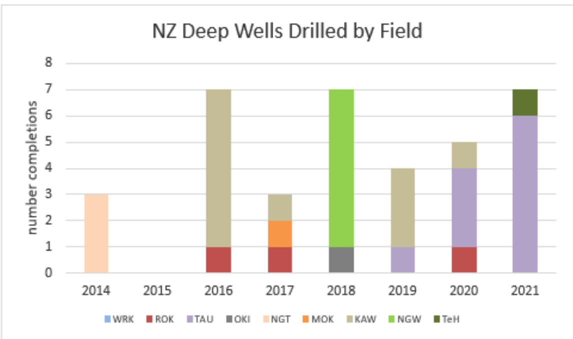

Figure 4.1: Recent Deep Drilling Activity (Sources: press reports, company annual reports)

Annual drilling will likely increase to firm up supply and injection capacity for developments TOPP2, OEC5, and Taheke. In addition, Mercury NZ has commenced a multi-year, make up drilling programme using Iceland Drilling's Tyr rig.

5. INDUSTRY STRUCTURING

5.1 New Entries

There were no new entries into the geothermal industry during the 2022 calendar year.

5.2 Mergers, Acquisitions, and Devestments

Throughout 2022, there were no significant transactions.

5.3 Regulatory Changes

During 2022 the Government worked towards replacing the current RMA 1991 Act (this governs geothermal permitting) with new legislation, the Natural and Built Environment Bill; to be passed into law by 2024. At the time of writing, the implications for geothermal operations and development are unclear. Case law around the new legislation will be required to fully understand the regulations.

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In addition, the Electricity Authority announced its intention to revise the high voltage transmission pricing (by Transpower, the government owned transmission company). The new pricing re-allocates transmission costs to encourage smaller scale renewable generation investment.

6. SERVICES SECTOR ACTIVITIES

6.1 Software

Visulation and analytical software is an increasingly important contributor to NZ's geothermal services sector.

During 2022, Seequent continued as the world's leading provider of geoscience application software and data management for the geothermal industry. Sales now span 6 continents with new engineering functions to improve field operational performance.

Similarly, Flow State Solutions found success as subscriptions to its popular Volsung suite of reservoir engineering packages rose in 2022. Subscribers have grown from local operators to international operators such as: Ormat, PGPC, PT Supreme, and ON Energy.

Meanwhile, Auckland University released a new version of its Waiwera reservoir simulator, and production-separation-injection optimisation software. These models form key management tools for fields in NZ and internationally.

6.2 Technical Services

2022 was a busy year for the technical services sector in engineering design, drilling & well services, geoscience services, and plant mechanical services. Success is stimulating increased services internationally.

In steamfield design, Worley's and MTL progressed steamfield design at Tauhara 2.

Jacobs continued international engineering design and reservoir management work for clients in Indonesia and Africa (under MFAT's East Africa support programme).

In well services, MB Century, Western Energy, and JRG Energy all completed assignments with international clients in Africa, SE Asia, North America and Central America.

In geoscience, both the University of Auckland and GNS advise clients on reservoir modelling and resource development in Japan and Iceland. Similuarly, NZGAL[4] (GNS) continued supplying world class analytical services to Japan, PNG, Taiwan, Indonesia and the Philippines.

6.3 Research

During the year the University of Canterbury, through the Geothermal Resource Research Group, continued its research into ORC power systems, supplementing geothermal with biomass, CO_2 capture & sequestration, hydrothermal hazards, and epithermal deposits.

GNS Science, through Dr. Cornel de Ronde and Dr. Fabio Caratori, continued their geoscience surveys (bathymetry, gravity, magnetics) of geothermal lakes in the Rotorua area. Through this effort, GNS has released high-resolution bathymetric maps of Rotomahana, Rotoiti, Tarawera with insets showing the other geoscience data.

In addition, de Ronde and colleagues progressed research into seafloor hydrothermal systems related to submarine arc volcanoes along the Kermadec arc and elsewhere. This research is progressively establishing the location and frequency of these systems, some springs expelling 320°C fluids directly on the seafloor.

Geothermal Next Generation research, headed by Dr. Isabelle Chambefort, continued its work in characterising low-temperature systems, extracting energy under supercritical conditions, and direct heat applications. The supercritical research continued groundbreaking investigations into using isotopes to track the movement of geothermal fluids, modelling well performance and the solubility of quartz under supercritical conditions.

6.4 Foreign Aid

During 2022 the Ministry of Foreign Affairs and Trade's (MFAT's) funded geothermal technical support to Indonesia, the Caribbean, the Philippines, and East Africa. In-country training included concept modelling, drilling, completions, steamfield and power plant selection & design, geomodelling, technical assistance, and general capacity building. Remote training was tailored to individual partner needs and included a variety of technical subjects relevant to individual projects.

Through this country-to-country assistance, MFAT helps to keep the New Zealand geothermal sector internationally relevant, visible and aligned with global partners, whilst continuing to build enduring relationships spanning 60 years..

6.5 Education & Training

During 2022, education at the University of Auckland and other institutions continue to recover from the restrictions imposed by COVID-19 pandemic.

Remote learning suddenly became mainstream for all education providers, presenting significant challenges for field-based education programmes like the Post Graduate Certificate in Geothermal Energy Technology (PGCert) course at the Geothermal Institute. In 2021 the PGCert ran the first fully audio-visual recorded field trip, which made it possible for international students to attend the field trip remotely, observe the field measurement techniques and apply the field data to their studies; this continue in 2022. From 2023 we are running in-person classes and field trips for all students.

Figure 6.1 provides the Geothermal course enrolment numbers, showing the impact of the pandemic on student numbers. The number of enrolments has increased in 2022; with the return of some of some internationally funded scholarship students. There is a significant increase in the number of enquiries and applications. In 2023 numbers have increased by >150 % from those of 2022 and are getting close to pre-COVID-19 levels.

Since 2019 most of the students enrolled in the different GEOTHERM papers (Figure 6.1) are enrolled in the 120 or

[4] NZ Geothermal Analytical Laboratory

180 points Master of Energy degrees. Not many students complete the one semester (60 points) PGCertGeothermTech. This was very evident in 2016 when the 180 points master was introduced. Therefore, fewer students do the geothermal project (GEOTHERM 689) to complete the geothermal PGCert.

With the boom in geothermal development, there has been a significant demand for trained graduates with geothermal energy training. The New Zealand geothermal industry also has more staff with higher (Masters and PhD) qualifications than at any time before. This allows these companies to undertake research and development projects in-house. Some companies (e.g. Contact Energy Ltd.) sponsor some of their new staff to attend the geothermal PGCert course.

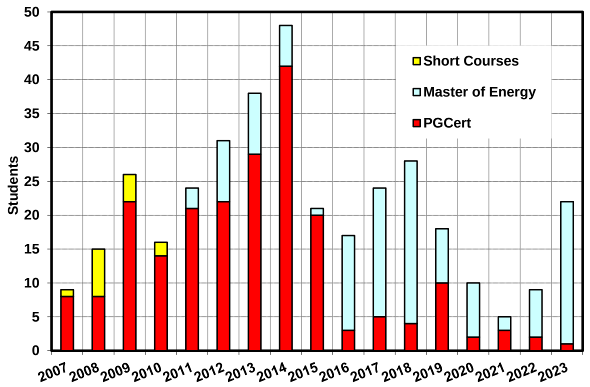

Figure 6.1: PGCert enrolment numbers since the start of the course in 2007

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Sources, Abbreviations and Acronyms

Statistical Sources:

Electricity Authority Wholesale Market Files (on-line); MBIE Electricity Statistical File; contributions by Contact Energy, Ngati Tuwharetoa Geothermal Assets, Top Energy, Mercury Energy, Tuaropaki Power, and Eastland Energy.

Wells:
PDR production well; **APR** appraisal well; **INJ** injection well; **OBS** observation/monitoring well

Prime Movers:
CST condensing steam turbine**; 1F** single flash**; 2F** double flash; **3F** triple flash**; ORC** organic Rankine cycle (binary plant); **OCGT** open cycle gas turbine; **CCGT** combined cycle gas turbine

Energy Units:
GWh: gigawatt hours
kWh: kilowatt hours
MW: megawatt
Nm^3 : normal cubic metre (at standard conditions)
g: grams

Currency: unless otherwise indicated, all dollar amounts are in New Zealand Dollars.

Other:
MBIE Ministry of Business Innovation and Employment**; MFAT** Ministry of Foreign Affairs and Trade; **OEM** original equipment manufacturer; **NCG** non-condensable gasses (CO_2, CH_4, H_2S, etc.);

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