2020 Annual NZGA Geothermal Review

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Welcome to our second annual NZ geothermal industry update. Each year we try to review what is happening as NZ de-carbonises and the geothermal industry expands. This year, the commentary focuses on on-going operations as well as carbon emissions, carbon substitution, and a review of MFAT activities.

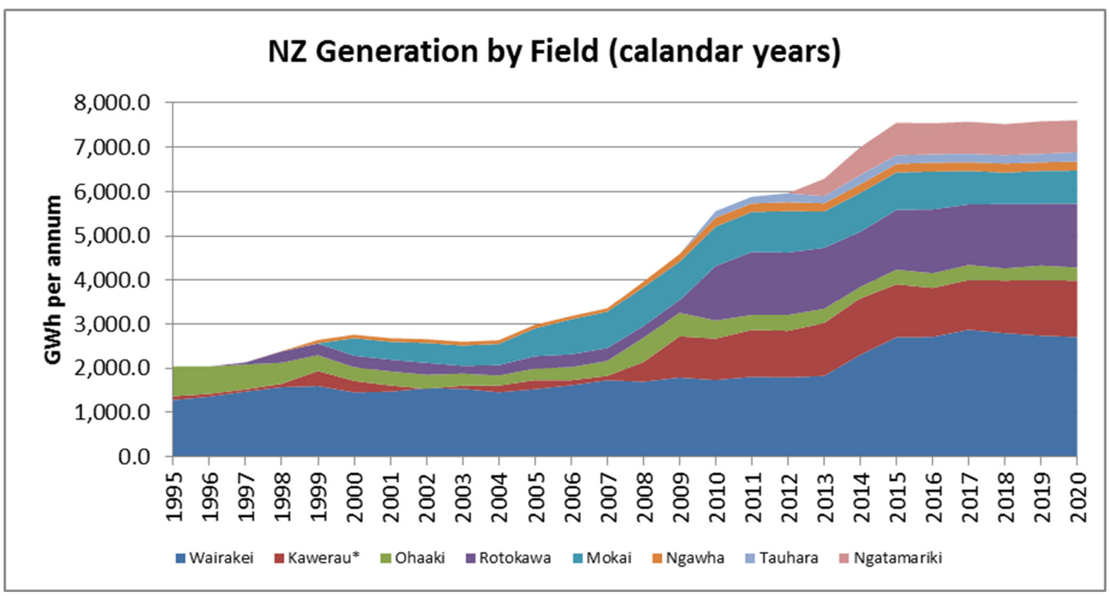
This being a COVID year, we first want to acknowledge the operations and maintenance staff across the industry that endured isolation from their families to protect the nation's electricity system during the lockdown of April-May 2020.

1.0 Electricity Power Supply

1.1 Electricity Output increase

Despite the COVID lockdown, geothermal electrical generation increased to 7,610 GWh, exceeding the 7,600 threshold for the first time. Production was consistent among all fields (Figure 1.1) with Kawerau and Rotokawa both having strong performance.

Figure 1.1: Geothermal Power Generation by Field

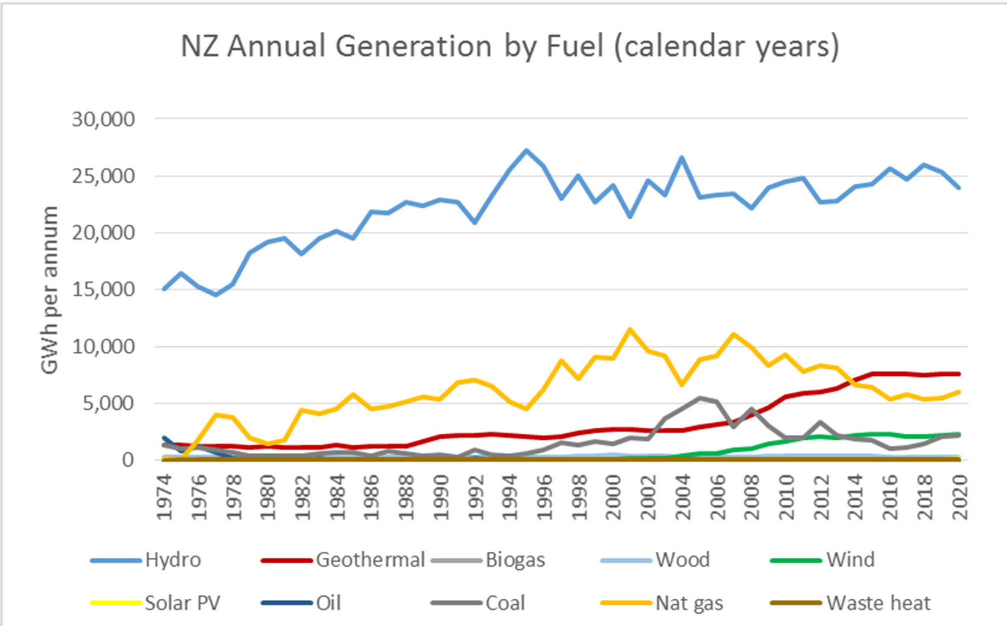


Sources: NZ Electricity authority, MBIE, company operating reports

1.2 Contribution to NZ Power supply

Geothermal comprised 17.4% of the nation's total power generation in 2020, on par with 2019 and steady since 2015 (Figure 1.2). Renewable generation fell slightly for the year from 82.4% to 80.8% due to dry hydrological conditions.

Figure 1.2: Annual NZ Power Generation by Fuel

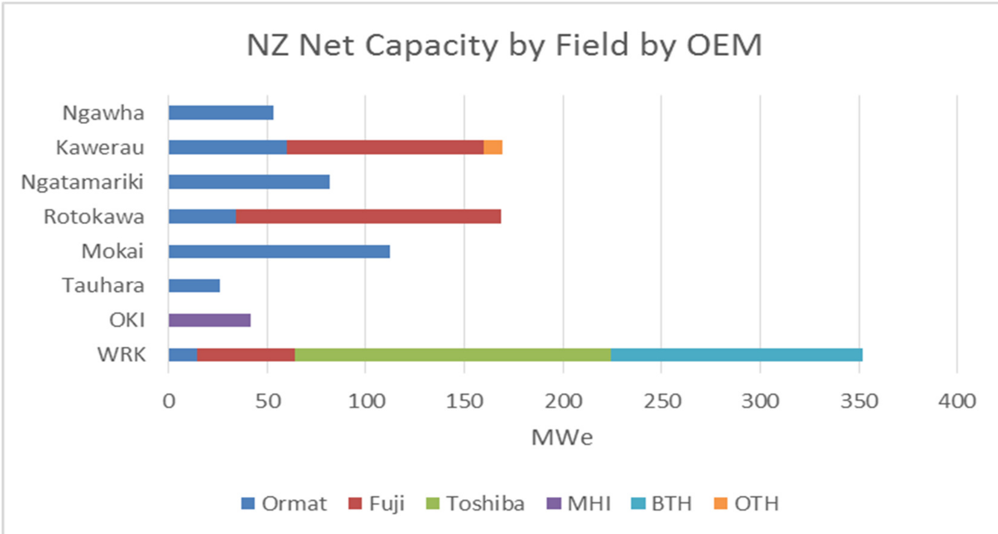


Sources: MBIE

1.3 Generation Capacity Changes

The commissioning of Ngawha OEC4 (31.5 MWe) at the end of 2020 raises New Zealand's total net capacity to 1,027 MWe from 21 power facilities. Ormat remains the largest original equipment manufacturer (OEM) with 385 MWe (Figure 1.3), followed by Fuji (285 MWe) and Toshiba (160 MWe). The British Thompson & Houston units at Wairakei remain the oldest operating steam turbines in the geothermal industry.

Figure 1.3: Net Capacity by Field by OEM



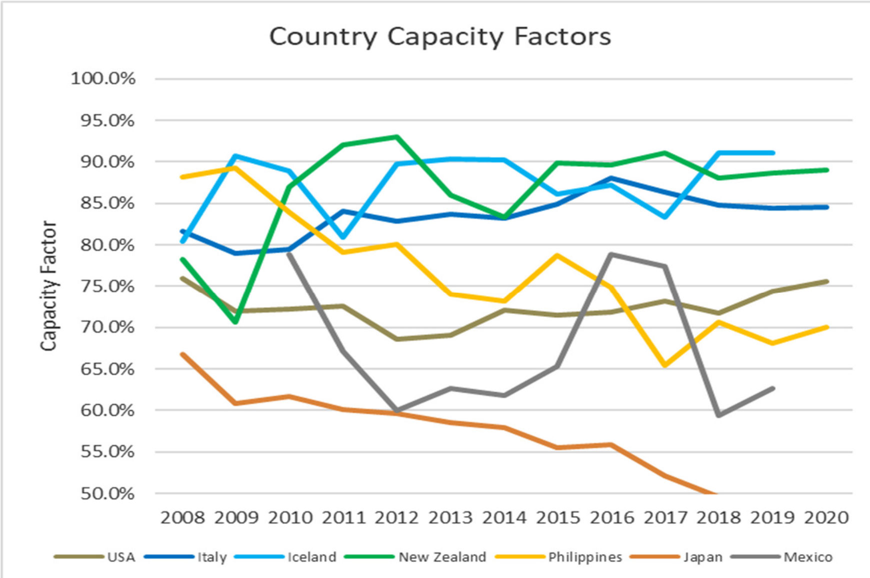
Sources: company annual reports

1.4 Comparative International Performance

While national geothermal statistics for 2020 will not be fully available until mid-year, the results for 2019 (Figure 1.4) again show Iceland, New Zealand and Italy with capacity factors consistently above 85%. Japan, Mexico, and the Philippines display variable to declining capacity factors. The USA's national capacity factor has remained steady as declining production from its older fields like Coso has been offset by new fields in Nevada. National capacity factors for Turkey and Indonesia are supressed by the high-capacity growth rate and are not displayed here.

Such aggregate statistics reflect many variables and can be difficult to interpret as the trends reflect resource effects rather than operating performance. However, the overall picture reflects the experience that generation from some geothermal fields declines over time while others have sufficient recharge and injection to maintain output for extended time periods.

Figure 1.4: Capacity Factor by Country



Sources: US EIA, JPN Annual Statistical Summary, CFE Ano Reporte, DOE the Philippines, Enel operating report, NZ MBIE, Orkustofnun

1.5 Direct Use Update

While the industry continued its quest to increase the direct use of geothermal energy by industry, Covid delayed many of these efforts during 2020, reflecting a decrease in business confidence precipitated by the pandemic. The NZ Geoheat Group continued its sterling efforts in lobbying central government, with good success.

There was one notable success: in late 2020 Geo40 commissioned their first commercial scale silica production plant on the Ohaaki Field. This plant processes 6800 tonnes per day of separated geothermal water prior to reinjection, producing colloidal and precipitated silica products.

2.0 Carbon Emissions and Displacement

2.1 Annual Discharges and Trends

Calendar year 2020 CO2e emissions data appears in the below (Table 2.1); the figures represent CO2-equivalent emissions data, including methane x25 as per the NZ regulations. These data have been provided to the New Zealand Geothermal Association by operators of the geothermal power stations. Generation data has been verified against data from the Electricity Authority (EMI website).

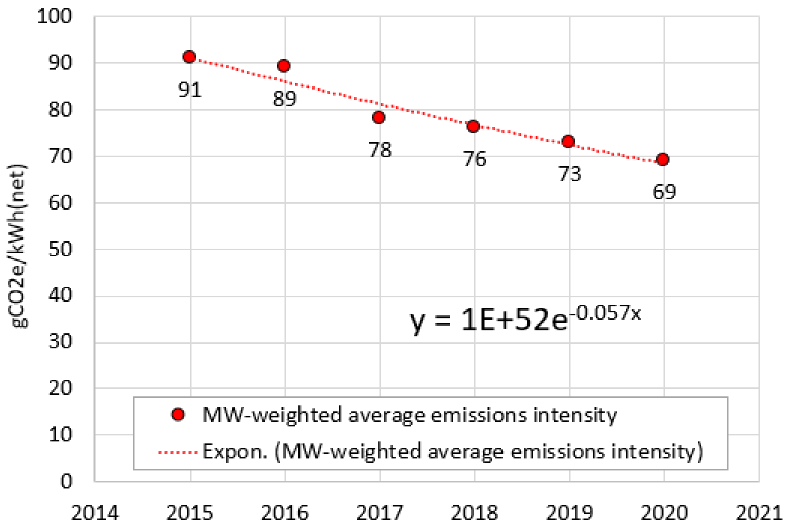
Table 2.1 Geothermal CO2e emissions data for calendar year 2020

Station	Total Steam	Emissions factor	Net Generation GWh	Total CO2e	Emissions rate	Emissions intensity
	t	t CO2e/ t steam	GWh	t	t CO2e/day	gCO2e/kWh(net)

Wairakei	9,889,705	0.00200	1119	19,779	54	18
Te Mihi	9,995,170	0.00480	1265	47,977	131	38
Poihipi	2,498,278	0.00490	319	12,242	34	38
Ohaaki	2,720,613	0.03330	297	90,596	248	305
Te Huka	1,374,041	0.00780	209	10,718	29	51
Rotokawa	1,784,039	0.01465	239	26,136	72	109
Nga Awa Purua	7,841,465	0.00823	1200	64,535	177	54
Mokai	5,163,703	0.00460	752	23,753	65	32
Ngatamariki	3,914,410	0.00960	721	37,578	103	52
Kawerau	7,024,449	0.01578	931	110,846	303	119
TOPP1	964,505	0.01060	178.7	10,224	28	57
TAOM	1,023,524	0.01000	210.8	10,235	28	49
GDL	224,733	0.01300	69.1	2,922	8	42
Ngawha	756,846	0.08469	205	64,097	175	313
MEDIAN						52
25th PERCENTILE						39
75th PERCENTILE						96
MW WEIGHTED AV						69

The MW-weighted average emissions intensity of the 14 geothermal power stations in the above table is 69 gCO2e/kWh(net). This has declined from 73 gCO2e/kWh(net) in CY2019, and is part of a decline trend over the past 6 years (Figure 2.1). The exponential decline rate is 6% per year.

Figure 2.1: Exponential decline of MW-weighted average emissions intensity for 6 years from 2015 to 2020 (modified from McLean et al. (2020).



These emission data are operational emissions only. The full lifecycle emissions for geothermal can be estimated by adding 10 gCO2e/kWh(net) to account for emissions associated with materials and construction, maintenance and decommissioning (Fridriksson et al., 2017). The full lifecycle CO2e emissions from NZ geothermal power stations for CY2020 can therefore be estimated as 79 gCO2e/kWh(net) as a MW-weighted average.

Other sources of energy are compared on the basis of median lifecycle emissions intensity, which would be 62 gCO2e/kWh(net) for NZ geothermal. This compares to lifecycle emissions from other renewables of 44 for solar photovoltaics, 19 for hydro and 11 for wind. Fossil fuels have median lifecycle emissions intensities an order of magnitude higher, of 450 gCO2e/kWh(net) for gas combined cycle plants, and 980 for coal.[1]

Fridriksson, T., Merino, A.M., Orucu, A.Y. and Audinet, P. (2017): *Greenhouse Gas Emissions from Geothermal Power Production*. Proceedings 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 13-15, 2017.

McLean, K., Richardson, I., Quinao, J., Clark, T. and Owens, L. (2020): *Greenhouse gas emissions from New Zealand geothermal: power generation and industrial direct use*. Proceedings 42nd New Zealand Geothermal Workshop, Waitangi, New Zealand, 24-26 November, 2020.

<u>2.2 Contributions to carbon reductions – structural fossil fuel displacement</u>

Since 2008, flat consumption combined with new geothermal generation has significantly displaced thermal generation from the NZ dispatch stack. This has supressed New Zealand's electricity carbon emissions (Figure 2.2).

New wind and solar generation have similarly compressed thermal dispatch but only intermittently. During periods of normal hydrology, wind dispatch de-couples from hydro and tends to both lower thermal dispatch and spot prices. However, during dry periods, traders use wind to displace (and

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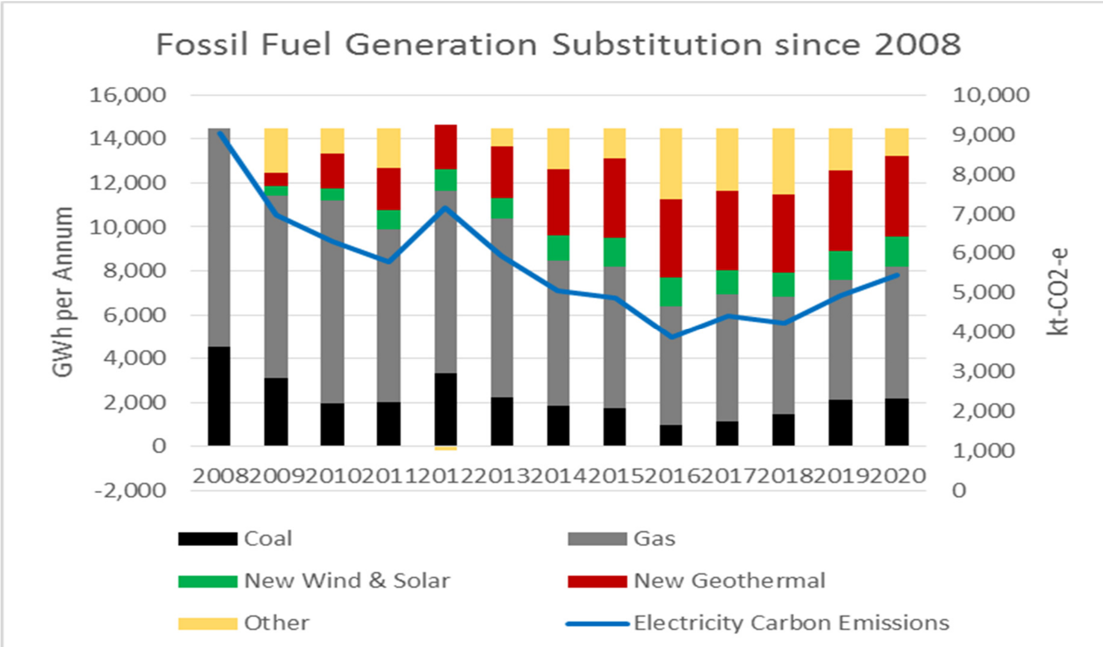
[1] More details will be presented at the NZGA Winter Seminar on 29th July 2021 in Taupo, and published at the New Zealand Geothermal Workshop in November 2021.

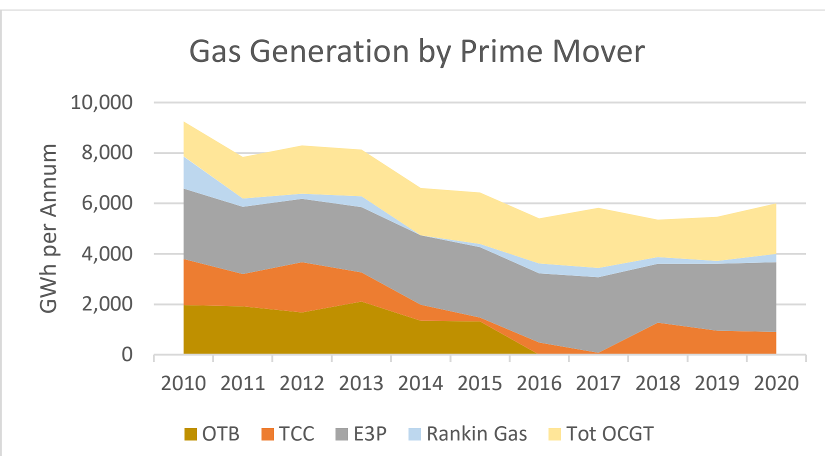
conserve) hydro storage, leaving thermal to fill marginal supply and set prices. This maximises the employment of more carbon intensive, open cycle gas turbines (Figure 2.3).

Figure 2.2: Renewable Substitution for Thermal Generation NZL



Sources: MBIE, company operating reports, NZ Electricity Authority, NZ Electricity Market

Figure 2.3: Gradual Attrition of Gas-fired Generation by Prime Mover



Sources: MBIE, NZ Electricity Market; GNE operating reports

2.3 CO2 Reinjection Indicatives

Both Mercury Energy and Contact Energy have announced pilot schemes to examine the feasibility of injecting non-condensing gasses (NCGs[2]) from binary plants. Top Energy has already experimented with limited NCG re-injection and is investigating further. These developments follow

[2] These include CO_2, CH_4, and H_2S

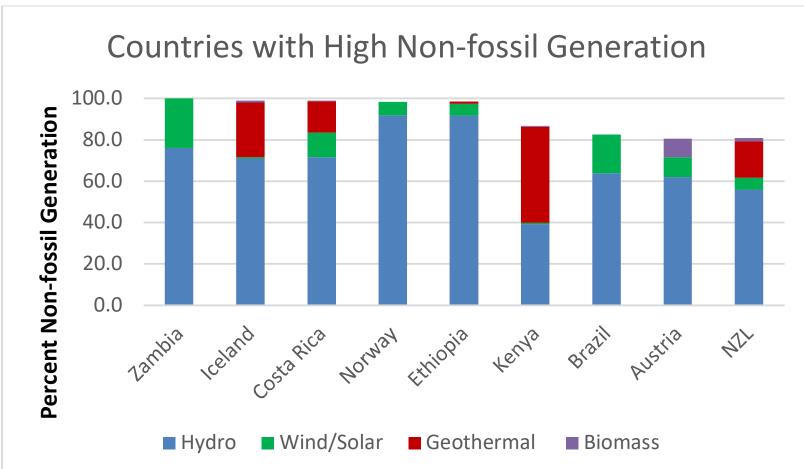
from Ormat's experience in reinjecting NCGs at Puna binary plant. While details are not yet available, these experiments look to accelerate in 2021.

While the economics of NCG injection should improve as carbon prices in NZ rise, tax incentives would help accelerate this investment.

<u>2.4 Geothermal Role in International Decarbonisation</u>

International statistics continue to highlight the importance of geothermal generation in "greening" electric power. Strikingly, several countries that have already achieved more than 80% non-fossil generation heavily employ hydro and geothermal power (Figure 2.4). Countries utilising large quantities of wind and solar power (Denmark and Germany in particular), rely heavily on international power trading to balance their grid systems.

Figure 2.4: Power Generation by Fuel Type for High Non-fossil Electricity Systems



3.0 Drilling and Completions Activity

<u>3.1 Wells Drilled in 2020</u>

Despite the two-month COVID lockdown, the drilling and well services sector increased activity as operators drilled 7 deep and 7 shallow wells during 2020 (Table 3.1). Most of the activity centred at Tauhara Field as Contact Energy appraised the field for expansion. MB Century Rig 32 drilled 5 of the deep wells and Big Ben two.

Table: 3.1 Calendar 2020 drilling statistics

Field	Deep				Shallow			Total
	APR	PRD	INJ	OBS	PRD	INJ	OBS	
Ngawha								0
Rotorua						2		2
Tauranga					2		1	3

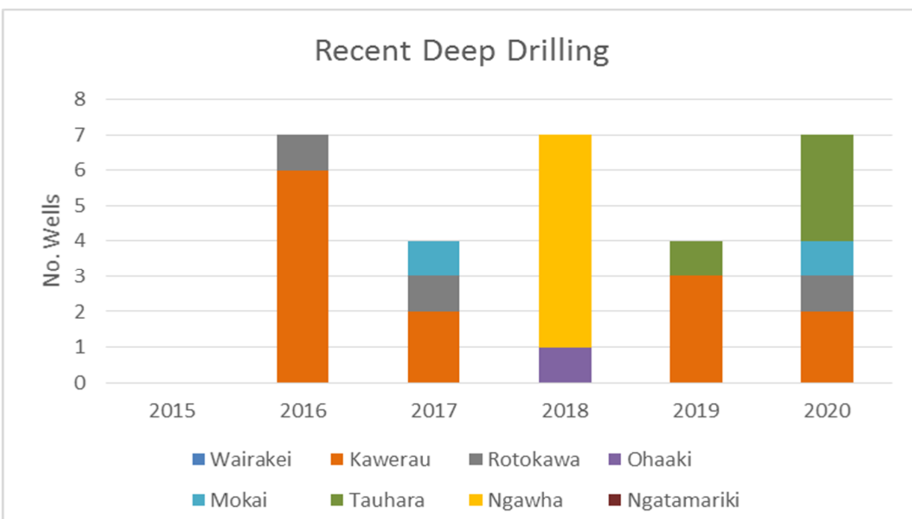
Kawerau		2						2
Rotokawa		1						1
Mokai				1				1
Ngatamariki								0
Wairakei								0
Ohaaki								0
Tauhara	1	2			2			5
Totals	1	5		1	4	2	1	14

Sources: press reports, Environment Waikato, BOP Regional Council

3.2 Drilling Trends

Drilling activity has generally increased since a nadir in 2015 (Figure 3.1). Kawerau was the most active field (13 wells) with Ngawha second (6 wells) supporting the OEC4 development.

Figure 3.1: Recent Deep Drilling Activity



Sources: press reports, company annual reports

4.0 Services Sector Activities

4.1 MFAT Global Geothermal Initiatives

MFAT's global energy programme continued to give focus to geothermal support throughout 2020. However, Covid-19 altered the geothermal operating context, altered our partners short term priorities, and significantly disrupted MFAT's support initiatives. As a result, delivery of our geothermal programmes significantly slowed during the year while we, together with our suppliers and partners, assessed the impacts of the pandemic and recalibrated our programmes accordingly.

Through these efforts, MFAT successfully pivoted all our geothermal programmes for remote and online delivery, which has enabled technical assistance to continue to through the Covid-19 pandemic. While the 100% remote model in many cases has not been ideal and required creativity, patience, and perseverance, it has helped keep the New Zealand geothermal sector relevant, visible and active with our global partners.

In East Africa, under our regional facility MFAT:

- delivered an online webinar in slimhole drilling technology, and an online short course in geothermal project management around the ARGeo; this week we are commencing delivery of a geothermal webinar series for the East Africa region; nine webinars will be delivered covering a range of technical disciplines from surface geochemistry, well testing, the UNFC classification system, lower temp resources, project feasibility studies and more;
- re-designed and commenced technical advice for the GDC Kenya, to support their technical and managerial responsibilities at the Menengai Geothermal Field, all via remote means; the project has potential for wider applicability across the region;
- provided remote technical support to partners in Djibouti and Tanzania to prepare and submit numerous funding applications to the GRMF; outcomes of the GRMF are not yet announced, but the project enabled us to deepen relationships and strengthen capacity;
- commenced a technical assistance and capacity building project supporting partners in Ethiopia, Djibouti and Tanzania through their upcoming drilling programmes; the project is delivered via an innovative online platform which enables seamless collaboration among the 3 partners, document transfer, real time 'chat' access to our experts, as well as webinar and live online learning.

In the Caribbean, under our regional facility MFAT:

- collaborated with the OECS and engaged widely with geothermal partners to explore opportunities for direct uses across the region; this study will be disseminated shortly, and we hope to progress a direct use project through to feasibility stage;
- provided remote technical support to the Government of Grenada through the procurement process for exploration drilling services, which will lead to further support;
- is delivering a package of work partnering with the UWI, supporting surveying and mapping of a new geothermal resource in the northern region of Dominica; this resource is planned to be developed into a Green Industrial Eco Park by the GCF;
- is currently exploring how we can partner with the WB to make progress in St Lucia.

In Indonesia MFAT:

- provided technical assistance (under GEOINZ) to Badan Geologi (BG) in their role in the Government Drilling Programme. This involved reviewing conceptual models for drilling, running workshops on drilling strategies and joining BG on field visits;

- continued supporting SNI (Indonesian National Standard) through input into documents and meetings; COVID caused a shift of Government of Indonesia priorities, stalling regulatory change within this sector and pausing our usual regulatory support to EBTKE;
- provided technical assistance to PT SMI to develop a framework, evaluation and provide advice on the Candradimuka proposal from GeoDipa;
- conducted, in collaboration with Ormat, a highly successful industry workshop at the end of 2020 that included a series of weekly webinars on developing lower temperature geothermal resources;
- maintained regular contact with Partners in order to keep connected and adjust to new developments and restrictions during the rapidly changing environment of COVID.
- Continued to provide, under NZSTIGS, vocational training for geothermal trades, technicians and plant operators to increase the skills and capability of the geothermal workforce; Covid restrictions migrated training from in-person to online; this required developing new material to align with online learning and teaching.

4.2 Other Service and Promotional Activities

Despite COVID, 2020 proved a busy year for the geothermal service sector. Some of the highlights include:

- Jacobs was appointed owners engineer by Supreme Energy for Muara Laboh phase 2 (65 MW) development. In addition, MFAT selected Jacobs to lead the East Africa Drilling Support project.
- Solenis and Nalco both successfully completed chemical well cleanouts and improved chemical solutions.
- Software developer Sequent (provider of Leapfrog) continued their expansion into the mining sector.
- The NZ geothermal Institute introduced new Tough 2, reservoir simulation software.
- The Geoheat Action Group released their second action plan in March 2020. Funding was only secured through June 2020 and so the business development position was suspended. Despite COVID disruptions, the Geoheat Action Group has continued supporting dialogue between the geothermal community and the Climate Change Commission to ensure advice to Government recognised the substantial benefits that geothermal energy.

4.3 New Technology:

Geo40 overcame numerous COVID issues to almost complete their new NZ $20m silica extraction facility (North Plant) at Ohaaki Field. This plant will process 6,800 tonnes per day of separated geothermal water prior to reinjection, producing colloidal and precipitated silica products. After commissioning, the company will move ahead marketing their nano-particle colloidal silica and investigate the commercial extraction of lithium, cesium, and antimony.

4.4 Geothermal: The Next Generation

GNG progressed at a rapid pace since the start of the Programme in October 2019.

Over 2020 GNG made progress in exploring and delineating Aotearoa supercritical geothermal targets by improving magnetotelluric and seismic modelling. We are analysing the fracture pattern in the greywacke to be able to couple the permeability framework with high temperature modelling. The programme is also supporting PhD students looking at: the status of the magmatic crust underneath the TVZ from a petrological approach (in collaboration with the University of Wellington) and developing numerical simulation of the supercritical resources underneath New Zealand geothermal systems (in collaboration with the ETH Zurich).

The recent addition of an ultra-high temperature reactor to the GNS Science Wairakei research Centre Experimental geochemistry laboratory is taking the previous maximum experimental temperature from 400°C to 700°C. This expands the research scope beyond conventional geothermal conditions (<350°C), to be able to simulate the supercritical geothermal conditions (>400°C) essential for understanding the thermochemistry of supercritical reservoir, their connection to magma and their behaviour upon injection with or without non condensable gas (e.g. CO_2).

More than 54 blog updates and knowledge outreach posts have been released under www.geothermalnextgeneration.com and pushed under our social media platforms. We aim to communicate not only about supercritical resources but as well advocate for geothermal in general. More updates for the coming months are already in planning to communicate first about our scientific findings and their relevance but also on relevant scientific facts (e.g. what is the Taupo Volcanic Zone?).

Finally following the New Zealand Geothermal Workshop GNG session on supercritical geothermal, the Supercritical Strategy Steering group is pushing discussions and consultation on the key themes: Science, Engineering, Regulatory, Investment and CO_2 management. We are expecting a high-level draft of New Zealand's supercritical strategy by the end of 2021.

4.0 Industry M&A and Restructuring

4.1 New Entries

There were no new entries into the geothermal industry during the 2020 calendar year.

4.2 Mergers and Acquisitions

There were no mergers or acquisitions in the geothermal industry during the 2020 calendar year. However, during the first quarter 2021 there were two significant transactions:

- US based Bentley Systems Group entered into a definitive agreement to acquire Seequent. The transaction awaits US and NZ regulatory approvals; and
- Contact Energy acquired all the shares of Western Energy Services, a Taupo well services company.

5.0 Looking forward

5.1 New Developments

Tauhara II: Contact Energy announced that it will proceed with its Tauhara power station this will be the second geothermal development at the Tauhara field near Taupo, New Zealand. Construction has started with an anticipated commercial operations date (COD) of mid-year 2023.

The project team, headed by Tim Boyce, selected a 152 MWe, triple flash, condensing steam turbine proposal from Fuji Electric. This turbine will be the world's largest geothermal single-shaft generating unit. After exiting the turbine, steam will be quenched in a direct (spray) contact condenser with a hybrid, 2-stage combination steam-ejector and liquid-ring-vacuum-pump to purge NCGs.

Contact's construction team, led by Alan de Lima, will deliver HP, IP, and LP steam to the power island from the steamfield. Construction is underway with Hicks Bros currently completing station and steamfield earthworks. Jacobs will provide the detailed steamfield design. This will include acid injection to manage silica scaling in the separated water reinjection system.

From the power island gate, steam will travel through a wash water spray system and demister (scrubber) before entering the turbine.

Mark Green leads Contact's drilling programme and has retained MB Century to provide drilling services (Rig 32) for the production and injection wells. The first well TH-29 spudded in March; drilling will continue through 2021.

Taheke: In mid-2020, the Government announced an Infrastructure grant of $11.9 million to the Taheke JV (Proprietors of Taheke 8C & Adjoining Blocks Incorporation and Eastland Generation). Appraisal drilling for the 25 MWe project is due to commence in mid-2021. Ben Gibson reports that the partners are well underway with initial investigations and planning.

5.2 Government Decarbonisation Initiatives

As provided in legislation, the Minister for Climate Change established the NZ Climate Change Commission (CCC) in Dec 2019. Over the 2020 year, the CCC formulated the steps necessary for NZ to meet its Paris CO_2 emission reduction obligations. The CCC released its initial report in January 2021.

The CCC recommended converting light vehicles and railroads to electricity. This will stimulate electricity consumption. The increased supply would be met by new wind, solar, and geothermal generation.

Epilogue

New Zealand and the Geothermal Industry both weathered COVID and have emerged fitter and more capable of facing the challenge of extending decarbonisation at home and internationally.

NOTES

Abbreviations and Acronyms

Wells

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

Prime Movers

CCGT combined cycle gas turbine; **OCGT** open cycle gas turbine

Other

MBIE Ministry of Business Innovation and Employment**; MFAT** Ministry of Foreign Affairs and Trade; **OEM** original equipment manufacturer; **NCG** non condensable gasses (CO2, CH_4, H_2S, etc); **TCC** Taranaki Combined Cycle Station; **OTB** Otahuhu Combined Cycle Station; **E3P** Huntly Combined Cycle Station; **WB** World Bank; **GDC** Geothermal Development Company (Kenya); **GEOINZ** the European Union geo-capacity project; **EBTKE** Direktorat Jenderal Energi Baru Terbarukan (Indonesia); **GRMF** Geothermal Risk Mitigation Facility; **NZSTIGS** **GCF** Green Climate Fund; **ARGeo** African Rift Geothermal Development Conference; **UNFC** United Nations framework for resource classification.

Sources

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