NZGW
New Zealand
Geothermal Workshop

44th New Zealand
GEOTHERMAL WORKSHOP

Handbook

23-25 November 2022

ISSN 2703-4275

Contents

Welcome

44th New Zealand Geothermal Workshop

Welcome to the 44th New Zealand Geothermal Workshop (NZGW).

The NZGW is now firmly slotted into the worldwide geothermal community calendar. It is an opportunity for professionals, researchers and students interested in geothermal energy to network, discuss and share their experiences. This year's programme comprises a wide range of technical and scientific papers and a full-stream dedicated to industry updates.

Geothermal energy is going from strength to strength as many countries recognise it as a key resource towards a net zero carbon emission target.

We are especially pleased to have our overseas visitors here in Aotearoa New Zealand after two years of COVID-19 travel restrictions.

The NZGW workshop also marks the closing of the academic year for our 17th Geothermal Post Graduate Certificate course. We welcome our graduates to the geothermal community and wish them successful careers.

We thank all our sponsors for allowing us to run the workshop while keeping the registration fee as low as possible and subsidising the social functions.

We hope everyone has an enjoyable and fruitful time.

Conveners:

Sadiq J. Zarrouk
John O'Sullivan
Bridget Lynne
Mike O'Sullivan
Michael Gravatt

2022 Partners

GEOTHERMAL INSTITUTE

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GNS SCIENCE TE PŪ AO

MB Century

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MARUBENI ITOCHU STEEL

slb

2022 Awards

Geothermal Institute

Best Geothermal Earth Science Paper

New Zealand Geothermal Association

Best New Zealand Paper

Best Student Paper

General Information

The following information is provided as a guide to the Workshop. If you have any queries, please visit the registration desk.

Registration desk

For any questions, please visit the registration desk during Workshop hours.

If the registration desk is unattended, please call 027 807 9928.

Workshop catering

Lunches, morning, and afternoon teas will be served in the Level 4 Foyer of the Engineering building, University of Auckland.

Dietary requirements

Vegetarian options are provided with each meal break. Care has been taken to ensure all advised dietary requirements are catered to. If you specified your dietary requirements when registering, please make yourself known to the catering staff.

Mobile phones

During all presentations please switch off or turn your mobile phones to silent.

Presentations

As a courtesy to our presenters, please ensure you arrive at each session venue prior to the start of presentations.

Presenting authors

Presentation slots are 15 minutes long with 3 minutes scheduled for questions. Each session chair will be keeping strictly to time.

If you are scheduled to give a presentation, please ensure your PowerPoint is uploaded well in advance of your presentation time, preferably during the catering breaks or prior to the start of each day. Visit the registration desk for details on how to upload your presentation.

Cameras and electronic recording

No electronic recording of presentations is permitted in any form without the express written permission of Workshop organisers and speakers.

Urgent messages and lost property

Urgent messages for delegates and lost property can be directed to the registration desk.

Messages and lost property will be held there for collection until the conclusion of the Workshop.

Wi-Fi Access

Please use the UoA Guest Wifi network and login details below

Username: nzgw2022conference@uoawifi.com

Password: 8beRTRt9

Social Events

There are a number of social events available to attendees. If you have not already arranged your tickets to these events, please visit the registration desk.

Workshop Reception

Tuesday, 22nd November 2022
Faculty of Engineering 20 Symonds Street

This will be a 'drinks and nibbles' event open to all registered Workshop delegates. No ticket required.

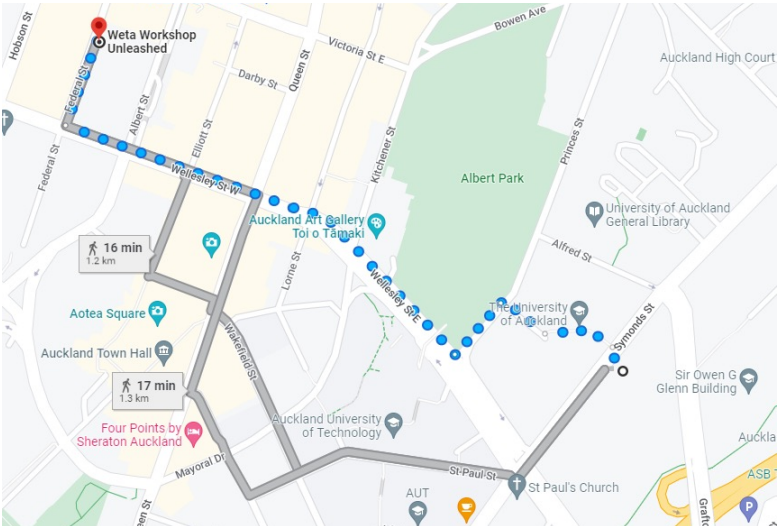
Workshop Dinner

Thursday 24th November 2022,
6:30pm – 10:00pm

*Tour experiences will begin from 6:30 and run until 7:10. Delegates who arrive late may not be able to be accommodated to take the Unleashed Tour but will join the dinner.

Weta Workshop Unleashed
Level 5, 88 Federal Street, Auckland 1010

Explore interactive and immersive make-believe film sets, focusing on the worlds of horror, fantasy and sci-fi. It's your chance to get up-close and hands-on with enchanting environments, resident creatures, one hyper-realistic giant, a galactic robot, and much more.



Please note that transportation to the workshop dinner venue is not provided.
The venue is a 13-17 min walk from the workshop venue.

Auckland Information

The following information is provided as a guide to Auckland. If you have any queries, please visit the registration desk.

Emergencies, medical needs and illnesses

If you have an emergency you can contact the police, paramedics and fire department by calling 111 from any landline or mobile phone.

The workshop venue is:

Faculty of Engineering,
20 Symonds Street,
Waipapa Taumata Rau |
University of Auckland,
Auckland

If you require non-emergency medical attention during the workshop, please inform the registration desk.

Getting around

Taxis and airport shuttles
There are many taxi companies to choose from in Auckland. We suggest:

Blue Bubble Taxis 0800 228 296
www.bluebubbletaxi.co.nz

Auckland Co-op Taxis 00 300 3000
www.cooptaxi.co.nz

Super Shuttle 0800748 885 shared airport transfers direct to/from your accommodation
www.supershuttle.co.nz

SkyBus 24hrs a day, direct bus transfers to Auckland Airport from downtown Auckland
www.skybus.co.nz




Piha beach, (top left), Wynyard Quarter (top right), Ferry Building (bottom left), Cornwall Park (bottom right).

Nearby Services

Pharmacy and Post Shop
Level 1 Kate Edgar Information Commons
Corner Alfred & Symonds Street

Eat & drink in Auckland

Where to start? Auckland has more great places to eat and drink than we could hope to recommend. For current reviews visit:

Metro Eats Auckland
www.metroeats.co.nz

Check the Top 50 Restaurants 2022, Cheap Eats and Best Bars lists.

The Urban List
www.theurbanlist.com/auckland

Places to Visit

Visit Waiheke Island for some of the best vineyards in New Zealand, including the University's own award winning Goldie vineyard.

Take a walk on one of Auckland's 50 volcanoes. For a quick trip, visit Mt Eden or One Tree Hill or for a day trip take the ferry out to Rangitoto Island.

View **www.aucklandnz.com** for more ideas.

Keynote Speakers

Jim Lawless

Independent Consultant and a Director of Polaris Infrastructure

Jim is currently an independent consultant and a director of Polaris Infrastructure which has renewable energy projects in Nicaragua and other Latin American countries. This builds on a previous role to the end of 2010 as Geothermal Resources Practice Leader for Sinclair Knight Merz (now part of Jacobs Engineering). He has been President of the New Zealand Geothermal Association, on the Board of the International Geothermal Association and founding Chairman of the Western Pacific Regional Branch thereof. During his 29 years with SKM and predecessor companies. he played a major part in most of the company's geothermal projects worldwide. He also maintained an interest in mineral exploration. This has been of assistance in him taking the lead technical role in developing and administering the Australian Geothermal Reporting Code for Resources and Reserves.

With a background of 35 years international experience in geoscience, he has in recent years taken a key role in promoting the appropriate development of geothermal energy in South East Asia, especially Indonesia, with assignments for NZ MFAT, the World Bank and the UK government. Starting in 2011, he has helped guide MFAT's policy in renewable energy development in Indonesia.

The ~~10~~ ~~25~~ 55 (And Counting) Most Common Mistakes in Geothermal Development

Jim Lawless, Lawless Geo-Consulting, Auckland, New Zealand

Jim Randle, GT Management, Jakarta, Indonesia

Phil White, Panda Geoscience, Taupō, New Zealand

Although geothermal development worldwide is a success story, there have also been sub-optimal results. A number of common themes have been observed. The most important over-arching reason for failure (other than simply poor quality resources) appear to be: (1) lack of communication between scientific disciplines and between the resource and engineering design teams, (2) failure to maintain flexibility, updating and changing working assumptions as the project progresses, (3) lack of recognition of the requirements of long term operation of a successful project such as operability and steam quality, and (4) lack of recognition that geothermal development is fundamentally an economic activity and the project must make financial sense both initially and into the future.

Notes

Dr Sophie Pearson-Grant

Senior Geothermal Geophysicist, GNS Science

Dr Sophie Pearson-Grant is a senior geothermal geophysicist at GNS Science. Her expertise lies at the interface of earth sciences and numerical modelling. She joined the geothermal group at GNS in 2010 after completing a Presidential Doctoral Fellowship at University of South Florida, USA and an undergraduate masters at Leeds University, UK. During her studies, she collected geophysical measurements on 4 continents and at 11 active volcanoes. Modelling this data led to a focus on the complex pathways that fluids take from the heat source to the surface, which has been her specialty ever since. Her work has won awards at 3 international conferences, received a prestigious Marsden Fast-Start grant, and been featured on radio and in the NZ Herald, US GeoHeat bulletin, and Wilderness magazine.

Sophie has a passion for protecting the environment, and the fundamental role that geothermal energy can play in reducing fossil fuel use and powering communities.

Fluid flow at different scales in the geothermal fields of New Zealand

Sophie Pearson-Grant, Ted Bertrand, Warwick Kissling, Craig Miller, Samantha Alcaraz, Lucy Carson, Penny Doorman, Cornel de Ronde, Sarah Milicich, John Burnell

New Zealand is blessed with a range of geothermal resources in some very complex geological settings. Geothermal fluid flow results from the interaction of water with heat sources, permeable pathways, and topographic influences. A lot of work has gone into understanding fluid flow in individual geothermal fields for production, but what can we learn about fluid flow processes when we don't have much well data? Or when we want to understand fluid circulation on a larger scale? New insights can be gained by merging increasingly extensive geophysical and geological surveys of the central North Island of New Zealand into numerical flow models. I will present examples from four very different settings: Tauranga low-temperature geothermal system, the pre-1886 eruption Pink and White Terraces hydrothermal systems at Lake Rotomahana, the Okataina Volcanic Centre, and the wider Taupō Volcanic Zone. Simplified fluid and heat flow models show that there is no one dominant process, and that there are still many open questions around the locations, natural lifecycles, and sustainability of geothermal systems. Combining regional-scale research with the geothermal industry's collective knowledge, we can start to answer these questions and thereby work out ways to sustainably manage these diverse systems and get more geothermal energy to the grid, industries, and our communities.

Notes

Dr Meseret Zemedkun

Head of UNEP Southern Africa Offices and Lead on Regional Energy Programme in Africa, UNEP

Dr Meseret Teklemariam Zemedkun is an internationally recognised and acclaimed Ethiopian geothermal energy professional with over 20 years of experience in the energy field, management, project management, and international donor relations and investment. Since 2011, she has worked at the United Nations Environment Programme's Africa office in Kenya as Programme Manager for Africa Rift Geothermal Development Programme (ARGeo) and as Regional Energy Programme Manager, where she has led the development of energy initiatives, policies, and programmes in Africa.

Meseret has also served as a member of the International Geothermal Association (IGA) Board of Directors and was elected by IGA to chair the African Geothermal Branch. She has served as an international consultant on geothermal energy assignments, including the African Union Commission and UNIDO. She played a major role in the realisation and development of the African Geothermal Center for Excellence.

Dr Zemedkun is a champion of capacity building in Africa. She has been a regular faculty member of UN University – Geothermal Training Programme in Iceland for many years and has trained geothermal staff in Africa as an invited scholar. She has also been instrumental in initiating and developing programmes for supporting Women Entrepreneurs in the Energy sector in Africa, implementing this programme with various partners through the Africa Women Energy Entrepreneurs Framework (AWEEF). For New Zealand, Meseret is a trusted guide in successfully delivering many Geothermal Institute-led training packages for East African geothermal professionals – education opportunities funded by the New Zealand Ministry of Foreign Affairs and Trade Aid programme.

Geothermal Outlook in Africa: Opportunities and Challenges

Notes

Robin Zuza

Director of Global Exploration, Ormat Technologies Inc.

Robin Zuza is the Director of Global Exploration at Ormat Technologies, Inc. Ormat is a leading renewable energy provider operating over 1GW of geothermal power across six countries and an extensive exploration portfolio globally. Robin has been with Ormat for six years starting as an exploration geologist focused on East African opportunities before transitioning into management. She currently manages a technical team with bases in both Reno and Jakarta.

Prior to making the switch to geothermal, Robin was a senior geologist for an oil and gas company focused on exploration opportunities in California. Robin received both her Bachelor's degree in Engineering Geology and Master's degree from the University of California, Los Angeles. Her Master's researched focused on structural mapping and analysis of the northeastern Tibetan Plateau.

Global Geothermal Exploration and Growth – the Ormat Case Study

Robin C. Zuza, Simon J. Webbison

Ormat Technologies is one of the leading geothermal companies in the world and is unique in the number of fields it operates and the variety of its operating portfolio. Ormat currently operates twenty-three geothermal fields, the largest of any operator, with a non-operating shareholding in two other geothermal fields. These are across six different countries: USA, Kenya, Indonesia, Guadeloupe (France), Guatemala and Honduras.

Ormat is the only geothermal operator with fields hosted in amagmatic fault-controlled basins, high-enthalpy volcanic systems, and sedimentary basins with exploited resources ranging in encountered highest natural state temperatures of >315°C to 127°C.

Ormat has successfully had consistent growth in installed geothermal capacity through time with greenfield exploration globally, targeted acquisitions and staged developments/ expansions. Key to our organic growth has been a focused investment in both low-enthalpy and high-enthalpy opportunities through being open to development of both upflow and/ or the outflow within a geothermal system. Advancements in technology have been a key enabler of this flexibility in the development approach, as has the development of a world-class resource team.

This keynote paper will provide the Ormat Case Study of Exploration and Growth and will cover future plans, with a focus on key learnings that allow for successful growth.

Notes

44th New Zealand Geothermal Workshop Programme

Tuesday 22 November			
3:00	Registration Open		
5:30-7:00	**Welcome Reception | University of Auckland Engineering Building**		
Wednesday 23 November			
8:00	Registration Open		
8:30	Housekeeping: Sadiq J. Zarrouk		
8:45	Welcome and Opening: Sadiq J. Zarrouk and John O'Sullivan, Co-Directors, Geothermal Institute, The University of Auckland		
9:00	**KEYNOTE TITLE: The ~~10 25~~ 55 (and Counting) Most Common Mistakes in Geothermal Development** **Keynote Speaker | Jim Lawless, Consultant, Lawless Geo-Consulting, New Zealand**		
9:45	**MB CENTURY | INDUSTRY UPDATE |** Justin Lloyd, Robert Mandjes		
10:00	Morning Tea		
	Session 1.1 - INDUSTRY UPDATES	Session 1.2 - RESERVOIR MODELLING 1	Session 1.3 - ENVIRONMENTAL & SOCIAL
	SESSION CHAIR | Scott Henderson	SESSION CHAIR | Mike O'Sullivan	SESSION CHAIR | Ru Nicholson
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
10:30	**HALLIBURTON | INDUSTRY UPDATE |**	69 | MODELLING SOURCE NETWORKS WITH THE WAIWERA GEOTHERMAL FLOW SIMULATOR - Adrian Croucher	11 | CHANGING THE WAY WE MANAGE THE ROTORUA GEOTHERMAL SYSTEM - Penny Doorman
10:45	**SEEEQUENT | INDUSTRY UPDATE |** Jeremy O'Brien	40 | MODELLING THE ROTORUA GEOTHERMAL SYSTEM - John Burnell	14 | METERING GEOTHERMAL TAKES IN ROTORUA – PROJECT UPDATE - Mariana Zuquim
11:00	**AECOM NEW ZEALAND LTD | INDUSTRY UPDATE |** Peter Geoghegan	70 | PRODUCTION HISTORY MODELLING OF A LOW ENTHALPY GEOTHERMAL RESERVOIR USED FOR DISTRICT HEATING: EXAMPLE OF THE PARIS SEDIMENTARY BASIN - Joris Popineau	8 | GEOTHERMAL LAKES AND POOLS OF THE WAIKATO REGION, NEW ZEALAND - Katherine Luketina

11:15	**SOLENSIS NZ LTD | INDUSTRY UPDATE |** Philip Slijp	34 | PROBABILISTIC MWE ESTIMATION USING EXPERIMENTAL DESIGN AND RESPONSE SURFACE METHODOLOGY: FINDINGS FROM FOUR FIELDS - Anthony Ciriaco	13 | TAURANGA GEOTHERMAL SYSTEM – AN OVERVIEW - Mariana Zuquim
11:30	**SCHLUMBERGER | INDUSTRY UPDATE |** Jorge Alejandro Ruiz Torres	76 | MODELLING A REINJECTION NETWORK - Kevin Koorey	27 | RECENT OBSERVATIONS OF GROUND DEFORMATION AT TVZ GEOTHERMAL SYSTEMS USING MULTI-TEMPORAL INSAR - Jim McLeod
11:45	**NALCO WATER /ECOLAB | INDUSTRY UPDATE |** David Rodman, Karl Barrie	2 | INTEGRATION OF GEOSCIENCE, GEOMECHANICS AND GEOSTATISTICS METHOD TO MODEL THE FRACTURE DISTRIBUTION IN NATURALLY FRACTURED GEOTHERMAL RESERVOIR - Muhammad Ikhwan *VIRTUAL PRESENTATION*	32 | HERPETOFAUNA SURVEY OF GEOTHERMAL ECOSYSTEMS IN THE WAIKATO REGION - Katherine Luketina
12:00	**XCALIBUR MULTIPHYSICS | INDUSTRY UPDATE |** Craig Annison	78 | WELLBORE SIMULATION AND EXERGY PROFILE OF OLKARIA DOMES - Saeid Jalilinasrabady *VIRTUAL PRESENTATION*	81 | 2021 ANNUAL NEW ZEALAND GEOTHERMAL VIEW - Ted Montigue
12:15	Lunch		
	Session 2.1 - INDUSTRY UPDATES	Session 2.2 - **GEOCHEMISTRY**	Session 2.3 - PRODUCTION & MANAGEMENT 1
	SESSION CHAIR | Samantha Alcaraz	SESSION CHAIR | Bridget Lynne	SESSION CHAIR | Oliver Maclaren
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
1:15	**KEYNOTE TITLE: Fluid flow at different scales in the geothermal fields of New Zealand Keynote Speaker | Dr Sophie Pearson Grant, Senior Geophysicist, GNS Science, New Zealand**		
2:00	**WESTERN ENERGY | IMPROVEMENT ON CLEANOUT TECHNOLOGY |** Josh Anderson		
2:15	**WESTERN ENERGY | INDUSTRY UPDATE |** Karl Spinks	58 | APPLIED CO2 FLUX TO MONITOR NATURAL EMISSION FROM GEOTHERMAL FIELD, NEW ZEALAND - Jimmy Yang	37 | NON CONDENSABLE GAS REINJECTION TRIAL AT NGATAMARIKI GEOTHERMAL POWER PLANT - Shima Ghafar

2:30	**NZGA | INDUSTRY UPDATE |** Kennie Tsui	56 | HOT OR COLD: A REVIEW OF GEOTHERMOMETRY AT THE KAWERAU AND NGĀ TAMARIKI FIELDS, TAUPŌ VOLCANIC ZONE, NEW ZEALAND - John Mering	28 | DIGITIZATION OF NGATAMARIKI GEOTHERMAL POWER PLANT - Mohamed Dabbour
2:45	**MARUBENI-ITOCHU TUBULARS OCEANIA | INDUSTRY UPDATE |** Christian Tedaldi	10 | TE PUIA SPRINGS, GISBORNE, PAST AND PRESENT FLUIDS - Agnes Reyes	53 | THE STEAMFIELD PROCESS DESIGN AND OPTIMISATION TOOL (SPDOT) - Cristo Umanzor
3:00	Afternoon Tea		
	Session 3.1 - INDUSTRY UPDATES	Session 3.2 - **GEOPHYSICS**	Session 3.3 - PRODUCTION & MANAGEMENT 2
	SESSION CHAIR | Mike Allen	SESSION CHAIR | Bridget Lynne	SESSION CHAIR | Eylem Kaya
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
3:30	**NZTE - Indonesia | INDUSTRY UPDATE |** Putri Wuningsari *VIRTUAL PRESENTATION*	15 | AIRBORNE GRAVITY, ELECTROMAGNETIC AND MAGNETIC DATA FOR GEOTHERMAL EXPLORATION - Craig Annison	36 | CONCEPTUAL MODEL UPDATE FOR THE ROTOKAWA GEOTHERMAL FIELD, NEW ZEALAND - Aimee Calibugan
3:45	**NZTE - Phillippines | INDUSTRY UPDATE |** Maricon Popanes-Lim *VIRTUAL PRESENTATION*	65 | SURFACE HEAT LOSS ASSESSMENT OF GEOTHERMAL FIELDS IN THE TAUPŌ VOLCANIC ZONE, USING REMOTE AND TERRESTRIAL TECHNIQUES - Anya Seward	47 | CHEMICAL DOSING FOR TE MIHI GEOTHERMAL STATION COOLING TOWERS: UPDATE - Morris Young
4:00	**NZTE Taiwan | INDUSTRY UPDATE |** Peg Tsai *VIRTUAL PRESENTATION*	41 | SHALLOW GEOPHYSICAL TOOLS TO INVESTIGATE THE POTENTIAL EXTENT OF SUBSIDENCE ANOMALIES ASSOCIATED WITH HYDROTHERMALLY ALTERED AND COMPRESSIBLE CLAYS - Chris Bromley	33 | DELIVERABILITY CURVE ANALYSIS FROM FLOW PERFORMANCE TEST DATA - Ahmad Fahmi Fanani *VIRTUAL PRESENTATION*
4:15	**NZTE - Japan | INDUSTRY UPDATE |** Jessica Tisch *VIRTUAL PRESENTATION*	80 | EFFECTS OF REINJECTING DILUTED POOL WATER INTO THE ROTORUA GEOTHERMAL SYSTEM - Lucjan Sajkowshi	

Thursday 24 November			
8:45	Housekeeping: Sadiq J. Zarrouk		
9:00	**KEYNOTE TITLE: Geothermal Outlook in Africa: Opportunities and Challenges** **Keynote Speaker: Dr Mereset Zemedkun, Head of UNEP Southern Africa Offices and Lead on Regional Energy Programme in Africa, UNEP**		
9:45	**GEOTHERMAL INSTITUTE | INDUSTRY UPDATE |** Sadiq J. Zarrouk, John O'Sullivan		
10:00	Morning Tea		
	Session 4.1 - INDUSTRY UPDATES	Session 4.2 - RESERVOIR MODELLING 2 / SCALING AND CORROSION	Session 4.3 - DIRECT USE
	SESSION CHAIR | Brian White	SESSION CHAIR | John O'Sullivan	SESSION CHAIR | Bart van Campen
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
10:30	**UPFLOW | INDUSTRY UPDATE |** Paul Siratovich	3 | ANALYSING CYCLIC WELL BEHAVIOUR VIA TIME SERIES ANALYTICS AND RESERVOIR SIMULATION - Paul Michael Abrasaldo	22 | TAURANGA GEOTHERMAL SYSTEM: TEMPERATURE DISTRIBUTION - Lucie Janku
10:45	**EASTLAND ENERGY |INDUSTRY UPDATE |** Ben Gibson or Alice Pettigrew	73 | FIXED AND RANDOM EFFECTS ERROR MODELS FOR GEOTHERMAL SIMULATOR CALLIBRATION - Oliver Maclaren	82 | EFFECT OF RAINFALL ON LOW-HEAT GROUND SOURCE HEAT PUMPS IN NEW ZEALAND - Brad Mudgway
11:00	***WAIKATO REGIONAL COUNCIL | INDUSTRY UPDATE |*** Katherine Luketina	7 | INSIGHTS FROM REACTIVE TRANSPORT MODELS BASED ON BASALT-WATER EXPERIMENTS - Dale Emet Alter	57 | ANALYTICAL AND NUMERICAL MODELLING OF A COAXIAL BOREHOLE HEAT EXCHANGER TO EXTRACT GEOTHERMAL ENERGY - Rohit Duggal
11:15	**BAY OF PLENTY REGIONAL COUNCIL | INDUSTRY UPDATE |** Penny Doorman	17| EXPLORING THE USE OF TEMPERATURE TRANSIENT ANALYSIS DURING PRESSURE FALLOFF TESTING IN GEOTHERMAL WELLS – Sadiq J. Zarrouk	21 | COMMERCIAL ARRANGEMENTS UNDERPINNING AOTEAROA NEW ZEALAND'S INDUSTRIAL SCALE GEOTHERMAL OPERATIONS - Isabelle Chambefort
11:30	**JACOBS | INDUSTRY UPDATE |** Alex Batten	52 | MOVING THE CALCIUM SILICATE (CASIL) PILOT PLANT TO KAWERAU - Thomas Borrmann	6 | THE TE AROHA LOW ENTHALPY GEOTHERMAL SYSTEM, NEW ZEALAND: REVIEW AND ANALYSIS - Katherine Luketina

11:45	**WING | INDUSTRY UPDATE |** Wing Committee Member	77 | SCALING RATE REDUCTION AT WAIRAKEI BINARY THROUGH APPLICATION OF SCALE INHIBITOR - Sophia Richardson	62 | ESTIMATION FOR HEAT LOSS TO THE WORKING FLUID IN THE HEAT EXCHANGER OF AN ORGANIC RANKINE CYCLE FOR A GIVEN CONCENTRATION OF GASES - Anu Choudhary
12:00	**CONTACT ENERGY | INDUSTRY UPDATE |** Jacqui Nelson	31 | IMPROVED ENERGY HARVEST POTENTIAL FROM HIGHLY CORROSIVE GEOTHERMAL FIELDS: LABORATORY FORMULATION DEVELOPMENTS - Cheng-yueh Wu *VIRTUAL PRESENTATION*	79 | PROPOSAL OF CROP DRYING BY ANALYSIS OF GRAIN FARMS WITHIN CLOSE PROXIMITY OF MENENGAI GEOTHERMAL RESOURCE IN KENYA VIA REMOTE SENSING - John Ngethe *VIRTUAL PRESENTATION*
12:15	Lunch		
1:15	**KEYNOTE TITLE: Global Geothermal Exploration and Growth – the Ormat Case Study** **Keynote Speaker | Robin Zuza, Director of Global Exploration, Ormat Technologies, Inc., USA**		
2:00	**GNS SCIENCE | INDUSTRY UPDATE |** Isabelle Chambefort, John Kennedy		
	Session 5.1 - NEW MBIE INVESTMENT		
	SESSION CHAIR | Mark Battley		
	Lecture Theatre 401.401		
2:15	**MBIE INVESTMENT TRENDS -** Alison Slade, Principal Investment Manager & Fund Lead for the Endeavour Fund , MBIE		
2:30	**REVERSING CARBON EMISSIONS IN GEOTHERMAL ENERGY PRODUCTION: TE ARA WHAKAMUA** - Sadiq J. Zarrouk, Eylem Kaya		
2:45	**GREATER ELECTRICITY GENERATION AND INDUSTRIAL HEAT OPPORTUNITIES FROM EXISTING AND GREENFIELDS GEOTHERMAL RESOURCES** - Jim Johnston		
3:00	**ADAPTING TO CLIMATE CHANGE THROUGH STRONGER GEOTHERMAL ENTERPRISES** - Shane Cronin		
3:15	**PŪHIKO NUKUTŪ: A GREEN HYDROGEN GEOSTORAGE BATTERY IN TARANAKI** - David Dempsey		
3:30	**DISCUSSION**		
3:45	Afternoon Tea		

	Session 6.1 - REFLECTIONS ON OUR ENERGY STUDY TOUR IN ICELAND - SPONSORED BY THE GEOTHERMAL INDUSTRY	Session 6.2 - GEOTHERMAL GEOLOGY	Session 6.3 - NEW & EMERGING TECHNOLOGY BEING OFFERED IN NEW ZEALAND
	SESSION CHAIR | Kennie Tsui	SESSION CHAIR | Rony Nugraha	
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
4:15	Nga Tauira o Rūaumoko: Dotty Raroa Mahora Hepi-Manuel Keiha Nicol Corey Ruha *(VIRTUAL)*	24 | GEOTHERMAL: THE NEXT GENERATION - ADVANCING THE UNDERSTANDING OF NEW ZEALAND'S SUPERCRITICAL RESOURCES – PROGRAMME UPDATE - Isabelle Chambefort	Open discussion moderated by: Sadiq J. Zarrouk (Geothermal Institute) and Jaime Quinao (Jacobs)
4:30		83 | HISTORIC FLOW CONDITIONS PRESERVED IN SILICEOUS SINTER VENT WALLS OF THREE NEWLY-EXPOSED HOT SPRING VENTS AT ORAKEI KORAKO, NEW ZEALAND - Bridget Lynne	
5:00 - 6:00	**NEW ZEALAND GEOTHERMAL ASSOCIATION ANNUAL GENERAL MEETING**		
6:30	**NZGW Conference Dinner** **Wētā Workshop Unleashed | SkyCity**		
10:30			

Friday 25 November			
9:15	Housekeeping: Sadiq J. Zarrouk		
9:30	**TRIVENI TURBINES | INDUSTRY UPDATE |** Bharat Sanghi		
9:45	**TAHEKE PROJECT UPDATE |** Aroha Campbell		
10:00	Morning Tea		
	Session 7.1 - INDUSTRY UPDATES	Session 7.2 - FUTURE	Session 7.3 - DRILLING and WELL TESTING
	SESSION CHAIR | Katie McLean	SESSION CHAIR | Michael Gravatt	SESSION CHAIR | Adrian Croucher
	Lecture Theatre 401.401	Lecture Theatre 405.460	Lecture Theatre 405.470
10:30	**WING PANEL - Paving the way: A WING-led discussion on the tangible returns of progressive values and policies in the workplace** Chair: Gabby Buchanan (WING/Western Energy) Panellists: Robin Zuza (Ormat Technologies), Jan Bibby (Contact Energy), Guillermo Merelo (The University of Auckland) and Ben Pezaro (Mercury)		
11:00	**MERCURY ENERGY | INDUSTRY UPDATE |** Beth Wotherspoon	30 | GRADUATE GEOTHERMAL TRAINING IN THE EUROPEAN ECONOMIC AREA - Juliet Newson	38 | QUANTITATIVE PHASE ANALYSIS OF HTCC-EM LOGS - Richard Williams
11:15	**FLOW STATE SOLITIONS LTD | INDUSTRY UPDATE |** Jonathon Clearwater	39 | AN AUSTRALIAN GEOTHERMAL RENAISSANCE? - Rosalind Archer *VIRTUAL PRESENTATION*	45 | DEVELOPMENT OF DOWNHOLE COOLING CHARTS TO PREVENT DRILLING PROBLEMS IN GEOTHERMAL WELLS THROUGH WELLBORE TEMPERATURE SIMULATION - Sara Ishikawa
11:30	**STRIKE STIMULATION | AN INNOVATION IN GEOTHERMAL WELL STIMULATION - RECENT PATENT APPLICATION FILED** - Mark Horwell	23 | GEOTHERMAL HYDROGEN WELL MODELLING - Isaac Severinsen	4 | LWD ACQUISITION OF CALIPER AND DRILLING MECHANICS ON GEOTHERMAL DRILLING OPERATION, A CASE STUDY IN SORIK MARAPI FIELD – INDONESIA - Nikolai Sirait
11:45	**MITCHELL DAYSH | INDUSTRY UPDATE |** Noel Kortright	25 | CARBON NEGATIVE GEOTHERMAL: FINANCIAL ANALYSIS FOR COMBINED GEOTHERMAL, BIOENERGY AND CARBON DIOXIDE REMOVAL - Karan Titus	12 | 3-D MODELLING OF SOKORIA GEOTHERMAL FIELD, ENDE, FLORES, INDONESIA - Larasati Triwening *VIRTUAL PRESENTATION*
12:00	Lunch		

1:00	**GEOTHERMAL RISING STUDENT CHAPTER (NEW ZEALAND & OCEANIA) INAUGURAL MEETING**
	1. Introduction and importance of the chapter
	2. Introduction to Geothermal Reservoir Modelling - John Burnell
	3. Carbon dioxide emissions from geothermal power generation - Katie McLean
	4. Closing Remarks
2:00	Workshop awards and close - Sadiq J. Zarrouk, John O'Sullivan

Abstracts

2 | INTEGRATION OF GEOSCIENCE, GEOMECHANICS, AND GEOSTATISTICS METHOD TO MODEL THE FRACTURE DISTRIBUTION AND PERMEABILITY IN NATURALLY FRACTURED GEOTHERMAL RESERVOIR

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Keywords: *geothermal, fracture, DFN, reservoir, modelling*

It is well-known that geothermal reservoirs are mostly controlled by secondary permeability, for instance, natural fractures zone and fault, as the natural conduit for geothermal fluid flow. However, not all natural fractures contribute to the fluid flow. In this paper, we attempt to identify the contributed-natural fractures to hydrothermal flow by using the geoscience data, geomechanics and geostatistics method in the naturally-fractured reservoir characterization through the discrete fracture network (DFN) model.

A geomechanics method is used to filter the fractures along the borehole so the fractures input in the modelling only uses the critically-stressed fractures as the possible permeable fractures. This driver is converted into an intensity log and mainly controls the vertical spacing fracture distribution in the 3D model. In the horizontal dimension, we utilize the deterministic surface fault model and microearthquake (MEQ) events distribution, which is interpreted as an indication of fluid flow through fault or fracture to give us geologically reasonable spatial control in modelling the DFN. To confirm the modelled flowing natural fractures distribution, we upscale the DFN model into the permeable zone model. The permeability calculation parameter is derived from the assumption that we generate from image log data such as aperture and modelled fracture length. This permeability model will compare with the actual feedzone or depth of sweet spots in the well which has been proved to contribute to the fluid flow. The discrete fracture network model derived from this method gives a fit permeability model with the actual flow condition in the well-scale. The reason is that the permeability control, in this case, is mostly associated with fracture intensity. In other words, a high-intensity fracture zone with a certain orientation penetrated by the well will give high permeability magnitude, thus characterizing the reservoir through the DFN model will be a benefit.

Session 1.2

3 | ANALYSING CYCLIC WELL BEHAVIOUR VIA TIME SERIES ANALYTICS AND RESERVOIR SIMULATION

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Keywords: *Geothermal energy, machine learning, feature engineering, time-series analytics, fractional dimension, reservoir modelling*

The geothermal energy industry has always been in constant flux with the advent of new technology and the rich experience of long-time geothermal operators. However, the industry's growth has been tempered by the inherent risks associated with geothermal energy extraction, particularly by unfavourable drilling outcomes.

In this study, we looked at the characteristics of a low permeability geothermal production well exhibiting weak discharge metrics relative to other nearby wells. Fluctuations in the maximum discharge pressure of the target well have caused interruptions in its utilisation resulting in additional costs and downtime for the geothermal operator.

The performance of the target well was analysed using sensor data from the surface facility, and a workflow based on systematic time-series feature engineering for improved utilisation of the well was proposed. A predictive model was trained using the extracted time-series features and evaluated to forecast the occurrence of low discharge pressure events in the target well. The same dataset was then used to develop a reservoir model that captured the behaviour of the target well observed during post-drilling completion tests and while producing into the surface facility.

Session 4.2

4 | LWD ACQUISITION OF CALIPER AND DRILLING MECHANICS AS A NEW APPROACH ON GEOTHERMAL DRILLING OPERATION, A CASE STUDY IN SORIK MARAPI FIELD – INDONESIA

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Keywords: *Geothermal Drilling; Geothermal Formation; Geothermal Technologies; LWD; Vibration; Caliper; Case Study.*

The geothermal drilling environment presents many obstacles that limit the use of directional-drilling and logging-while-drilling (LWD) technologies, such as borehole washout, mud losses, severe vibration, and high temperature. The case study presented in this paper demonstrates a novel practice to enhance data logging in geothermal drilling by deploying advanced telemetry and LWD technologies. This operation aims for continuous improvement in geothermal drilling operations.

The case study covers the 12.25-in. hole section of well XXE-05 in the Sorik Marapi Geothermal Field. The LWD string consisted of electromagnetic (EM) telemetry, pressure while drilling (PWD), vibration (DDSr), and acoustic calliper (ACAL). Through this tool configuration, the operator acquired drilling mechanics and calliper logs in real-time and recorded mode, enabling effective monitoring and evaluation of wellbore stability.

Throughout the real-time acquisition, EM telemetry provided a data rate to the surface unit three times faster than conventional tools. Furthermore, with the integration of calliper and drilling mechanics data (vibration and equivalent circulating density), the borehole conditions became more visible to the directional driller, allowing better control of drilling parameters to minimize vibration and achieve optimum hole cleaning in washed-out or tight formation sequences. The recorded data from the calliper sensor indicated an average of 8.6% washout for the entire 12.25-in. interval. Washout intervals were compared with loss occurrence during drilling and the presence of smectite-bearing paleosols, showing that the washout zones associate with the latter, supporting the smectite-bearing paleosol model in explaining

the cause of stuck pipe incidents in the Sorik Marapi field. In addition, measurements of hole ovality were compared with the interpreted fault trend, providing further insight into the existing model. In general, this LWD case study has given added value through geothermal borehole characterization, from drilling hazard identification to subsurface analysis.

Identified challenges while running LWD in this geothermal environment were addressed for future improvements, such as the effect of tool eccentricity and the impact of vibration. Perusal of both real-time and recorded calliper and drilling-mechanics data has opened various possibilities for maximizing the sensor usage in future wells.

Session 7.3

6 | THE TE AROHA LOW ENTHALPY GEOTHERMAL SYSTEM, NEW ZEALAND: REVIEW AND ANALYSIS

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Keywords: geothermal, low-enthalpy system, geyser, carbon dioxide, Te Aroha, aragonite, New Zealand.

All available data related to the Te Aroha low enthalpy geothermal system were collated and analysed. The geothermal system produces low temperature bicarbonate and mineral-rich fluid, historically used directly for drinking and bathing, although drinking the water is now discouraged. To extract higher quantities of fluid from the system to satisfy the demand, bores have been drilled within the domain. As of 2014, there are three geysering (self-discharging) bores, within the Domain, and geysering is driven by the release of carbon dioxide gas from solution.

The Te Aroha Domain is a historic area with collected data dating back to 1889. The data can be used to determine how the system has been affected by exploitation. All the relevant studies conducted on the Te Aroha domain have been analysed to gain a further understanding of the geothermal system.

This work gives an insight into the geological setting of the geothermal resource and models and interprets the system using the available wellbore pressure and temperature data.

Session 4.3

7 | INSIGHTS FROM REACTIVE TRANSPORT MODELS OF BASALT AND WATER EXPERIMENTS

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Keywords: *TOUGHREACT, reactive transport, numerical model, supercritical, basalt*

TOUGHREACT™ was used to create reactive transport models to match the results of detailed laboratory simulations of the interactions between tholeiitic basalt and distilled de-oxygenated water. The fluid-rock interaction experiments were carried out under two sets of conditions, one under subcritical conditions (350 °C and 490 bar) and the second under supercritical conditions (400 °C and 500 bar). The experimental environments are associated with seafloor spreading centres and mid-ocean ridges.

Methodologies were developed for building the reactive transport models, focusing primarily on the reaction thermodynamics and kinetics parameters at high temperature and pressure conditions. Initial geochemical assumptions made for the models were also validated and updated during model calibration.

Based on the model, precipitation rates deviated significantly from the combination of the estimated kinetic parameters and mineral surface area estimates, while there is an agreement in terms of dissolution rates. In concurrence with experimental results, mineral solid solutions dissolved stoichiometrically in the model except for bytownite, whose albite component was preferentially dissolved, resulting in its alteration to anorthite. The volumes of basalt glass in the samples were also higher than experimental estimates based on the models. Sulfide inclusions in the glass were added to the model assumptions to explain the observed sulfate and sulfide concentrations while the glass dissolved. The potassium concentration trends in the effluents also necessitated the inclusion of K-feldspar in the model system.

Session 4.2

8 | GEOTHERMAL LAKES AND POOLS OF THE WAIKATO REGION, NEW ZEALAND

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Keywords: *Waiotapu, Rotokawa, Taupō Volcanic Zone, Lake Rotowhero, Lake Whangioterangi, Lake Ngakoro, Lake Orotu, Lake Rotokawa, Champagne Pool.*

This paper, abridged from a chapter in a forthcoming book, (Özkundakci et al., in press, 2022), describes the major geothermal lakes and pools in the Waikato Region in terms of their setting, physical characteristics, geomorphology, geochemistry, and invertebrate and microbial ecology. It draws on research on Waikato geothermal lakes published from the 1950s to 2022.

Session 1.3

10 | TE PUIA SPRINGS, GISBORNE, PAST AND PRESENT FLUIDS

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Keywords: *Te Puia, fluid inclusions, fluids, geochemistry***.**

Currently, the Te Puia hot springs discharge up to 71-77°C CH_4-rich Na-Ca-Cl fluids with Cl concentrations of 5100-9800 mg/kg, gas:water ratio of 0.1, and an estimated annual water flowrate of ~2.85 x 105 m^3/a. Fluid inclusions in calcite veins from sinter mounds adjacent to hot springs yield homogenization temperatures (median: 80°C) and salinity (8300 mg/kg Cl), similar to present-day surface discharge measurements suggesting that spring temperatures and Cl contents have been relatively constant since the hot springs appeared, probably <140k years ago. However, gas ratios in fluid inclusions deviate from present-day measurements. In particular, fluid inclusions contain higher relative concentrations of CO_2 and H_2S and lower relative concentrations of hydrocarbons. Within the hydrocarbon fraction, fluid inclusion gas contains higher concentrations of C2+ alkanes, as compared to vent gases, and detectable benzene. This suggests some temporal variability in volatile composition, while temperatures and TDS remained relatively unchanged.

Session 2.2

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11 | NGA WAI ARIKI O ROTORUA CHANGING THE WAY WE MANAGE THE ROTORUA GEOTHERMAL SYSTEM

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***Keywords:** geothermal system, Rotorua, sustainable management, geothermal surface features, system management plan.*

The current review of the Rotorua Regional Geothermal Plan and the development of a system management plan (SMP) for the Rotorua Geothermal System is involving a comprehensive process. The process so far has included reviewing and integrating complex datasets, taking into account evolving planning processes, providing for competing community values, and giving effect to a partnership approach under the Treaty of Waitangi (Te Tiriti). The focus of work to date has been on building an evidence-base to inform our management approach, which has included assessing the state or health of the geothermal system and the review of the Council-owned Rotorua geothermal reservoir model. One of the main challenges has been refining a protection area around the Whakarewarewa geyser field, and in translating modelling results into meaningful predictions and allocation limits that supports the objectives of the plans. Co-design of parts of the SMP with Māori, and wider community engagement, has been integral to the development of the SMP. These unique perspectives are reflected in the scope of the SMP, which extends beyond the traditional technical content, to include principles of management that reflect a te Ao Māori perspective. Protecting surface features and intergenerational customary uses, while providing for extractive uses, has required careful consideration in our long-term objectives. The identification of limits on use is one of the tools we will use to achieve these objectives. Managing community and industry expectations around increased use of geothermal within sustainable limits of the system, remains a challenge.

Session 1.3

12| 3D MODELLING OF SOKORIA GEOTHERMAL FIELD, ENDE, FLORES, INDONESIA

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***Keywords:** 3D geothermal modelling, Leapfrog, Sokoria, geological model*

Sokoria geothermal field is one of a volcanic-hosted geothermal system located in East Nusa Tenggara, Indonesia, precisely in Kelimutu volcanic complex. The thermal manifestations are distributed on the flank of the volcano and mainly consist of acidic lakes, fumaroles, and springs. Several 3G studies and surveys have been conducted in this geothermal area, including more than five deep wells drilling.

Geothermal geoscience is a three-dimensional (3D) science, thus the best way to present it is through a 3D model, as the limitations of a two-dimensional (2D) model might reduce the detailed nature of field scale data. One of the methodologies and tools to generate a 3D model is by using 3D modelling software, which in this case is Leapfrog Geothermal software. Leapfrog Geothermal is specifically designed for the geothermal industry and provides the integration of geothermal datasets.

This study aims to create a 3D conceptual model that represents the geological and geothermal systems of the field. This study utilises secondary data such as geological, geophysical, geochemistry, well data, and raster data from openly sourced platforms, with additional analysis to facilitate the extent of the model. Despite the lack of subsurface data, application of the modelling method is fruitful and hopefully could be utilized for any future consideration in developing the field.

Session 7.3

13 | TAURANGA GEOTHERMAL SYSTEM – AN OVERVIEW

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Keywords: *Tauranga geothermal system, warm system, direct use, discharges.*

The Tauranga Geothermal System (TGS) is an extensive warm water system with few geothermal surface features. Geothermal-groundwater (GGW) is produced at 30-70 °C from wells mostly 200-600 meters deep. The TGS is available for sustainable use and development, and discharges are managed to minimise the effects on the receiving environment. The main uses are for space and water heating for municipal pools, private domestic space and water heating and mineral pools, and space heating for greenhouses. The use of GGW for irrigation and frost protection is not considered a 'geothermal use' nor a method of discharge. However, it accounts for around 24% of the allocated geothermal water from the TGS. This paper describes the current situation with geothermal takes and discharges from the TGS, aspects of chemistry relevant to the use and discharges to various receiving environments, and the current knowledge of the geothermal energy resource. This is based on published technical reports, historical data stored in the Bay of Plenty Regional Council (BOPRC) archives, and data from resource consent applications and compliance processes. BOPRC is currently building its body of knowledge on this large geothermal system to inform and improve the integrated management of this large geothermal-groundwater resource.

Session 1.3

14 | METERING GEOTHERMAL TAKES IN ROTORUA – PROJECT UPDATE

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Keywords: *Rotorua Geothermal System, metering, efficiency, flow loop, heat meter, surface features, conservation.*

As part of the review of the Rotorua Regional Geothermal Plan, the Bay of Plenty Regional Council (BOPRC) established a metering project team to develop and effectively implement metering of the geothermal takes for fluid and energy in Rotorua. Currently, data on the actual use of the geothermal takes is of low accuracy and does not reflect the use profile over time. Therefore, this data is not suitable for developing a finer understanding of how different patterns and use levels affect the geothermal system, including the vulnerable geothermal surface features. BOPRC is closing this gap by starting to require continuous metering of ~75% of the water and heat takes from the Rotorua system.

To achieve that, BOPRC first developed, trialled and proved a flow loop system that can meter the geothermal water takes with reasonable accuracy. Lately, BOPRC has also identified heat meters as a suitable method for monitoring heat and water takes in Rotorua. Take size thresholds in which different metering requirements would be required (e.g. spot measurements, continuous metering) were defined, based on the distribution of take sizes, user profile and geographical coverage, to close spatial gaps, particularly on the 1.5 km mass abstraction exclusion zone, which protects the geyser flat. The analysis of the flow loop trial data showed that the actual use profile mirrored the expected profile for the different types of use (e.g. domestic, commercial). Cost estimates for implementing metering for each user affected by the new metering requirement were carried out to understand the financial implications of those measures to the consent holders. The results showed that the costs are considered reasonable and proportional to the different user profiles and the new metering requirements. This project is now in the stages of rolling out to the largest users.

Session 1.3

15 | AIRBORNE GRAVITY, ELECTROMAGNETIC AND MAGNETIC DATA FOR GEOTHERMAL EXPLORATION

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Keywords: *Geothermal Exploration, HeliFalcon, AGG, airborne gravity gradiometry, Helitem, AEM, airborne electromagnetics, airborne magnetics, time domain electromagnetics*

Advances in airborne geophysical technologies have enabled rapid and efficient acquisition of high-resolution gravity, electromagnetic and magnetic datasets in rugged volcanic terrains.

HeliFalcon® airborne gravity gradiometer (AGG), and Helitem® airborne electromagnetic (AEM) and magnetic systems have been used to acquire high-quality multiphysics datasets which have proven effective for geothermal exploration.

A case study from a project in Japan is used to demonstrate how the acquisition, processing,

and integrated interpretation of high-resolution airborne datasets, along with other available information, is providing significant benefit to geothermal assessment programs.

Session 3.2

17 | EXPLORING THE USE OF TEMPERATURE TRANSIENT ANALYSIS DURING PRESSURE FALLOFF TESTING IN GEOTHERMAL WELLS

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Keywords: *temperature transient analysis, pressure falloff testing, geothermal well.*

The transient temperature analysis could cast different information from geothermal formations. One technique that utilises transient temperature analysis is the static formation temperature test, a method that has several decades in use. On the other hand, a new technique called Temperature Transient Analysis (TTA) has been used in the last few years. This method uses the transient temperature data generated during pressure buildup or falloff tests to estimate certain parameters from geothermal reservoirs that could complement the analysis carried out using Pressure Transient Analysis (PTA). The present paper explores the possible outcomes that could be obtained using Temperature Transient Analysis (TTA) in conjunction with Pressure Transient Analysis (PTA).

Session 4.2

21 | COMMERCIAL ARRANGEMENTS UNDERPINNING AOTEAROA NEW ZEALAND'S INDUSTRIAL SCALE GEOTHERMAL OPERATIONS

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Keywords: *geothermal energy, geothermal electricity generation, renewable energy, business structure, direct use, geoheat, Geothermal: The Next Generation (GNG)*

Geothermal energy offers a proven, indigenous, renewable resource, with capacity to supply greater levels of primary energy, green electricity and green heat as New Zealand transitions to a lower emission, more climate resilient economy.

Deeper geothermal exploration could lead to additional growth in the geothermal sector, supplying more renewable energy for New Zealand as the nation decarbonises. However, exploring deeper comes with a greater risk profile than present geothermal developments that are accessing shallower resources.

New Zealand's legislative environment has established the regulatory regimes that manage access to geothermal energy resources, environmental effects, health and safety, and the rights associated with land ownership, including rights to geothermal resources.

This paper overviews the current business venture arrangements of large geothermal operations, both electricity and process heat (geoheat), and considers what type of business venture arrangements might be best placed to accelerate deep geothermal exploration and with successful exploration the subsequent development investment.

Session 4.3

22 | TAURANGA GEOTHERMAL SYSTEM: TEMPERATURE DISTRIBUTION

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Keywords: *Tauranga geothermal system, temperature logs, geothermal gradient*

The city of Tauranga in the Bay of Plenty region of New Zealand lies on a warm (30 – 70°C) water geothermal resource classified as Geothermal Management Group 5 by the Bay of Plenty Regional Resources Plan. Despite the widespread use of the resource, mostly for bathing and frost protection and irrigation, this reservoir's temperature distribution and extent is poorly understood.

We constructed subsurface temperature maps in 50 m depth intervals to 300 m below sea level using temperature profiles from 40 wells in the Tauranga and Maketu low-temperature geothermal fields to constrain the resource and localise the hottest zone. These maps "slices" show two temperature anomalies.
One, hotter (~50°C) but poorly constrained due to insufficient data, lies southwest of Maketu Peninsula between Maketu and Te Puke. The other is below the city of Tauranga. Both thermal anomalies are confirmed by other evidence.
The Maketu anomaly has been subject to interest since the 1960s due to the presence of nearby hot springs and a low resistivity anomaly. The Tauranga anomaly is expected as hundreds of water wells are used mostly for domestic and recreational purposes, with discharge temperatures mostly in the range of 35–45°C.

Additional measurements, especially temperature logs in more wells in the area, as well as thermal conductivity and permeability measurements on samples of representative

lithologies (rhyolites, andesites, ignimbrites and sediments of the Tauranga Group), are needed for a deeper understanding of this low-temperature geothermal resource and its potential commercial use.

The Maketu anomaly is supported by geological, geophysical and hydrogeological evidence, so it might be worthy of further exploration.

Session 4.3

23 | GEOTHERMAL HYDROGEN WELL MODELLING

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Keywords: *Geothermal hydrogen well, renewable energy, green hydrogen, wellbore modelling*

A geothermal hydrogen well is a potential renewable energy solution to utilise otherwise unused geothermal or hydrocarbon wells as a passive source of hydrogen. This solution uses thermoelectric generators (TEG) to produce high current, low voltage electricity in situ. The electrical current is also used in situ to produce hydrogen through electrolysis of water. The solution is circulated in a coaxial borehole heat exchanger (CBHE) with the electrolyser situated in the annulus. This circulating fluid is necessary for electrolysis but also removes unwanted heat from the TEG and electrolyser. This work describes the developed solution and accompanying model in detail. A one-dimensional ordinary differential equation is used to simulate the heat transfer from the reservoir through the TEG, electrolysis and CBHE sections, predicting power and hydrogen production along the length of the well. An optimisation is performed to maximise hydrogen production rate while minimising parasitic pump and cooling tower power.

Session 7.2

24 | GEOTHERMAL: THE NEXT GENERATION, ADVANCING THE UNDERSTANDING OF NEW ZEALAND'S SUPERCRITICAL RESOURCES – PROGRAMME UPDATE

Isabelle Chambefort[1], Craig Miller[1], Bruce Mountain[1], Brian Carey[1] and the Geothermal: The Next Generation Team[1,2,3,4,5,6,7]

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Keywords: *Geothermal: the Next Generation, Explore, Understand, Integrate, Supercritical.*

New Zealand is endowed with generous geothermal resources. NZ's deeper, currently untapped, supercritical geothermal resources have the potential to provide a source of renewable energy. New Zealand's unique tectonic setting, with its active rifting arc, producing voluminous magma and outstanding heat flow, delivers exceptional opportunities for geothermal development.

Started in October 2019, the Geothermal: the Next Generation MBIE research programme aims to resolve the critical geological, geophysical and geochemical questions on supercritical reservoir formation, and identify the technological challenges of establishing supercritical geothermal as part of the solution for Aotearoa's carbon neutral energy future.

The research team is composed of New Zealand and overseas geophysicists, geologists, experimental geochemists, reservoir and geodynamic modellers, as well as, economic and Māori strategic investment advisors.

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Here we present an update on the main objectives, relevance, future linkages, and the initial results three years into this challenging and strategic scientific endeavour. Aotearoa New Zealand's supercritical journey is underway and on display through www.geothermalnextgeneration.com and associated social media connections.

Session 6.2

25 | CARBON NEGATIVE GEOTHERMAL: FINANCIAL ANALYSIS FOR COMBINED GEOTHERMAL, BIOENERGY AND CARBON DIOXIDE REMOVAL

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Keywords: *Geothermal, BECCS, CO2 sequestration, forestry residues, energy economics*

Coupling bioenergy with carbon capture and storage (BECCS) is a net carbon negative process that has been highlighted by the Intergovernmental Panel on Climate Change as an important technology for offsetting greenhouse gas emissions. Despite their proposed efficacy as both a power production and negative emissions tool, BECCS technologies currently lack widespread use due to their high costs. Coupling geothermal fields with BECCS operations by dissolving biogenic CO2 in geothermal brine could reduce the transportation and injection costs by leveraging geothermal reinjection apparatus for sequestration.

Dissolved biogenic CO2 could be stored more safely in a geothermal reservoir through pressure maintenance, sidestepping leakage concerns from storing buoyant supercritical CO2. Additionally, geothermal and bioenergy synergize as electricity generation technologies, leading to higher utilization efficiencies.

Our analysis shows that geothermal-BECCS plants could have operational emissions intensities of -137 gCO2/kWh to -928 gCO2/kWh, offsetting 30% to 206% of the emissions from a standard natural gas plant. For the CO2 price of NZD 80/tonne in 2022, geothermal-BECCS could have a levelized cost of electricity (LCOE) of NZD 163 to 203/MWh, cheaper than overseas standalone BECCS estimates NZD 267 to 426/tonne. For a projected CO2 price increase of NZD 160/tonne by 2035 suggested by the Climate Change Commission, geothermal-BECCS plants could have LCOEs as low as NZD 29 to 54/MWh. This would be more competitive than geothermal plants while also removing up to 110,000 tonnes of CO2 a year.

Session 7.2

26 | THE ~~10~~ 25 55 (AND COUNTING) MOST COMMON MISTAKES IN GEOTHERMAL DEVELOPMENT

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Keywords: *Geothermal development, economics, strategy, plant design, exploration, drilling.*

Although geothermal development worldwide is a success story, there have also been sub-optimal results. A number of common themes have been observed. The most important over-arching reason for failure (other than simply poor quality resources) appear to be: (1) lack of communication between scientific disciplines and between the resource and engineering

design teams, (2) failure to maintain flexibility, updating and changing working assumptions as the project progresses, (3) lack of recognition of the requirements of long term operation of a successful project such as operability and steam quality, and (4) lack of recognition that geothermal development is fundamentally an economic activity and the project must make financial sense both initially and into the future.

Keynote 9am 23rd November

27 | RECENT OBSERVATIONS OF GROUND DEFORMATION AT TVZ GEOTHERMAL SYSTEMS USING MULTI- TEMPORAL INSAR

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Keywords: *Tokaanu, Ngā Tamariki, Zealand, StaMPS, geothermal, volcanic, subsidence, InSAR, Sentinel*

Ground deformation data captured by Interferometric synthetic-aperture radar (InSAR) satellites is of increasing interest for environmental monitoring of geothermal systems worldwide. This study investigates recent deformation patterns associated the Ngā Tamariki and Tokaanu geothermal systems in the Taupō Volcanic Zone (TVZ), New Zealand. At Ngā Tamariki, InSAR agrees with 2019-21 levelling survey results, which provides confidence in the method. At Tokaanu, vegetation covers most of the study area, which may degrade InSAR results and overwhelm subtle deformation signals.

Session 1.3

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28 | DIGITALISATION OF NGATAMARIKI GEOTHERMAL POWER PLANT

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Keywords: *Digital Twin, OEC, Ngatamariki, Integrated, Process Simulation.*

With the commitment of the New Zealand Government to achieve carbon neutrality by 2050, the country is facing the challenge of replacing their coal and natural gas-derived electrical generation with renewable energy. One such method is increasing geothermal energy generation either by development of new plant, or optimization of existing plants. To assist in optimization, geothermal plants can be digitalised to assist the operator to predict working conditions of the plant. The ability to determine where loss in efficiency is occurring in the plant results in rectification becoming more seamless.

This paper discusses the methodology of taking large amounts of plant data of an existing plant and deriving a digital twin for Ngatamariki in the process simulator Symmetry. An initial set of real time data from an Organic Rankine Cycle plant were used to calibrate and calculate pressure drops and heat transfer coefficients across the plant components using regression that is built into Symmetry using different start and stop boundaries. These boundaries are important to allow regression on unit operation parameters to be more effective. An important aspect of this methodology is recognizing the importance of boundary locations. For example, inlets into pumps and turbines as typically boundary ends. This is due to the hard constraint of the material phase e.g liquid, or gas entering them. The results from using this approach are a quick and yet effective digital twin, with errors ranging from 0.5% to 4.5% absolute.

Session 2.3

30 | GRADUATE GEOTHERMAL TRAINING IN THE EUROPEAN ECONOMIC AREA

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Keywords: *geothermal engineering education, EU strategic partnership and Erasmus Mundus programmes, student mobility, international training, applied sciences, renewable energies utilization, geothermal training, geothermal energy*

Intensive graduate courses in geothermal energy have traditionally been the remit of nations with a long tradition of high temperature geothermal utilization: Iceland, Italy, Japan, and New Zealand. In addition, El Salvador has had a Spanish language Geothermal Diploma Course for Latin America since 2010, courses in Indonesia, taught in Indonesian, and African geothermal training

is under development. However, increasing impacts of climate change, geopolitical conflict and related refugee movement has drawn attention to the need for clean, renewable and sustainable energy worldwide. This attention has created interest in geothermal research and utilization in many countries that do not have high temperature, tectonic margin or volcano-related, geothermal systems. This paper discusses the ongoing development of an EU-funded European Erasmus + Strategic Partnership dealing aiming at the construction of a geothermal course curriculum for international students, involving Iceland France, Germany and Croatia.

Session 7.2

31 | IMPROVED ENERGY HARVEST POTENTIAL FROM HIGHLY CORROSIVE GEOTHERMAL FIELDS: LABORATORY FORMULATION DEVELOPMENTS

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Keywords: *Neutralization, Taiwan Geothermal Energy, Volcanic Geothermal Field, Sustainable Energy.*

To meet the urgent demands of Taiwan's energy diversified governmental policy by 2025, we take on the endeavor of expanding the exploitation operations focusing on screening potential geothermal resources across whole region. Numerous examples of the acidic conditions of geothermal fluid observed exhibit presence of extremely corrosive fluids (pH < 2) at the sites investigated; thus, any attempt of building full-scale power plant and whole project would be cost prohibited under such harsh conditions. To alleviate some of these unique challenges, we explored the potential of developing injective amendments and formulations targeting for the production wells, aiming to effectively neutralize extreme acidity of geothermal fluids in-situ to allow better transport of hot fluid while provide reliable power generation and safe plant operations.

We have successfully developed several potential formulations indicating some unique characteristics as, 1. reasonable chemical dosage (0.5 to 2.3 wt%), 2. rapid reaction rate (between minutes to few hours), 3. elevated temperature activated (reactions occurred only after reach the threshold level), 4. safe chemicals and low cost, 5. minimum or no scaling formation or line plugging concern (unlike simple alkaline case).

Results of this study reveal the newly developed formulations can be easily adapted to a variety of fields inherited with strong to extreme acidic geothermal fluid conditions. And they demonstrated superior performance in modifying acidic geothermal water to weak acid or neutral, and the post treated samples showed no sign of scaling after few weeks or extended period. We anticipated the improved chemicals offer great potential to mitigate the excessive damages caused by acid erosion of the pipelines and generators, while reduce the maintenance costs of pipes and machinery. Further investigations are underway to verify the effectiveness of these formulations for a variety of geothermal fluids retrieved from sites under different site-specific conditions to collect additional engineering data for the planned field pilot test.

Session 4.2

32 | HERPETOFAUNA SURVEY OF GEOTHERMAL ECOSYSTEMS IN THE WAIKATO REGION

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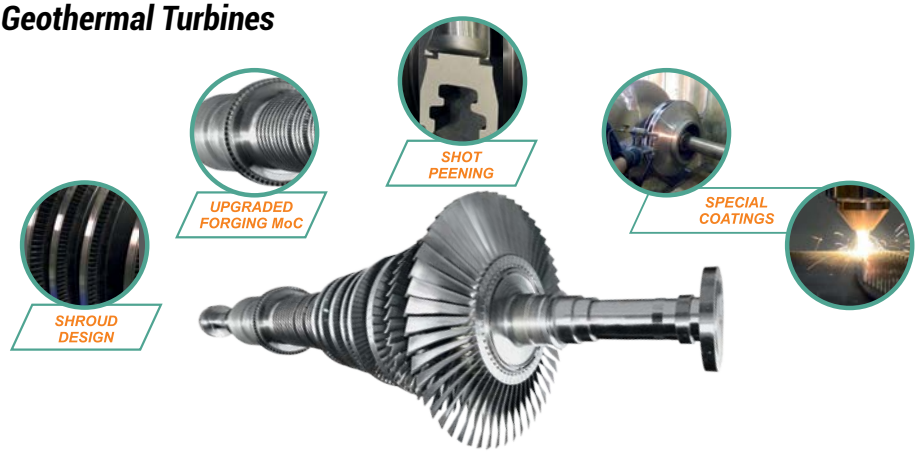
Keywords: *Wairakei, Reporoa, Orakei Korako, Craters of the Moon, Longview Rd, fauna, skink, Oligosoma, tracking tunnel.*

The indigenous ground dwelling fauna of geothermal ecosystems in the Taupō Volcanic Zone is relatively poorly understood. A tracking tunnel survey was conducted with the aim of identifying the ground-dwelling vertebrates living in geothermal habitats at four sites in the Taupō Volcanic Zone, with the specific intent of locating and identifying native lizard populations at these sites. 162 tracking cards were collected from a total of 60 tracking tunnels over a period of 40 days. The tracks recorded on the tracking cards were identified, and Chi squared (X^2) analysis was performed to identify the strength of the relationships between the type of prints detected, the vegetation type at the tunnel, and the site from which the tunnels were collected. In total, the prints of six different terrestrial vertebrate species and groups of vertebrates were identified. The common brushtail possum (Trichosurus vulpecula), the European hedgehog (Erinaceus europaeus), various rat species (Rattus sp.), an unidentified mustelid species (Mustela sp.), house mice (Mus musculus) and an unidentified skink species, likely indigenous, (Oligosoma sp.) were detected at these sites. Print detection exhibited a relationship with both site and with vegetation type, though it was unclear whether site related factors or vegetation related factors had the more significant effect on the distribution of terrestrial vertebrates. This study is the first of its kind to find evidence of a lizard association with a geothermal habitat in New Zealand. Additional research will be necessary to identify the species of the lizard detected.

Session 1.3

Life Enhancement program for Geothermal Turbines



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33 | DELIVERABILITY CURVE ANALYSIS FROM FLOW PRODUCTION TEST DATA

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Keywords: *flow production test, deliverability output curve*

The Flow Production Test is an alternative method to frequently update well deliverability curves with minimum disturbance to power plant generation. This method has been conducted in our fields such as Lahendong (Fanani, 2020), Ulubelu (Sugiharto, 2020), and Lumut Balai. There have been several approaches used to create a deliverability curve from Flow Production Test data. An analysis will be performed to compare the most suitable deliverability curve equation for each well.

Session 3.3

34 | PROBABILISTIC MWE ESTIMATION USING EXPERIMENTAL DESIGN AND RESPONSE SURFACE METHODOLOGY: FINDINGS FROM FOUR FIELDS

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Keywords: *Probabilistic, Prediction, Experimental Design, Response Surface Methodology, Polynomial Model.*

Stochastic power (MWe) capacity prediction from a calibrated reservoir model through building a polynomial model and implementing Monte Carlo simulation is the main focus of this work. The polynomial model is the fitted response of the numerical model to changes in the model's uncertain parameters. Six key stochastic parameter sets were chosen to build several versions of the numerical model using the Experimental Design (ED) and Response Surface Methodology (RSM) framework. This approach was tested and implemented in the calibrated reservoir model of the Rotorua, Ohaaki, Wairakei and Leyte Geothermal Fields using four Experimental Designs (ED): the three-level Full Factorial, two-level Full Factorial, three-level Box-Behnken and two-level Plackett-Burman design. Overall, the ED-RSM framework using the Plackett-Burman fractional design proved to be a practical approach for estimating potential capacity from a calibrated natural-stated model using the chosen six uncertain parameters: permeability in the x, y and z-direction, porosity, reinjection enthalpy (RI Enthalpy), and the fraction of reinjection (%RI).

Session 1.2

36 | CONCEPTUAL MODEL UPDATE FOR THE ROTOKAWA GEOTHERMAL FIELD, NEW ZEALAND

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Keywords: *Rotokawa, conceptual model*

This paper presents the updated conceptual understanding of the Rotokawa geothermal field, which is located within the Taupō Volcanic Zone, New Zealand. The Rotokawa geothermal field has an installed capacity of 174 MWe and is a joint venture between Mercury NZ Ltd and Tauhara North No. 2 Trust. Analyses of the data obtained from additional make-up well drilling, updates on the field stratigraphy, and the detailed review of the field and individual

well performance 10 years since the Nga Awa Purua plant commissioning, have led to changes in the conceptualised field reservoir geometry, upflow location, deep hydrology of the system, and connectivity to the overlying intermediate aquifer.

Session 3.3

37 | NON CONDENSABLE GAS REINJECTION TRIAL AT NGATAMARIKI GEOTHERMAL POWER PLANT

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Keywords: NCG, Carbon Emissions, Ngatamariki, Process Design, Trial, Chemistry

As a baseload low emissions source of renewable energy, geothermal development will play a key role in the transition to a low carbon future. On average, the emissions intensity from currently producing geothermal power stations in New Zealand is 73gCO_2e/kWh (McLean, Richardson, Quinao, Clark, & Owens, 2020). While this is significantly lower than many other sources of power generation, there is still an opportunity for the industry to reduce greenhouse gas emissions in the coming years.

This paper describes the feasibility studies and initial results for large scale testing of reinjection of 'Non-Condensable Gases' (NCGs) into the Ngatamariki geothermal reservoir. The testing aimed to trial reinjection of a quarter of the power station's produced NCGs into the brine stream as an opportunity to reduce emissions and evaluate NCG injection as a means of addressing mineral scaling in the formation. Key design considerations from a reservoir, chemistry, and process engineering viewpoint are discussed.

Session 2.3

38 | QUANTITATIVE PHASE ANALYSIS OF HTCC EM LOGS

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Keywords: *Casing, Inspection, Corrosion, Electromagnetic, Quantitative.*

Quantitative Phase Analysis (QPA) provides a way to report quantitative thickness measurements of HTCC-EM logs in wellbore casing. Without QPA, thickness measurements are reported qualitatively. QPA analyses the reduction in thickness of particular defects and eliminates certain errors. Any areas that have no defects are deemed to have no thickness loss. The result is a quantitative report for the whole log.

Session 7.3

39 | AN AUSTRALIAN GEOTHERMAL RENAISSANCE?

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Keywords: *Australia, geothermal exploration*

Australia had high hopes for geothermal energy – with high profile enhanced geothermal projects (e.g. Paralana and Habanero) ultimately being unsuccessful. Is now the time for an Australian geothermal renaissance? The use of binary units offers scope to generate electricity from lower temperature resources, admittedly at lower efficiency than higher temperature resources. What will it take for geothermal to flourish in Australia? Have the recent issues at the Winton plan put a "chill" into the sector?

This paper summarises the current state of geothermal permit applications in Australia and where possible overlays the boundaries of permit applications onto a basemap of temperature at 5km depth. The nature of the commercial entities applying for permits is also considered.

Session 7.2

40 | MODELLING THE ROTORUA GEOTHERMAL SYSTEM

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Keywords: Rotorua, Conceptual Model, Reservoir Model, TOUGH2, Temperature Matching, Pressure Drawdown, Heat Flows.

The Rotorua Geothermal Field is an area of major geyser activity in Aotearoa New Zealand. The field was subjected to extraction of geothermal fluid by hundreds of households for heating and other purposes from the 1950's. After the decline of some of the thermal features was recognised in the mid-1980's an extensive monitoring programme was developed to provide an understanding of the system dynamics. Many aspects of that monitoring programme continue through to the current day including pressure and temperature monitoring. The Bay of Plenty Regional Council are currently undertaking a review of the Rotorua Geothermal Plan. Alongside of that review an update of a numerical reservoir model that was developed in 2004 has been carried out.

One of the challenges with modelling the Rotorua system is that very few wells have been drilled to more than 200m. As a consequence, the data is strongly biased towards the shallow parts of the system. In this paper we will use new data from Rotorua and information from other producing geothermal systems to inform a conceptual model that incorporates the deeper reservoir at Rotorua. We will also present a review of monitoring data collected at Rotorua, describe the conceptual model and the updated numerical reservoir model.

Session 1.2

41 | SHALLOW GEOPHYSICAL TOOLS TO INVESTIGATE THE POTENTIAL EXTENT OF SUBSIDENCE ANOMALIES ASSOCIATED WITH HYDROTHERMALLY ALTERED AND COMPRESSIBLE CLAYS

Brook Keats[1], Chris Bromley[1], Robert Reeves[1], Michael Rosenberg[1], Lauren Coup[1], Thomas Brakenrig[1], Nick McDonald[1], and Krista Randell[1]

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***Keywords:** subsidence, geophysics, compressible clay, ground penetrating radar, time-domain electro-magnetics, electro-kinetic seismic.*

Identifying the potential extent of future subsidence associated with deeply buried compressible clay-rich materials of hydrothermal origin, is a useful objective for planning and hazard assessment purposes. Geotechnical assessments of foundation conditions are often undertaken in advance of construction and infrastructure projects, but these typically focus on detailed shallow investigations using tools such as cone penetrometers and shallow core drilling. Geophysical methods, however, can offer a more cost- effective means of covering larger areas and penetrating to greater depths where subsidence and ground deformation effects might become an issue, especially for buildings, in the future. This study reviews the application of a variety of shallow geophysical tools to help map the extent and depth of buried hydrothermally altered clay-rich materials that might compact when subjected to

pore pressure decline (e.g. a drop in groundwater level) or an increase in surface loading. Methods include ground penetrating radar (GPR), electro-magnetic soundings (TEM), resistivity mapping, electro-kinetic soundings (EKS), seismic refraction and reflection, and seismic attenuation. The results are presented of trial GPR, TEM, and EKS surveys at Crown Park, Taupō, across an area of known subsidence anomalies. Previous measurements here revealed changes in subsidence rates over time, and nearby core-drilling has revealed the anomalous physical properties of some highly compressible clay-rich materials.

Session 3.2

45| DEVELOPMENT OF DOWNHOLE COOLING CHARTS TO PREVENT DRILLING PROBLEMS IN GEOTHERMAL WELLS THROUGH WELLBORE TEMPERATURE SIMULATION

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Keywords: *downhole cooling, wellbore simulation, geothermal gradient, drilling depth, vertical depth*

In high temperature geothermal well drilling in Japan, it is sometimes reported that MWD tools get damaged because of its insufficient heat resistant temperatures of approximately 175°C to 200°C. To avoid such troubles of downhole tool failure, it is important to properly cool the inside of the wellbore by drilling fluid circulation. The effect of downhole cooling was analyzed and evaluated by downhole temperature simulation, and it was found that the well diameter and pump rate have a significant effect on the downhole temperature. The objective of this study was to create a chart for different well diameters that would allow us to determine the drilling pump rate required to reduce the downhole temperature to 175°C.

The wells used in the simulations were set up based on drilling data from NEDO (the New Energy and Industrial Technology Development Organization) Geothermal Development Promotion reports. Numerical simulations were carried out using the modified wellbore temperature simulation program GEOTEMP2 originally developed at Sandia National Laboratories.

A simple correlation chart between well conditions and pump rates was computed for mud and water as drilling fluids. The correlation chart has the vertical axis as the target depth and the horizontal axis as the geothermal temperature gradient. The ranges of the vertical and horizontal axes were determined from well data drilled in past NEDO geothermal development promotion studies, and the geothermal formation temperature was assumed to vary linearly with depth as assigned by the temperature gradient.

As a result of the simulations, it was found that drilling fluid with mud provided better cooling than only using water for all well diameters. In addition, it was confirmed that the required pump rate increases as the diameter of the well decreases.

Session 7.3

47 | CHEMICAL DOSING FOR TE MIHI GEOTHERMAL STATION COOLING TOWERS: UPDATE

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Keywords: *Cooling water, microbiological control, algae, biocides, Sulphur Oxidising Bacteria, Te Mihi, cooling tower.*

The chemical dosing for Te Mihi geothermal power station cooling tower water had previously been investigated and optimised. This involved continuous dosing of 30% caustic soda for pH control of the cooling water, with periodic shock doses of a quaternary ammonium bio-dispersant/biocide and glutaraldehyde biocide for microbiological control. While initially successful, the caustic consumption and expenditure steadily increased over several years.

This work presents an updated review of the chemical dosing history at Te Mihi power station and performance-based improvement to the caustic chemical dosing system. The results of successful offline biocide dose trails on each cooling tower during a scheduled maintenance outage are also detailed.

Session 3.3

52 | MOVING THE CALCIUM SILICATE (CASIL) PILOT PLANT TO KAWERAU

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Keywords: *Silica scale prevention, calcium silicate technology, geothermal energy, enhanced electricity generation, reduced maintenance, molybdenum blue test, molybdenum yellow test, silica analysis.*

Silica scale formation due to supersaturation in geothermal brine results in the formation of intractable silica scale deposits in pipes, heat exchangers and reinjection wells. This is a major problem in liquid dominated geothermal fields worldwide. Heat energy extraction and hence electricity generation are adversely affected, and blockages of process equipment and reinjection wells necessitate costly maintenance and plant downtime. We have developed a proprietary technology that definitively prevents the scale formation and enables full utilisation of geothermal resources for electricity generation and direct-heat applications.

Our technology addresses the problem by producing a nanostructured calcium silicate (CaSil), which is formed in and recovered from geothermal brine in an automated pilot scale operation. The process lowers the silica saturation index (SSI) substantially below 1 within seconds. Laboratory work and batch field worked showed that the technology is applicable to a range of brine compositions, temperature, and pressure conditions. The CaSil material does not stick to metal surfaces because of its unique surface chemistry, significantly reducing maintenance costs for process equipment and reinjection wells as well as plant downtime.

From commissioning of an initial proof-of-concept plant in 2017, through the construction (November 2019) and operation of our pilot plant (2019 to 2021) we were located on the Wairakei geothermal field. Mid 2021 we were invited to relocate the pilot plant to the Kawerau geothermal field. The new field and chemicals in the Kawerau brine posed some challenges and surprises regarding the on-site silica analysis of samples (molybdenum blue and yellow tests)

but reconfirmed that our overall process is very robust and can cope with very different brine compositions. We successfully operated the pilot plant for several weeks in 2021 and 2022 and present insights from the operation.

Session 4.2

53 | THE STEAMFIELD PROCESS DESIGN AND OPTIMISATION TOOL (SPDOT)

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Keywords: *Steamfield design and optimisation, Primary Separation, Steam Purity, Pipelines Sizing, Condensate Drain Pots.*

The Geothermal Institute has been developing a tool for process design and optimisation of geothermal steam gathering systems by integrating a compilation of several geothermal practitioners' published theories and field experiences over the past eight decades. The tool aims to solve the typical challenges identified in geothermal steamfields worldwide, such as flow capacity bottlenecks, excessive pressure drop and steam quality and purity problems.

The tool is fundamentally an arrangement of logically interconnected mathematical blocks representing the different elements and components of a steamfield configuration, such as primary separators, pipe sections, condensate drain pots, scrubbers, and demisters. The program calculates a range of physical and thermofluids processes for each standalone block, including pressure drop, heat transfer, condensate generation, mineral dilution, and thermodynamic properties. The recalculated geothermal fluid properties become inputs for the subsequent block, and the iteration continues until the analysis of the entire system is achieved.

We provide the results of a few optimisation exercises in a steam line to improve the steam quality and purity upstream of the turbine inlet.

Session 2.3

56 | HOT OR COLD: A REVIEW OF GEOTHERMOMETRY AT THE KAWERAU AND NGĀ TAMARIKI FIELDS, TAUPŌ VOLCANIC ZONE, NEW ZEALAND

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Keywords: *Geothermometer, silica, NaK, NaKCa, enthalpy deficit, Kawerau, Ngā Tamariki*

Geothermometers are widely employed to determine reservoir enthalpy in both exploration and production scenarios. This paper evaluates the conditions under which silica and cation geothermometers provide valid temperatures, with case examples from the Kawerau and Ngā Tamariki reservoirs. Geothermometry temperatures are presented in conjunction with tracer flow testing (TFT) and downhole survey results (i.e. PTS). Notably, at both fields, enthalpy deficit conditions are identified, where enthalpy determined from quartz solubility (i.e. Fournier and Potter, 1982a,b) exceeds TFT and PTS values. In this paper, an iterative spreadsheet-based approach is demonstrated for correcting enthalpy deficit. The spreadsheet method presented here provides comparable outputs to the WATCH geothermal chemical speciation software package, with corrected TQtz using either approach within <1°C. At both Kawerau and Ngā Tamariki, corrected quartz thermometry provides valid characterization of near-well reservoir conditions, as established by comparison to feedzone PTS temperatures. At Kawerau, cation geothermometer (NaK, NaKCa) results are lower than TQtz and PTS temperatures. Lower cation geothermometer temperatures likely indicate incomplete equilibration of cation ratios as fluids transit from lower temperature injection zones to production areas, while quartz temperatures demonstrate that enthalpy remains stable in production areas. These examples highlight that correcting for enthalpy deficit improves the accuracy of quartz geothermometry.
In cases where equilibrium is not attained, geothermometers may be used to diagnose the impact of ongoing changes in reservoir state due to production, reinjection, or marginal fluid incursion. Incorporating geothermometry into routine monitoring can enable better conceptual understanding of changes in reservoirs over time.

Session 2.2

57 | ANALYTICAL AND NUMERICAL MODELLING OF A COAXIAL BOREHOLE HEAT EXCHANGER TO EXTRACT GEOTHERMAL ENERGY

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Keywords: *Geothermal Energy, Oil and Gas Wells, Petroleum Fields, Borehole Heat Exchangers, Method of Characteristics.*

Unused wells in petroleum fields are readily available as a potential source of geothermal energy. To produce geothermal heat in a viable manner, borehole heat exchangers may be used in some of the available deep wells (> 500 m). Therefore, we aim to develop a rigorous modelling technique to evaluate such systems in deep oil and gas wells.

We examine a mathematical model based on unsteady-state heat conduction for the coupled borehole-reservoir system. Using the analytical technique, our paper presents cases evaluated using the Method of Characteristics. We briefly discuss the challenges encountered while using the above method for a non-linear hyperbolic system of partial differential equations in a practical scenario. Finally, we adopt a numerical technique based on the Finite Difference Scheme to analyse transient heat transfer in a coupled wellbore-reservoir system. The paper also discusses a hypothetical case that uses borehole heat exchangers to supply geothermal heat in a greenhouse.

We conclude that the numerical technique based on the finite difference scheme is appropriate to study deep borehole heat exchanger systems. The hypothetical case study of a greenhouse demonstrates the feasibility of using such systems to supply geothermal heat. Future work should perform a detailed economic study and develop a more rigorous analytical method to optimise the design of multi-borehole systems.

Session 4.3

58 | APPLIED CO_2 FLUX TO MONITOR NATURAL EMISSION FROM GEOTHERMAL FIELD, NEW ZEALAND.

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Keywords: *CO2 flux, CO2 emission, temporal and spatial variation, Taupō volcanic zone, Tauhara geothermal field, Wairakei geothermal field, Karapiti, Rotokawa geothermal field.*

Soil CO2 flux measurements could be used in geothermal areas to constrain surface CO2 emissions and to monitor degassing anomalies from volcanic, tectonic, or anthropogenic activities. However spatial and temporal variations in a utilised geothermal field are difficult to assess at a large scale due to the prerequisite of a lengthy CO2 flux survey and lack of monitoring data outside the power stations.

In this study, we analyse the temporal and spatial variations of soil CO2 flux and soil temperature in the Taupō region. Fortnightly monitoring between 2019 to 2022 at 8 stations across the Tauhara and Wairakei geothermal fields provide insight into changes of seasonal variations and geothermal activities. Carbon dioxide flux at 2 stations at Karapiti and 1 background site in the Wairakei geothermal field remain constant over the 2.5-year interval of monitoring.

In contrast, CO2 flux at the 5 stations at Crown Park in the Tauhara geothermal field fluctuated synchronously.

To understand the broader distribution of natural degassing and to compare the CO2 flux over decades, we mapped the CO2 at Karapiti, Wairakei geothermal field (2021, 2003, 2018) (n=123), "Ring of Fire", Tauhara geothermal field (2006, 2022) (n=646), and Rotokawa geothermal field (2003, 2011, 2022) (n=380). Differences in the CO2 flux distribution and total emission over a decade suggest possible changes to fluid pathways, permeability zones and/or reservoir conditions. The result gives important statistical insight into time constraints for future surface CO2 surveys and monitoring strategy in the geothermal field.

Session 2.2

62 | ESTIMATION FOR HEAT LOSS TO THE WORKING FLUID IN THE HEAT EXCHANGER OF AN ORGANIC RANKINE CYCLE FOR A GIVEN CONCENTRATION OF GASES

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Keywords: *Geothermal Energy, gases, heat exchanger, process model, efficiency, Organic Rankine Cycle, geothermal fluid.*

Geothermal Energy is the thermal energy derived from the earth's subsurface, often extracted from steam or hot water. It is a clean, reliable, and promising source of renewable energy. However, geothermal fluids brought to the surface through production wells contain non-condensable gases and minerals. These gases can reduce the heat transfer efficiency process in the surface plant, impacting the turbine's efficiency when used to generate electricity. The gases mainly constitute CO2.

The paper demonstrates two process models one calculating the output from the turbine for similar input conditions as in one of the geothermal powerplant in New Zealand and the second calculating the change in heat transfer efficiency of the heat exchanger for a given concentration of gases in the geothermal fluid. The second process model is a cut-down model of the heat exchanger from the complete process model developed, which helps understand the loss of efficiency in heat transfer when geothermal fluid with different concentrations of gases passes through it. The heat exchanger is run for a range of values of the concentration of gases. The primary focus is on evaluating the change in heat transfer efficiency in the heat exchanger.

Session 4.3

65 | SURFACE HEAT LOSS ASSESSMENT OF GEOTHERMAL FIELDS IN THE TVZ, USING REMOTE SENSING AND TERRESTRIAL TECHNIQUES

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***Keywords:** Heat loss, thermal infrared, remote sensing, Karapiti, Waimangu, Waiotapu, Rotorua.*

Assessment of surface heat loss in geothermal areas can provide information and insight into the size and character of underlying geothermal resources. It also provides a method to monitor changes to a geothermal system and assess geothermal hazards related to movement of subsurface steam. Additionally, variations in fluid flow pathways may result in changes of geothermal feature characteristics and fluid discharge at the surface.

This paper presents findings from heat loss assessments at several geothermal areas within the Taupō Volcanic Zone, including Karapiti (part of the Wairakei-Tauhara geothermal system), Waimangu geothermal valley, Waiotapu Geothermal Field, and Rotorua Geothermal Field. Methods for surface heat loss determination include, direct heat flux measurements using a water-based calorimeter, inferred heat flux assessments from temperature-depth relations, spring and stream flow assessments, and inferred heat fluxes from remote aerial thermal infrared (TIR) and satellite TIR assessments. This paper will compare results and findings from these surveys.

Session 3.2

69 | MODELLING SOURCE NETWORKS WITH THE WAIWERA GEOTHERMAL FLOW SIMULATOR

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***Keywords:** Reservoir models, numerical modelling, flow simulator, Waiwera, sources*

Models of production history and future scenarios for real geothermal fields generally require an interconnected network of source and sink terms to represent production wells (including make-up wells), groups of these wells, separators and reinjection back into the reservoir. The AUTOUGH2 flow simulator includes a system for doing this, but it is somewhat inflexible, partly

due to limitations imposed by the input file format.

We have recently added source network modelling capability to the Waiwera flow simulator, using a completely redesigned system which offers greater flexibility and new possibilities, including an improved way to represent multi-feed production wells. It also works in parallel both on shared-memory machines (e.g. desktops) and distributed-memory machines (e.g. high-performance computing clusters).

Session 1.2

70 | PRODUCTION HISTORY MODELLING OF A LOW ENTHALPY GEOTHERMAL RESERVOIR USED FOR DISTRICT HEATING: EXAMPLE OF THE PARIS SEDIMENTARY BASIN

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Keywords: *Deep sedimentary basin, geothermal modelling, district heating, production history matching, Dogger, Waiwera.*

Exploitation of the geothermal energy in the Paris sedimentary basin started in the early 1970's, accessing the hot brine contained in the mid Jurassic carbonate rocks series, the Dogger. More than a hundred wells have been drilled to depths ranging from 1400 to 2000 meters, often using the doublet or triplet technology. Decades of production and reinjection have resulted in variations of the aquifer pressure and temperature in some areas. The characterization of the Dogger heterogeneities and the understanding of potential interconnections between the doublets areas of influence are essential to define sustainable management plans for current and future geothermal developments.

While the integration of a full-scale refined geological model into a reservoir model needs heavy computational resources, a simplified model gathering the main productive areas into one or two layers surrounded by sealed formations can be used to efficiently investigate the aquifer characteristics in a zone operating one or several doublets. Due to the high density of geothermal operations in the Paris sedimentary basin, regional numerical approaches are needed to assess potential interactions between doublets.

With this aim, the modelling of 13 doublets and 1 triplet intersecting the Dogger reservoir in the South part of Paris (Cachan/Orly) is performed, using a conventional double layer approach to simulate the natural state and production history of the area with the numerical simulator Waiwera from the University of Auckland in New-Zealand. The history matching to available production data is used to capture variations of the reservoir behaviour caused by natural and anthropogenic fluid flows in the heterogeneous Dogger reservoir. The geothermal reservoir properties and the production timeline are investigated during the calibration process, which uses a robust modelling workflow and a fast simulation to handle complex production history data.

Modelling a large scale geothermal field is valuable for understanding the pressure and temperature response in the productive areas, to suggest better monitoring of the geothermal resources, and to define future strategies for operating the reservoir in a sustainable way.

Session 1.2

71 | REVERSING CARBON EMISSIONS IN GEOTHERMAL ENERGY PRODUCTION: TE ARA WHAKAMUA

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Keywords: *Greenhouse gas emissions reduction, Carbon capture and storage, Carbon reinjection*

New Zealand is on the path to a low-emissions, climate-resilient future. The NZ parliament approved a bill to make NZ carbon neutral by 2050. These actions demand an accelerated and expanded electrification of our society and economy and aim to achieve 95% renewable generation by 2035. Geothermal energy is technically and economically viable and can provide steady and baseload electricity.

Our research aims to reduce greenhouse gas (GHG) emissions by creating processes enabling GHG entrapment, especially CO2, in solid form while boosting energy production from geothermal resources. The study requires the characterisation of geological, geochemical, geophysical, and fluid-dynamic properties to investigate and optimise potential trapping mechanisms. To overcome current GHG storage problems, we will present novel techniques to enhance GHG solubility in geothermal wastewater and inject agents into the deep rock to ensure permanent trapping.

Session: 5.1

73 FIXED AND RANDOM EFFECTS ERROR MODELS FOR GEOTHERMAL SIMULATOR CALIBRATION

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Keywords: *Reservoir modelling, geothermal model calibration, uncertainty quantification, fixed effects, random effects, multilevel error models.*

Standard approaches to geothermal model calibration typically assume independent, identically distributed Gaussian measurement noise about the model. However, in practice, models usually exhibit systematic errors, such as well-to-well offsets between measured data and the best-fit (calibrated) simulation model. Failure to account for these systematic errors can lead to bias and overconfidence in parameter estimates and predictions. The statistical regression literature often handles these issues using fixed or random effects error models; petroleum reservoir modelling and related fields have recently incorporated similar ideas. However, geothermal reservoir modellers have not yet adopted these methods, neglecting systematic errors or using ad-hoc methods of weighting observations. Here we review basic concepts of fixed and random effects error modelling and show how to apply them to account for the kinds of well-to-well discrepancies expected between models and real-world data. This approach relies on fairly straightforward mathematics and statistics but generally leads to much more reasonable results. Furthermore, these methods can easily be implemented in existing frameworks and software and typically require only minor additional computational costs.

Session 4.2

76 | MODELLING A REINJECTION NETWORK

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Keywords: *piping, reinjection, water hammer, pumping*

A case study is presented of a geothermal reinjection piping network model from the power station through to the reinjection wells. Commercial piping network modelling software has been used to model the static and dynamic response of the system and options for increasing capacity. The model includes a number of reinjection well analogues for modelling well behavior, including a well with the piping/casing modelled to the loss zone. The terrain includes elevation changes and the model needed to account for cavitation and column separation

Session 1.2

77 | SCALING RATE REDUCTION AT WAIRAKEI BINARY THROUGH APPLICATION OF SCALE INHIBITOR

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Keywords: *Binary, Silica scale, Calcite scale, Silicate, Metal Silicate, Chemical injection*

Silica scaling at the Wairakei binary plant heat exchangers increases resistance to flow and thus causes reduced flow of separated geothermal water through the facility, wastage of geothermal energy and reduced power generation.

Historically this has been managed by mechanical or chemical cleaning of the heat exchangers on a performance basis, with associated cost and loss of generation during the cleaning outage.

Following a system review and improvements to the asset surveillance program, periods of

unusually high scaling rate were identified and, through integrated review, linked to downhole chemical injection (Nalco GEO907) deployed to inhibit calcite scaling in a production well.

Through plant trials, a link between the injection of this chemical and reduced silica scaling rate of the binary was demonstrated. This enabled an opportunity to reduce the scaling rate by over 90% through sustained injection of the chemical to the binary plant, independent of the production well flowing to the plant.

Session 4.2

78 | WELLBORE SIMULATION AND EXERGY PROFILE OF OLKARIA DOMES

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***Keywords:** exergy, Olkaria Domes, simulation, wellbore*

This paper presents exergy in the wellbore. Exergy analysis is considered between the wellhead and the reservoir with geothermal brine at saturated conditions. The field data input parameters were wellhead pressure, mass flow rates of steam and brine, wellbore diameter, and the reservoir depths (deeper/2nd depth and shallow). The pressure-temperature (PT) profile was simulated using the developed wellbore model. The exergy profiles estimated feed zone depths for a directional well. The research investigated liquid-dominated Olkaria Domes wells, OW-908, OW-921 and OW-924.

The profiles predicted convective and conductive heat transfer points. For a range of wellhead temperatures, the reservoir temperatures and formation pressure from the wellbore simulator were calculated.

The thermodynamic parameters (temperature and pressure) from the wellbore simulator were input parameters in the (Engineers Equation Solver) EES code. The calculated values in EES were entropy, enthalpy, and specific exergy. Exergy wellbore simulation of the geothermal reservoir predicted the geological stratification of the geothermal field. The study demonstrates the importance of connecting the reservoir and wellhead via a wellbore simulation and exergy profiles.

Session 1.2

79 | PROPOSAL OF CROP DRYING BY ANALYSIS OF GRAIN FARMS WITHIN CLOSE PROXIMITY OF MENENGAI GEOTHERMAL RESOURCE IN KENYA VIA REMOTE SENSING

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The direct use of geothermal energy is highly dictated by economics, thermal needs and the quality of thermal energy available. Several economic parameters that dictate the viability of direct utilization of geothermal resources are sustainable thermal energy demand, brine piping routes that encourage brine flow via gravity and an efficient flow rate of brine to match the thermal demand as well as short brine piping distances. The current research work analyses thermal demand near geothermal resources via remote sensing of agricultural activities and urban development. Clustering of crop types and crop-calendars will help analyze the viability of crop drying, greenhouse warming and aquaculture using geothermal energy. Urban density clustering aided in decision making on cascaded use of geothermal energy from industrial processing of agricultural goods to urban-heating and recreational spas. This

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research seeks to identify and match thermal needs to available geothermal resources via GIS mapping. The results show that the Menengai prospect is best suited for crop drying, industrial processing, spa and district heating. Priority being in that order.

Session 4.3

80 | EFFECTS OF REINJECTING DILUTED MINERAL POOL WATER INTO THE ROTORUA GEOTHERMAL SYSTEM

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***Keywords:** Rotorua Geothermal System, sustainability, geochemical modelling, microbiology, reinjection, bathing.*

This work presents the results of a geochemical modelling study into the potential effects of reinjection of dilute geothermal brine (i.e. dilution by bathing waters) into the geothermal aquifer of the Rotorua Geothermal System (RGS). It also summarizes the potential environmental effects from reinjection or discharge to surface waters, from both the release of pathogenic microorganisms, and the potential for biochemical changes to the environment by microbes.

The results of this study show that reinjection will have a small effect on the water composition of the shallow geothermal aquifer fluid proportional to the reinjection rate. At reinjection rates of 50 and 100 t day^{-1} (both at fluid temperatures of 120°C and 150°C) changes to the aquifer chemistry are minimal. Changes in the concentration of conservative elements will be insignificant as these are modelled to be within the ± 2% uncertainty of the aquifer brine composition. Less mineral precipitates are expected when injecting diluted brine compared to undiluted

A measurable change in pH is found only at high reinjection rate (800 tonne day^{-1}) up to 800m from the well. There will be a measurable pH change and substantial decrease in the SiO_2 concentration, which could impact surrounding wells and surface geothermal features.

Reinjection of water from mineral pools, or discharge to surface waters, poses a risk of release of human pathogens. Pathogens may infiltrate groundwater or surface water and present a hazard through inhalation, skin contact, or ingestion of contaminated food. Microorganisms identified in nearby surface features indicate that there may also be environmental risks from the natural geothermal microbial populations. These range from increased biofilm formation leading to reduced permeability, to the production of toxic and corrosive H_2S. The gradient of risk depends on the types of microorganism, volumes and dilutions of water reinjected, and the receiving environment, particularly temperature and pH. Filtration is recommended to remove the natural microbial population and pathogens and reduce the risk of adverse effects from their metabolic processes.

Session 3.2

81| 2021 ANNUAL NEW ZEALAND GEOTHERMAL VIEW

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***Keywords:** New Zealand, geothermal, Annual View, 2021.*

Despite the COVID-19 pandemic, New Zealand witnessed active development in the geothermal electricity sector in 2021, commencing the construction of the 168 MWe Tauhara power plant and a greenfield development at Taheke. There is, in total, over 1050 MWe of installed geothermal electricity generation capacity, which is typically contributing about 18.1 % of the national electricity supply.

In 2020, the NZ government declared a climate emergency. The NZ parliament approved a bill to make NZ carbon neutral by 2050. Both these actions demand an accelerated and expanded electrification of our society and economy and aim to achieve 95% renewable generation by 2035. While geothermal power generation results in very limited Carbon emissions, New Zealand's geothermal resources will have a key part to play as the country moves to this low emissions future. In addition, power producers have several successful non-condensable gasses (NCG) injection trials.

There are significant developments in the direct use of geothermal energy, with some industries using the Government Investment in Decarbonising Industry Fund (GIDI) to help them switch from fossil fuel to geothermal energy. Several large-scale direct-use projects are also underway in Ohaaki and Kawerau, and NZ's first hydrogen production from geothermal energy by Tuaropaki/Obayashi JV.

The NZ government continues to support the industry with several local and international initiatives, both in capacity-building and regional development in many parts of the world

Welcome to our third annual New Zealand geothermal industry update. This year's report summarises geothermal activities during the 2021 calendar year, including statistics and discussion. Key themes for the year include:

- Geothermal power contributes 18% of national generation;
- Future power projects in construction will lift this contribution to over 20% by 2024;
- Several direct-use projects were commissioned, including an exciting hydrogen facility;
- Carbon emissions per kWh continue to fall while operators are successfully trialling CO2 injection;
- Drilling and completions, testing, and workover activity continue at sustainable levels; and
- MFAT's international geothermal aid continues to make a difference in East Africa, the Caribbean and Indonesia.

Even with the COVID Pandemic receding, we need to acknowledge the stoic efforts of many operations, maintenance, and engineering staff across the industry who have overcome many obstacles to maintaining New Zealand's electricity supply.

Session 1.3

82 | EFFECT OF RAINFALL ON LOW-HEAT GROUND SOURCE HEAT PUMPS IN NEW ZEALAND

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Keywords: *Ground Source Heat Pumps; Geothermal Heat pumps; New Zealand Aquifer; Carbon Intensity; thermal balancing.*

Low-energy efficient technology that is reliable, cost-effective and has a low environmental footprint has become a key focal point in recent years. Heating and cooling account for a significant share of global energy demand and represent a significant opportunity for improvement. In this study, an alternative approach to contemporary applications of geothermal energy is presented, ground source heat pumps. To qualify the magnitude their opportunity presents, it is first critical to understand the mechanism they exploit and the physical properties that influence their operation

and performance. This study will therefore explore, how heat pumps achieve efficiencies over 100%, how efficiency changes with respect to depth and with a focus on the effects of rainfall and moisture content on the thermal balancing of the soil.

Session 4.3

83 | HISTORIC FLOW CONDITIONS PRESERVED IN SILICEOUS SINTER VENT WALLS OF THREE NEWLY-EXPOSED HOT SPRING VENTS AT ORAKEI KORAKO, NEW ZEALAND.

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Keywords: *Reactivation of buried hot spring vents, changes to surface activity, Orakei Korako, Ground Penetrating Radar, Scanning Electron Microscopy, siliceous sinter textures.*

Orakei Korako geothermal field is located in the Taupō Volcanic Zone, New Zealand, and is a protected geothermal system. In 2012, a Ground Penetrating Radar (GPR) survey, combined with a 1.5 m deep temperature probe survey was undertaken around the boardwalk at Orakei Korako. In 2019, following a small hydrothermal eruption, three new vents appeared at a site that was mapped in 2012 by GPR and downhole temperature measurements. Vent walls in each of the new vents expose a variety of siliceous sinter textures. In 2019, samples were collected from each vent and examined using Scanning Electron Microscopy (SEM) to determine paleo-hydrological and paleo-environmental conditions that occurred at the time the sinter formed. SEM observations determined all three vents were dominated by mid- temperature alkali chloride water (35-59 °C). Pristine microbial preservation within the sinter samples indicates one vent would have been a quiet pool with minimal water movement and overflow, while the other two vents would have had a higher discharge rate. Post-depositional dissolution textures were also documented in samples from two of the vents. Examination of the preserved sinter textures has enabled paleo-flow conditions to be identified, reconstruction of historic hot spring settings to be established and shown more recently, evidence of post-depositional over-printing via acidic steam condensate.

Session 6.2

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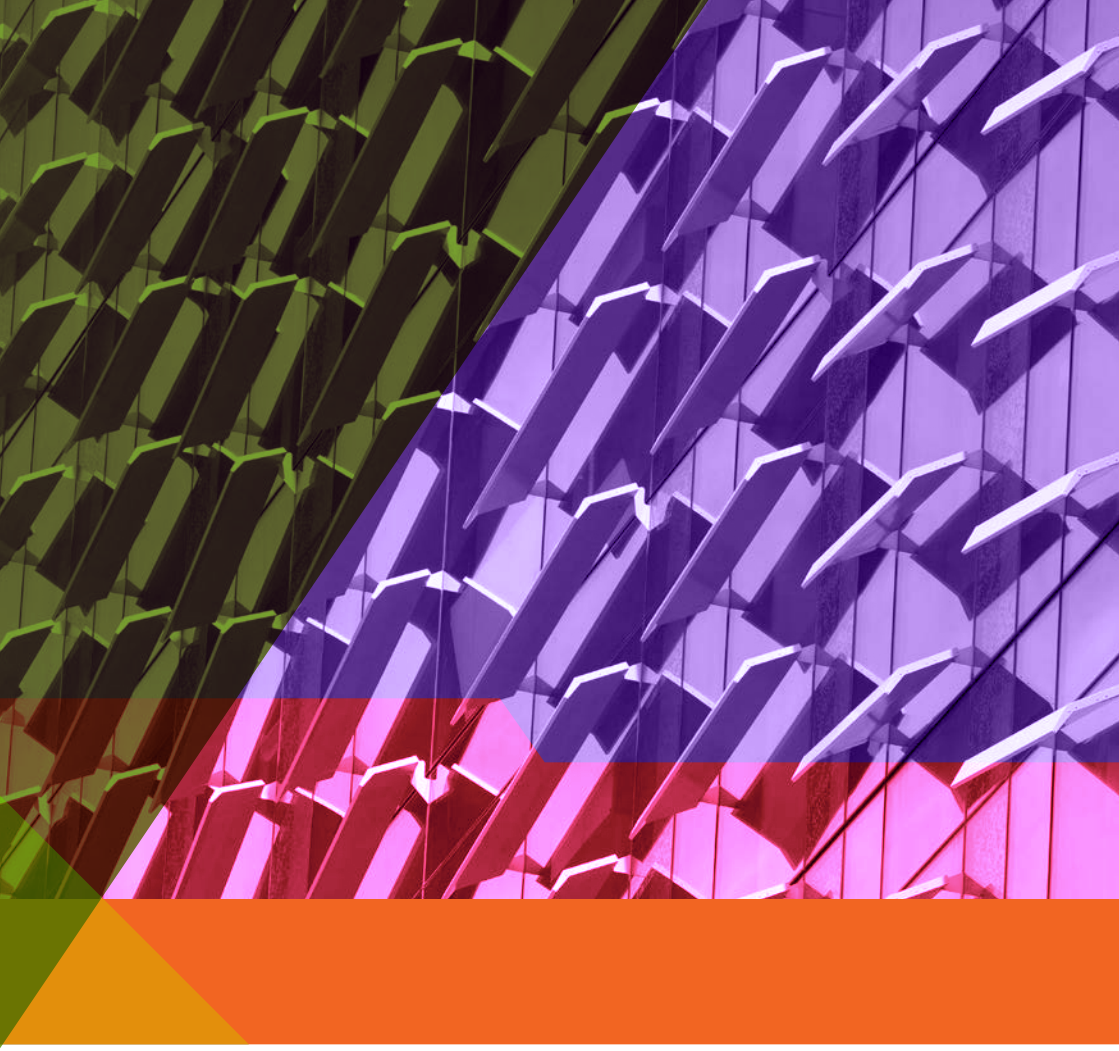

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