



NZGW
New Zealand
Geothermal Workshop



46th New Zealand
GEOHERMAL WORKSHOP

Handbook

20-22 November 2024

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Welcome

46th New Zealand Geothermal Workshop

This workshop comes at a time of significant global growth in geothermal development driven by research, innovation and new technologies. Governments worldwide, including New Zealand, recognise the important role that geothermal energy plays as we strive to meet our sustainable development goals. In addition to showcasing technical advances, the NZGW provides insightful industry updates. This is an excellent opportunity to stay informed and engaged with the latest trends and developments in our field. We also continue to witness an increase in demand for geothermal energy education. The Geothermal Institute is proud to contribute through our degree programmes and short courses, and we warmly welcome our graduates to the geothermal community. A special thank you to all our sponsors. Your generous support allows us to keep registration fees low and subsidise social functions, making this workshop accessible and enjoyable for all participants. Thank you for joining us, and welcome to what promises to be an inspiring and productive event.

Conveners:

Sadiq J. Zarrouk

John O'Sullivan

Bridget Lynne

Mike O'Sullivan

Michael Gravatt

2024 Partners



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2024 Awards

Bay of Penty Regional Council and Waikato Regional Council
award for the best paper on environmental, social and Mātauranga Māori

New Zealand Geothermal Association

Best Overall Paper Award | Best Student Paper Award | Best Poster Award

Geothermal Institute

Best Geothermal Earth Sciences Award

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 027 287 5183.

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

Log in: nzgw24@uoawifi.com

Password: aLSLjt4F



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.

Welcome Function

Tuesday, 19th November 2024, 5.30pm – 7pm
Faculty of Engineering 20 Symonds Street

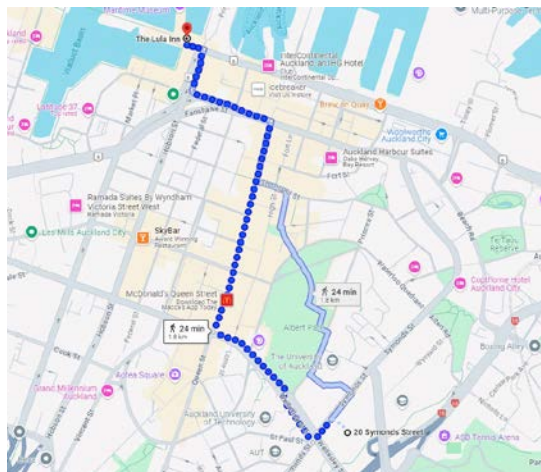
This will be a 'drinks and nibbles' event open to all registered Workshop delegates. No ticket required.

Workshop Dinner

Thursday 21st November 2022,
6:30pm – 10.30pm.

Lula Inn, 149 Quay Street, Auckland CBD

**Please note that transport to the workshop dinner venue is not provided. The venue is a 23-25 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.bluebubbl-taxi.co.nz

Auckland Co-op Taxis 00 300 3000

www.cooptaxi.co.nz

Super Shuttle 0800 748 885 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



Muriwai Gannet Colony, (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 Metro Top 50 Restaurants of the Year 2024, 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



Alfredo Battistelli

**Geothermal Reservoir Engineer Consultant,
Italy**

Alfredo Battistelli is a geothermal reservoir engineer consultant and member of IGA, SPE and UGI. From 1984 to 2018 he was a reservoir engineer and technical coordinator for different companies of Eni SpA, the former Italian National oil company. He contributed to R&D programs relevant to improved oil recovery processes, geological disposal of greenhouse and acid gas mixtures, and the modeling of organic contaminants migration in polluted sites.

He has been involved in feasibility studies, exploration and field development projects in geothermal prospects located in Italy, Bulgaria, Croatia, Poland, Turkey, China, Indonesia, Bolivia, Dominica, Saint Lucia, Djibouti, Ethiopia, Kenya and Tanzania. As geothermal reservoir engineer, he is at present involved in reservoir engineering studies, in the development of field conceptual models and in the definition of field development plans. He is in charge of resource assessment through the modelling of reservoir natural state and the forecast of field exploitation scenarios. He's co-author of EWASG, T2VOC, TMVOC, TMVOCBio, TMGAS, EOS1H and EOS2H computer codes of the TOUGH2/TOUGH3 family of reservoir simulators.

An overview of tools for the modeling of GHG storage, AGI and geothermal applications

Reinjection of NCG in geothermal fields operation has been started as a viable way to reduce the environmental impact deriving from their discharge to the atmosphere. Experiences gained in simulating similar activities in other contests may be quite helpful. Here below, experiences in developing and using numerical simulations tools for the handling of gas mixtures for GHG storage, AGI and geothermal applications are presented. The numerical codes belong to the TOUGH family of reservoir simulators developed at LBNL, subsequently modified for R&D purposes and for the needs of specific industrial applications.

Notes



Julfi Hadi

President Director, PT Pertamina Geothermal Energy Tbk

Julfi Hadi has over 30 years of extensive experience in the geothermal industry. He holds a Bachelor's and Master's degree in Geology from the University of Texas, USA. He began his career as an Exploration Geologist and received the Best Earth Scientist Award early on. Julfi has successfully executed numerous major project acquisitions and developed effective well-targeting strategies, including tariff adjustments and field expansions. He has played a key role in several significant geothermal projects, including Darajat Unit-2 & 3 resulted in the best well average output in the world at the time (18 MW/Well), Wayang Windu Unit-2 (110 MW) resulted in the highest productivity drilling average in the world (23 MW/Well), the IJEN Project (2 x 30 MW), and Sarulla Operation Ltd. (3 x 110 MW). In 2022, he completed the Senior Leadership Development Program from Harvard Business Corporate Learning.

Julfi has held several key positions throughout his career, including SVP Geothermal Assets at PT Medco Power Indonesia (2019 – 2023) and President Director at PT Medco Cahaya Geothermal (2019 – 2023). He is currently the President Director at PT Pertamina Geothermal Energy Tbk, overseeing a 1 GW project to be achieved by 2026, which includes Hululais Unit-1 & 2 (110 MW), Lumut Balai Unit-2 (55 MW), and 230 MW Co-Generation Projects spread across existing assets. Julfi also serves as the Chairman of the Indonesia Geothermal Association.

Geothermal development in Indonesia: Current and future directions.

Indonesia has committed to achieving net zero emissions (NZE) by 2060, with interim targets to reduce emissions by 31.89% unconditionally and 43.2% conditionally by 2030. Emissions are expected to peak at 1.24 GtCO₂-eq in 2030 and gradually decline to 0.54 GtCO₂-eq by 2050, nearing zero by 2060. Key initiatives to support this goal include phasing out coal-fired power plants, accelerating renewable energy (RE) development, expanding the use of electric vehicles (EVs), and implementing smart grids to integrate Variable Renewable Energy (VRE). The government's focus on energy self-sufficiency and energy security is essential for achieving targeted economic growth of 8%. In this context, geothermal energy, with its dependable baseload capacity, is a crucial element of Indonesia's energy transition strategy.

Geothermal energy stands out for its 24/7 consistent, clean power, playing a vital role in stabilizing the grid, meeting growing energy demands, and boosting energy security. Indonesia has an estimated geothermal potential of 23,591 MW, but only 2,597 MW are currently utilized, leaving vast untapped resources. Unlike intermittent energy sources like solar and wind, geothermal provides reliable energy that reduces reliance on imported fossil fuels and supports environmental sustainability. PT Pertamina Geothermal Energy (Tbk) (PGE) has over 40 years' experience managing geothermal projects, beginning with the operation of Kamojang Power Plant. With a paradigm shift, PGE is positioned to become a key driver in advancing Indonesian geothermal development, addressing challenges such as subsurface risks and technological limitations.

To overcome these challenges, PGE is deploying innovative solutions, including advanced technology for de-risking subsurface exploration, accelerating commercial operation dates (COD), reducing capital expenditure (capex), and expanding off-grid solutions.

Notes



Cheryl Jaworowski

Geologist Consultant, Wyoming, USA

Cheryl Jaworowski is a Wyoming Professional Geologist (P.G.1421), researcher and science educator. She received her M.S. (1985; Minor in Remote Sensing) and Ph.D. (1993) in Geology from the University of Wyoming. Positions held include the federal government (Yellowstone National Park and the U.S. Geological Survey), academia (Laramie County Community College, University of Wyoming and University of California Berkeley) and private industry (Northrop at NASA Ames Research Center). She has published 28 peer-reviewed journal articles, 2 book chapters 40 conference proceedings, and 101 Yellowstone National Park Geology Program Technical Internal Reports. Her main research interests are Quaternary geology, geologic field mapping, Yellowstone tephra and thermal infrared remote sensing.

Hydrothermal Monitoring of Yellowstone National Park Using Night-Thermal Infrared Remote Sensing (2005-2015)

Between 2005 and 2015, Yellowstone National Park (YNP) implemented a congressionally-funded, geothermal monitoring plan that examined the heat and water of the Yellowstone hydrothermal system. Natural fractures associated with the two resurgent domes and the associated Elephant Back fault zone, the Yellowstone caldera, and north-trending fault zones are important for the lateral and vertical flow of heat and water within the Park's extensive hydrothermal system.

This presentation focuses on the fixed-wing, night-thermal infrared (TIR) component of the geothermal monitoring plan. Initially, there were different TIR sensors employed to acquire night-TIR imagery (1m spatial resolution and 1oC) over high-priority hydrothermal areas (Mammoth Hot Springs, Norris Geyser Basin, the Upper Geyser Basin and Hot Spring Basin). Night-TIR imagery over low-priority hydrothermal areas such as the Central Plateau, Madison Plateau, Grand Canyon of the Yellowstone, West Thumb, Heart Lake, and hydrothermal areas outside the Yellowstone caldera were acquired after high-priority hydrothermal areas. High-priority hydrothermal areas had night-TIR acquisitions over several years; whereas low-priority hydrothermal areas may have only 1 baseline night-TIR image acquisition.

Notes



Jack Norbeck

Co-founder and Chief Technical Officer, Fervo Energy, USA

Jack Norbeck is co-founder and CTO at Fervo Energy, a geothermal company that has successfully deployed the first commercial-scale enhanced geothermal system in the United States. Jack leads Fervo's geothermal exploration and reservoir engineering strategy. Prior to co-founding Fervo in 2017, Jack was a Mendenhall Postdoctoral Fellow at the US Geological Survey. He holds a BS degree in civil engineering from University of Colorado, a MS degree in civil engineering from Colorado School of Mines, and a PhD degree in energy resources engineering from Stanford University. During his PhD studies, Jack spent a winter quarter as a visiting scholar with the Geothermal Institute at the University of Auckland.

Lessons learned from two successful EGS deployments in the United States

Fervo Energy is a geothermal developer that was founded in 2017 with the mission to accelerate the world's transition to sustainable energy by providing cost-effective, reliable geothermal energy. Fervo leverages recent innovations from the unconventional oil and gas industry, such as horizontal drilling and multistage completions, as the basis for a modern enhanced geothermal system design. Fervo is actively building and operating multiple EGS projects in the United States and began producing electrons to the grid in 2023. In this talk, we will review two of Fervo's projects in detail, as well as evaluate the growth potential for EGS in the United States, New Zealand, and the world.

Notes

46th New Zealand Geothermal Workshop Programme

Tuesday 19 November	
3:00	Registration Open
5:30	Welcome Reception University of Auckland Engineering Building Drinks and canapés sponsored by Utrex Ltd
7:00	
Wednesday 20 November	
8:00	Registration Open
8:30	Mihi whakatau
8:40	Housekeeping: Sadiq J. Zarrouk
8:45	Welcome and Opening: Piaras Kelly, Head of Department, Department of Engineering Science and Biomedical Engineering, Sadiq J. Zarrouk and John O'Sullivan, Co-Directors, Geothermal Institute, The University of Auckland
9:00	WORKSHOP AWARDS
9:15	KEYNOTE TITLE: Geothermal development in Indonesia: Current and future directions. Keynote Speaker Julifi Hadi, President Director, PT Pertamina Geothermal Energy Tbk, Indonesia
10:00	MORNING TEA
	Session 1.2 - RESERVOIR MODELLING 1 SESSION CHAIR Adrian Croucher Lecture Theatre 405.460 75 Numerical experiments with a model of a supercritical geothermal system – John O'Sullivan, Michael O'Sullivan
10:30	Session 1.3 - DRILLING & WELL TESTING 1 SESSION CHAIR Ryan Tonkin Lecture Theatre 405.470 38 Building resilience: Designing well testing equipment and procedures for powerful wells – Chris Horan
10:45	76 Uncertainty quantification of reservoir models to assess the potential of Greenfields: A case study on inclusion of multiple conceptual models – Michael Gravatt 56 Correcting for variations in borehole diameter in fluid velocity profiles – Flavia Purnomo

11:00		92 Using T2well for simulating coupled wellbore-reservoir simulations – Rony Nugraha	85 How to Design, Iterate and Continually Improve PDC Drill Bits for Geothermal Drilling – Ellie Krause
11:15		12 Numerical reservoir modelling and resource assessment of the Nevado del Ruiz Volcano (NRV) geothermal field, Colombia – Andres Pinzon Mendez	19 Pressure and temperature transient analysis of geothermal wells with low permeability – Jorge Alberto Rangel Arista
11:30		93 Updates to the Salton Sea lithium extraction geothermal model – John O'Sullivan	30 CO2 injection well design in the geothermal Industry – Colin Finnegan
11:45		94 Towards a new framework for the systematic assessment of Indonesia's undeveloped geothermal resources – John O'Sullivan	36 Accurate location of feed zones: Assessing obscuration by the liner in geothermal wells through analysis of fluid velocity profiles – Joel Trent
12:00	LUNCH AND POSTER SESSION		
1:30	MB CENTURY INDUSTRY UPDATE Robert Mandjes		
1:45	44 Reducing greenhouse gas emissions from NZ geothermal power stations – Katie McLean NZGA		
	Session 2.1 - INDUSTRY UPDATES SESSION CHAIR Farrell Seiga Lecture Theatre 401.401	Session 2.2 - PRODUCTION & MANAGEMENT 1 SESSION CHAIR Eylem Kaya Lecture Theatre 405.460	Session 2.3 - DIRECT USE & SOCIAL ENGAGEMENT / COMMUNITY ENGAGEMENT SESSION CHAIR Ru Nicholson Lecture Theatre 405.470
2:00	MERCURY NEW ZEALAND INDUSTRY UPDATE Ben Pezaro	13 Operational experiences and asset management of geothermal pipelines at Wairakei – Robert Dudley	7 Investigating the geohat potential of the Tauranga geothermal system – Yale Carden
2:15	EASTLAND GROUP INDUSTRY UPDATE Ben Gibson	53 Rotokawa Upgrade Project: Midlife geothermal power plant development and optimisation – Leigh McLellan	84 Interpretation of the first thermal response test in Central Asian countries – Hikari Fujii

2:30	CONTACT ENERGY INDUSTRY UPDATE Bridget Ayling	46 Lessons learned from the Rotokawa condensation-induced water hammer incident – Ivo Lemmens	18 Overview of the Rotokawa-Mokoia geothermal system, Bay of Plenty, Aotearoa New Zealand – science, monitoring and use – Mariana Zuquim
2:45	WESTERN ENERGY INDUSTRY UPDATE Marcus Prestney		28 Polaris renewable energy, Empowering communities – Jim Lawless
3:00	AFTERNOON TEA		
	Session 3.1 - INDUSTRY UPDATES SESSION CHAIR Katie McLean Lecture Theatre 401.401	Session 3.2 - GEOTHERMAL GEOLOGY 1 SESSION CHAIR Bridget Lynne Lecture Theatre 405.460	Session 3.3 - SCALING & CORROSION 1 SESSION CHAIR Wei Guo Lecture Theatre 405.470
3:30	BAY OF PLENTY REGIONAL COUNCIL INDUSTRY UPDATE Penny Doorman	58 Geothermal The Next Generation – 5 years of findings to propose a new exploration phase for New Zealand – Isabelle Chambefort	17 Subsurface corrosion mitigation experience through acid fluid neutralization in the Tiwi geothermal field, Albay, Philippines – Jean Mary Libato-Avila
3:45	WAIKATO REGIONAL COUNCIL INDUSTRY UPDATE Katherine Luketina	90 Targeting faults with geothermal wells – why bother? – Phil White	3 Optimised chemical cleaning of geothermal wells: A laboratory study – Alan Ferguson
4:00	MITCHELL DAYSH INDUSTRY UPDATE Mason Jackson	67 Unveiling the Subsurface Dynamics: A multi-analytical approach for constructing geothermal model of Huangzui volcano, Taiwan – Ting Jui Song	64 Learnings from 50 chemical well cleaning and stimulations across various well types, formations and countries – Logan Muller
4:15	GEOTHERMAL INSTITUTE INDUSTRY UPDATE Sadiq J. Zarrouk, John O'Sullivan	39 Well-Scale Permeability Classification on the Indonesia Conventional Geothermal Reservoir – Muhammad Ikhwani	
4:30	JACOBS INDUSTRY UPDATE Darryn Wise	45 Conceptual model of the Roseau Valley geothermal system, Dominica, Lesser Antilles – Ryan Libbey	
4:45	JRG ENERGY INDUSTRY UPDATE Duncan Steven	9 Active fault delineation studies using soil gas survey in the North-Ghoubbet geothermal prospect – Youssef Samod	

Thursday 21 November

8:45	HOUSEKEEPING			
9:00	KEYNOTE TITLE: An overview of tools for the modelling of GHG storage, AGI and geothermal applications Keynote Speaker Professor Alfredo Battistelli, Geothermal Reservoir Engineer Consultant, Italy			
9:45	TRIVENI TURBINES DMCC INDUSTRY UPDATE Siddarth Tomar			
10:00	MORNING TEA			
	Session 4.1 - INDUSTRY UPDATES SESSION CHAIR Clare Baxter Lecture Theatre 401.401	Session 4.2 - GEOCHEMISTRY 1 SESSION CHAIR Michael Rowe Lecture Theatre 405.460	Session 4.3 - RESERVOIR MODELLING 2 SESSION CHAIR John O'Sullivan Lecture Theatre 405.470	
10:30	SOLENSIS INDUSTRY UPDATE Daniel Wilson	63 Development of a flow through multi Input chemical-water-gas-rock reactor for the purpose of geothermal non-condensable gas injection reaction testing – Claire Newton	68 Stored heat calculations – Time for Review – Brian White	
10:45	AECOM NEW ZEALAND INDUSTRY UPDATE Shivam Naidu	66 Deciphering geochemical traits of metapelitic orogenic geothermal systems: Insights from the Lushan geothermal field in Taiwan – Yi-Chia Lu	49 Investigations of reservoir response to net-negative CO ₂ reinjection using full-scale geothermal reservoir models – Abigail Swanepoel	
11:00	CASIL TECHNOLOGIES INDUSTRY UPDATE Jim Johnston	33 Extracting geothermal potential areas in Ecuador using hydrogeochemical data and their principal component analysis – Danilo Ibarra, Kotaro Yonezu	52 Numerical assessment of carbon sequestration in a 3D rhyolite-hosted reservoir – Dale Emert Altar	
11:15	SUPERIOR PERFORMANCE DESIGN GROUP (SPD) INDUSTRY UPDATE Colin Finnegan	73 Geochemical parameters for evaluating brine outfield injection impact at Salak, Indonesia – Risa Prameswari Putri	31 Reactive transport modelling of fluid-NCG reinjection in Nga Tamariki geothermal field – Yefamikha Siahaan	
11:30	MARUBENI-ITOCHU TUBULARS OCEANIA (MITO) INDUSTRY UPDATE Rafer Kong	29 The effect of CO2 co-injection on silica scaling in acid-dosed subduction zone geothermal brines – Akira Kamiya	24 Reactive transport modelling of NCG-reinjection at Ngawha geothermal field – Vaibhav Rajput	
11:45	ECOLAB INDUSTRY UPDATE David Rodman	40 Expanding the limits of experimental water-rock interaction: The supercritical laboratory at GNS Science – Bruce Mountain		

12:00	LUNCH			
1:00	KEYNOTE TITLE: Hydrothermal monitoring of Yellowstone National Park (2005-2015) using night-thermal infrared remote sensing Keynote Speaker Dr Cheryl Jaworowski, Geologist Consultant, Wyoming, USA			
1:45	Geothermal Institute website launch Bettina Way			
	Session 5.1 - INDUSTRY UPDATES SESSION CHAIR Mason Jackson Lecture Theatre 401.401	Session 5.2 - DRILLING & WELL TESTING 2 PRODUCTION & MANAGEMENT 2 SESSION CHAIR Oliver Maclaren Lecture Theatre 405.460	Session 5.3 - ENVIRONMENTAL ASPECTS SESSION CHAIR Rony Nugraha Lecture Theatre 405.470	
2:00	GNS SCIENCE INDUSTRY UPDATE Isabelle Chambefort	54 Real-time incident detection in geothermal drilling operations using machine learning solutions – Aira Aspiras	42 Ecology, history and management of geothermal vegetation and habitats in the Ngā Tamariki geothermal system, Waikato, Aotearoa New Zealand – Chris Bycroft	
2:15	MTL INDUSTRY UPDATE Richard Belcher	86 Post-drilling outer casing cement remediation and recommissioning of a Rotokawa well – Matt Kelley & Daniel Chaparro	25 Comparison of satellite-based InSAR methods for monitoring geothermal areas at Rotokawa: PS versus SBAS – Mark Harvey	
2:30	GALLAGHER INSURANCE INDUSTRY UPDATE James Coldman	80 Over pressure protection in geothermal plants – Kevin Koorey	37 Unlocking our potential: a superhot geothermal future for Aotearoa New Zealand – Deborah Kissick	
2:45	IXOM INDUSTRY UPDATE Noel Gerente		11 Understanding geothermal regulation in New Zealand. A day in the life of the regulator – Penny Doorman	
3:00	AFTERNOON TEA			
	Session 6.1 - INDUSTRY UPDATES SESSION CHAIR Mike Allen Lecture Theatre 401.401	Session 6.2 - SCALING & CORROSION 2 SESSION CHAIR Jimmy Yang Lecture Theatre 405.460	Session 6.3 - GEOCHEMISTRY 2 & GEOTHERMAL GEOLOGY 2 SESSION CHAIR Bei Nugoro Lecture Theatre 405.470	

3:30	INDONESIA – AOTEAROA NEW ZEALAND GEOTHERMAL ENERGY PROGRAMME (PINZ) INDUSTRY UPDATE Greg Ussher, Evelyn Gunawan	71 Stress corrosion cracking failure of a geothermal steam piping rupture disc – Sigit Prabowo	21 A pioneer application of downhole tracer injection in geothermal production well – Fabian Hanik
3:45	NZTE - Indonesia INDUSTRY UPDATE Putri Wuningsari	48 Application of machine-learning for the prediction of formation rate of silica scale from geothermal water – Saefudin Juhri	95 Characterisation of tonalite and andesite prior to reaction with CO2-rich fluids – Bridget Lynne
4:00	NZTE - Philippines INDUSTRY UPDATE Maricon Popones-Lim	6 Case study of the CaSil technology at Dieng, Indonesia – Successfully eliminating silica scale – Thomas Borrmann	23 Comparative study of silica inhibitor versus pH modification in the geothermal system – Arsyian Sasoni
4:15	WING INDUSTRY UPDATE Clare Baxter, Michael Gravatt	79 Extending the life cycle of geothermal wells: Effective strategies for scale removal – Rochelle Longval	34 Conceptual model of slate formation: A case from the Lushan geothermal field, Taiwan – Sheng Rong Song
4:30	SEEQUENT INDUSTRY UPDATE Jeremy O'Brien	65 Iron sulfide deposition and inhibition and its impact on geothermal brine pumps – Fritz Monterozo	
6:30	NZGW CONFERENCE DINNER - Lula Inn, 149 Quay St, Auckland CBD		
10:30			

Friday 22 November			
8:45	HOUSEKEEPING		
9:00	KEYNOTE TITLE: Lessons learned from two successful EGS deployments in the United States Keynote Speaker Dr Jack Norbeck, Co-founder and Chief Technical Officer, Fervo Energy, USA		
9:45	Geothermics: A New Zealand issue? Sadiq J. Zarrouk		
10:00	MORNING TEA		
	Session 7.1 - INDUSTRY UPDATES SESSION CHAIR Mike Allen Lecture Theatre 401.401	Session 7.2 - HINDSIGHT & FORESIGHT SESSION CHAIR Michael Gravatt Lecture Theatre 405.460	Session 7.3 - SCALING & CORROSION 3 SESSION CHAIR Angus Yeh Lecture Theatre 405.470
10:30	NGĀWHĀ GENERATION INDUSTRY UPDATE Fabian Hanik	74 New Zealand annual geothermal review 2023 – Ted Montague, Sadiq Zarrouk	51 Deposition behaviour of elements composing of a silica scale formed from a geothermal water – Kotaro Yonezu
10:45	CONDOR ENERGY INDUSTRY UPDATE Josh Anderson	35 Superhot geothermal – A net zero window of opportunity for New Zealand? – Chris Bromley	43 Identifying formation scale in geothermal wells – Katie McLean
11:00	UPFLOW INDUSTRY UPDATE Andy Blair	87 The role of groundwater monitoring in the sustainable development of the Ngā Tamariki field – John Mering	15 Unlocking the full geothermal potential: How the CaSil technology can eliminate silica scaling and create new business opportunities – Michael Schweig
11:15	INTERGROUP INDUSTRY UPDATE Sam Clive	20 Reimagining geothermal power plants: Green Hydrogen, Lithium and CO2 removal from New Zealand's future geothermal stack – Karan Titus	22 Enhancing the viability of calcite inhibition systems via targeted dose rate reduction – Alan Ferguson
11:30	WORKSAFE NEW ZEALAND INDUSTRY UPDATE Nick Dawtry	62 Is the Australian geothermal industry "gathering steam"? – Rosalind Archer	

11:45		47 Prioritization of geothermal field development in Indonesia for energy transition: A multi-criteria decision analysis approach – Hadyan Perdana Putra	
12:00	LUNCH		
1:00	WING – Walk & Talk, Auckland Domain: (meet at Level 4 reception)		
		Session 8.2 - GEOPHYSICS SESSION CHAIR Jennifer Eccles Lecture Theatre 405.460	
2:00		60 Geophysical imaging of the Paeroa Fault: Insights from a dense nodal seismic array – Brook Keats	
2:15		70 Refining geological models through 3D gravity modelling at Wairakei, Tauhara and Rotokawa geothermal fields – Jenny Barretto	
2:30	WORKSHOP CLOSE – Sadiq J. Zarrouk, John O'Sullivan		

Abstracts

3 | Optimised Chemical Cleaning of Geothermal Wells: A Laboratory Study

Alan Ferguson¹, Gabby Buchanan², Courtney Fox¹, David Fletcher³, Katie McLean¹, Jonathan Wynands¹, James Asquith¹ and Michael Rosenberg⁴

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3 David Fletcher Consulting, Karitane, New Zealand

4 GNS Science, 114 Karetoto Road, Taupō, New Zealand

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Keywords: *Geothermal production well, geothermal reinjection well, formation scale, silica scale, calcite scale, chemical cleaning, well recovery, stimulation.*

The chemical cleaning of geothermal production and reinjection wells is a helpful maintenance activity in treating formation scale. Removal of this troublesome scale can be used to maximise generation, increase the useful life of wells and defer the drilling of new wells. While we have had several successful chemical workovers of both production and reinjection wells in recent years, there have also been scenarios where the uplift was not as expected, or the recovery was short lived. In an effort to explain the behaviour we have observed, we have undertaken a thorough laboratory study to understand the efficacy of the chemicals typically used to chemically clean geothermal wells and find the optimal chemical mix for both production and reinjection wells. We employed a systematic, statistical experimental design approach to allow testing of a range of variables and chemical types

in the smallest number of experiments possible. These baseline results have given us valuable insight into the optimal chemical selection for production and reinjection wells to provide the best chance of success when applied in the field. This paper summarises the results of several hundred experiments across different scale types and formations and discusses the implications of the results for future well workovers.

Session: 3.3



6 | Case Study of the CaSiI Technology at Dieng, Indonesia; Successfully Eliminating Silica Scale

Thomas Borrmann¹, H Putri Fraser¹, James Johnston¹, Michael Schweig¹, Ilen Kardani², Delvirah Singkuang², Ayu Gracia Ade Sumartha², Andhika Putera Utama² and Aditya Yuda Kencana²

1 CaSiI Technologies Ltd, c/- BW Miller Dean, Level 9, 94 Dixon Street, PO Box 11253, Wellington 6142, New Zealand

2 PT Geo Dipa Energi, Aldevco Octagon Building 2nd Floor, Jalan Warung Jati Barat Raya No. 75, South Jakarta 12740, Indonesia.

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Keywords: *Geothermal, Dieng, silica, silica scale, calcium silicate, CaSiI, simulated geothermal brine, silica saturation index, electricity generation.*

The CaSiI technology is a proprietary innovative new technology that eliminates silica deposition and scaling from geothermal brine, supersaturated in silica. The technology has been developed and successfully demonstrated at development plant scale operation over six years in four New Zealand geothermal fields.

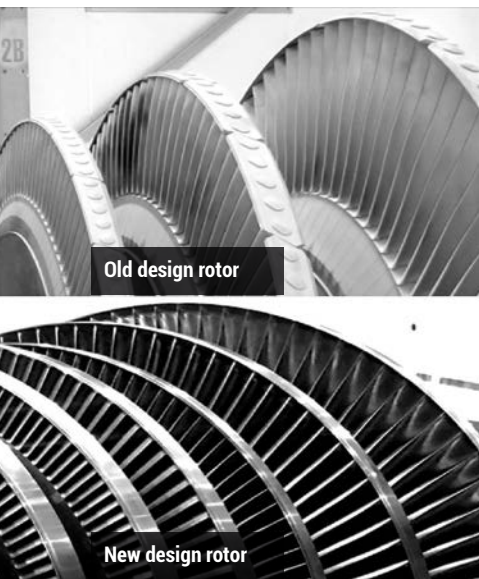
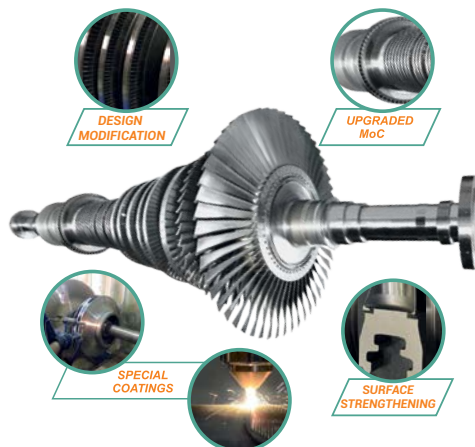
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Client Overview

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Client Challenges

The client faced a triad of formidable issues:

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- Rotor Material Enhancement

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This paper reports an initial study on the application of the CaSil technology to the silica supersaturated, hyper-saline brine from the Dieng geothermal field, Indonesia. Problematic dissolved silica is rapidly captured as a nanostructured calcium silicate material before silica deposition and scaling can occur. This yields a treated brine that can be cooled to unprecedented low temperatures without silica scaling, thereby enabling more heat energy to be accessed and electricity generated from the same brine flow than is currently possible.

Samples of brine from the Dieng-1 well that had been acidified after collection were provided by Geo Dipa Energi to CaSil Technologies for analyses and an initial assessment of the suitability of the CaSil technology to prevent silica scaling. Using atomic absorption and UV visible spectroscopies, electrochemistry, and titrations the main constituents of the brine were identified. Based on this, a simulated brine

was generated and used to test and identify the potential of the proprietary CaSil technology to reduce silica levels and the Silica Saturation Index, SSI, of this high silica, hyper-saline brine accordingly.

Another intention of these trials was to explore effects from the borate buffer system due to the high boron content of the brine, on the CaSil technology and the reduction of the Silica Saturation Index (SSI) to levels where additional heat can be harnessed and electricity generated without inducing silica scaling. Autoclave reactions were used to simulate field specific high temperature and pressure reaction conditions.

The successful laboratory trials using the simulated brine were confirmed using the Dieng brine samples provided in further experiments. These show the pathway for possible field trials, which promise that by incorporating the

CaSil technology, additional heat recovery and electricity generation from the Dieng resource can be achieved without silica scale formation, thereby unlocking the full energy potential and utilisation of this geothermal resource.

Session: 6.2



7 | Investigating the Geoheat Potential of the Tauranga Geothermal System

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Keywords: *Geoheat, low temperature geothermal, regional development, Tauranga Geothermal System, decarbonisation, resource management.*

The Tauranga Geothermal System (TGS) covers an area of approximately 875 km², extending from Waihi Beach in the north to Te Puke-Maketu in the south. Being a low temperature single aquifer geothermal system, it ranges in temperature from ~15 °C (ambient) to ~70 °C at depths of 700m. Although these temperatures are too low for electricity generation, they have good potential for heating.

Geoheat is the use of geothermal energy for heating purposes either directly or indirectly, using heat pumps. Current geoheat applications in the TGS include bathing, space heating, water heating, irrigation and frost protection. Due to its ability to replace gas heating and to

reduce electrical demand and carbon emissions, geoheat is an important part of the energy transition.

To this end, the Bay of Plenty Regional Council (BOPRC) commissioned an investigation into the geoheat potential of the TGS.

The investigation adopted a holistic approach by integrating the technical groundwater and geothermal elements with stakeholder consultation on current practices, management implications and how these align with regional economic development considerations.

Resource characterisation of the TGS presents a readily accessible source of sustainable thermal energy. Integrating this finding with socio-economic factors further concludes that geoheat use of the TGS could provide significant energy, economic, environmental and health benefits to the region.

Greater use of the TGS' geoheat potential must be balanced with sustainable management of the resource. This report outlines guidance to ensure good system design, appropriate technology selection, and ensuring compliance of installation techniques. This work will inform the Tauranga System Management Plan (which is currently being developed by BOPRC). It will also guide any future changes to balance the environmental and economic benefits of an increased uptake of geoheat with the long-term sustainability of the resource.

Session: 2.3



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9 | Active Fault Delineation Studies Using Soil Gas Survey in the North Ghoubbett Geothermal Prospect

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Keywords: Mercury, radon, carbon dioxide, skewness, Quantile plot

Soil gas surveying (carbon dioxide, Radon and mercury soil sample) are important assets for geothermal resource exploration. Several surface manifestations, in particular, fumaroles occur in the North-Ghoubbet geothermal field and have not yet been examined by those techniques. Therefore, this study aims to determine the flow of geothermal fluids by examining the soil CO₂ flux, radon and mercury distribution to detect buried structures that may infer permeability for the Nord-Ghoubbet geothermal area as a preliminary investigation. Anomalous distribution of the following soil gas (Radon (Rn), dioxide carbon (CO₂), mercury (Hg) etc...) should be the "halos" of underground geothermal system and frequently used for the first phase of geothermal. Soil gas samples were obtained by hammering steel pipes in the ground to penetrate the ground to a depth of 0.6~1.0 meter. In total, 86 points were measured by CO₂ (using a Kitakawa Gas detector), and mercury (The samples were analysed by a mercury analyser, NIC, MA 3000 at Kyushu University) at the same points. And 76 points for radon (using radon detector "RD-200"). In this study area, they are no background values measured for radon and CO₂ concentration, for that statistic analysis were applied to determine the threshold value (the anomalous concentration). According to the calculated descriptive statistics, the skewness must be

close to zero and doesn't exceed 0.1 but in the data, the skewness is very high which means the data are not a normal distribution, the data is either log-normally or exponentially distributed. Quantile plot (The quantile-quantile (q-q)) plot were used to analyse the data and data appear as a lognormal distributed. The cumulative probability plots were used also to perform statistical analyses and classify the anomalies distribution.

The anomaly distribution highlighted the lowest value is located in the Moudououd horst with a significantly lower concentration, 0.01% of CO₂, 1.3071 ppb of mercury and a relatively low-value anomaly of 1 cpm for the radon gas survey. The highest CO₂ and mercury anomalous concentrations were located at the Afay, Anale and Qeridaba areas with 2.5% CO₂ and 1000 ppb of mercury, and the anomalous concentration of radon (for the thorium 220Rn with more than 100 cpm, and the radon 222Rn more than 10 cpm) concentrate to the Afay area. In the central part of the study area, the fumaroles and altered ground were distributed, and also the soil gas sampling was concentrated in this area. The NNW and NW structures are dominant and coincide with structures already exist in the study are by soil gas analysis. The buried structures can be estimated as active faults, which may be a conduit path of gas emanations.

Session: 3.2



11 | Understanding Geothermal Regulation in New Zealand: A Day in the Life of the Regulator

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Keywords: *Geothermal regulation, rules, consent conditions, compliance, Kawerau Geothermal System, Rotorua Geothermal System*

The Bay of Plenty's geothermal systems are managed by the Bay of Plenty Regional Council under the Resource Management Act 1991 (RMA). The council manages geothermal through its various policy documents. These are developed through a consultative process and within legal requirements. It lays out our approach to management, and the requirements and obligations that must be met for the use of the geothermal resource. It is our contract with the community.

Policy implementation is often where the success of this approach will be decided. Regional policies and rules lay out consenting pathways, and the suite of consent conditions to be expected. These conditions are usually agreed pre- consenting, or through a hearing process and can be

upheld through a Court of law, including via enforcement action. On the surface it might appear a 'big stick' approach - and it can be. But our methods are also non regulatory, including guidelines, education, and incentives.

Implementation therefore involves a careful balancing act, working closely with resource users who are part of the community, and have distinct obstacles and challenges. Companies that are owned by iwi have another level of scrutiny and are accountable to their people.

Consent and compliance processes differ hugely depending on the geothermal system. In development systems like Kawerau, consent conditions are prescriptive and consent holders are well resourced to meet consent conditions. In systems like Rotorua, small users have relatively high compliance costs with limited resources or knowledge. This presents unique challenges, and a different regulatory approach. This paper will explore some examples of compliance practices in the Bay of Plenty Region.

Session: 5.3



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12 | Numerical Modelling and Resource Assessment of the NRV Geothermal Field, Colombia

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Keywords: *Nevado del Ruiz Volcano (NRV), geothermal modelling, resource assessment, uncertainty*

The Nevado del Ruiz Volcano (NRV), located in the central cordillera of Colombia, is one of the most monitored volcanoes in the world due to its destructive capability. Thanks to this, there is abundant information regarding its surrounding structures and the behaviour of the edifice itself. This information has been used over the years to study the potential of the area to produce geothermal energy; however, because of the political and economic circumstances of the country, geothermal development has been slow and disorganised, and exploration projects have focused on understanding its geology and the geochemistry of the surface features associated with it, but the underground structures have not yet been extensively studied.

This research aimed to gather the open-source information of the field and compile it to create a geological model of the area using Leapfrog Energy 2023.1. Furthermore, this geological model was used to create a discretised numerical reservoir model, using AUTOUGH2, that matched the estimated subsurface structures and the surface manifestations found in the zone.

The calibrated numerical model of the NRV obtained matched the expected flow patterns of the field, which were estimated based on two groups of surface manifestations: group one (G1), of acidic nature, located to the west of the volcano and believed to correspond to the upflow of the field, and group two (G2), located

further away from the volcano in its north-western flank, which presented alkali-chloride mixed waters and is believed to be the outflow region.

Additionally, this numerical model was used to perform a resource assessment and predict, considering uncertainty, how much power the field could produce based on a resource assessment method developed by Dekkers et al. at the University of Auckland. Using this method, the estimated NRV mean power production potential was above 150MWe over an exploitation period of 25 years, with a confidence interval P90 of about 100MWe and P10 of about 200MWe.

Session: 1.2



13 | Operational Experiences and Asset Management of Geothermal Pipelines at Wairakei

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Keywords: *Wairakei, pipelines, operational experience, asset management, corrosion, erosion, scaling, water hammer.*

Contact Energy has a risk-based monitoring programme on its pipelines, maintaining pressure integrity to ensure safe, reliable operation and compliance with legislation. The monitoring programme has been developed over time from technical knowledge and operational experience.

When the Wairakei geothermal field was first developed in the 1950s, there was no industrial knowledge for transporting geothermal fluids cross-country, particularly two-phase flow. Early scientific and metallurgical research established that low carbon steel was a suitable material for construction of pipelines and most steamfield equipment.

Once operation started, experience showed us what the damage mechanisms were, together with how to identify and monitor them. This knowledge was used to modify the inspection programme. Together with that, external and process threats such as tree fall, vehicles collisions, ground washouts and water-hammer events shaped how we operate and maintain our equipment. Minor improvements have been made to designs but sixty years of operational experience have proven the soundness of the early pioneers' decisions. Combined, this has given the confidence to safely run the plant with a comprehensive management plan for the assets along with simple monitoring requirements.

This paper outlines some of the knowledge and those experiences, how these have shaped our approach to pipeline safety and how challenges are addressed.

Session: 2.2



14 | Numerical Modeling of Hydrothermal System in the Western Region of Kirishima Volcano in Kagoshima Prefecture, Japan

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Keywords: *Kirishima Volcano, hydrothermal system, conceptual model, numerical model*

Well-developed geothermal areas exist in the Ogiri and Shiramizugoe areas, located in the western part of the Kirishima Volcano. As understanding the hydrothermal system is extremely important for sustainable geothermal development, numerical models of hydrothermal systems under natural conditions have been developed to investigate both areas. However, the reproduction of pressure profiles in this area remains an issue, and one possible reason is the existence of an impermeable layer between the Ogiri and Shiramizugoe areas. Thus, in this study, we classified the part of the NW fault between the Ginyu and Shiramizugoe faults that are distributed in a high-density area, estimated from the airborne gravity anomaly method survey (Nishijima, 2016). We created a model wherein the Ogiri and Shiramizugoe areas are independent of each other by the impermeable layer owing to low permeability. Simulations were conducted using HYDROTHERM-Version 3.2 (Kipp et al., 2008) to investigate the hydrothermal system.

The simulation results indicated that the calculated pressure profiles of the wells located in the target area were approximately 5 MPa higher than the measured values. As all voids

in this model were saturated with water up to the surface block, the differences between the calculated and actual groundwater levels can be attributed to the fact that the calculated pressure values exceed the measured values. Therefore, when the influence of the groundwater surface is corrected using the pressure determined from the simulation, the pressure difference between the Ogiri and Shiramizugoe areas can be reproduced. Therefore, we developed a model that can explain the temperature and pressure in this area by reducing the permeability of the NW fault distributed in the high-density area between the Ogiri and Shiramizugoe areas.

Session: Poster Session



15 | Unlocking the Full Geothermal Potential: How the CaSil Technology can Eliminate Silica Scaling and Create New Business Opportunities

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Keywords: *Geothermal, Silica Scaling, CaSil Technology, Calcium Silicate, Silica Extraction, Direct-Use, Reinjection*

Silica scaling continues to pose a worldwide challenge in the full exploitation of geothermal reservoirs. As dissolved silica precipitates during cooling and steam production, it forms an intractable scale that blocks pipework, heat exchangers and reinjection wells. These deposits significantly lower the efficiency of heat exchangers, resulting in a direct reduction in electricity and revenue generation over time.

Regular and costly maintenance is required which leads to plant downtime. Conventional silica scale mitigation techniques are not wholly successful and come with drawbacks such as high cost or corrosion risks.

The innovative and proprietary CaSil technology introduces a disruptive method of transforming dissolved silica entities into a novel calcium silicate (CaSil) product, forming discrete particles that remain suspended and do not adhere to metal surfaces. This process achieves a significant reduction in the silica saturation index to well below 1 within seconds. The robust technology is adaptable to a wide range of brine compositions, regardless of the initial silica concentration, ensuring dependable elimination of silica scaling. Moreover, the CaSil technology facilitates the safe reduction of brine temperatures beyond current limits without inducing any silica scaling. This presents novel business prospects for utilising additional process heat in sectors like greenhouses, aquaculture, or milk powder production, supporting the efforts to decarbonise industrial processes. The CaSil technology can seamlessly integrate with existing geothermal operations, or greenfield plants, offering a versatile solution.

This paper presents updated data from our development plant which was successfully operated across four different geothermal resources in New Zealand. The effectiveness and robustness of the technology which can unlock the full potential of geothermal resources are highlighted. Additionally, data based on laboratory experiments are discussed, addressing the applicability of the technology to high silica, hypersaline geothermal brines such as the Dieng field in Indonesia.

Session: 7.3



17 | Subsurface Corrosion Mitigation Experience through Acid Fluid Neutralization in the Tiwi Geothermal Field, Albay, Philippines

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Keywords: *Downhole neutralization, corrosion, acid fluids, acid sulfate fluids, fluid pH, Tiwi geothermal field, Philippines*

Utilization of wells with acid fluid production is a continuing challenge in many geothermal fields but such conditions also offer considerable opportunity if successfully addressed. One well in the Tiwi Geothermal field in the Philippines was producing near-neutral benign fluids until early 2000 when it started to produce fluids with 2.3 to 3.3 pH. Continuous utilization became impossible without risking the integrity of the production wells and downstream facilities forcing the well to be shut-in for a prolonged period.

A cost-effective means to utilize the well was proposed through downhole neutralization. Injection of caustic soda through capillary tubing was pilot-tested to mitigate the corrosion on the casing and pipeline. Well-53 has been producing over 3 – 4 MW of additional steam since the start of NaOH dosing with acceptable pH levels while maintaining low corrosion rates. Several improvements in the dosing facility and procedures have been identified to enable more real-time monitoring and greater flexibility in terms of operation.

The success of the acid neutralization test opens up opportunities not only in the utilization of other idle acid-fluid producing wells and future new wells in acidic areas of Tiwi, but also in the feasibility of developing greenfield low pH geothermal reservoirs.

Session: 3.3



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18 | Overview of the Rotokawa-Mokoia Geothermal System, Bay of Plenty, Aotearoa New Zealand – geoscience, monitoring and use

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Keywords: *Rotokawa-Mokoia Geothermal System, geoscience, community engagement, direct use, sustainability, environmental.*

The Rotokawa-Mokoia Geothermal System (RMGS) is located on the eastern side of Lake Rotorua. The system is classified as Group 3 (conditional development) under the Bay of Plenty Regional Natural Resources Plan (RNRP) and the Regional Policy Statement (RPS), where extraction of geothermal water, heat and energy is provided for where significant adverse effects on Significant Geothermal Features (SGF) are avoided, remedied or mitigated. This paper presents high-level information gathered from over 50 years of geoscientific research and reporting, monitoring and the collation of use data by the Bay of Plenty Regional Council (BOPRC). The paper aims to summarise and present this available information in an accessible way for community engagement purposes for the current BOPRC Plan Change 11 (RNRP review) program. The RMGS extends from Mokoia Island to the northwest through to Rotokawa in the southeast, including the Rotorua Airport area and the bed of Lake Rotorua between Mokoia Island and the Airport. The main thermal areas are around the southeast shoreline of the Island and around Rotokawa. The geothermal surface features in both areas are fed by the same source aquifer at depth. The RMGS is relatively small compared to other high-temperature systems of the Taupō Volcanic Zone (TVZ). Subsurface temperatures are up to 115 °C at less than 100 m depth within the RMGS. While this is a relatively cool thermal resource

compared to other high-temperature systems of the TVZ, the produced temperature suits the energy requirements for end uses (for example space and water heating). Current levels of use of geothermal water and energy is very low, however, being a small system, it is difficult to determine what this low level of use means to the health of the geothermal system and its surface features. An assessment of the size and hydrogeology of this geothermal resource would help to understand opportunities for sustainable use, while protecting the significant geothermal surface features in the area as directed by the current and future planning frameworks.

Session: 2.3



19 | Pressure and Temperature Transient Analysis of Geothermal wells with low permeability

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Keywords: *Geothermal, well testing, Pressure transient analysis, Temperature transient analysis, low permeability*

Geothermal well testing is performed during completion activities. The test provides insight into the wellbore and reservoir properties, such as permeability, skin factor, skin radius, boundaries, and faults. Traditionally, the analyses are performed with a focus primarily on pressure



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transients, potentially overlooking valuable information in the temperature transient, which can improve predictive models. This study analyses pressure and temperature transients of two sets of geothermal well test data with low permeability. By adding the temperature analysis, this study aims to examine the temperature behaviour and enhance the reliability of well-test analysis by considering the contribution of temperature analysis. The results show that the temperature response is related to the reservoir's permeability and the wellbore temperatures. At the same time, the pressure can stabilise even when the temperature remains transient.

Session: 1.3



20 | Reimagining geothermal power plants: Green Hydrogen, Lithium and CO2 removal from New Zealand's future geothermal stack

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Keywords: *Hydrogen, direct air capture, lithium,
techno-economics, energy transition*

Geothermal energy is an important low-carbon source of electricity (~1000 MWe) and heat (~8 PJ/year) for Aotearoa New Zealand. The high capacity factors of New Zealand's geothermal power plants allow for base load firming in the electricity grid. Additionally, direct-use heat

applications range from timber-drying to space heating. However, as valuable as electricity and direct heat are for domestic decarbonisation, there is growing potential for New Zealand to contribute to international markets with low-carbon exports and services.

Three emerging technologies with strong synergies with geothermal are: (1) green hydrogen, (2) brine-derived lithium and (3) atmospheric CO₂ removal. In this study, we evaluate the potential of each technology against a future geothermal generation stack, currently unbuilt but expected to come online between 2030 and 2050. The estimated potential of these fields is 735 MWe. All three technologies have export pathways, albeit immature, that may help geothermal developers find favourable market applications more easily.

In addition to parasitic load, we assess the secondary resources required to achieve this value-stacking. This includes the water load for green hydrogen production and the low-grade heat for direct air capture (DAC). Finally, we assess the cost of these products and compare them to conventional electricity generation. We estimate potential annual production of 60 kt of green hydrogen, 1.2 kt of lithium and 4 Mt of CO₂ removed with possible revenues of (NZD) \$300, \$16 and \$700 million per year respectively.

Session: 7.2



21 | A Pioneer Application of Downhole Tracer Injection in Geothermal Production Wells

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Keywords: *geothermal, geochemistry, tracer testing, TFT, tracer dilution*

The principles of tracer flow testing were implemented to test the assumption of a down flow within a geothermal well bore's open hole section in Ngawha geothermal field.

The production well had a pre-existing anti-calcite dosing system, however it had lower than expected calcium returns compared to those typical with the fluid chemistry in the geothermal field. The possibility of a small down flow existing above the dispersion head needed to be eliminated as one of the possible causes, prior to investigating other hypotheses.

To verify this possibility, a downhole tracer injection test was planned and conducted in conjunction with a standard surface tracer flow test. The test results show that both downhole tracer injection and standard surface tracer flow tests achieved almost the same flow rate and total enthalpy results. These tests have proven that full returns were taking place at the current dispersion head set depth.

In addition, these tests have also proven that even with a less-than-optimal tracer mixing distance, a homogeneous tracer flow in the two-phase pipeline can be achieved.

Session: 7.3



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22 | Enhancing the Viability of Calcite Inhibition Systems via Targeted Dose Rate Reduction

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Keywords: *Calcite scale, production well, inhibition system, inhibition chemical.*

Calcite scaling of Te Ahi Tamou (geothermal) production wells is an issue that requires ongoing attention and maintenance to maintain generation. Chemical cleaning is an important maintenance activity where the well is flashing in the formation, while broaching and live well cleanouts using air hammer are mechanical means to recover production when the scaling occurs within the wellbore. These methods have the limitation of accepting loss of production as the well scales up between interventions (Moya et al, 2005). Calcite inhibition systems (CIS) are a viable alternative that, when functioning correctly, remove the need for mechanical workovers and can maintain production without the need to accept productivity losses.

The installation of CIS on 13 of our production wells has been successful in allowing us to maintain a clear wellbore in wells that would typically have scaled up rapidly. As part of an ongoing optimisation of our systems, we have undertaken a targeted programme of work to optimise our chemical dose rates to reduce our operational costs and enhance the viability of installing CIS in further wells. This paper details the steps taken to reduce our chemical usage, while still maintaining clear wells. Dose

rates have been tuned through assessment of chemical trends, comparison of calcite saturation of similar wells, analysis of operational data and through the use of an XY caliper tool to assess the effectiveness of reduced dosing rates. Analysis of this data has given us confidence that our targeted dose rate reductions have been successful and has allowed us to realise valuable operational savings that increases the appetite for future installations to maintain production for our wharehiko (geothermal power stations).

Session: 6.3



23 | Comparative Study of Silica Inhibitor Versus pH Modification in the Geothermal System

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Keywords: *Silica Inhibitors, Silica Deposition, Field Evaluation*

In the cold injection system of Geo Dipa Energi (GDE) Dieng Unit, amorphous silica deposition remains a significant challenge. Amorphous silica deposition can be detrimental and require costly cleaning of the piping in the surface equipment and injection well.

Historically, pH depression with sulfuric acid (H₂SO₄) has been used to delay silica polymerization. However, the addition of sulfuric acid can lead to severe corrosion problems within the plant, and this has led to the development of alternative approaches to reduce silica deposition.

This paper documents the results from a series of field tests that were conducted to optimize the performance of a new silica inhibitor DPI-920. Key performance indicators were: Brine transfer pump discharge pressure, Silica inhibition percentage, and deposition rate.

The new silica inhibitor yielded significant improvements and an economic benefit of close to 20% versus sulfuric acid (annual projection)

Session: 6.3



24 | Reactive Transport Modelling of NCG-Reinjection at Ngawha Geothermal Field

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Keywords: Reactive transport simulation, Ngāwhā geothermal field, NCG reinjection, TOUGHREACT™

Geothermal energy stands as a well-established, dependable, and sustainable source for generating electricity and providing district heating at lower temperatures. In striving to meet New Zealand's ambitious climate targets, geothermal power producers have taken bold

steps to drastically reduce the country's carbon emissions. One noteworthy example is the Ngāwhā Geothermal plant operated by Top Energy, which initiated Non-Condensable Gases (NCGs) reinjection directly on site starting in May 2022 with OEC1. This innovative approach has since been expanded to other units as of early 2023, marking significant progress towards achieving carbon neutrality. This presents an interesting research question: exploring the effects of additional NCG reinjection on key reservoir parameters through a comprehensive modelling study for Ngāwhā field.

Reservoir modelling is crucial in comprehending how fluids move within geothermal reservoirs. However, very few studies are performed that incorporate the chemical interaction occurring between fluid and rock *in situ*. To understand what happens to injected NCGs and how it chemically alters the reservoir, conducting reactive transport modelling becomes essential. This approach provides detailed insights into how these changes evolve spatially and over time. Such information is crucial for effectively managing resources and gaining confidence in our understanding of the complex thermal, hydraulic, and chemical processes occurring underground.

In this study, 1D numerical models were set up to address the above research aims. One of the primary reinjection wells, NG11, was chosen for detailed analysis. A 1D MINC radial model was generated in TOUGHREACT™ using publicly accessible information on Ngāwhā field. The MINC approach was selected to represent the highly fractured nature of the Ngāwhā field more accurately. The results from our study provide insights into the principal minerals expected to dissolve and/or precipitate, the subsequent changes on porosity and permeability, and effect of injected CO₂ for various scenarios. Three different reinjection scenarios were modelled, and the results suggest that calcite dissolution increases with higher NCG reinjection content. Out of the others minerals considered, pyrite,

illite, and albite showed strong tendency for precipitation. Due to the high dissolution rate of calcite compared to other minerals, its effect on overall change in porosity was profound, which led to an increase in porosity. Significantly, the injected CO₂ stayed in the aqueous phase due to non-precipitation of calcite and other carbonate minerals.

Session: 4.3



25 | Comparison of Satellite-Based InSAR methods for Monitoring Geothermal Areas at Rotokawa: PS versus SBAS

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Keywords: Rotokawa, StaMPS, SBAS,
geothermal, subsidence, InSAR, Sentinel.

This study utilises freely available Sentinel-1 satellite InSAR data to map surface deformation at the Rotokawa thermal area between 2014 - 2024. Three InSAR methods are used to examine the area: PS InSAR (StaMPS), and two SBAS methods (GMTSAR and LiCSBAS). While StaMPS provides the best resolution to localised deformation, both SBAS methods have the advantage of providing total coverage across the survey area. LiCSBAS can efficiently process very long time series (i.e. 10 years) and may be applied to very large areas (> 1000 km²). A disadvantage of LiCSBAS is that it may not resolve localised areas of surface deformation,

e.g. small subsidence bowls (< 200 m radius). This is a limitation of the method, which utilises a coarser grid and averages signals over a wider area.

Session: 5.3



26 | Deep underground structure and hydrothermal modeling inferred from integrated geophysical surveys

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Keywords: Kuju volcano, Otake-Hatchobaru
geothermal field, Supercritical geothermal
system, Conceptual model

A detailed study of the deep geothermal system in Kuju volcano, central Kyushu, Japan. This study was part of a project funded by the New Energy and Industrial Technology Development Organization (NEDO) to explore supercritical geothermal resources. This study involves the development of a hydrothermal conceptual model that incorporates geophysical, geological, and geochemical data. Geophysical surveys, such as magnetotellurics (MT), seismic, gravity, and fumarole gas analyses, were conducted.

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The conceptual model indicates that faults in the Hatchobaru area may act as pathways for magmatic fluids, contributing to the high-temperature zone identified on the western side of Mt. Kuroiwa. The model also suggests the existence of an up-flowing path for volcanic fluids. The geological setting of the Kuju volcanic complex is characterized by faults aligned in an east-west direction owing to north-south extensional stress. The study also discusses the resistivity structure, which reveals a low-resistivity zone associated with faults near the Hatchobaru-Otake power plant. Additionally, the model inferred the presence of a magma chamber and identified pathways for magmatic fluid flow. A numerical simulation using the TOUGH2 was conducted to validate the model. The simulation results closely matched the observed temperature and pressure data, although further refinement of the model is recommended for greater accuracy.

Session: Poster Session



28 | Polaris Renewable Energy, Empowering Communities

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Keywords: *Nicaragua, San Jacinto, Sustainability, Communities, Social investment, Community Development, Stakeholder Engagement, Social impact, Community empowering, Materiality, Strategy.*

As a Company, the opportunity to make a positive impact, while investing in our projects is a fundamental driver of our commitment to Sustainability. We are committed to contribute to the neighbouring communities of the projects we operate in, prioritizing those activities and projects of sustainable development and social investment that mean substantive changes in the quality of life and well-being of the entire community. We are determined to foster the local economy by maximizing local employment and procurement opportunities.

For us, it is important to build trust-based relationships with all stakeholders while maintaining active listening and promoting open channels of consultation and participation.

This philosophy is fundamental to align our Company with the United Nations Sustainable Development Goals (SDGs), mitigate risks, build positive relationships, and generate a significant and lasting impact on the communities where we operate.

For many years, starting with our operations in the San Jacinto-Tizate Geothermal Power Plant in Nicaragua, we have focused our community development efforts in areas that we consider fundamental, such as education, community infrastructure, agriculture, health and sports. This program positively impacts the lives of five communities and approximately 5,000 people.

The social impact generated by the different actions we have carried out, whether small or large, have contributed to the fact that these communities are now more resilient; with access to water services, that positively impacts their human rights; with children and youth more prepared for life; with small producers that are now properly technified and equipped; as well as communities supported by infrastructure that assists healthy recreation and integration.

In this way, our management has demonstrated that engaging positively with local communities helps to build trust and gain support for our projects and its operations.

Session: 2.3



29 | The Effect of CO₂ Coinjection on Silica Scaling in Acid Dosed Subduction Zone Geothermal Brines

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Keywords: Carbon emissions, non-condensable gas, CO₂ reinjection, silica scale.

Geothermal energy is not inherently carbon neutral; it releases non-condensable gases (NCG) during energy production. Although geothermal energy is a strong contender in the low-carbon energy space, it must reduce these emissions to compete effectively with other renewable energy sources. For this reason, capturing and reinjecting NCG is an emerging method being implemented and considered by the geothermal industry.

However, carbon emissions are not the only concern in geothermal energy production. Another common issue faced by the geothermal industry is silica scaling. At the interface between the reinjection brine and reservoir rock, shifts in pH can cause amorphous silica scale to form. Previous research has suggested that the co-injection of CO₂ with acid-dosed brines may help inhibit this scaling.

To investigate this potential solution, we conducted two reinjection simulation experiments using a high-pressure and high-temperature (HPHT) flow-through system to replicate conditions typical of island-arc geothermal systems, such as those in Japan, Indonesia, and The Philippines. The significant geothermal energy potential in these regions

makes studying these systems essential. In the experiments, we used a synthetic geothermal brine and exposed it to andesite + calcite.

Our results indicate that adding CO₂ to acid-dosed brines can significantly reduce the rate of silica scaling in the reservoir. In our experiments, introducing 2000 ppm CO₂ into the fluid maintained a low pH solution, resulting in almost no scaling—a stark contrast to the outcomes observed without adding CO₂. These results suggest that the co-injection of CO₂ in geothermal power plants will be beneficial in reducing plant emissions while at the same time mitigating silica scaling within the reservoir.

Session: 4.2



30 | CO₂ Injection Well Design in the Geothermal Industry

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Keywords: *New Zealand, Drilling, CO₂,
Geothermal, Well Design, Drilling, Completion,
CCS, Cement, Metallurgy, Phase Behavior,
Regulations, Monitoring*

The geothermal industry is keen to reduce the climate impact for all their operations. Capturing associated CO₂ and reinjecting it returns the naturally occurring geothermal CO₂ back underground to where it came from.

Globally, CO₂ re-injection is still in its infancy. In all of Australia, there is only one CO₂ injection project currently in operation and globally there are still many valuable lessons being learned.

Many aspects of drilling CO₂ injection wells are similar to drilling a conventional geothermal well though there are significant differences between them. This paper shall discuss key differentiators between conventional well design techniques and CO₂ injection wells. Areas addressed include:

- Regulations
- Geological Characterization
- Metallurgy
- Cementing
- Load cases
- Well integrity
- Monitoring and Verification
- Risk Assessment
- Contingency planning including geothermal control
- Design process
- Legacy wells and abandonment of existing wells

There are two options available for CO₂ injection: re-using existing wells with remediation, workover, or recompletion activities, or drilling new wells dedicated to CO₂ injection. Each option has its own advantages and disadvantages, but the main goal is always to ensure that the wellbore and reservoir can securely hold the CO₂ for an extended period without any leaks into sensitive zones, such as to an aquifer or the atmosphere.

To choose the most suitable well design, it is important to have a thorough understanding of the pressure and temperature profile throughout the lifecycle of the well. These parameters will behave differently compared to a geothermal well. Analysis is necessary to accurately assess and mitigate any risks associated with the well.

To ensure the effectiveness of the CO₂ injection well, a monitoring and verification plan may be necessary to ensure the containment of CO₂ and

to identify any potential anomalies. Monitoring may include pressure, temperature, logging of tubing integrity, and even conducting seismic surveys.

Session: 1.3



31 | Reactive Transport Modelling of Fluid-NCG Reinjection in Ngā Tamariki Geothermal Field

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Keywords: reactive transport model, TOUGHREACT, NCG reinjection, Ngā Tamariki.

As global efforts intensify to realise a carbon-neutral future, the reinjection of non-condensable gases (NCG) into geothermal fields offers a promising option to reduce greenhouse gas emissions. The ongoing CO₂ reinjection program at Ngā Tamariki, which has been operational since October 2021, reinjects NCG from one of the binary units, reducing annual GHG emissions from the station by 25% (>8,000tCO₂e p.a.).

To provide quantitative insights into the geothermal reservoir response at Ngā Tamariki under various NCG reinjection conditions, and to assess mineral reactions and geochemical processes, 2D reactive transport modelling was conducted using TOUGHREACT v.4.13. The models aim to identify major precipitation and dissolution reactions of minerals and their long-term impacts on permeability and the

flow paths, elucidate the fate of reinjected NCGs and explore CO₂ trapping mechanisms for sequestration. By simulating both injection and production behaviour within the reservoir, the models examine the relationship between these and provide insights into geochemical alteration resulting from changes in the thermodynamic conditions.

Based on the 2D model, an increase of NCG reinjection from 0% to 25% of the total NCG of the plants widened the area of porosity-permeability enhancement, along with increased calcite and anhydrite dissolution, and reduced precipitation of pyrite. However, further increasing NCG reinjection from 25% to 50% was insignificant in terms of changes in porosity-permeability or the amount of anhydrite or pyrite. Only calcite exhibits a more widespread and enhanced dissolution response at the increased NCG reinjection rate.

Session: 4.3



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33 | Extracting Geothermal Potential Areas in Ecuador Using Hydrogeochemical Data and Their Principal Component Analysis

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Keywords: Geothermal exploration,
Geochemistry, Principal Component
Analysis (PCA), Ecuador.

This study advances geothermal exploration in Ecuador through the application of Principal Component Analysis (PCA) to both existing geochemical data from the literature and

new samples collected from previously little or unstudied springs, such as El Hondón, Salvafaccha, Quilotoa, Salinas de Bolívar, and Santa Rosa de Mamanguy. Ecuador's geothermal potential is significant, with six major geothermal plays covering 49.2% of the national territory, particularly in the northern and southern Andes, and parts of the southwestern coast.

A dataset comprising 451 samples was analyzed, including temperature, pH, and major ions, allowing for a comprehensive characterization of the geothermal waters. Geochemical classification using ternary diagrams was employed to assess the geochemical behavior, followed by the application of PCA to identify key factors influencing geothermal potential. Reservoir temperatures were estimated in the range of 68 to 155 °C for Quilotoa, 66 to 171 °C for El Hondón, 75 to 233 °C for Salvafaccha, and 62 to 231 °C for Oyacachi using alkali geothermometers. These estimated temperatures highlight the suitability of these

sites for future geothermal exploration, both for electricity generation and direct-use applications.

PCA results revealed that conservative ions (Cl^- , Na^+ , K^+) and temperature are key factors in the variability of geothermal waters, and identified several sites, including Portovelo, Nangulví, and Chimborazo among others, in the high-interest quadrant of the biplot, suggesting the existence of high-temperature hydrothermal systems. These findings highlight promising areas for future geothermal exploration and development.

Session: 4.2



34 | A Conceptual Model of Slate Formation: A Case from the Lushan Geothermal Field, Taiwan

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Keywords: *Slate Formation, Taiwan, Geothermal Conceptual model, Exploration*

Slate is a low-grade metamorphic rock commonly found in orogenic belts like the Taiwan Mountain Range. There are very few geothermal fields with power plants around the

world, making the Lushan geothermal field in central Taiwan quite unique. Geologically, this area is mainly composed of metamorphosed mudstone known as the Lushan Formation, which is one of the dominant rock types in Taiwan's orogenic belt. The rapid uplift and erosion from arc-continent collisions on the island have created a high geothermal gradient of over 50-60°C/km. This leads to a wide distribution of hot springs and thermal features along the river valleys.

In response to the growing demand for renewable energy and the need to reduce greenhouse gas emissions in Taiwan, we have conducted extensive geological, geophysical, and geochemical explorations in this region, resulting in a wealth of valuable data. We have integrated this information into a 3D geothermal and geological model using: (1) Data from a surface digital elevation model. (2) Local geological maps and profiles. (3) Core data and logging information from drilling wells. (4) 3D distribution results from MT surveys. (5) Borehole temperature measurements and up-to-date field surveys.

Preliminary results suggest that the shallow heat sources (less than 1,000 meters below the surface) in the Lushan geothermal field may originate from deeper locations to the southeast. However, when we take a broader view of the MT data, it appears that potential heat sources may actually be coming from the west or southwest, deep beneath the Chunyang area.

Session: 6.3



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35 | Superhot Geothermal – A Net Zero window of opportunity for New Zealand?

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Keywords: *superhot, supercritical, resource assessment, economics, geothermal generation projection, inventory.*

The installed geothermal capacity in New Zealand in 2024 is ~1.2 GWe with production of ~8 TWh /yr supplied onto the grid in 2023. The production supporting this generation infrastructure is all produced from wells shallower than 3.5 km depth, but with significant opportunity for additional energy production by accessing deeper resources.

GNS Science, through the MBIE Endeavour Research Programme, Geothermal the Next Generation (GNG), has been considering the deeper opportunity and has developed a Superhot Geothermal Inventory for onshore New Zealand geothermal prospects. Assessment has been undertaken using the United Nations Framework Classification for Resources.

Considering only identifiable resource volumes, outside of any regulatory protected geothermal systems, and within the depth range of 3.5 to 6 km, the inventory identifies that there is a possible additional capacity of up to ~3.5 GWe, producing about 29 TWh /yr.

An electricity market modelling study, prepared by Castalia Ltd (2023) forecast that superhot geothermal power plants could contribute up to an additional capacity of 2 GWe to the New Zealand grid by 2050. This is a consequence of the significant increase in demand, and hence

renewable capacity, forecast to be required as New Zealand transitions to Net Zero carbon emissions. Castalia modelled electricity market conditions out to 2050 and assessed the likely commercialisation date for superhot geothermal power plants. Additional capacity of 1.4 to 2 GWe is robust for superhot geothermal power plants producing electricity even at up to double the costs for conventional geothermal.

This is a significant strategic Net Zero opportunity for New Zealand. It should be investigated and evaluated, working towards realising superhot geothermal generation as part of the nation's energy transition.

Session: 7.2



36 | Accurate location of feed zones: assessing obscuration by the liner in geothermal wells through analysis of fluid velocity profiles

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Keywords: *Completion testing, stage testing, well testing, geothermal wells, cold water injection, perforated liner.*

The location of feed zones in geothermal wells is commonly identified using pressure, temperature, and spinner (PTS) data from a downhole tool during completion testing after the slotted liner has been installed in the well. To inform drilling decisions in some wells, these data are also collected during a stage test before liner installation. In both tests, water is injected into the well at a set of fixed flow rates.

It is typically expected that the presence of the liner will partially obscure feed zone locations in the data collected in completion tests. Quantifying this effect is important because a stage test is not always performed due to the additional cost and the chance of open-hole collapse. Meanwhile, completion testing is always carried out as it represents the final condition of the well. Additionally, quantifying this effect is important for situations where feed zone locations need to be known with higher accuracy. For example, to correlate the location of feed zones with geology logs, to effectively use a deflagration tool for feed zone stimulation and to assess the effectiveness of chemical clean jobs.

This 'obscuration' effect has previously been considered for the identification of feed zones using temperature logs. In that research, the effect of the liner was found to: make feed zones appear shallower by 17 m on average, widen the feed zone by 114% on average and make close-together individual feed zones appear to be one zone. Here, we consider the follow-up to that research: quantifying the degree to which the liner obscures the feed zone locations by comparing fluid velocity profiles acquired from the spinner tool during open-hole testing (stage testing) with those acquired after liner installation (completion testing). Several field examples are presented, from liquid-dominated wells in the Taupō Volcanic Zone.

Session: 1.3



37 | Unlocking our potential: a superhot geothermal future for Aotearoa New Zealand

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Keywords: *Geothermal, superhot, supercritical, regulatory planning, resource management, interconnectivity, system boundaries, consenting, freshwater, investment risk, political support, engagement, mana whenua, cultural values*

GNS Science, as part of the MBIE Endeavour Research Programme Geothermal: the Next Generation (GNG), has been considering the opportunity for superhot geothermal (> 400°C) resources in New Zealand. Superhot geothermal, with potentially zero CO₂ emissions, presents an opportunity to more than double current geothermal electricity generation from 2037.

With geoscience now “looking” deeper underground and with advances in geothermal utilisation and effects management in conventional geothermal systems, Is the existing regulatory planning framework fit for purpose for superhot geothermal?

As part of exploring this question, the authors have identified a range of questions focussed on unlocking Aotearoa New Zealand's geothermal potential. While not an exhaustive analysis, these questions and challenges need to be considered to address potential barriers to a superhot geothermal-powered future as we transition to Net Zero energy.

This paper identifies a range of regulatory and broader challenges and suggests initiatives to be explored to overcome them.

Session: 5.3



38 | Building Resilience: Designing well testing equipment and procedures for powerful wells

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Keywords: *well testing, production wells, LECM,
geothermal, flow testing, two-phase flow*

Testing geothermal production wells is a key step in the life cycle of a well asset. The owner of the well aims to quantify the value of the asset in terms of; MWe capacity, interaction with nearby wells and geochemistry during the well test.

Geothermal wells cost in the magnitude NZD\$10M to drill. This large cost drives the asset owner to drill the highest producing well possible. In recent years in New Zealand wells have drilled with larger diameter completions and are producing massive outputs. Well testing equipment has had to keep up with the increased demands. This paper explains how Western Energy and our partner Thermochem have innovated equipment and procedures to handle powerful wells.

Session: 1.3



39 | Well-Scale Permeability Classification on the Indonesia Conventional Geothermal Reservoir

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Keywords: *permeability, geology, structure,
image log.*

Effective permeability characterisation in geothermal wells is paramount for optimising geothermal energy production. This study investigates the interpretation of permeability control using image log data and injection spinner logs to classify and capture the various permeable zones within geothermal reservoirs from a well-scale perspective. The classification delineates five primary types of permeable zones: high-intensity fracture zones, large aperture fracture sets, permeable fault cores, pores or microfracture-supported formations, and permeable unconformities or lithological contacts.

High-intensity fracture zones, typically occurring in brittle formations such as lava or welded tuff, are identified by closely spaced fractures with small apertures. These zones are well captured by image logs and exhibit a gradual response in spinner logs if they are permeable. Large aperture fracture sets, characterised by noticeable and continuous conductive fractures, show abrupt responses in spinner logs, indicating high permeability. However, the conductivity of these fractures can be biased by the presence of conductive minerals, impacting the actual permeability estimation. Permeable fault cores are marked by significant displacements or washouts in the borehole wall, often recorded as drilling breaks. These zones can pose challenges in logging due to caliper disorientation and image loss, making it difficult to determine the actual fault orientation. Porous formations and lithological contacts, which

include interconnected pores and microfractures, enhance permeability and are well captured by image logs and under microscopic analysis. Lithological contact or unconformities, particularly angular unconformities or disconformities, can create permeable zones, but may sometimes be misinterpreted as faults.

Integrating multiple log analyses, including image, sonic, and density logs, is crucial for accurately identifying productive fractures and permeable zones. This approach addresses key challenges such as fracture continuity beyond the borehole, actual fracture permeability, and the geometry of fault planes in space. Additionally, understanding fracture kinematics through geomechanical analysis provides valuable insights into fracture characterisation. Non-fracture permeability, facilitated by porous formations and lithological contacts, also plays a significant role in well productivity. By comprehensively analysing these various permeable zones, this study enhances the understanding of reservoir hydrology and supports the effective planning and optimisation of geothermal wells, ultimately contributing to the successful exploitation of geothermal energy resources

Session: 3.2



40 | Expanding the Limits of Experimental Water-Rock Interaction: The Supercritical Laboratory at GNS Science

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Keywords: *experimental geochemistry, water-rock interaction, supercritical, corrosion, silica scaling, CO2 re-injection*

The Experimental Geochemistry Laboratory (EGL) at GNS has expanded its capabilities into the supercritical pressure-temperature region through new equipment purchases and the support of funding from the Geothermal: The Next Generation (GNG) programme. With experimental work spanning water-rock interactions, mineral solubilities, scaling/corrosion simulations, and CO2 reinjection, the laboratory contributes to advancing geochemical understanding and industry practices in the geothermal setting. With the expanded capability the lab can conduct such studies at the more extreme temperature and pressure conditions of the supercritical environment. Experimental work at supercritical conditions completed to date includes seawater - basalt interaction, water/brine - greywacke interaction, CO2 – brine co-injection into greywacke, and mineral solubilities (quartz and anhydrite). These experiments aid in understanding the effects of water-rock interaction at supercritical conditions



in geothermal reservoirs and geochemical reactions in future power station infrastructure.

Session: 4.2



42 | Geothermal Vegetation in the Ngā Tamariki Geothermal System: Ecology and Management

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Keywords: *Ngā Tamariki, Tauhara, geothermal system, electricity generation, geothermal vegetation monitoring, restoration*

The Ngā Tamariki Geothermal System (NTGS) is located c.20 kilometres north of Taupō and has around six hectares of geothermal vegetation and habitat. The system contains many relatively small and active geothermal manifestations that are widely dispersed in and alongside Orakonui Stream, Waikato River, and Mangamingi Stream. The diversity of geothermal habitats includes steamy habitats (alongside springs and streams), sinter deposits, wetlands, and thermally heated ground providing habitat for key geothermal plant species. The NTGS is classified as a 'Development Geothermal System' by Waikato Regional Council. Rotokawa Joint Venture operate a geothermal power station in the NTGS. An 82MW geothermal power plant was commissioned in 2013, with consent granted for an extension in 2024. Regular monitoring of geothermal surface features and geothermal vegetation has been undertaken since 2012. Recently, a restoration management plan

with a focus on key geothermal habitats at the Orakonui site has been prepared in collaboration with mana whenua (Ngati Tahu-Ngati Whaoa) and key stakeholders. The plan provides advice to manage key threats to vegetation and species in geothermal habitat here, particularly management of pest plants. This paper provides a summary of known site history, ecological values, monitoring results, an overview of restoration options, and recommendations for future management.

Session: 5.3



43 | Identifying formation scale in geothermal wells

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Keywords: *Geothermal wells, formation scaling, chemical cleaning, identifying scale type, vertical discharge, productivity/injectivity index, pressure transient analysis.*

Operational geothermal wells tend to block up over time with mineral deposits, leading to declines in well capacity and ultimately generation. The mineral deposits are called "scale" – and can be calcite, silica, silicates, or a mix. The issue affects both production and reinjection wells. In production wells, scale forms where there is boiling. In reinjection wells, scale forms as minerals exceed the saturation limit of the reinjected fluid. Scaling can be within

the wellbore (“wellbore scale”), or the reservoir beyond the wellbore (“formation scale”).

Wellbore scale is easier to identify as it can be accessed directly within the wellbore using wireline tools, such as calipers or gauge rings. Formation scale is more difficult to identify as it sits outside of the accessible wellbore and cannot be detected by any of those direct methods.

The presence of formation scale has typically been inferred indirectly, by ruling out other culprits. If a well is declining rapidly, and the decline cannot be explained by changes in reservoir conditions, and no wellbore scale is found, then formation scale is assumed to be the culprit. However, a higher level of certainty is desirable to decrease the risk to the operator of unsuccessful chemical cleans, as methods to remove formation scale (chemical cleaning) are expensive.

There are several methods for identifying formation scale more directly and with more certainty. These include: vertical discharge methods, tracking of productivity/ injectivity index, and tracking of skin factor and permeability from pressure transient analysis. This paper reviews all methods of identifying formation scale, both indirect and direct, for production and reinjection wells, and provides examples. This is intended as a guide to decrease the risk of chemical cleaning jobs, and can also form the basis for well monitoring program design.

Session: 7.3



44 | Reducing greenhouse gas emissions from NZ geothermal power stations

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Keywords: *Geothermal emissions, greenhouse gases, carbon, non-condensable gases (NCGs), New Zealand ETS, CO₂ reinjection, NCG reinjection.*

Geothermal reservoirs contain naturally-occurring greenhouse gases, in the form of CO₂ and methane. In most cases the process of generating electricity using geothermal reservoir fluids results in the release of some greenhouse gases into the atmosphere. This means that the operational emissions intensity (scope 1 emissions) of geothermal power stations is not zero.

The operational emissions from the geothermal power stations in NZ have been collated and published each year since 2018 by the New Zealand Geothermal Association Emissions Working Group. The full lifecycle emissions are also estimated, to allow comparison to emissions from other renewable energy sources. The five previously published datasets are reviewed in this paper, along with the latest dataset from calendar year 2023. Changes and trends are identified, for the industry overall, and for individual power stations.

The change of most interest is the elimination or reduction of emissions from some power stations. This has been achieved by reinjection of the greenhouse gases back into the reservoir. This method effectively closes the loop on the gases and returns them to where they came from. This has so far been achieved at three geothermal power stations – Ngāwhā, Te Huka and Ngā Tamariki. This common and important emissions challenge has given rise to a cooperation between all the geothermal generators in New Zealand, enabling the decarbonisation effort to progress faster. The effect of this effort on the emissions can be seen in this paper.

Session: Wednesday 20 November, 01:45 PM



45 | Conceptual model of the Roseau Valley geothermal system, Dominica, Lesser Antilles

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Keywords: *Dominica, Wotten Waven, Conceptual Model, Caribbean, Lesser Antilles, Outflow, Island Arc*

The Roseau Valley (Wotten Waven) geothermal system is a prolific high-temperature resource situated in the southern highland regions of the volcanic island of Dominica in the Lesser Antilles. Three intermediate diameter (6-1/8" bottomhole) wells and four standard sized wells (8.5" bottomhole) have been drilled at the prospect area between 2012 and 2023.

The results of these wells and other geoscientific investigations reveal a broad, ~400 m-thick, 240-255°C outflow reservoir that is channeled through fractured andesitic volcanics and directed to the southwest from a likely upflow situated adjacent to the ~25 ka Morne Microtrín dacite dome. In contrast to some of the other documented seawater-influenced resources of the Lesser Antilles (e.g., Bouillante, Nevis, Garibaldi Hill), the reservoir at Roseau Valley is a lower salinity, meteoric- water-derived, 0.5 wt% TDS Na-Cl fluid, with 0.2-0.5 wt% dissolved NCGs. High permeability (productivity indices of 60-240 kg/s/bar) is documented in the field, with key structural features being the West-striking Trafalgar and Papillote Faults. Image log data provide further context for fracture orientations associated with these structures, and also give insight into the maximum principal horizontal stress direction in the field area through the analyses of drilling induced tensile fractures. These analyses help place the permeability controls at Roseau Valley in the broader context of the intra-arc stress regime in the Lesser Antilles.

Ormat will be constructing a 10 MW-net power plant at Roseau Valley through 2024-2025, which is expected to supply approximately 50% of the island's peak electricity demand. Expansion of this plant in the near future will enable the island to achieve its goal of 100% renewable energy before 2030.

Session: 3.2



46 | Lessons Learned from the Rotokawa Condensation Induced Water Hammer Incident

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Keywords: Condensation Induced Water Hammer, Steam Hammer, Learning from Incidents, Rotokawa

This paper details the conditions that can lead to Condensation Induced Water Hammer (CIWH) and seeks to raise awareness for the potential catastrophic nature of these events and the major impact they can have in terms of Health and Safety and how this risk can be managed during the design phase of a project as well as during normal operation.

The sequence of events that led to the CIWH incident that occurred at Mercury's Rotokawa site is presented including the key lessons learned related to plant design, human behaviour, and operational processes, as well as the corrective actions that were taken.

Session: 2.2



47 | Prioritisation of Geothermal Field Development in Indonesia for Energy Transition: A Multi-Criteria Decision Analysis Approach

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Keywords: Geothermal Power Plant, Energy Transition, Techno-Economic Analysis, GEOPHIRES v2.0, Multi-Criteria Decision Analysis, Analytical Hierarchy Process.

Indonesia is committed to complying with the Paris Agreement on Climate Change and has outlined its energy transition strategies through the LTS-LCCR 2050. One of the renewable energies that can replace fossil fuel plants is geothermal energy. Although promising, geothermal energy is known for its high investment cost and risk, so careful prioritisation and decision-making are required. This paper aims to develop a comprehensive decision-making framework to give insights to decision-makers and stakeholders.

This paper's proposed framework uses a combination of techno-economic multi-criteria decision analysis. GEOPHIRES v2.0 is used for techno-economic analysis. Analytical Hierarchy Process (AHP) is suggested for the multi-criteria decision analysis to evaluate the geothermal fields using various sustainable development criteria. Three scenarios of the LTS-LCCR 2050 (CPOS, TRNS, and LCCP) are used as the basis for weighting to determine the field prioritisation, which is reflected through the final AHP scoring. The above framework is applied to ten different geothermal greenfield projects across Indonesia. The results are ranked and compared using the above developed framework. Comparison with other rankings (e.g. RUPTL 2021-2030) leads to insights into the decision-making process and method.

This work suggests that fields located on Sumatra Island and Java Island should be prioritised more highly in the context of energy transition. A more comprehensive result can be achieved by including new variables in the indicator level of the AHP structure.

Session: 7.2



48 | Application of Machine-Learning for the Prediction of Formation Rate of Silica Scale from Geothermal Water

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Keywords: *machine learning, artificial intelligence, silica, scaling, geothermal*

Utilization and development of geothermal energy are still hindered by scaling and corrosion to this day. Scaling is particularly troublesome as it can occur in almost all locations in geothermal power plants, i.e., in production wells, on surface facilities, in reinjection wells, and even in the reservoir rock formation around the reinjection wells. However, there is no single and universally applicable mitigation method to date, due to the

unique characteristics of each geothermal water and the complexity of scale formation. This study aims to better understand and quantify silica scaling assisted by artificial intelligence (AI), i.e., supervised machine learning (SML).

The SML was used to predict the formation rate of silica scale based on the physicochemical characteristics of geothermal water and the kinetics of polymerization of silicic acid in geothermal water and adsorption of silicic acid on the surface of scale substances. These data were used as input parameters in the training data. The data was obtained from onsite batch experiments in several geothermal power plants in Japan. The rate of silica scale formation from onsite plate immersion experiments using stainless-steel plate was used as the output parameters. This experiment was conducted for up to 5 hours in the corresponding geothermal power plants.

The produced models are evaluated based on their percent relative root means squared error (%RRMSE) value when used to predict unknown data, i.e., non-training data. Our study showed that the model can achieve %RRMSE value of 15 which is in the good category, i.e., the model can accurately predict the formation rate of silica scale within 5 hours. Furthermore, the model will be trained to predict the formation rate of silica scale for up to 5 days and beyond. This study is expected to aid geothermal power plants to mitigate the silica scale problem more efficiently.

Session: 6.2



49 | Investigations of Reservoir Response to Net-Negative CO₂ Reinjection using Full-Scale Geothermal Reservoir Models

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Keywords: report, report, report, data, paper TBC

Geothermal power production is a renewable form of base-load electricity generation. However, it is not an emissions-free process due to non-condensable gases such as CO₂ found naturally underground that are mixed into the working fluid. With the global push toward more sustainable operation of infrastructure, good management of the CO₂ emissions in geothermal fields has financial, environmental and cultural benefits. One strategy is to inject 100% of the CO₂ produced by the system in what is known as a net zero reinjection scheme. Furthermore, additional CO₂ can be captured from other processes, such as the burning of biomass fuels in hybrid biomass geothermal power generation plants and added to the existing reinjection streams. This is known as a net negative injection scheme.

However, successful sequestration of CO₂ using these methods requires knowledge of how the reinjection strategies affect the system, particularly relative to its natural state. Direct monitoring of all the CO₂ emissions across the surface of the geothermal system in sufficient detail is impractical. Estimation of these emissions can be done using numerical modelling, where short-term CO₂ accumulation under the clay cap is used as a proxy for CO₂ emissions in the long term. This project used a synthetic model to perform numerical simulation of a no CO₂ reinjection production scenario, 100% CO₂ reinjection scenario and a 110% CO₂

reinjection scenario using Waiwera, an open-source geothermal flow simulator.

In the case with no CO₂ reinjection we observe a steady decline in production CO₂. The two cases where we reinject CO₂ (100% and 110%) we show production CO₂ is consistent with the base case for the first 3.5 years, then we observe a steady increase over the duration of the simulation. In the base case, CO₂ is leaving the model either through production or the surface. When injection of CO₂ is occurring, the CO₂ is replenished in the production zone of the reservoir from reinjection and the up flow resulting in elevated CO₂ production and more CO₂ going through the alteration in time.

Session: 4.3



51 | Deposition Behavior of Elements Composing of a Silica Scale from a Geothermal Water

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Keywords: Silica scales, Coexisting elements, Deposition behavior, Geothermal water, Metal plate immersion method

Silica scales, which precipitate from geothermal waters, contain some elements such as Al, Na,

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K, Mg and Ca as major constituents in addition with Si. The movement of the elements from geothermal water to surface of stainless-steel (SUS) plates was examined by the metal plate immersion method. Change in the concentration of the elements deposited on the surface with time was measured by a LA-ICP-MS. From the plot of the concentration of each element against the immersion time of SUS plates in a geothermal water, the followings were made clear: (1) the deposition of Si (silicic acid) correlated with that of Al, suggesting that Al may contribute the deposition of silicic acid, (2) Na, K, and Ca may be incorporated in the silica scale due to neutralization of a permanent negative charge on the 4-coordinated Al.

Session: 7.3



52 | Numerical Assessment of Carbon Sequestration in a 3D Rhyolite Hosted Reservoir

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Keywords: Carbon sequestration, Fluid-rock interaction, Reactive transport simulation, NCG, Rhyolite, TOUGHREACT™

L Carbon dioxide produced from geothermal operations may be captured and reinjected for safe and long-term storage to reduce emissions. However, this comes with key process challenges and potential reservoir management risks, requiring careful assessments during the technology testing phase and when gauging long-term resource performance.

The reaction of injected carbon dioxide with minerals in the reservoir formation to form carbonate minerals has the greatest capacity for storage permanence. A critical determinant for carbon mineralisation success is the reservoir rock; for example, the mineralisation of CO₂ in basaltic rocks rich in divalent cations, e.g. Ca²⁺ and Mg²⁺, has been proven in Iceland. This work investigates the carbon sequestration potential in hydrothermal systems hosted in silicic rocks with lower divalent cation content, e.g., geothermal systems in New Zealand.

Numerical models were used in this study to assess carbon storage via mineralisation in a 3-dimensional hypothetical liquid-dominated geothermal reservoir hosted in rhyolite tuff, the corresponding sequestration potential, and the possible risks, e.g., breakthrough and surface leakage. Model results show that though mineralisation is expected during 40 years of concurrent mass extraction and CO₂ reinjection, <1% of the injected CO₂ was converted to carbonates during that period. After operations were discontinued, carbon dioxide mineralisation increased further to >12% in the subsequent 60 years of modelled time. Models to assess the effectivity of methods aimed at promoting mineralisation, i.e., adding divalent cations to the reinjected fluids or pH neutralisation, suggest short-term improvements in mineralisation rates but no significant effect in the long term.

Session: 4.3



53 | Rotokawa Upgrade Project: Midlife Geothermal Power Plant Development and Optimisation

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Keywords: *Rotokawa, Ngā Awa Pūrua, Rotokawa Upgrade, Acid Dosing, Enthalpy Management, Acid Dosing, Separation*

Mercury operates the Rotokawa and Ngā Awa Pūrua geothermal power plants on the Rotokawa geothermal field located in the North Island of New Zealand. Over time, the geothermal fluid enthalpy has declined. The Rotokawa Upgrade project was initiated to mitigate the impact of this enthalpy decline on the generation output of the two power stations.

This midlife upgrade project sought to rebalance the steam and brine flows from the Rotokawa reservoir between the two power stations. The rebalancing was completed through the installation of two new separators and by increasing the brine processing capability of the Rotokawa Power Station. The project has extended the operational life of Ngā Awa Pūrua at design enthalpy and has resulted in a generation uplift at the Rotokawa power station.

The upgrade project was fully commissioned at the end of 2021. This paper presents the upgrade objectives, specific design aspects of the upgrade project, the performance of the generation equipment and ongoing optimisation efforts implemented over the two plus years since its completion.

Session: 2.2



54 | Real-time Incident Detection in Geothermal Drilling Operations using Machine Learning Solutions

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Keywords: Geothermal drilling, Incident Detection, Risk Reduction, Machine Learning

Geothermal energy, while a reliable low-carbon resource, represents only a small fraction of global renewable capacity due to high upfront costs and resource risks. Drilling wells accounts for a substantial portion of geothermal project costs; successful drilling is thus crucial for geothermal projects. Finishing wells on-time and on-budget has always been a challenge for operators and mostly has modest success rates.

Overall drilling efficiency can be improved by increasing the rate of penetration (ROP) and reducing non-productive times (NPT). Geothermal systems present unique challenges like fault structures, severe lost circulation, and high temperatures that lead to potentially expensive incidents. Leveraging machine learning technologies offers promise in addressing these drilling challenges and optimising operations.

The drilling incident detection system using systematic and automated feature engineering on time-series data was able to successfully predict incidence of hole-related NPT. This system can potentially be deployed and assist drilling personnel in making tactical decisions during drilling, in the future, thereby reducing operational risks and enhancing overall drilling efficiency and cost performance.

Session: 5.2



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56 | Correcting for variations in borehole diameter in fluid velocity profiles

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Keywords: *Well testing, geothermal wells, stage testing, completion testing, pressure-temperature-spinner (PTS) logging, caliper logging*

Pressure-temperature-spinner (PTS) data is the most common dataset collected in geothermal wells. It provides valuable information about the well and reservoir, such as feed zone characteristics, well conditions, and well injectivity or productivity. A combination of temperature and fluid velocity profiles (calculated from spinner response) are used to accurately identify the location of feed zones in the well, and how much each feed contributes under certain conditions.

However, analysing the fluid velocity profile is often not straightforward when the borehole is heavily washed out. In this situation, the spinner data does not only reflect the actual feed zones but also the variation in borehole diameter. This interferes with feed zone interpretation, potentially providing misleading information about the well or reservoir.

Currently, to differentiate between the effects of feed zones and changing borehole diameter, reservoir engineers would look at a caliper log, which provides a physical measure of well bore diameter (if available), and visually compare the shape of it to the spinner data. This is an imprecise exercise and can fail to definitively determine whether there is a feed zone present within a washout, for example. Another current method is the spinner ratio method (Grant & Bixley, 1995), which divides one fluid velocity profile by another from a different flow rate

to give a ratio. The limitations of this are: the requirement to have two high quality fluid velocity profiles, complications in aligning the datasets, and the tendency for the ratio to be very noisy.

This work therefore explores ways to explicitly remove the effects of changing diameter from the fluid velocity profile by means of applying a correction method based on caliper data. This has been recently enabled by an increase in open-hole caliper data collection. The correction method was applied to field data from three wells in Wairakei geothermal field, with significant changes to feed zone interpretation as a result of the correction.

Session: 1.3



58 | Geothermal the Next Generation: Five years of findings to propose a new exploration phase for New Zealand

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Keywords: *Geothermal the Next Generation, supercritical, exploration, magnetic, heat flow, magnetotelluric, fracture and modelling*

After 5 years of research, the Geothermal: the Next Generation team delivered on exploration, understanding, integration of the science, and communication of the challenges facing discovery and exploitation of supercritical geothermal resources. We summarise the findings and new models of the programme that increased and challenged our understanding of the supercritical geothermal possibility for New Zealand. Here, we particularly focus on the exploration part of the programme and propose a new potential phase of geothermal exploration

for New Zealand geothermal.

New seismic, magnetic, heat flow and gravity models were produced with a specific focus on the southern part of the central Taupō Volcanic Zone / Te Ahi Tupua. From seismic tomography, we identified a deep large area of partial melt that is the heat source for the Wairakei – Tauhara and Rotokawa geothermal fields. For the first time, we compile geology and geophysics models of these fields. We refined the buried geology underneath the area by proposing a new geological model that better fits observed gravity and magnetic data to constrain the deep stratigraphy likely to be intercepted by deeper drilling. We characterised fracture patterns and orientation and proposed a new understanding of the distribution of basement terranes that are likely to be the reservoir rocks below the current drilled depths. We modelled the hydrothermal fluid circulation around large, deep-seated silicic magma reservoirs and around shallower magmatic heat sources to understand the fluid

properties at those conditions. Furthermore, we simulated the magmatic degassing of shallow silicic intrusions to elucidate how hydrothermal convection is affected by magmatic degassing. We ultimately identified where the prime targets are for exploration drilling to develop supercritical resources.

With the government's goal to double renewable electricity generation and achieve this through increased production from renewable, low-carbon energy sources that promote equity and improved socio-economic outcomes for Aotearoa New Zealand, along with wind and solar, geothermal is key to deliver on this vision. With the existing but limited additional conventional geothermal resources, supercritical geothermal and superhot deep enhanced geothermal systems may just be the solution needed.

Session: 3.2



60 | Geophysical imaging of the Paeroa Fault: Insights from a dense nodal seismic array

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Keywords: *Seismology, dense nodal seismic array, ambient noise, Paeroa fault.*

The Paeroa Fault is one of the longest and most active multi-strand faults in the Taupō Rift, capable of generating Mw6.8+ ruptures on a millennial timescale. At its northern end the Paeroa Fault splays into the Ngapouri fault and is surrounded by several active geothermal features. Mapping the fault strands and their dip

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angle is important to understand earthquake hazards, fluid flow pathways and links between faulting, volcanism, and geothermal activity.

Over the summer of 2023/24 we deployed a dense nodal seismic array (DNSA) across the northern termination of the Paeroa fault, straddling the deep resistivity boundary along the northern boundary of the Waiotapu and Waimangu geothermal systems. The survey deployed 147 short-period and broadband nodal seismometers recording continuously for a period of ~4 weeks and collected new closely spaced gravity data.

In the initial analysis we have cross-correlated and stacked more than 1000 station-station pairs. The derived dispersion spectra for station-station pairs show clean fundamental surface-wave dispersion for Z-Z components for frequencies between 0.3 and 2 Hz. We will apply additional processing approaches to also retrieve higher modes, and to retrieve information for a wider bandwidth. We will then jointly invert the

Rayleigh and Love dispersion curves to construct a three-dimensional S-wave velocity model, likely imaging to c. 2 km in depth across the spatial extent of the array for combined interpretation with a new 3D gravity model of the area. We anticipate that our derived 3-D S-wave velocity model will reflect the subsurface heterogeneity across the Paeroa Fault, as well as imaging the northern boundary of the Waimangu and Waiotapu geothermal systems, delineating subsurface faults associated with local seismicity.

With this study we aim to show that DNSA surveys are an effective non-invasive geophysical method for imaging shallow faults in the TVZ, for seismic hazard planning and geothermal exploration.

Session: 8.2



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62 | Is the Australian Geothermal Industry “Gathering Steam”?

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Keywords: *Geothermal, Geothermal Exploration, Australia*

The Australian geothermal sector is seeing unprecedented levels of permit activity with a total of 125 granted geothermal permits, accepted geothermal applications or retention licences, as of August 2024. This paper explores the nature of the industry in Australia at the current time. Tenement holders are a mixture of large corporates (e.g. Santos) to smaller ventures. Permit activity is spread across a range of geological settings and in areas which overlay residential, rural and remote areas of Australia. The greatest level of activity is in South Australia (43 tenements), followed by the Northern Territory (33) and Queensland (26). Western Australia has seen new permit activity with 14 permits awarded in mid-2023. Those permits are the first awarded in that state since 2011.

Proposed projects include overlapping resource tenures such including coal mines and oil or gas fields. Other projects are considering repurposing oil wells, the interplay between geothermal and hydrogen, silica production, proximity to population and infrastructure and direct use. Some projects are in government designated “renewable energy zones”. Both conventional well/drilling technology is being considered as well as newer closed loop designs.

While new Australian projects have not yet started to deliver electricity to the grid, we believe the sector in Australia is “gathering steam” (idiomatically) in the sense that the industry is gaining momentum in a market where new renewable energy installations are usually dominated by (intermittent) wind and

solar. This work concludes by summarising the opportunities geothermal has in Australia, and the roadblocks to its further development.

Session: 7.2



63 | Development of a Hydrothermal Multi Input Flow-through a Water-Gas-Rock Reactor for Geothermal Non-Condensable Gas Injection Reaction Testing

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Keywords: *reactor, hydrothermal, water-rock interaction, NCG, reinjection, carbon sequestration, scaling, reservoir, mineralisation, CO₂*

A flow-through multi-input chemical-water-gas-rock reactor for geothermal non-condensable gas (NCG) reinjection testing is in the final stages of the commissioning process at The University of Auckland. This apparatus can react simulated geothermal brines with gas supplied via a pressurised dissolution column and up to two secondary chemical inputs supplied via high-pressure, low-flow metering pumps with rock or any other solid material at temperatures up to 230°C and pressure up to 30 bar (gauge). At temperature below 155°C, this apparatus can constantly monitor solution pH via a high pressure and temperature-rated pH electrode. An additional feature of this system is the ability to obtain grab samples at reaction temperature and pressure, without the need for a sample

cooling, which has the advantage of retaining all components of the reaction solution in the sample, which may otherwise precipitate and deposit within cooling and pressure regulation equipment. Although this equipment is initially intended to test methods of NCG injection into geothermal reservoir rock, this apparatus also has significant potential to simulate many other natural and industrial hydrothermal and geothermal physicochemical processes.

Session: 4.2



64 | Learnings from 50 chemical well cleaning and stimulations across various well types, formations and countries

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Keywords: *well cleaning, reinjection wells, production wells, production well stimulation, acidizing, silica removal*

In this paper we discuss learnings from over 50 well interventions conducted in different parts of the world in a variety of formation types from Hot volcanic basalt, schists marble to sedimentary tuffs. These include dry steam wells, two phase and single-phase fluid wells.

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The patented Solenis Method has provided dramatically improved results over traditional techniques and has enabled companies to recover and enhance wells to recover full capacity from formation scaling of silica calcite and other minerals. In some cases, wells have improved their maximum capacity by 10-fold. The original investigation included over 900 hours of laboratory analysis and comparisons of different formation types and with the range of different chemicals to try and predict, the best intervention results.

Now, with over 50 field examples we are able to relate the infield results to the Lab modelling and testing. The learnings have been valuable in terms of what can be achieved and what conditions and processes are and aren't appropriate in different cases. Learning from common mistakes made and well intervention techniques that can be avoided is valuable for the industry.

Session: 3.3



65 | Iron Sulfide Deposition and Inhibition and Its Impact on Geothermal Brine Pumps

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Keywords: *brine pump, iron sulfide, mineral scaling*

In geothermal systems, iron sulfide can be considered as one of the most challenging

scales because of the impacts of the deposits formed. This type of scale is usually intermixed with amorphous silica and metal silicates, which in turn, forms tenacious and hard deposits that can be observed in both surface and subsurface facilities. In one case in the Philippines, deposition of iron sulfide along the brine reinjection system negatively impacts the capacity of the brine pump. Aside from scaling along the pipelines, iron sulfide deposition was also observed inside the pump casing which causes the rapid decline of pump capacity. Without operable pumps, the plant is forced to shut down and do manual cleaning to regain normal operations. Dumping of the brine to maintain separator level was also being done because of limited reinjection capacity due to pump capacity decline. Deposition mechanism of iron sulfide was studied, and it was confirmed that existing chemical and mechanical conditions were conducive in the precipitation of this scale. A new inhibition program was studied based on existing cases for metal silicate and sulfide inhibition to check if the same principle can show positive impact on this type of application.

The goal of the inhibition program is to preserve the capacity of the brine pump by minimizing scaling. This will maintain existing or reduce (or to some extent, eliminate) brine dumping rate. It can be observed that before the new inhibition program, the brine dumping rate increases steeply over time. The new inhibition program was able to slow down the steep increase of the dumping rate. This was further demonstrated after the silencer cleaning where it can be observed that the brine dumping rate was consistently controlled for 1 month at 25 kg/s compared to 43 kg/s. Comparing to the baseline, monomeric silica retention increased during the trial which is a good indicator of lesser scaling potential. It was observed that monomeric silica retention increased by 300%. Silica may not be visible in the XRF or XRD analyses because the sample was limited to the brine pump internals only. Aside from quantitative measurements, qualitative observations were also made during

the trial. It is worth noting that during an outage were the brine pump was put out of service, no manual barring was done to restart the pump. It was a good indication of the chemical program difference in comparison to the previous experiences of the site.

Session: 6.2



66 | Deciphering Geochemical Traits of Orogenic Lushan Geothermal field in Taiwan

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Keywords: Lushan geothermal field, helium isotopic ratios, chemical components, hydrogen and oxygen isotope composition

The Lushan Geothermal Field, located within Taiwan's metapelitic orogenic belt, is recognized for its high geothermal gradient, making it a promising site for geothermal power plant development. The Silica geothermometer



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estimates indicate reservoir temperatures of up to 137°C in Chunyang, 153°C in Milegu, 183°C in Lushan/Truwan, and 151°C in Mahebo. Despite the highest temperatures recorded in the Lushan/Truwan area, the risk of landslides suggests that future drilling should be concentrated in the Chunyang and Milegu areas.

Seasonal variations significantly influence the chemical composition of hot springs in the Lushan Geothermal Field. During the dry season, the waters are primarily Na₂CO₃-rich, whereas in the wet season, they shift to Ca(HCO₃)₂ or even CaSO₄. The δD and δ¹⁸O values exhibit a concentrated pattern during the dry season and a more dispersed pattern during the wet season. These isotopic values do not clearly distinguish between the different areas within the geothermal field, such as Chunyang, Milegu, Lushan/Truwan, Mahebo, and Jingying, and variability within the same area suggests possible differences in local water circulation systems. The similarity between the δD values of hot spring water and those of local rivers and groundwater indicates that the geothermal waters are likely derived from heated shallow groundwater rather than deep circulation or recharge from higher elevations. The RA ratio of helium isotopes indicating a crustal source mixed with atmospheric components. Furthermore, the hot spring waters are either saturated or supersaturated with minerals, highlighting the potential for scaling issues that must be addressed in any future geothermal power plant development in the area.

Session: 4.2



67 | Constructing geothermal conceptual model of Huangzui Volcano, Northern Taiwan

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Keywords: *Tatun, Geothermal, conceptual model.*

The Huangzui volcano, situated within the Northern Tatun Volcano Group (TVG), stands as a focal point for geothermal exploration and development in Taiwan. From the 1970s to the 1980s, Taiwan CPC and the Industrial Technology Research Institute (ITRI) undertook extensive drilling campaigns, resulting in over 10 exploration wells being drilled in the region, with the deepest well reaching a depth of 2025 meters and encountering a maximum temperature of 160°C. Recently, a 1MW geothermal power plant utilizing shallow steam pockets to generate electricity was constructed in this region, marking the first geothermal power plant built in a volcanic region of Taiwan.

The magnetotelluric data, combined with geochemical analyses and drilling results, reveal that at the northern side of the Huangzui



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volcano's hydrothermal products in the volcanic formations are predominantly characterized by smectite and kaolinite at greater depths. Transitioning into the sedimentary basement, an alunite zone predominates, alongside ore-forming minerals such as enargite and zunyite, indicating a high acidity and high sulphidation epithermal environment, with an intrusive dike occurring at a depth of 1,000 meters. The central lava flow acts as a lateral barrier to fluid flow, while the fracture system in this region exhibits high-angle dips. As a result, temperature profiles of exploration wells away from the geothermal manifestation indicates conductive heat transfer rather than convection due to lack of fluid circulation. Subsequently, the infiltration of meteoric water into the volcanic fluid results

in the production of immature, steam-heated waters sourced from a shallow low-pressure steam reservoir at 0 to 200 meters asl.

Session: 3.2



68 | Stored Heat Calculations – Time for Review

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Keywords: *Stored heat calculations, power density calculations, geothermal development.*

This paper reviews some preliminary methods of assessing power potential of geothermal fields (particularly stored heat and power density), while (re)introducing an additional stored mass calculation.

Equating stored heat estimates with two different reference temperatures (e.g. USGS's original ambient temperature versus a 180°C abandonment temperature) shows that recovery factor is a function of reference temperature and reservoir temperature ($R_a = R_b \times (T_{res} - T_b) / (T_{res} - T_a)$). This is not always recognised, such that differing recovery factors from different reference temperatures have been mixed in calculation schemes and ascribed to formation type or effects of reservoir temperature. Alternatively, reference temperatures have been changed without adjustment of recovery factors from the original reference temperature.

The paper brings the various methodologies into a single power density graph to show how they may relate particularly to accessible depth of reservoir, porosity and temperature. The family of curves suggests that Wilmarth's "Main Sequence" and "Hot Arc" lines may require re-examination. The convergence of various quick capacity assessments about real world data either speaks to the usefulness of these methods, or to the dominance of the stored heat paradigm in ultimate sizing of geothermal developments.

Nearly twenty years ago, the USGS revised its stored heat calculation methodology which included stochastic modelling and led to a recalibration of recovery factor for condenser reference temperature using a limited database

of US operating geothermal power stations. In the last twenty years many stations have been added globally such that a significant database of real-world operating plant could be created for recalibration of the recovery factors in stored heat calculations. If the associated numerical reservoir simulations for these plants are also considered in the recalibration, then a clear view on sustainable capacity for each field would be available for this recalibration purpose.

The paper calls for a review of stored heat methodology and especially recovery factor, ideally using a single reference temperature as a means of calibrating effects of formation type and reservoir temperature as examples. It then goes on to question who could lead such an initiative.

Session: 4.3



70 | Refining geological models through 3D gravity modelling at Wairākei, Tauhara and Rotokawa geothermal fields

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Keywords: *gravity, forward modelling, inversion, geological model*

Three-dimensional forward and inverse modelling of gravity data from Wairākei, Tauhara and Rotokawa geothermal fields were undertaken to reconcile geological models with

geophysical observations. Our aim is to improve areas of the geological model unconstrained by drilling through utilising geophysical information. We developed a starting geological block model using well log data where each geological unit is assigned a density based on petrophysical data. We converted the block model into a vertical prism (VP) model for geophysical modelling. Initial forward modelling of the VP model showed a large misfit between observed and calculated gravity in several areas indicating areas where the geological model did not match geophysical data. To improve the fit, we undertook inversion modelling. Gravity inversion was performed on the VP model in three ways: 1) geometry inversion of basement depth in areas with no well data; 2) homogeneous inversion to get best fit densities distributed uniformly within geological units, and 3) heterogeneous inversion where density distribution was allowed to vary within each geological unit. The resulting geological model shows that greywacke basement is probably present beneath Wairākei at >3000 m depth. The model also suggests the presence of a low-density vertical zone cutting through the Rotokawa Andesite and underlying greywacke interpreted to be a buried vent focusing fluid flow and manifesting on the surface as Lake Rotokawa. Other minor refinements to the geological model were made that are consistent with gravity observations. We show that refinement of geological models through forward and inverse modelling of dense geophysical datasets helps enhance subsurface models and guide future drilling plans.

Session: 8.2



71 | Stress Corrosion Cracking Failure of a Geothermal Steam Piping Rupture Disc

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Keywords: *Stress corrosion cracking, rupture disc, geothermal, steam piping*

Rupture discs are typically installed on the high-pressure carbon steel geothermal steam piping as a safety overpressure protection device. In a geothermal power station, a rupture disc burst without any evidence of an overpressure event. The rupture disc was rated for 17 bar, well above the steam piping operating pressure of 12 bar. This paper presents failure analysis results of the burst event of this rupture disc. The results indicated that the primary damage mechanism was chloride stress corrosion cracking (Cl-SCC), which led to change in the stress distribution on score lines and compromised the disc integrity. This paper also discusses materials selection options for the rupture disc with better resistance to Cl-SCC.

Session: 6.2



73 | Geochemical Parameters for Evaluating Brine Outfield Injection Impact at Salak, Indonesia

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Keywords: *Salak, brine injection, reservoir process, steam cap development, marginal recharge, reservoir chloride, geochemistry mixing model*

Salak Geothermal Field has implemented brine infield injection since it began commercial production in 1994. While infield injection provides pressure support to sustain production, it can also lead to reservoir cooling, negatively impacting the production wells if the injected brine does not heat up before reaching the producers. This cooling process has caused a significant decline in production in several two-phase production wells at Salak. To address this issue and ensure long-term reservoir performance, brine injection was relocated to the outfield and edge-field area. Integrated reservoir analyses, including reservoir, geochemistry, and geophysics data, are being conducted to monitor the impact of brine outfield injection on the production wells. Various geochemical parameters and methods, such as chloride, enthalpy, non-condensable gas (NCG), and the 7-component Geochemistry Mixing Models, are being used to evaluate the marginal recharge influx and steam cap development following the implementation of outfield injection. Three years after the implementation, two-phase production wells at Salak show a decreasing chloride trend, indicating a reduced impact of brine injection breakthrough. The 7-component Geochemistry Mixing Model also suggests

more contribution from the Mass-In-Place (basal upflow) and less contribution from brine injectate, with no increase in marginal recharge influx despite the continuous drop in reservoir pressure and increasing voidage. Enthalpy and total NCG data have increased, implying steam cap development. This is further confirmed by reservoir data, which shows a decreasing liquid level and improved production performance. Overall, brine outfield injection at Salak appears to have a positive impact by accelerating steam cap development and has effectively halted further cooling in the reservoir.

Session: 4.2



74 | 2023 Annual Aotearoa New Zealand Geothermal Review

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Keywords: *New Zealand, Aotearoa, geothermal, annual review, 2023.*

This paper summarises the key metrics and activities of the Aotearoa New Zealand Industry over the calendar year 2023.

During 2023, geothermal electricity generation fell by 3.45% to 7,758 GWh due to planned and forced station outages. This output supplied 17.8% of New Zealand's electricity. Total renewable generation increased to 88% of the national electricity supply.

The net installed geothermal capacity remained steady at 1033 MWe from 20 stations in 8 fields. Roughly 65% of capacity is older than 10 years, and 20% of capacity is older than 30 years.

Over the next five years, generation will likely increase by 24% to over 10 TWh per annum with the addition of new plants Tauhara (174 MWe), Te Huka Unit 3 (50 MWe), TOPP2 (49 MWe), and Ngā Tamariki expansion (46 MWe).

Operators drilled five deep wells and four shallow wells for the year. This activity will likely increase in support of generation developments.

The geothermal industry's CO₂e emissions fell materially during the year due to re-injection schemes at Ngāwhā, Ngā Tamariki, and Te Huka.

The service sector continues to evolve with the amalgamation of software firms and increased technical service exports.

NZ universities continued to support the industry. Geothermal student enrolments at the NZ Geothermal Institute continue to recover from the COVID-19 low.

Session: 7.2



75 | Numerical experiments with a model of a supercritical geothermal system

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Keywords: *Supercritical geothermal system, numerical model.*

We have set up a numerical model of a supercritical geothermal system and used it to carry out numerical experiments on the natural state of the system and its response to various production/injection scenarios. The model is based on a synthetic geothermal system that we use in teaching various courses on geothermal modelling, but we have extended the area of the model considerably and deepened it to ~8km. Thus, the model is large enough to act as a whole-of-system model and includes a supercritical zone at depth. In the experiments on the natural state model, we investigate what permeabilities are required at depth to allow the formation of a supercritical zone. In the experiments on the production scenarios, we investigate deep and mid-depth production and deep and mid-depth injection giving four possible scenarios.

Session: 1.2



76 | Uncertainty quantification of reservoir models to assess the potential of Greenfields: A case study on inclusion of multiple conceptual models

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Keywords: *Geothermal reservoir simulation, Uncertainty quantification, Resource assessment, Pico Alto Geothermal Field, Alteration model*

In geothermal resource developments, resource assessment has an important role especially for the decision making, since the assessment determines the possible production capacity of the field. However, because of its invisibility underground, there are many uncertainties which affect the reliability of the resource assessment. They include quality and interpretation of survey data and parameter settings on the resource size.

In this study, the significance of the difference in clay cap interpretations by experts on resource assessment was investigated. Two 3D models for a geothermal field, Pico Alto Geothermal Field in the Azores, Portugal, were built with two different clay cap interpretations. The two clay caps, an "Expanded Clay Cap" and "Constrained Clay Cap" were postulated by different geologists. While these clay caps have similarities in terms of location, the estimated size differs to some extent. The results of the resource assessment, both with new method for green-field systems and with stored heat method, were compared in the two models.

As a result, the difference of the clay cap distribution affected both resource assessments, but it has a smaller impact on the new resource assessment method. The model with the Expanded Clay Cap was assessed to have a larger geothermal resource by a factor of 1.3 times by the new method and 2.5 times for the stored heat method compared to the Constrained Clay Cap model. The smaller impact of the different clay cap in the new method is due to its utilization of uncertainty quantification with more detailed data such as its inclusion of simulation processes, which effectively mitigate uncertainties. In conclusion, we decided that the new method is more suitable for resource assessment in green-field geothermal systems.

Session: 1.2



79 | Extending the Life Cycle of Geothermal Wells: Effective Strategies for Scale Removal

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Keywords: *Geothermal, scaling issue, well recovery, scale removal, wellbore cleaning, acidizing, mechanical cleaning, electro-hydraulic pulsing*

Geothermal energy, a sustainable and renewable resource, plays a vital role in the global energy supply. To guarantee peak performance and longevity of geothermal wells, it is essential to implement a wellbore operation and maintenance strategy.

A fundamental component of this strategy is to address the formation of scale attributed to mineral precipitation from the brine during the reinjection and production process. The accumulation of the scale deposits significantly impacts the lifespan and efficiency of geothermal wells by restricting fluid flow, reducing wellbore performance and often leading to premature well failure.

Various methods for scale removal, including both conventional techniques, such as chemical and mechanical methods, and the more recent innovative technique of electro-hydraulic pulsing, have been assessed to understand their advantages and challenges in achieving successful outcomes. All these techniques will be examined and compared by analyzing case studies from New Zealand and across the globe.

Determining the appropriate scale removal technique depends on specific wellbore conditions, operational requirements, regulatory constraints, and economic considerations. Furthermore, the integration of various treatment methods can optimize performance and operational costs.

Implementing a proactive strategy for regular wellbore cleaning will extend the operational life of geothermal wells, ultimately enhancing the economic viability of a geothermal project.

Session: 6.2



80 | Overpressure Protection in Geothermal Plants

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Keywords: *Overpressure protection, vessels, piping, rupture discs, safety valves, burst disks, two-phase*

The protection of geothermal power plant, and steamfield piping and equipment, from overpressure due to well pressure and flow presents challenges that are uncommon in other types of industrial plant. Geothermal applications need to allow for well output, two-phase flow, cross-country piping elevation changes, and cold gas. The following topics are discussed in this paper: issues and solutions regarding safety valves and burst disks, valves and disk sizing and selection, location of safety devices, piping design considerations for thrust loads, and containment of discharge fluid. The history of overpressure protection in New Zealand is also presented to provide context to the configurations found in different geothermal plants.

Session: 5.2



84 | Interpretation of the first thermal response test in Central Asian countries

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Keywords: Ground source heat pump, thermal response test, ground heat exchanger, Tajikistan.

Ground Source Heat Pumps (GSHP) systems have been widely distributed in several regions of the world due to the low operation costs and environmentally-friendliness. In Central Asian countries, however, the number of installations is very limited due to the low recognition of the GSHP system and its advantages.

Akita University, Japan and the National Science Academy of Tajikistan are currently carrying out a

five-years joint project for the promotion of GSHP systems in the Republic of Tajikistan (hereafter, called as Tajikistan) with the sponsorship by the Japanese government. To demonstrate the applicability of the systems in dry countries like Tajikistan, a closed-loop GSHP system of 10kW cooling and heating capacity will have been installed in the capital city, Dushanbe in Autumn, 2024. For the evaluation of the heat exchange capability of the ground at the location, a Thermal Response Test (TRT) was carried out in September 2023 at a Ground Heat Exchanger (GHE) of 105 m deep near one of the buildings in the Academy. The TRT consists of a heating period of 2 days followed by a temperature recovery period of 2 days. The inlet and outlet temperatures of circulation fluid were measured every 1 minute, while the temperature distributions in the GHE were measured using an optical fiber sensor. The graphical interpretation of the TRT showed that the average thermal conductivity of the ground is around 1.9 W/m/K, which is reasonably high to introduce GSHP systems. The thermal resistance of the GHE, on the other hand, was estimated quite high in the shallow part of the formation due to the low groundwater level which exists 50 m below ground level.



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Based on the geological information and GHE specifications, an analytical simulation model of the GHE based on the cylindrical source function was constructed and was validated using the TRT results. A case study on the thermal properties of grouting material of the GHE was then carried out using the model for improving the performance of the GSHP system. The simulation indicated that the heat exchange capacity of the GHE could be improved by 20% by improving the thermal conductivity of the grouting material.

Session: 2.3



85 | How to Design, Iterate and Continually Improve PDC Drill Bits for Geothermal Drilling

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Keywords: *Drill bit design, offset analysis, geothermal drilling, performance improvement, PDC bits, continuous improvement, drilling optimization.*

Geothermal Drilling is a high-cost operation and has a large upfront cost to any new power station project. Drilling a well requires setting a series of casing strings that are drilled to a suitable depth to provide pressure containment of the surrounding wellbore fluids. The production section is normally a longer open hole section and is drilled to access a geothermal reservoir. This is typically the most challenging section to drill and complete.

Successfully drilling each section, requires an understanding of the geology, wellbore and formation hazards or challenges as well as the directional objectives. A wholistic approach is required to assess the optimum drilling strategy to complete the section with minimal cost. This is usually achieved by minimising drilling days in the form of increased rate of penetration (ROP), however can also be achieved by minimising drilling tool wear and reducing open hole risk and potential hole problems.

This paper focuses on Polycrystalline Diamond Compact (PDC) drill bit design, selection and iteration processes to increase rate of penetration and subsequently reduce cost per meter drilled in geothermal operations. It will detail offset analysis techniques, dull grading and cutter failure mechanism recognition, drill bit manufacturer selection, continual improvement design iteration processes and drilling parameter optimisation.

A good geothermal drilling strategy is balanced by utilising a well-designed custom drill bit, followed by suitable bottom hole assembly (BHA) selection and then drilled with ideal parameters – weight on bit, flow rate & revolutions per minute (RPM). The output of successfully completing this, results in smoother drilling, a bit that stays sharper for longer, and less accumulative tool & drill string wear by minimising on bottom drilling hours.

This paper will demonstrate how to analyse and execute a custom drill bit design and drilling strategy that will suit your field and application.

Session: 1.3



86 | Post Drilling Outer Casing Cement Remediation and Recommissioning of a Rotokawa Well

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Keywords: Rotokawa, well engineering, cement squeeze, well workover, well warm-up model, commissioning

This paper describes the successful remediation of a geothermal production well in Rotokawa, New Zealand six years after its drilling which left it with an incomplete cement job on an outer casing annulus. As an initial risk mitigation prior to commissioning in 2017, a pack-off assembly was added to the effected annulus to contain any shallow hot aquifer fluids, to allow thermal expansion of trapped water between the casings, and to allow the well to be put into service. While this was effective initially, the cement job in this annulus continued to degrade over time, allowing the release of shallow fluids through the annulus and pack-off. The leak rate became unmanageable, and the well was shut in November 2022 until a proper repair could be implemented. The repair plan included upgrading the annulus pack-off hardware and conducting a reverse cementing method to re-cement in the casing. To reduce the potential of failure of the 24" casing connections and risk of casing collapse, a detailed re-commissioning warmup program was designed to slowly release potentially trapped water in cement voids between the casings. This program included a prescriptive flow schedule developed using a volumetric and heat transfer-based digital model of the wellbore fluid movement which was calibrated and confirmed by implementing downhole wireline and surface monitoring techniques. The well has since been

returned to service, with monitoring showing that the repair job was competent. The reverse cementing and warmup modelling methods should be useful on future similar types of well interventions.

Session: 5.2



87 | The role of groundwater monitoring in the sustainable management and operation of the Ngā Tamariki Geothermal Field

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Keywords: groundwater, monitoring, geochemistry, sustainable geothermal development, Taupo Volcanic Zone

The extensive network of monitoring wells at the Ngā Tamariki Geothermal Field provides valuable information guiding the sustainable management and operation of the resource. In total, 34 shallow and intermediate wells are monitored for chemistry, pressure, water level, temperature, which give a detailed overview of a complex groundwater system above the deep geothermal reservoir.

The reservoir is overlain by three distinct hydrogeological units, including: a confined intermediate aquifer hosted within rhyolite lavas and breccias, an aquitard complex predominantly hosted within the Huka Falls Formation, and a shallow unconfined aquifer hosted in the Oruanui Formation and Taupō Pumice Alluvium. Chemistry and temperature monitoring indicate an upwelling of reservoir fluid into the northern part of the intermediate aquifer through a leak in

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the underlying clay-cap. Monitoring wells in the south contain cold sodium-bicarbonate waters, commonly encountered in Taupō and Middle Waikato catchments.

The objective of this paper is to provide a brief overview of the information obtained from the Ngā Tamariki groundwater monitoring program starting with the baseline sampling in 2009-2011, followed by the startup of the Ngā Tamariki binary plant in 2013, and continuous operation through to the present. We provide description of sampling and downhole monitoring techniques and share lessons learned associated with the ongoing maintenance of the network. Ultimately, the groundwater monitoring program provides comprehensive understanding of the regional groundwater system and supports the safe and sustainable operation of the field, with capability for early detection of responses to development.

Session: 7.2



90 | Targeting faults with geothermal wells – why bother?

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Keywords: *Fault, targeting, geothermal, wells, Lidar*

The principal objectives in drilling geothermal wells are generally to obtain permeability (injection wells), or permeability plus temperature (production wells). A significant number of exploration and production wells are unsuccessful, and that is often because they do not find sufficient permeability. Targeting faults can increase the overall success rate, and increase the productivity of individual wells, if the faults are accurately located and the local tectonics are properly understood.

Session: 3.2



92 | Using T2well For Simulating Coupled Wellbore-Reservoir Simulations

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Keywords: *Wellbore, Reservoir, 3D Model, Natural State, Production, Simulator, Tightly Coupled*

Geothermal modelling plays a crucial role in the successful development of geothermal fields. It aids in the planning of resource utilization, as well as the assessment and management of geothermal fluid production to achieve optimal performance. An important application of a wellbore/reservoir model is conducting future scenario simulations to make accurate forecasts using a well-calibrated reservoir model. To accurately simulate the future performance of geothermal wells, it is crucial to understand the coupling requirements to effectively integrate wellbore and reservoir simulators. T2Well is a simulator for non-isothermal and multiphase fluid flow that can model tightly coupled wellbore-reservoir flow. T2Well extends the capabilities of the numerical reservoir simulator TOUGH2 by integrating a wellbore sub-domain into the numerical grid, allowing it to compute flow in both the wellbore and the reservoir concurrently and efficiently. However, it appears that there are no published examples where T2WELL has been applied to a full-scale convective 3D geothermal model.

This paper presents a 3D coupled wellbore-reservoir model developed following geothermal reservoir modelling best practices. We utilized T2Well with a pure water equation of state, EOS1, to fulfil the necessary model setup requirements

for a hot, convective geothermal system with reservoir temperatures ranging from 250°C to 270°C. The initial conditions for the fully coupled wellbore-reservoir simulation are based on the results of the natural state simulation of a synthetic geothermal field. The model was then used to simulate transient, late transient, and pseudo-steady state production phases for a geothermal well over a one year period.

Session: 1.2



93 | Updates to the model of lithium extraction from the Salton Sea Geothermal Field

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Keywords: *Geothermal reservoir simulation, Salton Sea, Lithium, Chloride, Imperial Valley, Waiwera*

The Salton Sea Geothermal Field (SSGF) is one of the largest geothermal resources in the world with an estimated resource potential of nearly 3 GW (Kaspereit et al., 2016). It has only been partially exploited due to its high salinity and partial coverage by the Salton Sea. Stakeholders are now focused on better exploiting the field for geothermal energy production and using the lithium-rich geothermal brine as a source of lithium for battery production.

Our numerical model of the SSGF has been used to investigate different options for optimising the extraction of lithium from the system. The model has a chloride-NCG-water equation of

state with lithium represented as a passive tracer (Araya and O'Sullivan, 2022, Dobson et al., 2023, O'Sullivan et al., 2023a). It uses a dual porosity approach for the production history and future scenarios to provide an accurate representation of reinjection returns and chemical breakthrough by reinjection fluid that is dilute in lithium. Publicly available data has been used to calibrate both the natural state and production history models.

Most recently future scenarios were run to investigate the influence of the location of reinjection wells on both pressure support and lithium concentrations in the produced geothermal brine. They showed that lithium production can be enhanced without adversely affecting energy production by careful targeting of reinjection. The results of the simulations show the importance of careful monitoring, robust modelling and detailed planning for supporting the extraction of lithium from the SSGF.

To enhance the robustness of the modelling of the SSGF a new round of model development was initiated this year with the support of Lawrence Berkeley National Laboratory and the US Department of Energy's Geothermal Technologies Office. The details of the model development and the forward plan are presented here.

Session: 1.2



94 | Towards a New Framework for the Systematic Assessment of Indonesia's Undeveloped Geothermal Resources

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Keywords: *Resource Assessment, Indonesia, Geothermal Reservoir Simulation, Uncertainty Quantification, Waiwera*

The National Energy General Plan (RUEN) of Indonesia targets the production of 10 GWe from geothermal by 2030 and further increases to 17.5 GWe by 2050. Robust assessments of Indonesia's undeveloped geothermal resources are required to help prioritize systems for development.

A new method for resource assessment has been developed by the Geothermal Institute at the University of Auckland, which leverages modern geothermal modelling tools and cloud computing. The method uses the same data that are available for traditional stored heat calculation but also includes reservoir physics, wellbore physics and realistic energy extraction scenarios to provide more accurate forecasts. This framework has been used on commercial and research projects and can be applied in less than a month using widely available computational resources.

This paper discusses the application of the method to five undeveloped geothermal systems in Indonesia. The study was undertaken in collaboration with the Geological Agency (GA) of Indonesia and the Directorate-General of New Renewable Energy and Energy Conservation (EBTKE) as a step towards establishing a new

framework for the systematic assessment of Indonesia's undeveloped geothermal resources. The resource assessment framework was applied to each of the five systems; Ciremai, Kotamobagu, Maritaing, Massepe, and Papandayan. This included the development of new digital conceptual models and numerical reservoir models for each system using geoscientific data from the Geological Agency. The resource assessment results for each field are presented in a standard format, and it is envisioned that the results and the models could be made publicly available in a database of Indonesia's geothermal resources in the future.

Session: 1.2



95 | Characterisation of tonalite and andesite prior to reaction with CO₂-rich fluids

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Keywords: Andesite, tonalite, core, reversing carbon emissions, CO₂-rich injectate

The physical properties of two cores from high-temperature geothermal fields were examined and characterised as part of CO₂-rich fluid injection investigations. One core is tonalite from injection well NM9 (3201.1–3201.55 m

depth) in the Ngā Tamariki geothermal field, New Zealand. The second core is andesite from 972.3–972.6 m depth, from well N3 in the Palinpinon geothermal field, the Philippines. To characterise the rock properties of the cores, analytical methods used included: (1) Scanning Electron Microscopy to assess microscopic void dimensions, distribution, connectivity and to examine reactive surfaces, (2) X-Ray Diffraction and petrography to determine the mineralogy, (3) X-Ray Fluorescence to identify elemental compositions, (4) Computerised Tomography and density and porosity measurements to establish rock density, and connected flow pathways, (5) Porosity and seismic velocity testing, to assess rock porosity, and (6) Compressibility testing to document rock strength.

The tonalite and andesite core samples were then placed inside an experimental chamber and saturated with CO₂-rich fluid. The experimental chamber conditions were 140°C and 10 barg within a chamber containing pure water saturated with CO₂. The resulting fluid had a measured pH of 5.5. Samples were exposed to these conditions for 24 hours. The same analytical methods used to characterise the tonalite and andesite samples at the pre-experiment stage, will be repeated after they have been saturated with CO₂-rich fluid inside the experimental chamber. To date, compressibility testing has been performed on both the tonalite and andesite cores post-experimental chamber analyses. Compressibility results revealed a weakening of both the tonalite and andesite cores after exposure to CO₂-rich fluid.

Session 6.3

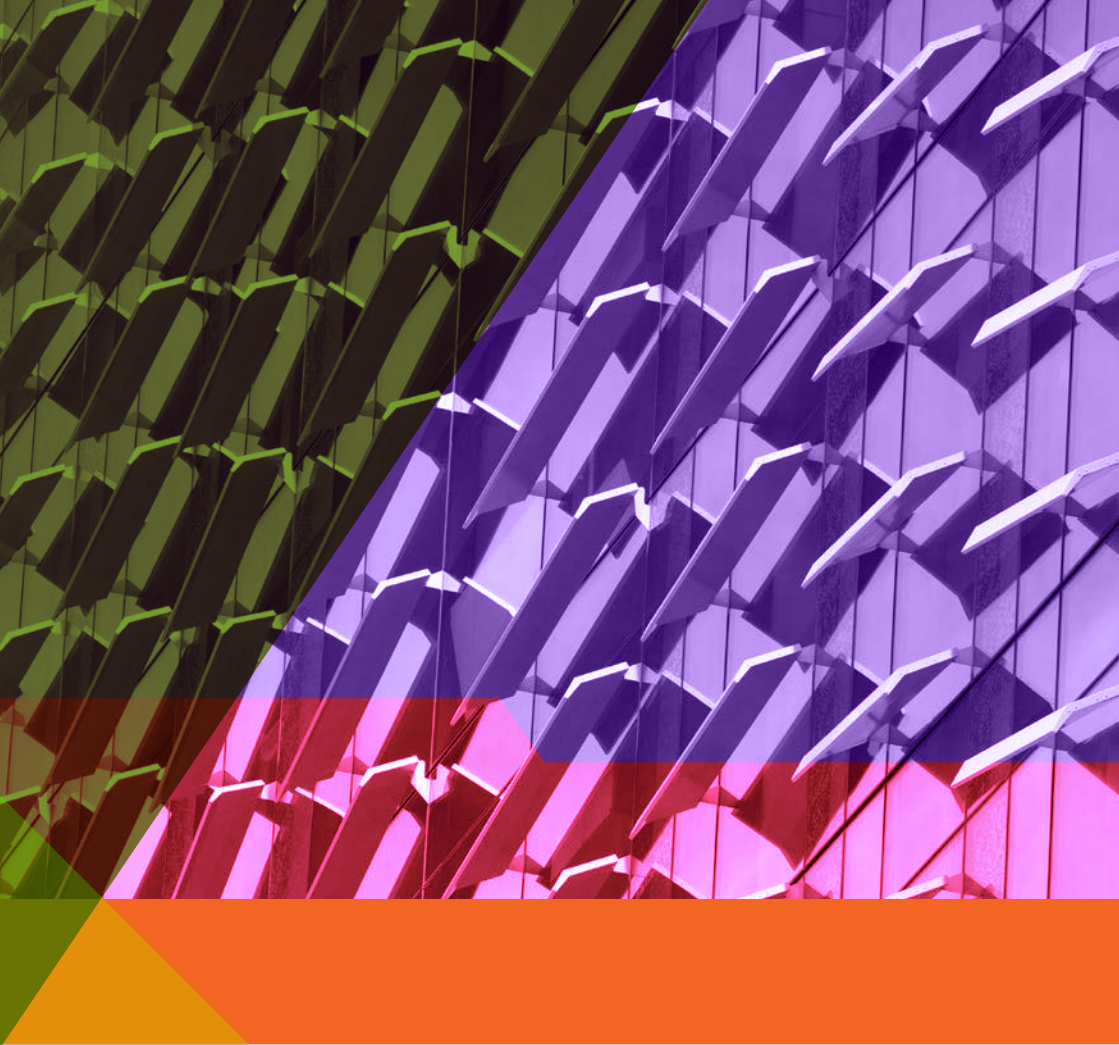


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