ANNUAL RESEARCH REPORT

2023-2024

energi SIMULATION

VISION

" Creating a more sustainable energy future through simulation research. "

energi
SIMULATION

We believe that:

"Diversified sources of affordable energy are required to meet growing and changing global demand driven by improving standards of living and population growth"

"Petroleum and Natural Gas will continue to contribute to global progress while technological advances will reduce their impact on the environment"

MISSION

" Promote and fund university research in energy resource modelling with industry collaboration and technology transfer. "

Our Company

Energi Simulation is a not-for-profit organization based in Calgary, Alberta, Canada. Founded in 1978, Energi Simulation promotes and financially supports research and graduate students through research grants at universities. Our mandate is to invest in leading edge research and innovation in energy resource modelling. The organization is unique for its self-funded strategy, where it has the financial freedom to invest in research, development, and innovation without having to rely on external sources of funding.

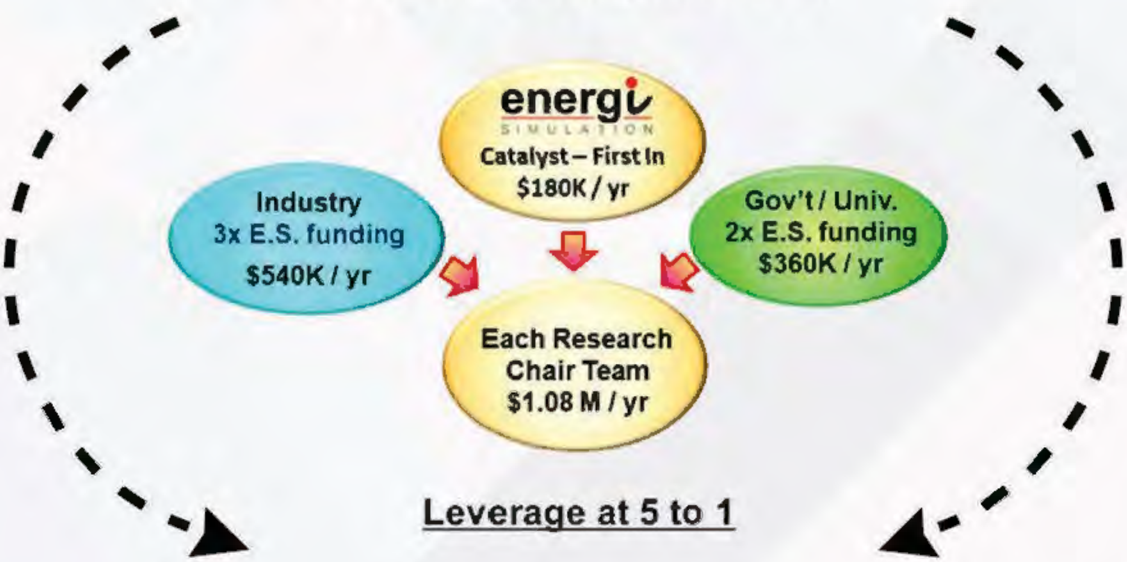
Milestones

$52 Million
own research funding

$250 Million
ind./univ. sponsorship

1,000
students graduated

Our Funding Model

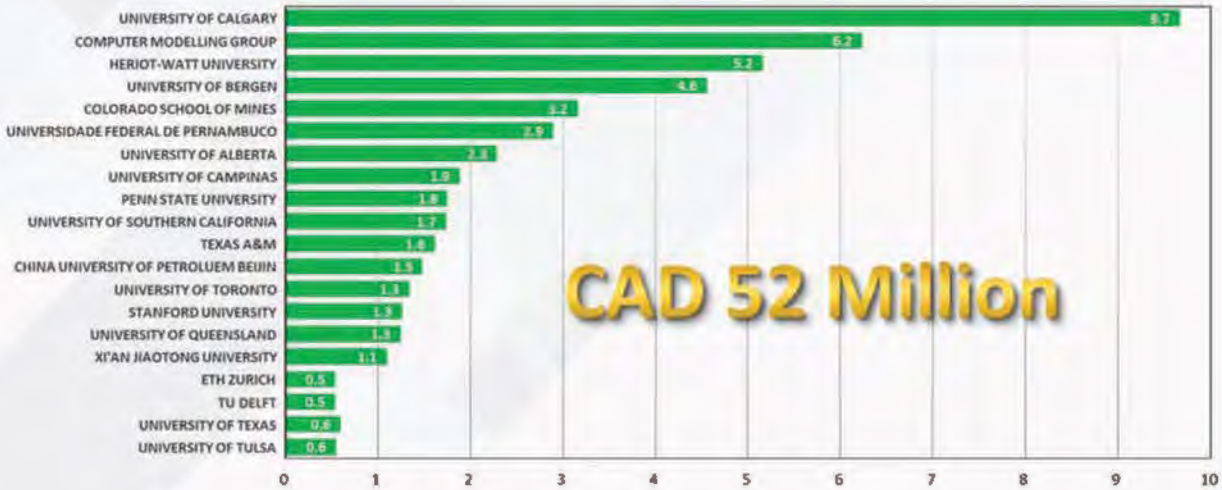


Our History

- **1978** – Computer Modelling Group Established @ Univ. of Calgary
- **1985** – Frank Meyer Joined CMG
- **1997** – Research Focus Retained 63% of Shares
  - Publicly Traded Retains IP and Customers → CMG
    - $750 MM Market Cap
    - 600+ Customer Companies
    - 60+ Countries
- **2010** – Sale of most CMGL shares
  - $75 MM Fund
  - 13 Chairs
  - 300 + Researchers
  - 1000 + Papers Written
- **2017** – Rebranded to Energi Simulation

Research Sponsorship

We are thrilled to share that Energi Simulation has invested $52 million in research since our inception, which shows our continuous commitment to sponsoring simulation research with the desire to drive progress and make a meaningful impact on the world



Supporting Global Research

Energi Simulation has supported 19 universities and 37 professors over the last 2 decades. Currently we are supporting 13 Research Chairs from 10 different universities from around the globe.

*Current supported universaties are indicated by a red dot on the ring around the globe.

Energi Simulation Summit

Every year, Energi Simulation hosts an *'Energi Simulation Summit'*, where our Research Chairs and their students share their current/ongoing research to industry and the academic community. The summit is hosted in a hybrid format (in-person & virtual), so that everyone from around the world can attend our biggest research event of the year. In addition to the summit, the organization hosts a private event called the *'Energi Simulation School'*, where Chair's students get the opportunity to learn relevant topics from Oil & Gas, Geothermal and CCUS in workshops and lessons hosted by a group of Research Chairs and industry guest speakers.

For the first time in the company's history, Energi Simulation hosted it's *Energi Simulation Summit 2023* internationally in The Hague, Netherlands. In the future, following the success of the ES Summit 2023, Energi Simulation will continue to look for opportunities to host outside of Calgary.

ES Summit 2023, The Hague Conference Centre, The Hague, Netherlands

Energi Simulation Board of Directors + spouses, ES Team and Research Chairs, The Hague, Netherlands

Energi Simulation Summit 2023

➤ **300** Attendees

➤ **37** Countries

Research Chair, Maren Brehme, presenting at the ES Summit 2023

Student Poster Session, ES Summit 2023

Keynote Speech by Mark Stoelinga, Manager of Energy & Infrastructure for Port of Rotterdam

ES Team; Andrew Seto, Aneta Monica and Ricardo Garza

Energi Simulation School 2023

ES School Group Photo, Delft University of Technology

Geothermal Well site visit by ES BOD and team, Delft University of Technology

TU Delft

Research Chairs in 2023

UNIVERSITY OF CALGARY
Dr. Zhangxing (John) Chen
Reservoir Simulation

USC University of Southern California
Dr. Behnam Jafarpour
Subsurface Energy Data Science

TU Delft
Dr. Sebastian Geiger
Sustainable GeoEnergy

UNIVERSITY OF TORONTO
Dr. Giovanni Grasselli
Fundamental Rock Physics and Rock Mechanics

TEXAS
The University of Texas at Austin
Dr. Ryosuke Okuno
Carbon Utilization & Storage

TU Delft
Dr. Hadi Hajibeygi
Subsurface Storage & Multiscale Modelling

UNIVERSITY OF ALBERTA
Dr. Rick Chalaturnyk
Reservoir Geomechanics

ETH zürich
Dr. Maren Brehme
Geothermal Exploration and Operation

HERIOT WATT UNIVERSITY
Dr. Arne Skauge
Low Net Carbon EOR

Universidade Federal de Pernambuco
Dr. Leonardo Guimarães
Reservoir Modelling and Robust Optimization

UNICAMP
Dr. Denis Schiozer
Short-term Reservoir Management and Digital Fields Concepts

HERIOT WATT UNIVERSITY
Dr. Eric Mackay
CCUS and Reactive Flow Simulation

UNIVERSITY OF CALGARY
Dr. Roman Shor
Geothermal Systems

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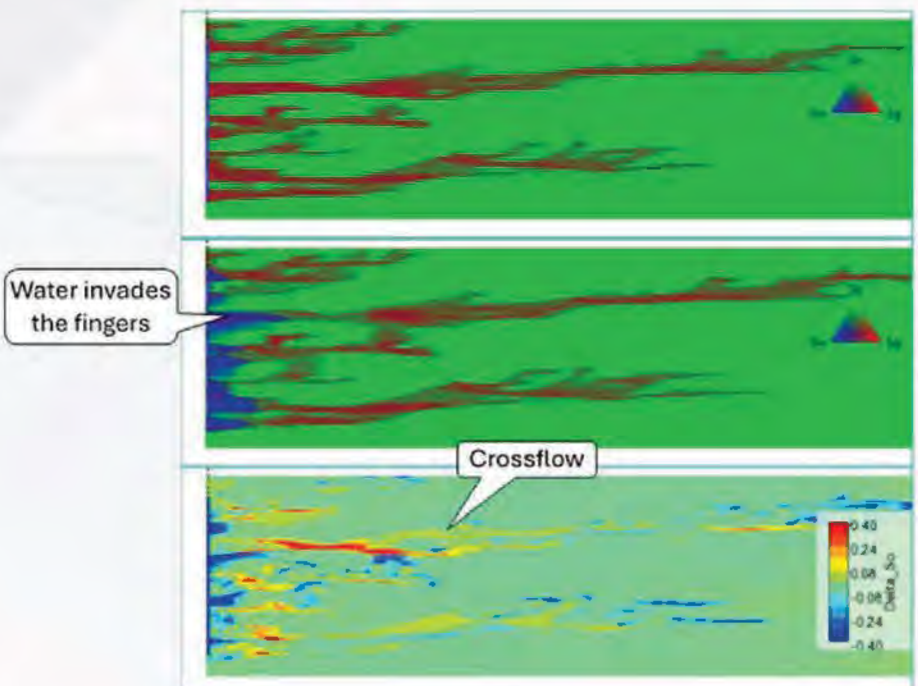
Theme: Low Net Carbon EOR

Background

For about seven decades, water alternating gas (WAG) injection has been applied as an enhanced oil recovery (EOR) method to improve sweep efficiency in the reservoir. It is well-recognized that gas/water do not drive oil from the injection to production wells in a piston manner. Rather, substantial differences in oil, water and gas viscosity values result in 'fingering' of gas/water flow into the reservoir.

Research Focus

To model viscous instability during WAG EOR processes, Dr. Arne Skauge and his research team have been researching to better understand the complexity of 3-phase fluid flow, compositional effects, and viscous fingering.



Three-Phase plot
Time: 50 days, or 0.1 PV injected – end of the first gas slug

Three-Phase plot
Time: 55 days, or 0.11 PV injected – start of the water injection

Delta S_o
S_o variation after the end of the first gas slug, 5 days into water injection

$$\Delta S_o = S_o(t = 55) - S_o(t = 50)$$

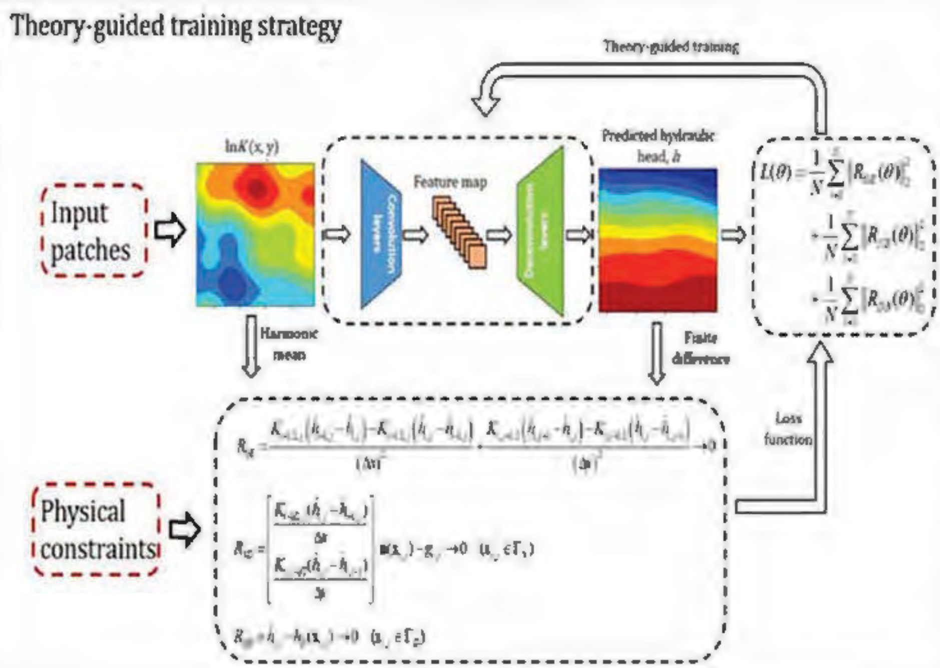
Outcome

Creating and invoking models for WAG hysteresis and crossflow in viscous fingers, the team found that WAG had the largest impact for immiscible gas flood case and crossflow accelerates oil production. Many industry sponsors of the program have benefited from these models in generating more realistic production forecasts for better investment and reservoir management decision making, while minimizing the carbon footprint by optimizing the EOR process. Novel modelling approaches are being developed for viscous flow in waterflood, polymer flood, WAG and foam-assisted WAG flood processes.

Theme: Reservoir Simulation

Background

With the aim to reduce water consumption in the steam-assisted gravity drainage (SAGD) process for bitumen recovery from the vast oil sand resources in Canada, Dr. John Chen and his research team developed robust solvent-assisted SAGD reservoir simulation models. Pilot projects have been successfully implemented in the industry.



Research Focus

To further enhance speed and accuracy, which are desirable attributes of a reservoir simulator, Dr. Chen's recent research focus has been on enhancing the simulator's capability with physics-informed spatial-temporal artificial intelligence/machine learning algorithms. The approach has a lower data dependence and higher noise immunity than data-driven methods.

Dr. Chen's concept of incorporating partial difference equations into the theory-guided training process enables sound physics-based modelling for more robust and realistic results.

Outcome

The world-class reservoir simulator developed by Dr. Chen's team has helped the industry to increase energy resources, reduce capital/operating costs, enhance energy recovery, drive energy efficiency, while reducing environmental footprints of their commercial projects. The sophisticated simulator may certainly be used in other areas such as geothermal energy, CCUS (carbon capture, utilization and storage), and UHS (underground hydrogen storage) projects.

Research Updates

University of Toronto - Dr. Giovanni Grasselli

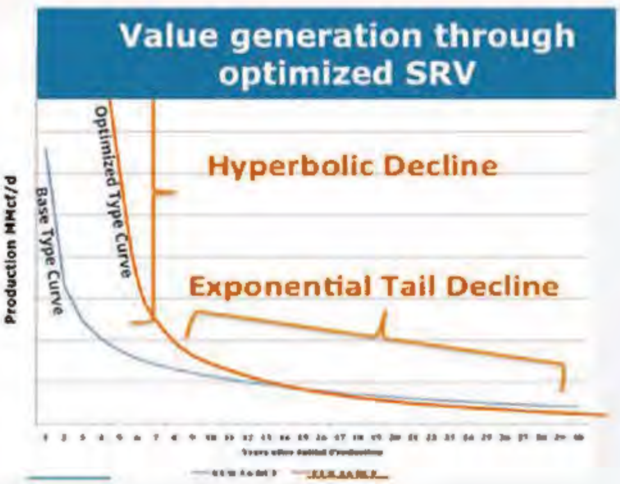
Theme: Fundamental Rock Physics and Rock Mechanics

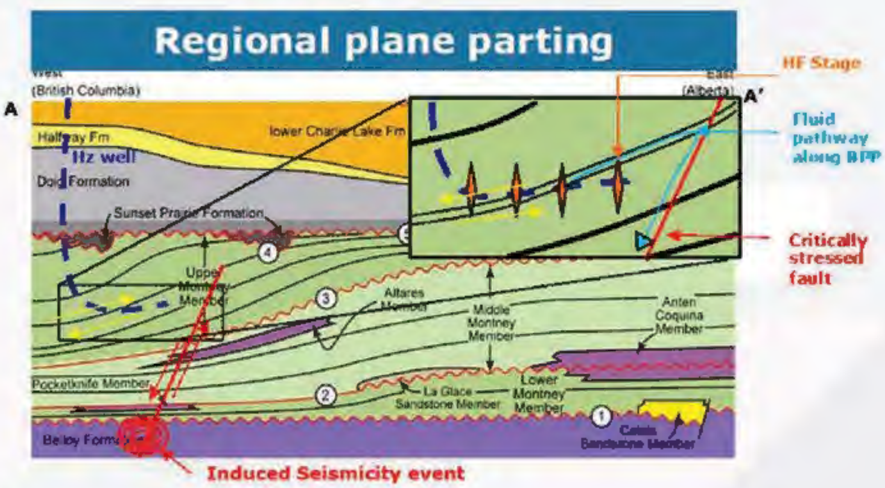
Background

Hydraulic fracturing is usually employed to help enhance the effective permeability for hydrocarbon production from unconventional (tight) reservoirs. It is also used to improve fluid flow in enhanced geothermal systems for heat extraction or power generation. According to classical geomechanics theory, hydraulic fracture would grow along the maximum principal stress direction (i.e. perpendicular to the minimum principal stress direction). Hence, well completion practices have generally been following this guiding principle. Multi-million dollars have been spent by operators on hydraulic fracturing, aiming to increase the productivity of subsurface energy extraction projects.

Research Focus

Dr. Giovanni Grasselli and his research team at the University of Toronto has developed a state-of-the-art laboratory system to observe and measure hydraulic fracturing behaviour of rock matrices under various stress conditions. A significant finding from laboratory testing was that the bedding plane in the rock fabric, not principal stress, dictates the stimulated reservoir volume (SRV) by hydraulic fracturing. Rock strength, fracture network, and fabric anisotropy (bedding planes) are critical and often overlooked in understanding how the rock mass will fracture during hydraulic fracture operations. Accounting for the opening of bedding planes can not only help to improve hydraulic fracture modeling, but also allow for more realistic estimation of the SRV and recovery factor, which are critical for reserves evaluation and development planning.





Outcome

Layered anisotropy is present in all unconventional plays which may be exploited by optimizing bedding plane partings to increase SRV and ultimate recoveries. Identification of ultra-low strength planes and their mechanism of failure could also help to mitigate future induced seismicity and casing deformation events.

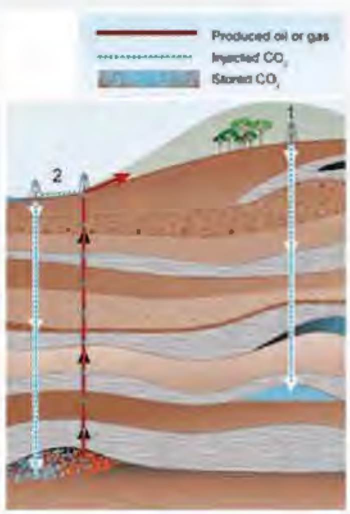
Theme: Reservoir Modelling and Robust Optimization

Background

While Brazil is one of the global leaders in supplying renewable energy to its population of about 220 million, about a third of its total energy comes from hydrocarbon sources. To help optimize the development and minimize the environmental footprint of oil and gas reservoirs in the region, Dr. Leonardo Guimarães and his research team conduct laboratory experiments, build reservoir models, and develop field optimization schemes.

Research Focus

Their chemo-mechanical-elastoplastic models can be used to provide realistic forecasts for CO_2 enhanced oil recovery (EOR) development and carbon storage projects. Main research focus topics are on reservoir cap rock integrity, mineral dissolution/precipitation effects on porosity and permeability, changes in roughness and fracture opening, rock and fracture geomechanics, and water weakening (chemo-mechanical mechanism).



(IPCC Report, 2015)

- **Oil fields**

1- Depleted reservoirs (gas/oil)
2- Enhanced oil recovery

- **Saline Aquifers**

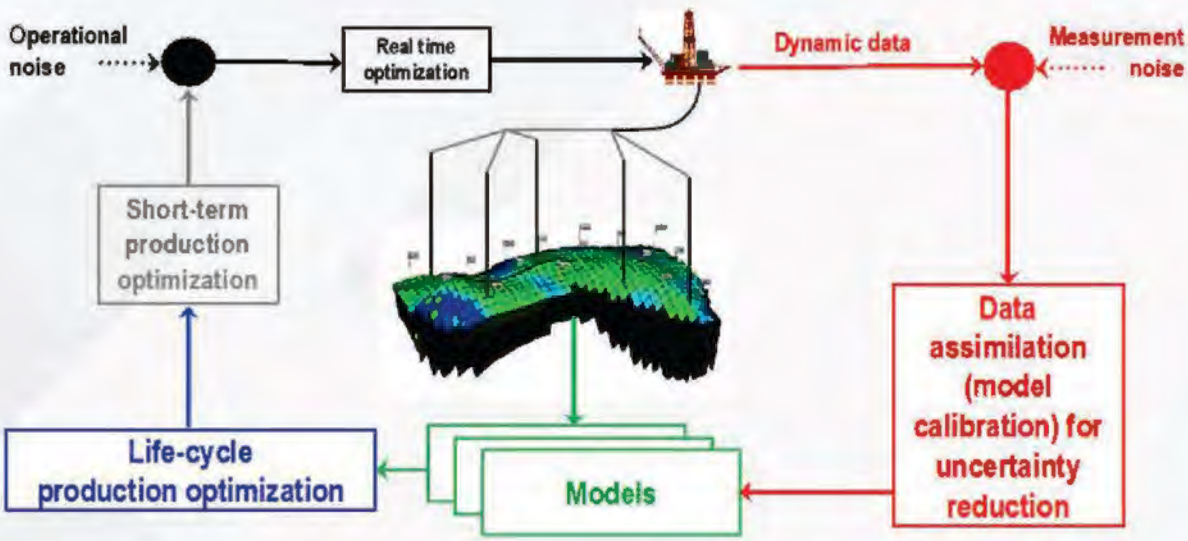
3- Deep unused saline water-saturated reservoir rocks.

Outcome

Results from the carbonate acidification experiments indicated that pre-consolidation stress (which increases the risk of pore collapse), tensile and shear strengths would decrease when the cementing mineral is dissolved. Acid treatment of fractures has altered their hydro-mechanical properties, but for the tests carried out, mechanical actions, such as shearing and compression, seem to have a greater impact. Research is ongoing for improvements to the elastoplastic model based on critical states theory, taking into account the loss of stiffness of the material when it is acidified.

Theme: Short-term Reservoir Management and Digital Fields Concept

CLFDM (Closed-loop Field Development and Management)



Background

Dr. Denis Schiozer and his research team have successfully developed a world-class integrated reservoir management program to assist in the real-time modelling and planning of short-term, long-term, and life cycle field development for the prolific oil and gas reservoirs in Brazil.

Outcome

The CLFDM methodology has been adapted by major operators and successfully been applied to the giant pre-salt carbonate fields with permanent 4D and intelligent completions, water-alternating-gas (CO_2) injection, and gas-driven optimization.

Research Focus

Recognizing that reservoir simulation models are often used for life cycle or long-term forecasts, but lack short-term predictability, for field development, Dr. Schiozer further enhanced his 12-step closed-loop field development and management (CLFDM) methodology to improve the quality of short-term production forecasts and decisions.

Life cycle optimization models that include uncertainty / risk analyses with probabilistic outcomes are very computationally intensive for an integrated reservoir, wellbore and surface facilities model. The process may take months to complete. Adopting a deterministic approach, by including vertical lift performance tables, in their closed-loop cycle optimization for short-term effects and decisions would result in a much faster process (in days). Also, accounting for operational noise (problems in implementation), real-time optimization on the digital fields (models) could generate automatic decisions for the operator.

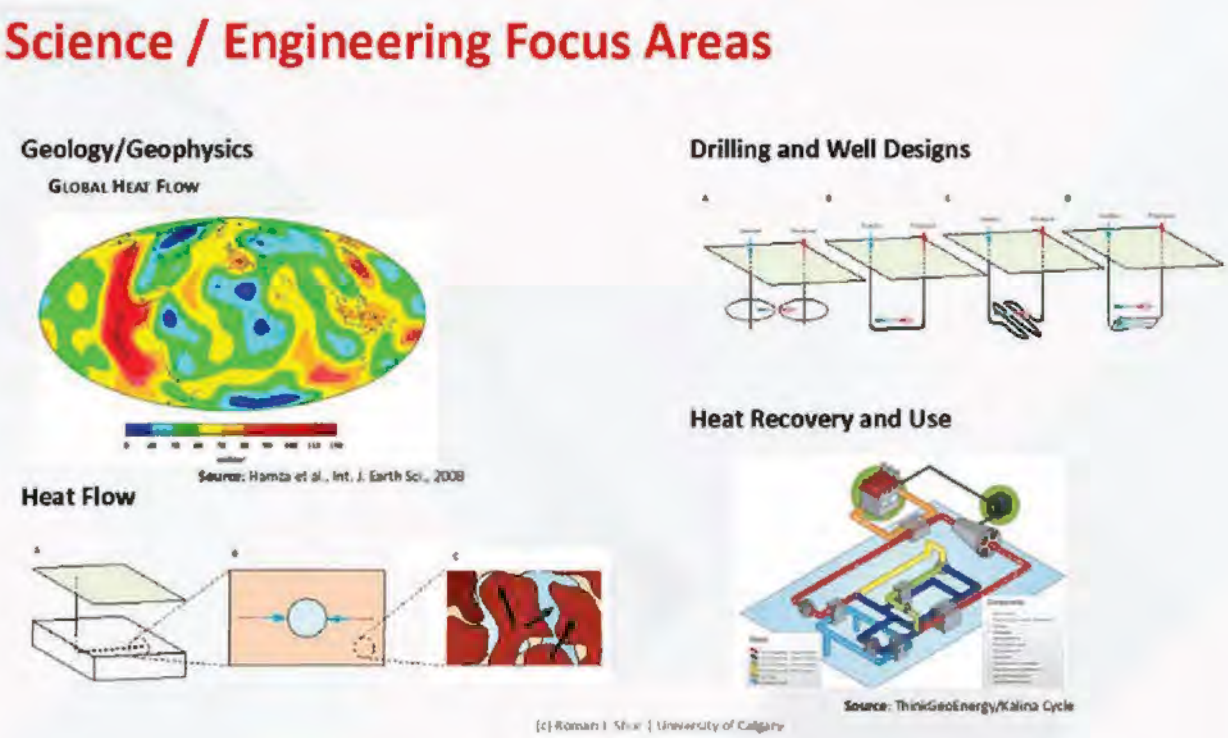
Theme: Geothermal Systems

Background

Since the establishment of the Energi Simulation Centre for Geothermal Systems Research at the University of Calgary in August 2022, Dr. Roman Shor and his research team have been working towards the vision of 'Geothermal Anywhere' through improved exploration, drilling efficiency, well layouts, reservoir management, surface facilities, energy conversion, heat re-use and close collaboration and buy-in from the community.

Research Focus

The figure below shows the key technical areas that the research team at the Centre are currently working towards the better understanding and designing of geothermal systems that should ensure their technical and economical viability. We look forward to seeing positive results from the team to support geothermal energy development projects in the coming years.

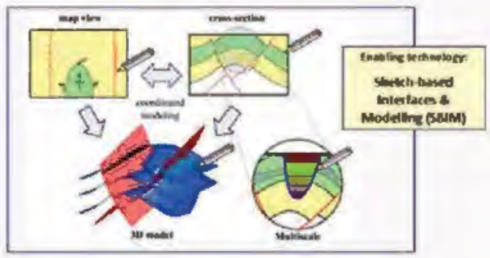


Theme: Sustainable GeoEnergy

Background

Geological heterogeneity is the key control on fluid flow in a reservoir and influences engineering and management decisions. It is multi-scale, complex and is sparsely sampled and inherently uncertain. Many industry players are faced with the limited amount of geological data and the high cost of obtaining such data through drilling more wells, in their efforts to reduce the geological uncertainties for their geothermal energy, carbon capture and storage, underground hydrogen storage, or other geo-energy projects.

Rapid Reservoir Modelling (RRM)



Available as open source at https://bitbucket.org/rapidreservoirmodelling/rrm/src/main/

Research Focus

Dr. Sebastian Geiger and his research team, in close collaboration with Imperial College London and the University of Calgary, have developed the open-source Rapid Reservoir Modelling (RRM) software tool for fast assessment of geological uncertainties. Employing a sketch-based interfaces and modelling technology, the tool could quickly generate multiple realizations of subsurface formations. Through flow diagnostics in RRM, reservoir pressure, time of flight, swept/drained reservoir regions, displacement efficiency, and many other parameters could be generated for comparison. The process is extremely fast, allowing the user to explore key uncertainties and quantify operational risks. Having selected the most representative realization, the reservoir model may then be used as input for flow simulation, planning wells and forecasting rates.

Outcome

The funders of the RRM consortium, as well as other companies and startups who have downloaded the open-source version, are using RRM for various in-house applications. Published applications for RRM include real-world case studies, such as the Northern Lights CCS project, the Delft Geothermal Project, or groundwater contamination in India. A first university is currently exploring how to use RRM in the context of mining.

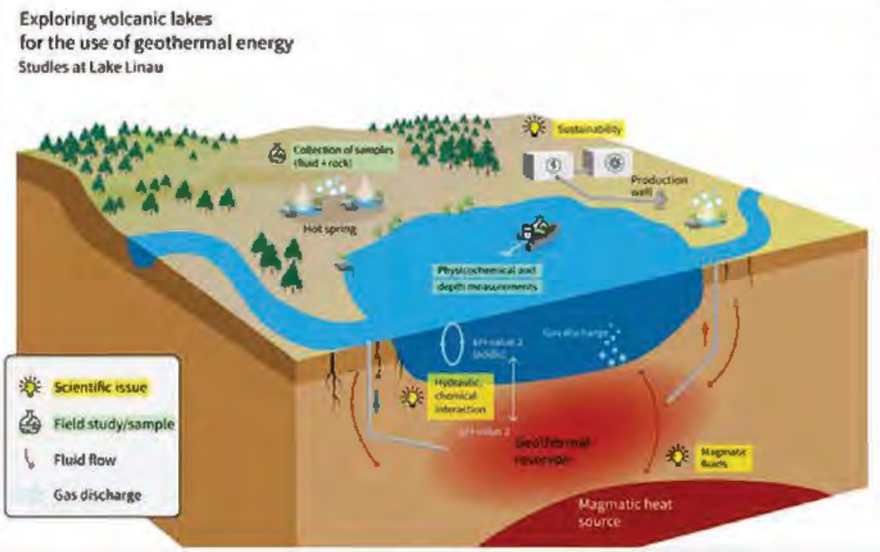
Theme: Geothermal Exploration and Operation

Background

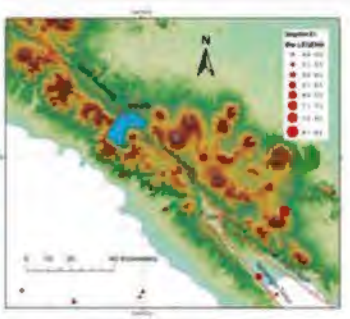
Recognizing that a holistic approach is needed to increase worldwide geothermal energy use, Dr. Maren Brehme and her newly established Energi Simulation Group for Geothermal Exploration and Operation (EXPO) focuses on three strategic research areas: 1) geothermal systems understanding, 2) effective utilization of systems, and 3) system response to utilization, involving laboratory work, numerical simulation and field implementation. Real-scale and real-time data are obtained from wells in geothermal fields, power plant infrastructure, hot springs, or surface outcrops.

Research Activities

In 2023, the EXPO team conducted three field studies at Lake Ranau - South Sumatra, Lake Zurich and Lake Cadagno, including field data collection and analysis to optimize well locations for better chance of successful geothermal energy extraction projects.



As an example, the Great Sumatran Fault system and fractures and fluid outflow were successfully mapped. Two types of hot spring water were also identified.



Low-cost pre-exploration underwater, with mapping, sampling, and big data analysis, provides an estimate of the geothermal energy sources in and around a waterbody, allowing techno-economic evaluation for future development potential which may be significant.

Research Updates

University of Texas at Austin - Dr. Ryosuke Okuno

CCUS
Carbon Capture, Utilization and Storage

Theme: Carbon Utilization & Storage

Background

One of our three newly established research chairs in the CCUS is Dr. Ryosuke Okuno at the University of Texas at Austin. His research focuses on CO_2 nano-bubble (NB) and use of formate for carbon capture and storage. These novel fluids have the potential of reducing the carbon footprint of CO_2 EOR projects and enhancing the amounts of CO_2 that could be stored in subsurface reservoirs.

Research Focus

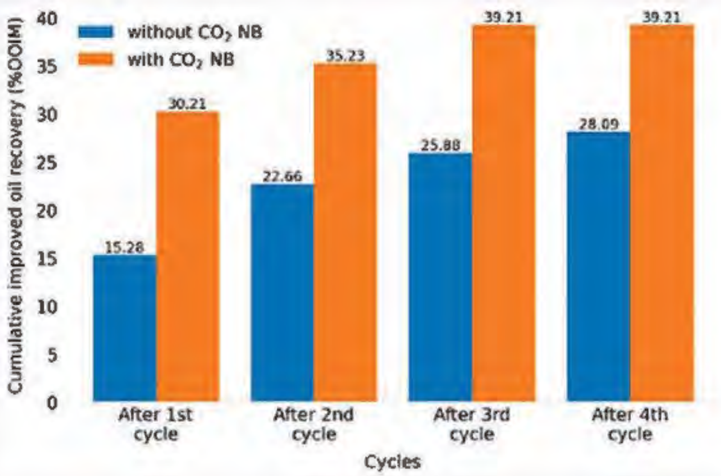
Supported by many international and domestic industry sponsors, Dr. Okuno and his research team have a world-class experimental set up to study aqueous nanobubble with nitrogen and CO_2 and model the thermodynamics of nanobubble dispersion. The effects of pressure, salinity, and pH on CO_2 concentration are also being evaluated for proper design of carbon utilization and storage projects.

Outcome

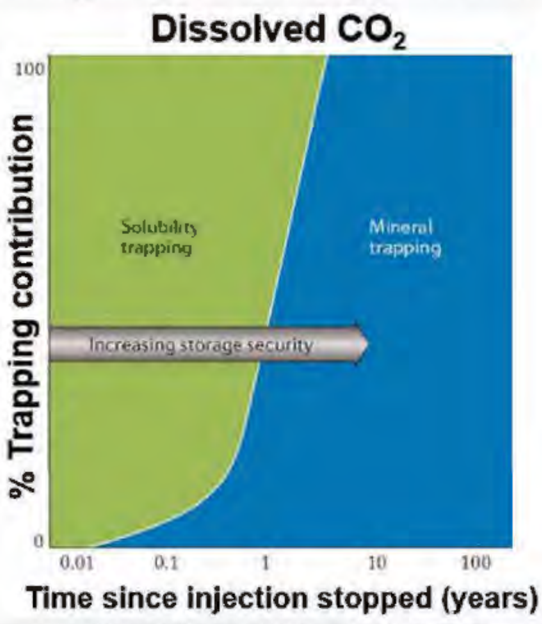
Preliminary results on NB testing indicate that 1) it is possible to solve for thermodynamic properties of aqueous nanobubble fluid, 2) the existence of bubbles is important to increase the level of gas supersaturation in the aqueous phase, and 3) bubbles by themselves are not the main contribution to the total amount of gas in the aqueous nanobubble dispersions.

As the complex behaviour of nano-bubbles could be characterized and modelled, implications on EOR and carbon storage projects may then be revealed. Dr. Okuno's research results should prove useful in supporting the global energy transition initiatives.

- Enhanced oil recovery



- Geologic carbon sequestration



Snæbjörnsdóttir et al. 2020

Research Updates

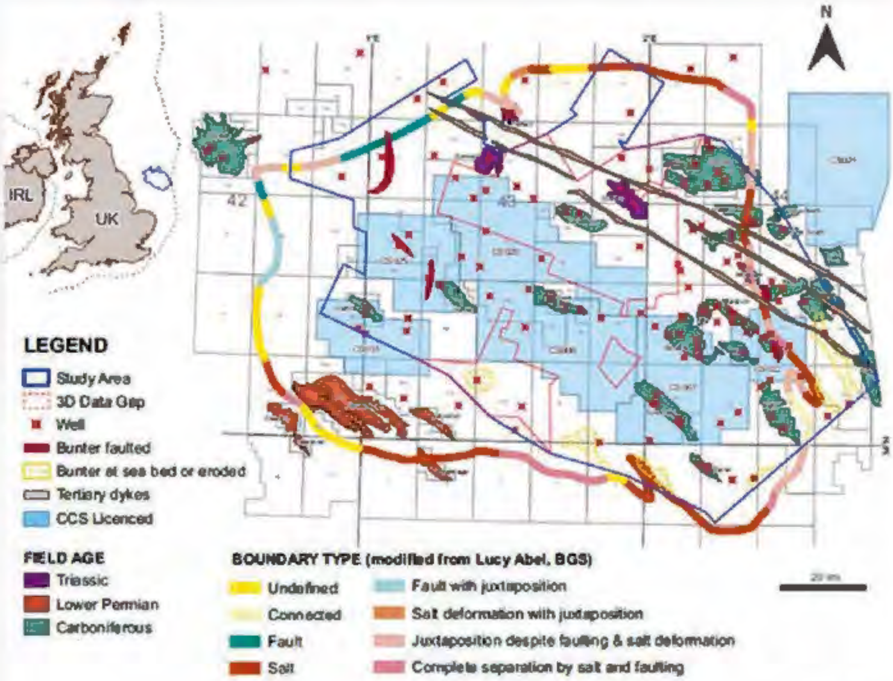
Heriot-Watt University - Dr. Eric Mackay

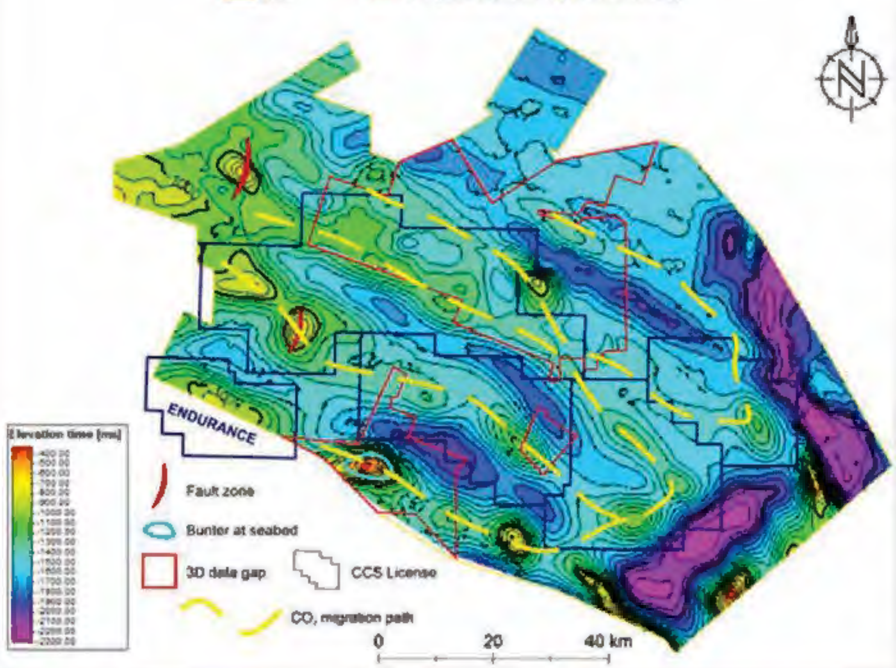
CCUS
Carbon Capture,
Utilization
and Storage

Theme: CCUS and Reactive Flow Simulation

Background

With world-renowned expertise in flow assurance and scale technology, Dr. Eric Mckay has expanded his research work into the CCUS area, while continuing reservoir engineering studies where fluid-fluid and fluid-rock chemical reactions are important.





Research Focus

His reactive transport modelling has been used to understand subsurface gas storage (CCUS, hydrogen), manage mineral scaling in wells (oil, geothermal), and account for chemistry in EOR (WAG, altered salinity). A regional basin study of CO_2 injection helped to address issues of pressure interferences and plume migration beyond spill points, as these are becoming immediate challenges and opportunities for CCUS projects around the world.

Near the well bore, injection of dry CO_2 will always cause some halite (NaCl) precipitation. Modelling shows that this is significant only with high salinity brine. During pressure depletion, flow assurance challenges should be considered.

Outcome

Research work is continuing to advance the understanding of geo-chemistry and gas (CO_2, hydrogen) storage in mature hydrocarbon systems, taking advantage of the available data, infrastructure, and expertise, as well as considering the risk of plume migration out of complex boundaries at a wider basin level.

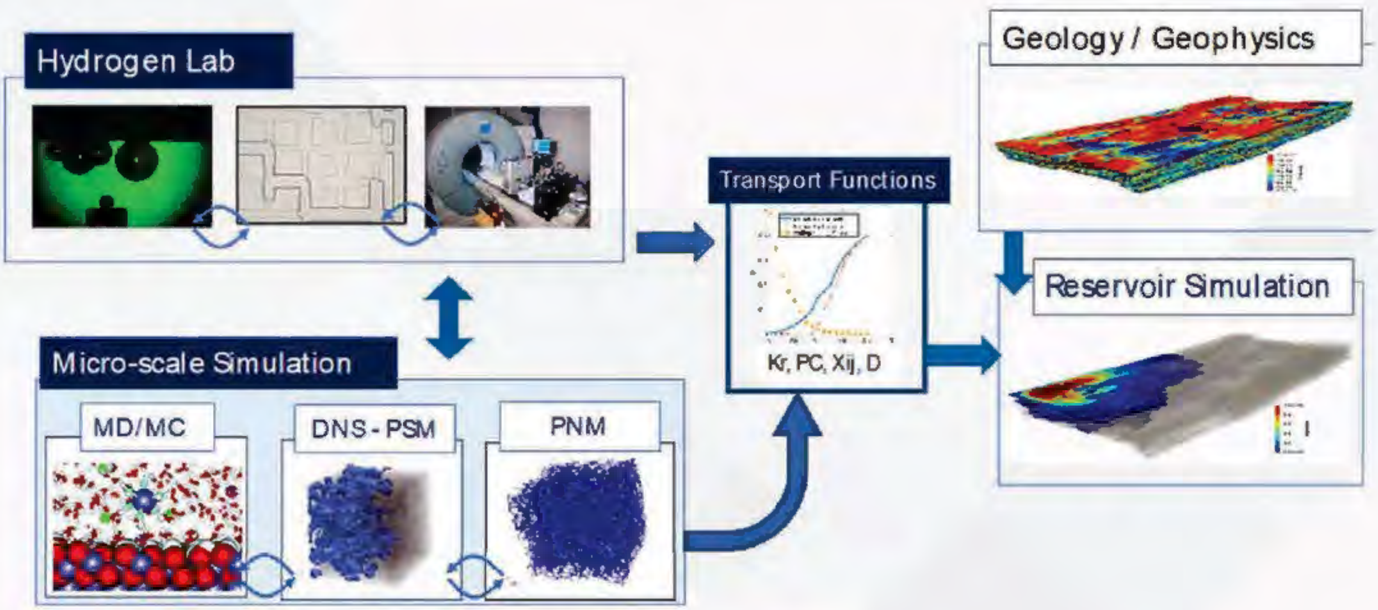
Theme: Subsurface Storage & Multiscale Modelling

Background

Dr. Hadi Hajibeygi is one of our three new CCUS research chairs, with primary focus towards building confidence in underground hydrogen storage (UHS) and CO_2 storage. As fluid characterization by relative permeability (Kr) and capillary pressure (Pc) curves is rather ad-hoc with limited data support in the literature, Dr. Hajibeygi decided to design and run specific experiments to help ascertain these much-needed lab-driven curves

Research Focus and Outcome

Through their multi-scale experimental-numerical modelling work, Dr. Hajibeygi and his research team were able to validate the wettability characterization (Kr and Pc curves), and mechanical integrity (reliable material characterization under cyclic loading - characterize with ensemble of cyclic experiments). Major differences in Kr and Pc curves were found with respect to the literature. The finding has significant implications on the evaluation and planning of UHS and CO_2 storage projects, as the injectivity, gas plume migration and storage capacity from previous estimates may not be realistic. Additional laboratory testing and numerical modelling are being conducted to help arrive at more robust models to support the industry in energy transition.



Research Updates

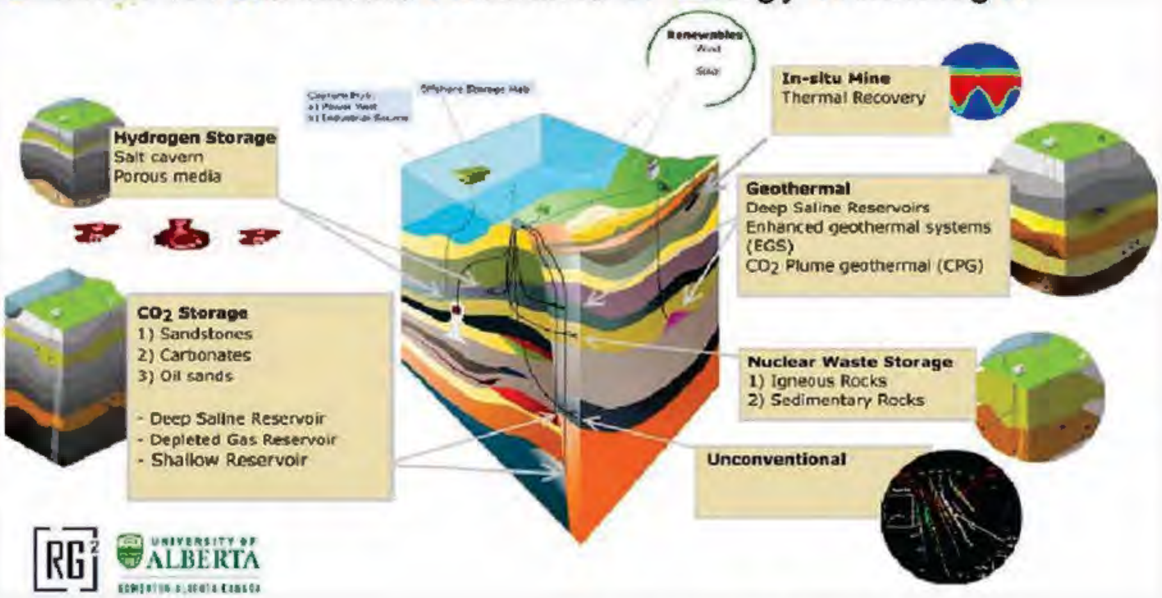
University of Alberta - Dr. Rick Chalaturnyk

Reservoir Geomechanics

Theme: Reservoir Geomechanics for Unconventional Reservoirs

GeoSAFETY

Geoscience for Subsurface Assurance oF Energy TechnologYs



Background

Having assembled a team of talented researchers and graduate students, and being well-equipped with a world-class geomechanics laboratory (including a physical centrifuge, high-temperature high-pressure triaxial stress and thermal conductivity / diffusivity test cells) at the University of Alberta, Dr. Rick Chalaturnyk's Reservoir Geomechanics Research Group ([RG]^2 - "RG-squared") has been providing excellent support to the industry, addressing techno-economic challenges of unconventional resources, geothermal energy and CO_2 storage projects for many years. Through laboratory testing, physical modelling, reservoir simulation and field piloting, [RG]^2 has investigated and helped define guidelines for caprock integrity and allowable operating pressure for thermal recovery projects. They have also been involved with the measurement, monitoring, and verification programs for many CO_2 storage projects in Canada.

Research Focus

The latest initiative of the [RG]^2 is called GeoSAFETY, involving lab testing and reservoir modelling to support unconventional resources, geothermal energy, and carbon sequestration development efforts. The goal is to establish dedicated CO_2 storage hubs as standalone, viable business entities within the CCS value chain. This could lead to site characterization and performance predictions under uncertainty and economic challenges, and to questions about how much subsurface information is needed to meet regulatory, public, and internal risk management expectations.

GeoSAFETY will revisit two projects (Weyburn Phase 1a and Aquistore) that have collected world-class datasets for commercial scale, real operations. The team will deploy modern geoscience workflows to assess what "right" means and what does a "minimum" dataset look like for constraining subsurface performance assessment.

Research Updates

University of Southern California - Dr. Behnam Jafarpour

Data Science

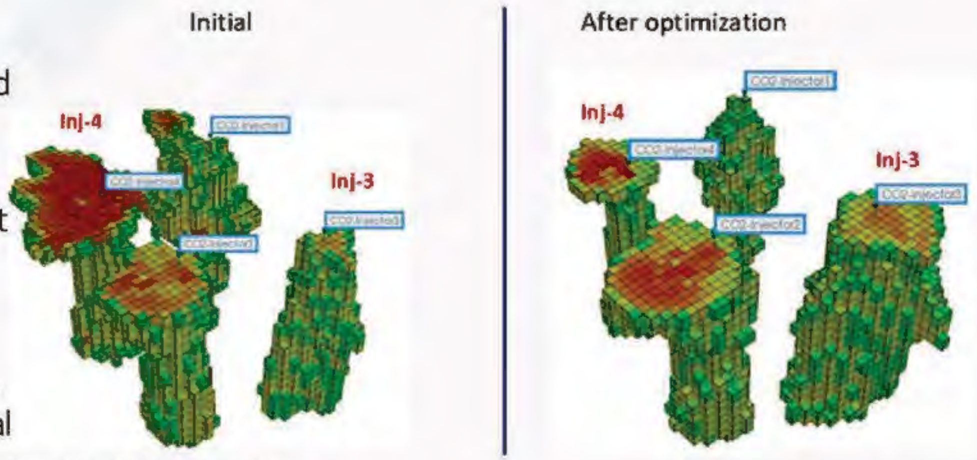
Theme: Subsurface Energy Data Science

Background

To properly explore and develop subsurface energy from hydrocarbon, geothermal or other resources, the complex geosystems need to be characterized with limited data, and the field development plans would need to be optimized for safe, effective and efficient operations. As advances in artificial intelligence (AI) are growing exponentially nowadays, many practitioners are invoking AI to assist in optimizing their current operations or solving complex problems. Recognizing the trend, Energi Simulation established a research chair program, led by Dr. Behnam Jafarpour, with a focus on subsurface energy data science, at the University of Southern California in July 2022.

Research Focus

Using active learning to build reliable proxy models, Dr. Jafarpour has proved that the AI-powered tool would reduce computation without compromising fidelity/accuracy. This approach converges to better solution with few simulations. Applications to waterflooding and geological CO_2 storage have shown promising results.



Optimization results

Efficient Field Performance Optimization with AI-Powered Proxy Models

Outcome

Dr. Jafarpour and his research team will continue to develop and apply their data science expertise to support the industry, in their geothermal energy, CCUS, and hydrocarbon resource development projects.