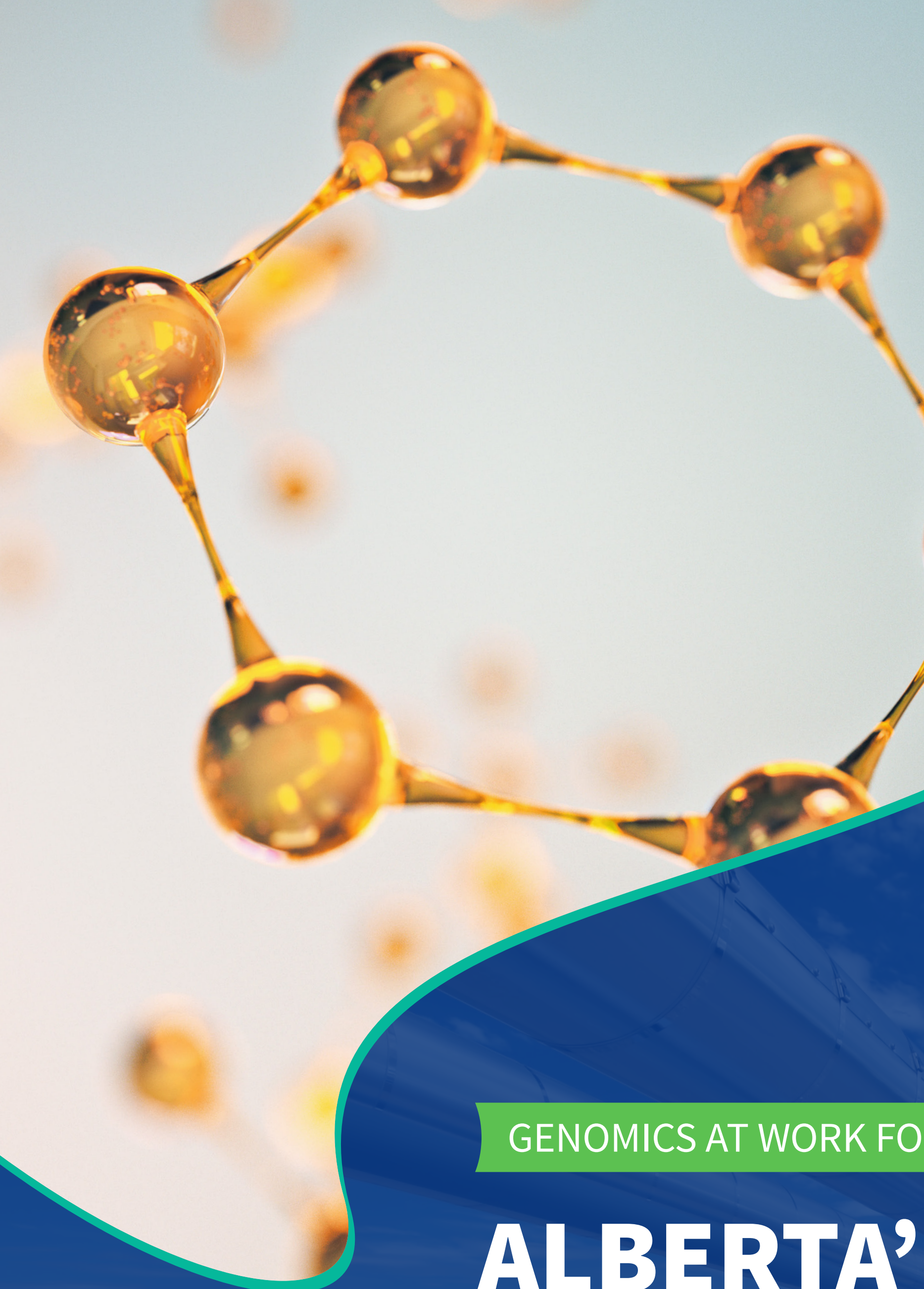


GENOMICS AT WORK FOR

ALBERTA'S ENERGY SECTOR

What We Heard Workshop Summary

FEBRUARY 2025

Genome Alberta

As a not-for-profit research funding organization, we're here to help initiate, fund and manage genomics partnerships and research. Together, we will catalyze genomics solutions that benefit Albertans and the world.

Established in 2005, Genome Alberta is part of a Canadian network for building international leadership in genomics and other 'omics research, developing specific Life Sciences research platforms to address and support regional priorities.

Genome Alberta has enabled **$605M** of genomics research and has helped secure **$126M** of federal research funds for Alberta-led projects, creating thousands of Alberta jobs and enabling 27 spin-off companies. This includes over **$70M** invested into a portfolio of environment and energy-related research.

We add significant value to the provincial innovation ecosystem by:

- Working collaboratively with innovation entities to drive technology development and implementation.
- Securing significant federal funds for Alberta-led research and increasing innovation support for our provincial priorities.
- Ensuring scientific excellence is supported by social sciences research and addressing ethical, legal and environmental barriers.

OUR **VISION**

To inspire and catalyze genomics solutions that benefit Albertans and the world.

OUR **MISSION**

To promote and support genomics solutions for end-user needs to create value and investment opportunities through excellent science, technology and application development, collaborations and partnerships.

EXECUTIVE SUMMARY

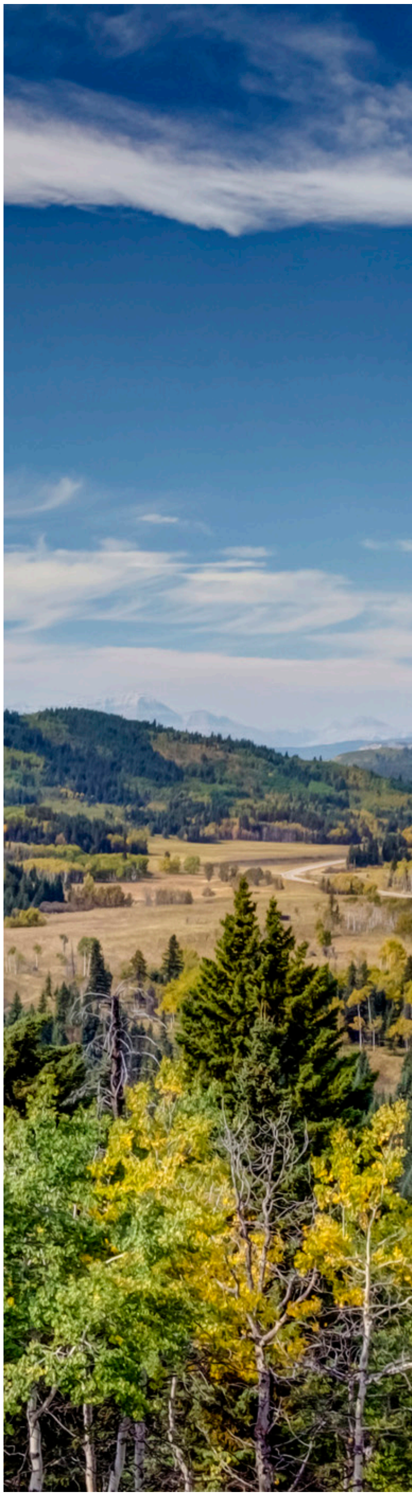
Genome Alberta has long championed the role of genomics in advancing innovation across sectors critical to Alberta's economy and environment. With over **$70 million** invested into a portfolio of environment and energy-related research, the organization continues to explore how genomic technologies can support both the optimization of current energy operations and the province's emissions reduction and energy development goals.

Recognizing the growing need to align scientific advancements with operational realities, Genome Alberta hosted a virtual stakeholder engagement session on February 20, 2025, titled *Genomics at Work for Alberta's Energy Sector*.

The event brought together more than **90 participants** from across Alberta's energy ecosystem—spanning oil and gas, renewable energy, biotech, academia, government, and the not-for-profit sectors. Through two expert panel discussions and interactive polling, participants explored the potential of genomic tools to be adopted by the energy sector to improve operations, drive innovation through biotechnology, and achieve environmental benefits.

PANEL 1 focused on opportunities and challenges for applying genomics to optimize natural resource management and environmental reclamation in the energy sector. Panellists discussed five key themes:

- **Microbial Tools:** Application of genomics to inform microbial strategies for oil recovery, corrosion prevention, and bioremediation.
- **Site Remediation and Reclamation:** Use of genomic tools to establish environmental baselines, assess cumulative impacts, and monitor or enhance soil and vegetation recovery.
- **Cross-Sector Collaboration and Engagement:** The critical role of academia-industry-regulator partnerships in scaling genomic innovations and supporting real-world deployment.
- **Economic and Policy Considerations:** Importance of aligning genomic innovations with environmental and social impact frameworks, funding mechanisms, and regulatory compliance.
- **Community Engagement:** The importance of improving transparency and trust through open communication between those with genomics expertise and others across various disciplines, sectors, and interests.



PANEL 2 explored the potential for genomics to enable a greener future through energy-derived clean technologies. Discussions focused on the following five themes:

- **Environmental DNA (eDNA) for Biodiversity Monitoring:** The use of eDNA for non-invasive, high-sensitivity ecological monitoring to support environmental assessments and reclamation.
- **Synthetic Biology and Engineered Microbial Solutions:** Engineering microbes for more effective conversion of methane to less harmful emissions, or production of higher value products of hydrogen or alternate energy sources.
- **Carbon and Emissions Technologies:** Genomic approaches to monitor and verify carbon storage and low-carbon fuel pathways.
- **Clean Technology Commercialization Considerations:** Addressing funding gaps, regulatory change to support new technology adoption and market integration for genomic innovations.
- **Education and Communication:** Improving genomics literacy across sectors, supporting interdisciplinary training, and fostering public trust.

Audience polling confirmed strong alignment with these focus areas, with waste and environmental management, emissions reduction, and biodiversity surveillance ranking as top challenges for genomics to address. Participants also indicated economic and technical barriers as the most significant hurdles to broader adoption.

WHAT'S NEXT

Based on the insights shared during the session, key priorities were identified to accelerate the responsible adoption of genomics in Alberta's energy sector.

- **Support Field Validation of Genomic Tools:** Bridge the gap between lab-scale innovation and field-scale application by supporting demonstration-scale projects, prioritizing multi-sector partnerships, and requiring pre- and post-deployment performance metrics.
- **Promote Open Science and Data Interoperability:** Foster collaborative learning and reduce duplication via open data sharing, development of standard ontologies and metadata, and encouraging cross-project sharing of genomic baselines.
- **Data Infrastructure Building:** Business value can be enhanced by integrating big data, AI, and genomics through a multi-step approach involving bioinformatics, with machine learning enabling efficient, low-risk modelling of microbial processes and synthetic biology applications.
- **Commercialization, Economic and Impact Metrics:** Quantify the cost-benefit, environmental and social impact metrics of genomic-driven innovation in the energy sector.
- **Facilitate Regulatory Readiness and Policy Engagement:** Enable genomic tools to be integrated into environmental regulation and compliance frameworks by supporting co-development with regulators for protocols, field validation, and guidance documents.
- **Build Capacity Through Workforce Development**: Equip the energy sector with the skills to adopt and implement genomic tools via workforce training programs, cross-sector fellowships and internships, and develop applied curricula through academic partnerships.
- **Societal Engagement**: Ensure that genomic tools are trusted, locally relevant, and culturally appropriate by encouraging co-development and knowledge-sharing integrated into project design. Translating genomic outputs into easy to understand, community-accessible formats.

The discussion and learnings from the engagement session will guide the development of future Genome Alberta programs to support the application of genomics into Alberta's energy sector and contribute to a more innovative and sustainable energy future.

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INTRODUCTION

Genome Alberta is a driver of genomics innovation, facilitating the deployment of genomics solutions in Alberta's key economic sectors, including energy and environment sectors. To date, over **$70 million** has been invested into a portfolio of environment and energy-related research accelerating the development and adoption of genomic technologies.

Previously, Genome Alberta has taken part in collaborations with innovation ecosystem partners to identify key energy and environment sector challenges and how genomics-based approaches could resolve them. Two main themes emerged from these past sessions around improved efficiency in current energy processes, and transitioning to a greener energy future. Each of these themes are described below with specific examples of sector challenges and relevant genomic technology solutions.

Increasing efficiency by optimizing current energy processes can improve natural resource management and environmental reclamation efforts. Consumption of fossil fuels for a wide range applications, which present challenges to decarbonize, is expected to continue over the following decades. Maximizing efficiency at each industrial process stage and implementing robust environmental reclamation procedures can decrease the lifecycle impact of extracting fossil fuel resources. Examples from oil recovery, corrosion prevention, tailing pond treatment, and oil spill remediation are listed below.

- **Microbial enhanced oil recovery:** In conventional oil operations, microbial enhanced oil recovery uses specially selected, or potential use of engineered, microorganisms to enhance oil recovery. Genomic analysis of microorganisms that produce surfactants, biofilms, or gases (such as CO_2) can optimize enhanced oil recovery techniques by improving oil flow or reducing viscosity.
- **Microbially influenced corrosion prevention:** Using a genomics approach to control infrastructure corrosion and well souring can enhance understanding of microbial genetic pathways, enabling the development of targeted prevention and control methods. Genetic engineering techniques could also disrupt biofilm formation effectively.
- **Oil sands tailings ponds clean-up:** Treating process affected water stored in tailings ponds to acceptable levels using constructed wetlands is of interest. Large-scale water re-use is common and also presents challenges for treatment to remove contaminants, which results in both environmental concerns and considerable cost. Treatment of used water with microorganisms is being explored as a viable, cost-effective solution.

- **Oil spills bioremediation:** The development and improvements for better effluent clean-up processes with bioremediation by microbial and plant communities in soil or freshwater through, notably, omics-based technologies, is key to environment restoration after energy-related activities. Synthetic biology is a tool to design microorganisms capable of breaking down a wider range of oil compounds.

Clean energy sector can adopt certain technologies originally intended for use in the conventional oil and gas sector (including oil sands operations). The opportunity to reduce the environmental impacts of the energy sector requires a better understanding of the processes to develop and safely scale-up these technologies while applying them to renewables and alternative energy. Examples from biohydrogen storage, methane mitigation, geothermal energy, carbon storage, and biodiversity monitoring are listed below.

- **Hydrogen production and storage:** The production of biohydrogen and storage in sub-surface environments is technically challenging due in part to the poorly understood role of microorganisms in such processes. Genomic approaches such as genetic profiling can improve understanding and, for example, permit development of strategies to prevent hydrogen consumption by subsurface microbes.
- **Methane mitigation:** Methane is a potent greenhouse gas and efforts are underway to reduce these emissions. Genomic solutions can be applied to develop biofilters to reduce these emissions. Genomic approaches can be used to optimize the conversion of methane to valuable by-products including biofuels.
- **Geothermal energy:** Certain inactive oil and gas wells can be converted to produce clean geothermal energy. Genomic approaches can be used to surveil reservoir maintenance, enhance resource recovery, and monitor environmental health.
- **Carbon storage:** Genomic technology can be applied to optimize the use of plants or soil microorganisms to capture and store carbon. Identifying metabolic bottlenecks allows development of strategies to increase the efficiency of these systems for carbon sequestration or conversion. The subsequent storage of carbon dioxide in subsurface environments is also a challenge similar to hydrogen storage regarding unknown microbial processes underground.
- **Biodiversity surveillance:** Environmental risk assessment, monitoring and compliance with regulationis key for species and habitat conservation. Analysis of environmental DNA (eDNA) can be used to establish detailed biodiversity baselines, monitor temporal changes, and assess cumulative effects of the energy sector activities to support sustainable natural resource management.

[1] Genomics in Canada's Energy & Mining Sectors (2019) Genome Alberta

Building on this earlier work, Genome Alberta has newly undertaken a broader engagement with diverse stakeholders to explore the opportunities and challenges surrounding the application of genomics technologies in the Alberta energy sector and update priority areas.

On February 20, 2025, Genome Alberta hosted an online Genomics at Work for Alberta's Energy Sector engagement session to explore how genomic tools can support natural resource management, remediation efforts, and clean technology development aimed at reducing environmental impacts from energy resource development. The session brought together over 90 professionals across diverse sectors with the following representation: industry including oil and gas (including oil sands), renewable energy, and bio-tech sectors (40%); research including universities and research institutes (34%); government/regulators ranging from government scientists to regulators (18%); and the not-for-profit sector (8%) (Figure 1.) The full list of **47 participating organizations** is on the inside back cover of the report.

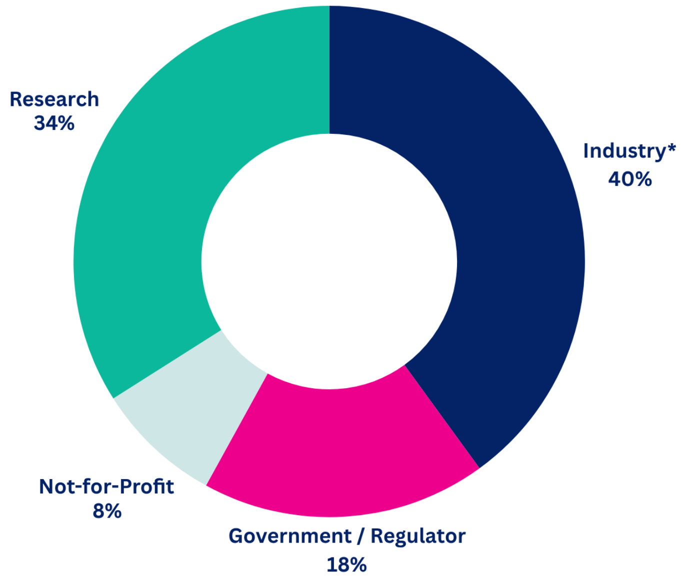


Figure 1. Sectors represented by participants. N=91

***Industry affiliated participants include oil and gas, renewable energy and bio-tech sectors.**

The workshop aimed to explore the challenges and opportunities of applying genomics technologies to advance Alberta's energy industry.

The objectives of the engagement session were to:

- Provide a forum to engage the energy community about the current state of genomics technologies in Alberta's energy sector;
- Discuss any barriers to genomics technology adoption and implementation;
- Understand what changes are needed to drive genomics-enabled energy innovation in Alberta forward; and
- Identify and prioritize areas for genomics-enabled energy to inform investment through research funding programs.

The online engagement session featured ten subject matter experts representing diverse sectors to bring multiple perspectives to the discussion. The session included two separate panel discussions addressing the two main themes of the application of genomics toward: improved efficiency in current energy industry practices related to the environment; and developing clean technologies. Panel members and a summary of each panel discussion are presented on the following pages.

PANEL 1: OPPORTUNITIES AND CHALLENGES FOR GENOMICS TO OPTIMIZE NATURAL RESOURCES MANAGEMENT AND RECLAMATION EFFORTS.

PANELLISTS INCLUDED:

- **Dr. Carolina Berdugo-Clavijo,** Environmental Research Advisor, Imperial Oil Resources Limited
- **Dr. Jayne Rattray,** Tailings Biogeochemist, Canadian Natural Resources Limited (CNRL)
- **Dr. Lisa Gieg,** Professor of Environmental Microbiology, Department of Biological Sciences, University of Calgary
- **Dr. Mark Summers,** Vice President of Agriculture and Environment, Alberta Innovates
- **Dr. Soheil Asgarpour,** retired former CEO and President of Petroleum Technology Alliance Canada (PTAC), current Chair of the Council of Canadian Academies

PANEL 1 SUMMARY

Panellists contributed insights from the perspective of energy companies, industry association, academia, and provincial government innovation agency. The panel discussion centered on leveraging genomic tools and microbial approaches to improve environmental outcomes and operational efficiencies across the energy operations lifecycle with particular focus on tailings pond management, water treatment, and reclamation. Using microbial tools to enhance oil recovery and mitigate greenhouse gas emissions were highlighted as opportunities to improve the operational efficiency and environmental sustainability of oil extraction and post-extraction processes. Microbially-influenced corrosion of infrastructure was identified as another important industry problem that may be addressed using genomic tools. Key applications of genomic approaches included bioremediation of hydrocarbons and tailings, as well as monitoring microbial communities as a measure of soil and ecosystem health for post-extraction site reclamation. Challenges were underscored related to field scalability, lack of standardized reclamation metrics, and regulatory barriers that slow adoption of new biological tools. Panellists emphasized that stronger industry-academic partnerships that help communicate the economic and environmental benefits of genomic approaches will be essential to scale these technologies within the energy industry.

PANEL 2: OPPORTUNITIES AND CHALLENGES FOR GENOMICS TO ADVANCE INNOVATIONS IN OIL AND GAS-DERIVED CLEAN TECHNOLOGY TO REDUCE ENVIRONMENTAL IMPACTS.

PANELLISTS INCLUDED:

- **Dr. Ian Gates**, Professor, Department of Chemical and Petroleum Engineering, University of Calgary
- **Grace Meikle**, Director for Technology Impact, Emissions Reduction Alberta
- **John McDougall**, CEO of SynBioBlox Innovations
- **Dr. Beth Richardson**, Assistant Professor of Microbial Ecology, Department of Biology, Mount Royal University
- **Dr. Lisa Stein**, Professor and Canada Research Chair in Climate Change Microbiology, Department of Biological Sciences, University of Alberta

PANEL 2 SUMMARY

Panellists contributed insights from the perspective of academia, entrepreneurial innovation, and provincial government agency for climate solutions.

The panel discussion focused on the potential for synthetic biology and environmental DNA (eDNA) tools to support the transition to a greener future. Speakers explored how genomics could contribute to low-carbon innovations through microbially-derived hydrogen production, and synthesizing tailored microbes for methane capture and tailings treatment. The panel noted the promise of eDNA tools to non-invasively monitor biodiversity and surveil ecosystem health. Such genomic tools have the potential to assist environmental assessment and reclamation efforts through both the establishment of environmental baselines and the assessment of cumulative impacts over time. Panellists highlighted the need for: adaptive regulatory framework, improved communication strategies and transparency in environmental monitoring, and stronger academic-industry collaborations to support the commercialization of early-stage genomic technologies.

This report summarizes insights from the panel discussions, interactive polls, and Q&A sessions during the engagement session, supplemented by expert consultations and scientific publications. The discussions highlighted key challenges to advancing the adoption of genomics-based tools in Alberta's energy sector.

DISCUSSION

PANEL 1: OPPORTUNITIES AND CHALLENGES FOR GENOMICS TO OPTIMIZE NATURAL RESOURCES MANAGEMENT AND RECLAMATION EFFORTS

The first panel discussion explored the potential for genomic tools to be leveraged by the energy sector to support natural resources management and reclamation. Five main themes emerged from the discussion: microbial tools; site remediation and reclamation; cross-sector collaboration; economic and policy considerations; community and public engagement. Each theme is expanded below, along with opportunities and challenges highlighted during the panel discussion.

THEME 1: MICROBIAL TOOLS

Microbial processes and genomic technologies can be leveraged by the energy sector both in operations and during remediation processes. Operationally, genomics can be applied to costly industrial challenges such as corrosion control using microbial risk management for proactive maintenance, and to enhance oil recovery utilizing microbial tools. Panelists highlighted how understanding microbial communities through genomics can lead to better monitoring, intervention, and sustainable remediation strategies.

OPPORTUNITIES

- **Microbially Influenced Corrosion Management:** Genomic sequencing can be applied to identify corrosion-causing microbes in infrastructure such as pipelines and tanks. Early detection enables proactive interventions, reducing maintenance costs and environmental risk.
- **Microbial Enhanced Oil Recovery:** Stimulating beneficial microbial activity in subsurface environments can increase oil recovery by reducing viscosity or enhancing pressure. This approach could be applied to improve yield from aging reservoirs while lowering overall environmental impact of the operation.
- **Bioremediation:** Selection of naturally occurring beneficial microbial communities can be used to break down contaminants in tailings ponds and remediation sites. These biological approaches may offer a more sustainable alternative to conventional chemical treatment and support accelerating ecological recovery.

- **Genomic Monitoring Tools:** Genomic techniques allow researchers and operators to track microbial diversity, abundance, and function over time. These tools serve as indicators of soil health, biomarkers of broader ecological integrity, remediation progress, and the effectiveness of reclamation practices.
- **Data Infrastructure Building:** The energy industry has an opportunity to integrate genomic tools within big data infrastructures and expand its use of machine learning and artificial intelligence. The adoption of such innovations will support the energy sector's efforts towards, for example, sustainable practices and add value to their business.

CHALLENGES

- **Scalability:** Technologies that perform well in the lab often face operational challenges in diverse and uncontrolled field conditions. Variability in temperature, pH, and geochemistry can hinder microbial effectiveness. While promising in controlled settings, microbial solutions are not yet fully proven in full-scale operations across varying climates and geologies. Close collaborations between researchers and operators can support research translation and commercialization of promising approaches.
- **Standardization:** Harmonized protocols for sample collection and processing as well as data analysis have been developed in recent years and may benefit from ongoing efforts. Standardization is key to reproducibility and confidence in comparing results across sites. Developing shared protocols is critical for commercial adoption of such biological technologies. Developing genomic field and laboratory methodologies approved through the Canadian Standards Association, for example, was critical for the successful commercialization of eDNA analysis of water samples. Such an approach could be replicated for microbial genomic tools.
- **Uncertainty in Regulation:** Regulatory frameworks are difficult to navigate, fragmented across jurisdictions, and lack clear pathways for approval of genomics-based technologies. In particular, field testing of new biological technologies faces significant regulatory hurdles—particularly when genetically engineered organisms are involved, due to concerns of unintended impacts to local ecosystems. There is a lack of clear guidance on how genomic tools can be accommodated within existing environmental monitoring and compliance frameworks. Improved collaboration between researchers, industry and regulators to help inform changes to regulation and remove barriers to adoption.

Environmental DNA (eDNA) is the genetic material organisms leave behind in their environment, including in water, soil and air.

THEME 2: SITE REMEDIATION AND RECLAMATION

Site remediation and reclamation of disturbed ecosystems impacted by energy operations are of high priority for industry, regulators, and the Alberta public. Remediation refers to addressing contamination in soil, water, or air. Reclamation aims to restore a site to its original condition or to an acceptable condition set by regulation. The panel emphasized how genomic tools can provide deeper insight into the biological state of industrially impacted sites and their recovery potential. Discussions explored how genomic tools can track the success of biological interventions to promote site remediation. Genomics can be applied to create ecosystem diagnostics tools to establish baseline biodiversity measurements, assess cumulative effects of industrial activities, and track ecosystem recovery. Biology-based indicators can be used to inform planning, execution, and validate ecosystem health. Tracking biological metrics to inform adaptive management during remediation processes can support more effective and measurable reclamation outcomes to support re-establishment of productive ecosystems.

OPPORTUNITIES

- **Ecosystem Rebuilding:** Combining soil amendments with microbial inoculants, restoration strategies can mimic and promote natural succession processes. These approaches accelerate ecosystem recovery and improve the likelihood of successful site reclamation. Genomics technologies can be applied to monitor microbial communities as metrics to track improvements in water quality and soil health recovery.
- **Vegetation Recovery Tracking:** Soil microbiome community analysis using genomic tools can indicate when conditions are suitable for revegetation. Tracking microbial functions as a bio-indicator of long-term plant health and stability can allow for adaptive management in site remediation and reclamation.
- **Establish Baseline Conditions:** Genomic tools can be applied to map pre-disturbance biological conditions, provide a scientific foundation for tracking cumulative effects of industrial activities, and establish restoration benchmarks along the path to achieve ecological reclamation goals.
- **Data-Driven Success Metrics:** Biological indicators at the molecular level, such as functional gene abundance and microbial diversity indices, offer a new generation of genomic-based monitoring tools to evaluate ecosystem health over time.

CHALLENGES

- **Long Timelines:** Ecological reclamation can be a long-term process depending on the type of contaminant, which can vary between days to decades to re-establish biological habitat to meet regulatory and/or societal expectations. Thus, short-term validation of reclamation methods can sometimes be difficult.

- **Limited Field Data:** Much of the genomics-based reclamation work to date has been undertaken as laboratory experiments and small-scale pilots. Larger field trials with long-term datasets are needed to build industry and regulatory confidence in these new genomic approaches to remediation and reclamation.
- **Diverse Site Conditions:** Alberta's energy industry has impacted a wide range of diverse sites. Remediation and reclamation sites vary widely in the nature of their hydrology, native substrate, historic ecosystems and biological communities. The variability and complexity of geological, chemical, physical and biological conditions complicates the development of standardized methodologies.
- **Funding Uncertainty:** Long-term projects can be hindered by short funding cycles and lack of consistent financial support. Often trialing innovative solutions at reclamation sites are funded as one-time, short-term projects. This approach is challenging considering the long-time frame for ecological reclamation and thus limits the possibility of long-term monitoring and accurately evaluating efficacy or site rehabilitation. Patient investment in new remediation and reclamation innovations by funding agencies and industry is required to support such long-term endeavors.

Effective deployment of novel genomics tools to the energy sector requires integration between researchers developing the tools, industry operators implementing them, and regulators approving their use.

THEME 3: CROSS-SECTOR COLLABORATION

Cross-sector and interdisciplinary collaboration to accelerate industry adoption of genomic innovations emerged as a recurring message throughout the discussion. Effective deployment of novel genomics tools to the energy sector requires integration between **researchers** developing the tools, **industry operators** implementing them, and **regulators** approving their use. Thus, forging academic-industry-regulator partnerships is essential for the successful deployment of genomic and biological tools to address relevant operational and environmental applications of importance to the energy sector.

OPPORTUNITIES

- **Partnership Models:** Academic-industrial collaboration projects supporting genomic innovation in the energy sector could be co-funded through a partnership between academia, funding agencies, industry stakeholders and government entities, such as regulators. Such a partnership model would demonstrate the benefits of joint planning between academia, industry operators, and regulators. This model would help align research outcomes with industry operational requirements and field needs, thus increasing the probability of successful deployment and commercialization of genomic and biological innovations in the energy sector.
- **Knowledge Sharing Platforms:** Shared, centralized data repositories can be used to host microbial and genomic data from various sites to improve comparability across projects. Inter-operable metadata standards would make environmental genomics

more accessible and increase transparency and trust in data integrity. Such knowledge sharing platforms would facilitate the evaluation of the efficacy of new genomic innovations in improving industrial processes, remediation and reclamation treatments.

- **Pilot Studies:** Working collaborations between researchers and energy companies are required for microbial and genomics-based treatments to be successfully scaled from the lab bench to operational conditions. Pilot studies hosted in industrial settings generate real-world data, de-risk the tested technology to build trust in novel approaches, and increase the probability of successful adoption of novel biologically-based approaches by industry.

CHALLENGES

- **Data Privacy and Ownership:** Industrial partners may be reluctant to share operational data or genetic information due to Intellectual Property (IP) concerns, commercial sensitivities, regulatory risk, liability concerns, or reputational implications.
- **Inconsistent Goals:** Academic timelines for publishing and student supervision may not align with industry's need for quick, scalable solutions. Funding agency's timing of calls for proposals for novel innovations may not align with timelines to address pressing problems faced by industry. Permitting schedules and regulation modernization cycles may further complicate coordination to facilitate scaling innovative genomic and biological solutions for industry adoption.
- **Lack of Integrated Framework:** Without a formal structure connecting funding, research, industrial field trials, and policy development, adoption of new genomic innovations by industry risks being slow and fragmented. An integrated framework coordinated by a cross-sector entity with stable funding could be beneficial to accelerate commercialization of suite of biological tools for adoption broadly across the energy sector.

THEME 4: ECONOMIC AND POLICY CONSIDERATIONS

For genomics and microbial tools to gain broad adoption by the energy sectors, it will require the new technologies' business case to be economically viable. Market demand may be strengthened through modernization of environmental regulations to consider the full accounting of environmental and social costs of industry activities. Furthermore, environmental, social, and governance considerations of some government funding programs and corporate shareholder pressure may act as levers for the uptake of new innovations to mitigate industrial impacts. Many genomic innovations and microbial tools provide benefits to the energy industry that align with government policy goals related to greenhouse gas emissions reduction, environmental sustainability, and climate solutions.

OPPORTUNITIES

- **Impact metrics:** As the energy sector faces increasing pressure from government and shareholders to demonstrate environmental performance, genomic approaches offer high-resolution data to track emissions reduction, biodiversity and ecological health indicators. Genomic approaches offer measurable impact metrics to provide transparency in reporting impact to public stakeholders to gain social license.
- **Public Funding:** Funding programs from funding agencies are essential to bridge the gap from research to operational trials on industry sites. De-risking early-stage pilot projects encourages experimentation to catalyze innovation adoption.
- **Risk Mitigation:** Co-funding from public granting agencies reduces the financial burden on individual companies who are exploring higher-risk, high-impact technologies. Considering that, for example, the genomic applications for reclamation offer long-term returns on investment, co-funding models allow companies more flexibility to trial novel technologies without bearing the full financial risk.

CHALLENGES

- **Regulatory Adaptation:** Despite growing interest from industry, regulatory pathways for approving the use of genomic tools remain underdeveloped or misaligned with existing approval structures. As a result, promising innovations may face delays at the regulatory interface, particularly when field deployment is required. Coordinated efforts among researchers, industry leaders, and regulators can be helpful to modernize policy frameworks, improve access to decision-relevant data, and increase regulatory confidence in genomics-based approaches for environmental permitting activities.
- **Market Value:** While scientifically compelling, the business case for genomic reclamation tools is still developing, particularly when benefits accrue over long timelines. Companies may be hesitant to invest in novel biological technologies which are high risk and where the return on investment is difficult to forecast.

- **Limited Commercial Pathways:** Without established standards and acceptance by regulators, industrial procurement for genomic tools can be challenging. Overcoming these barriers will provide a commercialization pathway to scaling biological solutions beyond pilot stage. Subsequently, additional implementation challenges will need to be overcome including that few suppliers and service models are currently available to provide genomic technology tailored to energy operations.

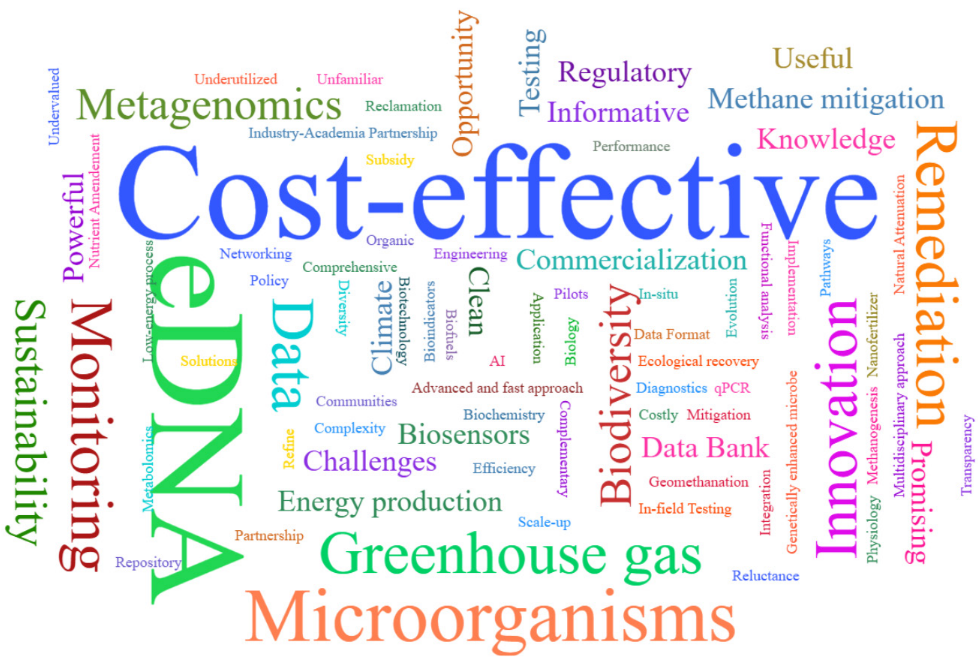


Figure 2. Responses from participants on what words come to mind when thinking of genomics/biological tools in the energy sector. Responses (N)=143

THEME 5: STAKEHOLDER AND COMMUNITY ENGAGEMENT

The panel emphasized the critical importance of clear and transparent communication between multidisciplinary groups, various stakeholders agencies and communities, especially with the novel use of complex technologies like genomics and synthetic biology. Also, social license was deemed essential for the ethical and effective use of biological tools by the energy sector for natural resource management and environmental reclamation.

OPPORTUNITIES

- **Transparency in Monitoring:** The quantitative nature of genomic data lends itself to transparent communication of environmental monitoring data. Opportunities to share biological impact metrics in an accessible way would help to more broadly communicate the progress of ecological reclamation efforts and thus foster accountability.
- **Scientific Complexity:** The technical nature of genomics can create communication barriers with the public. Genomics can be seen as inaccessible or abstract, creating a barrier to meaningful community participation. Crafting effective and compelling storytelling that communicates the value of genomic impact metrics to a non-scientific audiences remains a great opportunity in this sector.

CHALLENGES

- **Relationship and Trust Building:** Establishing and maintaining trust requires long-term engagement, relationship-building, and consistent communication with stakeholders and communities involved in energy projects. Relationships require time, consistency, and co-ownership.

PARTICIPANT FEEDBACK

POLLING QUESTION:
RANK CHALLENGES THAT COULD BE ADDRESSED WITH A BIOLOGICAL APPROACH

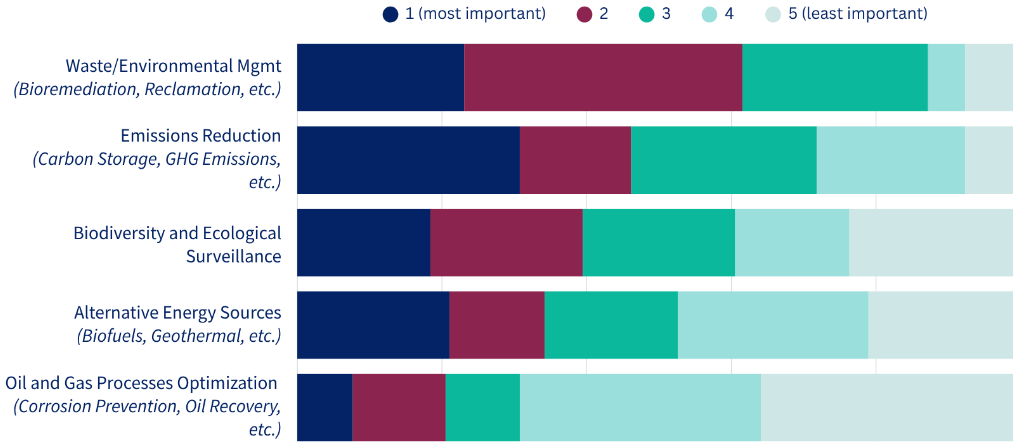


Figure 3. Participants ranked a set of challenges, from most to least importance, within Alberta's energy landscape that could be addressed with a biological approach. N=39

PANEL 2: OPPORTUNITIES AND CHALLENGES FOR GENOMICS TO ADVANCE INNOVATIONS IN ENERGY-DERIVED CLEAN TECHNOLOGY TO REDUCE ENVIRONMENTAL IMPACTS

The second panel discussion explored the potential for genomic tools to catalyze and advance innovations in clean technologies. Five main themes emerged from the discussion: environmental DNA (eDNA) and biodiversity monitoring; synthetic biology and engineered microbial solutions; carbon and emissions technologies; clean technology commercialization considerations; communication, education, and public engagement. Each theme is expanded below, along with opportunities and challenges highlighted during the panel discussion.

THEME 1: ENVIRONMENTAL DNA (eDNA) FOR BIODIVERSITY MONITORING

eDNA can strengthen tracking of environmental compliance during operations, inform reclamation planning and execution, and facilitate adaptive management based on timely scientific findings.

Panellists discussed how environmental DNA (eDNA) is reshaping environmental monitoring of ecosystems and natural habitats in the energy sector. One of the major value propositions of eDNA tools is providing a detailed understanding of biodiversity across terrestrial and aquatic systems without physically disturbing habitats or harming higher organisms. The application of eDNA approaches to establish biodiversity baselines and reclamation assessments were highlighted as a key to advance in environmental stewardship.

OPPORTUNITIES

- **Non-Invasive Assessment:** eDNA allows for the detection of species presence/absence and ecosystem changes without the need for physical trapping, observation, or handling higher organisms. Ecological disturbance during eDNA sampling is minimized due to the collection of environmental media such as water, soil, feces, instead of directly collecting destructive tissue samples from organisms. Due to its non-invasive nature and high-resolution detection sensitivity, eDNA sampling is particularly suited for surveying sensitive habitats and rare species.
- **Baseline and Impact Tracking:** These genomic tools support the establishment of detailed ecological baselines and can be used to monitor the status of biological diversity during and after operations impacting natural ecosystems. Due to the reduced cost, increased sensitivity, and rapid analysis of eDNA samples, data can inform natural resource management. Thus, eDNA can strengthen tracking of environmental compliance during operations, inform reclamation planning and execution, and facilitate adaptive management based on timely scientific findings.

- **Broad Application Scope:** Panellists emphasized that eDNA can be deployed in diverse settings—from tailings ponds and wetlands to soil and air. Furthermore, eDNA permits assessment in remote environments or during seasons previously incompatible with traditional survey methodologies, such as winter fish monitoring in ice-covered waterbodies by collecting water samples through ice bore holes for eDNA analysis. This flexibility makes eDNA an attractive tool to support environmental compliance across the complex landscape of energy operations.

CHALLENGES

- **Methods Standardization:** Standardization of field sample collection and laboratory analytical methods are critical for regulatory and industry acceptance. Leadership has been taken by some companies to support the development of standardized methods for freshwater collection and analysis of eDNA. However, additional methodologies require standardization in regards to analysis of eDNA in different media (sediment, feces, etc.).
- **Data Interpretation Complexity:** False positive and false negative results yielded from eDNA analysis can result from improper sample handling or laboratory error. These issues can be resolved by including sampling and analytical blanks and controls in the protocols. Understanding the biology of the species of interest and its life history will inform the field sampling protocol and data interpretation. Unexpected findings catalyze additional research and can uncover migration of species into or out of habitats, or novel speciation events when a population has become genetically isolated from its nearest cousins.
- **Limited Regulatory Acceptance:** Despite its scientific robustness and strong value proposition, eDNA is not uniformly accepted across all regulatory frameworks as a primary method for environmental compliance or permitting.

THEME 2: SYNTHETIC BIOLOGY AND ENGINEERED MICROBIAL SOLUTIONS

The discussion centered on the emerging role of synthetic biology in environmental and energy applications. Engineered microbes can serve both in bioreactors and clean technology platforms, offering targeted interventions for greenhouse gas emissions reduction, hydrogen production, and bioremediation.

OPPORTUNITIES

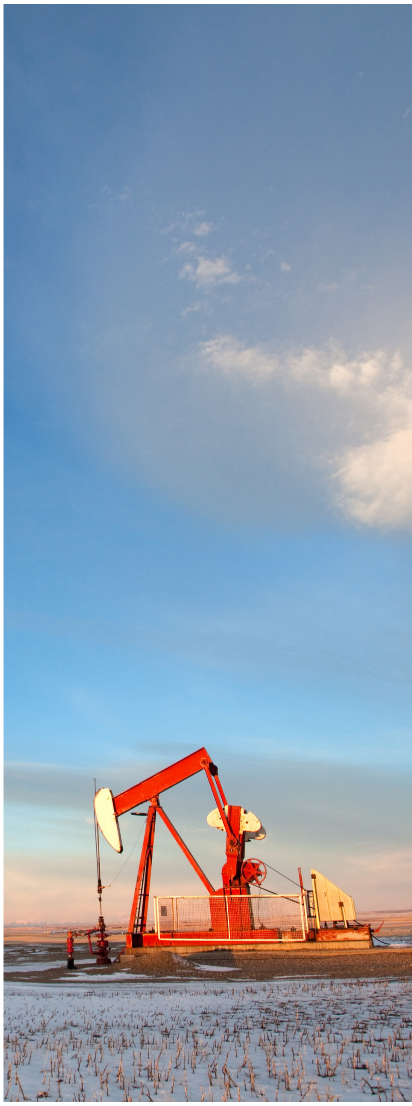
- **Methane Bioconversion:** Engineered microbes are being developed to transform the potent greenhouse gas methane into benign or commercially valuable compounds such as methanol. This synthetic biology application could mitigate methane emissions from venting and flaring operations.
- **Waste to Value-added Products:** Precision engineering can be applied to custom-design microbes to adapt to extreme environments present in energy operations. Through synthetic biology, engineered microbes can be designed to convert waste streams in processing into value-added products. Previously discussed was the bioremediation application of engineered microbes to enhance their effectiveness in degrading hydrocarbons and processing other contaminants in tailings ponds and reclamation sites.
- **Hydrogen Production:** Biological pathways for hydrogen generation offer low-emission alternatives to traditional fossil-fuel-based methods. For example, engineered microbes can be designed to ferment specific feedstocks to produce hydrogen with a lower environmental footprint.
- **Data Infrastructure:** Raw genomic sequence data requires sophisticated bioinformatics and taxonomic reference libraries, with specialized technical expertise to interpret. Standardization of methodologies and thoughtful data management is required to ensure comparability across projects, and panelists discussed this topic as an interesting future step for the industry.

CHALLENGES

- **Deployment Validation:** While promising in lab environments, synthetic biology tools require real-world demonstrations across diverse field conditions to allow for industry confidence and adoption.
- **Environmental Containment:** Communities have concerns about the risk of engineered organisms escaping into natural ecosystems and eliciting unintended ecological consequences. Panellists stressed the need for rigorous containment strategies and ecological impact assessments. Gaining public trust and navigating regulatory hurdles will be critical for adoption.

THEME 3: CARBON AND EMISSIONS TECHNOLOGIES

Genomic technology can support the development and monitoring of carbon mitigation strategies such as carbon capture and storage and low-carbon fuel production. Genomics enables novel methods for verifying carbon transformations and emissions reductions.



OPPORTUNITIES

- **Carbon Tracking and Verification:** Microbial indicators and functional gene markers can serve as biological evidence of carbon dioxide capture, conversion, or long-term storage. This biological carbon tracking metric supports third-party verification and enhances trust in carbon accounting systems. Accurate verification is critical for a robust and scientifically valid carbon credit market.
- **Low-Carbon Fuel Innovation:** Genomics can be used to validate the environmental performance of new low-carbon fuels, such as biogenic hydrogen, by monitoring microbial responses or emissions-related microbial signatures throughout the supply chain. Pairing biogenic hydrogen production and carbon mitigation with genomic assessment tools enables lifecycle analysis.

CHALLENGES

- **Alignment with Emissions Standards:** Current regulatory tools and carbon credit frameworks are based on physical or chemical measurements. Conventional emissions protocols could benefit from implementing frameworks to account for microbial or genomic metrics.
- **Long-Term Monitoring Needs:** High-quality carbon credits are those that sequester carbon for long periods of time. Consistent and reliable monitoring techniques are required to confirm that stored carbon remains sequestered for decades or longer. Financial investment and infrastructure to support such long timelines can be lacking. However, high-quality long-term monitoring via genomic tools could create confidence in the feasibility of adaptive management to maintain long-term carbon storage solutions.

THEME 4: CLEAN TECHNOLOGY COMMERCIALIZATION CONSIDERATIONS

The successful adoption of genomic innovations in clean technologies depends on regulatory acceptance, strategic funding, and clear commercial pathways. Market challenges and policy gaps that are slowing progress were highlighted.

OPPORTUNITIES

- **Funding Support:** Various Alberta funding agencies are actively supporting innovative clean technology projects that demonstrate milestones and scalability, providing crucial momentum for early-stage innovation. Such funding could support the development of genomic technology to generate climate solutions.
- **Commercialization Partnerships:** As previously discussed, effective collaborations between academia, industry, and regulators can help bridge the gap between lab bench research and regulatory approval for the implementation of novel climate solutions in an industrial setting. These partnerships are key for the successful commercialization of novel genomic applications to support clean energy technologies.
- **Investment and Metrics:** Synthetic biology and other genomics approaches can not only provide solutions to mitigate greenhouse gas emissions, but can also provide data to track and verify metrics. Metrics tracking, for example, methane emissions or carbon storage can be provided as a commercial service offering. This information aligns with environmental and social metrics of interest to impact investors in climate solutions.

CHALLENGES

- **Slow Regulatory Adaptation:** As previously discussed, regulatory permitting processes have not traditionally included consideration of genomic tools. If innovation policy and climate policy would include genomic tools as a consideration, then adoption of these new technologies to support clean technology development would be accelerated.
- **Innovation Funding Gaps:** For many deep-science climate solution innovators, despite securing early-stage seed funding, investment support wanes during pilot demonstration and scale-up phases. Bridging this funding gap can pave the way for the successful commercial development of genomic solutions to be adopted by industry.
- **High Cost and Long Horizons:** As previously discussed, the return on investment for genomic tools applied to deep science climate solutions can sometimes take years to materialize. In these cases, such long commercialization paths may discourage conservative industries from committing to adopting new technologies without co-funding or strong regulatory incentives.

THEME 5: EDUCATION AND COMMUNICATION

Effective public science education and transparent communication are crucial to gain social license and acceptance of sensitive genomic tools, like synthetic biology, in environmental applications. Discussions highlighted the need for transparency and inclusion to address social dynamics to accelerate adoption of emerging genomic technologies.

OPPORTUNITIES

- **Workforce Gaps and Capacity Building:** A shortage of interdisciplinary professionals who can navigate biology, data science, and energy operations was noted. Greater investment in training and cross-sector education is needed. Encouraging students and researchers to seek interdisciplinary expertise and industry experience increases the likelihood of successful research translation of genomic tools to industrial commercialization. Cross-disciplinary training also facilitates the identification of potential technologies to be applied from one sector to another.
- **Knowledge Democratization**: Visualizing complex genomic data in community-accessible formats like maps or dashboards serves to democratize science knowledge. Sharing data in this way can positively engage community stakeholders, thus supporting social license to employ novel genomic technology. Such communication tools could illustrate the results of genomic-based monitoring of greenhouse gas emissions, integrity of carbon storage, and biodiversity maps from eDNA data.

CHALLENGES

- **Technical Complexity:** The specialized language and methodologies of genomics can be daunting to non-specialists. Simplified communication and outreach materials are essential.
- **Trust in New Technology:** Without transparency and evidence of safety, public skepticism, especially toward synthetic biology, can stall project development and launch of new genomic technology. Proactive engagement and monitoring frameworks that engage third-party verifiers would help address these concerns.

PARTICIPANT FEEDBACK

POLLING QUESTION:
RANK BARRIERS THAT IMPACT APPLICATIONS OF BIOLOGICAL TECHNOLOGIES

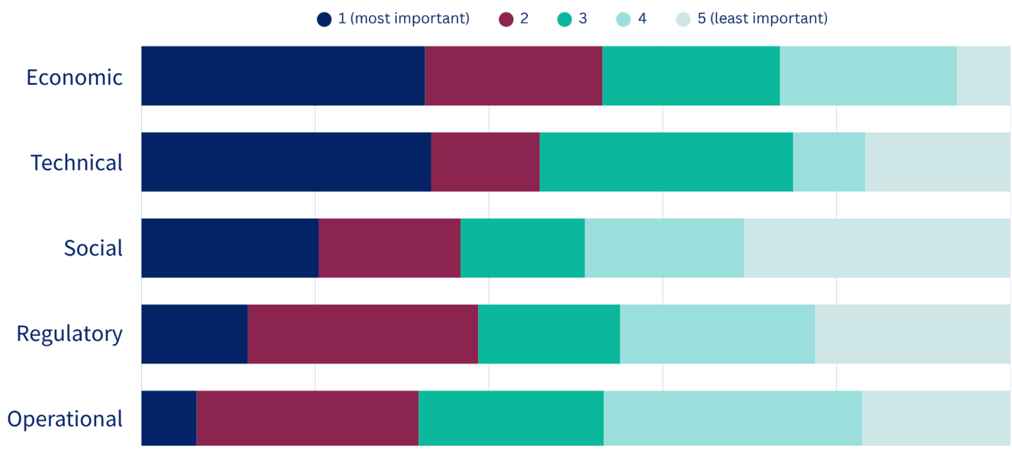


Figure 4. Participants ranked a set of barriers, from most to least importance, that impact the application of genomics/biological tools in the energy sector. N=49

WHAT'S NEXT

To accelerate the responsible adoption of genomics in Alberta's energy sector, several strategic priorities emerged from the workshop discussions: field validation of genomic tools, promote open science and data interoperability, data infrastructure building, commercialization, economic and impact metrics, regulatory readiness and policy engagement, build capacity through workforce development and societal engagement.

FIELD VALIDATION OF GENOMIC TOOLS

To bridge the gap between laboratory innovation and operational deployment, field validation of genomic tools is essential. Panellists noted that many new promising technologies in bioremediation, microbial monitoring, and synthetic biology are predominantly confined to controlled research environments and need testing in complex, real-world settings. Supporting demonstration-scale projects is critical to understanding how these tools perform under diverse field conditions and to building industry confidence. The field testing of genomic tools by the energy sector could be accelerated by employing a multidisciplinary consortia approach involving academic researchers, site operators, and industry partners. Field trials would include robust pre- and post-deployment performance metrics to support evidence-based evaluation and reporting.

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PROMOTE OPEN SCIENCE AND DATA INTEROPERABILITY

To avoid duplication of effort and promote collaborative learning, a commitment to open science and data standardization is vital. Workshop participants highlighted the fragmentation of microbial and genomic datasets across organizations as a major limitation to scaling innovation. To address these challenges, genomic data can be deposited into open, standardized repositories, with appropriate safeguards in place for privacy and proprietary information. Additionally, support is needed to develop common ontologies, metadata templates, and visualization platforms that facilitate cross-project integration. An example of ongoing efforts is the collaboration between academics and industry stakeholders for the co-development of industry standards for genomic tools related to microbially-influenced corrosion prevention. This enables the development of standards to facilitate commerce, promote agreement between buyers and sellers, assist in meeting regulatory requirements, and define testing methods. Also, harmonizing eDNA and microbial baseline data, especially from similar regions, will also enhance regional planning, monitoring continuity, and cumulative effects assessments.

The integration of machine learning and big data infrastructures can transform the energy sector—speeding up sustainable innovation and optimizing microbial bioremediation through in silico testing and predictive analytics.

DATA INFRASTRUCTURE BUILDING

The energy industry has an opportunity to develop big data infrastructures and use machine learning and artificial intelligence. The adoption of such innovations will support the energy sector's efforts towards, for example, sustainable practices and add value to their business. A multi-step approach suggested during the consultation meeting for the adoption of such approach included: identifying key areas and sites for remediation, monitoring microbial communities on-site using genomic tools and geochemical data, and tailoring the approach to improve the outcome using bioinformatics (for example, the bioaugmentation of a certain microbial species that harbours genes for bioremediation of a specific compound of interest would improve performance). The integration of bioinformatics tools into existing data infrastructure is a logical next step for the implementation of the energy industry practices around the further use of genomics tools. In line with this, consideration of strategies for data storage is necessary for the adoption of genomic innovations by the energy industry. Big data generated from genomic analyses requires infrastructures to be used and analyzed alongside other types of operational data (engineering, geological, etc.). The role of machine learning was discussed in terms of synthetic biology as well. A clear advantage of using machine learning for this is the possible implementation of hundreds of possible metabolic pathways and visualization or modification of the dynamics of a microbe. This approach has the advantage of being done quickly and with a lower risk of failure, and in silico rather than requiring an extensive amount of time and cost in the laboratory, doing manual testing commerce, facilitate agreement between buyers and sellers, assist in meeting regulatory requirements, and define methods of testing.

COMMERCIALIZATION: ECONOMIC AND IMPACT METRICS

Demonstrating the economic value, environmental and social impact of genomics is critical for attracting industry investment for commercialization. While technical performance is important, operators must also justify expenditures to executives and shareholders based on clear cost-benefit and sustainability and community outcomes. Research translation and commercialization efforts could be more effective by incorporating modeling of economic and impact metrics into project deliverables. Comparative studies contrasting genomic solutions with conventional practices can further highlight the relative benefits. The development of quantifiable indicators, such as biodiversity scores, microbial degradation rates, or emissions mitigation markers, will strengthen the case for genomics in environmental and social impact reporting frameworks.

REGULATORY READINESS AND POLICY ENGAGEMENT

The integration of genomic tools within environmental policy and compliance frameworks is essential for their broader adoption. Throughout the workshop, regulatory uncertainty was cited as a key barrier to scaling eDNA and synthetic biology and remediation applications. These genomic and biological tools often lack formal recognition within monitoring protocols and permitting approvals, leaving operators hesitant to adopt such innovations due to perceived environmental regulatory risk. The genomic community has an opportunity to engage directly with regulatory bodies to co-develop genomic protocols, pilot validation studies, and produce accessible guidance documents. Such a framework for dialogue would facilitate alignment between innovation and regulation.

BUILD CAPACITY THROUGH WORKFORCE DEVELOPMENT

As genomic technologies become more relevant to environmental and energy operations, the need grows to equip the energy sector workforce with the knowledge and skills to implement them effectively. Many frontline and operational staff currently lack exposure to genomics, while much of the technical expertise remains concentrated in academic settings. The energy sector can benefit from Genome Alberta's public science educational programming which contributes to training and knowledge mobilization. Other effective strategies include collaborative internships, fellowships, and continuing education programs that sit at the intersection of genomics and energy. Partnering with post-secondary institutions to develop applied curricula will help build a robust pipeline of qualified talent.

SOCIETAL ENGAGEMENT

To ensure that genomic tools are trusted, culturally relevant, and ethically applied, societal engagement is necessary throughout project design and implementation. Panellists emphasized that social license, particularly in land-use and biodiversity monitoring contexts, depends on meaningful partnerships. Co-development or knowledge-sharing opportunities strengthen initiatives that incorporate community-partnered biomonitoring using eDNA or metagenomics. Translation of technical outputs into accessible, community-facing formats, including biodiversity dashboards and environmental indicators, could be co-developed with local partners, further strengthening relationship and validating the utility of genomic tools.

The discussion and learnings from the engagement session will inform the development of future Genome Alberta programs to support the application of genomics into Alberta's energy sector and contribute to a more innovative and sustainable energy future.

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