Enhancing Energy Production and Environmental Outcomes through Genomics

The case for innovation

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Genome Alberta
3553-31 Street NW Suite 115,
Calgary, Alberta T2L 2K7
Phone: (403) 503-5220
Fax: (403) 503-5225
www.genomealberta.ca

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Public Policy Forum
1405-130 Albert St
Ottawa, ON K1P 5G4
Tel: (613) 238-7160
Fax: (613) 238-7990
www.ppforum.ca

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EXECUTIVE SUMMARY

On February 17, 2012, Genome Alberta and the Public Policy Forum convened a day-long workshop in Calgary to explore the potential of genomics to enhance energy production through more efficient recovery and mitigate the environmental impact of hydrocarbon extraction. Leaders from research institutions, industry, government and non-profit organizations took part in a discussion aimed at exploring the potential for innovation in this field, and sought to uncover how to capitalize on this opportunity to lead in improving environmental outcomes and energy innovation.

Canada, Alberta in particular, has a strong natural resource base and a robust energy sector but is often criticized for lacking a drive to innovate and improve productivity. Some argue that our rich endowment of natural resources has made us complacent. The energy sector is in fact more innovative than popular perception; nevertheless, in the face of growing concerns over environmental impact, there is room for improvement.

In seeking to reduce the environmental impact of extraction and enhance hydrocarbon production, recent strides have been made in metagenomics, which is based on the ability to uncover and analyze the genetic potential of organisms in environmental and relevant industrial process samples. Microbial communities have existed in the environment for millions of years, and we have begun to understand their capacity to clean up toxic spills. But, with the advent of powerful new technologies, we can now understand how these processes take place and how they can be leveraged.

From a global perspective, metagenomic research has already begun to make substantial contributions to the energy sector in key areas, such as microbial influenced corrosion of pipelines, reservoir souring, tailings ponds emissions and bioremediation. Given the potential benefits genomics holds for the inseparable desires to both develop energy resources and protect the environment, building on these leading examples of success is imperative. For example, in the short-term, metagenomic research can contribute substantially to environmental outcomes through work on more effective bioremediation techniques. Genomics research also has the potential to be transformative through *in situ* bio-refining, converting residual oil into accessible methane, and identification of novel genes in the deep biosphere that have the potential to contribute to the production of value-added hydrocarbon products.

To date, work in the hydrocarbon energy sector shows that metagenomics presents an important opportunity to support innovation. A strong foundation of research, in some cases yielding spectacular results, has now been built which demonstrates that environmental stewardship *and* hydrocarbon energy production can be substantially enhanced through

metagenomics. Canada has the unique opportunity to work in this field thanks to an abundance of natural hydrocarbon resources and the foundations of the necessary genomics infrastructure provided by organizations such as Genome Canada, the Genome Centres and the Canada Foundation for Innovation. Acting on this opportunity will require changes in approaches and policies across all sectors – government, research institutions and industry. With appropriate leadership and a drive towards definable objectives, the case can be made that this field is poised to advance energy innovation and serve as a test model for a new, collaborative approach for innovation in Canada. This has the potential to give Canada a competitive edge in energy, and allow us to lead the way in responsible energy production.

Reaching this potential entails the establishment of a system which supports research and the translation of metagenomics to industry applications. This will require the integration of research infrastructure, along with a greater focus on training key researchers who operate such infrastructure, in order to address present shortages of highly qualified personnel. Industry partnerships will also need to be enhanced, particularly as research seeks to move into the field with applications for hydrocarbon resources. Research institutions, such as universities, will be required to build upon multi-disciplinary research collaboratives in order to allow more cross-pollination of research, which is essential for the advancement of hydrocarbon metagenomics. As well, governments will need to consider how best to transition to longer-term, larger-scale funding approaches which can help fully integrate industry as an active partner. Industry too must seek to become a more active partner in leading new initiatives, and in proactively seeking out partnerships with research institutions.

Achieving these changes will require certain framework conditions to be met. Champions in all sectors who can help unify the calls for partnerships and support must step to the forefront. Focusing on key objectives will be essential in order to ensure the best use of resources across all disciplines and institutions. At the same time, we must have a strong commitment to the flexibility and openness necessary to facilitate a collaborative approach.

These basic conditions for success will form the foundation for the development of an urgently needed cross-sector action plan to advance genomic research in the hydrocarbon sector. The case for supporting continued innovation in this field is solid, but it is incumbent upon leaders in the private sector, research institutions, and government to help develop an action plan to take advantage of this opportunity. Many potential models exist for advancing this field, but all require cross-sector leadership and collaboration in order to move forward. This is the principal requirement for enhancing hydrocarbon energy production through genomics – a collaboratively developed plan which all sectors can embrace. Development of such a plan, based upon a few preliminary steps outlined in this paper, should be the next step for stakeholders.

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A. INTRODUCTION

Energy Innovation

Canada aims to establish its credentials in the global market as an energy superpower, and Alberta is a focal point of this effort. The province's vast reserves of oil and natural gas, together with ample sources of renewable energy, help make this objective attainable. However, this drive can easily be stalled if we become complacent. We must not be satisfied to simply develop these resources; we must develop them to their highest potential while minimizing environmental impact.

In Canada, natural resource industries, and the energy sector specifically, are major drivers of the economy. Over $140 billion was contributed to real GDP (11%) by resource industries in 2010, and they continue to drive growth in capital investment and exports[1]. Much of this activity is directly attributable to energy resources, such as Alberta's hydrocarbon reserves.

With this rapidly increasing economic prominence, the eyes of the world are on Canada – and the need to focus on both improving environmental outcomes and maximizing productivity in the energy sector grows. Canada has a productivity problem, with current business sector productivity sitting at only 72% of US levels[2]. To address this gap we must begin to focus on opportunities to improve our performance, and the prime example of such opportunity is energy sector innovation.

Unfortunately, the energy sector and natural resource industries in general, have a somewhat ill-deserved reputation for being innovation laggards. Evidence suggests that this reputation may not reflect the on-the-ground reality of new energy developments and the potential of the energy sector. However, it is still of paramount importance to improve Canada's overall innovation outcomes, and this can be accomplished by enhancing our strength and competitiveness in energy. The economic potential, combined with equally important environmental benefits, make energy sector innovation a Canadian imperative.

Foundational Research

Through metagenomics, Canada has an opportunity to lead on energy innovation, particularly in the hydrocarbon sector. Although the field of metagenomic research and analysis is somewhat novel, it has already been employed with remarkable success by the hydrocarbon industry. For example, the understanding of the organic processes and novel

[1] Natural Resources Canada, as cited in *Innovation in Canada's Energy Sector*, Public Policy Forum, publication pending
[2] *Leading Innovation*, Public Policy Forum, 2012

microbes which broke down the vast quantities of oil after the Deepwater Horizon oil spill was due in large part to metagenomic research[3].

Technological developments are now driving metagenomic advancements at a rapid rate and allowing us to transform our basic knowledge of microbial communities into effective tools for harnessing their power to aid in hydrocarbon recovery and improve environmental outcomes. Strong intellectual capital and research capacity exists within our research institutions. These assets are capable of making great contributions to advancing energy innovation, especially if this foundational research can be properly leveraged and shown to have valuable applications to industry objectives. Early applications, such as metagenomics research in microbial influenced corrosion, have demonstrated that there is room for this science to play a role in advancing energy innovation in the industry.

The potential of metagenomics applications in the hydrocarbon sector is not limited to enhancing current production systems, though contributions in this area should surely not be ignored. Metagenomic innovation provides the opportunity to enhance the recovery of hydrocarbon resources and also to improve bioremediation of production sites. Both advances can make substantial contributions to reducing the environmental impact of hydrocarbon extraction processes.

Energy and the environment are inherently inseparable in terms of hydrocarbon resource development. Applied metagenomics solutions have the proven potential to make valuable contributions at this nexus by helping to understand the complex ecosystems in which resources exist; by aiding in resource recovery; and by allowing for more effective remediation of the environment to its original state. With proper direction, foundational research in this field can lead to great energy innovation.

Public Policy

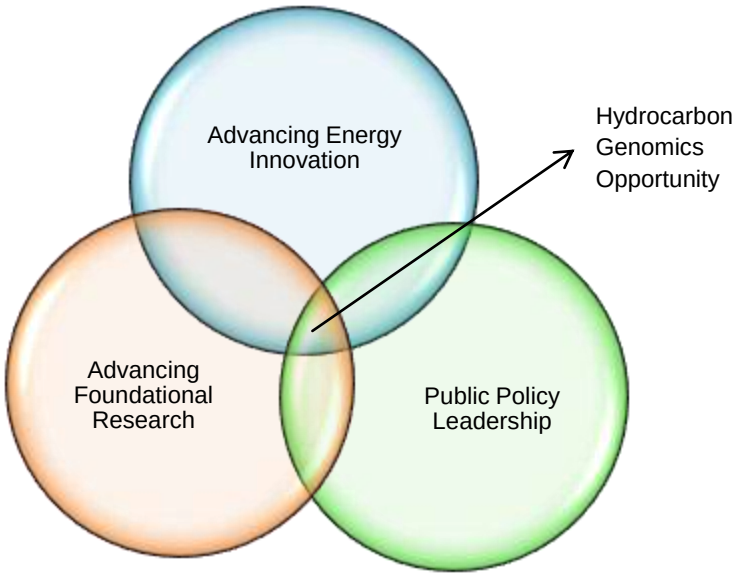
Supporting this potential requires a re-examination of public policy which facilitates innovation. A well-considered analysis demonstrates that current policies are not well suited to take full advantage of this opportunity. In order to fully advance solutions for hydrocarbon resource development through genomic research there is a need for policy leadership to help change the system which currently supports foundational research and energy innovation. Many of the opportunities in this field are dependent upon financial support and technological advancement. Public policy must clearly orient itself to facilitating these necessary changes.

The need for change is not limited to one sector. Leadership is needed from within industry and research institutions, as well as federal and provincial governments. Within government,

[3] Hazen et al. Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science 2010; 8:330

leadership must recognize the unique potential of this field to contribute to national and provincial goals (e.g. energy innovation and improved environmental outcomes), and must ensure that policy changes are made to accommodate this potential. Within industry, leadership is needed to work more collaboratively with research institutions to help pull this technology into industrial applications. Within research institutions, leadership is required to evolve existing structures in order to ensure that barriers to collaboration and partnership are removed and broader, industry-focused work may be done.

Hydrocarbon Genomics Opportunity



Opportunity

With the three mutually supportive goals of advancing energy innovation (including both production and environmental outcomes), advancing foundational research, and providing public policy leadership for change, there is a compelling opportunity for metagenomics to develop indispensable hydrocarbon energy solutions.

This opportunity requires that leaders and stakeholders across all sectors (industry, research institutions and government) collaborate to advance a strong case in support of the innovation potential of this exciting field.

B. THE CASE FOR INNOVATION

With the research and application advances currently underway, there is an opportunity to make substantial contributions to the hydrocarbon sector through genomic research. Canada has the potential to lead in this field through a properly supported innovation initiative seeking to advance energy innovation, foundational research and public policy.

However, Canada will only be able to capitalize on this opportunity if certain key changes are made, and if the leaders are found to help facilitate these changes. In undertaking this venture, the opportunity also exists to create and test a new made-in-Canada strategy for supporting and leading innovation. Improving outcomes in the hydrocarbon sector through metagenomics has the potential to provide a primary example of the systems change needed to better advance innovation across the energy sector and the economy more broadly in our country.

- *Case:* Hydrocarbon-based energy outcomes can be significantly enhanced through genomic research and applications. This work is making, and will continue to make, real contributions to the energy sector in terms of production and environmental outcomes and has the ability to serve as a demonstrator of collaborative, cross-sector innovation leadership which other sectors can emulate.

- *Objective*: To make the hydrocarbon energy sector a leading contributor to energy and environmental innovation within the next 10 years through genomics research, and in doing so, demonstrate an effective new model for collaboration and support.

This is an achievable objective. The foundational research currently underway creates a strong platform on which to build better industrial applications and to advance scientific knowledge. Recent metagenomic research has contributed to addressing numerous issues which are critical to the industry, including enhanced hydrocarbon production. Several examples demonstrate the considerable added-value this science holds in application:

1. **Biocorrosion**
   Microbial influenced corrosion (MIC) is a multi-billion dollar problem facing the oil industry. By identifying the microorganisms causing corrosion, metagenomic analysis allows operators to implement strategies that successfully control corrosion.

2. **Microbial Souring**
   Souring, the generation of toxic and corrosive H_2S (sour gas) following water injection, is a problem affecting a large fraction of the world's oil reservoirs. By understanding

microbial population dynamics, metagenomics can facilitate the creation of efficient methods for controlling souring that don't rely solely on environmentally unfriendly biocides.

3. **Bioremediation**
   By identifying the microorganisms and genetic pathways capable of detoxifying or eliminating toxic compounds, metagenomics can be used to develop biological solutions to clean up impacted sites in a less expensive and more environmentally friendly manner compared to alternative technologies.

4. **Monitoring of Tailings Ponds**
   Microbial communities have positive (accelerating pond settling, degrading toxins) and negative (generation of greenhouse gases) impacts on tailings ponds. By using metagenomic analysis to identify the microbial communities active in tailings ponds, operators are developing strategies employing indigenous microorganisms to accelerate settling and minimize toxicity and green-house-gas emissions.

5. **Prediction of Risk from Closed Tailings Ponds**
   Demonstrating low residual activity for indigenous organisms in the first closed and capped tailings pond has enabled better prediction of future risk. This provides the tailings pond owner a greater degree of confidence that this pond closure strategy will result in a stable closure site that is not likely to release H_2S or other emissions.

Given the benefits demonstrated to date, and the very rapid technological advancements in generating metagenomics data, the potential contributions of metagenomic research to the hydrocarbon sector cannot be ignored. Thus, it is imperative that an appropriate framework is developed to help leverage this innovation potential.

C. SCIENCE AND POLICY NEEDS

In order to take advantage of the innovation opportunity in the hydrocarbon sector made possible by metagenomics research, it is essential that policy leaders across industry, research institutions and government be fully cognizant of the policy changes and scientific advancements required.

These needs fall into three basic categories:

1. Identifying where the opportunities exist to advance the application of the science to hydrocarbon extraction in the near-term and beyond.

2. Understanding the current resources and capabilities in the sector and the gaps that may exist within the research community, industry and government.

3. Accepting the changes that will be required in existing systems in order to help facilitate the continuing development of this field.

Advancing Hydrocarbon Resource Development through Genomics

A consensus on the ability to contribute to the hydrocarbon sector is well established within the genomics research community. Previous examples have demonstrated that the science can make invaluable contributions to industrial processes. However, it is important not to see metagenomics as a panacea for all innovation ills in the hydrocarbon energy sector. Rather, a detailed understanding of where contributions can reasonably be made in the short term and beyond is needed so that policy leaders across all sectors can work towards achievable goals.

In the near term, the opportunities to improve upon the existing applications of genomic research to the sector are significant. First among these opportunities is the use of metagenomics to address environmental challenges and improve bioremediation outcomes. Genomics also already makes a considerable contribution to the industry by providing an understanding of the processes behind microbial influenced pipeline corrosion, and will continue to do so. The development of biosensors, such as gene chips, can also help researchers and field engineers better catalogue the existing microbial communities and genes present in the environment.

Longer-term opportunities to enhance hydrocarbon sector innovation are closely related to improving upon our ability to recover hydrocarbon resources, and to ensuring that these resources best suit our market needs. The potential does exist for microbial communities, when properly employed, to generate biogenic fuels from existing conventional hydrocarbon resources (e.g. conversion of residual oil in reservoirs into retrievable methane). It remains to be seen whether markets will dictate a need for this tool, but given the reduced emissions profile of such fuels the chance to develop this capacity should not be ignored. *In situ* bio-refining of hydrocarbons may also be a fruitful line of business, particularly if undertaken with the input of metagenomic research.

In the long term, the ability to use metagenomic analysis to explore novel microbial communities in the sub-surface and deep biosphere is essential – not for what we know exists in these communities, but for what we do not know. The diversity of life in the deep biosphere is an unmatched source for novel genes and novel biosynthetic pathways which have untold potential to contribute across the research spectrum. These novel genes and pathways will have application in industries beyond energy generation.

The potential areas of contribution are numerous, and Canada can capitalize on this important growing sector. It should be noted that key areas of research under hydrocarbon related genomics, such as bioinformatics, synthetic biology and metabolic engineering,

systems biology and computational modeling of biological systems, were all recently named among the top ten global technology trends by the World Economic Forum[4]. The ability of genomic research in the hydrocarbon sector to utilize and enhance these technological areas further reinforces its potential to make valuable, applicable contributions within its field and beyond.

Current Resources, Capabilities and Gaps

A broad consensus exists that Canada, particularly Alberta, possesses the building blocks of the necessary intellectual and infrastructure capacity to actively pursue this innovation opportunity. But, in order to succeed, we must know where the gaps exist, and how existing resources can be better employed to lead this effort.

Current resources within and across the research and industrial communities are not ideally aligned to support new work in metagenomics-enabled applications. Within research institutions it is essential to develop an integrated approach that spans existing research silos. In the scientific realm, biology, chemistry, geology and engineering are all directly implicated in the research objectives, and investigators must work collaboratively across their disciplinary boundaries. This spirit must extend beyond these core sciences as well. For example, highly sophisticated computer modeling of biological systems is required to advance the understanding of how microbial communities interact, and economic analysis is needed to reinforce the value of the work to Canada's innovation potential and continued economic growth.

Strides are being made in this area. The recent introduction of Campus Alberta Innovation Program Chairs in Reservoir Biogeoscience and Biotechnology Applications of Deep Biosphere Metagenome are promising starts in encouraging greater interdisciplinarity and direct support towards this research area.

This broader push for more collaborative work is essential, given the many research communities currently active in the hydrocarbon field. However, collaborative and interdisciplinary work will only yield substantial results if certain other issues are first addressed. Physical infrastructure for research is one such issue.

Infrastructure for research is well funded in Canada, and high-end equipment for key processes, such as gene sequencing, is readily accessible. Genome Canada and the Canada Foundation for Innovation have served the community well by providing billions of dollars of investment. This has helped to build a strong foundation of research with well-established facilities. Though infrastructure investment is still needed to facilitate collaborative metagenomics projects, the challenge lies in the fact that the facilities which do exist are not always fully integrated into the larger genomics research architecture. There is

[4] http://forumblog.org/2012/02/the-2012-top-10-emerging-technologies/

no simple way to ensure that these capabilities are directed towards reaching shared objectives. In order to ensure relevance in the hydrocarbon sector, this must be corrected.

Physical infrastructure issues are not only linked to facilities of government-supported research institutions. Industry must also play a key role in working towards facilities integration. A key gap in the system, at present, is the absence of large scale-up facilities and demonstrator sites. Only industry can effectively provide such sites, and in order to do so companies operating in the energy sector must become more fully engaged in the larger research effort.

Highly qualified personnel are of paramount importance to achieving the objective of leading the hydrocarbon sector towards enhanced energy innovation. While physical infrastructure is often adequately-funded, the support for personnel to utilize and maintain this infrastructure falls short. Current systems in research institutions are not properly focused on training the right type of personnel (i.e. highly qualified staff who can work to apply the science). There is too little attention paid to applicable outputs of research. Opportunities for researchers to interface with industry are also lacking, and existing structures (e.g. university research services offices) are poorly oriented towards facilitating collaborations between research institutions and industry. In order for foundational research to lead to energy innovation, especially in biotechnology, it is essential to establish multiple points of interface. Recent efforts in this area, such as the NSERC Industrial Research Chair in Petroleum Microbiology at the University of Calgary, are a promising start. Further efforts to align research institutions with industry-based research are required.

Metagenomics research is being actively applied to the hydrocarbon sector, and Canada must keep pace with international competitors in order to gain an advantage in this critical field. As with any science, challenges and opportunities for development still exist. Next generation sequencing technology has made it relatively easy to generate sequence data. However, making proper use of this data remains somewhat challenging. Improving the means to analyze data sets is essential and focus must be placed upon supporting bioinformatics projects. This is another area where interface and collaboration with industry is key. Leading oil sands companies have recently begun to hire bioinformaticians to help analyze data from hydrocarbon projects. Further industry partnerships on such ventures will provide great value. Issues with data also exist in low quality annotations in existing databases. Work to improve the quality of this data, and the mechanisms to analyze it, is also required.

Development of reproducible controlled experiments is also challenging due to the heterogeneous nature of the environment in which hydrocarbon resources exist. Exploration of methods through which these experiments can be conducted and replicated will be necessary in order to establish the validity of results through peer review. Experimentation in this field is difficult given the tremendous scale of hydrocarbon resource developments.

While lab-based analysis is crucial, field testing will also become essential in short order. Again, industry partnerships will be required to help facilitate this work.

Finally, a gap currently exists with the general public, the media, and by extension governments, as to the understanding and acceptance of this valuable science. A broad variety of stakeholders are today linked to hydrocarbon resources. In furthering their development through genomics it is imperative to ensure these stakeholders are well informed about the benefits and potential risks of this work. All relevant stakeholders must be engaged. This includes governments, particularly in areas where regulatory approval is required. As awareness grows, the potential of the field to contribute to industrial and environmental goals will be enhanced, and more open collaboration among all stakeholders will be possible.

Required Changes

To best advance hydrocarbon energy metagenomics, a number of changes are required. And, there are certain examples of required changes which demonstrate how adaptations can be readily made to advance the field. By embracing these specific changes, hydrocarbon genomics can serve as an effective test case for broader adoption of new models of innovation.

The need for better cross-sector collaboration is well established. Facilitating this will require changing the way research institutions work. Canada currently has a highly segmented research community, with universities characterized by greater numbers of faculty silos than other leading centres around the world. This fragmentation increases bureaucracy and reduces opportunities for collaboration. Shifts to more flexible and open research approaches should be encouraged, such as that supported by the NSERC Idea-to-Innovation grants system. Research institutions must also be better attuned to industry needs, including the need to build compelling business cases for industry involvement when seeking corporate partnerships.

Industry must also change. Companies operating in the Canadian energy sector must resist their tendency towards conservative innovation approaches, and should develop a more collaborative approach to working with researchers and partnering on large scale research projects (e.g. field tests). The industry partnership of the Oil Sands Leadership Initiative and the recent establishment of the Canadian Oil Sands Innovation Alliance offer promising examples of changes in this area.

The role of government in this sphere is two-fold: regulatory and funding. Knowledge gaps inside regulatory agencies can cause delays in the application of new technologies. To address this issue, those with knowledge and expertise in the sector must take the lead and reach out to governments, and all other stakeholders, to reinforce the value of these applications.

The other primary role of government is as a funder of research and proof-of-concept applications; but government cannot be the sole funder. Large scale innovation requires large scale coordinated support. Support must be substantial, long-term (i.e. 5-10 years) and able to accommodate inclusive and integrated research structures.

The structure of collaborative support arrangements should change to reflect the stage of the research in question. In pre-competitive phases of research, opportunities for research institution-led structures with industry participation, or public-private partnerships, should be considered. In later stages, industry-led work with research institutions focused on providing key solutions is preferred. Researchers should be exposed to clearly defined industry challenges so that work undertaken is relevant and applicable to industry. Successful ventures, such as the cross-sectoral Advanced Energy Consortium for precompetitive micro and nanotechnologies material research in the petroleum sector, demonstrate that with appropriate support, research institutions and industry researchers can effectively and productively collaborate.

Global connectivity is essential to the entire research enterprise. Canada and Alberta should be a global center of excellence and a central point in growing a network of expertise in this field. We must place renewed focus on attracting and enhancing international connections in order to develop new industrial technologies and markets for applications.

These changes can help create valuable results in terms of energy innovation, environmental outcomes and demonstration of an effective, integrated model of innovation support. Enacting these changes in the mechanisms of support for this field is a matter of urgency. While current support may be adequate for current research interests, it will not be possible to significantly advance metagenomics-enable applications without sufficient changes in support systems.

D. ACHIEVING THIS OBJECTIVE

An overall objective has been established: employing genomics research to make the hydrocarbon sector a leading contributor to energy innovation within the next 10 years -- and by doing so, to demonstrate an effective new model for innovation collaboration and support in the energy sector.

To lead the development of this field, an action plan which meets the needs of all stakeholders and catalyzes necessary science and policy changes, is essential. To initiate development of this plan, several framework conditions must be met, and key actions must be taken:

1. ***The identification and involvement of champions across sectors.*** It is imperative that these individuals have the profile to help develop leadership-level awareness of the opportunity, and the authority to help lead the development of collaborative, integrated models for supporting the field.

- **Recommendation:** Genome Alberta, leading an alliance of partners, should put forward a call for self-identification of potential leaders within key stakeholder organizations (government, industry and research institutions) to help champion this action plan initiative, utilizing the subset of stakeholders represented at the February 2012 workshop as a network to distribute the call. Once a group of potential leaders has been identified, it will be the responsibility of Genome Alberta and its partners to bring these individuals together to decide amongst themselves which select few shall serve as the primary champions, and what roles other stakeholders will play in supporting the actions of the champions within and across each sector. Organizations, such as the Petroleum Technology Alliance of Canada, may be called upon to help solicit champions in key sectors, such as industry.

2. ***Developing the focus and drive across the various sectors and disciplines that hold a stake in this objective.*** It will be easy, given the variety of potential partners in this space, for divergent concerns to distract from the principal goal but, every effort must be made to avoid this. Foundational research must be advanced with the goal of creating solutions to real-world problems. Projects must be designed with a clear view to application and industry must be able to participate in a way that meets their strategies and market needs. Regular contact between research institutions and industry is critical so that researchers are aware of what industry requires, and industry is aware of what can be reasonably delivered within specific timeframes.

- **Recommendation:** It will be the responsibility of Genome Alberta and other partners, acting with the input and direction of sectoral champions, to launch a deliberative process which brings together the principal industry stakeholders (i.e. top companies and consortiums) and leaders from government and research institutions to:

i) Identify the key areas of research interests for industry-led initiatives over the short, medium and long term.

ii) Agree on the necessary structural and support conditions which can make foundational and applied hydrocarbon genomics research feasible and rewarding for industry and which can catalyze activity at the research institution-industry interface.

3. ***Cultivating a degree of openness among research institutions, governments and industry, towards supporting hydrocarbon industry advancements through genomics.*** Flexibility and the willingness to experiment will be key to the success of this enterprise.

- **Recommendation:** Champions must work to identify and orient stakeholders in specific sectors to become more open to potential collaborations. Genome Alberta and other partners should also keep and actively maintain a list of stakeholders in all sectors who wish to be kept apprised of ongoing activities in this area, including those who could potentially take part in the multi-sector working arrangements (research institutions-industry-government) identified in condition 2.

4. ***Instilling a collaborative mindset among all stakeholders***. A collaborative orientation is the essential pre-condition for success. More than simply cooperation, a strong spirit of partnership across and within sectors is required. If metagenomics-enabled applications are to become a key pillar of Canadian energy and environmental innovation, and in order to serve as a new model for innovation support in Canada, all stakeholders must adapt to open collaboration.

- **Recommendation:** A multi-sector 'status-check' workshop (building upon the foundation of the February 2012 workshop) should become an annual information-sharing event, and the broadest possible participation should be sought from across all sectors. Genome Alberta and other partners should convene this session, but industry, government and research institution champions should be responsible for attracting multi-stakeholder perspectives; identifying promising areas of current or potential research in hydrocarbon metagenomics; and actively leading changes within their sector to help facilitate collaborations.

E. CONCLUSION

The case for advancing hydrocarbon genomics is clear. The potential for innovation is strong. With a central hub, such as Genome Alberta, leading an alliance of organizations working to coordinate leadership and support, we can not only advance energy innovation in Canada, but also demonstrate collaborative, cross-sector innovation which other sectors can emulate. In a country which has substantial hydrocarbon reserves, and a vital need to improve its innovation and environmental outcomes, this extraordinary opportunity cannot be ignored. Genome Alberta, and other partner organizations, must work to create the conditions to advance policy changes in this sector, in order to allow genomics research in the hydrocarbon sector to fulfill its potential for Canada.

In recognizing the gaps which currently exist in the research and policy spheres, and by taking note of necessary changes, we foresee strong potential for this field. With the input of key leaders; a clear research focus; an open research orientation; and a collaborative mindset among all stakeholders, the objective of enhancing hydrocarbon energy production through genomics can certainly be achieved. The immediate need is for a plan of action

outlining how various elements of the innovation system can work together to achieve this objective, building upon the framework conditions outlined above.

Over the next year, Genome Alberta and partner organizations will work to coordinate development of a multi-sector action plan, beginning by working with other organizations to identify champions; discussing new working arrangements with industry; opening communication among key stakeholders in the field; and creating spaces which facilitate multi-sector collaboration. Over the next five years, with the action plan underway, metagenomics can and should be a much more flourishing field of collaborative research, with key projects underway to test new methods on a large scale. Success will follow success. In ten years, Alberta can be a global center of excellence in the field, and genomic research can be a principal contributor to advancing energy innovation, and improving Canadian innovation at large.

The fundamental case for supporting innovation in this field dictates that leaders in all sectors must recognize its value. Champions will work across the field to develop and execute a plan of action, building upon the framework conditions recommended above. A truly collaborative action plan will benefit all stakeholders, and represents the most effective means of leveraging the significant potential of genomics to contribute to enhancing hydrocarbon production and environmental outcomes.

Appendix A: Workshop Program

Application of Genomics to Hydrocarbon Resource Development:
status, opportunities and reality check

February 17, 2012
The Calgary Westin (320 4th Avenue SW)

8:20 am – 8:30 am Welcome by David Bailey, President and CEO of Genome Alberta

Session Chair: Gijs van Rooijen, Chief Scientific Officer, Genome Alberta

8:30 am – 9:00 am Keynote Speaker on Metagenomics and Innovation Policy

Gerry Protti, Vice-Chair, Alberta Innovates Technology Futures

9:00 am – 9:15 am Introductory Remarks

Elizabeth Cannon, President of the University of Calgary

9:15 am – 10:00 am Keynote Speaker on Metagenomics and Bioremediation

Terry Hazen, University of Tennessee

10:00 am – 10:15 am Coffee Break

10:15 am – 11:00 am Keynote Speaker on Metagenomics and Hydrocarbon Energy Production

Steve Larter, University of Calgary

11:00 am – 12:00 pm **Panel 1:** Will genomics based technologies revolutionize hydrocarbon extraction and mitigate its environmental impact?

- Steven Larter, University of Calgary
- Jason Switzer, Pembina Institute
- Eddy Isaacs, Alberta Innovates - Energy & Environment
- Terry Hazen. University of Tennessee
- Vincent Saubestre, Oil Sands Leadership Initiative

Moderator: Tom Jack, University of Calgary

12: 00 pm – 1:00 pm Lunch

1:00 pm – 2:00 pm **Panel 2:** Is there currently the intellectual and infrastructure capacity to develop and apply genomic based biotechnologies to the hydrocarbon sector?

- Steven Larter, University of Calgary
- Pierre Meulien, Genome Canada
- Elizabeth Edwards, University of Toronto
- Mehrdad Hajibabaei, University of Guelph
- Paul Willems, Energy BioScience Institute /BP

Moderator: Tom Jack, University of Calgary

2:00 pm – 3:00 pm **Panel 3:** What are the possible funding models to drive genomics based innovation in the hydrocarbon sector in Alberta and Canada?

- Subodh Gupta, Cenovus Energy
- Vincent Saubestre, Oil Sands Leadership Initiative
- Paul Willems, Energy BioScience Institute /BP
- Marvin Fritzler, Alberta Research & Innovation Authority
- Pierre Meulien, Genome Canada

Moderator: Tom Jack, University of Calgary

3:00 pm - 3:30pm Concluding Comments

David Mitchell, President and CEO, Public Policy Forum

Appendix B: Workshop Participants

Application of Genomics to Hydrocarbon Resource Development:
status, opportunities and reality check
February 17, 2012, Calgary

Anita Arduini
Program Director, Carbon Management Canada

Matthew Ashby
President and CSO, Taxon Biosciences

David Bailey
Chief Executive Officer, Genome Alberta

Rene Barendregt
Associate Dean, University of Lethbridge

Rishi Batra
Technology Analyst, Innovate Calgary

Alex Bolton
Energy Resources Conservation Board

Damon Brown
University of Calgary

Karen Budwill
Scientist, Alberta Innovates Technology Futures

Sean Caffrey
Project Manager, Genome Alberta

Elizabeth Cannon
President, University of Calgary

Joseph Cassinat
Reservoir Engineer, Cenovus Energy

Daphne Cheel
Executive Director, Cross Ministry Initiatives, Alberta Advanced Education & Technology

Nicolas Choquette-Levy
Project Coordinator, Oil Sands Leadership Initiative

Ryan Conway
Research Associate, Public Policy Forum

Chris Dambrowitz
Director - Strategic Initiatives, Biorefining Conversions Network

Steven Dew
Associate Dean (Engineering), University of Alberta

Kim Dockens
Microbiologist and Water Treatment, Baker Hughes

Peter Dunfield
Professor, University of Calgary

Elizabeth Edwards
Professor, University of Toronto

Tom Erickson
Co-President, First Green Partners

Klaus Fiebig
CSO, Ontario Genomics Institute

Marvin Fritzler
Board Chair, Alberta Research & Innovation Authority

Robert Froehlich
Associate, Norton Rose Canada

Lisa Gieg
Professor, University of Calgary

Randy Goebel
Chair, Alberta Innovates Academy, Alberta Innovates Technology Futures

Ying Gravel
Director of Programs, Genome Alberta

David Grier
Sr. Strategist, Innovation Saskatchewan

Alexander Grigoryan
University of Calgary

Subodh Gupta
Chief, Technology Development, Cenovus

Mehrdad Hajibabaei
Professor, University of Guelph

Steve Hallam
Canada Research Chair in Environmental Genomics, UBC

Leslie Hardy
Senior Hydrogeologist, AMEC Environment & Infrastructure

Terry Hazen
Endowed Professor University of Tennessee

Josie Hendrickson
Office Manager, Genome Alberta

Scott Hierath
Director, Market Access - Pipelines, Government of Alberta

Richard Howlett
Director, Business Development, Genome BC

Casey Hubert
Royal Society Research Fellow, Newcastle University

Marlene Huerta
Business Development Manager (nanoAlberta), Alberta Innovates Technology Futures

Eddy Isaacs
Chief Executive Officer, Alberta Innovates Energy and Environment

Tom Jack
Professor, University of Calgary

Song Jin
CTO, Next Fuel Inc

Kevin Keough
Alberta Innovates Bio Solutions

Steven Larter
Professor, University of Calgary

Markus Lemke
VP Business Development, Dycor Technologies Ltd.

Ed McCauley
Vice-President (Research), University of Calgary

Pierre Meulien
Chief Executive Officer, Genome Canada

David Mitchell
President and CEO, Public Policy Forum

Chris Pepin
Policy Analyst / Research Officer, Government of Saskatchewan

Reno Pontarollo
CSO, Genome Prairie

Gerry Protti
Vice Chair, Alberta Innovates Technology Futures

David Reese
Vice President, Licensing, Innovate Calgary

Vincent Saubestre
Executive Director, Oil Sands Leadership Initiative

Dominic Sauvageau
Assistant Professor, University of Alberta

Christoph Sensen
Director, Visual Genomics Centre University of Calgary

Susan Skone
Professor, University of Calgary

Heather Smith
Program Coordinator, Genome Alberta

Chris Somerville
Director, Energy Biosciences Institute

Mike Spear
Director of Communications, Genome Alberta

Richard Stadlwieser
Senior Business Economist, Advanced Education and Technology

Andrew Stephens

Jason Switzer
Director, Corporate Consulting and Engagement Program, Pembina Institute

Stella Thompson
Vice Chair, Genome Alberta

Courtney Turich
Senior Geochemist, Conoco Phillips

Raymond Turner
Professor, University of Calgary

Rick Urbat
Group Lead, Reservoir Characterization, Encana

Prasad Valupadas
Alberta Environment and Water

Gijs van Rooijen
CSO, Genome Alberta

Monica Varga
Industrial Technology Advisor, NRC IRAP

Tim Wade
President, Tim Wade Consulting Inc.

Joseph Westrich
Manager Emerging Technologies Subsurface, Shell International E&P, Inc.

Paul Willems
TVP Energy Biosciences Institute, BP

Sandra Wilson
University of Calgary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