FRONTIER SCIENCE ROUNDTABLE

BRIEF

Natural Resources Canada

WISE
WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY

WGSI
Waterloo Global Science Initiative

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ABOUT THE FRONTIER SCIENCE ROUNDTABLE

On September 25, 2017, the Office of the Chief Scientist (OCS) at Natural Resources Canada (NRCan), Waterloo Global Science Initiative (WGSI) and the Waterloo Institute for Sustainable Energy (WISE) held a roundtable discussion on the potential of today's frontier scientific research to disrupt tomorrow's energy system.

The Frontier Science Roundtable's purpose was to share with Generation Energy – a national dialogue on Canada's path to a low-carbon future hosted by Natural Resources Canada – a science perspective on the potential of today's frontier scientific research to disrupt tomorrow's energy system. The Generation Energy campaign invited all Canadians to contribute their ideas on how Canada should develop its resources more sustainably and invest in the energy of tomorrow. The information collected through Generation Energy will be used to design an approach for how the federal government can work with provinces and territories to create the affordable energy and innovative jobs Canadians want.

In advance of the Frontier Science Roundtable, OCS undertook a bibliometric analysis to create a map of current research fronts relevant to energy system evolution. The analysis selected the most relevant Clarivate Analytics Research Fronts and then clustered them into thematic groups that address common questions or problems based on shared assumptions. The resulting science map represents conceptual proximity amongst and between research fronts.

To build upon this map of current research fronts, roundtable participants were drawn from diverse focus areas including machine learning, nanomaterials and science fiction and were tasked with considering how **uncertainty** of research outcomes and **convergence** of research disciplines could affect Canada's long-term energy future. The 2050+ timeline and framing of the discussion encouraged new ideas regarding both physical and theoretical frameworks, as well as the policy and funding ecosystem needed to realize the opportunities that may arise. The roundtable did not seek consensus. Rather, its intent was to generate feedback and insights that can help inform future policy and investment.

FRAMING

The roundtable's opening panel discussion, moderated by Ivan Seminiuk, Science Correspondent at *The Globe & Mail*, tackled Canada's energy present and energy future and featured Donna Kirkwood, Chief Scientist, Natural Resources Canada / Government of Canada; Jatin Nathwani, Executive Director, Waterloo Institute for Sustainable Energy; and Linda Nazar, University Professor & Canada Research Chair Solid State Energy Materials, University of Waterloo.

Key discussion points from the panel:

- We must acknowledge the historical influence of fossil fuels on Canada's current energy profile and the extensive role fossil fuel and other resource extraction plays in Canada's economy.
- There is agreement that decarbonizing Canada's energy system means ensuring quality of environment, and therefore life, for future generations.
- Reframing key energy concepts will be essential to engaging Canadians in the energy transition: consider renewable energy as a resource-based energy source and present energy as a service rather than a commodity.
- Looking forward to 2050 and beyond creates the space for new perspectives and a wider realm of possible breakthroughs.
- Perspectives from many disciplines will be needed to achieve breakthroughs. *See Box 1 on CRISPR.*
- The perspectives and traditional knowledge of Indigenous peoples provide a crucial source of information that can be used to inform a sustainable energy future for all Canadians. It is important to co-develop with Indigenous communities the capacity to lead energy research and projects and to co-develop solutions.
- Canada must provide incentives for high risk research including consistent financial support for long-term projects.
- A forward-looking, cohesive energy strategy will attract Canadian researchers from many disciplines to the energy space.

BARRIERS

Some of the breakout groups of roundtable participants felt it was important to begin their discussions by addressing current barriers to energy transitions and energy-directed research:

- It was felt that the majority of the general public is unwilling to sacrifice their comfort for environmental reasons. A factor to consider here is the low cost of fossil fuels in Canada.
- Interventions are needed in order to foster sustainable behaviours (e.g. purchasing choices), but there are political challenges to establishing these practices.
- Canada has "infrastructure inertia" (e.g. a large, established and reliable grid with corresponding regulation and financial structures) that limits new, acceptable innovations to those that are compatible with current grid system.
- Scientists need to think more broadly about the grand challenges associated with energy (e.g. issues of access, equity).

Box 1: CRISPR

Opening panel moderator Ivan Seminiuk, Science Correspondent for The Globe and Mail, used Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) as an example of breakthrough science that has come from an unexpected place. Identifying repeated gene sequences in Streptococcus thermophilus (one of the bacterial strains used in the product of yogurt) allowed the dairy industry to develop bacterial strains that were resistant to infection. Now, CRISPR has been proven as a versatile and groundbreaking tool for editing genomes.[1]

1. Cohen, J. (2017). How the battle lines over CRISPR were drawn. Science. Retrieved from: http://www.sciencemag.org/news/2017/02/how-battle-lines-over-crispr-were-drawn

ROUNDTABLE THEMES

Uncertainty – How can we stimulate the discovery process?

By definition, the outcome of research is not known in advance. Discovery is somewhat unpredictable. When working at the frontiers of science, predictability is even more challenging. Scientists can expect some product/knowledge to come out of their research efforts, but exactly what will be discovered or when cannot be predicted. Roundtable participants agreed that striking the right balance of directed and discovery research is a challenge and they approached the question of stimulating the discovery process from a variety of angles:

Energy specific considerations:

- Energy, while foundational to scientific work and livelihoods, is often taken for granted as in most communities it is ubiquitous and invisible to the user. Better communicating the value of energy could lead to more engagement and interest in energy applications. *See Box 2 on Advanced Research Projects Agency – Energy.*
- Energy challenges are often equity challenges. Preserving the status quo of our current energy system perpetuates the disadvantages faced in marginalized communities including Indigenous communities.
- Managing energy through artificial intelligence (AI) and Internet of things (IoT) are research areas ripe for discovery.

Box 2: Advanced Research Projects Agency – Energy
The Advanced Research Projects Agency – Energy (ARPA-E) was authorized by the United States Congress in 2007 in response to an evaluation of steps policymakers could take to help the U.S. compete, prosper, and stay secure in the 21st century.[2] Since its inception, ARPA-E has supported early stage energy technologies that have the potential to be radically transformational with funding, technical assistance and business advice.[3]

Risk-taking

- To stimulate discovery, the scientific community must better communicate the value of risk-taking to individual researchers as well as institutions. Consider the narratives used by the start-up and entrepreneurship community to promote "high risk, high reward" thinking. *See Box 3 on the Canadian Institute for Advanced Research.*
- Another lesson from the start-up and entrepreneurship community is "failing forward." There is as much value in a negative result as a positive one and sharing this information leads to less repetition and more efficient progress.
- If academia is unable to support risk-taking, researchers will take their talents to more risk-tolerant communities like industry.
- The value of curiosity-driven research must also be communicated to the public to ensure their support.

Box 3: Canadian Institute for Advanced Research
The Canadian Institute for Advanced Research (CIFAR) was widely acknowledged by roundtable participants as an organization that appropriately supports discovery research.[4] An often told supportive story is that of the University of Toronto professor Geoffrey Hinton's CIFAR supported research into neural networks that has revolutionized artificial intelligence. "Everyone else was doing something different. [...] We should give (CIFAR) a lot of credit for making that gamble," said Hinton's collaborator Yoshua Bengio, co-director of CIFAR and professor at Université de Montréal, in a 2015 interview with the Toronto Star.[5]

2. ARPA-E. (2017a) ARPA-E History. Retrieved from: https://www.arpa-e.energy.gov/?q=arpa-e-site-page/arpa-e-history
3. ARPA-E. (2017b). ARPA-E About. Retrieved from: https://arpa-e.energy.gov/?q=arpa-e-site-page/about
4. Canadian Institute for Advanced Research. (2017). About. Retrieved from : https://www.cifar.ca/about/
5. Allen, K. (2015). How a Toronto professor's research revolutionized artificial intelligence. Toronto Star. Retrieved from: https://www.thestar.com/news/world/2015/04/17/how-a-toronto-professors-research-revolutionized-artificial-intelligence.html

Long term partnerships and funding

- One of the strongest conclusions from the roundtable was the need for administrative and financial support for long-term research partnerships. *See Box 4 on Future Earth.* Crucial elements of this include:
- Support for multidisciplinary teams,
  - Participants identified that multidisciplinary teams often "fall through the cracks of the Tri-Councils (NSERC, SSHRC and CIHR)";
- Support for global collaborations,
  - Includes support for networking and travel to build relationships and recognize emerging research trends;
- Support for knowledge transfer and dissemination,
  - Includes communicating to general public and data sharing between researchers;
  - Financial support for publishing in open access journals;
- And adaptable funding that responds to changing project priorities.
- Clustering research around global challenges, like energy, could attract more researchers and support to multi-disciplinary projects. *See Box 5 on Arizona State University.*
- Carbon taxes are a potential source of funding for energy-directed research.
- Participatory Action Research is a research method that can yield robust partnerships and ensure the participation of marginalized communities in discovery research.
- Partnerships, particularly those involving industry, can pose a challenge to intellectual property ownership making up-front and robust agreements essential to partnership brokering.

Box 4: Future Earth

Future Earth is a 10 year initiative to advance sustainability science globally. Five global hubs coordinate and catalyze new research projects and partnerships that are supported by an open network of multidisciplinary scientists and an a core of established global projects with influential research programmes.[6]

Trend forecasting

- Roundtable participants highlighted the limits of using bibliometric analyses to predict trends. The trend map presented at the roundtable did not identify AI, IoT or cloud computing as emerging research areas though they were identified by the organizers and participants as areas of interest. The presented trend map did not identify areas where Canada is leading which was viewed as a shortcoming.
- Bibliometric analyses relying on citations are particularly susceptible to distortion. Citation protocols differ from discipline to discipline[7] (eg. research that is affordable to engage in as a young researcher because of existing lab infrastructure may be overrepresented).
- Trend forecasting can also have the negative effect of forcing research into a particular narrative in order to be considered for funding.
- Forecasting must also include sociological aspects of implementing technologies.

Diverse perspectives

- More than "working beyond silos," space must be made for non-Western perspectives to inform discovery research.
- Indigenous perspectives informed by traditional knowledge should be meaningfully engaged in discovery research.

Box 5: Arizona State University

An example of breaking down academic silos cited by many roundtable participants are the problem-focused interdisciplinary research institutes of Arizona State University (ASU). This institutional innovation allows researchers from many disciplines to focus their efforts on specific problem areas rather than traditional disciplines.[8]

6. Future Earth. (2017). Who we are. Retrieved from: http://www.futureearth.org/who-we-are
7. Haustein, S., Lariviere, V. (2015). The Use of Bibliometrics for Assessing Research: Possibilities, Limitations and Adverse Effects. Retrieved from: http://crc.ebsi.umontreal.ca/files/sites/60/2015/10/HausteinLariviere_revised2.pdf
8. Arizona State University. (2017). Institutes & initiatives. Retrieved from: https://research.asu.edu/institutes-initiatives

Curiosity

- Often students and new researchers need training and encouragement to pursue curiosity-driven research.
- Supporting teaching in universities improves knowledge transfer to new generations of students and can communicate the value of curiosity-driven research.
- Scientists must be encouraged to be curious about the societal impacts of their research and to collaborate with social scientists.
- "Payback" on investments in discovery research shouldn't be viewed in economic terms.
- To engage a broader population in curiosity-driven research, researchers could consider communicating results at earlier stages to better illustrate process.

Canada's strengths and gaps

- Canada is a stable, peaceful place to live and do research and has a unique opportunity in the current global political climate to become a discovery research leader.
- However, with a homogenous research population and a financial infrastructure that doesn't support risk, Canada is not a destination for discovery research.
- Because discovery research is not encouraged in Canada's research community there is a risk that new developments in science and technology will simply maintain status quo (e.g. plugging in renewables, not considering limitations of existing grid infrastructure).
- There are few receptors for research, even among those who are part of the process (e.g. utilities provide data but don't implement or share results).
- Canada needs to identify areas of potential leadership (e.g. bioenergy, hydroelectricity) to promote engagement in energy research.
- Canada is lacking a strong narrative around energy transitions; this is viewed to be a political choice influenced by Canada's economic dependence on extractive industries including oil and gas.

Convergence – How can we accelerate the discovery process?

We take our definition of convergence from the National Science Foundation: "Convergence can be characterized as the deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks for addressing scientific and societal challenges and opportunities."[9]

It's identified by two primary characteristics:
- Deep integration across disciplines
- Driven by a specific and compelling problem

Furthermore: "Convergence does not rest on a particular scientific advance but on a new integrated approach for achieving advances."[10]

Roundtable participants considered the following areas crucial to accelerating discovery:

Supportive structures

- Basic research requires a unique set of supports, a crucial pillar of which is academic freedom. However, without appropriate financial and administrative structures, even research with high breakthrough potential cannot flourish. *See Box 6 on Perimeter Institute for Theoretical Physics.*
- Participants highlighted the German model of establishing research institutes dedicated to discovery research as a supportive structure that Canada could pursue for its own discovery research. *See Box 7 on Max Planck Society.*

Communication

- Storytelling is as important within the research community as it is to engaging the general public. Reframing energy as a basic need and enabling service as well as including energy as part of the narrative around climate change are examples of storytelling generated by the roundtable.

Box 6: Perimeter Institute for Theoretical Physics
Founded in 1999, Perimeter Institute for Theoretical Physics is an independent Canadian basic research institute. The private-public partnership model through which the institute operates allows researchers the academic freedom to pursue curiosity-driven research and collaborations.[11]

- Encouraging the general public to think on longer timelines can lead to better acceptance of discovery research and changes to the energy system.
- Dedicated events like the roundtable are a useful tool to build relationships, break down silos and co-develop research narratives.
- Supporting organizations that operate outside of academia or industry that help to translate scientific research into action and make it accessible for other sectors and the general public could be a vehicle for improved communication.

Enabling convergence

- High-level recognition (e.g. political, academic and industry leaders) that energy challenges are multidisciplinary is essential to creating a supportive administrative and funding environment for convergence.
- Deep integration across disciplines requires time and freedom to build trust.
- Within academia, the following strategies were proposed to enable convergence:
  - Problem-based departments, rather than traditional disciplines;
  - Incentive models that show appreciation and prestige for multidisciplinary research;
  - Policies and funding that allow for international collaboration;
  - Active networks for sharing knowledge across disciplines.

Box 7: Max Planck Society
The 83 institutes and facilities that are a part of the Max Planck Society (the group of institutes focused on basic research) have produced 18 Nobel Laureates and over 15,000 publications annually. However, while those numbers are impressive, the true success lies in the model that centers people at the heart of the research organization allowing for freedom in staffing, program development and collaboration that is supported with long term financial and administrative support.[12]

9. National Science Foundation. (2016). Convergence research at NSF. Retrieved from: https://www.nsf.gov/od/oia/convergence/index.jsp
10. Sharp, P., Hockfield, S., Jacks, T. (2016). Convergence: The Future of Health. Massachusetts Institute of Technology. Retrieved from: http://www.convergencerevolution.net/2016-report/
11. Perimeter Institute. (2017). History. Retrieved from: http://perimeterinstitute.ca/about/about/history
12. Max Planck Society. (2017). Portrait. Retrieved from: https://www.mpg.de/short-portrait

SUMMARY/RECOMMENDATIONS

- There was excitement and appreciation from the roundtable participants that "science is back" within the Government of Canada. There is great promise seen in engaging the scientific community in policy decisions.
- A high-level position statement on energy transition from the Government of Canada would bring attention to the energy space as a research area open for new ideas and researchers.
- Roundtable participants identified "working within silos" as a barrier to stimulating and accelerating discoveries. Concerted effort within policy, academia and industry is required to address this challenge.
- Lack of diversity, including lack of Indigenous perspectives, was seen by roundtable participants as an impediment to discovery. Embracing non-Western world views allows for new perspectives to stimulate and accelerate discovery.
- Specific recommendations for government research funding are to improve support for multidisciplinary research projects that "fall through the cracks" of current Tri-Council mandates and prioritize long term, flexible funding for discovery research that covers research, collaboration and dissemination.

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