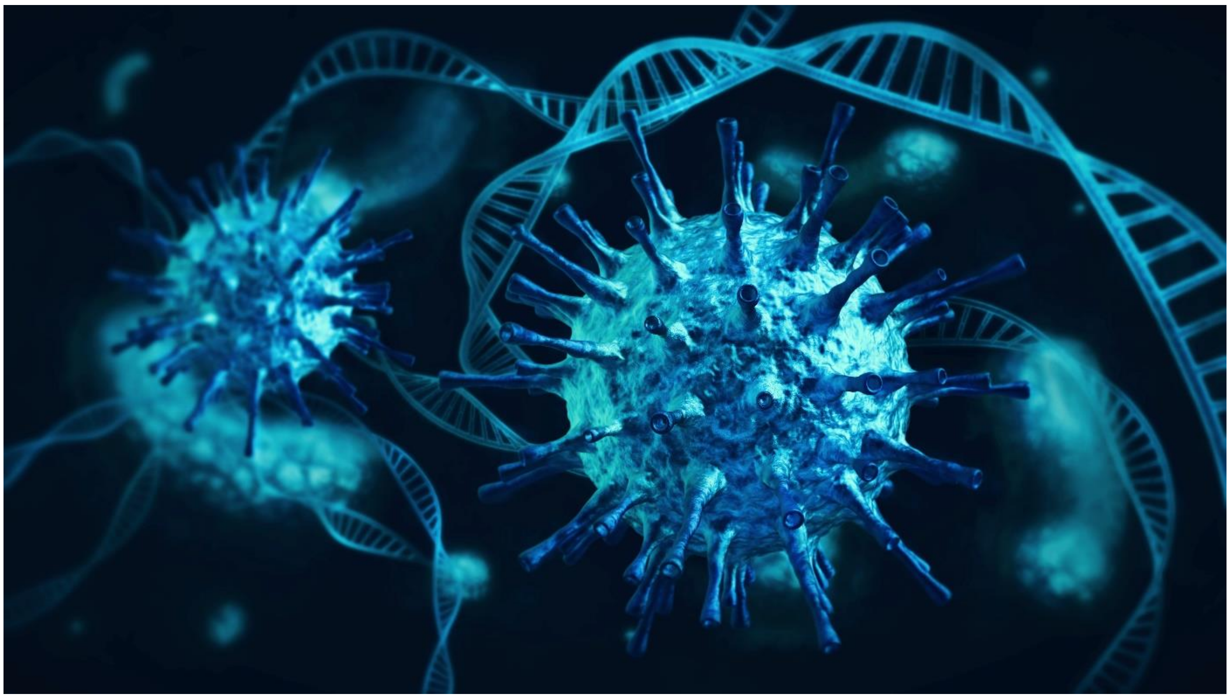
GenomeQuébec

Consultation Report



Surveillance and the Fight Against Pathogens and Antimicrobial Resistance

June 2022

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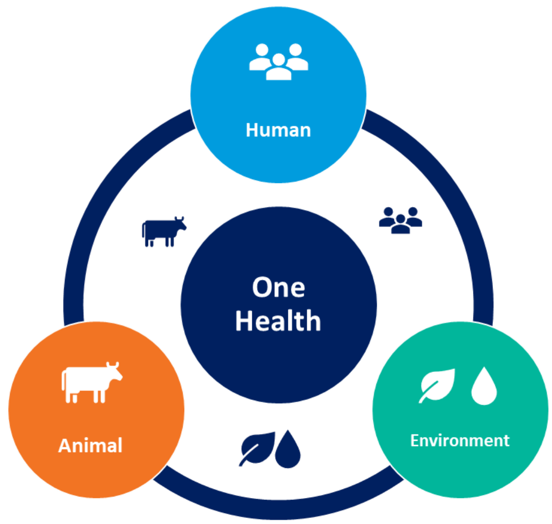
Executive Summary

Over the past two years, the COVID-19 pandemic has generated significant socioeconomic impacts throughout the world. It has shown us, nevertheless, the power of scientific research and, more specifically, of genomics,[1] which was instrumental in identifying the virus at the beginning of the pandemic and has made it possible to understand how it spreads, develop rapid tests, identify new therapeutic molecules, develop and market vaccines, and compile huge amounts of data to track the evolution of the disease and the emergence of variants worldwide. The risk of epidemics caused by emerging pathogens will continue to increase. Added to this concern is **antimicrobial resistance (AMR)**, which occurs when bacteria, viruses, fungi and parasites change over time and no longer react to drugs, making infections more difficult to treat and increasing the risk of disease propagation and death. The fight against pathogens is a cross-sectoral challenge; by encouraging collaboration between sectors, the **"One Health" approach** facilitates the study of the health (or pathogenic infections) of all living beings at the interface between animals, humans, and the environment.



It is in this context that Génome Québec carried out a consultation process in the fall of 2021, to gather the opinion of provincial experts regarding surveillance and the fight against pathogens and antimicrobial resistance. Four questions were addressed by experts from various disciplines:

1. What are the cross-sectoral (health, agriculture, environment) **priority needs** of users (government, public health, clinicians, industry) in Quebec?

2. What are the multidisciplinary **omics solutions** to be developed?

3. Where would the **investment** from Génome Québec have the most impact, either by *de novo* creation, by synergy with existing initiatives, or by building on previous investments?

4. How to ensure the adoption and **sustainability of the proposed solutions**?

[1] The term "genomics" is used in the broad sense and includes all the "omics" sciences, such as metagenomics, proteomics, metabolomics, etc.

As a result of the discussions held during the consultation, Génome Québec has summarized the consensus around the following recommendations:

Recommendation 1

Ensure that the government's Integrated Strategy to Prepare for Health Risks,[2] to be implemented by the government, includes a multisector genomic surveillance program and surveillance network based on the "One Health" approach.

Recommendation 2

Use selection criteria set out in research funding programs to encourage transdisciplinarity, interactions across different sectors, and partnerships with public health, human and animal health, the government and industry. The development of rapid, accurate and affordable diagnostics and the discovery of new therapies and alternatives to antimicrobials to combat AMR should be, in the short term, the subject of a call for proposals.

Recommendation 3

Develop or federate an integrated database (with established standards and associated metadata) that is high-quality and cybersecure, and that complies with FAIR data principles (**F**indable, **A**ccessible, **I**nteroperable and **R**eusable), for the benefit of researchers, clinicians, decision makers, public health and industry. This initiative will also include bioinformatics and statistical tools to facilitate adoption by users who are not experts, as well as an interface with artificial intelligence to optimize the use of data for prevention, prediction, diagnostic and treatment.

Recommendation 4

Entrust Génome Québec with a mobilization role to establish a place of exchange of ideas, collaboration, and co-construction, such as thematic workshops, to enable experts from various disciplines and sectors to share their knowledge and break down silos.

[2] The Plan pour mettre en œuvre les changements nécessaires en santé (Plan to Implement the Necessary Changes in Health), launched in March 2022 by the Quebec government, mentions that "the government is banking on the development and adoption of an integrated national health risk preparedness strategy," which will include "formalizing an oversight mechanism that allows for continuous risk analysis and mobilization of teams when needed."

Background

The COVID-19 pandemic has generated significant economic impacts throughout the world. After two years of pandemic and more than 15,000 deaths in Quebec, the government estimates costs at $24.1 billion, and the burden could increase with the next waves. Yet, for decades, scientists have been sounding the alarm by showing that such zoonoses could potentially emerge and affect human health (Morens, et al., 2020). Among the risk factors is the encroachment of civilization on wilderness areas, which reduces natural barriers and encourages the emergence of zoonoses, transmissible by pathogens between animals and humans. Scientists estimate that, in humans, more than six out of ten known infectious diseases are of animal origin, and three out of four new or emerging infectious diseases come from animals (Zoonotic Diseases, 2022).

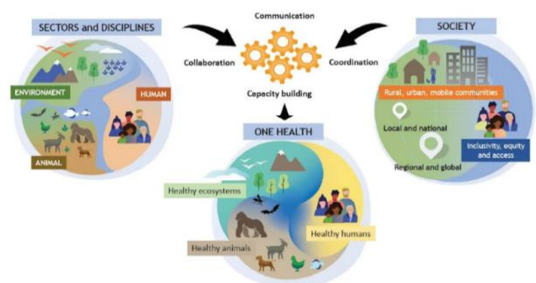
Nevertheless, the pandemic showed us the power of scientific researchers and, more specifically, of genomics (Saravanan, et al., 2022), which made it possible to understand how the virus spreads, develop rapid tests, identify new therapeutic molecules, develop and market vaccines, and compile huge amounts of data to track the evolution of the disease and the emergence of variants worldwide.

The risk of epidemics caused by **emerging pathogens** will continue to increase. Add to this **antimicrobial resistance** (AMR),[3] which occurs when bacteria, viruses, fungi, and parasites change over time and are no longer sensitive to drugs, making infections more difficult to treat and increasing the risk of disease spread, severe illness and death (World Health Organization, 2020). In Canada, first-line AMR accounts today for 26% of bacterial infections and could increase greatly in the coming years (Council of Canadian Academies, 2019). Internationally, **AMR has become one of the ten major threats to public health** with more than 700,000 deaths in 2019, and a projected 10 million deaths per year between now and 2050, at a cost of US$10 trillion (Bailey, Kougioumoutzi, & Anholt, 2021) (Antimicrobial Resistance Collaborators, 2022). In addition, in a context of climate change, a temperature increase of one degree could increase the resistance of certain microorganisms tenfold and encourage the migration of pathogens from the hottest to the coldest regions.

The fight against pathogens is a cross-sectoral issue: "One Health" approach

"One Health" is an approach to designing and implementing programs, policies, legislation, and research in which multiple sectors communicate and work together to achieve better public health outcomes for all living beings.

By encouraging collaborations in all sectors, the "One Health" approach makes it possible to study the transmission of pathogenic agents between animals, humans, and the environment, as well as their impact in sectors such as human health, animal health, agriculture, and the environment. This approach is especially relevant in the areas of **food safety**, **the control of zoonoses** and **AMR**.



Source: One Health High-Level Expert Panel (OHHLEP) of the United Nations Environment Programme (UNEP) (who.int)

[3] Antimicrobials – including antibiotics, antivirals, antifungals and antiparasitics – are medicines used to prevent and treat infections in human beings, animals and plants (Organisation mondiale de la santé, 2020).

To reduce our vulnerability to emerging or endemic pathogens and AMR, scientific and public health experts can implement various measures. For example, in April 2020, during the pandemic, Genome Canada and the six regional genome centres, including Génome Québec, established the Canadian COVID-19 Genomics Network (CanCOGeN). Using large-scale sequencing of SARS-CoV-2 and human hosts, the network was able to track the origin, spread and evolution of the virus, characterize the role of human genetics in the COVID-19 disease, and guide the urgent decisions that Canadian health authorities needed to take during the pandemic. In the same way, **genomics can also play a central role in understanding and combating AMR**, notably by fine-tuning diagnostic tools and prevention measures, developing monitoring capability and discovering new treatments.

As mentioned in the Québec government's Plan pour mettre en œuvre les changements nécessaires en santé (Plan to Implement the Necessary Changes in Health), "Unfortunately, the COVID-19 pandemic will not be unique. Other pandemics threaten to come knocking on our door in the future. We must learn lessons from the current crisis to be ready to face the next threat" (translation). It is in this context that Génome Québec carried out a consultation process in fall 2021, to gather the opinion of provincial experts regarding **surveillance and the fight against pathogens and antimicrobial resistance**.

The consultation process took place in two phases. In fall 2021, 12 individual interviews were conducted with experts (the list of participants is presented in Appendix 1) to identify the main issues; the results are presented in Appendix 2. Following this, a virtual consultation session was organized in March 2022, with 30 experts (academic, private, and governmental) from various disciplines and sectors (human health, animal health, public health, agriculture, environment) to discuss the needs and common solutions and to expand on the issues identified during the individual interviews (the list of invited participants is presented in Appendix 3).

Four questions, formulated based on the information gathered during phase 1, were addressed:

1. What are the cross-sectoral (health, agriculture, environment) **priority needs** of users (government, public health, clinicians, industry) in Quebec?

2. What are the multidisciplinary **omics solutions** to be developed?

3. Where would the **investment** from Génome Québec have the most impact, either by *de novo* creation, by synergy with existing initiatives, or by building on previous investments?

4. How to ensure the adoption and **sustainability of the proposed solutions**?

Highlights

This section presents the issues and priorities identified by the participants during the virtual consultation session held on March 18, 2022.

The Issues

- Data banks exist in several locations, but **access** is limited, and the banks of various disciplines, such as human health and animal health, do not communicate with each other.
- The data generated by different tools or processes are not harmonized or cannot be shared.
- **Multidisciplinarity** leads to **governance issues**, for the use of databases, which must be addressed in advance.
- Because it is not economically viable, the pharmaceutical industry withdrew from research and development of new antimicrobials.
- During the pandemic, actors in the human health sector mobilized to develop COVID-19 surveillance and tracking tools. No government policy has yet been put in place to ensure the sustainability of agreements, the surveillance of emerging pathogens and AMR.
- Other than screening by microbiological culture and PCR tests, few **population surveillance tools** are available.
- In research, multidisciplinarity gives rise to large-scale projects, which require coordination and sustained funding over several years.
- The exchange of ideas, communication and **collaboration** should be improved to enable experts from various disciplines and sectors to share their knowledge and break down silos.
- There is a need to reframe the regulation currently based on microbiological methods for molecular methodologies (omics).

Priority Needs

Surveillance of pathogens and AMR

- Implement a **provincial multisystem surveillance program** (human, animal, soil, water) for pathogens and AMR to detect and rapidly predict new health threats and improve sharing between the three sectors.
- Develop new **portable detection tools** that are easy to use and interpret under various conditions of use (laboratory, farms, food production chain, medical clinics, hospitals, etc.).
- Develop or federate **an integrated data**base (with established standards and associated metadata) that is high-quality and cybersecure and complies with FAIR data principles (**F**indable, **A**ccessible, **I**nteroperable and **R**eusable), for the benefit of researchers, decision makers and industry. This initiative will also include bioinformatics and statistical tools to facilitate adoption by users who are not experts, as well as an interface with artificial intelligence to optimize the use of data for prevention, prediction, diagnosis, and treatment.
- Define and put in place methods, standards and protocols that are harmonized to ensure the **quality of the data** and facilitate **sharing**.
- Raise awareness among the public and decision makers about the issue of AMR.

Fight against pathogens and AMR

- Encourage private sector investment by partners.
- Prepare for the next pandemic; have pipelines of candidate drugs ready and the required capability to deploy them.
- Develop **new diagnostic tests** for all species, making it possible to precisely guide the choice of treatment, as well as new therapies to combat AMR.
- Take advantage of Quebec's extensive expertise in **artificial intelligence to accelerate innovation** in the areas of prevention and prediction, diagnostics, and treatment of pathogens, and develop a portfolio of therapeutic products ready to begin Phase II and III clinical trials when the new health crisis emerges.
- Develop easily accessible and applicable alternatives to antimicrobials.

Multidisciplinary Omics Solutions

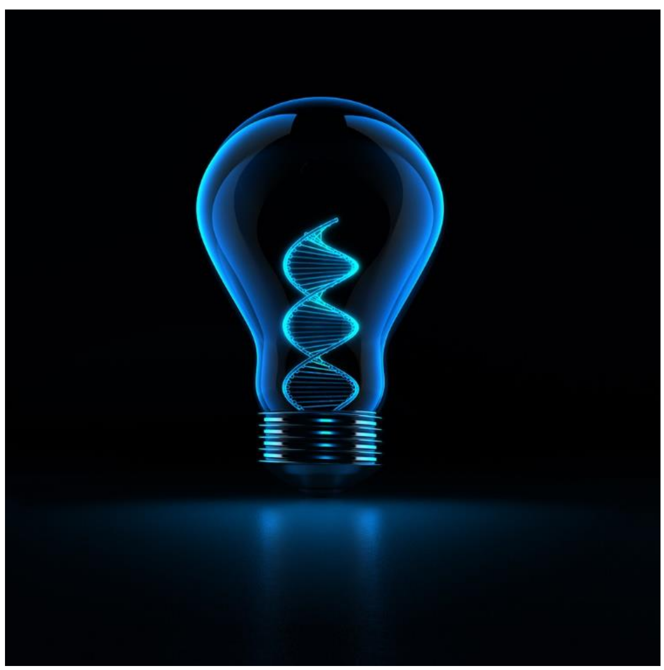
- **Strengthen ties between the research sector and public and private end users**, which will enable researchers to gauge the performance of technologies and products undergoing trials or being marketed and, if necessary, adjust their work.
- Foster the development of diagnostic tools for emerging pathogens and AMR that are rapid, easy to use, affordable, sensitive, specific, accurate and applicable to several species and environments.
- Use artificial intelligence to define new paradigms for the **interpretation of genomic data** at the transdisciplinary interface for the modelling, prediction and discovery of diagnostics and therapies.
- **Integrate genomics into government policies** for surveillance and fight against pathogens, and evaluate new public health approaches, such as tracking pathogens in wastewater.
- Use omics tools to track and study the transmission of AMR and pathogens between sectors and establish a link between analyses in the field and the risk to health.

Investment Opportunities

- Since genomics is a cross-cutting technology, it would be relevant to encourage multidisciplinarity within funded projects by focusing on a "One Health" approach.
- Invest in **open science** (data, tools, publications, etc.) by ensuring the accessibility and interoperability of data.
- Invest in projects (through open funding programs) whose themes and priorities are determined by researchers.
- Fund the discovery of new antimicrobials to combat AMR, including more basic research to gain the required knowledge that will encourage the private sector to begin the next stage of development. Funding of this critical stage is not adequately covered.
- Develop new **omics indicators** for more effective **molecular** and epidemiological **surveillance** of pathogens.
- Support the implementation of a **multisectoral database**.
- Federate existing resources.
- Use the strength of the network to identify knowledge gaps that should be filled, for example, by organizing workshops.
- Encourage **partnerships** between research, industry, and provincial and federal public agencies (CIHR, PHAC, MSSS, MAPAQ, etc.) and ensure synergy between the ecosystem players.

Sustainability of Solutions

- Make data accessible as quickly as possible and safely; simplify the interpretation of omics data for users by focusing on easy to use and affordable bioinformatics and statistical tools.
- Offer **easy and rapid diagnostic tools**, enabling adoption by users, and ensure sustainability as a means of detecting pathogens.
- Establish a place for the exchange of ideas and collaboration to enable experts from various disciplines and sectors to share their knowledge and break down silos.
- Encourage structural measures that ensure synergy between research, users and industry in all sectors.
- Mobilize stakeholders – researchers, government departments and industries – in advance ("early engagement") and **develop collaborations** to ensure the implementation, commercialization, and sharing of knowledge.
- Encourage the training of the next generation of scientists.
- Develop **educational** and awareness programs encouraging **public engagement** and social acceptance.
- Use GE^3LS[4] expertise to mobilize stakeholders, encourage transdisciplinarity and define the relevant issues for the design of projects and competitions, for instance by examining the burden of morbidity or evaluating the cost and benefit of change to practices or new interventions.



[4] Genomics and its ethical, environmental, legal, and social aspects.

Recommendations

Thanks to initiatives put in place to fight against COVID-19, Quebec has strengthened its genomics capabilities and emerged better equipped to face current, emerging, and future threats to the health of humans, animals, and the environment (including plants), as well as those tied to AMR.

As a result of the discussions held during the consultation, Génome Québec has summarized the consensus around the following recommendations:

Recommendation 1

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Acknowledgements

Génome Québec wishes to thank all the experts who contributed greatly to the success of this consultation, with special mention to four experts, Roger Lévesque, Dao Nguyen, Hélène Carabin and Jesse Shapiro, who accepted to be rapporteurs during the session and to review and comment on this report.

Génome Québec also wishes to thank Diana Iglesias, Laetitia Sabatier, Caroline Telekawa, Annina Spilker, and the other team members who helped prepare and carry out this consultation, and Alexandra Roy for the work of synthesizing and writing the report.

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Appendices

Appendix 1. List of participants – Individual interviews with experts (Phase 1)

Name	Title / Expertise	Institution
Cécile Aenishaenslin	Veterinarian, Epidemiologist, One Health	Faculty of Veterinary Medicine, Université de Montréal
Janice Bailey	Scientific Director	Fonds de recherche du Québec - Nature et technologie (FRQNT)
Yann Joly	Professor, Centre of Genomics and Policy; Health Law and Bioethics	McGill University
Paul L'Archevêque	Director of Innovation	Ministère de la Santé et des Services sociaux du Québec
Sandrine Moreira	Genomics, Bioinformatics	Laboratoire de santé publique du Québec - Institut national de santé publique du Québec
Dao Nguyen	Director of the McGill Antimicrobial Resistance Centre; Microbial Genomics and Microbiology	McGill University
Marc Ouellette	Director of the Infectious Disease Research Centre	Université Laval
Caroline Quach-Thanh	Pediatrician, Microbiologist, Infectious Diseases specialist; Professor, Department of Microbiology, Infectious Diseases & Immunology	CHU Sainte-Justine; Université de Montréal
Michel Roger	Medical Director, Microbiologist, Infectious Disease specialist	Laboratoire de santé publique du Québec - Institut national de santé publique du Québec
Karine Thivierge	Medical Biology Clinical specialist	Laboratoire de santé publique du Québec - Institut national de santé publique du Québec
Paul Thomassin	Professor of Natural Resource Sciences; Agricultural and Environmental Economy	McGill University
Louis Valiquette	Chair, Department of Microbiology and Infectious Diseases	Faculty of Medicine and Health Sciences, Université de Sherbrooke

Appendix 2. Methodology

In the fall of 2021, twelve individual interviews were conducted with experts to identify major issues (Phase 1). Following this, a virtual meeting was organized on March 18, 2022 (Phase 2) with 30 experts (academic, private, and governmental) from various disciplines and sectors (human health, agriculture, environment) to discuss needs and common solutions, and to prioritize and refine the issues identified during the individual interviews. Four questions formulated based on the information gathered during the individual interviews of fall 2021 were then sent to the experts in preparation for the consultation.

During the virtual consultation session, participants were placed in four rooms. This distribution ensured the presence of different expertise in each room. A moderator from Génome Québec facilitated the session in each room, using the Padlet interactive platform, and a member from Génome Québec took notes on the discussion. The experts were invited to add their answers to the four questions on the platform. Following this, a discussion took place to summarize the key messages discussed around each question. One of the experts was designated as rapporteur responsible for conveying the findings of the room during the plenary session, which was held with all the experts at the end of the consultation. The list of individual answers collected from experts in the four rooms is available in Appendix 5. The report was prepared based on the discussions and findings from the group consultation held in March 2022 (Phase 2).

Appendix 3. Issues identified during individual interviews

Prevention	Surveillance	Diagnostics	Treatment	Data Platforms	Artificial Intelligence	Cross-sectorial
Discovery and characterization of new pathogens	Use of a representative sample for pathogen detection (wastewater)	Development of POC tests	Non-antibiotic treatment	Governance	Prediction	Overuse of antibiotics in agriculture
Geographical distribution of pathogens	New technologies / Need of standards, validation, interoperability (eDNA)	Reference labs	New molecules/agents	Sustainability	Epidemiological monitoring	Data infrastructure and bandwidth
Reservoirs	Mechanisms of transmission, emergence factors	Use of “hard to grow” organisms	Implication of big pharma (R&D today in academic and SME context)	Sharing	Modelling	Talent and expertise: sample collection, processing, and analysis
	Farm to fork			FAIR principles	Clinical use of metagenomics	Multidisciplinary work and bringing different sectors together
				Crosstalk genomics-bioinformatics	AI and drug discovery	Protocols, standards, and quality assurance
				Centralized data repository		
				Automated analysis and reporting		

Appendix 4. List of invited participants – Consultation session with experts (Phase 2)

Nom	Titre / Expertise	Organisation
Sadjia Bekal	Microbiologist	Institut national de santé publique du Québec
Yoshua Bengio	Artificial Intelligence	Mila, Université de Montréal
France Brunelle	Afri-Food Omics	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
Hélène Carabin	Epidemiologist, Veterinarian, One Health	Université de Montréal
Alex Carignan	Epidemiologist	Université de Sherbrooke
Cristina Cismasu	Data Specialist	Gordon Foundation
Caroline Côté	Agronomist, Biological risks of agricultural practices	Research and Development Institute for the Agri-Environment
Marc-André D'Aoust	Executive Vice President Innovation, Development and Medical Affairs	Medicago
Pierre-Marie David	Sociologist and Pharmacist	Université de Montréal
Arnaud Droit	Computational Genomics	Centre de recherche du CHU de Québec - Université Laval
Ève Dubé	Medical Anthropologist	Université Laval
Yvon Fréchette	Innovation Advisor	Ministère de l'Économie et de l'Innovation du Québec
Dominic Frigon	Environmental Biotechnology	McGill University
Richard Gold	Intellectual Property in Life Sciences	McGill University
Patricia Hudson	Scientific Director	Institut national de santé publique du Québec
Caroline Huot	Environmental Health - Water	Institut national de santé publique du Québec
Barry Husk	Environmental Research and Public Policy	BlueLeaf Inc.
Alejandra Irace-Cima	Social and Preventive Medicine	Institut national de santé publique du Québec; Université de Montréal
Yann Joly	Professor, Centre of Genomics and Policy; Health Law and Bioethics	McGill University
Roger Lévesque	Systems Biology	Institute of integrative biology and systems (IBIS), Université Laval
Joseph Mancini	Vice President, and Head of Biological Sciences	adMare BioInnovations
Jean-François Masson	Chemistry and Clinical Analysis	Université de Montréal
Philippe Morency-Potvin	Microbiologist and Infectious Diseases Specialist	Université de Montréal
Dao Nguyen	Director of the McGill Antimicrobial Resistance Centre; Microbial Genomics and Microbiology	McGill University
François Sanschagrin	Medical Biology Advisor	Ministère de la Santé et des Services sociaux du Québec
Jesse Shapiro	Epidemiology and Genomics	McGill University
Christiane Thibault	Scientific Director	Institut national de santé publique du Québec
Paul Thomassin	Professor of Natural Resource Sciences; Agricultural and Environmental Economy	McGill University
Mike Tyers	Systems Biology and Synthetic Biology	Institute for Research in Immunology and Cancer, Université de Montréal
Daniel Verreault	Microbiologist	Ministère de l'Environnement et de la Lutte contre les changements climatiques du Québec
Manuela Villion	Microbiologist	Ministère de l'Environnement et de la Lutte contre les changements climatiques du Québec
Antony Vincent	Microbial Genomics and Microbiology	Université Laval

Appendix 5. Individual answers collected from experts in break out rooms (Phase 2)

Room	Needs	Omics solutions	Investment opportunities	Sustainability of solutions
1	Multi-system surveillance programs (humans, animals (wildlife, domestic), environment (water, soil)) for pathogens and AMR Ability to track (increasingly complex) markers in several "environmental" reservoirs with high genomic accuracy Identify Legionella strains in water-cooling towers and make the link with clinical isolates Paradigms considering the different units of quantification, resolution of systems, and experimental approaches of the disciplines involved To have medicines on hand for humans and animals, ready to go into Phase II/III trials, when the next pandemic/crisis arises, need for new treatments (i.e., antibiotics, phage, probiotics). That is, not wait for a crisis to act New paradigms for interpreting data at transdisciplinary interfaces Approach to better understand and model the appearance of resistance or of zoonoses	Improve computational drug discovery by testing out predictions in the lab. This is being promoted by the CACHE project, led by the Structural Genomics Consortium Improve the detector that has a lower detection limit, providing more genomic information at a lower cost to increase surveillance capability Connection models between environmental reservoirs to better understand the dissemination of various agents Link with the potential for infection Multi-system diagnostic tools Epidemiological studies aligned with genomics analyses; link between analyses and the health risk Development of diagnostic tools for pathogens and AMR that are rapid, easy to use, affordable, sensitive, specific, accurate and applicable to several species and environments	To invest in open science – open data, publications, tools, materials, and no patents – public-private partnerships to develop diagnostics, drugs and other interventions Long-term monitoring program Show the added value of transdisciplinarity Molecular update of the regulation Monitoring of biodiversity for the health of lakes and waterways The hardest thing for the "One Health" approach is its operationalization and demonstration of its added value. "One Health" projects are very costly and rarely supported, which makes proving added value rare Molecular and epidemiological monitoring programs to develop new omics indicators and to reframe the regulation at the molecular level based currently on microbiological culture methods	Both pandemic and AMR suffer from market failures given the uncertainty of timing and target. This means firms underinvest in proactive development. To solve this problem, we need partnerships that draw on multiple forms of incentive – not patents – to collaborate before. It is less expensive to invest now than when a crisis hits. Data interpretation tool Break down silos and educate Approach to include various stakeholders and users, even if the experimental protocols are somewhat deficient; common exploratory projects Develop new, open-science compatible, commercialization strategies to ensure access and affordability
2	Identify treatment "responders/non-responders" Establish a risk/prediction factor to infection or remission based on molecular data Integrative genomics in three sectors with complementary databases Data integration via artificial intelligence Foster the integration of projects and avoid silos Collection of environmental, human, animal data that are coordinated and more systematic to enable the surveillance and rapid detection of new threats Early engagement of all the Quebec population to familiarize them with genomic innovation and facilitate adoption (e.g., RNA vaccines) Anticipatory ethics to identify any potential risks before	Consider the possibility of analysis and antibiotic resistance in non-clinical samples (animal and human health) Develop indicators (AI) useful in clinical care management Portable/rapid, easy to use technologies to provide prediction algorithms with evidence-based data Capability to identify an optimal treatment for a patient, i.e., rapid susceptibility test using a sample AI to model and predict the properties of new potential antimicrobial drugs (e.g., antimicrobial peptides) AI to explore a space for therapeutic candidates (e.g., biological sequences, antimicrobial peptides, small molecules) in interaction with	Consider association with existing programs, such as COVID in wastewater, by targeting certain environments, e.g., extended-care homes Fund laboratories and infrastructure to maintain the expertise developed during the pandemic to meet new challenges, using expertise developed during the response to the pandemic There is a lack of a long-term reference laboratory to maintain the capability sustainable testing in Quebec. Climate change and AMR prediction, ID of new pathogens Given the current low commercial appeal of developing new antibiotics, it is vital that governments invest in both research and development of new antibiotics. This need can	Ongoing funding of structures that ensure synergy between research/users/industry (agri-food and pharmaceutical) Ensure the sustainability of the expertise developed during the pandemic to avoid a loss of competencies in Quebec Complementary and integrated projects that are supported by shared databases and AI Support of Génome Québec and various government departments to integrate omics and eco-omics technologies Technology transfer to be ensured to users Interpretation guides to be developed Importance of the standardization of

Room	Needs	Omics solutions	Investment opportunities	Sustainability of solutions
	proceeding and to demonstrate to the population that scientists have given due consideration to address safety concerns before proceeding Optimal use of health data (among others) coupled with omics data Possibility of putting in place a common platform between all the sectors? Development of an effective and rapid network (taking advantage of AI and high-throughput screening) to develop new antibiotics Life cycle (pooling, FAIR access, development of tools and management) of data – sustainability – federated model Project in its own right to define standards? Development of new molecules (environmental impact?) New diagnostic/detection tools Knowledge gap and new diagnostic technology; guidance for these changes Educational component (adaptation, early engagement, participation of users, integration by government departments)	a high-volume experimental (in vitro) testbed Protocols for collection, sharing and pre-established permitted use; committee of access to sensitive data Artificial intelligence and AMR prediction Integrated pathogen detection and identification technology more than the PCR test Pursue development of DNA tools Multidisciplinarity committee to discuss research and improve public dialogue – people want to hear what the scientists have to say, not just communication experts and ethicists	conflict with the current funding model of 50% government / 50% business, and therefore requires a decision by the government A significant government investment could have a major positive impact on the development of the industrial ecosystem around the discovery of drugs in QC: on the one hand, businesses could use the most transverse technology (such as AI) on targets other than AMR; and, on the other hand, the market for antimicrobials (to be reshaped internationally) could eventually make their development profitable, giving currently funded Quebec companies a head start Surveillance – monitoring - network, research centre, provincial vision Retain expertise	processes; quality system development Involve stakeholders in the set-up and completion of projects A vision and funding focused on the mid-term/long term. I know that this is not easy! Research centre

Room	Needs	Omics solutions	Investment opportunities	Sustainability of solutions
3	Surveillance and prediction in three sectors and communication between sectors Novel therapeutics and incentives for private sector (partnerships) and speed of development Increase awareness of the public and the decision makers on the importance of AMR Pandemic preparedness (incl. readiness of pipelines and capacity) Pooling already funded initiatives in terms of results – Networking existing initiatives – Funding What is the extent of AMR gene spread across sectors? Random population surveillance of respiratory pathogens Trans-sectorial is not happening that much between health – agriculture and environment at the public health level, silos should be deconstructed Capture/monitor key pathogens in environment – from wastewater, e.g., to recreational waters; improve water quality management tools Academic-industry collaboration in basic and applied research areas, including One Health strategy Movement of AMR from agriculture through the supply chain to the retail sector and to human health. Surveillance of AMR movement – salmonella, campy, etc. One of the priorities is the economic impact of changes in management, regulation, etc. Comprehensive surveillance in Quebec, including human, animal, food, and environmental partners, shared with academic researchers to guide their research and development based on public health needs We see AMR in the environment but still don't know the extent of spread into hospitals. This is at the core of One Health.	Multidisciplinarity itself is very useful AI, SynBio, Chem Biology, GE3LS, nanotech, biosensors Methods to detect AMR genes at low frequency & link with genomes (Cheaper) multi-pathogen oligo panels Metagenomics Solutions span detection of known and novel pathogens (bacterial, fungal, viral), fundamental biology of pathogens, innovative omics-driven strategies for development of new diagnostics and therapeutics, including AI-driven and synthetic biology approaches Surveillance is needed and most importantly reporting. There needs to be a connection between exposure and burden of disease. Use of omics to verify the movement of AMR through the system. Need to invest in GE3LS research. In particular, the benefits and costs of changes in management and interventions. Standardized genomic tools and secure platforms qPCR or amplicon panels to track ~400 known AMR genes Hi-C DNA cross-linking to link AMR genes with bacterial species	Investigator-initiated open funding calls AMR not sufficiently funded by CIHR – need for investment in basic science/knowledge Workshops before funding call Network of networks Capacity to tackle both slow and fast-acting threats Gap analysis Investment in knowledge-to-practice or implementation science (in line with point 4) Centralize/standardize data Opportunities lie at the interface of multiple disciplines, e.g., AI, synthetic biology, functional genomics; also, draw together across fields to break biomedical vs. animal health silos, etc. Investment in integrated models of health and economics/policy Seek partnership with foundations such as Bill and Melinda Gates Foundation. Canada has partnered with BMGF on other large projects.	Key: Putting GE3LS research (incl. burden of disease, management) and user input at beginning to define projects/calls Rapid and secure data sharing Radical requirement for early data sharing Collaboration with federal agencies: PHAC, StatCan, CoVaRR-Net, etc. GE3LS researchers are involved early on in the research Solutions are designed in partnership with end users Carefully assess barriers to research, which may often be at the level of industry competence and academic depth; ensure programs have chance for long-term funding support; assess commercial incentives and develop mechanisms to offset business model liabilities Need for more research funding; working with end users to assist in the policy/economic analysis of AMR; the development of impact assessment models, agent-based models and macroeconomic impact models

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4	Rapid and effective surveillance tools of antibiotic-resistant genes (including mobile DNA elements) Development of easily accessible and applicable alternatives to antibiotics Genetic characterization and characterization of the antibiotic resistance profile of emerging pathogens in sources of drinking water, wastewater, treated water and distributed water Genetic characterization and characterization of the antibiotic resistance profile of food pathogens causing outbreaks in humans and the link to environmental pathogens in the food sector Accessible point of care diagnostics that can improve AMU Identify toxicity/pharmaceutical pollution fields Genomic Screening for new pathogens – a priority should be to incorporate various institutions rapidly when faced with pandemic screening Lessons from the pandemic: what surveillance tools were lacking? Metagenomics of wastewater and usefulness for epidemiological surveillance Links between environmental factors and genetic factors in the origin of diseases from a population perspective Support intersectoral interdisciplinary networks, teams, services Recognize tensions between productivism needs and public health needs Effective use of data generated by public funds Cost of sequencing, democratization of sequencing to promote surveillance Useful tools for bioinformatics analyses	National surveillance platform and tools to analyze the management of genomics data to foster better surveillance Genomic sequencing and proteomics should provide the quickest data in identification and also potential avenues for therapeutic intervention. Initiatives to improve the surveillance of various environments (AI?) Metagenomic characterization of various environments (microbial networks) Open data model program to characterize and share results with integrated interpretation solutions Precautions regarding omics solutions Emerging technologies, cost/effectiveness Biosecurity monitoring, supplements to antimicrobials	Emergence of pathologies connected to modes of production Program promoting a partnership with industrial companies of various sizes and from different sectors and different underfunded tools according to importance Partnership with Compute Canada? “One Health” approach and links between various environment-animal-human sectors Investments in next generations and robotic screening across multiple institutions to have capabilities to ramp up sequencing efforts and use of AI to quickly access international databases Sectors where there is government adoption of opportunities Build on existing or emerging “clusters” of expertise (academic, governmental, industry) in Quebec Opportunities to partner with Genome Canada for pan-Canadian efforts Funding of bioinformatics tools Funding of modest projects PHAC, MAPAQ, CFI, NSERC Use of AI to analyze AMR data	Multidisciplinary and participatory research Adequate Quebec-specific cost/economic and risk assessment Development of user-friendly, updated and accessible interface for data access Promote collaboration with industrial partners Best practice is to collaborate across Quebec universities to see who can provide needed capabilities; also, to establish AI platforms internationally Provide for communication tools intended for government decision makers Mobilization of all sectors involved (key influential persons in their field) in advance Make generated data available to other researchers to enable them to re-use them Not profitable for inc. vs. investment Business development groups within companies. They are responsible for developing collaborations. Development of collaborations with small biotech firms and academia – a little earlier stage Problem of "incentives" Rethink a business model to support AMR solutions Canadian antimicrobial coalition