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Navigating The Future of Seasonal and Pandemic Influenza in Canada: A National Foresight Analysis on Pandemic Influenza Vaccine Readiness

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Note: The findings and conclusions expressed in this report are those of the authors and do not necessarily reflect the official positions or policies of the individuals interviewed or their respective organizations.

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1. Introduction

The influenza vaccine landscape is evolving rapidly, presenting both opportunities and challenges for Canada's pandemic preparedness and response strategy. Scientific innovations such as broadly protective and universal influenza vaccines, novel vaccine delivery methods, new adjuvants, AI-driven surveillance and antigen design, and mRNA and other vaccine platforms could transform the field. Meanwhile, increased supply chain risks, declining vaccine confidence, and significant geopolitical shifts are risks and challenges that may disrupt the use of those new technologies or directly result from it. These trends underscore the need for foresight analysis to anticipate change and prepare for future scenarios to navigate the future of seasonal and pandemic influenza in Canada.

The National Collaborating Centre for Infectious Diseases (NCCID) was asked by the Public Health Agency of Canada (PHAC) to assist with a foresight analysis for pandemic influenza vaccine preparedness. With a tight timeline, NCCID consultants determined rapid, but comprehensive methods to conduct a scan of current discourse and solicit insights from key informants from public health, vaccine regulation and industry.

In this report, foresight analysis provides a structured approach to examining how emerging developments—rather than established trends alone—may shape future system performance. It explores the dimensions that will influence influenza vaccine policymaking and key public health decisions in the future by identifying emerging opportunities and risks associated with societal, geopolitical and technological change. This report examines Canada's influenza vaccine readiness through a foresight lens, identifying six signals of change from a rapid review of literature, key informant interviews, and a structured prioritization exercise with experts. The six signals of change represent potentially significant developments characterized by uncertainty, strategic relevance, and system-level implications. They were assessed by the experts for their potential impact on and probability to significantly influence vaccine readiness, as well as their anticipated timeframes of influence.

This analysis does not aim to provide a comprehensive or predictive account of the future. Rather, it identifies a set of plausible developments that may influence vaccine readiness over the coming decade. The findings are intended to support strategic thinking and preparedness planning under conditions of uncertainty, rather than to prescribe specific policy actions.

In our analysis, we recognize the "influenza vaccine system" as an integrated set of processes spanning the full lifecycle of influenza vaccine development and deployment, including interconnected and iterative processes across stages.

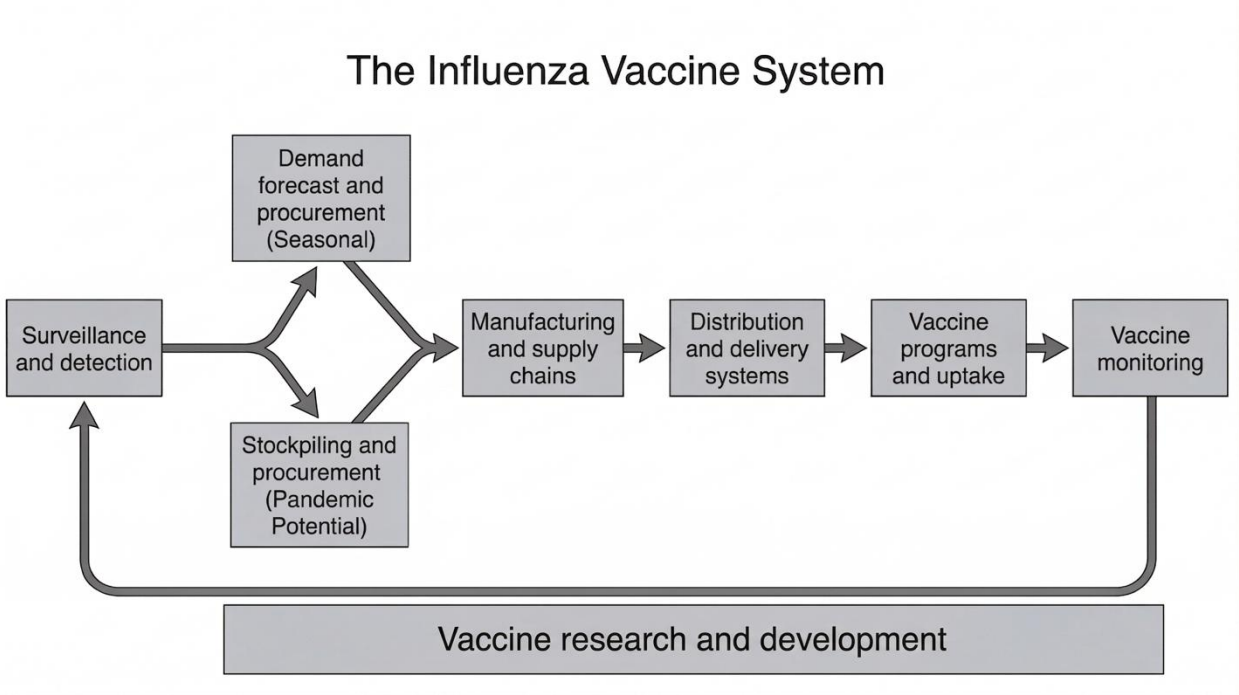

Figure 1: The influenza vaccine system

This includes:

- **Surveillance and detection,** including monitoring of circulating strains and emerging zoonotic threats across human, animal, and environmental systems and creation of intelligence to inform public health decision;
- **Vaccine research and development**, including early scientific exploration, preclinical and clinical vaccine development, scientific review and regulatory approvals;
- **Demand forecast (seasonal), stockpiling (pandemic) and procurement**, including coordination mechanisms to predict seasonal vaccine demand, pandemic stockpiling needs, and seasonal and pandemic procurement processes;
- **Manufacturing and supply chains,** including domestic production capacity, and global access to supply chain components and key information to inform manufacturing;
- **Distribution and delivery systems,** including logistics, and public health program implementation across jurisdictions;
- **Public engagement and uptake,** including public trust in vaccines, communication, and access to vaccines;
- **Vaccine monitoring,** including surveillance of vaccine effectiveness and adverse events.

Each of these components is central to achieving vaccine readiness for public health emergencies or pandemics. Understanding their interdependence can highlight areas of tension, potential vulnerabilities, and opportunities for strengthening both seasonal influenza systems and pandemic preparedness.

The analysis presented in this report draws on three complementary sources:

1) a rapid landscape scan of peer-reviewed and grey literature to establish current knowledge and contextual trends;
2) key informant interviews with experts across the influenza vaccine system; and
3) a prioritization survey used to assess the relative impact, likelihood, and timeframe of identified signals.

The literature review was not designed to be exhaustive, but rather to provide a targeted foundation for interpreting emerging signals and situating expert insights within broader scientific and policy developments. These sources are integrated throughout the report, with the "Current Landscape" section providing a baseline against which signals of change are later identified and analyzed.

2. The Current Landscape of Influenza

As noted, this section provides a baseline overview of the current influenza landscape, drawing on a targeted rapid review of existing literature and surveillance data. Rather than offering a comprehensive synthesis, it highlights key dynamics relevant to understanding how future signals of change may emerge and interact within the influenza vaccine system.

2.1 Global and Canadian Influenza Trends

Influenza is widely recognized as one of the most persistent and dynamic threats to global health, due to its ability to rapidly evolve and evade existing population immunity. While seasonal influenza is often perceived as a routine annual occurrence in both Northern and Southern hemispheres, it represents a substantial global burden, causing between 290,000 and 650,000 deaths worldwide each year (1) .

In Canada, influenza trends are monitored through FluWatch+, a human health national surveillance system for respiratory viruses. Influenza is among the 10 leading causes of death, causing 15,000 hospital stays and 3,500 deaths annually in Canada (2,3). Several groups are at heightened risk of being exposed, infected, or experiencing complications. While older adults are at greater risk of infections and serious complications than younger adults, children under five are also at high risk of infection as they are more likely to be exposed through daycare, preschool and school settings (3). Pregnant women have a higher risk of complications from infection than other adults, and the developing fetus also faces the potential for negative outcomes (3). Individuals living in First Nations, Inuit and Métis communities are at increased risk of severe influenza due to several intersecting social and structural factors that result from historical and present colonialism (4,5). Generally, Canada experiences seasonal resurgence of influenza in the fall, with higher case activity, severity and mortality varying by populations at higher risk of exposure and infection, as well as strain circulation (2).

The conditions shaping influenza risk are becoming more complex. Increasing interaction between human, animal, and environmental systems, caused by – and accelerating alongside – increased global mobility and ecological change, is contributing to more dynamic patterns of transmission (6). Highly pathogenic avian influenza (HPAI) and other zoonotic strains continue to circulate globally, raising concerns about the potential for novel strains with pandemic potential. These dynamics are also shaped by broader social and economic systems, including global trade, agricultural production, and patterns of human mobility, which influence both the emergence and spread of influenza viruses. Taken together, these trends suggest the importance of understanding influenza not solely as a virological phenomenon, but as part of a broader and interconnected social, ecological, and economic system.

2.2 Zoonotic Dynamics and Transmission Pathways

The risk of an influenza antigenic shift – sudden, major change in the influenza A virus resulting in a new hemagglutinin (HA) or neuraminidase (NA) protein – is predominantly associated with zoonotic spillover from animal reservoirs, rather than mutation during human influenza virus circulation (7,8). These cross-species dynamics create opportunities for viral mutation and reassortment, contributing to the emergence of novel strains with pandemic potential.

In Canada, risks are particularly concentrated at interfaces between human activity and animal populations, including the poultry sector and regions along migratory bird pathways (9). These transmission dynamics reinforce the importance of monitoring influenza across species and environments, as early signals of emerging strains may originate outside traditional human health surveillance systems.

Importantly, influenza transmission is shaped by the closer global interconnectedness of human and animal species. For example, emerging strains can spread rapidly across national borders through increased travel, trade, and wildlife and human migration. These dynamics underscore the importance of understanding influenza readiness, not only as a national issue, but as part of a broader global ecosystem (10).

2.3 Canada in a Global Influenza Context

Canada's influenza vaccine system is reliant on, and collaborates with, global systems of surveillance, research, and vaccine development. The World Health Organization (WHO)'s Global Influenza Surveillance and Response System (GISRS) plays a central role in influenza vaccine response worldwide and in Canada (11,12). Through this network, WHO facilitates collaboration among countries, laboratories, and partners to monitor virus evolution, guide vaccine composition, and support pandemic preparedness. It ensures timely sharing of viruses, data, and resources, strengthens national capacities, and provides technical guidance to support effective global response and public health decision-making. WHO holds semi-annual meetings (in February for Northern Hemisphere members

and in September for Southern Hemisphere members) to formalize strain recommendations based on global surveillance data (12). Manufacturers receive these recommendations and initiate production.

Seasonal vaccine production spans approximately 12 months from surveillance to vaccine delivery, with traditional egg-based manufacturing—which represents 80% of the global seasonal and pandemic vaccine production capacity—requiring at least 6 months from strain receipt to first delivery of final product (13). Cell culture technologies offer substantially faster timelines, producing vaccines in 6-8 weeks following strain receipt, although these newer technologies face different constraints, including lower virus yields and adventitious agent concerns (14,15). Critical bottlenecks in the influenza vaccine production process include the requirement for strain recommendations up to a year in advance, tight regulatory timelines with limited flexibility, and egg supply dependencies for the egg-based platforms (15–17).

The seasonal influenza vaccination system can be understood as a continuous "baseline" for pandemic preparedness. Annual vaccination programs provide opportunities to maintain infrastructures through "warm readiness" frameworks, maintain and test distribution systems, and build public familiarity with vaccination (18). In this sense, seasonal influenza programs function as a form of ongoing system rehearsal, shaping the capacity to respond to future pandemics.

However, important differences remain between seasonal and pandemic contexts. Pandemic responses require rapid scaling of vaccine production, accelerated regulatory processes, and the ability to respond to novel emerging strains and shifting epidemiological patterns. Recent pandemic experience has highlighted key dynamics relevant to influenza preparedness, including both the potential for rapid innovation—particularly in vaccine development—and the challenges of coordinating response across jurisdictions, managing supply chains and stockpiling, and maintaining public trust (19).

Canada's influenza vaccine system is thus embedded within a broader global ecosystem of research, manufacturing, and governance, in part reflecting the constraints of operating within a relatively small domestic market. Vaccine development and production rely on international collaboration, including shared surveillance data, cross-border supply chains, and regulatory alignment (11). At the same time, recent investments in domestic biomanufacturing capacity reflect a growing emphasis on strengthening self-sufficiency, sovereignty and resilience (20).

These dynamics create tension between global interdependence and domestic autonomy. Canada benefits from participation in international networks but remains vulnerable to disruptions in global supply chains and shifts in geopolitical relationships. Understanding how this balance evolves is central to assessing future vaccine readiness. Although widely regarded as a highly efficient system and a model of international collaboration, the global system for influenza vaccine production contains numerous points of potential vulnerability and demonstrates limited flexibility in responding to antigenic drift and shift. These dynamics highlight key tensions—between global coordination and

domestic capacity, stability and disruption—that shape the context within which future signals of change are emerging.

These baseline conditions establish the context within which emerging signals of change are developing and highlight the need for a foresight analysis to support decision-makers in anticipating and preparing for disruptive changes through appropriate investments and strategic planning. Foresight can help anticipate surprising events, build early warning systems, and support resilient strategies, policies, and programs (21).

The objectives of this foresight analysis are therefore to: (1) identify signals that could influence Canada's future pandemic influenza vaccine readiness; and (2) prioritize those signals considered most likely to be disruptive. The following section builds on this foundation to identify and assess key signals that may shape Canada's pandemic influenza vaccine readiness over the near-, medium-, and long-term.

3. Beyond the Horizon – Foresight into Canada's Pandemic Influenza Vaccine Readiness

3.1 Interview and Survey Methods

Fourteen interviews were conducted with key informants – individuals from a wide spectrum of expertise (academic research, surveillance, vaccine manufacturing, vaccine procurement, sentinel networks, Indigenous health, and public health decision makers). Following analysis of the interview findings, a prioritization survey was sent to the key informants to rank signals of change that represent emerging developments characterized by uncertainty, strategic relevance, and potential system-level impact (22). Insights derived from key informant interviews and the survey are presented in aggregated and de-identified form.

Interviews were by invitation (purposive sampling) and lasted about one hour each. Interview questions were semi-structured (Appendix 1). The interviews were conducted online and were recorded for analysis purposes only. The recordings will be destroyed at the end of this project.

Through the key informant interviews, we identified **six signals of change**, grouped under **three themes or "dynamics"** (Table 1). To support the prioritization of signals, a structured survey with open-text options, was distributed to interview participants using Survey Monkey; 9 key informants responded to the survey. The survey asked respondents to evaluate each signal across three dimensions: (1) impact on Canada's pandemic influenza vaccine readiness, (2) probability that the signal would significantly influence readiness, and (3) anticipated timeframe of influence.

Impact and probability were assessed using ordinal scales (ranging from very low to very high), which were subsequently converted into numerical scores (1–5) to allow for comparison across signals (22–24). Respondents were asked to indicate whether each signal would strengthen or weaken readiness, which was coded on a scale from –2 (strongly weakens) to +2 (strongly strengthens). The anticipated timeframe during which the signal may impact influenza readiness was categorized as near-term (1–5 years), medium-term (5–10 years), or long-term (10+ years). Mean scores were calculated across respondents for each dimension to provide a comparative assessment of the relative influence of each signal. Given the small sample size, results are presented as descriptive averages intended to support comparative interpretation rather than statistical inference.

The survey results provide a comparative view of how experts assess the relative importance and timing of the six signals. Across all signals, mean impact scores ranged from 3.67 to 4.44, indicating that respondents consistently viewed these developments as having moderate to high potential influence on Canada's pandemic influenza vaccine readiness. Probability scores were similarly high (3.78–4.33), suggesting that respondents considered most signals likely to materialize or exert meaningful influence.

This foresight exercise does not seek to predict a single future outcome, but rather to identify a range of plausible developments that may shape influenza vaccine readiness in Canada. By examining emerging signals across scientific, geopolitical, and social domains, the analysis is intended to support strategic thinking and preparedness planning under conditions of uncertainty.

3.2 Emerging Findings

Six signals of change were identified and grouped under three "dynamics".

- Scientific and Technological Dynamics
    - Signal 1 — Emerging **vaccine technologies** and platforms
    - Signal 2 — Zoonotic influenza and patterns of **transmission** across One Health
- Global Political and Economic Dynamics
    - Signal 3 — Protectionism, **trade relations** and barriers and changing international relationships
    - Signal 4 — Stagnating **global investment** in surveillance infrastructures and global decline in research investment
- Social and Governance Dynamics
    - Signal 5 — The rise of **misinformation** and decline in trust
    - Signal 6 — Growing inequalities and lack of **data** to inform **equity** response including on vaccine coverage and trust

The six themes identified in the interviews were reinforced by the quantitative findings of the prioritization survey (Table 1). Differences between signals emerge more clearly when examining their anticipated effects on readiness and their projected timeframes. Signals associated with geopolitical

dynamics and public trust—particularly trade relations (Signal 3) and misinformation and trust (Signal 5)—were assessed as having high impact and probability in the near term, with negative implications for readiness. In contrast, scientific and technological signals, such as vaccine platform innovation (Signal 1), were viewed as highly impactful but more likely to strengthen readiness over a medium-term horizon.

Table 1: Comparison of Strategic Signals as Ranked by Key Informants

Signal	Impact (1-5)	Probability (1-5)	Readiness Effect (-2 to 2)	Anticipated Timeframe
Signal 1: Vaccine Technologies	4.33	4.22	+1.44 (Strengthens)	Medium-term (5-10 years)
Signal 2: Transmission	3.67	3.78	+0.56 (Strengthens)	Medium-term (5-10 years)
Signal 3: Trade Relations	4.44	4.33	-0.89 (Weakens)	Near-term (1-5 years)
Signal 4: Global Investment	4.33	4.00	-1.44 (Weakens)	Near-term (1-5 years)
Signal 5: Misinformation/Trust	4.25	3.89	-1.22 (Weakens)	Near-term (1-5 years)
Signal 6: Data/Equity	3.67	3.78	0.00 (Neutral/Mixed)	Near-term (1-5 years)

Overall, a clear pattern emerged highlighting that while system pressures are near-term, the technological opportunities are medium-term. No long-term (10+ years) signals were identified in this exercise, suggesting that expert attention—and perceived system pressures—is currently concentrated on near- and medium-term dynamics. This suggests that while technological innovation offers a robust path toward medium-term autonomy, Canada faces a critical window during the next five years where social and political instability may outpace its technical capabilities.

4. Signals of Change in a Shifting Global Context

This section describes each of the six signals of change in the three domains. It highlights a range of issues identified by key informants under each signal grounded in scientific literature, while considering existing and emerging trends that are on the horizon. It analyses how these trends can potentially interact to accelerate or disrupt pandemic influenza readiness in Canada.

4.1 Scientific and Technological Dynamics

These signals relate to emerging scientific advances and surveillance capabilities that may influence future influenza vaccine development, and regulatory authorization.

Signal 1—Emerging vaccine technologies and platforms

- Rapid advances in vaccine platforms (e.g., mRNA, protein-based) and alternative delivery systems (e.g., intranasal, microneedle/microarray patches) could significantly accelerate vaccine development timelines, improve rapid adaptability to emerging strains, and facilitate delivery and or uptake, though these advances may also involve higher costs and more complex manufacturing processes.
- However, key informants emphasized uneven readiness across platforms, including:
  - limited understanding of immune correlates of protection;
  - challenges scaling manufacturing; and
  - regulatory frameworks that remain oriented toward established evaluation and production models, including the use of animal models (such as ferrets) to assess immune response and approval pathways historically designed around egg-based vaccine production, which may not fully align with the characteristics or performance measures of newer vaccine platforms.
- While the development of a universal influenza vaccine remains a long-term ambition, experts described current progress toward a universal vaccine as incremental—focused on enhancing protection of existing approaches—rather than transformative in the near term.
- A key uncertainty is whether new platforms can achieve consistent effectiveness and longer-term immunity across diverse populations (i.e., need for increasing representation and equity in clinical trials) and if new advances can be swiftly integrated into routine production systems.

Signal 2—Zoonotic influenza and patterns of transmission across One Health

- Increasing complexity in human–animal–environment interactions is elevating the threat of zoonotic spillover events.
- Experts highlighted critical gaps in surveillance:
  - fragmented data systems across sectors and jurisdictions;
  - limited monitoring of higher-risk populations (e.g., farm workers); and

        - uneven integration of animal, environmental, and human health data.
    - Emerging tools (e.g., metagenomics, wastewater surveillance, AI modeling) offer expanded detection capacity but raise concerns about generating large volumes of non-actionable data.
    - A major uncertainty is whether Canada can operationalize a truly integrated One Health surveillance system–integrated across sectors and provinces and territories–capable of early detection, reporting and response.

4.2 Global Political and Economic Dynamics

These signals relate to changes in global funding, geopolitical relationships, and supply chains that may impact vaccine production and equitable access.

Signal 3—Protectionism, trade relations and barriers and changing international relationships

- Canada remains deeply embedded in global vaccine supply chains and has historically relied on strong alignment, in particular with U.S. research, manufacturing, regulatory and distribution systems.
- Experts identified growing geopolitical uncertainty including:
    - potential export restrictions and vaccine nationalism, including the possibility of countries prioritizing domestic supply during a crisis;
    - uncertainty and lack of predictability of Canada–U.S. collaboration; and
    - disruptions to global supply chains (e.g., for seed strains, active pharmaceutical components, laboratory components, adjuvants, eggs).
- Domestic biomanufacturing investments represent progress, but concerns remain about:
    - long-term commercial viability (e.g., economies of scale and profitability);
    - dependence on global supply chain components for domestic supply; and
    - the need for sustained interpandemic procurement strategies to maintain infrastructure viability.
- This signal reflects uncertainty over how Canada will balance global interdependence with domestic capacity, including what elements of vaccine readiness should be secured nationally versus through international collaboration.

Signal 4—Stagnating investment in surveillance infrastructures and global decline in research investment

- Pandemic preparedness relies on sustained global investment in research, surveillance, and collaborative infrastructures.
- Experts raised concerns about:
    - decline in U.S. funding for global health and multilateral institutions including the WHO, resulting in weakening of capacity of international institutions and collaborations;

        - decline in U.S. funding in research, including in vaccine research; and
        - instability in Canada for sustained funding for key influenza surveillance networks (Canadian Immunization Research Network–CIRN, Canadian Sentinel Practitioner Surveillance Network–SPSN), and networks established during COVID-19 (e.g., many COVID networks were not renewed, such as CoVaRR-Net).
    - Reduced investment could slow innovation in vaccine platforms, surveillance tools, and foundational science.
    - A key uncertainty is whether Canada or other partners will compensate for potential gaps in global research capacity.

4.3 Social and Governance Dynamics

These signals relate to public trust, health system governance, and the ability to ensure equitable vaccine distribution and uptake.

Signal 5—The rise of misinformation and decline in trust

- Experts identified both declining public trust and the spread of misinformation and disinformation as distinct but interconnected challenges to vaccine uptake and public health response.
- The information environment is rapidly evolving, shaped by:
    - algorithmically curated social media;
    - emerging generative AI tools; and
    - declining trust in government and scientific institutions.
- Traditional top-down communication strategies are increasingly ineffective, with growing need for:
    - trusted community messengers;
    - transparency and acknowledgment of uncertainty; and
    - more "upstream" communication about the social value of vaccines before an emergency.
- This signal reflects uncertainty about whether public health systems can adapt communication strategies to maintain trust in future crises. While misinformation shapes the information environment, declining trust in institutions reflects broader social, political, and historical dynamics that cannot be addressed through communication strategies alone.

Signal 6—Growing inequalities and lack of data to inform equity-informed responses, including on vaccine coverage and trust

- Current vaccination data systems are often fragmented and lack the granularity needed to monitor coverage, risk, and access across populations.
- Experts emphasized the importance of:
    - disaggregated data;

        - integration across jurisdictions; and
        - improved vaccine registries.
    - Equity considerations include:
        - ensuring Indigenous data sovereignty (e.g., OCAP© principles) and the necessity of building relationships and capacity for First Nations, Inuit and Métis leadership;
        - more diverse representation in clinical trials;
        - identifying non-traditional risk groups; and
        - the potential for vaccine delivery processes that increase inequities (e.g., mass clinics, online appointment systems).
    - Demographic shifts, including population aging, further complicate vaccine planning and delivery.
    - This signal reflects uncertainty around whether data systems and governance structures can support equitable vaccine distribution in future pandemics.

5. Recommendations for Strengthening Pandemic Influenza Vaccine Readiness in Canada

Building on the signals identified above, this section outlines key areas where Canada's influenza vaccine readiness systems may require strengthening in the face of emerging challenges.

5.1 Strengthening Surveillance Through a One Health Approach

Vaccine readiness and pandemic preparedness increasingly depend on the capacity for early detection across human, animal, and environmental systems, rather than reactive responses once transmission is established. However, current surveillance systems remain fragmented across sectors and jurisdictions, limiting the ability to detect and act on emerging zoonotic threats in a coordinated way. Strengthening a One Health approach will require more integrated data systems through improved coordination across sectors (academia, government, industry) and levels (municipal, provincial/territorial, national, international) that bring together human, animal, and environmental health information, alongside expanded surveillance in high-risk interfaces such as agriculture, wildlife, and occupational settings. The erosion of multilateralism at the global level is likely to undermine the international cooperation essential for effective strain identification and the surveillance of vaccine effectiveness, creating a higher need for Canada to demonstrate leadership in influenza surveillance and research.

At the same time, emerging technologies—including genomic sequencing, wastewater-based surveillance, and AI-supported modeling—are rapidly expanding the volume and scope of available data. While these tools offer significant potential, they also introduce new challenges related to interpretation, prioritization, and decision-making. Strengthening surveillance systems will therefore require clearer pathways from data generation to intelligence to inform public health decisions, and

mechanisms to manage increasing data complexity and uncertainty. Ultimately, the goal is not only to expand surveillance capacity but to ensure that surveillance is purposeful, actionable, coordinated, and sustainable over time.

5.2 Investing in a Responsive and Connected Vaccine System

Recent investments in domestic biomanufacturing of vaccines represent important progress toward strengthening national capacity (25). However, domestic production capacity alone is insufficient without sustained long-term procurement strategies to maintain operational readiness between pandemics, including with new domestic and global supply agreements and innovation in supply agreements approach that can guarantee suppliers with a market share. At the same time, Canada will remain embedded in global vaccine supply chain and dependent on international partnerships.

Building resilience in this context requires a more connected and continuous approach to vaccine system planning. This includes strengthening interpandemic purchasing and planning to sustain manufacturing capacity, improving coordination across federal, provincial, territorial, and global actors, and ensuring that regulatory processes are able to adapt quickly in emergency contexts. Canada needs a model of vaccine readiness that is not episodic or crisis-driven, but maintained as an ongoing, integrated system that is less vulnerable to geopolitical shifts.

5.3 Leveraging Emerging Technologies for Improved Vaccine Performance

Advances in vaccine technologies—including mRNA technologies, protein-based approaches, combination vaccines, novel adjuvants and novel delivery systems such as intranasal vaccines and microneedle patches—offer significant opportunities to improve both seasonal and pandemic influenza vaccine response. These technologies have the potential to reduce production timelines, increase adaptability to emerging strains, enhance the quality and duration of vaccines across different populations, and improve uptake and programmatic sustainability, thereby reducing the number of doses needed for population protection and the need for "an annual race" to produce seasonal influenza vaccines.

Perceived as the "holy grail" of influenza research, universal influenza vaccines have the potential to be a one-dose-for-life approach to several circulating and emerging strains of influenza. Currently, the plan outlined for the development of a universal influenza vaccine aims for at least 75% protection against symptomatic influenza, with protection lasting for one year and for all age groups (26). To date, no vaccine candidate has achieved this goal; however, ongoing efforts to enhance the breadth and durability of protection in existing vaccine approaches suggest a pathway of incremental improvement. Advances in understanding immune correlates of protection, imprinting, and cellular immunity, alongside efforts to elicit broadly neutralizing antibody responses, are expected to support incremental progress toward this goal (27,28) . The Canadian influenza research community is relatively small, and

sustained support and investment in maintaining Canadian expertise will be necessary to maintain Canada's innovative capacity.

Significant barriers continue to hinder both incremental improvements in vaccine performance and the development of a revolutionary universal vaccine. Foremost among these are persistent gaps in our understanding of complex immune responses and correlates of protection, alongside the technical and logistical challenges of harmonizing regulatory reviews and scaling new manufacturing and delivery systems. Furthermore, existing regulatory frameworks often lag behind technological breakthroughs, potentially delaying the deployment of next-generation platforms.

Addressing these challenges requires a shift from a strictly virological model to an immuno-epidemiological approach that accounts for diverse population-level immune histories. Ultimately, technological advancement cannot succeed in a vacuum; it must be reinforced by regulatory modernization, robust data integration, and sustained investment in basic science. This is especially critical as the recent erosion of U.S. research funding threatens global progress, requiring other global players such as Canada and the European Union to play a more prominent leadership role in filling these geopolitical gaps.

5.4 Strengthening Trust, Governance, and Equity in Vaccine Systems

Public trust is a key factor in vaccine confidence and, in turn, effectiveness of pandemic responses. Public trust shapes both vaccine uptake and the broader perceived legitimacy of public health interventions. Alongside the acceptability of vaccines, accessibility is equally important. Governance and data systems play a critical role in determining how vaccines are distributed and which populations are reached (29–31). Public trust is a critical determinant of vaccine uptake and the perceived legitimacy of public health interventions. However, declining trust reflects broader dynamics beyond misinformation alone, including perceptions of institutional transparency, accountability, and past experiences with public health systems (32,33).

Addressing this challenge requires moving beyond one-way communication approaches toward more relational strategies that prioritize dialogue, responsiveness, and engagement with community concerns. Trusted community-based messengers, as well as sustained engagement outside of crisis periods, are likely to be central to maintaining confidence in vaccination programs.

Data systems are a key enabling factor in this context, but their effectiveness depends on the strength of the relationships and governance structures that underpin them. In the Canadian context, there are ongoing opportunities to build more coordinated and trusted data governance systems through partnerships across federal, provincial, territorial, and community actors. Initiatives led by organizations such as the Canadian Institute for Health Information (CIHI), along with broader national discussions on health data governance and interoperability, provide a foundation for strengthening collaboration and trust (34). More integrated vaccination registries (with a One Health focus), improved

monitoring of coverage across populations, and the incorporation of equity considerations into planning and evaluation can support more targeted and effective vaccination strategies. Experts also emphasized the importance of respecting Indigenous data sovereignty, strengthening partnerships with communities, and embedding equity considerations within system design from the outset rather than addressing them retrospectively (35).

6. Conclusions

This foresight analysis identifies a growing misalignment between the pace of emerging threats to Canada's pandemic influenza vaccine readiness and the development of mitigating solutions that could strengthen our readiness. Across both interview findings and survey results, social and geopolitical risks — particularly those related to public trust, misinformation, and global supply dynamics — are expected to exert significant influence in the near term. In contrast, many of the scientific and technological advances that may strengthen vaccine effectiveness and response capacity are anticipated to mature over a longer timeframe. Open-text responses from experts to the survey reinforce this perspective, highlighting both the promise of vaccine innovation and the uncertainty surrounding its timing and implementation.

This exercise had limitations. First, our sample was limited to 14 key informants, with nine responding to the prioritization survey. While expertise spanned a broad range of perspectives across the influenza vaccine system, the number of participants remained relatively small. A larger and more diverse sample may have produced more nuanced interpretations of the identified signals.

Second, many experts interviewed were heavily involved in the COVID-19 pandemic response, which likely shaped how they reflected on pandemic preparedness and vaccine readiness during the exercise.

Third, no signals were identified as having primarily long-term (10+ year) implications. This may reflect the extent to which current social, political, technological, and geopolitical dynamics are evolving rapidly and unpredictably, making it more difficult to anticipate developments further into the future.

Overall, this foresight analysis emphasizes the importance of coordination across surveillance, research, and response systems, as well as the need to balance global interdependence with domestic capacity. The analysis also underscores the roles of trust, governance, and equity, including the importance of transparent communication, trusted partnerships, and flexible approaches to identifying and supporting at-risk populations.

The findings point to the need for a model of vaccine readiness that is continuous rather than episodic and integrates seasonal influenza systems with pandemic preparedness while remaining adaptable to emerging threats. The analysis highlights the importance of addressing near-term system pressures—including trust, data fragmentation, and global supply dependencies—while medium-term scientific

and technological solutions continue to develop with sustainable support. Together, these dynamics underscore the importance of strengthening coordination, flexibility, and resilience across the vaccine system as a whole.

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Appendix 1

Interview Guide

Preamble

Thank you for agreeing to participate in the interview process for the Public Health Agency of Canada (PHAC) **foresight analysis to identify signals that could influence Canada's future pandemic influenza vaccine readiness**.

The influenza vaccine landscape is changing rapidly, creating both opportunities and challenges for Canada's pandemic influenza vaccine readiness. To prepare for disruptive changes and anticipate the needs for strategic planning and appropriate investments, the Agency is working with the National Collaborating Center for Infectious Diseases (NCCID) to initiate a series of interviews across relevant sectors to inform this foresight process.

During this 60 min interview, we will ask you a series of questions to better understand how new technologies, innovation, changing social trends and geopolitical shifts may influence how Canada must prepare and plan for its pandemic influenza vaccine.
We will be recording the interview for analysis purposes only. All the responses will be anonymized, and the recordings and transcripts will be kept in a secured location, until the project is completed.

Do we have your consent to proceed to the interview and recording?
The questions will cover topics including Influenza transmission dynamics, warning signals and surveillance, emerging technologies, procurement planning and supply chain, geopolitical shifts and social trends, equity, and future scenarios. We understand you may be more comfortable answering some questions than others. Feel free to focus on the questions you are more comfortable with, and skip over the one you are not.

Interview Questions

1. **Expertise:** Can you describe your current role and how it relates to influenza vaccines?
    a. From your vantage point, what are you currently watching most closely in the influenza vaccine space?
    b. What developments concern you the most?
    c. What developments excite you the most?

2. **Transmission dynamics:** How do you expect patterns of influenza transmission evolving over the next 20 years?
    a. Are there early indicators that influenza seasonality may shift in Canada?

b. What assumptions about influenza transmission might become unstable in the next 10–20 years?
c. Are there environmental or One Health trends that policymakers are underestimating?
d. What factors do you see influencing these patterns (e.g. climate change, urbanization, animal and human migration, food industry, conflicts)? What will be the implication for vaccine development and procurement?

3. **Warning and surveillance:** How would you characterize the current state of influenza surveillance in Canada and globally?
    a. What are the weak points in Canada's influenza surveillance system?
    b. Are there technological shifts (e.g., metagenomics, AI-based modeling) that could dramatically improve or destabilize surveillance?
    c. What would an early warning failure look like?

4. **Emerging technologies**: What are the key emerging technologies that will change the landscape of influenza vaccines in the next 20 years?
    a. Are there technological shifts (e.g., AI, mRNA vaccine, Universal vaccines) that could dramatically improve vaccine development?
    b. What do you think will accelerate and delay the adoption and use of these innovations?

5. **Procurement Planning and Supply Chain**: What have been the key challenges for influenza vaccines supply, procurement and demand forecast in your perspectives?
    a. What would be solutions to help resolve those challenges?

6. **Geopolitical shifts and social trends**: What in the current geopolitical context and emerging social trends do you anticipate will impact Canada's future pandemic influenza vaccine readiness?
    a. How do you anticipate they will impact vaccine equitable access, manufacturing, and distribution in the next 20 years?
    b. How should Canada's post-COVID biomanufacturing strategy intersect with influenza preparedness?
    c. What shifts in public trust or vaccine attitudes could influence influenza vaccine uptake?
    d. Are there populations whose vaccine confidence trajectories differ from national trends?
    e. What would deteriorating trust look like in practical terms (e.g., coverage rates, misinformation ecosystems)?

7. **Equity**: Are there specific populations the government of Canada should pay special attention to in the next 20 years to ensure its influenza vaccine strategy is equity-driven?
    a. What would be key strategies to develop to ensure these populations are being included?
    b. How might inequities undermine Canada's pandemic influenza readiness?

c. What investments today would prevent inequitable access in a future pandemic?
d. How should equity factor into decisions about R&D, procurement, and distribution infrastructure?
e. Beyond traditional "high-risk groups," are there populations whose vulnerability may increase in the future?
f. What structural barriers to influenza vaccination might persist or worsen?

8. **Government readiness**: If you were advising the government today, what are the most important capabilities or investments it should prioritize now to ensure long-term equity-driven influenza vaccine readiness under the current geopolitical conditions and climate of uncertainties?

9. **Future scenarios**: Reflecting on your answers, how do you imagine the future for influenza vaccines in Canada? What would be the ideal scenario for optimal outcomes? What do you see as the worst case scenario?

10. **Positioning Canada**: What would be critical for Canada when imagining optimal outcomes for influenza vaccines?
    a. What assumptions about influenza vaccine readiness do you think policymakers currently hold that may not hold in 10–20 years?

Closing the interview

- Is there anything else you would like to share with us that you think would be important to consider?
- We will send you a prioritization survey, once we have completed all the interviews. This will take 15 min of your time, and it will help us prioritize the signals we will find during this foresight exercise.
- Are there other resources that you can think of that we should look for to inform this foresight analysis?

We thank you for your time and your thoughts. A summary of the foresight findings will be shared with you once the analysis is complete.