

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

7.1.6 Electricity Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Electricity Generation											
Wind (Onshore & Offshore)	<i>Priority</i> Decarbonization Pathway Expected to provide significant portion of power in a net-zero future. Canada has a vast wind resource on land and coastlines.	Deploy Support deployment with permissive regulatory environments. Educate public to reduce safety and environmental misconceptions.	 Clean power but needs storage to handle intermittent generation.	 One of the cheapest sources of new electricity, with low operating costs. Offshore wind costs remain higher. Intermittency may add costs.	 Drives jobs in manufacturing, construction, and maintenance. Boosts rural incomes through land leases and taxes. Positions Canada for export opportunities.	 Fully commercial—mature technology deployed widely. Offshore wind is less mature in Canada but proven in Europe.	 Integrates well with modern grids but challenges remain with regard to balancing and storage.	 Typically requires new transmission from wind areas to demand centres.	 Generally accepted but local opposition can be significant. Community involvement can improve acceptance. Offshore has higher acceptance.	 Aligned with federal and most provincial clean energy goals. Backed by utilities, provincial plans, the wind industry, and some landowners.	 No air pollution or water use during operation. Some issues with noise, migratory bird or bat deaths, and landscape impacts.
Utility-Scale Solar PV	<i>Priority</i> Decarbonization Pathway Costs now rival or beat new gas, and suitable land/rooftop area is ample.	Deploy Support deployment with permissive regulatory environments and R&D in cold-climate regions.	 Clean power (assuming panel lifecycle emissions are managed) but needs storage to handle intermittent generation.	 Cost-competitive with or cheaper than new natural gas generation in certain provinces. Intermittency may add costs.	 Construction and maintenance jobs. Draws private investment, boosts local tax revenues, and supports innovation and exports.	 Technology is proven. Multiple large solar farms operate in Canada. Performance in cold climates being demonstrated.	 Easy to connect at various scales, but high adoption needs better grid management.	 Most useful when paired with storage or hydro, but output varies seasonally.	 Strong support. Local concerns about land use can arise.	 Utilities for grid planning. Governments and regulators for meeting clean energy targets. Industry and communities through deployment.	 No direct emissions and improves air quality and health. Recycling of panels is immature.
Small-Scale & Residential Solar PV	<i>Potential</i> Niche Pathway Constrained by roof space and economics but still material.	Engage Upgrade local grid infrastructure to allow for smart metering. Provide financing options to assist in managing upfront costs.	 Clean power (assuming panel lifecycle emissions are managed).	 Costly without incentives but offers savings and local grid benefits. Costs are gradually declining.	 Local job creation in installation, sales, and manufacturing. Widespread adoption spurs investment within communities.	 Mature with numerous installations in Canada.	 Requires sunny, grid-connected areas or remote areas paired with batteries. Can require backup through winter.	 Integrates easily on rooftops with little land or new infrastructure needed. Some smart meters and local grid upgrades needed.	 Generally very high public acceptability with no notable opposition.	 Consumers and municipalities for cost savings and energy independence. Mixed views from utilities for grid impacts and revenue concerns.	 Clean, quiet energy source with reduced grid strain during peak times. Minimized land impact. Recycling of panels is immature.

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Building-Integrated Solar PV	Niche Pathway Typically only used in showcase buildings.	Deploy Encourage interest from developers and building owners with financing mechanisms. Provide workforce training for installation. Work to integrate micro generation with the larger electricity grid.	 Clean power (assuming panel lifecycle emissions are managed).	 Costs have dramatically declined over time. Economics can depend on regional incentives. Return on investment occurs in solar panel lifespan.	 Industry is well established. Some opportunities for local installers and domestic material production.	 Commercially Mature.	 Best on sun-exposed surfaces in space-limited urban buildings. Must be integrated into building design and meet codes.	 Supply chain is early commercial.	 Widely accepted and non-disruptive.	 Niche interest among innovation-focused stakeholders, with limited utility impact due to small scale.	 When paired with storage they provide resilience in power outages and reduce peak demand. Can sell energy back to the grid. Immaturity of recycling panels and differing lifespan from building materials.
Hydro (Reservoir)	Decarbonization Pathway Forms the backbone of Canada's decarbonized baseload power. In the future, new generation will be challenging.	Deploy Support new builds where site conditions are economical and expansions where feasible. Collaborate with Indigenous communities. Expand and improve transmission infrastructure.	 Achieves net zero. Some GHG emissions associated with initial flooding and land changes, but these can be mitigated over time.	 New generation is likely to be capital-intensive, with long payback but low operating cost. Competes well on cost per MWh if sites are appropriate.	 Large projects spur employment. Limited new dam opportunities, but exporting hydro power can generate revenue.	 Mature technology with decades of operation.	 Compatible with grid needs. Some concerns about impact of changing climate on reservoir levels.	 Large dams require extensive transmission build-out to deliver power. New projects still face logistical challenges.	 Historically mixed — strong opposition from Indigenous groups and environmentalists for new large dams. Shared equity or co-governance with Indigenous communities can improve acceptability.	 Provincial utilities for reliable baseload and storage capacity. Relevant to Indigenous communities where there are equity stakes, co-governance, and early engagement.	 Delivers clean energy balancing other intermittent renewables (water reservoir storage). However, can lead to flooding of ecosystems and Indigenous lands.
Hydro (Run-of-River)	Niche Pathway Strong fit where geography allows, yet cannot scale to a large national share.	Deploy Support buildout where site conditions are favourable. Collaborate with Indigenous communities.	 Can supplement big hydro reservoirs.	 Cost per kWh can be competitive in favourable sites.	 Regional construction and contracting opportunities for smaller firms. In Indigenous or rural areas, can spur local economic activity.	 Proven technology and mature. Deployments in Canada are ongoing but site-specific.	 Particularly suitable for remote or smaller grids.	 Integration is simple, but remote projects need new transmission lines on a smaller scale.	 Generally more accepted than large dams. Local opposition still possible from environmental groups and Indigenous communities.	 Local and Indigenous communities looking for development. Provincial utilities looking for incremental additions to the grid.	 Avoids large reservoir flooding and has a lower ecological footprint. Can have a negative impact on river health.

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Nuclear (Conventional Reactors)	Decarbonization Pathway Makes up a large share of non-emitting baseload. Development beyond current assets is limited.	Deploy Future support may be relevant in provinces with uranium supply chains or long-standing operational experience.	Zero-emission, steady power. Requires decarbonized mining and waste management to handle upstream and downstream emissions.	Costly and have a history of significant cost overruns and schedule delays. Interest where nuclear supply chains are being built out.	Supports high-skilled jobs via refurbishments. Limited new builds constrain broader economic growth potential.	Mature and reliable. Large reactors remain complex with limited recent innovation.	Fits well but requires major scale, long timelines, and is less flexible for variable renewables.	Strong nuclear supply chains and fuel security, but new builds require major infrastructure and could strain current capacity.	Mixed and region-dependent. Strong backing in some areas (e.g., ON) but persistent concerns over safety and waste in others (e.g., BC, NS).	Ontario and industry group interest. National momentum is building. Investment shifting away from large new builds.	Waste product difficult to manage and some security and safety concerns. Waste heat can have negative impacts on water quality.
Nuclear (Small Modular Reactors)	Potential Decarbonization Pathway Successful deployment has not yet occurred in Canada. Cost and schedule overruns may pose significant barriers.	Incubate Support R&D, pilots, and demonstrations. Build out supply chains capable of manufacturing SMR fuel sources and modular parts.	Zero-emission, steady power. Requires decarbonized mining and waste management to handle upstream and downstream emissions.	Unclear — still in development. Capital costs per kW are not well established.	Could drive major job creation, exports, and domestic industry growth.	Research & prototype stage. No SMR is commercially deployed in Canada yet. Proven in small test reactors.	Some SMR designs well-suited to smaller grids, industrial sites, and remote areas. More flexibility for grid operators.	Strong nuclear supply chain foundations but suitability varies by reactor design. Some SMRs require new fuel sources, modular manufacturing capacity, and upfront supply-chain investment.	Cautious but growing - strong near existing plants, mixed in remote areas, limited nationally.	Backing from federal and some provincial governments, utilities, and heavy industry. Align with decarbonization and energy reliability goals.	Waste product is difficult to manage and some security and safety concerns. Waste heat can have negative impacts on water quality.
Geothermal Power (Closed Loop, Conventional, and Deep)	Potential Decarbonization Pathway Geothermal has potential for generating net-zero electricity and heat.	Enable Support closed loop R&D as well as pilot and demonstration projects. Support longer-term development of deep geothermal.	Conventional geothermal releases some carbon dioxide. Closed loop and deep geothermal are more promising for net zero.	Not currently cost-competitive in Canada currently due to high drilling and capital costs. Potentially viable in remote areas.	Potential dependent on cost-effectiveness. Can create jobs in drilling and operations, reduced fuel imports in remote communities, and exportable tech.	Demonstration stage with one closed loop project under construction in Canada. Deep geothermal in early research.	Site-dependent and best suited to regions with accessible heat at depth. Deep geothermal has wider geographical applicability.	Can leverage oil & gas infrastructure and expertise with standard equipment and a ready supply chain.	Significant concerns of seismic activity for conventional geothermal. Support from off-grid Indigenous communities with closed-loop systems.	Western provinces, oilfield service firms, and federal innovation programs as a transition opportunity. Utilities are cautious.	Small land footprint and co-benefits (usable heat, grid stability, consistent performance, etc.). Can affect water quality if conventional geothermal is used.

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Biomass Power (Combustion)	Niche Pathway Feedstock supply is limited. Likely only economical and net-zero in very niche circumstances such as on-site power generation.	Don't Prioritize Unlikely to have a role in mainstream power generation. Watch for niche opportunities to support local or on-site power generation.	 Dependent on biomass carbon intensity, land change, and transport emissions. Likely requires CCS to achieve net zero.	 Costlier per kWh than wind or solar. Can be viable at small scale near cheap waste feedstock.	 Opportunities in rural and Indigenous communities through local jobs and valorization of forestry residues. Limited growth potential.	 Mature, proven technology widely used in Canada, especially at pulp mills.	 Baseload or on-demand power in biomass-rich regions. Requires developed fuel supply chains and consistent feedstock.	 Challenges around feedstock availability and industry competition.	 Mixed — higher when using waste feedstocks at small, clean facilities. Concerns of sustainability, traffic, and air pollution.	 Minimal interest from utilities, urban planners, and energy developers due to supply risks and higher costs.	 Total lifecycle emissions are variable. Air quality pollutants can be worse than burning natural gas. Land use changes can be negative.
Gas with CCS	Bridge Pathway Can be used as a backup power source while renewables are built out or marginal balancing in a net-zero system.	Don't Prioritize Watch for local or regional power reliability issues. Could be useful as backup power.	 Difficult to capture all emissions with CCS. Requires negative emissions to offset lifecycle emissions (extraction, transport, and combustion).	 Costly due to CCS. Needs subsidies but may become moderately competitive for baseload power.	 Protects existing energy jobs and supports regional CCS industries. Development depends on CCS demand and innovation.	 Demonstration stage. Technology for post-combustion capture from gas turbines is being tested.	 Best for steady-output roles. Can support flexible power with efficiency trade-offs in peaking or cycling applications.	 Benefits from existing infrastructure but requires new CO ₂ pipelines and strong methane management.	 Generally accepted if seen as a climate solution. Opposition remains over continued fossil fuel reliance and CO ₂ storage concerns.	 Relevant to gas producers and suppliers, Alberta, and industries needing firm power.	 Aids grid stability. Air quality and health issues with conventional combustion.
Coal with CCS	Dead-End Pathway Not required in Canada to reach net-zero.	Dismiss Difficult to fit with existing operations and infrastructure.	 Requires carbon offsets which can be limited. Perpetuates use of materials that will have little functionality in a net-zero economy.	 Very high cost and poor economics. can double the cost of electricity. More costly than renewables or gas + CCS.	 Apart from CCS, which has limited growth prospects, there are better opportunities in other clean energy sectors.	 Coal power plants are mature, but CCS is demonstration stage at scale, with one project in Saskatchewan.	 Frequent maintenance outages observed and requires suitable geology to store CO ₂ nearby. Coal phase-out makes this operationally irrelevant.	 Uses existing coal infrastructure with added capture units and CO ₂ pipelines. Coal fleet is being phased out.	 Negative due to coal but moderate CCS acceptability.	 Policies and utilities move to phase out coal entirely.	 Issues with air quality and health from exhaust. Water demand and upstream emissions (associated with mining) are high.

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 Grid Infrastructure and Electricity System Expansion and Improvements											
Inter-provincial Interties	Enabling Pathway Can reduce costs for decarbonization and increase grid resilience.	Deploy Encourage provincial collaboration and support interties that improve power reliability and security.	 Ensures reliability with renewable generation. Clean power can be available when local supply is limited.	 Economics can be positive depending on the projects. Funding is available but requires collaboration between parties.	 Reduces reliance on the U.S. and creates domestic jobs through infrastructure construction and maintenance. Generates domestic demand for electrical equipment manufacturing.	 Transmission technology is mature, but autarchical approach historically hampered progress.	 Provinces operate and plan resources individually. Some connections are geographically difficult with long timelines.	 New or larger transmission lines are required.	 Transmission lines often face local opposition. Shared ownership with Indigenous communities can help build support.	 Greater flexibility and reliability for users. Complexity with provincial collaboration and planning.	 Enhances power reliability in Canada and lowers decarbonization costs but requires new or expanded transmission corridors, leading to potential land disruptions.
International (U.S.) Interties	Enabling Pathway Not a priority for decarbonizing Canada. With political tensions and tariffs, economics have some risk.	Don't Prioritize Most connections and exports already established. Monitor for new export opportunities. Prioritize provincial interties.	 Offers an export opportunity for Canada's excess renewable power.	 Economics depend on the project and power demand within U.S. regions.	 Already a mature industry. Exports could grow with excess domestic power and increasing decarbonization requirements in the U.S.	 Already occurs in every province bordering the U.S.	 Requires strong collaboration between provinces and states, which can be difficult due to misalignment on goals, planning or regulations.	 Requires upgrades to existing transmission lines.	 Transmission lines often face opposition, as they require support across multiple jurisdictions. Additionally, international political tensions may heighten public scrutiny.	 Strong political tensions due to tariffs. Requires many parties to collaborate.	 Both countries benefit from increased reliability in the power grid and cleaner electricity. Some land use changes.
Grid Improvements	Priority Enabling Pathway Necessary to accommodate increased power demand. Raises grid efficiency, reliability, and resilience.	Deploy Support with stable financing. Support testing and piloting of new technologies and build out regulatory environment to include these.	 Integral to the net-zero future and its associated electrical demand across Canada.	 Cost structures vary by the type of improvement. Funding is available for some options.	 Installation and construction jobs in areas completing improvements.	 Depending on the technology, some are established (underground transmission lines) and some are emerging (smart grids).	 Proven technologies can integrate seamlessly whereas newer technologies can be complex with slow regulatory processes.	 Capacity and transmission will need to expand so that location specific needs are met.	 Improved grid reliability is seen positively but increased visible power lines may have opposition.	 Highly important to power companies for improving grid reliability, but viability depends on payment structures and government support to make business cases feasible.	 Improved reliability of electricity delivered to customers.

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Power Storage	Enabling Pathway Necessary to reach net zero where power supply is primarily supported by intermittent renewables.	Enable Support R&D so economics improve and demonstration or deployment where contexts are economically positive. Reduce regulatory hurdles for new technologies.	Prevents excess generation going to waste and mitigates issues related to the intermittency of renewable energy sources.	Costs vary by technology but are falling. Currently and only cost-competitive in certain contexts (remote locations or peak shaving).	Vary by technology but opportunities and projects are emerging associated with domestic jobs.	Some technologies (hydro reservoirs) well developed where others (grid batteries or pumped storage hydropower) at varying levels of commercialization and deployment.	Improved grid operations, Can help with diurnal peaks. Seasonal battery storage not yet feasible or economic.	Will require some changes to connect to the grid but should reduce the burden on infrastructure.	Depends on technology, location and size of projects not widely implemented yet.	Aligns with objectives to improve grid reliability, counteract peaking, and work with intermittent renewable generation.	Counteracts the intermittency of renewable generation.
Demand Side Management	Enabling Pathway Required to reduce and manage overall power demand.	Deploy Support regional and local testing and piloting to determine the best methods and subsequent deployment.	Reduces need for new power generation.	Often cheaper for governments than adding additional electrical infrastructure.	Frees electricity for industry, export, and trade.	Implemented in some locations in Canada with mild success compared to other locations.	Is mainly implemented through policy and regulations which may have downstream effects on operations.	Functions with existing infrastructure and can reduce burden on the existing system.	Resistance to utility-controlled demand. Programs need to be communicated clearly to the public.	Can offer large savings. Seen as very favourable to utilities and large electricity users.	Reduces environmental burden through avoided power generation and grid peak loads. Lowers energy costs.
Energy Efficiency	Enabling Pathway Required to reduce end demand for power.	Deploy Provide education to manufacturers, installers, retrofitters, and purchasers on the benefits of high-efficiency assets. Offer financing mechanisms to help with up-front costs where relevant (i.e. low-income and cold-climates).	Reduces need for new power generation.	Often cheaper than adding additional electrical infrastructure. Funding can vary widely by application and region.	Job growth in many end-use sectors with retrofits and technology installations or upgrades.	Maturity of high efficiency technologies vary by sector and application.	Typically requires purchase of new assets.	Can require import of new end-use technologies. Reduces burden on existing infrastructure.	Understanding and perceptions of efficient equipment can vary widely. Higher-efficiency appliances may also carry higher up-front costs, raising equity concerns.	Inconsistent information leads to limited understanding, causing many stakeholders to undervalue the effectiveness and deprioritize adoption.	Cost savings for consumers and providers. Reduces environmental burden through avoided power generation and grid peak loads. Lowers energy costs.

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7.2.5 Hydrogen Pathways Table

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Autothermal Reformation with Carbon Capture and Storage (ATR & CCS)	Potential Decarbonization Pathway Provides significant GHG reductions in hydrogen production.	Enable Invest in oxygen production, and CO ₂ supply in regions with natural gas and geological storage. Support demonstration and prioritize regulatory and infrastructure frameworks.	 Significant GHG reductions. Very high capture feasible via pure O ₂ feed. May require removals for residual emissions. Requires upstream methane capture.	 Moderate premiums from incumbent. More efficient capture process than steam methane reformation + CCS.	 Drives oxygen and CCS services. Regional job growth.	 Demonstration phase.	 High capture efficiency with simplified CO ₂ capture. Requires oxygen production and integration.	 Requires hydrogen pipelines and storage or nearby industrial users. Needs O ₂ supply, CO ₂ compression hubs and storage.	 Generally accepted but public concern over hydrogen safety and CCS leakage.	 Hydrogen producers and natural gas industry as a longer-term net-zero hydrogen production strategy.	 Some concerns about CO ₂ and hydrogen leakage and continued upstream methane emissions.
Steam Methane Reformation with Carbon Capture and Storage (SMR & CCS)	Bridge Pathway Cannot eliminate emissions. Use as an opportunity to codevelop CCS.	Don't Prioritize Do not lead with new investment in CCS retrofits for SMR. Focus investments on ATR and CCS. Allow existing assets to run through their lifespans.	 Offers moderate emissions reduction but cannot reach net zero without combination with negative emissions due to dilute flue gas.	 Moderate premiums from incumbent. High capital costs for retrofit with CCS infrastructure and ongoing operational complexity.	 Maintains existing industrial base and jobs in regions with natural gas resources. Drives CCS services.	 Mature and deployed in Canada.	 Compatible with existing SMR plants, but flue gas capture retrofit is complex.	 Requires hydrogen pipelines and storage or nearby industrial users. Needs CO ₂ compression hubs and storage.	 Generally accepted but public concern over hydrogen safety and CCS leakage.	 Hydrogen producers and natural gas industry as near-term emissions reduction strategy.	 Air pollution concerns. Some concerns about CO ₂ and hydrogen leakage and continued upstream methane emissions.
Pyrolysis of Natural Gas	Potential Niche Pathway Beneficial in regions with natural gas supply and with technical maturity. Provides significant GHG reductions in production.	Incubate Fund R&D and pilot projects to prove commercial viability. Develop markets for carbon black.	 Enables net-zero hydrogen with solid carbon byproduct. May require removals for residual emissions. Requires upstream methane capture.	 Moderate premiums from incumbent. Higher gas consumption. Emerging tech with pilot costs.	 Potential market for carbon black. New manufacturing opportunities.	 Pilot/ demonstration stage.	 Operates similarly to SMR but yields solid carbon. Requires reactor modifications.	 Requires solid carbon- handling supply chain. Nascent support. Requires hydrogen transport and storage or nearby users.	 No particular concerns. Public is unfamiliar with carbon black products.	 Hydrogen producers. Maturity and markets for products limiting uptake.	 Avoids flue gas emissions. Produces marketable carbon black product. Risk of continued upstream methane emissions.

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Electrolysis with Clean Power	Decarbonization Pathway Can produce net-zero hydrogen.	Enable Invest in electrolyzer supply chains and grid interconnections. Support deployment in regions with surplus clean electricity.	 Fully decarbonizes when powered by clean electricity.	 High premiums compared to SMR. Cost declines with renewables.	 Stimulates electrolyzer manufacturing and grid integration.	 Mature but limited commercialization.	 Compatible with existing water and power infrastructures with minor adjustments. Flexible scaling.	 Requires grid upgrades, high-voltage interconnects, electrolyzer supply chain. Requires hydrogen transport and storage or nearby users.	 Highly favourable where clean power exists.	 Hydrogen producers and utilities have begun developing some commercial projects.	 Complements renewable electricity generation. Integration as storage and transportation option. Supports grid balancing.
Biowaste Gasification	Potential Niche Pathway Likely only economical and net-zero in very niche circumstances.	Don't Prioritize Watch for improvements in feedstock costs and conversion efficiency. Prioritize investments if site-specific conditions demonstrate viability.	 Moderate GHG reduction. Dependent on sustainable feedstock availability.	 High operation, maintenance, and feedstock costs.	 Creates rural jobs. Supports waste management and circular economy.	 Demonstration stage.	 Requires biomass pre-processing. Fits waste-to-energy sites.	 Needs certified biomass supply chains. Limited scalability. Requires hydrogen transport and storage or nearby users.	 Waste management supportive. Public views mixed.	 Waste operators and municipalities.	 Reduces landfill emissions. Provides local feedstock management. Competition with other sectors for feedstocks.
Byproduct of Industrial Processes	Niche Pathway Only available from limited chemical production pathways.	Deploy Support capture and utilization of existing byproduct hydrogen streams where economical.	 Moderate GHG reduction. Leverages concentrated process streams.	 Highly viable where hydrogen concentrated. Minimal incremental cost depending on purity of hydrogen byproduct.	 Very limited opportunity to expand as hydrogen supply is dependent on other industries and finite.	 Fully commercial.	 Direct integration into existing process off-gas capture systems.	 Uses on-site infrastructure.	 Broadly accepted as efficient waste valorization.	 Supported by chlor-alkali and petrochemical industries.	 Cost-effective hydrogen supply. Reduces flaring. Improves overall plant efficiency.

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Natural or Geological Hydrogen	Potential Decarbonization Pathway Potential for large GHG reductions but maturity is currently too low to determine overall role.	Don't Prioritize Track geological exploration results and early research. Commit capital when resource potential and extraction methods are clear.	 Fully decarbonized hydrogen.	 Potential to be very low cost, but still speculative.	 Opportunity to develop hydrogen production in regions that find geological potential.	 Research phase; no real-world applications.	 Some geological hydrogen production methods fit with existing utility systems; others would require modification.	 Requires build out and supply of new facilities and technologies.	 Similar concerns to other resource extraction operations	 Some research and early geological exploration are occurring in Canada.	 Some concerns with water pollution depending on the method of production.

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d	Deep lifecycle emission reductions with forestry and other organic residues.	Higher direct production cost than HEFA but cheaper per tonne of CO₂ abated. Still requires policy support and offtake certainty.	Strong domestic potential. Integrated biorefineries, forest and agricultural residue value chains, and Canadian opportunities in gasification and FT.	Integrated FT-SAF at commercial scale is pilot/demo. Limited Canadian deployment.	Drop-in replacement for jet fuel. No aircraft or fuelling infrastructure changes required.	Biomass and residue supply chains emerging. FT synthesis and low-carbon H₂ infrastructure not yet at scale. Aviation blending infrastructure is in place.	Generally positive. Waste valorization and residue use are supported by communities.	Forest sector and waste managers for waste valorization. Federal government funding R&D.	Multiple co-benefits: waste diversion, forest management support, co-production of renewable diesel. No food competition or land use change concerns.
		Moderate to deep lifecycle reductions depending on feedstock/crop chosen and associated land use changes. Crop-oil HEFA can exceed some fossil fuel intensities. Would require removals for net zero.	High costs relative to fossil jet fuel. Viability depends on policy support.	Moderate opportunity for domestic production in crop oil (i.e. canola) regions. Limited Canadian IP. Technology is imported.	Commercial globally. Canadian facilities are emerging.	Drop-in replacement for jet fuel. No aircraft or fuelling infrastructure changes required.	Compatible with existing blending and distribution infrastructure. Sustainable feedstock supply is the main constraint on domestic scale.	Virgin crop oils face growing food-vs-fuel and land-use concerns. Concerns less acute for Canadian canola given its stable cropland base.	Some airlines and airports actively purchasing fuel, limited by cost and supply. Federal regulations in progress; some provinces are further ahead.

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 Heavy Duty Diesel End Users											
Renewable Diesel	Niche Pathway Drop-in fuel compatibility and strong lifecycle reductions. Supports hard to electrify end users. Long term net-zero alignment requires sustainable feedstocks and removals.	Deploy Continue support to ensure cost parity. Provide education to end-users on drop-in capabilities.	 Drop-in fuel, delivering significant lifecycle CO ₂ cuts. Net zero requires sustainable feedstocks and complementary carbon removal.	 Currently requires support for price parity.	 Potential for domestic production and associated jobs.	 Commercial and rapidly scaling.	 Fits existing diesel engines and distribution networks without retrofit. Better cold-weather performance than some alternatives.	 Uses existing storage and pipelines but can be difficult to procure.	 Concerns of competition with food crops.	 Interest from hard hard-to-electrify industrial end users (i.e. trucking fleets). Developing interest from fuel producers to supply emerging markets, but confusion remains with properties of other alternative fuels.	 Improves air quality while retaining energy density. Risk of locking in diesel dependency for end users who could otherwise electrify.
Biodiesel	Potential Dead-End Pathway Provides near-term emission reductions using existing engines and infrastructure. Blending limits and feedstock availability limit uptake.	Don't Prioritize Not drop-in. Provide information on the quality differences between renewable diesel and biodiesel.	 Can cut tail-pipe CO ₂ significantly, but blending limitations exist with unmodified engines. Net zero requires sustainable feedstocks and complementary carbon removal.	 Costs greater than fossil fuel diesel.	 Creates domestic demand for used cooking oil and canola oil, boosting farm and refining sectors. Competes with food.	 Commercial, but climate-grade quality still improving.	 Compatible with diesel engines to B20. Cold weather performance and material sedimentation limit higher blends.	 Separate heated tanks are needed in winter. Logistics become complex above the B20 blend.	 Generally positive when made from wastes. Land-use change for virgin crops draws scrutiny.	 Can be less relevant than renewable diesel.	 Improves lubricity and reduces particulate matter. Offers a practical bridge until zero-emission drivetrains dominate.

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PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Heat and Power Production											
Renewable Natural Gas (RNG)	<i>Potential Niche Pathway</i> Complements hard-to-electrify end uses and applications. Limited feedstocks constrain scale.	Enable Support projects that reduce methane emissions from waste. Focus funding on projects with secured long-term end users.	 Moderate GHG reduction. Methane capture benefits. Net-zero requires sustainable feedstocks and complementary carbon removal.	 Viable with support. Cost competitive under supportive policy environment.	 Creates jobs in waste management and valorizes agricultural residues.	 Emerging commercial.	 Compatible with existing pipelines and end-use equipment.	 Fully compatible with gas networks. Limited by feedstock availability and interconnection.	 Varying acceptance. Issues with increased traffic and odours. Seen as waste valorization.	 Seen as economic addition for agricultural and waste management. Gas utilities to leverage existing networks.	 Reduces fugitive methane. Potential for fertilizer production.
 Light Duty Vehicles											
Ethanol	Dead-End Pathway Limited lifecycle emissions reductions and sustainability concerns make ethanol unlikely to have a meaningful role in net zero.	Dismiss Not net-zero in its primary use of light duty vehicle decarbonization. Support transition to other pathways.	 Limited GHG reductions. Food-vs-fuel controversies over land use and feedstocks.	 Affordable and viable with support.	 Low value-add. Small rural jobs. Competes with food.	 Fully commercial.	 Compatible with gasoline blending up to E10. Higher blends need flex-fuel vehicles.	 Incompatible with existing pipelines beyond 10% blends. Requires new infrastructure.	 Mixed: accepted historically but declining due to sustainability concerns.	 Provincial regulators and oil refiners. Limited OEM engagement.	 Reduces gasoline emissions modestly. Supports legacy ethanol plants.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Advanced Bio and Synthetic Fuel Pathways											
Advanced Biofuel (Biomass-to-liquids)	Niche Pathway Delivers deep emissions reductions where sustainable feedstocks/ biogenic CO ₂ and low-carbon electricity exist, but restricted by localized and limited ability to obtain feedstocks.	Incubate Support R&D projects.	 Achieves high emissions reductions but requires substantial biomass feedstocks/biogenic CO ₂ and clean power. Feedstocks used must be decarbonized. May still require removals.	 High production costs due to complex multi-step conversion. Requires supportive policy environment.	 Creates integrated biorefineries and supports biogenic carbon capture build-out. Some provinces developing demonstration projects.	 Pilot/ demonstration.	 Drop-in compatibility with all diesel engines and aviation turbines.	 Requires biomass or biogenic carbon supply chains, gasification plants, and synthesis facilities. Forestry residue supply chain exists.	 No particular concern.	 Forest sector and waste managers for waste valorization. Federal government funding R&D.	 Multiple co-benefits: waste diversion, forest management support, co-production of renewable diesel and SAF. No food competition or land use change concerns.
Synthetic / E-Fuel	Potential Niche Pathway Potential for net-zero compatibility with offset or directly captured CO ₂ and low-carbon hydrogen.	Don't Prioritize Watch to see if economics or maturity improve; support if progress is made.	 Potential for deep lifecycle reductions. Carbon intensity depends directly on the H ₂ source and how CO ₂ is captured or offset.	 Not viable. High electricity input and low conversion efficiencies. Costs hinge on low-carbon H ₂ and CO ₂ capture/offset maturing at scale.	 Long-term manufacturing potential. Requires new industrial clusters.	 R&D/Concept.	 Drop-in compatibility with all diesel engines and aviation turbines.	 Requires low-carbon hydrogen, captured or offset CO ₂ (i.e. from direct air capture), and synthesis plants. No existing supply chain.	 Public awareness is low. Acceptance will depend on framing. Conceptually attractive as a “drop-in” net-zero fuel.	 Research institutions, energy ministries as a long-term feedstock-secure fuel production pathway.	 Unaffected by biomass supply chain instabilities.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Targets one element of oil and gas production emissions. Reduces significant near-term GHG emissions. Would require complementary measures including carbon removals to get to net zero.	Low cost compared to other direct GHG management measures. Potential to recover saleable gas, partially offsetting costs.	Growing market for specialized oil and gas equipment. Canada has many technology firms and can export tech and expertise.	Many technologies mature and used across Canada.	Integrates with existing processes.	Relies entirely on existing upstream infrastructure. Well-established domestic supply chain of equipment manufacturers, service companies, and measurement technology providers.	Reduces pollution. Broadly accepted.	Relevant to governments and producers as frequently lowest cost abatement option.	Can improve air quality around operations.
Can eliminate meaningful share of emissions from specific facilities. Does not address very dilute upstream sources or end-use combustion. Will require additional removals.	Adds operating cost without revenue generation. Requires strong policy signals.	Potential for CCS expertise as an export.	Mature for some applications. Used internationally and in Alberta.	Retrofits feasible at large point sources. More complex at distributed upstream facilities.	Requires CO₂ pipelines and storage hubs. Alberta geology is well-characterized but transport network is limited.	Public concern around long-term leakage and liability. Mixed Indigenous perspective.	Strong industry interest. Weak regulatory signals.	Co-benefits through CO₂ feedstock for industrial uses. Continued environmental concerns from oil and gas production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electrification of upstream operations electric drives, grid-tied facilities, co-gen displacement, vehicle fleet and equipment electrification	Decarbonization Pathway Essential to decarbonizing the energy used in oil and gas production. Requires decarbonized electricity.	Deploy Prioritize transmission build-out into oil sands basins. Requires supportive policy environment.	Can decarbonize many upstream operations, equipment and process heat, but dependent on decarbonized electricity.	Economics currently challenged and would require significant policy intervention.	Stimulates demand for clean power, transmission, and electrical trades. Retains regional employment.	Deployed at Canadian sites, including some oil sands in-situ operations.	Requires facility redesign and reliable grid access or substantial decarbonized on-site generation.	Requires significant transmission build-out and generation capacity additions.	Generally supported. Transmission corridor siting can attract opposition.	Limited stakeholder engagement.	Reduces local air pollution and noise. Risk of stranding existing assets.
Hydrogen Fuel Switching Cogeneration and gas turbines, process boilers, compression drives, vehicles and equipment	<i>Potential Niche Pathway</i> Viable decarbonization lever for combustion assets where electrification is difficult. Dependent on low-carbon hydrogen supply.	Enable Advance where low-carbon hydrogen supply is credible and off-take is firm. Prioritize turbine hydrogen-readiness in new cogeneration builds.	Can achieve significant CO ₂ reductions. Net zero only achievable with near-zero upstream methane leakage and high-capture rate CCS and removals.	Economics currently challenged and would require significant policy intervention.	Leverages Alberta's existing gas processing expertise and CCS-ready geology for hydrogen production.	Maturity varies by technology.	Existing cogeneration units can blend hydrogen. Sole use of hydrogen will require substantial upgrades or equipment replacement and NOx control systems.	No dedicated hydrogen supply infrastructure exists at O&G production sites. Requires new production facilities, compression, pipelines or on-site storage.	Safety concerns around hydrogen flammability and storage.	Alignment with government hydrogen strategies. Active investment by some producers and OEMs in hydrogen-ready turbine upgrades.	Repurposes sector expertise. Produces NOx emissions but better overall air quality.
Low-Energy Extraction Technologies Solvent-assisted steam-assisted gravity drainage (SAGD), radio-frequency and electro-magnetic heating	<i>Potential Enabling Pathway</i> Could be part of a net-zero system provided decarbonized production. May reduce the energy intensity — and potentially emissions — of in-situ oil sands extraction.	Incubate Support R&D, field pilots, and transparent reporting of real-world performance data before commercial scaling.	Reduces energy intensity and associated emission but does not eliminate emissions. Requires decarbonized production.	Potential operational cost savings from lower steam and energy use. High capital costs.	Canadian-led R&D ecosystem with IP and service industry potential.	Pre-commercial. A few pilots and demonstrations exist with limited long-term field data.	Can retrofit some SAGD assets. Requires process changes and operator training.	Largely uses existing oil sands infrastructure and well pads.	Mixed perception. Performance claims are held primarily by industry. Limited independent verification.	Relevant to government and academia with pilots. Important to industry if cost savings occur.	Energy and water savings. Reduced steam-to-oil ratio. Land-use impacts persist.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
On-Site Clean Power Generation (Small modular reactors, solar and wind)	Enabling Pathway Provides low-carbon electricity and/or heat directly to remote upstream facilities where grid access is absent or unreliable. Enables electrification of operations.	Incubate Avoid scaling investment ahead of proven economics. With improvement continue R&D and pilot funding for SMRs and electrothermal storage. Advance regulatory frameworks for nuclear deployment in Alberta.	 Can fully decarbonize on-site power and heat when powered by zero-emission sources.	 Solar and wind cost-competitive in some contexts but intermittency requires storage investment. Small modular reactors uneconomic for oil sands applications under current conditions.	 Small modular reactor development would leverage Alberta's engineering and supply chain base and create high-skilled jobs.	 Solar and wind mature but limited application in remote northern sites. Small modular reactors are not commercially available in Canada and are not proven at remote sites.	 Small modular reactors co-location with SAGD facilities creates new regulatory and safety challenges. Solar/wind requires storage and backup to match continuous 24/7 steam demand.	 No nuclear supply chain established for remote locations. SMR components require new manufacturing pathways. Renewable on-site power supply chains more developed.	 Public awareness of nuclear energy in Alberta is low. Opposition exists from communities near proposed sites and some Indigenous groups. Renewable opposition also exists.	 Alberta and federal governments actively exploring small modular reactors. Some interest from producers but economics are the limiting factor. Renewables have a low-level of interest.	 Improved air quality from zero-emission power generation. Potential to export power surplus to the grid. Timelines may create significant stranded asset risk if oil sands demand declines faster than anticipated.
Net-Zero Products from Hydrocarbon Resources											
Blue Hydrogen (Natural gas Reforming with CCS, methane pyrolysis, autothermal reformation with CCS)	Niche Pathway Leverages Canada's gas resources and geological storage to generate net-zero energy. Contingent on very low upstream methane leakage.	Enable Advance where end-use demand is firm. See hydrogen section for detail.	 Can approach net zero only at high capture rates and with near-zero upstream methane emissions. May require carbon removals for residual emissions.	 More cost-competitive than green hydrogen. Contingent on gas prices, capture costs, and durable policy signals.	 Leverages existing gas processing expertise and subsurface storage. Export potential through Western corridors.	 Steam methane reforming with CCS is commercial internationally. Other technologies are in demonstration and pre-commercial.	 Builds on existing gas-processing practices. Integrates with proposed CCS hubs.	 Requires hydrogen demand, new hydrogen distribution, storage, and CCS network build-out.	 Concerns of upstream methane leakage. Safety concerns related to hydrogen handling.	 Some investment by major producers. Interest from some provincial governments.	 Repositions gas assets for a decarbonized economy. Extends fossil fuel production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
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Electricity Production from Natural Gas with CCS	<i>Potential Niche Pathway</i> Can be used as a backup power source while renewables are built out or for marginal balancing in a net-zero system. Potential export opportunity.	Incubate Support R&D for carbon capture from existing natural gas assets. Watch for local or regional power reliability issues.	 Difficult to capture all emissions with CCS. Requires negative emissions, which can be limited, to offset lifecycle emissions.	 Costly due to CCS. Needs subsidies but may become moderately competitive for baseload power.	 Electricity export potential in limited regional circumstances.	 Demonstration stage. Technology for post-combustion capture from gas turbines is being tested.	 Best suited to baseload or steady-output roles, cycling and peaking operation reduces capture efficiency. Retrofitting existing plants is feasible but requires significant site engineering.	 Benefits from existing infrastructure but requires new CO ₂ pipelines and strong methane management.	 Opposition remains over continued fossil fuel reliance and CO ₂ storage concerns.	 Relevant to gas producers and suppliers, Alberta, and industries needing firm power.	 Offers reliable low-carbon power and aids grid stability. Air quality and health issues with conventional combustion.
Non-Combustion Uses for Bitumen (i.e. Carbon fibre, asphalt binder, energy storage devices)	<i>Potential Niche Pathway</i> Extracts value from bitumen, avoiding combustion emissions.	Incubate Continue targeted R&D and build market linkages into carbon-constrained value chains.	 Avoids combustion emissions from bitumen. Requires up-stream abatement of methane and CO ₂ . May require removals.	 Long-term outlook unclear and varies by product. Competition from cheaper feedstocks.	 Diversification opportunity for Alberta. Demand for carbon materials is growing.	 Mostly laboratory and early pilot stage.	 Requires new processing facilities separate from conventional refining.	 Requires new supply chains, manufacturing capacity, and networks. Asphalt binder faces specific transportation difficulties.	 Concerns about tailings, land disturbance, and reclamation.	 Active government-funded ecosystem. Producers supportive as feedstock suppliers, end use commitments limited.	 New markets and reduced reliance on combustion revenue. Continued upstream environmental liabilities.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Resource Diversification											
Lithium Extraction from Oilfield Brines (Direct Lithium Extraction)	Enabling Pathway Repurposes sector capital, infrastructure, and workforce to supply critical minerals for the broader energy transition. Does not directly reduce oil and gas emissions.	Incubate Support piloting, validation, and integration with existing oilfield infrastructure; align with federal and provincial critical minerals strategies.	 Supports the broader net-zero transition rather than abating sector emissions directly.	 High capital costs. Costs expected to fall as technology matures. Price exposed to global lithium markets.	 Diversification opportunity. Builds on subsurface and brine-handling expertise. Battery supply chain opportunities.	 Pilot and demonstration stage. Provincial projects advancing, but no commercial operations to date.	 Uses existing wells, brine handling, and operational know-how. Minimal disruption from operations.	 Leverages existing facilities and well pads. Downstream critical mineral supply chain is nascent in Alberta.	 No particular concerns.	 Strong alignment with federal critical minerals strategies. Active industry participation.	 Low land disturbance. Regional diversification. Workforce transition pathway for oilfield service firms.
Geothermal Power (Closed loop, Conventional, and Deep)	Enabling Pathway Geothermal has potential for generating net-zero electricity and heat. Can transition oil and gas expertise to a net-zero industry.	Enable Build up regulatory frameworks. Support transitioning expertise. Support closed loop R&D as well as pilot and demonstration projects.	 Conventional geothermal releases some carbon dioxide. Closed loop geothermal is more promising for net zero.	 Not cost-competitive in Canada due to high drilling and capital costs. Potentially viable in remote locations.	 Established Canadian leadership in advanced geothermal. Drilling and subsurface, expertise transferable from oil and gas. Strong technology export potential.	 Demonstration stage with one closed loop project under construction in Canada. Deep geothermal in early research. Conventional geothermal is mature.	 Drilling, subsurface knowledge, and brine management map directly from oil and gas operations. Alberta regulatory framework includes provisions for well conversion. Site-dependent and best suited to regions with accessible heat at depth.	 Can leverage oil & gas infrastructure and expertise with standard equipment and a ready supply chain. Closed-loop systems require specialized tools not yet in domestic supply chains.	 Significant concerns of seismic activity for conventional geothermal. Support from off-grid Indigenous communities with closed-loop systems.	 Western provinces, oilfield service firms, and federal innovation programs as a transition opportunity. Utilities are cautious. Active investment in Canadian technologies.	 Baseload zero-emissions power —addresses intermittency of other renewables. Low land and water footprint. Can affect water quality if conventional geothermal is used.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

8.1.5 LDVs Pathways Table

			Table 1: Summary of the Role of Different Pathways in the Net-Zero Transition								
			Economic			Technical			Social		
Pathway Elements	Role in Net-Zero System	Signal to Decision-Makers	Alignment with Carbon Neutrality	Economic Viability	Economic Development Opportunity	Maturity	Operational Fit	Infra-structure and Supply Chain Suitability	Social Acceptability	Relevance to Stakeholders	Related Benefits and Costs
Battery Electric	Priority Decarbonization Pathway Backbone of LDV decarbonization.	Deploy Mass deployment now. Scale charging infrastructure.	Zero tailpipe emissions. Dependent on decarbonizing grid electricity and supply chain (net-zero lifecycle vehicles).	Purchase cost still higher than ICE vehicles but improving. Total cost of ownership often at or below ICE with lower fuel/maintenance.	Strategic opportunity: batteries/critical minerals and assembly. Links to autonomous vehicle development.	Mass market deployment, battery range continues to increase as costs fall. Future technological improvements possible.	Works across Canada. Winter range and multi unit home charging remain serious operational constraints.	Rapidly expanding public charging. Grid planning underway. Some regional disparities in grid readiness and charger deployment.	No particular concern.	Compelling to emerging producers. Alignment among governments and utilities with sales targets. Some opposition from incumbents.	Air quality and health gains. Vehicle-to-to-grid energy storage potential. Prepared for connection with autonomous technologies. Lifecycle emissions and pollution associated with battery production and disposal.
Plug-in Hybrid Electric	Bridge Pathway Useful in the near term to facilitate transition to battery electric. Good for long trips/cold regions when charged frequently. Not a fully decarbonized solution.	Deploy Deploy PHEVs. as a complementary option for BEVs. Scale charging infrastructure.	Meaningful reductions only with high electric miles share. Complements transition to BEVs but not compatible with net zero.	Competitive total cost of ownership in some use cases. Lower upfront cost than BEVs but higher than ICE.	Targeted value in engineering, dealerships, and service. Limited incremental manufacturing advantage vs. BEVs.	Fully commercial across segments. Extensive Canadian availability.	Works with today's fuelling plus home/workplace charging. Ideal for rural/long distance drivers who can plug in.	Compatible with existing retail fuel network and Level 2 charging. Minimal new infrastructure required.	Pragmatic. Acceptance drops when real world emissions underperform. Helps accustom consumers to vehicle charging and eases range anxieties.	Automakers and some provinces use PHEVs to meet near term ZEV targets. Crediting is bounded in the federal standard.	Mixed: benefits depend on charging behaviour. Fewer local air quality gains if driven mostly on gasoline. Lifecycle emissions and pollution associated with battery production and disposal.
Hybrid Electric (gasoline engine with battery and regenerative braking)	Dead-End Pathway Small GHG cuts but retains gasoline lock in. Absent from credible net-zero LDV end state.	Dismiss End support. Prioritize support for BEVs and PHEVs.	Limited emissions reduction and slows transition to better alternatives. perpetuates fossil fuel use.	Competitive with ICE vehicles.	Not relevant in a decarbonizing world.	Fully commercial.	Works with today's fuelling and improves vehicle acceleration.	Compatible with existing retail fuel network.	No particular concerns.	Less relevant to government and producers than BEVs and PHEVs as they are not compatible with net zero.	Continued reliance on fossil fuels. Doesn't address air quality concerns. Slows transition to better alternatives.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hydrogen Fuel Cell	<i>Potential Niche Pathway</i> Applicable in regions or remote areas where very long range is required, or local hydrogen infrastructure is well established.	Don't Prioritize Very niche applications (remote or robust hydrogen infrastructure).	Achieves zero emissions when supplied with low-carbon hydrogen.	Vehicles and hydrogen costs are high in most locations. Dependent on hydrogen cost reduction and policy support.	Could help drive local hydrogen economy growth and spur jobs in hydrogen production, refuelling, and fuel-cell manufacturing.	Some models exist. Focus is on developing medium- and heavy-duty vehicles.	Good for long-range vehicles or where hydrogen infrastructure is present. Most LDV applications are better suited for BEVs.	Need new, large-scale hydrogen fuelling network which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	Supported in regions with hydrogen build out or remote areas. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	Most stakeholders backing BEVs and PHEVs for LDVs. Some interest from provincial or municipal governments where hydrogen is present or electrical infrastructure is lacking.	No air pollution. Supports renewable integration, and enables broader hydrogen use across sectors.
FUELS											
Ethanol-Blended Gasoline	Dead-End Pathway Small lifecycle GHG cuts but retains combustion lock in. Absent from credible net zero LDV end state.	Dismiss Phase out. Focus efforts on other solutions with net-zero alignment and more economic opportunity.	Delivers modest GHG reductions via blending but can't fully decarbonize LDVs.	Low incremental cost increase for E10. Viability tied to feedstock prices.	Targeted gains for farm regions and existing biorefineries. Limited growth vs. ZEV supply chains. Not relevant in a decarbonizing world.	Fully commercial and ubiquitous in Canada.	Drop in up to E10 across existing vehicle fleet. Higher blends need engine compatibility.	Uses current storage, pipelines, and retail fuelling. No new networks required.	Mixed. seen as lower carbon but concerns persist on land use and air toxins. Acceptance is context specific.	Supported by fuel producers and some provinces. Peripheral for long term LDV decarbonization.	Continued air pollution. Limited co benefits. Upstream land/water impacts can offset gains unless strong safeguards are applied.
Synthetic gasoline	<i>Potential Dead-End Pathway</i> No Canadian deployments, and outcomes hinge on scarce, costly clean power and captured CO ₂ .	Don't Prioritize May be relevant in the future in very remote applications. No action currently until maturity and economics improve.	Can be very low carbon when produced with clean hydrogen, electricity, and CO ₂ , suited for remote niches.	Production costs much higher than conventional gasoline with viability dependent on high, long-term subsidies and very cheap renewable power.	Could generate niche projects but scale is very uncertain.	Novel solution in R&D phases, no commercial supply.	Works in all current gasoline vehicles with no retrofits. Fuelling, maintenance, and driver practices remain unchanged.	Downstream distribution is compatible. Upstream supply chains are nascent and require significant new investment and coordination.	Public awareness is low. Acceptance will depend on framing. Conceptually attractive as a "drop-in" net-zero fuel.	Refineries, fuel suppliers, and some OEMs to preserve combustion assets.	Benefits are offset by large energy losses. Net benefits materialize only in narrow circumstances (i.e., no electrification option).

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
TRANSPORTATION SYSTEMS											
Modal Shift (to public transit or active mobility)	Enabling Pathway Reduces car dependence and associated emissions, applicable mostly to urban areas.	Deploy Continue to improve and build out well-designed transit systems. Provide education, incentives, and policy support to encourage modal shift.									
			Proven to reduce car trips and emissions when paired with better service.	Urban infrastructure construction and operational funding for transit poses financing challenges.	Supports service expansion and economic productivity.	Mature.	Strongest in dense cores with viable transit alternatives.	Mass transit and bicycle infrastructure investments required for urban centres.	Acceptance grows post-implementation as benefits materialize.	Cities, provinces and utilities use these to meet goals.	Traffic, safety, air-quality gains. Equity improves with targeted discounts.
Shared Mobility Models	Enabling Pathway Reduces vehicle ownership; associated with significant life-cycle emissions reductions, especially when integrated with autonomous vehicles.	Deploy Integrate with existing transit systems. Provide education on use of digital platforms.									
			Reductions depend on methods chosen, vehicles used, and integration with automation.	Reduced necessity for personal car ownership comes with significant household savings.	Growth in service-based economy. Increases transit efficiency. Benefits concentrated to urban regions.	Commercial. Ride-hailing, car-sharing, and micro mobility used today. Profitability and integration with public transit still evolving.	Strong fit in urban contexts with some changes to transit coordination, use of digital platforms, and travel behaviours. Operations more difficult in rural or low-demand areas.	Largely compatibility with existing infrastructure with modest digital, fleet, or road upgrades.	Generally accepted due to convenience and cost saving. Access and equity issues in smaller communities.	Relevant to urban locations, transit providers, and private stakeholders. Automakers have taken note. Engagement strongest in cities.	Reduced vehicle ownership, congestion, and parking demand. Can improve transportation accessibility. Some concerns with transit replacement if not integrated.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

8.2.5 MHDVs Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Vehicles											
Battery Electric	<i>Priority</i> Decarbonization Pathway Can decarbonize most MD and some HD vehicles.	Deploy Accelerate fleet adoption and charging infrastructure buildout for MHDV applications. Prioritize return-to-base and short-haul segments first.	 Runs on clean electricity with no tailpipe emissions. Requires decarbonized electricity and supply chain.	 Higher upfront costs but dropping. Cost parity in many segments expected soon as battery prices fall. Total cost of ownership can be positive, especially for medium duty, urban delivery, or passenger transit.	 Promotes battery, charger, and truck manufacturing. OEM activity and government support can allow leadership in clean transport tech and exports.	 Commercially mature for MDVs and buses. Long-haul HDVs are in early adoption, with range and weight challenges. Advances in battery chemistries may be required for the heaviest duty vehicles.	 Ideal for short-haul, return-to-base operations where daily travel is local or regional. Strong performance for most MDVs but limits in long-haul or heavy-load use. Improves driving (torque).	 Needs major charging and grid upgrades. Depot, highway chargers, and utility coordination to handle the added load.	 Acceptance growing. Range and charging concerns remain.	 Fleet interest to cut diesel and maintenance costs. Governments, utilities, manufacturers for new markets and climate goals.	 Cuts emissions, reduces noise, eliminates air pollution, and lowers maintenance costs. Supports a cleaner, smarter grid with vehicle to grid charging.
Hydrogen Fuel Cell Electric	<i>Potential</i> Decarbonization Pathway Covers long-haul/payload use cases where BEVs hit range and weight limits.	Enable Invest in hydrogen refuelling corridors and support demonstration fleets for long-haul and heavy-payload applications.	 Achieves zero emissions when supplied with low-carbon hydrogen.	 Expensive vehicles and high hydrogen prices. Competitiveness dependent on lower hydrogen cost, larger-scale production, and policy support.	 Could drive hydrogen economy growth and spur jobs in hydrogen production, fuelling, and fuel-cell and vehicle manufacturing.	 In a late-demonstration, early commercial stage—mostly in pilot use.	 Enables zero-emission operations with diesel-like range. Ideal for long-haul, heavy-duty use with high range and fast refuelling needs. Improves driving (torque).	 Need new hydrogen fuelling networks along major freight corridors which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	 Cautiously supported. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	 Draws interest from energy firms, truck manufacturers, and trucking companies. Serves governments and broader hydrogen economy.	 Cuts emissions, reduces noise, eliminates air pollution, lowers maintenance costs, and preserves payload. Some concerns with fuel cell recycling.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hydrogen Combustion	<i>Potential Decarbonization Pathway</i> Covers long-haul/payload use cases where BEVs hit range and weight limits. Less efficient than FCEVs.	Enable Support demonstration fleets and investment in hydrogen fuelling corridors alongside FCEV development. Treat as a complement to FCEVs, not a replacement.	Achieves near-zero emissions when supplied with low-carbon hydrogen.	Lower base cost than FCEVs; avoids reliance on expensive minerals and catalysts, but lower efficiency overall. Competitiveness is still dependent on lower hydrogen cost, larger-scale production, and policy support.	Could drive hydrogen economy growth and spur jobs in hydrogen production and refuelling. Narrower supply chain opportunity than FCEVs as it doesn't require fuel cell components.	On-road testing has begun. Underlying high-pressure direct injection technology is commercial with many units sold globally.	Ideal for long-haul, heavy-duty use with high range and fast refuelling needs. Less suited for short urban hauls.	Need new hydrogen fuelling networks along major freight corridors which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	Cautiously supported. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	Draws interest from energy firms and OEMs. Serves governments and broader hydrogen economy.	Near-zero tailpipe CO ₂ and diesel-like performance with no payload penalty. NOx emissions require aftertreatment. Less energy-efficient than FCEVs, meaning higher hydrogen consumption per km.
Renewable Natural Gas (RNG)	<i>Potential Niche Pathway</i> Leverages existing compressed and liquified natural gas fleets and waste gas but remains niche and supply constrained.	Enable Support RNG projects tied to hauling (i.e. waste management) with secured end users.	Can be net zero with decarbonized feedstocks.	Without incentives, high production costs can make it less viable than diesel or fossil gas.	Create jobs in waste management and rural areas, but the total market is modest and capped by feedstock availability.	Drop-in fuel for compressed and liquified natural gas vehicles.	Best for transit and refuse trucks with centralized fuelling. Requires new assets with natural gas engines.	Can flow through existing gas pipelines and stations, but fuelling infrastructure for NG trucks is sparse and feedstock collection/supply chains are still developing.	Broadly accepted and seen as a practical waste-to-fuel solution when sourced from genuine waste.	Utilities, waste managers, farmers, and certain fleets view RNG as valuable.	Avoids direct methane emissions from wastes. Impact is constrained by feedstock and questions about life-cycle reductions once upstream impacts are counted. Does not address air pollution from combustion.
Natural Gas (NG)	Dead-End Pathway Does not facilitate transition to net zero. Provides limited emissions reductions relative to diesel.	Dismiss Redirect support to initiatives focused on electrification and building out production and use of renewable fuels.	Incompatible with net zero. Limited emissions reduction. Investment into assets that lengthen the timeline to decarbonization.	Natural gas is currently inexpensive. Costs can be higher where new or upgraded distribution lines, high compression, or liquification are required.	Short-term expansion of natural gas markets. Longer term prospects limited.	Technologically mature.	Best for transit and refuse trucks with centralized fuelling. Requires new assets with natural gas engines. Worse performance with lower torque.	Can flow through existing gas pipelines and stations, but fuelling infrastructure for NG trucks is sparse and feedstock collection/supply chains are still developing.	Perceived similarly to all fossil fuel use in vehicles.	Some interest from fleet operators to reduce emissions and costs. Strong relevance to existing gas suppliers.	Lowers but does not eliminate air quality concerns with cleaner combustion compared to diesel. Increases long-term reliance on natural gas, slowing the transition to electrification or clean fuels.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Drop-in Fuels											
Renewable Diesel (RD)	Bridge Pathway Provides immediate, drop-in cuts while zero-emission trucks and charging build out. Feedstocks limit scalability.	Deploy Maximize drop-in renewable diesel use across existing fleets now while zero-emission vehicles scale up. Ensure feedstock sustainability governance is in place.	 Drop-in fuel, with lifecycle CO ₂ cuts. Net-zero requires carbon removal. Combustion persists and sustainable feedstocks are finite.	 Higher production cost than diesel. Viable where policy support offsets fuel premiums.	 Supports refinery jobs, rural economies, and feedstock markets. Growth is limited by feedstock constraints.	 Fully commercial, drop-in fuel. Dominant production processes (i.e. hydrotreated vegetable oil) mature, with several large-scale facilities operating globally. Established technology licensors.	 Drop-in fuel ideal for near-term fleet decarbonization without new equipment or operational changes.	 Existing fuel storage, pipelines, and retail networks work for RD. Main gaps are upstream (sustainable feedstock availability and refining capacity scale-up).	 Accepted when made from sustainable waste feedstocks and used as a bridge. Concerns over land-use competition.	 Fleets seeking fast GHG cuts. Fuel producers and farmers benefiting from new markets. Policymakers aiming for near-term climate progress and rural investment.	 Delivers reduced particulate matter and NO _x emissions in existing fleets. Benefits are tempered by feedstock limits and land-use change concerns.
E-Fuels	Potential Dead-End Pathway No Canadian deployments and outcomes hinge on scarce, costly clean power and captured CO ₂ .	Don't Prioritize Track international developments in e-fuel production costs and efficiency. Invest if economics fundamentally improve.	 Can be near-zero-carbon when produced with clean electricity and CO ₂ , suited to hard-to-electrify niches.	 Production costs much higher than conventional diesel with viability dependent on high, long-term subsidies and ultra-cheap renewable power.	 Could create niche projects (electrolyzers, CO ₂ capture, synthesis plants) but market scale is uncertain.	 Only small pilot plants exist globally. No commercial-scale supply for road transport.	 Works in all current diesel vehicles with no retrofits. Fuelling, maintenance, and driver practices remain unchanged.	 Downstream distribution is compatible. Upstream is nascent. Requires significant new investment and coordination.	 Public awareness is low. Acceptance will depend on framing. Conceptually attractive as a “drop-in” net-zero fuel.	 Refineries, fuel suppliers, and some OEMs to preserve combustion assets.	 Benefits are offset by large energy losses.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Complementary Technologies											
Hydrogen-Diesel Co-Combustion Retrofits	<i>Potential Bridge Pathway</i> Simultaneously helps build out hydrogen economy and lower emissions on diesel assets until they can be retired. Not a net-zero end state.	Incubate Support retrofit for existing long-haul fleets in near-term, particularly where BEV adoption faces constraints. Invest in hydrogen fuelling corridors.	 Reduces diesel use and lowers emissions but not a net-zero end state. Compatible with low-hydrogen supply buildout.	 Low-cost retrofit. Competitiveness dependent on lower hydrogen cost and policy support.	 Could drive hydrogen economy growth and spur jobs in hydrogen production and refuelling.	 Proven at scale but with limited applications. Some development still needed to adapt to broader range of makes and models.	 Requires retrofit of existing diesel vehicles. Reversible and does not void OEM warranties. Seamlessly switches back to diesel if hydrogen runs out.	 Hydrogen supply remains the primary infrastructure constraint. Retrofit kits can be installed through local fleet dealerships and mechanic shops, reducing deployment barriers compared to new vehicle purchases.	 Some concerns with hydrogen cost and safety.	 Draws interest from energy firms and OEMs. Enables operators to meet near term emission targets and build familiarity with hydrogen.	 Lowers air quality impacts but does not eliminate emissions. No loss to payload.
Catenary Electric Systems	<i>Potential Niche Pathway</i> Potentially viable on fixed, high-throughput corridors.	Don't Prioritize Redirect resources toward battery-electric and hydrogen solutions with broader applicability.	 Electrifies at point of use, but corridor-bound infrastructure limits national scalability.	 Demands high upfront investment and only becomes viable with heavy, continuous use. Depends on public or consortium funding.	 May generate localized economic activity in construction and electrical equipment.	 Proven in demos, with reliable operation on short highway stretches. Lacks large-scale integration, standardization, and commercial deployment.	 Suits fixed, high-traffic routes like freight corridors or industrial loops. Poorly matched to flexible, irregular trucking.	 Demands major infrastructure along roads, grid upgrades, and regulatory coordination. Low applicability in Canada with low population density and long transportation distances.	 Uncertain. Concerns about visual impact, cost, and relevance.	 No clear stakeholder advocates in Canada at this time.	 Cuts tailpipe emissions and noise, reduces battery mineral demand, and lessens road wear. Concerns about impacts on other road users.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

8.3.5 Mass Transit Pathways Table

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Transit Technologies											
Electric Rail Transit (subways, LRT/trams, commuter rail)	Decarbonization Pathway Already the low-carbon backbone in cities. Expanding/modernizing electrified rail displaces diesel services and high-GHG road travel.	Deploy Support deployment of electrified rail with policy, financing, and investment. Enable growth of Canadian electric rail manufacturing capacity.	 Zero tailpipe emissions when running on clean power systems.	 Capital-intensive but justified on high-demand corridors. Viability rises with ridership and public co-funding.	 Strong Canadian rail manufacturing base (i.e., Alstom) and project delivery supply chains.	 Commercially mature.	 Best fit on dense, fixed routes. Replaces congested/slow bus routes in larger cities.	 Requires major capital works and grid connection but draws on established suppliers.	 Generally popular and accepted where it improves speed/reliability.	 Cities, provinces and federal funders see it as core to mobility.	 Cuts air pollution, eases congestion, improves urban livability.
Battery-Electric Buses (BEBs)	Decarbonization Pathway Scalable option for bus decarbonization.	Deploy Scale fleet procurement and depot charging infrastructure. Coordinate with utilities to ensure grid readiness for full fleet transition.	 Zero tailpipe emissions when running on clean-power systems.	 Today higher upfront cost vs. diesel. Viability improves with public support and charging optimization.	 Canadian OEM strength (New Flyer, Nova Bus) and supply-chain jobs.	 Deployment scaling from pilots to fleets.	 Strong fit for urban routes and return-to-depot operations.	 Needs depot/on-route chargers and utility coordination. Smart charging to manage grid impacts.	 Positive where reliability and comfort improve	 Transit agencies slowly adopting. Requires strong coordination from utilities. Larger cities starting to incorporate into planning.	 Better air quality, less noise.
Hydrogen Fuel-Cell Buses	Niche Pathway Complementary option where range/uptime needs challenge BEBs. Canada has H ₂ /fuel-cell industrial strengths.	Enable Support targeted pilots in corridors where range or uptime needs exceed battery-electric capability. Invest in refuelling infrastructure alongside vehicle trials.	 Zero tailpipe emissions when supplied by low-carbon H ₂ .	 Vehicle and fuel costs are much higher. Viability hinges on H ₂ price/infrastructure.	 Domestic capabilities in fuel cells and buses. Potential to anchor H ₂ value chains.	 Some pilots underway to validate technology.	 Useful for longer uninterrupted routes/high uptime and quick refuelling.	 Requires new H ₂ production, storage and refuelling networks.	 Mixed. Interest exists, but costs, safety, and infrastructure questions remain.	 Agencies and OEMs piloting. Supported in federal programs alongside BEBs.	 Air-quality gains. Operational flexibility in cold climates and long duty cycles.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Renewable Diesel for Existing Commuter Rail	Bridge Pathway A stop-gap to cut emissions where rail electrification isn't yet possible.	Deploy Procure renewable diesel as an immediate drop-in measure for diesel commuter rail while electrification is built out. Support scaling of RD production.	 Drop-in fuel, with lifecycle CO ₂ cuts. Net zero requires carbon removal. Combustion persists and sustainable feedstocks are finite.	 Not competitive with incumbent, except areas where policy supports offsets fuel premiums.	 Supports refinery jobs, rural economies, and feedstock markets. Growth is limited by feedstock constraints.	 Fully commercial, drop-in fuel. Dominant production processes (i.e. hydrotreated vegetable oil) mature, with several large-scale facilities operating globally. Established technology licensors.	 Drop-in fuel ideal for reducing near-term fleet emissions without new equipment or operational changes.	 Existing fuel storage, pipelines, and retail networks work for RD. Main gaps are upstream (sustainable feedstock availability and refining capacity scale-up).	 Accepted when made from sustainable waste feedstocks and used as a bridge. Concerns for forestry and food competition remain.	 Fleets seeking fast GHG cuts. Fuel producers and farmers benefiting from new markets. Policymakers aiming for near-term climate progress and rural investment.	 Delivers reduced particulate matter and NOx emissions in existing fleets. Benefits are tempered by feedstock limits and land-use change concerns.
Transportation Systems											
Transit-Oriented Urban Planning	Priority Enabling Pathway Dense, mixed-use development near corridors to boost transit use and cut car dependence.	Deploy Implement and strengthen transit-oriented zoning and density policies at all levels of government now. Align housing and climate goals.	 Locks in low-carbon travel by design.	 Infrastructure requires significant upfront investment but can yield strong long-term economic returns including increased productivity, higher tax revenues, and reduced household transportation costs.	 Infill, housing, and jobs around stations.	 Mature planning tools	 Works across climates. Depends on zoning and political will.	 Starts from existing networks with targeted upgrades.	 Support rises with affordability and good urban design. There could be some opposition to densification from local residents.	 Important to city/provincial climate and housing goals. Implementation faces governance fragmentation and local opposition.	 Health, safety, walkability, and affordability gains.
Modal-Shift Levers (e.g. congestion pricing, fare integration)	Enabling Pathway Reduces car dependence and associated emissions, applicable mostly to urban areas.	Deploy Advance congestion pricing, fare integration, and service improvements now. Reinvest revenues into transit expansion and equity measures.	 Proven to reduce car trips and emissions when paired with better service.	 Revenues can recycle into transit. Distributional design matters.	 Supports service expansion and economic productivity.	 Many global precedents with robust evaluations.	 Strongest in dense cores with viable transit alternatives.	 No major new physical infrastructure. Enforcement/IT back-end needed.	 Acceptance grows post-implementation as benefits materialize.	 Cities, provinces and utilities use these to meet goals.	 Traffic, safety, air-quality gains. Equity improves with targeted discounts.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Net zero with a decarbonized electrical grid.	Cost competitiveness varies by region and building type. Residential single units most often achieve parity, but economics weaken for multi-unit and commercial buildings, in cold climates, and where gas is cheap.	Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international.	Commercially mature for residential applications across Canada. Well-established and growing for commercial and institutional buildings.	Used across Canada in buildings. Less efficient in very low temperatures.	Upgrades to grid and generation may be needed to accommodate increased demand.	No particular concern.	Increasing interest from utilities and HVAC companies as the need to decarbonize becomes clearer. Interest from some building owners in terms of savings. Some hesitancy from contractors to recommend newer technologies, preferring to stick with incumbents.	Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.
Net zero with a decarbonized electrical grid.	Installation significantly more expensive than ASHP but efficiency and operational savings are greater. Payback periods lengthy.	Some potential for domestic assembly, drilling, installation, and distribution jobs. Manufacturing is typically international.	Mature for residential, and commercially available for commercial and institutional buildings.	Site suitability is a constraint; not all buildings have suitable land area or soil conditions. More efficient than ASHP overall and in cold climates specifically.	Upgrades to grid and generation may be needed to accommodate increased demand. Specialized drilling equipment may not be available in remote/rural areas. Community and district applications face gaps in standards.	No particular concern.	Growing interest from institutional building owners, developers, and utilities for large scale and district projects. Limited residential interest and more niche than air source heat pumps. Some hesitancy from contractors to recommend newer technologies, favouring to stick with incumbents.	Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Dual Fuel (Hybrid) Heat Pump Systems (Heat pump & natural gas or fuel oil furnace as a back-up)	Bridge Pathway Applicable until clean electricity is widely affordable, available, and reliable.	Deploy Support deployment where electricity is expensive or climates are very cold through education, incentives, building codes, and subsidies that assist with capital costs. Provide workforce upskilling.	 Significant GHG reductions but still some GHGs associated with fossil fuel combustion.	 Similar economics to ASHP. Can be cost competitive in some regions.	 Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international.	 Mature for residential, and commercially available for commercial and institutional buildings.	 Used across Canada in buildings. Dual fuel can compensate when temperatures are very low.	 Requires electricity and incumbent heating source (i.e. natural gas, fuel oil), which are available in almost all locations in Canada.	 Well accepted. Viewed positively in terms of cost savings.	 Increasing interest from utilities as need to decarbonize becomes clearer. Interest from building owners in terms of savings. Some hesitancy from contractors to recommend newer technologies, favouring to stick with incumbents.	 Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.
Dual Fuel (Hybrid) Heat Pump Systems (Heat pump & renewable natural gas or hydrogen furnace as a back-up)	Potential Niche Pathway Applicable where clean electricity access is limited, clean fuels are accessible, and where a back-up furnace may be required (i.e. extreme cold or remote regions)	Incubate Support development of hydrogen and RNG supply chains as well as R&D projects using clean fuels as heat pump back-ups.	 Significant GHG reductions but may require removals. Can be net-zero with sustainable feedstocks.	 Worse economics than dual fuel with fossil fuels as clean fuels carry premiums. Hydrogen furnaces have very high capital costs.	 Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international. Can support RNG and hydrogen production.	 RNG is a drop-in fuel and mature, with some utilities offering purchase. Hydrogen furnaces have lower maturity in early-stage demonstration.	 RNG is a drop-in fuel and requires no modifications. Hydrogen requires replacement of existing furnace and appliances.	 Requires RNG or hydrogen, which have limited supply and require substantial infrastructure build out to connect generation to broader consumption. Additionally, electricity is needed.	 Well accepted. Viewed positively in terms of cost savings. Some concerns around safety of hydrogen.	 Some interest from utilities as need to decarbonize becomes clearer. Some hesitancy from contractors to recommend newer technologies, preferring to stick with incumbents.	 Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants. RNG has indoor air quality concerns.
Baseboard or Electric Furnace	Niche Pathway Relevant for some buildings where heat pumps are not practical.	Deploy Support in contexts where heat pumps are not viable (i.e. as a back-up to heat pumps and/or in very cold regions).	 Net zero with a decarbonized electrical grid.	 More expensive in regions with low-cost natural gas, but widely used.	 Already a mature industry, supports existing jobs.	 Commercially mature.	 Used across Canada in buildings.	 Requires upgrades to the electrical grid and generation to accommodate new demand.	 Widely accepted and used in many households across Canada.	 Established market alternative.	 Very low overall environmental impact. High electricity demand, inefficient compared to heat pumps.

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Hydrogen in Place of Natural Gas	<i>Potential Niche Pathway</i> Could be relevant in specific geographies where the availability and price of net-zero hydrogen are positive.	Don't Prioritize Support if niches emerge in locations with substantial hydrogen infrastructure buildout.	 Can eliminate heating emissions if hydrogen is net zero. Some concerns around hydrogen leakage and associated GHGs.	 Potential for high costs for net-zero hydrogen. Viability is location specific.	 Domestic potential to produce net-zero hydrogen and build up a surrounding industry.	 Low blends currently piloted in some locations in Canada.	 New appliances and modified furnaces are required.	 Gas infrastructure requires substantial upgrading. Supply of net-zero hydrogen as an energy source is currently very limited.	 Concerns around safety may cause mixed views in communities.	 Limited interest. Some relevance from existing natural gas producers and utilities to continue use of gas networks.	 Some concerns around safety due to leakage and high flammability. Substantially reduces indoor air quality concerns.
Natural Gas	Dead-End Pathway GHG emissions occur at point of use, cannot achieve net zero.	Dismiss Phase out use of natural gas in buildings using building codes and other policy instruments.	 Produces emissions during combustion, transport, and production. Methane leakage remains a concern.	 Low cost compared to other heating alternatives.	 Already a mature industry, supports existing jobs.	 Commercially Mature.	 Used currently across Canada in many locations and types of equipment.	 Incumbent technology in many locations. Some regions are difficult to reach with pipelines.	 Generally, widely accepted and used in many households across Canada.	 Important to industry and utilities.	 Increasing concern with indoor air quality issues.
Renewable Natural Gas	<i>Niche Pathway</i> Applies in specific contexts such as a facility or community. Not applicable at large scale given limited feedstock.	Don't Prioritize Support development of feedstock including biogas capture and biomethane in appropriate contexts.	 Only net zero if RNG fully displaces fossil natural gas. Requires low-carbon feedstocks. Methane leakage remains a concern.	 Costs vary by geography and can be very high depending on availability of feedstocks.	 Some local opportunities especially for waste or organics management facilities.	 Some small-scale or local deployment and use. Not used frequently for building heat beyond blending with conventional NG.	 As a drop-in fuel for natural gas.	 Uses incumbent technology. Can be difficult to connect some RNG suppliers to the existing NG network.	 Should receive the same level of acceptance as conventional NG.	 Interest and some investment in various regions in Canada from utilities and feedstock suppliers.	 Increasing concern with indoor air quality issues. Waste valorization.
Synthetic Natural Gas	<i>Potential Dead-End Pathway</i> Supply cannot meet demand with current maturity and costs. Prolongs use of dead-end assets.	Dismiss Economics and maturity limit viability.	 Net zero in principle but requires net-zero hydrogen and biomass or direct air capture. Methane leakage remains a concern.	 Very high cost. Depends on reliable and low-cost supply of net-zero feedstocks or offtake of carbon.	 Limited by feedstock or carbon storage availability.	 In early research phase.	 Is a drop-in fuel for NG which is used currently across Canada in many locations and types of equipment.	 Uses incumbent infrastructure. Can be difficult to connect supply to NG network. Major buildout of feedstock supply chains required.	 Likely to be socially acceptable.	 Still in research, so not relevant to many stakeholders at this time.	 Indoor air quality issues. Methane leakage during transport and production.

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Biomass Combustion	Niche Pathway Could be used in remote locations where electricity isn't available, in district energy systems, and/or as a back-up heating system.	Don't Prioritize Relevant where other options are not applicable.	 Can be net-zero when feedstocks are decarbonized.	 Viability depends on location.	 Largely developed. Potential for local economic development in remote or Indigenous communities.	 Commercially mature.	 Used mainly in residential buildings in some areas of Canada.	 Supply chains exist today but are unlikely to scale. Difficult logistics in moving feedstocks.	 Some concerns about indoor air quality but widely accepted and used in many residences.	 Unlikely to expand beyond current measures.	 Can use forestry residues. Air quality and health concerns.
 Building Design and Energy Systems											
Net-Zero Design for New Builds	Priority Enabling Pathway Buildings need to be built so that they will not require future net-zero retrofits.	Deploy Implement and accelerate net-zero building codes now at the municipal, provincial, and federal level. Support training programs to certify the workforce.	 Net zero with a decarbonized electrical grid. Further decarbonization can be achieved when low-carbon materials are used for building.	 Upfront costs may be higher. Can be cost competitive over the lifecycle of a building.	 Large opportunity for job creation. Housing deficit and building for climate resilience provide opportunity for net-zero building industry to grow. Anchor tenant for low-carbon building materials.	 Emerging industry. Some buildings exist in Canada.	 Requires training for builders to learn new codes and technologies.	 Relies on access to or production of clean electricity and heat pump technologies. Infrastructure and maturing supply chains are available in most locations.	 Viewed positively as it can improve air quality, comfort, noise, lighting and operational costs. Some wariness around efficacy and upfront cost.	 Some builders are adopting practice as a competitive advantage. Wariness around upfront cost premium.	 Improvements to health and comfort of people living or using the buildings. Air quality improves.
Retrofitting for Existing Builds	Priority Enabling Pathway Retrofits are required to reduce emissions from the current building stock.	Deploy Support retrofits with financing mechanisms, especially where affordability is a concern or deep retrofits are required. Provide consumer education. Support training programs to certify the workforce.	 Net zero with a decarbonized electrical grid. Further decarbonization can be achieved when low-carbon materials are used for building.	 Many investments pay for themselves through energy savings over time. Deep retrofits are more challenging.	 Large opportunity for job creation. Housing deficit and building for climate resilience provide ample opportunity for net-zero buildings industry to grow.	 Building technologies relatively mature but finance mechanisms and approaches to mass retrofits are still emerging.	 Requires builders to learn new codes. Installation of newer technologies requires training. Deep retrofits can cause significant disruption to building operations and are best timed with lifecycle of assets.	 Relies on access to or production of clean electricity and heat pump technologies. Infrastructure and maturing supply chains are available in most locations.	 Viewed positively as it can improve air quality, comfort, noise, lighting, and operational costs. Some wariness around efficacy and upfront cost.	 Undervalued by building owners who rent or lease, especially where tenants pay utilities.	 Improvements to health, air quality, and comfort of people living in or using buildings.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
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District Energy Systems (Powered by Net-Zero Energy)	Enabling Pathway Reuses waste heat and can reduce costs for building heating where applicable.	Deploy Support buildout where waste heat is available and buildings are clustered.	 Aligned if powered by net-zero energy. Emissions reductions from increased efficiency but only applicable where buildings are clustered.	 High upfront cost but return on investment occurs from reduced energy costs.	 Municipalities or private companies will have major design and installation work.	 Commercially mature. Limited deployment currently.	 Can be integrated into buildings and communities at design stage. More challenging to retrofit existing urban infrastructure.	 New infrastructure required. Challenging for planning systems, coordination of multiple owners and stakeholders. Project execution and management difficult.	 Viewed positively for new builds but may be some controversy with retrofits.	 Some relevance to gas utilities as an alternative business model as decarbonization proceeds.	 Reduces air pollution and burden on the energy system.
Solar Panels on Buildings	Enabling Pathway Relevant to regions and buildings with good sun exposure.	Deploy Deploy financing mechanisms for developers and building owners. Provide workforce training for installation. Pilot programs to integrate micro-generation with the larger electricity grid, working collaboratively with utilities.	 Can be part of net-zero buildings (assuming panel lifecycle emissions are managed).	 Costs have declined dramatically over time. Economics can depend on regional incentives. Return on investment occurs over solar panel lifespan.	 Industry is well established. Some opportunities for local installers.	 Commercially mature.	 Power output likely not high enough to meet all needs in conventional buildings.	 Supply chain is mature.	 Widely accepted and non-disruptive. Some pushback over aesthetics.	 Some interest from building firms and owners. Recognized in federal net-zero strategy for transforming Canada's buildings.	 When paired with storage, provides resilience in power outages and reduces daily peak demand. Can sell energy back to the grid. Issues with disposal and differing lifespan from building materials.
Building-Integrated Solar PV	Enabling Pathway Relevant to regions and buildings with good sun exposure.	Deploy Technologies and materials maturing. Support further development of materials, approaches, standards, and demonstration.	 Can be part of net-zero buildings (assuming material lifecycle emissions are managed).	 Costs have declined dramatically over time. Economics can depend on regional incentives. Return on investment occurs over solar panel lifespan.	 Industry still emerging. Opportunities for materials and construction will expand with maturity.	 Commercially available with demonstrated projects in Canada. Not a mainstream solution.	 Requires retrofit (new roofs, facades, windows etc.). Better suited for new build construction. Must be integrated into building design codes.	 Supply chain is emerging.	 Widely accepted and non-disruptive.	 Niche interest among innovation-focused stakeholders, with limited utility impact due to small scale.	 When paired with storage, provides resilience in power outages and reduces peak demand. Can sell energy back to the grid. Immaturity of recycling panels and differing lifespan from building materials.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.1.5 Mining Pathways Table

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Mining Equipment and Processes											
Battery Electric & Trolley Assist Mining Equipment	Priority Decarbonization Pathway Can fully displace mobile diesel, which is the largest source of mine site emissions.	Deploy Invest in site electrification, charging infrastructure, and workforce training.	 Zero tailpipe emissions. Enables net-zero operations when powered by clean electricity.	 Higher capital costs offset by lower fuel and ventilation reducing operating costs. Tax incentives can improve payback.	 Canada can design, test, and assemble equipment. Exportable know-how from labs and operating mines. Could be combined with autonomous and connected vehicle technology.	 Commercial for many underground loaders/trucks. Open-pit ultra-class battery electric haulage still emerging.	 Strong fit, especially underground. Needs charging/trolley integration and upskilled maintenance and labour.	 Requires site charging power, batteries and/or trolley. Off grid mines need microgrid upgrades.	 Cleaner air and lower noise improve worker health/safety.	 Seen as a solution to reduce emissions and costs where appropriate, less relevant to open pit or legacy operations.	 Air quality and safety gains. Less heat/ventilation energy. Lower local pollution.
Hydrogen Fuel-Cell Mobile Equipment (haul & utility)	Potential Niche Pathway Useful where long duty cycles, heavy haul or fast refuelling challenge batteries.	Incubate Fund demonstrations for heavy-haul and long-cycle mining applications where batteries face limitations. Develop on-site hydrogen production	 Zero tailpipe emissions when supplied with low-carbon H ₂ .	 Vehicle and fuel costs are high. Viability hinges on H ₂ price and on site production/ logistics.	 Targeted opportunities across H ₂ value chains (electrolyzers, storage, service), but unclear near-term scale.	 Demonstrations only. Not in commercial production for mining fleets.	 Operationally attractive for long blocks/quick refuelling. Requires new fuelling protocols and training.	 New H ₂ production, storage, and dispensing must be built at remote sites.	 Generally positive where safety is robustly managed. Air quality benefits valued.	 OEMs and a few miners are piloting. Interest is real but not universal.	 Air quality and ventilation reductions in underground settings.
Transform Extraction & Processing	Enabling Pathway Cuts energy use and diesel haulage. Complementary to clean power and offsets declining ore grades. Block caving reduces surface disturbance and GHGs in suitable deposits.	Enable Invest in process redesign and electrified material movement where productivity and emissions benefits align.	 Significant energy reductions from efficiency gains.	 Often attractive on operational savings and throughput. Capital costs vary by site/process.	 Canadian engineering/R&D has global export potential.	 Mixed maturity: some technologies proven. Others at pre-scale.	 Broadly applicable with process redesign. May require stoppages or staged retrofits.	 Uses/optimizes existing plants with targeted upgrades.	 Fewer tailings/water impacts and safer operations raise acceptance.	 Strong operator interest when productivity improves.	 Less water use/tailings and noise. Smaller surface footprint in some methods.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Renewable Diesel (RD)	Bridge Pathway Can help reduce emissions from diesel equipment while electric options are being commercialized.	Deploy Maximize drop-in renewable diesel use across existing fleets while electrification scales.	Drop-in fuel, with some lifecycle CO ₂ cuts. Combustion emissions persist and sustainable feedstocks are finite.	Higher production cost than diesel. Viable where policy support offsets fuel premiums.	Supports refinery jobs, rural economies, and feedstock markets. Growth is limited by feedstock constraints.	Fully commercial, drop-in fuel. Dominant production processes (i.e. hydrotreated vegetable oil) mature, with several large-scale facilities operating globally. Established technology licensors.	Drop-in fuel ideal for near-term fleet decarbonization without new equipment or operational changes.	Existing fuel storage, pipelines, and retail networks work for RD. Main gaps are upstream (sustainable feedstock availability and refining capacity scale-up).	Accepted when made from sustainable waste feedstocks and used as a bridge. Concerns over land-use competition.	Fleets seeking fast GHG cuts. Fuel producers and farmers benefiting from new markets. Policymakers aiming for near-term climate progress and rural investment.	Delivers reduced particulate matter and NO _x emissions in existing fleets. Benefits are tempered by feedstock limits and land-use change concerns.
On-Site Energy Generation											
On-site Renewables & Storage Microgrids (Solar, Wind, and Battery Storage)	Priority Enabling Pathway Off-grid mines rely on diesel. Hybrid microgrids cut fuel, cost, and GHGs.	Deploy Support hybrid microgrid deployment at off-grid and remote mine sites. Build enabling frameworks for grid interconnection.	Enables low carbon electricity for mine loads and electric fleets. Key to decarbonizing remote sites.	Site specific economics. High upfront costs. Some operational offsets with avoided diesel and reliability gains but today largely reliant on subsidies.	Room for Canadian suppliers/ integrators.	Commercial components with multi-year field results in Canada. Current deployments custom designed, widespread deployment is challenging.	Works across various geographies with adequate storage/controls. Adds microgrid complexity and requires upskilling.	Integrates with existing diesel systems. Grid connection added where feasible.	Strong community support when it reduces noise, spills and local pollution.	High priority for miners seeking cost stability, power resilience and sustainability outcomes.	Health/air quality gains and energy security benefits for nearby communities. Improves reliability of power supplies.
Small Modular Reactors (SMRs) for Mine Power	Potential Niche Pathway Zero-carbon heat/power is attractive for remote sites, but SMRs are pre-commercial with cost and waste concerns. High potential if delivered.	Don't Prioritize Track SMR development timelines and costs but do not anchor plans to this technology. Prioritize proven electrification and renewable alternatives.	Enables net-zero electricity for mine loads and electric fleets.	Costs and financing are uncertain. Decommissioning and waste obligations weigh on viability.	Could leverage Canada's nuclear ecosystem, but near-term market is unclear.	Pre-commercial. No mine deployments.	Conditionally applicable. Matching unit size to load and siting is complex.	New fuel, logistics, and regulatory systems required.	Public concerns about safety and waste reduce acceptance.	Emerging interest from nuclear fuel suppliers. No clear interest from mining.	Potential community co-benefits such as reliable power and use of waste heat in buildings, but long-term waste and decommissioning challenges. Improved air quality.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Waste and Recycling											
CO₂ Mineralization in Ultramafic Tailings	<i>Potential Niche Pathway</i> Potential storage solution for CO ₂ . Permanently captures and stores CO ₂ in magnesium rich tailings. Optional in sector-wide pathways.	Incubate Fund pilot, monitoring, and process optimization at sites with suitable geology.	 Could be a direct CO ₂ capture and storage method or negative emissions option.	 Business case depends on process cost and carbon credit revenue.	 Emerging niche service or carbon credit production method. Domestic IP and technology development. Potential branding as “net negative” metals.	 Pilots underway. Sustained field data still developing.	 Integrates with tailings management. Process control and monitoring needed.	 May need grid connection or another source of renewable energy. Equipment supply chain is nascent as technology is maturing.	 Converts tailings ponds into environmental assets.	 Growing interest from government and academia with ongoing studies and pilots.	 Stabilizes tailings, reduces dust and long term risks while sequestering CO ₂ .
Metal Recycling & Recovery	<i>Enabling Pathway</i> Limits primary extraction needs and creates new revenue streams. Complements—not replaces—primary mining.	Enable Strengthen regulatory frameworks for recycled content and e-waste recovery. Invest in collection, sorting, and quality assurance infrastructure.	 Net-zero metal production when powered by clean energy.	 Economics vary by metal and collection/ sorting costs. Mature for some streams, nascent for others.	 Expanding e-waste and tailings re processing can grow domestic jobs and IP.	 Many processes already commercial. Others emerging.	 Uses existing smelters/ refineries. Requires new feedstock logistics.	 Collection and quality assurance systems are the constraint, not technology.	 Public support for waste reduction and circularity.	 Miners and smelters are beginning to integrate recycled inputs.	 Cuts land/water impacts and community exposures. Reduces biodiversity pressure.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.2.5 Cement Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Heat											
Alternative Fuels (biomass and waste)	Bridge Pathway Limited by biomass and waste availability.	Deploy Support supply chain buildout and connection of kilns to waste or biomass sources.	 Reduces kiln heating and energy emissions. Reduction depends on fuel carbon intensities. Fuel substitution typically isn't 100%.	 Depends on the fuel sources and availability but can be less expensive than other solutions as it leverages existing assets.	 Can create niche economic clusters and rural jobs tied to biomass/waste supply chains. Production of low-carbon construction material.	 Commercial and used globally. Full-scale plants in Canada. Very high rates of substitution are difficult to achieve.	 Strong fit. Alternative fuels can often be integrated with existing burners and fuel handling. High substitution complicates operations.	 Conditionally suitable as reliable local supply chains are needed to ensure consistent supply of alternative fuels.	 Mixed acceptance. Depends on whether waste-derived fuels are perceived as incineration and on air and water emissions.	 High relevance for cement operators and provinces. One of the most deployable near-term levers for kiln heat. Appears in major cement facilities in Canada.	 Co-benefits include waste diversion. Concerns around air pollutants and lifecycle. Uncertainty if biomass/waste is not sustainably sourced.
Electrification	Potential Decarbonization Pathway Could fully eliminate kiln energy emissions if used with decarbonized electricity.	Incubate Fund R&D.	 Eliminates kiln heating and energy emissions with decarbonized electricity. Must be combined with efforts to manage process emissions.	 Economics are uncertain and depend on availability of affordable low-carbon electricity. Requires major retrofits.	 Production of low-carbon construction material.	 Large scale prototypes underway globally, research and development occurring mostly abroad.	 Requires substantial process redesign. Easier for greenfield sites.	 Requires very high-capacity electrical interconnections which may require grid infrastructure upgrades.	 Generally positive with visible reduction in fossil fuel combustion.	 Interest where low-carbon electricity is available and there are strong carbon commitments. Some pilot projects in Canada.	 Reduction in air pollution. Large electricity requirement, so there may be competition for low-carbon electricity.
Hydrogen	Potential Decarbonization Pathway Could fully eliminate kiln energy emissions if used with net-zero hydrogen.	Incubate Fund Canadian demonstrations and pilots. Support buildout of hydrogen supply chain and infrastructure or co-location of production with cement kilns.	 Can reduce combustion-related CO ₂ when hydrogen is low-carbon.	 Depends on availability of affordable low-carbon hydrogen.	 Strategic opportunity with regional hydrogen and cement production hubs. Production of low-carbon construction material.	 Global commercial-scale demonstrations have occurred. Still in research and development.	 Conditionally applicable for kiln heat with fuel system modifications. High substitutions not tested. Evidence indicates it is applicable without major retrofit.	 Requires establishment of low-carbon hydrogen supply chain and infrastructure.	 Generally acceptable, but there can be some concern around the safety of hydrogen.	 Interest where hydrogen sources may become available.	 Reduced air pollution. Higher system complexity.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hybrid Energy Mix (combination of alternative fuels, electrification and/or hydrogen)	<i>Potential Decarbonization Pathway</i> Could either serve as a decarbonization, enabling, or niche pathway depending on market development. Must be combined with process emissions management.	Incubate Fund Canadian demonstrations and pilots. Develop guidance on optimizing fuel choice for regional advantages.	 Can significantly reduce kiln heat emissions assuming input energy sources have low carbon intensities and fossil fuels are eventually eliminated from the energy mixture.	 Allows for adjustment to lowest-cost and most available mix. Operational costs rise with multiple systems.	 Depends on the fuel types chosen. Can contribute to broader industrial electrification or hydrogen strategies, but does not necessarily achieve economies of scale.	 Global commercial-scale demonstrations have occurred with hydrogen and alternative fuels. Many mixes still in R&D.	 Retrofitting can be incremental and work well in brownfield sites. Facility changes will depend on the energy types selected.	 Infrastructure and supply chain is dependent on the energy sources chosen. Multiple supply chains provide flexibility but also increase complexity of coordination.	 Issues will depend on energy blend chosen, but should be generally accepted.	 Relevance is high as research, piloting, and demonstration have typically occurred with hybrid strategies (partial integration of one or more of the identified heating pathways).	 Depends on hybrid mix, but may lower burden on infrastructure and maintenance schedules. Expedited progress if facilities can substitute new energy types in partial amounts.
 Low Carbon Cement											
Alternative Chemistries	<i>Potential Niche Pathway</i> Can lower clinker production emissions and energy requirements but contingent on commercialization.	Incubate Fund R&D.	 Can lower energy and process emissions associated with clinker production (lower firing temperatures, clinker blending requirements, or direct emissions). Reduction depends on chemistry used.	 Vary with chemistry and availability of feedstocks. Estimated costs are currently higher than incumbents.	 Develop new mineral and cement precursor supply chains with export potential. Some chemistries may have improved structural or chemical properties.	 Alternative chemistries are at different levels of R&D. More research needed to determine which chemistries are suitable for which cement applications.	 Some chemistries may fit well into existing production processes while others may require different firing temperatures and curing times. Development of standards and regulations is required.	 Supply chains are immature for materials needed for new chemistries. Domestic sourcing may be available for some materials while others may need established international sourcing.	 Affordability of materials, particularly as it applies to housing, will be a concern. Some skepticism may occur around use of new materials.	 Interest is rising with Canadian stakeholders. Likely to be caution around adopting materials with fundamentally different chemistries in construction.	 Benefits will depend on the alternative. Could be cement with improved properties.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical				Social	
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Carbon Capture Utilization and Storage	<i>Potential</i> Decarbonization Pathway Can be used to manage either energy or process-related emissions.	Enable Support buildout of CO ₂ infrastructure in regions with geological storage and projects that incorporate utilization of capture carbon.	Without radical change to cement chemistries, essential to get to net zero.	Potentially viable pending policy, funding tools, etc.	Strong opportunity to be an anchor tenant for the CCUS industry.	Multiple projects leading to full scale are under construction in Canada. Globally advanced projects are also underway.	Feasible with high emissions capture for both energy and process emissions. Requires additional operational expertise, space, and energy. Can be added during retrofit schedules.	Needs CO ₂ pipelines and storage access. Hub models and permitting capacity are constraints. Some regions with natural storage are better positioned.	Some concerns regarding CO ₂ leakage from storage.	Investment from multiple Canadian companies, active research environment.	Links to broader applications including hydrogen production. Captured CO ₂ can be injected into concrete for strengthening. Extra burden on electrical infrastructure and capacity.
Supplementary Cementitious Materials (SCMs)	Enabling Pathway Recognized broadly as a strategy for reducing clinker use and associated emissions.	Deploy Support scaling for commercial SCMs and R&D for new SCMs. Build out supply chains that align SCM production with Canada's natural resource endowment. Accelerate regulatory changes.	Significantly reduces clinker use and associated emissions. Near-term lever while other technologies develop. Cannot reach net zero alone as clinker emissions are not eliminated with incumbent cement chemistries.	Economics depend on the material. New materials may and need support as supply chains scale.	Opportunity to build new supply chains for SCMs, repurpose local industrial waste. Align Canada's natural resource endowment clustering mining with cement.	Varies according to the SCM. Many have high maturity but as those are exhausted, more novel options will need R&D to mature.	Little change required. SCMs are incorporated at the mixing stage. Curing times may need adjustments and standards and regulations will need to be developed.	Scaling alternative SCMs may require new processing facilities, quarries, and logistics.	No particular issues. Proof of sustainability performance with environmental product declarations will improve optics.	Very high relevance, used today broadly across industry today. Seen as an essential near-term decarbonization lever by many stakeholders.	Benefits will depend on the SCM. Could improve cement properties. Industrial waste diverted from landfills.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Optimizing Material Use and Lifespan											
Optimizing Design	Enabling Pathway Near-term solution to reduce lifecycle emissions by lowering clinker demand.	Deploy Update standards to include new materials and design practices. Provide best practices for material choice. Support scaling of mass timber supply chains.	 Material efficiency and reduced over-specification save costs and emissions. Complements supply-side measures.	 Can reduce overall project costs by lowering material use, avoiding unnecessary margins beyond calculated factors of safety, extending asset lifetimes with longer-lasting materials, and using lower-cost materials.	 Grows sustainable building sector expertise and domestic advanced wood products. Adds high-value services and products to exports rather than just raw material.	 Material-efficient design and substitution are well-established practices. Mass timber and hybrid wood-concrete systems are commercial but broader adoption is uneven.	 Some training or reskilling is needed to broadly implement sustainable design practices and materials. Codes and standards may need to be updated.	 Established supply chains. Some expansion will be needed to scale mass timber products.	 Generally well accepted as framed as innovation and climate leadership. Some concerns with fire safety.	 High relevance to many stakeholders up and down the supply chain. Increasing demand for optimized design as a cost-saving measure. Greening government strategy.	 Reduces waste, lowers lifecycle costs. Support for building out the forestry sector and manufacturing.
Recycling	Enabling Pathway Recycled concrete as substitute for aggregates, replaces primary materials but does not target larger clinker emissions.	Deploy Scale recycling infrastructure. Support R&D focused on incorporating recycled concrete as SCMs.	 Compliments other pathways by replacing primary materials required as aggregates in concrete. Repurposes otherwise wasted materials.	 Often good economics, especially when landfill tipping fees are high. Provides local source of aggregates.	 Moderate local job creation at concrete recycling facilities.	 Widely practiced in Canada primarily for roads. More development is needed to reuse fines and aggregates.	 Requires crushing and sorting facilities. No changes to cement plants. Effective when planned into demolitions.	 Recycling infrastructure is uneven across regions. Transport distances can be cost prohibitive, especially in rural areas.	 Concrete recycling is well understood, practiced today, and socially accepted.	 Highly relevant to some stakeholders including waste management in municipalities, and green infrastructure.	 Reduces landfill burden. Lowers lifecycle emissions from quarrying. Benefits strongest when transport distances are low.

Criteria Status

■ ■ ■ ■ ■ Fails to meet criteria ■ ■ ■ ■ ■ Meets in some respect
■ ■ ■ ■ ■ Not promising ■ ■ ■ ■ ■ Potentially meets criteria
■ ■ ■ ■ ■ Meets criteria

10.3.5 Steel and Iron Pathways Table

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Ironmaking											
Direct Reduced Ironmaking (DRI) with Net-Zero Hydrogen	Decarbonization Pathway The only scalable net-zero option available today.	Enable Support commercial-scale DRI projects. Invest in hydrogen supply infrastructure and align policies and/or subsidies to close the cost gap.	 Can be net zero but depends on the carbon intensity of hydrogen.	 Net-zero hydrogen costs are high and require carbon pricing or some type of subsidies.	 Potential economic opportunities in producing low-carbon hydrogen and iron for domestic and international markets.	 A full-scale green hydrogen iron plant operates in Sweden.	 Requires process and regulation changes to switch operations from natural gas to hydrogen.	 Requires hydrogen supply chain and infrastructure which is not established, as well as stable supply of DR-grade iron ore pellets.	 Can be some concern around the safety of hydrogen.	 Seen by some producers and government as a feasible option, but significant investment risk still exists with uncertain carbon pricing and dependencies on hydrogen market.	 Better air quality with discontinuation of natural gas combustion.
Biomass based charcoal, or “biochar”	Niche Pathway Limited by biomass availability and competition, and carbon intensity of biochar.	Incubate Support Canadian pilot projects to establish performance data and feedstock logistics. Develop biomass supply chains while managing competition with other sectors.	 Can be net zero or even negative emissions, but only when coupled with high enough carbon capture rates.	 Biochar is more expensive than coal and coke but may have lower energy requirements for production.	 Canada is building the largest biochar plant in North America.	 A few pilots and demonstrations have occurred globally. Large-scale testing to begin in Canada.	 Biochar and coke have different properties, so complete substitution does not work for all furnaces.	 Supply chain for biochar is emerging. Biomass logistics and procurement can be difficult.	 Lacks public visibility but will have similar concerns to operating a regular BF.	 Some steel plants in Canada have already committed to trying biochar. The government is investing in biochar.	 Avoids methane from waste decomposition.
Molten Oxide Electrolysis	Potential Decarbonization Pathway Could produce net-zero iron without combustion.	Incubate Fund R&D partnerships and monitor international demonstration progress.	 Achieves net zero and can reduce lifecycle emissions associated with mining and waste.	 Higher capital and operational costs than other alternatives. High-temperature processes with large electrical demand.	 Technology is not developed or deployed in Canada. Abundant clean electricity offers an advantage.	 Full scale is expected soon. Demonstration plant in Brazil produces some iron.	 Easier maintenance because of multiple small vessels operating independently. Retraining and regulation changes required.	 Requires scale-up of net-zero electricity. Lower quality inputs can be used in production.	 No particular concerns. Environmental impacts are very low.	 Investments into the technology from companies that operate in Canada.	 Works with all iron grades. Byproduct is oxygen, no air quality concerns. No water or hazardous chemicals are needed.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electro-winning	Potential Decarbonization Pathway Could produce net-zero iron without combustion.	Incubate Track pilot results and support research collaborations. Prepare enabling conditions should the technology reach commercial readiness.	 Achieves net zero and can reduce lifecycle emissions associated with mining and waste.	 Modularization could reduce costs to the point of competitiveness with incumbent steel production.	 Technology is not developed, tested, or deployed in Canada.	 One project in pilot phase internationally and a few other research groups in Europe and Australia.	 Easier maintenance because of multiple small vessels operating independently. Retraining and regulation changes required.	 Requires scale-up of net-zero electricity. Lower quality inputs can be used in production.	 No particular concerns at this time, but full environmental impacts unknown.	 Backed by the biggest steelmaker in the U.S. and climate tech investors.	 Can use lower-grade ores and tailings, less mining product is wasted. Environmental impacts are not yet well documented.
Hot Briquetted Iron (HBI)	Enabling Pathway Decouples steel and iron production so that iron can be manufactured where low-carbon energy (i.e. hydrogen) is available and shipped to steel facilities in other provinces.	Deploy Advance HBI production capacity. Position Canada as a low-carbon HBI exporter. Build out hydrogen supply where HBI is produced.	 De-couples iron and steel production so each may be produced in a region with access to a relevant low-carbon energy source.	 Slightly higher capital and operating costs due to additional processing step. Transportation costs may rise if steel production is completed far from iron production.	 Creates a new export opportunity of low-carbon HBI from DRI. Canada has abundant hydrogen production potential compared to other countries.	 Commercial technology with two HBI plants in the U.S.	 Requires installation of briquetting equipment into existing DRI plants. Need the space to add this process downstream of hot DRI production.	 Fits into the existing supply chain and transportation for global shipping. Improves supply chain by decoupling iron and steel.	 No particular concerns.	 Linkage to lowering emissions may not be well understood.	 HBI can improve product quality out of EAFs and produce basic grade steels with lower-grade scrap, reclaiming scrap and reducing waste.
Co-located Iron and Net-Zero Hydrogen Production	Enabling Pathway Increases feasibility of critical ironmaking pathway.	Enable Invest in co-location planning and infrastructure at existing DRI sites. Support regulatory and permitting frameworks for integrated hydrogen-iron facilities.	 Improves access to low-carbon-intensity hydrogen.	 Better economics than separate production. Transportation and storage costs are significantly reduced.	 Potential economic opportunities in producing low-carbon hydrogen and iron for domestic and international markets.	 A couple of pilot hydrogen hubs operate in Canada with other sectors as end users.	 Space can be limited near existing steel plants so can constrain hydrogen production. Zoning is already industrial for iron production.	 Storage and transport infrastructure for hydrogen is avoided. Local H ₂ consumption reduces the need for robust supply chains. If steel production is present, electrical grid requirements may add complexity.	 Can be some concern around the safety of hydrogen.	 Aligns with iron producer interests as it lowers the risk of investing in hydrogen as a fuel by securing supply.	 Land use changes near existing iron facilities. Positive air quality benefits. Potential for other industries to cluster near hydrogen hubs.

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 Iron and Steelmaking											
Carbon Capture and Storage (CCS) for Blast Furnaces (BF) and Basic Oxygen Furnaces (BOFs)	Bridge Pathway Provides emission reductions so long as BF-BOF remains in use.	Don't Prioritize Track existing projects but prioritize hydrogen DRI and EAF pathways. Support CCS technologies and CO ₂ transport and storage networks.	 Cannot get to net zero alone due to multiple off-gas sources and dilute flue gases.	 High costs even where government support is available.	 Potential economic opportunities in CCS supply chain.	 Demonstration; one steel facility operates with CCS outside of Canada.	 Allows for continued use of BFs and BOFs. Regulations and permitting can be difficult. Capture rate is currently low.	 Requires buildout of carbon offtake infrastructure and supply chain.	 Skepticism about the continued use of fossil fuels and carbon leaks. Need to engage community to gain support.	 Expected to become less relevant as many steelmakers planning for low-carbon steelmaking are opting for hydrogen DRI.	 Doesn't fully address local air pollution. Continued coal mining upstream emissions.
 Steelmaking											
Electric Arc Furnaces (EAFs)	Priority Decarbonization Pathway Used widely today to recycle scrap steel. Can be combined with decarbonized ironmaking to produce primary decarbonized steel.	Deploy Accelerate the transition to EAF steelmaking by supporting grid and scrap supply chain investment.	 Already widely implemented and replaces basic oxygen furnaces, eliminating combustion emissions. Requires decarbonized electricity.	 Current successful technology that runs economically today.	 Supports construction jobs but can reduce steel jobs with higher-efficiency operations. Potential to meet domestic and international demand for low-carbon steel.	 Commercial and widely used globally and in Canada.	 Significant operator training hours needed to switch from BF-BOF as the operating process is different.	 Electrical demand is tripled per tonne of steel. Scrap steel can't fully meet demand. Can be issues with obtaining enough high-quality scrap steel or decarbonized iron.	 No particular concern. Local air quality benefits.	 Switchover already being implemented by two Canadian steel companies.	 Uses more recycled steel. Significantly reduces air emissions.

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 Casting, Hot Rolling, and Reheating											
Heat Batteries	Potential Decarbonization Pathway Could support all casting, hot rolling, and reheating temperatures with net-zero heat, contingent on commercialization for higher temperatures.	Incubate Fund demonstrations for high-temperature applications in steelmaking. Support development of co-located clean power to improve economics.	 Net zero but depends on carbon intensity of electricity.	 Currently relies on carbon credits or restructuring of electrical rates for competitive pricing. Capital costs expected to fall.	 Some research is occurring on coupling thermal batteries with nuclear power. Useful to multiple Canadian industries.	 Commercially available up to middle operating temperatures. Technology for high temperatures is expected to be commercial within the decade.	 Would need to replace current furnaces, and align with equipment replacement timelines, but operates very similarly. Can use renewables to provide industrial heat, avoiding intermittency.	 Strongly tied to availability and pricing of electricity. Functions better with co-located clean power.	 Change is implemented within a facility. May be pushback with land changes with buildout of renewables.	 Fits long-term goals but low relevance because this affects a small portion of energy and emissions.	 Land required to co-locate renewables. Less air pollution from replacement of combustion furnaces.
Industrial Heat Pumps	Potential Niche Pathway Can be net zero with clean electricity, but applies to very specific low-temperature use cases.	Incubate Fund targeted demonstrations for low-temperature steelmaking applications. Monitor technology advances toward higher temperature capabilities.	 Net zero, but depends on carbon intensity of electricity.	 Could be cost competitive for low low-temperature use cases.	 Not developed in Canada. Could be useful to multiple Canadian industries.	 Early commercial deployments in U.S. and Europe. Hasn't been used within steel and iron sector.	 Only provides low temperature heat, so useful for limited types of reheating.	 Requires clean electricity. Industrial heat pump supply chain is emerging.	 Change is implemented within a facility and therefore probably not public facing.	 Fits long long-term goals but low relevance because this effects a small portion of energy and emissions.	 Less air pollution from replacement of combustion furnaces. HFC leakages are possible from refrigerants.
Fuel Switching (RNG or Hydrogen)	Niche Pathway Low-carbon fuel substitution. Availability will depend on location and adoption by other closely located sectors.	Enable Support biofuel and hydrogen production. Focus on facilities where fuel switching can be paired with broader decarbonization.	 Reduces combustion emissions in product manufacturing and casting, but dependent on feedstock carbon intensities.	 Hydrogen and biofuels carry cost premiums.	 Could boost Canada's bioenergy and hydrogen sectors.	 Some fuel-switching options are already commercially available.	 Low-disruption for biofuels that are drop-in. More significant retrofit required for hydrogen.	 Requires some infrastructure: biofuels need storage. Hydrogen needs more substantial upgrades.	 Supported for cutting GHGs and improving air quality, though biomass fuels raise some forestry concerns.	 Fits long long-term goals but low relevance because this effects a small portion of energy and emissions.	 Reduces air pollutants.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Potentially meets criteria
- Meets criteria
- Not promising

10.4.5 Aluminium Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Aluminum Smelting											
Inert Anodes	Priority Decarbonization Pathway Essential for net-zero smelting.	Enable Support full scale validation and subsequent mass deployment through policy, financing, and regulations.	 Sector-wide implementation could reduce aluminum production emissions substantially.	 Could cut facility operating costs, though costly to adopt initially.	 Positions Canada as a smelting tech leader, creating jobs and export opportunities in the long term.	 Late R&D, though full-scale validation is still pending.	 Require new cell designs and maintenance routines but build on existing smelting processes.	 No major external infrastructure is needed. Canada's hydro power complements inert anodes within modified smelters.	 No concern.	 Key to net-zero goals, with strong backing from producers and government.	 Eliminate carbon anode production, improve safety, air quality, and potentially reduce costs.
CCS	Potential Dead-End Pathway Serves as a last resort retrofit if primary solutions stall.	Don't Prioritize Unlikely to be relevant in this sector as other pathways are emerging. Monitor as an option for residual emissions.	 Cannot fully eliminate direct emissions. Requires significant electricity so grid carbon intensity matters.	 Costly.	 Adds cost without boosting productivity or value, waste gas management step.	 Still testing lab and pilot-scale technologies.	 Technically feasible but CCS could complicate smelter operations and maintenance.	 CCS faces major infrastructure gaps with lack of CO ₂ pipelines and storage sites.	 May win support if it preserves jobs and cuts emissions, but CO ₂ pipelines and storage could face local opposition.	 Producers see CCS as a last resort — being explored mainly to complement carbon-free smelting.	 Lack of CO ₂ storage where aluminum is produced. End-use cases for CO ₂ can also be enablers for more emissions.
High-Amperage Smelting Pots	Bridge Pathway Near-term efficiency and emissions improvements to conventional smelting. Part of net zero if modifiable to work with inert anodes.	Deploy Support with green procurement or other policy measures. Scale deployment on asset replacement cycles, but ensure investment in inert anode technology proceeds in parallel.	 Reduces emissions per tonne significantly through improved cell efficiency and lower anode effects, but does not eliminate process CO ₂ from carbon anode consumption.	 More efficient than incumbent technologies, with lower operating costs. Capital investment in new smelting cells is substantial and most cost-effective when timed to asset replacement cycles.	 The primary technology is proprietary, and the owner operates in Quebec. Deployment generates significant construction activity and regional economic benefits. Operational expertise is exportable, with active deployment studies underway.	 Mature with full-scale deployment, currently scaling with a major expansion.	 Requires replacement of existing smelting cells and associated infrastructure, but leverages existing site assets, grid connections, and workforce skills. Process fundamentals are identical to incumbent technology.	 Requires little change to external infrastructure. Performance is contingent on access to clean, reliable, and abundant electricity.	 Substantially reduces existing air quality emissions and associated community concerns.	 Supported by Canadian producers and governments. Directly relevant to regions with abundant clean electricity and to customers facing increasing carbon intensity requirements.	 Significant particulate matter reductions improve worker and community air quality. Does not eliminate carbon anodes. Reduces energy consumption per tonne, lowering demand on the electrical grid.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Wetted Cathodes	Enabling Pathway Specialized efficiency upgrade — valuable in enhancing an already green aluminum production system.	Incubate Support R&D and pilots.	 Wetted cathode technology can cut cell energy use, improving efficiency and reducing emissions.	 High upfront cost, but longer cell life and energy savings can offset it over time.	 Minimal impact.	 Still in R&D. Not yet commercially proven for long-term aluminum cell use. May require more research to combine with inert anodes.	 Requires modifications to the cell design and operating practices.	 Little to no external infrastructure is needed. Implemented within smelting pots.	 Unlikely to face public scrutiny.	 Not a focal point since it doesn't directly drive big emissions cuts on its own.	 Cuts electricity use and may boost output, lowering costs and indirect emissions per tonne.
 Casting and/or Manufacturing											
Fuel Switching (i.e. hydrogen or biofuels)	Niche Pathway Low-carbon fuel availability will depend on location and adoption by other closely located sectors.	Enable Build out relevant infrastructure or supply chain to improve fuel procurement logistics. Support increased production of alternative fuels.	 Dependent on fuel carbon intensities. Reduces combustion emissions in product manufacturing and casting.	 Hydrogen or biofuels can carry premiums.	 Could boost Canada's bioenergy and hydrogen sectors.	 Some fuel-switching options are already commercially available.	 Low-disruption — biofuels are largely drop-in.	 Requires some infrastructure — biofuels need storage. Hydrogen needs more substantial upgrades.	 Widely supported for cutting GHGs and improving air quality, though biomass fuels raise some land-use concerns.	 Cuts emissions in ancillary operations, aligns with policy priorities, and expands markets for some energy suppliers.	 Reduces air pollution but not completely. Land-use changes for fuel production can be negative.
Heat Batteries	Potential Decarbonization Pathway Applicable for all temperatures required.	Incubate Support demonstrations and pilots in regions with low-cost electricity.	 Depends on carbon intensity of electricity.	 Very costly. Relies on carbon credits or restructuring of electrical rates for competitive pricing. Capital costs are expected to fall over time.	 Opportunities for Canadian manufacturers. Creates demand for on-site power generation technologies. Useful to multiple industries.	 A few commercial plants globally, designed for most required temperatures. Awaiting full-scale deployment in Canada.	 Would need to replace current furnaces but operates very similarly.	 Functions best when co-located with clean power. Strongly tied to availability and pricing of renewable electricity and natural gas.	 Change is implemented within a facility. May be pushback with land changes to build out renewables.	 Fits long term goals but low relevance because this affects a small portion of energy and emissions.	 Land required to co-locate renewables. Less air pollution from replacement of combustion furnaces.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Industrial Heat Pumps	Niche Pathway Can be net zero with renewable electricity but applies to specific low-temperature use cases.	Incubate Support demonstrations and pilots.	Depends on carbon intensity of electricity.	Only cost-competitive for low temperatures.	Not developed in Canada. Useful to multiple Canadian industries.	Early commercial deployments in U.S. and Europe. Have not been used within aluminum sector.	Only provides low to medium temperature heat. Applicable to a few types of manufacturing.	Requires clean electricity.	Change is implemented within a facility and therefore probably not public-facing.	Fits long term goals but low relevance because this affects a small portion of energy and emissions.	Less air pollution from replacement of combustion furnaces. HFC leakages are possible from refrigerants.
Alumina Refining											
Electric Calcination	Potential Decarbonization Pathway Eliminates fossil fuel use in calcination and enables steam recycling substantially reducing emissions and energy.	Incubate Support R&D and scale support as technology matures.	Eliminates emissions from calcination step. Depends on carbon intensity of electricity.	Electric calciners need major capital investment. Operating costs vary with provincial electricity prices.	Jobs generated through retrofit of existing facilities. Multinationals that operate in Canada are building expertise with the technology.	Piloted by companies that operate in Canada but R&D is occurring mainly in Australia.	Alters refinery equipment and process flow, but can be designed to fit existing sites.	Requires large, steady power. May need grid upgrades, on-site substation, or storage for continuous operation. May require buildout of co-located renewables.	Unlikely to face public scrutiny.	Adds major new grid load — key for utilities, planners, and policymakers aiming for deep decarbonization.	Enables waste-heat recovery from electric systems.
Mechanical Vapour Recompression (MVR)	Decarbonization Pathway Greatly reduces power and water demand.	Incubate Support pilots or demonstrations in the aluminum sector and then scale support for mass deployment.	Cuts refining emissions substantially by eliminating heating emissions associated with refining.	Cost parity with steam systems and offers lower operating costs, particularly with low-cost hydro.	Modernizes refineries, maintains jobs, and builds Canadian expertise in MVR which can be applicable in other industries.	Commercial in other industries but still in early trials for alumina refining. No Canadian uptake; pilots show near-term potential.	Can be added to Bayer-process refineries as a high-efficiency evaporation step without major changes.	Uses standard industrial equipment and is considered a low-risk, modular retrofit — not a full rebuild.	Unlikely to face public scrutiny.	Aligns with producer net-zero targets. Fits federal decarbonization priorities. Meets customer demand.	Reduction in water use by capturing and reusing steam that would be lost. May require buildout of co-located renewables.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electric Boilers	Niche Pathway Viable in specific regions or retrofit phases, but less resource optimal than MVR long term.	Don't Prioritize Watch economics; if there is improvement support adoption and trial of technology where electricity is low-cost. May complement MVR.	 Depends on carbon intensity of electricity.	 Viable in low-cost electricity regions like QC, but upfront costs exceed those of gas boilers.	 Not a major economic driver, though it may benefit boiler industry.	 Electric boiler technology is well-established.	 Operationally straightforward. Operation unaffected — same function.	 Have strong power access but need auxiliary infrastructure for peak loads.	 Eliminates on-site emissions without use of fossil fuels. Electric equipment widely supported.	 Assists in reaching emissions targets, boosts utility demand, and offers easy wins for policymakers.	 High-efficiency boilers cut maintenance costs. Improved air quality and safety with no combustion.
Hydrogen Calcination	Potential Niche Pathway Key long-term lever and essential where electric calcination isn't feasible.	Don't Prioritize Watch maturity and economics. With improvement this may become relevant where hydrogen infrastructure is robust.	 Reduces combustion emissions in product manufacturing and casting but dependent on hydrogen carbon intensities.	 Low-carbon hydrogen calcination is costly and energy-intensive, with limited commercialization. Significant calciner retrofits likely required.	 Could make alumina an anchor tenant for hydrogen. Regions with hydrogen potential do not have strong overlap with current alumina-production regions.	 Hydrogen for alumina refining is in pilot stage, with research trials in Australia.	 Same calcination as natural gas, but with water vapour instead of CO ₂ . Combustion needs adjustments.	 Needs major new infrastructure — hydrogen production, storage, and air separation units.	 Hydrogen supported as a clean fuel, though storage and safety raises some concerns.	 Fits long-term decarbonization goals and government plans but isn't a top priority sector wide.	 No harmful byproducts.
∞ Lifecycle Emissions											
Recycling	Enabling Pathway Cuts primary production emissions. Must be supplemented with a standard production pathway.	Deploy Improve recycling infrastructure and education to maximize lifespan of materials.	 Significantly reduces processing emissions as smelting is eliminated.	 Cost-effective and established — Canada has high recycling rates, though gains beyond that face higher costs.	 New recycling facilities create jobs and boost the competitiveness of Canadian aluminum.	 Practices and technology have been used for decades (i.e., automotive parts, building materials, etc.).	 Recycling facilities may need to be scaled up. Significant challenges to increasing consumer facing recycling.	 Basic infrastructure exists, but gaps in collection, sorting, and program consistency remain. Recycling rates are high for construction and automotive materials but lower or unknown for other products.	 Widely accepted and initiatives can lead to new facilities.	 Industry interest to reduce costs and emissions. Producers to meet consumer demand.	 Reduction in energy use, bauxite mining, and landfill waste.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.5.5 Chemicals and Plastics Pathways Table

Fails to meet criteria Meets in some respect Potentially meets criteria Meets criteria			Economic		Technical			Social			
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Process Energy											
Low-Carbon Hydrogen (heat)	Decarbonization Pathway Applicable for heat applications where electric options are not viable and clean hydrogen is available.	Enable Support demonstration where economics are positive. Build out hydrogen generation and supply infrastructure.	 Reduces carbon intensity, but only net-zero with CCS or certified low-carbon supply.	 Hydrogen costs falling near hubs. Retrofits cheaper than full electrification when capital-constrained.	 Supports gas utility transition strategies. Strengthens hydrogen supply chain.	 Burner and control modifications are feasible at scale for hydrogen. Full-scale hydrogen plant under development.	 Minimal layout changes and short outages. Useful for peaking or reliability where electric power is constrained.	 Requires verified H ₂ supply and sometimes new storage. Trucking or pipelines depend on regional ecosystems. On-site fuel generation or hubs reduce infrastructure burden.	 Mixed views: sustainability of feedstocks and hydrogen safety are concerns and acceptance improves with transparency.	 Relevant to utilities and operators for near-term decarbonization planning. Canadian deployment occurring today.	 Concerns with methane leakage from blue hydrogen production.
Electrified Steam Crackers	Potential Decarbonization Pathway Applicable to high-temperature furnace heat as grids expand and decarbonize.	Incubate Support research and demonstration in Canada. Build out grid infrastructure.	 Electrified heaters eliminate combustion emissions from core furnace combustion. Depends on grid carbon intensity.	 Business case hinges on abundant, reliable, low-cost clean power. Early projects require co-funding.	 First-mover advantage in low-CO ₂ resins, advanced controls, high-skill electrical/automation jobs at resin hubs.	 Demo/early commercial globally.	 Major furnace revamps during multi-year turnarounds. Extensive control upgrade and operator training. Modification of tail gas used in process.	 Requires major grid infrastructure upgrades and reliable electricity.	 Generally acceptable. Local concerns focus on grid buildouts. Air and noise benefits help.	 Strategic for polyethylene/poly propylene producers in ON/AB/QC resin corridors.	 Eliminates furnace NO _x . Finer temperature control improves yields. Scaling electrical grid may have land-use concerns.
Electric Arc Furnaces (EAFs)	Niche Pathway Relevant for electro-thermal sub-processes meeting some high-temperature heat needs.	Enable Support demonstrations with positive economics. Build out grid infrastructure.	 Delivers zero-emission process heat when powered by clean electricity. Depends on grid carbon intensity.	 Economics depend on duty cycle, electricity price, and retrofit scope. Usually secondary to e-boilers/ e-crackers in chemical plants.	 Limited domestic opportunity beyond specialized OEMs/contractors. Part of broader industrial electrification.	 Mature in metals. Limited chemical deployments.	 Works where electro-thermal heating can be substituted without product impacts. Best aligned with batch or discrete operations.	 Requires high-capacity electrical feeds and transformers. Supply chain available via metals sector vendors.	 Positive with fewer combustion emissions onsite.	 Relevant to select intermediates or allied operations at multi-industry complexes. Not a sector-wide lever.	 Eliminates onsite flue gas, reducing NO _x and particulates. Precise temperature control can improve yields.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electric Boilers, Industrial Heat Pumps, Heat Batteries, Mechanical Vapour Recompression (MVR)	Niche Pathway Relevant to preheating, steam & hot-water loops at ammonia, resins, and solvents plants, excludes cracker furnaces that burn byproduct fuel.	Enable Support demonstration with dedicated funding, then deploy where cost effective along with grid buildout.	Delivers zero-emission steam, hot water, and low-temperature heat with decarbonized electricity. Abatement is smaller where site steam comes from cogeneration with CCS.	Capex moderate. Operational costs tied to electricity. Attractive where power purchase agreements, load management, or on-site generation exist.	Drives demand for Canadian equipment/services and grid buildout.	Technologies are commercial globally. Canada lacks deployments.	Needs spare waste heat and a nearby higher-temperature use for it. Adds little where site heat is already well integrated. Install during turnarounds; requires high-voltage training.	Needs interconnection capacity and stable, clean electricity. On-site renewables and storage can hedge availability and price risk for continuous chemical loads.	Generally positive. Seen as clean industry investment.	Top action for utilities, operators, and provinces seeking rapid Scope-1 reductions and electrification of heat and steam services.	Lower NOx/PM, improved operator safety, better temperature control, and efficiency. Frees gas for higher-value chemical synthesis.
Renewable Natural Gas (RNG)	Niche Pathway Works as an option where sustainable feedstocks exist and can meet supply. Feedstock scarcity limits scale.	Enable Support demonstration where RNG supply is secure	Only net zero if RNG fully displaces fossil natural gas. Requires low-carbon feedstocks. Methane leakage remains a concern.	RNG scarce and premium-priced. Retrofits cheaper than full electrification when capital-constrained.	Supports gas utility transition strategies. Strengthens RNG supply chain.	RNG is mature with limited deployment.	Drop-in fuel. Useful for peaking or reliability where electric power is constrained.	May be difficult for suppliers to connect to existing infrastructure, limiting supply. Competition for biomass.	Broadly accepted and seen as waste valorization.	Relevant to utilities and operators for near-term decarbonization planning. Canadian deployment occurring today.	Concerns with methane leakage from RNG transport and combustion.
On-site Clean Electrical Generation	Priority Enabling Pathway Required to meet the electrification demands of the chemicals and plastic sector.	Deploy Build out on-site clean electricity generation as existing assets reach end-of-life.	Reduces burden on the electrical grid and ensures electricity used is generated from non-emitting sources.	Many methods of on-site generation are at cost parity or can provide operational savings depending on scale.	Generates more jobs on-site at chemical and plastic facilities.	Many technologies for clean on-site generation are commercial today and have been implemented in other Canadian sectors.	Training of staff to maintain and operate the new processes. Depending on the technology, layout or available space may be a concern.	Reduces burden on electrical infrastructure. Most technologies have established supply chains.	Positive as grid power demand is lowered and more local jobs may be generated.	Power demand is expected to be very high, so on-site power generation will be essential. Current focus may be more on direct emission sources.	Reduced burden on electrical grid.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Primary Feedstock Substitution											
Low-Carbon Hydrogen (feedstock)	Decarbonization Pathway Has relevance to ammonia and methanol production.	Enable Support demonstration where economics are positive. Build out hydrogen generation and supply infrastructure.	 Directly decarbonizes Canada’s large ammonia/ methanol production by replacing emissions- intensive hydrogen. Only net-zero with certified low-carbon supply.	 Hydrogen cost tied to electricity and/or capture performance and CO2 storage availability. Early offtake contracts help.	 Opens manufacturing, logistics, and export opportunities anchored in industrial hubs. Net-zero fertilizer production.	 Technologies commercial. Regional scaling and integration with CO2 handling still developing.	 Strongest fit where hydrogen can be produced on-site. Minimal product reformulation required.	 Requires low-carbon hydrogen infrastructure. Benefits from colocation with chemical production and proximity to CCS hubs for blue pathways.	 Mixed views: sustainability of feedstocks and hydrogen safety are concerns, and acceptance improves with transparency.	 Aligns with provincial strategies and export ambitions for low-carbon ammonia and methanol.	 Concerns with methane leakage from blue hydrogen production.
Biomass	<i>Potential Decarbonization Pathway</i> Applicable to some chemical production processes where sustainable feedstocks are available and production pathways are mature.	Incubate Support research and development of production pathways.	 Renewable carbon source for chemicals/ plastics. Life-cycle benefits depend on sourcing, land use, and competition with other sectors.	 Costs high due to preprocessing, conversion complexity, and logistics. Potentially viable where residues/ biogenic CO2 are accessible.	 Can create niche economic clusters and rural jobs.	 Emerging. Several routes remain pre-scale in Canada requiring further R&D/demos.	 Best where stable biomass supply exists. Requires new processes and technologies but can integrate with up- or downstream technologies.	 Requires certified supply chains, preprocessing facilities, and consistent specs. Obtaining sufficient volumes close to demand is challenging.	 Public support higher when feedstocks are non-food, local, and transparently certified. Caution around land-use impacts.	 Relevant to specialty chemicals, bioplastics, and regions with forestry/ agricultural residues.	 Repurposes waste biomass. Possible land use concerns.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Carbon Capture											
Carbon Capture and Storage (CCS)	Niche Pathway Essential for large, steady point sources. Cannot stand alone due to energy needs, dispersion, and cost.	Enable Support pilots and demonstrations. Build out CO ₂ transport and storage network.	 Captures process and combustion CO ₂ at chemical clusters. Decentralized emissions have lower capture efficacy. Net zero requires negative emissions.	 High capital and operational costs. Viability improves with price certainty (e.g., contracts for difference) and shared hubs lowering transport/ storage costs.	 Growth in engineering, construction, and storage services. Fosters CO ₂ network buildout leveraged by other sectors.	 Components mature. Site-level integration and optimization continue.	 Best on concentrated, steady streams. Requires additional electrical and space for capture units and compression. Substantial increase in operational complexity	 Needs CO ₂ pipelines and storage. Hub models and permitting capacity are decisive constraints. Some regions, like Alberta, are further ahead.	 Support improves with monitoring, reporting, verification standards, and Indigenous partnerships.	 Prioritized in AB/ON/QC clusters to maintain production and jobs while cutting emissions.	 Reduction in air pollution emissions from gas combustion. Some concerns about CO ₂ leakage.
Demand Reduction in Use of Chemicals and Plastics	Priority Enabling Pathway Avoids tonnes of primary feedstock production by addressing systemic inefficiencies across other sectors.	Deploy Incentivize demand reduction of carbon-intensive products and sustainable product substitution.	 Directly reduces upstream production, transport, and disposal emissions.	 Variable by sector and product but can provide cost savings through improved practices or products. Some costs associated with program design and monitoring.	 Opportunities for producers of alternative products.	 Many practices are well established or demonstrated systems within Canada.	 May require some logistical changes for reuse of goods.	 New sustainable product offerings need to be developed for some sectors.	 Reducing waste resonates with public. Behaviour change barriers exist for durable product models and food habits. Acceptability varies by product.	 Some practices are accepted today. Varies by sector.	 Varies by sector.
Product Design	Priority Enabling Pathway Avoids tonnes of primary material and improves recyclability, durability, and reusability.	Enable Build policy to incentivize or mandate design of products for reuse, recycling, and repair. Support product R&D.	 Design for circularity reduces lifecycle emissions, enables closed-loop material use, and lowers primary production.	 Often positive over product lifetime (reduced material/ production costs, extended use). Upfront R&D and redesign costs can be high.	 Stimulates innovation, eco-design industries, and repair, remanufacturing, and recycling markets. Creates skilled design and service jobs.	 Eco-design principles established. Application uneven across sectors (packaging and electronics ahead, others lagging).	 Requires changes to design workflows, new material specifications, and skilled labour for redesign and repair.	 Requires buildout of recycling, reuse, and repair supply chains and infrastructure. Improve product labelling and standards. Practical in sectors with established EPR and circular economy standards.	 Public support for durability, reparability, and reuse. May be resistance with redesign costs and adapting reusable formats.	 Some interest among manufacturers, brand owners, retailers, policymakers, and recyclers. Directly linked to extended producer responsibility frameworks.	 Can reduce waste, lower resource extraction, improve product longevity, and foster repair/reuse cultures.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Recycling and Systems											
Mechanical Recycling	Priority Enabling Pathway Cuts primary resin demand and creates lower-carbon feedstock. Cannot meet demand alone and only works with high-quality plastics.	Deploy Continue to build out collecting and sorting infrastructure. Mandate or incentivize producer buyback.	 Avoids up- and downstream emissions by substituting primary feedstock. Some emissions could be associated with energy use in recycling.	 Current cost-competitiveness is heavily tied to oil and gas pricing, demand, and collection.	 Generates local jobs in waste-handling facilities. Can encourage smart and sustainable product design.	 Mature technology.	 Functions similarly to traditional waste collection. May require additional logistics planning or training. Only works with high-quality plastics.	 Collecting and sorting high-quality plastics can be complicated. Market impacted by primary product prices if not mandated or incentivized. Not all locations have recycling infrastructure.	 Generally well accepted and implemented in many Canadian regions. Positive association with reduced landfilling.	 Secondary plastics can have impurities, making them less desirable. Relevant where mandates, EPR systems, company sustainability targets, or zero plastic waste strategies exist.	 Reduced burden on landfills and primary resource extraction and associated land use and water- and air-quality impacts.
Chemical Recycling: Thermal Plastic Conversion (Pyrolysis and Gasification)	Enabling Pathway Cuts primary feedstock demand by creating synthetic oil and gas but cannot meet demand alone.	Incubate Support pilots and demonstration. Improve existing collecting and sorting infrastructure.	 Reduces unmanaged disposal emissions and avoids upstream emissions but can add direct or energy-related emissions. Net-zero alignment may require carbon capture.	 Capital-intensive. Economics depend on tipping fees, heat, power, or product revenues, and stringent pollution controls.	 Generates local jobs where facilities are built. Development beyond a waste management solution depends on the buy-in for products (syngas, synthetic-oil, or carbon black).	 Pyrolysis and gasification have been demonstrated or are used in Canada today with coal or wood feedstocks.	 Typically requires buildout of a new facility with extensive permitting. Fits with current waste collection and management operations.	 Requires buildout of new supply chains for products.	 Health and air-quality concerns are moderate for gasification and pyrolysis as the process is contained.	 Relevant mainly to municipalities managing non-recyclable fractions. As supply chain expands, interest in products (synthetic gas, synthetic oil, and carbon black) may grow in relevance.	 Sanitation and land use improved from reduced landfilling and high recovery of hard-to-recycle plastics. Some air quality concerns.
Chemical Recycling: Depolymerization and Dissolution	Potential Enabling Pathway Cuts primary resin demand by creating lower-carbon feedstocks, but functions only with certain plastics. Cannot meet demand alone.	Incubate Support research and development. Improve existing collecting and sorting infrastructure.	 Avoids up- and downstream emissions by substituting primary feedstock. Can be energy intensive and requires decarbonized electricity.	 High energy-related costs for depolymerization. High capital costs. Economics dependent on oil and gas pricing. Requires green premiums.	 Improves the quality of products offered in the secondary market. Minimal product degradation. Generates local jobs.	 Pre-commercialization.	 Some methods are selective for the type of plastic or are incompatible with impurities. Requires new facilities or additions to existing facilities.	 Collecting and sorting high-quality plastics can be complicated. Market impacted by primary product prices if not mandated or incentivized. Not all locations have recycling infrastructure.	 Public recycling practices already well accepted. Skepticism about the efficacy of chemical recycling.	 Relevant where mandates, EPR systems, company sustainability targets, or zero plastic waste strategies exist.	 Avoids downgrading of plastics, keeping them in the economy longer and reducing landfill burden. Waste products may be harmful.

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Recycling Standards, Product Labelling, and Improved Extended Producer Responsibility (EPR)	<i>Priority Enabling Pathway</i> Critical for secondary plastic and chemicals market and primary feedstock demand reduction.	Deploy Implement improved plastic tracking and product labelling. Deploy standardized EPR systems.	Raises diversion and recycled content, decreasing primary resin production and associated upstream emissions.	Can provide cost savings through material recovery. Costs are shared between producers and governments.	Recovers economic value that might otherwise be landfilled. Encourages designing for recycling.	Approaches tested, mature, and proven.	Fits with existing recycling logistics and facilities.	Requires establishing consistent and clear product labels as well as tracking plastics as they move through supply chains.	Strong public support. Visible benefits reinforce participation.	Central to industry/ government roadmaps. Complements production decarbonization.	Litter/leakage reduction. Supports procurement of low-carbon materials.
Residual Emissions and Waste											
Incineration with Energy Recovery	<i>Niche Pathway</i> Last-resort option for managing waste. Limited role in a circular, low-carbon system.	Monitor Support where no other options exist.	Reduces unmanaged disposal emissions but can add direct or energy-related emissions. Applies to most or all plastics. Alignment typically requires capture or offsets.	Capital-intensive. Economics depend on tipping fees, heat, power, or product revenues, and stringent pollution controls.	Generates local jobs where facilities are built.	Mature technology used in Canada today.	Typically requires buildout of a new facility with extensive permitting. Fits with current waste collection and management operations.	Requires district energy or power interconnections. Strict emissions monitoring. Ash handling and disposal logistics.	Incineration is contested locally due to concern over health risks.	Relevant mainly to municipalities managing non-recyclable fractions.	Reduced landfilling and provision of district heat/power. Air- and water-quality concerns.
Plastic Composting	<i>Potential Niche Pathway</i> Option for specialized plastics. Limited role in a circular, low-carbon system.	Enable Develop labelling regulations and consumer guidance. Support R&D of low-temperature compostable plastics.	Applicable for very specifically manufactured plastics. Some GHGs associated with composting.	Composting facility capital and operating costs can be higher due to heat requirements. Requires more expensive compostable plastic inputs.	Generates local jobs where facilities are built. No development beyond a waste management solution.	Some bioplastics are produced and composted in Canada today, but many are mismanaged.	Some composting facilities do not get hot enough to degrade bioplastics, requiring new facilities or retrofit.	Upstream supply chain issues with manufacturing compostable plastics and then downstream with sorting these for compost.	Same level of acceptability to traditional composting. Requires education programs on labelling and composting correctly.	Requires specialized products with sufficient labeling. Typically only relevant with single-use consumer-facing products (utensils, plastic bags, etc.). Variable government interest.	Nutrients and carbon are recycled as fertilizer for agriculture. Air- and water-quality impacts are low.

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Direct Air Capture (DAC)	Potential Niche Pathway Negative emissions backstop for unavoidable process/end-of-life emissions.	Incubate Support R&D and pilots.	 Offsets the remaining embodied carbon emissions in products. Requires decarbonized electricity.	 Currently high cost/kWh. Niche this decade pending technological improvements and clean-power availability.	 Engineering, construction, and storage services growth. Fosters CO ₂ network buildout leveraged by other sectors.	 Emerging deployments. Integration experience growing via pilots tied to CCS hubs.	 Adds energy load and siting complexity. Procurement via long-term contracts.	 Needs CO ₂ offtake/storage and low-cost clean electricity.	 Neutral-to-cautious due to perceived costs. Support improves when framed as small residual share.	 Limited near-term role. Strategic hedge for firms/governments targeting full net-zero balance sheets.	 Potential issues with land use and carbon leakage.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

11.1.5 Agriculture and Agrifood Pathways Table

				Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Animal Agriculture											
Advanced Manure Management	Priority Decarbonization Pathway Substantially reduces methane from manure systems, but residual emissions remain, requiring integration with broader livestock decarbonization strategies.	Deploy Offer financing mechanisms and/or adopt offset protocols with financial benefits. Provide extension services on selecting economical options relevant to farm size.	 Anaerobic digestion, acidification, or separation substantially reduce manure methane. Residual emissions remain.	 Some methods low cost while more advanced systems are capital intensive. Project economics depend on scale, off farm substrates, and credit/incentive access.	 Development of manure management technologies and expertise. Co-development of biogas generation. Buildout of nutrient recovery. Reduced dependence on imported fertilizers.	 Most techniques are mature with commercial adoption occurring in Canada. Capital-intensive technologies are more limited.	 Some strategies (i.e. more frequent manure removal) require few changes. Other strategies require installation of technologies, retrofit of existing buildings, and worker training.	 Infrastructure for equipment supply largely established. Biogas offtake is difficult; consuming on-site reduces challenges.	 Acceptance is generally high as long as odour and traffic remain limited.	 Many farms already employ manure management techniques with uptake in technology adoption.	 Improved nutrient recycling and displacement of synthetic fertilizers reduces lifecycle emissions and water pollution. Biogas reduces reliance on fossil fuels.
Fermentation-Based and Cultured Proteins	Potential Decarbonization Pathway Offers potential for major livestock emission displacement, but scalability, cost, and lifecycle performance remain uncertain.	Incubate Support research and development. Build out regulatory environment.	 Potential for large reductions if powered by clean energy and scaled.	 Cost competitiveness at scale is expected soon. Costs currently remain higher than most conventional products.	 Canada has a large primary agricultural industry which can support growth in bioprocessing. Opportunities for IP and R&D from established research organizations.	 Some products are commercial. Many others are in various phases of research, development, and scaling.	 New food manufacturing facilities will need to be built out with novel processes. Regulatory environment needs development.	 Commercial manufacturing and ingredient supply chains are nascent, with limited retail availability.	 Acceptance is mixed as products can be perceived as highly processed. Safety and health are concerns.	 Ongoing research in Canada. Some companies present in Canada.	 Can reduce land use and air and water pollution. Creates food supply resilience. Further studies of health and environmental implications required.

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Plant-Based Proteins	Priority Enabling Pathway Gradual shifts in demand toward less livestock and emissions-intensive products. Enables deep structural emissions reductions where applicable.	Deploy Support expanding manufacturing of higher value chain plant-based protein products with financing mechanisms. Provide education to consumers on the benefits of plant-based proteins.	Can achieve net zero with zero-emissions crop practices.	Plant based proteins are typically lower cost to produce and purchase than animal-based proteins.	Canada has a major pulse market. Development and production of plant-based proteins (higher-value products) in the same supply chain would create significant IP, export, and job opportunities.	Plant-based protein products produced and consumed regularly in Canada. Some development underway to improve nutritional equivalence, scalability, and digestibility.	Some scaling of food processing facilities or buildout of new manufacturing processes will be required.	Canada has an established and well-positioned plant-based protein supply chain which can readily be expanded. Infrastructure to transport crops and food products is established.	Plant-based proteins are widely accepted. Most consumers choose both animal and plant-based proteins and choices in diet vary by region. Concern over high salt, fat, sugar, and additives in many products.	Increasing demand for plant-based proteins from consumers drives market interest. Pulse producers looking for value add.	Reduced water and land use when replacing animal-based protein, potential health benefits when a part of balanced diets. Many products are not nutritionally equivalent to livestock-based products.
Enhanced Animal Genetics	Enabling Pathway Reduces livestock emissions intensity. Cannot eliminate biogenic methane and must be combined with other livestock measures.	Incubate testing and demonstration. Provide extension services to farmers on how to select for and the benefits of selecting low methanogenic genetics.	Selective breeding reduces enteric methane intensity but does not eliminate emissions. Must pair with other measures.	Low incremental cost. Leverages existing breeding programs and AI. Benefits accrue herd wide over time. Operational savings from improved feed conversion.	Some opportunity for Canadian IP and R&D. Expands Canada's leadership in dairy genomics and exportable genetics services.	Genetic selection used widely today for a variety of purposes. Canadian research groups testing large-scale low-cost ways to select for low methanogenic genetics.	Integrates seamlessly into existing breeding programs.	Uses established milk recording, mid infrared spectroscopy, and genomic platforms.	Non intrusive and animal welfare neutral. Generally, well accepted.	Many stakeholders are involved in data sharing for ongoing research. Herd-level emissions reductions without changing facilities.	Tracking genetics accurately improves diversity, animal health and longevity.
Improved Feed Digestibility and Quality	Enabling Pathway Reduces enteric methane per unit output. Doesn't eliminate emissions. More effective when combined with other measures.	Deploy Provide regionally specific information on growing and selecting high quality feed. Support development of additives.	Higher forage quality and specific additives cut methane per unit output but not to zero.	High quality feed may have cost increases, but these can be balanced by the improvements in performance.	Builds demand for Canadian feed innovations and forage quality services.	Practices are commercial today. Efficacy varies by diet. More advanced approaches, including additives are in R&D.	High compatibility. Some changes to harvest timing and storage but fits with existing systems. Implemented through routine ration adjustments.	Uses existing feed supply chains, labs, and advisory networks.	Seen as positive as it aligns with better animal nutrition.	Recognized by all stakeholders as a path forward. Seen positively due to alignment with efficiency and emissions intensity.	Improved productivity and feed efficiency. Some approaches also reduce upstream emissions associated with crop production.

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Modified Grazing Practices	Enabling Pathway Improves soil carbon and pasture efficiency in suitable regions, but impacts are context-specific and insufficient alone to achieve net zero.	Deploy Provide regionally specific extension services to farmers including case studies. Support local demonstrations.	Can build soil carbon and reduce emissions if optimized. Outcomes are climate/soil dependent.	Lower-cost measure requiring better planning, fencing and water distribution.	Growth in advisory services and R&D.	Grazing best management practices (rotational, adaptive, rest periods) are widely practiced. Better provision of information required to improve grazing practices.	Fits with existing practices; may require small modifications such as the addition of more fencing and improved planning.	Infrastructure and supply chain are in place.	Acceptance high with improved pasture productivity.	Producers can benefit from improved animal performance and forage utilization. Research is still ongoing.	Improved soil carbon stocks, water retention, drought resilience, soil structure, and biodiversity. Pasture productivity is maintained or improved.
Enhanced Soil and Pasture Management	Enabling Pathway Builds soil carbon and reduces input needs, but sequestration limits and variability mean it must complement direct methane reductions.	Deploy Provide regionally specific extension services to farmers including case studies. Support local demonstrations.	Practices increase soil organic carbon and reduce inputs but are complementary to enteric/manure abatement.	Measures such as adding trees to pastures or nutrient planning have low to moderate costs and can improve forage yields.	Growth in advisory services and R&D.	Pasture reseeded and soil nutrient management are mature. Other techniques are not well documented or standard in Canada.	Compatible with existing livestock systems. Mainly requires changes to planning.	Infrastructure and supply chain are in place.	Acceptance high with improved yields and low costs.	Valuable to farms with grazing animals. Some practices are commonplace others are less understood and in R&D phases.	Improved soil carbon stocks, nutrient and water retention, soil stability and biodiversity in pastureland. Reduced nitrogen runoff. Shade and shelter where trees are planted.

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PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Crop Agriculture											
Efficient Fertilizer Application and Use	Decarbonization Pathway Reduces nitrous oxide emissions through improved nitrogen management but cannot fully eliminate soil emissions.	Deploy Continue to provide high-quality extension services on fertilizer application best management practices and their benefits.									
			Lowers N ₂ O emissions materially. Not a full abatement to zero. Requires other measures to offset remainder.	Potential return on investment from reducing fertilizer inputs through optimizing rate, source, timing and placement.	Growth in advisory and training services.	Nutrient stewardship is well established in Canada.	Small modifications to planning and application practices may be required.	Infrastructure and supply chains are largely in place.	High acceptance for water quality benefits.	Policy and government support is high. Lower operational costs are relevant to farmers.	Demand reduction of primary fertilizers, improvements in water quality from reduced nitrogen loss.
Vertical Farming	Potential Niche Pathway Can significantly reduce land and input pressures for select crops if powered by clean electricity, but scale and crop applicability remain limited.	Incubate Support R&D. Assist with financing in favourable economic conditions.									
			Can reduce land and pesticide use. Dependent on electricity carbon intensity.	Economics remain challenging due to high capital and power costs. Profitable niches exist near urban markets and for premium produce.	Opportunity for more variety in plants grown in Canada. Development of IP. Generates agricultural jobs in urban, remote, and northern communities.	Commercial for some crops. Largely still in demonstration and pilot phases as economic outcomes are mixed.	Requires buildout of new facilities, specialized skills and training, and tightly controlled climates.	Depends on access to low-cost, reliable, clean power.	Generally positive for local year-round food supply.	Viewed as complementary to traditional farming. Relevance in limited markets. Costs and power constraints limit widespread interest.	Significantly reduces water, pesticide, and fertilizer use. Shortens transport distance to consumers. Can integrate waste heat and renewables.
No or Low Till	Enabling Pathway Supports soil carbon retention and reduces fuel use, but sequestration is variable and insufficient on its own for net zero.	Deploy Provide regionally specific extension services. Support monitoring soil organic carbon to ensure effectivity in local conditions.									
			Supports soil organic carbon retention and fuel savings. Effects vary by region/soil.	Can improve yields under the right conditions. Reduces operational fuel costs. Stronger economics in the Prairies.	Growth in advisory and training services and supply of specialized agriculture tools.	Practices are widely adopted in Canada. Long-established in Prairies.	Fits with existing farming practices.	Used widely today across Canada with established equipment supply chains.	High acceptance low public impact.	Used widely by farmers for lower fuel costs, soil health, and potential yield benefits.	Can improve or conserve soil water and nutrient retention. In the right conditions higher yield can occur.

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Greater Use of Cover Crops	Enabling Pathway Enhances soil resilience and nitrogen retention.	Deploy Provide regionally specific extension services. Support research and monitoring focused on optimizing crop selection in local conditions.		 Relatively low-cost measure. Potential to increase yield in some cases when optimal cover crops are chosen. Optimal combination of amendments can improve yields.	 Advisory and training services.	 Use of cover crops is common. Resources exist provincially and federally advising on species selection.	 Typically fit with growing seasons. Main modifications are to planning.	 Seed supply chains are well established in Canada.	 High acceptance low public impact.	 Relevance is high to producers due to potential yield increases. Many government organizations offer advisory materials, but financial support is low.	 Reduces or prevents soil erosion. Can assist with pest or weed control. Improves overall soil health.
Adding Organic Amendments	Enabling Pathway Improves soil health and nutrient cycling, but net emissions depend on amendment sourcing and management practices.	Deploy Support further buildout of organic fertilizer market with financing mechanisms, regulatory changes, and extension services on best management practices.		 Many organic amendments are low cost as they are sourced from waste (i.e. compost, manure, sludge). Optimal combination of amendments can improve yields.	 Market generated around use of otherwise wasted materials.	 Organic amendments are used widely today. Research occurring to optimize combinations to simultaneously maintain productivity and reduce GHGs.	 Fits within existing cropping systems and equipment. Some concern over metals and other contaminants in sludges.	 Compost, sludge, and manure used widely today. Established supply chains.	 Mostly accepted. Some amendments require management of pathogens and odour.	 Interest from producers in low-cost fertilizer supplements or replacements. Attractive for soil health and waste diversion goals.	 Increased microbial diversity and soil health. Waste management solutions. Improved nutrient cycling and reduced reliance on primary fertilizers. Odour issues.
Biochar Addition	Enabling Pathway Can increase soil organic carbon and may mitigate N ₂ O emissions from soil.	Enable Support R&D and demonstration projects. Develop carbon credit protocols and quality standards.		 Production costs are high. Requires policy support.	 Supports domestic biochar production. Market generated around use of otherwise wasted materials.	 Demonstration and trials occurring in Canada. Further research on long-term impacts on soil health, productivity and carbon retention required.	 Can be applied using equipment, but density makes handling and application more difficult.	 Supply chain is emerging. Production in Canada is being built out.	 Accepted when produced from forestry residues.	 Some interest in terms of carbon credit generation.	 Can increase microbial activity, reduce nutrient leaching and improve water retention. May reduce biomass available for other sectors' decarbonization.

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Greater Inclusion of Pulses in Rotations	Enabling Pathway Reduces reliance on synthetic nitrogen through biological fixation, but broader system emissions persist.	Deploy Provide regionally specific extension services. Monitor soil nitrogen levels to ensure effectivity in local conditions.	Legumes (pulses) can fix nitrogen from atmosphere, reducing required synthetic nitrogen fertilizer needs. Type of pulse and environmental conditions dictate effectivity.	Can increase yields, diversify revenues, and decrease risk over time. Reduces operational costs associated with nitrogen fertilizer input.	Can encourage value added processing and export growth for Canada's pulse sector, strengthening domestic supply chains.	Mature agronomic practice widely used in Canada. Improvements continue with research selecting for higher nitrogen fixing genetics.	Fits within existing cropping systems and equipment. Main changes are to planning.	Seed supply chains well established in Canada.	High acceptance; low public impact.	Supported by producers, processors, and governments as a practical lever to reduce fertilizer related emissions and improve resilience.	Improves soil structure and rotation diversity. Can reduce nitrate leaching and upstream fertilizer manufacturing emissions. Can break pest/disease cycles.
Multicropping (Including Intercropping, and Increased Frequency and Diversity of Rotations)	Enabling Pathway Improves nutrient cycling and reduces input intensity, but emissions reductions vary by crop, region, and management.	Deploy Provide regionally specific extension services to farmers, including case studies. Support local R&D and pilots on optimizing rotations to reduce GHGs.	Reduces emissions by increasing soil organic carbon, reducing nitrogen fertilizer application, and withdrawing CO ₂ from the atmosphere. Impacts are rotation specific.	Economics depend largely on selecting crops and rotations optimized for the soils and climate. Improves long-term profitability and diversifies revenues.	Growth in seed sales and advisory and training services. Can support local processing facilities.	Multicropping is mature, but optimizing crop rotations to reduce GHGs is still in R&D.	Modifications to planning are required. May require investment in equipment or training. Adds complexity to operations	Generally compatible with existing systems. May require regional market development for new crops .	High acceptance; low public impact.	Involvement from government and academia with ongoing R&D. Used by farmers but uncertainty around which systems are best.	Diversifies revenue streams. Improves resilience to pests and environmental impacts (i.e. drought or late frosts). Improves nutrient cycling and soil structure.
Precision Agriculture	Enabling Pathway Improves input efficiency and reduces waste, but emissions reductions depend on adoption levels and integration with broader crop reforms.	Deploy Provide extension services on precision agriculture and financing mechanisms for small or remote farms to enable equitable access to tools.	Reduces input related emissions through better timing, rate, and placement.	Capital costs may require larger-scale operations. Can reduce operating costs including chemical and fuel inputs improving profitability.	Growth in advisory and training services and supply of digital or precision agriculture tools.	Used on some farms in Canada, especially in the Prairies. Some technologies in R&D.	Some training on new digital or precision agriculture tools.	Access to newer digital or precision agriculture tools may be difficult in remote areas and for small operations.	High acceptance with reduced water pollution.	Relevant to producers as operational costs and yields can be improved.	Lower inputs (chemicals and fuels). Improved soil health and crop resilience. Reduced nutrient and pesticide runoff. Better data for decision making.

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 All Agriculture											
Improved Regional-Specific Data Collection and Monitoring	<i>Priority</i> Enabling Pathway Foundational for accurate measurement, verification, and targeted mitigation. Essential for scaling credible, region-specific net-zero strategies.	Deploy Support mass deployment with financing mechanisms and extension services. Continue support of R&D to optimize systems.	 Enables accurate measurement of emissions and carbon retention, improves policy design, carbon credit integrity, and mitigation strategies.	 Upfront costs can be high for software, sensors, and data systems. Improved measurements reduce uncertainty, optimize inputs, and can improve yields.	 Growth in ag-tech firms in Canada and analytics and advisory services.	 Many technologies are emerging with increasing adoption. Optimization of these systems is occurring with further research and development.	 Integrate with existing operations.	 Implementation depends on broadband access, cloud computing infrastructure, and standardized data frameworks.	 Broadly accepted, with concerns around data privacy and ownership.	 Relevant to all stakeholders. Many ongoing projects collecting and aggregating data relevant to GHG reductions.	 Can improve yields, soil health, waste management, biodiversity, and climate resilience.
Organic Farming	Enabling Pathway Reduces synthetic input reliance and can lower emissions intensity in some systems but yield trade-offs and livestock emissions may limit net-zero potential.	Enable Support demonstration and extension services focused on minimizing yield losses. Improve supply chain regulations for organic certifications.	 Can reduce reliance on synthetic fertilizers, fuel, and pesticides lowering emissions. Can improve soil carbon retention, but may lower yields. GHG outcomes depend on circumstances.	 Viability depends on price premiums and certification costs. Some producers benefit from lower input costs, but yield penalties can reduce margins. Production does not yet satisfy consumer demand in Canada.	 Moderate opportunities in certification, advisory services, and value added markets/export niches.	 Mature and widely practiced, with established standards and supply chains, though adoption remains limited in Canada.	 Requires land management changes including a transition period. May require new equipment or more labour.	 Supply chain traceability and certifications add complexity.	 High acceptance aligning with environmental and animal welfare concerns.	 Government and producers for food security. Food retailers and brands to meet demand for organic food.	 Reduces pesticide and chemical fertilizer use and can improve biodiversity and soil health. May reduce nutrient losses, though land use trade offs can arise if yields are lower.

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 On-Farm Energy use											
Battery Electric Vehicles and Equipment	<i>Potential Decarbonization Pathway</i> Electrifies on-farm energy use	Enable Support electrical grid expansion and upgrade in rural areas. Provide financing mechanisms to assist with piloting and demonstrating new technologies on farms.	 Net zero with clean electricity.	 Lower energy and maintenance costs than incumbent. High upfront costs and uncertain resale value. Expected to improve over time.	 Creates opportunities for Canadian clean tech manufacturing and service jobs and rural electrification services.	 Entering the market for small/medium equipment and specialty tractors. Heavy duty applications are still in demonstration.	 Good fit for light to medium duty tasks with predictable schedules. Requires charging access and may face downtime constraints during peak seasons. Currently prohibitive for heavy-duty vehicles.	 Grids may require expansion or capacity upgrades in many rural areas.	 Accepted as noise and air pollution are reduced.	 Lack of access to high-capacity power limits interest from producers. Some equipment models emerging in Canada.	 Reduces air and noise pollution. Enables greater ability to automate.
Heat Pumps	<i>Potential Decarbonization Pathway</i> Can significantly reduce emissions from fossil fuel heating applications.	Enable Support electrical grid expansion and upgrade in rural areas. Provide financing mechanisms to assist with piloting and demonstrating new technologies on farms and food and beverage manufacturing facilities.	 Can eliminate emissions from space and water heating in farm buildings, grain drying, greenhouses, and some food manufacturing. Emission reductions depend on availability of net-zero electricity.	 Often cost effective where electricity is low carbon and competitively priced. Economics improve with efficiency upgrades and incentives, though retrofit costs can be a barrier.	 Moderate opportunities for Canadian HVAC manufacturing/ins tallation and rural electrification services.	 Technologies are commercial globally. Agricultural applications are emerging with pilots and applied research underway. Limited models for very cold weather or high-temperature operations.	 Potential fit in many applications but may require some modifications or retrofits to existing heating systems.	 Requires grid access, high capacity, and clean grids. Grids may require expansion or capacity upgrades in many rural areas.	 No particular concerns.	 Some interest from Canadian research groups. Proven efficiency increases for greenhouse operations. Government support is limited.	 Eliminates air emissions and reduces fuel price exposure.
Hydrogen Powered Heavy Machinery	<i>Potential Niche Pathway</i> Offers a potential zero-emission option for heavy equipment.	Incubate Fund R&D of heavy-duty hydrogen farming equipment.	 Hydrogen could decarbonize heavy equipment where electrification is impractical. Net emissions reductions depend on low-carbon hydrogen supply.	 Currently high cost due to hydrogen production, storage, and limited refuelling infrastructure. Not competitive yet in most use cases.	 Longer term opportunity for Canadian hydrogen and heavy equipment innovation—partic ularly in regions investing in clean hydrogen hubs.	 Largely in research and pilot phases.	 Could offer fast refuelling and long runtimes, but handling/storage and safety protocols add operational complexity for farms. Would need new equipment.	 Requires refuelling infrastructure. Hydrogen transport/storage logistics and standards are still developing.	 Some safety perceptions and unfamiliarity may slow uptake.	 Interest from governments is growing, but farmers are unlikely to adopt hydrogen until costs and fuelling access improve.	 Reduces noise/air pollution. Potential to pair with renewable H ₂ production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Renewable Diesel (RD)	Bridge Pathway Provides near-term emissions reductions using existing equipment, but may require removals for net zero.	Enable Develop policies that assist with increased fuel costs and limited rural access to RD. Support until maturity increases for electric or hydrogen equipment.	 Lowers lifecycle GHGs compared to fossil diesel but not a net-zero end-state. Emission reductions depend largely on feedstock sustainability and carbon intensity.	 Not currently cost competitive in rural areas without policy supports.	 Opportunities in Canadian biofuel production but limited by feedstock supply.	 RD is mature. Procurement can be difficult especially in rural areas.	 RD is drop-in.	 Large volumes required to make economic case for fuel distribution.	 Concerns of competition with food crops.	 Appeals to farmers as it reduces emissions in the near term without changing equipment.	 Reduces waste and associated management as fuels are typically produced from waste. Land-use change concerns. Air pollution persists.
On-Farm Renewable Power Generation (Wind and Solar)	Enabling Pathway Can use land simultaneously for power generation and farming. Can also supplement grid-supplied electricity for farming operations.	Deploy Develop supportive policies where appropriate. Provide resources that assist implementation.	 On-farm wind and solar can displace fossil energy use on farms and/or farmland can generate renewable electricity without compromising farming operations.	 Economics have improved. Upfront capital and interconnection can be barriers.	 Supports local economic development through installation/maintenance jobs and domestic clean energy supply chains. Potential revenue diversification for farms.	 Technology is mature and applications are commercial on many farms in Canada.	 Generally practical where land/roof space and grid interconnection exist. Can support remote/off grid operations but add complexity.	 Interconnection regulations and distribution capacity can constrain projects.	 Some rural opposition to large utility scale developments.	 Strong interest from farms, rural communities, and utilities. Adoption is rising as reflected in Canadian farm surveys.	 Can reduce fuel use and air pollution. Can improve energy resilience, and enables pairing with electric vehicles/heat pumps.
On-Site Biogas Production (Biomethane /Renewable Natural Gas Production)	Enabling Pathway Can create closed-loop energy systems using agricultural residues, but scalability and lifecycle performance vary.	Enable Provide resources and develop policy to lower barriers to interconnection and fuel offtake. Support R&D and demonstration.	 On-site biofuel can cut emissions and displace fossil fuels for heat and power. Emissions reductions depend on feedstock sustainability and processing methods.	 Mostly economic where scale is large. Capital costs high, especially for digesters; operational complexity can increase costs. Interconnection and offtake can be cost prohibitive.	 Creates rural jobs and generates economic product from wastes.	 Biogas production is mature. Deployment can be difficult and limited to regions with policy support and larger-scale farms.	 Training for operators and feedstock logistics and planning are required. Requires consistent feedstock, which can be difficult to obtain from a single farm's operations.	 Interconnections can be cost prohibitive or unavailable in remote locations. Permitting and standards can be complex.	 Generally accepted as process produces energy from waste. Odour and truck traffic can introduce public concerns.	 Mainly relevant to large livestock farms for energy cost reductions and diversified revenue. Governments interested in biogenic methane reductions.	 Provides methane mitigation, renewable energy, and digestate. Recycles nutrients and may reduce reliance on synthetic fertilizer.