Transitioning Saskatchewan's Electricity System

Pathways to a Reliable, Cost-Effective, Clean Electricity Grid by 2035

Executive Summary

In keeping with the recommendations of the International Energy Agency and the Intergovernmental Panel on Climate Change, Canada is part of a growing list of advanced economies including the U.S., the U.K., and the European Union that have committed to transitioning their respective electricity systems to net zero greenhouse gas emissions by 2035. A timely transition to clean electricity provides the foundation for achieving an economy-wide target of net zero emissions by mid-century.

In 2022, 72% of the electricity supply in Saskatchewan came from fossil fuel generators. Among the provinces, Saskatchewan had the highest intensity of emissions per kWh. If Canada is to meet national emissions reduction targets, Saskatchewan must markedly advance the current level of ambition and the projected timeline of transition to a clean electricity future.

This review summarizes recent reports published by Canada Energy Regulator (CER), the Alberta Electricity Supply Organization, the Pembina Institute, and academic researchers that have modelled viable, cost-effective pathways of transition of electricity supply in Saskatchewan and Alberta under scenarios of near-zero, net-zero, and net-negative emissions by 2035.

Least cost pathways of transition are defined by available clean electricity resources along with policy drivers and funding options. Southern Saskatchewan has the highest in-land potential for renewable power generation in Canada. The Western Canadian Sedimentary basin located under much of the southern half of the province is a world class resource for the geological storage of carbon dioxide captured by industrial processes. Rail transport is in place to access large volumes of sustainably sourced residue biomass from out of province forestry and forest management industries. There are additional opportunities to develop provincial biomass supply industries based on agricultural residues and other waste biomass streams.

All scenarios of transition to clean electricity in Saskatchewan include a substantial build out of renewables. By 2035, 40-60% of the electricity supply will come from wind and solar. This level of grid penetration by renewables will be balanced by dispatchable thermal generators, energy storage, and interprovincial flows of electricity through a new build transmission corridor that links hydro-rich and renewables rich regions of Western Canada. Carbon capture and storage (CCS) can cut emissions from natural gas combined cycle (NGCC) power plants by over 90%. By 2035, near zero emissions NGCC power plants with CCS will be important contributors to the energy mix in Saskatchewan under most of the clean electricity transition scenarios described in this review.

The CER's report, *Canada's Energy Future 2023,* is of particular significance in that provincial electricity systems were integrated with the national target of an economy-wide transition to net zero emissions by 2050. Nationally, Canada's electricity supply will transition to net zero emissions by 2035 and then, going forward, to net atmospheric withdrawal of CO_2 as required to offset residual emissions from agriculture and other difficult to abate sources. In the CER model, based on access to biomass and geological storage, negative emissions Bioenergy with Carbon Capture and Storage (BECCS) generators will be located in Saskatchewan and Alberta. Potentially, existing suitable coal-fired generators in Saskatchewan could be retrofitted to CCS and fuel switched to biomass. BECCS facilities are dependent upon revenues generated from atmospheric withdrawal of CO_2. Carbon revenues in excess of $100 per tonne will cover the cost of biomass procurement and carbon capture and storage such that industry and consumers can be supplied with low-cost negative emissions electricity. Revenues can come from the sale of carbon offsets on the open market or from a federally guaranteed carbon pricing system.

Recently, the federal government released the details of the draft Clean Electricity Regulations. The regulations provide some flexibility for continued operation of existing unabated gas plants as required for Saskatchewan to complete a cost-effective transition to a clean electricity supply. However, there is an opportunity to design a provincial equivalency that better aligns with the reality of resource potential and existing infrastructure in Saskatchewan. Specifically, emissions from the fleet of generators could be pooled such that atmospheric withdrawal from BECCS facilities could offset emissions from unabated gas plants. This would allow for continued operation of existing gas plants to end of life without compromising an ambitious agenda for transitioning to net negative emissions by 2035.

When considering the federal tax credits available for carbon capture and storage projects along with the recent budget announcement of substantial clean energy funds, upwards of $5 billion in federal assistance are available to Saskatchewan to assist with transitioning to clean electricity by 2035. If SaskPower and the government of Saskatchewan were to remain fixated on executing a low ambition plan, the province will turn down billions of dollars in economic development.

Provision of clean, low-cost, reliable electricity can be achieved in Saskatchewan by 2035 and would be welcomed by consumers and by industry looking to produce low carbon products. A commitment to an ambitious clean electricity transition plan in partnership with the federal government, equity providers, and other stakeholders would be in the best interests of Saskatchewan and Canada.

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David D. Maenz, Ph.D.

The over-arching goal of the Paris Agreement is to limit global surface warming to well below 2°C and ideally no more than 1.5°C above average surface temperatures of the pre-industrial era (1). Achieving this level of ambition requires that advanced economies transition to net zero emissions by 2050. Canada is one of 133 countries (which together account for 83% of global emissions) that has established a Net Zero target date (2). The Canadian Net-Zero Accountability Act became law on June 29th, 2021, and established Canada's commitment to achieving net-zero emissions by 2050 (3).

The International Energy Agency (IEA) is the world authority in providing analysis and policy recommendations to governments and industry regarding the global energy sector. In 2021, the IEA published a flagship report on pathways of transition to net zero emissions by 2050 (4). This report was updated in the 2022 IEA World Energy Outlook (5). Under the IEA Net Zero Emissions (NZ) scenario, electricity supply sectors in advanced economies rapidly transition to net zero emissions by 2035. Total electricity supply increases by 3.3% on an annual basis leading to a 50% increase by 2035. The transition to NZ electricity sectors by 2035, along with the increase in generation capacity, provides the foundation for electrification (clean electricity replacing fossil fuel use) and thus deep cuts in emissions within the transportation, industry, and buildings sectors of advanced economies.

Canada, the United States, the EU, and the UK have all established a goal of transitioning to a Net-Zero national electricity sector by 2035 (6). A timely transition to clean electricity across Canada is an essential pillar in completing an economy-wide transition to Net Zero emissions by mid-century.

The Opportunity for Canada to Build a Net Zero Emissions or Net Negative Emissions Electricity Sector by 2035. Canada has the fourth largest installed hydropower capacity in the world, and in 2019, 60% of Canada's electricity supply came from zero emissions hydro power (7). In total, 81% of the country's electricity was generated by zero emissions sources (hydro, nuclear, and renewables). This existing capacity for clean power generation in combination with untapped regional potential for renewables, places Canada in an advantageous position to complete a timely transition to clean electricity. Southern Saskatchewan has the highest regional potential for wind energy in Canada.

In addition to an abundance of hydro and renewables, Canada's forestry, agriculture, and municipal sectors produce vast quantities of residue biomass that can be collected and used on a sustainable annual basis. Canada's forestry sector produces about 46 million tonnes per year of dry residues (8). Canada also produces another 48 million tonnes of agriculture residues and 25 million tonnes of dry municipal solids waste annually (8). The energy content of this waste biomass is 2 to 3-fold greater than the energy content of the total quantity of coal burned in Canada in 2013 (8).

In recent years, wildfires have had devasting impacts on human settlements, GHG emissions, and natural ecosystems. This trend is driven by droughts and heat waves associated with a changing climate. In the absence of adaptation and mitigation efforts, the severity and frequency of wildfires are projected to continually increase over the coming decades and triple or quadruple by 2100.

A program of sector-wide forest management to suppress wildfire and insect infestation is essential if Canada intends to effectively adapt to climate change and to achieve ambitious targets to cut GHG emissions. Forest treatments designed to reduce the likelihood and severity of wildfires consist of forest floor fuel removal and mechanical thinning. These treatments will remove large quantities of low-grade, high-risk biomass from treated areas. By removing undergrowth, established larger trees are relieved of competition which limits growth. The result, over time, is an increase in the volume of standing timber and thus an increase net atmospheric CO_2 withdrawal from forested areas.

Sustainably sourced biomass from forest management, forestry and agriculture residues, and municipal solid wastes can be used for heat production and/or electricity generation or it can be converted to secondary energy carriers such as hydrogen. Bioenergy with Carbon Capture and Storage (BECCS) generally refers to the use of biomass to produce heat and/or electricity with capture of CO_2. The carbon in the biomass was removed from the atmosphere during the growth stage of the plants and during combustion reacts with oxygen to form CO_2. Captured carbon dioxide is then permanently stored in geological formations and isolated from the biosphere. As such, BECCS is a negative emissions technology because the net result is that carbon is removed from the biosphere and sequestered within the lithosphere in deep geological storage. On a life cycle assessment basis that tracks emissions along the full biomass supply chain, a BECCS power plant can function to remove up to 1,100 kg of CO_2 from the atmosphere per MWh of electricity generated (9).

The Western Canada Sedimentary Basin (WCSB) is a massive, in-land, stable geological formation found under much of Alberta and Saskatchewan (10). The WCSB is ranked as a world-class resource for the safe, cost-effective, and permanent storage of CO_2 captured from industrial processes. Implementation of BECCS at scale in Alberta and Saskatchewan, in combination with clean hydro, nuclear and renewables can transition Canada's electricity sector to net negative emissions by 2035.

Despite Canada's natural resource potential to produce clean electricity, there are challenges to completing this transition within 12 years. As it stands, electricity supply in Canada consists of various regional grids with limited or no connectivity. Regulations governing the generation of electricity falls under provincial jurisdiction. Canada's current structure of largely isolated electricity grids and regulatory frameworks is not conducive to an optimized use of resources as required to transition to NZ or Net Negative (NN) emissions within 12 years. Without a clear set of policies and regulations designed to drive decarbonization and a cooperative approach to planning, funding, and risk sharing between the federal government and the provinces, existing grids currently based on fossil fuel power plants, are likely to be delayed in completing the transition. Continued emissions from electricity generation in Saskatchewan, Alberta, New Brunswick, and Nova Scotia past 2035 will compromise the national NZ ambition and may position these provinces at a competitive disadvantage as surrounding economies rapidly decarbonize.

Clean Electricity Regulations. On August 10th, 2023, the federal government published the details of the proposed Clean Electricity Regulations (11). The core components of the regulations can be summarized as follows:

1. An emissions intensity standard of 30 t CO_2eq/GWh comes into effect as of Jan 1, 2035.
2. All gas plants commissioned after Jan 1, 2025, must meet this standard.

3. Gas plants commissioned before Jan 1, 2025 can continue to operate to the latter of Jan 1, 2035 or 20 years from the date of commissioning.
4. Existing gas plants can continue to operate post Jan 1, 2035, as contributors to meeting peak demand and to backup renewables. However, gas generator units are restricted to 450 hours per year of operation (i.e. 18.75 days of continuous operation) and can emit no more than 150 kt of CO_2 per year.

The regulations are designed to provide the stringency necessary to drive down emissions from Canada's electricity supply system to a near zero outcome by 2035, while allowing continued limited operation of unabated gas plants in regions currently dependent upon fossil fuels to generate electricity.

Key to the stringency of the regulations is application of the standard to all gas power plants commissioned after Jan 1, 2025. Unabated (without carbon capture and storage) gas plants would be limited to less than 10 years of operation and thus would be uneconomic to build. New build gas plants equipped with carbon capture and storage technology could meet the emissions standard and thus allow natural gas to continue to be used to fuel electricity generation.

The proposed regulations minimize the financial impact of stranded assets in jurisdictions currently dependent primarily on fossil fuels by allowing all existing or under construction units to operate for up to 20 years.

Limited operation of existing gas plants post-2034 can contribute to grid reliability under periods of peak demand and as a backup to renewables.

In theory the proposed Clean Electricity Regulations provides the stringency required to drive a timely transition of Canada's electricity system along with the flexibility needed to control costs in provinces that currently rely on fossil fuels for power generation.

A well-designed set of regulations does not ensure a successful transition. A massive shift in electricity supply infrastructure will be required in Saskatchewan and Alberta and there are serious concerns as to the practicality and costs of achieving a year 2035 NZ or NN transition. However, recent modelling work completed by Canada Energy Regulator and other reputable organizations has provided some much-needed clarity as to the viability and costs of potential pathways of transition to a clean electricity system.

Canada Energy Regulator (CER) Net Zero Scenarios. In July 2023, the CER published *Canada's Energy Future 2023* (12). This report describes 3 scenarios of transition for the Canadian economy going forward to mid-century. In the Current Measures scenario, the modelling does not require a net-zero emissions outcome for Canada by 2050. In the Global Net-zero scenario, the model requires an economy-wide transition to NZ emissions by 2050 along with a rapid pace of global climate action that is consistent with limiting future warming to 1.5 C. In the Canada Net-zero scenario, a year 2050 net-zero outcome is required for Canada; however, global action is insufficient to limit future warming to 1.5°C.

Existing federal and provincial policies, such as the year 2030 phase out of coal-fired electricity, were incorporated in the model along with assumptions as to commercial readiness and future costs of technology options. The main driver of transition was an "aggregate cost of carbon" that was adjusted via an iterative process until a year 2050 economy-wide NZ outcome was achieved. This "aggregate cost of carbon" was not an assumed carbon price or policy but rather a modelling tool used to drive down emissions along least-cost pathways without technology restrictions. Future climate policies will consist of a mix of regulations, incentives, and carbon pricing designed to achieve the same NZ outcome. The specific pathway to NZ will vary with the suite of policies implemented and evolving status of technology costs and maturity. As such, the Futures 2023 report should be considered as an illustration of one viable pathway to NZ emissions. The report describes a series of "what if" alternatives to the underlying assumptions that could alter the timeline of deployment and relative contribution of a given technology to the process of transition to a low carbon economy.

Under the NZ scenarios, by mid-century, residual emissions from Canadian agriculture and other difficult to abate niche sources amount to about 165 Mt CO_2eq/y (25% of current total emissions). These emissions are offset by atmospheric withdrawal via a combination of nature-based solutions, direct air capture, and industrial processes using biomass with carbon capture and storage (Figure 1). The electricity sector becomes an important contributor to atmospheric withdrawal through the deployment of BECCS.

> *"The electricity system, which decarbonizes by 2035 and achieves net-negative emissions thereafter, is the backbone of our net-zero scenarios."*
>
> *Canada's Energy Future 2023*Report (12)

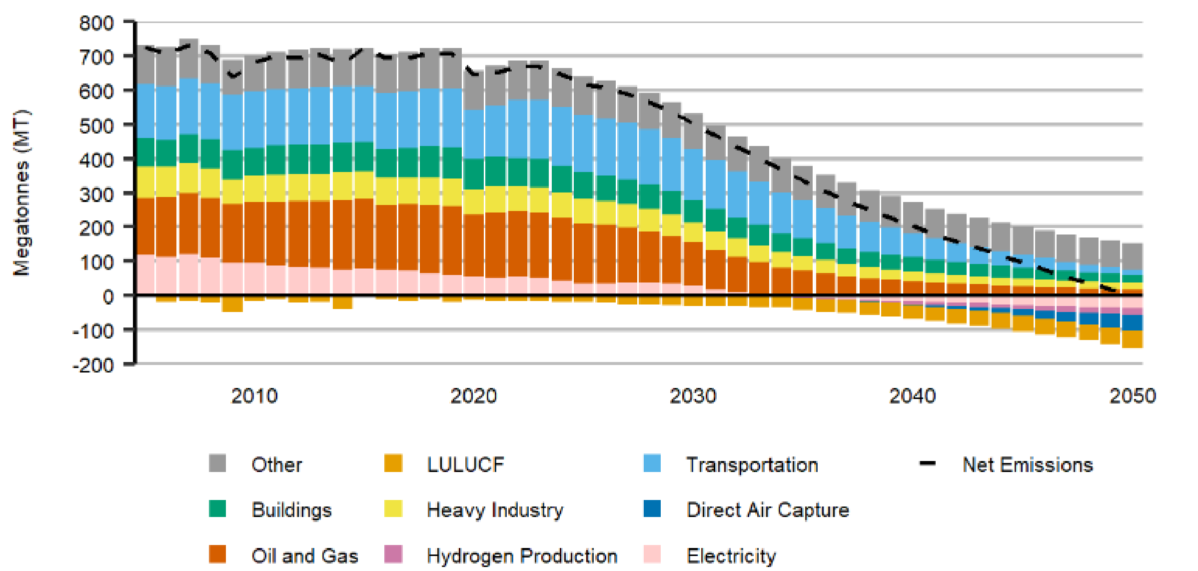

Figure 1. Canada Energy Regulator, GHG emissions by economic sector under the Global Net-zero Scenario. By 2050, residual emissions from agriculture and other difficult to abate niche sources are offset by atmospheric CO_2 withdrawal from nature-based solutions plus industrial processes. The electricity system in Canada is forecasted to remove 36 Mt/y of CO_2 from the atmosphere in 2050 via Bioenergy with Carbon Capture and Storage (BECCS) plants located primarily in Alberta and Saskatchewan. Taken from CER Futures 2023 report (12).

By mid-century, electricity demand is predicted to double with electrification of transportation, buildings, and industrial practices. As described in the CER report, the challenge going forward is to build out capacity with a mix of zero and negative emissions options.

The CER report provides details of the least-cost model output of future energy mixes and timelines for deployment of options to generate and supply electricity along with projected impacts on residential electricity costs on a yearly basis for each province going forward to 2050.

*Canada's Energy Future 2023***Report: Illustrative Pathway for the Transition of Saskatchewan's Electricity System to Net Negative Emissions by 2035.**

The outcome of the CER least cost model for the future installed capacity by energy source in Saskatchewan is shown in Figure 2. Electricity demand in Saskatchewan is predicted to increase by 40% by 2035 and to more than double by mid-century. In the model, future demand is met by a build out of negative emissions BECCS facilities, renewables, small modular nuclear reactors, and natural gas generators equipped with carbon capture and storage, along with hydro, and a net inflow of power via interprovincial transmission lines. Electricity generation in Saskatchewan would transition from a source of substantial GHG emissions to net atmospheric withdrawal of carbon dioxide. The electricity sector of Saskatchewan becomes an important contributor to an economy-wide decarbonization pathway leading to a NZ outcome for Canada by 2050.

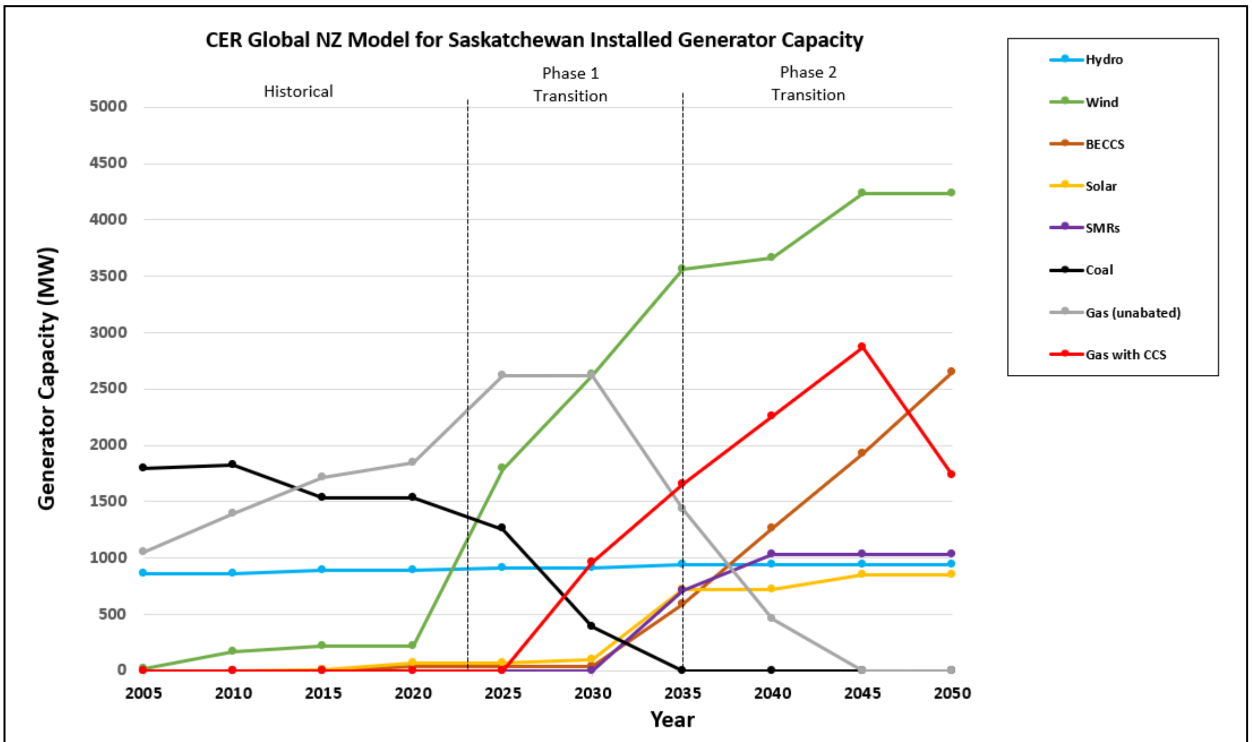

Figure 2. CER Global NZ model of future installed generator capacity in Saskatchewan. Phase out of fossil fuel generators follows the federal mandate for coal and the proposed clean electricity regulations for unabated gas units. Capacity is replaced and increased over time by wind, solar, gas plants with carbon capture and storage (gas with CCS), small modular nuclear reactors (SMRs), and bioenergy with carbon capture and storage (BECCS). Data taken from the CER Futures 2023 report (12).

Phase out of unabated fossil fuel generators. Coal-fired generators will be mostly shut down by 2030 following the federal mandate. In accordance with the Clean Electricity Regulations, no further unabated natural gas facilities beyond those currently under construction should be added to the fleet. By 2035 about 1,000 MW of capacity from unabated natural gas generators currently in operation would be shut down. The recently completed Chinook Power plant can continue operations until 2039 and the Great Plains Power Station that is currently under construction can run for 20 years to 2044. As previously described, under the Clean Electricity Regulations, existing natural gas units can continue to operate on a limited basis post 2034 as contributors to help meet periods of peak demand and to back up renewables.

Build out of negative emissions BECCS capacity. In the CER model, negative emissions BECCS facilities are located in Saskatchewan and Alberta to provide proximity to geological storage of captured carbon. The model predicts an aggressive timeline for BECCS installation with 592 MW of capacity in place by 2035. By mid-century over 2,600 MW of BECCS is predicted for Saskatchewan. With full implementation, these generators would operate near capacity on a continuous basis with the potential to withdraw over 22 Mt/y of CO_2 from the atmosphere. By mid-century, BECCS is forecasted to supply 37% of Saskatchewan's electricity supply (Figure 4). In the CER Global NZ scenario, BECCS facilities in Saskatchewan account for half of the total atmospheric CO_2 withdrawal from Canada's future electricity system.

Revenues from negative emissions are essential for cost-effective implementation of BECCS. Negative emissions facilities would be paid per tonne of atmospheric CO_2 withdrawal and this payment could mirror the emissions tax applied to consumer use of fossil fuels. Under the present federal schedule, carbon pricing escalates to $170/t by 2030. Figure 3 shows the impact of carbon pricing revenues on the levelized cost of electricity for a BECCS retrofit of the SaskPower Shand coal-fired generator. The model assumes fuel switching to British Columbia wood pellets. Without carbon pricing revenues, the LCOE for the BECCS plant is over twice that of a similar sized new build natural gas combined cycle (NGCC) facility. However, if the utility is paid $70 per tonne of CO_2 withdrawn from the atmosphere, the cost of electricity is comparable to the gas facility. At higher carbon prices, the BECCS retrofit

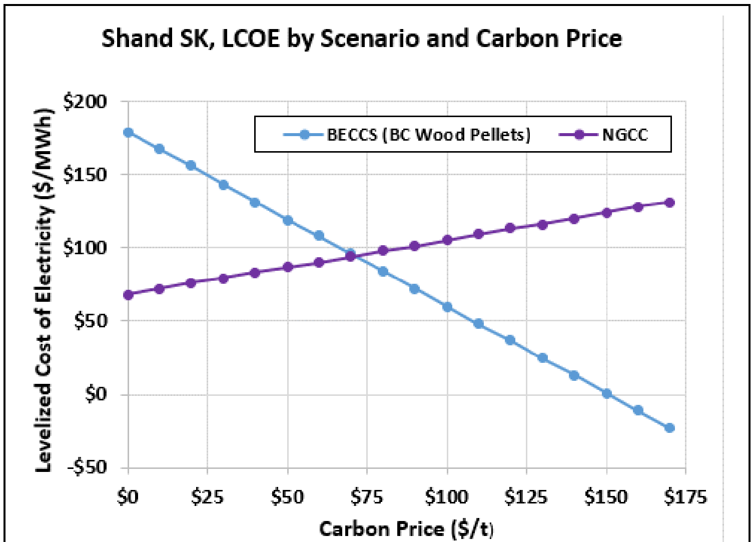

Figure 3. Impact of carbon pricing on the Levelized Cost of Electricity (LCOE) of a new build natural gas combine cycle generator and a BECCS retrofit of the SaskPower 300 MW Shand coal-fired facility. The BECCS facility is assumed to be paid the indicated carbon price per tonne of atmospheric CO_2 withdrawal. The BECCS retrofit is fueled by British Columbia wood pellets. Delivered cost of wood pellets set to $9.47/GJ (13). LCOE calculator kindly provided as a personal communication by Dr. Brett Dolter (University of Regina). Calculator was based on the Shand feasibility study completed by the International CCS Knowledge Center for retrofitting the Shand thermal power plant to second generation CCS (14).

becomes cost advantageous. Potentially, carbon revenues from atmospheric withdrawal can off-set system-wide costs such that consumers and industry can be supplied with low-cost negative emissions electricity.

A portion of the revenues collected from carbon pricing systems already in place in Canada could be funneled to negative emission facilities. The societal value of negative emissions in the global effort to combat climate change is considerable and thus can provide the economic basis for implementation.

Build out of renewables. The CER model predicts a rapid expansion of renewables in Saskatchewan. By 2035, 3,500 MW of wind capacity is on-line with further expansion to 4,500 MW by mid-century. Solar contributes to the energy mix with about 700 MW to be installed by 2035. Wind and solar are projected to supply 39% of Saskatchewan's electricity by 2035 (figure 4).

Small modular nuclear reactors. The model predicts an aggressive timeline for construction of small modular nuclear reactors in Saskatchewan with 2 x 350 MW units on-line by 2035 and a third added to the fleet by 2040.

Natural gas with carbon capture and storage. New build natural gas fired generators equipped with CCS will play an important role in Saskatchewan's future electricity sector. The CER model predicts 1,600 MW of installed capacity by 2035 with up to 3,000 MW in operation by 2045. Gas with CCS provides bulk electricity and contributes to grid reliability as a backup to renewables. Some continued operation of unabated gas peaker plants may be required post 2040.

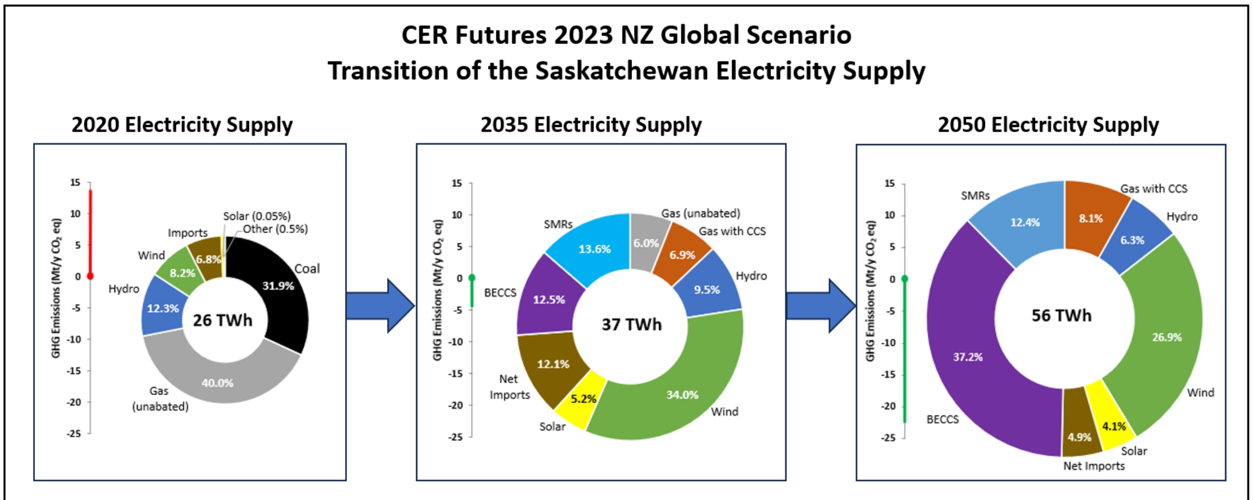

Figure 4. CER Global NZ model of Saskatchewan's future electricity supply. Supply from fossil fuel generators is replaced by negative emissions BECCS, renewables, gas plants with CCS, SMRs and net inflows from interprovincial transmission. Gas plants (unabated and with CCS), interprovincial transmissions and energy storage (not shown) provide grid reliability to meet demands and back up renewables. Electricity supply doubles by 2050. By 2035, the system removes over 4 Mt/y of CO_2 from the atmosphere. With further expansion of BECCS capacity, carbon dioxide removal increases to 23 Mt/y by 2050 and is an important contributor to achieving the national ambition of an economy-wide transition to net zero emissions by 2050. Data taken from the CER Futures 2023 report (12).

Hydro. The installed capacity of hydro in Saskatchewan is projected to remain constant over the next 30 years.

Interprovincial flows of electricity. Interprovincial transmission and intertie agreements will play an important role in Saskatchewan's future clean electricity system (figure 5). The system will link renewables rich regions with hydro rich regions of Western Canada. As such, Saskatchewan will have access to remote hydro resources that contribute to grid reliability and supply. Excess power from renewables will flow out of province to hydro-rich regions such that reservoirs can accumulate hydro for later use. In the CER model, interprovincial transmission corridors are operational by 2035 with an estimated initial inflow 9,500 GWh/y to Saskatchewan. Annual outflows are estimated at 5,100 GWh such that net interprovincial flows will provide about 12% of Saskatchewan's electricity in 2035.

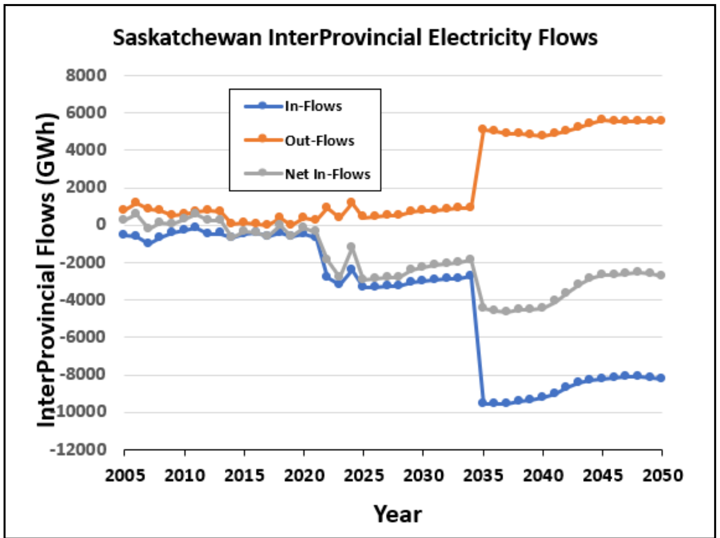

Figure 5. CER Global NZ model of Saskatchewan's interprovincial flows of electricity. Interprovincial transmissions infrastructure and intertie agreements are in place by 2035. Excess power generated via renewables in Saskatchewan flows to hydro rich regions. Reservoirs accumulate hydro and power flows from hydro rich regions to Saskatchewan as needed. The model anticipates a net annual inflow that provides 12% Saskatchewan's total supply in 2035. Data taken from the CER Futures 2023 report (12).

Energy storage and green hydrogen. Battery storage, pumped hydro and compressed air storage can potentially contribute to balancing electricity supply from renewables and thus contribute to grid reliability and efficiency. In addition, there is potential to generate "green" hydrogen via electrolysis using excess electricity. By mid-century total production of green hydrogen from electrolysis in Canada is estimated at 8 Mt/y with 1.5% of this total produced in Saskatchewan. The CER predicts 1.5 GW of storage capacity in Canada by 2035 expanding to 9 GW by mid-century. The report does not provide estimates of energy storage to support electricity grids on a provincial basis.

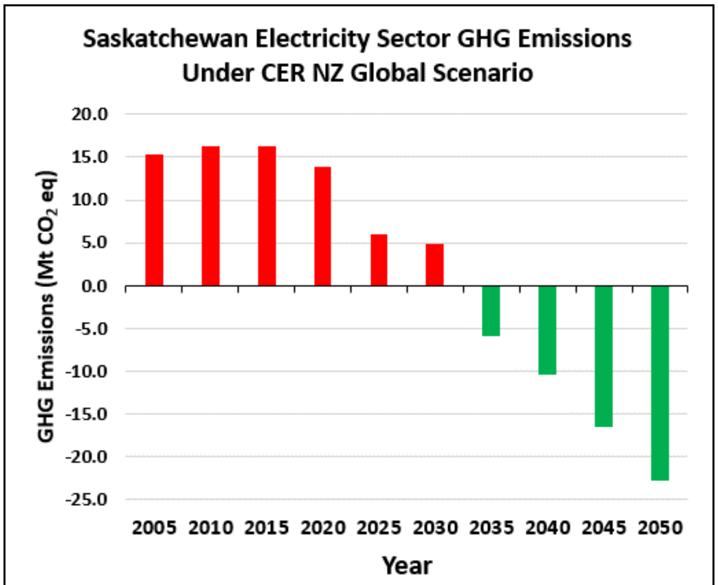

Figure 6. GHG emissions under the CER Global NZ model of Saskatchewan's electricity system. As negative emissions BECCS plants come on-line, the system transitions from emissions (red bars) to withdrawal (green bars) of atmospheric carbon dioxide.

Greenhouse gas emissions. Under the CER Global NZ scenario, Saskatchewan's electricity system quickly transitions from a serious source of GHG emissions to net atmospheric withdrawal of carbon dioxide (figure 6). By 2035 with 600 MW of BECCS capacity on-line, net negative emissions amount to over 4 Mt/y of atmospheric CO_2 withdrawal. Going forward to mid-century with a further expansion of BECCS capacity, carbon dioxide removal increases to 23 Mt/y.

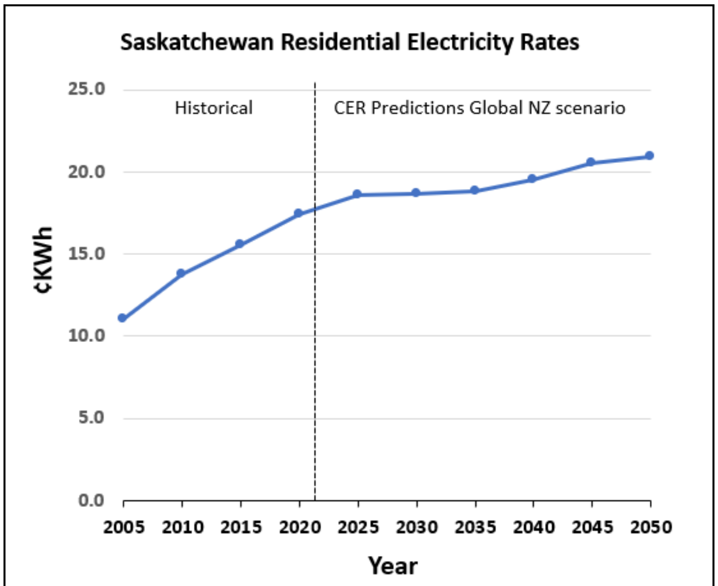

Figure 7. Historical residential electricity rates in Saskatchewan and CER Global NZ model of future rates Data taken from the CER Futures 2023 report.

Residential rates for electricity. The CER model predicts no change in residential rates for electricity in Saskatchewan going forward to 2035 (figure 7). By 2050, the model forecasts a modest 10% increase in residential rates.

Capital costs and federal assistance in funding. The CER model provides cost estimates for installed capacity for renewables, gas plants with CCS, and SMRs. Drax has published estimates for the cost of installing new build BECCS units in North America (15). Total cost of capacity installation in Saskatchewan over the next 27 years is estimated $41.4 billion with over half of this to be spent between 2024 and 2036. These estimates do not include the costs of transmission infrastructure and grid modernization.

It should be noted that these projected costs are not incremental to the costs of alternate lower ambition scenarios whereby the transition to net zero is delayed until 2050. Saskatchewan's fleet of generators is aging and will require replacement and a doubling of capacity with clean energy options regardless of the timing of a net zero outcome.

In the 2023 federal Budget, considerable funding was announced to support a clean electricity transition. An estimated $25.7 billion will be available between 2024 and 2035 through the Clean Electricity Investment Tax credit (16). An additional $10 billion for clean power and $10 billion for clean growth infrastructure is available in preferential financing from the Canada Infrastructure Bank (16). On a per GW basis, provinces that currently rely on fossil fuels to generate electricity will receive more support from the federal government. An estimated $2.6 billion will be available to qualifying clean electricity projects in Saskatchewan (16).

This funding is in addition to previously announced tax credits for carbon capture, storage and use projects. Eligible projects can receive a tax credit covering 50% of the cost of carbon capture equipment (17). Projects must be run between 2022-2030 to encourage rapid uptake. The tax credits are reduced by 50% for projects run between 2031 and 2040 (17). The CER Futures 2023 model predicts considerable installation of carbon capture and storage in Saskatchewan for BECCS and future gas generators. These tax credits would cover a significant portion of the costs of transition for Saskatchewan.

An assessment of the incremental costs of an ambitious transition of Saskatchewan's electricity supply requires information as to the projected costs of SaskPower's current low ambition plan to complete the

NZ transition by 2050. SaskPower and the government of Saskatchewan have indicated that $28 billion would be spent between now and 2035 under an assumed pathway to NZ electricity by 2050 and that electricity rate would increase by 2.6% per year (18). Other than these high-level numbers, no further details are available. It should be noted that, in using CER assumptions as to technology costs, one arrives at an estimated total cost of $21.8 billion by 2035 to install the equipment under the Global NZ scenario and that no change in residential rates are predicted up to 2035.

Table 1: CER Global NZ Projected Installation Costs			
	$/kW	**MW installed**	**$M**
Wind*			
Phase 1	$1,900	2,745	$5,216
Phase 2	$1,752	675	$1,183
Total Wind		**3,420**	**$6,398**
Solar*			
Phase 1	$790	525	$415
Phase 2	$535	135	$72
Total Solar		**660**	**$487**
NGCC with CCS*			
Phase 1	$3,705	1,654	$6,128
Phase 2	$2,625	1,210	$3,176
Total NGCC+CCS		**2,864**	**$9,304**
SMR*			
Phase 1	$9,262	705	$6,530
Phase 2	$8,348	326	$2,721
Total SMR		**1,031**	**$9,251**
BECCS**			
Phase 1	$6,022	592	$3,565
Phase 2	$6,022	2,055	$12,375
Total BECCS		**2,647**	**$15,940**
Phase 1 total			**$21,853**
Phase 2 total			**$19,528**
Totals			**$41,381**
*Phase 1 (2024-2034) and Phase 2 (2035-2050) installed costs set to CER 2022 estimates (12)			
**BECCS installed cost set to new build Drax estimate for North America (19).			

Risks and Uncertainties. Without doubt, the transition pathway outlined under the NZ scenarios in the CER Futures 2023 report is challenging and ambitious. Of particular concern is the simultaneous build out of renewables, BECCS, natural gas with CCS, SMRs, and interprovincial transmission capacity over a brief 12-year time period to 2035. The list of “what if” factors in the report acknowledges the key uncertainties of the model. Again, it should be noted that the energy mix for future electricity generation is the outcome of a least-cost modelling exercise that is subject to change based on the evolving status of technologies and policies options. If, for example, SMR commercialization is delayed or overly costly, the energy mix could shift to alternative zero emissions options. Potentially, energy storage technologies may emerge as a cost-effective option that would allow for further grid penetration by renewables and thus lessen the dependence on higher cost SMRs and gas with CCS. Regardless of the energy mixed used in the transition, low-cost renewables will be an important component. Further, an ambitious negative emissions outcome will require several thousand MW of installed BECCS capacity along with a build out of renewables.

“BECCS First” Pathway for the Transition of Saskatchewan’s Electricity System to Net Negative Emissions by 2035.

The CER model assumed a shut down of the existing coal fired units in Saskatchewan by 2030 followed by installation of new build BECCS facilities, the first of which comes on-line by 2035. This approach ignores the opportunity for a cost-saving CCS retrofit and life extension of existing coal-fired assets. As described below, a BECCS First pathway could facilitate continued operation of most of the existing fleet of fossil fuel generators in Saskatchewan to end of life.

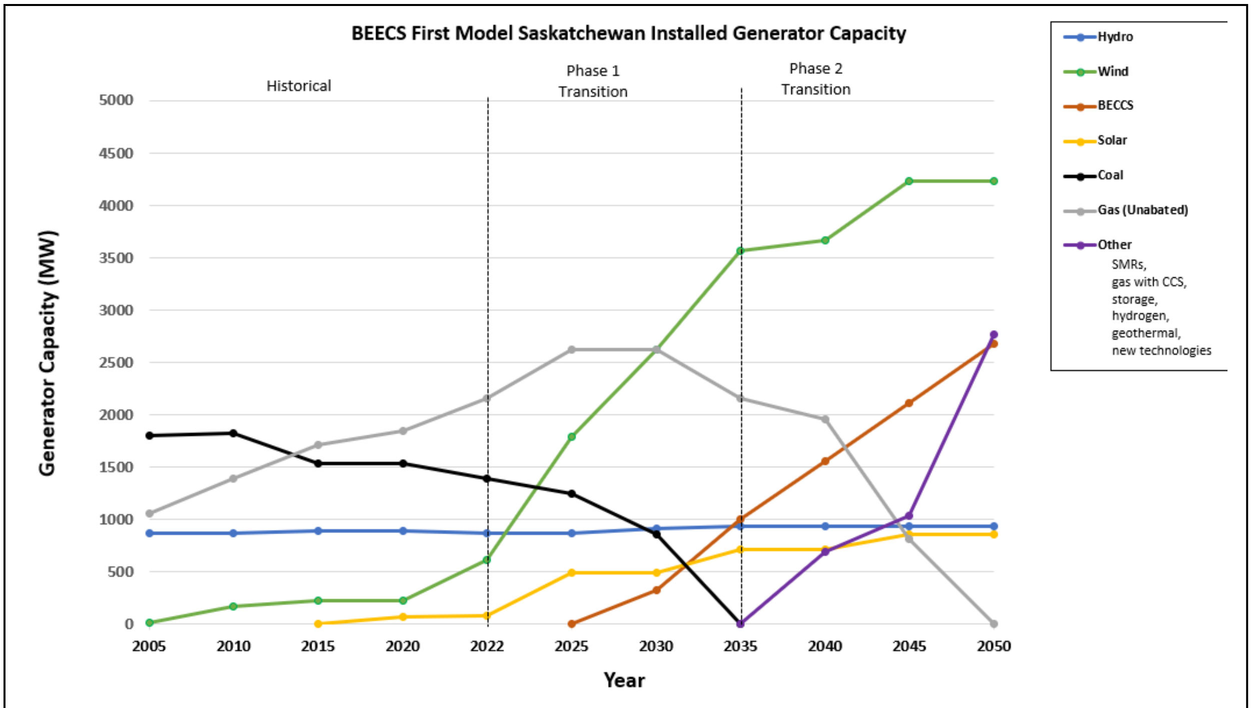

Figure 8. BECCS First pathway of future installed generator capacity in Saskatchewan. Available coal-fired units are retrofitted to BECCS. Build out of wind and solar. Existing gas plants are run mostly to end of life based on an assumed Saskatchewan equivalency provision to the Clean Electricity Regulations. Additional new build BECCS added after 2035. The mix of "other" additional capacity added after 2035 will be dependent on costs and commercial readiness of options.

The International CCS Knowledge Center completed a feasibility study on a retrofit and life extension of the Shand 300 MW coal-fired generator to carbon capture and storage (14). Converting Shand to CCS would cost about $1 B. This feasibility study would apply to all 4 of SaskPower 300 MW class units currently in operation (Boundary Dam 6, Poplar River 1 and 2, and Shand). Fuel switching to sustainable biomass would complete the transition of these units (along with Boundary Dam 3) to negative emissions BECCS. The estimated costs of a BECCS retrofit of existing assets is consistent with about a 45% savings relative to the cost of a green field BECCS plant of similar size. If Saskatchewan were to prioritize a BECCS retrofit and life extension of existing assets, the full federal 50% CCS tax credit would apply along with the full tax credit for building carbon trunks and geological storage infrastructure. In addition, this project would be eligible for federal clean electricity funding. Considering the importance of BECCS in the CER NZ scenarios, the government of Saskatchewan could partner with the federal government and potentially other equity providers and private industry players to ensure adequate support and financing for this critical first build BECCS project in Canada. In the UK, Drax is constructing the world's first commercial scale 500 MW BECCS power plant based on retrofitting a former coal-fired unit (19). This facility has undergone a fuel switch from coal to biomass with BC wood pellets as a primary feedstock and is scheduled to come on-line as a BECCS facility in 2027. A technical cooperation between Drax and SaskPower would serve to mitigate risks of implementation in Saskatchewan. By 2035, retrofitted BECCS units could be operating near capacity on a continuous basis to provide baseload power. After correcting for the parasitic load of carbon capture, this initial fleet of BECCS plants would generate about 7.8 TWh (21% of projected supply in 2035) while functioning to withdraw 8.3 Mt of carbon dioxide from the atmosphere (figure 9).

BECCS First Model
Transition of the Saskatchewan Electricity Supply

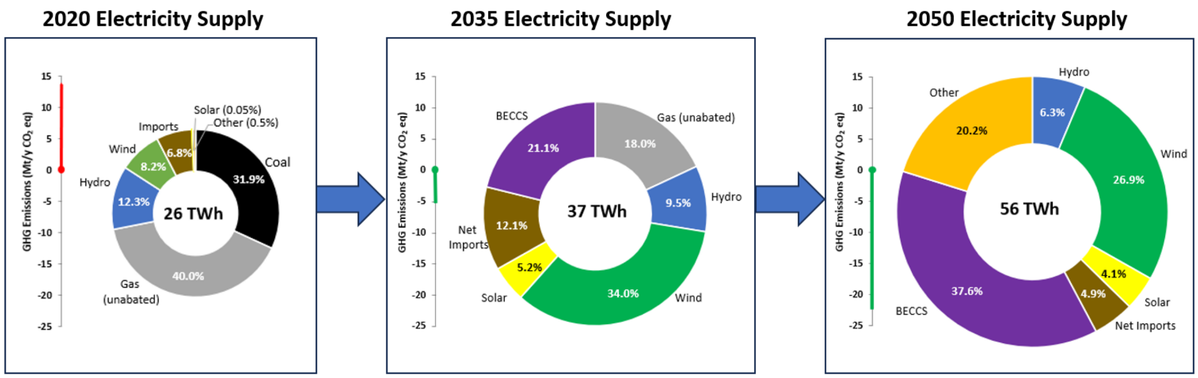

Figure 9. Energy mix for Saskatchewan's electricity Supply under a BECCS First transition pathway. By 2035, existing coal-fired units have undergone a retrofit to CCS and life extension. Shut down of existing gas plants is delayed and the costs of transition are lower. Risks associated with a demanding timeline for installation of SMRs and gas plants with CCS are mitigated. Other options for electricity supply (SMRs, gas with CCS, green hydrogen, storage, geothermal, new technologies) are added after 2035 and are dependent upon relative costs and commercial readiness. The level of ambition to transition Saskatchewan's electricity system to net negative emissions as described for the CER Global NZ scenario is not compromised.

Given the magnitude of carbon dioxide withdrawal under the BECCS First pathway, the impact of continued operation of existing unabated gas plants post-2035 on provincial GHG emissions is minimal. The clean electricity regulations could be modified to include a provision for a Saskatchewan equivalency whereby most of the fleet of existing unabated gas generators could run to end of life (figure 8). Assuming a build out of renewables similar to that described for the NZ scenarios in the CER report, there would be no need to add gas plants with CCS to the fleet by 2035. With the possible exception of some additional small peaker plants, existing unabated gas plants along with interprovincial flows would provide the flexibility to meet peak demand and to backup renewables. GHG emissions from continued operation of gas plants post 2035 would approximate 3.2 Mt/y such that the complete system would operate with a net-negative emissions of about 5 Mt per year. This level of carbon dioxide removal exceeds that of CER model without the costs and uncertainties associated with adding capacity as SMRs and new build gas plants with CCS by 2035.

Table 2: BEECS First Projected Installation Costs

	$/kW	MW installed	$M
Wind*			
Phase 1	$1,900	2,745	$5,216
Phase 2	$1,752	675	$1,183
Total Wind		**3,420**	**$6,398**
Solar*			
Phase 1	$790	525	$415
Phase 2	$535	135	$72
Total Solar		**660**	**$487**
BECCS			
Phase 1**	$3,312	997	$3,302
Phase 2***	$6,022	1,675	$10,087
Total BECCS		**2,672**	**$13,389**
Other****			
Phase 1	$5,000	0	$0
Phase 2	$5,000	2,764	$13,820
Total BECCS		**2,764**	**$13,820**
Phase 1 total			**$8,932**
Phase 2 total			**$25,162**
Totals			**$34,094**

*Phase 1 (2024-2034) and Phase 2 (2035-2050) installed costs set to CER 2022 estimates (12)

**BECCS Phase 1 CCS Knowledge Center Shand feasibility study (14)

***BECCS Phase 2 installed cost set to new build estimate for North America (19)

****Other based on assumed cost of 3 x 350 MW SMRs and 1,733 MW of gas with CCS. CER 2022 estimates.

Continued operation of existing gas plants along with a coal-to-BECCS retrofit of coal-fired units eliminates the costs associated with stranding these assets before designed end of life. Potentially a BECCS First pathway could provide $7 billion in cost savings with most of this avoided expenditure realized between 2024 and 2035.

The global need for energy storage and zero emissions technologies may well lead to advances in commercial readiness and cost-effectiveness of emerging technologies. The assumption that SMRs and gas with CCS will be required along side renewables may well be challenged by advances in energy storage, grid management and other options for electricity generation. The BECCS First pathway buys time as technologies mature.

Other Pathways of Transition of Saskatchewan's Electricity Supply to Net Zero or Near Zero Emissions by 2035.

Jaccard and Griffin Model for Saskatchewan's Year 2035 Electricity Supply Under NZ scenarios. Jaccard and Griffin (20) compared year 2035 projections of Net Zero energy mixes for electricity generation at the national and provincial levels under a Status Quo scenario and an Environmentally Constrained scenario. No limits were placed on technologies available for inclusion in the Status Quo scenario. The Environmentally Constrained scenario accounted for possible environmental and economic risks associated with the following technologies: CCS, new build large hydro, new build nuclear (large and SMRs) and BECCS. These options were constrained in the model. To compensate for these constraints; demand side management, load shifting, and short and long-term storage were added or increased as needed. It should be noted that, unlike the CER NZ scenarios, provincial electricity sector projections were not linked to a national, economy-wide, year 2050 net zero outcome. As such there were no

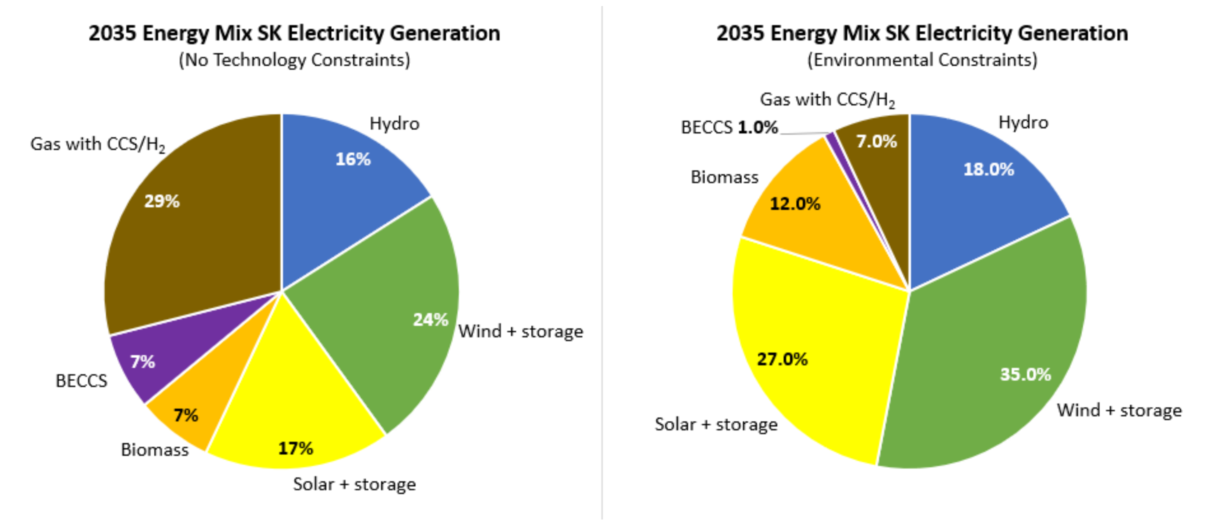

Figure 10. Jaccard and Griffin (20) model of energy mixes for Saskatchewan's electricity supply in 2035 under net zero emissions scenarios. In the Status Quo scenario no constraints are placed on technologies. In the Environmentally Constrained scenario, constraints limit the use of nuclear, CCS with gas and BECCS. By 2035, coal plants are shut down and existing gas plants are mostly shut down or retrofitted to CCS. Renewables are balanced by storage, interprovincial transmission, and dispatchable natural gas or hydrogen power plants. Biomass (with and without CCS) contributes to the 2035 energy mix. Carbon dioxide withdrawal via BECCS generators offsets residual emissions from thermal sources to arrive at a NZ outcome for both scenarios.

drivers of a net negative transition for electricity generation to offset residual emissions in the broader economy.

In both NZ scenarios, renewables play an important role in transitioning electricity generation in Saskatchewan (figure 10). Renewables are balanced by dispatchable thermal generators, energy storage and interprovincial flows. Low emissions dispatchable thermal generators consist of natural gas plants with CCS (retrofitted and/or new builds) and possibly hydrogen fueled simple cycle peaker plants. Larger unabated existing NGCC plants are either shut down or retrofitted with CCS. Under the Environmental Constraints scenario, the contribution of gas with CCS and BECCS is scaled back and replaced by renewables and biomass. In both scenarios, BECCS is required to offset residual emissions from other sources. The authors mention the potential for net negative emissions in Saskatchewan and the associated revenue potential for offsetting emissions outside of the provincial electricity sector.

Dolter and Rivers Model for Build Out of Excess Renewables Capacity in Saskatchewan. Saskatchewan's renewables resource potential is among the highest in Canada. With interprovincial transmission in place, Dolter and Rivers (21) estimate that over 27 GW of wind capacity installed in Southern Saskatchewan would be optimum for Western Canada. Electricity generated from this magnitude of renewables would be close to double projected provincial demand in 2050. Under this scenario, Saskatchewan becomes the renewables powerhouse of Western Canada with substantial exports to neighboring regions. Full leverage of the potential for wind energy in Saskatchewan requires co-optimization of the construction of generation and transmission assets (21).

Alberta Electricity System Operator (AESO) Energy Mix Models Under Near Zero Emissions Year 2035 Scenarios of Transition for Alberta's Electricity System. Recently, the AESO published a report on pathways for a timely transition of Alberta's electricity supply system to Near Zero emissions (22). The Pembina Institute followed up the AESO report with a further consideration of costs and options for a clean electricity transition in Alberta (23).

The AESO report provides an in-depth analysis of technology options, grid reliability, risks, and cost of transition. Given the similarities in resource potential for electricity generation between Saskatchewan and Alberta, the AESO report provides some useful information for consideration in designing a clean electricity transition pathway in Saskatchewan.

In contrast to the Canada Energy Regulator Futures 2023 report and the Jaccard and Griffin models, the scenarios assessed by AESO and the Pembina Institute did not include negative emissions options for generating electricity. In addition, large nuclear and small modular reactors were not considered based on cost uncertainties and projected timelines for implementation that would extend beyond 2035.

The AESO evaluated a Dispatchable Dominant scenario, a First-Mover Advantage scenario and a Renewables and Storage Rush Scenario (figure 11). By 2035, co-generation facilities in Alberta are predicted to supply about 50% of the total electricity. These facilities provide a constant supply of bulk power and thus can be considered separately from the mix of other dispatchable and non-dispatchable generators. In each scenario co-generation facilities were assumed to cut emissions (primarily through retrofit of gas plants to CCS) in line with emissions reduction achieved in transitioning the remainder of the electricity supply sector of the province.

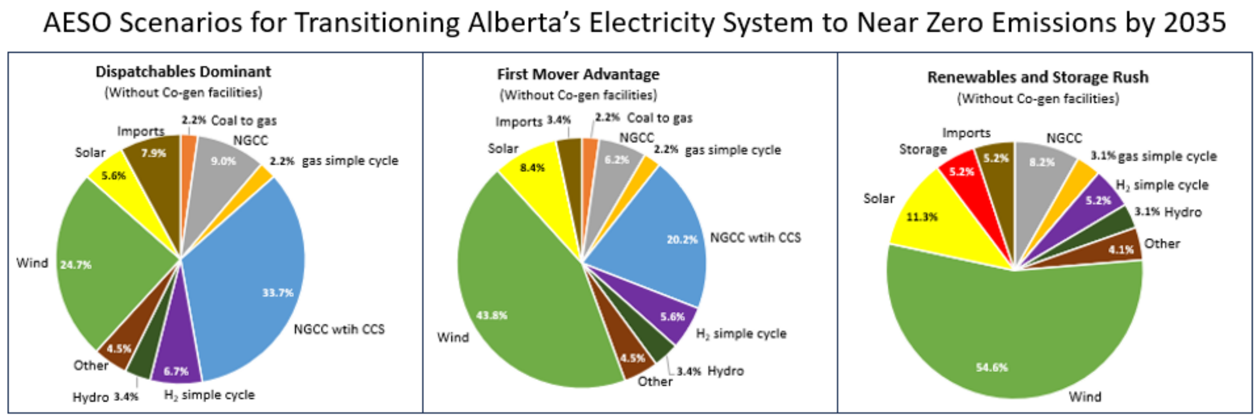

Figure 11. Alberta Electricity System Operator models of energy mixes for Alberta's electricity supply in 2035 under near zero emissions scenarios (22). Co-generation facilities are considered separately. The Dispatchables Dominate scenario is based on a mix of thermal power plants and renewables with 34% of generation from natural gas combined cycle plants with CCS. In the First Mover Advantage scenario, renewables are the dominant supplier of electricity and are backed up by dispatchable natural gas and hydrogen generators. In the Renewables and Storage Rush scenario, wind and solar provide 66% of the total supply. Storage (battery, pumped hydro and compressed air) along with dispatchable thermal power plants contribute to grid balancing and back up of renewables. All 3 scenarios can be described as near zero emissions in that continued limited operation of gas plants will release 4-5 Mt/y of CO_2. However, relative to the historical 2005 baseline reference for emissions from electricity generation in Alberta, a 90% cut in emissions will have been realized.

The AESO projects a 22-25% increase in cumulative systems costs by 2035 when compared to a reference case without emissions reduction targets (22).

Recently, the Pembina Institute in collaboration with researchers at the University of Alberta published the results of modelling a set of 6 "Zeroing In" scenarios of transition to a clean electricity supply for Alberta by 2035 (23). In 4 of these scenarios, year 2035 residual emissions of 6-7 Mt were predicted. This level of residual emissions was slighter higher than anticipated under the AESO clean electricity scenarios. The other 2 scenarios forecast only 2 Mt/y of residual emissions. Interestingly, in comparing projected costs with the AESO net zero scenarios, the Pembina Institute anticipates a $27-28 billion savings in the costs of transition. The Pembina Institute anticipates cost reductions driven by rapid deployment of low-cost wind and solar, expanding transmission interconnections and storage capacity. The year 2035 predicted consumer cost of electricity under the Pembina "Zeroing In" scenarios is less than the cost of electricity forecasted under the AESO reference scenario without emissions reduction targets.

Conclusions and Next Steps.

In 2022, fossil fuel generators accounted for 72% of Saskatchewan's electricity supply. Among the provinces, Saskatchewan had the highest intensity of emissions per kWh generated. On the surface, a complete transformation to a clean electricity supply for Saskatchewan within 12 years is daunting.

Without doubt there are legitimate questions as to the practicality, costs, and reliability of supply under such an aggressive timeline of transition.

However, in reviewing Saskatchewan's resource potential in the broader context of national net zero ambitions, viable cost-effective pathways of transition to a reliable supply of clean electricity by 2035 become apparent.

In this review the author has compiled and compared modelling work completed by reputable researchers and organizations on pathways of transition to near zero emissions, net zero emissions and net negative emissions for the electricity supply sectors in Saskatchewan and Alberta. This body of work can be summarized as follows:

1. **The important future role of renewables**. All of the scenarios described in this review are consistent in describing high grid penetration by renewables in a future clean electricity supply for Saskatchewan. The renewables energy potential of southern Saskatchewan in combination with low costs and low risks of implementation supports this conclusion.
2. **Interprovincial Transmission Corridors.** By 2035, renewables and hydro rich regions of western Canada will be linked by a new build east-west transmission corridor. Dispatchable power from hydro generators can flow as needed to renewables rich regions and excess power generated by renewables can, in-turn, flow to hydro rich regions. Intertie agreements between provinces to regulate flows will be in place by 2035. This transmission corridor along with grid modernization and demand side management will contribute to optimum grid penetration by low-cost renewables without compromising the reliability of supply.
3. **Natural gas with CCS.** In all scenarios, with the exception of the BECCS First and the AESO Renewables and Storage Rush options, near zero emissions natural gas plants with CCS contribute to the year 2035 clean electricity mix. In the AESO Dispatchables Dominant scenario, NGCC with CCS accounts for 34% of the electricity generated in Alberta. Commercial-scale implementation of CCS in Saskatchewan takes advantage of the geological storage potential of the Western Canada Sedimentary Basin. In Saskatchewan, pipelines and injection sites comparable to the Alberta Trunk will need to be constructed. While there are technical and cost uncertainties for CCS applied to gas power plants, the global need for this technology is driving the pace of development and commercialization.
4. **Continued Role of Unabated Thermal Energy Post 2035.** In all scenarios, existing natural gas plants continue to contribute, to varying degrees, to a clean electricity supply in Saskatchewan. Dispatchable simple cycle gas peaker plants will likely play an important role in the future energy mix. Peaker plants could be fueled by hydrogen as an alternative to natural gas. With the exception of the BECCS First scenario, existing larger NGCC plants are either retrofitted to CCS, decommissioned, or used in a limited a backup role to support renewables.
5. **The Potential Role of Storage and Green Hydrogen**. Dispatchable energy storage as grid scale batteries, pumped hydro, or compressed air are mentioned in the CER scenarios and are incorporated into the energy mix in the Jaccard and Griffin scenarios and the AESO Renewables and Storage Rush scenario. Further research and modelling of the potential role of energy storage to balance renewables is warranted. Potentially excess electricity from renewables could be used to generate green hydrogen by electrolysis.
6. **The Potential for Negative Emissions BECCS in Saskatchewan**. The CER NZ scenarios integrate electricity sectors at the provincial level with the national economy-wide NZ 2050 target. In 2050, industrial carbon dioxide withdrawal is required to offset residual emissions from agriculture and other niche sources. BECCS facilities function to withdraw about 40 Mt/y of CO_2

from the atmosphere. BECCS facilities are located primarily in Saskatchewan and Alberta based on proximity to geological storage. By 2035, a build out of renewables and BECCS can transition electricity generation in Saskatchewan from a serious source of greenhouse gas emissions to atmospheric withdrawal of carbon dioxide. As described in the BECCS First scenario, a focus on implementation of BECCS and renewables at scale in Saskatchewan can allow continued operation of existing gas plants post 2035 without compromising the magnitude of net negative emissions. As such, capacity replacement of these gas plants with zero emissions options is deferred. Commercial scale implementation of BECCS requires sufficient revenues per tonne of atmospheric CO_2 withdrawal to cover costs of biomass procurement and CCS. A carbon price of over $100 per tonne would allow BECCS facilities to generate low-cost negative emissions electricity that would be welcome by industry and consumers.

The energy mixes and timelines of transition to clean electricity in Saskatchewan as described in this review are illustrations of what can be done. What is required - without delay - is an acknowledgement of the need for greater ambition and a commitment to a year 2035 clean electricity transition on the part of SaskPower and the government of Saskatchewan.

The proposed federal clean electricity regulations are subject to a consultation period that ends November 2nd of this year. The government of Saskatchewan has an opportunity to submit a proposal for a provincial equivalency aligned with the unique set of provincial resources and existing infrastructure.

A provincial equivalency to the clean electricity regulations could be based on pooling emissions from the fleet of generators. Within the fleet, carbon dioxide withdrawal from BECCS facilities would exceed emissions from other thermal generators. As such existing unabated gas plants could continue to operate without restrictions, after Jan 1, 2035. Under this regulation, gas plants could be replaced at end of life with zero emission options.

With negative emissions BECCS-based scenarios, revenue from carbon dioxide withdrawal can come from the sales of offsets on the open market or from a federally funded carbon pricing system. Ideally, the carbon price would be set to incentivize optimal build out of BECCS in Saskatchewan. The pricing system could be backed up and guaranteed for the coming decades under the federal government's proposed Carbon Contracts for Difference whereby a government agency is contractually obligated to guarantee a future carbon price.

When considering federal tax credits for CCS projects, along with announced clean energy programs, up to $5 billion in federal funding could be available to assist with transitioning Saskatchewan to a clean electricity supply by 2035. If SaskPower and the government of Saskatchewan were to remain intransient and fixated on executing a low ambition transition plan, the province will, in effect, turn down billions of dollars in federal assistance in accelerating the transition to a clean electricity supply.

Given the national importance of negative emissions in meeting economy-wide NZ targets, potentially, BECCS projects could be administered and funded through a formal partnership between levels of government and could include private equity investors that are targeting clean energy projects. In Saskatchewan, provision of low-cost negative emissions electricity would attract industry looking to produce and export low carbon products.

We are just beginning to witness the devasting consequences of the global failure to take serious action to mitigate climate change. In Canada there is no longer any time to waste on federal-provincial squabbles that amount to little more than defending jurisdictional rights to pollute. Saskatchewan has the responsibility to act. A commitment to an ambitious plan to transition to a clean electricity system by 2035 in partnership with the federal government, equity providers and other stakeholders would be in the best interests of Saskatchewan and Canada.

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