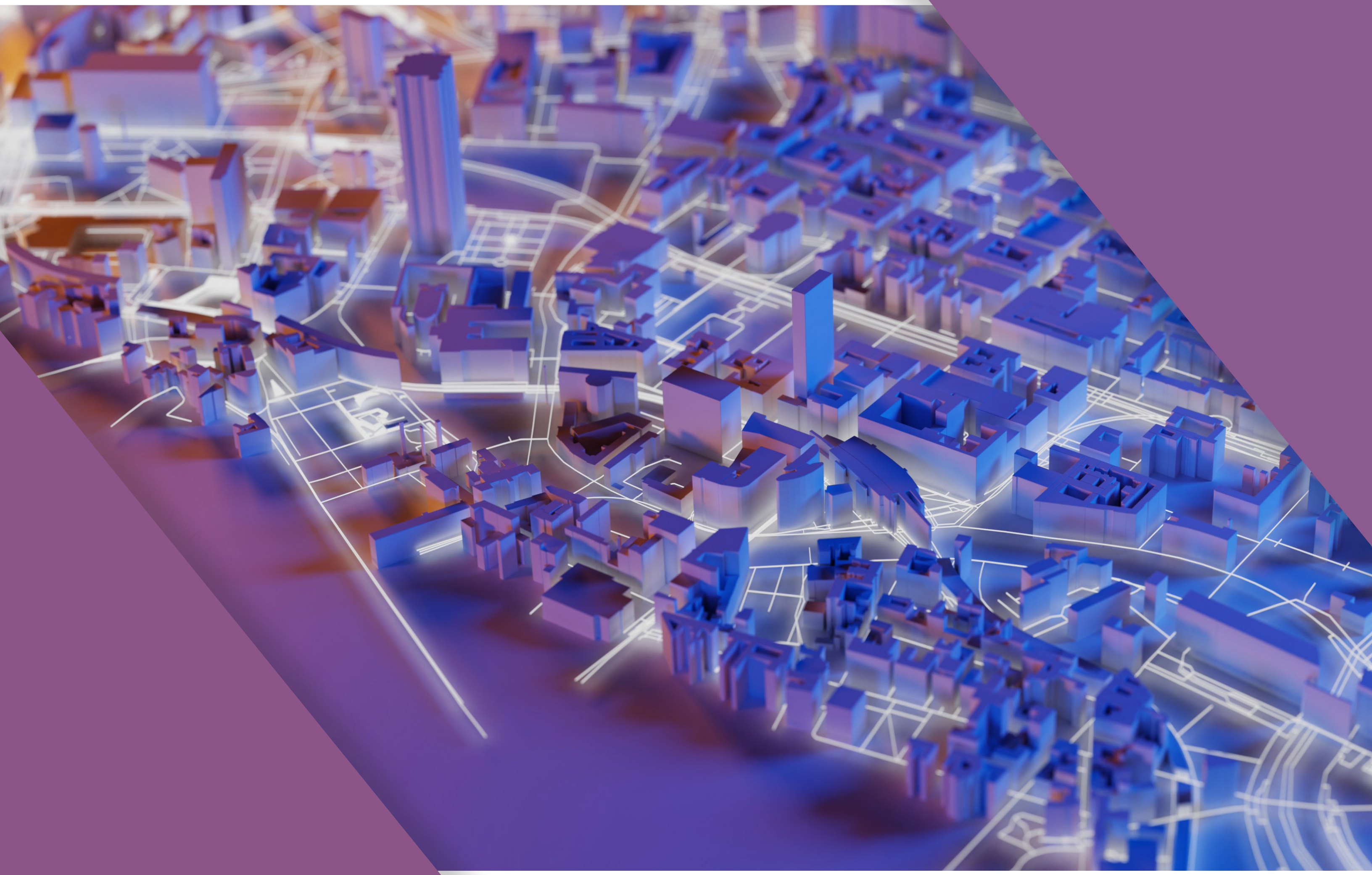

AESO 2021
Technology Forward Publication

NOVEMBER 2021

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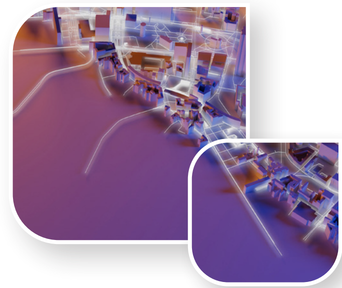


Executive Summary

The evolution of technology is happening at an unprecedented pace and the AESO is excited to collaborate with industry partners to prepare for the future of the grid.

Rapid technological advancements are transforming Alberta's power system with very significant and potentially far-reaching implications for the future of the province. These technologies are in varying states of maturity and encompass everything from electric vehicles (EVs), advancements in hydrogen and Carbon Capture, Utilization and Storage (CCUS), to power flow controllers and Dynamic Line Ratings (DLR), to name just a few.

As a leader in enabling the transformation of Alberta's electricity system, the AESO is working to understand how these new and emerging technologies could impact the province's electrical grid, markets and tariffs as well as possible related impacts to Alberta residents, businesses and industries.

Planning the future of the transmission system is central to the role of the AESO. We recognize a reliable, affordable, cost-effective electricity system is critical to Alberta's economic future. In support of that outcome, we have created this publication, *Technology Forward*, as a means of engaging with stakeholders across the electricity value chain – from generation to consumption – to hear their perspectives on the future of electricity in Alberta, and the technologies that are shaping it.

"Technology across the electricity value chain continues to advance at an accelerating pace and the AESO is proactively assessing the future implications to Alberta's power system, markets, tariffs and regulatory policy as these technologies become commercialized and adopted, globally and here in Alberta. The AESO is excited about the grid of the future and we remain committed to ensuring reliable and affordable electricity along this journey."

- Dennis Frehlich, *Vice President, Grid Reliability, AESO*

The AESO is committed to monitoring the technology landscape and fostering a culture of technology awareness and sharing. Publishing this report is the first step. The AESO welcomes industry and stakeholder perspectives on the future of electricity and we encourage dialogue with us through stakeholder sessions, both in-person and through our Technology Advocate[1] initiative.

We hope you find this report both informative and insightful. We look forward to engaging with you as we provide leadership to power Alberta today and into the future.

[1] https://www.aeso.ca/grid/grid-related-initiatives/technology-integration/

Purpose

Agility and flexibility are critical in understanding the impacts of technology. This publication examines what technology exists and the ways that the AESO will be impacted as technology advances.

The AESO recognizes it must be agile in response to changing industry technologies. Key to this approach is cross-functional collaboration with industry, stakeholders and government to understand and anticipate new technologies and prepare for potential challenges.

The purpose of this document is to provide:

- An overview of technologies at various stages of maturity across the electricity value chain;
- Summarize the stage of development and pace of adoption of these technologies, within Alberta;
- Highlight technologies we believe will influence the industry in Alberta within the next 10 years; and,
- Encourage dialogue among industry and stakeholders on the pace of technology adoption as it pertains to the electricity value chain in Alberta.

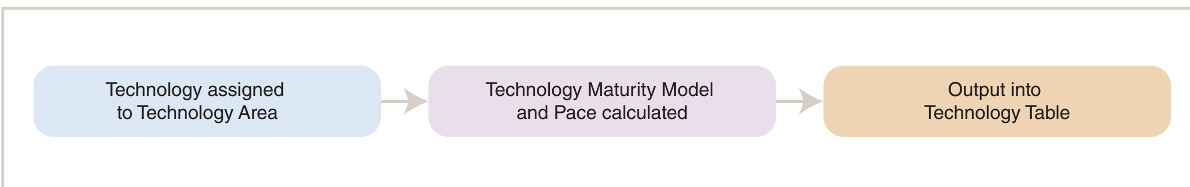
APPROACH

Overview

A structured model and process provides consistency and clarity as the AESO examines and assesses the various technologies and their potential implications to the grid in Alberta.

Globally, grid-related technologies continue to evolve, and the AESO recognizes that a comprehensive understanding of the underpinnings of each technology is unrealistic. Therefore, we are examining what technologies are most relevant to Alberta's electricity system. We have grouped technologies into technology areas, assigned a current state of technology maturity, as well as a technology pace of advancement in order to assess their potential impact on our system.

These technologies have been categorized in tables that highlight the specific technology area, the pace at which the technology is advancing, and, ultimately, the impact that these various technologies may have in Alberta.



Any technology that has the potential to impact the Alberta Interconnected Electric System (AIES) within the next 10 years is further characterized by its current state of development at the time of this publication and possible integration into our grid.

Technology Areas

The AESO identified a spectrum of technologies spanning the global electricity industry. These were evaluated, compared and filtered based on:

- Operating characteristics
- Number of vendors offering similar products
- Degree of impact on system function

These technologies were then assigned, labelled according to common industry language and categorized. Some technology areas were further divided into distinct sub-areas to address the specific application of technologies or to provide greater clarity.

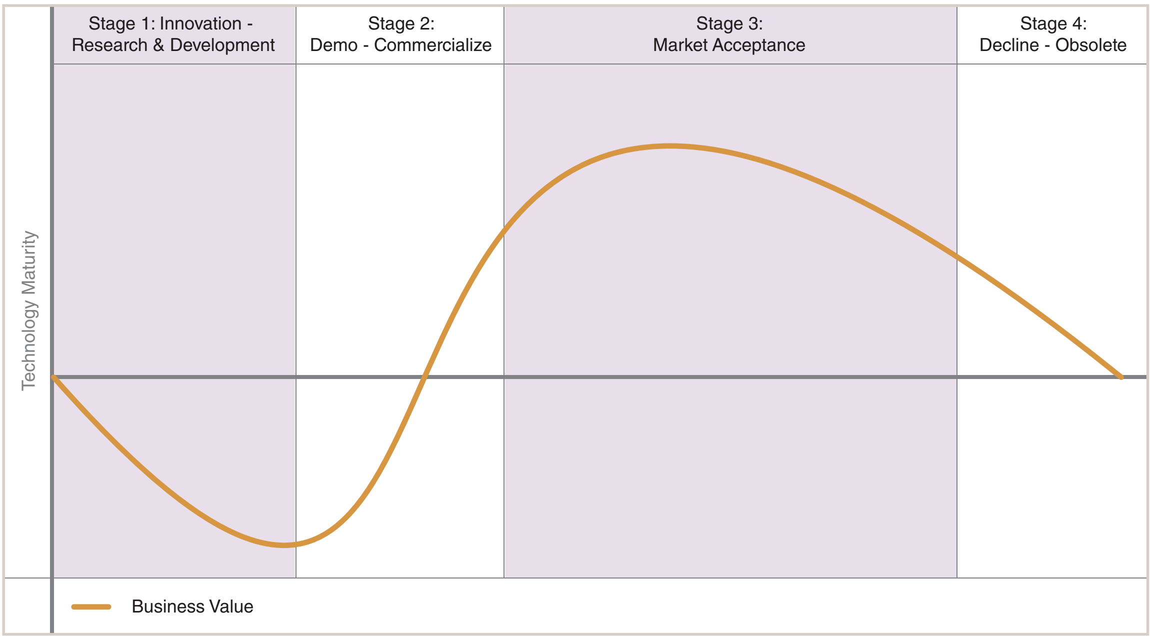
The technology areas the AESO has focused on are:

- Generation (supply)
- Load (consumption)
- Storage
- Transmission
- Telecommunications
- Information Technology

While telecommunications and information technology are broad categories, in this report they are viewed within the narrower context of their potential impacts on the electricity industry.
The AESO elected to focus on areas that are expected to provide value to the AIES as well as those where change might have a greater impact on the grid. As there is potential for some overlap across technology areas, certain technologies are represented in more than one area.

Technology Maturity Model

The technology tables and highlighted evaluations presented are based on a four-stage technology maturity model. This model captures global technological advancements from the initial research phase to an end-of-life cycle or obsolescence phase.



This model is the basis for placing technologies within the four stages. In addition to assigning technologies at appropriate levels, this model further examines the pace of development.

The stage and pace are broadly defined as follows:

Technology

- **Stage 1 (Innovation – Research & Development)** – AESO to monitor
  - Technology researched or developed but not mature enough to be adapted for market use or commercialization
- **Stage 2 (Demo – Commercialize)** – AESO to assess integration
  - Technology ready for commercial use but not widely adopted in the electricity industry
- **Stage 3 (Market Acceptance)** – AESO to facilitate integration or maintain
  - Technology widely used in the industry but not necessarily in Alberta
- **Stage 4 (Decline – Obsolete)** – AESO to maintain or retire
  - Technology in use; appears to have stopped maturing or is obsolete and no longer considered for market use

Technology Pace

- **Slow or Stalled Pace (yellow)**
  - Technology matured; no improvement or progression and unlikely to change
- **Medium Pace (blue)**
  - Normal progression
  - Technology maturity not progressing quickly
- **Fast Pace (green)**
  - Technology quickly advancing to the next technological stage; improving or enhancing within its current stage

Technology Tables

The technology tables are the outputs once the Technology Maturity Model has been applied to each technology and the subsequent pace has been identified.

As there is an opportunity to further categorize certain technologies, some technologies are assigned a sub-type to group more appropriately.

Note: These tables provide a global view of technology and may not necessarily be applicable or relevant to Alberta. Technologies that will have greater applicability for the AIES are addressed by the table in the Alberta Opportunity sections.

TECH AREA		Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Tech Category	Tech Sub-Category	–	–	–	Technology E
		Technology A	Technology B	Technology C	–
		–	–	Technology D	Technology F

Technology Scan

The AESO understands that a comprehensive list of all grid-related technologies is unrealistic and has elected to cover the technologies that are most likely to impact Alberta in the next 10 years.

The Technology Scan represents the AESO's view of global technology development. It involves the identification and classification of the various technologies in the electricity value chain and provides an overview of their relevance to Alberta. The Technology Scan contains highlights and trends of technologies that have the potential to impact Alberta's electricity system within the next 10 years. These trends consider opportunities that may be unique to Alberta, or industry improvements that are relevant to Alberta.

Technologies were selected from the technology tables based on their pace and relevance to Alberta's grid. Other technologies that are not progressing or are more than 10 years away from possibly impacting the grid or stakeholders were not highlighted in this document.

GENERATION

Introduction

The generation landscape is dynamic and has been changing since the first large-scale power grids became a reality. Traditionally, advancements in generation technology are often in response to the demands of electricity producers, consumers and public policy; however, there has been a noticeable shift in recent years. New solutions to increasing energy demand, emissions-reduction objectives and the desire for sustainable generation are being adopted and driven by new advancements in technology.

GENERATION		Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Thermal Generation	Fossil Fuel	—	Fuel Cells	Natural Gas Technologies:	Coal (Rankine Cycle)
		—	Residential/Small-Commercial Combined-Heat-and-Power (CHP)	Brayton Cycle (Simple Cycle and Combined Cycle)	Diesel Compression Ignition Engine
		—	—	Otto Cycle	—
		—	—	Rankine Cycle	—
		—	—	Organic Rankine Cycle	—
		—	—	Cogeneration	—
		—	—	Gasification	—
	Hydrogen	—	Fuel Cells	—	—
		—	Steam Methane Reformation	—	—
		—	Autothermal Reformation	—	—
		—	Electrolysis	—	—
	Nuclear	Fusion (Rankine Cycle)	—	Fission (Light Water, Heavy Water [Rankine Cycle])	—
		Small Modular Reactors	—	—	—
Renewable Generation	Wind	Kites	VAWTs	HAWTs (Onshore and Offshore)	—
		Airborne Wind Turbines	—	—	—
		Bladeless Wind Turbines	—	—	—
		Wind powered Thermal Energy System (WTES)	—	—	—
	Solar	Space-Based Solar Generation	Thin Film, Organic Cells	Photovoltaic: Mono/Multi-Crystalline, Concentrated Cells	—
		Building Integration	—	Heliostat, Concentrated Solar (Rankine Cycle)	—
	Hydro	—	Micro-Hydro	Dammed Hydro	—
		—	—	Run of River Hydro	—
		—	—	Irrigation Hydro	—
	Biofuels	—	—	Biomass (Rankine Cycle)	—
		—	—	Landfill Gas	—
		—	—	Biogas	—
	Waste	—	—	Waste Heat Recovery Unit	—
		—	—	Organic Rankine Cycle	—
	Geothermal	Enhanced Geothermal System	—	Dry Steam	—
		Closed Loop	—	Flash Steam	—
		—	—	Binary Cycle	—
	Alternative Tech.	Piezoelectric Generators	—	—	—
Emissions Control	Carbon Dioxide	Direct Air Carbon Capture	Carbon Capture, Utilization and Storage:	—	—
		—	Absorption	—	—
		—	Adsorption	—	—
		—	Chemical Looping Combustion	—	—
		—	Bacterial / Algae	—	—

ALBERTA OPPORTUNITIES

Generation

Rapid advancements in generation technologies have been made in recent years, driven by a strong focus on reducing emissions in electricity generation. Renewables generation has become more efficient, while emissions pricing has prompted fossil-fuel generation technology to incorporate emissions controls and fuel switching. Government policies on energy development and carbon emissions have impacted many industry participants. Innovative solutions to increase efficiency and sustainability are now driving greenhouse gas reductions, and existing technologies continue to be refined while new technologies continue to emerge.

Renewable Generation

Wind

Wind-powered electricity generation has contributed to Alberta's electricity system since the 1990s, and advancements in technology have recently made it even more of a significant renewable generation source. Horizontal axis wind turbines (HAWTs) have been the primary wind technology of choice for large-scale global wind generation. HAWTs have increased significantly in swept area and size since their introduction into the AIES in the early 1990s, and today modern HAWTs can be 90 metres in height with 4.8 megawatt (MW) turbines on tubular steel towers.

Increasingly, new technologies are designed and proposed that may have applications in distribution-connected and building-integrated wind technologies, including vertical axis wind turbines (VAWTs) and bladeless wind turbines. Research is now being done to test the use of kites as a method of harnessing wind energy.

Wind generation can produce alternating current or direct current electricity, depending on the configuration of the turbine, and both types of generators have connected to the AIES within the existing regulatory framework.

Solar

Solar-power generation has increased dramatically in Alberta over the past several years. This technology can generally be divided between solar photovoltaic (PV) and solar-thermal electricity generation.

Solar PV technology has been used in commercial applications since the 1950s, but recent advancements in production and efficiency have driven down the cost and substantially improved the economics of solar PV cells. At present, the most widely used solar cells in commercial power generation are silicate crystalline cells, which also have the highest efficiency among current solar PV technologies. Various other solar PV technologies are in development and may present economic advantages in the future.

Solar PV systems produce direct current electricity, which can be inverted to produce an alternating current and can therefore be readily connected to the AIES within the existing regulatory framework and AESO rules. Large-scale solar PV installations continue to add capacity to the AIES as costs become more competitive and conversion efficiencies increase.

Solar thermal technologies are unique in that they reflect, or concentrate, solar energy to create usable heat. Several technologies have been used to convert the heat to electrical energy including Rankine-cycle turbines, organic Rankine-cycle turbines and Stirling engines. Configurations of solar thermal technology include linear concentrating systems, solar power towers, and solar dish/engine systems.[2] Solar thermal electric power generation operations have been installed in many parts of the world, and the technology is well understood and accepted by the market.

[2] http://ets.aeso.ca/ets_web/ip/Market/Reports/CSDReportServlet

The City of Medicine Hat had a concentrated parabolic collector system, augmenting power generation in the Rankine-cycle of its combined cycle plant; however, the unit was retired in 2019 after only five years of operation.[3] While the technology is mature and accepted by the market, it is generally an uneconomic way to transform solar energy into electrical energy because the capital and operating costs are higher than solar PV technologies. In some applications, solar concentrators are used to focus light onto PV cells, which is a novel adaptation of solar concentration and solar PV. When solar-thermal generation produces electricity via a Rankine-cycle turbine, the resulting electricity can be easily integrated into the AIES.

Hydro

Hydroelectric systems were among the first forms of large-scale electricity generation. The technology is mature and has been in operation in Alberta since the late 1800s. Hydroelectric configurations include dammed hydro reservoirs, run-of-river hydro, irrigation hydro and pumped hydroelectric storage. Hydroelectric-generation applications are limited by the hydrology and landscape of an area. As such, finding sites with quality hydrology and economically developable resources can be challenging. However, a 2010 report by Hatch Engineering for the Alberta Utilities Commission (AUC) identified approximately 42 terawatt-hours-per-year (TWh) of hydroelectric generation potential which would be derived primarily from sites on the Athabasca River, Peace River, Slave River and the North Saskatchewan River.[4]

Geothermal

Geothermal technologies involve the use of heat from the earth. Geothermal energy systems draw on the natural heat within the earth to drive conventional power generation technologies. Three geothermal power plant technologies are available to convert hydrothermal fluids to electricity: dry steam, flash steam and binary cycle. Each depends on the state of fluid (steam or water) and its temperature. The dry steam and flash steam are used directly within a steam turbine. With binary cycle, the geothermal heat is run through a heat exchanger, whereby a secondary fluid with a low boiling point is pumped through the heat exchanger where it is vaporized and then directed through a turbine. A key limitation of this technology within the Alberta context is that most mapped and accessible geothermal potential – and the proximity to transmission infrastructure – lies within hot sedimentary aquifers that have temperatures that only support a binary cycle.

All three forms of geothermal energy technology are commercialized and in use around the world. The technology is stable and viable but to date has not been commercialized anywhere in Canada. There are a number of small projects currently underway to prove the viability on the Prairies, and in Alberta specifically. The development potential for abandoned hydrocarbon wells to be used as geothermal sources for power generation in Alberta is being actively explored at the time of this publication.

Waste Heat

Waste heat recovery can be used to produce electricity in a variety of applications and from a variety of sources. Rankine-cycle and organic Rankine-cycle technologies are often used to generate electricity using waste heat, depending on the temperature of the heat source. These technologies are well developed and accepted by the market as useful methods of converting waste heat into a valuable byproduct.

[3] https://www.cbc.ca/news/canada/calgary/solar-thermal-power-plant-mothballed-medicine-hat-1.5137428

[4] https://ceri.ca/assets/files/Study-155-Full_Report.pdf

Bioenergy

Bioenergy sources include biomass, biogas and biofuels, which are generally differentiated by their state of matter (solid, gas or liquid, respectively). These technologies are advanced and all three are currently used in Alberta. Most of the existing biomass facilities in Alberta rely on feedstock from the forestry sector which can be used as a fuel source in a Rankine-cycle operation. Biogas operations may occur at landfills, water treatment sites, agricultural sites or industrial sites that have gaseous byproducts. Operational examples of biogas electricity sites are numerous in Alberta, including the Landfill Gas Recovery site at Cloverbar, Slave Lake Pulp Mill Biomethanation and Power Generation Project, and the Bonnybrook Wastewater Treatment Plant biogas facility. Liquid biofuels — often methanol and ethanol — can be used in power generation or transportation. The Enerkem Waste to Biofuels and Chemicals Facility currently produces liquid fuels and chemicals, although they are not directed for use in the electricity sector.

Distributed Energy Resources

The installed capacity of distributed energy resources (DERs) is increasing in the Alberta electricity generation sector. Small wind turbines, PV arrays, cogeneration assets, combined-heat-and-power assets, natural gas-fired assets and biomass assets can all produce electricity at the distribution level. Advancements in micro-generation and small-scale distributed generation technology have enabled consumers to satisfy some of their own electricity demands as producers. In Alberta, the *Microgeneration Regulation*[5] and *Small Scale Generation Regulation*[6] create an environment where small electricity producers may benefit from their own on-site generation.

Alberta's electricity industry must prepare for a different future state, where the traditional one-way power flow will shift to a highly variable two-way power flow between the consumer and the AIES. It is anticipated DER growth and its integration with the AIES will drive significant changes for the AESO, distribution facility owners (DFOs), industry participants and consumers in Alberta. In addition to the advancements in this space, the AESO is actively monitoring the real-time impact of DERs in Alberta. Published in 2020, the *AESO Distributed Energy Resources Roadmap*[7] provides the AESO's vision for the future of this technology in Alberta. As DER initiatives across Alberta continue to advance, stakeholders will be apprised of the latest information in this space on the AESO's website.[8]

Thermal Generation

Fuel Cells

Fuel cells are electrochemical cells that convert chemical energy into electrical energy, heat and water via redox reactions. There are many different types of fuel cells that operate using different electrolytes. Fuel cells can operate using hydrogen, hydrocarbons, ammonia and other fuels. Although fuel cells were invented in 1838,[9] commercial applications for their use have been limited, though some commercial products exist. Fuel cells generally have higher electrical efficiencies and lower operating costs than combustion technologies. However, the capital cost of fuel cells is currently much higher than combustion alternatives and, as such, fuel cells represent a niche market today. Looking ahead, opportunities for future fuel cell deployment may increase with government support for hydrogen and combined-heat-and-power (also known as cogeneration). Fuel cells are also well suited to distributed on-site generation due to their high efficiency, low noise and useful heat production. Advancements in fuel cell technology could lead to capital cost reductions that could make them competitive with conventional combustion technologies.

[5] https://www.qp.alberta.ca/documents/Regs/2008_027.pdf

[6] https://www.qp.alberta.ca/documents/Regs/2018_194.pdf

[7] https://www.aeso.ca/assets/Uploads/DER-Roadmap-2020-FINAL.pdf

[8] https://www.aeso.ca/grid/grid-related-initiatives/distributed-energy-resources/

[9] https://fuelcellsworks.com/knowledge/history/

Nuclear

Fission

Nuclear fission was first discovered in the 1930s, and by the early 1950s the first nuclear reactors were producing electricity and nuclear fission reactions have been harnessed for power generation for more than 60 years.

Nuclear fission reactors have very low fuel costs and relatively low operating costs compared to fossil-fuel technologies. Nuclear fission releases millions of times more energy than chemical reactions do using the same mass of fuel, so it could theoretically meet a significant amount of the world's energy needs with negligible greenhouse gas emissions. The proven nature of nuclear fission-generation, low operating costs, and zero-emissions profile of this technology make it a primary candidate for a low-carbon transition. However, nuclear fission is very capital intensive and the construction timelines are long compared to other technologies, which makes it a less appealing investment.

In recent years, development of nuclear fission power generation has declined as a result of waste management and safety concerns coupled with poor economics of the technology. Going forward, the design and development of a new generation of smaller "modular" fission reactors may improve the economics and safety of the next generation of nuclear fission reactors.

Small Modular Reactors

Small modular reactors (SMRs) are a broad categorization of nuclear fission reactors. SMRs have existed for decades in military and naval applications but have only been commercialized in limited examples. Currently, Russia's modern ice-breaker fleet is powered by SMRs. More than 70 SMR designs have been proposed, and a few demonstration units are now under construction. Mass commercialization efforts have been stymied by an inability of proponents to achieve sufficient orders to warrant commercialization. Generally, 40 or more orders will be required to economically commercialize SMR production facilities, which represents the largest barrier to large-scale commercialization.

It is feasible that SMRs could be commercialized within five to 10 years. Several prototypes are under construction, and if sufficient order capacity can be obtained, the technology to factory produce SMRs is available. At this point in time, however, no mass production facility exists for commercial SMRs.

Alberta is a potential location for SMRs due to the high thermal demands of the hydrocarbon industry, and the large amount of baseload power required to support industrial activity. SMRs could be applied to steam-assisted gravity drainage (SAGD) and cyclic-steam stimulation (CSS) oil extraction techniques and could also be used in power generation. Alberta has agreed to collaborate on the advancement of SMRs as a clean energy option to address climate change and energy demands.[10]

Hydrogen as a Fuel Type

Hydrogen is an ideal fuel from an emissions perspective, since the only byproduct of hydrogen combustion is water, and there are no greenhouse gas emissions from the combustion of the fuel. However, hydrogen has a number of unique characteristics that create challenges for its adoption in power generation. Special augmentation of conventional fossil-fuel generation technologies is required to enable hydrogen fueling in gas turbines. Fuel nozzles, burners and turbine blades

[10] Alberta signs small modular nuclear reactor MOU | alberta.ca

require design changes to optimize their performance when fueled by hydrogen. Hydrogen has a higher burning temperature compared to methane and has a higher flame speed. Major turbine manufacturers are designing new turbines and retrofit technologies to enable hydrogen burning at power stations. Reciprocating internal combustion engine manufacturers have also modified engine designs to accommodate the unique characteristics of hydrogen combustion, and several models now exist that can burn 100 per cent hydrogen. The technology to burn hydrogen in power generation may impact project economics but is not likely to be a barrier to its adoption as a fuel source. Hydrogen fuel can be created from many different feedstocks including hydrocarbons and water.

Hydrogen

Steam Methane Reforming

At present, hydrogen can be most economically derived from a process called steam methane reforming. It involves chemically separating methane, first into carbon monoxide and hydrogen, and then separating water and carbon monoxide into hydrogen and carbon dioxide. The process is energy-intensive and produces a high-cost fuel, hydrogen, from a low-cost fuel, methane. However, the resulting carbon dioxide stream is very concentrated, and it can be compressed and sequestered at a lower cost than carbon dioxide from mixed gas streams. When carbon sequestration is included in chemical reforming of hydrocarbons, the product is often referred to as “blue hydrogen,” as opposed to “grey hydrogen,” which is produced using the same techniques without carbon sequestration. The cost of hydrogen production from steam methane reforming is dependent on the cost of the feedstock, the capital cost of the facility, the conversion efficiency of the facility, and the revenues available from byproducts.

Generally, the cost of hydrogen from steam methane reforming will always exceed the cost of the feedstock (usually methane) on a heat content basis. However, if the cost of carbon is higher than the cost of hydrogen production with carbon sequestration, then steam methane reforming may be an economic alternative to burning methane in power generation.

Autothermal Reforming

Autothermal reforming (ATR) is a process that can be used instead of, or in combination with, steam methane reforming to produce hydrogen and carbon monoxide. ATR uses steam in an oxygen-rich environment to partially oxidize a hydrocarbon feedstock, splitting the hydrocarbon into a synthesis gas composed of hydrogen and carbon monoxide. A catalyst is used in the ATR process to enhance the reactions. The product gases can then be burned or further processed into additional hydrogen and a rich stream of carbon dioxide, which can be sequestered. The carbon dioxide stream available from ATR is generally more concentrated than steam methane reforming and can be compressed and stored more easily as a result. Consequently, ATR is is considered to be a more economical way to produce hydrogen than steam methane reforming and also offers more operational flexibility.

Electrolysis

An alternative to chemical reformation of hydrocarbons into hydrogen is the electrical separation of water molecules into hydrogen and oxygen. The process requires direct-current electricity and an electrolyte that produces chemical reactions at the electrodes (anode and cathode). Advancements in polymer electrolyte membrane (or proton exchange membrane) electrolyzers are anticipated to reduce the cost of electrolysis when compared to conventional alkaline units.

When the electricity required for electrolytic hydrogen production is sourced from clean or renewable sources, it is often referred to as “green hydrogen.” Green hydrogen costs have declined significantly with improvements in electrolysis techniques and falling renewable electricity production costs. However, the cost of green hydrogen from electrolysis is generally more expensive than fossil-fuel feedstock alternatives and is highly variable based on the underlying cost of the reactant and electricity. For hydrogen fuel to be a competitive alternative to fossil-fuel generation, carbon taxes will need to be higher than the cost of hydrogen production with CCUS, plus the generation capital required to operate using hydrogen.

Carbon Capture, Utilization and Storage

Greenhouse gas emissions have been the defining issue of thermal energy in the 21st century. The desire to mitigate human-induced climate change impacts has spurred investment in CCUS technologies. Carbon capture techniques can be implemented via pre-combustion, post-combustion and oxy-fuel technologies at highly concentrated carbon dioxide sources. Direct air carbon capture (DAC) has also been successfully tested in ambient atmospheric conditions. Each technique offers benefits and challenges depending on the carbon capture application, and the suite of technologies will likely play an important role in global decarbonization efforts.

Pre-combustion Technologies

Pre-combustion carbon capture technologies involve separating hydrogen and carbon from hydrocarbon feedstocks; the carbon can then be compressed and sequestered prior to combusting the hydrogen for power generation.

In Alberta, pre-combustion technologies for carbon sequestration are currently used at Athabasca Oil Sands Project’s Quest carbon capture and storage facility, completed in 2015 near Edmonton. Although pre-combustion technologies are not directly used in the electricity industry today, similar techniques can be implemented to produce pure hydrogen as a fuel. The facility captures and sequesters over one megatonne of carbon dioxide annually into a saline formation near Thorhild, Alberta. [11] At the time of publication, the facility has not experienced any detectable leaks from the Basal Cambrian Sands injection reservoir. The operation of the facility is reported to be very successful, with 99.6 per cent availability and minimal maintenance issues.[12] The facility generates revenue from the creation of carbon offset credits. Hydrogen produced at the facility is used in the Scotford upgrader facility.

The Alberta Carbon Trunk Line project captures carbon dioxide from the Nutrien Redwater Fertilizer ammonia production facility and the North West Redwater Sturgeon Refinery using the Rectisol acid gas removal process. Carbon is transported via a 240-kilometre pipeline and stored in underground formations, including existing oil wells. At full capacity, the project will store 14.6 million tonnes of carbon dioxide annually.[13]

[11] https://open.alberta.ca/dataset/f74375f3-3c73-4b9c-af2b-ef44e59b7890/resource/ff260985-e616-4d2e-92e0-9b91f5590136/download/energy-quest-annual-summary-alberta-department-of-energy-2019.pdf page i, Executive Summary.

[12] https://open.alberta.ca/dataset/f74375f3-3c73-4b9c-af2b-ef44e59b7890/resource/ff260985-e616-4d2e-92e0-9b91f5590136/download/energy-quest-annual-summary-alberta-department-of-energy-2019.pdf page 12-1

[13] ACTL System – Alberta Carbon Trunk Line

Post-combustion Technologies

Post-combustion carbon capture technologies capture carbon dioxide from exhaust gas steams, such as the emissions stack of a power generation facility. Exhaust gases from power generation usually have a carbon dioxide content of less than 15 per cent in coal power generation and approximately four per cent in natural gas generation.[14] Since the carbon dioxide is less concentrated than the stream of CO_2 that results from pre-combustion sequestration, the CO_2 must be separated using solvents, sorbents or membrane systems. Post-combustion CCS can require significant amounts of solvent or sorbent chemicals; it can also drive a large amount of parasitic load at power generation facilities, which generally leads to higher carbon capture costs. However, the ability of the technology to be retrofit to existing facilities may increase its prominence in the future.

Oxy-fuel: Allam-Cycle

Oxy-fuel power generation involves enriching inlet air with oxygen, such that the flue gas produced from a combustion process is a rich stream of carbon dioxide. The source oxygen is generally separated from ambient air using an air separation unit; the fuel is then combusted in an oxygen-rich turbine or boiler environment. The carbon dioxide within the flue gas can then be purified, compressed and sequestered. There are several different designs of oxy-fuel power generation facilities. In Alberta, an Allam-Fetvedt-cycle power plant has been proposed by Kanata Power Plant LP.[15] Oxy-fuel technology has demonstrated zero net emissions at a 50 MW test facility in La Porte, Texas, using natural gas fuel.[16] The technology uses a specially designed Toshiba Brayton-cycle turbine driven by supercritical CO_2. The turbine drives a generator that produces electricity, and the rich emissions stream is separated into purified water and CO_2 which can be used to cool the turbine and can also be sequestered. The purified water can be used or sold, while the CO_2 can be pumped into storage. The Allam-Fetvedt cycle may achieve an efficiency of 60 per cent, including all parasitic plant load.[17] Several full-scale 280-to-300 MW facilities are planned in Colorado, Illinois, the United Kingdom and Alberta in the coming years.

Direct Air Carbon Capture

As an alternative to capturing emissions at the point of source, DAC removes CO_2 from ambient air using fans and solvents or sorbents. DAC generally requires larger energy input per unit of carbon dioxide removed, because ambient air has a low concentration of CO_2. Emissions Reduction Alberta provided support for a pilot by Carbon Engineering that was able to remove one tonne of CO_2 per day and proved the viability of the technology. Though capital cost considerations are still a significant barrier to the widespread adoption of this technology, technological innovations and increasing costs of carbon are improving the economics of DAC.

Generation Summary

The generation landscape is changing and evolving at a fast pace. Carbon neutrality, efficiency and advanced manufacturing techniques are creating new and more effective ways of producing electricity. A variety of generation technologies are advancing to meet consumer demands and government requirements. It is anticipated that these trends will have a significant effect on the traditional generation mix that supplies the grid. The existing regulatory framework and ISO Rules are not currently viewed as an impediment to the integration and development of these technologies. As the generation mix transitions and adapts, the impact on the system and market may evolve. The AESO will continue to monitor and assess any impacts on system planning, project connections, market rules and operating procedures to identify potential issues.

[14] https://netl.doe.gov/coal/carbon-capture/post-combustion

[15] https://www.thenewswire.com/press-releases/1kEjFXxO9-indigenous-partnership-catalyst-for-energy-transition-and-zero-carbon-future.html

[16] https://www.powermag.com/300-mw-natural-gas-allam-cycle-power-plant-targeted-for-2022/

[17] https://en.wikipedia.org/wiki/Allam_power_cycle

ELECTRICAL LOAD

Energy demand (commonly referred as “electrical load” or “load”) continues to evolve in the context of the Alberta grid. Unique among most North American jurisdictions, Alberta load is mostly composed of industrial activities, with 65 per cent of Alberta Internal Load (AIL) attributed to the oil sands and petrochemical sectors. Commercial load accounts for around 20 per cent, residential consumption represents approximately 13 per cent, and farm demand is around three per cent of AIL.[18] Across all consumer sectors, new technologies are increasingly being tested and integrated, with a particular focus on technological advancements that facilitate decentralization of energy resources (multi-directional management and control of resources as opposed to the traditional uni-directional approach), enabling the management of consumption and on-site generation (prosumers), and the reduction of CO_2 emissions.

The current landscape of load technologies is composed of four categories:

1. **Energy efficiency technologies**
   - These types of technologies are well established in Alberta and have been an area of constant innovation and experimentation across various consumer sectors.
2. **Electrification of the transportation sector**
   - The electrification of the transportation sector is rapidly evolving and expected to test physical limits and impact operation of the power system–starting at the distribution level and eventually the transmission system.
3. **Buildings and demand-side management**
   - Buildings account for a large block of overall energy (including electricity and gas) consumption. The way they consume and produce electricity is changing as a result of numerous enabling technologies. One of the main areas is the rise in demand-side management (DSM) technologies that respond to pricing signals and/or optimize on-site energy generation to match consumption. The pace of DSM sub-technologies varies due to upfront capital costs, availability of government incentives, consumer needs and desire for greater energy management control, and value that they provide. Further details on the DSM sub-technologies are explained below, with particular emphasis on those with rapid pace and high impact to the Alberta grid.
4. **Industrial load**
   - Significant changes to Alberta’s industrial mix will manifest in different load patterns due to the percentage of industrial load in AIL. Some industrial activities have electric and thermal requirements that make the economics of self-supply – also referred to as behind-the-fence (BTF) configurations – more attractive and executable. Increasingly more stringent environmental standards and carbon policies are exerting pressure on established industrial sectors in Alberta to reduce their overall energy consumption and/or offset emissions with new technologies (such as hydrogen production)[19] these de-carbonization efforts may lead to changes to typical load patterns.

[18] For more details, see the AESO’s Delivered Cost of Electricity Report: https://www.aeso.ca/assets/Uploads/AESO-Delivered-Cost-of-Electricity-Report-FINAL-31May2020.pdf

[19] Hydrogen facilities are an example of a technology that could have multiple impacts on the electricity sector in Alberta. Hydrogen facilities can be considered as an industrial load, as a fuel supply for power generation, as a form of chemical-based energy storage, or as a combination of the above. The AESO includes hydrogen in each of the load, generation and storage technology streams to monitor developments and applications that may impact the electricity value chain.

LOAD		Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Energy Efficiency	Residential, Commercial and Industrial	—	—	Lighting	—
		—	—	Refrigeration	—
		—	—	Ventilation, Fans & Pumps	—
		—	—	Compressed Air Systems	—
Transportation	Residential, Commercial and Industrial	Medium- and Heavy-Duty (Long and Short-Haul) Electric Vehicle Fleets	Electric Vehicles and Plugged-in Hybrids (Excl. V2G and V2X Capability)	—	—
		Transit and Delivery (Long- and Short-Haul) Fleet	—	—	—
		Electric Vehicle-to-Grid [V2G] and Vehicle-to-Everything [V2X] Technologies	—	—	—
Buildings	Residential, Commercial and Industrial	Renewable Natural Gas Heating (Replaces Fossil-Based Gas Heating)		District Energy Systems	—
		—	—	Demand-Side Management/ Smart Appliances:	—
		—	—	- Smart Furnace/ Thermostat	—
		—	—	- On-Site Generation (PV Solar)	—
		—	—	- Smart Meters	—
		—	—	- Space Heating (Direct Resistance/Baseboard Heating, Heat Pumps),	—
		—	—	- Space Cooling (AC, Reversible Heat Pumps)	—
		—	—	- Refrigeration	—
		—	—	- Lighting and Security	—
		—	—	- Water Heating	—
Emerging Economic Sectors/Activities	Industrial	Biofuel (Bio-Diesel and Bio-Gasoline) Production	Emissions-Intense Sectors Under Pressure to De-Carbonize (e.g., Oilsands, Steel, Cement)	Industrial Combined-Heat-and-Power	—
		—	Hydrogen (Electrolysis) Production	Behind-the-Fence Configurations	—
		—	Carbon Capture, Utilization and Storage Process	Behind-the-Meter Configurations	—
		—	—	Cryptocurrency Mining	—

Alberta Opportunities

Transportation

The transportation sector accounts for approximately 25 per cent of Canada's greenhouse gas emissions (GHG), of which almost half comes from passenger vehicles and light trucks.[20] Medium- and heavy-duty trucks are the second-largest source of emissions from the transportation sector. Electrification of the transportation sector has become a global trend to reduce GHG emissions, and on June 29, 2021, the Government of Canada set a mandatory target for all new light-duty vehicles and passenger trucks sales to be zero-emission by 2035.[21] Meanwhile, a growing number of automotive manufacturers have announced zero emission vehicle (ZEV) targets of their own.

Light-duty electric vehicle (EV) sales in Alberta have grown significantly in recent years and are expected to continue that trend. Several cities in Alberta have started to use electric buses for public transportation, with the intention of more gasoline-fuelled buses eventually being replaced by electric buses. The Government of Canada aims to add 5,000 electric buses to Canada's transit and school fleets by the end of 2024.[22] Medium-and heavy-duty electric fleets are still being piloted in Canada, with various announcements from large retailers and delivery agencies.

The AESO has studied the penetration level of EVs and is expecting a higher adoption rate in the future in Alberta due to a combination of governmental policy support, rising commitments from automotive manufacturers, declining EV purchase costs, further improvements in battery technology and ongoing construction of more charging facilities.[23]

Currently there are three different charging methods for EVs: Level 1 chargers, Level 2 chargers, and DC fast chargers (also known as Level 3 chargers).[24] Most EV charging will occur at the distribution level — although certain large-scale EV charging might need to connect to transmission facilities. Charging times will vary depending on the types of EV and if the charging infrastructure has AC or DC capabilities. EV charging will increase electricity demand, especially during peak hours.[25] At present, residential electricity charges are typically based on a flat rate with no price differentiation based on the time of day of consumption. This creates a risk of significant load ramps if consumers charge their EVs at similar times. As a result, EV load could be volatile and concentrated, which could impact the AESO's real-time operation and system reliability.

The wide adoption of EVs in Alberta presents both economic and technical challenges. Although the cost of light-duty EVs has been dropping, the cost of electric buses and medium- and heavy-duty EV trucks is significantly higher than gasoline-fuelled vehicles in the same category. Additionally, some distribution systems can support only two or three EVs charging at the same time in the same area.[26] As a result, DFOs could face increasing challenges and investment requirements as EV penetration increases, and consumers may face increased costs due to replacement capital. Charging infrastructure for electric buses — especially electric school buses and medium- and heavy-duty EV trucks — can be expensive and potentially complicated. Certain large-scale charging

[20] https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/zero-emission-vehicle-infrastructure-program/21876

[21] https://www.canada.ca/en/transport-canada/news/2021/06/building-a-green-economy-government-of-canada-to-require-100-of-car-and-passenger-truck-sales-be-zero-emission-by-2035-in-canada.html

[22] https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-infrastructure-and-communities-mandate-letter

[23] EV forecast was included in the AESO's 2019 Long-Term Outlook (LTO) and 2021 LTO, which can be found on the AESO's website: https://www.aeso.ca/grid/forecasting/

[24] https://electricvehicles.bchydro.com/charge/choosing-a-home-EV-charger

[25] The AESO's 2021 LTO Reference Case forecast approximately 120 MW of average demand growth and nearly 400 MW of peak demand growth by 2040. The Clean-Tech scenario results in 1,185 MW of average demand growth and slightly over 3,900 MW of peak demand growth attributable to EV charging profiles

[26] https://calgary.ctvnews.ca/electric-vehicle-use-expected-to-skyrocket-in-alberta-in-next-decade-1.5350893

stations may need to connect to the transmission system and, as a result, transmission upgrades may be required. Vehicle maintenance could be complicated and added technician and driver training may be required due to a shortage of experts to operate and maintain EV fleets. Moreover, one battery charging cycle may be insufficient to power an EV truck through a full-haul cycle, e.g., trucks used for long-distance delivery or for oil sands mining. Cold-weather conditions may also pose additional costs to maintain EV fleets.

The AESO will continue to monitor, assess and coordinate between all parties, as this will be critical to the ongoing reliable operation of Alberta's grid as EV penetration increases.

Vehicle-to-Grid (V2G)/Vehicle-to-Everything (V2X) is a technology that enables energy to be pushed back to the power grid from the battery of an electric car.[27] Currently, it is a project-based business [28] and there are only a few pilot projects in Canada. The V2G/V2X standards are still under development in Canada and there have not been any applications in Alberta yet. The technology of building V2G/V2X charging facilities and compatible vehicles is also in a very preliminary stage.

V2G/V2X may ultimately offer several advantages:

1. It reduces the total cost of owning the EV by selling energy back to the grid;
2. It eases grid capacity constraints and provides flexibility to the power system. This could offset the increased electricity demand and lower overall energy costs. Bi-directional equipment can export power from the vehicle to external loads, including an electric power system such as the electric utility grid; and,
3. EVs could support the electric grid in a state of emergency when V2G/V2X has been implemented extensively enough.[29]

Despite these benefits, most charging devices of V2G/V2X are DC chargers, and converting a DC charger to an AC to return power to the grid will add an additional cost to V2G/V2X. While V2G/V2X has the potential to provide opportunities for the automobile industry to be involved in the electricity industry, it also raises questions of how the car industry could play a role in the energy sector in the future.

Demand-side Management Technologies

Advancements in wireless telecommunication and Internet-based solutions have led to an increase in demand-side management (DSM) technologies. DSM technologies enable customers to modify their overall energy consumption (intra-day or intra-week shifts of load in response to price signals). DSM technologies also integrate on-site production of energy (in most cases from renewable sources such as solar generation) to offset consumption and, depending on the configuration and arrangements with local utilities, allow for excess production to be exported to the grid. DSM technologies include smart appliances (heating, cooling, refrigeration), lighting and security applications, smart meters, energy storage systems and micro-generation resources. Alberta customers are increasingly adopting DSM technologies. This is being driven by increased regulatory clarity (*Micro-generation Regulation*), the introduction of new government incentives, reductions in capital costs, and a growing desire by consumers to manage their own energy usage and sources and to minimize their exposure to transmission and distribution charges.

Solar micro-generation represents the most popular DSM technology with more than 104 MW of installed capacity in August 2021, propelled by an annual growth rate of 138 per cent over the past

[27] https://www.virta.global/vehicle-to-grid-v2g

[28] https://www.virta.global/vehicle-to-grid-v2g

[29] https://www.virta.global/vehicle-to-grid-v2g

five years.[30] Solar micro-generation is increasingly popular in residential and commercial buildings and has been installed across over 270 municipalities in Alberta. It offers a key advantage of matching generation with peaking hours of consumption, therefore reducing cost to consumers. As the penetration and concentration of solar micro-generation increase in certain pockets of the grid, the impact to the AESO's system reliability, planning and operations is becoming more evident. This is due to intermittency of generation caused by cloud coverage and a corresponding lack of visibility to grid operators; unlike utility-scale solar generation, micro-generation resources do not have telemetry linkages that inform grid operators of their real-time generation status.

The AESO has ramped up its efforts to manage these emerging issues by improving modelling tools and incorporating more advanced meteorological forecasting, cataloguing static data of micro-generation and other DERs, and assessing technical requirements, including telemetry, for further integration of DERs, among others.[31] In addition, the AESO is committed to studying the variability that intermittent resources introduce to net demand via the system flexibility assessments and ongoing studies of frequency regulation reserves requirements to ensure grid reliability.[32]

The adoption of other DSM technologies has also increased over the past few years. Although aggregated estimates are not widely available, there were more than 30,000 smart thermostats (programmable and Internet-connected thermostats that facilitate greater monitoring and control) installed in residential buildings in 2017-2020 by the former Energy Efficiency Alberta.[33] It remains unclear whether these smart appliances are or can be connected to a central agent (an aggregator) to manage load that responds to pricing signals.

However, given that the presence of aggregator business models is increasing across other jurisdictions in North America, the AESO will continue to monitor these trends in Alberta and determine whether changes are required to enable additional integration.

Electrical Load Technology Summary

Technological trends are expected to change the typical consumption patterns of Albertans and how they interact with the AIES. At present stages and rates of adoption, the existing regulatory framework and ISO Rules do not present a barrier to the integration of these emerging technologies. It is worth noting that while the concentration and penetration of some of these technologies may increase over time, the impact on the power system and market may manifest in different ways. The AESO remains committed to monitoring and assessing their impact to system reliability and planning, grid connections, market rules and/or operating procedures as issues are identified. In the case of EVs, the AESO will continue to engage with DFOs to monitor and assess ongoing impacts to distribution networks arising from coincident charging and required infrastructure upgrades.

[30] For more details on Alberta's micro-generation and small distributed generation resources, see https://www.aeso.ca/market/market-and-system-reporting/micro-and-small-distributed-generation-reporting/

[31] More details on the AESO' DER roadmap integration activities, see https://www.aeso.ca/grid/grid-related-initiatives/distributed-energy-resources/

[32] See the AESO's system flexibility assessment studies here https://www.aeso.ca/market/market-and-system-reporting/system-flexibility-assessment/

[33] Energy Efficiency Alberta annual reports include more details: https://open.alberta.ca/publications/energy-efficiency-alberta-annual-report

ENERGY STORAGE

Energy storage technologies help balance supply and demand on the electrical grid. As electricity systems evolve, there is an industry-wide recognition of the need to deploy additional new and flexible storage solutions. It's projected wind and solar energy will account for almost 40 per cent of global electricity generation by 2040, up from seven per cent today. [34] Demand for energy storage resources is expected to increase as batteries enable electricity storage, particularly from variable, non-dispatchable renewable energy resources such as wind and solar. Energy storage resources can provide many other direct benefits for the power system, including frequency regulation, peak shaving, deferral or substitution of investments in transmission and black-start capability.

Energy storage refers to the process of capturing electric energy produced at one time for use at a later time. Such a process enables electricity produced at times of low demand, low generation cost or from intermittent energy sources to be used at times of high demand, high generation cost or when no other generation is available.

In August 2019, the AESO published an *Energy Storage Roadmap*.[35] This roadmap sets out the AESO's plan to integrate energy storage technologies into the AIES and the Alberta electricity market framework. As part of the roadmap initiatives, the AESO published the *Long-Term Energy Storage Market Participation Draft Recommendation*[36] paper. It recommends solutions that would allow for improved electricity market participation by energy storage assets. The AESO initiated a stakeholder engagement process regarding the proposed Energy Storage ISO Rule Amendments pursuant to AUC Rule 017[37] based on the recommendation contained in this paper.[38]

STORAGE	Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Electric Technologies	Superconducting Magnetic Energy	–	–	–
Mechanical Technologies	Stacked Blocks	Flywheels	Pumped Storage Hydro	–
	–		Compressed Air Energy Storage	–
Electrochemical Technologies	–	Redox Flow Batteries (RFB)	Lithium Ion Battery	Lead Acid
	–	Sodium-Based Battery Storage	–	–
Chemical Technologies	Hydrogen Energy Storage	–	–	–

[34] Energy Storage Investments Boom as Battery Costs Halve in the Next Decade https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/

[35] https://www.aeso.ca/assets/Uploads/Energy-Storage-Roadmap-Report.pdf

[36] https://www.aeso.ca/assets/Uploads/Long-term-Energy-Storage-Market-Participation-Draft-Recommendation-FINAL-17FEB2022.pdf

[37] https://www.auc.ab.ca/Shared%20Documents/rules/Rule017.pdf

[38] https://www.aeso.ca/stakeholder-engagement/rules-standards-and-tariff/energy-storage-rule-amendments/

Alberta Opportunities

Lithium-Ion Battery

Large-scale battery storage systems are increasingly being used across Alberta's power grid. In 2021, two battery storage systems accounted for 30 MW of power capacity, the maximum amount of power output a battery can provide at any given moment. Both battery projects in Alberta were based on lithium-ion chemistry.

Lithium-ion technology currently represents more than 90 per cent of the installed power and energy capacity of large-scale battery storage in operation in North America. The increasing share of lithium-ion batteries in storage systems is being driven by declining costs and by the ramp-up in production to meet the growing demand for EVs.

Lithium-ion is currently the battery technology of choice for grid-scale storage projects. This is due to their high-cycle efficiency (they don't lose much energy between recharge and discharge), fast response times, and high energy density (stored energy per unit of weight).

We expect lithium-ion batteries will remain the battery of choice for developers as their costs continue to decline over the next five years.

Redox Flow Batteries

Redox flow batteries (RFBs) offer significant potential for grid-scale applications due to their unique ability to decouple power and energy density in the system. The ability to decouple energy and power within the cell stack means that to increase capacity and storage duration, the electrolyte tanks that store energy simply need to be scaled up.

Redox flow storage has advantages over other storage technologies, such as flexible modular design/operation, scalability, low Levelized Cost of Storage (LCOS) and a long lifecycle of between 20,000 and 25,000 cycles.[39] Fast responsiveness, high round-trip efficiency (RTE) and negligible environmental impacts also provide RFBs with multiple advantages when employed on the grid.

RFBs typically operate at energy conversion efficiencies of 70-85 per cent[40] and can be easily scaled from the kWh to MWh energy range. The energy storage capacity of an RFB can be increased by simply increasing the concentration of the electrolyte or by increasing the volume of the electrolyte. Thus, the cost associated with scaling up of RFBs is much less when compared to traditional secondary batteries, making them particularly attractive for grid-scale applications.

Moreover, RFBs benefit from low degradation rates and long lifetimes, typically ranging from 10-15 years of operation. The AESO expects to see several RBF projects come online in Alberta over the next five to 10 years.

Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) involves converting electrical energy into high-pressure compressed air that can be released at a later time in order to drive a turbine generator to produce electricity. CAES systems use off-peak or low-cost electricity to compress air and store it in a reservoir (an underground cavern or aboveground pipe) or vessels. When electricity is needed, the compressed air is heated, expanded and directed through an expander or conventional turbine generator to produce electricity.

CAES plants show very high availability and reliability. A 290 MW, four-hour CAES plant has been operating in Germany since 1978, demonstrating strong performance with 90 per cent availability and 99 per cent starting reliability.[41] CAES technology in the range of 25-290 MW has been

[39] Redox Flow Batteries Advantages for Stationary Energy Storage Market https://www.idtechex.com/en/research-article/redox-flow-batteries-advantages-for-stationary-energy-storage-market/20342

[40] https://medium.com/batterybits/redox-flow-batteries-a-technology-for-the-grid-scale-d799e4510907

[41] http://www.fze.unisaarland.de/AKE_Archiv/AKE2003H/AKE2003H_Vortraege/AKE2003H03c_Crotogino_ea_HuntorfCAES_CompressedAirEnergyStorage.pdf

achieved. Fast startup is another significant advantage of CAES technologies, with a startup time of about nine minutes for emergency start and about 12 minutes under normal conditions.[42]

The growth of CAES on a global scale is limited by its reliance on a specific type of geological structure. However, for locations where it is suitable, it can provide a viable option for storing energy in large quantities and for long periods of time.[43] There is currently one CAES project in the AESO connection project list.[44]

Pumped Hydro Storage

Pumped hydroelectric energy storage is a large, mature and commercial utility-scale technology currently utilized at many locations in North America and around the world. Canada's only pumped storage facility, a 174 MW plant, is located in Ontario.[45] Pumped-storage facilities store gravitational potential energy by pumping water from a reservoir up to another reservoir at a higher elevation.

When electricity is needed, water is released from the upper reservoir through a hydroelectric turbine into the lower reservoir to generate electricity. The main drawback of this technology is its need for abundant water resources and unique geographic elevation. There is currently one pumped hydro-storage project in the AESO connection project list.[46]

Energy Storage Summary

Energy Storage is changing the way electricity is consumed, as it enables renewables integration to better match supply and demand. Recent developments in battery storage technology have achieved significant cost reductions through technology improvements and scaling up of manufacturing. As battery costs continue to decline, greater attention will be focused on unlocking the full potential of this technology.

While providing many significant benefits to the power grid, energy storage projects currently face a variety of challenges and risks in the Alberta market.[47]

The AESO's Energy Storage Roadmap outlines the AESO's plan to facilitate the integration of energy storage technologies into AESO Authoritative Documents (ADs) and all applicable grid and market systems. The AESO is currently in the process of amending both the tariff structure and market rules to accommodate the unique aspects of energy storage resources into the Alberta electrical system.

The AESO also launched a Fast Frequency Response pilot (FFR Pilot Competition) to procure new technology capability to provide fast-acting transmission system reliability service for the potential sudden loss of imports from the Alberta-B.C. Intertie and the Montana-Alberta Tie Line. The AESO announced the FFR Pilot through its Energy Storage Roadmap progress updates, and the learnings from the FFR Pilot will support the long-term implementation of an FFR service.[48]

As initiatives across Alberta continue to advance in this landscape, stakeholders will be apprised of the latest information pertaining to energy storage on the AESO's website.[49]

[42] Renewable Energy System Design https://www.sciencedirect.com/book/9780123749918/renewable-energy-system-design

[43] Renewable Energy System Design https://www.sciencedirect.com/science/article/pii/B9780123749918000040

[44] https://www.aeso.ca/grid/projects/connection-project-reporting/

[45] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2016/market-snapshot-pumped-storage-hydro-largest-form-energy-storage-in-canada-growing-contributor-grid-reliability.html

[46] https://www.aeso.ca/grid/projects/connection-project-reporting/

[47] Alberta Electric System Operator announces new energy storage procurement opportunity https://www.osler.com/en/resources/regulations/2020/alberta-electric-system-operator-announces-new-energy-storage-procurement-opportunity

[48] https://www.aeso.ca/assets/Uploads/ES-Progress-Update-Feb-2021-FINAL-17FEB2021.pdf

[49] https://www.aeso.ca/grid/grid-related-initiatives/energy-storage/

TRANSMISSION

The transmission system is a complex, robust system consisting of a network of transmission lines and substations that deliver power to all areas of the province. With transmission technology advancing, the AESO foresees numerous implications for Alberta's grid. The grid includes towers (or poles), insulators, conductors, hardware and foundations that transport electricity between substations. The substation includes the control building and major equipment such as transformers, breakers, reactors and other apparatuses that carry and distribute the electricity across the grid and to homes and businesses through the distribution system. Substations also contain the supervisory control and data acquisition (SCADA) and protection equipment used to monitor the status, control the operation, and protect the reliability and safety of the transmission system. Substation technology developments are advancing, and the digitalization of substations has the potential to increase adaptability as new DERs are added and advanced protection schemes are deployed. For integration into the AIES, industry needs to consider how best to prepare and leverage the available substation data to address such challenges as increased DER and inverter-based resources (IBRs). For transmission lines, several technology developments — such as dynamic line ratings, high-temperature conductors and solar emissivity conductive coating — promise the benefit of increasing the power flow capability of existing transmission lines and enabling higher power flow capability on lighter conductors. With continuing advancements in material sciences and power electronics, it is now more economic and feasible to extend the capability and useability of existing transmission line structures, and, in certain scenarios, it might make sense to defer the need for new lines to be built.

For substations, technology developments are slowly advancing the digitization of substation measurements, communication and equipment. Additional monitoring and data sources from the substation are expected to drive new analytics and applications for transmission control centres and distribution systems. The availability of data, more refined control over power flow, and the need for faster response to changes on the power system, are driving these technology developments. These technologies are making substations smarter and more responsive to scenarios or risks on the power system and, ultimately, they are focused on prolonging the life of the infrastructure that already exists. Optimizing existing infrastructure in Alberta is preferable to breaking new ground where appropriate, and the AESO is monitoring these technologies closely.

TRANSMISSION	Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Lines	Superconductors	Solar Emmissivity Conductor Coating	High Temperature Conductor	—
	—	Dynamic Line Ratings	Flexible Alternating Current Transmission Systems (FACTS)	—
	—	Modular Static Synchronous Series Compensator (SSSC)	High Voltage Direct Current (HVDC)	—
	—	Drone/Robotic Applications	Underground Cables	—
Substation	Solid State Breakers	Hybrid Circuit Breakers	Real-Time Monitoring and Equipment Management	Circuit Switcher
	Virtual Protective Relays	Non-Conventional Instrument Transformer	Synchrophasor Applications	Faulting Switch
	—	Digital Substation (IEC 61850)	Smart Grid	—
	—	Time-Domain/Travelling-Wave Line Protection	—	—
	—	Centralized Feeder Protection	—	—

Alberta Opportunities

Dynamic Line Rating

There are a variety of different technologies being commercialized that provide dynamic line ratings (DLR) for transmission lines. Historically, transmissions lines have received static winter and summer line ratings (power flow capability in megawatts); these line ratings comprise engineering safety tolerances applied to cover different loading (power flow) and weather conditions, e.g., wind, temperature, solar, and ice/snow accumulation. With DLR, active monitoring of a transmission line provides a calculated dynamic rating based on current loading and weather conditions which allows transmission lines to safely operate closer to their engineered-rating threshold. Several pilots have been deployed in Alberta and more deployments are anticipated in the future.

It is anticipated that DLR technology will have an impact on Alberta's grid going forward. As a result, the AESO is launching an initiative in 2022 to assess various DLR technologies and determine if an existing DLR technology can be economically deployed in Alberta.

Solar Emissivity Conductor Coating

A transmission line's rating is typically limited based on the temperature at which sag (lengthening of the conductor due to heating) is within the transmission line clearances (distance from ground, roadways, trees, other conductors) for safe operation. Conductors also have temperature limits where permanent mechanical damage results. The application of conductor coatings that increase solar emissivity and reduce absorption will allow for higher line ratings from lighter conductors due to the increased cooling and reduced heating properties. High-temperature conductors can withstand higher temperature operation and have reduced sag, and this will also allow for higher line ratings from lighter conductor materials. Both of these technologies are being deployed throughout Alberta, and the AESO is monitoring the implementation and adoption of this technology as it grows in popularity.

Time-Domain/Travelling-Wave Line Protection

Time-domain/travelling-wave line protection principles have been combined in a new commercial product that results in ultra-high speed transmission line protection. Faster fault-clearing increases system stability and can allow for higher power flows and increased generation connections. The technology also provides very accurate identification of fault location, which can speed up field troubleshooting and repairs; can operate independently of fault current levels, which can help with inverter-based resource (IBR) adoption; and shows potential for multi-terminal lines created by T-tap (tapping directly to existing transmission lines instead of substations) connections of existing transmission lines.

Drone and Robotics

The use of drones is increasing across many industries, including the electricity industry. Drones allow for faster inspections of transmission systems, including tower structures and transmission lines. Accurate measurement of transmission lines and substations using drones and light detection and ranging (LIDAR) allows for detailed analysis and modelling of facilities. Vegetation management and tower maintenance plans can also be optimized based on the data collected. In Alberta, aerial robotics are being used in conjunction with drones to rapidly apply bird-flight diverters on transmission lines to reduce impacts . Other future applications are highly likely as the technology continues to mature.[50]

[50] https://calgaryherald.com/news/local-news/made-in-calgary-robot-aims-to-bolster-bird-safety-at-power-lines

Modular Static Synchronous Series Compensator

Modular static synchronous series compensator (SSSC) is a rapidly developing technology that allows for a refined control of power flows on the transmission system with a relatively small and scalable substation or tower footprint. Modular SSSC allows the optimization (push or pull) of power flows by adjusting the reactance of a transmission line pushing power to another line to avoid congestion and overloading. This technology will impact how the transmission system is modelled, controlled and operated in control centres. Modular SSSC installations allow grid operators to manage power flows by dynamically increasing or decreasing line reactance, pulling power towards or pushing power away from the line to which it is attached. This technology is able to divert power from overloaded lines to underutilized ones and capture more value from the existing grid. As a modular device, the solution can be scaled up or down to support the dynamic needs of the transmission and distribution system or be redeployed to other parts of the grid.

The AESO is considering the use of modular SSSC devices as an alternative in several projects currently under investigation. The cost to optimize a 138kV system is approximately $10 million, and with short lead times (contract to delivery in less than one year), modular SSSC devices allow emerging system needs to be met more quickly and at a lower cost than more traditional alternatives. Modular SSSC installations have been used by other grid operators around the world and clearly demonstrate the potential to deliver a more flexible and dynamic grid.

Smart Grid

There are many different approaches and technologies that can be considered “Smart Grid.” In general, the term denotes the coordinated integration of systems and resources, e.g., loads, small generation and battery storage. In Alberta, there are several projects[51] underway that are intended to demonstrate and test newer Smart Grid solutions. In Edmonton, EPCOR is deploying a solar PV facility with an integrated battery energy storage system and intelligent distributed energy resource management system (DERMS) at the E.L. Smith Water Treatment Plant.[52] In Calgary, there is a project focused on deploying advanced monitoring and controls to accommodate bi-directional power flows on the downtown secondary network from solar PV.[53] At present, Smart Grid technology is being deployed to large urban centres to provide benefits to distribution system operators through integration opportunities, accurate load analytics and faster outage response. Smart Grid optimizes the use of available electric system facilities using either information exchange or collection. Continued optimization efforts will require involvement of the AESO and participants across the electricity value chain.

Transmission Summary

Transmission line technology developments are focused on increasing power flow capability and optimizing the usage of existing transmission lines. Key benefits include longer usage of existing transmission structures and facilities and deferral of new transmission builds. When integrating new materials and conductor technologies in Alberta, the industry needs to consider any specialized monitoring or maintenance required and involve the AESO early in the process to facilitate potential rule changes or variance requests.

For technologies that involve power electronics with numerous components, industry needs to consider the reliability and potential failure modes, and how these dynamic technologies will impact the operation, modelling and contingency analysis in the power system control centres.

[51] https://www.nrcan.gc.ca/sites/nrcan/files/environment/Smart-Grid-2020-eng.pdf

[52] https://www.epcor.com/products-services/infrastructure/construction-projects/el-smith-solar-farm/Pages/default.aspx

[53] https://www.enmax.com/NewsAndEventsSite/Documents/ENMAX-and-Cadillac-Fairview-to-test-network-innovation.pdf

TELECOMMUNICATIONS

Telecommunications provide our control centres the critical data needed to monitor, analyze and control the Bulk Electric System (BES) and dispatch generation in Alberta. Telecommunications protect system stability by accelerating fault detection and clearing, and by supporting remedial action schemes (RAS) used to respond quickly to undesirable system conditions. Microwave radio and fibre optic cables make up the core telecommunication network used to support the transmission system and will continue to be used for critical services.

The demand for telecommunications continues to increase as new technologies and applications are developed that require effective and reliable data exchange. Telecommunications plays a key supporting role for other technologies, allowing for smarter applications, increased situational awareness and the optimization of existing transmission assets. The type and reliability of telecommunications required depends on the criticality of the data to ensure the safe and reliable operation of the BES.

Key technological developments in telecommunications include the increased availability and capability of data exchange through commercial/private/hybrid wireless broadband networks and through deployed low Earth orbit satellites. These technologies and other edge network[54] solutions are being driven by an increased need for data collection from the growing number of DERs and the increasing importance of the distribution system.

TELECOMMUNICATIONS	Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
	–	Low Earth Orbit (LEO) Satellites	Commercial Wireless Broadband	Geostationary Orbit (GO) Satellites
	–	Private Wireless Broadband	Meter Data Collection	Leased Analog Services
	–	Hybrid Radios	Spread Spectrum Radio	Power Line Carrier
	–	Remote GOSSE/61850	MPLS/Packet-Based Telecommunications	–
	–	SCADA Cloud Application (Distribution)	Microwave Radio	–
	–	–	Open-Air Optical Laser	–
	–	–	Fibre Optic Equipment	–
	–	–	Digital Mobile Radio	–
	–	–	Encryption and Security	–

Alberta Opportunities

Private/Commercial/Hybrid Wireless Broadband

Commercial wireless broadband networks have experienced exponential growth in terms of bandwidth capability and coverage due to the explosion of smartphone usage and continuing investment by telecommunication operators (telcos) in newer systems, e.g., 4G LTE and 5G. The use of these commercial networks for data collection is a cost-effective means for distribution operators and DERs and for non-critical transmission services. In April 2021, a Canadian Radio-Television and Telecommunications Commission (CRTC) decision [55] supported advanced electric utility access to

[54] Edge network, last-mile, or last-hop communications are telecommunications used from the core network to reach the end-user or end-device (e.g. cell tower to cell phone).

[55] https://crtc.gc.ca/eng/archive/2021/2021-130.htm

commercial wireless networks, making possible hybrid commercial and private wireless networks that could support growing DER connections and other utility data and voice needs, such as meter reading and distribution automation. The deployment of private or hybrid wireless broadband networks by utilities, which could carry more critical services such as DER teleprotection, is a technology worth exploring and will likely depend on the density and continued growth of DER and other distributed data sources.

Low Earth Orbit Satellites

The deployment of low Earth orbit (LEO) satellite Internet constellations with lower latency and higher capacity is a telecommunication technology that may be leveraged in the future. Access for utilities and the overall reliability and performance of these new satellite Internet services remains unproven but is expected to improve as more satellites are deployed and their operations stabilize. In the near term, these systems will likely be evaluated for backup data services at select facilities and will be considered for more applications in the future given their relatively low connection cost.

Edge Radio Solutions

As more DER facilities supply power to the grid and T-tap connections are made to the BES, there is increased need for cost-effective and reliable network-edge solutions to support the necessary protection applications such as RAS, breaker failure and transfer trip. These protection applications typically have slower latency requirements than what is required for transmission line teleprotection. Pilot projects have been deployed in Alberta that test the use of unlicensed spread-spectrum solutions and hybrid licensed/unlicensed solutions with mixed results.

Further development and testing in this area are expected as more DER and T-tap connections are made.

Encryption and Security

The encryption and security of telecommunications is a fundamental consideration for any new and existing telecommunication service. Efforts aimed at securing critical services and protecting the overall operation of the BES will continue to advance as technologies evolve and new best practices are developed. Alberta will continue to strive for best practices and meet the North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) requirements intended to support these efforts. While not new, this is an evolving and important technology area. Further discussion on encryptions and security can be found in the Information Technology section.

Telecommunication Summary

Telecommunications are essential to the operation of the power system. They enable new technologies and applications that are being developed to address changes in the electrical system, such as increased DERs and IBRs, and to optimize the usage of our existing facilities. For integration into Alberta, industry needs to consider what technologies and applications their network(s) will need to support in the future, what telecommunication technologies and networks can be used based on the risk and impact to the electrical system, how we secure and protect our critical networks, and how the telecommunication network(s) can be used to best support the whole of Alberta’s electricity value chain.

INFORMATION TECHNOLOGY

When discussing innovations in information technology in the power industry, we cannot consider them as a separate individual technology but rather as a collection of technologies that complement each other to provide a comprehensive platform for a future intelligent and distributed grid. Agility to adapt to technological transformation is needed to accommodate the rapid changes happening in the generation, transmission and distribution of electric power spaces. This often implies the increasing application of sensors, computers and communication–a way to increase the intelligence of the grid. As the AESO is seeing firsthand with all of the aforementioned advancements, being flexible and agile while operating a reliable grid can prove challenging. Looking ahead, advancements in the information technology space as they relate to the grid will prove to be beneficial as the industry proactively works to ensure the best technologies are being used and adopted.

INFORMATION TECHNOLOGY	Stage 1: Innovation	Stage 2: Commercialization	Stage 3: Market Acceptance	Stage 4: Obsolescence
Data	General AI	Deep Learning	Big Data	—
	—	—	Machine Learning	—
Computing	Energy as Service	Block Chain	Cloud Computing	—
	Quantum Computing	—	—	—
Preventive & Maintenance	—	Robotics	—	—
	—	3D Printing	—	—
Edge	—	Edge Computing	—	—
	—	Internet of Things (IoT)	—	—
Security	Quantum Encryption	—	CyberSecurity	—
Extended Reality	—	Augmented/Mixed Reality (AR/MR)	Virtual Reality (VR)	—
Networking	—	—	SDWAN	—

Alberta Opportunities

Networking

State-of-the-art sensor technology and enhanced communication networks, such as wireless broadband and LEO satellite Internet in combination with software-defined wide area network (SDWAN), allow new and advanced ways to monitor, control and maintain critical infrastructure on the power grid. Increasingly better and less expensive sensors are being developed which, in combination with modern information and communications technology, open up a new world of interconnected systems and components. Sensors and communications systems (often called the Internet of Things [IoT]), are expected to play a crucial role in the progress of the future power grid.

Potential future applications could include:

- Residential micro transactions
- Sensor data purchased or sold
- Micro administration, and automation, of commercial and residential energy consumption

The IoT enables us to identify conditional and environmental changes in substations, as well as monitor ground faults and protection, oil and gas levels in transformers and temperatures in windings, terminations and joins. Based on data from these sensors, IoT solutions can combine advanced physical models and data-driven analysis to provide valuable information about the condition, aging, faults and degradation of the power grid's critical components. More efficient methods of maintenance and production are now being realized with the aid of robotics technology,[56] which simplifies challenging maintenance work, and 3D Printing, which allows for "just-in-time"[57] solutions to inventory, removing the need for carrying a lot of costly "non-mass market" complex components.

Adoption of these technologies allows asset owners to predict when components in the grid will fail and, as such, has the potential to provide cost savings. This technology falls under the category of condition-based maintenance,[58] as opposed to scheduled maintenance, which is common today. This will enable more efficient asset management and maintenance of facilities, which will prove economically favourable in the long run.

With increasing adoption of the IoT, the grid will become decentralized thanks in large part to the proliferation and penetration levels of DERs. The grid is evolving from a one-way system—where power flows from centralized generation to consumers—to a platform that can detect, accept and control decentralized consumers and production assets to allow power and information to flow as needed.

While these changes are promising, there are numerous challenges related to the introduction of IoT sensors in the power system. The introduction of large numbers of decentralized, uncontrolled and unmonitored generators could threaten balance, degrade power quality or potentially endanger the grid in ways unknown. A new balance between centralized cloud computing[59] and edge computing[60] is required. There are other critical issues to contend with. In a distributed environment, different cyber threats and more vulnerabilities would be introduced, which would lead to new requirements and enhancements for cyber security technologies.

[56] Robotics - The use of physical machines to perform tasks.

[57] Just in Time - When demand is fulfilled to meet need as close as possible to when demand is expected.

[58] Condition-based maintenance is maintaining equipment based on real-time sensor data and predictive modeling versus hours of use or recurring dates.

[59] Cloud computing – Data is processed centrally offsite.

[60] Edge computing - Data is processed locally in a distributed network and/or on a local device.

Additionally, the IoT would generate an enormous amount of data on the network, requiring new ways to manage it. This means other technologies such as big data, quantum computing, artificial intelligence (AI), specifically machine learning (ML) and deep learning (DL), would need to be considered. And the emergence of extended reality[61] technologies such as virtual reality (VR),[62] Mixed Reality (MR)[63] and Augmented Reality (AR)[64] has introduced new visualization and experiences in control room environments.

Big Data, Data Science, Artificial Intelligence, Machine Learning and Deep Learning

There are many different types of AI, but they can generally be divided into the following categories: artificial general intelligence (AGI) and artificial narrow intelligence (ANI). AGI, which is still in its infancy, simulates human intelligence, while ANI can perform very specific tasks very well, though they are limited in scope. Many of the ANI applications are currently accepted by the electricity market. The increase in the number of connected devices leads to ever-larger amounts of data being collected, therefore increasing the need for extensive data processing and storage. Transmitting, storing and analyzing the enormous amounts of data generated by IoT-based sensor systems places enormous demands on data analysis and computing. As a result, employing effective big data analytics will play a critical role, not only for the efficient operation and planning of electric grids, but also for the development of proper business models and decision-making for key stakeholders.

As the energy market becomes more volatile, data science applications such as probabilistic congestion assessment and capability assessment become increasingly essential to optimize the transmission system. These applications provide big data analytics with a holistic approach to evaluate the reliability impacts with comprehensive risk indices. Due to the complex nature of energy markets and the operation of electrical grids, machine learning (ML), a form of AI, has been an increasingly powerful tool to help reduce the risk associated with energy transmission. ML techniques provide an efficient way to analyze and make appropriate decisions pertaining to the grid.

ML functionalities include:

- Anticipating grid failure or fault detection
- Preventing brownouts with real-time monitoring
- Balancing the grid
- Differentiating power system disturbances from cyber attacks
- Detecting energy theft
- Predicting consumption price

Even with all these advantages, ML still has some limitations and therefore needs to rely on other technologies to be successful. One such technology is deep learning (DL), an emerging area for feature extraction and the handling of huge amounts of data.

61 Extended Reality (XR) refers to all real-and-virtual environments generated by computer graphics and wearables. XR is the umbrella category that covers all the various forms of computer-altered reality, including: Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR).

62 Virtual Reality (VR) encompasses all virtually immersive experiences. These could be created using purely real-world content (360 Video), purely synthetic content (Computer Generated), or a hybrid of both.

63 Mixed Reality (MR) removes the boundaries between real and virtual interaction via computer-generated objects which can be visibly obscured by objects in the physical environment.

64 Augmented Reality (AR) is an overlay of computer-generated content on the real world. The keynote here is that the augmented content doesn't recognize the physical objects within a real-world environment.

Following is a comparison of the advantages that DL provides over ML:

- ML lacks the capability to manage high-dimensional data, i.e., terabytes or petabytes of data.
- DL has sufficient power for managing high-dimensional data as well as focusing on the exact features; this is known as feature mining.

Quantum Computing

As the world's energy networks expand, in addition to the requirements of AI, ML and DL, the complexity of the systems will grow in parallel. The expansion of DERs along with the emerging new type of loads will exponentially increase the volumes of data needed to uphold, process and optimize grids. This growth will place increased strain on existing infrastructure and computing power, and contemporary computers are not ready to serve the grids that will employ these technologies. As computations become more difficult and time consuming, one potential solution is to leverage the power of quantum computing.[65]

Quantum computing presents several unique options, including the ability to:

- Solve complex data optimization challenges
- Offer high-fidelity sensing
- Provide fail-safe communication and security

As quantum computing is understood at the time of this publication, the AESO believes it has the potential to impact and benefit the electricity industry, as follows:

- **Grid Optimization:** Accelerated processing of energy system data will allow grids to deal with a high penetration of volatile renewables and enable enhanced flexible and dynamic network operation within a system that might include billions of networked DERs. Problems such as grid topology control, synthetic grid inertia modelling and large-scale cross-network transactive energy will also be more manageable. In addition, the adoption of sophisticated probabilistic congestion assessment and capability assessment toolsets provide efficiency in identifying grid optimization opportunities.
- **Energy Asset Optimization:** Offers the potential to solve complex modelling challenges for dynamic energy systems such as heat, wind and water flow on a large scale.
- **Grid Security and Communication:** Enhances the complexity of cryptographic techniques using quantum key distribution and other emerging solutions to securely transmit important asset control data between nodes.
- **Customer Analytics:** Integrates and understands large volumes of customer data injected from smart metres, buildings and online user data to make better predictions on customer preferences and needs.

[65] Quantum computing applies the properties of physics at the atomic and sub-atomic level in quantum physics to the processing of information. Standard computers operate with binary digits or 'bits' with values of either 0 or 1. The quantum bits, or qubits, of quantum computers on the other hand can hold the values not only of 0 and 1 but also both values at the same time

In keeping with the rapid pace of advancements in quantum computing, many organizations have begun evaluating the possible use of quantum platforms using cloud-based environments due to security concerns. The AESO is monitoring the outcome of these efforts and will be evaluating the results accordingly.

Cloud Computing

Cloud computing is becoming commonplace, and, as such, it is a technology that the electricity industry is looking to leverage. In addition to eliminating the need for physical data centres, cloud computing opens up the possibility of creating a hybrid model that provides convenient, on-demand network access to a secure, shared pool of resources.

Cloud computing is generally understood to be in the market acceptance phase. The electricity industry has witnessed some obvious benefits of leveraging this technology in relation to managing the grid.

Several noteworthy characteristics of cloud computing include:

- On-demand service
- Ubiquitous network access
- Location independent resource pooling
- Rapid elasticity (scalable provisioning)
- Measured service

Edge Computing

Edge computing is a technology that may be relevant when the limitations of cloud computing are too restrictive. For example, there are situations when computations running centrally in the cloud might not be appropriate. Also, DERs typically generate large amounts of data daily; this data is then pushed to a centralized platform service to be processed, analyzed and ultimately acted upon. As a result, these assets may generate more useful data than infrastructure can efficiently move. Bandwidth issues and cyber security concerns also increase as more assets are connected.

In edge computing, computation is performed on distributed device nodes, reducing processing speed and security concerns. Batch uploads are sent on scheduled intervals for wider trend analysis across assets.

In edge computing, software applications, data and services are situated closer to the asset. It is understood that edge data application and processing would be faster than traditional data transfer and centralized processing by a factor of 1,000.

Edge computing presents an alternative to cloud computing by bringing computing closer to users and the source of the data.

There are many benefits associated with using edge computing to empower the grid, including:

- Low latency
- Data privacy
- Data security
- Reliability and efficiency
- Reduced bandwidth allowing for the collection of more data

Blockchain

Blockchains are a unique data management system that identifies and tracks changes (transactions) within the system digitally and shares this information with distributed computers connected to the network. These computers check and add new entries (transactions) into the ledger if proven correct by the majority of the computers connected to the system.

The increasingly decentralized and digitally connected electricity system needs a secure solution for communication, automation and documentation. A well-functioning electricity system is dependent on data being shared correctly, quickly and uniquely with the relevant actors within the system. Blockchains promise a more efficient and resilient infrastructure. This is especially true when comparing existing systems to manage all IoT data in distributed electricity systems, while also allowing for a new level of transparency, tamper resistance and security. With blockchain technology, a distributed ledger technology (DLT), it's been possible to replace central organizations – or governments – due to the technology creating trusted transactions and functionality that could not be previously done and relied on without the participation from the central and/or middle institutions.

Cyber Security

Although new technologies present new possibilities for monitoring components on power grids in the future, vulnerability to cyberattacks may also increase. As more Internet-connected sensors are installed in critical infrastructure, the number of potential points of attack will increase.

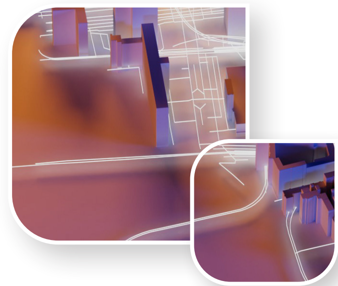
An attack can have serious consequences on the power grid. Physical infrastructure (power components) can be destroyed or become limited in their functionality, the control of the system can be lost, or sensitive information can end up in the wrong hands.

An attack can take different forms; we often distinguish between device attacks (where a compromised sensor can be used to spread a virus disguised as measurement data), data attacks (where data is inserted, modified or removed from the communication stream, tricking the system into making the wrong decisions), and network attacks (typically denial-of-service attacks where the network is flooded with traffic, making the services inaccessible or delayed).

An attack can also come as a combination of those mentioned above with the realization that new threats and attack strategies are being constantly developed. This is an important challenge with IoT solutions in the power grid, and it is necessary to implement robust cyber defense systems to minimize these risks.

Information Technology Summary

Power grids around the world are transforming to become more intelligent to keep up with the unprecedented advancement in new technologies. Driving this transformation is the acquisition and processing of real-time data. System operators like the AESO are adapting to this rapidly changing landscape. The challenge for the AESO and other ISOs is to leverage new capabilities, strike the right balance between centralized and distributed operations, applications and decisions, and also to plan the application of a hybrid infrastructure. It’s anticipated the grid will become more resilient in the future as these capabilities are deployed across a broad range of applications. Going forward, the AESO will pay close attention to the ongoing advancement of these technologies while continuing to ensure the grid is reliable and efficient for all.



Summary

The advancements and pace at which technology continues to evolve is impressive. The AESO is excited about the grid of the future and is looking forward to hearing all perspectives.

Technology is transforming all sectors of the electricity industry, with significant implications and opportunities for Alberta and the AESO. The speed of this transformation requires a proactive and strategic approach to enable new technologies while mitigating possible adverse impacts. As the AESO continues to learn about new and emerging power system-related technologies, it is important to hear the perspectives of industry partners and stakeholders. In order for us to collectively ensure a reliable, cost-effective and affordable electricity system into the future, all industry partners and stakeholders must work together to the benefit of all Albertans.

The AESO is committed to engaging in dialogue with industry experts on the transformation of the province's electricity system. We look forward to bringing concerned parties, technology experts and stakeholders together to understand all areas of concern and interest relating to technology. Working together, we can ensure Alberta's electricity system continues to meet the needs of all Albertans and supports Alberta's bright economic future.

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