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INTERNATIONAL CENTER
ON SMALL HYDROPOWER

World Small Hydropower Development Report 2022

Northern America

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Table of Content

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Northern America

Countries: Canada, Greenland, United States of America

INTRODUCTION TO THE REGION

The electricity sectors of Canada, Greenland and the United States of America (USA) reflect the relative size of their economies and electricity demand. The USA is the second-largest producer and consumer of electricity in the world, after the People's Republic of China, and has a highly diversified energy mix for electricity generation that includes every major type of energy source in addition to a variety of emerging technologies. However, thermal power, primarily from coal and natural gas, still plays the main role in electricity production in the country, accounting for 67 per cent of installed capacity and 60 per cent of generation in 2020 while hydropower accounted for just 8 per cent of installed capacity and 7 per cent of generation. By contrast, hydropower forms the mainstay of electricity generation in both Canada and Greenland, providing 59 per cent of generation in Canada in 2019 and nearly 80 per cent in Greenland in 2020. Canada is one of the global leaders in hydropower generation and a net electricity exporter. The accessible hydropower resources of Greenland are limited relative to the mass of water stored in glaciers across the country, but are sufficient to provide for the energy needs of its small population.

The structure of the electricity sector in the USA is highly decentralized, with the national grid functionally operating as several independent grid regions and electricity markets and over 3,300 private and public electric utilities engaged in production, transmission and distribution of electricity across the country. In Canada, the electricity sector is dominated by provincial Crown corporations operating as vertically integrated utilities, with interconnections between provincial grids mainly running north to south and having limited interconnectivity across the east-west axis. The electricity sector in Greenland largely consists of mutually isolated mini-grids supplying power to individual settlements, although a single state-owned utility company is responsible for managing the entire sector.

An overview of the electricity sectors of the countries in the Northern America region is provided in Table 1.

Table 1. **Overview of Northern America**

Country	*Total population (million people)*	*Electricity access, total (%)*	*Electricity access, rural (%)*	*Total installed capacity (MW)*	*Electricity generation (GWh/year)*	*Hydropower installed capacity (MW)*	*Hydropower generation (GWh/year)*
Canada	38	N/A	N/A	145,000	640,400	N/A	377,600
Greenland	0.1	100	100	230	540	91	430
USA	333	100	100	1,212,300	4,007,100	101,900	280,000
Total	**-**	**-**	**-**	**1,357,530**	**-**	**101,991**	**-**

Source: *WSHPDR 2022*[1]

Note: Data in the table are based on data contained in individual country chapters of the *WSHPDR 2022*; years may vary.

REGIONAL SMALL HYDROPOWER OVERVIEW

The definition of small hydropower (SHP) in Canada includes hydropower plants with an installed capacity of up to 50 MW, while in Greenland SHP refers to plants with a capacity of up to 5 MW. There is no nationwide definition of SHP in the USA.

A comparison of installed and potential SHP capacities in the region is provided in Table 2.

Table 2. **Small Hydropower Capacities by Country in Northern America (MW)**

Country	*Local SHP definition*	*Installed capacity (local def.)*	*Potential capacity (local def.)*	*Installed capacity (<10 MW)*	*Potential capacity (<10 MW)*
Canada	Up to 50 MW	4,504.0	15,000.0	N/A	N/A
Greenland	Up to 5 MW	N/A	N/A	9.0	183.1
USA	N/A	N/A	N/A	3,681.0	10,583.0
Total	**-**	**-**	**-**	**3,690.0**	**10,766.1**

Source: *WSHPDR 2022*[1]

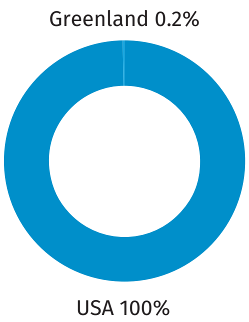
The total installed capacity of SHP up to 10 MW in Northern America is 3,690 MW, while potential capacity is estimated at 10,766.1 MW. Relative to the *World Small Hydropower Development Report (WSHPDR) 2019*, the installed capacity has decreased by 22 per cent while estimated potential capacity has decreased by 9 per cent, due to a lack of recent data on SHP up to 10 MW in Canada.

Both Canada and the USA have robust SHP sectors, which nonetheless form only a small fraction of the total installed hydropower capacities of these countries. Both countries have very significant untapped SHP potential, although due to the differences in the definition of SHP used in each country, a direct comparison is not possible. The SHP sector in Greenland is smaller by several orders of magnitude but accounts for a relatively larger share of the country's total hydropower capacity.

The SHP sectors in the USA and Canada are both undergoing active development, with many new plants built in recent years. Although both countries are well-supplied with electricity, SHP is promoted as a means to decarbonize electricity generation and, particularly in Canada, as a means of providing renewable power to remote communities still isolated from provincial electricity grids. In Greenland, little SHP development has taken place over the last decade.

The national share of regional installed capacity for SHP up to 10 MW by country is displayed in Figure 1, while the share of total national SHP potential utilized by the countries in the region is displayed in Figure 2.

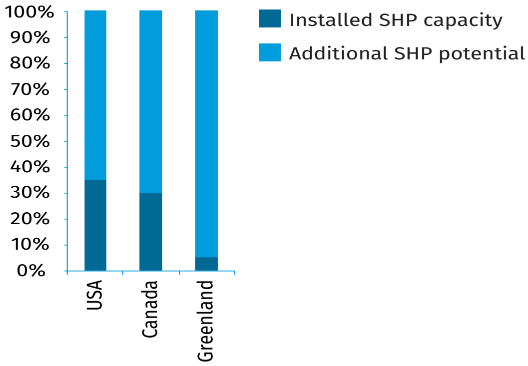
Figure 1. **Share of Regional Installed Capacity of Small Hydropower up to 10 MW by Country in Northern America (%)**



Source: *WSHPDR 2022*,[1] *WSHPDR 2019*[2]

Note: Canada is not included due to lack of data.

Figure 2. **Utilized Small Hydropower Potential by Country in Northern America (%)**



Source: *WSHPDR 2022*[1]

Note: For SHP up to 10 MW, except in the case of Canada where the local definition is used due to the lack of recent data on SHP up to 10 MW.

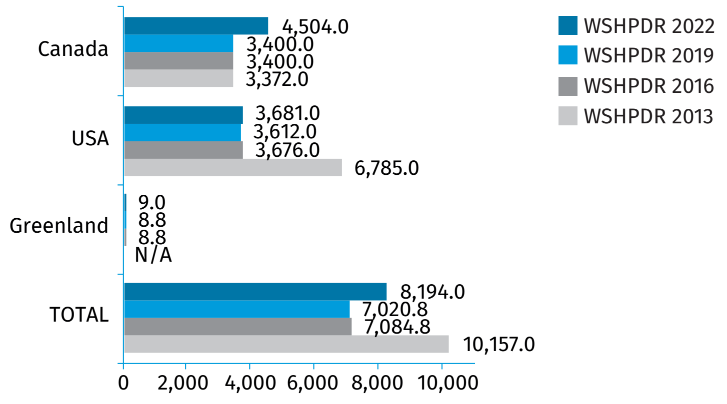
The total installed capacity of SHP in **Canada** was 4,504 MW for SHP up to 50 MW as of 2020, with a corresponding potential capacity of 15,000, indicating that 30 per cent has been developed. However, the estimate of SHP potential in the country is rather dated and based on unclear methodology, with an updated estimate currently under preparation. SHP construction in the country is very active, with several new plants commissioned every year. SHP development is spurred by the exhaustion of large hydropower potential in several provinces and ambitious decarbonization goals set by the national Government, particularly with regard to the phasing out of coal-fired power plants.

The total installed capacity of SHP up to 10 MW in **Greenland** is 9 MW, provided by two larger SHP plants as well as by a collection of micro-hydropower plants with a combined capacity of 200 kW. The SHP potential in the country is assessed at 183.1 MW, indicating that approximately 5 per cent has been developed. No new SHP construction has taken place since 2008, but one ongoing SHP project is planned to launch in 2023. Additional interest in SHP development in the country is mainly focused on micro-scale hydropower.

In the **USA**, the total installed capacity for SHP up to 10 MW was 3,681 MW as of 2021, provided by 1,679 SHP plants. The potential capacity of SHP up to 10 MW in the country is estimated at 10,583 MW, indicating that nearly 35 per cent has been developed so far. SHP development in the USA is actively ongoing as part of a general trend towards the development of renewable energy sources, as the federal, state and municipal governments have adopted clean energy targets and renewable portfolio standards (RPS), with several new SHP plants commissioned every year. Development of SHP in the country has focused on the construction of SHP plants on non-powered dams and water conduits, rather than new stream reaches. Private companies account for the majority of planned and proposed SHP projects, while public companies active in the sector are frequently municipalities interested in adding SHP capacity to non-powered water infrastructure they already own or operate.

Changes in the installed SHP capacities of the countries in the region compared to the previous editions of the *World Small Hydropower Development Report (WSHPDR)* are displayed in Figure 3.

Figure 3. **Change in Installed Capacity of Small Hydropower from *WSHPDR 2013* to *WSHPDR 2022* by Country in Northern America (MW)**



Source: *WSHPDR 2022*,[1] *WSHPDR 2013*,[2] *WSHPDR* 2016,[3] *WSHPDR 2019*[4]

Note: For SHP up to 10 MW, except in the case of Canada where the local definition is used due to lack of recent data on SHP up to 10 MW.

Climate Change and Small Hydropower

Across Northern America, runoff is anticipated to increase due to earlier snowmelt. With earlier snowmelt, lower summer flows are expected to diminish, which could reduce the hydropower generation in the summer months. Moreover, flood magnitude and frequency are increasing due to more frequent and more intense extreme precipitation events. This would require further investigation of potential impacts on seasonal and annual hydropower generation, as well as infrastructure risk assessment. In the USA, the fleet is expected to absorb part of the runoff variability due to the relatively large storage capacity. However, the undertaken analyses do not consider any other changes that could affect the capability to mitigate the runoff variability, such as the ageing of the fleet, water uses and environmental services.

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

In **Canada**, development of SHP is hindered by the lack of undeveloped economically feasible sites, which has eroded the cost-effectiveness of SHP in the country especially relative to other renewable energy sources. Additionally, a number of provincial programmes subsidizing SHP have been discontinued and a decrease in load growth has meant that the country is currently oversupplied with electricity. Opportunities for future development of SHP in Canada are considered to lie in the refurbishment of existing plants, ongoing replacement of capacities provided by thermal power and the provision of clean energy to remote communities. The regulatory framework of Canada is favourable to SHP development and public opinion is broadly supportive of SHP, provided sites are developed in consultation with local communities.

The main obstacles to SHP development in **Greenland** are the low demand for electricity and the lack of interconnections between communities, as well as a focus on the development of larger hydropower projects to provide for future energy needs. Enablers for development in the sector include the large untapped SHP potential and broad support for decarbonizing the country's energy mix, as well as the provision of government loans for all hydropower projects.

Barriers to SHP development in the **USA** include regulatory obstacles, lack of universal standards, risk aversion on the part of owners of water infrastructure and competition from other sources of power generation. Despite this, the environment for SHP development in the country is generally favourable. On a national scale, increased attention to renewable energy development, legislation promoting renewable energy targets and expediting SHP licensing, as well as technical innovations that are likely to reduce costs and increase the efficiency of SHP construction and operation are all driving active development in the sector. Incentives differ by state and locale but can include feed-in tariffs and access to net energy metering. Tax incentives for SHP are provided at the federal level as well as by some states.

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Canada

Richard Hendriks and Bryan Karney, University of Toronto

KEY FACTS

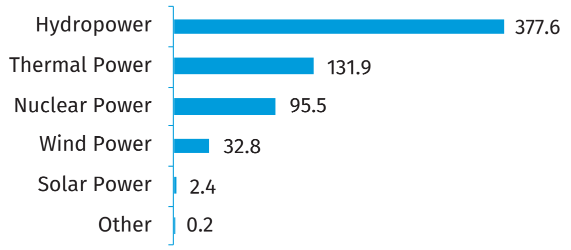
Population	38,008,005 (2020)[1]
Area	9,984,670 km^2 [2]
Topography	Canada is topographically and geographically diverse.[3] Along the Pacific coast, the Western Cordillera includes the Coastal Mountain and Rocky Mountain ranges, consisting of deep, glaciated river valleys, snow-topped mountain peaks and cold, glacier-fed rivers. Extending from Yukon territory through British Columbia and Alberta to the United States of America (USA), the Rocky Mountains include Mount Logan, the country's highest point at 5,959 metres above sea level.[2] The Interior Plains are dominated by flat crop and grazing lands, native grasslands and meandering rivers. Further east and north, the Canadian Shield is characterized by forested and rocky uplands and plateaus drained by an extensive network of lakes and rivers into Hudson Bay and its lowlands. The geologically ancient Appalachian Uplands, consisting of forested highlands and pastoral river valleys, extend south of the St. Lawrence Lowlands and across the Atlantic region. At over 240,000 km, the country has the world's longest coastline.[2]
Climate	The Canadian climate is highly variable.[4] Along the western coast, the Pacific maritime region has high precipitation, cool winters and warm summers, while the interior prairie region east of the Rocky Mountains experiences more extreme seasonal temperatures and less precipitation. The boreal region, extending across much of the country, has a continental climate — dry and humid summers with long, dry and very cold winters. The inland Great Lakes moderate the climate in the south-central regions, while the Atlantic maritime region along the eastern coast experiences moderate precipitation with cold winters and cool summers. Much of the far north is tundra with frigid winters and short summers. Average temperatures in summer range from 6 to 20 °C and in winter from -30 to +5 °C.[5]
Climate Change	Climate change is anticipated to increase annual precipitation in the coming decades while decreasing snowfall in almost all regions of the country. By the middle of this century, mean temperatures are forecast to increase moderately (by 2–3 °C) in the southern regions of the country and more extremely (by 3–5°C) in the northern regions.[6]
Rain Pattern	In the Pacific maritime region, annual precipitation ranges from 1,500 to 3,000 mm, almost entirely as rainfall.[4] The dryer interior prairies and northern boreal receive 300–800 mm of precipitation annually, with the Great Lakes – St. Lawrence region receiving 500–1000 mm.[5] Further north and away from open waters, precipitation has historically been dominated by snowfall.[6]
Hydrology	The country's two million freshwater lakes and more than 8,500 rivers encompass over 890,000 km^2, more than 9 per cent of the total area.[7,8] Twelve rivers extend more than 1,000 km, the longest being the Mackenzie River (4,250 km), which drains an area exceeding 1,800,000 km^2 into the Arctic Ocean. Twenty-four rivers have drainage areas exceeding 100,000 km^2, while 23 rivers have annual average discharges exceeding 1,000 m^3/s, with the highest being the St. Lawrence River with an average flow of 9,850 m^3/s.[8,9]

ELECTRICITY SECTOR OVERVIEW

The electricity generation sector in Canada had a total installed capacity exceeding 145 GW in 2017 and generated 640 TWh in 2019 (Figure 1), while exporting 60.3 TWh and importing 13.3 TWh to and from the USA.[10,11] Hydropower is the primary source of electricity generation providing 377.6 TWh, or 59 per cent of electricity nationally in 2019.

The share of electricity generated from renewable resources increased between 2010 and 2019 from 62 per cent to almost 65 per cent, while the share of non-emitting resources increased from 77 per cent to 79 per cent.[12] Six of ten Canadian provinces, comprising over 80 per cent of the population, produce almost all their electricity from non-emitting sources. Growth in generation from renewable sources, including hydropower, is expected to be focused on new generation within or supplying those provinces (Alberta, Saskatchewan, Nova Scotia and New Brunswick) where significant decarbonization of the grid remains essential to meeting the nation's commitments to reducing greenhouse gas (GHG) emissions.[1]

Figure 1. **Annual Electricity Generation by Source in Canada in 2019 (TWh)**



Source: Statistics Canada[11]

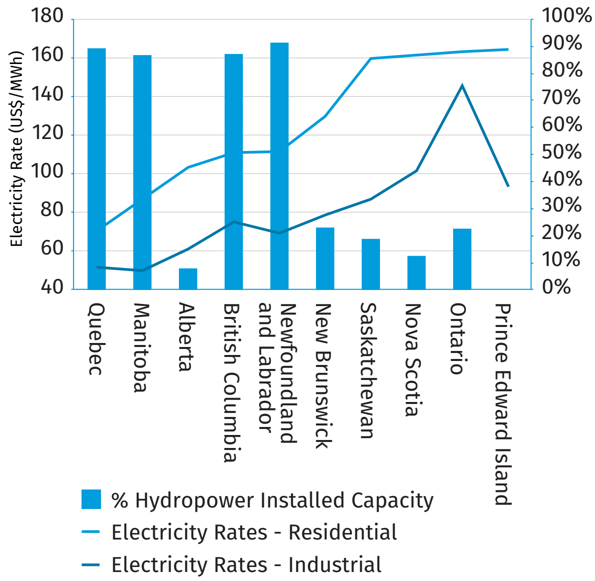
Over the past decade, Canada annually exported an average of 10 per cent of electricity generated, while importing an average of 2 per cent of electricity consumed.[11] Electricity services are available in all regions of the country, with 99.5 per cent of Canadians receiving electricity from locations on the interconnected Northern American grid and the remainder from remote micro-grids.[13]

The electricity sector of Canada is dominated by provincial Crown corporations operating as vertically-integrated utilities that own, control and plan generation, transmission and distribution. They are regulated by provincial utility boards.[14] This is exclusively the case in provinces (British Columbia, Manitoba, Québec and Newfoundland and Labrador) where large proportions (over 90 per cent) of electricity are generated by hydropower resources. Two of the provinces (Alberta and Ontario) have competitive markets, while the remainder have either Crown or private sector monopoly utilities. The Federal Government, through the Canada Energy Regulator (CER), retains jurisdiction for the issuance of permits for inter-provincial and international transmission lines, as well as the environmental assessment of international (>345 kV) and interprovincial (when designated by a CER order) transmission lines and any large-scale hydropower developments (>200 MW).[15,16]

Canada has a primarily north-south transmission network, intra-provincially and internationally, with limited transmission east-west between provinces. Five provinces (British Columbia, Manitoba, Ontario, Québec and Newfoundland and Labrador) have developed extensive northern hydropower resources and extra high voltage transmission to deliver electricity to southern load centres. A total of 49 transmission lines (over 60 kV) interconnect Canada to the United States, including the Manitoba-Minnesota Transmission Project, a 500 kV transmission line completed in June 2020.[17] Numerous recent studies have recommended expansion of the east-west transmission grid in support of system decarbonization.[18,19,20] Specifically, these studies advocated increasing interconnections between provinces dominated by dispatchable hydropower generation and those seeking to reduce dependence on coal generation while developing more intermittent renewable sources.

As a result of significant historical investment in hydropower resources, households and industry in Canada enjoy some of the lowest electricity prices within the Organization for Economic Cooperation and Development (OECD).[21] The benefits of this investment are most evident in those provinces in which hydropower resources make up a substantial proportion of total installed capacity, as shown in Figure 2.[10,22] With the noted exception of Alberta, which benefits from substantial electricity from lower-cost co-generation, the lack of additional low-cost hydropower potential in New Brunswick, Saskatchewan, Nova Scotia, Ontario and Prince Edward Island led to a reliance on thermal generation (fossil fuel and nuclear), resulting in higher production costs.

Figure 2. **Share of Hydropower in Total Installed Capacity (%) vs. Electricity Rates by Province in Canada in 2017 (USD/MWh)**



Source: Statistics Canada,[10] Hydro Québec[22]

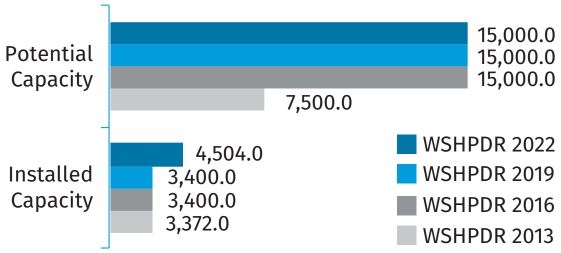
Historically, electricity prices in Canada have changed little with inflation over the past four decades. The only exception is the 1990s when several provinces, including Ontario and British Columbia, froze electricity rates.[23,24] In provinces with utility monopolies, responsibility for regulating electricity rates rests with provincial utility boards. Typically, these boards have a mandate for approving capital expenditures, reviewing financing and amortization costs, determining revenue requirements and establishing fair and reasonable electricity rates for ensuring safe and reliable access to electricity.[25,26] In the two provinces with competitive markets (Ontario and Alberta), residential and commercial customers have the choice of purchasing electricity from regulated retailers or from competitive retailers based on wholesale market prices, while industrial customers purchase directly from the wholesale market.[27,28]

SMALL HYDROPOWER SECTOR OVERVIEW

In Canada, there are several categories of small hydropower (SHP): micro-hydropower (less than 100 kW), mini-hydropower (100 kW – 1 MW) and small hydropower (1 MW – 50 MW).[29] Depending on the particulars of a given site, SHP facilities can be connected to the interconnected transmission system at voltages greater than 60 kV, to an interconnected distribution system at voltages lower than 60 kV or to a remote micro-grid at the appropriate system voltage.

As of 2020, the installed capacity of SHP (up to 50 MW) in Canada was 4,504 MW, excluding facilities under development.[30,31,32,33,34,35,36,37] The technical potential capacity was previously estimated by the Canadian Hydropower Association (now Waterpower Canada) to be 15,000 MW, or approximately 40–60 TWh/year depending on operational capabilities and capacity factors.[38] The underlying methodology for determining this estimate is not known; however, updated estimates are in preparation by Waterpower Canada.

Figure 3. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in Canada (MW)**



Source: BC Hydro,[30] Alberta Electric System Operator,[31] Independent Electricity System Operator,[32] Hydro Québec,[33,34] Newfoundland Power,[35] North American Cooperation on Energy Information,[36] Power Advisory LLC,[37] *WSHPDR 2013*,[39] *WSHPDR 2016*,[40] *WSHPDR 2019*[41]

Note: Data for SHP up to 50 MW.

The over 4,500 MW of SHP capacity (up to 50 MW) accounts for 5.5 per cent of total installed hydropower capacity in Canada. There are currently 447 operational SHP plants (up to 50 MW) in Canada with 317 of these having an installed capacity of not more than 10 MW.[36] This compares with 3,400 MW of SHP capacity (up to 50 MW) reported in the *World Small Hydropower Development Report* (*WSHPDR*) 2019 (Figure 3), which accounted for 4.2 per cent of national installed hydropower capacity. The change in the reported installed SHP capacity (up to 50 MW) primarily reflects access to better data, particularly for plants smaller than 1 MW, as well as reconciliation between utility and government sources, which had previously underreported the capacity of installed SHP. Since the *WSHPDR 2019*, which reported data to the end of 2017, the installed capacity of SHP capacity (up to 50 MW) increased by over 80 MW with the development of eight new plants (Table 1), while another seven plants totalling more than 50 MW are under development (Table 2).

Table 1. **List of Selected Operational Small Hydropower Plants in Canada**

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Plant type*	*Operator*	*Launch year*
Elliot Falls Expansion	Norland, Ontario	0.1		Run-of-river	Elliot Falls Power Corporation	2020
Little Burgess Expansion	Bala, Ontario	0.2		Run-of-river	KRIS Renewable Power Ltd.	2020
North Bala	Bala, Ontario	5.0	6.2	Run-of-river	Swift River LP	2020
Narrows Inlet	Sechelt, British Columbia	33.0	324.0	Run-of-river	tems sayamkwu Limited Partnership	2019
Winchie Creek	Ucluelet, British Columbia	4.0	156.5	Run-of-river	Winchie Creek Hydro Limited Partnership	2019
Yellow Falls	Smooth Rock Falls, Ontario	16.0	12.0	Run-of-river	Yellow Falls Power Limited Partnership	2019
Hunter Creek	Hope, British Columbia	11.0		Run-of-river	Hunter Creek Hydro Limited Partnership	2018
Trio Kwalsa	Mission, British Columbia	13.8		Run-of-river	Harrison Hydro Limited Partnership	2018
Namewaminikan	Beardmore, Ontario	10.0		Run-of-river	Namewaminikan Hydro Inc	2017
Norland Dam	Coboconk, Ontario	0.5		Run-of-river	Timber Run Hydropower Corporation	2017
Norman Expansion	Kenora, Ontario	2.7		Run-of-river	H2O Power LP	2017
Smooth Rock Falls Expansion	Smooth Rock Falls, Ontario	2.2		Run-of-river	Gemini-SRF Power Corporation	2017
Mistassini	ND de Laurette et Girardville, Québec	18.3		Run-of-river	Société en commandite Énergie Hydroélectrique Mistassini	2017
Big Silver	Harrison Hot Springs, British Columbia	40.6		Run-of-river	Big Silver Creek Power Limited Partnership	2016
Lorenzetta Creek	Laidlaw, British Columbia	3.2		Run-of-river	Zella Holdings Ltd.	2016
Silversmith Power & Light	Sandon, British Columbia	1.0		Run-of-river	Silversmith Power & Light Corporation	2016

Name	Location	Capacity (MW)	Head (m)	Plant type	Operator	Launch year
Canton Mill	Port Hope, Ontario	0.1		Run-of-river	Ian W. M. Angus	2016
Gitchi Animki Bezhig	Mobert, Ontario	12.0	14.0	Run-of-river	Pic Mobert Hydro Inc	2016
Gitchi Animki Niizh	Mobert, Ontario	10.0	21.0	Run-of-river	Pic Mobert Hydro Inc	2016
London Street Expansion	Peterborough, Ontario	5.9		Run-of-river	Peterborough Utilities Inc.	2016

Source: BC Hydro,[30] Independent Electricity System Operator,[28] Hydro Québec,[33,34] North American Cooperation on Energy Information,[36]

Table 2. **List of Selected Ongoing/Planned Small Hydropower Projects in Canada**

Name	Location	Capacity (MW)	Plant type	Developer	Planned launch year	Development stage
Manouane Sipi	Manouane	22.0	Run-of-river	Ville de La Tuque / Atikamekw de Wemotaci	2023	Pre-construction
Winston	St-Antoine de Riviere du Loup	2.5	Run-of-river	Winston Hydro	2023	Pre-construction
Chute du Quatre Milles	Forestville	5.5	Run-of-river	Énergie Hydroélectric Pessamit	2022	Construction
Chute du Six Milles	Forestville	13.2	Run-of-river	Énergie Hydroélectric Pessamit	2022	Construction
Little Rapids	Iron Bridge	0.3	Run-of-river	Gravel Power Corp	2022	Construction

Source: Independent Electricity System Operator,[32] Hydro Québec,[33,34]

As the development of large-scale hydropower projects concludes in several provinces, the focus is shifting to evaluating and investing in the refurbishment and expansion of existing hydropower infrastructure. As shown in Table 1, five expansions at existing SHP facilities were recently completed in Ontario. Other refurbishments and expansions are planned in different provinces.

While nearly all Canadians receive electrical service from the interconnected Northern American grid, nearly 200,000 residents in a total of 276 remote communities are serviced primarily by diesel generators (201 communities), micro-grids (26 communities) and remote hydropower generation (35 communities), including 19 SHP plants.[42] The outsized GHG emissions from remote diesel-powered communities represent an opportunity for emissions displacement by renewable forms of electricity generation, including SHP.

Provincial utilities have identified numerous SHP projects for potential development pursuant to resource planning and resource adequacy studies. The potential SHP projects summarized in Table 3 have been studied to various levels of pre-feasibility.

Table 3. **List of Potential Small Hydropower Sites in Canada**

Name	Location	Potential capacity (MW)	Head (m)	Type of site (new/refurbishment)
Tazi Twe	Fond du Lac River, Saskatchewan	50	36	New
Red Indian Falls	Exploits River, Newfoundland and Labrador	42	23	New
Island Pond	North Salmon River, Newfoundland and Labrador	36	25	New
Portland Creek	Main Port Brook, Newfoundland and Labrador	23	395	New
Round Pond	Bay D'Espoir, Newfoundland and Labrador	18	11	New

Source: CEAA,[43] Newfoundland and Labrador Hydro[44]

RENEWABLE ENERGY POLICY

The 2016 Pan-Canadian Framework on Clean Growth and Climate Change was an important step to achieving the country's commitment in the Paris Agreement to reduce GHG emissions by 30 per cent from 2005 levels by 2030.[45] Acknowledging that non-emitting electricity sources are foundational to deep decarbonization, the Framework aimed to increase the proportion of electricity generated from renewable and low-emitting sources, modernize electricity systems and reduce reliance on diesel generation in northern and remote communities.[45] Pursuant to the Framework, Environment and Climate Change Canada amended the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations in December 2018.[46] Of the 36 operating coal units as of 2017, the Regulations were expected to result in the shutdown or conversion to natural gas generation of 26 units by 2030, representing a combined generating capacity of nearly 8,000 MW.[46] Of the remaining units, six are expected to be shuttered by 2045 and the rest by 2065.

In December 2020, the Government of Canada released A Healthy Environment and a Healthy Economy plan, outlining the remaining proposals for achieving the country's commitments in the Paris Agreement. In terms of electricity, this report targets increasing the proportion of non-emitting electricity resources to 90 per cent by 2030 and to net-zero emissions by 2050.[47] Under a scenario in which significant electrification occurs across the economy, achieving this goal will require at least doubling generation from renewable sources of electricity.[47] The proposed gradual escalation of the carbon price from 50 USD/tCO_2e in 2022 to 170 USD/tCO_2e in 2030 will encourage further fuel-switching from emission-intensive heating, transportation and industrial processes towards those powered by lower-emitting electricity generated primarily from renewables.[48]

Provincially, British Columbia has shifted focus to the construction of the 1,100 MW Site C Project, a large-scale hydropower plant.[49] This resulted in discontinuing more than a decade of smaller-scale wind, hydropower and biomass development by independent power producers pursuant to a series of power calls initiated by the provincial utility, BC Hydro.[50,51] Alberta has committed to eliminating coal-fired electricity while adding a minimum of 5,000 MW of wind and solar power capacity by 2030, of which more than 2,000 MW is already approved, under construction or operating.[52,53] Saskatchewan is annually developing on the order of 100 MW of wind power and 20 MW of solar power, as Manitoba Hydro completes construction of the 695 MW Keeyask hydropower plant.[54] As a result, neither province is currently pursuing available SHP potential. Following the shuttering of its last coal facility in 2015, Ontario saw further development of 455 MW of SHP, wind and solar power pursuant to its large renewable procurement process, which concluded in 2016 with some approved SHP projects still under construction.[55] In Québec, several SHP plants are planned or under construction (Table 2), though new SHP procurement is not currently planned.[56] Nova Scotia recently commissioned the Maritime Link, a high-voltage direct current subsea cable from Newfoundland to deliver electricity from the recently completed 824 MW Muskrat Falls Project in Labrador while facilitating an export market for future development of SHP potential in Newfoundland.[57]

With the improving cost competitiveness of onshore wind and utility-scale solar generation across Canada, provincial governments and utilities have stepped back from programmes designed specifically to promote renewable generation. Feed-in tariff (FIT) programmes in Ontario and Nova Scotia have discontinued and dedicated renewable energy procurement programmes in British Columbia, Alberta and Ontario have concluded.[50,52,58,59,60] Due to continuing declines in costs, onshore wind and utility-scale solar generation are increasingly being developed outside of incentive programmes as distributed self-generation or as utility-scale resources competing directly in electricity markets.

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

No province in Canada currently has initiatives aimed specifically at the development of new SHP projects. At the same time, recent SHP development in Canada has included more than a dozen projects (up to 50 MW) of which several remain in planning or construction as shown in Table 3.[61]

Pursuant to the country's climate policy, Natural Resources Canada's recent ongoing investment programmes relevant to SHP include:

- Clean Energy for Rural and Remote Communities Programme: supports a suite of programmes that aim to reduce reliance on diesel fuel in rural and remote communities, including by directly funding expansion and refurbishment of existing SHP plants;
- Energy Innovation Programme: supports clean technology research and development, including clean energy planning in several remote communities proximal to potential future SHP development;
- Northern Responsible Energy Approach for Community Heat and Electricity Programme: funds renewable energy and efficiency projects in the northern territories of Canada, including assessments and feasibility studies of hydropower projects.[62,63,64]

SHP projects do not require environmental assessment at the federal level though federal departments have jurisdiction in relation to fish and fish habitat, species at risk and migratory birds.[65] The licensing process for SHP varies provincially, and typically involves environmental assessment, permitting in relation to facility construction and operations as well as ongoing environmental protection, monitoring and enforcement.

COST OF SMALL HYDROPOWER DEVELOPMENT

Provincial utilities report preliminary cost estimates for potential hydropower development sites within resource planning and resource adequacy studies. Levelized costs of energy for some of the more cost-effective SHP sites up to 50 MW are provided in Table 4, illustrating a cost on the order of 110–140 CAD/MWh (87–111 USD/MWh). These costs compare to typical levelized costs of 30–60 CAD/MWh (24–48 USD/MWh) for onshore wind resources in Canada.[66,67]

Table 4. **Small Hydropower New Facility Levelized Cost of Energy**

Project Name	*Location*	*Potential capacity (MW)*	*Average annual generation (GWh)*	*Site type*	*Capital costs (CAD/MW (USD/MW))*	*Levelized costs (CAD/MWh (USD/MW))*	*Study level*
Badger Chute	Exploits River, Newfoundland and Labrador	24	154	New	–	125 (99)	Screening

Project Name	Location	Potential capacity (MW)	Average annual generation (GWh)	Site type	Capital costs (CAD/MW (USD/MW))	Levelized costs (CAD/MWh (USD/MW))	Study level
ROR_110-120_BQL	North Coast, British Columbia	45	158	New	2.31 (1.83)	128 (101)	Screening
ROR_110-120_NC	North Coast, British Columbia	38	135	New	2.66 (2.11)	128 (101)	Screening
ROR_120-130_MCA	Mica, British Columbia	29	104	New	3.39 (2.68)	137 (108)	Screening
ROR_120_130_EK	East Kootenay, British Columbia	47	147	New	3.76 (2.98)	138 (109)	Screening
ROR_120-130_SE	Selkirk, British Columbia	28	88	New	3.12 (2.47)	139 (110)	Screening
ROR_120-130_VI	Vancouver Island, British Columbia	26	116	New	3.53 (2.80)	139 (110)	Screening
ROR_120-140_NC	North Coast, British Columbia	24	90	New	2.98 (2.36)	139 (110)	Screening

Source: BC Hydro,[67] Newfoundland and Labrador Hydro[46]

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Financing of SHP projects is generally through the private sector, since recent smaller-scale renewable energy projects in Canada are almost exclusively developed by independent power producers. Since subsidies and incentives for the development of renewable sources are increasingly no longer required to ensure competitiveness with conventional generation, particularly for onshore wind and solar power generation, SHP projects in Canada now compete against these other renewable technologies in direct procurement processes or in competitive electricity markets. Generally, this has resulted in less development of greenfield SHP projects, a trend that is anticipated to continue into the foreseeable future. The one exception is remote communities where federal programmes support the development of suitable SHP sites since the potential for other non-emitting alternatives is limited.

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

Existing SHP facilities in Canada have enjoyed relatively consistent climate and hydrological conditions over the past century. In the coming decades, the climate crisis is anticipated to increase annual precipitation by 5–15 per cent depending on location and future climate conditions, while also decreasing winter snowfall in almost all regions of Canada.[6] By the middle of this century, mean temperatures are forecast to increase by 2–3 °C in the southern regions of the country and by 3–5 °C in the northern regions.[6] Runoff is anticipated to increase into many of the country's important hydropower watersheds, with earlier snowmelt, a larger and earlier spring freshet and lower late summer and fall hydrologic flows.[68,69] Climate adaptation actions to date have included hydrology and glaciology impact studies, investigations of potential implications for seasonal and annual hydropower generation, as well as infrastructure risk assessments.[68]

Within Canadian climate policy, the emphasis on low-carbon electrification as a means to decarbonize the economy is anticipated to result in growing electricity demand over at least the next two decades. Provincial utilities that have included the effects of policies addressing low-carbon electrification are forecasting annualized average growth on the order of 0.5–1.0 per cent per year over the next two decades depending on the degree of electrification, rates of economic growth and other factors.[70,71] The effort to decarbonize the grid has been aided by electricity demand, which has remained relatively unchanged in Canada as a whole over the past decade. Annualized average growth was 0.3 per cent from 2007 through 2019, compared to 1.3 per cent per year for the period 1990–2007 and 5 per cent per year in the period 1960–1990.[11] The COVID-19 pandemic has resulted in a material decrease in electricity demand that is not expected to fully recover for at least five years.[72,73] Demand-side management measures are implemented in almost all provinces through combinations of codes, standards, programmes and conservation rates implemented by utilities or independent agencies. Energy savings performance in 2019 varied by province from less than 0.1 per cent to more than 1.2 per cent of annual domestic electricity sales with national savings averaging 0.4 per cent.[74] This compares to more than 2 per cent of annual domestic sales in some USA states and national average savings of 0.7 per cent of electricity sales across the USA, suggesting that Canada has considerable additional electricity conservation and efficiency potential.[75]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

Future new greenfield SHP development remains limited to isolated grid-connected sites that offer storage and provision of dependable capacity and dispatchability and to remote sites where development of competing alternatives is not technically or economically feasible. Refurbishment, including capacity additions and upgrades, of existing sites is likely to prove economic in most instances with only a few facilities being decommissioned.

There are several barriers to additional SHP development in Canada:

- Cost-effectiveness: The most technically and economically feasible SHP sites in Canada have already been developed. The recent and anticipated future declines

in the cost of energy from onshore wind and solar photovoltaics continue to erode SHP cost-competitiveness;
- Discontinued programmes and subsidies: The conclusion of prior FIT programmes, targeted subsidy programmes and targeted power calls at the provincial level result in a policy environment less supportive of SHP development;
- Low load growth: Load growth was already low in Canada in the decade prior to the pandemic. Post-pandemic, load is not anticipated to fully recover for at least five years, further deterring investment in SHP in the short to medium term.

In terms of the potential for refurbishment of existing SHP plants, Nova Scotia Power recently reviewed its entire hydropower fleet consisting of over 30 SHP plants totalling 169 MW of installed capacity.[76] This review and related analyses indicated that while refurbishment of much of the fleet is cost effective, some facilities are no longer considered used and useful and several others require further review to determine cost-effectiveness prior to investment in refurbishment.[73,77] BC Hydro determined in its most recent integrated resource plan that only 75 per cent of existing contracted hydropower plants (many of which are SHP plants) would be re-contracted.[78] This recognizes declines in the costs of competing resources, the high cost of refurbishment at some locations and the lower value of energy generated by non-storage hydropower during the spring freshet when its output is often surplus to requirements.

There are several enablers to additional SHP development in Canada:
- Regulatory support: The regulatory frameworks and licensing processes for SHP are mature across Canadian provinces and generally favourable to additional SHP development, while no environmental assessment required at the federal level;
- Low-carbon electrification: In the medium to long term, increasing electricity demand in support of low-carbon electrification will spur further investment in SHP, particularly in refurbishment and expansions at existing SHP plants;
- Public support: SHP remains one of the lowest-impact means of producing low-carbon electricity and continues to enjoy strong public support in Canada, particularly when sites are developed in consultation and collaboration with local and indigenous communities.

Overall, the competitive position of SHP suggests that, in the absence of future programmes targeting development, significant quantities of new SHP projects are unlikely to be developed. Natural Resource Canada's current programmes supporting the development of SHP to service diesel-dependent remote communities currently represent the primary enabler of SHP development in Canada.

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Greenland

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KEY FACTS

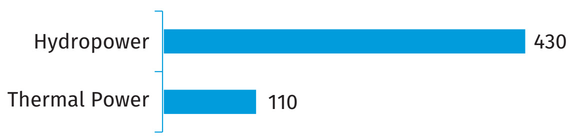
Population	56,421 (2021)[1]
Area	2,166,086 km^2 [1]
Topography	With two thirds of the island lying within the Arctic Circle, a flat, gradually sloping ice cap covers all but a narrow, mountainous, barren, rocky coast. The ice cap is up to 3 kilometres thick and contains 10 per cent of the world's resources of fresh water. Mountain chains run along the eastern and western coasts, with the highest peak, Gunnbjørn Mountain in the south-east, reaching 3,700 metres above sea level.[1,2]
Climate	The climate is Arctic to sub-Arctic, with a subtle influence of the Gulf Stream in the south-west. Winters are cold with average temperatures ranging from -7 °C in the south to -34 °C in the north. Summers are cool with mean temperatures normally not exceeding 10 °C.[2]
Climate Change	Temperature measurements carried out in south-west of Greenland since 1784, show an increasing trend, with the five warmest decades all having occurred in the last 100 years.[3] Between 1991 and 2019, an overall temperature increase of 4.4 °C was recorded in winter, of 2.7 °C in spring and of 1.7 °C in summer. The most significant warming trend has been observed in the west and north-west of the country, with up to 6–6.5 °C higher temperatures in winter. By the end of the century, temperatures are projected to increase by 5–7 °C.4 High-emission scenarios suggest that the melting of the Greenland ice sheet can contribute 9.9–17.8 centimetres to the global sea level rise. Rainfall is also projected to increase significantly.[5]
Rain Pattern	Much of the precipitation comes in the form of snow. Average annual precipitation ranges from 50 mm in the north to 1,900 mm in the south. Large areas of Greenland can be classified as Arctic deserts due to limited precipitation.[2]
Hydrology	Many of the hydropower potentials in Greenland depend on ablation from the ice cap. There are no large rivers in the country, the most significant one being the Børglum Elv in the north-east of the island.

ELECTRICITY SECTOR OVERVIEW

All towns and settlements in Greenland are running on isolated grids. The only exception are the towns of Qaqortoq and Narsaq in the south, which are both connected to the Qorlortorsuaq hydropower plant. Hydropower plants also power four other towns, but all other locations depend on electricity from diesel power plants. The state-owned utility company, Nukissiorfiit, is responsible for production and distribution of energy and water to all 17 towns and 53 settlements. In the south of Greenland, there are approximately 40 farms, not supplied by Nukissiorfiit. The farms are very isolated and therefore need their own energy supply. Most of them use diesel generators, but more are starting to use renewable energy, such as micro-scale hydropower and solar power.

Total installed capacity is approximately 230 MW.[6] Out of this, hydropower plants account for 91.3 MW. Additionally, in 2021, there was approximately 590 kW of solar power capacity and 50 kW of wind power capacity.[7] Total electricity generation in 2020 was approximately 540 GWh, of which hydropower accounted for almost 80 per cent, with the rest coming from diesel combustion (Figure 1).[8]

Figure 1. **Annual Electricity Generation by Source in Greenland in 2020 (GWh)**



Source: Statistics Greenland[8]

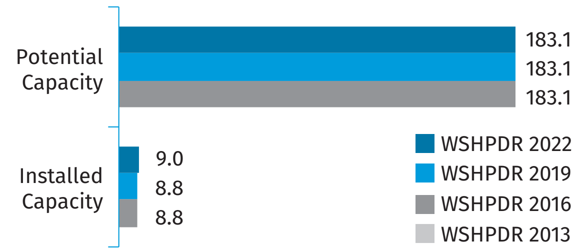
Greenland has universal electricity access.[9] The Government regulates the electricity tariffs. In 2018, the price structure was reformed and all private customers now pay the same price of 1.65 DKK/kWh (0.23 USD/kWh).[7] The fishing industry is subsidized with a discounted tariff, set at 41.5 per cent of the local production cost, but never higher than what the customers pay.

SMALL HYDROPOWER SECTOR OVERVIEW

Nukissiorfiit defines all hydropower plants above 5 MW as regular hydropower, whereas plants below 500 kW are defined as micro-hydropower and plants of 500 kW–5 MW capacity are defined as mini-hydopower.[7] Nationally, a distinction is often made between large hydropower for industrial use (above 100 MW), hydropower for supplying towns (1–50 MW) and settlements (below 1 MW) and micro-hydropower plants at off-grid farms (below 100 kW). This chapter will follow the 10 MW definition of small hydropower (SHP) for the purposes of comparison with the pervious editions of the *World Small Hydropower Development Report (WSHPDR).*

Following the 10 MW definition, there are two SHP plants (Table 1). In addition, there are at least seven active micro-hydropower plants with an estimated combined capacity of approximately 200 kW at off-grid farms in southern Greenland. Thus, total SHP installed capacity is approximately 9 MW, whereas the potential has been estimated at 183.1 MW.[6,10] Compared to the *WSHPDR 2019,* the installed capacity increased due to the inclusion of the micro-hydropower capacities, whereas the potential has remained unchanged (Figure 2).

Figure 2. **Small Hydropower Capacities in the WSHPDR 2016/2019/2022 in Greenland (MW)**



Source: Dall & Primdal,[6] *WSHPDR 2016,*[10] *WSHPDR 2019*[11]

Table 1. **List of Selected Existing Small Hydropower Plants in Greenland**

Name	*Location*	*Capacity (MW)*	*Head (m)*	*Operator*	*Launch year*
Qorlortorsuaq	Southern Greenland	7.6	128	Nukissiorfiit	2008
Tasiilaq	Eastern Greenland	1.2	100	Nukissiorfiit	2004

Source: Dall & Primdal[6]

Hydropower plants in Greenland operate on different grids and are sized according to the local needs. Therefore, even the smallest plants play an important role in the energy supply of local towns. In 2019, the Qorlortorsuaq and Tasiilaq SHP plants generated a total of approximately 33 GWh.[6] In addition to these two plants, there is one additional plant operating at less than 10 MW capacity. The hydropower plant in Sisimiut is equipped with two 7.5 MW turbines. One turbine is however enough to handle the peak load and there is a limited water resource. Therefore, the production very rarely exceeds 10 MW. In 2019, the Sisimiut plant generated 41 GWh.[6]

With the ice cap covering over 80 per cent of the total land area, Greenland has a large theoretical hydropower potential. The annual runoff is estimated to have an energy production potential in the order of 460–800 TWh. However, only a fraction of this energy is technically viable and even less is economically feasible.[12] Serious interest in developing the hydropower resources in Greenland started in the early 1970s. The initial mappings used topography maps to identify the biggest potentials. Later in the 1970s the first measurement stations were established. This effort intensified in the 1980s, with many field trips and detailed surveys carried out. At the same time, many of the most promising potentials had concepts drawn up. All of the sites identified and described are listed in an inventory from 2005.[13]

Greenland aims to expand hydropower capacity to reduce the use of fossil fuels for electricity generation. This includes larger-scale projects (55 MW expansion of the 45 MW Buksefjorden hydropower plant and construction of a new 21 MW plant at the fjord Kangersuneq approved in 2021), but also micro-hydropower projects.[14] Nukissiorfiit is looking to expand its renewable energy fleet with micro-hydropower projects and for this purpose has studied the existing micro-hydropower potentials. Kulusuk and Narsarmijit were identified as the villages with the best potential. The plant at Kulusuk is to be commissioned in 2023 and will supply the airport.[15]

RENEWABLE ENERGY POLICY

Naalakkersuisut, the Government of Greenland, has set the direction for the country's energy sector and Nukissiorfiit. The goal is to transition to renewable energy and that by 2030 the public energy supply must be, to the fullest extent possible, derived from renewable energy sources.[16]

Naalakkersuisut has also released a new strategy for the development of agriculture in Greenland in 2020, with a focus on increasing the use of hydropower by the farmers. Through better substitution opportunities for farmers, the Government will increase the incentive to invest in hydropower.

A number of private consumers and companies in the country have solar photovoltaics installed. In towns and settlements not already supplied with renewable energy from hydropower, excess electricity can be sold to Nukissiorfiit at a rate of 0.74 DKK/kWh (0.10 USD/kWh).[17]

All sizeable projects in Greenland are subject to an Environmental Impact Assessment (EIA). The Government organizes public hearings and has to approve the EIA before construction can start.

COST OF SMALL HYDROPOWER DEVELOPMENT

The construction costs of SHP projects vary widely from site to site. Since there is no centralized grid, the local energy consumption and the distance from the site to the town become very important parameters.

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

All hydropower projects in the country have so far been funded by loans from the Government.

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

With increasing ablation from the ice cap, the available water resources also increase. However, this mainly affects the large hydropower potential with catchments bordering the ice. The SHP potential is often concentrated closer to the towns in coastal areas and mainly depends on precipitation and melt-off from local glaciers. However, there have been observed some changes, with local glaciers disappearing and rain patterns shifting. This leads to increased runoff in some areas, while others are becoming drier, but this varies from site to site and is less conclusive.

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

So far, only a few SHP projects have been developed in Greenland, with some of the reasons listed below:

- Even the bigger towns and settlements in Greenland are small communities with only a few hundred to a couple of thousand people. Hence, the energy demand in any single place is limited;
- Long distances make it cost prohibitive to connect multiple settlements together;
- Difficult terrain and limited infrastructure lead to high construction costs.

The key enabling factors for SHP development in the country include:

- Large hydropower potential;
- Policy support for reducing fossil fuel use in favour of renewable energy with a particular focus on hydropower;
- Great support for hydropower in the local communities.

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United States of America

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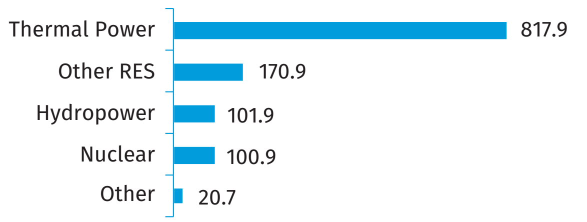
KEY FACTS

Population	332,457,501 (2022)1
Area	9,833,517 km2 2
Topography	The topography of the USA is varied. The eastern parts of the country consist of hills and low mountains, while the central interior is dominated by the Great Plains region. By contrast, the western parts of the country include high, rugged mountain ranges, with some volcanic activity in the Pacific north-west. The landscape of Alaska features rugged mountains as well as river valleys, while the landscape of Hawaii is dominated by volcanic topography. The highest point in the country is Mount Denali in Alaska, at 6,190 metres above sea level, while the lowest point is in Death Valley, California, at 86 metres below sea level.3
Climate	The climate of the USA varies widely: arctic in Alaska, tropical in Hawaii, Mediterranean in California, arid in the south-west and temperate across much of the country.4 State-wide averages of annual temperatures range from a high of 21.5 °C in Florida to a low of -3.0 °C in Alaska. For the entire USA, excluding Hawaii and Alaska, the annual temperatures averages 11.5 °C.5
Climate Change	Annual average temperature over the continental USA has increased by 1.0 °C between 1901 and 2016. Between 2021 and 2050, annual average temperatures are expected to increase by approximately 1.4 °C relative to the 1976–2005 baseline period. Sea level rise in some parts of the USA, especially on the East and Gulf coasts, is projected to be higher than the global average. Annual trends towards earlier spring snowmelt and reduced snowpack are already affecting water resources in the western part of the country, with adverse impacts on fisheries and hydropower, and are expected to continue.6
Rain Pattern	Precipitation averages in the USA vary according to location. State-wide averages of annual precipitation range between 1,618 mm in Hawaii and 241 mm in Nevada. The annual precipitation average nationwide is 767 mm. 4,7
Hydrology	The USA has approximately 250,000 rivers and canals, stretching for millions of kilometres. The two most important rivers in the USA are the Missouri River and Mississippi River. The Missouri River is the longest at 4,088 kilometres, while the Mississippi River is the largest in terms of water volume. The Mississippi flows through 10 states, originating in the Great Lakes and emptying into the Gulf of Mexico. Most rivers in the USA have had their flows adjusted or have been dammed. The longest completely natural, undammed river in the country is the Yellowstone River at 1,114 kilometres.8

ELECTRICITY SECTOR OVERVIEW

At the end of 2020, the total installed electricity capacity in the USA was 1,212.3 GW. Thermal power, including natural gas, coal and petroleum, provided 817.9 GW (67 per cent) of the total capacity, renewable energy sources (RES) other than hydropower provided 170.9 GW (14 per cent), hydropower provided 101.9 GW (8 per cent), nuclear power provided 100.9 GW (8 per cent) and other sources provided 20.7 GW (2 per cent) (Figure 1).[9]

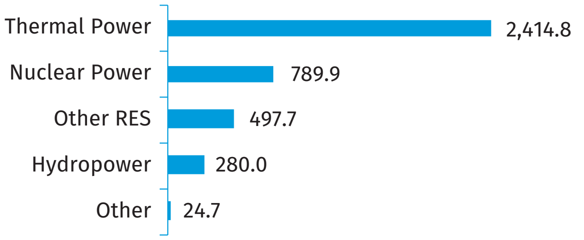
Figure 1. **Installed Electricity Capacity by Source in the United States of America in 2020 (GW)**



Source: EIA[9]

In 2020, annual utility-scale electricity generation was approximately 4,007.1 TWh. Thermal power provided 2,414.8 TWh (60 per cent) of total generation, nuclear power provided 789.9 TWh (20 per cent), RES other than hydropower provided 497.7 TWh (12 per cent), hydropower provided 280.0 TWh (7 per cent), and other sources provided 24.7 TWh (1 per cent) (Figure 2).[10]

Figure 2. **Annual Electricity Generation by Source in the United States of America in 2020 (TWh)**



Source: EIA[10]

Coal has been the largest single source of electricity supply in the USA for many years, being only recently overtaken by natural gas. Wind and solar power have also experienced significant growth, while the share of hydropower in total electricity generation has been relatively stable.[4] Total electricity consumption is forecast to increase by 0.6 per cent in 2022 and 1.4 per cent in 2023.[11] The electrification rate in the country is 100 per cent.[12]

The USA power grid connects approximately 4 million kilometres of feeder lines and over 725,000 kilometres of high-voltage transmission lines.[13] Historically, the electricity industry of the USA has comprised a mix of private and public utilities that generate and deliver electricity to customers within exclusive franchise service territories. Currently, more than 3,300 electric utilities operate across the country, with approximately 200 of them providing power to the majority of users. In the 1990s, some states and regions established competitive markets for both electricity generation and delivery. This process is often referred to as electric industry restructuring or deregulation and has resulted in new entrants to all segments of the electricity industry, including generation, transmission and delivery.[4]

Due to the historically exclusive nature of utility service territories, the electric industry has been subject to a high degree of regulation by federal, state, and local authorities. Investor-owned utilities are regulated by the states in which they operate. Municipal utilities are operated by local governments and are overseen by local elected or appointed officials. Electric cooperatives are governed by a board of directors elected from the cooperative's membership.[4]

In addition, the Federal Energy Regulatory Commission (FERC), an independent agency of the USA Government, regulates the interstate transmission of electricity. Independent System Operators (ISOs) administer the transmission grid on a regional basis, including some portions of Canada. These entities were established to provide non-discriminatory access to transmission for both electricity generators and distribution companies in competitive markets. The ISOs also perform centralized day-ahead dispatch of the generation resources in their service area to produce a least-cost production schedule for each hour of the next day, resolve gaps between generation and demand in real time and operate ancillary service markets. The USA wholesale electricity markets are displayed in Figure 3.[4]

Figure 3. **Wholesale Electric Power Markets in the United States of America**

Source: FERC[14]

Electricity tariffs in the USA are the product of a utility's generation, transmission, distribution and administrative costs as well as the return on investment in the case of investor-owned utilities. Wholesale electricity prices throughout the country trended higher throughout 2021, reflecting the increasing cost of natural gas for power generation. In Q3 2021, average electricity prices were 0.140 USD/kWh for residential consumers, 0.116 USD/kWh for commercial consumers and 0.076 USD/kWh for industrial consumers.[15]

The electricity sector faced additional challenges in 2021 due to the disruptions caused by the COVID-19 pandemic. As the economy of the USA began to emerge from its pandemic-induced recession, electricity sales rose 4 per cent through August 2021 over the previous year.[16,17]

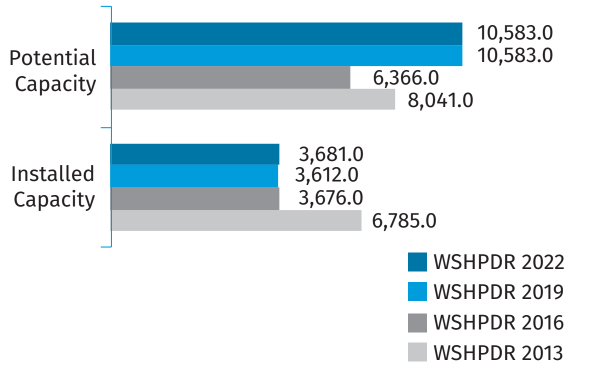
SMALL HYDROPOWER SECTOR OVERVIEW

There is no widely agreed-upon definition of small hydropower (SHP) in the USA. For the purpose of this chapter the up to 10 MW definition of SHP will be used.

In 2021, the total installed SHP capacity of the USA was 3,681 MW.[18] Total potential capacity was estimated at 10,583 MW, indicating that approximately 34 per cent of the total technical potential has been developed.[19,20,21,22,23,24] Relative to the *World Small Hydropower Development Report* (*WSHPDR*) *2019*, installed capacity increased by approximately 2 per cent, while potential capacity remained unchanged (Figure 4).

As of 2021, the existing SHP fleet of the USA consisted of 1,679 plants. The North-East and the South-West power market zones host the largest regional concentrations of SHP plants (544 and 460, respectively). During 2007–2021, the SHP fleet generated an average of 13,804 GWh per year, approximately 5 per cent of the total hydropower generation in the country.[18] A list of some recently launched SHP plants in the USA is displayed in Table 1.

Figure 4. **Small Hydropower Capacities in the WSHPDR 2013/2016/2019/2022 in the United States of America (MW)**



Source: *WSHPDR 2019*,[4] Johnson et al.,[18] Uria-Martinez et al.,[19] Kao,[20] Hadjerioua et al.,[21] Bureau of Reclamation,[22] Pulskamp,[23] Kao & Johnson,[24] *WSHPDR 2016*,[25] *WSHPDR 2013*[26]

Table 1. **List of Selected Existing Small Hydropower Plants in the United States of America**

Name	*Location*	*Capacity (MW)*	*Plant type*	*Operator*	*Launch year*
Reynolds Creek	Hydaburg	5.000	Reservoir	Haida Energy, Inc	2021
Campbellas Ferry Micro-Hydro Unit Project	Idaho	0.001	Run-of-river	Campbellas Ferry Ranch, LLC	2020
Crocker	Worcester	0.145	Run-of-river	Whitman River Dam, Inc.	2020
Gordon Faber Hydroelectric Project	Washington	0.161	Run-of-river	City of Hillsboro, Oregon	2020
Wallowa Lake County Service District Hydro Station Project	Wallowa	0.020	Run-of-river	Wallowa Resources Community Solutions Inc.	2020
Pioneer Valley Hydro Site Project	Gunnison	0.006	Run-of-river	Pioneer Valley, LLC	2020
C.C. Cragin Raw Water Supply Line	Gila	0.200	Run-of-river	Town Of Payson	2019
Roemer Water Filtration Facility Hydroelectric Project	San Bernardino	0.484	Run-of-river	West Valley Water District	2019
FMC 33B Micro-hydro Project	Delta	0.005	Run-of-river	Joseph W. Yeamans	2019
Deep Creek Hydroelectric Project	San Bernardino	0.800	Run-of-river	Mojave Water Agency	2019
B24 Hydroelectric Station Project	Los Angeles	0.150	Run-of-river	San Gabriel Valley Water Company	2019
Pueblo Dam	Pueblo	7.010	N/A	Colorado Springs Utilities	2019
Timothy Lake Powerhouse	Clackamas	1.200	Run-of-river	Portland General Electric Co	2018
Calligan Creek	Kings	6.000	Run-of-river	PUD No. 1 of Snohomish County	2018
Hancock Creek	Kings	6.000	Run-of-river	PUD No. 1 of Snohomish County	2018

Source: Johnson et al.[18]

As of 2021, the USA hydropower project pipeline contained 198 projects with a combined capacity of 1,039 MW. Of these, 168 were SHP projects with a total combined capacity of 299 MW. Potential hydropower projects in the USA are classified into three categories: non-powered dams (NPDs), new stream-reach development (NSD) and conduits. The majority of planned SHP projects in the project pipeline are NPDs or projects on water conduits, with only seven projects planned for development on new stream reaches. The median capacities of planned small NPD and NSD projects are 4.8 MW and 5 MW, respectively, while the median capacity of planned conduit projects is significantly smaller (0.17 MW).[27] The south-west is the leading region by the number of planned projects but ranks last in terms of proposed capacity, as most planned SHP projects in the region are of the conduit type. Several ongoing and planned SHP projects in various parts of the country are displayed in Table 2.

Table 2. **List of Selected Planned Small Hydropower Projects in the United States of America**

Name	*Location*	*Capacity (MW)*	*Developer*	*Development stage*	*Planned launch year*
Nuyakuk River Hydro Project	Nuyakuk Falls, AK	10.00	Nushagak Cooperative	Preliminary permit	2028
Brownville Hydroelectric Project	Jefferson County, New York	9.00	Paddy Hill Holdings	Preliminary permit	2028
Greybull Valley Hydroelectric Project	Greybull, WY	4.50	Greybull Valley Irrigation District	Under construction	N/A
Loma Rica Hydroelectric Station	Nevada, CA	1.44	Nevada Irrigation District	Issued licence	N/A

Name	*Location*	*Capacity (MW)*	*Developer*	*Development stage*	*Planned launch year*
Wallowa Lake County Service District Hydro Station Project	Eugene, OR	0.30	Eugene Water & Electric Board	Under construction	N/A

Source: Johnson et al.[18]

Private sector development accounts for 60 per cent of proposed projects and 72 per cent of the planned capacity in the project pipeline. Most private developers are not utilities and would therefore have to negotiate a power purchase agreement (PPA) with the local utility, transfer ownership of the project to a utility, or join an independent system operator/regional transmission organization (ISO/RTO) in order to market their electricity. Any of those options add complexity to the project development cycle relative to projects implemented by utilities themselves. Investor-owned power utilities typically undertake capacity additions at existing facilities, but as of 2021 were not pursuing any new hydropower projects. Local public developers such as cooperatives, publicly-owned utilities and political subdivisions (e.g., municipalities, irrigation and water districts) pursue some hydropower development. Political subdivisions are the most active public hydropower developers in the USA, focusing primarily on adding hydropower units to conduit infrastructure they own or operate.[27]

Projects in the pending permit and issued permit stages are those undergoing feasibility evaluations. Attrition rates are high at these early stages of the development process. A project with a pending application has submitted an application for a federal permit. Projects with issued authorizations have already received their federal authorization and are more likely to proceed to construction. However, additional steps required at the issued authorization stage and prior to starting construction include obtaining additional permits at the state or local level, finalizing engineering designs, negotiating PPAs and finalizing project financing. These additional steps often pose challenges for small project developers, resulting in delays and cancellations of projects.[4]

A national assessment of the SHP capacity and generation potential realized of NPDs identified 397 dams with technical potential capacities in the 1–10 MW range. The total estimated technical potential capacity for NPDs under 10 MW is approximately 2,500 MW. Their combined annual generation potential is 4,777 GWh.[19]

A national assessment of potential NSD sites published in 2014 identified a potential technical capacity of 4,321 MW across 1,035 sites under 10 MW. The annual generation potential of these sites was estimated at 23,374 GWh.[20] Several potential NSD sites are listed in Table 3.

Table 3. **List of Selected Potential Small Hydropower Sites in the United States of America**

Name	*Location*	*Potential capacity (MW)*	*Potential annual generation (GWh)*	*Type of site*
South Fork Nooksack River	Whatcom County, WA	9.4	60.8	New
Upper Nehalem River	Portland, OR	8.0	35.3	New
Mohawk River	Albany, NY	5.8	36.4	New
Middle Fork Nooksack River	Whatcom, WA	3.3	21.4	New
East Fork Lewis River	Skamania County, WA	1.5	8.4	New

Source: Johnson et al.[18]

No nationwide resource assessment of conduit hydropower has been carried out as of 2021, although some state and federal agencies have started to compile relevant data. A 2012 study by the Bureau of Reclamation examined the energy development potential at facilities owned by the Bureau.[22] The study and a related supplement found that 191 canals had hydropower potential and that 70 of those sites could be considered economically viable for development, estimating total potential capacity at 104 MW and total potential annual generation at 365 GWh.[23]

In 2018, Oak Ridge National Laboratory developed a methodology for the analysis of the untapped hydropower potential of public water systems. A total of approximately 12 MW of potential conduit hydropower capacity was found in Oregon and 34 MW in Colorado. Corresponding annual generation was estimated at 65 GWh/year in Oregon and 202 GWh/year in Colorado.[24]

RENEWABLE ENERGY POLICY

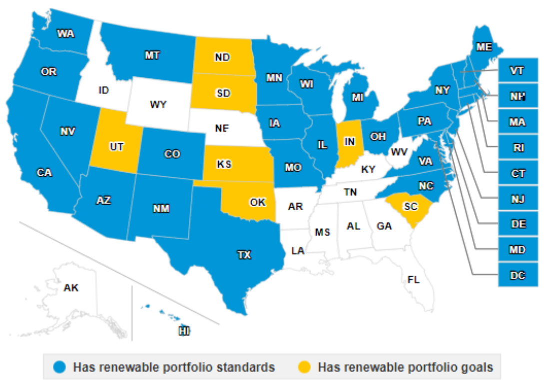
The Public Utilities Regulatory Policy Act (PURPA) of 1978 introduced competition into the USA electric power industry, particularly in the generation sector. PURPA conferred special rates and regulatory treatment on a new class of generators known as qualifying facilities (QFs). These consist of co-generation facilities and small power production facilities, with the latter defined as facilities generating 80 MW or less using a renewable energy source (i.e., hydropower, wind power, solar power, biomass, waste or geothermal power). PURPA required electric utilities to interconnect with and purchase power from QFs at the utility's "avoided cost," defined as the cost that the utility would otherwise incur in either generating the power itself or procuring power from other sources.[4,28]

With the Energy Policy Act of 2005, Congress made an important modification to PURPA, lessening PURPA's mandatory purchase obligation if FERC determines that QFs have non-discriminatory access to the market. In this context, FERC determined that an ISO generally provides a sufficiently competitive market structure to support elimination of the PURPA purchase requirement for utilities operating within the ISO. At the same time, however, FERC established that small QFs do not have non-discriminatory access to wholesale markets. Therefore, the PURPA purchase obligation for utilities remains in force for small QFs, making it possible for SHP generators to secure utility PPAs. In May 2018, FERC announced that it would launch a review of PURPA to examine issues involved in its implementation and ways to address them.[4,28] In July 2020, FERC updated PURPA regulations with Order 872, which could lead to reductions in the number of hydropower projects eligible to receive avoided cost rates and increase energy price risk for developers and owners of hydropower facilities under new PURPA contracts.[27]

The federal Government also provides tax incentives to spur RES development. Tax credits for the production of and investment in hydropower expired at the end of 2016, but were available for other RES facilities which had commenced construction prior to 31 December 2021. SHP has also been eligible for federal accelerated depreciation tax treatment and some states offer tax incentives and exemptions.[4]

Individual states in the USA have adopted policies to encourage RES development. The most prominent of these policies has been the adoption of a renewable portfolio standard (RPS). An RPS is a market-based policy that requires electric utilities and other retail electricity suppliers to supply a minimum percentage of their electricity sales from eligible RES. As of September 2020, 38 states and the District of Columbia had established an RPS or renewable portfolio goal, with 12 states and the District of Colombia setting a 100 per cent clean electricity target by 2050 or earlier (Figure 5).[29,30,31] RPS-related policy revisions adopted in recent years have additionally included increased RPS targets in many states.

Figure 5. **Renewable Portfolio Standards Status in the United States of America as of September 2020**



Source: DSIRE[30]

Common hydropower restrictions for RPS eligibility include those based on capacity, type and environmental sustainability criteria and often limit RPS eligibility to SHP only. One environmental standard is the Low Impact Hydropower Institute certification standard, used for RPS eligibility in a variety of states.[32] At the same time, many RPS policies have vintage requirements for new development, which can disqualify hydropower production from RPS eligibility.[4]

Feed-in tariffs (FITs) have been adopted by some states and utilities to incentivize electricity procurement from smaller renewable energy generators. An SHP system installed adjacent to a local electricity load can typically take advantage of net energy metering (NEM). Most states in the USA have some form of NEM requirement, providing a potent economic incentive for distributed renewable energy generation, including SHP.[4,31]

Renewable energy development in the USA is poised to accelerate in 2022 due to increasing concerns regarding climate change and widespread support for environmental, sustainability and governance (ESG) considerations. Measures adopted by the Biden administration to fully decarbonize the economy of the country, including the 2021 Infrastructure Investment and Jobs Act (IIJA), are helping spur activity in the renewable sector that will likely drive further growth.[33].

SMALL HYDROPOWER LEGISLATION AND REGULATIONS

Developers of SHP projects need to follow different approval processes depending on ownership, project type and other project attributes. Most projects require a FERC licence or an exemption from licensing. Although the exemption process is typically shorter than the licensing process, both processes usually require multiple years to complete. Seeking authorization for development of hydropower at U.S. Army Corps of Engineers (USACE)-owned dams involves obtaining a Section 408 approval from USACE in addition to a FERC licence. The two processes are usually implemented sequentially, with most of the work needed to obtain a USACE approval taking place after a FERC licence is issued. Securing federal authorization for development of hydropower at Bureau of Reclamation-owned dams does not typically involve FERC, but rather a Lease of Power Privilege process.[4,34]

The Hydropower Regulatory Efficiency Act of 2013 introduced a quicker, easier pathway to regulatory approval for the subset of projects involving the addition of hydropower to non-federal conduits (typically, existing pipelines and canals) with capacities of less than 5 MW. In the case of such projects, the developer must notify FERC of the intention to construct a hydropower facility. The project will typically complete the federal approval process and receive the “qualifying conduit” status within 60 days unless FERC or the public contest the project’s ability to meet the eligibility criteria.[4]

In October of 2018, Congress passed the America’s Water Infrastructure Act, which included provisions to help streamline federal regulatory approval processes for hydropower.

The bill shortens the FERC process for qualifying conduit determination required by the 2013 Hydropower Regulatory Efficiency Act from 60 to 45 days, reducing the length of the entire licensing process to 2 years from application to final decision, and replaces the 5 MW cap on qualifying conduit hydropower with a 40 MW cap. The bill also requires FERC to establish an expedited licensing process for NPD projects that will shorten the FERC decision timeframe for licence applications to two years or less. The bill also requires FERC, USACE and the U.S. Department of the Interior to develop a list of existing federal NPDs that have the greatest potential for hydropower development.[4]

COST OF SMALL HYDROPOWER DEVELOPMENT

The cost of SHP development in the USA has been examined in a 2015 report, which arrived at an average cost of 4,236 USD/kW for NPDs, 4,774 USD/kW for facilities built in canals or conduits and 5,320 USD/kW for NSD projects. Capacity-weighted averages are very close to the raw means for NPDs (4,515 USD/kW) and NSDs (5,558 USD/kW) but significantly lower for canal and conduit projects (3,213 USD/kW). This divergence indicates that canal and conduit projects display stronger economies of scale than the other project types.[27,35]

Ninety-one percent of hydropower plants built since 1980 and 97 per cent of those built since 2005 have had capacities below the 10 MW threshold. The small average size of new projects in the USA helps explain the higher average capital cost per kilowatt relative to global averages.[27,36]

FINANCIAL MECHANISMS FOR SMALL HYDROPOWER PROJECTS

Financial instruments used for hydropower project finance in the USA typically come from equity finance (public or private), debt finance, commercial lending and grants.[37]

The Office of Energy Efficiency and Renewable Energy's Water Power Technologies Office (WPTO) offers annual funding under the Hydroelectric Production Incentive Programme under Section 242 of the Energy Policy Act of 2005. A total of USD 7 million was to be available in 2022 for qualifying facilities. The programme provides funding for new hydropower projects on existing dams and other water infrastructure. The maximum payment per facility has been increased to USD 1 million per year, from the 750,000 USD/year limit in the previous round. Additionally, recent legislation amended the length of the eligibility window for applicants, with hydropower facilities placed in operation between 1 October 2005 and 30 September 2027 now being eligible for consideration of incentive payments. Applicants may receive up to 0.018 USD/kWh for hydropower generated during the calendar year 2020 incentive period, with a maximum of USD 1 million depending on the total kWh of eligible power generation.[38]

Some states have created programmes and policies specifically targeting SHP development. For example, in California some types of SHP projects are eligible for incentive funding through the state's Self-Generation Incentive Programme. Colorado provides USD 15,000 feasibility grants for eligible entities, as well as low-interest (2 per cent), 30-year loans that can fund project construction. Oregon provides financial assistance to SHP developers through the Energy Trust of Oregon.[4,39]

EFFECTS OF CLIMATE CRISIS ON SMALL HYDROPOWER DEVELOPMENT

The most important climate change impacts on hydropower generation in the USA are likely to be early snowmelt and change of runoff seasonality, and reservoir storage will gain increasing importance as a buffer against runoff variability. Climate change models predict an overall increase in runoff (up to 26 per cent) and in hydropower generation (up to 20 per cent) during 2031-2050, relative to the 1966-2005 baseline period. For regions with smaller storage capacities, variability of future hydropower generation will more closely follow anticipated changes in runoff. While current reservoir capacities are considered sufficient to absorb at least a part of the runoff, the issue of ageing infrastructure, competition for water use, and environmental services are likely to put additional pressure on the ability of the existing reservoirs to provide sufficient storage for stable hydropower generation on an annual basis.[40,41]

BARRIERS AND ENABLERS FOR SMALL HYDROPOWER DEVELOPMENT

The barriers to the development of SHP in the USA include the following:

- Regulatory approval challenges due to uncertain federal regulatory processes that have made it difficult for public- and private-sector investors to obtain long-term, low-cost financing to support project development;
- Competition from other sources of power generation and lack of adequate compensation for ancillary services;
- High operation and management costs for SHP plants;
- Lack of comprehensive information regarding potential SHP sites on conduits such as water supply pipelines, which represent perhaps the most economically-feasible type of new hydropower;
- Risk aversion regarding new technology on the part of dam and conduit owners as well as technical inspectors and a lack of understanding of SHP technologies in particular, in part due to a lack of extensive operational track records;
- Lack of standardized technology, as almost every hydropower project is custom-engineered and site-specific;
- Uncertainty in the cost, timing and technical require-

ments of grid interconnection;
- State and local regulatory policies, including regulatory issues associated with water quality certifications and other state and local environmental requirements.

Factors enabling SHP development in the country include:
- Recent advancement in standardized powertrain components, biologically-based equipment design and evaluation, additive manufacturing, modular civil structure design and alternative closed-loop pumped storage hydropower (PSH) systems can reduce the cost of SHP equipment, as well as improve performance and environmental stewardship;
- Increased attention to frameworks for assessing climate change impacts will improve the ability of hydropower projects to operate under resultant increases in water resource variability;
- Access to low-cost capital due to historical low interest rates is likely to encourage financing of SHP projects;
- An expedited licensing process introduced by the America's Water Infrastructure Act of 2018 will reduce uncertainties and risks related to project financing and implementation.

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