

**FEDERAL COURT**

BETWEEN:

CECILIA LA ROSE, SIERRA RAINE ROBINSON, SOPHIA  
SIDAROUS, MONTAY JESSE BEAUBIEN-DAY, by his guardian  
ad litem Sarah Dawn Beaubien, SADIE AVA VIPOND, HAANA  
EDENSHAW, ZOE GRAMES-WEBB, by her guardian ad litem  
Annabel Webb, LAUREN WRIGHT, SÁJ MILAN GRAY  
STARCEVICH, by her guardian ad litem Shawna Lynn Gray,  
MIKAEEL MAHMOOD, by his guardian ad litem Asiya Atcha,  
ALBERT JÉRÔME LALONDE, MADELINE LAURENDEAU,  
KIRA YOUNG by her guardian ad litem Sarah Cook, MADELEINE  
ROSE MEAD, by his guardian ad litem Katrina Mead, and  
LEANDREA TAYLOR REEVES

PLAINTIFFS

- and -

HIS MAJESTY THE KING IN RIGHT OF CANADA and THE  
ATTORNEY GENERAL OF CANADA

DEFENDANTS

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**EXPERT REPORT OF DR. MARK Z. JACOBSON**

**April 1, 2026**

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**Dr. Mark Z. Jacobson**

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## **Expert Report by Prof. Mark Z. Jacobson, Stanford University**

1. I, Mark Z. Jacobson, Ph.D., am a Professor of Civil and Environmental Engineering at Stanford University. I have been asked to prepare an expert report in the case *La Rose v. His Majesty the King in Right of Canada* (Court File No. T-1750-19). I am offering my expert opinions in my personal capacity, and I have personal knowledge of the facts stated herein.
2. I understand my duty under Rule 52.2 of the *Federal Court Rules* is to assist the court and not to assume the role of advocate for any party, and I certify that this report is made in conformity with that duty, and that if called upon to give testimony, I will do so in conformity with that duty. I have no prior relationship with any of the plaintiffs that might affect my duty to the court. Attached as **Exhibit A** is my signed Certificate Concerning Code of Conduct for Expert Witnesses.
3. I am submitting this Expert Report to answer the following questions, which are also listed in the attached retainer letter (**Exhibit B**).

**“In the context of energy infrastructure for a country, what constitutes a 100% clean and renewable energy system?”**

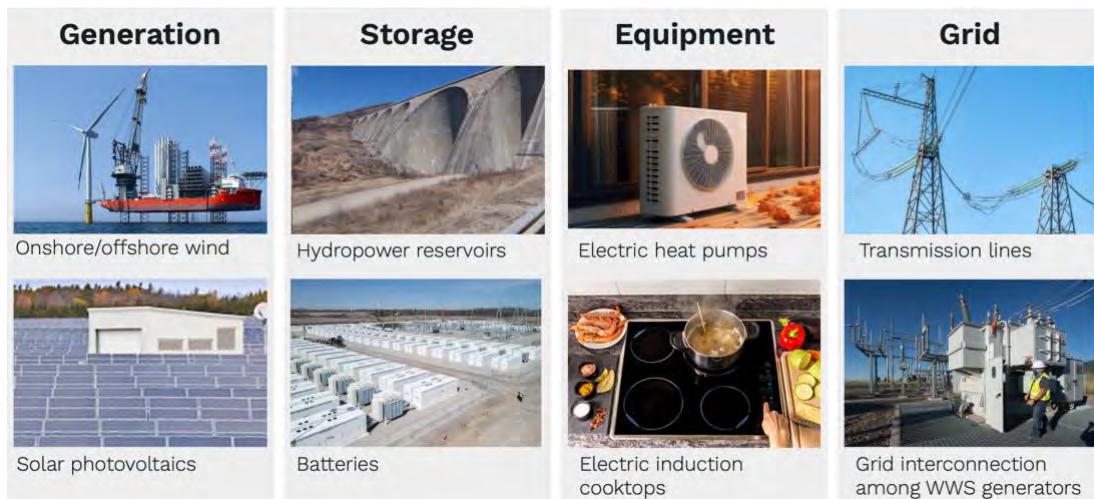
**“Is it feasible to transition Canada’s energy infrastructure to a 100% clean and renewable energy system by 2050?”**

**“What would a plan entail for transitioning Canada’s energy infrastructure to a 100% clean and renewable energy system by 2050?”**

**“What are the costs and benefits associated with transitioning Canada’s energy infrastructure to a 100% clean and renewable energy system by 2050 as compared with a business-as-usual system?”**

4. This report was prepared based upon my experience, expertise and peer-reviewed research about one technologically-feasible and economically-beneficial way to transition Canada off of a fossil fuel-dependent energy system to a 100% clean, renewable energy system, which I refer to as a wind-water-solar, or WWS, system, by 2050. A WWS system includes onshore and offshore wind, distributed and utility solar photovoltaics, concentrated solar power, geothermal electricity, hydroelectricity and small amounts of tidal and wave electricity. It also includes solar and geothermal heat, batteries, electric heat pumps, electric vehicles, electric high-temperature machines for industry, transmission and distribution lines, and many other features (e.g., Figure 1).

5. **Figure 1.** Some of the technologies in a WWS system. Figure 2 provides a more complete list. Photos from [1].



6. I conclude that Canada does not need to rely on fossil fuels to provide any of its energy for the nation or individual provinces, and that it is technically and economically feasible and advantageous, for Canada to transition to 100% clean, renewable energy for all energy purposes by 2050. Transitioning to a technically-

and economically-feasible clean, renewable energy system would result in much lower annual energy costs, health costs, climate costs, and land needs to Canada than does the current energy system.

## 7. BACKGROUND & QUALIFICATIONS

8. I have two bachelor's degrees with distinction from Stanford University, one in Civil Engineering and the other in Economics (1988). I also earned a master's degree in Environmental Engineering from Stanford University in 1988 and a second master's degree (1991) and a doctorate (Ph.D.) degree (1994) in Atmospheric Sciences from the University of California at Los Angeles (UCLA). A true and correct copy of my curriculum vitae is attached as **Exhibit C**.
9. Since 1989, I have been researching the impacts of human emissions of gases (among them carbon dioxide and other greenhouse gases) and particles (including black and brown carbon) from fossil fuels on air pollution, human health, and climate. Starting in 1999 and given the gravity of the health concerns associated with pollution from fossil fuels, I began examining in detail clean, renewable energy solutions to these problems.
10. With the goal of eliminating air pollution, global warming, and energy insecurity problems, my research has focused on studying and modeling a mix of WWS energy generators, appliances, and machines that use few resources, are quick to build, are affordable, and minimize pollution and waste. I recently published a book for energy non-experts called *Still No Miracles Needed*, to help people understand the common myths about energy and the feasibility of and benefits arising from shifting to clean, renewable energy.

11. One of the biggest myths that I encounter as an energy expert is that we need government to pay an exorbitant amount of money for a new energy system to move off of fossil fuels. This is a myth, because consumers pay for energy every day, whether it is through utility bills, vehicle fuel payments, or the energy cost baked into products that people purchase. However, with WWS, people pay less for energy across the board because WWS energy has no fuel cost, reduces waste heat and air pollution, and runs efficiently with appliances and machines.
12. Since 2009, I have developed roadmaps to transition the all-sector energy infrastructures of the world, each of the 50 United States, and now 150 countries, including Canada, to 100% clean, renewable energy by 2050. I have also researched providing up to 100% clean, renewable energy to remote Arctic communities, including in the Yukon and Alaska. I have written or co-authored a total of 196 peer-reviewed scientific papers to date, including 25 just on developing roadmaps (**Exhibit C**). The roadmaps I have researched, modeled, and published in peer-reviewed scientific publications set forth a pathway, in each country, for building on the country's existing energy infrastructure, namely by adding clean, renewable electricity and heat generators, while retiring fossil-fuel generators, over a number of years, and allowing for the normal retirement of nuclear power plants. The end result is to reliably power an entire country's all-sector energy system, thereby avoiding the enormous pollution and inefficiencies of the current energy system.
13. In this expert report, I summarize how my research pertains to Canada and how it demonstrates that no further fossil-fuel extraction, fossil-fuel infrastructure, or fossil-fuel combustion are needed to provide energy for Canada. I also give an

example of one (non-exclusive) technically- and economically-feasible pathway to move Canada away from fossil fuels for all energy purposes.

14. Implementing a technically- and economically-feasible 100% clean, renewable energy system in Canada aligns with my best scientific estimate of what is needed to limit climate damage and return atmospheric levels of carbon dioxide to 350 ppm [2] or less, which is the upper threshold climate scientists agree humanity should aim for to protect the Earth. Given how much the Earth has already heated and the current state of climate instability, every tonne of greenhouse gas pollution intensifies an already destabilized system and imposes more hardship on humanity. This report explains ways in which Canada can limit and eventually eliminate, by 2050, any further greenhouse gas emissions and therefore, heating of the Earth from such emissions.

15. I previously served as a testifying expert witness on similar topics addressed in this expert report, for the Youth Plaintiffs in *Rikki Held, et al. v. State of Montana et al.*, tried in June 12-20, 2023 before Judge Kathy Seeley, First Judicial District Court, Lewis and Clark County, Montana, U.S.A., in Case No. CDV-2020-307.

16. After preparing an expert report in that litigation, as well as a rebuttal expert report, and testifying under oath at a deposition, I appeared in Court on June 16, 2023, to testify under oath on the following topics: research related to the feasibility of substituting fossil fuels for clean, renewable energy in all sectors by mid-century in Montana, where all energy sectors include electricity, transportation, heating/cooling, and industry. I was qualified to testify as an expert on these topics, and my testimony was recorded and is available at <https://heldvmontana.ourchildrenstrust.org/>.

17. Further, the Court issued its Findings of Fact, Conclusions of Law, and Order on August 14, 2023, stating, “Dr. Jacobson is a well-qualified expert, and his testimony was informative and credible.” ¶¶ 269 (citing MJ [Mark Jacobson] trial testimony and demonstratives). The paragraphs from the Court’s opinion that reference my testimony (¶¶ 269-83) are attached to this expert report as **Exhibit E**.
18. The Court’s 2023 Order was affirmed in full by the Montana Supreme Court. *Held v. State*, 2024 MT 312.
19. **Question 1: “In the context of energy infrastructure for a country, what constitutes a 100% clean and renewable energy system?”**
20. A 100% clean, renewable energy system is an energy system that eliminates all gas and particle emissions into the air and water from energy production and use. Such gas and particle emissions affect human, animal, and vegetation health; works of art; agricultural productivity; water quality; structural integrity; and local and global weather and climate.
21. For example, gas and particle emissions from all human sources cause ~7.4 million human deaths and billions more illnesses per year worldwide [3,4] in addition to an average global warming of ~1.5 °C in 2024 relative to the 1850-1900 period [5,6]. About 90% of human-emitted air pollutant emissions and 75-80% of anthropogenic climate-damaging emissions originate from energy [7]. The rest are from non-energy sources listed in Paragraph 31.
22. The main energy sectors include the residential, commercial, industrial, transportation, agricultural-forestry-fishing, and military-other sectors. In my opinion, the most effective way and only short-term (on the 10-20-year time frame)

way to eliminate 100% of gas and particle emissions from all these sectors worldwide and in individual countries is to eliminate combustion in each sector; thus, to electrify as many non-electric technologies as possible and provide direct heat for the rest, where the electricity and direct heat come from only wind-water-solar (WWS) sources. WWS sources include onshore and offshore wind electricity, solar photovoltaic (PV) electricity, concentrated solar electricity, direct solar heat, geothermal electricity and heat, hydroelectricity, and tidal and wave electricity sources [8, which is included here as **Exhibit D**].

23. A WWS system consists of WWS electricity and heat generation, WWS storage, WWS equipment, and a grid that can transmit WWS electricity readily. Please see Figure 2. WWS electricity and heat are used to power all energy after near-full electrification of all energy. For example, WWS electricity is used to produce low- and high-temperature heat beyond what direct solar and geothermal heat produce. Low-temperature heat is needed to heat buildings, and high-temperature heat is needed for industrial processes. In a WWS system, low-temperature heat is produced with ground-source or air-source electric heat pumps. Such heat pumps use about one-quarter (one-third to one-fifth) the energy as burning gas, coal, or biomass to produce the same heat because heat pumps move heat rather than produce it. Electric heat pumps run in reverse to provide air conditioning. A combination of these technologies works in every country we have modeled, including in countries with very cold (Iceland, Norway, Sweden, Finland, Canada) and very hot climates.

24. For industry, electricity is used to provide high-temperature heat in electric arc furnaces, induction furnaces, resistance furnaces and boilers, dielectric heaters, electron-beam heaters, and heat pumps. In the case of mining, WWS provides electricity and heat, replacing combustion, thus eliminating mining-related energy emissions.
25. Electrifying buildings involves replacing gas, oil, or wood air and water heaters with electric heat pumps, replacing gas stoves with electric induction cooktops (which use 55% to 60% less energy than burning gas to provide the same heat for cooking) [10]; improving insulation; using energy-efficient appliances; and weatherizing homes. Adding rooftop solar PV provides this electricity directly to buildings, thus reducing the need for grid electricity.
26. Electrifying transportation involves replacing all gasoline, diesel, and other combustion vehicles with battery-electric (primarily) or hydrogen-fuel-cell-electric (for long-distance, heavy transport) vehicles.
27. Electrifying agriculture-forestry-fishing and the military similarly involves electrifying heating and transportation in those sectors and providing the electricity and heat with WWS.
28. WWS electricity in this system is also used to produce hydrogen for select applications: steel and ammonia production, long-distance aircraft and ships, and some grid electricity storage, but not for passenger cars (because this is inefficient) or heating homes (because electric heat pumps are much cleaner and more efficient)

or providing high-temperature heat for industry (because electric heating is cleaner).

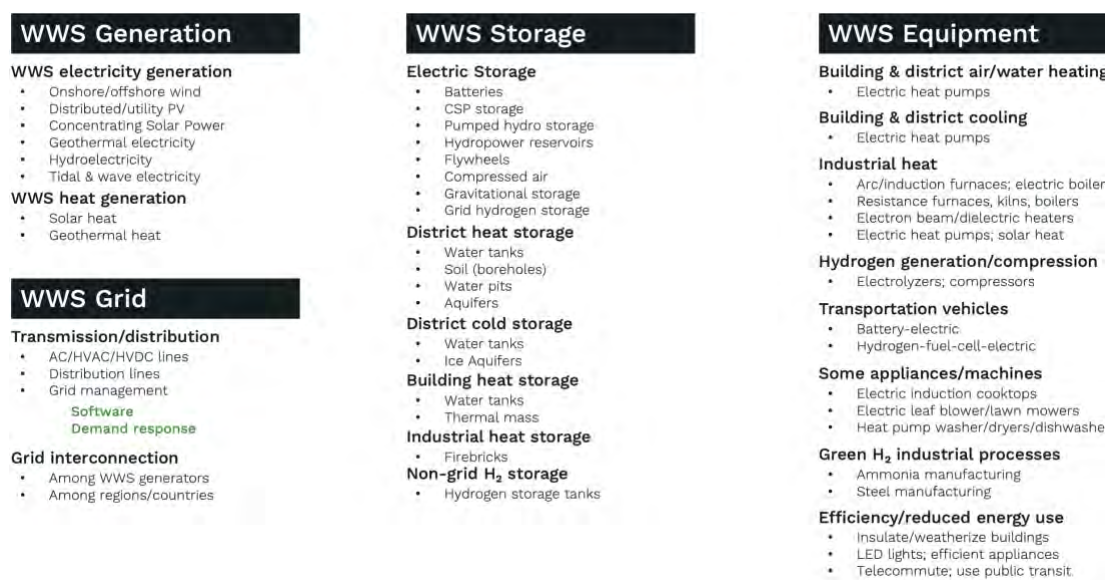
29. Because the wind does not always blow and the sun does not always shine, WWS storage is needed. WWS storage includes electricity storage, heat storage, cold storage, and hydrogen storage. The main electricity storage options today are existing hydropower dams, pumped hydro storage, and batteries, but other options are available (Figure 2). Low-temperature heat is often stored in water or soil. High-temperature heat is stored in a new technology, firebricks [11]. Cold is stored in water or ice. Hydrogen is stored in hydrogen storage tanks.

30. A WWS system also involves a well-connected electricity-transmission system, including some long-distance transmission through high-voltage direct-current (HVDC) lines. There is often a tradeoff between storage and transmission, so if transmission cannot be built readily, more storage is needed.

31. By electrifying all energy sectors as much as possible, providing direct heat for remaining energy, producing both the electricity and heat with WWS, and by allowing nuclear power plants to retire naturally, governments can eliminate, by 2050, 100% of the air pollutants greenhouse gases, and energy insecurity problems that arise from their current energy systems, including from the energy used to mine fossil fuels and uranium. Governments can also reduce substantially or eliminate non-energy emissions. These include methane from agriculture and waste; halogens from leaking refrigerants and other sources; nitrous oxide from fertilizers; and chemically-produced CO<sub>2</sub> from cement and steel production. This can be done

using a variety of existing techniques and technologies [7,8]. However, the focus of this report is on energy, not on non-energy processes and emissions. Ninety percent of air pollutant emissions and 75-80% of climate-damaging emissions are from energy.

32. **Figure 2.** Wind-water-solar (WWS) energy system. Adapted from Table S2 of [8]



33. **Is it feasible to transition Canada’s energy infrastructure to a 100% clean and renewable energy system by 2050?**

34. Yes, our research team (which has included dozens of researchers over the years) published several peer-reviewed 100% WWS plans for Canada as a whole between 2017 and 2026. Each published plan was an update to the previous published plan based on new energy installation and use data and cost data. **Exhibits D and F** provide the most recent plan. Exhibit D [8] is the peer-reviewed published paper summarizing plans for 150 countries, including Canada, and Exhibit F [9] is a concise summary of the Canadian plan taken from Exhibit D. From these plans, I conclude that transitioning Canada’s all-sector energy infrastructure to a 100%

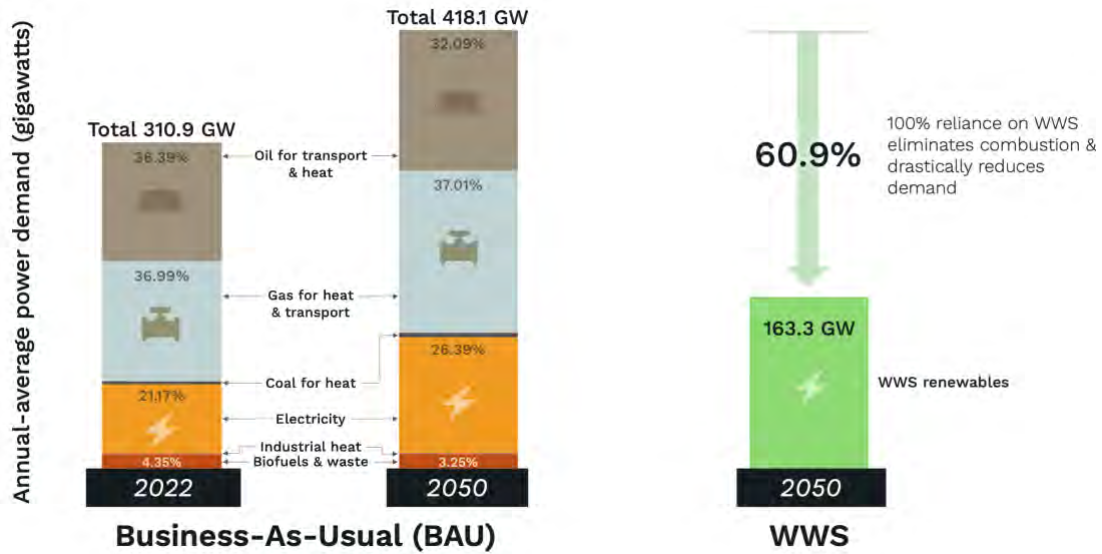
clean, renewable one by 2050 is feasible and will reduce Canada's annual energy costs and annual energy plus health plus climate costs (social costs) tremendously while minimizing land use. To illustrate, I will discuss our latest 100% WWS plan for Canada, published in 2026 (**Exhibits D** [8] and **F** [9]).

35. Before discussing Canada's transition to a WWS energy system, it is important to understand Canada's current energy system. In 2022, Canada's annual-average end-use power demand was supplied by the main sources listed below and shown in Figure 3. An annual-average power demand equals annual energy demand divided by the number of seconds in a year. Annual energy demand is also called total final consumption, which is the energy people actually use, as opposed to primary energy demand, which is energy in the chemical bonds of fuels. The main components of Canada's annual average power demand were

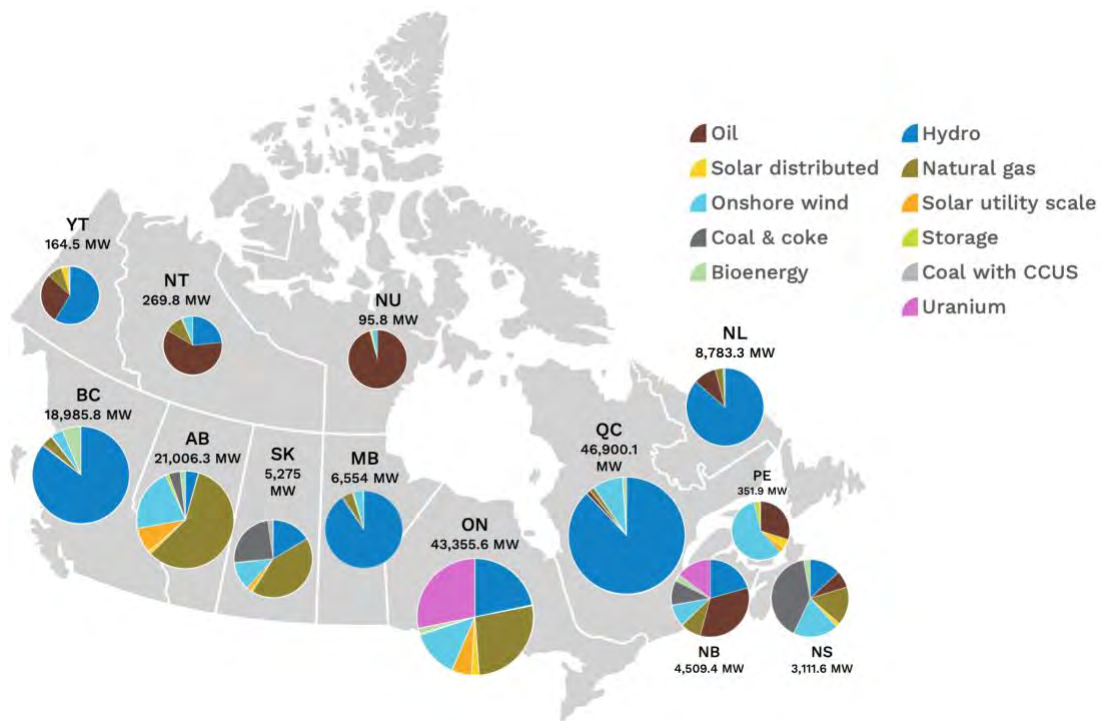
- a. oil for transportation and heat: ~36.39%;
- b. fossil gas for heat and transportation: ~36.99%;
- c. biofuels and waste for heat: ~4.35%;
- d. electricity: ~21.17%.

36. In 2024, Canada's electricity was produced 53.9% by hydro, 7.35% by wind, 1.48% by solar, 13.42% by nuclear, 3.95% by coal, 17.21% by fossil gas, 1.15% by oil products, and 1.54% by bioenergy. Figure 4 shows that electricity production varies significantly by province in Canada.

37. **Figure 3.** Canada's 2022 and projected 2050 annual-average end-use power demand and energy sources meeting such demand in a business-as-usual (BAU) case. Also shown is WWS demand in 2050 after converting BAU energy to WWS in 2050. Data from [8].



38. **Figure 4.** 2023 electricity nameplate capacity mix by region in Canada. Data from [12].



39. The roadmap I discuss below outlines one potential pathway for Canada to reach a 100% WWS system across all energy sectors by 2050. It is intended to be flexible and adaptable or refinable as necessary because there are many ways to eliminate

the use of fossil fuels. There are advantages to a fully integrated national energy system, which is what I have modeled. However, it can be less expensive in remote areas to build an energy system not connected to the rest of Canada's grid (a microgrid), which is why I have also researched and published studies examining the impacts of isolated versus grid-interconnected countries [13] and states [14] on electricity cost and reliability as well as on and remote microgrids, including in the Yukon [15] and in some Alaskan communities [16, 17]. In other words, it is my expert opinion that each of Canada's provinces can transition its current energy system to be completely independent of the rest of Canada. However, the plan I describe here is one of a fully-interconnected Canada. Such interconnection is mutually beneficial among provinces and technically and economically feasible given that interconnectivity already exists throughout much of Canada, especially across the southern provinces.

40. Based on my plan development for 150 countries and all U.S. states over the past 17 years, I conclude that, regardless of whether countries decide to develop clean, renewable grids state-by-state, province-by-province, or nationally, a 100% clean, renewable energy system is reliable, feasible, and significantly more affordable than current energy systems. The main barrier to a 100% WWS system is largely one of government policy and entrenched interests in maintaining a fossil-fuel energy system. Our research shows the barrier is not a technical or economic one.

41. **What would a plan entail for transitioning Canada's energy infrastructure to a 100% clean and renewable energy system by 2050?**

42. To derive our latest 2050 100% WWS energy plan for Canada [8] we took the following steps for 150 countries, including Canada. We started with annual end-

use energy demand data (also referred to as total-final-consumption, or TFC, data) from 2022, published by the International Energy Agency [18], converted it to power and projected the data to 2050, in a business-as-usual (BAU) scenario, for each of seven fuel types within each of six end-use energy sectors within each of the 150 countries (Figure 3). The seven fuel types include oil, fossil gas, coal, electricity, heat for sale, solar and geothermal heat, and wood and waste heat. The end-use energy sectors include the residential, commercial, transportation, industrial, agriculture-forestry-fishing, and military-other sectors. Energy use for transportation includes energy for ground, air, and marine transport, including for international aviation and shipping. The projections to 2050 assume moderate economic growth, population growth, energy consumption growth, modest energy policy changes that vary by world region, use of some renewable energy, modest energy-efficiency measures, and reductions in energy use (Note S2 of [8]).

43. Electricity is transmitted on an electrical grid and is sometimes stored for later distribution on the grid. Current electricity in Canada is produced from hydro, wind, solar, nuclear, fossil gas, coal, oil products, and bioenergy. An electrical grid consists primarily of an interconnected network of high-voltage transmission lines, lower-voltage distribution lines at the neighborhood level and closer to the ground than transmission lines or underground, and service lines that transmit electricity to buildings. A grid exists to transmit most electricity today in Canada (Figure 5). In addition, many new WWS sources can be built near existing transmission lines. However, some additional transmission lines and some upgrades in transmission capacity along existing lines will be needed in a 100% WWS system in Canada.

44. **Figure 5.** The transmission system in Canada and the United States in 2020. The numbers are the interprovincial electricity transfer rates in 2017. The percentages are the relative population in each province. Data from [19], [20].



45. The 2050 BAU projections of end-use demand were then used as a starting point to estimate how much electrical and direct heat energy might be needed if each BAU fuel type in each end-use sector were switched to electricity, electricity-produced hydrogen, low-temperature heat, or high-temperature heat, and if such electricity, hydrogen, and heat were provided by WWS. For example, air and water heating for buildings, originally provided by combustion heaters, was assumed to instead be provided by electric heat pumps. Human and cargo transport, originally provided by internal-combustion-engine vehicles, was instead provided by battery-electric vehicles for all but very-long-distance aircraft, ships, trucks, and trains, which were propelled instead by hydrogen-fuel-cell-electricity [21]. Industrial heat, originally provided by combustion furnaces and boilers, was instead provided by electric furnaces and boilers and firebrick storage.

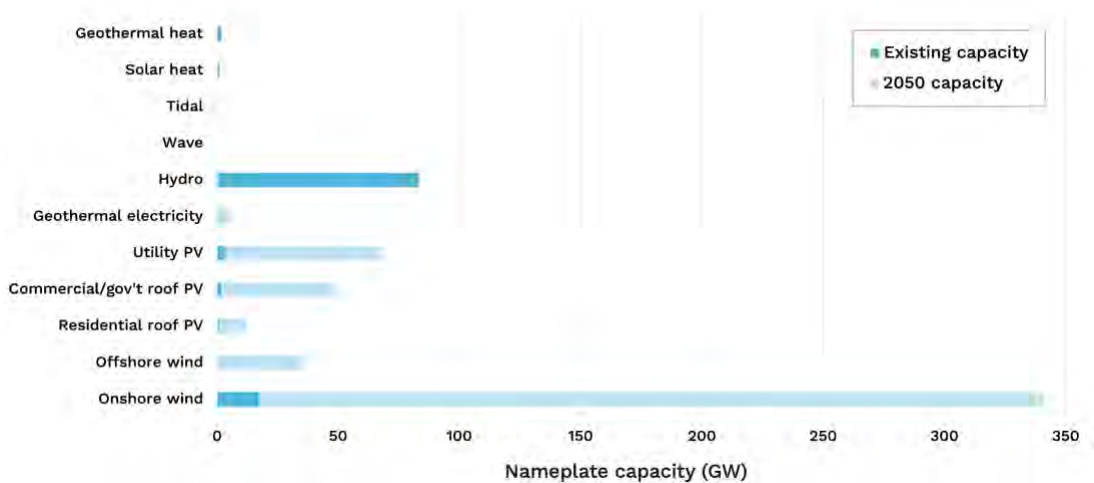
46. The resulting reductions in end-use energy demand were calculated with conversion factors that vary by fuel type within each energy sector [7, 8]. Overall results are shown in Figure 3. A resource analysis was performed for Canada, looking at Canada's particular resources and climate, to determine which WWS technologies could be developed feasibly, and a mix of WWS technologies was chosen for Canada based on this and other factors. The methodology for performing the resource analysis is set out in Ref. [8]. The 100% WWS goal is not a projection of what will happen in Canada based on present policies in the country. Instead, we selected 100% WWS because it is a way to address air pollution, climate, and energy security by 2050 in a technically feasible and economical way [8]. The Canadian plan we developed assumes that existing nuclear electricity continues until all nuclear reactors naturally retire, and that new nuclear reactors are not brought online. The reasons are severalfold. First, new nuclear is more expensive and takes much longer from planning to operation than new WWS technologies. In addition, new nuclear creates radioactive waste that must be stored for 200,000 years, produces 9 to 37 times the carbon-dioxide-equivalent emissions per unit electricity produced as wind, creates underground uranium mining lung cancer risk, creates a meltdown risk, and creates weapons proliferation risk (which is particularly high for small modular reactors). WWS eliminates all of these risks and issues. Our Canadian plan provides a feasible way for Canada to provide energy security while eliminating air pollution and climate-damaging emissions.
47. Results of the first step indicated that an all-sector transition to 100% WWS could reduce 2050 annual average end-use power demand in Canada by ~60.9% (Figure 3), with ~22.8 percentage points due to eliminating the energy used to mine,

transport, and refine fossil fuels and uranium, 32.2 percentage points due to the efficiency of electric vehicles, electric heat pumps, and electric furnaces over combustion versions, and ~5.9 percentage points due to reducing energy use and improving end-use energy efficiency (e.g., using more efficient light bulbs, refrigerators, dishwashers, etc.) beyond in a business-as-usual case (Table 1 of **Exhibit F** [9]).

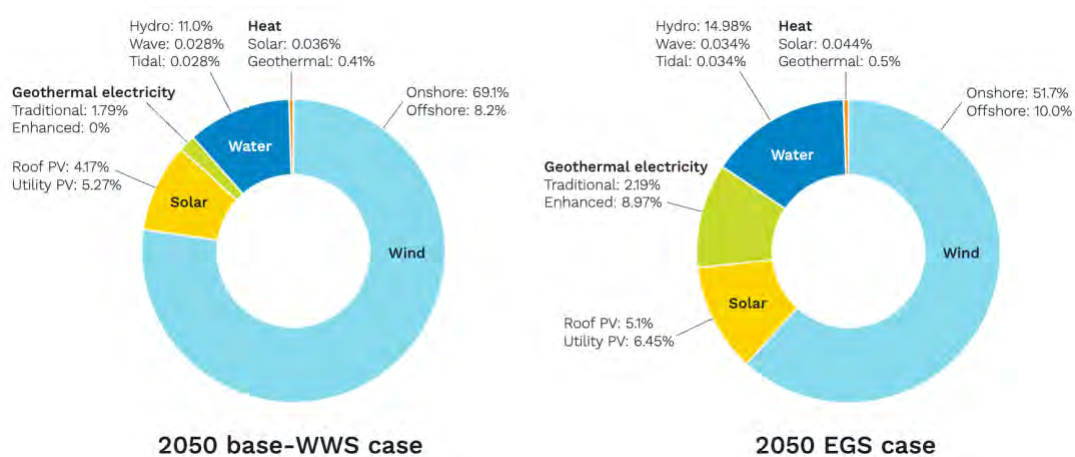
48. The resulting end-use demand after electrification is an annual-average (in 2050) electricity and heat power demand for all of Canada to be met by WWS (Figure 3). However, such a target does not account for the additional electricity and heat generation and storage needed to keep Canada's grid stable or for transmission and distribution losses. To account for these factors, a grid stability analysis was performed with the LOADMATCH grid model applied to Canada at a time step of 30 seconds over three years (2050 to 2052) to estimate the nameplate capacities of WWS generators and storage devices needed to meet Canada's all-sector energy demand every 30 seconds during these years. A nameplate capacity is the maximum continuous output of a generator. The grid analyses used 30-second wind and solar generation and building heating- and cooling-demand data for Canada as inputs. Such data were produced by a global weather-prediction model [8].
49. Table 5 of **Exhibit F** and Figure 6 show the resulting WWS nameplate capacities needed to power Canada with 100% WWS across all energy sectors in 2050 while keeping the grid stable. Table 7 of **Exhibit F** and Figure 7 show the percentages of Canada's energy demand that would be supplied by each generator. Note that these results are from only one scenario. Multiple mixes of WWS generators and storage are possible for keeping the grid stable at low cost. Ref. [8], in fact, provides a

second scenario, in which enhanced geothermal electricity is used to provide ~8.97% of Canada’s end-use demand. Table 7 of **Exhibit F** shows that, in the baseline scenario being discussed here, onshore and offshore wind provide 69.1% and 8.2%, respectively, of all of Canada’s 2050-2052 power supplied; rooftop and utility solar PV provide 4.2% and 5.3%, respectively, of supply; geothermal electricity and heat provide 1.8% and 0.41%, respectively, of supply; hydro provides 11.0%; wave and tidal provide 0.028% each; and solar heat provides 0.036%. The total sums to 100%.

50. **Figure 6.** Existing plus proposed nameplate capacities (gigawatts, GW) of different WWS heat and electricity generators needed to power Canada for all energy purposes in 2050 with 100% WWS while keeping the grid stable. Data from [8].



51. **Figure 7.** Percentage of Canada’s 2050 all-purpose energy demand supplied by WWS generators in two scenarios. The first (baseline) scenario is the one described in this report. The second scenario is one similar to the first, but enhanced geothermal provides ~8.97% of Canada’s annual energy demand. Data from [8].



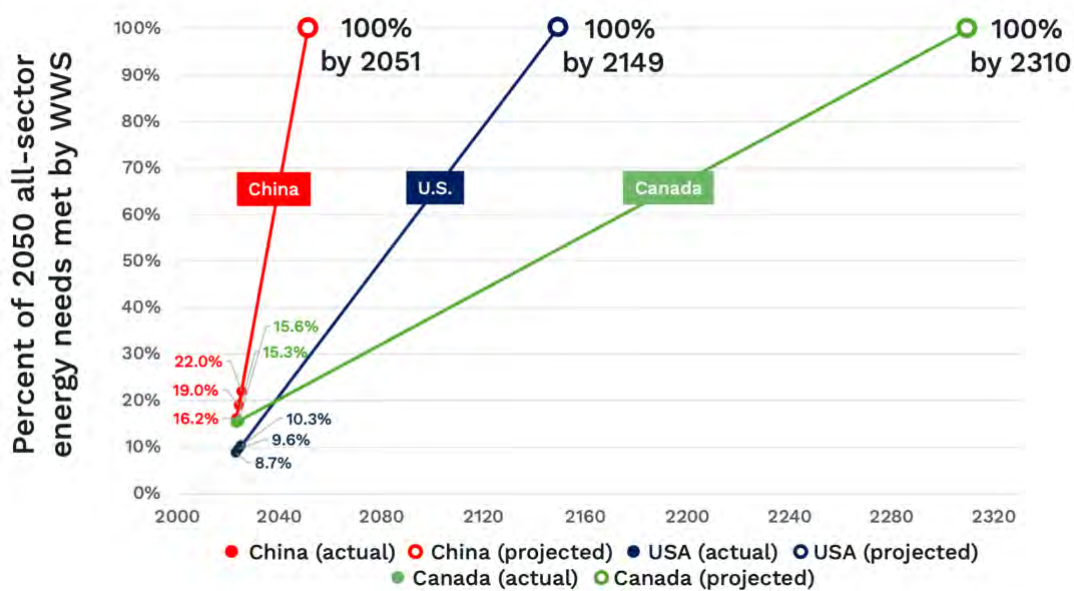
52. Table 8 of **Exhibit F** shows the storage needed to keep a well-integrated grid in such a system stable. The table shows that only existing hydro (83.3 GW) and pumped hydro (0.8 GW) are needed for grid electricity storage in the scenario considered. Batteries and grid hydrogen are not needed in this scenario to keep the grid stable. The reason is that existing hydro and pumped hydro provided sufficient energy and peaking power to fill in gaps between demand and WWS supply during the three years of simulation. The solution includes 35.8 GW of firebrick storage for industry to help eliminate the need for combustion furnaces. The solution also requires 22 GW of hot water thermal energy storage.

53. Canada has such abundant WWS resources, that even if there is an increase in energy demand above what our analysis projects, it will be feasible to accommodate that additional demand.

54. Despite Canada's potential to transition to 100% WWS across all energy sectors by 2050, Canada is far from that goal. Specifically, although Canada has a 2050 decarbonization target and already produced, in 2024, about 15.6% of all the end-use energy it needs to be 100% WWS across all energy sectors by 2050, its rate of growth of WWS between 2023 and 2024 was so slow that Canada may not reach

100% WWS across all sectors until past the year 2300 if it continues to grow WWS at its slow 2023-to-2024 growth rate [22]. Canada’s rate of adoption of WWS energy is slower than that of the United States, which is also falling far behind other nations. China is adopting WWS energy far more quickly than is Canada or the United States, as shown in Figure 8.

55. **Figure 8.** Years by which China, the United States, and Canada are estimated to reach 100% WWS across all energy sectors if they continue to increase WWS electricity installations at their 2024 or 2025 pace and electrify all energy. Data from [22].



56. **What are the costs and benefits associated with transitioning Canada’s energy infrastructure to a 100% clean and renewable energy system by 2050 as compared with a business-as-usual system?**

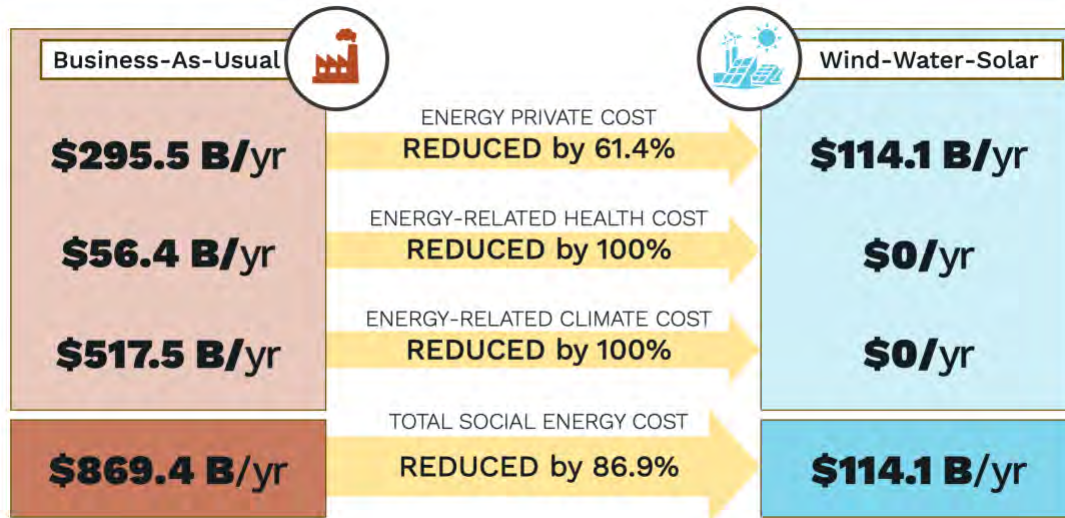
57. One of the most important benefits of implementing a WWS energy system by 2050 is that it limits further greenhouse gas emissions, air pollutant emissions, and climate damage. In other words, a 100% WWS system by 2050 (e.g. the system I

described above) results in an affordable and healthier energy system than does the current energy system in Canada. It also aligns with the scientific standard of returning atmospheric CO<sub>2</sub> to 350 ppm or less, which is the upper threshold of CO<sub>2</sub> almost all climate scientists agree humanity should aim for to protect natural systems on which humans depend [2]. Below I explain in detail what our research demonstrates in these respects.

58. The methodology for determining costs and benefits (including land-use changes and job changes) associated with transitioning to 100% WWS is provided in Ref. [8].

59. Under the base, or business-as-usual(BAU), case where Canada maintains its current energy system, that system results in a total social cost due to Canadian emissions in 2050 of ~\$869 billion per year, which includes a private energy cost of ~\$296 billion per year to Canadians (to meet Canada's energy needs for all purposes), plus a health cost of ~\$56.4 billion per year to Canadians, plus a climate cost to the world from Canadian emissions of ~\$518 billion per year (Table 12 of Exhibit F) (Figure 9). Canada's BAU private energy cost of \$296 billion is borne by energy producers, who pass those costs on to consumers. Governments sometimes subsidize those energy costs as well. The health and climate costs of the BAU energy system are borne by individuals in Canada.

60. **Figure 9.** 2050 annual private and social energy costs in the BAU and WWS cases for Canada. Social cost equals private plus health and climate costs. Data from [8].



61. The 2050 capital cost of an all-sector Canadian transition to 100% WWS is estimated to be ~\$794 billion (USD 2022) (Table 12 of **Exhibit F**). The annual cost of energy to all Canadians for a 100% WWS transition is ~\$114 billion per year (Table 12 of **Exhibit F** and Figure 9). This annual cost is both the annual private energy cost (cost of energy to consumers, not accounting for the health or climate costs, or externality costs, of energy) and the annual social energy cost (private energy cost plus health and climate costs) of WWS because WWS has zero energy-related health and climate costs.

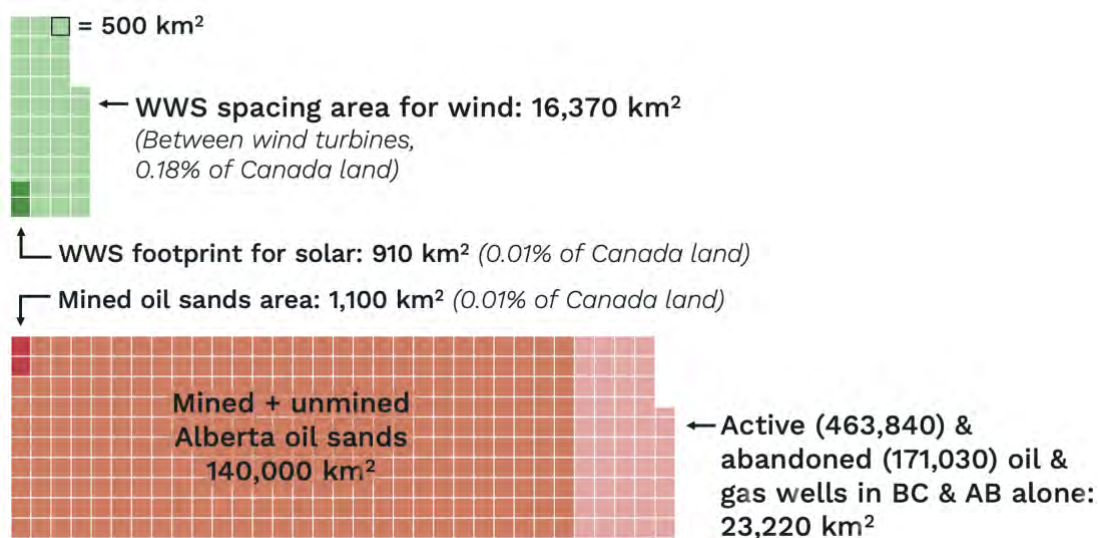
62. These energy costs, which include costs of electricity to heat, light and power buildings and electricity to power electric vehicles, etc., are borne by energy producers, who pass these costs on to consumers, just as in a BAU system. It is not the case that the government pays \$114 billion per year for this transition, just as the government does not pay the \$296 billion per year for the BAU energy system (although the government does sometimes choose to subsidize some energy costs). These costs are paid each year through energy sales.

63. As such, a Canadian 100% WWS energy system reduces annual private energy costs to Canada by 61.4% (from \$295.5 to \$114 billion per year) and annual social costs due to Canadian emissions by 86.9% (from \$869 to \$114 billion per year) in 2050 (Figure 9). The cost savings leave significant latitude to build out additional transmission capacity and to plan for additional future demand growth as needed.
64. For comparison, NOT transitioning (the BAU case) results in a total social cost due to Canadian emissions in 2050 of \$869 billion per year, which includes a private energy cost of \$296 billion per year to Canada plus a health cost of \$56.4 billion per year to Canada plus a climate cost to the world from Canadian emissions of \$518 billion per year (Table 12 of **Exhibit F** and Figure 9). As such, WWS reduces annual private energy costs to Canada by 61.4% (from \$295.5 to \$114 billion per year) and annual social costs due to Canadian emissions by 86.9% (from \$869 to \$114 billion per year) (Figure 9).
65. Given that WWS saves \$181 billion per year in private energy costs versus BAU, Canada's transition from BAU to WWS can result in the \$794 billion capital cost of a transition being paid off in only 4.4 years due to private-energy-cost savings alone. Given that WWS saves \$755 billion per year in social energy costs, a transition can result in a payback time of only 1.1 years in terms of social-energy-cost savings.
66. The health-cost savings from a transition are due to eliminating ~4,800 indoor-plus-outdoor-related air pollution deaths per year and tens of thousands more illnesses per year from BAU energy in Canada in 2050 (Table 13 of **Exhibit F**). The climate-cost savings are due to eliminating greenhouse gas emissions in Canada equivalent

to 893 million tonnes per year of CO<sub>2</sub> in 2050 in the BAU case (Table 13 of **Exhibit F**).

67. Another benefit of a WWS system compared with a BAU system is that a transition to 100% WWS is estimated to require only 0.01% of Canada's land for utility solar PV footprint on the ground and 0.18% of Canada's land for new onshore wind farm spacing (Table 14 of **Exhibit F**) (Figure 10). Such spacing area can be used for multiple purposes, including for ranching, farming, as rangeland, as open space, or to put solar on. No new land is needed for hydro, because our plan calls for no new hydro; just using existing hydro more efficiently. Offshore wind and rooftop PV do not require new land either. Thus, the total new land needed is only 0.19% of Canada's land, and most of that is open space.

68. **Figure 10.** New footprint and spacing areas required for the 100% WWS plan for all of Canada. Data from [8]. Footprint is land on the ground needed (for utility solar). Spacing is the open space between wind turbines. Also shown are the mined and unmined Alberta oil sands area and the estimated area required for abandoned and active oil and gas wells in British Columbia (BC) and Alberta (AB) alone.



69. Transitioning Canada to 100% WWS is estimated to result in a much lower percentage of land needed (0.19%) than in a country like the U.S. to transition (1.05%), which itself is less than the percentage of land currently needed for all U.S. energy (2.4%) [23]. Transitioning Canada to 100% WWS will also reduce the current land needed for all energy in Canada. For example, active and abandoned oil and gas wells in British Columbia and Alberta alone occupy an estimated 23,200 square kilometers (Figure 10), or 0.26% of Canada's land area (9.094 million square kilometers), which exceeds the 0.19% of land needed for 100% WWS. This does not include the oil and gas wells in other provinces, or pipelines, gas stations, storage facilities, or processing stations in any province. In another comparison, the Athabasca, Canada, tar sands area is ~140,000 square kilometers of area (1.56% of Canada), with 4,800 square kilometers (0.053% of Canada) of the area mineable and 1,100 square kilometers (0.01% of Canada) already mined (Figure 10). In sum, a 100% WWS system is projected to require much less land than does Canada's current energy system.

70. When calculating changes in jobs between a WWS and BAU system, I looked at the creation of jobs due to adding WWS energy and the loss of jobs due to eliminating BAU fuels. The calculation was not comprehensive in that it did not consider all aspects of job creation and loss. Nevertheless, based on this simplistic analysis, a transition to 100% WWS in Canada is estimated to result in job gains in the renewable electricity, heat, cold, and hydrogen generation, storage, and transmission industries and job losses in the fossil-fuel industry (Table 15 of **Exhibit F**). For example, our analysis did not account for job gains in the production of electric appliances, vehicles, and machines or in increasing building

energy efficiency or job losses in producing combustion equipment. In my expert opinion, I believe that accounting for those additional job gains and losses would likely result in a slight net gain or little net change in jobs due to a transition to WWS in Canada. Worldwide, a transition to 100% WWS is estimated to create a net of about 28 million more long-term, full-time jobs than are lost.

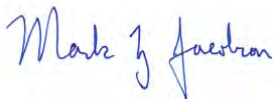
71. Regardless of job gains or losses, the financial-cost gains to Canada due to converting to WWS are so enormous (61.4% reduction in annual private energy costs and 86.9% reduction in annual social energy costs) (Figure 9), that they far outweigh, in my opinion, any potential net job losses in Canada. There are tremendous job training opportunities for workers throughout a WWS system, especially for electricians.

72. In sum, our study found that a transition to 100% WWS in Canada will likely eliminate air pollution mortality and morbidity from energy, eliminate greenhouse-gas emissions from energy, reduce private and social costs tremendously, and minimize land use. Changes in jobs are uncertain due to an incomplete calculation of job changes due to a transition.

73. One reason for the much lower energy costs with 100% WWS is the elimination of the need to mine continuously for fuels in Canada. The continuous mining for energy today results in mined materials that are orders of magnitude larger than the mined materials needed for the one-time mining for WWS machines and equipment, particularly as most of the materials mined for WWS machines and equipment, such as batteries, can be recycled. Fossil fuels, on the other hand, are used once – they are burned so cannot be recycled.

74. The elimination of mining for fossil fuels and uranium (which would otherwise consume 22.8% of all of Canada's end-use energy in 2050) [8] along with Canada's conversion to electric appliances, machines, and transport, as well as end-use efficiency improvements, is estimated to reduce Canada's overall end-use energy demand by ~60.9% (Figure 3) and reduce annual costs by 61.4% (Figure 9). On top of that, eliminating combustion, as a WWS system does, is estimated to reduce overall annual social (economic) energy costs with WWS by 86.9% compared with business-as-usual (Figure 9). These results should apply to all of Canada, including remote Arctic communities. In sum, a conversion to WWS appears to have very little downside and enormous benefits for Canada.

75. **Conclusion:** Canada has the resources to reliably power its energy needs across all sectors of its economy with a WWS energy system by 2050. I have provided a roadmap for one scenario and results for a second scenario [8] for a WWS system in Canada, but there are many other ways to transition the BAU system to WWS for all energy purposes. A 100% WWS energy system is technically feasible and economically superior to the BAU system. Due to the efficiency of WWS over BAU and WWS' elimination of mining, refining, and transporting of fossil fuels and, eventually, uranium, a WWS system also requires much less energy than a BAU system.



\_\_\_\_\_ Date: April 1, 2026.

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