COURT FILE NUMBER	**KB 848 of 2023**
COURT OF KING'S BENCH FOR SASKATCHEWAN	
JUDICIAL CENTRE	**REGINA**
APPLICANT	**SASKATCHEWAN ENVIRONMENTAL SOCIETY**
RESPONDENTS / Applicants	**SABRINA DYKSTRA, a minor by her litigation guardian CLAIRE DYKSTRA, JILL FORRESTER, RYAN HEISE, KAYLA HOPKINS, LYNN OLIPHANT, HAROLD PEXA, AMY SNIDER, and CLIMATE JUSTICE SASKATOON ORGANIZATION INC.**
RESPONDENTS / Respondents	**SASKATCHEWAN POWER CORPORATION, CROWN INVESTMENTS CORPORATION OF SASKATCHEWAN, and THE GOVERNMENT OF SASKATCHEWAN**

AFFIDAVIT OF R. A. HALLIDAY, P. Eng.

I, ROBERT HALLIDAY, P. ENG., of the CITY of SASKATOON, Saskatchewan, Vice President of the Saskatchewan Environmental Society (SES) and acting on their behalf, MAKE OATH AND SAY (or AFFIRM):

1. I am making this application to obtain an order declaring the SES an intervenor. If SES participates in these proceedings as an intervenor, SES intends on doing the following:

    a. Provide evidence on the impacts SaskPower's and the Government of Saskatchewan's decisions have had on the environment in deciding to continue developing new unabated fossil fuel electricity generation assets; and

    b. Provide evidence on achievable options SaskPower and the Government of Saskatchewan have to reach net-zero greenhouse gas emissions and alternatives to continue developing new unabated fossil fuel electricity generation assets.

BACKGROUND

2. I am a water resource engineer by training and experience. For the last 25 years, I was the president of R. Halliday & Associates, a consulting engineering firm. Prior to that I was director of Canada's National Hydrology Research Centre. My interest in SaskPower's generation matters was sharpened by the challenges the organization faced in meeting cooling water demands at the Boundary Dam Power Station during the 1980s drought. That matter was addressed by pumping the Estevan aquifer; 30 years later the aquifer still has not recovered. I have been qualified as an expert in court proceedings before on water management matters, particularly related to flooding and drainage. I have deep professional knowledge of matters pertaining to water and power production.

3. I am currently the Vice President of SES. I have been a member of SES for 20 years, a board member for 9 years, and Vice President for 6 years.

ABOUT SES

4. The SES is an incorporated non-profit and registered charity that operates primarily in the province of Saskatchewan. Attached as **Exhibit "A"** is a copy of our Articles of Incorporation. The SES has been actively working on environmental issues for more than 50 years, having begun in 1970, which was a time of vastly increased environmental awareness and the first Earth Day. SES's founding preceded that of the environmental departments and agencies of both the federal and provincial governments.

5. At first, SES (then known as the *Saskatoon* Environmental Society) ran solely on volunteers with an initial focus on protecting the South Saskatchewan River's riparian areas from negative impacts of unabated development in Saskatoon. This advocacy ultimately led to the creation of the Meewasin Valley Authority. As the need to address broader environmental issues became evident, the Saskatoon Environmental Society became the *Saskatchewan* Environmental Society.

6. SES has grown into a charity with members from throughout the province and beyond. At present, the SES has approximately 279 active, paying members,

which includes 223 memberships[1] (a person does not need a membership to participate in our activities or volunteer with us). Of these members, 271 reside in Saskatchewan. Our Facebook page has 3,169 followers and our X page (formerly Twitter) has 2,134 followers. While SES continues to be a volunteer-led organization, SES has employed paid staff since the mid 1980s. The organization and its Directors/staff have won awards for their environmental work, including: Green Community Member of the Year Award (Green Communities Canada, 2023); Resilience and Service Milestones (Green Communities Canada, 2023); Queen Elizabeth II Platinum Jubilee Medals (2023); Sustainability Awards (RCE Saskatchewan, 2023, 2021, 2020, 2019, 2018, 2017, 2016, 2015, 2014); Excellence in Environmental Education (EECOM, 2018); and Rob Dumont Energy Management Organization of the Year Award (2017).

7. An elected Board of volunteer Directors governs the activities of the organization and possess a variety of professional backgrounds, including in the arts, medicine, engineering, law, policy, science, accounting, consulting, and education. Collectively, the Board has extensive experience in various environmental issues including energy, climate change, sustainability, green buildings, water, and more.

8. Upon election by SES's members, each Director has the obligation to attend monthly board meetings, provide direction and support to the Executive Director (the staff position responsible for running the organization), ensure the financial well-being of the organization, and develop environmental policy while upholding the mission and values of the non-profit/charity.

9. SES's main areas of focus are climate change and energy solutions, water conservation, biodiversity preservation, and the reduction of toxins throughout the province. Attached as **Exhibit "B"** is a map of SES's projects and work across Saskatchewan since 2010. SES has focused its work on public education,

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[1] Membership is when an individual formally becomes part of SES through payment of a $20 annual membership fee. Memberships run the calendar year and allow members to vote at the Annual General Meeting, join the Board of Directors (after at least one year of active membership), receive pertinent environmental news from SES, and participate via other decision-making avenues. Note: Couples or families who have an SES membership count as "one membership" but also as "two (or more) members."

collaborating directly with proponents and government, and on environmental science and research.

10. SES has been driving public engagement by writing over 200 publications, backgrounders, responses to consultations, and letters to the government (at the municipal, provincial, and federal levels) and other relevant stakeholders. SES has also published over 100 editions of "The Environmental Resource," a newsletter of environmental issues, local events, and SES project updates for SES members, which are also archived in the National Library of Canada. SES has published reports on topics including sustainable energy strategies for Saskatchewan (2007); recommendations for the City of Saskatoon (2015), City of Regina (2016), and SaskPower (2013 and 2021) regarding greenhouse gas emissions reductions; specific energy projects in the province, such as the Chaplin Wind Farm (2016) and the Blue Hill Wind Energy Project (2018); transitioning to net-zero/low-carbon future (2017) and energy and employment (2021); and the Government of Saskatchewan's climate change plan (2018).

11. SES focuses on sound science, good management, civility, and the ability and desire to work with others. SES provides evidence-based perspectives grounded in the local Saskatchewan context. SES's knowledge is especially highlighted when the media contacts us for comments on environmental issues and policies that arise. In the past decade alone, SES has written over 40 press releases; conducted hundreds of interviews with various media outlets including Radio-Canada, CBC, Global, and CTV (and SES has been mentioned in over 500 print and broadcast news); and organized numerous press conferences on environmental issues. In the last three years, SES has given interviews on topics that include financial security related to renewable energy in Saskatchewan; climate action and the costs associated with climate change; steps the government and SaskPower needs to take to reduce emissions; IPCC reports; and transitioning to carbon-free electricity.

12. SES has provided recommendations and engaged with a number of energy-related corporations and ministries, including: meeting with wind power companies to provide advice and guidance on suitable locations for renewable energy

developments (2019); submitting feedback to the federal government on methane emissions (2018); meeting with the provincial Minister of Environment to discuss environmental issues (2015); participating in the Saskatchewan Citizens' Hearings on Climate Change with 36 other presenters and leading preparation of the final report on behalf of participants (2014). SES also created Saskatchewan's first renewable energy co-operative in 2014.

13. SES participated as an intervenor in *Reference re Greenhouse Gas Pollution Pricing Act,* 2021 SCC 11. SES, along with over ten other civil society organizations (collectively referred to as "*Climate Justice et al.*"), brought an application to intervene in the appeals of various provincial decisions on the constitutionality of the *Greenhouse Gas Pollution Pricing Act* to the Supreme Court of Canada. In this intervention, the court granted leave to *Climate Justice et al.* and the various other intervenors, with conditions on filing and written/oral submissions to ensure efficiency. *Climate Justice et al.* focused on highlighting the human rights aspect of the constitutional question using sound science. *Climate Justice et al.* relied on several pieces of evidence they previously filed in the lower courts, including a report by James Hansen, a world-renowned and award-winning climate scientist.

ELEMENTS OF STANDING

Sufficient Interest

14. The primary purpose of the SES is to accelerate the transition to a sustainable future and help people live sustainable lives. The health of our shared environment impacts the livelihoods and the well-being of all residents in Saskatchewan. The actions/policies of the government can directly affect each resident's ability to live sustainably through their regulations and policy choices. SES is therefore heavily invested in what the government does with respect to climate change. Since the positions put forward by the applicants relate to what the government is doing with respect to climate change, and given our mission statement and values, SES feels obligated to participate and contribute to this important court action on behalf of our members and all citizens of this province.

Delay

15. I am aware that delay can increase legal costs and use court resources. SES will avoid complicating and delaying these proceedings. SES intends to play a narrow and informative role to help the court consider alternative perspectives and present practical solutions on how to generate power sustainably. We do not intend on introducing evidence, making submissions, or filing briefs in such a way that causes delay; rather, we will strive to work with the dates set by the main parties.

Prejudice to the Parties

16. I am not aware of any prejudice that could be caused to any of the current parties with our involvement as an intervenor.

Widening the Lis

17. As stated above, our intention is to speak to the issues in the originating notice and SES will not introduce new issues.

Political Arena

18. SES is a non-partisan organization and registered charity that has worked with and critiqued the positions of all political parties in Saskatchewan, whatever party happens to be governing Saskatchewan, regardless of their ideology. SES has engaged with both the Government of Saskatchewan and Opposition over the past several years on climate change.

Position already Represented

19. SES is a unique organization with an extensive history grounded in Saskatchewan environmental advocacy. No other such organization exists in Saskatchewan. SES has worked both in the public sphere (with community groups, businesses, schools, and individuals), and with the government (at municipal, provincial, and federal levels), which gives us unique insight into all sides of the issue. SES has significant expertise in matters related to climate change and energy solutions. My understanding is that the constitutional analysis requires consideration of the real, practical impacts of the Respondent's actions. SES will be able to provide

evidence and insight into this and what alternatives are available, both technically and economically.

20. SES has focused on sustainable development and pathways to achieve a net-zero future. SES has a long history of advocacy related to SaskPower, power production technologies, and public education related to reliable, affordable, and sustainable electrical generation within the prairie region.

21. Unless otherwise directed by the court, and taking into consideration the evidence the other parties plan on bringing, we intend on providing evidence that includes, but is not limited to:

    a. Urgency of climate emergency: what data and scientists say about our current state and the need for change;

    b. The effectiveness of the Respondent's current actions, including their 2030/2050 goals and commitment to unabated coal-fired power stations;

    c. The Respondent's reasoning and justification for their current actions, such as infrastructure capacity and costs;

    d. Existing pathways to net-zero: interconnections with other jurisdictions; interconnections with currently available power sources within the province; demand side management (energy efficiency and conservation); and

    e. Emerging pathways to net-zero: technological developments, such as Carbon Capture and Sequestration, power sources (hydro, solar, wind, nuclear), and energy storage.

22. In particular, SES can provide valuable insight to the Court on d. and e. of paragraph 21 above and the technical aspects of how we can achieve net-zero. In 2013, the SES produced a report, *Yes They Can: A 2020 Vision for SaskPower,* that analyzed the greenhouse gas emissions situation in Saskatchewan. As lead author, I also wrote a follow-up report in 2021, called *Carbon-Free Electricity for Saskatchewan*, which outlines an updated list of 18 recommendations and how to achieve them. This report is a great summary of the opportunities SaskPower has

to work toward a net-zero this future. Attached as **Exhibit "C"** is a copy of this report. The SES followed up on the *Carbon-Free Electricity for Saskatchewan* report with a letter to SaskPower dated November 2, 2021, wherein the SES urged SaskPower to decarbonize electricity production by 2035 in line with other advanced economies and the projections from the International Energy Agency. Attached as **Exhibit "D"** is a copy of the November 2, 2021 letter to SaskPower.

23. We intend on calling witnesses who have expertise in:

    a. Electrical grids (i.e., how do we supply energy?)

    b. Renewables (i.e., how do we produce energy?)

    c. Abatement (i.e., how do we reduce carbon emissions?)

24. Specifically, we intend submitting expert affidavit evidence from Professor/Dr. Brett Dolter as a witness, whose area of study has been decarbonization and the economics associated with transitioning to net-zero. As faculty at the University of Regina, this witness lives in Saskatchewan and is familiar with our local context and has a strong research background in economics. He has a Master of Resource Management and Environmental Studies from UBC, a Master of Economics degree from the University of Victoria, as well as a PhD from York University, where he focused on pathways for greening the Saskatchewan grid. He has written several papers on modelling pathways to decarbonizing Canada, including on Saskatchewan specifically, as well as the economic and financial implications of transitioning. Attached as **Exhibit "E"** is a copy of his CV.

25. We also intend to call as a witness Dr. Mark Z. Jacobson, Professor of Civil and Environmental Engineering at Stanford University in California and Director of its Atmosphere/Energy Program. He is also Co-Founder of the Solutions Project. Professor Jacobson's career has focused on better understanding air pollution and global warming problems, and developing large-scale clean, renewable energy solutions to them. He has developed roadmaps to transition countries, states, cities, and towns to 100% clean, renewable energy for all purposes and computer models to examine grid stability in the presence of 100% renewable energy. Dr. Jacobson

has served on the Energy Efficiency and Renewables Advisory Committee to the U.S. Secretary of Energy. Based on his work, New York state and California have passed laws to achieve 100% renewable electricity. Dr. Jacobson and his group have developed Wind, Water and Solar plans for all 50 U.S. states, demonstrating how each state could make the transition to 100% renewable electricity. Dr. Jacobson has published 180 peer reviewed journal articles and six textbooks. He has testified before the U.S. House of Representatives and at U.S. Environmental Protection Agency hearings. In 2023, Dr. Jacobson served as an expert witness on behalf of 16 youth plaintiffs in the first climate case in U.S. history, *Held v. Montana*, to discuss the ability of Montana to transition to Wind, Water, and Solar electricity. Attached as **Exhibit "F"** is a truncated copy of Dr. Jacobson's curriculum vitae; in the interests of reducing materials, we have omitted from the exhibit his peer-reviewed journals, lectures/conferences, podcasts/documentaries, television, and op-eds. The following is a link to his full CV: https://web.stanford.edu/group/efmh/jacobson/vita/index.html

26. SES will be able to assist with compiling this evidence and giving the court a clear explanation of how it relates to us as a province. We can fill in the evidentiary and contextual gaps and help ensure that the court has the factual, economic, and scientific understanding of our current, future, and alternative realities in order to make a legally sound decision.

27. We are respectfully asking to be granted leave to participate as an intervenor so we can elaborate on the ways SaskPower could reach a net-zero emission future. I make this affidavit for no improper purpose.

SWORN BEFORE ME at)
the City of Saskatoon,)
in the Province of Saskatchewan,)
this 6th day of February, 2024.)
)
)
CRYSTAL K. RUSSELL)
A NOTARY PUBLIC)
for the Province of Saskatchewan.)
My Appointment Expires: October 31, 2024.)

R. A. HALLIDAY, P.Eng.

Form 8

Saskatchewan
Justice
Corporations
Branch

202149

Corporation Number

Certificate of Restated Articles of Incorporation

The Non-Profit Corporations Act, 1995

THIS IS EXHIBIT "A" REFFERED TO THE AFFIDAVIT OF ROBERT HALLIDAY SWORN BEFORE ME THIS 14th DAY OF FEBRUARY, A.D. 2024.

Crystal Russell

CRYSTAL K. RUSSELL
A NOTARY PUBLIC
for the Province of Saskatchewan.
My Appointment Expires:
October 31, 2024.

I hereby certify that

SASKATCHEWAN ENVIRONMENTAL SOCIETY INC.

has restated its articles of incorporation under section 167 of The Non-profit Corporations Act, 1995 as set out in the attached Restated Articles of Incorporation.

Given under my hand and seal

this 23rd day

of June 19 98

GOVERNMENT OF THE PROVINCE OF SASKATCHEWAN OFFICE OF THE DIRECTOR OF CORPORATIONS CANADA

Philip J. Flory, Director

Kd

3.2-1

Saskatchewan
Justice
Corporations Branch

Restated Articles of Incorporation — Form 4
The Non-Profit Corporations Act, 1995
(section 167 of the Act)

PROVINCE OF SASKATCHEWAN
REGISTERED
CORPORATIONS BRANCH

Please see reverse for instructions

Corporation No.: 202149

1. Name of corporation: Saskatchewan Environmental Society Inc.

2. The municipality in which the registered office is to be situated: Saskatooon

3. The classes of membership: There is only one class of membership. Membership is available only to individuals.

4. Right, if any, to transfer membership interest: none

5. Number (or minimum and maximum number) of directors: Min. 6, max. 12

6. The corporation is: a membership corporation ☐ or a charitable corporation ☒

7. Restrictions, if any, on activities the corporation may carry on or on the powers the corporation may exercise: The activities of the corporation are restricted to those which are in furtherance of the following objectives: to promote environmental quality and to encourage protection of the environment

8. Persons to whom remaining property is to be distributed in the course of liquidation and dissolution of the corporation: Registered Canadian charitable organizations as determined by the membership prior to dissolution.

9. Other provisions, if any:

See Annexe I

The foregoing restated articles of incorporation correctly set out, without substantive change, the corresponding provisions of the articles of incorporation as amended and supersede the original articles of incorporation.

Date	Name	Office Held	Signature
19 June 98	ANN COXWORTH	Board member	Ann Coxworth

Restated Articles of Incorporation, Form 7
The Non-Profit Corporations Act, 1995
Corporation No: 202149
Saskatchewan Environmental Society Inc.

ANNEXE I

9. Other provisions, if any:

9(i) A director of the corporation is required to currently be a member of the corporation and to have been a member of the corporation for a minimum of one year previous to nomination.

9(ii) All directors except the president, including the treasurer, shall be elected for a two-year term at the annual general meeting of the corporation. The terms of the directors shall be staggered so that half the board is elected each year. The president shall be elected annually by the membership for a one year term of office, and shall not serve more than 4 consecutive terms as president.

9(iii) A director may not receive remuneration for his/her service as a board member of the corporation, but he/she may receive remuneration for contracted work with the Society unrelated to his/her voluntary board role. He/she may also receive indemnification for reasonable expenses incurred as a board member on behalf of the corporation. In any matter that financially benefits a board member, a family member of a board member, or an organization or business that a board member is affiliated with, that board member must state his/her conflict of interest and remove him/herself from the meeting at which this is discussed and any/all deliberations associated with the matter. If there is disagreement about whether a conflict of interest exists, that question shall be determined by a vote of the board.

9(iv) The corporation may, at a legally called meeting of members, remove any director or directors from office by a majority vote of those members present at the meeting.

THIS IS **EXHIBIT "B"** REFFERED TO IN
THE AFFIDAVIT OF ROBERT HALLIDAY
SWORN BEFORE ME THIS 14th DAY
OF FEBRUARY, A.D. 2024.

Crystal Russell

CRYSTAL K. RUSSELL
A NOTARY PUBLIC
for the Province of Saskatchewan.
My Appointment Expires:
October 31, 2024.

Saskatchewan Environmental Society

CARBON-FREE ELECTRICITY FOR SASKATCHEWAN

by R. A. Halliday, Lead Author

of the Saskatchewan Environmental Society

April 27, 2021

THIS IS **EXHIBIT** "C" REFFERED TO IN THE AFFIDAVIT OF ROBERT HALLIDAY SWORN BEFORE ME THIS 14th DAY OF FEBRUARY, A.D. 2024.

Crystal Russell

CRYSTAL K. RUSSELL
A NOTARY PUBLIC
for the Province of Saskatchewan.
My Appointment Expires:
October 31, 2024.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2

INTRODUCTION 5

CHANGES IN THE SASKPOWER SYSTEM 6

CARBON CAPTURE AND STORAGE 8
RENEWABLE POWER 9
DEMAND SIDE MANAGEMENT 9
MANITOBA INTERCONNECTION 10
NET METERING 10

CHALLENGES AND OPPORTUNITIES 10

CARBON CAPTURE AND STORAGE – COAL-FIRED POWER STATIONS 11
GAS-FIRED GENERATING STATIONS 11
RENEWABLE POWER 13
MANITOBA INTERCONNECTION 14
DEMAND SIDE MANAGEMENT 14
SMALL MODULAR NUCLEAR REACTORS 15

CAPACITY REPLACEMENT AND EXPANSION OPTIONS 15

CARBON-FREE POWER BY 2040 17

BORDER CARBON ADJUSTMENTS 17
MANITOBA INTERCONNECTION 18
DISPATCHABLE POWER 18
ENERGY STORAGE 18
GRID MODERNIZATION AND SMART GRIDS 19

SES RECOMENDATIONS 19

REFERENCES 21

EXECUTIVE SUMMARY

In 2013, the Saskatchewan Environmental Society (SES) produced a report, *Yes They Can: A 2020 Vision for SaskPower*. The report provided basic information concerning greenhouse gas emissions in Saskatchewan and the SaskPower electricity generation system. The report went on to discuss vulnerabilities and opportunities associated with the SaskPower system. The report presented 18 recommendations covering the short, medium and long term. Short term recommendations could be achieved by 2020, medium term by 2030 and long term beyond 2050. About one-half of the recommendations had short term implications. This report examines and updates the analysis and recommendations from the 2013 report.

Since 2013, SaskPower has transitioned from being a coal-fired utility to a gas-fired utility while increasing its generating capacity by about 10 percent. Figure ES 1 shows generating capacity in 2013 and 2020. In 2018-19, SaskPower generated more electricity using natural gas rather than coal for the first time. That same year only 16 percent of SaskPower's electricity generation was from renewable sources.

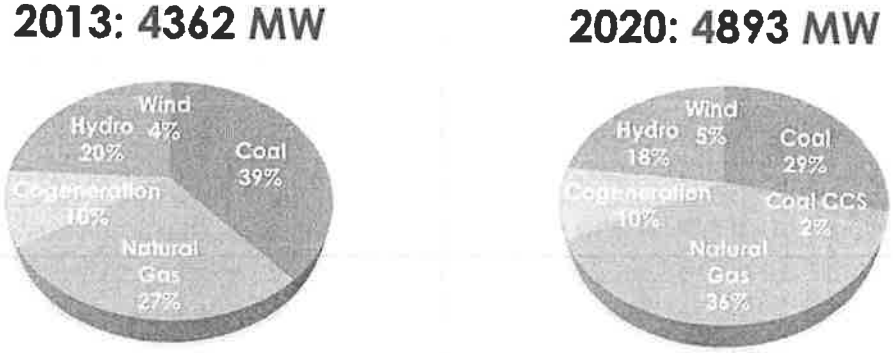


Figure ES 1. SaskPower's Generating Capacity.

Since 2013, SaskPower has committed to basing one half of its generation capacity on renewable sources by 2030, with particular emphasis on wind generation. The corporation has also committed to reducing greenhouse gas emissions to 40 percent below 2005 levels by 2030. Other developments since that time include the operation of Carbon Capture and Storage at Unit 3 of the Boundary Dam Power Station.

SaskPower has made good progress on implementing utility-scale wind generation facilities. These will come to fruition in the near future. On the other hand, there is little evidence of utility scale solar facilities. At present, only 10 MW systems are under development.

SaskPower has achieved its reduced target of 100 MW of demand side management (DSM). In 2007 the corporation had a target of 300 MW. DSM activity has also led to a small decrease in SaskPower's peak demand.

There are several challenges and opportunities in SaskPower's future. The first challenge is to get the utility off coal. While the closure of the remaining units at Boundary Dam Power Station has been announced as imminent, there have been no announcements regarding the Poplar River and Shand power stations. Presumably these also will be closed by 2030.

SaskPower has invested considerably in transitioning to becoming a gas-fired utility and plans to make additional investments in that regard. This leaves the corporation vulnerable to owning stranded assets as the world transitions to a net-zero carbon future by 2050. One opportunity for SaskPower could lie in opting for cogeneration facilities at sites such as potash mines rather that developing additional gas-fired power stations.

While SaskPower can meet its modest 2030 goal for renewable energy generation under its present course of action, meeting post-2030 targets will be very challenging. The best opportunity in this regard lies in strengthening the interconnections between SaskPower and Manitoba Hydro. Other opportunities include more aggressive action on incorporating solar power into the SaskPower grid and increasing attention to DSM.

The SES offers several recommendations for SaskPower's consideration.

1. SaskPower should commit to net-zero carbon emissions by 2040. To support this, its current 2030 goal should be enhanced to a goal of having one-half of its power generation from renewables by 2030. Being net zero by 2040 would be an ambitious target but should be viewed in the context of the planet needing to be net zero by 2050.

2. If a revised 2030 goal is to be met, SaskPower should pursue three options:
    a. Make a 1000 MW interconnection to Manitoba Hydro a high priority for completion by 2030.
    b. Continue to commission utility-scale wind farms up to the capability of the present grid. This would be in the order of 20 to 25 percent of capacity.
    c. Take the necessary steps to enable commissioning of utility scale solar stations by 2030. The target should be 500 MW of solar capacity.

3. SaskPower should formally announce its intent to decommission the Poplar River Power Station by 2030. This would remove uncertainty and allow appropriate transitional measures to be put in place at Coronach.

4. SaskPower should enhance its commitment to demand-side management to 500 MW.

5. SaskPower should continue to seek cogeneration opportunities in the order of 500 MW.

6. SaskPower should continue to investigate the feasibility of geothermal power production in the province.

7. SaskPower should continue to work on smart grid and related grid modernization technologies so that renewable power can be successfully integrated into its system.

8. SaskPower should pursue pilot projects related to energy storage using compressed air and large batteries and any other options. SaskPower should engage external expertise to develop a comprehensive plan for energy storage by 2023 and establish a pilot project by 2025.

INTRODUCTION

In 2013 the Saskatchewan Environmental Society (SES) produced a report, *Yes They Can: A 2020 Vision for SaskPower*. The report provided basic information concerning greenhouse gas emissions in Saskatchewan and the SaskPower electricity generation system. The report went on to discuss vulnerabilities and opportunities associated with the SaskPower system. The report presented 18 recommendations covering the short, medium and long term. Short term recommendations could be achieved by 2020, medium term by 2030 and long term beyond 2050. About one-half of the recommendations had short term implications. It may be useful, therefore, to consider how close SaskPower has come to meeting those recommendations. This report examines and updates the analysis and recommendations from the 2013 report. The report also reviews changes in SaskPower's generating capacity and policies in recent years.

Figure 1 shows the distribution of greenhouse gas (GHG) emissions in 2018 for Canada and Saskatchewan. From 2011 to 2018 Canadian GHG emissions have increased by two percent while those of the electricity sector have decreased by 18 percent, largely because of Ontario's closure of coal-fired power stations. In the same period, Saskatchewan's GHG emissions have increased by eight percent while those in the electricity sector have decreased by three percent. Since 2000 GHG intensity, as measured *per capita* or per unit of gross domestic product, has trended down even as actual emissions have increased.[1] Measures taken thus far to reduce GHG emissions, while useful, have been insufficient.

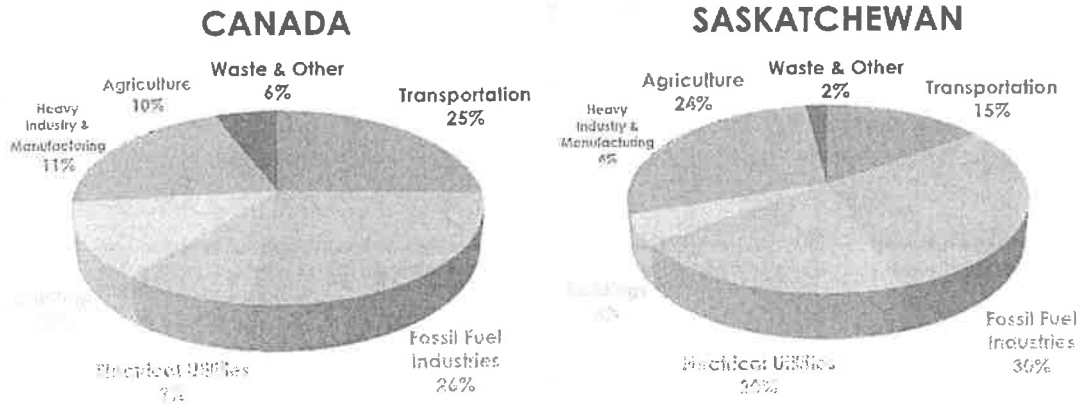


Figure 1. Greenhouse Gas Emissions – 2018.

In 2013, SaskPower produced 15.2 Mt of CO_2 equivalent and in 2020 produced about 16 Mt. While SaskPower is committed to reducing greenhouse gas emissions to 40 percent below 2005 levels by 2030, actual reductions still lie in the future. SaskPower's emissions will not attain

[1] SaskPower's GHG emissions may be levelling off as they did not increase from 2017 to 2018.

2005 levels until 2023. This places the likelihood of achieving more aggressive targets in some doubt. The corporation's modest goals and leisurely pace are a cause for concern.

CHANGES IN THE SASKPOWER SYSTEM

The current SaskPower system is shown in Figure 2, which illustrates the current SaskPower system map.

Figure 2. The SaskPower System.

Over the past several years SaskPower has transitioned from a coal-dominated utilty to a natural gas dominated utility. Figure 3 depicts the corporation's capacity in 2013 and 2020. In 2013, the installed capacity of the SaskPower system was 4362 MW. By 2020 this had increased to 4884 MW. There has been a slight decrease in conventional thermal-coal generation because of the conversion of one unit at the Boundary Generating Station to carbon capture and storage. The increase in generating capacity is made up for the most part by additional gas capacity added at the Queen Elizabeth Power Station in Saskatoon and the new Chinook Power Station at Swift Current. SaskPower has pledged to increase

generating capacity from renewable sources to 50 percent by 2030. At present about 25 percent of the corporation's capacity is from renewable sources.

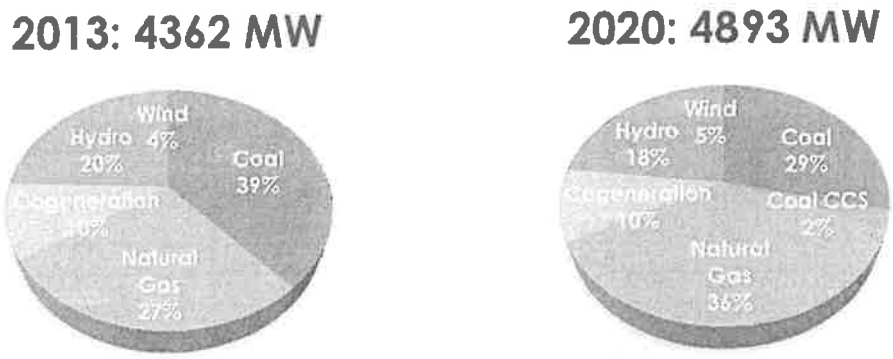


Figure 3. SaskPower's Generating Capacity.

SaskPower's installed capacity does not translate directly into power generation. It is noteworthy that 2018-19 is the first year in which the corporation generated more electricity from natural gas than from coal. In that same year only 16 percent of SaskPower's electricity generation came from renewable sources (SaskPower, 2020).

Environment Canada maintains a database of GHG emissions from large industrial sources. Any facility emitting more than 50,000 tonnes of CO_2 equivalent annually is entered into the database. Saskatchewan now records all such facilities emitting more than 10,000 tonnes of CO_2 equivalent. There are now 90 such facilities in Saskatchewan. Of these, electricity generation facilities, most of them owned by SaskPower, account for 20 percent of the 77.8 Mt of CO_2 equivalent produced in Saskatchewan in 2017. Table 1 displays the facilities related to electricity generation.

Table 1. GHG Emissions at SaskPower and Related Facilities.

Facility	Organization	Location	GHG Emissions (tonnes CO2 equiv.)	
			2009	2019
Boundary Dam PS	SaskPower	Estevan	7,321,598	5,501,399
Poplar River PS	SaskPower	Coronach	4,247,967	3,936,648
Shand PS	SaskPower	Estevan	2,152,063	2,362,553
Queen Elizabeth PS	SaskPower	Saskatoon	343,376	1,366,727
Meridian Cogeneration	TransAlta	Lloydminster	821,350	888,851
North Battleford GS	Northland Power	North Battleford		740,256
Cory Cogeneration	ATCO Power	Cory	529,613	607,709
Yellowhead PS	SaskPower	North Battleford		174,756
Landis PS	SaskPower	Landis		109,098
Spy Hill GS	Northland Power	Spy Hill		90,143
Meadow Lake PS	SaskPower	Meadow Lake		49,323
Boundary Dam Mine	Prairie Mines	Estevan	50,297	45,356
Poplar River Mine	Prairie Mines	Coronach		21,387
Total Emissions				**15,894,206**

There are other significant changes since the SES report in 2013. These include the evolution of Carbon Capture and Storage (CCS) in the province, renewable power developments, Demand Side Management (DSM), Manitoba interconnections, and changes in the net metering program.

Carbon Capture and Storage

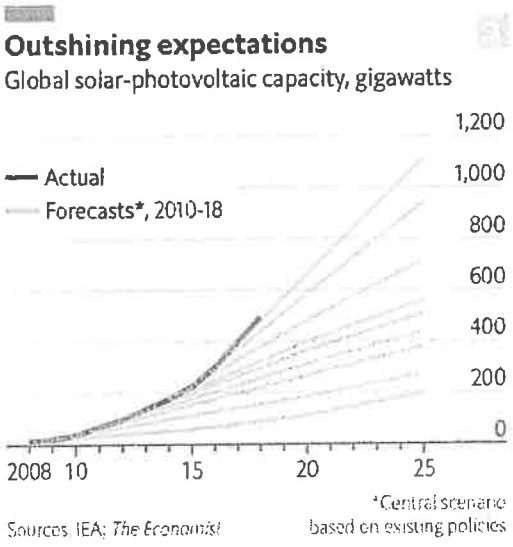
In 2014, operation began at the CCS conversion of Unit 3 at SaskPower's Boundary Dam Power Station. The unit has a capacity of 110 MW at a cost of approximately $1.5 billion (International CCS Knowledge Centre 2018). This was the world's first commercial scale CCS retrofit at a coal-fired power station. The unit uses amine solvents to strip both carbon dioxide and sulphur dioxide from the flue gas. The target is to remove 100 percent of sulphur dioxide and 90 percent of the carbon dioxide, making GHG output from the unit lower than from the equivalent natural gas station. The carbon dioxide produced is sold to Cenovas Energy for use in its enhanced oil recovery projects. There are still questions as to whether this CO_2 can be considered as permanently removed from the atmosphere. A test facility for sequestration of carbon dioxide in deep saline aquifers is also part of the project.

Although the unit has experienced problems in its early years of operation, it is becoming increasingly reliable and experiencing months-long periods of continuous operation. There is still an expectation that design carbon dioxide removal levels can be met.

Renewable Power

SaskPower has committed to reducing GHG emissions to 40 percent below 2005 levels by 2030. Part of that commitment will be met by decommissioning Units 4 and 5 at Boundary Dam Power Station and, probably, decommissioning the Poplar River Power Station. Some of that lost capacity will be made up by new gas-fired generating stations but the corporation has also committed to obtaining 50 percent of its capacity from renewable sources by 2030. The fate of the Shand Power Station is moot at this time. In 2013, SES recommended that all of SaskPower's coal-fired power stations be decommissioned at the end of their useful life.

At present, the lowest cost power available is wind power and the cost of solar power is almost as low. The dramatic decrease in the cost of wind and solar power was not anticipated in the 2013 SES report. Depending on specific situations, wind and solar costs are now just a little lower than those for natural gas-fired generation, based on what are known as levelized costs.



Although not evident in Figure 3, SaskPower has initiated a number of wind power installations. These will come to fruition in the near future. Additions to wind power capacity in Saskatchewan tend to be in the order of 200 MW for each project. In 2013, SES recommended that 20 percent of SaskPower's generating capacity be wind by 2020 and that 20 percent of power generation be wind by 2030.

Although Saskatchewan has the greatest solar power potential of any province in Canada, SaskPower is just starting to examine those opportunities. Proposed installations are in the 10 MW range. Currently, the sum of solar power produced by individual home and business owners in Saskatchewan is greater than that produced by SaskPower. The adjacent figure shows how actual growth in the development of solar-photovoltaic power has routinely exceeded International Energy Agency forecasts. SaskPower is also supporting an 8 MW biomass plant and is exploring geothermal possibilities near Estevan.

Demand Side Management

In 2007, SaskPower's commitment to DSM was 300 MW. This was subsequently reduced to 100 MW but the corporation states that 156 MW has been achieved to a large extent through commercial lighting and industrial energy optimization. A key metric pertaining to

DSM is reduction in peak demand. In 2019-20, DSM reduced SaskPower's peak demand by 6.7 MW. In 2013, SES recommended that the 300 MW commitment be reinstated.

Another development in reducing demand was Saskatchewan's adoption of the *National Energy Code for Buildings* in January 2019. This is a national model code that can be adopted by provincial and territorial governments. The code sets out technical provisions to address energy efficiency in the design and construction of new buildings and additions to existing buildings. It helps promote consistency among provincial and territorial building codes and, as such, represents a minimum code.

Manitoba Interconnection

In 2013, SES proposed that SaskPower should purchase 1000 MW of capacity from Manitoba Hydro as a means of aggressively improving its use of renewable power. At present, the corporation purchases 125 MW from Manitoba Hydro and is in the process of improving transmission line capacity to enable a purchase of an additional 215 MW beginning in 2022 (SaskPower 2020).

Net Metering

On November 1, 2019, SaskPower revised its net metering program to eliminate capital rebates on installations and to reduce the credit for excess energy to the grid to 7.5 cents/kWh, rather than the previous 14 cents/kwh. That is, credits would be charged at wholesale, rather than retail rates. The reason ostensibly was that the program had reached an arbitrary cap of 16 MW two years early.

CHALLENGES AND OPPORTUNITIES

SaskPower is gradually moving in the right direction but lacks a sense of urgency in meeting its modest 2030 target of sourcing 50 percent of its capacity from renewable power. This target can be compared to that of the new government in the United States' plan of eliminating carbon emissions from the electricity sector by 2035. Alberta's independent power producers have recently announced that they will be off coal by 2023. SaskPower is currently considering a commitment to non-carbon electrical power by 2050. Recent events by other jurisdictions render that commitment inadequate.

The SES supports an immediate change in the SaskPower 2030 target to having 50 percent of SaskPower's annual **generation** being from renewable sources by 2030. This target would be simply a stepping-stone to ensuring that SaskPower can source all of its electricity generation from non-fossil fuel sources by 2040. There are several considerations in meeting such a target.

Carbon Capture and Storage – Coal-fired Power Stations

SaskPower is committed to closing down the remaining non-CCS units at Boundary Dam Power Station in 2021 and 2024. As stated earlier in this report, the Poplar River Power Station will be decommissioned although it is unlikely that this will happen before 2030. The only remaining opportunity for an additional coal-fired CCS facility in Saskatchewan would be the conversion of the 276 MW Shand Power Station to CCS. In the normal course of events the Shand station would reach the end of its useful life in 2042, but federal policy requires that coal-fired generating stations be closed by 2030. According to a report by the International CCS Knowledge Center (2018), it's possible that CCS at Shand could be implemented for about one-third of the cost of CCS at Unit 3 of the Boundary Power Station. Assuming this optimistic capital cost scenario is correct, parasitic load would reduce the capacity of the Shand unit to about 210 MW. This means that converting Shand to CCS would provide 210 MW capacity at a cost of about $500 million. This is high-cost power.

The cost of power generated by the CCS unit at Boundary Dam Power Station is defrayed to a considerable extent by sales of carbon dioxide to the oil industry. Enhanced oil recovery using carbon dioxide injection may increase existing oil field lifetimes by about 20 years. That is less than the anticipated lifetime of a CCS facility. The potential for sales of carbon dioxide to the oil industry for the entire anticipated life of a CCS station therefore depends on not only selling to existing fields, but also on as yet undeveloped oil fields. The viability of installing CCS at Shand will depend on the outlook for future oil field development in south-eastern Saskatchewan. In the era of the climate change crisis, future oil field developments in North America are fraught with uncertainty. SaskPower will have to make a decision concerning CCS at Shand by 2025. In general, the markets for industrial carbon dioxide are much smaller than the quantities that would be produced by significant adoption of CCS.

Gas-fired Generating Stations

SaskPower has added a number of gas-fired generating stations in recent years and two additional stations, a 353 MW station at Moose Jaw, and at least one at a location still to be determined, are under development. As stated earlier in this report, natural gas, not coal, is the current fuel of choice for SaskPower. All of SaskPower's gas-fired stations now use combined-cycle technology. Nonetheless, in the looming era of emissions-free electricity, gas-fired plants are an anachronism. SaskPower risks its proposed stations becoming stranded assets or, perhaps, being obliged to add CCS capability or pay for carbon offsets[2] to continue operation for their usual lifetimes. There are also concerns that fugitive methane emissions associated with some natural gas production makes this fuel almost as GHG-intensive as coal (Tollefson 2013, Chan *et al.* 2020).

[2] Canada's policy with respect to the sale of carbon offsets is still under development. It is unlikely, however, that a GHG emitter would be able to cover all emissions from a site through the purchase of carbon offsets.

SaskPower has power purchase arrangements for electricity from two private sector gas-fired generating stations with a total capacity of 360 MW. These stations will reach their useful life in the early 2030s. SaskPower needs to be diligent in ensuring that private sector investments in gas-fired electricity generation do not foreclose longer term objectives for producing carbon-free electricity.

There are additional opportunities related to cogeneration of electricity in the province. Experience with the 249 MW facility at the Cory Potash mine near Saskatoon and the 228 MW facility near Lloydminster has proven cogeneration to be reliable and successful. Instead of burning natural gas to produce only industrial heat, these facilities also produce electricity. Additional cogeneration capacity in the order of 500 MW could help replace decommissioned coal-fired stations. A commitment to cogeneration would reduce the risk of owning stranded gas-fired power station assets. There are potential cogeneration opportunities associated with potash mining and with the proposed Paper Excellence pulp mill at Prince Albert.

Another possibility for natural gas-fueled power stations is to re-fuel them using hydrogen. Hydrogen fuel cells have been used in transportation for decades and work is progressing related to hydrogen-fueled conversions of thermal power stations.

Generally, hydrogen fuel is defined by colours, depending on the means of production. There are four versions of hydrogen, three of which depend usually on natural gas as a feedstock and one that uses water as a feedstock. Grey hydrogen can be made from natural gas, coal or biomass and produces significant carbon dioxide emissions. Much of the hydrogen produced today is grey and is used to make ammonia, or in the oil and gas sector. If the carbon dioxide produced by making grey hydrogen is captured and stored by means of CCS technology, the hydrogen is known as blue hydrogen. Minor GHG emissions remain, however. Finally, natural gas – primarily methane, CH_4, – can be stripped of its hydrogen using a process known as molten metal pyrolysis to produce pure hydrogen and pure carbon, known as carbon black, which has a number of industrial uses. The hydrogen produced is known as turquoise hydrogen and its production is GHG-free. That said, markets for carbon black are limited and turquoise hydrogen production in the Canadian Prairies poses other challenges.

Hydrogen can also be produced using electrolysis of water. Referred to as green hydrogen, it is also GHG-free if the electricity supply used is GHG-free. It takes about nine litres of water to produce one kilogram of hydrogen. There is likely sufficient water supply from the North Saskatchewan River to enable a limited amount of green hydrogen production. One challenge, however, relates to the energy demand for low-temperature electrolysis. Renewable energy supplies do not produce waste heat that could be used to reduce power demands for electrolysis.

Salt caverns can be used for storage of hydrogen. Bulk storage of hydrogen in Saskatchewan would be quite feasible.

Today's natural gas turbines can be fueled by a mixture of natural gas with some additional hydrogen. There is an embrittlement challenge in using pure hydrogen with moving or vibrating components. It is unlikely that existing turbines can be converted to pure hydrogen fuel. A new generation of hydrogen-fueled power stations will not be available before 2030.

Renewable Power

If SaskPower is to meet its renewable capacity goal by 2030, the corporation must decommission and replace 1410 MW of coal-fired capacity with almost exclusively emissions-free capacity in the next 10 years. The need for capacity increases must also be considered. The utility has acquired experience in developing the wind energy sector and one-half of the replacement power could be from wind without necessitating significant investments in grid improvements and storage. SaskPower is on a path that would meet that target.

Another opportunity lies in the development of a 420 MW hydro-electric generating station at The Forks – 18 km downstream of the confluence of the North and South Saskatchewan rivers. Like the Nipawin generating station, this would be essentially a run-of-the river facility. This project encompasses the territory of the James Smith First Nation and could not be developed without their concurrence and support. The First Nations Power Authority could be instrumental in developing such a project.

SaskPower has designed a small-scale, low-head, 40 MW hydroelectric generating station known as Tazi Twé. It could be developed at Elizabeth Falls on the Fond du Lac River if and when electricity demand for northern mines is sufficient to justify the project. There are other small-scale hydro opportunities in the province, but these should be considered special situations, not part of the path to a renewable future.

Some of the additional renewable generating capacity could come from solar photovoltaic generating stations but SaskPower's limited experience with solar power makes this a challenge. In contrast, a 465 MW solar project is now under construction in Alberta. Saskatchewan's solar resource is unparalleled in Canada and is generally best in the area south of the TransCanada Highway. One might expect that one or two utility-scale 300 MW systems could be commissioned near Coronach or Estevan in the next decade. These locations would also facilitate connections to existing transmission lines.

Locating solar installations near Coronach and Estevan could help in the redeployment of some SaskPower workers directly affected by coal-powered station shut-downs. Decarbonizing electrical power production in the province has significant consequences for both communities. A thoughtful approach to making the transition to renewable power should benefit communities and individual workers (Carlson *et al.* 2018).

Solar power becomes increasingly attractive as SaskPower's peak demand switches from a winter peak to a summer peak. At present, the record winter peak demand is 3792 MW while the record summer peak is 3524 MW. The change in timing of peak demand will likely occur before 2030. A significant investment in solar power is warranted, in the order of 500 to 1000 MW.

The development of significant biomass or geothermal capacity is also constrained by SaskPower's lack of experience. One fairly recent biomass development is what is known as Bioenergy with Carbon Capture and Storage (BECCS). Many European companies are converting coal-fired power stations so that they can be fueled by biomass, usually wood pellets imported from the United States. While biomass fuel can be thought of as "fast coal" the carbon cycle calculations are complex. The addition of CCS to a biomass power station raises the prospect of "negative carbon". One such example is the 4000 MW Drax Power Station in England. Carbon pricing in Europe has made conversions financially attractive. Is it worth considering the Shand Power Station as a candidate for such a conversion?

In the case of geothermal power, it is not yet clear if the province has sufficient potential to make this a realistic option. The Deep Earth Energy Production (DEEP) project is investigating geothermal potential in the Deadwood Formation in the Williston Basin near Torquay. A 20 MW plant is under design. The project is supported by funding from Natural Resources Canada.

Manitoba Interconnection

The most straightforward means by which SaskPower can meet its 2030 renewable power goal is by implementing transmission lines from Manitoba Hydro to Saskatchewan (White-Crummy 2019) totaling 1000 MW capacity. The SES proposed this in 2013. The capital cost of such a line would be in the order of $1.8 billion, a little more than SaskPower paid to develop 110 MW CCS capacity at Boundary Generating Station. If development of such a transmission line were tied directly to the closure of SaskPower's coal-fired generating stations, it would be reasonable to anticipate that the federal government would pick up half the cost of the line. This could be an appropriate investment for the Canada Infrastructure Bank. Indeed, the bank has a notional allocation of $2.5 billion for interprovincial transmission lines.

Demand Side Management

Reducing power demand through conservation and energy efficiency is the least cost option in meeting current and future power demands. It would be reasonable at the very least for SaskPower to re-instate its 2007 demand side management target, thereby avoiding adding 300 MW of capacity by 2030. An overall DSM target of 500 MW appears feasible. The implementation of smart meters will also assist demand side management.

Small Modular Nuclear Reactors

Small Modular Reactors (SMRs) are generally defined as nuclear reactors with a design capacity of 300 MW or less. For a utility as small as SaskPower, 300 MW is a reasonable increment of generating capacity. In theory, an SMR uses modular technology and factory fabrication to deliver the finished reactor to a site. The idea is that many, many identical SMRs would be produced in a single factory, leading to significant cost savings. There are myriad SMR designs, none of which have been commissioned, although Ontario Power Generation is working with vendors to bring a grid-scale SMR on-line by 2028 at its Darlington Power Station. SMR proposals use various cooling methods such as pressurized water, liquid metal, molten salt, or gas. Natural Resources Canada is working with several provinces, including Saskatchewan, on an SMR Action Plan. SaskPower will evaluate the potential deployment of 900 MW of generating capacity between 2035 and 2042 using SMRs (SMR Action Plan: SaskPower 2021). The development of a 300 MW SMR is a somewhat different alternative to larger existing designs and SaskPower does not intend to be a leader in SMR development as it was with CCS.

SES has long held the view that nuclear power would not be an appropriate choice for Saskatchewan. Given the present timelines for SMR development and progress to date, it is unlikely that a financially viable unit will be available in time to play a role in SaskPower transitioning to a non-carbon future. The reality is that designing, testing, problem-solving, licensing, and commercializing an SMR product can only be realized with enormous government subsidies and will take decades. The perpetual problem of managing nuclear waste remains, irrespective of the size of the generating station. Like power produced by coal-fired power stations, power from nuclear reactors is not usually dispatchable. In addition, the nuclear industry is fraught with cost and timetable overruns.

CAPACITY REPLACEMENT AND EXPANSION OPTIONS

Table 2 summarizes the existing and proposed possibilities for adding to SaskPower's capacity by 2030. The additions include projects that are virtually certain and some that are more speculative. Two gas-fired stations will unquestionably be constructed, as will several wind generating stations, two small solar photovoltaic stations, and a 100 MW capacity connection to Manitoba Hydro. Future capacity needs, GHG reduction targets, and renewable power commitments can be met if SaskPower implements the proposed connections to Manitoba Hydro even if the Shand Generating Station is shut down.

Table 2. Capacity Replacement and Expansion Options Being Considered by SaskPower.

Project	Type	Capacity in MW	Status	Non-carbon
Shand GS	CCS Coal	220	Under Consideration	no
Great Plains GS	Natural Gas	353	Contract Awarded	no
Natural gas - Other	Natural Gas	353	Under Development	no
Blue Hill	Wind	177	Under Construction	yes
Golden South	Wind	200	Under Construction	yes
Capstone Wind	Wind	10	Under Construction	yes
Foxtail Grove	Solar	10	Under Construction	yes
Highfield	Solar	10	Under Development	yes
Birtle to Tantallon	Interconnection	100	Under Construction	yes
50-200 MW RFP	Wind	up to 400	Contract award 2021	yes
Winnipeg to Regina	Interconnection	215	Under Consideration	yes
TOTAL		2,048		

In a recent document (SaskPower 2021), SaskPower specifically states that the loss of 1400 MW of conventional coal generation will be made up by the addition of 1118 MW of natural gas generation, 685 MW of wind generation, 190 MW of hydro imports, and 183 MW of solar, geothermal and other. Comparing this statement to Table 3 implies that Shand CCS will not go ahead, nor will a major interconnection with Manitoba Hydro. The shortfall would be made up by additional natural gas power stations.

Although the path to 2030 is feasible, the significant reliance on additional natural gas power stations comes with considerable risk as outlined earlier in this report. The alternative would be for SaskPower to continue operating the stations for their lifetime while implementing CCS and purchasing carbon offsets to compensate. This would be expensive power. Other options from which non-carbon power increments could be selected are shown in Table 3. These are all alternatives identified by SES in 2013, but the capacity figures have been adjusted to meet current realities.

Table 3. Other Capacity Replacement and Expansion Options.

Project	Type	Capacity in MW	Status	Non-carbon
Cogeneration	Natural gas	500	SES Proposal	yes
The Forks	Hydro	420	Needs FN Concurrence	yes
Southern Sask.	Wind	600	SES Proposal	yes
Coronach/Estevan	Solar	500	SES Proposal	yes
Conservation	DSM	350	SES Proposal	yes
Winnipeg to Regina	Interconnection	700	SES Proposal	yes
TOTAL		3,070		

Beyond 2030, the challenge for SaskPower is considerable if carbon-free generation by 2040 becomes the goal. Matching the American goal of carbon-free by 2035 can only be achieved by implementing CCS or buying carbon offsets for 1700 MW of gas-fired generation to avoid decommissioning in the next 15 years. It should be noted that Canada's major hydropower utilities are either carbon-free already or will be by 2030. Ontario Power Generation plans to be carbon-free by 2040. Alberta plans to be off coal by 2023.

CARBON-FREE POWER BY 2040

However, SaskPower can easily meet its commitment to having 50 percent of its installed capacity in renewable power by 2030 based on decommissioning conventional coal-fired generating stations, investing in wind and solar power, and making a major connection to Manitoba Hydro. The corporation can also meet an upgraded goal of 50 percent generation from renewable power with further investments in hydro power, utility-scale solar power, and demand-side management. In effect, some 1700 MW of gas-fired power generation must be decommissioned and replaced.

There are several challenges in these next steps. Two are external to Saskatchewan and others are within the province.

Border Carbon Adjustments

Border Carbon Adjustments or Border Tax Adjustments (BAT) are taxes on imported products by countries that pay for their GHG emissions on countries or companies that do not. This concept has been discussed for at least 20 years and is very much in the thinking of the European Union (EU) (Hontelez 2007). Such a tax related to aviation fuel is already part of the EU approach. The general consensus is that a BAT will clear GATT and WTO rules (Pauwelyn, 2012). As one of the world's highest per capita producers of GHGs and a significant exporter of commodities, it is not out of the question that Saskatchewan would be vulnerable to

imposition of BATs by American and EU governments that take climate change seriously. Indeed, the situation in Saskatchewan and Alberta could make Canada vulnerable to such impositions. In effect, Saskatchewan could find itself on the wrong side of a "carbon fence".

Manitoba Interconnection

There are various opportunities for SaskPower to strengthen its connection to Manitoba Hydro. At present there is a hiatus in American demand for power from Manitoba, but this could change as the United States embarks on an aggressive agenda to remove carbon from the power generation process. The benefits of a robust connection go beyond simple power purchases. The interconnections enable exchange of power generated by ephemeral sources such as wind and solar, reducing grid stability issues. A more significant interconnection also would allow both utilities to decrease distribution system energy losses by incorporating elements of grid modernization and smart grid optimization. (About 10 percent of electrical energy generated is lost in transmission and distribution systems. Power engineers speak of conservation of VARs (volt-ampere-reactive power).)

Dispatchable Power

Dispatchable power is power whose supply can be readily adjusted to meet demand. Hydroelectric and gas-fired power supplies are dispatchable while coal-fired and SMR supplies are not. Neither are intermittent supplies like wind and solar. The challenge for SaskPower in moving to a non-carbon system is to develop sufficient additional dispatchable supply in addition to present and future hydroelectric generating stations. The connection to Manitoba will help in this regard. Developing utility-scale energy storage systems is another.

Energy Storage

There are currently several opportunities for energy storage in Saskatchewan. Currently, complementary operation of hydro operations with intermittent wind power allows water to be stored in Lake Diefenbaker when the wind or solar power stations are producing and to generate hydro power when they are not. As wind and solar facilities expand this can continue.

Saskatchewan's sub-surface geology provides another energy storage opportunity, namely using Compressed Air Energy Storage (CAES). The province has a long history of using salt caverns for natural gas storage at depths of 800 to 1200 m. Caverns are created by brine washing. The quantity of brine used is about three times the cavern size. Brine is disposed of in deep groundwater formations, like the Deadwood formation. For CAES, off-peak energy is used to pump air into the cavern and when energy is required the compressed air is released through a turbine to generate electricity. Several storage methods exist with systems that have a capacity of a few hundred megawatts and the ability to store a few thousand megawatt-hours of power (B. Brunskill, personal communication 2020).

Advances in battery storage also provide opportunities for managing intermittent power sources. Tesla has introduced utility-scale energy storage based on the company's lithium-ion Megapak. A 100 MW unit was installed in South Australia at a cost of US$50 million. It was deemed to have saved US$40 million in its first year through stabilizing and balancing the grid. An expansion to 150 MW is underway. In 2013, California passed legislation requiring investor-owned utilities to provide 1325 MW of storage by 2024. That storage is currently being installed. SaskPower is currently installing a 20 MW system in Regina. Battery storage systems, whether existing or proposed, serve only to smooth daily fluctuations in power generation. They are inadequate in coping with longer-term fluctuations.

Many countries are making commitments to requiring all new vehicles to be internal combustion engine-free by 2025 to 2035. Quebec, thus far, is the only Canadian jurisdiction to make such a commitment. A large fleet of electric vehicles in Saskatchewan, combined with smart grid and related technology, would provide an opportunity for storing surplus energy.

Whether hydro, compressed air or battery, these storage options all provide dispatchable power aimed at levelising power supply. At present compressed air and battery systems will levelise supply over days, not weeks.

Grid Modernization and Smart Grids

Integrating large-scale intermittent renewable energy sources, decentralized energy supplies and bidirectional energy flows requires significant investments in the electrical grid. The end result of investments in advanced metering, communications, control systems, and computer processing is commonly described as a smart grid. These new systems tend to include advanced digital meters that give consumers better information and automatically report outages, relays that sense and recover from faults in the substation automatically, automated feeder switches that re-route power around problems, and batteries that store excess energy and make it available later to the grid to meet customer demand. Natural Resources Canada is funding smart grid projects throughout Canada and SaskPower is participating in that program (Natural Resources Canada 2020).

SES RECOMENDATIONS

In the last several years SaskPower has made very little progress on reducing GHG emissions. In its 2013 report SES offered proposals as to how carbon emissions could be significantly reduced but the slow pace of SaskPower's transition to decarbonizing its power generation leaves the 2030 goals of reducing GHG emissions to 40 percent below 2005 levels and to having one half of its generating capacity based on renewables by 2030 a challenge. The SES offers several recommendations for SaskPower's consideration.

1. SaskPower should commit to net-zero carbon emissions by 2040. To support this, its current 2030 goal should be enhanced to a goal of having one-half of its power generation from renewables by 2030. Being net zero by 2040 would be an ambitious target but should be viewed in the context of the planet needing to be net zero by 2050.

2. If a revised 2030 goal is to be met, SaskPower should pursue three options:
    d. Make a 1000 MW interconnection to Manitoba Hydro a high priority for completion by 2030.
    e. Continue to commission utility-scale wind farms up to the capability of the present grid. This would be in the order of 20 to 25 percent of capacity.
    f. Take the necessary steps to enable commissioning of utility scale solar stations by 2030. The target should be 500 MW of solar capacity.

3. SaskPower should formally announce its intent to decommission the Poplar River Power Station by 2030. This would remove uncertainty and allow appropriate transitional measures to be put in place at Coronach.

4. SaskPower should enhance its commitment to demand-side management to 500 MW.

5. SaskPower should continue to seek cogeneration opportunities in the order of 500 MW.

6. SaskPower should continue to investigate the feasibility of geothermal power production in the province.

7. SaskPower should continue to work on smart grid and related grid modernization technologies so that renewable power can be successfully integrated into its system.

8. SaskPower should pursue pilot projects related to energy storage using compressed air and large batteries and any other options. SaskPower should engage external expertise to develop a comprehensive plan for energy storage by 2023 and establish a pilot project by 2025.

REFERENCES

Chan, E., D.E.J. Worthy, D. Chan, M. Ishizawa, M.D. Moran, A. Delcloo, and F. Vogel, 2020. Eight-year Estimates of Methane Emissions from Oil and Gas Operations in Western Canada are Nearly Twice Those Reported in Inventories. *Environmental Science and Technology*. 54: 14899-14909.

Coxworth, Ann, 2021. *Small Modular Nuclear Reactors*. Saskatchewan Environmental Society. Saskatoon, SK. 2 pp.

Carlson, H., Fisher, J., and Malena-Chan, R., 2018. *Bridging the Gap: Building bridges between urban environmental groups and coal-producing communities in Saskatchewan*. Climate Justice Saskatoon. Saskatoon, SK. 50 pp.

Government of Canada and many other, 2021. *Small Nuclear Reactor Action Plan*. Saskatchewan and Bruce Power Chapters. Government of Canada, Ottawa.

Hontelez, J., 2007. *Time to Tax the Carbon Dodgers*. BBC News.

International CCS Knowledge Centre, 2018. *The Shand CCS Feasibility Study – Public Report*. International CCS Knowledge Centre, Regina, SK. 124 pp.

National Research Council of Canada 2017. *National Energy Code for Buildings*. NR24-24/2017E. National Research Council, Ottawa, OM. 244 pp.

Natural Resources Canada, 2020. Smart Grid Program Overview. Natural Resources Canada, Ottawa, ON. 16 pp.

Pauwelyn, J. 2012. Carbon Leakage Measures and Border Tax Adjustments under WTO Law. In D. Prevost and G. Van Calster (eds), *Research Handbook on Environment, Health and the WTO*. Edward Elgar Publishing, Cheltenham, UK.

Prebble, P., M. Asmuss, A. Coxworth, and B. Halliday, 2018. *Prairie Resilience is Not Enough: The Saskatchewan Environmental Society's Response to the Saskatchewan Government's Climate Change Plan*. Saskatchewan Environmental Society. Saskatoon, SK. 43 pp.

Saskatchewan Environmental Society, 2013. *Yes They Can: A 2020 Vision for SaskPower*. Report prepared for submission to Saskatchewan Power Corporation. Saskatchewan Environmental Society. Saskatoon. 43 pp.

SaskPower 2020. *2018-19 Annual Report*. SaskPower, Regina.

Tollefson, Jeff, 2013. US government underestimated methane emissions. *Nature News & Comment.*

Wittrock, V. 2016. *Climatic Extremes and the Energy Sector's Vulnerability: Now and in the Future - Focus on the Canadian Portion of the Souris River Watershed: A Literature Review.* Prepared for Environmental Systems Assessment Canada Ltd as part of the Natural Resources Canada Adaptation Platform Energy Working Group. SRC Publication No. 13757 - 1E16. 78 pp.

White-Crummy, A., 2019. SaskPower exploring $1.8-billion link with Manitoba Hydro. *Saskatoon Star-Phoenix,* 2019-12-08.

TELEPHONE
1.306.665.1915

EMAIL
info@environmentalsociety.ca

WEBSITE
www.environmentalsociety.ca

MAIL
PO Box 1372 Saskatoon SK S7K 3N9

OFFICE
220 20th Street West Saskatoon

November 2, 2021

Mike Marsh
President and Chief Executive Officer
SaskPower
2025 Victoria Avenue
Regina SK
S4P 0S1

Dear Mr. Marsh,

Re: SaskPower's Zero Carbon Future

Earlier this year the Saskatchewan Environmental Society (SES) issued a report entitled *Carbon-free Electricity for Saskatchewan*. Among other things that report called on SaskPower to be carbon-free by 2040, ten years earlier than SaskPower's target. Recent developments, both international and national, have led us to revise our opinion.

The European Union will obtain 80 percent of its power from non-carbon sources by 2030. The United States has a non-carbon electricity target of 2035 and the British government also plans to eliminate fossil fuels from power generation by 2035. The 2035 goal is consistent with a call by the International Energy Agency for advanced economies to decarbonize electricity production by 2035 and other economies by 2040.[1] Even more recently, the recently re-elected federal government has pledged net-zero electricity by 2035. Well-known energy economist Dr. Mark Jaccard has proposed that federal "policies set a net-zero deadline [for provincial electrical systems] of 2030 for B.C., Manitoba, Quebec, Newfoundland and Labrador and P.E.I., but of 2035 for Alberta, Saskatchewan, Ontario, New Brunswick and Nova Scotia."[2]

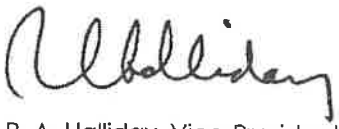
These commitments by our principal trading partners and the federal government will put increasing pressure on SaskPower to make a similar commitment. This pressure could include the full application of the federal carbon tax to power generation from hydrocarbons after 2035. The challenge for SaskPower lies in its commitment to natural-gas power stations. At present, SaskPower has about 1000 MW of natural-gas capacity that will not reach end of operational life until after 2035. As well, the corporation has 360 MW under construction at Moose Jaw and a further 360 MW planned expansion. A significant portion of SaskPower's generating capacity therefore risks becoming either a stranded asset or a source of high-cost power if carbon offsets must be purchased.

There are solutions of course. The existing power stations could be fitted with carbon capture technology or re-fueled with liquid biofuels, but these are potentially expensive and technologically challenging solutions. Enriching natural gas fuel with blue, green or turquoise hydrogen helps, but does not solve the problem.

[1] International Energy Agency 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector.
[2] https://markjaccard.blogspot.com/2021/08/a-zero-emission-canadian-electricity.html

The Saskatchewan Environmental Society takes the view that SaskPower will be obliged to join the developed economies in being a carbon-free producer by 2035 and must plan accordingly. As an immediate measure SES calls for cessation of currently planned expansion of natural gas generating capacity. In effect, this means the proposed station near Saskatoon or near Shand should not go ahead. Replacing existing capacity could be accomplished by strengthening interconnections with Manitoba Hydro and commissioning utility-scale solar power stations in 300 MW tranches. These options were discussed in our report from earlier this year. As stated in that report we remain convinced that there would be federal support for interprovincial grid interconnections.

Yours truly,



R. A. Halliday, Vice-President, Saskatchewan Environmental Society

c.c. The Honorable Don Morgan, Minister of Crown Investment Corporation

Brett Dolter, PhD

Assistant Professor
Department of Economics, University of Regina
Associate Member of Johnson-Shoyama Graduate School of Public Policy
Associate Member of Clean Energy Technologies Research Institute

THIS IS **EXHIBIT** "E" REFFERED TO IN THE AFFIDAVIT OF ROBERT HALLIDAY SWORN BEFORE ME THIS 14th DAY OF FEBRUARY, A.D. 2024.

Crystal Russell

CRYSTAL K. RUSSELL
A NOTARY PUBLIC
for the Province of Saskatchewan.
My Appointment Expires:
October 31, 2024.

Department of Economics
University of Regina
3737 Wascana Parkway
Regina SK S4S 0A2
Email: Brett.Dolter@uregina.ca
Phone: (306) 551-2738

ACADEMIC APPOINTMENTS

Assistant Professor (2018 – present)
Department of Economics, University of Regina (2018 – present)
Associate Member, Johnson Shoyama Graduate School of Public Policy (2023 – present)
Associate Member, Clean Energy Technologies Research Institute (2021 – present)

Postdoctoral Research Fellow (2017 – 2018)
Faculty of Arts, University of Regina

David Suzuki Foundation Fellow (2017 – 2018)
David Suzuki Foundation

Postdoctoral Research Fellow (2016 – 2017)
Institute of the Environment, University of Ottawa.
Supervisor: Nicholas Rivers (UOttawa)

Sessional Lecturer (2007 – 2010)
Department of Economics, University of Regina

EDUCATION

Ph.D. in Ecological Economics (2011 – 2015)
Faculty of Environmental Studies, York University
Dissertation: "Greening the Saskatchewan Grid"
Advisors: Peter Victor (YorkU), Mark Winfield (YorkU), Ellie Perkins (YorkU), Ken Belcher (University of Saskatchewan)

M.A. in Economics (2010 – 2011)
Department of Economics, University of Victoria
Major Paper: "Exploring the Dynamics of a Global Pollutant: Strategic Interaction in the Carbon Kuznets Curve."
Advisors: Peter Kennedy (UVic), Emma Hutchinson (UVic), Elisabeth Gugl (UVic)

M.A. in Resource Management and Environmental Studies (2003 – 2006)
Resource Management and Environmental Studies, University of British Columbia
Thesis: "The Spirit of Localism: Determinants of Pro-Environmental Behaviour in Ecovillages."
Advisors: William E. Rees (UBC), Rob Van Wynsberghe (UBC)

B.A. Hons. Combined Degree in Economics and Geography (1998 – 2003)
Departments of Economics and Geography, University of Regina
Honours Thesis: "The EligAbility Gap: Economic and Spatial Analysis of the Potential for Energy Efficiency Retrofits in Regina, Saskatchewan"
Advisors: Marion Jones (URegina), Ben Cecil (URegina)

PUBLICATIONS

Refereed Journal Articles

J1. **Dolter, Brett**, Madeleine Seatle, Madeleine McPherson (2023) "When the Sun Sets on Net Metering: How the cancellation of Net Metering Impacted the Potential Adoption of Residential Rooftop Solar Photovoltaics in Regina, Saskatchewan." *Challenges in Sustainability*. 10:1, pp. 47-76. DOI: 10.12924/cis2023.10010047. (Open-access)

J2. Winter, Jennifer, **Brett Dolter**, G. Kent Fellows (2023) "Carbon Pricing Costs for Households and the Progressivity of Revenue Recycling Options in Canada." *Canadian Public Policy*. 49:1, pp. 13-45. DOI: 10.3138/cpp.2022-036. (Open-access)

J3. **Dolter, Brett**, G. Kent Fellows, and Nicholas Rivers (2022) "The Cost Effectiveness of New Reservoir Hydroelectricity: British Columbia's Site C Project." *Energy Policy*. 169, pp. 1-26. DOI: 10.1016/j.enpol.2022.113161. (Open-access)

J4. **Dolter, Brett** (2021) "Greening the Saskatchewan Grid: A case study in deliberative energy modelling." *Ecological Economics*. 183. DOI: 10.1016/j.ecolecon.2021.106966. (Open-access)

J5. **Dolter, Brett** and Martin Boucher (2018) "Solar Energy Justice: A Case-Study Analysis of Saskatchewan, Canada." *Applied Energy*. 225, pp. 221-232. DOI: 10.1016/j.apenergy.2018.04.088.

J6. **Dolter, Brett** and Nicholas Rivers (2018) "The Cost of Decarbonizing the Canadian Electricity System." *Energy Policy*. 113, pp. 135-148. DOI: 10.1016/j.enpol.2017.10.040.

J7. **Dolter, Brett** and Peter Victor (2016) "Casting a Long Shadow: Demand-based Accounting of Canada's Greenhouse Gas Emissions Responsibility." *Ecological Economics*. 127, pp. 156-164. DOI: 10.1016/j.ecolecon.2016.04.013.

J8. Winfield, Mark and **Brett Dolter** (2014) "Energy, Economic and Environmental Discourses and their Policy Impact: The Case of Ontario's Green Energy and Green Economy Act." *Energy Policy*. 68, pp. 423-435. DOI: 10.1016/j.enpol.2014.01.039.

J9. Arbuthnott, Katherine and **Brett Dolter** (2013) "Escalation of commitment to fossil fuels." *Ecological Economics*. 89, pp. 7-13. DOI: 10.1016/j.ecolecon.2013.02.004.

J10. **Dolter, Brett** and Katherine Arbuthnott (2010) "Any Risk Is Unacceptable – Cultural Identity, Ethics and Support for the Nuclear Industry in Saskatchewan." *Prairie Forum*. 35:2, pp. 79-112. http://hdl.handle.net/10294/15623 (Open-access)

Books

B1. Victor, Peter and **Brett Dolter** (Eds.) (2017) *Handbook on Growth and Sustainability*. Northampton MA: Edward Elgar.

Book Chapters

C1. **Dolter, Brett** and Peter Victor (2017) "From Growth to Sustainability." In Peter Victor and Brett Dolter (Eds.) *Handbook on Growth and Sustainability*. Northampton MA: Edward Elgar.

C2. Henderson, Norman, Elaine Barrow, **Brett Dolter**, and Edward Hogg (2010) "Climate change impacts and management options for isolated northern Great Plains forests." In David Sauchyn, Harry Diaz, and S. Kulshreshtha (Eds.) *The New Normal: The Canadian Prairies in a Changing Climate*. University of Regina Press, Regina SK.

Dictionary Entries

D1. **Dolter, Brett** (2023) "Peer Review Process" and "Deliberative Multi-Criteria Analysis". In Brent M. Haddad and Barry D. Solomon (Eds.) *Dictionary of Ecological Economics*. Northampton MA: Edward Elgar.

Book Reviews

R1. **Dolter, Brett** (2022) "A full life exploring our full world – Herman Daly's Economics for a Full World: His Life and Ideas, Peter Victor (2022)." *Ecological Economics*. DOI: 10.1016/j.ecolecon.2022.107508.

Government and Utility Reports

G1. **Dolter, Brett** (2023) Affordability Impacts of the Clean Electricity Regulations on Residential Customers. Environment and Climate Change Canada.

G2. **Dolter, Brett**, Richard Morgenstern and Nicholas Rivers (2018) Energy prices and manufacturing plant competitiveness in Ontario. Ontario Ministry of Environment.

G3. **Dolter, Brett** and Martin Boucher (2017) Let's Talk Solar: Final Report on Solar Power Public Engagement. SaskPower, Regina SK. https://www.saskpower.com/our-power-future/powering-2030/-/media/FF2E6E3DE81A44AEA487EBF7225A138A.ashx.

G4. Victor, Peter and **Brett Dolter** (2013) Demand-Based GHG Accounting for Canada. Environment Canada.

G5. Jones, Marion, Adam Mills and **Brett Dolter** (2009) Bridging the 'EligAbility Gap' - Improving Life Quality for Vulnerable Households in Regina's North Central Neighbourhood. SaskHousing Corporation.

G6. **Dolter, Brett** and Lyndon Lisitza (2008) Economic Modelling of Carbon Sequestration and Emission Reductions in Saskatchewan Agriculture. Saskatchewan Ministry of Environment.

G7. Peters, Jotham, Noel Melton, Chris Bataille, and **Brett Dolter** (2008) Analysis of Greenhouse Gas Abatement Opportunities in Saskatchewan. Saskatchewan Ministry of Environment.

G8. **Dolter, Brett** (2007) How to Keep Our Homes Cool Without Warming the Planet. Saskatchewan Ministry of Environment.

G9. Friedman, Avi, Robert Bjerke, Thomas Green, and **Brett Dolter** (2005) Solar City: Affordable Solar Housing in Regina. City of Regina.

G10. Henderson, Norman, Elaine Barrow, Edward Hogg and **Brett Dolter** (2002) Climate Change Impacts on the Island Forests of the Great Plains and the Implications for Nature Conservation Policy. Prairie Adaptation Research Collaborative.

Non-Profit Reports

N1. Harland, Kate, Jason Dion, **Brett Dolter**, Christiana Guertin, and Andrew Patrick (2023) Clean Electricity, Affordable Energy: How federal and provincial governments can save Canadians money on the path to net zero. Canadian Climate Institute, Ottawa ON. https://climateinstitute.ca/wp-content/uploads/2023/06/Clean-Electricity-Affordable-Energy.pdf.

N2. **Dolter, Brett** and Jennifer Winter (2022) Electricity and Affordability in Canada's Energy Transition: Options for rate design and electricity system funding. Canadian Climate Institute, Ottawa: ON. https://climateinstitute.ca/wp-content/uploads/2022/09/Electricity-

and-equity-canadas-energy-transition.pdf.

N3. Bardutz, Emily and **Brett Dolter** (2020) Regina's 100% Renewable Energy Target: Survey results measuring support for the target and related actions. Regina Energy Futures Project. https://www.uregina.ca/arts/research/assets/regina-energy-futures-survey-final-report-sept-2020.pdf.

N4. **Dolter, Brett** and Tom Green (2019) Zeroing in on Emissions: Canada's Clean Power Pathways – A Review. David Suzuki Foundation. https://davidsuzuki.org/science-learning-centre-article/zeroing-in-on-emissions-canadas-clean-power-pathways-a-review/.

N5. Lipp, Judith and **Brett Dolter** (2016) The Power of Community: Community-owned renewable energy. Toronto Renewable Energy Co-operative. https://www.trec.on.ca/wp-content/uploads/2016/06/TREC_Primer_Jun28_Approved_Final-LR.pdf.

N6. **Dolter, Brett**, Malin Hansen, and Denise MacDonald (editors). (2006) EcoLiving: Working Together for a Sustainable World. Regina EcoLiving, Regina SK.

Policy Commentary

W1. Winter, Jennifer, **Brett Dolter** and G. Kent Fellows (2021) "Is Carbon Pricing Progressive or Regressive? It Depends How Governments Use the Revenue." Smart Prosperity Blog. https://institute.smartprosperity.ca/CarbonPricingRevenue.

W2. G. Kent Fellows, **Brett Dolter** and Nicholas Rivers (2020) "The Economics of Site C Shouldn't Scare Us Away from Decarbonizing Electricity." University of Calgary School of Public Policy Blog. https://www.policyschool.ca/the-economics-of-site-c-shouldnt-scare-us-away-from-decarbonizing-electricity/

W3. **Dolter, Brett**, G. Kent Fellows, Nicholas Rivers (2020) "Is the Site C Project worth its growing price tag?" University of Calgary Energy & Environmental Policy Trends. https://www.policyschool.ca/wp-content/uploads/2020/12/Energy-Trends-Site-C-Project.pdf.

W4. **Dolter, Brett** (2017) "How Saskatchewan's Climate Policy Falls Short." Policy Options. http://policyoptions.irpp.org/magazines/december-2017/how-saskatchewans-climate-change-strategy-falls-short/.

W5. **Dolter, Brett** and Nicholas Rivers (2017) "Connecting Canada with New High-Voltage Direct Current Transmission Lines." C.D. Howe Intelligence Memos. https://www.cdhowe.org/intelligence-memos/dolter-and-rivers-connecting-canada-new-high-voltage-direct-current-transmission.

W6. **Dolter, Brett** (2017) "Electrify Everything." Alternatives Journal. https://www.alternativesjournal.ca/science-and-solutions/electrify-everything.

W7. **Dolter, Brett** (2016) "The Saskatchewan Climate Change White Paper." Policy Options. http://policyoptions.irpp.org/magazines/november-2016/the-saskatchewan-climate-change-white-paper/.

W8. **Dolter, Brett** (2016) A Response to Saskatchewan's Climate Change White Paper. Canadian Centre for Policy Alternatives and Saskatchewan Environmental Society. https://www.policyalternatives.ca/publications/reports/response-saskatchewan's-climate-change-white-paper.

W9. **Dolter, Brett** and Peter Victor (2016) "Guest Blog: Casting a Long Shadow – Canadian Consumption-Based Contributions to Global GHG Emissions." Smart Prosperity Blog. http://institute.smartprosperity.ca/content/guest-blog-casting-long-shadow-canadian-consumption-based-contributions-global-ghg-emissions.

TEACHING

Assistant Professor
Department of Economics, University of Regina (2018 – present)

Econ 499 Honours thesis supervision
3.0 credit undergraduate thesis course. Supervised four Honours students who have completed their theses: Fall 2019, Winter 2020, Winter 2021, and Fall 2021. Currently plan to supervise a fifth Honour's student during the Winter 2024 semester.

Econ 480 Capstone Seminar in Economics
3.0 credit undergraduate course with 4-10 students. Co-taught six times: Fall 2018, Winter 2019, Fall 2019, Winter 2021, Fall 2021, and Winter 2022.

Econ 373 Climate Change Policy (cross-listed with GES 396AM) (*created course)
Created this 3.0 credit undergraduate course in Fall 2018. Enrolment ranges between 15-35 students. Taught three times in total: Fall 2018, Winter 2021, and Winter 2023.

Econ 351 Cost-Benefit Analysis
3.0 credit undergraduate course with 25-40 students. Taught four times: Fall 2019, Fall 2020, Fall 2021, and Fall 2023.

Econ 274 Ecological Economics (*created course)
Created this 3.0 credit undergraduate course in Summer 2007 as a sessional lecturer (see below). Enrolment ranges between 25-40 students. Taught once in Spring 2018 am scheduled to teach it again Spring 2024.

Econ 201 Microeconomics
3.0 credit undergraduate course with 100-105 students. Taught three times: Fall 2018, Winter 2019, and Winter 2023.

Econ 100 Introduction to Economic Issues
3.0 credit undergraduate class with 100-105 students. Taught in Fall 2023 and Winter 2024.

Sessional Lecturer
Department of Economics, University of Regina (2007 – 2010)

Econ 100 Introduction to Economic Issues
Taught this course three times in total: Fall 2008, Winter 2009, and Winter 2010.

Econ 274 Ecological Economics (*created course)
Created the course and taught it four times in total: Summer 2007, Summer 2008, Spring 2009, and Spring 2010.

ACADEMIC SUPERVISION

Honours Thesis Supervisor* (4 completed, 1 in progress)
(*The University of Regina only has a special-case Master's program in Economics so opportunities to supervise graduate students are limited)
Department of Economics, University of Regina

- Calum Donaldson (2023-2024) In progress.
- Liam Zwarych (2021) "Does the Yearly Average Concentration of PM2.5 Motivate Canadians to Improve their Air Quality?"
- Madeleine O'Connor (2020-2021) "Energy in Transition: Conditions for the Adoption of Small Modular Reactors in Saskatchewan"
- Emily Bardutz (2019-2020) "Influence of the Built Environment on Commute Mode Choice: Evidence from Sixteen Canadian Cities"
- Matt Boehm (2019) "Modelling the Impact of Climate Change on Wheat Production: An Econometric Analysis of Climate Change and Wheat Yields in Saskatchewan"

Graduate Supervision (1 PhD completed, 4 PhD students in progress, 1 intern)

- Majid Mohajeri, PhD committee. Petroleum Systems Engineering, URegina (2023-2027)
- David-Ross Hopley, PhD committee. Engineering, URegina. (2022-2026)
- Clarisse Uwamahoro, PhD committee. Johnson-Shoyama Graduate School (JSGS) of Public Policy, URegina. (2021-2025)
- Angel Chow, PhD committee. JSGS, URegina. (2020-2024)
- Madeleine Seatle, PhD committee. Dissertation title: "The balancing act of renewable transitions: Modelling demand response programs to facilitate variable renewable energy integration at the city-scale." Civil Engineering, University of Victoria. (2020-2023)
- Robbi Humble, MITACS internship co-supervisor. Royal Roads University (2019-2020)

Research Assistant Supervision (8 in total)

- Calum Donaldson, Undergraduate student in Department of Economics (2023) [supported by Faculty of Graduate Studies Undergraduate Research Award]
- Jacob Smith, Undergraduate student in Department of Economics (2022)
- Sheena Stewart, Undergraduate student in Department of Psychology (2020)
- Emily Bardutz, Undergraduate student in Department of Economics (2019 – 2020)
- Nigel Olesen, Undergraduate student in Department of Economics (2020) [supported by Faculty of Graduate Studies Undergraduate Research Award]
- Grace Schaan, Undergraduate student in Department of Geography (2019)
- Larissa Shasko, Graduate student in JSGS (2019)
- Taya Triffo, Undergraduate student in Philosophy, Politics, and Economics (PPE) (2019)

External Examiner (3 in total)

- Bright Baffoe, Master's Defense. Agricultural & Resource Economics. University of Saskatchewan (2023)
- Alida Salman, Master's Defense. JSGS. University of Regina. (2021)
- Tim Crownshaw, PhD Comprehensive Exam. McGill University. (2018)

RESEARCH GRANTS

Awarded External Funding

SSHRC Partnership Grant (2023-27) "The International Ecological Footprint Learning Lab: Training, research, and novel application." ($2,486,161) Principal Investigator (PI): Peter Victor (York University). Participant: **Brett Dolter** et al.

SSHRC Partnership Development Grant (2023-24) "Canadian Climate Policy Partnership" ($200,000) PI: Jennifer Winter (University of Calgary). Participant: **Brett Dolter** et al.

MITACS Accelerate (2023-24) "Sustainable energy production with minimized and acceptable environmental impact." ($1,600,000) PI: Saman Azadbakht (University of Regina). Co-supervisor: **Brett Dolter** et al.

City of Saskatoon Research Junction (2022) "Supporting energy efficiency in low-income rental housing." ($29,997) PI: Martin Boucher (University of Saskatchewan). Collaborator: **Brett Dolter.**

Energy Modelling Initiative (2020) "Examining the Value of the Site C megaproject using a Linear Programming Model of Western Canadian Electricity infrastructure and generation with endogenous investment." ($15,000) PI: G. Kent Fellows (University of Calgary). Co-applicants: **Brett Dolter** and Nicholas Rivers.

SSHRC Partnership Grant (2019) "Community Appropriate Sustainable Energy Security (CASES) partnership." ($2,500,000) PI: Bram Noble (University of Saskatchewan. Collaborator: **Brett Dolter** et al.

Mitacs Accelerate Internship Funding and David Suzuki Foundation (2019) "Municipal Energy Futures Project: A Case Study of Regina, Saskatchewan." ($30,000) PI: Ann Dale (Royal Roads University). Co-PI: **Brett Dolter.**

Smart Prosperity Institute's Greening Growth Partnership (2018) "Carbon Pricing Costs for Households and Revenue Recycling Options in Canada." ($39,257) PI: Jennifer Winter (University of Calgary). Co-applicants: **Brett Dolter** and G. Kent Fellows.

Trottier Foundation (2018) "Canadian Renewable Integration and Municipal Energy Futures Modelling." ($125,000) PI: Madeleine McPherson (University of Victoria). Co-applicant: **Brett Dolter**.

David Suzuki Foundation Research Fellowship (2017-2018) ($50,000) PI: **Brett Dolter**.

Ontario Ministry of Environment and Climate Change (2017) "Competitiveness and leakage in Ontario's cap and trade system for greenhouse gas emissions." ($17,800) PI: Nicholas Rivers (UOttawa). Co-applicant: **Brett Dolter**.

SSHRC Postdoctoral Fellowship (2016-2017) "Regional Energy and Climate Policy Analysis in Canada." ($80,000) PI: **Brett Dolter.**

SSHRC Joseph-Armand Bombardier Doctoral Scholarship (2014-2015) "Greening the Saskatchewan Grid." ($35,000) PI: **Brett Dolter**.
SSHRC Doctoral Fellowship (2011-2014) "Greening the Saskatchewan Grid." ($60,000) PI: **Brett Dolter**.

Sustainable Prosperity Research Grant (2014) "Greenhouse Gas Emissions Accounting in Canadian Goods and Imports." ($8,000) Principal Investigator: Peter Victor (York University). Co-applicants: **Brett Dolter.**

SSHRC Canada Graduate Scholarship (2004-2005) ($17,500) "The Spirit of Localism: Determinants of Pro-Environmental Behaviour in Ecovillages." PI: **Brett Dolter**.

Awarded Internal Funding

Undergraduate Research Award, Faculty of Graduate Studies and Department of Economics (2023) "Competitiveness in the Canadian Manufacturing Sector." ($11,349.97) Co-PIs: Calum Donaldson and **Brett Dolter.**

Research and Action Fund, Faculty of Arts (2022) "Landfill Recycling Project." ($4250) PI: Rob Deglau, EnviroCollective. Advisory committee member: **Brett Dolter.**

President's Publication Fund and Arts Publication Fund (2022) Open access publishing of Winter, Dolter, Fellows (2023) paper in *Canadian Public Policy*. ($1000) PI: **Brett Dolter.**

President's Publication Fund and Arts Publication Fund (2021) Open access publishing of Dolter (2021) paper in *Ecological Economics*. ($3000) PI: **Brett Dolter.**

Undergraduate Research Award, Faculty of Graduate Studies and Department of Economics (2020) "The Distributional Impact of Carbon Pricing." ($8,400) Co-PIs: Nigel Olesen and **Brett Dolter**.

AWARDS AND HONOURS

- Nomination for Barbara Godard Dissertation Prize (2015)
- Phillips Prize for Research Excellence in Environment & Resource Economics (2011)
- University of Victoria Van Dusen Fellowship (2010)
- University of Regina Inspiring Sessional Award (2009)
- Saskatchewan Environment Award of Excellence (2007)
- University of British Columbia Graduate Entrance Scholarship (2003)
- University of Regina President's Medal (2003) ("The President's Medal is presented at each Convocation to an undergraduate student receiving a first degree who best exemplifies the combination of academic studies with leadership qualities.")
- Office of Energy Efficiency Student Energy Ambassador (2003)
- University of Regina Dean's Honour List (1998-2003)
- University of Regina President's Leadership Program Certificate (2001)
- Campion College's Reverend Peter Nash scholarship (2000-2001)
- Valedictorian of graduating class Greenall High School (1998)

SELECT PROFESSIONAL POSITIONS PRIOR TO APPOINTMENT

Senior Policy Analyst
Green Policy, Ministry of Environment – December 17, 2007 to June 15, 2008
I coordinated the Green Energy component of the Green Initiatives Fund. This involved designing programs to increase energy efficiency and promote renewable energy; coordinating the administration of programs; negotiating contracts; reporting on the status of programs; and evaluating the results of Green Energy programs.

Policy Analyst
Green Policy, Saskatchewan Environment – January 7, 2007 to December 14, 2007
I co-designed a funding program that supported sustainability projects in Saskatchewan (the Green Initiatives Fund); wrote submissions to the Treasury Board; managed the delivery of government funding to grant recipients, which involved contract negotiation and interpreting legislation; and analyzed policy on issues such as climate change.

Junior Policy Analyst
Saskatchewan Environment – October 2, 2006 to January 4, 2007
In this half-time position I wrote a research report on ways to keep residential buildings cool in the summer without air-conditioning.

Planning Assistant
City of Regina Urban Planning – June 1, 2003 to August 21, 2003
I worked with housing coordinator Bob Bjerke to coordinate the development of an energy-efficient, affordable demonstration home (the Montague Street house in North Central, Regina).

Research Assistant
Department of Economics, University of Regina – January 1, 2005 to June 30, 2005
I worked as research assistant to my undergraduate supervisors, Dr. Ben Cecil and Dr. Marion Jones. We updated the results of my undergraduate thesis, which focused on the economic viability and environmental benefits of energy efficiency retrofits.

Research Assistant
Prairie Adaptation Research Collaborative (PARC) – May 1, 2002 to August 30, 2002
I assisted Dr. Norman Henderson in creating a report on climate change impacts on prairie island forest ecosystems. This research was included in an edited volume of climate change adaptation research.

CURRICULUM VITAE

Last Updated January 11, 2024

Mark Z. Jacobson
Professor of Civil and Environmental Engineering
Director, Atmosphere/Energy Program
Yang and Yamazaki Environment and Energy Building
Civil and Environmental Engineering, Mailcode 4020
473 Via Ortega, Room 397
Stanford University
Stanford, CA 94305-4020, USA
Tel: (650) 723-6836
Fax: (650) 723-7058
Email: jacobson@stanford.edu
Internet: http://www.stanford.edu/group/efmh/jacobson
Twitter:

THIS IS **EXHIBIT "F"** REFFERED TO IN THE AFFIDAVIT OF ROBERT HALLIDAY SWORN BEFORE ME THIS 14th DAY OF FEBRUARY, A.D. 2024.

Crystal Russell

CRYSTAL K. RUSSELL
A NOTARY PUBLIC
for the Province of Saskatchewan.
My Appointment Expires:
October 31, 2024.

Degrees and Employment

B. S., with distinction, Stanford University, Civil Engineering, 1988
B. A., with distinction, Stanford University, Economics, 1988
M. S., Stanford University, Environmental Engineering, 1988
M. S., UCLA, Atmospheric Sciences, 1991
Ph. D., UCLA, Atmospheric Sciences, 1994
Research Asst., UCLA, Atmospheric Sciences, 1989-1994
Teaching Assistant, UCLA, Atmospheric Sciences, 1989-1994
Postdoctoral Student, UCLA, Atmospheric Sciences, June-September, 1994
Assistant Professor, Civil and Environmental Engineering, Stanford University, 1994-2001.
Associate Professor, Civil and Environmental Engineering, Stanford Univ., 2001-2007
Professor, Civil and Environmental Engineering, Stanford University, 2007-present
Professor by Courtesy of Energy Resources Engineering, Stanford Univ, 2007-2010
Associate Director, Environmental Fluid Mechanics Laboratory, Stanford University, September, 1996-2004.
Director and co-founder, Atmosphere/Energy Program (link), Dept. of Civil and Environmental Engineering, Stanford University, 2004-present.
Senior Fellow, Woods Institute for the Environment (link), January 2008-present
Senior Fellow, Precourt Institute for Energy (link), January 1, 2010-present
Co-founder, The Solutions Project (link), July 10, 2011-present.

Scientific Background

Mark Z. Jacobson's career has focused on better understanding air pollution and global warming problems and developing large-scale clean, renewable energy solutions to them. Toward that end, he has developed and applied three-dimensional (3-D) atmosphere-biosphere-ocean computer models and solvers to simulate and understand air pollution, weather, climate, and renewable energy systems. He has also developed roadmaps to transition countries, states, cities, and towns to 100% clean, renewable energy for all purposes and computer models to examine grid stability in the presence of 100% renewable energy. Jacobson has been a professor at Stanford University since 1994. His research crosses two fields: Atmospheric Sciences and Energy, each discussed next.

Atmospheric Sciences

Jacobson started computer modeling in 1990. He developed over 85% of the computer code for the world's first 3-D urban air pollution model coupled, with feedback, to meteorology. He then

developed the first coupled 3-D global air pollution-weather-climate model and first unified nested global-through-urban air pollution-weather-climate model, GATOR-GCMOM. Zhang (2008) calls Jacobson's unified model "the first fully-coupled online model in the history that accounts for all major feedbacks among major atmospheric processes based on first principles." Many features in GATOR-GCMOM are now mainstream in other models worldwide. For these models, he coded the world's fastest (at the time) ordinary differential equation solver in a 3-D model for a given level of accuracy (SMVGEAR). He also developed solvers for aerosol and cloud coagulation, breakup, condensation/evaporation, freezing, dissolution, chemical equilibrium, and lightning; air-sea exchange; ocean chemistry; greenhouse gas radiation absorption; and land-surface processes. Thousands of researchers have used computer codes he has developed.

In 2000 and 2001, Jacobson applied his model to discover that black carbon, the main component of soot air pollution particles, may be the second-leading cause of global warming in terms of radiative forcing, after carbon dioxide. Several subsequent studies, including the highly-cited review by Bond et al. (2013), confirmed his finding.

Jacobson's finding about black carbon's climate effects resulted in his invitation to testify to the U.S. House of Representatives in 2007 and formed the original scientific basis for several proposed laws and policies. These included U.S. Senate Report 110-489 (Black Carbon Research Bill of 2008), U.S. House Bill 7250 (Arctic Climate Preservation Act of 2008), U.S. House Bill 1760 (Black Carbon Emissions Reduction Act of 2009), U.S. Senate Bill 849 (2009 Bill for the U.S. EPA to research black carbon), U.S. Senate Bill 3973 (Diesel Emission Reduction Act of 2010), European Parliament Resolution B7-0474/2011 (Resolution calling for black carbon controls on climate grounds), the 2012 multi-country Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, led by Hilary Clinton, California Senate Bill 1383 (2016 Bill to reduce black carbon), and California's 2002 rule to not allow diesel vehicles to have higher particle emissions than gasoline vehicles.

For his black carbon discovery and modeling, Jacobson received the 2005 American Meteorological Society Henry G. Houghton Award, given for his "significant contributions to modeling aerosol chemistry and to understanding the role of soot and other carbon particles on climate" and a 2013 American Geophysical Union Ascent Award for "his dominating role in the development of models to identify the role of black carbon in climate change."

Jacobson's 2008 and 2010 findings that carbon dioxide domes over cities have enhanced air pollution mortality through its feedback to particles and ozone resulted in another invitation for him to testify in the U.S. House of Representatives in 2008 and to testify twice in U.S. Environmental Protection Agency (EPA) hearings. In the first EPA hearing he was called as the State of California's only expert witness to testify on how carbon dioxide can damage health locally by increasing temperatures and water vapor. This testimony served as a direct scientific basis for the EPA's 2009 approval of the first regulation in U.S. history of carbon dioxide (the California waiver).

Energy

With respect to energy, in 2001 Jacobson published a paper in Science examining the ability of the U.S. to convert a large fraction of its energy to wind. In 2005, his group developed the first world wind map based on data alone. His students and he subsequently published on the impacts of hydrogen fuel cell vehicles on air quality and climate, on reducing the variability of wind energy by interconnecting wind farms; on integrating solar, wind, geothermal, and hydroelectric power into the grid; on integrating offshore wind and wave power; on comparing ethanol with gasoline; and on mapping U.S. offshore wind resources.

In 2008, he carried out a review of proposed energy technologies to address air pollution, global warming, and energy security, concluding that wind-water-solar (WWS) technologies resulted in the greatest benefits. In 2009, he coauthored a plan, featured on the cover of Scientific American, to determine if powering the world for all purposes with WWS was possible. In 2010, he was invited

to participate in a TED debate. From 2010-2012, he served on the Energy Efficiency and Renewables advisory committee to the U.S. Secretary of Energy. In 2011, he cofounded The Solutions Project non-profit, which combined science, business, culture, and community, to educate people about science-based 100% clean, renewable energy roadmaps for 100% of the people.

In 2013, 2014, and 2016, he and his students developed roadmaps to transition New York, California, and Washington State, respectively, to 100% WWS. Jacobson's New York energy roadmap resulted in an invitation for him to appear on the Late Show with David Letterman on October 9, 2013. Jacobson was then asked by the New York governor's office to provide more information about a possible transition of New York to 100% WWS. In 2016, the governor proposed and passed a 50% renewable law (the New York Clean Energy Standard). Also in 2016, and in 2018, the New York Senate proposed New York Senate Bills S5527 and S5908A, respectively, for the state to go to 100% renewable electricity. The texts of both bills state, "This bill builds upon the Jacobson wind, water and solar (WWS) study..." In 2019, New York State implemented Jacobson'd goal for the electricity sector by passing a law to go to 100% renewable electricity.

Similarly, on October 27, 2014, after the publication of Jacobson's California WWS roadmap, the California governor's office invited Jacobson to meet with the governor's policy advisors to discuss the roadmap. In January, 2015, the governor proposed and, shortly after, obtained passage of a law (SB 350) for California to move to 50% renewable electricity. In 2018, this law was updated for the state to go to 100% renewable electricity (SB 100).

In 2015, Jacobson and his group published WWS plans for all 50 states and a continental-U.S.-wide grid study assuming 100% WWS. The grid paper earned Jacobson and his coauthors a 2016 Cozzarelli Prize from the Proceedings of the National Academy of Sciences, given for "outstanding scientific excellence and originality." The plans and grid study were updated for the 50 U.S. states and individual U.S. regions in 2022. The publication of these roadmaps, together with their dissemination by the Solutions Project and dozens of other nonprofits, resulted in the widespread awareness of Jacobson's plans and the growth of the 100% renewable energy movement. Jacobson's science-based plans resulted in all three Democratic presidential candidates for the 2016 election making 100% renewable energy part of their platform. Senator Sanders included Jacobson's roadmaps on his web site and, after the election, wrote an op-ed with Jacobson in the Guardian calling for a transition to 100% renewables.

To date, activists inspired by Jacobson's plans have encouraged 17 U.S. states (CA, CT, HI, IL, ME, MN, NC, NE, NJ, NM, NV, NY, OR, RI, VA, WA, WI), the District of Columbia, and Puerto Rico to pass laws or Executive Orders requiring a transition of up to 100% clean, renewable electricity. At the federal level, eight laws and resolutions were proposed calling for the U.S. to move to 100% renewable electricity or all energy. These included House Resolution 540 (2015), House Bill 3314 (2017), House Bill 3671 (2017), House Bill 330 (2019); Senate Resolution 632 (2019), Senate Bill 987 (2019), House Resolution 109 (2019), and Senate Resolution 59 (2019). All were inspired by Jacobson's plans. For example, the first, House Resolution 540, states: "Whereas a Stanford University study concludes that the United States energy supply could be based entirely on renewable energy by the year 2050 using current technologies."

House Resolution 109 and Senate Resolution 59 are the proposed U.S. Green New Deal. As stated by Dr. Marshall Shepherd, "Professor Mark Jacobson at Stanford University has been a longtime leader in climate science and renewable energy transition. Many of the assumptions in the Green New Deal seem to be anchored in his scholarship." The main goals of the Green New Deal, to transition the U.S. to 100% renewable energy by 2030, came from Jacobson and Delucchi's 2009 Scientific American paper.

In 2009 and 2011, Jacobson developed plans to transition the world to 100% WWS. In 2017-2018, he developed more detailed plans and grid studies for 139 individual countries. These were updated

for 143 countries in 2019 and 145 countries in 2022. To date, 61 countries have enacted policies calling for 100% renewable electricity.

The Sierra Club supported the Jacobson roadmaps, and in 2013, asked him to help with a campaign to encourage cities around America to adopt 100% WWS laws. Ultimately, he and his students published plans for 53 towns and cities (2018) and 74 metropolitan areas (2020). To date, about 160 U.S. cities and over 400 cities worldwide have enacted policies to transition to 100% renewable electricity. Over 400 international companies have committed to 100% renewables in their global operations. In 2023, Jacobson served as an expert witness on behalf of 16 youth plaintiffs in the first climate case in U.S. history, Held v. Montana, to discuss the ability of Montana to transition to WWS. The plaintiffs prevailed.

For his research and leadership in Energy, Jacobson received the 2013 Global Green Policy Design Award for the "design of analysis and policy framework to envision a future powered by renewable energy." In 2016, he received a Cozzarelli Prize. In 2018, he received the Judi Friedman Lifetime Achievement Award "For a distinguished career dedicated to finding solutions to large-scale air pollution and climate problems." In 2019 and 2022, he was selected as "one of the world's 100 most influential people in climate policy" by Apolitical. In 2022, he was recognized as "World Visionary CleanTech Influencer of the Year" by the CleanTech Business Club. In 2023, he was named one of the top 100 people globally "who have made an impact on the world this year" among "innovators across various industries, including art, entertainment, business, and philanthropy," by Worth magazine.

Additional Work and Impact

To date, Jacobson has published about 180 peer-reviewed journal articles and given (since 1994) ~750 invited talks. In 2004, he founded and has ever since directed the Atmosphere/Energy Program at Stanford. Jacobson has written six textbooks, including Fundamentals of Atmospheric Modeling (1999) and Atmospheric Pollution: History, Science, and Regulation (2002). These two books, plus second editions in 2005 and 2012, respectively, relate primarily to his work in Atmospheric Sciences. The last two, 100% Clean, Renewable Energy and Storage for Everything (2020) and No Miracles Needed (2023), relate to his work in Energy.

Based on the impact of his research through citations to papers, Jacobson is ranked as the most impactful scientist in the world in the field of Meteorology & Atmospheric Sciences among those with their first publication past 1985. Among scientists publishing in any year from 1788 to 2021, he is ranked #12 in that field. In the Energy field, he is ranked #6 among those with their first publication past 1980 and #16 among those with their first publication in any year. He is also ranked #1,843 among all fields, among all 10 million scientists in history.

Awards, Scholarships, and Fellowships

Yale Book award, 1982

Distinguished Scholar Award, Palo Alto Unified School District, 1983

Faculty Cup award, "Presented in recognition of outstanding academic achievement and leadership by the administration and faculty of H. M. Gunn Senior High School," 1983

National Merit scholarship, 1983

Harvard College Honorary National Scholarship,"Highest award given by Harvard University to members of incoming class, based on academic distinction and extracurricular achievement," 1983

NCAA-ITCA scholar-athlete of the year award, 1985, 1986, 1987

Division I NCAA-ITCA Academic All-American, 1987

Stanford University Tennis scholarship, Stanford University, 1986-7

Department of Civil Engineering academic fellowship, Stanford University, 1987

Second place, ASCE hazardous waste essay writing competition, 1987

Chancellor's fellowship, UCLA, 1989

Neiburger teaching award, UCLA, 1992

Dissertation Year fellowship, UCLA, 1993-4

NSF Career Early Development Award, 1995-1998

Powell Foundation Award, Stanford University, 1995-1996

Frederick Terman Fellowship, Stanford University, 1997-2000

Presidential Research Grant for Junior Faculty, Stanford University, 1998

NASA New Investigator Award, 1999-2002

Research Incentive Award, Office of Technology and Licensing Stanford Univ., 2001-2002

American Meteorological Society Henry G. Houghton Award "for significant contributions to modeling aerosol chemistry and to understanding the role of soot and other carbon particles on climate," 2005

Editors' Citation for Excellence in Refereeing, Journal of Geophysical Research-Atmospheres, 2005 (link)

Most-accessed article April-June 2007; second-most-accessed article July-September 2007, in the Journal, *Environmental Science and Technology*, "Effects of ethanol (E85) versus gasoline on cancer and mortality in the United States." (link)

Partial share of the 2007 Nobel Peace Prize as a research contributor to and reviewer of the Intergovernmental Panel on Climate Change 3rd and 4th Assessment Reports, cited for "efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

Editor Highlight in Geophysical Research letters for "On the causal link between carbon dioxide and air pollution mortality," February 2008. (link)

Top three most popular research news stories of 2008 published by Environmental Research Web: "Carbon dioxide increase causes air pollution deaths," a news story on "On the causal link between carbon dioxide and air pollution mortality." (link)

Top three "Most Interesting Science and Technology News of 2008", by Blogher, "Review of solutions to global warming, air pollution, and energy security," (link to story)(link to article)

Economist.com "noteworthy journal article" for January 2009, "Review of solutions to global warming, air pollution, and energy security." (link to story)(link to article)

Top-downloaded paper, "Influence of future anthropogenic emissions on climate, natural emissions, and air quality," all Journal of Geophysical Research Journals, May 2009.(link)

All-time top downloaded paper in *Energy and Environmental Science* as of June 2012, "Review of solutions to global warming, air pollution, and energy security." (link)

One of the top two science stories of 2009 according to *Science of the Times*, "A path to sustainable energy by 2030," *Scientific American*, November 2009.(link)

American Geophysical Union Research Spotlight, "Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health," July 29, 2010. (link)

Top-cited first author, Stanford University School of Engineering, all departments, for first-authored papers published since Jan. 1, 1994.

Sixth all-time Science and Technology TED Talks, "Debate: Does the world need nuclear energy," behind Stephen Hawking (1) and James Watson (5) (link)

Editors' Citation for Excellence in Refereeing, Journal of Geophysical Research-Atmospheres, 2012 (link)

American Geophysical Union Ascent Award, for "his dominating role in the development of models to identify the role of black carbon in climate change," 2013. (link)

Atlas Award honoring climate heroes, Danville, California, November 16, 2013. (link)

Top-scoring article in Energy and Environmental Sciences: Ten Hoeve, J.E., and M.Z. Jacobson, Worldwide health effects of the Fukushima Daiichi nuclear accident, Energy and Environmental Sciences, 2012; October 28, 2013 (link)(paper)

Global Green Award, Policy Design, New York City, December 3, 2013, "Honoring the 'design' of analysis and policy framework to envision a future powered by renewable energy. Research and work focused on New York and California has provided an alternative path to the future," (link)

41st highest cited climate paper out of 120,000, with 961 citations as of July 8, 2015 (Jacobson, M.Z., Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols, Nature, 409, 695-697, 2001)" (link) (spreadsheet) (paper)

Named by Grist50 as one of top 50 "Innovators, organizers, and visionaries who will lead us toward a more sustainable future, in the coming year (and beyond), January 16, 2016," (link)

Highest-cited two papers in Energy Policy between 2011 and 2016: Jacobson and Delucchi, 2011; Delucchi and Jacobson, 2011 (link) (pdf) (pdf)

Cozzarelli Prize, Awarded February 23, 2016 "for outstanding scientific excellence and originality" to 6 out of ~3,000 papers published in 2015 in the Proceedings of the National Academy of Sciences. Each of the six papers represents an area of research. This prize was awarded in the area of "Applied Biological, Agricultural, and Environmental Sciences" for Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, and B.A. Frew, A low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes (link) (paper)

American Geophysical Union, EOS Research Spotlight, "Roadmaps to transition countries to 100% clean, renewable energy for all purposes to curtail global warming, air pollution, and energy risk," published in Earth's Future, December 5, 2017. (link)

Judi Friedman Lifetime Achievement Award, "For a distinguished career dedicated to finding solutions to large-scale air pollution and climate problems. Professor Jacobson has carried out original and important research on the feasibility of wind, water and solar energy to meet the needs of buildings, cities, states and countries around the world. In so doing, he has given scientific rigor to a public discussion that is central to the survival of humanity. As a co-founder of the Solutions Project, he is providing a scientific basis for a collective movement to promote 100% renewable energy," presented by People's Action for Clean Energy (PACE), Hartford, Connecticut, November 8, 2018. (video)

World's 100 most influential people in climate policy for 2019, from Apolitical, March 20, 2019. (link)

World's 2nd top influencer in Environmental Sustainability, from Onalytica. June 26, 2019. (link)

All-electric showcase award, Silicon Valley Clean Energy, for being a "leader within our community who is reducing local emissions and promoting a healthier community with their advanced electric technologies and building designs," September 23, 2019. (link)

World's #1 academic influencer on Smart Grids, from Onalytica, October 23, 2019. (link)

Visionary CleanTech Influencer of the Year, World Clean Tech Awards, 2021 Edition, Dubai, UAE, March 14, 2022. (link)

Ranked as the most impactful scientist in the world in the field of Meteorology & Atmospheric Sciences among those with their first publication past 1985. Among scientists publishing in any year from 1788 to 2021, he is ranked #12 in that field. In the Energy field, he is ranked #6 among those with their first publication past 1980 and #16 among those with their first publication in any year. He is also ranked #1,843 among all fields, among all 10 million scientists in history. October 10, 2022. (link)

Named among the top 100 people globally who "have made the most significant impact on the world this year" among "innovators across various industries, including art, entertainment, business, government, non-profits, and philanthropy," by Worth Magazine, December 5, 2023. (link)

Grants

U.S. EPA Global Air Pollution Modeling, 1994 - 1997
U.S. EPA Urban Air Pollution, 1995-1998
National Science Foundation, Climate Modeling, 1997-2000
National Science Foundation, Climate Modeling, 2001-2004
U.S. EPA Climate Modeling, 2001-2002
U.S. EPA Climate Modeling, 2002-2003
NASA Climate Modeling, 2004-2007
Global Climate and Energy Project, Effect of hydrogen on air pollution, 2004-2007
NASA Climate and Air Pollution Modeling, 2004-2007
U.S. EPA, Climate Effects on Air Pollution, 2007-2011
NASA Effects of Aerosols on Clouds, 2007-2010
U.S. Army, Transport of Airborne and Waterborne Particles Center, 2007-2012
Federal Aviation Administration, Effects of contrails on climate, 2007-2009
U.S. Dept. of Energy, Effects of hydrogen on the atmosphere, 2007-2009
Precourt Institute for Energy Efficiency, Optimizing renewable energy, 2008-2009
Federal Aviation Administration, Effects of low-sulfur jet fuel on climate, 2008-2009
National Science Foundation, Measuring and modeling organic aerosols, 2008-2011
Federal Aviation Administration, Effects of Aviation on Climate, 2009-2013
Federal Aviation Administration, Effects of Rerouting Polar Aircraft, 2009-2010
Federal Aviation Administration, ACCRI, 2010-2012

National Science Foundation, Effects of absorbing aerosols on clouds, 2012-2014
Federal Aviation Administration, Effects of Aviation on Climate, 2011-2015
National Aeronautics and Space Administration, Megacity changes, 2012-2015 National Science Foundation, Modeling satellite correlations of cloud properties, 2015-2018
Woods Institute for the Environment, Developing 100% clean, renewable roadmaps for towns and cities, 2017-2018
Innovation Fund Denmark, RE Invest – Renewable energy investment strategies, 2017-2021
U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), Building a self-sustaining microgrid for remote communities and military bases, 2022-2025

Courses taught
CEE 063/263C Weather and Storms
CEE 064/263D Air Pollution and Global Warming: History, Science, and Solutions
CEE 263A Air Pollution Modeling
CEE 263B Numerical Weather Prediction
CEE 176B/276B 100% Clean, Renewable Energy and Storage for Everything

Public online courses
XEIET 100 Clean, renewable energy and storage for a sustainable future
XEIET 200 Planning for a sustainable future with wind, water, and the sun

Unique Features of GATOR-GCMOM (Click here)

Ph. D. Thesis
Jacobson M. Z. (1994) *Developing, coupling, and applying a gas, aerosol, transport, and radiation model to study urban and regional air pollution*. Ph. D. Dissertation, Dept. of Atmospheric Sciences, University of California, Los Angeles, 436 pp. (pdf)

Books
Jacobson, M. Z., *Fundamentals of Atmospheric Modeling*. Cambridge University Press, New York, 656 pp., 1999. (link)

Jacobson, M. Z., *Fundamentals of Atmospheric Modeling, Second Edition*, Cambridge University Press, New York, 813 pp., 2005. (link)

Jacobson, M. Z., *Atmospheric Pollution: History, Science, and Regulation*, Cambridge University Press, New York, 399 pp., 2002. (link)

Jacobson, M. Z., *Air Pollution and Global Warming: History, Science, and Solutions*, Cambridge University Press, Cambridge, 375 pp., 2012 (link)

Jacobson, M. Z., *100% Clean, Renewable Energy and Storage for Everything*, Cambridge University Press, New York, 427 pp., 2019 (link)

Jacobson, M. Z., *No Miracles Needed*, Cambridge University Press, New York, 437 pp., 2023 (link)

Peer-Reviewed Journal Articles as First Author

1. Jacobson, M. Z., and R. P. Turco, SMVGEAR: A sparse-matrix, vectorized Gear code for atmospheric models, *Atmos. Environ., 28A*, 273-284, 1994. (link)

2. Jacobson, M. Z., R. P. Turco, E. J. Jensen, and O. B. Toon, Modeling coagulation among particles of different composition and size, *Atmos. Environ., 28A*, 1327-1338, 1994. (link)

3. Jacobson, M. Z., and R. P. Turco, Simulating condensational growth, evaporation, and coagulation of aerosols using a combined moving and stationary size grid, *Aerosol Sci. and Technol., 22*, 73-92, 1995. (link)

4. Jacobson, M. Z., Computation of global photochemistry with SMVGEAR II. *Atmos. Environ., 29A*, 2541-2546, 1995. (link)

5. Jacobson, M. Z., A. Tabazadeh, and R. P. Turco, Simulating equilibrium within aerosols and non-equilibrium between gases and aerosols, *J. Geophys. Res., 101*, 9079-9091, 1996. (link)

6. Jacobson, M. Z., R. Lu, R. P. Turco, and O. B. Toon, Development and application of a new air pollution modeling system. Part I: Gas-phase simulations, *Atmos. Environ., 30B*, 1939-1963, 1996. (link)

7. Jacobson, M. Z., Development and application of a new air pollution modeling system. Part II: Aerosol module structure and design, *Atmos. Environ., 31A*, 131-144, 1997. (link)

8. Jacobson, M. Z., Development and application of a new air pollution modeling system. Part III: Aerosol-phase simulations, *Atmos. Environ., 31A*, 587-608, 1997. (link)

9. Jacobson, M. Z., Numerical techniques to solve condensational and dissolutional growth equations when growth is coupled to reversible reactions, *Aerosol Sci. Technol., 27*, 491-498, 1997. (link)

10. Jacobson, M. Z., Improvement of SMVGEAR II on vector and scalar machines through absolute error tolerance control. *Atmos. Environ., 32*, 791-796, 1998. (link)

11. Jacobson, M. Z., Studying the effects of aerosols on vertical photolysis rate coefficient and temperature profiles over an urban airshed, *J. Geophys. Res., 103*, 10,593-10,604, 1998. (link)

12. Jacobson, M. Z., Isolating nitrated and aromatic aerosols and nitrated aromatic gases as sources of ultraviolet light absorption, *J. Geophys. Res., 104*, 3527-3542, 1999. (link)

13. Jacobson, M.Z., Effects of soil moisture on temperatures, winds, and pollutant concentrations in Los Angeles, *J. Appl. Meteorol., 38*, 607-616, 1999. (link)

14. Jacobson, M. Z., Studying the effects of calcium and magnesium on size-distributed nitrate and ammonium with EQUISOLV II, *Atmos. Environ., 33*, 3635-3649, 1999. (link)

15. Jacobson, M. Z., A physically-based treatment of elemental carbon optics: Implications for global direct forcing of aerosols, *Geophys. Res. Lett., 27*, 217-220, 2000. (link)

16. Jacobson, M. Z., Global direct radiative forcing due to multicomponent anthropogenic and natural aerosols, *J. Geophys. Res., 106*, 1551-1568, 2001. (link)

17. Jacobson, M. Z., Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols, *Nature, 409*, 695-697, 2001. (link)

18. Jacobson, M. Z., GATOR-GCMM: A global through urban scale air pollution and weather forecast model. 1. Model design and treatment of subgrid soil, vegetation, roads, rooftops, water, sea ice, and snow., *J. Geophys. Res., 106*, 5385-5402, 2001. (link)

19. Jacobson, M. Z., GATOR-GCMM: 2. A study of day- and nighttime ozone layers aloft, ozone in national parks, and weather during the SARMAP Field Campaign, *J. Geophys. Res., 106*, 5403-5420, 2001. (link)

20. Jacobson, M. Z., and G. M. Masters, Exploiting wind versus coal, *Science, 293*, 1438-1438, 2001. (link)

21. Jacobson, M. Z., Analysis of aerosol interactions with numerical techniques for solving coagulation, nucleation, condensation, dissolution, and reversible chemistry among multiple size distributions, *J. Geophys. Res., 107* (D19), 4366, doi:10.1029/2001JD002044, 2002. (link)

22. Jacobson, M. Z., Control of fossil-fuel particulate black carbon plus organic matter, possibly the most effective method of slowing global warming, *J. Geophys. Res., 107* (D19), 4410, doi:10.1029/ 2001JD001376, 2002. (link)

23. Jacobson, M. Z., Development of mixed-phase clouds from multiple aerosol size distributions and the effect of the clouds on aerosol removal, *J. Geophys. Res., 108* (D8), 425, doi:10 1029/2002JD002691, 2003. (link)

24. Jacobson, M. Z., J. H. Seinfeld, G. R. Carmichael, and D.G. Streets, The effect on photochemical smog of converting the U.S. fleet of gasoline vehicles to modern diesel vehicles, *Geophys. Res. Lett., 31*, L02116, doi:10.1029/2003GL018448, 2004. (link)

25. Jacobson, M.Z., and J.H. Seinfeld, Evolution of nanoparticle size and mixing state near the point of emission, *Atmos. Environ., 38*, 1839-1850, 2004. (link)

26. Jacobson, M. Z., The short-term cooling but long-term global warming due to biomass burning, *J. Climate, 17*, 2909-2926, 2004. (link)

27. Jacobson, M.Z., The climate response of fossil-fuel and biofuel soot, accounting for soot's feedback to snow and sea ice albedo and emissivity, *J. Geophys. Res., 109*, D21201, doi:10.1029/2004JD004945, 2004. (link)

28. Jacobson, M.Z., A solution to the problem of nonequilibrium acid/base gas-particle transfer at long time step, *Aerosol Sci. Technol, 39*, 92-103, 2005. (link)

29. Jacobson, M.Z., A refined method of parameterizing absorption coefficients among multiple gases simultaneously from line-by-line data, *J. Atmos. Sci., 62*, 506-517, 2005. (link)

30. Jacobson, M.Z., Studying ocean acidification with conservative, stable numerical schemes for nonequilibrium air-ocean exchange and ocean equilibrium chemistry, *J. Geophys. Res., 110*, D07302, doi:10.1029/2004JD005220, 2005. (link)

31. Jacobson, M.Z., W.G. Colella, and D.M. Golden, Cleaning the air and improving health with hydrogen fuel cell vehicles, *Science, 308*, 1901-1905, 2005. (link)

32. Jacobson, M.Z., D.B. Kittelson, and W.F. Watts, Enhanced coagulation due to evaporation and its effect on nanoparticle evolution, *Environmental Science and Technology, 39*, 9486-9492, 2005. (link)

33. Jacobson, M.Z., Effects of externally-through-internally-mixed soot inclusions within clouds and precipitation on global climate, *J. Phys. Chem. A. 110*, 6860-6873, 2006. (link)

34. Jacobson, M.Z., and Y.J. Kaufmann, Wind reduction by aerosol particles, *Geophys. Res. Lett., 33*, L24814, doi:10.1029/2006GL027838, 2006. (link)

35. Jacobson, M.Z., Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States, *Environ. Sci. Technol., 41*, 4150-4157, 10.1021/es062085v, 2007. (link)

36. Jacobson, M.Z., Y.J. Kaufmann, Y. Rudich, Examining feedbacks of aerosols to urban climate with a model that treats 3-D clouds with aerosol inclusions, *J. Geophys. Res., 112*, D24205, doi:10.1029/2007JD008922, 2007. (link)

37. Jacobson, M.Z., On the causal link between carbon dioxide and air pollution mortality, *Geophysical Research Letters, 35*, L03809, doi:10.1029/2007GL031101, 2008. (link)

38. Jacobson, M.Z., Effects of wind-powered hydrogen fuel cell vehicles on stratospheric ozone and global climate, *Geophys. Res. Lett., 35*, L19803, doi:10.1029/2008GL035102, 2008. (link)

39. Jacobson, M.Z., The short-term effects of agriculture on air pollution and climate in California, *J. Geophys. Res., 113*, D23101, doi:10.1029/2008JD010689, 2008. (link)

40. Jacobson, M.Z., Review of solutions to global warming, air pollution, and energy security, *Energy and Environmental Science, 2*, 148-173, doi:10.1039/b809990c, 2009. (link)

41. Jacobson, M.Z., and D.G. Streets, The influence of future anthropogenic emissions on climate, natural emissions, and air quality, *J. Geophys. Res., 114*, D08118, doi:10.1029/2008JD011476, 2009. (link)

42. Jacobson, M.Z., Effects of biofuels vs. other new vehicle technologies on air pollution, global warming, land use, and water, *Int. J. Biotechnology, 11*, 14-59, 2009. (pdf)

43. Jacobson, M.Z., and M.A. Delucci, A path to sustainable energy by 2030, *Scientific American*, November 2009 (cover story). (link)

44. Jacobson, M.Z., The enhancement of local air pollution by urban CO_2 domes, *Environ. Sci. Technol., 44*, 2497-2502, doi:10.1021/es903018m, 2010. (link)

45. Jacobson, M.Z., Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health, *J. Geophys.Res., 115*, D14209, doi:10.1029/2009JD013795, 2010. (link)

46. Jacobson, M.Z., and D.L. Ginnebaugh, Global-through-urban nested three-dimensional simulation of air pollution with a 13,600-reaction photochemical mechanism, *J. Geophys. Res., 115*, D14304, doi:10.1029/2009JD013289, 2010. (link)

47. Jacobson, M.Z., Numerical Solution to Drop Coalescence/Breakup With a Volume-Conserving, Positive-Definite, and Unconditionally-Stable Scheme, *J. Atmos. Sci., 68*, 334-346, doi:10.1175/2010JAS3605.1, 2011. (link)

48. Jacobson, M.Z., and M.A. Delucchi, Providing all Global Energy with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure, and Materials, *Energy Policy, 39*, 1154-1169, doi:10.1016/j.enpol.2010.11.040, 2010. (link)

49. Jacobson, M.Z., J.T. Wilkerson, A.D. Naiman, and S.K. Lele, The effects of aircraft on climate and pollution. Part I: Numerical methods for treating the subgrid evolution of discrete

size- and composition-resolved contrails from all commercial flights worldwide, *J. Comp. Phys., 230*, 5115-5132, doi:10.1016/j.jcp.2011.03.031, 2011. (link)

50. Jacobson, M.Z., and J.E. Ten Hoeve, Effects of urban surfaces and white roofs on global climate, *J. Climate, 25*, 1028-1044, doi:10.1175/JCLI-D-11-00032.1, 2012. (link)

51. Jacobson, M.Z., Investigating cloud absorption effects: Global absorption properties of black carbon, tar balls, and soil dust in clouds and aerosols, *J. Geophys. Res. 117*, D06205, doi:10.1029/2011JD017218, 2012. (link)

52. Jacobson, M.Z., J.T. Wilkerson, S. Balasubramanian, W.W. Cooper, Jr., and N. Mohleji, The effects of rerouting aircraft around the Arctic Circle on Arctic and global climate, *Climatic Change 115*, 709-724, doi:10.1007/s10584-012-0462-0, 2012. (link)

53. Jacobson, M.Z., and C.L. Archer, Saturation wind power potential and its implications for wind energy, *Proc. Nat. Acad. Sci. 109*, 15,679-15,684, doi:10.1073/pnas.1208993109, 2012. (link)

54. Jacobson, M.Z., R.W. Howarth, M.A. Delucchi, S.R. Scobies, J.M. Barth, M.J. Dvorak, M. Klevze, H. Katkhuda, B. Miranda, N.A. Chowdhury, R. Jones, L. Plano, and A.R. Ingraffea, Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight, *Energy Policy 57*, 585-601, 2013. (link)

55. Jacobson, M.Z., J.T. Wilkerson, A.D. Naiman, and S.K. Lele, The effects of aircraft on climate and pollution. Part II: 20-year impacts of exhaust from all commercial aircraft worldwide treated individually at the subgrid scale, *Faraday Discussions, 165*, 369-382, doi:10.1039/C3FD00034F, 2013. (link)

56. Jacobson, M.Z., C.L. Archer, and W. Kempton, Taming hurricanes with arrays of offshore wind turbines, *Nature Climate Change, 4*, 195-200, doi:10.1038/NCLIMATE2120, 2014. (link)

57. Jacobson, M.Z., M.A. Delucchi, A.R. Ingraffea, R.W. Howarth, G. Bazouin, B. Bridgeland, K. Burkhart, M. Chang, N. Chowdhury, R. Cook, G. Escher, M. Galka, L. Han, C. Heavey, A. Hernandez, D.F. Jacobson, D.S. Jacobson, B. Miranda, G. Novotny, M. Pellat, P. Quach, A. Romano, D. Stewart, L. Vogel, S. Wang, H. Wang, L. Willman, T. Yeskoo, A roadmap for repowering California for all purposes with wind, water, and sunlight, *Energy, 73*, 875-889, doi:10.1016.j.energy.2014.06.099, 2014. (link)

58. Jacobson, M.Z., Effects of biomass burning on climate, accounting for heat and moisture fluxes, black and brown carbon, and cloud absorption effects, *J. Geophys. Res., 119*, 8980-9002, doi:10.1002/2014JD021861, 2014. (link)

59. Jacobson, M.Z., S.V. Nghiem, A. Sorichetta, and N. Whitney, Ring of impact from the mega-urbanization of Beijing between 2000 and 2009, *J. Geophys. Res., 120*, 5740-5756, doi:10.1002/2014JD023008, 2015. (link)

60. Jacobson, M.Z., M.A. Delucchi, G. Bazouin, Z.A.F. Bauer, C.C. Heavey, E. Fisher, S. B. Morris, D.J.Y. Piekutowski, T.A. Vencill, T.W. Yeskoo, 100% clean and renewable wind, water, sunlight (WWS) all-sector energy roadmaps for the 50 United States, *Energy and Environmental Sciences, 8*, 2093-2117, doi:10.1039/C5EE01283J, 2015. (link)

61. Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, and B.A. Frew, A low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all

purposes, *Proc. Nat. Acad. Sci., 112* 15,060-15,065, doi: 10.1073/pnas.1510028112, 2015. (link)

62. Jacobson, M.Z., M.A. Delucchi, G. Bazouin, M.J. Dvorak, R. Arghandeh, Z. A.F. Bauer, A. Cotte, G.M.T.H. de Moor, E.G. Goldner, C. Heier, R.T. Holmes, S.A. Hughes, L. Jin, M. Kapadia, C. Menon, S.A. Mullendore, E.M. Paris, G.A. Provost, A.R. Romano, C. Srivastava, T.A. Vencill, N.S. Whitney, and T.W. Yeskoo, A 100% wind, water, sunlight (WWS) all-sector energy plan for Washington State, *Renewable Energy, 86*, 75-88, 2016. (link)

63. Jacobson, M.Z., M.A. Delucchi, Z.A.F. Bauer, S.C. Goodman, W.E. Chapman, M.A. Cameron, Alphabetical: C. Bozonnat, L. Chobadi, H.A. Clonts, P. Enevoldsen, J.R. Erwin, S.N. Fobi, O.K. Goldstrom, E.M. Hennessy, J. Liu, J. Lo, C.B. Meyer, S.B. Morris, K.R. Moy, P.L. O'Neill, I. Petkov, S. Redfern, R. Schucker, M.A. Sontag, J. Wang, E. Weiner, A.S. Yachanin, 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for 139 countries of the world, *Joule, 1*, 1-14, doi:10.1016/j.joule.2017.07.005, 2017. (link)

64. Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, and B.V. Mathiesen, Matching demand with supply at low cost among 139 countries within 20 world regions with 100% intermittent wind, water, and sunlight (WWS) for all purposes, *Renewable Energy 123*, 236-248, doi:10.1016/j.renene.2018.02.0092018, 2018 (link)

65. Jacobson, M.Z., V. Jadhav, World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels, *Solar Energy 169*, 55-66, 2018 (pdf)

66. Jacobson, M.Z., M.A. Cameron, E.M. Hennessy, I. Petkov, C.B. Meyer, T.K. Gambhir, A.T. Maki, K. Pfleeger, H. Clonts, A.L. McEvoy, M.L. Miccioli, A.-K. von Krauland, R.W. Fang, and M.A. Delucchi, 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for 53 towns and cities in North America, *Sustainable Cities and Society, 42*, 22-37, doi:10.1016/j.scs.2018.06.031, 2018 (pdf)

67. Jacobson, M.Z., S.V. Nghiem, A. Sorichetta, Short-term impacts of the mega-urbanizations of New Delhi and Los Angeles between 2000 and 2009, *J. Geophys Res. 124*, 35-56, 2019 (pdf)

68. Jacobson, M.Z., Short-term impacts of the Aliso Canyon natural gas blowout on weather, climate, air quality, and health in California and Los Angeles, *Environmental Science and Technology, 53*, 6081-6093, doi:10.1021/acs.est.9b01495, 2019 (pdf)

69. Jacobson, M.Z., The health and climate impacts of carbon capture and direct air capture, *Energy and Environmental Sciences, 12*, 3567-3574, doi:10.1039/C9EE02709B, 2019 (pdf)

70. Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, S.J. Coughlin, C. Hay, I.P. Manogaran, Y. Shu, and A.-K. von Krauland, Impacts of Green New Deal energy plans on grid stability, costs, jobs, health, and climate in 143 countries, *One Earth, 1*, 449-463, doi:10.1016/j.oneear.2019.12.003, 2019 (link)

71. Jacobson, M.Z., A.-K. von Krauland, Z.F.M. Burton, S.J. Coughlin, C. Jaeggli, D. Nelli, A.J.H. Nelson, Y. Shu, M. Smith, C. Tan, C.D. Wood, and K.D. Wood, Transitioning all energy in 74 metropolitan areas, including 30 megacities, to 100% clean and renewable wind, water, and sunlight, *Energies, 13*, 4934, doi:10.3390/en13184934, 2020 (pdf)

72. Jacobson, M.Z., On the correlation between building heat demand and wind energy supply and how it helps to avoid blackouts, *Smart Energy, 1*, 100009,

doi:10.1016/j.segy.2021.100009, 2021 (pdf)

73. Jacobson, M.Z., The cost of grid stability with 100% clean, renewable energy for all purposes when countries are isolated versus interconnected, *Renewable Energy, 179* , 1065-1075, 2021 (pdf)

74. Jacobson, M.Z., A.-K. von Krauland, S.J. Coughlin, F.C. Palmer, and M.M. Smith, Zero air pollution and zero carbon from all energy at low cost and without blackouts in variable weather throughout the U.S. with 100% wind-water-solar and storage, *Renewable Energy, 184* , 430-444, doi:10.1016/j.renene.2021.11.067, 2022 (pdf)

75. Jacobson, M.Z., A.-K. von Krauland, S.J. Coughlin, E. Dukas, A.J.H. Nelson, F.C. Palmer, and K.R. Rasmussen, Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries, *Energy & Environmental Sciences, 15*, 3343-3359, doi:10.1039/d2ee00722c, 2022 (pdf)

76. Jacobson, M.Z., A.-K. von Krauland, K. Song, and A.N. Krull, Impacts of green hydrogen for steel, ammonia, and long-distance transport on the cost of meeting electricity, heat, cold, and hydrogen demand in 145 countries running on 100% wind-water-solar, *Smart Energy, 11*, 100106, doi:10.1016/j.segy.2023.100106, 2023 (pdf)

77. Jacobson, M.Z., Should transportation be transitioned to ethanol with carbon capture and pipelines or electricity? A case study, *Environmental Science and Technology, 57*, 16,843-16,850, doi:10.1021/acs.est.3c05054, 2023 (pdf)

78. Jacobson, M.Z., Batteries or hydrogen or both for grid electricity storage upon full electrification of 145 countries with wind-water solar? *iScience, 27*, 108988, doi:10.1016/j.isci.2024.108988, 2024 (pdf)

Additional Peer-Reviewed Journal Articles (Alphabetical)

79. Archer, C. L., and M. Z. Jacobson, Spatial and temporal distributions of U.S. winds and wind power at 80 m derived from measurements, *J. Geophys. Res., 108* (*D9*) 4289, doi:10.1029/2002JD002076, 2003. (link)

80. Archer, C. L., M.Z. Jacobson, and F.L. Ludwig, The Santa Cruz eddy. Part I: Observations and statistics, *Mon. Wea. Rev., 133*, 767-782, 2005. (pdf)

81. Archer, C. L. and M.Z. Jacobson, The Santa Cruz eddy. Part II: Mechanisms of formation, *Mon. Wea. Rev ., 133*, 767-782 , 2005. (pdf)

82. Archer, C.L., and M.Z. Jacobson, Evaluation of global wind power, *J. Geophys. Res, 110*, D12110, doi:10.1029/2004JD005462, 2005. (link)

83. Archer, C.L., and M.Z. Jacobson, Supplying baseload power and reducing transmission requirements by interconnecting wind farms, *J. Applied Meteorol. and Climatology, 46*, 1701-1717, doi:10.1175/2007JAMC1538.1, 2007. (link)

84. Archer, C.L., and M.Z. Jacobson, Geographical and seasonal variability of the global "practical" wind resources, *Applied Geography, 45*, 119-130, 2013. (link)

85. Bahadur, R., L.M. Russell, M.Z. Jacobson, K.A. Prather, A. Nenes, P.J. Adams, and J.H. Seinfeld, Importance of composition and hygroscopicity of BC particles to the effect of BC

31. Debate, Meeting the renewable energy challenge symposium, University of Iowa, October 15, 2014. Debate question. Should we go to 100% renewable energy. Audience vote: 68% to 25% in favor after debate. (link)

32. China air pollution panel, Freeman Spogli Institute, Stanford University, December 15, 2014.

33. Will renewables replace fossil fuels? The Energy XChange, September 28, 2015 (audio)

34. How California can switch from fossil fuels to renewable energy, Screening of Dear Governor Brown, Beverly Hills, California, November 4, 2015.

35. White House roundtable discussion on the decarbonization of the U.S. electricity sector by 2050, Washington, DC, August 25, 2016 (connected remotely).

36. Combatting climate change: the role of nuclear power, University of Michigan Energy Institute, Ann Arbor, Michigan, September 26, 2016 (video)

37. Emcee and panelist following screening of "Before the Flood," a documentary produced by Leonardo di Caprio, directed by Fisher Stevens, and distributed by National Geographic, Stanford University, October 27, 2016.

38. Panel discussion on the future of district heating, 4th International Conference on Smart Energy Systems and 4th Generation District Heating, Aalborg University, Aalborg, Denmark, November 14, 2018 (video)

39. Panel discussion with Rep. Laura Friedman about Diablo Canyon Nuclear Plant, Mothers for Peace, May 4, 2023 (presented remotely).

Congressional Testimony

1. July 12, 2005. Written testimony on a comparison of wind with nuclear energy to the U.S. House of Representatives Subcommittee on Energy and Resource.

2. October 18, 2007. Oral and written testimony on the role of black carbon as a factor in climate change and its impact on public health. U.S. House of Representatives Committee on Oversight and Government Reform, Washington, D.C. (link)

3. April 9, 2008. Oral and written testimony on the relative impact of carbon dioxide on air pollution health problems in California versus the rest of the U.S., U.S. House of Representatives Select Committee on Energy Independence and Global Warming, Washington, D.C. (link)

4. November 19, 2015. Oral and written testimony on powering the 50 United States and 139 countries with 100% wind, water, and solar power for all purposes, U.S. House of Representatives, Energy and Commerce Committee, Washington, D.C.(schedule) (written testimony)

Environmental Protection Agency Testimony

1. March 5, 2009. Oral testimony invited by the State of California at the Environmental Protection Agency Hearing AMS-FRL-8772-7, California State Motor Vehicle Control

Standards; Greenhouse Gas Regulations; Reconsideration of Previous Denial of a Waiver of Preemption, Arlington, Virginia. (link)

2. Oral testimony at the Environmental Protection Agency Hearing: Endangerment and cause or contribute findings for greenhouse gases under the Clean Air Act, Arlington, Virginia, May 18, 2009. (link)

Government Advisory Boards

1. United States Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) Federal Advisory Committee (ERAC) to the United States Secretary of Energy, October 2010-August 2012.

2. City of San Francisco Task Force to Provide 100% Renewable Electricity by 2020, Jan., 2011-May, 2012.

3. United States Environmental Protection Agency Advisory Council on Clean Air Compliance Analysis, Panel to evaluate a draft EPA report to Congress on the climate and health effects of black carbon, February 9, 2011-April, 2012. (link)

Documentaries and Podcasts

"Doomsday Tech," History Channel series, Modern Marvels, produced by Scott Goldie and Anthony Lacques, Dec. 28, 2004.

Science advisor, "Global Warming: Are we melting the planet," hosted by Tom Brokaw, Discovery Channel, BBC, NBC News Productions, January, 2006.

Alternative fuels and renewable energy, Discovery Channel Canada, produced by Frances Mackinnon, March 8, 2007; aired March 29, 2007.

"The Ethanol Maze," Nebraska Public Broadcasting System (PBS), Perry Stoner, Producer, December 2007; aired June 19, 2008.

Climate change and air pollution, Public Broadcasting System (PBS), Joy Leighton and Bob Gliner, Stanford, California, June 26, 2009.

Documentary on Renewable Energy, Future Earth/MSNBC, Helen Lambourne, Boulder City, Nevada, July 13, 2009.

Dutch Television Documentary on the Plan for a Sustainable Future, February 12, 2010.

Documentary on Energy, Peter Bromley, Dec. 10, 2010.

"Renewable Energy and the Future," MBN, South Korean Television, May 21, 2011.

"Gasland 2," Josh Fox, Director; Trish Adlesic, Producer, July 12, 2011.

"Beyond the Light Switch," co-written by Ed Moore, host David Biello, Feb. 9, 2012. (link)

"Groundswell," produced by Renard Cohen, September 3, 2012.

"The Future of Energy," produced by Maximilian DeArmon, May 3, 2013.

Canadian Broadcasting Corporation, May 10, 2013. (video)