Breathing in the benefits

How an accelerated coal phase-out can reduce health impacts and costs for Albertans

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About Us

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions, and convene diverse sets of stakeholders to identify and move toward common solutions.

The Asthma Society of Canada (ASC) is a national charitable volunteer-supported organization solely devoted to enhancing the quality of life and health for people living with asthma and associated allergies through education, advocacy and research. Since 1973, the ASC has been providing health education services to consumers and health care professionals. Our vision at the ASC is to empower every child and adult in Canada with asthma to live an active and symptom-free life.

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TLA is driven to achieve its vision to create a world free of lung disease so we can all breathe easier.

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Executive summary

With the phase-out of coal power announced by the province in November 2015, Albertans stand to avoid significant health impacts caused by coal pollution. By extension, a further accelerated phase out of coal power facilities would both hasten and amplify those avoided health impacts. The health benefits and costs savings in avoided health outcomes would be significant, and should be considered in the government's planning of the coal phase-out from now to 2030.

While the provincial government has announced a coal phase-out, they have not yet released a transition schedule. This analysis assesses the relative benefits of an accelerated stepwise transition away from coal, as proposed by the Pembina Institute, versus the back-loaded phase-out that other analyses have posited.

In 2012, when the federal government finalized its coal regulations that — in effect — reduce electricity generation from coal plants, Environment Canada (as it was called at that time) estimated considerable health impacts would be avoided, using highly regarded modelling techniques. Logically, these significant benefits from reducing coal necessarily mean that the use of coal for power generation causes considerable health impacts in the first place.

By extrapolating the health benefit results from Environment Canada's analysis, this report highlights the full impact of coal-fired generation in Alberta and indicates attainable benefits associated with the province's coal phase-out. When the federal government weakened its proposed coal regulations back in 2012 in response to lobbying from some coal generators, allowing coal plants to continue unabated longer than first proposed, it left health savings on the table. Alberta can now grasp these savings by accelerating our transition away from coal-fired electricity.

The findings are notable. Figure 1 shows that over and above the benefits reported in the 2012 regulations, phasing out coal sooner can amplify the health impacts we can avoid by 2035.

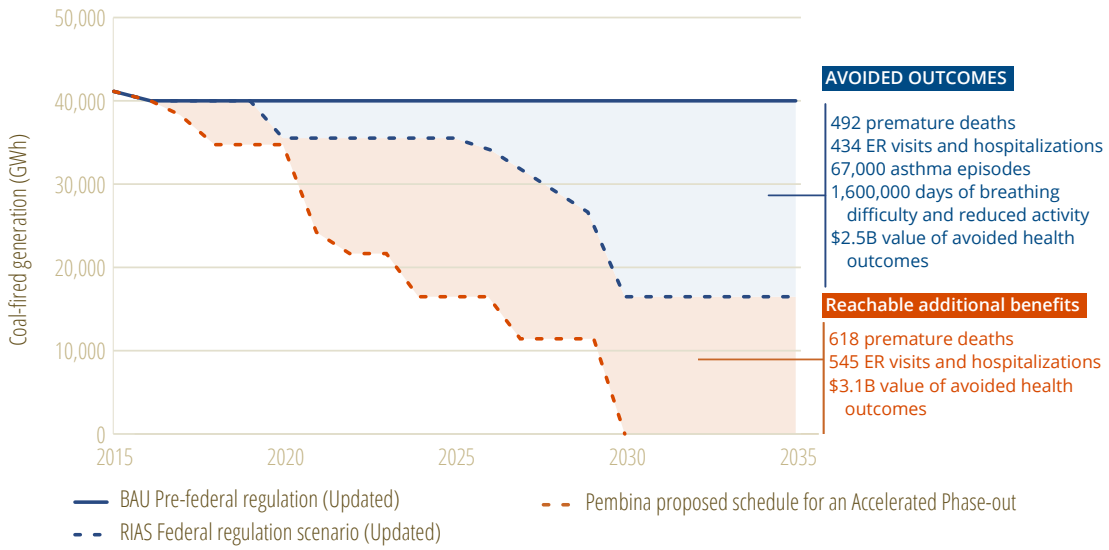

Figure 1. Additional health benefits associated with an accelerated coal phase-out

With an accelerated phase out of coal power between now and 2030, in a stepwise fashion of phasing out a relatively steady generation each year, Alberta could more than double the benefits associated with the previous federal regulation between 2015 and 2035. This would translate in the avoidance of approximately:

- 600 premature deaths
- 500 ER visits and hospitalizations
- 80,000 asthma episodes
- 2 million days of breathing difficulty and reduced activity
- Nearly $3 billion in socio-economic value of health outcomes

1. Introduction

In November 2015, the Government of Alberta announced its Climate Leadership Plan, which includes measures to reduce Alberta's reliance on unabated coal for electricity generation.[1] One of the most significant policies is the commitment to phase out pollution from coal-fired electricity by 2030, replacing the generation with cleaner sources of electricity. By implementing new performance standards, the province's carbon levy will also make coal generators pay for more of the externalized costs they currently impose on society. By partially removing this public subsidy for coal power, it will make coal less competitive and reduce the burning of coal for electricity.

Alongside a growing set of jurisdictions internationally, Alberta is looking at the big picture and recognizing the poor economics of the continued use of coal power. The province has identified health impacts, along with the climate benefits, as a central reason for transitioning away from coal-fired electricity. Globally, this sentiment is echoed: the health care benefits and saved costs, as well as the availability of affordable alternatives, are a driving impetus for the move away from coal power and are resoundingly affirmed in scientific literature worldwide.

This report describes the results of an analysis published by the federal government estimating the health impacts that a transition from coal-fired power avoids. It extrapolates those results to estimate the higher scale of avoided health impacts from an accelerated phase-out of unabated coal power.

1.1 Previous assessment of coal power's health costs in Alberta

In March 2013, three health organizations — the Asthma Society, Canadian Association of Physicians for the Environment and the Lung Association — and the Pembina Institute published *A Costly Diagnosis*, a report which cast light on the health impacts of coal-fired electricity generation in Alberta.[2] It reported the volume of emissions from Alberta's coal plants and the human health impacts of these air contaminants. *A Costly*

[1] In the context of this report, 'abatement' refers to methods to reduce greenhouse gas emissions.

[2] Tim Weis, Noah Farber, Kristi Anderson, Farrah Khan, Beth Nanni, Benjamin Thibault, *A Costly Diagnosis: Subsidizing coal power with Albertans' health* (2013). http://www.pembina.org/pub/2424

Diagnosis describes in greater depth the types of effects, pathways and health impacts that coal pollution has on human health.

It also explored the full costs, including the health impacts, of coal power in Alberta using a model of health impacts from pollution. The results were checked against the magnitude of benefits projected by Environment Canada in its regulatory impact analysis statement (RIAS) for its 2012 coal GHG regulations.[3] The results indicated that each year, coal pollution leads or contributes to:

- 700 visits to Alberta's emergency departments
- 80 hospital admissions related to respiratory and cardiovascular problems from short-term air pollution exposure
- over 4,800 asthma symptom days (person-days of missed work or school for asthma suffers owed to their illness)
- more than 100 premature deaths of Albertans.

The estimated total economic damages associated with these and other health impacts tallied $300 million per year. These estimates appeared conservative relative to other models and studies in other jurisdictions, as well as by comparison to a straight-forward extrapolation of the RIAS results. Nevertheless, the report acknowledged that health impacts mediated through the environment are complex processes and that these are indicative, not definitive, estimates.

The costs represented a 0.7–2.1 ¢/kWh additional cost of coal to society: over and above the costs of the energy to consumers, these were the estimated "external" costs of each unit of coal-fired power, imposed on society as health costs for which the coal generators did not pay. The upper end of the range approximates recent current market prices for electricity in Alberta, showing that these estimated health costs are significant. When the social cost of greenhouse gases — another externality — was added, the true unpaid costs of coal-fired electricity (ranging from 3.6–13.7 ¢/kWh) can far outstrip the market value of that electric energy.

[3] Environment Canada, Regulatory Impact Analysis Statement (RIAS), *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations* (2012). Available in Canada Gazette Part II, Vol. 146, No. 19. http://publications.gc.ca/collections/collection_2012/gazette/SP2-2-146-19.pdf

1.2 Alberta's opportunity to capture health benefits through climate action

Albertans stand to avoid these health impacts and costs more quickly with the province's concerted and purposeful move away from coal-fired electricity generation.

We know that coal-fired electricity generation in Alberta contributes to health problems for Albertans in numbers that are significant. This is beyond dispute. In 2012, Environment Canada finalized federal coal regulations that impose strict greenhouse gas (GHG) emissions limits on end-of-life coal plants. The regulations were widely panned for having been weakened, giving coal plants longer than necessary to operate without abatement. At the same time, Environment Canada modelled a reduction in coal-fired electric energy relative to the previous, unregulated "business-as-usual" scenario. They also used internationally respected modelling approaches to estimate the health benefits of this reduction in coal power output and found considerable avoidance of health impacts and costs, particularly in Alberta. Logic states that if reducing coal-fired electricity reduces health impacts, then conversely the burning of coal for electric energy must cause health impacts.

The Environment Canada analysis now allows us to estimate the health benefits of a more meaningful schedule for transitioning away from coal pollution. By extrapolating the regulatory impact analysis of the 2012 federal coal regulations, this report highlights the full impact of coal-fired generation in the province and indicates attainable benefits associated with the province's coal phase-out. It also assesses the relative benefits of an accelerated stepwise transition away from coal versus the back-loaded phase-out that some analysis has posited.

2. Coal-fired electricity and health impacts in Alberta

2.1 Coal-fired electricity generation in Alberta

Alberta has six coal plants comprising 18 individual units, accounting for a combined capacity of nearly 6,300 MW in 2015 (Figure 2). Alberta burns more coal for electricity than the rest of Canada combined. In 2015, the province generated 64% of its metered electricity by burning coal.[4] The majority of the province's coal power capacity is concentrated in the Wabamun area west of Edmonton.

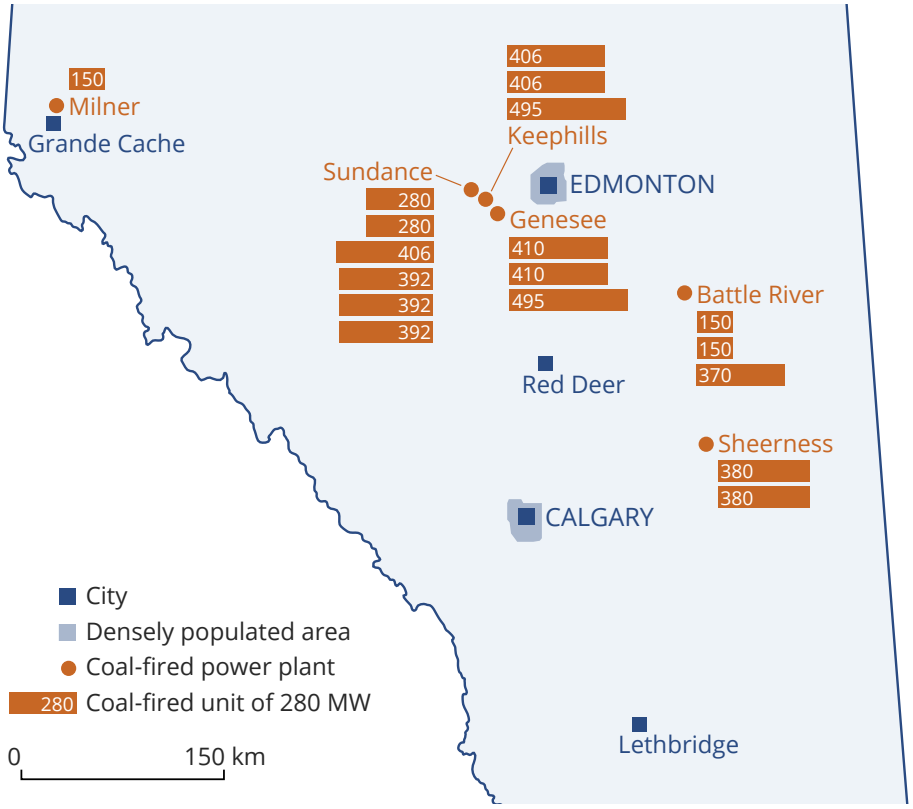

Figure 2. Alberta has six coal plants with a total of 18 power units

[4] Alberta Electricity System Operator, "AESO 2015 Annual Market Statistics." http://www.aeso.ca/market/8856.html. Metered electricity is the electric energy that reaches our interconnected electricity system and is sold through the province's power market. It excludes electricity that is produced and consumed on-site, never making it onto the grid or market.

While coal-fired electricity continued to grow in Alberta until recently, many OECD jurisdictions have been actively moving away from coal for over a decade. Ontario completed a coal phase-out in 2014. In the U.S., the Clean Power Plan and stringent pollution control requirements have combined with the ailing economics of coal power relative to alternative energy sources to accelerate coal plant retirements.

As part of its Climate Leadership Plan, Alberta announced in November 2015 that it would phase out pollution from coal-fired electricity generation by 2030.[5] This places Alberta in a leading group of coal-burning jurisdictions that announced coal phase-outs in the run up to and after the Paris Climate Conference in December 2015:

- the U.K. and Austria will phase out unabated coal-fired generating stations by 2025[6]
- New York is aiming to phase out coal power plants by 2020[7]
- Oregon passed a law to ban coal power by 2030[8]

These leading actions are sparking coal phase-out conversations in a number of other developed nations (such as Italy and Germany), while developing countries are taking serious measures to supply their growing energy needs with alternative sources instead of coal.[9] Additionally, many banks and investments firms worldwide are choosing to no longer invest in coal in developed countries.

A critical driver for the international trend is the global imperative to restrain climate change within the internationally agreed-to commitment of 2°C and target of 1.5°C. Coal power, with its uniquely high-carbon output and readily available economic alternatives, is an obvious target for GHG reductions to attain these objectives. Indeed,

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[5] Alberta Government, "Climate leadership: Ending coal pollution." http://www.alberta.ca/climate-coal-electricity.cfm

[6] BBC News, "UK's coal plants to be phased out within 10 years", November 18, 2015. http://www.bbc.com/news/business-34851718; ICIS, "Austria to close coal plants by 2025, worth up to 1.5m tCO_2e", November 23, 2015. http://www.icis.com/resources/news/2015/11/23/9946462/austria-to-close-coal-plants-by-2025-worth-up-to-1-5m-tco2e/

[7] Devin Henry, "New York governor aims to phase out coal by 2020", *The Hill*, January 13, 2016. http://thehill.com/policy/energy-environment/265786-ny-gov-aims-to-phase-out-coal-by-2020

[8] Wayne Barber, "Oregon governor signs bill into law phasing out coal-fired power", *Renewable Energy World*, March 16, 2016. http://www.renewableenergyworld.com/articles/2016/03/oregon-governor-signs-bill-into-law-phasing-out-coal-fired-power.html

[9] E3G, "G7 coal scorecard - 2016 update." https://www.e3g.org/library/japanese-coal-report; Cecilia Yap, Andreo Calonzo and Dan Murtaugh, "It just got harder to build coal plants in the Philippines," *Bloomberg*, July 10, 2016; Ian Johnston, "China suspends building of new coal power stations as electricity demand declines," *Independent*, July 13, 2016.

here at home, coal-generated electricity is a significant contributor to Alberta's overall GHG emissions, with five Alberta coal plants among the top 10 emitting facilities in Canada (Table 1).

Table 1. Top 10 greenhouse gas emitting industrial facilities in Alberta in 2013

Facility	Total GHGs (Mt)
Syncrude Mildred Lake and Aurora North	12.5
Sundance Electric Power Generating Plant	**12.2**
Genesee Generating Station	**9.0**
Suncor Energy Oil Sands Mine	8.4
Keephills Electric Power Generating Plant	**7.6**
Sheerness Generating Station	**4.8**
Firebag In Situ Oilsands	4.7
Cold Lake In Situ Oilsands	4.6
Horizon Oil Sands Mine	4.5
Battle River Generating Station	**4.4**

Note: Coal-fired power plants in bold
Source: Environment and Climate Change Canada[10]

Closer to home, however, local (state, provincial and national) decisions to transition away from coal are driven equally by the imperative for improved air quality and health outcomes for residents. This is evident in each of the many developed jurisdictions that have announced or are considering a coal phase-out, as well as the developing countries that are curbing their coal use and discussing moratoriums on new builds.

This is the global climate context wherein the Alberta government recognized the phase-out of coal-fired electricity pollution by 2030 as one of the four pillars of its Climate Leadership Plan. This plan ultimately gives credence to the global recognition that coal is no longer a sound economic choice for electricity generation in most jurisdictions. In the meantime, coal-fired electricity continues to damage the health of Albertans and impose costs on the health care system and the province's economy.

[10] Environment and Climate Change Canada, "Reported facility greenhouse gas data." http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A

2.2 Coal plants emissions

In 2014, coal plants in Alberta emitted 40% of the sulphur dioxide (SO_2), 11% of the nitrogen oxides (NO_x), and 37% of the mercury (Hg) from man-made sources in the province (Figure 3). Other harmful pollutants from coal activities include lead, cadmium, hexachlorobenzene, dioxins and furans, polycyclic aromatic hydrocarbons, and arsenic.

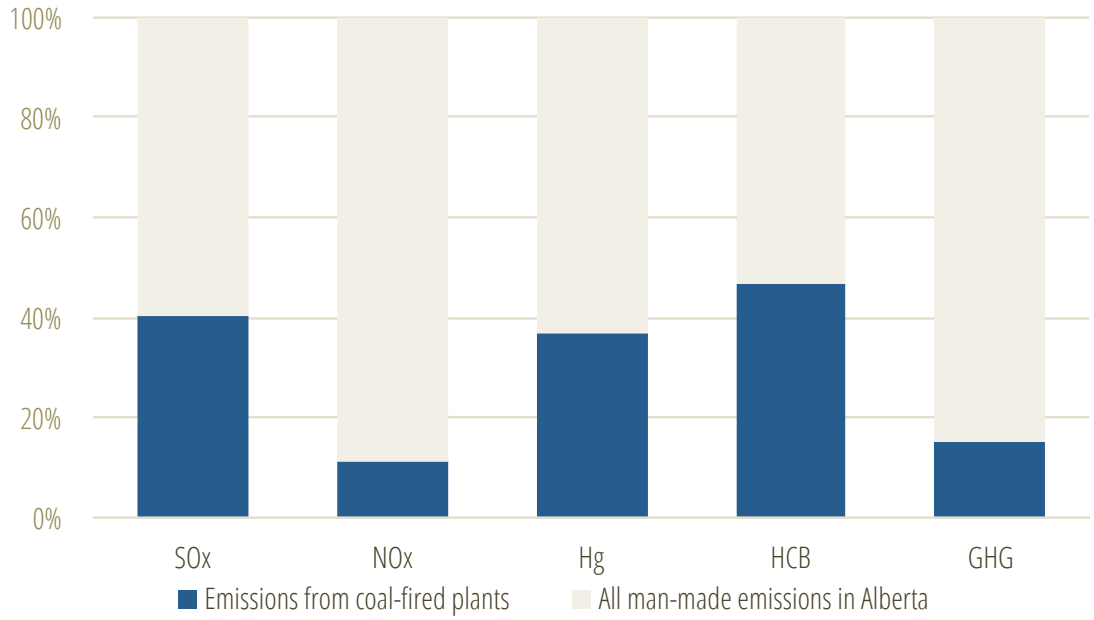

Figure 3. Contribution from coal-fired power plants to overall man-made emissions in 2014 in Alberta

Data source: Government of Canada[11]

When it comes to air pollution, all coal-fired power plants are not created equal. Sixteen coal units that were commissioned before the 2000s were equipped with older coal-burning technology and do not employ the best available technology economically achievable for pollution reductions. They emit significantly more SO_2 and NO_x emissions than other major electricity generation sources. Newer coal units in Alberta (Genesee 3 and Keephills 3, commissioned in 2005 and 2011 respectively) use more efficient supercritical technology and employ pollution controls that reduce NO_x and

[11] Government of Canada, "Air Pollutant Emission Inventory." http://open.canada.ca/data/en/dataset/4d7f1350-c707-4a2b-8cd3-7eed1b41d415

SO_2 air emissions considerably.[12] In 2015, the cleaner units made up 18% of the 42,550 MWh of coal generation, with the remaining 82% coming from older units.[13] Even though the newer units emit one-quarter of the SO_2 and NO_X of the average of older units, they still emit more than six times as much NO_x as a new combined cycle natural gas plant. Figure 4 demonstrates this comparison while also illustrating that natural gas plants emit no SO_2 at all.

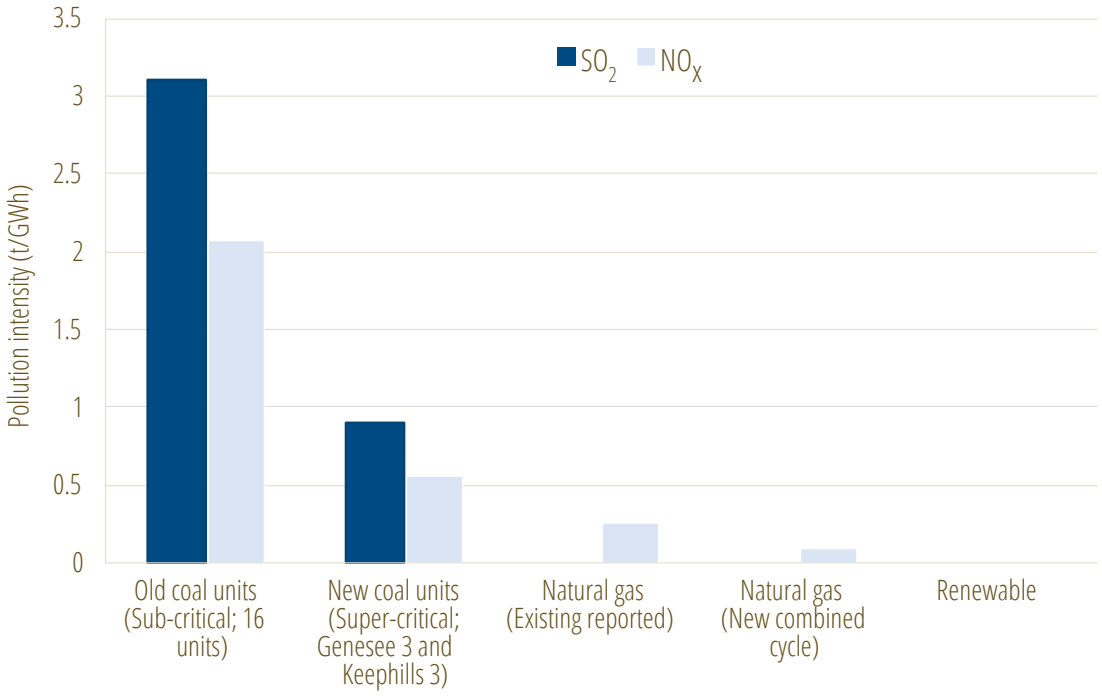

Figure 4. SO_2 and NO_x pollution from electricity production

Data source: Alberta Environment and Parks[14]

Because they are very large, coal plants concentrated in particular locations have a stronger prevalence in some airsheds than others. Figure 5 shows the proportion of total emissions in the Edmonton Census Metropolitan Area that coal plants emit, a product of the three very large coal plants west of Edmonton. Indeed, a 2014 report from the

[12] The sixteen older units use subcritical technology, while the two units commissioned after 2000 are equipped with supercritical technology.

[13] Alberta Environment and Parks, "2006 to 2015 Annual Reports From Generators." http://www.environment.alberta.ca/apps/etr/Documents.aspx

[14] "2006 to 2015 Annual Reports From Generators," Calendar year 2014.

Government of Alberta suggests that approximately 40% of the NO_x and nearly 60% of the SO_2 produced in the Edmonton region come from coal-fired electrical generation.[15]

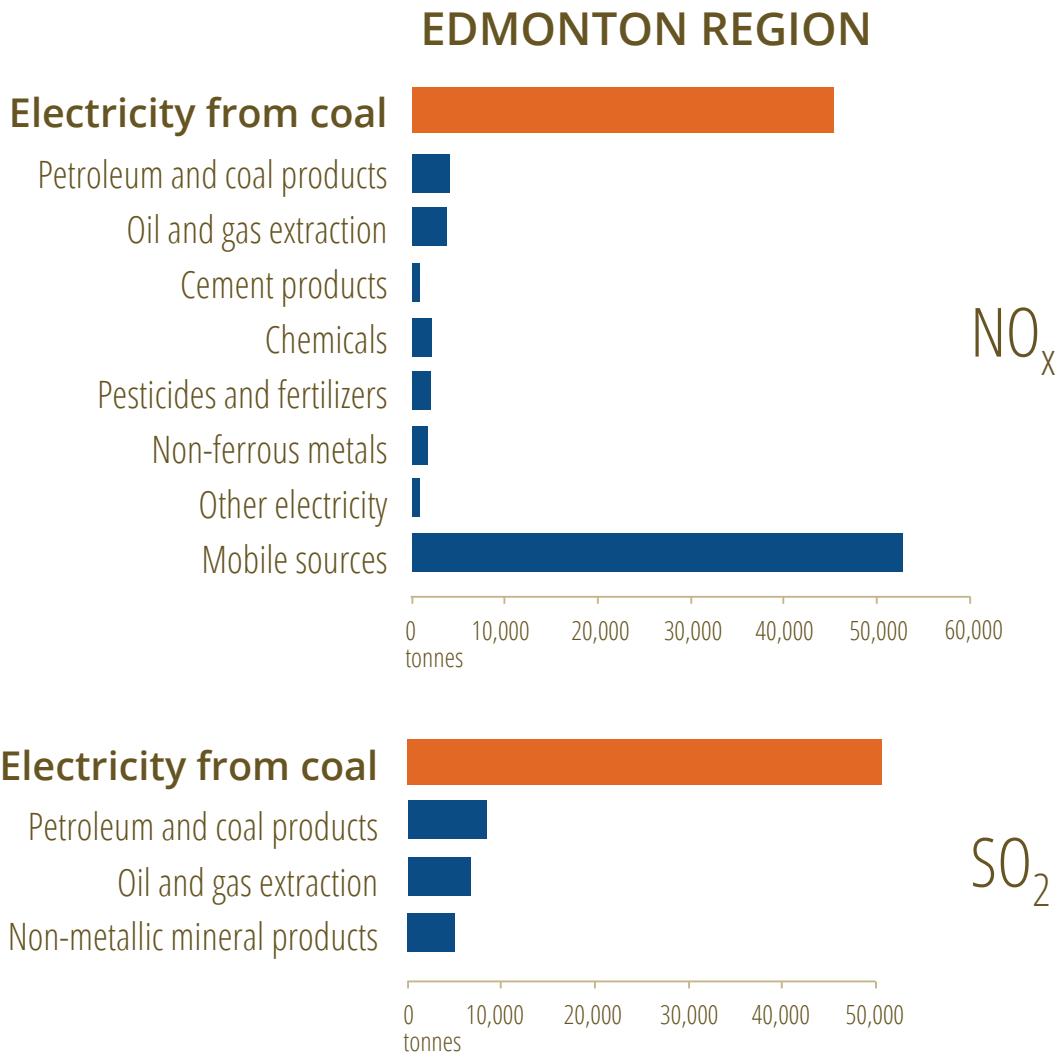

Figure 5. Coal plants remain a dominant source of important air contaminants in the capital region

Data source: Environment Canada and Alberta Environment[16]

[15] Government of Alberta, *Capital region fine particulate matter science report* (2014). http://open.alberta.ca/dataset/51e77770-bf72-4851-8a6b-240d0f5b3856/resource/88698cff-7d86-4dc7-964a-4dc6d0433c04/download/2014-CapitalRegion-PM-ScienceReport-Dec2014.pdf

[16] Environment Canada, *National Pollutant Release Inventory*. https://www.ec.gc.ca/inrp-npri/; Mobile source data from Alberta Environment, *Capital Region Fine Particulate Matter Science Report* (extrapolated from Figure 21). https://open.alberta.ca/dataset/9781460120736. Category names have been simplified. Minor sources are not shown.

2.3 Health impacts of coal plant emissions

The health impacts of coal's air pollutants have been extensively documented. Coal-fired plants emit large volumes of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) — two common air pollutants that can harm human health directly when present in the ambient air we breathe. Short- and long-term exposures to NO_2 and SO_2 have been linked to increases in respiratory ailments, diseases and premature deaths, while exposures to SO_2 have also been linked to cardiovascular ailments.[17]

A 2016 study from Health Canada draws alarming new conclusions about the direct impacts of SO_2. While short-term exposures have already been linked to respiratory morbidity in sensitive populations such as people with asthma, children, unborn children and the elderly, it appears that these populations are also more susceptible to adverse effects when exposed to SO_2 at current ambient levels. The study also suggests there may be a causal relationship between long-term, low-level exposure to SO_2 and adverse reproductive outcomes such as congenital heart defects and preterm delivery.[18]

Both gaseous NO_x and SO_2 also react with other elements in the atmosphere to produce fine particulate matter ($PM_{2.5}$), the air pollutant that has been most clearly and consistently linked to chronic cardiovascular and respiratory diseases, including lung cancer.[19] Long-term exposure to particulate matters is proven to be associated with higher rates of cardiovascular diseases such as ischemic heart disease, dysrhythmias, heart failure, and cardiac arrest.[20] More recent evidence suggests that $PM_{2.5}$ may also be associated with increases in adverse birth outcomes, development of childhood respiratory diseases, development of cognitive disorders, and increased rates of diabetes.[21] With respect to asthma specifically, a 2015 study funded by the European Union shows a strong link between exposure to air pollutants such as NO_2 and $PM_{2.5}$ and

[17] World Health Organization, *Review of evidence on health aspects of air pollution – REVIHAAP Project* (2013). http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report

[18] Andrew Read, *Sulphur Dioxide and Health: Summary of recent findings from Health Canada* (Pembina Institute, 2016). http://www.pembina.org/pub/sulphur-dioxide-and-health

[19] *Review of evidence on health aspects of air pollution.*

[20] C. Arden Pope et al., "Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease," *Circulation* 109 (2004), 1.

[21] *Review of evidence on health aspects of air pollution*.

the development of asthma during childhood and adolescence.[22] So, these air contaminants contribute to the development of asthma in the first place, then exacerbate asthma symptoms later.

Coal plants emit fine particulates directly ("primary PM"), but it is "secondary PM" formed from NO_x and SO_2 that is the major culprit behind the high levels of $PM_{2.5}$ measured in Alberta's Capital[23] and Red Deer regions,[24] and likely across the province.[25] These airsheds are overloaded with NO_x and SO_2.

The chemical composition of the fine particulate matter can vary based on the pollutants present, and health impacts will be different based on the specific chemicals. Secondary particles formed through reactions with NO_x and SO_2 have a higher impact to human health than primary PM. As Environment Canada states: "While the primary PM emissions from the electricity sector are important, it is the secondary PM formation resulting from NO_x and SO_x emissions, which has the greatest human health impact."[26]

Coal plants are also a significant source of mercury, a persistent toxic that accumulates in the aquatic food chain.[27] Prenatal and early life exposure to mercury, resulting from the consumption of mercury-contaminated fish, has been linked to adverse developmental impacts such as reductions in cognitive abilities and motor skills.[28] Researchers have attributed 3.2% of intellectual disability cases in the United States to

[22] Ulrike Gehring et al., "Exposure to air pollution and development of asthma and rhinoconjunctivitis throughout childhood and adolescence: a population-based birth cohort study," *The Lancet Respiratory Medicine,* 3, 12.

[23] Alberta Environment and Parks, *Capital Region Fine Particulate Matter Science Report* (2014). http://open.alberta.ca/dataset/51e77770-bf72-4851-8a6b-240d0f5b3856/resource/88698cff-7d86-4dc7-964a-4dc6d0433c04/download/2014-CapitalRegion-PM-ScienceReport-Dec2014.pdf

[24] Alberta Environment and Parks, *Red Deer Fine Particulate Matter Science Report* (2016). http://aep.alberta.ca/air/management-frameworks/canadian-ambient-air-quality-standards-for-particulate-matter-and-ozone/documents/RedDeerFineParticulateScience-Apr2016.pdf

[25] Alberta Environment and Parks, *Alberta: Air Zones Report 2011-2013* (2015). http://aep.alberta.ca/air/management-frameworks/canadian-ambient-air-quality-standards-for-particulate-matter-and-ozone/documents/AlbertaAirZonesReport-2011-13-Sep2015.pdf

[26] RIAS, 2048.

[27] Canadian Council of Ministers of the Environment, *Canada-Wide Standards for Mercury Emissions from Coal-Fired Electric Power Generation Plants* (2006). http://www.ccme.ca/files/Resources/air/mercury/hg_epg_cws_w_annex.pdf

[28] Ibid.

mercury exposure and valued these excess cases at $2.0 billion per year.[29] Women of childbearing age, pregnant women, children and populations that depend on fish as a traditional food source, are at greatest risk from mercury.[30]

Last but not least, Alberta's coal power plants emit significant amount of greenhouse gases emissions, which by contributing to climate change will impact the health of Albertans in the long term — and global citizens more broadly. The vast majority of scientists agree that climate change will substantially affect our environment and health. As an example, a 2009 collaboration between The Lancet and University College London examined the potentially disastrous effects that climate change could have on health across the globe, and concluded it could potentially be the biggest global health threat of the 21st century.[31]

More information on other contaminants common to coal combustion can be found in *A Costly Diagnosis*, which reviews the scientific literature connecting coal-fired power and human health impacts in greater detail.

[29] L. Trasande, C. Schechter, K.A. Haynes, P.J. Landrigan, "Mental retardation and prenatal methylmercury toxicity," American Journal of Industrial Medicine, 49(2006), 3. http://www.ncbi.nlm.nih.gov/pubmed/16470549

[30] *Canada-Wide Standards for Mercury Emissions from Coal-Fired Electric Power Generation Plants*.

[31] UCL Lancet Commission, "Managing the Health Effects of Climate Change," The Lancet 373 (2009), 9676. http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(09)60935-1/fulltext

3. Modelling health effects and health savings

In 2008, the Canadian Medical Association published results from their Illness Cost of Air Pollution (ICAP) model, which estimated the health impacts associated with air pollution across the country and the value of those health impacts. Working from the ICAP model estimates, *A Costly Diagnosis* estimated the impact of air pollution from Alberta's coal-fired plants on the health of Albertans in 2012.[32] The model estimated that, each year, emissions from Alberta's coal-fired plants were associated with:

- 700 visits to Alberta's emergency departments;
- 80 hospital admissions related to respiratory and cardiovascular ailments;
- Over 4,800 asthma episodes, which are days when asthma sufferers must miss work or school due to their illness;
- The premature deaths of more than 100 Albertans.

In addition, the ICAP model estimates that total economic damages in Alberta associated with the health impacts of air pollution from coal plants was in the range of $300 million annually.

Also in 2012, Environment Canada finalized federal coal regulations to impose carbon dioxide limits on new, and existing coal plants after they have reached the end of their useful lives. The regulations require most units to meet the emission rates of a combined cycle natural gas plant (an emissions performance standard) before they reach 50 years in age. As part of the final regulations, Environment Canada published a cost-benefit analysis of the regulations, known as a Regulatory Impact Analysis Statement (RIAS). Environment Canada assumed for this modelling most units would be unable to meet the emissions performance standard economically and would therefore close, including all existing units in Alberta, such that reductions in coal power translate into direct reductions in all coal emissions. The RIAS modelled the health impact implications of the new regulation versus a business-as-usual (BAU) scenario over a 20-year time frame (2015-2035) using a health benefit model that is similar to the ICAP model.

[32] *A Costly Diagnosis*.

By interpolating the RIAS results specific to Alberta, we can derive an estimate of the incremental health benefit for Albertans of an incremental reduction in generation from Alberta's coal plants. Then, by extrapolating the RIAS results, we can project the additional health benefits to be gained by accelerating the phase out of coal plants over and above the benefits that would result from the 2012 federal regulations.

3.1 Regulatory Impact Analysis Statement (RIAS) health benefit approach

The health benefits modelling used in Environment Canada's RIAS for its 2012 federal coal regulations took a three-step approach:

1. It started with Environment Canada's Environment Energy and Economy Model of Canada (E3MC) to estimate electricity demand, to be met by various generation technologies including coal-fired power plants, and therefore predict emissions from each coal-fired unit.
2. It then employed the Unified Regional Air-quality Modelling System (AURAMS) to predict how the emission changes associated with reduced coal generation would affect local ambient air quality, using three-dimensional state-of-the-art modelling.[33]
3. It used the ambient air quality outputs to estimate the incremental health and environmental benefits using the Air Quality Benefits Assessment Tool (AQBAT). AQBAT is an internationally respected computer simulation program developed by Health Canada to estimate the human health costs and/or benefits associated with changes in ambient air quality that arise from changes in air contaminant emissions.[34]

Figure 6 shows the conceptual flow of this three step modelling.

[33] RIAS, section 7.2.4 . This AURAMS model incorporates information on the emissions changes with "information on wind speed and direction, temperatures, humidity levels, and existing pollution levels, in order to predict how these emissions changes would impact local air quality."

[34] See Appendix B for more information about AQBAT.

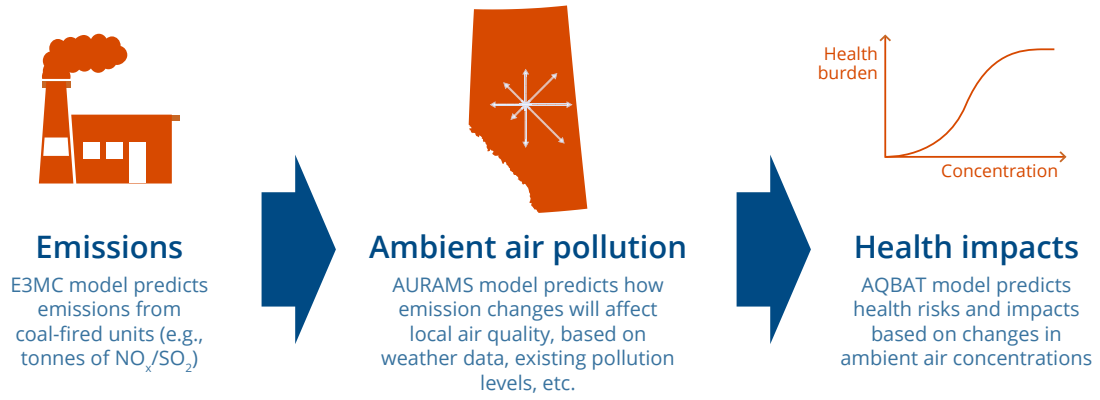

Figure 6. RIAS methodology: from emissions to health burden and cost for society

Environment Canada notes that its methodology (particularly the extrapolation of benefits from 2030 out to 2035) "provides conservative estimates for health and environmental benefits" because emissions reductions will actually increase over time.[35]

3.2 Summary of RIAS findings

The RIAS results of the 2012 federal coal regulations found that more than half of the cumulative avoided health impacts between 2015 and 2035 will take place in Alberta (Table 2). Additionally, the results found that nearly two-thirds of all the premature deaths and asthma episodes in Canada would be in Alberta. Environment Canada found that a 252,000 GWh reduction in coal-fired electricity generation in Alberta correlates with significant health benefits, such as the avoidance of 590 premature deaths and 520 emergency room visits and hospitalizations over the 20-year modelling period.

[35] RIAS, section 7.4.2.

Table 2. Cumulative avoided health impacts for selected health outcomes in Canada and Alberta between 2015 and 2035

		Canada	Alberta
Premature mortality		900	590
Emergency room visits and hospitalization		800	520
Asthma episodes		120,000	80,000
Days of breathing difficulty and reduced activity		2,700,000	1,900,000
Present value in 2015 of total avoided health outcomes (millions of 2015 dollars)[36]	Ozone related	$1,200	$740
	$PM_{2.5}$ related	$3,200	$2,100
	Total	$4,600	$3,000

Source: Environment Canada[37]

Figure 7 illustrates the modelling conducted by Environment Canada for Alberta for the RIAS. The shaded area between the solid line (i.e. BAU) and the dotted line (i.e. the implementation of the 2012 federal coal regulations) represents the coal generation reduction levels used by Environment Canada to calculate cumulative avoided health impacts (summarized at right in Figure 7).[38] The health benefits are due predominantly — but not entirely — to the lower ambient levels of $PM_{2.5}$ and ozone that result from the reduced coal-fired electricity generation. These levels account for 70% and 25%, respectively, of the total present value of avoided health costs in Alberta from reducing coal-fired electricity (Table 2).

[36] The "value of (avoided) health outcomes" (or "socio-economic value") represents the cumulative value of the risks associated with different health outcomes due to air pollutants emitted by coal-fired generation. This includes the benefit of avoided medical costs, the benefit of increased worker productivity, the benefit of avoiding pain and suffering, and the social benefit of reducing the risk of premature death. The exact ratio of how much of the benefits are due to avoided medical costs, versus how much are because of worker productivity or any of the other costs, varies based on which pollutants, which health endpoints, and which regions of the country are under analysis. See Appendix B for more information about the AQBAT model.

[37] RIAS, table18.

[38] As noted in the RIAS, "all the CAC reductions and associated health and environmental benefits presented are incremental and attributable to the Regulations" (section 10).

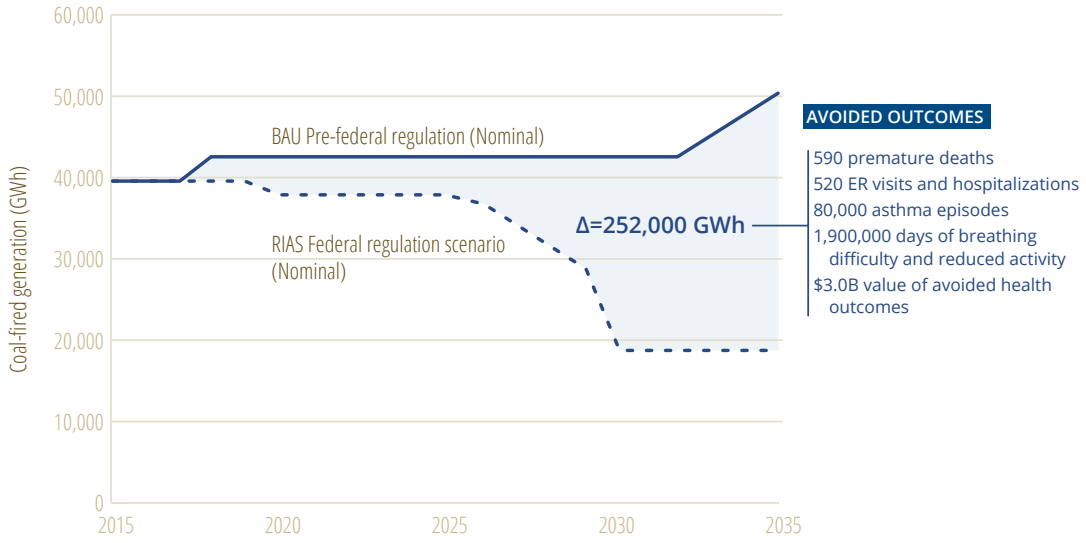

Figure 7. RIAS findings of health benefits associated with coal generation reduction in Alberta

Data source: Environment Canada[39]

The RIAS also estimates the health impacts prevented due to avoided mercury releases, which affect humans through deposition followed by bioaccumulation through the food chain. Over the 2015-2035 RIAS study time frame, the modelled coal power reduction was estimated to result in 3,607 kg less mercury released, providing a value of $14 million in avoided health impacts in Alberta, using a conservative estimate of the cost of health impact per kg of mercury.[40] However, Environment Canada notes that these costs are limited to the neurodevelopmental impacts of mercury, whereas emerging scientific evidence at that time suggested that mercury may also be connected to heart disease and premature death, an impact that could potentially magnify the cost of mercury by 50 times. Environment Canada chose not to include this much larger number in their analysis because of uncertainties, but noted that this clearly makes their analysis conservative. We estimate that including this would place mercury's impacts more in the range of $710 million, raising the total costs summarized above by nearly a quarter.[41]

[39] Health benefit data from RIAS. Numbers for electricity generation are approximated for illustration purposes as Environment Canada did not publish sufficient information about its model. See methodology in Appendix A2.

[40] RIAS, section 7.4.2.

[41] Ibid.

The results make clear that reduced coal emissions in Alberta will avoid health impacts, thereby lowering the associated costs of health impacts for Alberta's economy. Environment Canada has not published sufficient information about its model or results to determine where these avoided health impacts would be located in Alberta. However, it does indicate that most of these avoided costs are due to improved ambient $PM_{2.5}$ concentrations. $PM_{2.5}$ is the key air quality problem in the population-rich Capital and Red Deer regions, which are often downwind from the Wabamun plants where the bulk of coal combustion takes place.[42]

3.3 Interpolating Environment Canada's findings for Alberta

The RIAS analysis of benefits from coal generation reductions, conducted by Environment Canada, is currently one of the most detailed analyses available of the health impacts of coal plants. Interpolating avoided health impacts per 1,000 gigawatt hours (GWh) from the RIAS results generates incremental health factors for each unit of coal-fired generation in Alberta. These can then be employed to estimate the scaled-up avoided health impacts that will result from an accelerated coal phase out (see Chapter 4).[43]

3.3.1 Health impact factors of coal-fired generation in Alberta

Table 3 summarizes Environment Canada's findings of cumulative avoided health impacts in Alberta and the estimated health impact factors based on the indicated 252,000 GWh generation difference between the two scenarios.[44] It also extrapolates these factors to all generation in 2015, which can be used to check against other

[42] For a visual of the wind dispersion of pollution from the Wabamun area coal plants relative to Edmonton and Red Deer, see https://www.youtube.com/watch?v=RirxmdsZaew

[43] Detailed methodology can be found in Appendix A.

[44] It is important to note that these numbers are statistical estimates, based on the overall changes in per capita risks. This means Environment Canada modelling predicts that over the period 2015–2035 the proposed regulations would reduce mortality risks in Alberta, resulting in an estimated approximately 590 fewer premature deaths in the province. However, this does not mean that there will be 590 specific, identifiable individuals who will be "saved" in Alberta. Thus, the "health benefits" of the proposed regulation are not the number of lives "saved" per se, but rather the reduction in the average per capita risk. Similarly, the values in the economic benefit column do not measure the benefit of the individual lives saved, or hospitalizations prevented. Rather, this is the aggregated benefit of the reduction in individual risk levels across the province. RIAS.

estimates of coal-fired generation's health impacts, like the ICAP analysis in *A Costly Diagnosis*.

Table 3. Cumulative avoided health impacts and avoided health impact per 1,000 GWh of coal-fired generation in Alberta.

	RIAS analysis for AB	Our calculations	
	Cumulative avoided health impacts (2015-2035)	Health impact per 1,000 GWh of coal-fired generation[45]	Annual health impact extrapolated to 2015 coal-fired generation[46]
Premature deaths	590	2.3	92
Emergency room visits and hospitalization	520	2.1	81
Asthma episodes	80,000	317	12,506
Days of breathing difficulty and reduced activity	1,900,000	7,540	297,015
Socio-economic value of health outcomes (2015$)[47]	$3,000 million	$12 million	$461 million

Extrapolated to the amount of electricity generated in 2015, these per-1,000-GWh health-impact factors estimated that, in 2015, coal-fired generation contributed to 92 premature deaths and health outcomes valued at approximately $460 million, as illustrated in Figure 8. These figures are fairly consistent with the numbers previously estimated in *A Costly Diagnosis* — that is, 100 premature deaths and a $300 million cost per year.

[45] Health impact factors in this table vary from the ones published in *A Costly Diagnosis* (p. 55) due to a change in methodology. Factors published in this report are deemed far more conservative for a variety of reasons including those listed in section 3.3.2.

[46] The 2015 coal generation data reflects a low-end view of capacity factors from coal-fired power plants in Alberta because all plants were online (including Sundance 1 and 2, which returned to service in 2013) and capacity factors were depressed by the province's aberrant supply glut.

[47] Figures were originally made available in 2010$. They were converted into 2015$ using the Bank of Canada's inflation calculator (see Appendix A).

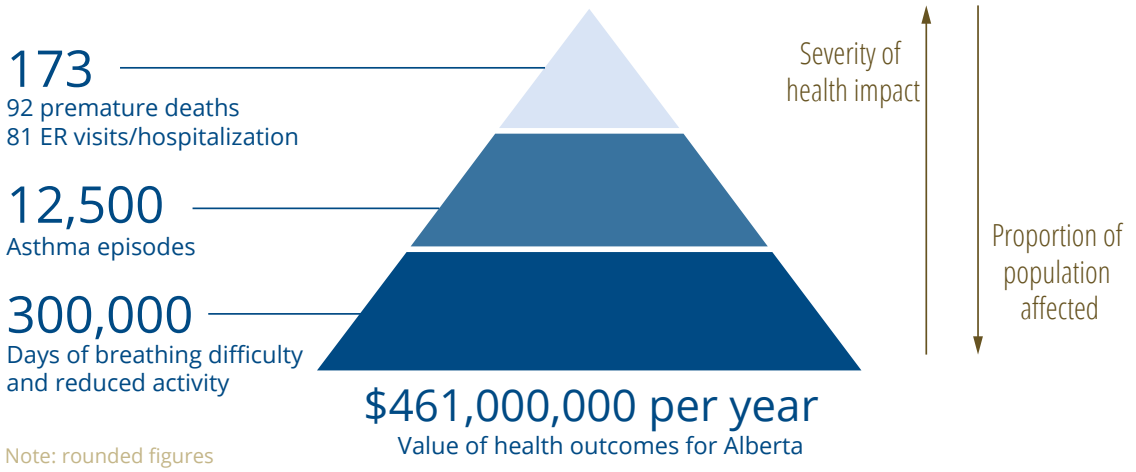

Figure 8. Impact on Albertans' health from coal-fired electricity in 2015

Data from Table 3; figure adapted from Health and Environment Alliance[48]

3.3.2 Caveats

The principle behind extrapolating the RIAS benefits to calculate impacts is straightforward: if there are avoided health impacts from reducing coal generation then by necessity there must be health impacts of the coal generation to start.

Nevertheless, two important caveats must be acknowledged due to the lack of published information around the assumptions and the model used by Environment Canada. First, the correlation between air contaminants and health impact may not be as linear as this analysis suggests: some air contaminants need to reach a certain threshold to inflict specific health outcomes — though, it should be noted, that there is no safe threshold for the main ambient air contaminants that Environment Canada modelled, ozone and $PM_{2.5}$,[49] so any non-linear threshold effect is mitigated for this analysis. The straight line extrapolation adopted in this analysis lacks the sophistication of the combined AURAMS/AQBAT modelling approach, which accounts for pollution interaction in the air and perhaps also for non-linear ambient air quality health impacts.

[48] Figure idea from Health and Environment Alliance, *The Unpaid Health Bill: How coal power plants make us sick* (2013), 10. http://www.env-health.org/IMG/pdf/heal_report_the_unpaid_health_bill_how_coal_power_plants_make_us_sick_final.pdf.

[49] Environment Canada, *Canadian Smog Science Assessment - Highlights and Key Messages* (2012). https://www.ec.gc.ca/Publications/AD024B6B-A18B-408D-ACA2-59B1B4E04863%5CCanadianSmogScienceAssessmentHighlightsAndKeyMessages.pdf

Second, this analysis does not account for the differences in location and performance of coal units in Alberta. Some coal units are closer to — and perhaps more commonly upwind — of major population centres. At the same time, as noted earlier, the two newest coal-fired plants in Alberta (Keephills 3 and Genesee 3) use control technologies to emit significantly less SO_2 and NO_x than older units, as shown in Figure 4.[50] For these reasons, it is a simplification to treat every GWh of coal power the same with no regard for its source and location.

Having said this, the federal government's RIAS analysis of 252,000 GWh of reduced coal output included not only a reduction from retired, older "dirty" coal plants, but also a reduction because new "cleaner" coal generating capacity would not be built under the regulations.[51] As such, in calculating the health impact factors of coal electricity generation, our denominator (the 252,000 GWh of coal power reduced) includes the reduction in energy produced by newer "cleaner" coal plants as well as by older "dirtier" coal plants.

There are further reasons to believe that the analysis here is, in fact, conservative:

- The RIAS estimates are themselves conservative, particularly the use of low-range estimates of mercury impacts on health.
- The RIAS incorporates increased emissions from gas-fired generation, which reduces their overall health savings, meaning a lower "health impact per GWh of coal reduced" factor in this analysis.
- The value of avoided health outcomes over the 2015-2035 period in the RIAS are discounted to present value, but the factor is applied to today's generation numbers for today's annual health impacts.

Finally, our analysis assumes that all benefits found in Alberta are due to coal generation reduction in the province only — i.e., they are not related to decreases in generation in other provinces, even though the RIAS explicitly illustrates that coal reduction in coal-based provinces has benefits in non-coal-based provinces. Because prevailing winds flow westward across the Prairies, Alberta would expect to be impacted by emissions from British Columbia — but British Columbia does not use coal to

[50] "Air Pollutant Emission Inventory."

[51] The BAU scenario includes the construction of five new coal power plants in Alberta between 2015 and 2035 that would be avoided under the 2012 federal regulation or have to be equipped with carbon capture and storage technologies. For example, the 450 MW Milner expansion, which would have had to be built with NO_x and SO_2 controls as required under Alberta's CASA regulations, was avoided by the federal regulations. See RIAS ("the Regulations prevent some planned coal units from being built"; "the majority of retired and avoided capacity occurring in Alberta").

generate electricity, and thus coal generation reduction from that province will have no impact on Alberta. However, coal generation in Alberta could be expected to affect Saskatchewan, Manitoba and potentially Ontario.

4. Health benefits of accelerated coal phase-out

When the federal government weakened its proposed coal regulations back in 2012 in response to lobbying from some coal generators, it allowed coal plants to continue unabated longer than first proposed,[52] and left health savings on the table. Alberta can now grasp these savings by accelerating our transition away from coal-fired electricity.

Having interpolated health impact factors per 1,000 GWh of coal generation from Environment Canada's own analysis of its coal-fired GHG regulations, this analysis now extrapolate these factors to produce a ballpark estimate of the scaled-up benefits of an accelerated coal phase-out, which is under development in Alberta.[53]

4.1 Phase-out scenarios

As mentioned above, Alberta announced a phase-out of coal power by 2030. The Reference Case in the Alberta Electric System Operator (AESO)'s 2016 Long-term Outlook, released in May, includes a schedule of coal unit closures to meet this 2030 commitment. In the early years, for the oldest six units, there is no deviation from the existing federal coal regulatory schedule. The 2030 deadline accelerates the schedule for the six units that the federal regulations allow to operate without abatement beyond 2030. For the middle six units, beginning in the late 2020s, the schedule for expected closure is advanced by one year for each of the units, presumably to create a slightly more measured closure schedule in the lead-up to the 2030 end date, to avoid too much capacity closure in just a couple of years.[54]

It is possible, however, to institute unit closures along a more stepwise schedule that realizes moderate capacity closures year after year, like a gradual staircase. In 2015, the Pembina Institute proposed a meaningful and measured schedule for phase-out or stringent emissions management requirements that allows investors a reasonable

[52] Mike De Souza, "Feds pressured by coal industry to weaken regulations, records reveal," *Postmedia News*, April 22, 2012.

[53] Detailed methodology can be found in Appendix A.

[54] Alberta Electric System Operator, *2016 Long-term Outlook* (2016), 32. http://www.aeso.ca/downloads/AESO_2016_Long-term_Outlook_WEB.pdf

opportunity to recoup invested capital based on reasonable investment expectations.[55] The schedule progressively moves to a 40-year end-of-life schedule, with the 2030 end date. This schedule is fairly closely aligned with the Alternate-policy Scenario in the AESO Long-Term Outlook.[56] The retirement date assumptions from both the AESO Reference Case and the Pembina Institute's proposed schedule are found in Appendix A.2.1. Figure 9 shows the how coal generation is reduced under the two scenarios.

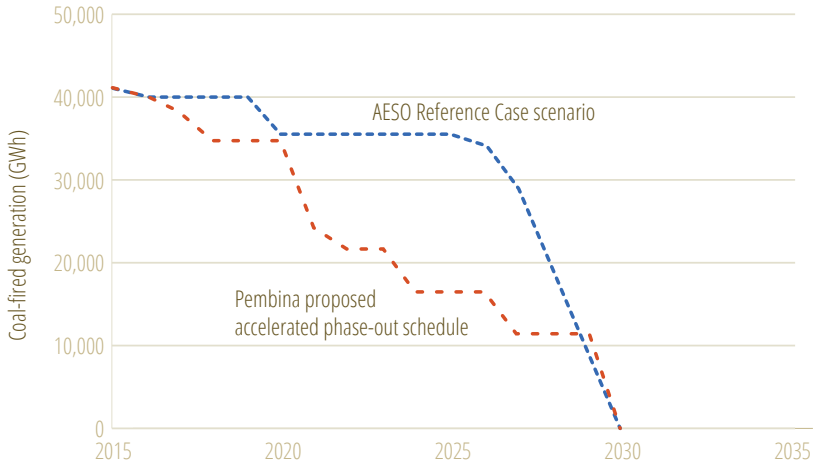

Figure 9. Phase-out scenarios used in this estimate

To compare phase-out benefits, first the two scenarios (BAU and 2012 federal regulations) from the 2012 RIAS were updated to better align with the state of the coal industry in Alberta in 2016. These two scenarios are referred to as 'Updated' (as opposed to 'Nominal') in the rest of this report — notes regarding modifications included in these scenarios can be found in Appendix A.2. Figure 10 shows the updated RIAS scenarios.

[55] Ed Whittingham, *Alberta Climate Panel Submission* (Pembina Institute, 2015), 7. https://www.pembina.org/pub/alberta-climate-panel-submission; Tom Marr-Laing and Ben Thibault, *Early coal phase-out does not require compensation* (Pembina Institute, 2015), 3. http://www.pembina.org/reports/coal-compensation-brief.pdf

[56] *2016 Long-term Outlook, 19.*

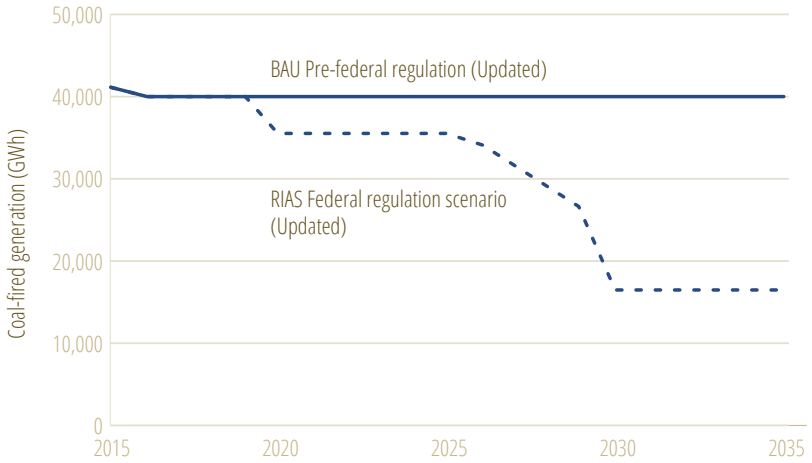

Figure 10. Updated RIAS scenarios used for comparison

The updated RIAS federal regulation scenario is the new baseline on which the 2030 Alberta coal phase-out is applied.

4.2 Health impacts of phase-out

Extrapolating the Environment Canada RIAS by applying the per-1,000-GWh health-impact factors to the additional coal-fired generation reductions projected under each of the two phase-out scenarios gives the proportionally additional health savings of the accelerated phase-outs. The caveats articulated in Section 3.3.2 also apply to this extrapolation.

As Table 4 shows, the AESO Reference Case, which represents the feasible minimum of what the province has so far announced on phasing out coal pollution by 2030, almost doubles the benefits in avoided impact on Albertans' health and the associated costs of these health impacts. The more accelerated schedule that the Pembina Institute proposed will achieve pollution reductions more quickly and will more than double the avoided health impacts and costs. The additional avoided health impacts for both modelled accelerated phase-out scenarios are over and above Environment Canada's estimated avoided health impacts in its federal coal regulations' RIAS.

Table 4. Cumulative avoided health impacts under federal regulation and following an accelerated coal-phase out schedule

	Cumulative avoided impacts under RIAS Federal regulation scenario (Updated)	Avoided health impacts from an accelerated coal-phase out schedule, additional to updated RIAS Federal regulation scenario	
		AESO Reference Case Scenario	Pembina proposed accelerated phase-out schedule
Premature deaths	492	306	618
Emergency room visits and hospitalization	434	270	545
Asthma episodes	66,760	41,468	83,856
Days of breathing difficulty and reduced activity	1,585,539	984,869	1,991,583
Value of avoided health outcomes (2015$)	$2,462 million	$1,529 million	$3,093 million

Figure 11 illustrates how the phase-out of coal pollution under the Climate Leadership Plan, under a variety of scenarios, will realize additional health and economic benefits. While the 2012 federal regulation is deemed to avoid 492 premature deaths over the 2015-2035 period, the AESO 2016 Long-term Outlook Reference Case scenario suggests an Alberta coal phase-out by 2030 will avoid an additional 306 premature deaths over the same period. These additional avoided premature deaths could jump to 618 if the province implements an accelerated coal phase-out in line with the Pembina Institute's proposal. The AESO's Alternate-policy scenario for coal unit closures provides a quite similar impact in terms of health and economic savings because the schedules are closely aligned.

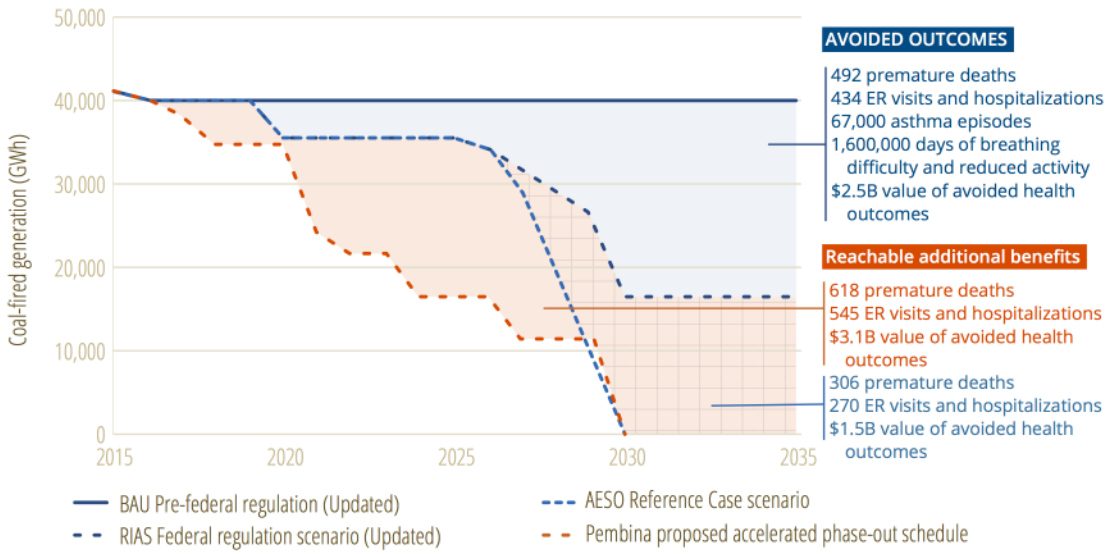

Figure 11. Additional health benefits associated with an accelerated coal phase-out

Note: Detailed methodology pertaining to the modelling of each of the scenarios can be found in Appendix A.

5. Conclusion

Coal-fired electricity generation has a significant impact on Albertans' health and the costs of health impacts to Alberta's economy. Extrapolating the results of Environment Canada's health modelling used for its 2012 federal coal regulations RIAS, the annual consequences of coal-fired power pollution's contribution to health impacts in Alberta could be in the range of:

- 100 premature deaths and nearly as many hospitalizations and emergency room visits
- 10,000 asthma episodes
- 300,000 days of breathing difficulty and reduced activity
- $450 million in socio-economic value of avoided health outcomes

This creates unnecessary and avoidable pressure on Albertans' health and Alberta's health budget and economy.

Environment Canada estimated that the coal power reductions from its 2012 coal GHG regulations will avoid 590 premature deaths and total $3B in avoided health outcomes in Alberta between 2015 and 2035. By an extrapolation of those results, Alberta's announced 2030 phase out of coal power pollution would nearly double those savings in that time frame. With a more ambitious phase-out schedule of older units between now and 2030, this same extrapolation would realize those savings sooner and in still larger magnitude. Over and above the federal savings, the Pembina Institute's proposed schedule for phasing out coal units could avoid approximately an additional:

- 600 premature deaths
- 500 ER visits and hospitalizations
- 80,000 asthma episodes
- 2 million days of breathing difficulty and reduced activity
- Nearly $3 billion in socio-economic value of health outcomes

Appendix A. Methodology

Calculations in this analysis derive from the Regulatory Impact Analysis Statement (RIAS) for the 2012 Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations.[57]

While the model and assumptions used in the RIAS are not fully detailed, Environment Canada associates specific health and economic benefits in Alberta with a difference of 252,000 GWh in generation between 2015 and 2035. This generation reduction comes from the modelling of two scenarios (business-as-usual and the new regulation one) where the capacity factors used for supercritical and subcritical units are unclear. For this reason, as well as the fact that all units differ in their emissions intensities and their impacts on population (due to proximity to population densities), it is a simplification to treat every GWh of coal power, no matter where it comes from, as the same.[58]

A.1 General modelling interpolation and extrapolation approach

A.1.1 Health and economic impact per unit of generation

Health and economic impacts from coal-burning per unit of generation were interpolated by dividing the impact listed in the RIAS[59] by the difference in generation between the two considered scenarios, the business-as-usual scenario and the regulatory scenario. While the authors' modelling indicates a difference of 234,000 GWh between the two scenarios, the higher RIAS number of 252,000 GWh was used.[60]

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[57] Environment Canada, Regulatory Impact Analysis Statement (RIAS), *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations* (2012). Available in Canada Gazette Part II, Vol. 146, No. 19. http://publications.gc.ca/collections/collection_2012/gazette/SP2-2-146-19.pdf

[58] See also Section 3.3.2.

[59] RIAS, Table 10.

[60] The difference can be explained by the differential capacity factors used under the two scenarios, as mentioned in the RIAS: "the average capacity utilization at coal-fired units in Canada is 91% by 2035 (increasing to 95% under the regulatory scenario)" (RIAS, p. 2033). See also note in section A.1.3.

This approach assumes linearity between the incremental change in air contaminant release and the incremental change in health impact.

A.1.2 Additional health benefits under a variety of coal phase out scenarios

The accelerated phase out of coal units between 2015 and 2030 will have an impact on the health of Albertans and the province's economy. This impact was calculated by extrapolating the cumulative generation change over the period with impact factors per GWh previously calculated.

This reduction in generation is calculated for the period 2015-2035 for two scenarios (AESO Reference Case and the Pembina Institute's proposed schedule) against a revised version of the RIAS scenarios, which were updated to reflect the most recent developments in unit closures, unit restarts and new unit development.

A.1.3 Inflation of avoided health costs

Values of avoided health outcomes are estimated by Environment Canada in the RIAS in 2010$. They were converted into 2015$ using the inflation calculator from the Bank of Canada.[61]

A.2 Scenarios and generation differentials

Data used to model benefits associated with an accelerated coal phase-out in Alberta is publicly available at www.pembina.org/pub/breathing-benefits.

A.2.1 Assumed retirement years for coal-fired units in each of the scenarios

Analysis in this report makes use of six scenarios, with different retirement years for each of the coal-fired units. Table 5 displays the retirement schedule taken into consideration in the authors' modelling, with notes explaining modifications.

[61] Bank of Canada, Inflation Calculator. http://www.bankofcanada.ca/rates/related/inflation-calculator/

Table 5. Coal-fired units details and assumed retirement year under six scenarios

Coal-fired unit	Capacity (MW)	Commissioned year	End of economic life (Fed Reg)	Retirement year under following scenarios					
				BAU Pre-federal regulation (Nominal)	RIAS Federal regulation scenario (Nominal)	BAU Pre-federal regulation (Updated)	RIAS Federal regulation scenario (Updated)	AESO Reference Case scenario	Pembina proposed accelerated phase-out schedule
Milner 1[62]	144	1972	2019	2044	2019	2015	2015	2015	2015
Battle River 3	149	1969	2019	2044	2019	2044	2019	2019	2016
Battle River 4	155	1975	2025	2050	2025	2050	2025	2025	2016
Sundance 1	288	1970	2019	2011	2011	2044	2019	2019	2017
Sundance 2	288	1973	2019	2011	2011	2044	2019	2019	2017
Sundance 3	368	1976	2026	2051	2026	2051	2026	2026	2020
Sundance 4	406	1977	2027	2052	2027	2052	2027	2026	2020
Sundance 5	406	1978	2028	2053	2028	2053	2028	2027	2020
Sundance 6	401	1980	2029	2054	2029	2054	2029	2028	2020
Battle River 5	385	1981	2029	2054	2029	2054	2029	2028	2021
Keephills 1	395	1983	2029	2054	2029	2054	2029	2028	2023
Keephills 2	395	1983	2029	2054	2029	2054	2029	2028	2023
Sheerness 1	400	1986	2036	2061	2036	2061	2036	2027	2026
Sheerness 2	390	1990	2040	2065	2040	2065	2040	2027	2026
Genesee 1	400	1989	2039	2064	2039	2064	2039	2029	2029
Genesee 2	400	1994	2044	2069	2044	2069	2044	2027	2029
Genesee 3	466	2005	2055	2080	2055	2080	2055	2029	2029
Keephills 3	463	2011	2061	2086	2061	2086	2061	2029	2029
Swan Hills	319	2015	N/A	2065	2065	N/A	N/A	N/A	N/A
Milner 2	450	2018	N/A	2068	N/A	N/A	N/A	N/A	N/A
Endogenous Advanced Coal 1	400	2033	N/A	2083	N/A	N/A	N/A	N/A	N/A

[62] Milner was assumed to run on 100% on coal until 2015. In the updated scenarios, it is assumed to cease operation at the end of 2015, based on its suspension announced in Spring 2016. While Milner seems to be operating again, it is more conservative to avoid overstating the impact of the accelerated coal phase-out by assuming it closes in all scenarios.

Endogenous Advanced Coal 2	400	2034	N/A	2084	N/A	N/A	N/A	N/A	N/A
Endogenous Advanced Coal 3	400	2035	N/A	2085	N/A	N/A	N/A	N/A	N/A

Notes

Retirement years. Power plants are assumed to retire on December 31 of the indicated retirement year. In the RIAS, it is specifically mentioned that 'Coal-fired units do not operate in the retirement year' – this explains why years in this table differ from the source.

Commission years. Similarly, power plant units are assumed to start production on January 1 of the commission year indicated in the table.

Capacity factors. A capacity factor of 75% is uniformly used to estimate electricity generation from all units between 2015 and 2035 for all scenarios. This is the capacity factor referenced for coal in 2012 in the RIAS.[63] It also roughly represents the capacity factor that coal has realized in the last five calendar years, once we control for the Sundance 1 and 2 force majeure (75.58%).[64]

On the one hand, this capacity factor is conservative as capacity factors could increase over time, as coal generators often expect to operate at higher capacity factors than the low levels seen in recent years. As such, the total amount of coal generation assumed by the units is low across all scenarios, making the difference in energy between scenarios conservative. On the other hand, shutting down units could lead to higher utilization of remaining units, which would lessen the coal energy differential between scenarios. However, along with the phase out of coal emissions by 2030, the Alberta government has committed to replacing two-thirds of Alberta's coal generating capacity with renewable energy.[65] By substituting a large portion of the retiring coal capacity with fuel-free power that bids at the bottom of the merit order, the difference in capacity factor for remaining coal units will be reduced. While RIAS mentions their model uses

[63] RIAS, Table 1.

[64] Calculated based on data from: Alberta Electric System Operator, *2015 Annual Market Statistics Data File*, http://www.aeso.ca/downloads/2015_Annual_Market_Statistics_data_file.xlsx; and Alberta Electric System Operator, *2016 Long-term Outlook Data File*, http://www.aeso.ca/downloads/2016_LTO_Data_File.xlsx. If the Sundance 1 and 2 force majeure is excluded from the calculation (i.e., included in the capacity denominator), the average capacity factor from 2011-2015 is 71.70%.

[65] Alberta Government, "Climate leadersihp: Ending coal pollution." http://www.alberta.ca/climate-coal-electricity.cfm

variable capacity factors to balance generation and demand, our modelling with fixed capacity factor only leads to a 7% difference when calculating generation gap between the two scenarios.

A.2.2 Power plant coal units included and excluded within each scenario

The following explains inclusions or exclusions of units in each of the scenarios:

Business-as-usual Pre-federal regulation (Nominal): This scenario is the business-as-usual (BAU) scenario outlined in the RIAS. The document specifically expects six units to be built under this scenario: Keephills 3 (2011), Milner 2 (2018), Swan Hills (equipped with CCS technology – 2015) as well as three Endogenous Advanced Coal units (2033, 2034, and 2035).[66] The document also indicates that "for other units, it is assumed they do not automatically retire at the end of their useful life, but instead are refurbished [...] and continue generating electricity as the lowest cost option for another 25 years".[67] Sundance 1 and 2 were deemed as permanently shut down at the time the assessment was conducted and therefore not included in this scenario.

RIAS Federal regulation scenario (Nominal): The RIAS mentions that "under the regulatory scenario modelled, coal units retire (close) at the end of their useful life or continue operating if they employ CCS".[68] It also indicates a year for each of the ten units retiring under this scenario.[69] It is assumed that all non-CCS coal units envisaged in the BAU are excluded in this scenario as the RIAS states that "the Regulations prevent some planned coal units from being built".[70] As a consequence, Swan Hills is the only unit that comes online under this scenario. Finally, Sundance 1 and 2 were deemed as permanently shut down at the time the assessment was conducted and therefore not included in this scenario.

Business-as-usual Pre-federal regulation (Updated): This scenario is a modified, more realistic version of the nominal pre-federal regulation scenario as envisaged in the

[66] RIAS, section 7.1.5.

[67] Ibid.

[68] Ibid., section 7.1.6.

[69] Ibid., Table 6.

[70] Ibid., section 7.3.6.

RIAS. In this scenario, Milner 1 is shut down in 2015[71], and Sundance 1 and 2 are back online[72] and keep operating until 25 years after the end of their economic life. Also, other than Keephills 3, which was commissioned in 2011, all new units planned in the original BAU are not included in this scenario.

RIAS Federal regulation scenario (Updated): Similarly, this scenario is a modified, more realistic version of the nominal post-federal regulation scenario as envisaged in the RIAS, from the vantage of 2015. In this scenario, Milner 1 is shut down in 2015[73], and Sundance 1 and 2 are back online[74] and operate till the end of their economic life. Also, the Swan Hills power plant is not built under this scenario. It was necessary to produce this scenario to reflect the reality of the BAU as seen from the beginning of 2016 (the federal regulation scenario with Sundance 1 and 2 online and Milner permanently suspended), to assess the implications of the Alberta phase-out policy options.

AESO Reference Case scenario: This scenario uses the retirement years from the Reference Case scenario found in the AESO 2016 Long-term Outlook.[75] The only change made to this scenario was to retire Milner 1 in 2015 – while the unit was suspended in Spring 2016 and may resume operations, the 2015 retirement across all scenarios produces a more conservative result of the differential between scenarios.

Pembina proposed accelerated coal-phase out schedule: This scenario uses the retirement years proposed by the Pembina Institute.[76] Retirement years for Keephills 3 and Genesee 3 were modified from 2030 to 2029 since it is assumed no coal-fired unit can run in 2030.[77] Again, Milner 1 was assumed to retire at the end of 2015.

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[71] Milner 1 was suspended in Spring 2016, however this scenario considers a closure in 2015 for a more conservative result.

[72] Both units were returned to production in December 2013.

[73] Milner 1 was suspended in Spring 2016, however this scenario considers a closure in 2015 for a more conservative result.

[74] Both units were returned to production in December 2013.

[75] Alberta Electric System Operator, *2016 Long-term Outlook*, Appendix A. http://www.aeso.ca/downloads/AESO_2016_Long-term_Outlook_WEB.pdf

[76] *Early coal phase-out does not require compensation*, 4.

[77] Pembina accelerated coal-phase out schedule was published prior to the official announcement of phasing out coal by 2030.

Appendix B. AQBAT overview

Health Canada uses the Air Quality Benefits Assessment Tool (AQBAT) to estimate the benefit of improvements in air quality. Within this model, air quality improvements are defined based on the ambient levels of several key pollutants – especially $PM_{2.5}$ and ground level ozone. The model also includes 18 different health risks, ranging from the risk of experiencing asthma symptoms to the risk of premature death. A list of all the pollutants and all the health risks included in AQBAT is provided in Table 6.

Each of the pollutants modelled by AQBAT is linked with one or more of the health risks. A reduction in pollutant levels reduces the health risks for Canadians exposed to that pollutant. For each change in a health risk, the model then assigns an economic value drawn from the available medical and economic literature. These values differ for each type of health risk. For some health risks, the economic values are associated almost entirely with avoided pain and suffering. For other risks, the economic values are driven by avoided medical costs or increased productivity. For the reductions in the risk of premature death, the economic values are based on estimates of the social benefit of reducing the risk of premature death.

Once the model has determined how much risks will be lowered, and what the economic value of reduced risks are, the model aggregates risk reductions and economic values over the affected population, to determine the number of avoided illnesses, and the net economic benefit, for a particular census division. This process is replicated in 288 Canadian census divisions, based on estimated air pollution levels in each census division.

Provincial and national estimates are then calculated simply by adding up the health impacts and economic benefits by census division.

Table 6. Health risks linked to air pollution that are measured by AQBAT

Health endpoint	At risk population	Linked to these pollutants
Acute mortality	All	CO, NO_2, O_3, SO_2
Acute respiratory symptom days	All adults and non-asthmatic children 5-19	O_3, $PM_{2.5}$
Adult chronic bronchitis	25+	$PM_{2.5}$
Asthma symptom days	Asthmatic (14.3%) children 5-19	O_3, $PM_{2.5}$
Cardiac hospital admissions	All	$PM_{2.5}$
Cardiac emergency room visit	All	$PM_{2.5}$
Child acute bronchitis episodes	Children 5-19	$PM_{2.5}$
Chronic exposure cerebrovascular mortality	25+	$PM_{2.5}$
Chronic exposure COPD mortality	25+	$PM_{2.5}$
Chronic exposure ischemic heart disease mortality	25+	$PM_{2.5}$
Chronic exposure lung cancer mortality	25+	$PM_{2.5}$
Chronic exposure respiratory mortality	30+	O_3
Chronic exposure respiratory mortality	All	O_3
Elderly cardiac hospital admission	65+	CO
Minor restricted activity days	Non-asthmatic children 5-19	O_3
Respiratory emergency room visit	All	O_3, $PM_{2.5}$
Respiratory hospital admissions	All	O_3, $PM_{2.5}$
Restricted activity days	All adults and non-asthmatic children 5-19	$PM_{2.5}$

Source: Correspondence with Health Canada