B.C. Shale Scenario Tool

Technical report

Maximilian Kniewasser, Matt Horne

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The Pembina Institute is a national non-partisan think tank that advances clean energy solutions through research, education, consulting and advocacy. We have spent close to three decades working to reduce the environmental impacts of Canada's energy production and use in several key areas:

- driving down energy demand by encouraging energy efficiency and transportation powered with cleaner energy sources;
- promoting pragmatic policy approaches for governments to avoid dangerous climate change, such as increasing the amount of renewable energy plugged into our electricity grids;
- and — recognizing that the transition to clean energy will include fossil fuels for some time — advocating for responsible development of Canada's oilsands and shale gas resources.

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Contents

List of Figures

List of Tables

1. Introduction

The relatively recent ability to combine horizontal drilling and hydraulic fracturing (fracking) has made vast reserves of natural gas in British Columbia's northeast economically attractive. Because of the province's relatively close proximity to Asia and increasing competition to supply gas to the U.S., B.C. has targeted liquefied natural gas (LNG) exports to Asia as a primary opportunity to develop a market for those reserves.

There are currently 19 proposals for LNG terminals along B.C.'s coast. While most of these projects are unlikely to be developed, if even a few proceed, the LNG terminals will create considerable pressure to increase the development of B.C.'s shale gas resources in the northeast. The environmental impacts of such development could be significant and the magnitude of those impacts have not been thoroughly explored or addressed.

The Pembina Institute — with modelling support from Navius Research — developed a scenario-planning tool that can be used to better understand these environmental impacts. In particular, the tool allows users to explore the potential implications of:

- Different levels of LNG and shale gas development
- Different source basins for the gas (e.g. Montney or Horn River)
- Different technologies and practices designed to limit environmental impacts (e.g. reducing methane leaks or recycling wastewater).

The tool is not a predictive tool regarding how much LNG — if any — will proceed, where the source gas will come from or how effectively the province will limit environmental impacts. Rather, it seeks to clarify the potential environmental impacts of LNG and shale gas development under different scenarios defined by the user.

The remainder of this report discusses:

- The main factors users can select to develop different scenarios (Section 2).
- An overview of eight scenarios developed by Pembina to illustrate the range of potential environmental impacts under different assumptions (Section 3).
- Information on the structure of the tool to help users orient themselves (Section 4).
- Next steps indicating how the tool can be best used with its current functionality and how that functionality can be improved over time (Section 5).
- Appendices that describe the main model parameters and the sources for the information (Appendix A), and catalogue the comments received through the review process and Pembina's responses to those comments (Appendix B).

2. Levers in the tool

The B.C. Shale Scenario Tool provides three main inputs that determine the environmental impacts of various shale gas development scenarios. They are:

1. **How much gas is developed.** The tool allows users to define: 1) the amount of LNG development that occurs and the timing of that development, and 2) the combined amount of gas exports to B.C.'s traditional North American markets and domestic gas use.

2. **Where the gas comes from.** The tool allows users to define the percentage of gas coming from six producing regions: conventional B.C. reserves[1], the Montney, the Horn River, the Liard, the Cordova, and Alberta. The percentages can be changed over time and the tool calculates the number of wells and environmental implications based on factors specific to each basin (e.g. gas from the Horn River requires more water for fracking and results in more greenhouse gas emissions than gas from the Montney.

3. **The technologies and practices used to develop the gas.** The model has options to specify environmental policy outcomes for GHG emissions, water use for fracking and wastewater production (e.g. how much methane emissions are reduced relative to current practice, or how much wastewater is used for fracking instead of freshwater). The policy outcomes for GHG emissions, water use and wastewater can be set independently. The outcomes can also be specified by gas basin to explore scenarios where policy approaches differ by region (e.g. more electrification in the Montney than the Horn River). For GHG emissions, users can specify if the policies apply to new and/or existing infrastructure.

[1] Note: Conventional also includes others, such as the Jean Marie and Cadomin basins. We chose to include them with conventional as they often use more conventional techniques and are different from the horizontal fracturing techniques used in the Montney and Horn River.

3. Scenarios

The Pembina Institute developed eight scenarios to illustrate a range of LNG development and environmental policy. The findings demonstrate the wide range of environmental impacts that results from those scenarios. The scenarios and their findings are summarized in the tables and figures below.

Table 1: Summary of settings for eight different shale gas development scenarios

Scenario	**LNG development**	**Net gas export to Alberta / U.S. and domestic demand**	**Technologies and practices to reduce environmental impact**			**Notes**
			Summary	Carbon	Water Use	
Option 1	3 LNG terminals (36 Mt of LNG per year in total)	Constant at 2014 levels	Current technology and practice	No change	No change	
Option 2	3 LNG terminals (36 Mt of LNG per year in total)	Constant at 2014 levels	Significant improvement	50% improvement for upstream (New stock), CCS (All stock), Leak repair (All stock), and LNG electrification (All stock)	44% improvement (25% Water recycling and 25% Saline water use)	
Option 3	5 LNG terminals (82 Mt of LNG per year in total)	Constant at 2014 levels	Current technology and practice	No change	No change	The LNG development in these two scenarios aligns with the 82 Mt LNG scenario published by the Ministry of Natural Gas Development and the Oil and Gas Commission
Option 4	5 LNG terminals (82 Mt of LNG per year in total)	Constant at 2014 levels	Significant improvement	50% improvement for upstream (New stock), CCS (All stock), Leak repair (All stock), and LNG electrification (All stock)	44% improvement (25% Water recycling and 25% Saline water use)	
Option 5	1 LNG terminal (12 Mt of LNG per year in total)	Constant at 2014 levels	Current technology and practice	No change	No change	

Option 6	1 LNG terminal (12 Mt of LNG per year in total)	Constant at 2014 levels	Significant improvements	50% improvement for upstream (New stock), CCS (All stock), Leak repair (All stock), and LNG electrification (All stock)	44% improvement (25% Water recycling and 25% Saline water use)	
Option 7	1 LNG terminal (12 Mt of LNG per year in total)	Drops by 50% by 2040	Significant improvements	50% improvement for upstream (New stock), CCS (All stock), Leak repair (All stock), and LNG electrification (All stock)	44% improvement (25% Water recycling and 25% Saline water use)	Scenario designed so that gas development in B.C. follows a path similar to global gas demand in a world with strong climate change policy.
Option 8	1 LNG terminal (2.5 Mt of LNG per year in total)	Drops by 50% by 2040	Exceptional improvements	75% improvement for upstream (New stock), 75% CCS (All stock), 75% Leak repair (All stock), and 100% LNG electrification (All stock)	44% improvement (25% Water recycling and 25% Saline water use)	Designed to achieve significant cuts in GHG emissions that could potentially be in line with B.C.'s climate targets.

Table 2: Summary of eight different shale gas development scenarios (2030)

Scenario	Wells drilled	GHG emissions (kt CO2e)	Freshwater use (million m^3)	Wastewater (million m^3)
Option 1	786	27,479	16.79	5.81
Option 2	737	16,681	8.90	3.08
Option 3	1,409	49,521	29.38	10.21
Option 4	1,309	28,975	15.42	5.36
Option 5	472	15,972	10.34	3.56
Option 6	450	10,745	5.57	1.92

Option 7	298	8,872	3.97	1.36
Option 8	222	6,243	1.52	0.49

Figure 1: New wells drilled for eight shale gas development scenarios

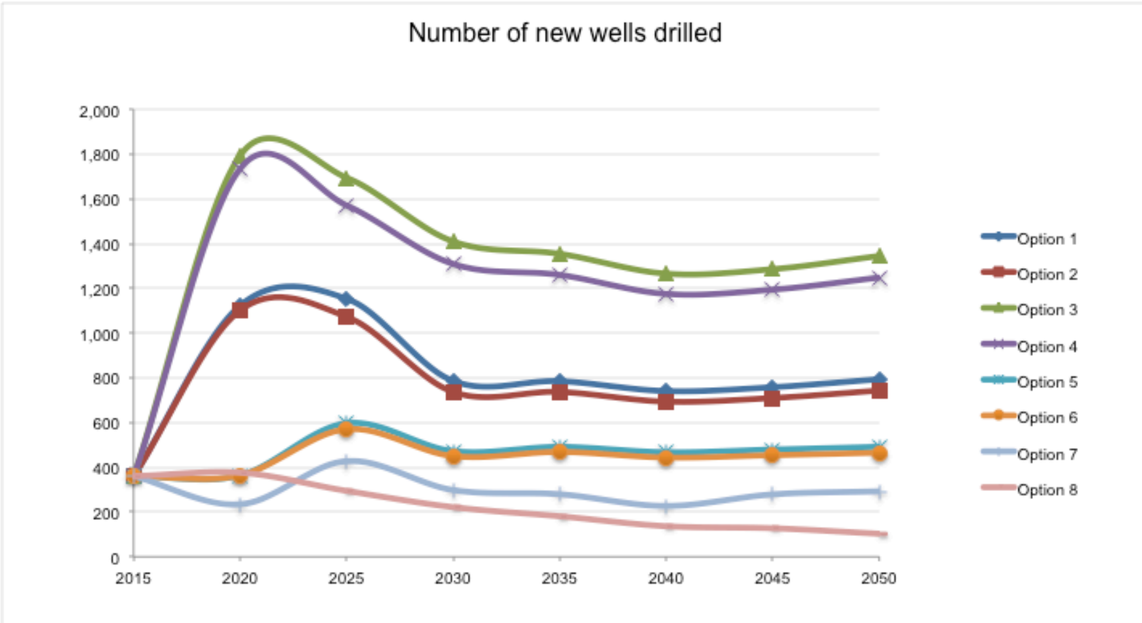


Figure 2: GHG emissions for eight shale gas development scenarios

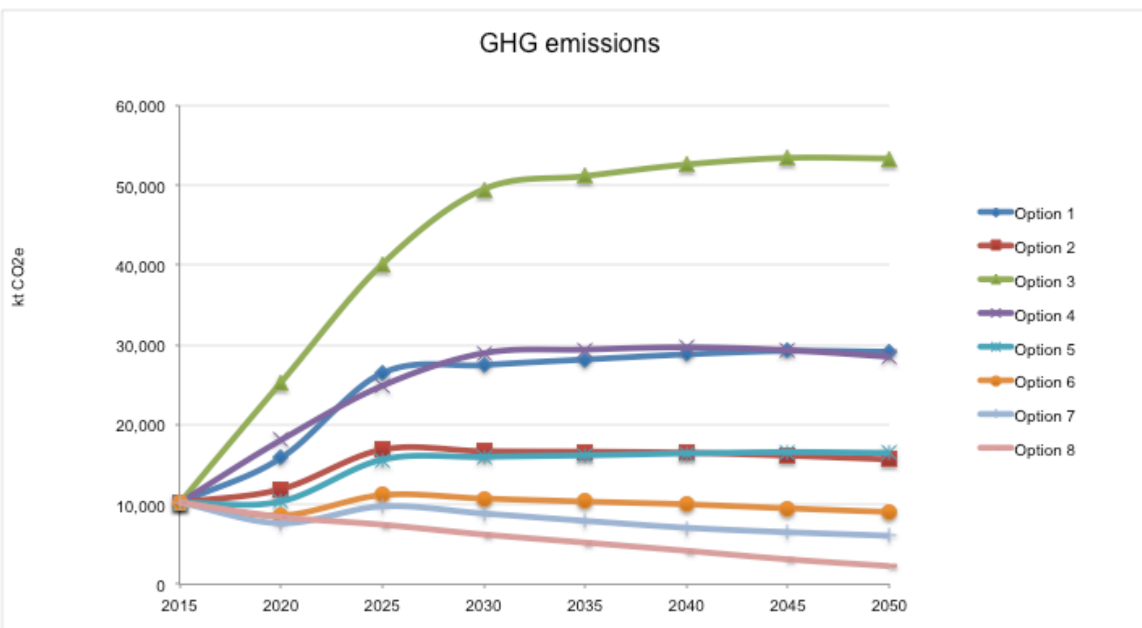


Figure 3: Freshwater use for eight shale gas development scenarios

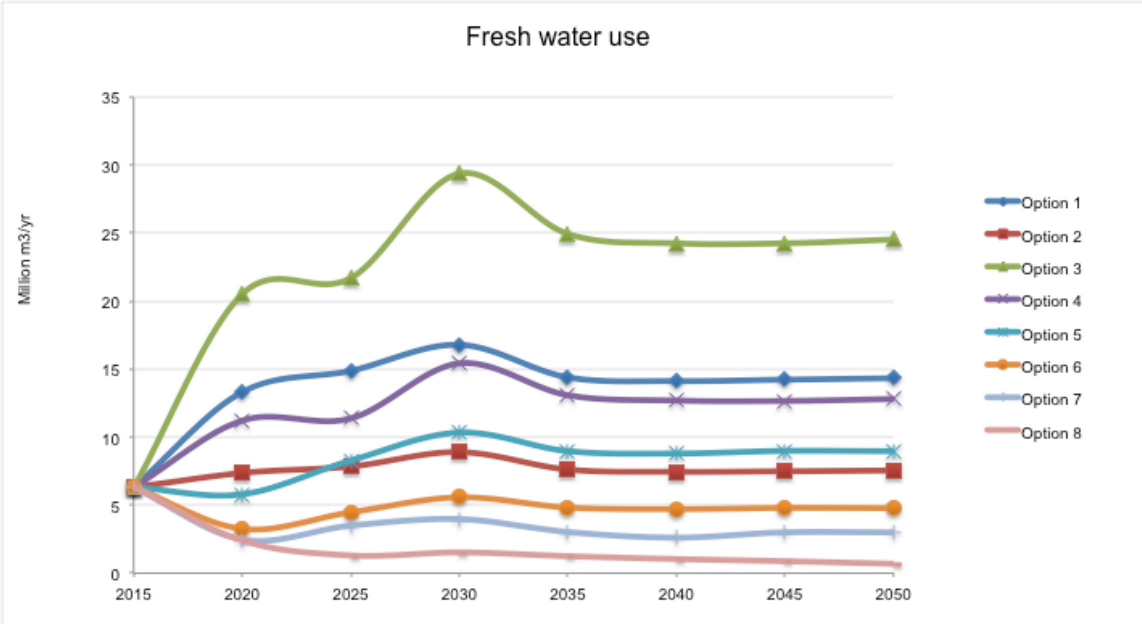
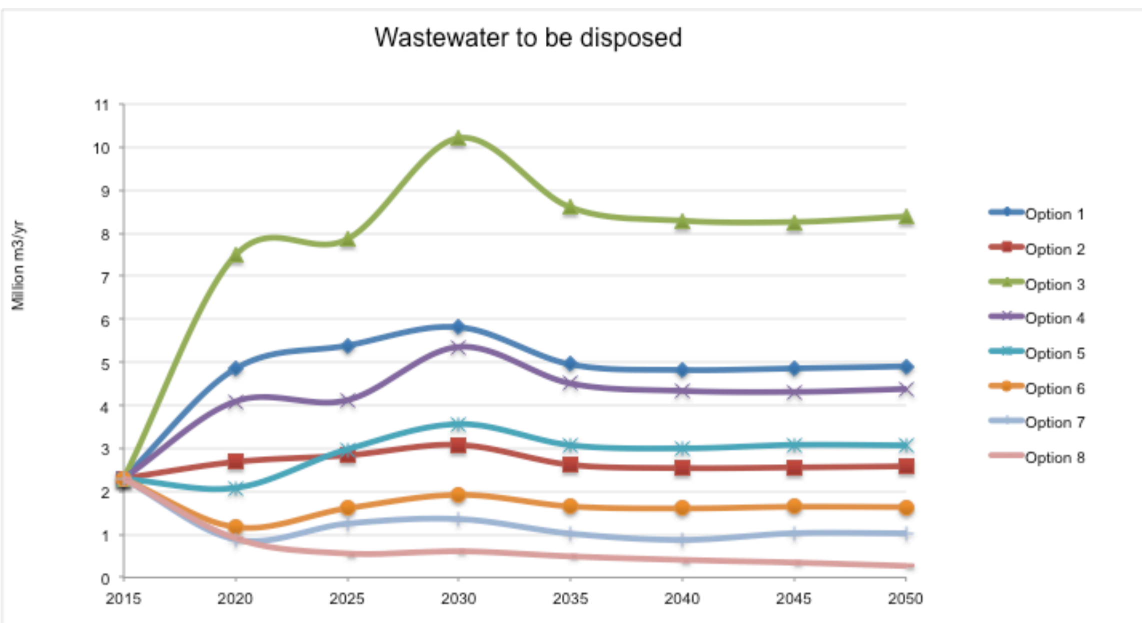


Figure 4: Wastewater production for eight shale gas development scenarios



4. Navigating the tool

The B.C. Shale Scenario Tool is controlled in one of two ways:

1. By the "Simple scenario analysis" tab. This tab has several pre-set scenarios that can be used as a starting point to understand the implications of different levels of development and policy.
2. By the "Inputs" tab. This tab allows users greater control over the amount of LNG and shale gas development, where the gas comes from and environmental policies applied.

In general a blue tab means an input is possible in this tab. A green tab gives information. White tabs are mostly background calculations.

Detail on each tab is found in the table below and more complete instructions for the tool can be found in the video manual.

Table 3: Summary of main tabs in the B.C. Shale Scenario Tool

Tab Name	Tab Description
Simple analysis	The “Simple analysis” tab allows users to quickly explore eight different pre-set development scenarios. If users desire more control of the scenarios, they can use the tabs described below.
Inputs	Complete functionality of the tool is controlled by the “Inputs” tab. Changes to the amount of gas development, where the gas comes from and environmental policy outcomes are made in this tab.
Summary + scenario comparison	The “Summary + scenario comparison” tab summarizes the inputs and outputs and provides several summary charts. The tab also allows users to save outputs from three separate scenarios that can then be easily compared to one another based on the number of wells drilled, GHG emissions, fresh water use and wastewater.
Detailed outputs	The “Detailed outputs” tab provides more detailed outputs for the scenario being explored. Users can explore the numbers and use them as needed.
Numbers in context	The “Numbers in context” tab provides several comparators for the outputs of a given scenario.

	For example: GHG emissions are compared to the equivalent number of cars and the province's 2020 and 2050 targets.
Environmental pricing	The "Environmental pricing" tab explores the potential effects from environmental pricing. Users can specify the level and coverage on prices applied to GHG emissions, freshwater use and wastewater production. The model is not currently dynamically linked to technological or economic responses to these environmental prices (e.g. efforts to reduce GHG emissions intensity in response to a higher carbon tax) and therefore represents the maximum net revenue to government.
Methane Sensitivity	Methane is an important component of the GHGs from B.C.'s natural gas sector. How significant it is in terms of carbon dioxide equivalents depends on the volume of methane emitted (or the leakage rate), the global warming potential of methane and the time horizon being considered. This tab enables users to understand the implications of changing those parameters.
Parameters + Emission Factors	All environmental parameters and emission factors are found in the "Parameters + Emission Factors" tab. These parameters can be changed as required by the user or as better information becomes available. An important exception is the well production functions that are defined in a separate tab called "Initial Prod and Well Decline". These functions can also be changed as better information becomes available on production and decline rates from the various producing basins.

5. Next steps

The priority next steps for the B.C. Shale Scenario Tool that Pembina has identified are grouped into two categories: a) taking advantage of the current functionality and b) building on the existing functionality. These next steps are in addition to ongoing maintenance to the tool to fix bugs as they are identified and updating model parameters as better information becomes available (e.g. GHG emission factors and well production decline rates). The tool has been designed to be publicly available and future iterations will follow the same approach.

5.1 Taking advantage of current functionality

- *Develop scenarios for specific LNG terminal proposals.* The tool enables specific LNG proposals to be defined so the full picture of environmental impacts can be better understood and how stronger policies could limit those impacts.
- *Develop scenarios for specific regions within the Peace.* The tool currently provides results for northeast B.C. as a whole and by major basin. With some additional assumptions it can also be used to develop more detailed results for a specific region in the northeast where there is interest in understanding what a given level of LNG development could mean at a regional or community scale.
- *Develop scenarios that represent more detailed policy designs.* The tool currently has the ability to represent a number of generic policy designs for GHG emission, water use and wastewater. It is also possible to use the tool to represent more detailed policies to understand how they could contribute to the province's environmental goals (e.g. developing a scenario that illustrates the potential if the province adopted a policy similar to the leading methane monitoring and control policies in the United States).

5.2 Building upon existing functionality

- *Change basin selection to be based on new production.* In the current version of the tool, basin selection is based on total production. Pembina plans to add functionality to have basin selection be based on new production instead of total production. New production may be a more intuitive approach to selecting the amount of gas coming from a certain region and guard against unrealistic swings in production from basin to basin.
- *Enable policies on existing infrastructure to be phased in over time.* The current version of the tool allows GHG policy outcomes to be applied to either all equipment or only new equipment at the various capital turnover dates. The former option results in a complete change over of existing stock. While this could be realistic over a longer time frame, it overestimates the likely response to government policy in the short-term. To address this, Pembina would like to add functionality that allows

existing infrastructure to be retrofitted over a specified period of time (e.g. 10% of existing pneumatic devices are upgraded annually).

- *Disaggregate LNG terminals.* Currently, all LNG terminals have the same emission intensity, and the "LNG terminal electrification" policy outcome function applies to all terminals equally. In reality, LNG terminals could have a broad range of GHG intensities and will respond differently to environmental policies. For future versions of the tool, Pembina plans to disaggregate each LNG terminal with that terminal's specified GHG intensity.
- *Include more sophisticated representation of land impacts.* How shale gas development impacts land is inherently complex. The actual area affected by development is often not very large relative to the northeast of the province. However, an important concern is the fragmentation of habitat from roads, pipelines, wellpads, seismic lines and other infrastructure associated with shale gas development. The current iteration of the tool explores these issues in a basic way. In a future version we plan to improve this representation to better understand and communicate the impacts of shale gas development on land in the northeast.
- *Represent changes in resource efficiency over time.* Currently, the tool treats the energy and water efficiency of shale gas development as static over time unless policy options are selected to require improvements. In reality, better technologies could improve energy and water efficiency while the quality of the shale gas resource could degrade negatively impacting those efficiencies. In a future version of the tool, Pembina would like to better represent some of these dynamics and give users the ability to make assumptions as to how they will evolve over time.

Appendix A. Assumptions and Parameters

Emissions factors

Sector	Source	Pollu tant	Basin	2011 Emissions Factor	Unit is t per
Natural Gas Production	Fuel Combustion - Heat	CO2	All	36.94	Well/yr
Natural Gas Production	Fuel Combustion - Engine/Turbine	CO2	All	188.30	number
Natural Gas Production	Glycol Dehydrator Off-Gas/Loading/Unloading/Storage Loss	CH4	All	0.06	million m3/yr
Natural Gas Production	Flaring	CH4	All	0.08	Well/yr
Natural Gas Production	Flaring	CO2	All	12.17	Well/yr
Natural Gas Production	Fugitive Equipment Leaks	CH4	All	0.59	Well/yr
Natural Gas Production	Reported Venting	CH4	All	1.13	Well/yr
Natural Gas Production	Unreported Venting	CH4	All	1.34	Well/yr
Gas Transmission, Distribution, Storage	Reported Venting	CH4	All	0.20	million m3/yr
Gas Transmission, Distribution, Storage	Fugitive Equipment Leaks	CH4	All	0.18	million m3/yr
Gas Transmission, Distribution, Storage	Fuel Combustion - Engine/Turbine	CO2	All	19.39	million m3/yr
Natural Gas Processing	Fuel Combustion - Heat	CO2	All	9.34	million m3/yr
Natural Gas Processing	Fuel Combustion - Engine/Turbine	CO2	All	52.53	million m3/yr
Natural Gas Processing	Glycol Dehydrator Off-Gas/Loading/Unloading/Storage Loss	CH4	All	0.01	million m3/yr
Natural Gas Processing	Flaring	CH4	All	0.02	million m3/yr
Natural Gas Processing	Flaring	CO2	All	3.65	million m3/yr
Natural Gas Processing	Fugitive Equipment Leaks	CH4	All	0.02	million m3/yr

Natural Gas Processing	Unreported Venting	CH4	All	0.01	million m3/yr
Natural Gas Processing	Formation CO2	CO2	Conventional /other BC	54.01	million m3/yr
Natural Gas Processing	Formation CO2	CO2	Montney	0.00	million m3/yr
Natural Gas Processing	Formation CO2	CO2	Horn River	218.78	million m3/yr
Natural Gas Processing	Formation CO2	CO2	Cordova	139.22	million m3/yr
Natural Gas Processing	Formation CO2	CO2	Liard	119.33	million m3/yr
Well Drilling, Servicing, and Testing	Fuel Combustion	CO2	All	415.14	New well/yr
Well Drilling, Servicing, and Testing	Flaring	CH4	All	1.35	New well/yr
Well Drilling, Servicing, and Testing	Flaring	CO2	All	233.60	New well/yr
Accidental releases	Surface casing vent flow/gas migration	CH4	All	1.01	Well/yr
LNG Production	All	CO2e	All	0.16	tLNG per year

Note: Based on Clearstone Engineering 2014

Emission factors continued: Formation CO_2 by basin

Basin	% formation CO2	t-CO2 / million m^3
Conventional	3.72%	54.01
Montney	1%	0.00
Horn River	12%	218.78
Cordova	8%	139.22
Liard	7%	119.33
Assuming pipeline spec CO2%	1.00%	

Alberta emission factors

Process	g CO2e/GJ
Fuel distribution and storage	1318
Fuel production	1122
Feedstock recovery	1898
Gas Leaks and flares	
CH4 venting	961
CH4 leaks	423
Flaring	670
Formation CO2	
CO2, H2S removed NG	863
Total	7255

Note: based on GHGenius weighted average numbers for shale gas. Further disaggregated by Pembina to fit the model functionality.

Other parameters

Parameter	Value
Methane emission factor	21
Retirement age of all stock that isn't wells/production	30

Well production parameters by basin

Basin	Thousand m3/day	Million m3/year
Conventional	48.0	18
Montney	75.0	27
Horn River	160.0	58
Codova	70.0	26
Liard	525.0	192

Water use and wastewater production parameters by basin

Basin	Water use for fracking (m^3)	Flowback (%)
Conventional	500	30%
Montney	9,000	45%
Horn River	79,500	30%
Cordova	43,000	40%
Liard	23,000	40%

Land-use parameters: number of wells per well-pad

Number of wells/well pad	Size in hectares (10,000 m2)
Conventional	1
Montney	16
Horn River	16
Cordova	10
Liard	10

Other land-use parameters

Parameter	Value
Size of conventional well-pad (Hectares)	1
Size of multistage well-pad (Hectares)	1.42
% Road construction relative to well-pad area	281%
% pipeline construction relative to well-pad area	75%
% Facilities relative to well-pad area	6%

Appendix B. Feedback catalogue from outreach of draft B.C. Shale Scenario Tool

In March and April 2015, a draft of the B.C. Shale Scenario Tool was shared with provincial government staff, First Nations, local governments, industry, academics and environmental groups. The following table compiles the unattributed comments received through that review period and Pembina's response.

Area	Reviewer comment	Pembina response
Layout / General		
	Set a default scenario of what is most likely/expected. Also provide a few key facts (i.e. what is production currently, what are the reserves of the gas basins, what extraction rate can be achieved, Consumption in B.C., trade flows etc.). This info could be default page, or section (perhaps to the right of the instructions). --> A likely /middle of the road scenario is also important as some people may be just focused on one issue, and want a reasonable start point (i.e. a water person has no idea about LNG units or production forecasts, and so having a middle of the road helps).	Regarding key facts: Added to this version of the tool (i.e. current production, info on size of LNG plants etc.). Regarding setting a default scenario in the inputs tab: We are not comfortable making a forecast on what is most likely to occur. For ease of operation, we have included a "Simple scenario analysis" functionality. This allows users to explore 6 different pre-set scenarios, by clicking one button.
	Raw gas option not very helpful.	We have removed this option.
	Decrease numbers in charts and make units clear	We have made many of the numbers larger (i.e. million m3 of water) and have tried to make the charts more easily understandable.
	Have a user manual in a separate 'manual' tab. Refer to "where in Manual" in input tab.	We have made a quick 10 minute YouTube video manual, describing the model, and link to it in the model. We are not producing an in-depth written manual for the tool.
	Need to make units more understandable/relatable.	In the "Inputs" tab, we have explained some of the units and

	put them in perspective of current production and planned development.
Put units into perspective. Include BC GHG emissions as quick reference; include comparators etc.	We have included a "Numbers in context" tab that compares the outputs to some easier to understand metrics.
More info to describe policies + inputs	We have included a few pop ups to further elaborate on the policy outcomes.
Password protect most sheets	We have protected all background calculation sheets after the “Parameters and emission factors” tab.
Lots of info to input. Be useful to have a quick tool option where you can chose facility and see impact of facility at different levels of development. For example, #### Group is very interested in upstream impact of ## LNG project, so tool would be useful to community if one could look at upstream impact of that project.	Regarding the linking of the tool of individual LNG projects to specific upstream assets. We have received this comment several times, but are not comfortable linking so many assumptions to one model. We have concerns with an automated link that assumes an LNG company will develop its own upstream assets if that LNG project moves forward. An LNG proponent may well buy from the market if prices are lower, or a mix of the two could happen. We are interested in working with First Nations and communities in the northeast to develop scenarios that are more relevant to specific regions.
In option 2 of the inputs tab, where are we supposed to get the total production % from for each basin? I see some of them are filled in, but are those numbers OGC or just samples to run the modelling? If they are from OGC, are they current to the last quarter or end of 2014? Also, how often will they be updated, or will it be up to user to populate.	As with the total amount of LNG development, we are not comfortable offering a forecast of where development is likely to occur, so it is up to the user to populate. Allows users to see the trade-offs from developing different regions.
A short tutorial video will be useful (5 minutes).	We have developed a 10 min tutorial video to accompany the tool.
Cordova and Liard likely won't be developed in next decade	We have still included Cordova and Liard as options that could be developed over the next 35 years. We are not offering a forecast or an indication as to how likely that

	development is.
Concern regarding response to policy on existing infrastructure. Response is too fast.	We include an option for GHG policy outcomes to apply to all stock or to only new stock, which is based on well retirement or a 30-year lifespan for other infrastructure. This does not apply to freshwater and wastewater policy outcomes though. In the future, we would like to improve the approach to existing infrastructure so that improvements could be phased in over time (e.g. replacing 10% of pneumatic devices with zero-bleed options every year).
Conventional NG production for 2015 (estimated in 40%) seems high. References from NEB are about 25 or 20%	We based our model on best available data and are confident it is a relatively accurate representation of reality. The cause for this discrepancy is that there are additional regions that are not covered in this model (such as the Jean Marie and Cadomin basins). We chose to include them with conventional as they often use more conventional techniques and are different from the horizontal fracturing techniques used in the Montney and Horn River. We have attempted to clarify this in the model documentation.
In the current model, parameters assume that NG production will increase (at least from 2014 to 2020). There is also a note stating that legacy production is presumed to stay constant after 2014. Would you consider an increase even in the absence of LNG development?	The revised version of the tool allows users to set both LNG demand and non-LNG demand. This allows users more ability to create the scenarios they foresee or want to evaluate.
It needs a lot more graphs that are easy to understand and show the trade-offs between the different input options.	We have included a scenario comparison function that focuses on communicating key findings and allows comparing up to three different scenarios through simple graphs.

	Notionally we believe the well counts generated seem high for the incremental LNG production. This is obviously sensitive to operating practices, however industry is moving to longer laterals.	Our well production numbers are based on the last available production data from the OGC (2013 Resource Estimate report). We intend to update well productivity parameters in subsequent versions of the model when information becomes more available.
	A minor point but gas production is quoted in the tool in mln m3/yr whereas industry more commonly uses mmcf/day so you might consider changing units for all upstream gas production data for ease of comparison.	Official BC numbers are based in metric. We explored including both units in the model, but the result seemed overly confusing and we chose to keep reporting in metric.
	While we appreciate the opportunity to comment, (### organization) will not be sending further feedback beyond what we have already provided. (### organization) continues to be concerned about the value of the tool in that it is largely redundant with respect to existing industry practices and provincial policy and regulatory requirements.	
	Tool is very complex — perhaps too complex for many potential users. Tough to know how to navigate the tool, especially if they are not experts. Too complex and end application escapes commenter. To make it more useable, need 1) more explanations of inputs, as well as process and how it toes together. Also need to clarify why one would use the simple over the complex. 2) Clarify numbers, and make references (i.e. what is LNG demand in mtpa roughly forecasted). 3) Also needs explanation on how the number of wells is calculated from the inputs.	1) We have included pop up bubbles and a short video manual to explain the inputs. We also included a "Simple analysis" that allows users to select one of 6 pre-set scenarios by only clicking one button. 2) We included a "Numbers in context" tab that compares the results to some easy to understand metrics. 3) Number of wells is calculated through a stock turnover model, which is driven by NG demand. Wells from different basins have NG production type curves that reference best available data.
GHG		
	Be able to set GHG intensity for each LNG plant, and not just one standard for all.	Unfortunately this is beyond our resources for the current version of the model, where we have focused the majority of functionality on upstream issues. We will hopefully incorporate LNG terminal disaggregation in a subsequent version of the tool.

Alberta is likely to supply gas to BC LNG developments and therefore should be included in the model.	Alberta has been added to the revised version of the tool.
I don't see the emissions intensity target anywhere. This would be a policy input.	The LNG emission intensity targets are in the parameters tab and inform the LNG facility calculations. It is currently set at 0.16 tCO_2/t-LNG, which is current target. Applying the "LNG electrification" input can further reduce this.
I wonder if you could somehow include the GWP for methane in your GHG emissions summary. It would be interesting to see if leakage from methane and CO_2, when taking the GWP of methane into account, is high enough for BC shale gas that it does not provide climate benefits over coal.	We have included a "methane sensitivity" tab that compares GHG emissions under different CH_4 leakage rates and GWPs.
Do transmission GHGs reflected the difference in transmission differences between gas destined for NWBC, lower mainland or Chicago. And for gas moving out of BC as gas, are the transmission GHGs from out-of-province included in our numbers.	Transmission GHG emissions are based on the average GHG intensity of gas transmission in BC, extrapolated by the growth in gas production. So, we are implicitly assuming that the average GHG intensity of future gas transmission is the same as it is today. We have not accounted for the potential change in "typical" distance and topography that might arise with new pipelines, not how this would affect energy or GHG from transmission. We will investigate opportunities to better address this issue future iterations of the model.
Some of the policies include measures to reduce emissions from unreported venting. I would suggest including sources and evidence that sustain the existence of unreported venting.	The unreported venting numbers are based on the 2014 Clearstone Inventory Report for Environment Canada that tries to address emissions, including from unreported venting from equipment. The methane leakage rate is low compared to academic studies and suggests that we are underestimating total methane emissions, rather than overestimating.
Formation CO_2 – You should probably use a % of the raw gas production required, rather than what I believe was used; which was a factor by basin and had units of million m^3/yr.	Our model works with the throughput per million m^3/yr. However, we have made a conversion to % CO_2 in the "Parameters and emissions factors" tab. Users can now simply

	specify the desired % of formation CO_2.
I did not see any shrinkage factors in there, so I wanted to confirm that the type curves used were sales gas. If so, you would have to gross up to raw to determine the GHG factors. Further clarification from commenter: Typically losses (shrinkage) are determined at various points along the supply chain. These losses vary by field and formation. It sounds like you have this sorted and we are just disconnected on verbiage.	Not sure if we entirely understand comment: The model calculates on raw gas data and the emission factors are based on raw gas. The gas used along the supply chain to create sales gas is accounted for and informs the GHG emissions (this we believe is the shrinkage factor you refer to).
You should use the sales gas curves to determine the number of wells required for a specific export volume. I believe this is what was done, but I did not convert units and compare the decline curves to source data. Further clarification from commenter: When I built these models I determined the shrinkage for the various areas for a typical well in order to develop a "sales gas " type curve, that way when I back calculated the number of wells from the export volume I could determine how many wells would be required to supply a specific sales/export volume. Once the number of wells were determined it was easy to gross up the sales volumes to raw volumes for the specific areas. I saw that you sourced OGC's type curves, as I recall they are raw volumes, but I did not confirm that this was the case or if it was that you have used shrinkage factors to determine the number of wells.	Not sure if we entirely understand the comment. Export volumes are given as sales gas. However, the number of wells to meet this includes the gas used/lost in getting the raw gas to the export stage, and therefore the number of wells is based on raw gas. Does this address your comment?
Commenter compared findings from Pembina scenario tool to this operator's actual finding. In general, for larger operations, our findings were similar (GHG) as for this operator's operation. However, the operators smaller operations have lower emissions in real life than what was forecasted by the Pembina tool. Note from operator, this is a small sample.	Interesting findings. Our model does not change emission intensity by size of operation. We will investigate this for future iterations of the model.
Given the range of industry practices around flaring and venting, we believe it's important for external users of the tool to understand what assumptions are being made and the relative impact of operating practices.	The numbers are based on the latest Clearstone Engineering reports, which try to assess emission numbers/factors for the industry as a whole, and not on a per operator basis. We realize that some operators will perform better, while others perform worse.
We'd recommend caution in using absolute numbers for GHG emissions and water usage unless these are benchmarked with actual trends over a sample number of years.	We benchmark our GHG numbers to the BC Facility GHG Inventory Report and found very similar numbers. We hoped to do the same for water use in the current version, but unfortunately water

		data availability was an issue and we were unable to complete this.
Water		
	No wastewater stored on surface in BC. All frack water must be discarded in underground wells	This was poorly communicated in first draft. We addressed this in the revised version.
	Adjust water use breakdown (Saline, recycled etc.) to what has happened in past in each basin (i.e. benchmark to reality)	We were unable to benchmark water use due to a lack of data. We will try and benchmark to reported data in forthcoming versions depending on data availability.
	Disaggregate water + wastewater policies, as these are very different from basin to basin	We have disaggregated water policy outcomes by basin in the revised version.
	Put water use into context of region	We have included a "Numbers in context" tab that compares findings to some easy to understand metrics, including water use in relation to the NE of BC.
	Flowback rates vary from basin to basin. Refer to Goss Report for more info.	Our parameters are based on literature and on discussion with experts. Due to the uncertainty around these parameters, we have made them easily changeable in the "Parameters and emission factors" tab. We will update the parameters in future versions if better numbers become available.
	Under wastewater policies you have wastewater treatment. That's not a policy option in BC if you're talking about flowback water, as this has to be disposed of in a deep injection well by law. You can, however, treat water used in the drilling process at industrial wastewater treatment facilities. More specificity on the source of wastewater here would be useful. And in any case, it would be useful to have an output for volumes of wastewater injected into disposal wells.	Regarding wastewater treatment: We have learned that some solution providers have water treatment options for produced water, but that this is almost non-existent in BC. We will keep this policy outcome in the tool to enable exploration of future changes in disposal/treatment requirements. Regarding more specificity on the source of wastewater: We have only included flowback water from fracking in the current version. We will keep in mind on possibly adding more water and

	wastewater sources in future iterations.
It would be nice to have more information on the source of withdrawals (river, lake, groundwater), and even the watersheds where withdrawals are occurring.	We have disaggregating water use by basin. The idea of disaggregating water sources is a good one. Unfortunately it is outside of our resources for this project at the current time. We will keep this in mind for future iterations of the model.
I see that you have wastewater stored on the surface in the detailed outputs. I'm just wondering why. This water will be disposed of somehow eventually depending on how contaminated it is and if it's flowback water. What was the rationale behind including this output? Is it because of concerns over contaminated water storage tank spills or leaks?	This was poorly communicated in our draft version. We wanted to highlight how much wastewater is temporarily being stored at the surface. This added unnecessary confusion. In the revised version we have changed language to wastewater to be disposed off in deep-water injection as an output.
Neither saline groundwater nor recycling is really "policy" questions. They are play-specific operational questions. I think it would be helpful to allow for greater granularity in setting the start time and % for specific plays.	We agree that geography plays a major role. However, we find that it is also a policy question. For example, if freshwater use were priced, it would encourage greater use of saline water and recycling of water. We have tried to communicate this better in the forthcoming version of the model. We have added functionality to allow disaggregation of setting water and wastewater policy outcomes by basin.
There is quite a bit of saline groundwater use occurring now. Both Encana and Nexen have saline groundwater systems in place (since about 2011 for Encana). Operators in the south Montney (Heritage) are installing saline groundwater wells.	We were not able to find the appropriate data to include water benchmarking in our tool at this point. We will keep this on our list of next steps for future iterations of the tool.

For "water recycling", operators will generally reuse as much of the flowback water as they can, based on an economic imperative to not have to drill and operate a disposal well, or not have to pay for 3rd party disposal. Disposal is expensive (e.g., $50-$125+ per m3 to a 3rd party disposal operator, including trucking charges). Much of the volume of reuse is based on the volume of flowback, which varies quite a bit among formations, but is generally 15-60% of the initial volume used for well completion (lowest in the Horn, highest in the Montney Heritage).	We used best data available to us at this point. We look to update the tool with more detailed data as it becomes available. Also, we have included an environmental pricing tab that shows maximum costs to producers from freshwater and wastewater pricing policies in the revised version.
Water use is more detailed than just "fresh water" or saline water". Municipal wastewater reuse is occurring (e.g., Dawson Creek – about 6000 m3/day available to Shell and others, in the Montney Heritage). It would be helpful to incorporate that – also, it might work better in the model as a volume rather than as a %.	We were not able to find the appropriate data to include municipal wastewater reuse in our tool. We will keep this on our list of next steps for future iterations of the tool.
I suggest you not have too much confidence in the estimate of water use per well in the Liard. There haven't been enough wells drilled to allow us to understand the usage. Based on similarity with the Horn, I would suggest using the same water volume per well as the Horn.	We adjusted Liard to be the same as the HRB water parameters.
Almost 1/4 of water use is from saline - companies moving there more and more. Also, water recycling has already been occurring.	We were not able to find the appropriate data to include water benchmarking in our tool. We will keep this on our list of next steps for future iterations of the tool. We have included saline water use and water recycling as policy outcome options.
Differentiate water policy by basin	We have disaggregated water policies by basin in the revised version.
Wastewater treatment is misleading. Too expensive and no one is moving in this direction	We have kept it as an option because costs and policy requirements could change over time.
The water impacts of shale gas development are very location specific. I'd defer to an expert in the field who could suggest parameters related to type of aquifer, recharge rate of aquifer, hydraulic connectivity to surface water, environmental flow needs of connected surface water, presence of fish and other aquatic species, and others. Review of Regulatory Framework Phase 2 Human Health Risk Assessment of Oil and Gas Activity in Northeastern British Columbia http://www.health.gov.bc.ca/library/publications/year/2014/health-risk-assessment-regulatory-framework-review.pdf. The Pembina scenario-planning tool could incorporate the BC regulations listed in	Unfortunately disaggregating water by aquifers and accounting for setbacks are outside our resources for this version of the tool. We will consider incorporating some of this functionality in subsequent versions.

	the HHRA reg. review that define minimum setback distances between a variety of oil and gas activities and characteristics such as water sources, residences, roads, and places of public concourse. For potential drinking water sources or places where people would reside or spend long periods of time, setback distances range from 50 m for exploration activities to 100 m for operating areas. The HHRA reg. review contains a number of Water Emission Scenarios at s 3.2.	
	Refer to OGC's site classification tool for O&G sites (https://www.bcogc.ca/node/5762/download), which prioritizes human health and environmental risk. Has parameters for surface + groundwater. It apparently contains "simple, objective criteria for characterizing environmental and human health risk based on easily obtainable site information"	Much of the info in this report is outside of the scope of our current project. We will keep it in mind for our next steps.
	I was a bit confused when it came to selecting the water recycling and then wastewater. It could help to have an explanation on how they are related to one another.	We have attempted to clarify in the revised version. In our tool, % of saline water is of the water still necessary after recycling has already satisfied some of the demand.
Land		
	For sources, mostly OGC data was used. Lots of shale gas related land issues are covered by FLNRO (ex. Long-term water license, gravel, communication towers etc.) Would not be a representative model if it did not include FLNRO applications.	The metrics we currently have included in the tool do a reasonable job to inform the issues covered by different agencies. We will continue to try and get better data over time to make sure the analysis is as good as possible.
	It would be really nice to have a spatial depiction (if possible) of development, even if it is at a coarse scale; can you add a map in a separate sheet with the basins and the terminal considered? It would be nice to have that complementary to the graphs.	We will explore how we could include a spatial representation in a subsequent iteration of the tool.
Economics		
	Are cost assumptions embedded in water + wastewater analysis? Can link what level treatment/saline use would be economical	We included maximum financial costs for carbon and water pricing. Literature review of technology costs/opportunities will be included in a future whitepaper, but will not be dynamically linked in the model at this stage.
	Can we put economic factors behind the scene and make compatible with framework? (if price falls by X, production falls by Y)	In our initial draft tool, well production was responsive to NG prices for all but conventional production, which was hardwired with fixed lifespan. This worked in the initial model that ran to 2030. However, this approach provided

		troubles when we extended the model to 2050. In the current version, all wells have a set retirement age and are not responsive to price.
	Being able to at least implicitly to embed economic assumptions would be great	We have added an 'environmental pricing' tab that shows maximum costs from carbon and water pricing.
	Add in AEEI (Autonomous Energy Efficiency Index). May be able to do so by adjusting the parameters.	This is outside of our resources at the moment, but we will keep it in mind for future iterations of the tool.
	Add in resource quality decline function through time.	This is outside our resources for the forthcoming version, but we will keep this in mind for future versions.