Evaluating Energy Efficiency of On-Farm Grain Conditioning Systems

Year Two Results and Findings

Team Alberta represents a working collaboration between four of Alberta's crop commissions: Alberta Barley, Alberta Canola, Alberta Pulse Growers and the Alberta Wheat Commission.

We work together with the aim to provide input to policy makers, ensure long-term access to markets, promote the sustainability of the crop sector, and advocate on behalf of farmers while enabling grass-roots advocacy by our farmer members.

3D ENERGY LIMITED

Evaluating Energy Efficiency of On-Farm Grain Conditioning Systems

Completed on April 7, 2021

The data collection and report prepared by: 3D Energy Ltd.

3D Energy is an energy, engineering, management and project development advisory company located in Alberta.

Contact: Luke Thibault
VGOC – 3D Energy
#160, 2121 Premier Way, Sherwood Park, Alberta
LThibault@vgoc.ca
780-391-1414
https://vgoc.ca/3d-energy/

Project prepared for Team Alberta

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Contact: Shannon Sereda
Alberta Wheat and Barley Commissions
ssereda@albertawheatbarley.com
587-899-5299

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The Canadian Agricultural Partnership is a five-year, $3 billion investment by Canada's federal provincial and territorial governments to strengthen and grow Canada's agri-food and agri-products sectors. This commitment includes $2 billion for programs cost-shared by the federal and provincial/territorial governments that are designed and delivered by provinces and territories.

Executive Summary

3D Energy and the Prairie Agricultural Machinery Institute (PAMI) have collaborated on a three-year-long study (2019-2021) to assess the energy consumption of grain drying in Alberta, Canada. This report illustrates combined data from 2019 and 2020. In 2019, a total of 36 in-bin systems and 5 continuous grain dryers were metered. In 2020, 18 in-bin systems and 2 continuous dryers were utilized. Of the 18 in-bin systems, 11 were direct-fired natural gas systems, 4 were indirect-fired natural gas-fired systems, and 3 bins were heated using solar air collectors. An additional 12 bins of aeration-only are included within the appendix.

Energy consumption per tonne of moisture removed (specific energy GJ/T $_{\text{Moisture Removed}}$) was the chosen energy performance metric, as it allows for easy comparison between different system types, regardless of initial grain moisture, final grain moisture, and volume of grain dried. Observations found in the 2019 and 2020 study will be used to compare different methods of grain drying based on specific energy, lowest operating costs, and lowest greenhouse gas emissions. Outcomes from these studies may act as a guideline for new producers looking to learn about different drying methods, or for existing producers to improve current systems. Table A includes energy consumption from all in-bin systems while Table B includes energy consumption from all Continuous drying systems.

Conclusions

- The natural air drying (solar) system resulted in the lowest specific energy consumption out of all in-bin dryers, and had an average specific energy of 1.6 GJ/Tonne of Moisture Removed over 2019 and 2020. This is a result of no costs associated with heating fuel consumption and represents electrical fan energy used for air circulation. These systems require favorable weather conditions and are therefore less reliable than comparable heated systems. They can be used as secondary systems but are not recommended as the primary grain conditioning method.

- The indirect fired systems observed throughout 2019 and 2020 and had an average specific energy of 5.6 GJ/Tonne of Moisture Removed while direct fired bins had an average specific energy of 9.6 GJ/Tonne of Moisture removed. The indirect fired systems tend to have a slightly lower thermal efficiency but require less run time due to the lower relative humidity of the supply air. The lower relative humidity of the supply air and shorter run times are the likely causes of the increased efficiency observed on the indirect heated systems, however, further study is required.

- Rooftop exhaust fans decrease specific energy by approximately 9% when compared to bins with passive venting.
- Burner cleaning and fuel optimization decrease specific energy by approximately 12% when compared to sub-optimal burners.
- A new air distribution system is being tested which may reduce specific energy by approximately 39% when compared to other distribution systems. Further analysis is required.
- Within 2019 and 2020, supply air temperature ranged from 13-55°C, averaging around 33°C. Increased supply air temperatures generally resulted in higher moisture removal rates, higher efficiency, and lower fuel consumption. This increased rate of moisture removal also results in a corresponding reduction in drying run times reducing the electricity consumption. However, bins utilizing high supply air temperatures should be closely monitored as bins that are too dry can cause excessive shrinkage and reduce profitability negating any savings. More research on optimal and maximum supply air temperatures for different grain types and air distribution systems is required.
- Two continuous flow driers were also metered and analyzed in 2020 and include an Alvan Blanch DF 22000 and a GSI-1222. Table B summarizes the specific energy values of each continuous dryer for each grain type. The Alvan Blanch DF 22000 had a range of specific energy of 4.1 to 9.1 GJ/Tonne of moisture removed while the GSI-1222 grain drier had a range of specific energy of 5.4 to 14.4 GJ/tonne of moisture removed. Further data collection and analysis is required.
- Sites metered for this grain conditioning study utilize a combination of electricity, natural gas, diesel, and propane. Fuel costs associated with grain drying have steadily increased each year due to the carbon levy. The current carbon price is \$30/tCO_2e, which will increase to \$50/ tCO_2e by 2022, and \$170/tCO_2e by 2030. This will result in drying costs increasing by more than 100%, from approximately \$0.04/Bushel today to \$0.10/Bushel by 2030 (for natural gas-fired systems). This can result in annual utility costs related to drying increasing from approximately \$1,500 to over \$3,000 for an average sized farm in Alberta.
- Using natural gas for heating purposes reduces operating costs and emissions with diesel being the next best option, followed by propane.
- Using electric heating for grain drying is not recommended as it has the highest operating costs and emissions. Electrical services would also need to be upgraded to satisfy the high electrical demand required for grain drying. Electricity's energy cost is on par with propane, which is 3-4 times higher than natural gas. Additionally, demand ratchets may apply year-round and would significantly increase overall costs.

Policy Considerations

Smaller farms are more sensitive to increases in operating costs such as utilities, fuel, labour and fertilizer. The average farm size in Alberta is trending upwards and as operating costs increase this trend will be accelerated threatening the feasibility of smaller operations. Grain drying is an unavoidable step required to prevent product quality deterioration and spoilage and is also difficult to predict. Some policy considerations are provided below to help reduce the operating cost of grain drying, while also reducing greenhouse gas emissions.

- Remove the carbon levy for natural gas and propane fuel consumption on meters specifically designated for grain drying (sub-metered on grain dryer). The proposed federal carbon levy will increase grain drying costs by over 100% for natural gas and up to 27% for propane-fired systems by 2030. This can result in annual cost increases of approximately $1,500 for average sized farms and up to $24,380 for large farms. Increased carbon pricing will not reduce emissions related to drying operations as drying is required to prevent spoilage and ensure grain quality. Increasing carbon prices will however put disproportionate pressure on smaller farms. Instead, incentives should be applied to encourage efficient grain drying technologies and practices.

- Expand natural gas infrastructure to supply grain drying sites currently using diesel or propane. Natural gas will reduce operating costs of drying when compared to diesel or propane, as well as emit approximately 30% less GHG emissions than diesel, and 17% less GHG emission than propane. Diesel is the second choice fuel for cost effectiveness; however, many large dryers are only compatible with natural gas or propane, therefore, if natural gas is not available, propane must be used.

- Incentivize and encourage farmers utilizing diesel or propane drying systems to switch to natural gas-fired systems through the use of rebates or tax incentives. The cost of installing a natural gas service could be subsidized to encourage the switch from propane or diesel to natural gas. On a larger scale, the natural gas infrastructure network should be expanded to provide access to more farming communities.

- Provide a grain drying specific rebate to producers who dry grain using methods with lower energy and emissions. This rebate could be calculated per bushel based on historical drying information and given to the producers when the grain is brought to market. More site-specific rebates could also be completed with the analysis of utility bills during the drying season. Rebates can also be supplied for the use of energy efficient methods such as Natural Air Drying (Solar) systems, burner cleaning and fuel optimization, rooftop exhaust fans and in-bin air distribution systems.

- Provide funding for research into in-bin drying system operations. Findings suggest higher efficiency is achieved when higher supply air temperatures are provided; however, damage to the grain can occur when supply air temperatures are too hot. This maximum temperature can vary depending on the type of grain dried, air distribution system, airflow rate, etc. Manufacturer supply air temperature recommendations are available for continuous dryers and batch dryers, however, no standard recommendation is available for in-bin drying systems. Research into maximum and optimum supply temperatures for different bin systems and operating parameters is recommended to optimize energy efficiency and reduce operating costs for in-bin systems.

In-Bin Drying Summary Measure Summary

Table A: In-Bin Drying Data

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)*	Initial Grain Moisture	Final Grain Moisture	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy (GJ/$T_{Moisture Removed}$)
2020	South	Wheat	Solar	57	15.5%	11.3%	373	-	0.6
2020	South	Wheat	Solar	108	15.3%	13.3%	732	-	1.2
2019	South	Wheat	Solar	99	15.5%	14.6%	374	-	1.5
2020	South	Wheat	Solar	51	17.5%	13.1%	1,371	-	2.3
2019	South	Wheat	Solar	61	15.4%	14.1%	612	-	2.8
2020	North East	Canola	Natural Gas	91	11.6%	9.5%	105	5.3	3.0
2020	North East	Canola	Natural Gas	91	12.6%	8.6%	232	12.1	3.6
2020	Central	Barley	Natural Gas	73	18.6%	15.5%	827	5.3	3.8
2019	South	Wheat	Solar	17	14.7%	13.0%	328	-	4.0
2019	North West	Barley	Diesel	111	18.0%	14.1%	250	17.3	4.4
2020	North East	Wheat	Natural Gas	122	15.5%	14.0%	329	7.7	5.0
2019	North East	Wheat	Natural Gas	122	13.1%	11.0%	824	9.8	5.1
2019	North East	Canola	Natural Gas	50	14.5%	8.1%	611	13.0	5.1
2019	North East	Wheat	Natural Gas	122	17.1%	12.1%	3,268	18.5	5.3
2019	North East	Canola	Natural Gas	49	13.2%	6.0%	992	14.5	5.6
2020	Central	Barley	Natural Gas	159	15.9%	12.0%	682	32.5	5.9
2019	North West	Wheat	Diesel	138	18.1%	14.0%	655	29.7	6.0
2019	North East	Canola	Natural Gas	48	14.5%	6.5%	2,041	14.0	6.0
2019	Central	Barley	Natural Gas	100	17.0%	15.7%	466	6.2	6.1
2019	North West	Wheat	Diesel	138	18.2%	13.9%	744	33.1	6.4
2019	Central	Wheat	Natural Gas	216	17.2%	14.0%	774	42.2	6.7
2020	North East	Wheat	Natural Gas	122	17.0%	15.5%	1,064	8.4	6.8
2020	Central	Barley	Natural Gas	54	19.0%	15.0%	420	13.2	7.1
2019	Central	Barley	Natural Gas	185	16.0%	13.5%	663	30.1	7.2
2019	Central	Wheat	Natural Gas	176	16.4%	13.7%	673	32.4	7.6
2020	Central	Barley	Natural Gas	65	16.3%	12.5%	976	15.5	8.0
2019	Central	Barley	Natural Gas	185	15.6%	14.0%	463	22.4	8.3
2019	Central	Canola	Natural Gas	98	12.3%	7.4%	633	35.4	8.3
2019	Central	Barley	Natural Gas	100	16.5%	16.0%	435	2.7	8.6
2020	North East	Wheat	Natural Gas	54	15.5%	14.5%	221	3.8	8.6
2019	Central	Wheat	Natural Gas	216	15.4%	14.0%	470	24.2	8.7
2020	North East	Wheat	Natural Gas	68	15.5%	14.0%	607	6.5	8.7
2019	North West	Wheat	Diesel	138	18.2%	16.8%	614	14.7	8.9

* Dried grain is recorded in wet bushels, while specific energy is adjusted to account for shrink losses

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)*	Initial Grain Moisture	Final Grain Moisture	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy (GJ/$T_{Moisture\ Removed}$)
2020	Central	Barley	Natural Gas	104	15.9%	13.0%	976	22.4	8.9
2020	Central	Wheat	Natural Gas	162	16.4%	14.5%	624	29.7	10.6
2019	Central	Wheat	Natural Gas	176	15.4%	14.0%	465	24.2	10.7
2019	Central	Barley	Natural Gas	189	15.9%	13.9%	635	37.9	10.9
2019	North East	Canola	Natural Gas	57	10.6%	8.0%	1,947	8.8	11.0
2020	Central	Barley	Natural Gas	174	18.5%	15.6%	1,032	55.3	12.1
2019	North East	Wheat	Natural Gas	122	16.7%	14.3%	3,553	21.7	12.2
2020	North East	Wheat	Natural Gas	81	16.0%	15.0%	783	7.2	12.5
2019	North East	Canola	Natural Gas	57	10.3%	7.4%	2,084	12.6	12.6
2020	Central	Canola	Natural Gas	132	13.1%	10.0%	872	46.8	12.7
2019	Central	Barley	Natural Gas	109	16.0%	13.8%	506	28.7	13.1
2019	Central	Wheat	Natural Gas	230	16.3%	14.3%	1,057	58.5	13.9
2019	North East	Wheat	Natural Gas	54	13.1%	10.1%	1,676	16.7	14.5
2019	Central	Wheat	Natural Gas	216	16.5%	15.1%	717	41.0	14.6
2019	North East	Canola	Natural Gas	57	11.1%	7.4%	2,457	20.8	14.7
2019	North East	Wheat	Natural Gas	108	20.0%	18.0%	2,788	21.3	14.8
2019	North East	Wheat	Natural Gas	95	13.9%	11.6%	2,914	28.7	18.5

Table B: Continuous Dryer Data

Year	Location	Grain Type	Dryer Model	Total Grain Dried (Tonnes*)	Initial Grain Moisture	Final Grain Moisture	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy (GJ/T$_{Moisture Removed}$)
2020	North East	Barley Seed	Alvan Blanch	98	17.7%	13.5%	514	14	4.1
2020	North East	Barley	Alvan Blanch	771	18.9%	12.4%	2,617	201	4.6
2020	North East	Oat Seed	Alvan Blanch	305	15.6%	12.4%	1,246	41	4.9
2019	Central	Wheat	Vertec 6600	650	15.9%	14.3%	887	48	4.9
2020	Central	Barley	GSI 1222	473	15.9%	13.1%	806	65	5.4
2019	North East	Barley	Alvan Blanch	793	17.8%	13.1%	3,370	191	5.8
2019	North East	Canola	Alvan Blanch	2,199	12.3%	8.5%	10,529	444	6.0
2019	North East	Wheat	Alvan Blanch	2,798	18.6%	13.1%	12,868	835	6.1
2020	North East	Wheat	Alvan Blanch	2,093	17.3%	13.3%	7,185	480	6.3
2019	Central	Canola	Vertec 6600	2,000	13.0%	10.5%	4,202	320	6.9
2019	North East	Wheat	Western 1600-24	6,583	18.2%	14.8%	8,536	1,537	7.3
2019	North East	Oats	Alvan Blanch	3,303	15.9%	12.3%	16,798	805	7.5
2019	North East	Canola	Western 1600-24	3,231	12.2%	9.8%	3,830	574	7.8
2020	Central	Wheat	GSI 1222	375	15.8%	13.3%	604	73	8.2
2020	North East	Wheat Seed	Alvan Blanch	187	15.9%	13.9%	794	29	9.1
2019	Central	Oats	Vertec 6600	120	16.1%	13.8%	220	26	10.2
2019	North East	Wheat Seed	Alvan Blanch	109	19.4%	14.7%	1,542	55	12.5
2020	Central	Wheat Seed	GSI-1222	58	18.1%	14.5%	279	28	14.4

* Dried grain is recorded in wet bushels, while specific energy is adjusted to account for shrink losses

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01 | Background

1.1 Teams and Qualifications

Client Details	3D Energy
Shannon Sereda Government Relations and Policy Manager Team Alberta ssereda@albertawheatbarley.com 403-219-6263	Luke Thibault Director of Operations 3D Energy LThibault@vgoc.ca 780-391-1414
Analysis and Report	
Mike Krokis	P.Eng, CEM, PE
Gordon Hussell	P.L. (Eng.), CEM, LEED AP BD+C
Kyle Boyko	TT, EMIT, LEED Green Associate

1.2 Scope of the Study

This study is in partnership with 3D Energy, PAMI, and Team Alberta. The Prairie Agricultural Machinery Institute (PAMI) is a diversified team located across the Canadian prairies. PAMI has expertise within agricultural, transportation, military, aeronautics, forestry, and mining industries, and is well known within the Alberta farming community for their research, design, and development of farming equipment evaluations and farming practices. Team Alberta is a collaborative partnership between Alberta Barley, Alberta Canola, Alberta Pulse Growers, and the Alberta Wheat Commission. These organizations provide invaluable knowledge and experience to producers throughout the province and will use findings within this study to enhance current information.

The primary goal of this study is to identify the energy consumption of different methods/systems for grain drying and to compare the results of each system analyzed to find areas of improvement and efficiency. Information gathered from this study will be used to advise Alberta producers on system energy costs of different drying systems and methodologies, with a purpose to optimize energy use and buffer the impacts of increased energy costs. Additionally, information gathered from this study will be used to enhance existing tools created by PAMI and Team Alberta on the estimated energy usage of drying systems, as well as verifying assumptions within the Benchmarking Study conducted by PAMI.

1.3 Methodology

The systems were operated by the cooperating producers using a "business as usual" approach to their grain drying and storage during harvest. The results represent real life conditions producers face and experience during their operational constraints.

The total thermal and electrical energy of all sites was metered and recorded throughout the entire drying process. Electricity, supply air (plenum) temperature, ambient air temperature, and ambient relative humidity were monitored and recorded using data loggers with logging intervals every hour throughout the drying process. Remaining measurement points, including thermal energy (natural gas, diesel, or propane) consumption; grain volume dried; initial grain moisture; final grain moisture; and grain temperature were recorded by participants for each bin and drying cycle. Manual measurements were conducted as often as possible, with a minimum of one before and one after the drying process.

Electricity meters installed on continuous dryers measure total dryer electricity consumption, including supply fan, internal augurs, and auxiliary equipment. Measuring total continuous dryer electricity consumption was not possible on all sites due to existing electrical wiring configurations; however, main supply fans were metered on all continuous sites. For sites without metering on auxiliary equipment, electricity consumption was estimated based on known motor capacity (HP) and known drying run times. Energy consumption of grain drying varies based on a range of conditions and is primarily affected by ambient air temperature, the moisture content of grain, bin type, rolling of grain during the drying process, and supply air temperature. Thermal energy consumption data was weather normalized to allow for standard comparison between all sites. Adjustment to the thermal energy consumption was conducted based on the standard ambient air temperature of 10°C.

Energy consumption per Tonne of Moisture Removed ($GJ/T_{MoitureRemoved}$) was calculated for in-bin and continuous drying systems. Dried grain volume was typically recorded in bushels, however, the conversion of bushels to tonnes was used for energy consumption metrics for moisture removal values. The seed for any grain type was assumed to be similar to the values listed above for their specific grain type. One tonne was assumed to be equivalent to[1]:

- 37 Bushels of Wheat
- 46 Bushels of Barley
- 44 Bushels of Canola
- 65 Bushels of Oats

The amount of moisture removed was calculated using the following formula:

$$Moisture\ Removed\ (t) = Grain\ Dried\ (t)\ x\ (Initial\ Moisture\ Content\ (\%) - Final\ Moisture\ Content\ (\%))$$

Greenhouse gas emissions energy conversion rates for each fuel type are as follows[2]:

- Natural Gas Energy Conversion: 1 GJ/GJ Natural Gas Greenhouse Gas Emissions: 0.05069 tCO_2/GJ
- Propane Energy Conversion: 0.02531 GJ/L Propane Greenhouse Gas Emissions: 0.00155 tCO_2/L
- Diesel Energy Conversion: 0.0386 GJ/L Diesel Greenhouse Gas Emissions: 0.0028 tCO_2/L
- Electricity Conversion: 0.0036 GJ/kWh Electricity Greenhouse Gas Emissions: 0.00057 tCO_2/kWh

Initial moisture content was gathered during bin loading. Moisture stratification typically occurs within bins throughout the drying cycle, resulting in lower grain levels being dry while upper grain layers being tough. To eliminate the stratification error of moisture measurements, an upper and lower grain moisture sample was conducted for each bin. An average of these two readings was used to calculate the average final grain moisture. For bins with internal mixing augurs, minimal moisture variation was assumed, regardless of the moisture sample location. Additionally, moisture cable readings were used for applicable bins. Therefore, the integrity of the moisture measurements is high. Grain moisture for continuous dryers was gathered via consistent sampling throughout the batch, or by automatic sampling technology located on the grain drier.

Wet grain values (bushels and tonnes) are displayed in all tables, however, shrink losses were accounted for within specific energy values using the following equation:

$$Shrink\ Loss = 100(Mi - Mf)/(100 - Mf)$$

1.4 Limitations

Manual measurements, including natural gas, diesel, and propane consumption; grain volume dried; initial and final grain moisture; and grain temperature were recorded as spot measurements and only represent a single point in time within the entire drying process. Most grain-related manual measurements were either conducted during grain transfer or spot measurements within the bin. Since these measurements are manually recorded by producers, human error may occur. Large outliers in data measurements were excluded from applicable calculations.

02 | Overview

Of the 36 in-bin systems initially participating within this study, 15 in-bin with natural gas heat, 3 in-bin with solar heat, and 12 in-bin with cooling/aeration provided information regarding grain drying/cooling. Not all 36 initially metered grain bins were utilized due to environmental factors such as dry weather or grain conditions, or other external factors. Of the five continuous drying systems initially participating in this study, only two were able to participate in 2020 due to minimal drying conditions or other external factors.

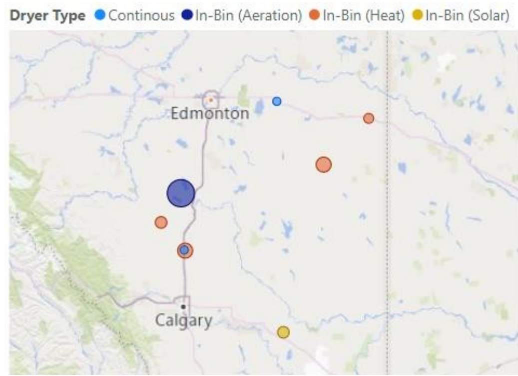

Figure 1: Location and Quantity of Grain Dryers/Bins for 2020 Study

Most of the grain drying systems within 2020 were located throughout central and north-east Alberta, as displayed in Figure 1.

2.1 Weather

As shown in Figure 2, 2020 consisted of heavy rainfall in late spring to early summer months, however, had more typical precipitation values in later summer months, and well below average values in harvest months. This allowed producers to take advantage of dry weather conditions during harvest and into grain drying season. Additionally, average ambient temperatures during 2019 drying cycles were approximately 1.6°C, while average ambient temperatures during 2020 drying cycles were approximately 11.1°C. As a result, most producers had much less grain to dry than in previous years, with some producers not requiring any drying.

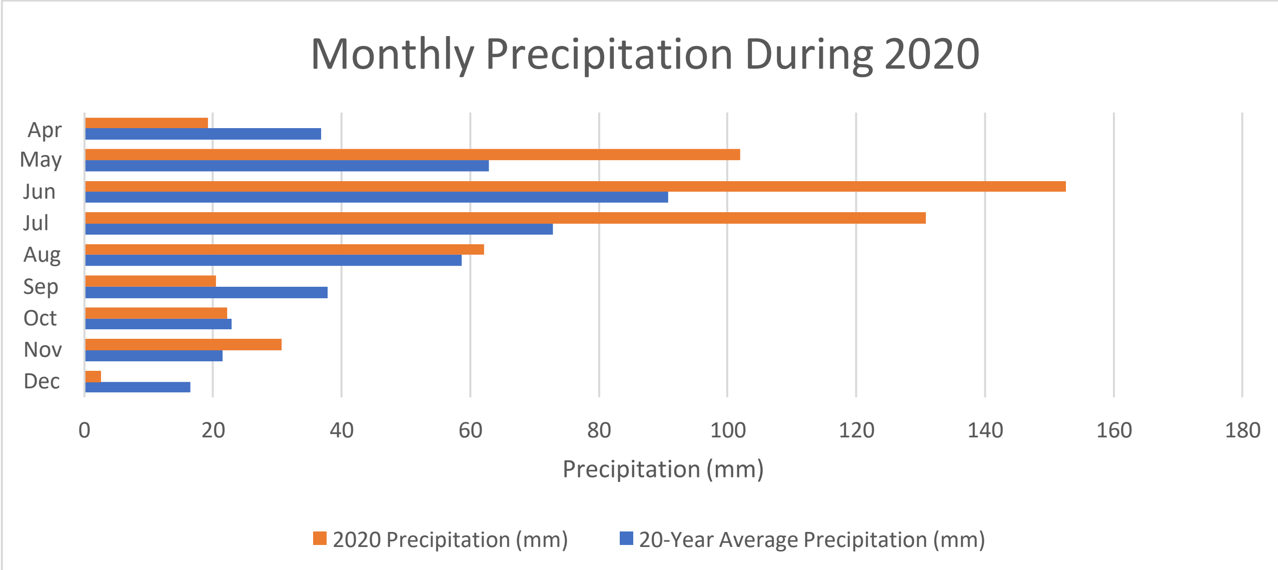

Figure 2: Monthly Precipitation for 2020

2.2 System Types

Most sites observed utilized in-bin natural air drying with supplemental heat for grain drying, however, multiple different types of heating sources, heating distribution, and equipment, bin types, etc. were present. The list below describes the different types of systems analyzed during this study. Continuous flow dryer descriptions are displayed within Section 4.

2.2.1 Natural Air Drying (Solar) Heating

Natural air drying or solar air heating was used on one site for grain drying purposes. This site consisted of thirty 90-foot pieces of irrigation pipe feeding the supply fan inlet. Ducting was assembled from the supply fan outlet to seven hopper bottom bins, each having a shutoff damper so only desired bins get airflow. This allows one supply fan to dry multiple bins simultaneously, up to a maximum of 2-3 bins depending on solar availability and initial grain condition. These pipes were painted black in previous years; however, they have faded due to sun exposure. The producer of this site mentioned that the increased temperature rise was negligible from when the collectors were painted black compared to the current, non-painted operation. This negligible temperature rise is mainly a result of the high velocity through the collectors. Typical solar air collectors prescribe 1-3 feet per minute for high-temperature rises (25-35°C) and 6-10 feet per minute for low-temperature rises (10-17°C), however, this system has air velocities ranging around 700-800 feet per minute through the collectors. Natural air drying systems have high energy efficiency potential but require favorable weather conditions and are therefore less reliable.

Figure 3: Solar Heating In-Bin Drying Site

2.2.2 Natural Gas Heating

Figure 4: Internal Augur Bin

The most common fuel type observed throughout this study was natural gas feeding a direct-fired heater (combustion flue supplied into the bin) with bin mounted supply fans. However, some sites consisted of indirect-fired natural gas heaters (combustion flue is exhausted to the atmosphere). Natural gas-fed systems varied from flat bottom to hopper bottom bins. One bin (Figure 4) consisted of an internal circulating augur to constantly turn and roll the grain during drying. Figures 5 and 6 display various indirect fired heaters and direct-fired heaters observed within this study.

Figure 5: Direct Fired Natural Gas Heaters

Figure 6: Natural Gas Indirect Fired Heaters (Left), Diesel Indirect Fired Heater (Right)

2.2.3 Aeration/Cooling

Due to dry weather conditions during harvest and warm temperatures during the drying season, many producers did not have much grain to dry. On certain sites where no drying occurred, aeration/cooling data was available. This data did not display any moisture reduction and only cooled the grain down to adequate storage temperatures. Therefore, this data was not thoroughly analyzed but is displayed within Appendix C.

03 | In-Bin System Analysis

3.1 Benchmarking

The energy consumption of all in-bin with heat systems analyzed within this study (2019 & 2020) is compiled to determine the typical Energy Use Intensity (EUI), expressed in GJ/Tonne of Moisture Removed, also known as specific energy. This allows bins of varying sizes, initial moisture contents, and final moisture contents to be accurately compared. Energy consumption data consists of all heating fuel and fan-related electricity consumption. Regardless of fuel types, all energy consumption was converted into GJ (see conversion factors for different fuel types). This allows for common energy use units to be compared between similar systems and allows producers to see how their systems perform compared to other systems located within Alberta.

Since the energy consumption of the in-bin systems varies with outdoor ambient temperature, all benchmarking data is weather normalized to account for variations in outdoor ambient temperature at different locations, times of the year, etc. This allows an accurate comparison between systems regardless of outdoor temperature.

Specific energy values of solar systems ranged from 0.6-3.9 GJ/Tonne of moisture Removed, averaging 1.6 GJ/Tonne of Moisture Removed. Fuel fired bins ranged from 2.4-18.5 GJ/Tonne of Moisture Removed, averaging 8.5 GJ/Tonne of Moisture Removed. As seen in Table 1, bins dried using solar air collectors were among the lowest specific energy out of all recorded bins within 2019 and 2020. This is predictable as all heating energy provided to the bins comes from a renewable, free source. Specific energy values of the solar systems were not adjusted to standard test conditions, as the temperature rise of the air is mainly a result of radiant energy from the sun.

Seven indirect fired heating systems were analyzed within 2019 while four were analyzed within 2020. Overall, indirect heaters were observed to be in the middle to lower regions of specific energy use when compared to direct-fired heaters. Some bins utilizing indirect heaters in 2020 were also equipped with an air missile air distribution system, which appeared to further reduce specific energy consumption for these bins. Within 2019 and 2020, bins that utilized indirect fired heating systems ranged from 2.4-8.9 GJ/Tonne of moisture Removed, with an average of 5.6 GJ/Tonne of Moisture Removed.

Twenty-two direct-fired heating systems were analyzed within 2019 while eleven were analyzed within 2020. Direct fired in-bin heating systems ranged from 3.8-18.5 GJ/Tonne of Moisture Removed, averaging around 9.6 GJ/Tonne of Moisture Removed. The bins within Table 1 are color-coded depending on the system/bin type, and are as follows:

Solar Heated Bins: (yellow)

Indirect Fired Bins: (blue)

Direct Fired Bins (Internal Mixing Augur): (orange)

Direct Fired Bins: No Colour

Table 1: 2019 and 2020 In-Bin Benchmarking Data

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Supply Air Temperature (°C)*	Airflow Per Bushel (CFM/Bu)	Specific Energy (GJ/T Moisture Removed)
2020	South	Wheat	Solar	54	2.3	13.9	2.2	0.6
2020	South	Wheat	Solar	106	2.1	16.9	1.1	1.2
2019	South	Wheat	Solar	99	1.3	15.9	1.0	1.5
2020	South	Wheat	Solar	49	2.1	17.3	2.5	2.3
2019	South	Wheat	Solar	61	0.5	16.0	0.9	2.8
2020	North East	Canola	Natural Gas	91	1.9	20-40†	0.6	3.0
2020	North East	Canola	Natural Gas	91	3.6	20-40*	0.6	3.6
2020	Central	Barley	Natural Gas	73	2.2	13.3	1.4	3.8
2019	South	Wheat	Solar	17	4.1	30.9	1.2	4.0
2019	North West	Barley	Diesel	111	4.1	30.9	1.2	4.4
2020	North East	Wheat	Natural Gas	122	1.8	26.6	0.9	5.0
2019	North East	Wheat	Natural Gas	122	2.5	20.8	1.0	5.1
2019	North East	Canola	Natural Gas	50	3.0	31.4	1.3	5.1
2019	North East	Wheat	Natural Gas	122	5.7	15.4	1.0	5.3
2019	North East	Canola	Natural Gas	49	3.2	27.5	1.3	5.6
2020	Central	Barley	Natural Gas	159	5.9	37.1	1.5	5.9
2019	North West	Wheat	Diesel	138	5.4	31.9	1.1	6.0
2019	North East	Canola	Natural Gas	48	3.5	23.4	1.3	6.0
2019	Central	Barley	Natural Gas	100	1.3	15.9	1.0	6.1
2019	North West	Wheat	Diesel	138	5.6	41.0	1.1	6.4
2019	Central	Wheat	Natural Gas	216	6.7	52.1	0.7	6.7
2020	North East	Wheat	Natural Gas	122	1.8	36.7	1.0	6.8
2020	Central	Barley	Natural Gas	54	2.1	35.6	5.3	7.1

* Supply air temperatures only display temperatures when the burner is operational.
† Supply air temperature sensors were faulty for these bins, therefore, they were separately analyzed in Section 3.4.4

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Supply Air Temperature (°C)*	Airflow Per Bushel (CFM/Bu)	Specific Energy ($GJ/T_{Moisture\ Removed}$)
2019	Central	Barley	Natural Gas	185	4.5	43.4	0.8	7.2
2019	Central	Wheat	Natural Gas	176	4.6	43.3	1.0	7.6
2020	Central	Barley	Natural Gas	65	2.4	22.1	1.5	8.0
2019	Central	Barley	Natural Gas	185	2.9	41.7	0.8	8.3
2019	Central	Canola	Natural Gas	98	4.5	49.4	1.6	8.3
2019	Central	Barley	Natural Gas	100	0.5	16.0	0.9	8.6
2020	North East	Wheat	Natural Gas	54	0.5	18.6	2.5	8.6
2019	Central	Wheat	Natural Gas	216	3.0	46.3	0.8	8.7
2020	North East	Wheat	Natural Gas	68	1.0	21.9	2.0	8.7
2019	North West	Wheat	Diesel	138	1.9	46.3	1.0	8.9
2020	Central	Barley	Natural Gas	104	2.9	21.9	0.9	8.9
2020	Central	Wheat	Natural Gas	162	3.0	37.3	2.0	10.6
2019	Central	Wheat	Natural Gas	176	2.4	49.3	1.0	10.7
2019	Central	Barley	Natural Gas	189	3.7	45.6	0.8	10.9
2019	North East	Canola	Natural Gas	57	1.4	15.7	1.5	11.0
2020	Central	Barley	Natural Gas	174	4.9	42.6	1.4	12.1
2019	North East	Wheat	Natural Gas	122	2.8	17.8	1.0	12.2
2020	North East	Wheat	Natural Gas	81	0.8	23.8	1.5	12.5
2019	North East	Canola	Natural Gas	57	1.6	16.0	1.5	12.6
2020	Central	Canola	Natural Gas	132	3.9	54.9	1.7	12.7
2019	Central	Barley	Natural Gas	109	2.3	38.3	1.7	13.1
2019	Central	Wheat	Natural Gas	230	4.5	52.7	0.7	13.9
2019	North East	Wheat	Natural Gas	54	1.6	25.1	2.6	14.5
2019	Central	Wheat	Natural Gas	216	3.0	50.7	0.8	14.6
2019	North East	Canola	Natural Gas	57	2.0	26.0	1.6	14.7
2019	North East	Wheat	Natural Gas	108	2.1	18.0	1.0	14.8
2019	North East	Wheat	Natural Gas	95	2.1	27.4	1.3	18.5

3.2 Year to Year Energy Use Comparison

Electricity consumption and heating fuel consumption was observed to be higher during the 2019 drying season versus the 2020 drying season, as seen in Figure 7. Electricity is consumed by supply fans and can draw more power when faced with higher static pressures. In 2019, the average static pressure seen throughout all available bins was approximately 6.2 inches of water column (In.), while the average static pressure seen in 2020 was 5.8 In. Additionally, electricity consumption is also proportional to fan operating hours. Bin drying cycles observed in 2019 ranged from 41 to 519 hours, averaging 195 hours, while drying cycles in 2020 ranged from 25to 234 hours, averaging 116 hours.

Heating fuel consumption was also observed to be higher in 2019 compared to 2020, caused by unfavorable weather and grain conditions during the 2019 harvest. This resulted in tougher grain in 2019 compared to 2020, as the average moisture removal per bin in 2019 was 3.2 tonnes (3.0%), compared to 2.6 tonnes (2.6%) in 2020. Additionally, overall warmer ambient air conditions during 2020 drying resulted in much lower supply air temperature rises, with an average air temperature rise of 33.1°C in 2019 compared to 26.8°C in 2020.

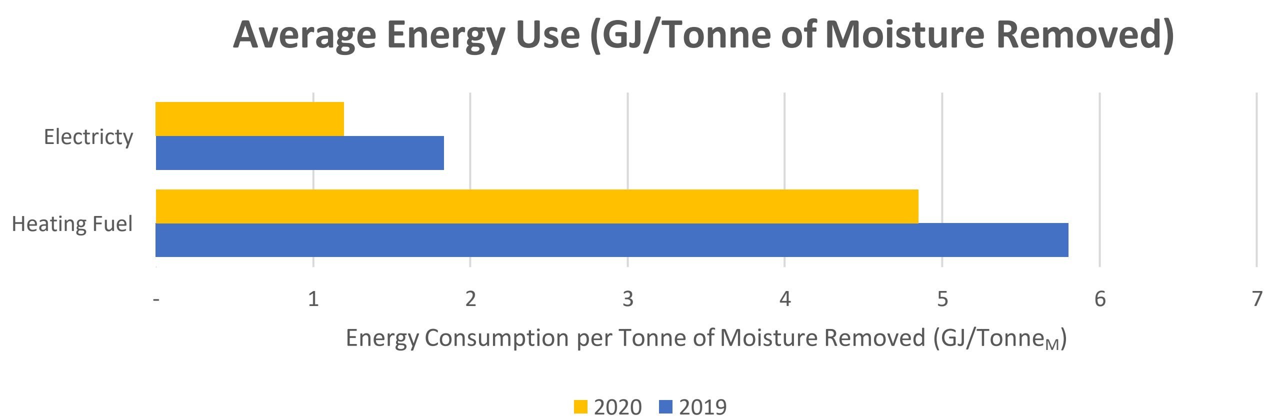

Figure 7: Average Energy Use Breakdown of In-Bin Drying Systems

3.3 Influential Consumption Variables

3.3.1 Supply Air Humidity

When the need for grain drying occurs, there is very little that can be controlled other than the operating conditions of the dryers and the amount each grain bin is filled. Increased supply air temperatures can greatly affect the drying capacity of the air. As noted in the 2019 grain conditioning study, increasing the temperature of the supply air by 30°C can reduce the air's relative humidity from 100% down to 14-16%, and increase the drying capacity of the air exponentially. This reduction in humidity due to an adequate temperature rise places minimal value on the ambient relative humidity. Drying during ambient conditions with high RH will not greatly affect the overall performance of the drying system.

The RH of the supply air, however, does have a moderate affect on the moisture removal rate. Figure 8 shows the moisture removal rate vs supply air relative humidity for indirect and direct-fired heaters. In both heater types throughout 2019 and 2020, bins that supplied lower RH air resulted in increased moisture removal rates, due to the increased drying capacity of the air.

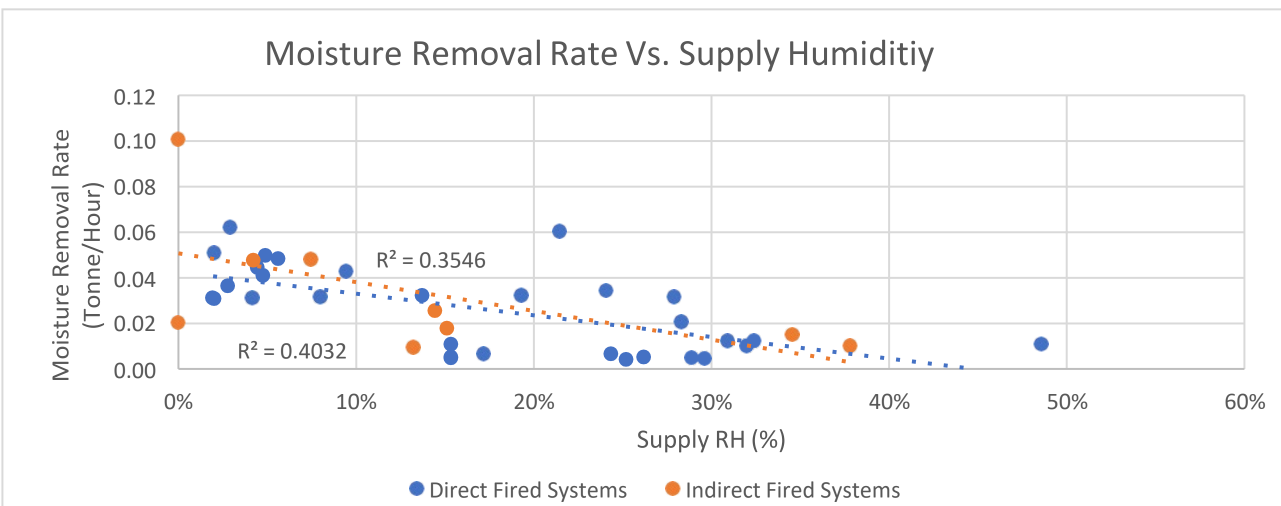

Figure 8: Moisture Removal Vs. Supply Air Humidity

3.3.2 Supply Air Temperature

Similarly, Figure 9 displays the moisture removal rate of the bins observed within 2019 and 2020 for indirect and direct-fired heaters when compared to supply air temperature. These values are related to Figure 8, as higher supply air temperatures reduce the supply air relative humidity, therefore, result in increase drying rates. This figure displays bins utilizing lower supply air temperatures, resulted in a lower moisture removal rate, while bins supplying higher air temperatures had quicker moisture removal rates. Direct fired heating systems did appear to have a more significant correlation between moisture removal rates and supply air temperatures than indirect-fired heaters. This is likely because direct-fired heating systems have more data samples than indirect heaters, resulting in data variation being less impactful on final conclusions. However, may also be a result of reduced combustion-related moisture in indirect fired heaters due to combustion gases being exhausted rather than supplied to the bin. This would result in indirect heaters to have lower supply air humidity while having similar supply air temperatures to direct-fired heaters. The difference in combustion moisture from indirect to direct heaters is theoretically small, therefore, more indirect-fired data samples are required to determine definitive conclusions.

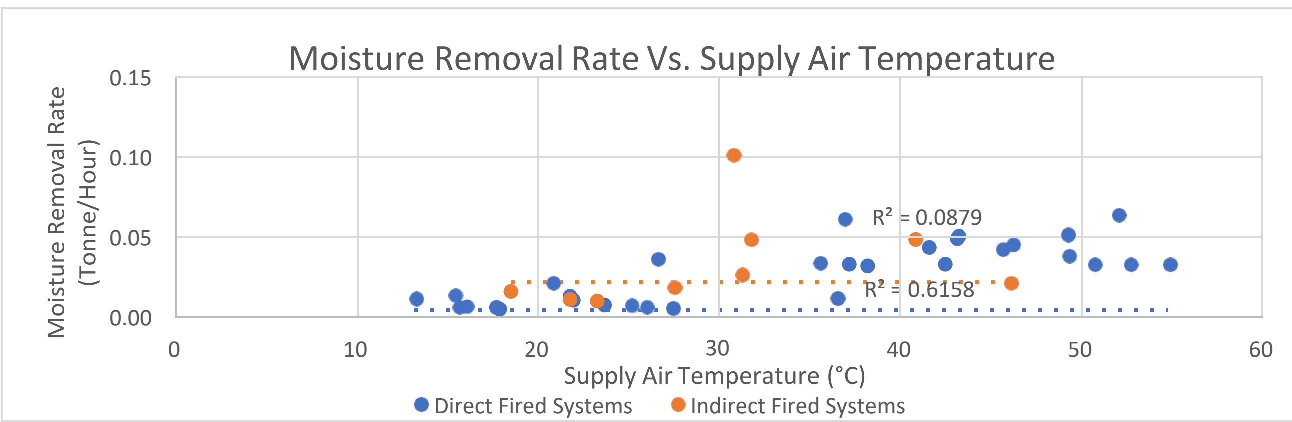

Figure 9: Moisture Removal Vs. Supply Air Temperature

Thermal energy delivered to the bins can be calculated using the following formula:

$$\frac{Btu}{Hr} = CFM\ x\ 1.944\ x\ Temperature\ Rise\ (°C) \quad \text{OR} \quad \frac{Btu}{Hr} = CFM\ x\ 1.08\ x\ Temperature\ Rise\ (°F)$$

This formula displays that there is a proportionate relationship between supply airflow (CFM) and temperature rise, meaning a decrease in supply airflow while keeping the same temperature rise will reduce thermal energy delivered to the bins, and vice versa. Airflow for in-bin drying systems is determined by the type of fan in use, the grain type, the bin airflow distribution system, and the fill level of the bin. Once drying is started on a particular bin, these factors will remain constant, with only a small variation in airflow due to reduced static pressure as the grain dries out. However, the temperature rise of the airflow is an operational parameter that the producer has full control over and can increase the supply air temperature by any incremental degree, up to the maximum output of the burner. The formula above states that since thermal energy use is linear to temperature rise, deciding to operate the supply airflow at a rise of 20°C versus 10°C will double the thermal fuel consumption. Likewise, rising the temperature from 10°C to 30°C will triple the thermal energy consumption.

Although increasing the supply air temperature will increase the drying capacity of the air, and therefore increase the moisture removal rate, additional data analyzed within 2020 suggests there is a diminishing return between increasing the supply air temperature and gas-related energy consumption. Table 2 displays the average moisture removal rate and total gas consumption depending on the supply air temperature for direct-fired heaters. The impact of increasing the supply air temperature appears to increase the overall natural gas consumption by a higher percentage than the moisture removal rate. An example of this is increasing the supply air temperature from 15°C to 25°C, resulting in increased natural gas consumption of 78%, while the moisture removal rate only increased by 71%. This may be because increasing the supply air temperature has an instantaneous effect on overall gas consumption, however, a prolonged effect on drying, as moisture must slowly wick up the grain.

Supply air temperatures for in-bin drying systems have been observed throughout the 2019-2020 grain study to range from 13.3-54.9°C. However, elevated supply air temperatures can hinder seed germination, and it is not suggested to use high supply air temperatures until further research is conducted on maximum supply air temperatures for in-bin heating systems.

Table 2: Impacts of Supply Air Temperatures on Moisture Removal Rates and Gas Consumption

Average Supply Air Temperature (°C)	Average Moisture Removal Rate (Tonne/hr)	Difference (%)	Average Total Gas Consumption (GJ)	Difference (%)
15	0.015	-	10.3	-
25	0.026	71%	18.3	78%
35	0.037	42%	26.3	44%
45	0.048	29%	34.3	30%
55	0.059	23%	42.3	23%

Figure 10 displays this phenomenon, as direct-fired heaters tend to have lower gas-related specific energy values with lower supply air temperatures. This was contrary to the findings within the 2019 grain study; however, more data samples are expected in 2021 which should result in more definitive conclusions. No definite correlation was observed for indirect fired heating systems, and increased data samples of indirect fired heater should decrease the sample variation.

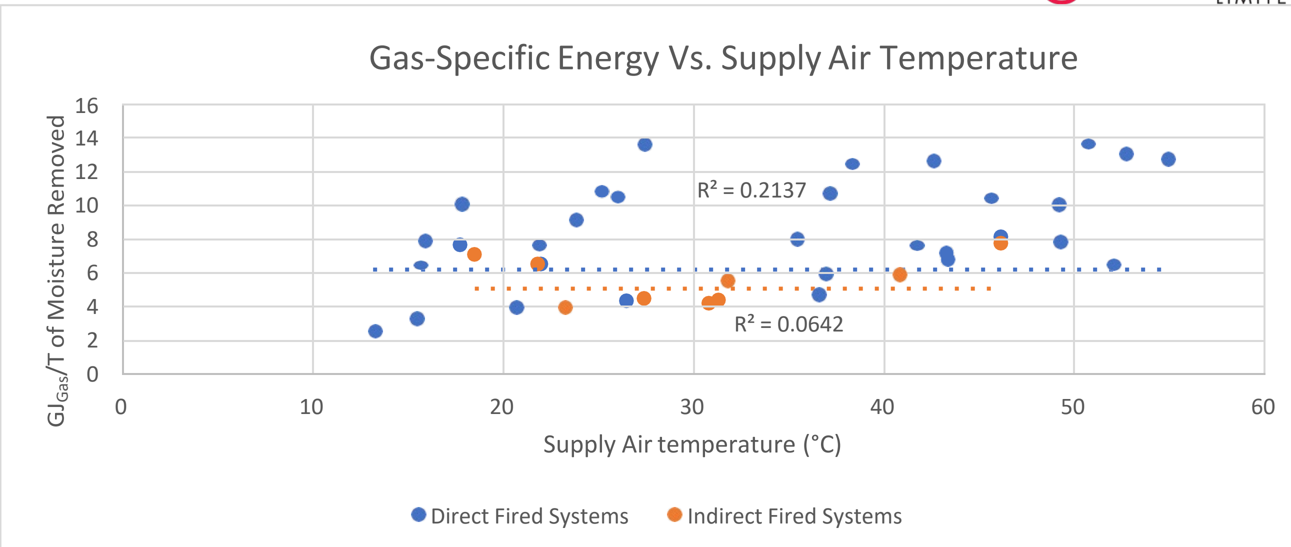

Figure 10: Gas related Specific Energy Vs Supply Air Temperature

3.3.3 Drying Run Times

Natural gas consumption is only part of the whole picture when it comes to grain drying. Electricity consumption can play a significant role in the costs and greenhouse gas emissions of drying operations. It requires approximately 280 kWh of electricity to equal the amount of energy in 1 GJ of natural gas. Electricity is approximately three times more expensive and emits approximately three times more CO_2e emissions than natural gas. Therefore, increasing supply air temperatures and decreasing hours may not decrease the specific energy, however, may decrease the overall drying costs and emissions. Figure 11 displays the specific cost of drying ($/Tonne of moisture removed) and suggests that it costs less to dry grain when operating hours are reduced, which would occur at higher supply air temperatures. Additionally, Figure 12 displays specific emissions (tCO2e/Tonne of moisture removed) and suggests lower emissions at reduced operating hours.

Although higher supply air temperatures generally increase drying rates and can reduce overall operating costs and emissions, bins utilizing high supply air temperatures must be closely monitored, as over-drying grain can increase shrink losses and reduce the profitability when taken to market, thereby, forfeiting all savings incurred during drying.

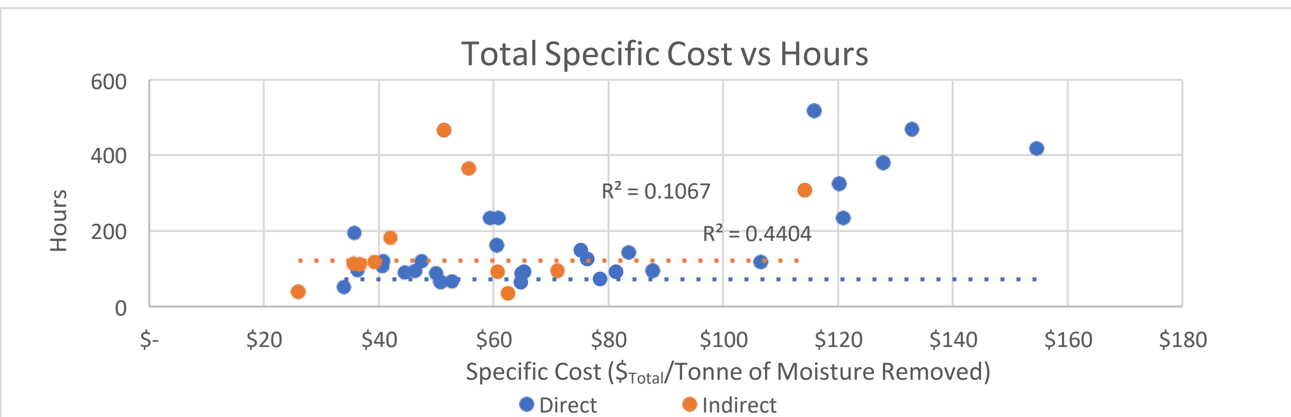

Figure 11: Specific Cost Vs Drying Run Time

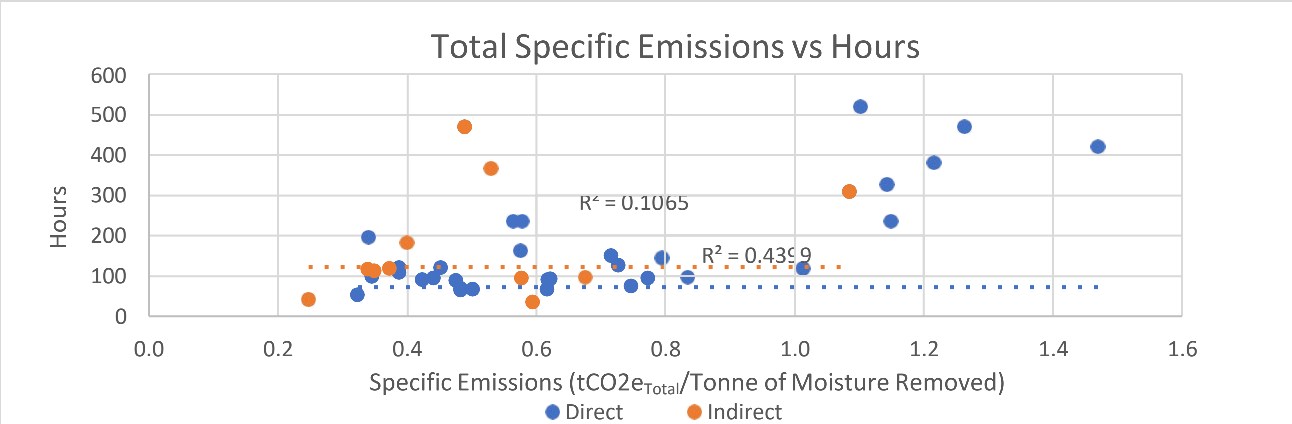

Figure 12: Specific GHG Emissions Vs Drying Run Time

Figure 13 displays the cost differences of two bins analyzed within this study. These bins both dried canola, however, Bin 2 was operated at an average supply air temperature of 16°C while bin 1 was operated at an average supply air temperature of 51°C. Bin 1 was observed to dry out 4 tonnes of moisture from canola in 126 hours. Bin 2 was observed to dry out 1.6 tonnes of moisture from canola in 327 hours. Although bin 2 has a lower energy consumption and operational cost at the 126-hour mark, it must operate an additional 201 hours to dry the grain enough for storage. This signifies the importance of reducing operational run times of grain dryers to avoid excessive energy costs.

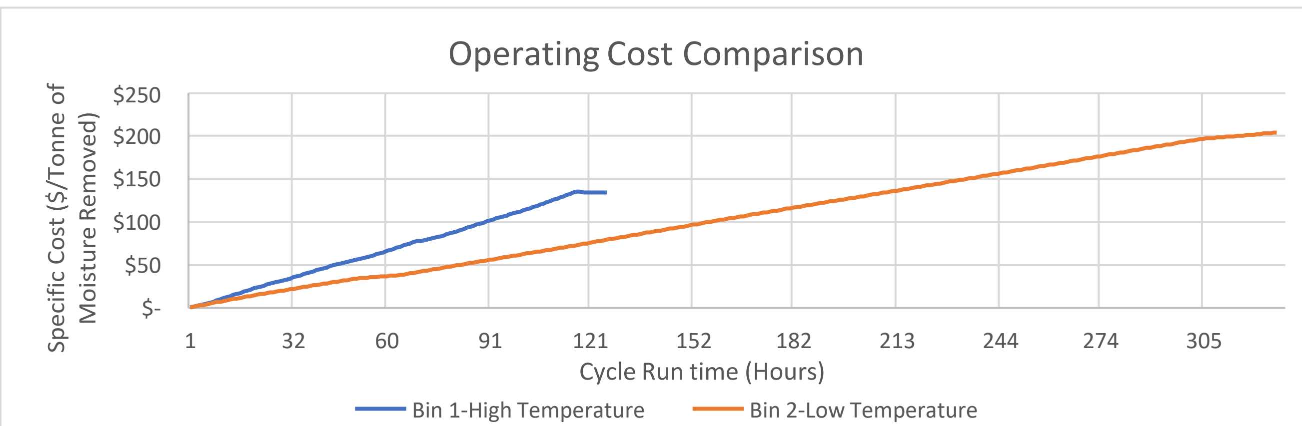

Figure 13: Operating Cost Comparison

3.3.4 Airflow Rates

The majority of recorded bins observed within this study ranged from 0.65-1.2 CFM/Bu, with some bins having airflows up to 5.3 CFM/Bu (based on wet bushel values). As seen in Figure 14, four bin ducting systems and heating types were observed within this study and consist of Direct Fired-Flat Bottom-Perforated Floor, Direct Fired-Hopper Bottom-Rockets, Indirect Fired-Hopper Bottom-Rocket, and Indirect Fired-Hopper Bottom-Side Wall. A fifth bin distribution type (Air Missile) was available, however, supply air temperature sensors for these bins became faulty during the drying season. Since adjusted gas consumption is based on ambient and supply air temperatures, these bins were not able to have ambient temperature adjustments and were excluded from the analysis. Specific analysis of this bin airflow system is described in Section 3.4.4.

A variety of specific energy values were observed throughout the different bin types during 2019 and 2020, however, they displayed minimal correlation between supply airflows per bushel (CFM/Bu) and specific energy. Airflow rates also did not appear to correlate with moisture removal rates, as supply air temperatures were a more important factor (Figure 15). Additional data in 2021 may result in energy-related better performance metrics.

Airflow rates will affect the supply temperature delivered to the bin and will typically vary between the start and end of each bin drying cycle. Reducing the airflow rate while keeping the same burner output will result in increased supply air temperatures while increasing the airflow will result in reduced supply air temperatures. As noted in previous sections, supply temperatures should be monitored and maintained below the high limit temperature, so damage does not occur. PAMI suggests an airflow rate of around 1 CFM/Bu to reduce the likelihood of causing damaging supply air temperatures.

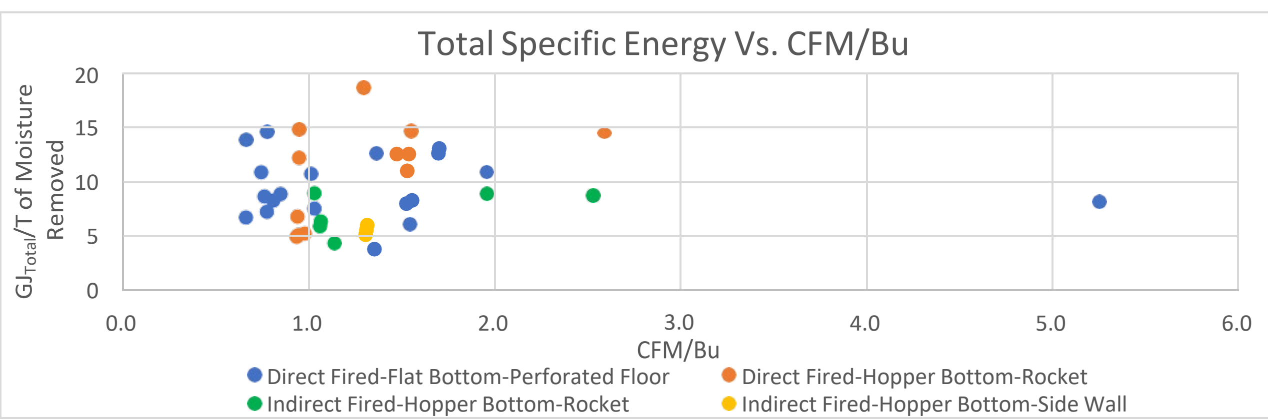

Figure 14: Specific Energy Vs. Airflow on Different Bin Types

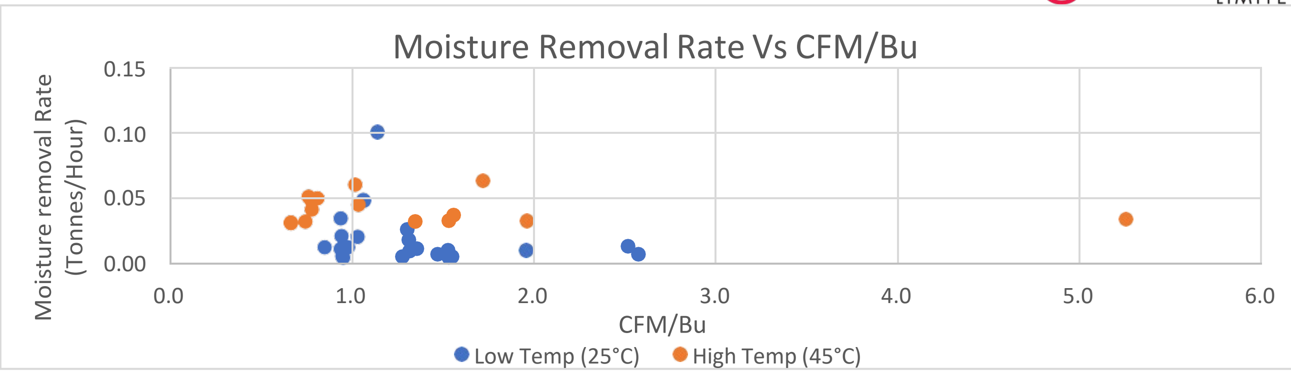

Figure 15: Moisture Removal Vs CFM/Bu at High and Low Supply Temperatures

3.3.5 Static Pressure

Electricity consumption within bin drying systems is primarily attributed to the supply fans. These supply fans must overcome the pressure of the grain to enable airflow throughout all grain layers for adequate drying. Pressure can vary depending on bin type, airflow distribution type, grain type, grain height, and grain moisture. Different bin air distribution systems can result in different static pressures within similar grains and grain volumes. Going to lower pressure air distribution systems can reduce static pressures, resulting in reduced fan power. Additionally, decreasing the height of the grain within the bin can also affect static pressure and fan power.

Table 3 displays the start and finish static pressures with the corresponding moisture reduction. As seen in a couple of different grain types, the static pressure is decreasing throughout the drying cycle, and the grain becomes less resistant to airflow the dryer it becomes.

Table 3: Static Pressure Reduction Over Drying Cycles

	Bin 1	Bin 2	Bin 3	Bin 4
Grain Type	Barley	Barley	Canola	Canola
Initial Static Pressure (Inches of H_2O)	4.2	4.2	10.5	9.5
Final Static Pressure (Inches of H_2O)	3.6	3.8	10.2	9.0
Moisture Reduction	3.9%	2.9%	4.0%	7.2%

Many fan manufactures have fan curves that display the electrical demand at given static pressures. Figure 16 displays a bin analyzed within 2019 and 2020, which verifies the electrical requirements at varying static pressures. These drying cycles were operated at different fill levels and grain types and display increased electrical demand on bins with increased static pressures. Although increased static pressures did increase the electricity demands of supply fans, they did not largely affect the overall electricity consumption of the drying cycle or the electricity-related specific energy, as hours of operation play a much more significant role in electricity-related specific energy. The electricity savings observed from operating supply fans at lower vs higher static pressures (fill levels) will increase the overall electricity consumption, as additional drying batches (run time) will need to occur to dry the required grain.

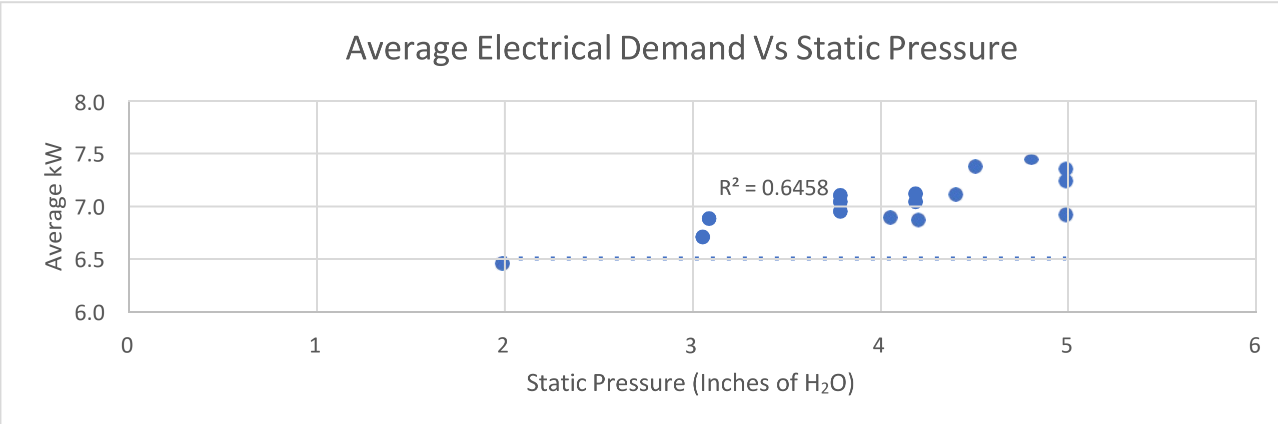

Figure 16: Average Electrical Demand Vs Static Pressure

3.4 Efficiency Measures

3.4.1 Rooftop Exhaust Fans

As air is forced into a grain bin, it causes moisture to move upwards, causing tougher grain at the top of the bin and dryer grain near the fan inlet/ducting. As the moisture in the upper grain layers evaporates, the air above the grain increases in humidity. This humid air must exit the bin through a sufficient area of rooftop venting, otherwise, the air will continue to increase in humidity until condensation on bin wall surfaces occur (depending on ambient conditions). Based on aeration fan manufacturers, the rule of thumb is 1 ft^2 of roof vent for every 1,000 CFM of airflow[3]. Roof vents allow air to passively exhaust the bin via pressure provided by the main supply fan, however, roof vent fans are available, which increases the exhaust rate of the humid air above the grain.

An active roof vent exhaust fan was present on a grain bin within the 2019 drying season, however, was not operational during the 2020 drying season. Drying cycles with the rooftop exhaust fan (2019) appeared to be slightly more efficient at removing moisture from the grain, as seen in Table 4. These cycles displayed average specific energy of 5.8 GJ/Tonne of Moisture Removed, compared to bins without a rooftop exhaust fan (2020), which displayed an average specific energy of 6.4 GJ/Tonne of Moisture Removed (9% reduction). Cycles utilizing the rooftop exhaust fan did display a slightly higher average electricity draw (7.1 kW) compared to bins with passive venting (6.8 kW), however, had increased moisture removal rates, resulting in reduced run times and a lower average cycle electricity consumption.

In addition to standard ambient temperature weather normalization, the supply air temperature for each drying cycle was adjusted to 30°C, to standardize operational parameters and focus on the energy consumption differences between a rooftop exhaust fan and passive venting.

Drying with Rooftop Fan: Drying without Rooftop Fan:

Table 4: Roof Vent Exhaust Fan Comparison

Grain Type	Total Grain Dried (Tonnes)	Initial Grain Moisture	Final Grain Moisture	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy ($GJ/T_{Moisture\ Removed}$)
Wheat	208	17.2%	14.0%	774	20.1	3.4
Barley	152	15.9%	12.0%	682	23.9	4.5
Barley	179	16.0%	13.5%	663	18.0	4.5
Canola	93	12.3%	7.4%	633	18.0	4.5
Wheat	170	16.4%	13.7%	673	19.5	4.8
Wheat	213	15.4%	14.0%	470	13.3	5.0
Barley	181	15.6%	14.0%	463	14.1	5.4
Wheat	52	19.0%	15.0%	420	10.3	5.7
Wheat	173	15.4%	14.0%	465	12.3	5.8
Canola	127	13.1%	10.0%	872	20.9	6.1
Barley	185	15.9%	13.9%	635	21.3	6.4
Wheat	224	16.3%	14.3%	1,057	27.4	7.0
Wheat	213	16.5%	15.1%	717	20.1	7.6
Barley	168	18.5%	15.6%	1,032	34.0	7.7
Wheat	159	16.4%	14.5%	624	21.8	8.0
Barley	106	16.0%	13.8%	506	20.2	9.5

3.4.2 Fuel-To-Air Optimization

The fuel-to-air ratio is important in any fuel-burning process to optimize energy efficiency and keep greenhouse gas emissions as low as possible. It is important to get enough air (oxygen) to the burners so that all combustibles in the fuel are ignited. This not only maximizes the heating output of the fuel but also converts any combustible components of the fuel to carbon dioxide, which is much less harmful to the environment than unburnt fuel. Although you want enough oxygen in the combustion chamber to ignite all the fuel, you also do not want an overabundance of air, as this can also lead to decreased energy efficiency. Fuel-to-air ratios depend on the fuel type; however, natural gas-fired burners typically operate at approximately 10 parts air to 1 part fuel.

The fuel-to-air ratio of any burner can become suboptimal over time due to dirt and debris within the burner orifice, or faulty/inaccurate sensors. Optimization and proper maintenance of the burners can lead to increased performance. A producer utilizing a continuous dryer performed maintenance on their dryer burners before harvest, which included fuel-to-air optimization and cleaning. This maintenance and optimization resulted in lower gas-related specific energy values in many different grain types. Drying cycles with optimized burners displayed an average fuel-related specific energy of 5.37 GJ/Tonne of Moisture Removed, while cycles with sub-optimal burners had an average specific energy of 6.12 GJ/Tonne of Moisture Removed, resulting in a reduction of 12%. Specific energy displays in the table below are only related to fuel consumption (excluding electricity) as burner optimization would only affect fuel consumption.

Sub-Optimal Burners: [white] Optimized Burners: [shaded]

Table 5: Fuel-to-Air Ratio Optimization Comparison

Grain Type	Total Grain Dried (Std. Tonnes)	Initial Grain Moisture	Final Grain Moisture	Normalized Fuel Use (GJ)	Fuel Related Specific Energy (GJ/$T_{Moisture\ Removed}$)
Barley Seed	93	17.7%	13.5%	14.2	3.6
Barley	148	22.3%	13.4%	50.9	3.9
Oat Seed	294	15.6%	12.4%	40.5	4.4
Barley	566	18.0%	12.2%	150.1	4.6
Barley	253	19.3%	12.9%	77.4	4.7
Canola	819	12.9%	8.8%	170.6	5.1
Wheat	1085	18.7%	12.9%	333.5	5.3
Wheat	166	18.3%	12.8%	52.3	5.7
Oats	1502	16.9%	12.6%	374.1	5.8
Canola	1058	12.1%	8.3%	231.3	5.8
Canola	231	11.1%	8.1%	42.2	6.0
Wheat	1997	17.3%	13.3%	480.1	6.0
Wheat	265	16.3%	13.3%	49.0	6.1
Barley	497	17.0%	13.2%	113.2	6.1
Wheat	1104	19.1%	13.2%	400.3	6.2
Wheat Seed	182	15.9%	13.9%	28.9	8.3
Oats	1664	14.9%	11.9%	431.0	8.6
Wheat Seed	123	19.4%	14.7%	55.0	9.5

3.4.3 Direct Vs Indirect Fired Heating

In the 2019 grain condition study, it was observed that most indirect heaters outperformed direct-fired heaters regarding energy efficiency. This proceeded to lead to more investigation into the comparison between these two heater types and resulted in an indirect fired heater being utilized on the same site as direct-fired heaters. Utilizing the two heater types on the same site was intended to reduce variables, such as producer methodology, bin type, and air distribution. The values observed from the 2020 site-specific direct vs indirect heater is displayed in Table 6.

Direct Fired Bins: Indirect Fired Bins:

Table 6: Direct Vs Indirect Heater Drying Cycles (2020)

Grain Type	Total Grain Dried (Tonnes)	Initial Grain Moisture	Final Grain Moisture	Supply Air Temperature (°C)	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy ($GJ/T_{Moisture\ Removed}$)	Specific Cost ($\$/T_{Moisture\ Removed}$)
Wheat	120	15.5%	14.0%	26.6	329	7.7	5.0	$60.91
Wheat	119	17.0%	15.5%	36.7	1064	8.4	6.8	$108.59
Wheat	53	15.5%	14.5%	18.6	221	3.8	8.6	$33.38
Wheat	66	15.5%	14.0%	21.9	607	6.5	8.7	$70.88
Wheat	80	16.0%	15.0%	23.8	783	7.2	12.5	$85.38

Although the direct fired heaters in the 2020 comparison appeared to have lower specific energy compared to indirect-fired heaters, indirect heaters did display the lowest and third-lowest specific cost; resulting in less expensive grain drying. Additionally, indirect heaters were operated at lower supply air temperatures than all direct fired heaters in the comparison. Although indirect fired heaters did not appear to have much correlation between supply air temperature and specific energy (as noted in Section 3.3.1 and 3.3.2), it will affect supply air relative humidity, which did correlate to increase moisture removal rates and reduced run times, which would increase natural costs but decrease electricity costs. A sample size of five does not provide sufficient trending information, and more comparison is required. However, throughout all 2019 and 2020 drying cycles, indirect heaters still appear to be among the lower consuming heaters, as illustrated in Section 3.1.

3.4.4 Air Missile Distribution System


Figure 17: Air Missile

Two bins observed within the 2020 study consisted of a new air distribution system type. This distribution type consists of a central perforated tube that stretches from the bottom of the bin to the top of the bin to deliver conditioned air.

Supply air temperature logging equipment became faulty midway through drying. Due to this sensor error, weather normalized gas consumption could not be completed as the supply air temperature is a determining factor. Because of this, these bins were not included within previous analysis'. This section is provided to compare these bins to other bins at estimated supply air temperatures to gather the range of potential specific energy values.

Data for the two bins are displayed within Table 7 and are grouped into three different test categories, with the only changing variable being supply air temperature. The supply air temperatures for the three groups were simulated at 20°C, 30°C, and 40°C. Overall, specific energy ranged from 2.4-4.0 GJ/Tonne of Moisture Removed (average of 3.4 GJ/Tonne of moisture removed at 30°C), and are among the lower ranges for all bins, as average specific energy for other indirect-fired bins and direct-fired bins were found to be 5.6 GJ/Tonne of Moisture Removed and 9.6 GJ/Tonne of Moisture Removed, respectively. Due to the physical characteristics of this distribution type, moisture variation between the bottom and top of the bin appear reduced. Only a small number of sample points was available for this air distribution type, and more data in coming years will add to the confidence of the results.

Table 7: Air Missile Data at various Estimated Supply Air Temperatures

Test #	Total Grain Dried (Tonnes)	Initial Grain Moisture	Final Grain Moisture	Estimated Supply Air Temperature (˚C)	Electricity Use (kWh)	Normalized Fuel Use (GJ)	Specific Energy ($GJ/T_{Moisture\ Removed}$)
1	91	12.6%	8.6%	20	232	13.9	4.0
	91	11.6%	9.5%	20	105	4.1	2.4
2	91	12.6%	8.6%	30	232	12.1	3.6
	91	11.6%	9.5%	30	105	5.3	3.0
3	91	12.6%	8.6%	40	232	11.7	3.4
	91	11.6%	9.5%	40	105	5.9	3.3

3.5 Operating Costs

3.5.1 Operating Cost Summary

As noted in previous study years, a large portion of energy consumption from grain drying is attributed to heating fuel consumption, however, depending on the operating parameters of the system, electricity can have equally high costs. Utility prices observed during the 2019 conditioning study ranged from $2.99-4.62/GJ for natural gas, an estimated price of $0.90/L for propane, an estimated price of $1.00/Liter of dyed diesel, and an estimated electricity price of $0.06/kWh. Similar base utility rates were used within costing analyses for the 2020 study, with additional carbon pricing applied when applicable.

Using the base utility rates described above, with the current carbon price $30/Tonne of CO_2e, 2019 utility costs ranged between $0.02-0.14/Bu ($0.07/Bu average) of grain dried for natural gas systems, $0.10-0.61/Bu ($0.34/Bu average) of grain dried for propane systems, and $0.07-0.48/Bu ($0.26/Bu average) of grain dried for diesel systems. This can equate to a total batch/cycle cost between $80-700 ($330 average) for natural gas systems, $480-3,060 ($1,680 average) for propane systems, and $360-2,380 ($1,290 average) for diesel systems, for a standard 5,000-bushel grain bin. These values differ from the 2019 grain conditioning study report, as these values illustrate the current carbon price of $30/Tonne of CO_2e, opposed to the previous carbon price of $0/Tonne of CO_2e used within the 2019 grain conditioning study.

Using the base utility rates described above, with the current carbon price $30/Tonne of CO_2e, 2020 utility costs ranged between $0.01-0.05/Bu ($0.03/Bu average) of grain dried for natural gas systems, $0.07-0.33/Bu ($0.14/Bu average) of grain dried for propane systems, and $0.05-0.25/Bu ($0.11/Bu) of grain dried for diesel systems. This can equate to a total batch/cycle cost between $55-270 ($142 average) for natural gas systems, $320-1,650 ($715 average) for propane systems, and $250-1,250 ($550 average) for diesel systems, for a standard 5,000-bushel grain bin. Costing data analyzed within 2020 resulted in reduced dryer operating costs compared to 2019, largely due to dry/warm weather conditions during harvest and drying season.

Combining the 2019 and 2020 drying data, utilizing the current carbon price of $30/Tonne of CO_2e, an average drying cost was observed to be $0.05/Bu of grain dried for natural gas systems, $0.27/Bu of grain dried for propane systems, and $0.21/Bu of grain dried for diesel systems. This can equate to an average batch/cycle cost of $265 for natural gas systems, $1,340 for propane systems, and $1,030 for diesel systems, for a standard 5,000-bushel grain bin.

3.5.2 Carbon Pricing

The federal carbon levy was introduced in Alberta starting January 1st, 2020, which prescribes increased costs on heating fuels based on their greenhouse gas emissions. Currently, the price of carbon is $30/tonne of CO_2e, with a $10/tonne of CO_2e increase coming in April of 2021. The previous federal carbon plan was scheduled to peak carbon pricing in 2022, at $50/Tonne of CO_2e, however, the federal government has recently presented their long term carbon pricing plan, which increases carbon pricing annually by $15/Tonne of CO_2e after 2022 until 2030, where it will be $170/Tonne of CO_2e.

The carbon levy is calculated per tonne of CO_2e emitted, therefore, different fuel sources will have different carbon prices due to their differing CO_2e emission rates. Table 8 displays the fuel prices observed within the 2019 grain condition study ($0/Tonne of CO_2e) to the projected federal carbon plan, peaking in 2030 at $170/tonne of CO_2e. Fuel costs within this table are depicted in their commonly billed units.

Electricity is not subject to the federal carbon levy as electricity systems operators currently have projections and strategies for the coming years to diversify and reduce emissions for the electricity grid as a whole. Additionally, dyed farm fuel (diesel) is currently exempt from the carbon levy, therefore, no cost increase will be present.

Table 8: Heating Fuel Cost Increases from Carbon Pricing Based on Commonly Billed Units

Start Date	Carbon Levy ($/t$CO_2$e)	Natural Gas Price ($/GJ)	Propane Price ($/L)	Dyed Diesel ($/L)	Non-Dyed Diesel Increase ($/L)
Pre-January-2020	$0	$2.99-4.62	$0.90	$1.00	$1.09
January-2020	$20	$4.00-5.63	$0.93		$1.15
April-2020	$30	$4.51-6.14	$0.95		$1.17
April-2021	$40	$5.02-6.65	$0.96		$1.20
April-2022	$50	$5.52-7.15	$0.98		$1.23
April-2023	$65	$6.28-7.91	$1.00		$1.27
April-2024	$80	$7.05-8.68	$1.02		$1.31
April-2025	$95	$7.81-9.44	$1.05		$1.36
April-2026	$110	$8.57-10.20	$1.07		$1.40
April-2027	$125	$9.33-10.96	$1.09		$1.44
April-2028	$140	$10.09-11.72	$1.12		$1.48
April-2029	$155	$10.85-12.48	$1.14		$1.52
April-2030	$170	$11.61-13.24	$1.16		$1.57

Table 9 represents the same information displayed in Table 8; however, all fuel prices are converted into common units ($/GJ). This accounts for the energy density of each fuel and allows for a more understandable comparison between fuel types. This table shows natural gas having the lowest cost of all available heating fuels regardless of the carbon levy. Therefore, natural gas is the recommended fuel type for grain drying compared to propane, dyed diesel, or non-dyed diesel.

Using the current carbon pricing, natural gas currently has the lowest operating cost per unit energy and can range between $4.51-6.14/GJ from site to site. Propane is the most expensive fuel source and has a fuel cost of approximately $37.39/GJ ($0.95/L), while dyed diesel and non-dyed diesel have a fuel cost of approximately $25.91/GJ ($1.00/L) and $30.42/GJ ($1.17/L), respectively.

Table 9: Heating Fuel Cost Increases from Carbon Pricing Based on Standard Units

Start Date	Carbon Levy ($/t$CO_2$e)	Natural Gas Increase ($/GJ)	Propane Increase ($/GJ)	Dyed Diesel ($/GJ)	Non-Dyed Diesel Increase ($/GJ)
Pre-January-2020	$0	$2.99-4.62	$35.56	$25.91	$28.24
January-2020	$20	$4.00-5.63	$36.78	$25.91	$29.69
April-2020	$30	$4.51-6.14	$37.39	$25.91	$30.42
April-2021	$40	$5.02-6.65	$38.01	$25.91	$31.14
April-2022	$50	$5.52-7.15	$38.62	$25.91	$31.87
April-2023	$65	$6.28-7.91	$39.53	$25.91	$32.96
April-2024	$80	$7.05-8.68	$40.45	$25.91	$34.05
April-2025	$95	$7.81-9.44	$41.37	$25.91	$35.14
April-2026	$110	$8.57-10.20	$42.29	$25.91	$36.23
April-2027	$125	$9.33-10.96	$43.20	$25.91	$37.32
April-2028	$140	$10.09-11.72	$44.12	$25.91	$38.41
April-2029	$155	$10.85-12.48	$45.04	$25.91	$39.50
April-2030	$170	$11.61-13.24	$45.96	$25.91	$40.59

Even if natural gas has the highest prescribed carbon price of $170/t$CO_2$e in 2030, it is still well below the cost of propane, dyed diesel, or non-dyed diesel with no carbon price, and is estimated to range between $11.61-13.24/GJ (excluding external commodity price variations). For diesel or propane combustion to become competitive with natural gas combustion, a carbon price of approximately $425-625/Tonne of CO_2e would need to be applied to natural gas and not applied to other fuels. Additionally, natural gas has the lowest greenhouse gas emissions compared to propane and diesel. Therefore, if natural gas is available for drying use it should be the preferred fuel source; however, if utilizing natural gas is unavailable, dyed diesel is the second most affordable fuel type, followed by regular diesel and then propane.

A commonly suggested alternative to using direct fuels such as natural gas, propane, or diesel is to utilize electricity for supplemental heating in grain drying applications. Although the carbon levy does not directly apply to electricity, its high cost of energy and demand charges can quickly make this option unrealistic. Electricity is billed based on the number of kWh consumed. A typical energy rate for electricity can range from $0.06-0.10/kWh, which is equivalent to $16.7-27.8/GJ. Right away, these electricity rates are similar to rates seen for propane or diesel and quickly become uneconomical when compared to natural gas. Even if you could buy electricity at a rate of $0.02/kWh ($5.6/GJ), transmission, distribution, and demand-related charges would apply, with additional infrastructure investment (service lines/transformer upgrades), which would also make using electricity an unsustainable and uneconomical option.

Overall, fuel prices will increase year after year due to the carbon levy, which will significantly increase operating costs for grain drying systems. Table 10 summarizes the range of total operating costs per bushel observed for the combined grain condition study years of 2019 and 2020, while also displaying the average values. Values are illustrated from 2019 (pre-carbon levy) until 2030. This table includes total variable utility costs (heating fuel and electricity); however, it does not include fixed utility fees or external market fluctuations.

Table 10: Utility Cost Projections for In-Bin Drying Systems per Bushel

Year	Natural Gas ($/Bu)	Propane ($/Bu)	Dyed Diesel ($/Bu)	Non-Dyed Diesel ($/Bu)
Pre-January-2020	$0.009-0.12 ($0.04)	$0.062-0.59 ($0.26)	$0.046-0.44 ($0.20)	$0.050-0.44 ($0.19)
January-2020	$0.010-0.13 ($0.05)	$0.064-0.60 ($0.26)		$0.052-0.47 ($0.20)
April-2020	$0.011-0.14 ($0.05)	$0.065-0.61 ($0.27)		$0.053-0.48 ($0.21)
April-2021	$0.012-0.15 ($0.06)	$0.065-0.62 ($0.27)		$0.054-0.49 ($0.21)
April-2022	$0.013-0.15 ($0.06)	$0.066-0.63 ($0.28)		$0.056-0.53 ($0.23)
April-2023	$0.015-0.17 ($0.06)	$0.068-0.64 ($0.28)		$0.057-0.55 ($0.24)
April-2024	$0.016-0.18 ($0.07)	$0.069-0.66 ($0.29)		$0.059-0.56 ($0.25)
April-2025	$0.018-0.19 ($0.07)	$0.071-0.67 ($0.29)		$0.061-0.58 ($0.25)
April-2026	$0.019-0.20 ($0.08)	$0.072-0.68 ($0.30)		$0.063-0.60 ($0.26)
April-2027	$0.20-0.21 ($0.08)	$0.074-0.70 ($0.31)		$0.064-0.61 ($0.27)
April-2028	$0.022-0.22 ($0.09)	$0.075-0.71 ($0.31)		$0.066-0.63 ($0.27)
April-2029	$0.023-0.23 ($0.10)	$0.077-0.72 ($0.32)		$0.068-0.64 ($0.28)
April-2030	$0.024-0.24 ($0.10)	$0.078-0.74 ($0.32)		$0.070-0.66 ($0.29)

As described above, natural gas should be the preferred fuel source for grain drying when compared to other fuel types. Although natural gas is the least expensive fuel type currently available in Alberta, drying costs will still increase significantly due to carbon pricing, and will greatly affect the bottom line of producers. Based on the current long term federal carbon pricing plan, the cost of natural gas will double in 2024 compared to 2019, with an additional increase of approximately 63% by 2030, resulting in natural gas being 226% (on average) more expensive than it was during the first grain conditioning study commenced in 2019. This will increase total average drying costs for natural gas systems from $0.042/Bu to $0.100/Bu, increasing 134% from 2019; from $0.26/Bu to $0.32/Bu for propane systems, increasing 27% from 2019, and from $0.19/Bu to $0.29/Bu for non-dyed diesel systems, increasing 49% from 2019.

Figure 18 displays the projected operating costs per 100 bushels associated with the Canadian federal carbon levy, depicted from no carbon levy (Pre-January-2020) to \$170/tCO_2e (2030) for natural gas systems. Values in this figure are summarized based on all in-bin fuel-fired systems observed within the 2019 and 2020 study. Drying seasons within 2019 and 2020 were considerably different. The average ambient temperature during 2019 drying was 1.6°C, while in 2020 it was 11.1°C. As noted in Section 3.3.1 and the 2019 grain conditioning report, ambient relative humidity does not significantly affect drying performance as long as a sufficient temperature rise is present. Additionally, 2019 consisted of wet weather conditions during harvest, while 2020 consisted of dry weather conditions during harvest and warm conditions during drying. This resulted in more moisture needing to be removed in 2019 for safe storage. Projected fuel costs per 100 bushels for 2019 had an average moisture reduction of 3.21%, while 2020 had an average moisture reduction of 2.58%. Therefore, projected fuel costs per 100 bushels will vary for moisture removal above or below these values.

With the increase of fuel prices from the carbon levy, total drying costs for in-bin systems utilizing natural gas will increase by approximately 6% per year until 2022, and then rise to 8% in 2023 and slightly decline annually until an increase of approximately 5% in seen 2030.

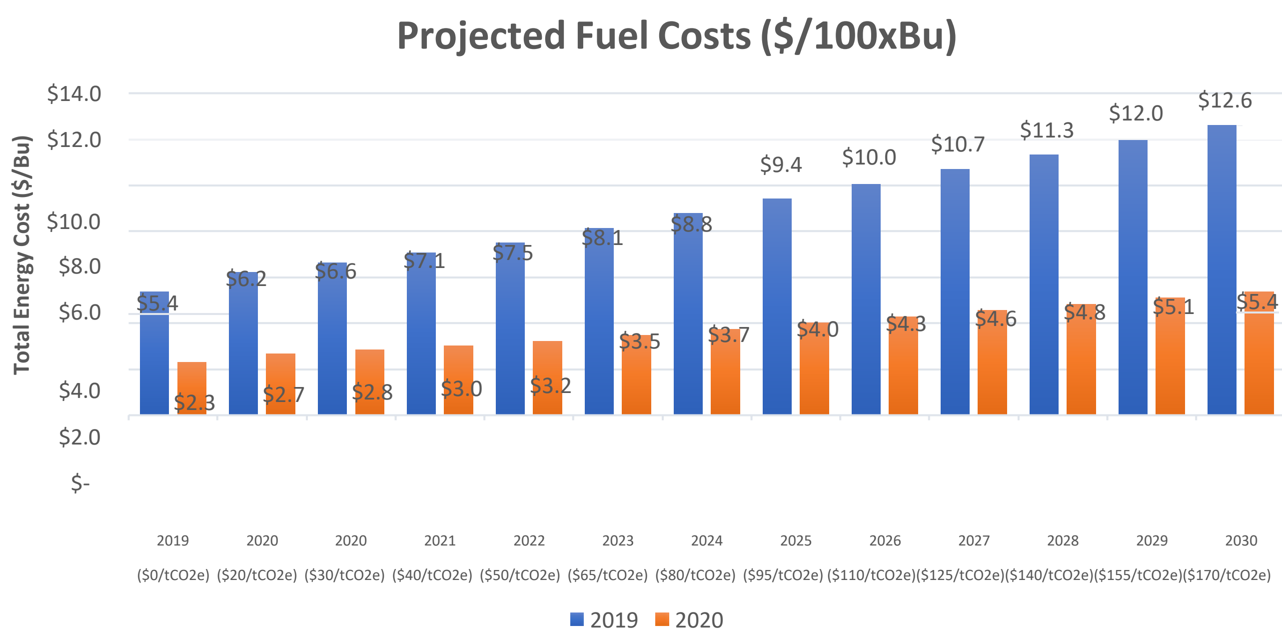

Figure 18: Total Utility Operating Cost Projections from Carbon Pricing (Natural Gas Systems)

Most farms utilizing in-bin drying observed within this study dried between 25,000-150,000 bushels in 2019 & 2020. Expected drying cost increases for the entire drying season per farm site, from no carbon levy (\$0/tCO2e) to \$170/ tCO2e in 2030, are displayed in Table 11. Values in this table are summarized based on all in-bin fuel-fired systems observed within the 2019 & 2020 study. Additionally, Table 12 displays the average total utility costs for natural gas-fired systems throughout at various carbon prices between $0/

tCO2e and $170/ tCO2e. Only natural gas was used in Table 12 as it is the most common fuel type within this study and displays the largest impact relative to the base fuel cost with no carbon levy.

Table 11: Expected Utility Costs Increases per Farm Site from $0/tCO$_2$ to $170/tCO$_2$ (2019 vs. 2030)

Seasonal Bushels Dried	Natural Gas ($)	Propane ($)	Non-Dyed Diesel ($)
25,000 Bu	$392-3,166 ($1,437)	$417-$3,820 ($1,734)	$496-5,394 ($2,374)
50,000 Bu	$784-6,333 ($2,874)	$835-7,640 ($3,468)	$991-10,787 ($4,748)
75,000 Bu	$1,176-9,499 ($4,312)	$1,252-11,460 ($5,202)	$1,487-16,181 ($7,123)
100,000 Bu	$1,568-12,665 ($5,749)	$1,669-15,280 ($6,936)	$1,983-21,574 ($9,497)
150,000 Bu	$2,352-18,998 ($8,623)	$2,504-22,920 ($10,403)	$2,974-32,362 ($14,245)

Table 12: Expected Utility Costs per Farm Site at Various Carbon Prices (Natural Gas)

Seasonal Bushels Dried	Total Gas Cost ($)						
	$0/tCO$_2$ (2019)	$30/tCO$_2$ (2020)	$50/tCO$_2$ (2022)	$80/tCO$_2$ (2024)	$110/tCO$_2$ (2026)	$140/tCO$_2$ (2028)	$170/tCO$_2$ (2030)
25,000 Bu	$1,067	$1,321	$1,490	$1,744	$1,997	$2,251	$2,505
50,000 Bu	$2,135	$2,642	$2,980	$3,487	$3,995	$4,502	$5,009
75,000 Bu	$3,202	$3,963	$4,470	$5,231	$5,992	$6,753	$7,514
100,000 Bu	$4,270	$5,284	$5,960	$6,975	$7,989	$9,004	$10,018
150,000 Bu	$6,404	$7,926	$8,941	$10,462	$11,984	$13,506	$15,028

Carbon levy rebates are available for Canadians; however, these rebate amounts are determined based on household size, therefore, they are primarily fixed. These rebates are designed to offset the cost of the carbon levy for residential heating and some vehicle fuel. Although these rebates may be "revenue neutral" to many Canadians who live in urban environments, they are not for producers who use carbon-based fuels for their residence, as well as any equipment garages, or process heating such as grain drying. The current rebates are values at $444 for the first adult, $222 for the second adult, and $111 for each child up to two children. This results in producers getting a rebate between $444-$888, depending on household size. Shaded values in Table 12 display the point when the maximum available rebate ($888) would not offset grain drying costs, assuming 100% of the rebate could go towards drying costs, which would not occur.

It will also be useful to quantify the expected cost increase on the typical Alberta farm. To accomplish this we have used the following assumptions to describe a typical or average sized farm in Alberta. Due to the high uncertainty related to these assumptions including precipitation and weather, this should be used for example purposes only.

A typical Alberta farm is approximately 1237 Acres (2016 Census of Agriculture) grows Wheat, Barley or Canola and uses an In-Bin natural gas fueled dryer. For this example, spring wheat is used with an average yield of 51.1 Bushels per acre (July 2018 Estimates Crop Production) resulting in 63,211 bushels. The amount of drying required is highly dependent on the annual local precipitation and weather conditions. For this example we estimated 50% of the yield required drying based on a data sampling from 2018, 2019 and 2020. Therefore, for this example, our typical Alberta farm can expect to dry 31,606 bushels. We will use this hypothetical typical Alberta farm to estimate the impacts of increasing fuel costs and to show the costs differences from farms using natural gas, diesel and propane. Typical costs for electricity are included however inflation is not. The following table shows how fuel costs are expected to rise along with increasing carbon tax rates.

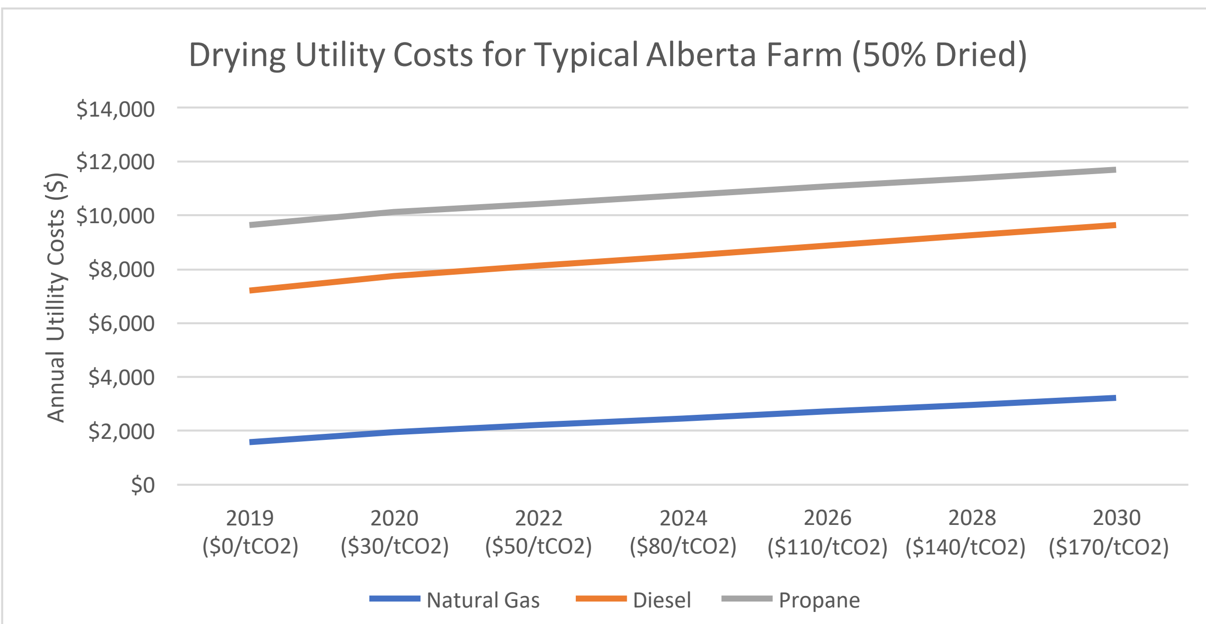

Figure 19. Utility cost for average Alberta farm

04 | Continuous Dryers

4.1 Drying Performance

Continuous grain dryers provide high efficiency, large volume grain drying. A variety of different dryers were metered within this study. The energy performance of continuous dryers was analyzed in terms of GJ/Tonne of Moisture Removed. The results are based on the operating temperature setpoints, grain flow rates, grain types, ambient environmental conditions, etc. during each drying cycle for each specific site. Specific energy results may vary based on the changing grain and environmental conditions listed above, and from operator setpoints and procedures. These setpoints and operating conditions may be different than manufacturer specifications and may not reflect an accurate comparison between observed data within this study and manufacturer specifications. Additionally, this study was not conducted in a controlled environment, therefore, error may exist within human measurements and/or different testing procedures/methodologies throughout data samples.

Five continuous flow grain dryers were metered within this study, however, only two systems were able to participate due to lack of drying or other unforeseen circumstances. The observed dryers within this study are as follows:

- Alvan Blanch DF 22000
- Western Grain Dryer 1600-24 - **No 2020 Data**
- GSI 1222
- Vertec 6600 (9 Tier-Upgraded) - **No 2020 Data**
- Vertec 5500 (5 Tier-Original) - **No 2020 Data**

Theoretical energy performance (GJ/Tonne of moisture removed) of each dryer was calculated using maximum grain flow rate (BPH), max heating output (MBH), electricity (kW) input, and % moisture removed at maximum capacity from their respective brochure/specifications. Although dryer specifications display operating values at full capacity, actual dryers analyzed were observed to mainly operate below full capacity. Additionally, due to the continuous operation of these dryers, changing inlet grain conditions and ambient environmental conditions cause outlet grain moistures and temperatures to fluctuate throughout the drying process. Average inlet and outlet grain moisture were used to calculate the energy performance of each dryer for each grain type. All field measured specific energy values are weather normalized based on a standard outdoor ambient temperature of 10°C. Brochure specifications and recoded energy performance are displayed in Table 13.

Table 13: Continuous Grain Dryer Brochure Vs. Observed Energy Performance*

Brochure Information	Alvan Blanch DF 22000	Western 1600-24	Upgraded Vertec 6600†	GSI 1222
	Grain Dryer Brochure/Specification Sheet Data			
Heating Capacity (MBH)	6,100	11,500	3,000	9,750
Total Electricity Load (HP)	45.3	90	42.5	78.8
Drying Capacity (T/h)	Wheat: 26 (20-15%)	Wheat: 58 (20-15%)	Wheat: 22 (20-15%)	Wheat: 29 (20-15%)
	Barley: 24 (20-15%)	Barley: 46 (20-15%)	Barley: 17 (20-15%)	Barley: 23 (20-15%)
	Canola: 16 (13-9%)	Canola: 48 (14-9%)	Canola: 18 (13-9%)	Canola: 24 (13-9%)
	Oats: 15 (20-15%)	Oats: 33 (20-15%)	Oats: 12 (20-15%)	Oats: 16 (20-15%)
Prescribed Specific Energy from Brochure ($GJ/T_{Moisture\ Removed}$)	Wheat: 5.0	Wheat: 4.3	Wheat: 3.0	Wheat: 7.3
	Barley: 5.5	Barley: 5.3	Barley: 3.8	Barley: 9.1
	Canola: 10.3	Canola: 5.1	Canola: 3.6	Canola: 8.7
	Oats: 8.9	Oats: 7.5	Oats: 5.3	Oats: 12.9
	Grain Drying Observed Data from 2019 Study			
Observed Specific Energy from Study ($GJ/T_{Moisture\ Removed}$)	Wheat: 6.1	Wheat: 7.3	Wheat: 4.9	Wheat: N/A
	Barley: 5.8	Barley: N/A	Barley: N/A	Barley: N/A
	Canola: 6.0	Canola: 7.8	Canola: 6.9	Canola: N/A
	Oats: 7.5	Oats: N/A	Oats: 10.2	Oats: N/A
	Seed (Wheat): 12.5	Seed: N/A	Seed: N/A	Seed: N/A
	Grain Drying Observed Data from 2020 Study			
Observed Specific Energy from Study ($GJ/T_{Moisture\ Removed}$)	Wheat: 6.3	Wheat: N/A	Wheat: N/A	Wheat: 8.2
	Barley: 4.6	Barley: N/A	Barley: N/A	Barley: 5.4
	Seed (Wheat): 9.1	Seed (CWRS): N/A	Seed (CWRS): N/A	Seed (Wheat): 14.4
	Seed (Oat): 4.9	Seed (Oat): N/A	Seed (Oat): N/A	Seed (Oat): N/A
	Seed (Barley): 4.1	Seed (Barley): N/A	Seed (Barley): N/A	Seed (Barley): N/A

The Alvan Blanch grain dryer resulted in average specific energy values of 4.6-7.5 GJ/Tonne of moisture removed for wheat, barley, canola, and oats throughout 2019 and 2020. Additionally, wheat, barley, and oat seed sorting/drying occurred, totaling 4.1 for barley seed. 4.9 for oat seed, and 9.4-12.5 GJ/Tonne of moisture removed for wheat seed. Drying within 2020 appeared to be more efficient in drying

* Not all grain dryer specifications listed drying capacity (T/h) for all grain types, therefore, drying capacities for grains not listed within the specifications were estimated using BPH for known grain types and Bu/tonne grain conversions.

† Grain Capacity (BPH) data was not available for the Vertec 6600, and was estimated to be 800 BPH for each grain type, as per similar 8-9 tier grain dryers

barley and wheat seed, however slightly less efficient in wheat. As noted in Section 3.4.2, this dryer did undergo a burner tune-up and maintenance before harvest.

The GSI-1222 grain drier resulted in average specific energy values of 5.4, 8.2, and 14.4 GJ/tonne of moisture removed for barley, wheat, and wheat seed, respectively.

In 2020, the Alvan Blanch drier was slightly less efficient in wheat compared to its specifications, however, it achieved better performance in barley. Similarly, the GSI-1222 was slightly less efficient in wheat compared to its specifications, however, it achieved better performance in barley. The differences in actual performance vs. theoretical performance may be a result of differing grain temperatures, moisture removal, operating setpoints from brochure values, or operator procedures differing from specifications. Additionally, dryers operating below maximum capacities (in grain flow rate and heat output) could result in differing efficiencies due to burner efficiency, airflow distribution, etc. Table 14 displays the actual measured setpoints, grain types, and energy consumption for all continuous dryer batches metered in 2019 and 2020.

Table 14: Continuous Dryer Data

Year	Location	Grain Type	Dryer Model	Total Grain Dried (Tonnes)*	Total Moisture Removed (T)	Plenum Temperature (°C)	Electricity Use (kWh)	Fuel Use (GJ)	Specific Energy ($GJ/T_{Moisture\ Removed}$)
2020	North East	Barley Seed	Alvan Blanch	98	3.9	55	514	14.2	4.1
2020	North East	Barley	Alvan Blanch	165	13.1	95	705	50.9	4.1
2019	Central	Canola	Vertec 6600	102	2.8	68	215	12.2	4.6
2020	North East	Barley	Alvan Blanch	606	32.7	95	1,912	150.1	4.8
2020	North East	Barley	GSI-1222	308	8.4	60 (Top), 77 Bot	516	38.5	4.8
2020	North East	Oat Seed	Alvan Blanch	305	9.2	50	1,246	40.5	4.9
2019	Central	Canola	Vertec 6600	82	2.9	68	172	13.8	4.9
2019	Central	Wheat	Vertec 6600	624	9.6	95	851	43.8	4.9
2019	North East	Barley	Alvan Blanch	273	16.3	65	1,649	77.4	5.1
2019	North East	Canola	Alvan Blanch	857	33.7	80	3,957	170.6	5.5
2019	North East	Wheat	Alvan Blanch	1162	62.7	87	5,206	333.5	5.6
2019	Central	Canola	Vertec 6600	102	3.1	68	215	16.5	5.7
2019	Central	Canola	Vertec 6600	105	3.0	68	220	16.5	5.7
2019	Central	Wheat	Vertec 6600	26	0.7	95	36	3.7	5.7
2019	Central	Canola	Vertec 6600	585	16.0	68	1,230	87.9	5.8
2019	North East	Wheat	Alvan Blanch	178	9.2	87	762	52.3	6.0
2019	North East	Canola	Western 1600-24	138	2.6	104	132	15.5	6.1

* Total grain dried is recorded in wet tonnes, while specific energy is adjusted to account for shrink loss

Year	Location	Grain Type	Dryer Model	Total Grain Dried (Tonnes)*	Total Moisture Removed (T)	Plenum Temperature (°C)	Electricity Use (kWh)	Fuel Use (GJ)	Specific Energy (GJ/$T_{Moisture Removed}$)
2019	North East	Oats	Alvan Blanch	1580	64.7	65	7,591	374.1	6.2
2019	North East	Canola	Alvan Blanch	1103	40.2	80	5,507	231.3	6.2
2020	North East	Wheat	Alvan Blanch	2093	79.9	87	7,185	480.1	6.3
2019	North East	Barley	Alvan Blanch	520	18.7	88	1,721	113.2	6.4
2020	North East	Barley	GSI-1222	165	4.31	60 (Top), 77 Bot	291	26.4	6.4
2019	North East	Wheat	Alvan Blanch	274	8.0	87	900	49.0	6.5
2019	North East	Wheat	Alvan Blanch	1184	64.7	87	6,001	400.3	6.5
2019	North East	Canola	Alvan Blanch	239	7.0	80	1,064	42.2	6.6
2019	North East	Wheat	Western 1600-24	5756	173.8	110	7,116	1,160.4	6.8
Continued									
2019	Central	Canola	Vertec 6600	234	5.2	68	491	35.1	7.1
2019	North East	Canola	Western 1600-24	2866	63.6	104	3,125	471.1	7.6
2019	Central	Canola	Vertec 6600	56	1.4	68	117	10.4	7.8
2019	Central	Canola	Vertec 6600	215	4.7	68	451	34.6	7.8
2019	Central	Canola	Vertec 6600	196	4.4	68	411	33.0	7.9
2020	North East	Wheat	GSI-1222	375	9.1	88 (Top), 71 (Bot)	604	72.9	8.2
2019	North East	Wheat	Western 1600-24	645	35.3	99	1,034	313.8	9.0
2020	North East	Wheat Seed	Alvan Blanch	187	3.5	55	794	28.9	9.1
2019	North East	Oats	Alvan Blanch	1723	50.0	65	9,207	431.0	9.3
2019	North East	Wheat	Western 1600-24	182	6.9	104	386	63.0	9.3
2019	North East	Canola	Western 1600-24	227	9.4	104	573	87.0	9.5
2019	Central	Canola	Vertec 6600	132	2.2	68	277	20.4	9.8
2019	Central	Oats	Vertec 6600	120	2.7	95	220	26.3	10.2
2019	North East	Wheat Seed	Alvan Blanch	109	4.9	55	1,542	55.0	12.5
2019	Central	Canola	Vertec 6600	106	1.3	68	222	15.4	12.9
2019	Central	Canola	Vertec 6600	86	1.7	68	182	23.7	14.1
2020	North East	Wheat Seed	GSI-1222	58	2.0	77 (Top), 60 (Bot)	279	28.1	14.4

4.2 Operating Costs

Most farms utilizing continuous flow dryers observed within this study dried anywhere between 100,000-450,000 bushels. Expected drying cost increases are expected over the coming years due to the carbon levy increases which will occur from now until 2030. Typical cost increases for the entire drying season per farm site, from no carbon levy to \$170/tCO_2e in 2030, are displayed in Table 15. Values in this table are summarized based on all continuous systems observed within the 2019 and 2020 study.

Continuous dryers typically operate on three-phase electricity services, which range from 208 V to 480 V. Typically, farm sites are not equipped with this service size, therefore, generators are commonly used to produce electricity for the continuous dryers. This can result in the carbon levy affecting the heating and electricity costs of drying. Electricity consumption typically makes up a small portion of total operating costs, however, sites utilizing natural gas generators for electricity production may see an additional increase ranging from 3.7-44.4%, depending on grain type and dryer efficiency. The average electricity cost increase from natural gas generators was calculated to be approximately 17.5%.

Table 15: Expected Utility Costs Increases per Farm Site from \$0/tCO_2 to \$170/tCO_2 (2019 vs. 2030)-Grid Electricity and Natural Gas Heating

Seasonal Bushels Dried	Natural Gas (\$)	Propane (\$)	Non-Dyed Diesel (\$)
100,000 Bu	\$954-13,338 (\$4,876)	\$1,150-16,091 (\$5,882)	\$1,336-19,111 (\$6,986)
200,000 Bu	\$1,907-26,676 (\$9,751)	\$2,301-32,183 (\$11,764)	\$2,733-38,222 (\$13,972)
300,000 Bu	\$2,861-40,013 (\$14,627)	\$3,451-48,274 (\$17,646)	\$4,099-57,334 (\$20,958)
400,000 Bu	\$3,814-53,351 (\$19,502)	\$4,602-64,365 (\$23,528)	\$5,466-76,445 (\$27,944)
500,000 Bu	\$4,768-66,689 (\$24,378)	\$5,752-80,456 (\$29,410)	\$6,832-95,556 (\$34,930)

Figure 20: Alvan Blanch DF 22000 (Top Left), Western 1600-24 (Top Right), Upgraded Vertec 6600 (Bottom Left), GSI-1222 (Bottom Right)

05 | Conclusion

The 2020 Grain Conditioning Study analyzed a total of 18 in-bin with supplemental heating drying systems. Of these bins, 11 were direct-fired natural gas systems, 4 were indirect-fired natural gas-fired systems, and 3 bins were heated using solar air collectors. Solar drying systems resulted in the lowest specific energy consumption out of all in bin dryers. This is a result of no fuel consumption required and only electricity used for air circulation. Indirect fired heaters were among the highest performing fuel-fired in-bin systems in terms of energy consumption per ton of moisture removed. This is likely because moist combustion air is exhausted to the atmosphere as opposed to being supplied to the bins. On average, indirect-fired heating systems consumed less energy per tonne of moisture removed than direct-fired heaters.

Typical supply air temperatures ranged from 13-55°C, averaging around 33°C. Reduced energy consumption and emissions were typically observed while utilizing higher supply air temperatures. This is a result of increased moisture removal rates with higher supply air temperatures combined with reduced drying times and therefore reduced electricity consumption. Shorter drying batches are preferred to reduce electricity (fan) consumption, which is generally more expensive and emits more greenhouse gas emissions than natural gas, diesel, and propane. However, if air supply temperatures are too high, damage to the grain can occur. Therefore, there is a balance between energy efficiency and final grain quality. Additionally, bins utilizing high supply air temperatures should be closely monitored, as bins that are over dry can cause excessive shrinkage and reduce profitability, forfeiting any savings from grain drying. More research on maximum and optimum supply air temperatures for different grain types and air distribution systems is required.

Two continuous flow dryers were also metered and analyzed. Of these dryers, the Alvan Blanch DF 22000 displayed an average weather normalized specific energy of 4.6 in barley, 6.3 in wheat, 4.1 in barley seed, 4.9 in oat seed, and 9.1 in wheat seed. This was better than its specifications in barley, however, it was slightly less efficient in wheat (seeds are not comparable to specifications due to lack of information). The GSI-1222 grain drier resulted in average specific energy values of 5.4, 8.2, and 14.4 GJ/tonne of moisture removed for barley, wheat, and wheat seed respectively. These values were observed to be higher than its specifications in wheat, but lower in barley.

Additionally, the implementation and scheduled increases of carbon pricing on heating fuels have resulted in high drying costs, which will continue to rise as the carbon levy increases. By 2030, the average in-bin system is expected to have drying costs rise from their current cost of $0.04/Bushel to $0.10/Bushel by 2030, increasing 134%. This can range from $1,440 for sites drying 25,000 bushels, to $24,380 for sites drying 500,000 bushels.

Utility costs for related to grain drying operations for a typical Alberta farm are expected to double over the next ten years due to the planned increases to the carbon tax.

Sites should utilize natural gas whenever possible for heating purposes to reduce operating costs and emissions, however, diesel is the next best option, followed by propane. Utilizing electric heating for grain drying should be avoided, as electricity has the highest operating costs and emissions, and would require a large infrastructure investment to service lines/transformers to be capable of the required demand need for grain drying. Multiple policy considerations are suggested to lessen the energy cost increases from the carbon levy, some of which include providing a grain drying rebate to producers when they bring their grain to market or excluding natural gas and propane from the carbon levy for designated grain drying meters.

Further data collection in 2021 will add to the data sample sizes of the 2019 and 2020 study and help reduce uncertainty in the conclusions. Suggestions based on findings within the 2020 study will be provided to participants and a re-evaluation of their systems will be conducted in 2021.

06 | Appendix

6.1 Appendix A-In-Bin Dryer Operating Conditions

The table below displays the same order as seen in Table 1 of this report (arranged based on the lowest specific energy to highest). Burner capacity was determined via burner nameplate values. Average burner output capacity was calculated using the following formula:

*Average Burner Output (Btu/hr)=Average Airflow during Burner Operation (CFM)*1.944*(Average Supply Air temperature during Burner Operation (°C)-Average Ambient Air Temperature during Burner Operation (°C))*

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Run Time (Hrs)	Burner Capacity (Btu/Hr)	Average Burner Output (Btu/Hr)	Average Burner Load Factor (%)	Average Btu/Bu
2020	North East	Canola	Natural Gas	91	1.9	25	225,000	79,819	35%	20.9
2020	North East	Canola	Natural Gas	91	3.6	55	225,000	122,641	55%	31.4
2020	Central	Barley	Natural Gas	73	2.2	195	100,000	30,513	31%	9.5
2019	North West	Barley	Diesel	111	4.1	41	1,200,000	310,504	26%	63.8
2020	North East	Wheat	Natural Gas	122	1.8	52	111,000	111,000	100%	25.1
2019	North East	Wheat	Natural Gas	122	2.5	120	111,000	111,000	100%	25.3
2019	North East	Canola	Natural Gas	50	3.0	115	225,000	133,762	59%	65.4
2019	North East	Wheat	Natural Gas	122	5.7	468	111,000	106,547	96%	25.1
2019	North East	Canola	Natural Gas	49	3.2	182	225,000	131,789	59%	66.4
2020	Central	Barley	Natural Gas	159	5.9	98	1,600,000	556,774	35%	79.8
2019	North West	Wheat	Diesel	138	5.4	112	1,200,000	342,422	29%	70.5
2019	North East	Canola	Natural Gas	48	3.5	367	225,000	137,325	61%	70.7
2019	Central	Barley	Natural Gas	100	1.3	120	100,000	52,319	52%	11.6
2019	North West	Wheat	Diesel	138	5.6	118	1,200,000	476,794	40%	98.4
2019	Central	Wheat	Natural Gas	216	6.7	107	1,600,000	495,622	31%	64.3
2020	North East	Wheat	Natural Gas	122	1.8	162	111,000	111,000	100%	25.1
2020	Central	Barley	Natural Gas	54	2.1	65	1,600,000	577,859	36%	242.6
2019	Central	Barley	Natural Gas	185	4.5	90	1,600,000	563,458	35%	68.3
2019	Central	Wheat	Natural Gas	176	4.6	95	1,600,000	515,090	32%	81.8
2020	Central	Barley	Natural Gas	65	2.4	234	100,000	69,281	69%	24.1
2019	Central	Barley	Natural Gas	185	2.9	68	1,600,000	389,393	24%	46.7
2019	Central	Canola	Natural Gas	98	4.5	144	1,600,000	711,028	44%	174.6
2019	Central	Barley	Natural Gas	100	0.5	94	100,000	50,447	50%	11.0
2020	North East	Wheat	Natural Gas	54	0.5	35	225,000	104,101	46%	52.7
2019	Central	Wheat	Natural Gas	216	3.0	67	1,600,000	508,158	32%	64.6
2020	North East	Wheat	Natural Gas	68	1.0	96	225,000	92,659	41%	37.7
2019	North West	Wheat	Diesel	138	1.9	93	1,200,000	434,741	36%	86.7

Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Run Time (Hrs)	Burner Capacity (Btu/Hr)	Average Burner Output (Btu/Hr)	Average Burner Load Factor (%)	Average Btu/Bu
2020	Central	Barley	Natural Gas	104	2.9	234	100,000	61,179	61%	13.2
2020	Central	Wheat	Natural Gas	162	3.0	93	1,600,000	596,086	37%	101.6
Continued										
2019	Central	Wheat	Natural Gas	176	2.4	81	1,600,000	655,294	41%	102.5
2019	Central	Barley	Natural Gas	189	3.7	90	1,600,000	504,568	32%	59.4
2019	North East	Canola	Natural Gas	57	1.4	308	111,000	111,000	100%	45.7
2020	Central	Barley	Natural Gas	174	4.9	150	1,600,000	567,141	35%	73.4
2019	North East	Wheat	Natural Gas	122	2.8	519	111,000	111,000	100%	25.4
2020	North East	Wheat	Natural Gas	81	0.8	118	111,000	111,000	100%	37.4
2019	North East	Canola	Natural Gas	57	1.6	327	111,000	111,000	100%	45.8
2020	Central	Canola	Natural Gas	132	3.9	126	1,600,000	856,695	54%	153.0
2019	Central	Barley	Natural Gas	109	2.3	74	1,600,000	539,906	34%	110.8
2019	Central	Wheat	Natural Gas	230	4.5	144	1,600,000	609,835	38%	73.5
2019	North East	Wheat	Natural Gas	54	1.6	236	111,000	111,000	100%	57.4
2019	Central	Wheat	Natural Gas	216	3.0	96	1,600,000	677,850	42%	86.2
2019	North East	Canola	Natural Gas	57	2.0	380	111,000	111,000	100%	46.2
2019	North East	Wheat	Natural Gas	108	2.1	470	111,000	111,000	100%	28.4
2019	North East	Wheat	Natural Gas	95	2.1	418	111,000	111,000	100%	32.6

6.2 Appendix B-Continuous Dryer Operating Conditions

The table below displays the same order as seen in Table 11 of this report (arranged based on the lowest specific energy to highest). Burner capacity was determined via burner nameplate values. Since airflow of each dryer was unknown and no operation is present without the burners being engaged (no cooling only mode), average burner output capacity was calculated using the following formula: *Average Burner Output (Btu/Hr)=Natural Gas Consumption (GJ)*947817(Btu/GJ)/Operating Hours*

Year	Location	Grain Type	Dryer Model	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Run Time (Hrs)	Burner Capacity (Btu/Hr)	Average Burner Output (Btu/Hr)	Average Burner Load Factor (%)
2020	North East	Barley Seed	Alvan Blanch	98	3.9	9	6,100,000	1,469,938	24%
2020	North East	Barley	Alvan Blanch	165	13.1	14	6,100,000	3,902,294	64%
2019	Central	Canola	Vertec 6600	102	2.8	8	3,000,000	1,706,714	57%
2020	North East	Barley	Alvan Blanch	606	32.7	38	6,100,000	3,383,592	55%
2020	Central	Barley	GSI-1222	308	8.4	26	9,750,000	1,312,362	13%
2020	North East	Oat Seed	Alvan Blanch	305	9.2	22	6,100,000	1,953,502	32%
2019	Central	Canola	Vertec 6600	82	2.9	6	3,000,000	2,346,732	78%
2019	Central	Wheat	Vertec 6600	624	9.6	30	3,000,000	1,508,460	50%
2019	North East	Barley	Alvan Blanch	273	16.3	26	6,100,000	2,640,926	43%
2019	North East	Canola	Alvan Blanch	857	33.7	62	6,100,000	2,627,729	43%
2019	North East	Wheat	Alvan Blanch	1162	62.7	85	6,100,000	3,520,462	58%
2019	Central	Canola	Vertec 6600	102	3.1	8	3,000,000	2,525,937	84%
2019	Central	Canola	Vertec 6600	105	3.0	8	3,000,000	1,903,358	63%
2019	Central	Wheat	Vertec 6600	26	0.7	1	3,000,000	3,000,000	100%
2019	Central	Canola	Vertec 6600	585	16.0	43	3,000,000	2,270,646	76%
2019	North East	Wheat	Alvan Blanch	178	9.2	13	6,100,000	4,049,138	66%
2019	North East	Canola	Western 1600-24	138	2.6	5	11,500,000	2,989,415	26%
2019	North East	Oats	Alvan Blanch	1580	64.7	114	6,100,000	3,812,761	63%
2019	North East	Canola	Alvan Blanch	1103	40.2	83	6,100,000	3,407,134	56%
2020	North East	Wheat	Alvan Blanch	2093	79.9	116	6,100,000	3,667,648	60%
2019	North East	Barley	Alvan Blanch	520	18.7	29	6,100,000	4,550,959	75%
2020	Central	Barley	GSI-1222	165	4.3	12	9,750,000	1,974,619	20%
2019	North East	Wheat	Alvan Blanch	274	8.0	16	6,100,000	3,179,612	52%
2019	North East	Wheat	Alvan Blanch	1184	64.7	91	6,100,000	4,613,207	76%
2019	North East	Canola	Alvan Blanch	239	7.0	17	6,100,000	2,800,557	46%
2019	North East	Wheat	Western 1600-24	5756	173.8	116	11,500,000	9,922,768	86%
2019	Central	Canola	Vertec 6600	234	5.2	17	3,000,000	2,467,839	82%
2019	North East	Canola	Western 1600-24	2866	63.6	70	11,500,000	6,740,547	59%
2019	Central	Canola	Vertec 6600	56	1.4	4	3,000,000	2,445,130	82%
2019	Central	Canola	Vertec 6600	215	4.7	16	3,000,000	2,389,400	80%

Year	Location	Grain Type	Dryer Model	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Run Time (Hrs)	Burner Capacity (Btu/Hr)	Average Burner Output (Btu/Hr)	Average Burner Load Factor (%)
2019	Central	Canola	Vertec 6600	196	4.4	14	3,000,000	2,321,926	77%
Continued									
2020	Central	Wheat	GSI-1222	375	9.1	31	9,750,000	2,293,106	24%
2019	North East	Wheat	Western 1600-24	645	35.3	19	11,500,000	11,500,000	100%
2020	North East	Wheat Seed	Alvan Blanch	187	3.5	13	6,100,000	1,697,518	28%
2019	North East	Oats	Alvan Blanch	1723	50.0	134	6,100,000	3,936,583	65%
2019	North East	Wheat	Western 1600-24	182	6.9	9	11,500,000	7,436,301	65%
2019	North East	Canola	Western 1600-24	227	9.4	15	11,500,000	5,796,911	50%
2019	Central	Canola	Vertec 6600	132	2.2	10	3,000,000	2,158,405	72%
2019	Central	Oats	Vertec 6600	120	2.7	8	3,000,000	3,000,000	100%
2019	North East	Wheat Seed	Alvan Blanch	109	4.9	23	6,100,000	2,860,924	47%
2019	Central	Canola	Vertec 6600	106	1.3	8	3,000,000	2,345,356	78%
2019	Central	Canola	Vertec 6600	86	1.7	6	3,000,000	3,000,000	100%
2020	Central	Wheat Seed	GSI-1222	58	2.0	13	9,750,000	1,822,725	19%

6.3 Appendix C-Aeration/Cooling Data

The table below displays aeration/cooling data available from one monitored site in 2020. This site only used natural air aeration to cool the grain down for long term storage. Two bins were observed to reduce moisture by 0.5-1%, however, the grain temperature was mainly reduced in all other bins without affecting moisture.

Year	Location	Grain Type	Total Grain Cooled (Tonnes)	Initial Grain Moisture	Final Grain Moisture	Initial Grain Temperature (°C)	Final Grain Temperature (°C)	Electricity Use (kWh)	Specific Energy ($GJ/T_{Moisture\ Removed}$)
2020	North West	Canola	114	10.5%	9.3%	12.0	-6.0	189	0.5
2020	North West	Canola	68	8.5%	8.5%	18.0	-5.0	135	-
2020	North West	Barley	111	14.6%	14.6%	25.0	-11.0	346	-
2020	North West	Barley	98	14.6%	14.6%	26.0	-11.0	225	-
2020	North West	Barley	111	14.8%	14.8%	31.0	-8.0	464	-
2020	North West	Canola	114	8.7%	8.2%	20.0	-8.0	156	1.0
2020	North West	Canola	61	9.8%	9.8%	17.0	-4.0	160	-
2020	North West	Barley	91	14.8%	14.8%	10.0	-8.0	450	-
2020	North West	Canola	116	9.3%	9.3%	23.0	-5.0	403	-
2020	North West	Canola	102	9.4%	9.4%	23.0	-6.5	296	-
2020	North West	Wheat	196	14.7%	14.7%	19.0	-2.0	214	-
2020	North West	Wheat	196	14.5%	14.5%	20.0	-7.0	292	-

6.4 Appendix D-Glossary

Bu-Bushel

T-Tonne

GJ-Gigajoule

kWh-Kilowatt Hour

BTU/Hr-British Thermal Unit per Hour

MBH-1000 X Btu/hr

CFM-Cubic Feet per Minute

RH-Relative Humidity

CO_2-Carbon Dioxide

CH_4-Methane

N_2O-Nitrous Oxide

°C-Degrees Celsius

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[1] https://www.agric.gov.ab.ca/app19/calc/crop/bushel2tonne.jsp
[2] https://open.alberta.ca/dataset/2a41f622-5ae4-4985-838f-497e6afd110c/resource/0ba7b3dc-0658-43dc-b977-4c9c35637f49/download/aep-carbon-offset-emissions-factors-handbook-v-2-2019-11.pdf
[3] https://www.aggrowth.com/en-us/brands/grain-guard/support-and-resources#:~:text=Air%20that%20has%20been%20removed,opening%20for%20every%201000%20cfm.