Evaluating Energy Efficiency of On-Farm Grain Conditioning Systems

Year Three Results and Findings

Project prepared for four of Alberta's Crop Commissions: Alberta Barley, Alberta Canola, Alberta Pulse Growers and the Alberta Wheat Commission.

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Year Three Results & Findings

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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, 2020 and 2021. A total of 37 in-bin systems including 5 continuous grain dryers were monitored across 14 locations throughout Alberta. The in-bin systems are a mixture of direct-fired natural gas systems and indirect-fired natural gas-fired systems. A few unique systems were also monitored including an indirect diesel fired systems and 3 bins heated using solar air collectors. Data on 12 unheated aeration-only style bins are included within the appendix.

Energy consumption per tonne of moisture removed (specific energy $GJ/T_{\text{Moisture Removed}}$) 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 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 learning 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 indirect fired systems had an average specific energy of 4.6 GJ/Tonne of Moisture Removed while direct fired bins had an average specific energy of 7.1 GJ/Tonne of Moisture removed (adjusted for energy consumption at 10°C ambient). Although the indirect fired systems have a slightly lower combustion efficiency, the supply air has a lower relative humidity (combustion gasses are exhausted) resulting in an overall lower specific energy when compared to direct fired systems. Therefore, the indirect fired systems condition grain more efficiently with shorter run times and have on average 65% of the fuel consumption of direct fired systems. Detailed analysis can be found in Section 3.4.3 **Direct Vs Indirect Fired Heating**.
- 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 1.4 GJ/Tonne of Moisture Removed. This low specific energy is a result of no heating fuel consumption and represents electrical fan energy used for air circulation. Although these systems can achieve low energy consumption, they require favorable weather conditions and are therefore less reliable than comparable heated systems. More information can be found in Section 2.1.2 **Natural Air Drying (Solar) Heating**.
- Rooftop exhaust fans decrease specific energy by approx. 9% when compared to bins with passive venting. Further analysis is recommended to confirm effectiveness and develop best practices. Analysis can be found in Section 3.4.1 **Rooftop Exhaust Fans**.
- Burner cleaning and fuel optimization decrease specific energy by approx. 12% vs sub-optimal burners. Further analysis is recommended to confirm effectiveness and develop best practices. Analysis can be found in Section 3.4.2 **Fuel-To-Air Optimization**.
- Increased supply air temperatures resulted in lower supply air relative humidity and higher moisture removal rates as expected. However, higher supply air temperatures did not correlate with lower specific energy consumption. Higher supply air temperatures did result in lower overall costs due to shorter drying run times resulting in less electricity consumption. Further study with a larger data set is recommended to explore this result. 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 each grain type and air distribution systems is required. Analysis can be found in Section 3.3.2 **Supply Air Temperature.**

- Continuous flow dryers were also metered and analyzed, the specific energy values of each continuous dryer for each grain type are summarized in Table B. For continuous dryers there was large variations in efficiency between drying sessions from 4.1 to 14.4 GJ/Tonne of moisture removed. However, the average efficiency of each model had very similar specific energy use ranging from 7.25 GJ/Tonne of Moisture Removed to 7.54 GJ/Tonne of Moisture Removed. This suggests that among continuous grain dryers, grain condition and environmental factors have a larger effect on drying efficiency than dryer brand or model. Further data collection and analysis is required. Analysis can be found in Section 4 **Continuous Dryers.**
- 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. The average Alberta farm was estimated to be 1237 acres producing 63,211 bushels of wheat and drying 50% of the yield. More details can be found in Section 3.5.2 **Carbon Pricing**.
- Using natural gas for heating purposes reduces operating costs and emissions when compared to alternative fuel sources. Natural gas has the least environmental impact followed by diesel, propane and then electricity.
- Using electric heating for grain drying is not recommended as it has the highest operating costs and results in the highest 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.
- Overall, continuous dryers had a combined specific energy of 7.6 GJ/Tonne of moisture removed which is higher than the specific energy consumption of both in-bin systems. The in-bin systems had an average of 4.6 GJ/Tonne of Moisture Removed for in-direct fired bins and an average of 7.1 GJ/Tonne of Moisture removed for direct fired systems. Burner cleaning and fuel optimization was shown to be effective and decreased specific energy by approx. 12%. Further analysis of a larger data set is recommended to analyze efficiency optimization of continuous systems in more detail. More details can be found in Section 4 **Continuous Dryers.**

Policy Considerations

The average farm size in Alberta is trending upwards (2016 Census of Agriculture) and as operating costs increase this trend will be accelerated. 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 including those in section 3.4 **Efficiency Measures**.

- 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. Details on the existing natural gas infrastructure are in section 2.3 **Natural Gas Infrastructure.**

- 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 extending and installing a natural gas service can be incentivised 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. Details on existing incentives are in section 1.6 **Current Incentives.**

- 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. More information can be found in section 3.4 **Efficiency Measures**

Further Study Recommendations

Additional study is recommended for the following areas of interest.

- In general, higher supply temperatures correlated with lower specific energy consumption for indirect fired systems but not for direct fired systems. Further research with a larger data set is recommended to explore this result.
- The maximum temperature can vary depending on the type of grain dried, air distribution system, airflow rate, humidity, etc. Manufacturers supply air temperature recommendation for continuous dryers and batch dryers, however, no standard recommendation is available for in-bin drying systems. Further study with a larger data set is recommended to explore this result. Maximum and optimum supply temperatures for different bin systems and operating parameters could optimize energy efficiency and reduce operating costs for in-bin systems.
- Further research is recommended to test the performance of high efficiency in-bin air distribution systems including the air missile type.
- Further analysis is recommended to identify the effectiveness and payback of each measure available for incentives listed in section 1.6 **Current Incentives.**
- A larger study including a multi-variate regression analysis could be conducted to explore the combined effects of environmental factors and various efficiency measures. This could include providing target values optimized for energy efficiency for airflow rates, static pressures, and supply air temperatures.

In-Bin Drying Summary Measure Summary

The following tables contain the data collected from each site over the three years of the study. Each line contains the combined average values of each grain type dried in that year. Each line contains the summation of multiple bins and multiple drying sessions. The tables are organized from lowest to highest Specific Energy which represents the overall energy consumed per Ton of moisture removed. Table A includes all the in-bin systems while Table B contains all the continuous drying systems.

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$_{\text{Moisture Removed}}$)
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
2021	Central	Rye	Natural Gas	127	15.0%	13.2%	898	3.1	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
2021	Central	Rye	Natural Gas	63	18.0%	13.0%	1,055	7.9	3.9
2019	South	Wheat	Solar	17	14.7%	13.0%	328	-	4.0
2021	North East	Canola	Natural Gas	40	12.0%	9.5%	124	3.6	4.1
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
2021	North East	Canola	Natural Gas	57	11.5%	10.0%	199	4.0	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

* 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	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
2021	Central	Rye	Natural Gas	114	15.5%	13.3%	898	14.3	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
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
2021	North East	Barley	Alvan Blanch	97	16.5%	12.2%	254	22	5.7
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
2021	Central	Wheat	Vertec 6600	325	17.9%	15.0%	573	57	6.4
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
2021	North East	Wheat	Alvan Blanch	995	16.9%	13.5%	1,862	279	8.8
2020	North East	Wheat Seed	Alvan Blanch	187	15.9%	13.9%	794	29	9.1
2021	Central	Wheat	Vertec 6600	85	18.5%	15.0%	315	25	9.2
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
2021	Central	Wheat	Vertec 6600	210	16.3%	14.8%	401	38	12.6
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

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1.2 Partners and Intent

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 Scope of the Study

The study contains fourteen separate participants at various locations in Alberta and monitors them through three years (2019-2021) of grain conditioning operations. Most of the grain drying systems were located throughout central and north-east Alberta, as displayed in Figure 1. A total of 37 in-bin systems participated in this study using a combination of grain conditioning methods including natural gas, diesel, solar, continuous and cooling/aeration only. Not all sites and bins submitted data each year due to various volumes of grain conditioning required and due to environmental factors, such as dry weather, grain conditions, or hail damage.

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

The study concludes in 2021 and includes in depth data analysis, technical recommendation on improving energy efficiency of grain conditioning operations, and policy considerations.

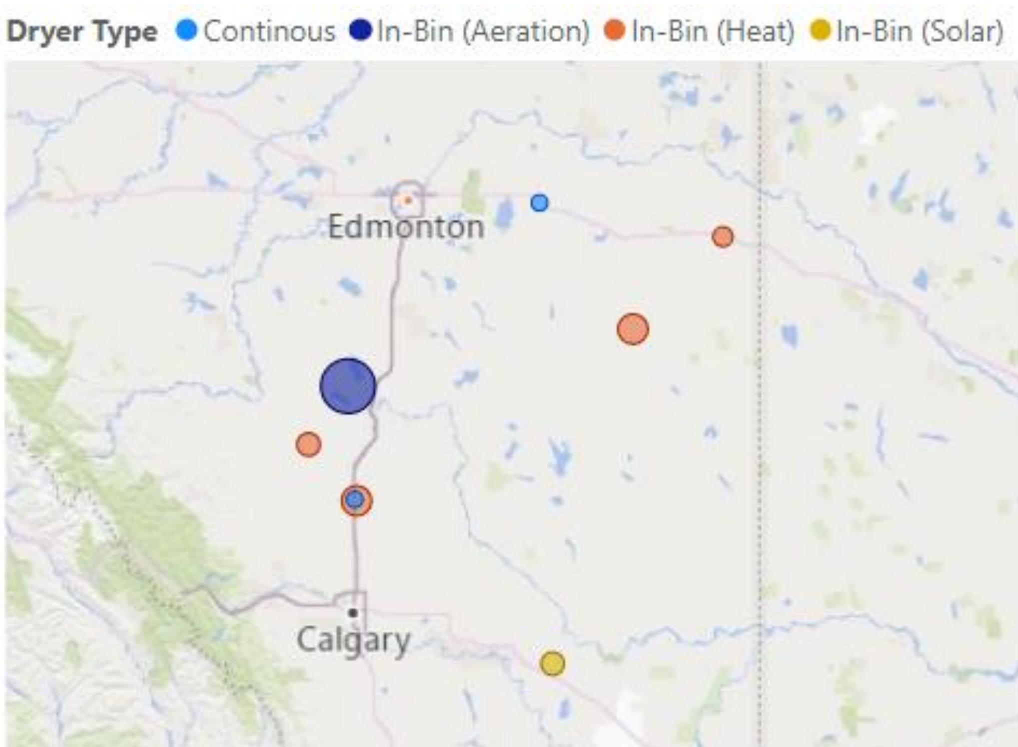


Figure 1: Location and Quantity of Grain Drying Bins

1.4 Methodology

1.4.1 Energy Monitoring Equipment

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 of one hour or fifteen minutes 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 including drying date and times, grain volumes, moisture %, temperature, static supply air pressure, and fuel consumption 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 normalized to the standard consumption set at an ambient air temperature of 10°C.

Data Loggers

This study demanded the use of several different types of data loggers.

HOBO Data Logging Device (Small): Model number H21-USB. Features a weatherproof enclosure, battery operation, and up to five sensor connections. Operating range using standard AA batteries is from -20°C to 50°C and a logging interval ranging from 1 second to 18 hours. The available memory for this device is 512 KB and you have the option for the device to stop logging or overwrite the oldest data once it's full.

HOBO Data Logging Device (Large): Model number U30-NRC. Features a weatherproof enclosure, a built-in rechargeable battery, and connections for five sensors with an option to expand to 10. The normal operating range is from -20° to 40°C and supports logging intervals from 1 second to 18 hours. The available memory for this device is 512 KB and you have the option for the device to stop logging or overwrite the oldest data once it's full.

Temperature Sensor (In-Bin): Model Number S-TMB-M0xx. Features a weatherproof design and a stainless-steel sensor tip. The measurement range is from -40°C to 100°C. The accuracy of the sensor is ± 0.2°C in an operating range of 0°C to 50°C. Response time is <2 minutes typical in 2 m/sec moving air flow. The sensor comes calibrated and has a listed drift specification of <0.1°C per year.

Temperature/RH Smart Sensor (Ambient): Model number S-THB-M0xx. Features a weatherproof design and a styrene polymer sensor tip. The measurement range is from 0-100% relative humidity at -40°C to 75°C. The accuracy of the sensor in the relative humidity range of 10% to 90% is ± 2.5%, while outside that range is typically ± 5%. The temperature accuracy is ± 0.21°C between 0°C and 50°C. Response time is typically 5 minutes in 1m/sec moving air flow.

Electrical Sensor: Model number S-UCC-M0xx. Features a weatherproof design and connects sensors with pulse inputs to data loggers. The maximum input frequency is 120Hz with a measurement range of 0 - 65,533 pulses per logging interval. The operating temperature range is from -40°C to 75°C. Connections use 24 AWG wires with 2 leads (white-pos, black-neg).

1.4.2 Assumptions and Conversion Rates

Energy consumption per Tonne of Moisture Removed ($GJ/T_{Moisture\ Removed}$) 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:

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

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

- Natural Gas Energy Conversion: 1 GJ/m3 Natural Gas Greenhouse Gas Emissions: 0.05069 tCO_2/m3
- 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 dryer.

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:

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

1.5 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, example: hail damage, bin auger malfunction.

1.6 Current Incentives

The Efficient Grain Handling Program (https://cap.alberta.ca/CAP/program/EGH) is currently active and provides incentives for energy efficient improvements at 50% of the improvement costs and capped at $100,000 per application. Primary producers are eligible who produce over $25,000 worth of commodities annually and have an Environmental Farm Plan or are working towards one. Eligible measures include;

- Enclosed Dryer Roof
- Enclosed Dryer Top Cover
- Automatic Moisture-based Controllers
- High-Efficiency Burners
- Variable Speed Drives (VSD) for Electric Motors
- Grain dryer PTO to Electric Motor Conversion
- Insulated Plenums
- Exhaust Air Recirculation Systems
- Heat Exchangers
- Gravity-Fill Roofs
- Electrical or gas submeters on Dryers
- Temperature and moisture monitoring cables for in-bin drying systems
- Thermostats or thermometers for plenum or burner temperature control on in-bin drying systems
- Adapter plates for efficiently fitting external heaters to in-bin drying systems
- Indirect-fired high-efficiency portable aeration dryers
- Automated bin fan control systems
- Pipeline to grain dryer – for costs incurred over and above those paid for by the Rural Gas Program to a maximum of $20k/applicant.

Further analysis is recommended to identify the effectiveness and payback of each measure.

02 | Analysis

2.1 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, equipment and bin types were present. The list below describes the different types of systems analyzed during this study. Continuous flow dryer descriptions are further analyzed in Section 4.

2.1.1 Natural Gas Heating

Figure 2: Internal Augur Bin

The most common fuel type observed throughout this study was natural gas feeding a downstream, 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 2) consisted of an internal circulating augur to constantly turn and roll the grain during drying. Figures 3 and 4 display various direct fired heaters and indirect-fired heaters observed within this study, respectively.

Figure 3: Direct Fired Natural Gas Heaters

Figure 4: Natural Gas Indirect Fired Heaters (Left), Diesel Indirect Fired Heater (Right)

2.1.2 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 5: Solar Heating In-Bin Drying Site

2.1.3 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.

2.2 Precipitation Analysis

The precipitation levels at seven locations that submitted data on overall grain yield and conditioning volumes were analyzed. We surveyed each participant requesting data on the total annual yield of each grain type harvested over the course of the study, as well as the total volume of grain that required conditioning. Precipitation data was collected from the Alberta Climate Information Service (ACIS, https://agriculture.alberta.ca/acis/) using the following weather stations nearest to each participant;

- Lacombe CDA 2
- Kitscoty
- Ranfurly Auto
- Rosemary IMCIN
- Wainwright CFB Airfield 21
- Dickson Dam
- Mundare AG

Historical growing season (April 1st – Sept 30th) precipitation levels were analyzed in Figure 6 from 1965 to 2021 for the seven weather stations. The historical trend is nearly flat and trending slightly downwards at approximately -0.5mm per year of precipitation although large annual variations exist. Note that end of season precipitation (August-Sept) has a greater impact on drying volumes then overall growing season precipitation. Further analysis is recommended to identify the magnitude of this impact.

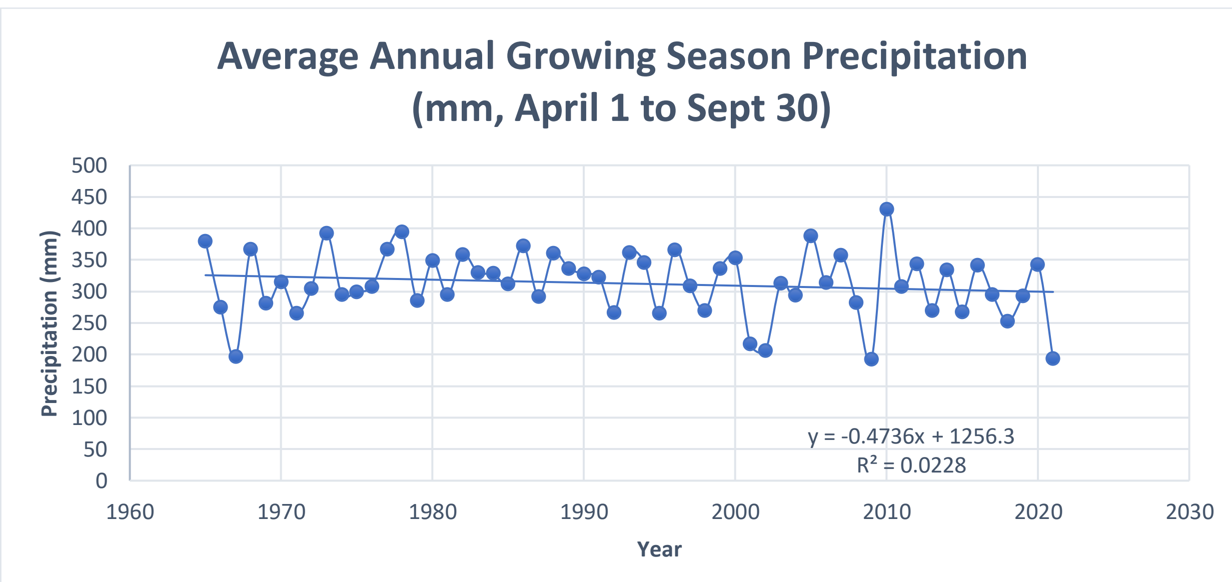


Figure 6: Historical Growing Season Precipitation

Annual precipitation levels over the period of the study were also analyzed as shown in Figure 7. 2020 consisted of heavier rainfall compared to the historical average while 2021 was much lower. This is reflected in the volume of grain conditioning which occurred in each year.

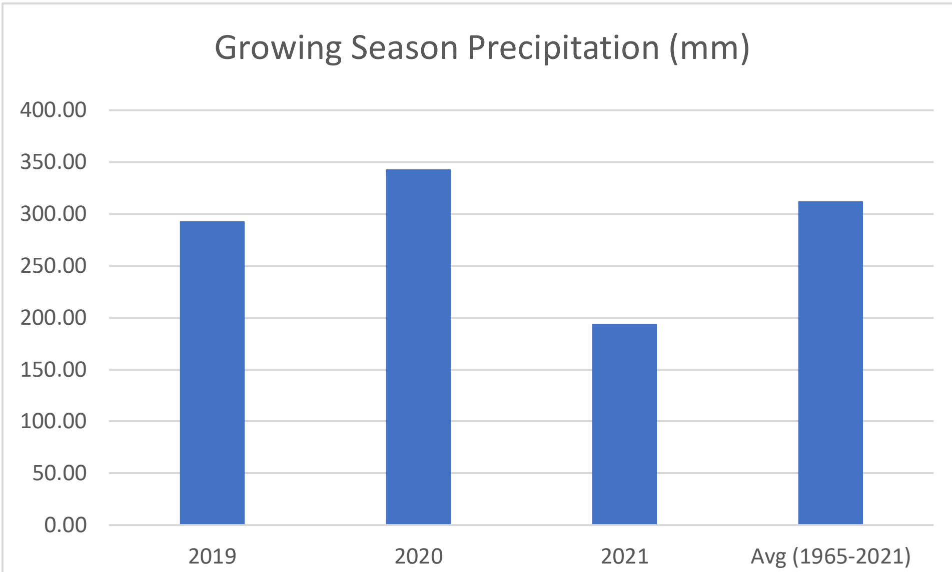


Figure 7: Growing Season Precipitation

Finally, the growing season precipitation levels were compared to the percentage of grain dried at each site in Figure 8 and the average tons of moisture removed annually over all locations in Figure 9.

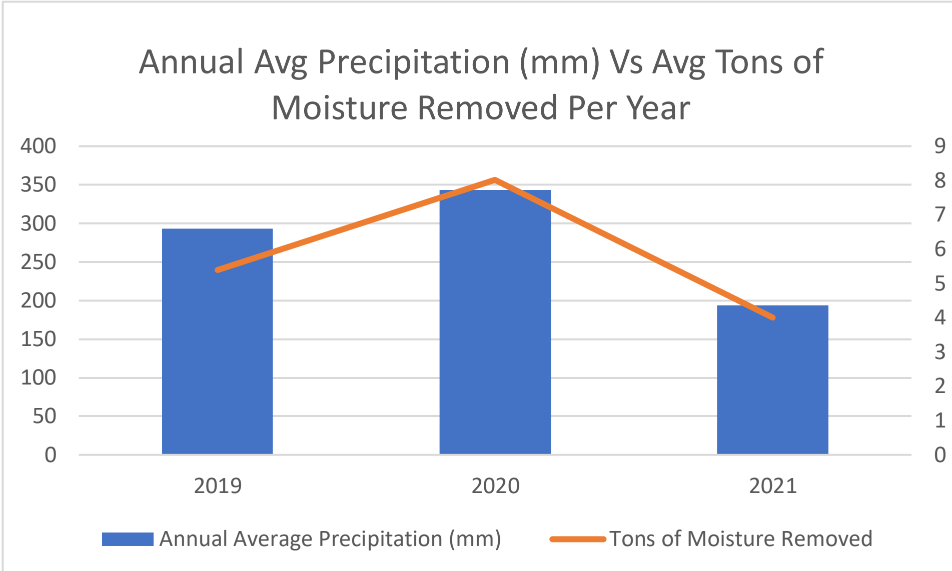


Figure 8: Precipitation Vs Average Tons of Moisture Removed

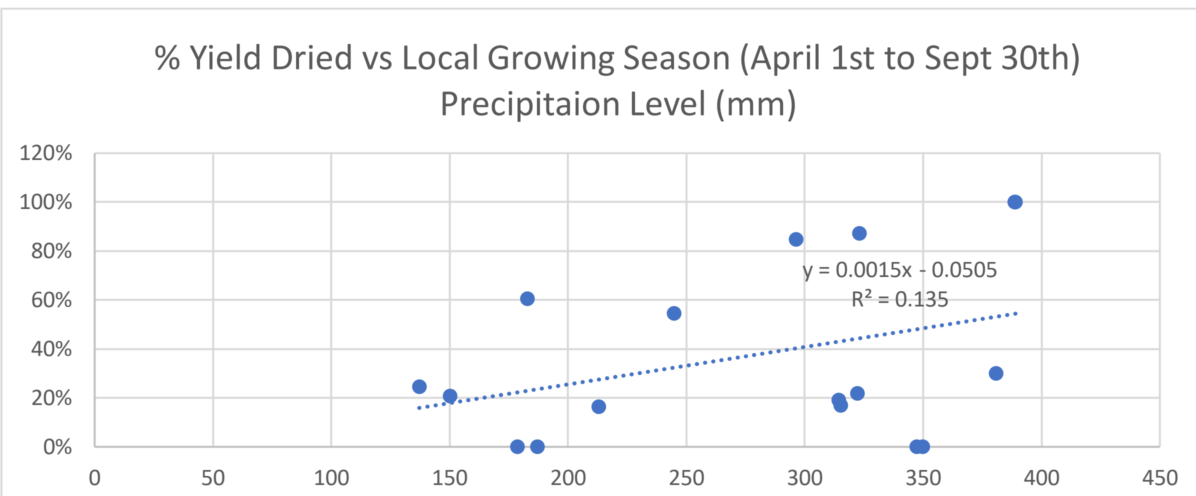


Figure 9: % Yield Dried Vs Precipitation

These results show that the % of drying required is weakly correlated to growing season precipitation volumes however a stronger correlation appears for the average tons of moisture removed from each site. The low correlation may be due to the unpredictability of local weather conditions and changing grain types and harvest sizes. Other environmental and market factors such as hail damage and grain pricing can impact the grain conditioning decisions. Therefore, although the growing season precipitation levels may correlate to the average mass of moisture removed it is not necessarily a good predictor of volume of grain conditioning to be expected and no clear trend of increasing or decreasing growing season precipitation levels was observed.

2.3 Natural Gas Infrastructure

Alberta has an extensive natural gas infrastructure (Figure 10) that can be used for grain conditioning operations where available. Natural gas is preferred due to its lower cost and lower GHG emissions compared with alternatives including diesel, propane and electricity. Rebates are also available to extend natural gas lines from the Efficient Grain Handling Program (https://cap.alberta.ca/CAP/program/EGH). Further information on the availability of natural gas infrastructure along with maps can be found here,

- https://www.gasalberta.com/contact/map
- https://open.alberta.ca/publications/rural-gas-utility-franchise-areas-map

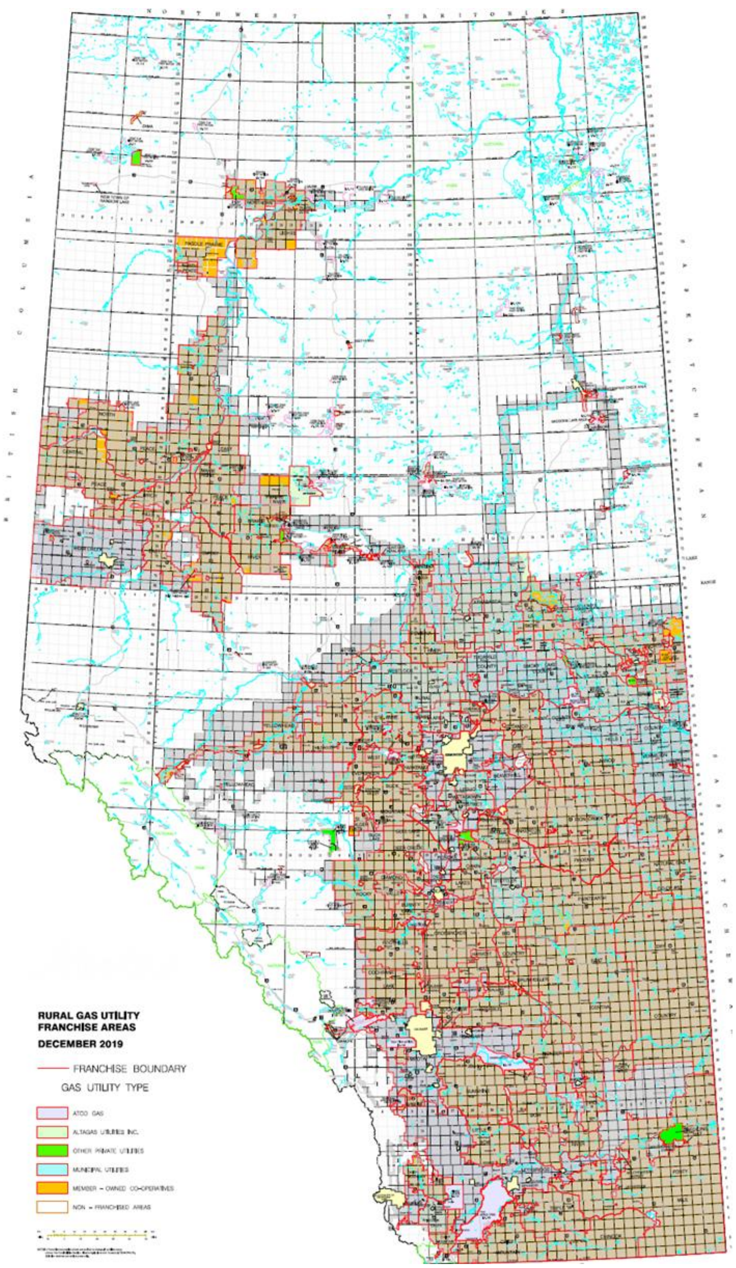


Figure 10: Alberta Natural Gas Infrastructure

03 | In-Bin System Analysis

3.1 Benchmarking

The energy consumption of all heated in-bin systems 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 10°C 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 0.6-4.0 GJ/Tonne of moisture Removed, averaging 1.4 GJ/Tonne of Moisture Removed. Fuel fired bins ranged from 2.8-18.5 GJ/Tonne of Moisture Removed, averaging 6.2 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. 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.

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 were also equipped with an air missile air distribution system, which appeared to further reduce specific energy consumption, however further study is needed. Bins that utilized indirect fired heating systems ranged from 2.4-8.9 GJ/Tonne of moisture Removed, with an average of 4.6 GJ/Tonne of Moisture Removed.

Direct fired in-bin heating systems ranged from 3.8-18.5 GJ/Tonne of Moisture Removed, averaging around 7.1 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:

Indirect Fired Bins:

Direct Fired Bins (Internal Mixing Augur):

Direct Fired Bins: No Colour

Table 1: 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
2021	Central	Rye	Natural Gas	124	2.2	23.0	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
2021	Central	Rye	Natural Gas	60	3.0	25.6	1.9	3.9
2019	South	Wheat	Solar	17	4.1	30.9	1.2	4.0
2021	North East	Canola	Natural Gas	91	1.0	30.0	1.3	4.1
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
2021	North East	Canola	Natural Gas	91	0.9	30.0	0.9	5.6
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

* 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

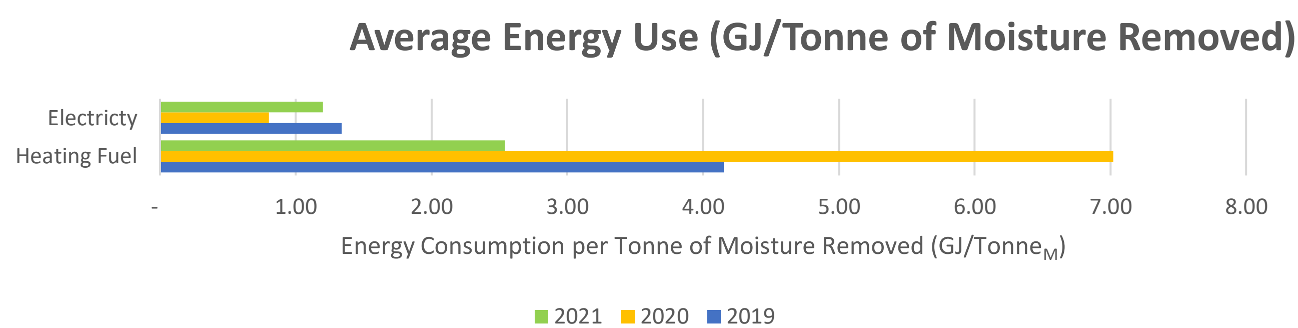
Year	Location	Grain Type	Fuel Type	Total Grain Dried (Tonnes)	Total Moisture Removed (T)	Supply Air Temperature (°C)	Airflow Per Bushel (CFM/Bu)	Specific Energy (GJ/T Moisture Removed)
2021	Central	Rye	Natural Gas	111	2.4	24.3	0.9	7.1
2020	Central	Barley	Natural Gas	54	2.1	35.6	5.3	7.1
2019	Central	Barley	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 fairly consistent over the three years as seen in Figure 11. 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 and 2021 was 5.8 In. Additionally, electricity consumption is also proportional to fan operating hours. Bin drying cycles observed in 2019 ranged from 41-519 hours, averaging 195 hours, while drying cycles in 2020 ranged from 25-234 hours, averaging 116 hours, and drying cycles in 2021 ranged from 43-187 hours, averaging 115 hours.

Heating fuel consumption was also observed to be higher in 2020 compared to 2019 and 2021, likely caused by unfavorable weather and grain conditions during the 2020 harvest. The average moisture removal per bin in 2019 was 3.2 tonnes (3.0%), compared to 2.6 tonnes (2.6%) in 2020 and 1.9 tonnes (2.6%) in 2021. Additionally, overall ambient air conditions can result in higher and lower supply air temperature rises, with an average air temperature rise of 33.1°C in 2019, 26.8°C in 2020 and 12.9°C in 2021.

Figure 11: 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 affect the drying capacity of the air. 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. Therefore, with an adequately high supply air temperature, 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 12 shows the moisture removal rate vs supply air relative humidity for indirect and direct-fired heaters. In both heater types, bins that supplied lower RH air resulted in increased moisture removal rates, due to the increased drying capacity of the air.

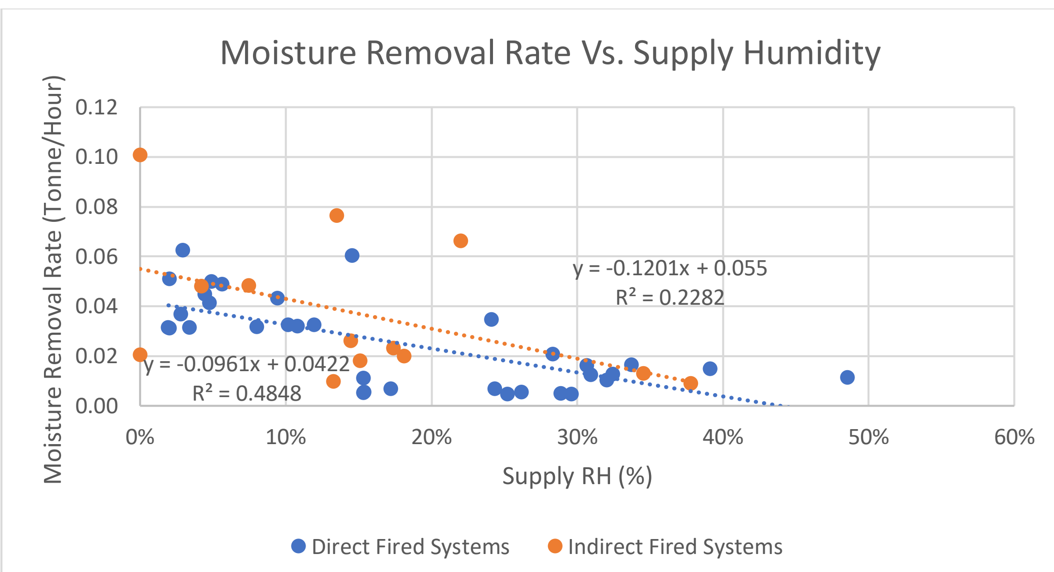


Figure 12: Moisture Removal Vs Supply Air Humidity

3.3.2 Supply Air Temperature

Similarly, Figure 13 displays the moisture removal rate of the bins observed for indirect and direct-fired heaters when compared to supply air temperature. These values are related to Figure 12, since as the supply air temperature increases the supply air RH decreases. Figure 13 displays bins utilizing lower supply air temperatures, resulted in a lower moisture removal rate, while bins supplying higher supply 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. The stronger correlation may also be a result of reduced combustion-related moisture in indirect fired heaters entering the bin. This would result in indirect fired heaters having a lower supply air humidity while having similar supply air temperatures when compared 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.

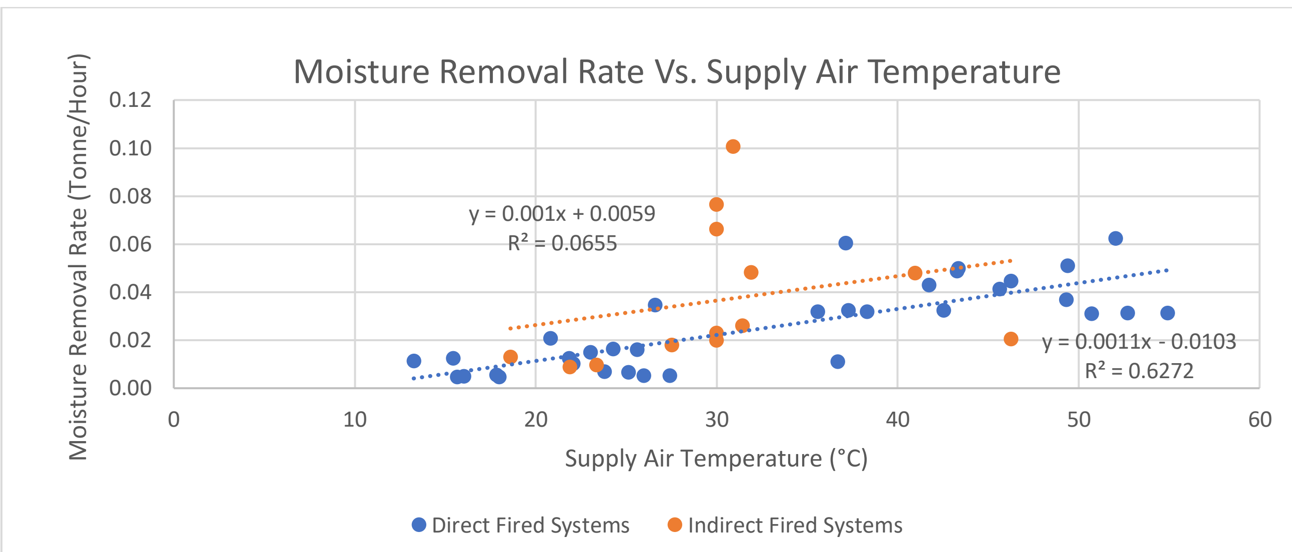


Figure 13: Moisture Removal Vs Supply Air Temperature

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. The operator can increase the supply air temperature 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 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 also increases the temperature of exhausting air and can reduce the overall efficiency of the system, thus negating the effect of the higher moisture removal rate.

Supply air temperatures for in-bin drying systems have been observed 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 14 displays this phenomenon, as higher supply air temperatures were expected to correlate with a lower specific energy. However, No definite correlation was observed for between supply air temperature and specific energy for either direct or indirect fired heating systems. Increased data samples are recommended to decrease the sample variation.

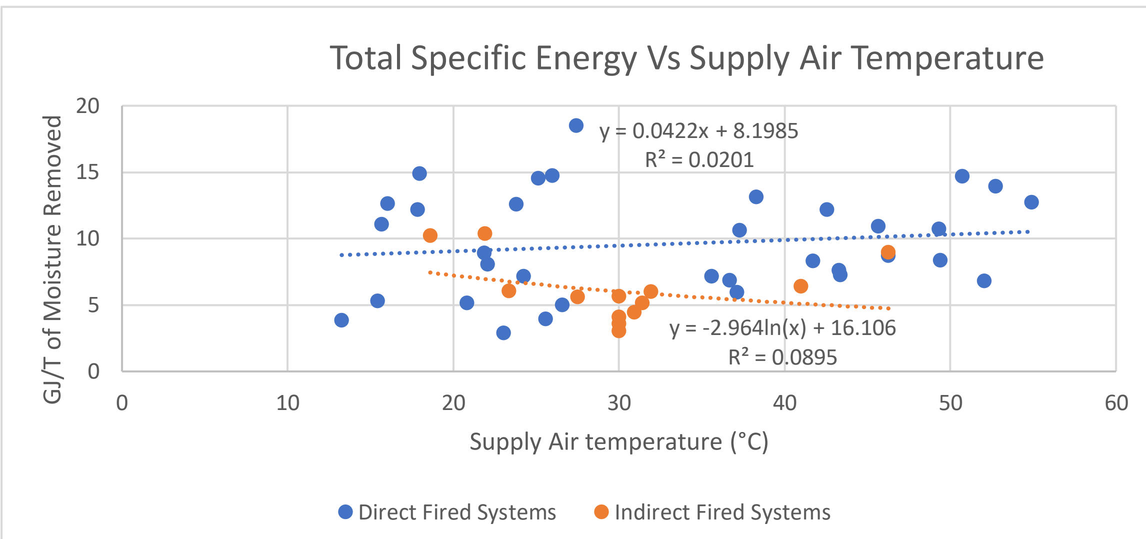


Figure 14: Gas related Specific Energy Vs Supply Air Temperature

Because drying efficiency of both direct and indirect systems does not highly correlate to supply air temperatures, increasing the supply temperatures will provide minimal gains. However, choosing an indirect system is recommended when possible.

3.3.3 Drying Run Times

Natural gas consumption is only part of the energy consumption 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 15 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 16 displays specific emissions (tCO_2e/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.

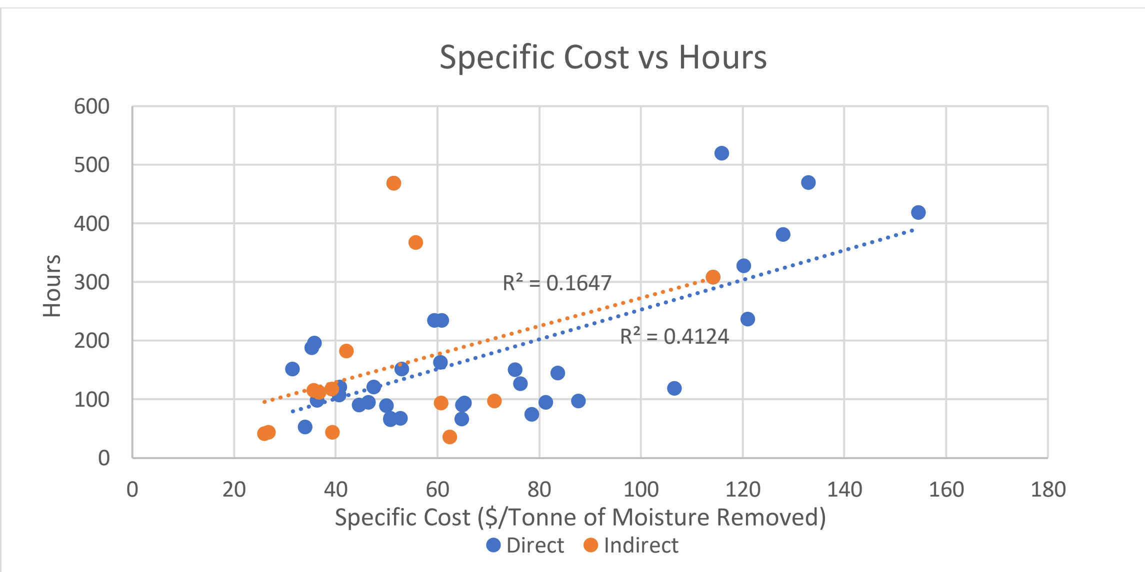


Figure 15: Specific Cost Vs Drying Run Time

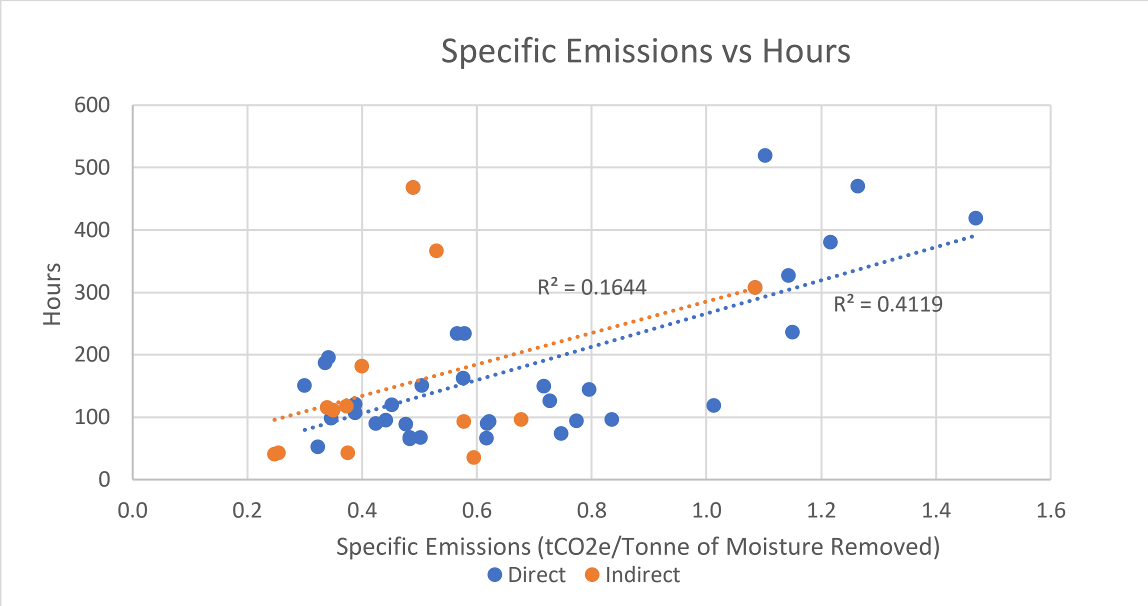


Figure 16: Specific GHG Emissions Vs Drying Run Time

Figure 17 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 (high temp) dried 4 tonnes of moisture from canola in 126 hours while Bin 2 (low temp) dried 1.6 tonnes of moisture from canola in 327 hours. Although bin 2 had a lower energy consumption rate, it must operate an additional 201 hours to dry the grain enough for storage. This signifies the value of higher supply temperatures and the importance of reducing operational run times of grain dryers to avoid excessive energy costs.

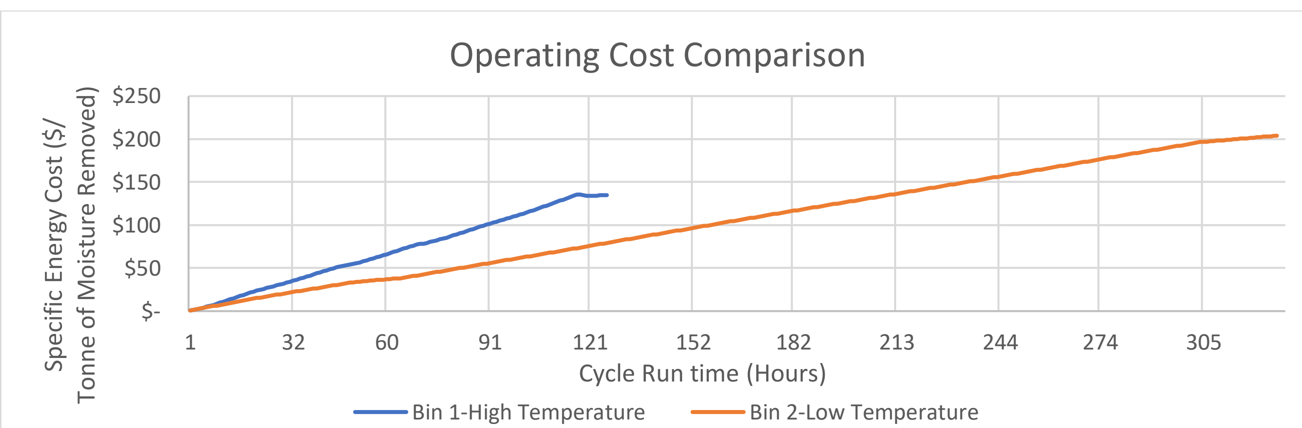


Figure 17: Operating Cost Comparison

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 18, 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, however, they displayed minimal correlation between supply airflows per bushel (CFM/Bu) and specific energy. Higher air flow rates do not increase efficiency suggesting that the exhaust air is not reaching saturation during drying operations and the air flow could be reduced while temperatures maximized.

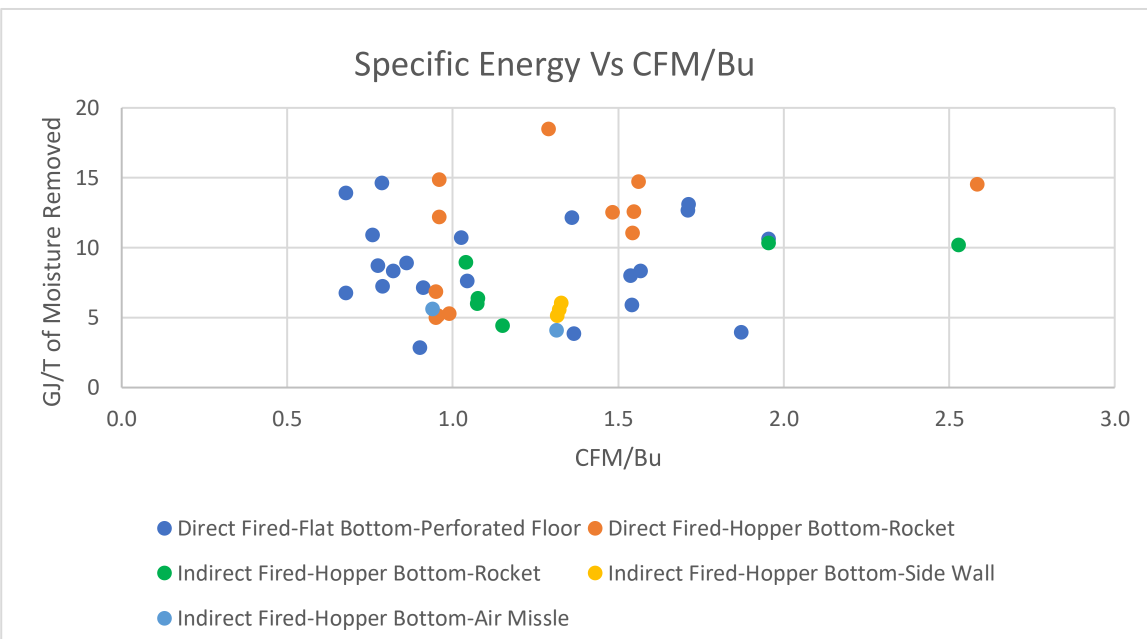


Figure 18: Specific Energy Vs Airflow on Different Bin Types

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. Increasing the airflow while keeping the same burner output 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. The low correlation between moisture removal and airflow rates shown in Figure 19 suggests that overall energy consumption may potentially be saved with lower fan speeds. However, this result was not shown as expected in Figure 18. Therefore, more research is needed. A larger data set may identify an airflow rate per bushel for optimum energy efficiency.

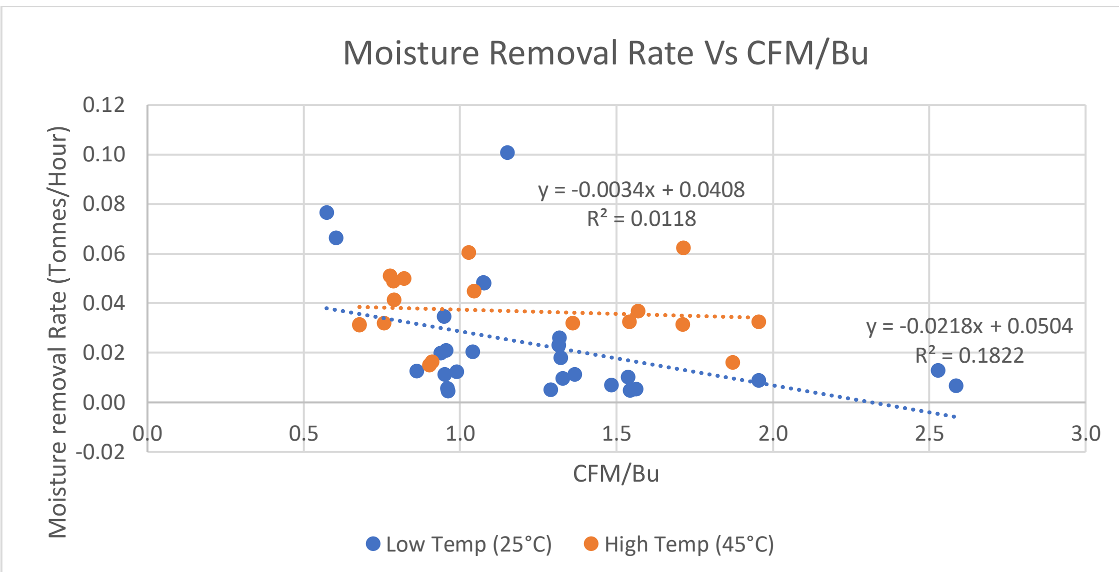


Figure 19: Moisture Removal Vs CFM/Bu at High and Low Supply Temperatures

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 20 displays a bin analyzed which verifies the electrical requirements at varying static pressures. These drying cycles were operated at different fill levels and grain types and displayed increased electrical demand with increased static pressures. Although increased static pressures did increase the electrical demand of supply fans, they did not largely affect the overall electrical specific energy of the drying cycle.

Hours of operation play a much more significant role in electricity-related specific energy. The electricity savings observed from operating supply fans at lower static pressures (fill levels) will also increase the overall run times producing a counter effect. Further research with a larger data set is recommended to measure target static pressure that is optimized for energy efficiency.

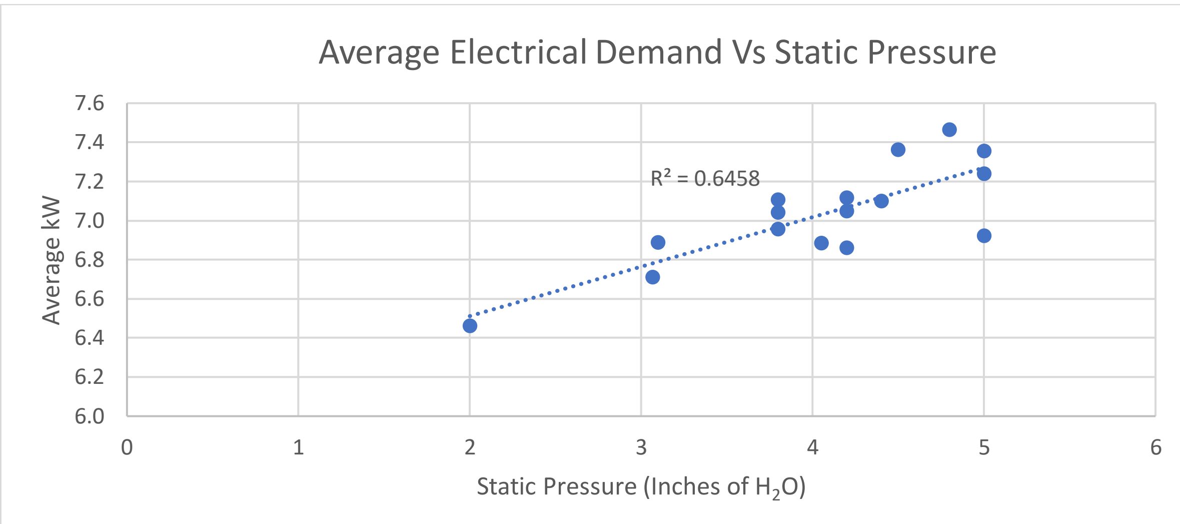


Figure 20: Average Electrical Demand Vs Static Pressure

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 and was only operational during the 2019 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 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: [shaded]

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 displayed 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

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 uncertainties, 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. Each line in Table 6 represents a drying session from an individual co-located bin in 2020.

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
In-Direct Fired Weighted Average							8.66	$54.18
Direct Fired Weighted Average							7.55	$84.83

The direct fired heaters in the 2020 comparison appeared to have lower specific energy of 7.55 GJ/T compared to indirect-fired heaters at 8.66 GJ/T. This result was unexpected and contradicts the overall results of the larger study. Additionally, indirect heaters were operated at lower supply air temperatures than all direct fired heaters in the comparison. Although specific energy did not appear to be correlated to supply air temperatures (as noted in Section 3.3.1 and 3.3.2), higher supply air temperatures do result in lower supply air relative humidity, which did correlate to increased moisture removal rates, reduced run times, and lower specific costs. This may explain why the indirect fired bins were found to have a lower specific cost of 54.18 $/T compared to direct fired bins at 84.83$/T. A sample size of five does not provide sufficient trending information, and more comparison is required. However, throughout all drying cycles, indirect heaters still appear to be among the lower consuming and lower cost heaters, as illustrated in Section 3.1.

3.4.4 Air Missile Distribution System

Figure 21: 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 4.6 GJ/Tonne of Moisture Removed and 7.1 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 appears reduced. Further analysis is recommended due to the small sample size available for this air distribution type.

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

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.

Using the base utility rates described above, with the current carbon price $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,
- $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, starting in 2019 ($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 ($/tCO$_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 ($/tCO$_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		$29.69
April-2020	$30	$4.51-6.14	$37.39		$30.42
April-2021	$40	$5.02-6.65	$38.01		$31.14
April-2022	$50	$5.52-7.15	$38.62		$31.87
April-2023	$65	$6.28-7.91	$39.53		$32.96
April-2024	$80	$7.05-8.68	$40.45		$34.05
April-2025	$95	$7.81-9.44	$41.37		$35.14
April-2026	$110	$8.57-10.20	$42.29		$36.23
April-2027	$125	$9.33-10.96	$43.20		$37.32
April-2028	$140	$10.09-11.72	$44.12		$38.41
April-2029	$155	$10.85-12.48	$45.04		$39.50
April-2030	$170	$11.61-13.24	$45.96		$40.59

Even if natural gas has the highest prescribed carbon price of $170/tCO$_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 $425-625/Tonne of CO$_2$e 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, it is the preferred fuel source. If natural gas infrastructure 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 and peak kWs reached. 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 during the grain condition study, 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)		$0.050-0.44 ($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)	$0.046-0.44 ($0.20)	$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 in 2019. This will increase total average drying costs for natural gas systems from $0.042/Bu to $0.100/Bu, up 134% from 2019. Propane systems will increase 27% from $0.26/Bu in 2019 to $0.32/Bu. Non-dyed diesel systems will increase 49% from $0.19/Bu in 2019 to $0.29/Bu.

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 $170/tCO$_2$e (2030) for natural gas systems. Values in this figure are summarized based on the average moisture removed in all in-bin fuel-fired systems. Drying seasons can vary significantly from year to year as well as the required tons of moisture required to be removed. Therefore, projected fuel costs per 100 bushels will vary depending on the year.

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% from 2023 to 2030 when it becomes an increase of approximately 5%.

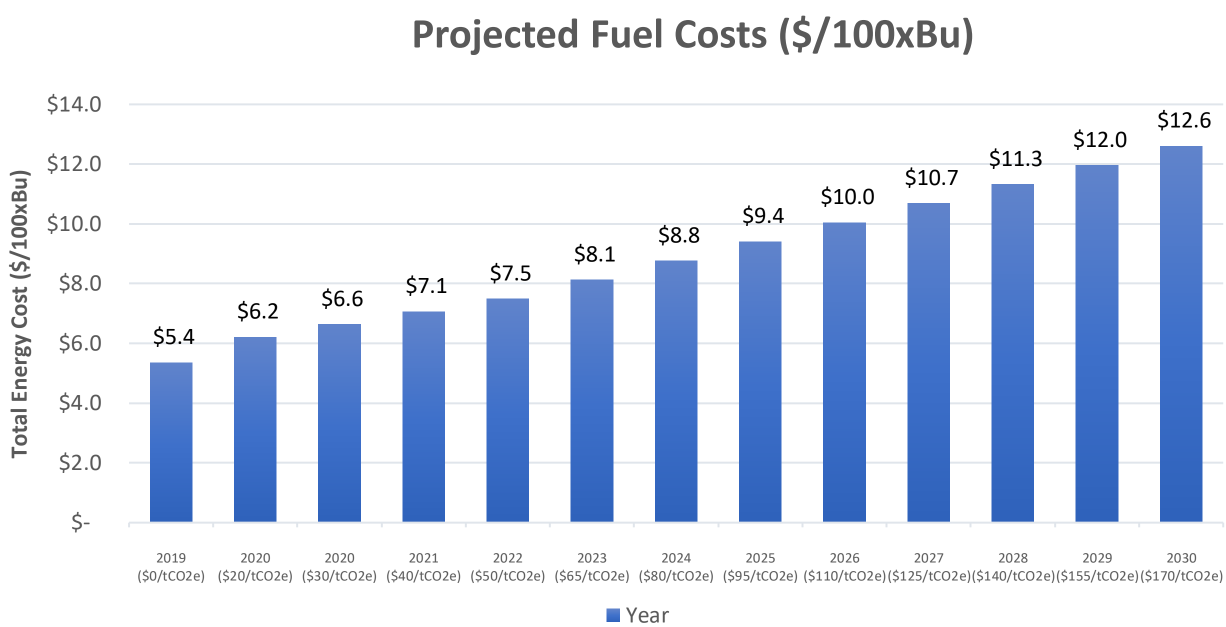


Figure 22: Total Utility Operating Cost Projections from Carbon Pricing (Natural Gas Systems)

Most farms utilizing in-bin drying observed within this study dried between 25,000-150,000 bushels. 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. Additionally, Table 12 displays the average total utility costs for natural gas-fired systems 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/tCO₂ to $170/tCO₂ (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.

3.5.3 Costs Estimate for Typical Farms

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 section should be used for example purposes only and is not predictive.

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, 2020 and 2021. 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 cost differences from farms using natural gas, diesel and propane. Typical costs for electricity are included however inflation is not. Figure 23 shows how fuel costs are expected to rise along with increasing carbon tax rates.

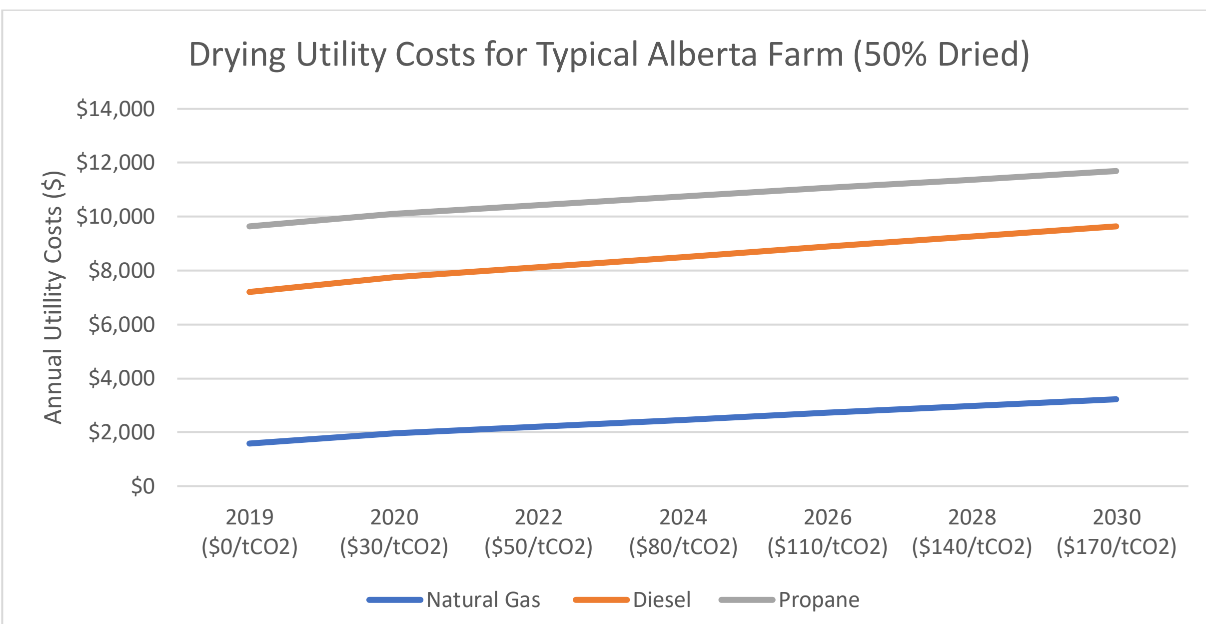


Figure 23. Utility cost for average Alberta farm

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, four 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
- GSI 1222
- Vertec 6600 - 9 Tier-Upgraded (no data for Vertec 5500 (5 Tier-Original))

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 ($GJ/T_{Moisture\ Removed}$)	Wheat: 6.1	Wheat: 7.3	Wheat: 4.9	
	Barley: 5.8			
	Canola: 6.0	Canola: 7.8	Canola: 6.9	
	Oats: 7.5		Oats: 10.2	
	Seed (Wheat): 12.5			
	Grain Drying Observed Data from 2020 Study			
Observed Specific Energy ($GJ/T_{Moisture\ Removed}$)	Wheat: 6.3			Wheat: 8.2
	Barley: 4.6			Barley: 5.4
	Seed (Wheat): 9.1			Seed (Wheat): 14.4
	Seed (Oat): 4.9			
	Seed (Barley): 4.1			
	Grain Drying Observed Data from 2021 Study			
Observed Specific Energy ($GJ/T_{Moisture\ Removed}$)	Wheat: 8.8		Wheat: 7.9	
	Barley: 5.7			

[*] 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. No data submitted for the Vertec 5500.

The Alvan Blanch grain dryer resulted in average specific energy values of 4.6-8.8 GJ/Tonne of moisture removed for wheat, barley, canola, and oats. Additionally, wheat, barley, and oat seed sorting/drying occurred, resulting in 4.1 GJ/Tonne of moisture removed for barley seed, 4.9 GJ/Tonne of moisture removed for oat seed, and 9.4-12.5 GJ/Tonne of moisture removed for wheat seed. As noted in Section 3.4.2, a burner fuel to air ratio tune-up reduced specific energy by approximately 12% on the Alvan Blanch dryer in 2020. The Alvan Blanch dryer was less efficient in wheat compared to its specifications, however, it achieved better performance in barley.

The GSI-1222 grain dryer 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. The GSI-1222 was also slightly less efficient in wheat compared to its specifications, and it achieved better performance in barley.

The Western grain dryer 1600-24 resulted in higher than specified specific energy for wheat and canola.

The Vertec 6600 grain dryer resulted in higher than specified specific energy for wheat, canola and oats.

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) can be expected to operate at lowered efficiencies. Table 14 displays the actual measured setpoints, grain types, and energy consumption for all continuous dryer batches metered, organized from highest to least efficient.

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
2021	North East	Barley	Alvan Blanch	97	4.0	95	254	21.6	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
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
2021	Central	Wheat	Vertec 6600	325	9.3	84	573	57.1	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
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

* 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/$T_{Moisture\ Removed}$)
2020	North East	Wheat	GSI-1222	375	9.1	88 (Top), 71 (Bot)	604	72.9	8.2
2021	North East	Wheat	Alvan Blanch	995	32.4	87	1,862	278.5	8.8
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
2021	Central	Wheat	Vertec 6600	85	2.8	68	315	25.0	9.2
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
2021	Central	Wheat	Vertec 6600	210	3.1	84	401	37.8	12.6
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.

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 4-44%, 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 24: Alvan Blanch DF 22000 (Top Left), Western 1600-24 (Top Right), GSI-1222 (Bottom Left), Upgraded Vertec 6600 (Bottom Right)

05 | Appendix

5.1 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
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

5.2 Appendix B-Continuous Dryer Operating Conditions

The table below displays the same order as seen in Table 14 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%
2021	North East	Barley	Alvan Blanch	97	4.0	20	6,100,000	886,209	15%
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%
2021	Central	Wheat	Vertec 6600	325	9.3	20	3,000,000	2,296,070	83%
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%

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	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%
2019	Central	Canola	Vertec 6600	196	4.4	14	3,000,000	2,321,926	77%
2020	Central	Wheat	GSI-1222	375	9.1	31	9,750,000	2,293,106	24%
2021	North East	Wheat	Alvan Blanch	995	32.4	118	6,1000,000	2,102,869	34%
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%
2021	Central	Wheat	Vertec 6600	85	2.8	11	3,000,000	1,896,780	63%
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%
2021	Central	Wheat	Vertec 6600	210	3.1	14	3,000,000	2,395,496	80%
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%

5.3 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	-

5.4 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.