Appendix F: Appliance Laboratory Analysis - Rapid Cook Ovens

Frontier Energy conducted additional laboratory testing on rapid cook ovens given the recent increased interest in the technology, particularly from larger chain accounts. Today's foodservice customers demand freshly cooked food and short wait times. Food must be cooked-to-order and served hot. This demand has encouraged many foodservice operators to shift their process from batch cooking-and-holding to rapid cooking. Quickly heating food from a refrigerated or frozen state in single batches has increasingly gained traction in the foodservice industry over the traditional method of cooking and holding large quantities of food in a ready-to-serve state. Blast chillers have facilitated this cooking process change by rapidly reducing the temperature of single serving packages of cooked food before being staged for rapid cooking. Vacuum sealing these single meal servings is also becoming common as a method of food prep for rapid cooking.

The table below shows the differences between the two cooking processes.

Table 1: Batch Cooking Vs Rapid Cooking Processes

	Batch Cooking	Rapid Cooking
Food Product Refrigeration	Refrigerated or Defrosted	Refrigerated or Frozen
Cooking Method	• Convection Oven • Combi Oven	• Rapid Cook Oven • Panini Press
Cooking Temperatures	300 – 400°F	450 – 550°F
Servings Cooked at a Time	5+	1-2
Ventilation Requirements	Type II Hood	Usually Ventless with Catalyst
Holding Method	• Hot Food Holding Cabinet • Steam Table • Blast Chiller (multistage cooking)	None, served right after cooking
Applications	• Catering and Hotels • Cafeterias • Full-Service Restaurants • Buffets	• Quick-Service Restaurants • Quick-Service Convenience • Full-Service Restaurants • Stores / Gas Stations • Cafes and Pastry Shops • Bars
Advantages	High customers served to labor spent ratio	Fast cook times, customer impression of freshness, single stage process

Disadvantages	Requires multiple steps, can lead to product waste if customers served is overestimated, can lead to long wait times	Cannot serve large volumes of customers, high energy density, product needs to be served immediately

Although the table above categorizes each cooking process by market segment, some operations may use a mix of both processes. For example, food can be prepped and pre-cooked using a batch cooking process, then blast chilled and reheated using rapid cooking techniques. A large cafeteria may have several batch cooked items and a separate cook station dedicated to serving rapidly cooked-to-order items.

Many quick-service restaurants are already making the process switch from batch to rapid cooking, while smaller bakeries, cafes, gas stations, and bars are expanding their food menus with the help of rapid cook ovens.

Current Rapid Cook Oven Technologies

Rapid cooking occurs at high temperatures of about 450-550˚F typically using a combination of convection, impingement, and/or microwaves. Oven cavities can be enclosed or open, or a hybrid of both. Microwave technology can only be used in models with closed cavities and no windows. Partially open cavity models using contact cooking include conveyor ovens and panini griddles. All rapid cook oven technologies use high-speed hot air to add crispiness to the food product. The random circulation of heated air in convection oven cooking is replaced with precise directional high-velocity hot air directed toward the food product in rapid cook ovens. Rapid cook ovens have high-temperature cooking chambers which run 100+˚F higher than conventional convection oven settings. Hot air velocity is also two to three times greater than convection ovens, which results in decreased cook times. Some models can also pulse microwave energy, giving the small cooking chambers even more power to reduce cook times.

Figure 1: Hot Air Impingement Rapid Cook Ovens

The elevated temperatures of rapid cook ovens allow for the use of catalysts that may qualify the oven for ventless operation if it passes the EPA 202 grease emissions threshold of 5.0 mg/m^3 (UL KNLZ) as well as NFPA96 and 101 fire safety standards. The emissions test is conducted using pepperoni pizza; most ovens are not allowed to be installed without a hood if raw protein product is being cooked.

Figure 2: Rapid Cook Ovens with Microwave

The following technologies are NOT considered rapid cook:

- Standard Microwaves without convection fans or resistance elements
- Panini Makers with no magnetrons
- Mini Combination Ovens

As of June 2019, there are four major equipment manufacturers in this field representing some of the largest foodservice conglomerates:

- Amana ACP (Ali Group)
- MerryChef (Wellbilt)
- TurboChef (Middleby)
- Ovention (Hatco)

Rapid cook ovens can be classified into four categories including: high temperature microwave ovens, door type hot air impingement ovens, conveyor hot air impingement ovens and microwave panini makers.

High-Temperature Microwave Ovens

High-temperature microwave ovens are one of the most popular rapid cook technologies, combining a heated cavity (typically in the range of 450-550˚F), dual convection fans, and microwave magnetrons. The cavity is enclosed with no windows and is usually smaller in volume compared to the size of the unit. The most popular models on the market are listed below:

- Amana ACP
  - ACE 14 and ACE 19
  - ARX1 and ARX2
  - AXP22T
- MerryChef
  - Eikon e2s
  - Eikon e3
  - Eikon e4s
  - Eikon e5
- TurboChef
  - Eco
  - Sota (i1) also Panini and Waterless Steamer
  - i3
  - Bullet
  - i5

Table 2: High-Temperature Microwave Rapid Cook Oven Models

	Amana	MerryChef	TurboChef
Small			

Medium			
Large			

Table 3: High-Temperature Microwave Rapid Cook Oven Dimensions

Cavity Size (W"x H"x D")	Amana	MerryChef	TurboChef
Small	ARX (12.3x7x12.3)	e2 (12x7x12)	Eco / Sota (12.5x7.2x10.5)
Medium	ACE (13x10.5x15)	e3 (13x12.6x12.8)	Bullet (15.5x6x14.5)
Large	AXP (16x10x15)	e4 (14.8x8.6x12.3)	I3 (19.4x6.9x12.8)
Extra Large	N/A	e5 (19.5x10.2x14.1)	I5 (24x10x14)

High-temperature microwave ovens have three energy consuming components:

- Resistance Electric Heating Element (highest input)
- Microwave Magnetron (some larger ovens have dual magnetrons)
- Air recirculation convection fan (approximately 100W)
- Controls (low energy)

Table 4: High-Temperature Microwave Rapid Cook Oven Input Rates

Power (micro+conv)*	Amana	MerryChef	TurboChef
Small	• ARX1 3.6 kW (1+3) • ARX2 6.0 kW (2+3)	• e2 4.5 kW (1+2.2) • e2s 6.0 kW (2+2.2)	• Eco 3.5 kW (2+2) • Sota 6.2 kW (3.2+6.0)

Medium	• ACE 14 3.2 kW (1.4+2.7) • ACE 19 5.3 kW (1.9+2.7)	• e3 4.7 kW (1+3) • e3s 6.2 kW (1.5+3.2)	Bullet 6 kW (3.5+NA)
Large	AXP 5.7 kW (2.2+2+3IR)	e4 6.2 kW (1.8+3.2)	I3 8.3 kW (N/A)
Extra Large	N/A	e5 6.2 kW (1.4+3.2)	I5 9.5 kW (N/A)

The total input rate for the ovens is listed in the table below. Microwave magnetron output power and resistance heating element power in kW are shown in parentheses, respectively. Some ovens do not allow the resistance heating element to operate at full power when the microwave is on as to have a lower amperage rating.

*Microwave power is shown as output instead of input, all specs shown at 208V 1PH.

Small and medium size high temperature microwave ovens are the most popular - some restaurants have two units, which can be operated simultaneously to double production capacity and have redundancy in case of an equipment failure. These would be 3-6 kW units which can be run off a single phase 208V 30A or 40A receptacle. The resistance elements are usually 2-3kW and the microwave magnetrons draw an additional 2-3 kW.

Door-Type Hot Air Impingement Ovens

Door-type hot air impingement ovens do not use microwave magnetrons. Instead, these ovens achieve elevated temperatures of 450-550˚F using resistance heating elements and high velocity air impingement to aid in product crisping. These closed cavity ovens usually have a glass door unlike their microwave counterparts. The models listed below are the most popular on the market:

- TurboChef
    - Fire
    - Single Batch
    - Double Batch
    - High h Batch
- Ovention
    - Milo Single
    - Milo Double
- Alto Shaam
    - Vector H2
    - Vector H3
    - Vector H4
    - Vector F3
    - Vector F4

Table 5: Door-Type Hot Air Impingement Ovens Models

	TurboChef	Ovention	Alto Shaam
Small (single cavity)			N/A
Medium (dual cavity)			
Large (3+ cavity)	N/A	N/A	

Table 6: Door-Type Hot Air Impingement Oven Dimensions and Input Rates

Dimensions and Input* Rate	TurboChef	Ovention	Alto Shaam
Small (single cavity)	• Fire (14.8x14.8) 3.7 kW • Single Batch (18.5x16.3x5.5) 5.6 kW • High h Batch (18.8x16.8x8) 5 kW	Milo Single (15.5x14.3x4) 7.2 kW	N/A
Medium (dual cavity)	Double Batch (18.1x17.1x3.3x2) 8.3 kW	Milo Double (17.5x18.3x4x2) 11.8 kW	Vector H2 (15x19x14) 5.2 kW
Large (3+ cavity)	N/A	N/A	• Vector H3 (15x19x21) 7.9 kW • Vector H4 (15x19x28) 10.6 kW

*Shown for 208V

Conveyor Hot Air Impingement Ovens

Conveyor hot air impingement ovens do not use microwave magnetrons. Instead, these ovens achieve elevated temperatures of 450-550˚F using resistance heating elements and high velocity air impingement to aid in product crisping. The food is placed on the conveyor belt which carries the food product through a heated cavity. Cooktime can be changed by adjusting the conveyor belt speed. Fans force air from the top of the cavity onto the food product. Constant moving of the product past the heating elements ensures uniform cooking. Heat settings can be adjusted separately for the bottom and the top. The models listed below are the most popular on the market:

- TurboChef
  - High h Conveyor 1618
  - High h Conveyor 2020
  - High h Conveyor 2620
- Ovention
  - Conveyor 2000
  - Shuttle 1718
  - Matchbox M1313
  - M360
- Lincoln
  - CTI V2500
  - 1180-1V

The conveyor belt is usually open on both ends of the cooking cavity, however Ovention makes batch conveyor models with closing doors that allows the product to enter the cavity, cook with the door closed, and then exit. Ovention also makes a model that uses a rotating turn table, where half of the turntable is inside the cooking cavity while the other half can be loaded with the next batch. These two designs limit the escape of hot air, which could reduce energy use.

Table 7: Conveyor Hot Air Impingement Oven Models

	TurboChef	Ovention	Lincoln
Small			N/A
Medium			

			
Large		N/A	

Table 8: Conveyor Hot Air Impingement Oven Dimensions and Inputs Rates

Cavity Dimensions and Input Rate*	TurboChef	Ovention	Lincoln
Small	High h Conveyor 1618 (16x18) 7.4 kW	• M360-12 (12x24) 6.4 kW • Shuttle 1200 (17x15) 6.7 kW • Matchbox 1313 (13x13) 7.0 kW	N/A
Medium	High h Conveyor 2020 (20x20) 40A	• M360-14 (14x27) 8.3 kW • Conveyor 2000 (20x21) 12.6 kW • Shuttle 2000 (20x21) 12.6 kW • Matchbox 1718 (17x18) 11.8 kW	DCTI V2501 (20x20) 6 kW
Large	High h Conveyor 2620 (26x20) 40A	Conveyor 2600 (26.5x21) 14.1 kW	1130-1V (x28) 10 kW

*Input rate shown for 3 phase 208V

Electric conveyor hot impingement ovens fill the void between electric conveyor toasters and large gas conveyor pizza ovens. Operating at similar temperatures, they can provide much faster production capacity than conveyor toasters without having the ventilation requirements of large gas conveyor pizza ovens.

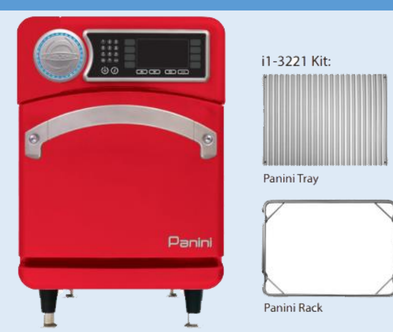
Contact Cooking with Microwave (Panini Presses)

Traditional panini presses are a contact cooking device which produces a crispy outer shell while the inside may stay at a colder temperature. The inner temperature depends on the product thickness, so traditional panini presses may overcook the outside while undercooking the inside. Microwave panini presses solve this issue by using the traditional contact cooking methodology for the outer shell but using microwave cooking to heat the inside of the product. This results in much faster cooktime and improved uniformity. The top and bottom contact plates have resistance heating elements, and the magnetron is usually located above or below the cooking surface. These types of microwave panini presses are much more expensive than conventional models due to the addition of the magnetron and its controls, with similar pricing to high temperature microwave ovens. Several microwave panini makers include:

- Electrolux 603874 Speedelight
- Nemco 6900 Panini Pro
- TurboChef Panini (i1)
- Amana AXP with Panini Attachment
- Merrychef e2s with Panini Attachment

Two high temperature microwave oven manufacturers have integrated the panini attachment into their cooking cavity as an option. The panini metal contact surfaces are heated by convection in a high temperature cavity, which compresses as the door is closed to contact the food product. The magnetron in the back of the oven cooks the inside of the food product.

Table 9: Microwave Panini Maker Models and Specifications

Electrolux	Nemco	TurboChef
		
Electrolux 603874 Speedelight (8.1" x 8.5") 5 kW (0.8 kW top 2x1 kW magnetrons)	Nemco 6900 Panini Pro (10.5" x 10.5") 4 kW (2 kW resistance, 2 kW magnetron)	TurboChef Panini (i1) (9.8" x 15.2") 6.2 kW (6 kW resistance, 3.2 kW magnetron)

Rapid Cook Oven Technology Consumption

Rapid Cook Oven Energy Comparison

The various rapid cooking appliance that have emerged over the past decade have their various pros and cons, along with their own specialized uses. Frontier Energy tested these technologies under controlled conditions to characterize and compare their energy consumption and production capacity. Using this summarized information, foodservice operators can better understand the equipment that might best suit the demands of their operation. An appliance like a high-temp convection conveyor toaster could be perfect fit for a high throughput kitchen, but unnecessarily raise energy cost for a smaller operation.

Table 10: Rapid Cook Oven Energy Comparison

	Conv with Micro	HT Conv Door	HT Conv Conveyor	Contact Micro
Production Capacity	Medium	Medium	Very High	Medium
Energy Intensity	High	High	Very High	Medium

Frontier Energy tested the ovens at 500˚F in both idle standby mode (using the setback mode where applicable) and cooking mode. The cooking method for each oven was based on a modification of the standard test methods ASTM F2238-16 (Rapid Cook Ovens) and ASTM F1817-17 (Conveyor Ovens). The testing for the various convection type ovens used the standard ASTM test product of thick crust pizza, cooking the pizzas from 38˚F to 195˚F. Various models of each category were tested where available, representing different sizes and demand requirements. The results from this testing are summarized in the tables below, exhibiting a minimum and maximum range for sizes where multiple units were available for testing.

Table 11: High Temperature Microwave Oven Energy Consumption Range

Size	Idle Rate (kW)	Cooking Input Rate (kW) and Production Capacity (lb/h)*
Small	0.68 kW (setback mode) – 0.82 kW	2.63 kW @ 16.7 lb/h – 4.95 kW @ 52.1 lb/h
Medium	1.20 kW – 1.33 kW	4.84 kW @ 49.7 lb/h
Large	0.72 kW (setback mode) – 1.78 kW	4.77 kW @ 54.5 lb/h – 5.76 kW @ 56.0 lb/h
Extra Large	0.99 kW	5.03 kW @ 48.6 lb/h

Table 12: Door-type Hot Air Impingement Oven Energy Consumption Range

Size	Idle Rate (kW)	Cooking Input Rate (kW) and Production Capacity (lb/h)*
Small (single cavity)	1.15 kW – 1.24 kW	1.99 kW @ 17.8 lb/h – 2.63 kW @ 28.4 lb/h
Medium (dual cavity)	2.08 kW – 2.88 kW	N/A
Large (3+ cavity)	1.58 kW	N/A

Table 13: Conveyor Hot Air Impingement Oven Energy Consumption Range

Size	Idle Rate (kW)	Cooking Input Rate (kW) and Production Capacity (lb/h)*
Small	2.34 kW	5.87 kW @ 55.7 lb/h
Medium	2.10 kW – 2.7 kW	3.43 kW @ 19.4 lb/h - 7.14 kW @ 56.7 lb/h

Panini Press Energy Comparison

The panini press with magnetrons were tested with a chicken quesadilla as the test product, since pizzas would not be appropriate for this application. Testing consisted of a back to back batch load of pre-prepared (using refrigerated cheese, warm chicken and room temperature tortilla) chicken quesadillas in order to test each unit under heavy-load cooking conditions. Cook times were determined based on metrics such as tortilla browning, internal temperature and quality of cheese melt inside the quesadilla and ranged between 20 and 30 seconds. The two units that performed the best were those who were specifically designed for panini/sandwich pressing. The third unit was a rapid cook oven modified with top and bottom plates for sandwich pressing capabilities. Standby idle energy, which is known to be one of the largest contributors to energy usage, was also measured for each unit. The unit with the lowest idle energy consumption had an eco-setback mode, which allowed it to idle at nearly half the rate of the other two units. The contact plates usually operate at 500-600F, but the setback mode lowered the temperature down to 400-500F during periods of inactivity.

Table 14: Microwave Panini Press Energy Consumption Range

Idle and Cooking	A	B	C
	A: 0.5 kW Idle, 2.13 kW cook @ 62.6 items/h	B: 1.1 kW Idle, 1.88 kW cook @ 47.0 items/h	C: 0.9 kW Idle, 4.30 kW cook @ 62.6 items/h

Figure 3: Example of 7 Run Batch Load

Food Product Variation Testing

A series of food products were chosen to test the performance of two units in three cooking scenarios. The first unit was a rapid cook hot air impingement deck oven, while the second unit was a hot air impingement conveyor oven with batch cooking capabilities. For the conveyor oven, when operating as a continuous conveyor, the cooking chamber is open at the entrance and exit of the oven with the conveyor belt set to a programmable constant speed. When operating as a batch cooking oven, the cooking chamber has doors that open to allow for loading/unloading food product and close during idle or cooking periods. Both the deck oven and the conveyor oven had programmable recipe features.

The cooking method for each oven was based on a modification of the standard test methods ASTM F2238-16 (Rapid Cook Ovens) and ASTM F1817-17 (Conveyor Ovens). The objective was to test and compare each cooking scenario with popular food products and the standard ASTM thick crust pizza test product. The final product was examined qualitatively (color, cheese melt, etc.) and quantitatively (internal temperature) to determine an appropriate cook time for each item. A corporate chef was evaluating the qualitative aspects of the cooking process. Sub sandwiches, refrigerated chicken wings, thin crust pizzas and refrigerated thick crust pizzas were cooked on wire mesh screens. Fresh chopped veggies were cooked on ½ size sheet pans.

Figure 4: Sub Sandwich Test

Figure 5: ASTM Specification Thick Crust Pizza Test

Figure 6: Chicken Wings Test

Figure 7: Roasted Vegetables Test

In summary, there was a strong correlation between products with a higher moisture content and energy consumed during cooking period per pound of food. Both ASTM and Thin Crust Pizzas consumed the least amount of energy per pound of cook product due to the lower moisture content and shorter cook duration. The chicken wings and vegetables were the two items that consumed the most energy per pound of cooked product. For the vegetables, this was a direct result of the high moisture content and the additional power required for the heating elements due to the cooling caused by vaporization. The chicken wings resulted in a higher energy consumption due to the longer cook time required to achieve an appropriate average internal temperature. On average, the deck oven consumed less energy per pound of cook product but yielded a lower production capacity for each cook item when compared to the conveyor oven. The rapid cook conveyor oven consumed on average nearly the same amount of energy per pound of cook product for both batch and conveyor mode. However, batch mode cooking resulted in a considerably lower production capacity.

Table 15: Food Product Cooking Comparison for Various Rapid Cook Oven Setups

	Appliance	Sandwich	Wings	Vegetables	TC Pizza	ASTM Pizza
Normalized Energy Consumption (Wh/lb)	Batch	301	358	304	188	177
	Conveyor	285	335	353	194	163
	Deck	197	234	251	152	114
	Batch	6.4	17.7	38.2	16.2	5.9

Moisture Content After Cooking (%)	Conveyor	10.8	16.2	45.3	9.4	7.5
	Deck	3.4	18.5	38.0	12.1	17.8

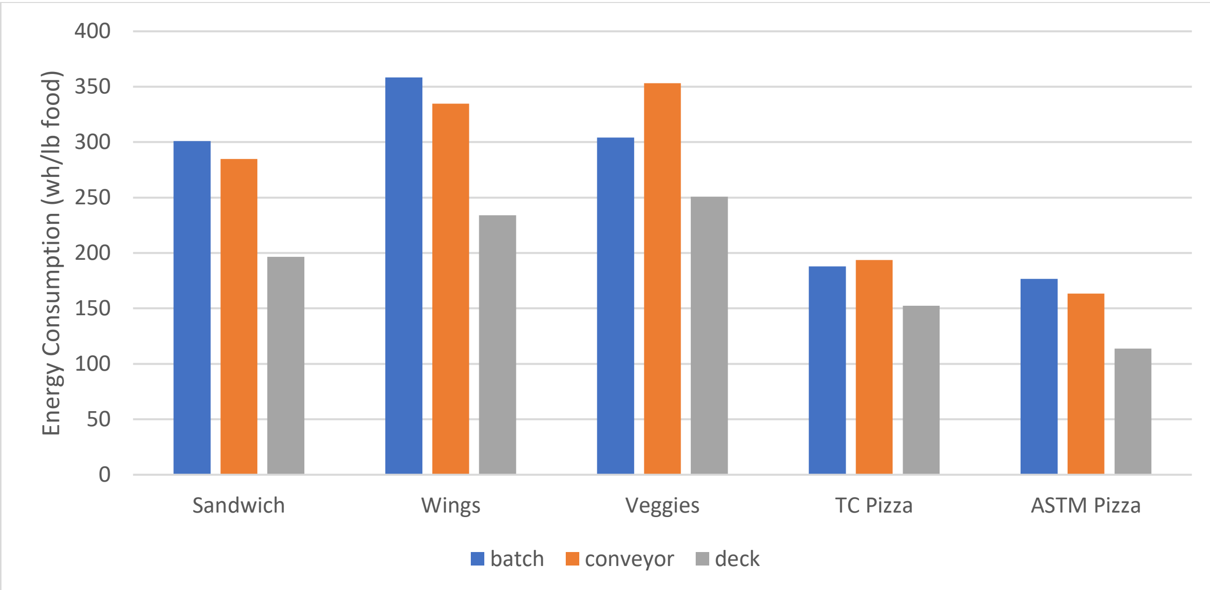


Figure 8: Comparison of Energy Intensity Required for Cooking Various Food Products

Frontier Energy observed that the moisture content of the cooked food product directly correlated to the oven input rate required to cook the food product on the appliance input rate for each cooking scenario. This data can be useful to a restaurant operator who wants to estimate energy usage and operating costs for menu items. Additionally, an operator may consider the demands of their operation. While a conveyor oven can achieve higher production capacities, it immediately sacrifices efficiency when not loaded in a continuous setting.

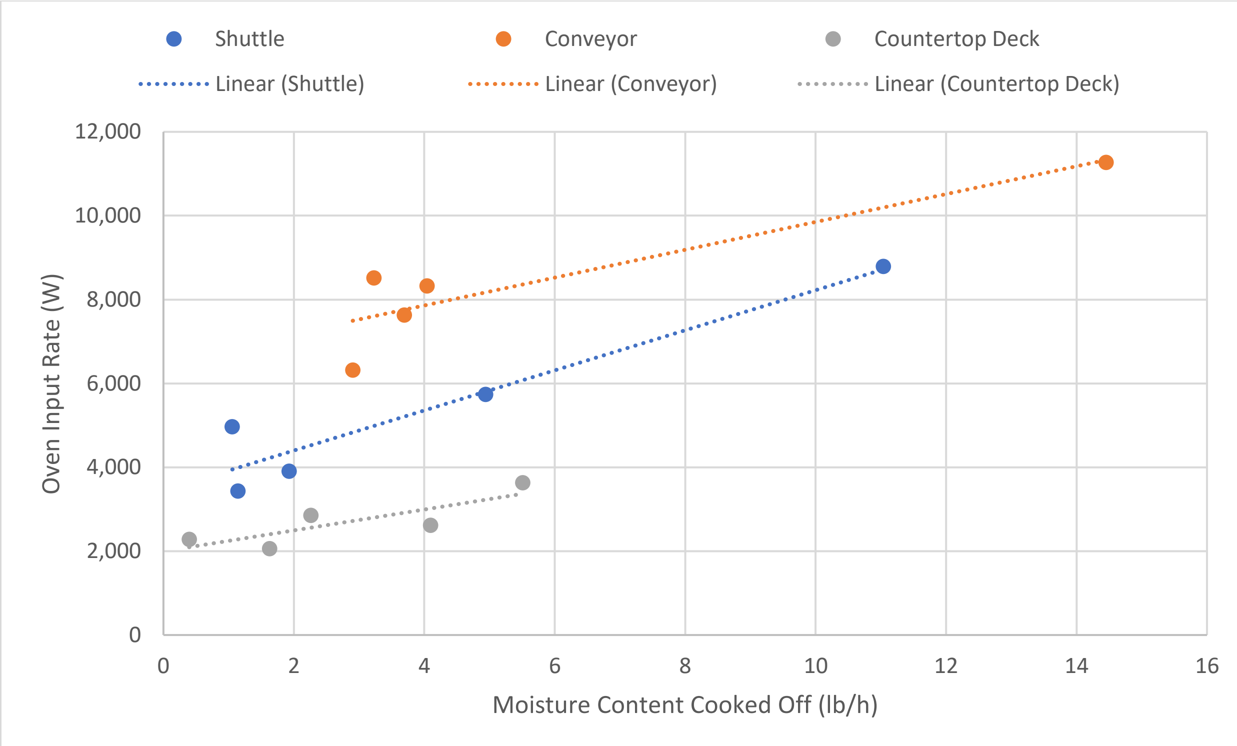


Figure 9: Energy Vs Food Moisture Content

Rapid Cook Oven Energy and Cost Analysis

Frontier Energy monitored rapid cook ovens installed in market segments ranging from small cafes to large cafeterias. With 343 days and 14.4 hours per day operation, the average energy consumption per rapid cook oven was 6964 kWh per year. Assuming a cost of $0.15 per kWh, the annual operating cost of each rapid cook oven is about $1,000 per year. The average cooking and idle energy rate based on the field data was 1.4 kW for rapid cook ovens.

Table 16: Rapid Cook Oven Site Energy Data

Site	Rapid Cook Oven Size	Hours of Operation	Days Per Year	kWh/day
Sandwich Shop	Medium	9.7	364	12.8
Cafeteria	Large	9.1	261	24.9
QSR	Small (2x)	24	364	22.6 + 27.7
Large Café	Small (2x)	16	364	16.2 + 18.3
Small Cafe	Medium	13.1	364	21.3
Average per Oven		14.4	343	20.3

Advanced panini presses used less energy than rapid cook convection ovens based on the data from two sites. With 313 days and 11 hours per day operation, the average energy consumption per panini press is 2066 kWh per year. Assuming a cost of $0.15 per kWh, the annual operating cost of each panini press is $300 per year. The average cooking and idle energy rate based on the field data was 0.6 kW for advanced panini press.

Table 17: Microwave Panini Press Site Energy Data

Site	Number of Advanced Panini Grills	Hours of Operation	Days Per Year	kWh/day
Large Café	2	18	364	12.1 + 9.6
Cafeteria	2	4.1	261	3.1 + 1.4
Average per Grill		11	313	6.6