An Introduction to: The Investigation Between Gas and Induction Stovetops:

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ABSTRACT

With the new UBC SUB project nearing completion of the design phase, the food services will be upgrading its kitchen equipment. The refresh of the new appliances gives an opportunity to explore new solutions to create a more economical, environmentally friendly and beneficial alternative. In order to examine each case in detail, the scope of this report will compare current gas stove and the recent induction cooktop technology. Each stovetop has their advantages and disadvantages. To organize and examine the cooktops against each other, the triple bottom line analysis is utilized. Using peer-reviewed journal articles, government patents and personal engineering fundamentals, each case can be examined with academic sources and without manufacturer bias. With this strategy, the team can confidently recommend that induction stovetop technology is more beneficial for the new UBC SUB.

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GLOSSARY

Cookware	Refers to the commercial grade pots and pans that will be used in the UBC foods and beverages department.
Discount Rate	The interest rate used in determining the present value of future cash flows.
Eco-Indicator value	A weighted numerical value representing the total environmental impact of a material or process.
Life Cycle Inventory	A complete detailed list of all materials and resource amounts used throughout the life time of a product
Pacemaker	An electronic medical device that send electrodes to the heart to increase the heart rate for patients.
Renewable Power	Energy/Power which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).
RFID	Radio-frequency identification: A technology that uses radio waves to exchange data between a reader and an electronic tag.
Spot Price	The Spot Price of a commodity, a security or a currency is the price that is quoted for immediate (spot) settlement (payment and delivery). Spot settlement is normally one or two business days from trade date.
Stakeholders	A person, group, organization, or system who affects or can be affected by an organization's actions. In the case of the new SUB this includes students, cooks, maintenance, administration, government and financiers.
Tight Gas	Tight gas refers to natural gas in underground reservoirs with low permeability. A generally accepted industry definition is reservoirs that do not produce economic volumes of natural gas without assistance from massive stimulation treatments or special recovery processes and technologies, such as horizontal wells.

1.0 INTRODUCTION

1.1 BACKGROUND

The building of the new Student Union Building (SUB) will offer new amenities and conveniences to many of the students enrolled at UBC. The new SUB will offer a place for students to meet, share ideas, study, and socialize.

As UBC continues to strive to be a global leader in campus sustainability, we endeavoured on a class wide project to analyse different aspects of the new SUB's design to understand the social, environmental, and economical implications of technological choices available. Our group took a detailed and concentrated look at different cooktop technologies that have been considered for the new SUB's commercial kitchens. With information provided by the new SUB planning team, the food and beverage department is one of the largest users of resources on campus. Due to this high resources consumption rate, our team felt that this was the most worth while project to tackle as its outcome could lead to a large reduction in resource use. A triple bottom line accounting method was used to compare induction and natural gas ranges, the two leading candidates for commercial cooktop technology. By implementing a triple bottom line analysis we were able to reach a concrete recommendation backed by research.

1.2 SCOPE

With a general reader in mind, this formal report will describe the analysis and justification for our final recommendation for cooktop technology at the SUB. The emphasis in this report is on the triple bottom line methodology, and the research conducted to support our conclusions. The topics include:

- Economic Analysis
- Environmental Analysis
- Social Analysis
- Final Recommendation

2.0 ECONOMICS

2.1 BREAKDOWN

Within the three pillars of triple bottom line accounting lays the economic arm of the project analysis. Some considers the economic analysis the cornerstone of the triple bottom line accounting as project finances and budget act as a catalyst for many decision.

Due to the large scope of the financial arm of the triple bottom line accounting method, it has been further subdivided as to attain a higher resolution for each component that affects the out come. The deconstruction of the project economics into each variable allows higher understanding and adaptability to current pricing conditions. The break down of the economic analysis is as follows:

1. Fuel Cost
    a. Raw Fuels
        i. Current Day Prices: Vancouver British Columbia
        ii. Future Price Forecasts using Supply Side Economics
    b. Fuel Consumption
        i. Natural Gas Ranges
        ii. Induction Ranges
2. Upfront Costs
    a. Relative Prices of Two Technologies
        i. Ranges
        ii. Cooking Utensils
    b. Expected Life and Replacement Costs
3. Key Indicators
    a. Complete Equations
    b. Normalized Price per Output

Once each aspect of the financial analysis has been investigated, we are then able to develop a mathematical architecture that can be used to model the economics of each technology given a unique set of current and future conditions. This approach lets the economics of the project to be quantified and manipulated based on real time information. This induced model flexibility provides an advantage for investors and stakeholders.

The proceeding is the formulation of the mathematical model that will be deployed to assess and compare the economics of each option.

Flexible Mathematical Model

The cost of both stovetop technologies can be broken into two separate sections. Fixed cost, which describe upfront costs of using the technology, and Induced costs, which models the day-to-day costs for using the technology. The upfront costs are described as autonomous cost in this model because these cost are established outside of the model and are not flexible; hence not a function of hours used or power output. The induced variables are functions of hours used.

Flexibility in this model pertains to the notion that not all variables are known; uncertainty is most evident in the future spot prices for energy inputs but expands past this. The hours used per day, number of days used per year, number of burners, daily capacity (always firing at full power vs. off for most of the day), and inflation all affect the economics. Working with appropriate ranges for these values we are able to "create" thousands of different environments in which economic comparison could be done. The flexible modeling method is primarily used to avoid becoming obsolete in the case of any predicted or assumed conditions being incorrect.

Autonomous Variables

Expected Life Time: t_l

Burner Unit Cost: U_c/t_l

Burner Quantity: N

Cook Ware Cost: C_c

In order to simplify the expression, each cost was divided in order to attain cost per unit. This allows the autonomous portion of the equation to be a function of only one free variable, N.

Cook Ware Cost Per Unit (C_c/N): C_λ

A discount formula was estimated for unit pricing. Full price is enforced for up to 5 units purchased, then a sinusoidal bulk discount formula is deployed to provide a discount that reaches a maximum of 70% full unit price at 20 units purchased. Below is the graphical discount expression (D_Δ) with formula.

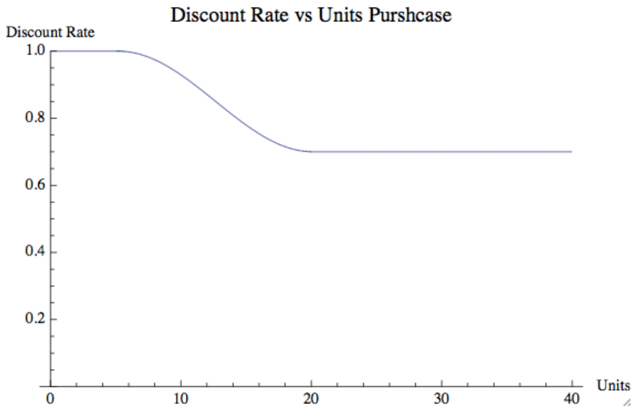


Figure 1: Discount Pricing Model

$$D_{\Delta} = f(x) = \begin{cases} 1, & x < 5 \\ 0.15 * \cos\left(\frac{\pi}{15}x + 5\right) + 0.85, & 5 \leq x \leq 2 \\ 0.7, & 20 < x \end{cases}$$

**The model can conversely be run for full unit price, independent of number of units purchased.

Induced Variables

Energy Cost:	E_c
Energy Quantity per Hour per Unit:	F
Replacement Costs:	R_c
Unit Lifetime (hours):	R_t

All of the induced variables expressed in terms of hours used and units.

Below is the combination of autonomous and induce costs for the stovetop analysis. As you can see there are two equations that take the same form, one of gas and one for induction. Once values are determined the graphs are overlaid to compare the economics of each. You will notice that the number of burners, and discount rate are the same for both; this is based on the following assumptions:

- A fixed number of stovetops will be used, regardless of technology.

- Discrepancies in efficiencies between the two will be accounted in hours ran in order to complete task, not by using more stovetops.
- Discounts from supplier, if any, will be the same.
- We assume that the sub is kitchen is to last at least 25 years.

$$C_g(\mathrm{N}, t_g, t_l))=(U_{cg}(t_l) + C_{\lambda g})(\mathrm{N} \cdot D_\Delta) +(E_{cg} \cdot F_g(t))(N) + (R_{cg}(t) \cdot R_{tg})(N)$$

$$C_i(\mathrm{N}, t_i, t_l))=(U_{ci}(t_l) + C_{\lambda i})(\mathrm{N} \cdot D_\Delta) +(E_{ci} \cdot F_i(t))(N) + (R_{ci}(t) \cdot R_{ti})(N)$$

These equations will output the unit cost per year. To attain the full lifetime cost you have to integrate function from time 2010 to 2035.

The proceeding section of the economic analysis uses research to attain values for each variable in order to achieve the most accurate cost for both induction and natural gas cook tops.

2.2 FUEL COSTS

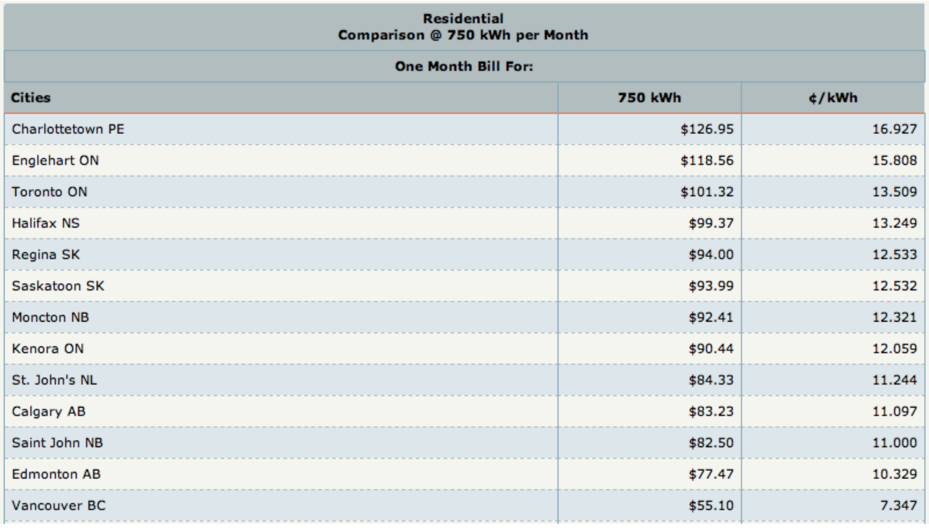
The two stovetop technologies use significantly different sources of fuel to power their operations. Natural gas stoves use natural gas as their fuel. This gas is commercially available and can be supplied by local companies. Induction stovetops use electricity power that will be supplied to the SUB. In the 75% schematic of the SUB ("New SUB Project: 2010, 74) the source of this electricity has not yet been determined, thus for comparison we will use both conventional and renewable electricity costs. The assumptions that are used in the fuel analysis are as follows:

- Infrastructure for gas lines will exist regardless of the stovetop choice, thus installation of gas lines are exogenous to this model and are not included cost.
- Though onsite electric generation is an option for the new SUB, with using excess heat to generate power a feasible solution, the electricity generated is not free. Onsite generated power still has an opportunity cost associated with it, which is the open market price. This is because the power can either be consumed by the sub or sold, because of this dynamic the power has a definite and measurable cost.

2.2.1 Raw Fuels (E_c)

2.2.1.1 Current Day Prices

<u>Electricity</u>



Residential
Comparison @ 750 kWh per Month

One Month Bill For:

Cities	750 kWh	¢/kWh
Charlottetown PE	$126.95	16.927
Englehart ON	$118.56	15.808
Toronto ON	$101.32	13.509
Halifax NS	$99.37	13.249
Regina SK	$94.00	12.533
Saskatoon SK	$93.99	12.532
Moncton NB	$92.41	12.321
Kenora ON	$90.44	12.059
St. John's NL	$84.33	11.244
Calgary AB	$83.23	11.097
Saint John NB	$82.50	11.000
Edmonton AB	$77.47	10.329
Vancouver BC	$55.10	7.347

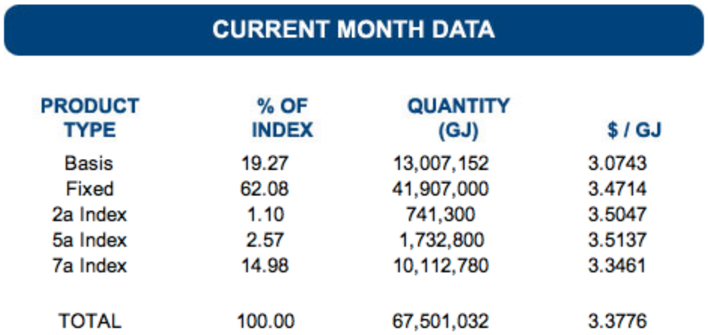
Figure 2: Current Day Electricity Prices in Canadian Cities

(Manitoba Hydro: 2010)

The following table from Hydro Manitoba compares current day prices of electricity across the country. Vancouver is listed as 7.347 cents/kWh. This will be used as a baseline cost for power. Renewable power is estimated by the Sub's 75% schematic as market price plus a 30% premium. This estimator costs renewable energy at 9.5511 cents/ kWh.

Natural Gas

When the sub was contacted to inquire on the price of natural gas they were paying it as found that the current sub is not metered and thus the cost could not be determined with this model. Instead we are using the Natural Gas Spot price on the TMX, in particular The AECO "C" spot price, which is the Alberta gas-trading price. This spot price has become one of North America's leading price-setting benchmarks. Below is the current spot as of March 2011. (TMX: 2011)



CURRENT MONTH DATA

PRODUCT TYPE	% OF INDEX	QUANTITY (GJ)	$ / GJ
Basis	19.27	13,007,152	3.0743
Fixed	62.08	41,907,000	3.4714
2a Index	1.10	741,300	3.5047
5a Index	2.57	1,732,800	3.5137
7a Index	14.98	10,112,780	3.3461
TOTAL	100.00	67,501,032	3.3776

Figure 3 : Current Gas Prices Western Canada

The following chart is a summary of initial conditions for energy prices

Natural Gas ($/ GJ)	Electricity ($/MWh)	Renewable Electricity ($/MWh)
3.3776	73.47	95.51

2.2.1.2 Future Price Forecast Using Supply Side Economics

Electricity

A forecast of future prices is being used to attain a better idea of what technology is more suited for the future. It was agreed on by our group that having a fixed energy price for the life of the product doesn't offer an accurate picture. Due to this observation, price forecasting has been developed to create multiple pricing scenarios that depict possible future conditions. By running multiple scenarios we are able to see under what pricing conditions does each technology flourish. The decision makers then can have more information rich model that can aid in the technology selection.

Three energy-pricing equations are used for each fuel type, a high, medium, and conservative price estimate. By plotting each of these pricing equations on the same graph we are able to create a feasible energy price band that can be useful in qualitative comparison.

The following is a price estimation of wholesale electricity prices in the Pacific Northwest (Northwest Power and Conservation Council: 2010, Appendix D p4). The North West Power Planning Committee (NWPPC) generated this forecast in 2009, on the basis of demand side economics and online power generation supply. The report figures are in US dollars and use a 2006 base year for comparison, thus this needed to be manipulated to model our project conditions. Below are the forecasted energy prices from the NWPPC, along with our normalized figures and equations.

Figure D-1: Forecast Range of Annual Mid-Columbia Wholesale Power Price

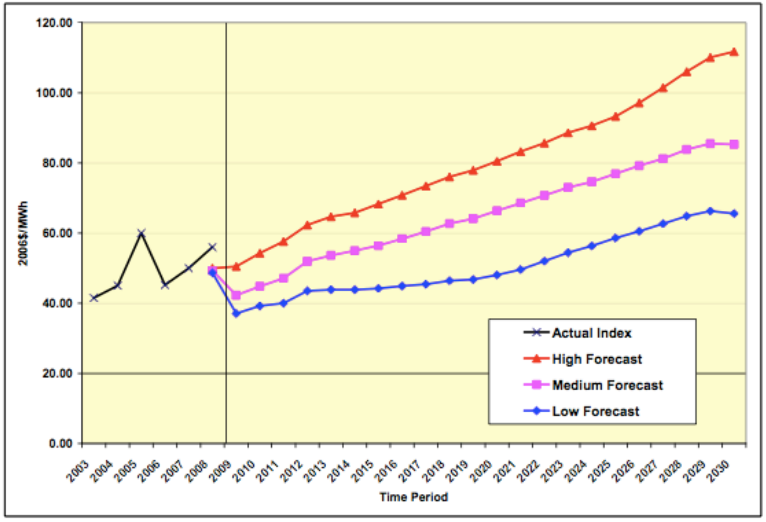


Figure 4: Forecast Range of Annual Mid-Columbia Wholesale Power Prices

The following equations are used as functions for different electricity forecast:

Low Forecast:	$E_c(t) = 0.1233t^2 - 496t + 49874$
Medium Forecast:	$E_c(t) = -0.0353t^2 - 146.1t + 150964$
High Forecast:	$E_c(t) = 0.0691 - 274.64t + 273062$
Low Renewable:	$E_c(t) = 0.1603t^2 - 644.8t + 64898$
Medium Renewable:	$E_c(t) = -0.0459t^2 + 189.3t + 196262$
High Renewable:	$E_c(t) = 0.0898t^2 - 357.05t + 354998$

*The following equations are all expressed in 2010 Base Year Canadian Dollars. All equations above were second order polynomial fits with a minimum R squared value 0.98.

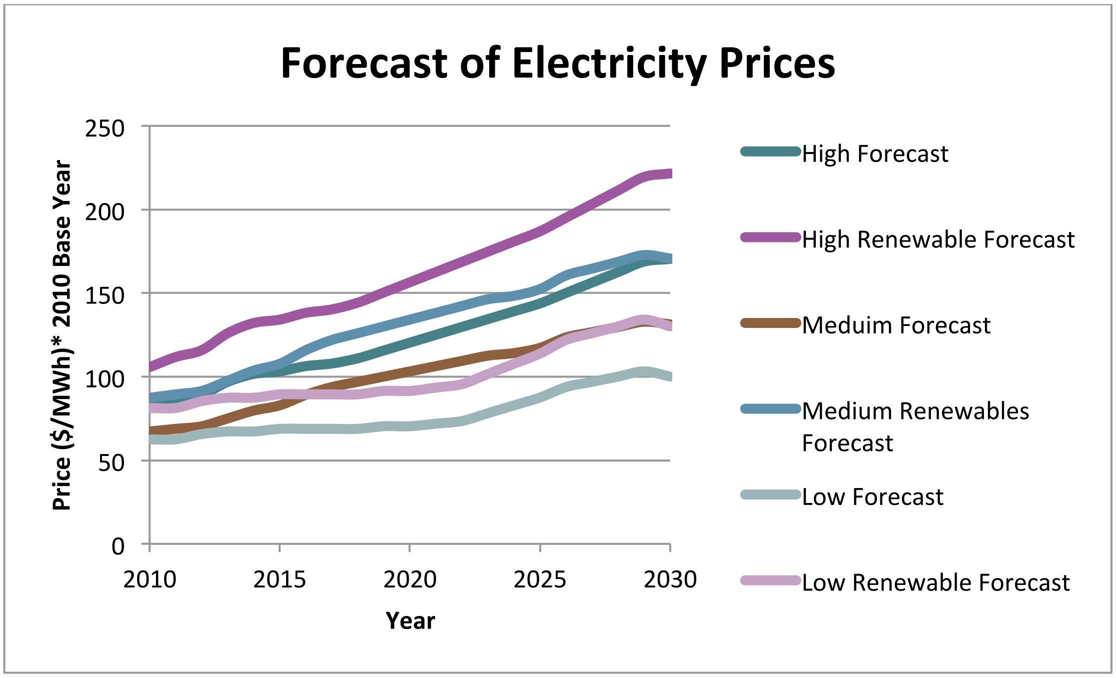


Figure 5: Forecast of Electricity Prices (Renewable and Conventional)

Natural Gas

Projection estimates were not nearly as detailed for natural gas as they were for electric prices. With Liquid Natural Gas (LNG) and tight gas plays emerging in recent years, natural gas prices are estimated to stay within a narrow range for the next 35 years. The increase in demand is to be tempered with advances these technologies. The following is a graph and formulas for two natural gas spot prices. Due the Alberta AECO spot price estimation not being available Henry and Lower 48 spot prices were used to develop mathematical equations that were later normalized to the Alberta AECO "C" spot price.

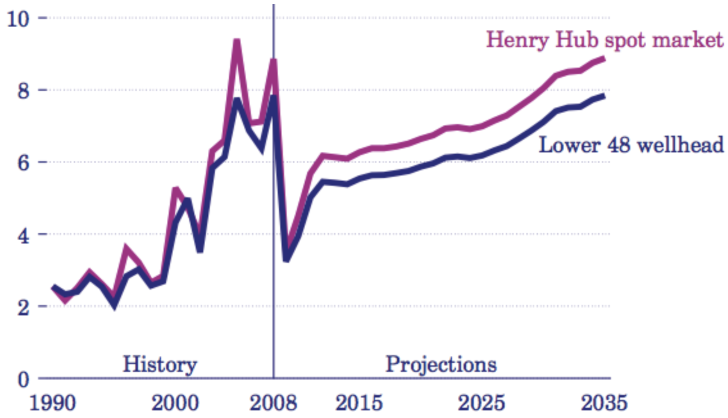


Figure 6: Natural Gas Projections from Annual Energy Outlook 2010

(US Energy Information Administration: 2010, 79)

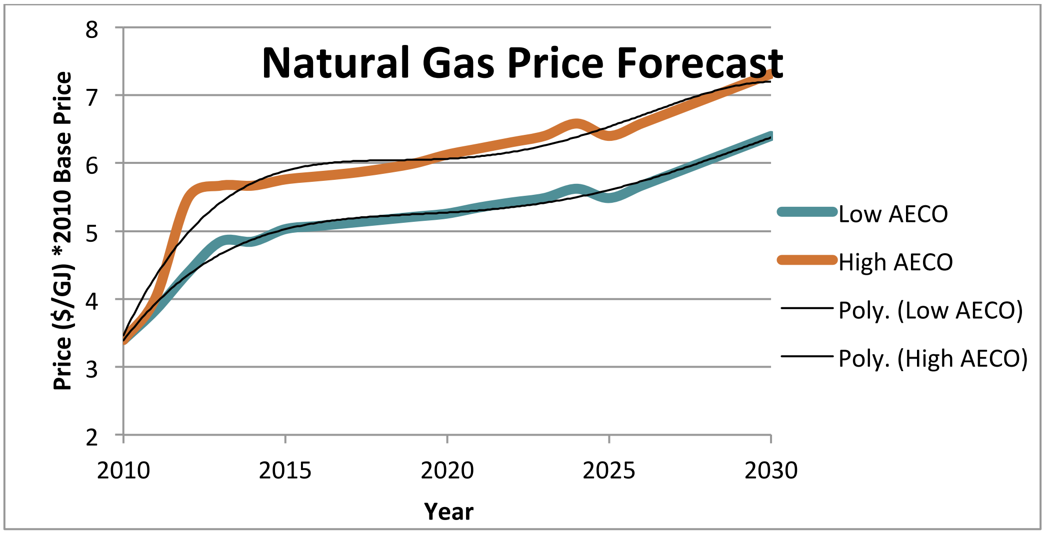
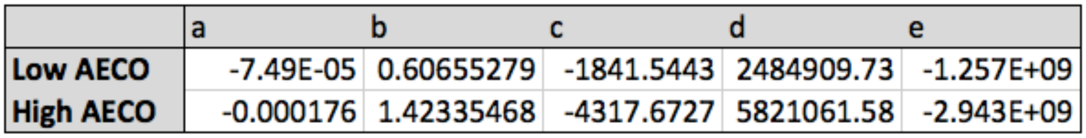


Figure 7: Natural Gas Excel Forecast Model

Based on the upper and low forecasts we used regression algorithms in MATLAB to attain an equation for their behavior. Below is the general equation form with a table of coefficients.

$$\boldsymbol{E_c(t) = at^4 + bt^3 + ct^2 + dt + e}$$



	a	b	c	d	e
Low AECO	-7.49E-05	0.60655279	-1841.5443	2484909.73	-1.257E+09
High AECO	-0.000176	1.42335468	-4317.6727	5821061.58	-2.943E+09

Figure 8: Coefficients for Gas Pricing Models

2.2.2 Fuel Consumption

The consumption of resources plays a critical role in the economics of these two technologies. The fuel consumption is based off both the efficiency of the range technology, the intensity of the operation preformed by the stovetop, and the amount of time the stovetop is used. Due to this complexity we have outlined a framework that will allow for realistic comparison of the two models, which include the three variables outlined above.

The frameworks goal is to roll three variables into one that we have named Energy Quantity per Hour per Burner Unit (F). This index value F is in the case of Natural gas is the amount of Gigajoules to complete day worth of tasks. As for electricity the index value F is the amount of MWh needed to complete the exact same day worth of tasks. Below is a demonstration of how F is used in the formula:

$$\boldsymbol{E_c\left(\frac{\$}{GJ}\right)\cdot F_g\left(\frac{GJ}{Day}\right) = \ Natural\ Gas\ Costs\ Per\ Day}$$

$$\boldsymbol{E_c\left(\frac{\$}{MWh}\right)\cdot F_i\left(\frac{MWh}{Day}\right) = \ Electricity\ Costs\ Per\ Day}$$

In order to generate the value for F we need to establish a baseline activity to calculate fuel consumption. For this we use the activity of boiling 1 liter of water. Using published values from research for induction and natural gas stoves we are able to use multiples of this energy use to estimate daily activities. The summation of all daily activities is to be converted to equivalent liters of water brought to boil.

The following is information that we used to attain values for Fi and Fg.

2.2.2.1 *Induction Ranges*

The main source of data was taken from research conducted by the Department of Hotel Catering; in the test a 240V main supply at 50Hz was used to power a 30kHz coil with a test surface diameter of 0.25m. Though out the experiment the power was at maximum level. The pan that was used was a pan that is common in commercial settings. These specifications are thought to be comparable to models used in the SUB. Below is the data obtained from this study.

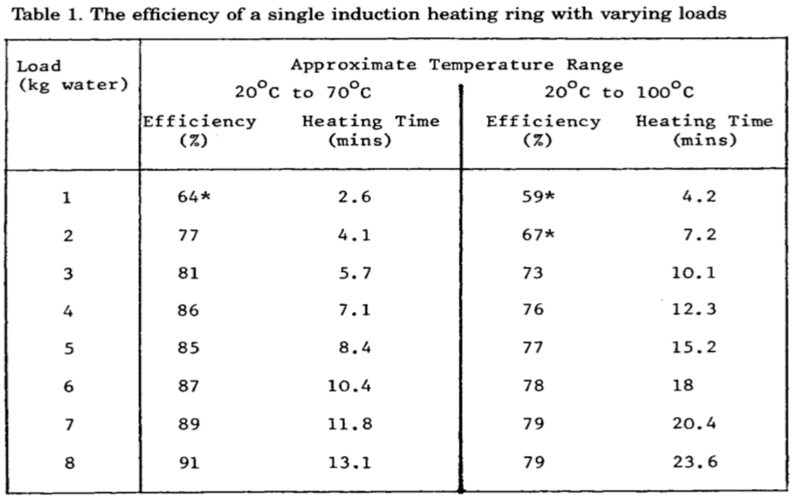
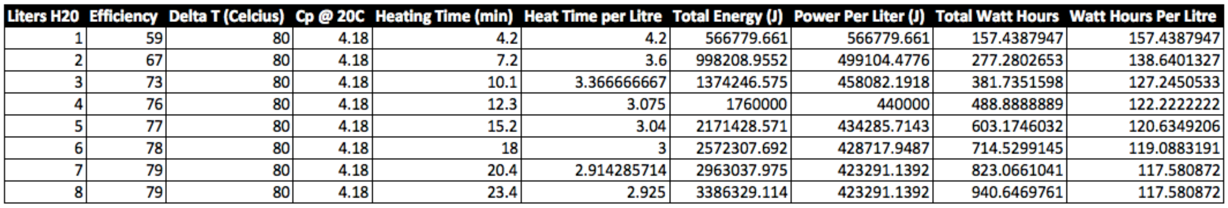


Table 1. The efficiency of a single induction heating ring with varying loads

Load (kg water)	Approximate Temperature Range			
	20°C to 70°C		20°C to 100°C	
	Efficiency (%)	Heating Time (mins)	Efficiency (%)	Heating Time (mins)
1	64*	2.6	59*	4.2
2	77	4.1	67*	7.2
3	81	5.7	73	10.1
4	86	7.1	76	12.3
5	85	8.4	77	15.2
6	87	10.4	78	18
7	89	11.8	79	20.4
8	91	13.1	79	23.6

Figure 9: Induction Boiling Experiment (Adams, A: 1985, 4)

This data was entered into a spreadsheet to calculate the power used in each test. From this an average power to boil one liter of water was estimated.



Liters H20	Efficiency	Delta T (Celcius)	Cp @ 20C	Heating Time (min)	Heat Time per Litre	Total Energy (J)	Power Per Liter (J)	Total Watt Hours	Watt Hours Per Litre
1	59	80	4.18	4.2	4.2	566779.661	566779.661	157.4387947	157.4387947
2	67	80	4.18	7.2	3.6	998208.9552	499104.4776	277.2802653	138.6401327
3	73	80	4.18	10.1	3.366666667	1374246.575	458082.1918	381.7351598	127.2450533
4	76	80	4.18	12.3	3.075	1760000	440000	488.8888889	122.2222222
5	77	80	4.18	15.2	3.04	2171428.571	434285.7143	603.1746032	120.6349206
6	78	80	4.18	18	3	2572307.692	428717.9487	714.5299145	119.0883191
7	79	80	4.18	20.4	2.914285714	2963037.975	423291.1392	823.0661041	117.580872
8	79	80	4.18	23.4	2.925	3386329.114	423291.1392	940.6469761	117.580872

Figure 10: Table of Energy Consumption with Per Liter Normalized Input

Based on the power calculations we concluded the following general performance parameters:

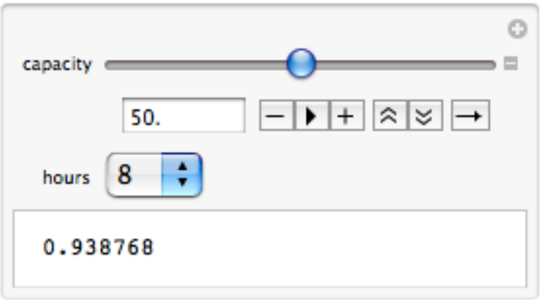
Parameter or Characteristic	**Value**
Average Boil Time	3 minutes 15 seconds (3.26 min)
Maximum Liters Boiled per Hour	18.4 Liters
Average Watt Hours per Liter	127.55 Wh

Using these characteristics we were then able to establish an index value for F with flexibility for the capacity ($\boldsymbol{\varepsilon}$) that the kitchen is being run at and hours per day ($\boldsymbol{\tau}$).

$$F_i = 127.55\frac{Wh}{L}\cdot 18.4\frac{L}{Hour}\cdot\frac{1\ MWh}{10^6 Wh}\cdot\ \varepsilon\cdot\tau\frac{Hours}{Day}$$

$$F_i = 0.00234692\cdot\ \varepsilon\cdot\tau$$

**Note Units of F is in MWh/day.

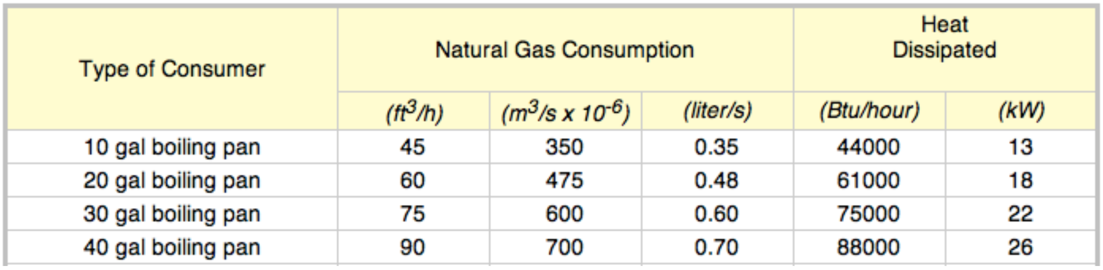


0.938768

Figure 11: Dynamic Mathematica 8 F Applet

*Figure 11 is a screenshot of a dynamic applet used to produce F for various capacity and hours. The top slider controls the capacity while the drop down button selects hours per day. The value of Fi is displayed in the box.

2.2.2.2 Natural Gas Ranges



Type of Consumer	Natural Gas Consumption			Heat Dissipated	
	(ft^3/h)	($m^3/s \times 10^{-6}$)	(liter/s)	(Btu/hour)	(kW)
10 gal boiling pan	45	350	0.35	44000	13
20 gal boiling pan	60	475	0.48	61000	18
30 gal boiling pan	75	600	0.60	75000	22
40 gal boiling pan	90	700	0.70	88000	26

Figure 12: Natural Gas Consumption for Boiling Water (The Engineering Toolbox: 2010)

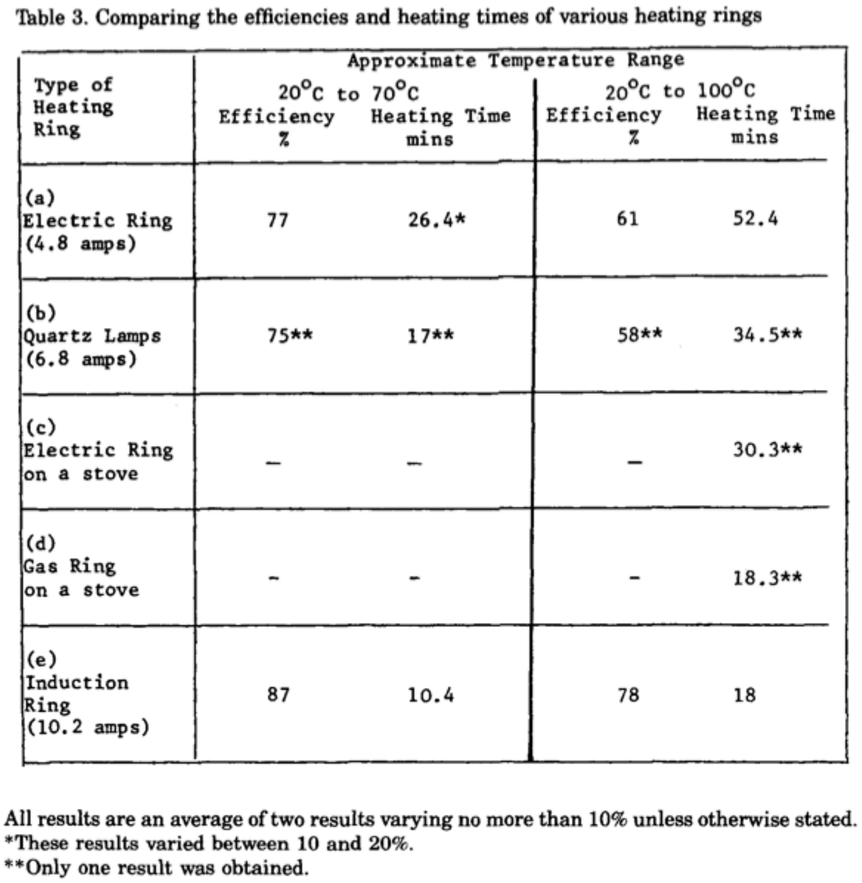


Table 3. Comparing the efficiencies and heating times of various heating rings

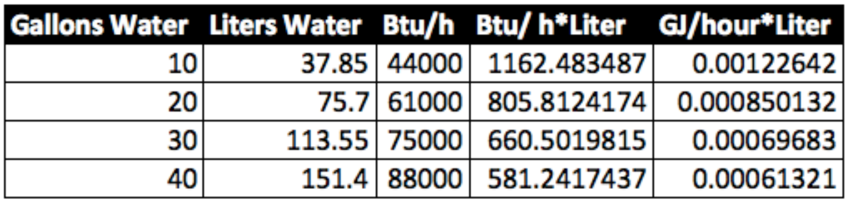
Type of Heating Ring	Approximate Temperature Range			
	20°C to 70°C		20°C to 100°C	
	Efficiency %	Heating Time mins	Efficiency %	Heating Time mins
(a) Electric Ring (4.8 amps)	77	26.4*	61	52.4
(b) Quartz Lamps (6.8 amps)	75**	17**	58**	34.5**
(c) Electric Ring on a stove	–	–	–	30.3**
(d) Gas Ring on a stove	-	-	-	18.3**
(e) Induction Ring (10.2 amps)	87	10.4	78	18

All results are an average of two results varying no more than 10% unless otherwise stated.
*These results varied between 10 and 20%.
**Only one result was obtained.

Figure 13: Comparative Boiling Time for Various Stovetop Technologies

(Adams, A: 1985, 6)

Using the data above attained from Engineering Toolbox we were able to calculated the numerical values for key parameters in the table below (Figure 14). Note data for the time to boil was provided with no measure of the fuel quantity, it is assumed that comparable models were used, thus a ratio of boil times was taken to determine the maximum output.



Gallons Water	Liters Water	Btu/h	Btu/ h*Liter	GJ/hour*Liter
10	37.85	44000	1162.483487	0.00122642
20	75.7	61000	805.8124174	0.000850132
30	113.55	75000	660.5019815	0.00069683
40	151.4	88000	581.2417437	0.00061321

Figure 14: Summary Table of Energy Consumption for Natural Gas Burners

Based on the power calculations we concluded the following general performance parameters:

Parameter or Characteristic	**Value**
Average Boil Time	3 minutes 19 seconds (3.31 min)
Maximum Liters Boiled per Hour	18.1 Liters
Average Fuel Used per Liter	0.000846648 GJ

Using these characteristics we were then able to establish an index value for F with flexibility for the capacity ($\boldsymbol{\varepsilon}$) that the kitchen is being run at and hours per day ($\boldsymbol{\tau}$).

$$\boldsymbol{F_g = 0.0008466\,\frac{GJ}{L} \cdot 18.1\,\frac{L}{Hour} \cdot\ \varepsilon \cdot \tau\,\frac{Hours}{Day}}$$

$$\boldsymbol{F_g = 0.015325 \cdot\ \varepsilon \cdot \tau}$$

**Note Units of Fg is in GJ/day.

2.3 UPFRONT COSTS

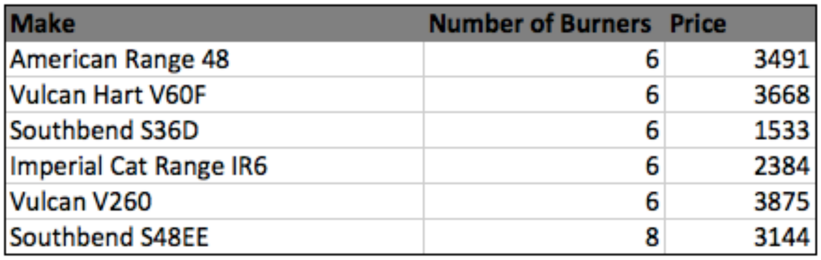
2.3.1 Relative Prices of Two Technologies

The upfront cost of the stovetop plays a large role in the economics, especially as upfront cost are relatively high. The upfront costs also act as a mental threshold in the decision making process. The following are cost estimated for implementing the two stovetop technologies. In order to generate the scope of prices for each technology, prices of multiple models were collected and a high and low estimate for total cost and cost per burner were established. For the direct comparison the price per burner is the most useful as it is assumed that equal amounts of burners are needed regardless of the technology choice. This same method of generating a price range for stovetops was conducted to determine the price for cookware.

When modeling the upfront costs for the stovetops and cookware it was assumed that they were to be purchased with cash in one single lump sum. Financing and longer-term payment plans would add extra variables that we did not have sufficient information to accurately model.

2.3.1.1 Gas Ranges

A small database of natural gas commercial ranges was generated to establish an estimate for the price. Gas ranges had a large variance in sizes, amount of burners, and other features. Due to this six ranges were selected that had comparable features. The following is table includes the ranges and a summary of prices used in the model. Adding or subtracting half a standard deviation from the mean constructs the high and low estimates, this gives a 67% cumulative probability range.



Make	Number of Burners	Price
American Range 48	6	3491
Vulcan Hart V60F	6	3668
Southbend S36D	6	1533
Imperial Cat Range IR6	6	2384
Vulcan V260	6	3875
Southbend S48EE	8	3144

Figure 15: Prices for Gas Ranges (Prices From: Nextag.com)

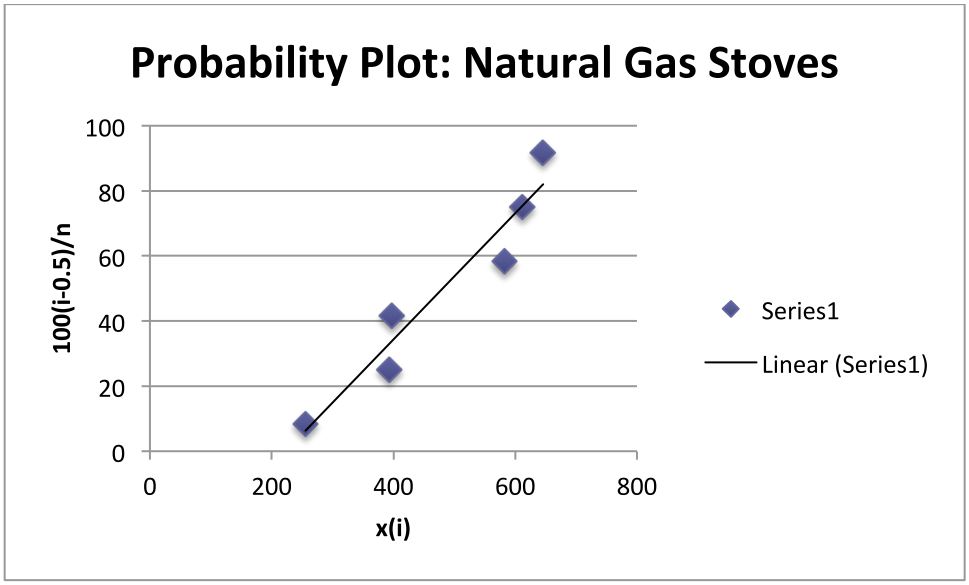
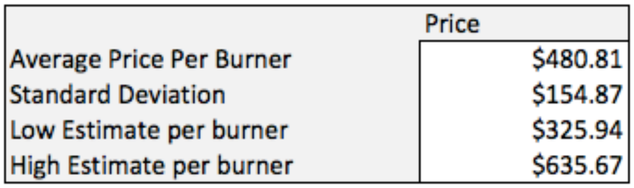


Figure 15: Probability Plot to prove normal distribution

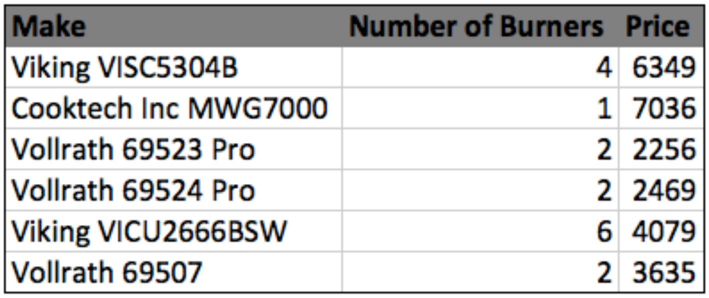


	Price
Average Price Per Burner	$480.81
Standard Deviation	$154.87
Low Estimate per burner	$325.94
High Estimate per burner	$635.67

Figure 16: Summary Table of Natural Gas Range Costs

2.3.1.2 Gas Ranges

The same techniques as the natural gas stoves were used to collect price data on induction stoves and later formulate a predicted price. There was a large discretion in the types of commercial ranges available; unlike gas the majority of induction are single burner. Computing the price per range attempts to make this comparable but there is a built in error as single cooktops are usually more expensive. The results and summary are as follows.



Make	Number of Burners	Price
Viking VISC5304B	4	6349
Cooktech Inc MWG7000	1	7036
Vollrath 69523 Pro	2	2256
Vollrath 69524 Pro	2	2469
Viking VICU2666BSW	6	4079
Vollrath 69507	2	3635

Figure 17: Prices for Induction Ranges (Source: Nextag.com)

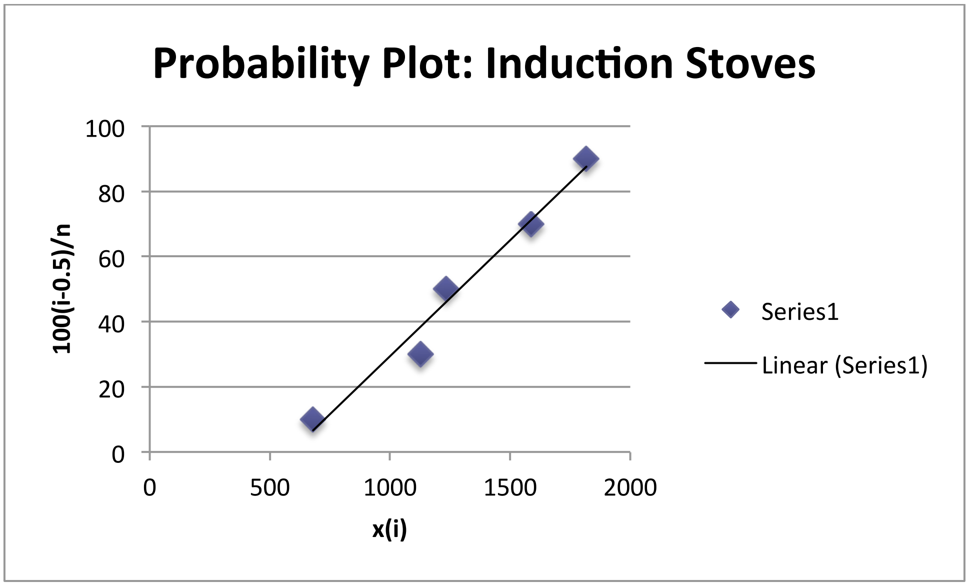
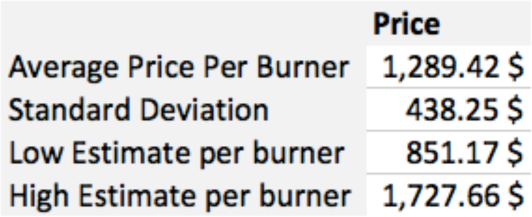


Figure 18: Probability Plot to prove normal distribution



	Price
Average Price Per Burner	1,289.42 $
Standard Deviation	438.25 $
Low Estimate per burner	851.17 $
High Estimate per burner	1,727.66 $

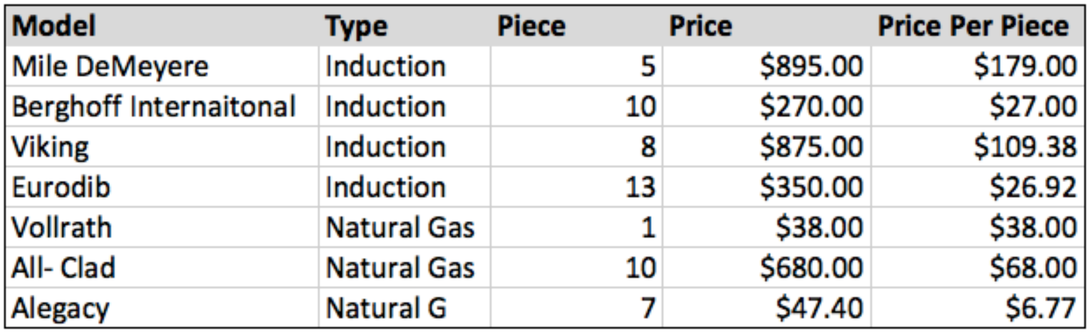
Figure 19: Summary Table of Induction Range Costs

*Note The Cooktech MWG7000 was removed, as it was an obvious outlier and affected the mean and standard deviation too much.

2.3.1.3 Cookware

It was originally thought that the price in cookware difference would have a profound effect on the economics of the two technologies. Once a formal investigation to the price of cooking pots and pans began it was determined that the quality of the utensil had a much larger difference on the price, rather then the technology it is compatible with. The following is a short list of comparable pots with prices listed. As you can see the range is massive, and thus a model cannot be accurately developed that predicts the effect of price differences to the overall economics. It is predicted the induction cookware will on average cost more but this trend is weakly supported by data.

For the model we will set the price of cookware to an arbitrary value of $50 per pot. This value doesn't affect the direct comparison because both equations will be divided by C_c.



Model	Type	Piece	Price	Price Per Piece
Mile DeMeyere	Induction	5	$895.00	$179.00
Berghoff Internaitonal	Induction	10	$270.00	$27.00
Viking	Induction	8	$875.00	$109.38
Eurodib	Induction	13	$350.00	$26.92
Vollrath	Natural Gas	1	$38.00	$38.00
All- Clad	Natural Gas	10	$680.00	$68.00
Alegacy	Natural G	7	$47.40	$6.77

Figure 20: Cookware Costs Database

*Based off the proceeding table we assume that $\boldsymbol{C_{\lambda g} = C_{\lambda i}}$

2.3.2 Expected Life and Replacement Costs

As with all technologies, the lifetime of the product is finite. In order to have an accurate picture to overall finances we have to put thought into the expected life of each technology. It is important not to overlook the relative life of these technologies as replacing this unit is very pricy and can greatly affect the economics in the long term.

This does pose a great challenge because we are unable to predict the upcoming changes to induction and natural gas technologies, and in turn how these technological strives are going to affect the price of the units. Like future predictions for energy input costs we have used a range of scenarios to model future conditions. It is a well knows phenomena the price of a fixed technology decreases with time. That is new technologies are expensive at first but, years later the cost to obtain the exact same technology decreases substantially (usually in a exponential manner). Due to the relatively new introduction of induction stoves to the commercial setting we might infer that future model could cost significantly less in the future. Natural gas stoves are in the opposite side of the spectrum, due to its heavy use in commercial settings the prices seem to have settled.

Based on the two observations above we have developed a multiple scenario model. Below is a screen shot of an applet along with a description of the three scenario, and assumptions.

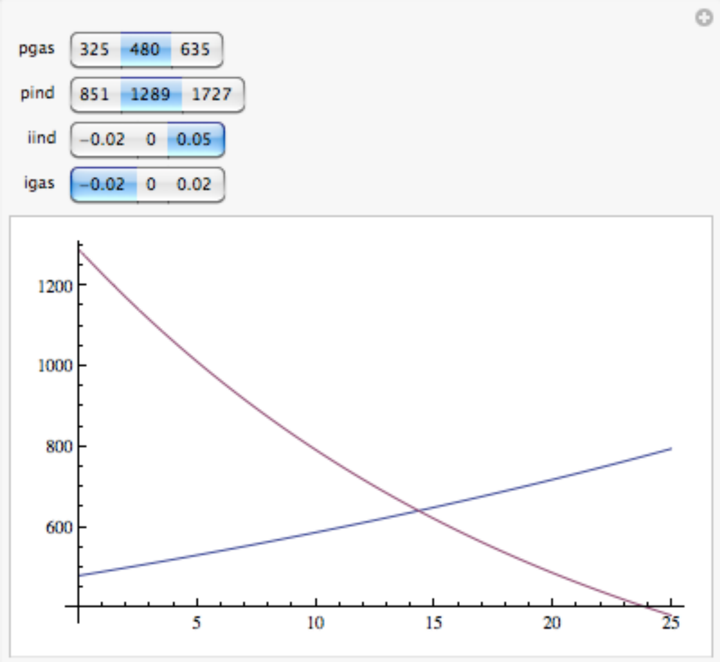

pgas 325 480 635
pind 851 1289 1727
iind −0.02 0 0.05
igas −0.02 0 0.02

Figure 21: Interest Rate Combined with Diminishing Cost Equations

- The two top lines (pgas, pind) are used two select the prices used select the starting price for each technology. The options available in the applet are the low, medium, and high estimate from the prior section.
- The bottom two lines (iind, igas) are the discount rates. The first option -0.02 is the expected price using a 2% inflation estimate. The second option is 0; this indicates that the rate of price reduction for a constant technology is equal to inflation. The proceeding options are different discount rates for each technology spanning from %2 to 10% discount pre year. Further consulting with a professional would allow for a better estimate of this value.

The model was built off a present value-pricing model used for bonds (see equation below). This does an excellent job at capturing the current day price for future purchases at discount rates, but doesn't exhibit exponential decays for new technology pricing.

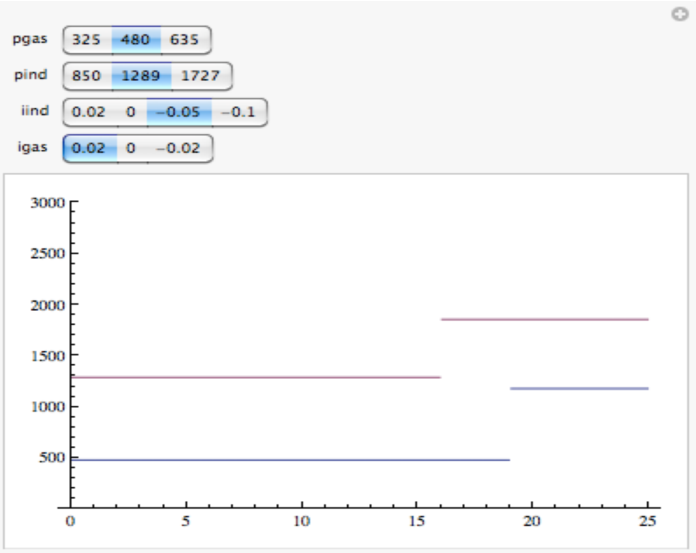
Present Value = Future Value *(1+yearly discount rate)^(year period)

$$PV = FV \cdot (1+i)^t$$

Now that pricing for future replacements have been established, we now have to determine the replacement period for each of the technologies. Information was very limited for commercial units, thus residential lifetimes were used. A consensus from multiple websites yields the following:

Natural Gas Life:	19 years
Electric Life:	16 years

Combining this new information with the discount applet above, we a new now have a model that can predict the combination of upfront and replacement costs for multiple scenarios. One example of unit expenditure is shown in figure 22 below.



pgas 325 [✓ 480] 635

pind 850 [✓ 1289] 1727

iind 0.02 0 [✓ −0.05] −0.1

igas [✓ 0.02] 0 −0.02

Figure 22: Interest Rate Combined with Diminishing Cost Equations Lifetime Replacement Costs

2.4 KEY INDICATORS

2.4.1 Complete Equations

Section 1-3 of the economic section of the report outlined the variables used to develop comparison equations, and point estimates for these variables. Below is the original governing equations and equations with manipulation to augments them into a per burner form.

(1) $C_g(\mathrm{N}, t_g))=(U_{cg}+C_{\lambda g})(\mathrm{N}\cdot D_\Delta)+(E_{cg}\cdot F_g)(t\cdot N)+(R_{cg}\cdot R_{tg})(t\cdot N)$

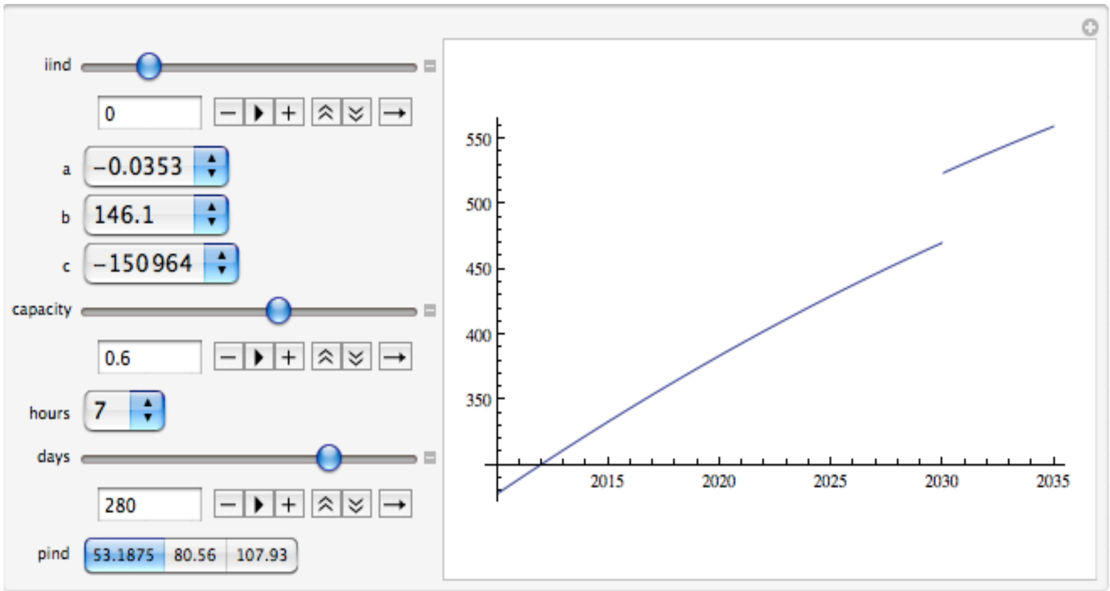
(2) $C_i(\mathrm{N}, t_i))=(U_{ci}+C_{\lambda i})(\mathrm{N}\cdot D_\Delta)+(E_{ci}\cdot F_i)(t\cdot N)+(R_{ci}\cdot R_{ti})(t\cdot N)$

- Divide each equation by **(N)** based on assumptions outlined on p.x.
- Subtract unit cost from (1) and (2) as investigation yielding no proof of a concrete price difference.
- Discount formula drops out in the per burner form.

(3) $C_g(t_g)=U_{cg}+(E_{cg}\cdot F_g)(t)+(R_{cg}\cdot R_{tg})(\mathrm{t})$

(4) $C_i(t_i)=U_{ci}+(E_{ci}\cdot F_i)(t)+(R_{ci}\cdot R_{ti})(t)$

Equations 3 and 4 will be used for the direct comparison between the two technologies. Below are graphical visualizations of equation 3 and 4. Note the slide bars, drop down menus, and buttons allow for the changing of variable’s in each of the equations to create new pricing “environments”.



iind 0

a −0.0353

b 146.1

c −150964

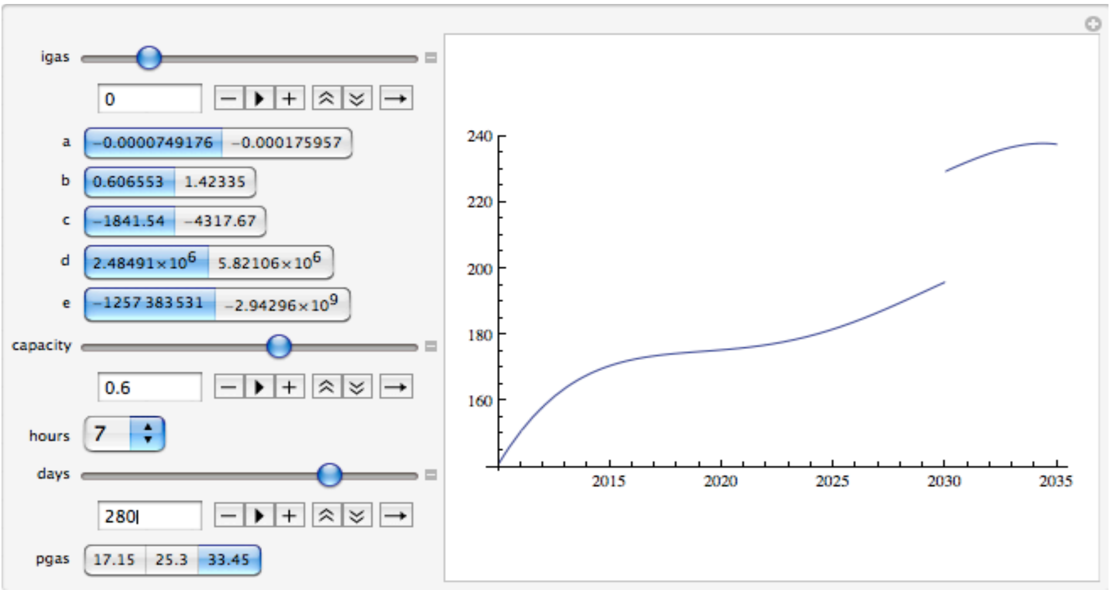
capacity 0.6

hours 7

days 280

pind 53.1875 | 80.56 | 107.93

Figure 23: Operation Cost per year for Induction Stoves.



igas 0

a −0.0000749176 | −0.000175957

b 0.606553 | 1.42335

c −1841.54 | −4317.67

d 2.48491×10^{6} | 5.82106×10^{6}

e −1257 383 531 | -2.94296×10^{9}

capacity 0.6

hours 7

days 280

pgas 17.15 | 25.3 | 33.45

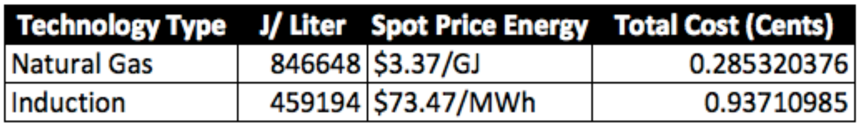
Figure 24: Operations Cost per year for Natural Gas stoves.

As you can see from Figure 23 and 24, the economics for natural gas stoves with the same capacity, hours per day, and days per year, favor the natural gas technology. Just by inspection you can see that once you integrate these two curves to obtain total cost, the induction stoves are close to order of two times more expensive. We ran a large batch of different pricing models using different combinations of operation and pricing models. In almost all of the cases, natural gas was the clear favorite in terms of economics.

The only time in which induction stovetops became more economically feasible is when there was a difference in the capacity. It is feasible that you could have a much lower capacity for induction stove tops as they are only on when you need to use them, while natural gas stoves may be running at all times. This discrepancy in capacities is what brings the economics into the same range. It should be noted that this relationship of independent capacities exists on a mathematical level, but is not directly supported by research of any kind. This observation does merit further research into the capacity/ operation conditions of real commercial kitchens.

2.4.2 Normalized Price per Output

A key indicator that we based our recommendation around is the normalized price per unit of output. For this indicator we used empirical data used in section XX of the report to find the price in current day dollars to boil one liter of water. This value was extrapolated from the analysis we conducted to determine the energy input, fuel cost, and technology efficiency in prior sections.



Technology Type	J/ Liter	Spot Price Energy	Total Cost (Cents)
Natural Gas	846648	$3.37/GJ	0.285320376
Induction	459194	$73.47/MWh	0.93710985

Figure 25: Summary of Fixed Output Costs

We compared the data in the summary table above with published data on the efficiencies of these two technologies. A consensus between various sources indicates efficiency levels around 80-85% for induction with 35-50% for natural gas. From our own analysis we found that we were inline with published data, comparatively natural gas we determined to be half as efficient as induction.

It is interesting to note that while the efficiency of induction stoves are much higher (54% of energy used in natural gas), the price is almost three times higher on a normalized basis. This led us conclude again, that natural gas stoves are highly favorable from an economic standpoint.

3.0 ENVIRONMENT

3.1 ENERGY CONSUMPTION

It is important to analyze the lifespan energy usage and efficiency values for both stove technologies. Total energy usage values give an indication of a variety of environmental impacts as they enable the calculation of total lifespan emissions. These lifespan emission values represent the bulk of the associated environmental costs for both stove types, and are thus of key importance. The energy efficiency of both stoves is also an important environmental consideration as it indicates each product's ability to limit the amount of waste energy in the cooking process.

The formula used to calculate lifetime energy use was as follows:

$E = P * N * D * L * (3600s/hour)$

E = *Lifetime Energy Input (GJ)*

P = *Average power input (GW)*

N = *Hour usage per day (hours)*

D = *Day usage per year (days)*

L = *Stove lifespan (years)*

In calculating *E* for both stoves we assumed the following values for the time usage parameters:

N = 8 hours per day

D = 250 days per year

L = 19 years

3.1.1 Gas Stove Energy Use

Based on test data from an in-kitchen appliance performance report from the Food Service Technology Center, the median power input to a high power six burner gas range stove is approximately 30 kBtu/h per burner (Yap et al: 1998, iii).

First a conversion factor n is applied where:

$n = 2.9307107 \times 10^{-7}$ (GW)/(kBtu/h)

Thus, assuming all time parameters to be accurate, and assuming full capacity, the lifetime energy input to a six burner 180 kBtu/h gas stovetop is:

$E = n\ P\ N\ D\ L\ (3600s/hour)$

$= (2.9307107 \times 10^{-7})(180)(8)(250)(19)(3600)$

$E_G = 7216$ GJ (1203 GJ per burner)

It must be noted that in all likelihood the gas stove's capacity will vary unpredictably on an hourly basis, and thus actual lifetime energy input E will in all likelihood be lower than calculated.

3.1.2 Induction Stove Energy Use

Based on data for the Garland 2.5KW Induction Range Top, the median power input to this single plate induction stove cooker was measured as 2.61KW (Cesio et al: 1996, 3-1). Assuming that all input time parameters are correct, and assuming full capacity, the lifetime energy input to a six plate (15.66KW) induction stovetop is:

$E = P\ N\ D\ L\ (3600s/hour)$

$= (0.00001566)(8)(250)(19)(3600)$

$E_I = 2142$GJ (342GJ per plate)

It must be noted that to find lifespan energy use in terms of GJ of gas used at the gas/steam power plant, the E value for the induction stove must be divided by the efficiency of the plant. Thus for an assumed plant efficiency of 50%, the indirect lifespan gas energy use of the induction stove would be E/(0.5) = 4284GJ (684GJ per plate).

It must also be noted that due to internal energy management systems present in most induction cookers, this value should be taken as a maximum value. It assumes that during each stove's daily eight hour use each plate is constantly cooking, with very minimal downtime. As with the gas stove, this E value will in reality be lower due to unpredictable cooking patterns.

3.1.3 Efficiency: Gas vs. Induction

When examining the energy efficiency of induction and gas range stoves, it is important to find the relationship between the stove's energy input (in terms of fuel or electricity), and its output (effective heat energy that is ultimately transferrable to food). It must also be recognized that a stove's efficiency will depend on a variety of factors including cooking method, stove technology, temperature, and humidity (Jungbluth et al: 1997, 6).

Sources indicated a maximum gas stove efficiency of just over 50% (Jungbluth et al: 1997, 6), and a maximum induction stove efficiency of 84% (Sorensen et al: 2008, 3-3). From direct energy input, induction stoves are almost twice as efficient at transferring energy to food. The power source for the new Student Union Building, however, must be taken into account here. If the current source is to continue being used, the efficiency of the gas/steam generated electricity conversion process must be looked at. By assuming a realistic plant energy conversion efficiency of 50%, it can be concluded that induction stoves in the new sub would experience reduced indirect efficiencies comparable to those of gas stoves.

3.1.4 Summary

Assuming correct time input parameters and a gas/steam plant efficiency of 50%, as well as not taking into account variable cooking patterns (both stoves at full capacity), the induction stove will indirectly use **4284GJ** of gas generated energy, while the gas stove will use **7216GJ** of gas generated energy, both in their respective nineteen year life spans.

3.2 ENVIRONMENTAL IMPACT OF EACH TECHNOLOGY

3.2.1 Environmental Life Cycle Analysis

All areas of a product's life will inevitably have environmental effects, from the extraction of raw materials to the manufacturing and packaging processes, and most importantly, the lifetime usage of energy. In order to definitively compare technologies in terms of the environmental impact they have throughout their lifespan, a standardized life cycle analysis (LCA) system must be used. Without the use of such a system we are left with a very ambiguous task of quantifying each technology's environmental impact.

3.2.1.1 Problems associated with LCA`s

To date, the problems associated with these systems are mainly due to the difficulty of interpreting the results yielded by LCA's. While it is possible to definitively find a technology's impact in certain environmental areas such as the greenhouse effect and ozone layer depletion, it is difficult to compile and produce a total environmental impact encompassing all areas of environmental concern (Jungbluth, 1997).

Another obstacle to correct interpretation of LCA's is the expensive, time consuming nature of gathering environmental data over the course of a product's lifespan. In most cases a detailed comprehensive LCA cannot be completed during the design of a particular technology.

3.2.2 Eco-Indicator 99 Analysis

The Eco-Indicator 99 is a tool developed by several companies, research institutes and the Dutch government that offers solutions to the main problems with LCA's. The goal of this tool is to allow designers and engineers to easily compare multiple technologies in terms of their environmental impacts. Each material process contributing to the working life of a product is ultimately given an Eco-Indicator number, with a higher number corresponding to a higher environmental impact. The designer or customer then creates a life cycle inventory of individual components, processes and energy inputs that are present throughout a technology's lifespan. Once this is complete the indicators are looked up for each process and totaled.

3.2.2.1 Eco-Indicator Points System

Indicators have already been calculated for a variety of processes, including steel, aluminum, thermoplastics, and paper production, as well as actual manufacturing processes (injection molding, rolling, turning, welding…etc.). Indicators have also been produced for a variety of energy generation and waste process (Goedkoop, Effting, & Collignon, 2000).

This comprehensive list of eco indicators for many processes allows a designer to list off amounts of each material and types of processes used in the lifespan of a product and compile their respective eco-indicator values to find a total value for the entire product.

3.2.2.2 Scope and Limitations of the Eco-Indicator 99 Analysis

A potential drawback to this method of life cycle analysis is that it requires specific target levels of emissions for each material and process. These target levels have to be decided on collectively by scientists, and there is often disagreement on the required target values. There is also inevitably a degree of subjectivity in the decided weighting of each environmental impact. The figure below shows the damage model path taken to assign Eco-Indicator values to each material process. Each step as expected contains some degree of subjectivity, and that should be taken into account when using the final eco-indicator value.

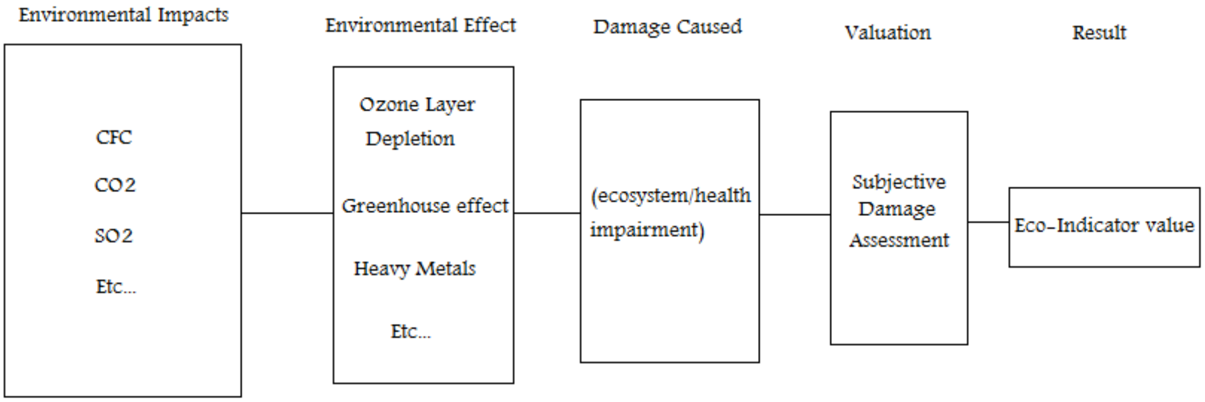


Figure 26 : Eco-Indicator Damage Model

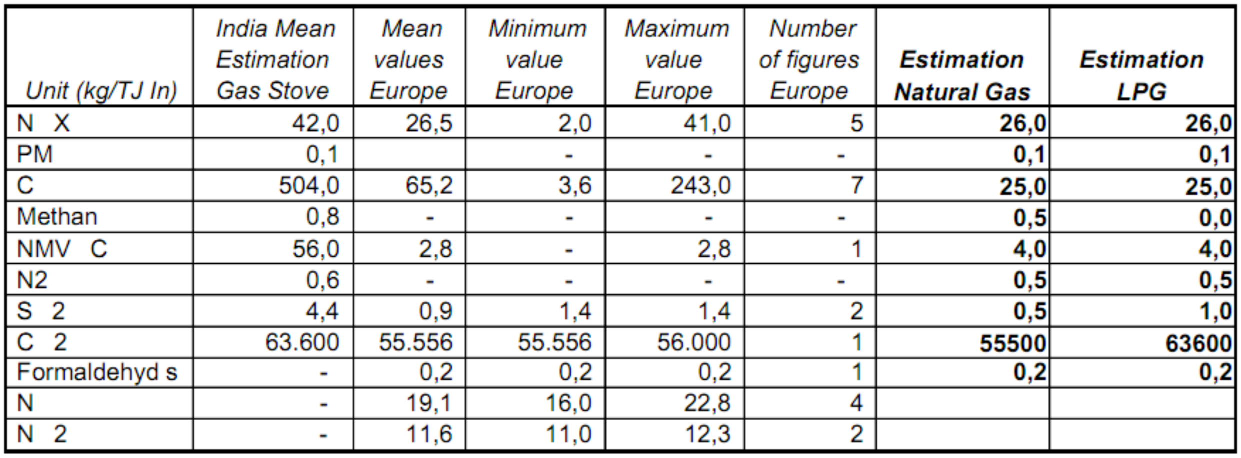
It should be recognized that this method of environmental analysis allows the comparison of two products based on standards with a degree of subjectivity. It is important to use this analysis in a way that adheres to specific assumptions. In this analysis, obtaining material inventories for induction stove production was not possible. This analysis only encompasses environmental impacts due to lifespan energy consumption which, as stated earlier, has by far the largest environmental impact for both stove types.

3.2.2.3 Comparison of Gas and Induction Stoves

As calculated earlier, the estimated lifespan energy consumptions for both specified stove models at maximum full time capacity were:

Six Burner180kBtu/h Gas Stove:	7216GJ (7.216TJ)
Six Plate 15.66KW Induction Stove:	4284GJ (4.284TJ)

The table below gives figures for estimated emissions in kg per terajoule (TJ) due to the combustion of natural gas (Jungbluth et al: 1997, 10).



Unit (kg/TJ In)	*India Mean Estimation Gas Stove*	*Mean values Europe*	*Minimum value Europe*	*Maximum value Europe*	*Number of figures Europe*	***Estimation Natural Gas***	***Estimation LPG***
N X	42,0	26,5	2,0	41,0	5	**26,0**	**26,0**
PM	0,1		-	-	-	**0,1**	**0,1**
C	504,0	65,2	3,6	243,0	7	**25,0**	**25,0**
Methan	0,8	-	-	-	-	**0,5**	**0,0**
NMV C	56,0	2,8	-	2,8	1	**4,0**	**4,0**
N2	0,6	-	-	-	-	**0,5**	**0,5**
S 2	4,4	0,9	1,4	1,4	2	**0,5**	**1,0**
C 2	63.600	55.556	55.556	56.000	1	**55500**	**63600**
Formaldehyd s	-	0,2	0,2	0,2	1	**0,2**	**0,2**
N	-	19,1	16,0	22,8	4		
N 2	-	11,6	11,0	12,3	2		

Figure 27 : Estimated emissions per Terajoule of combusted natural gas energy

Based on values in column seven, the significant total lifespan emissions for both stove tops can be found. The table below shows lifetime emissions of Nitrogen Oxides (NOx), Carbons (C), and Carbon Dioxide (CO2) for both stove types.

Emission	Unit Amount (kg/TJ)	Gas Stove Emissions For 7.216TJ (kg)	Induction Stove Emissions For 4.284TJ (kg)
NOx	26.0	187.6	111.4
C	25.0	180.4	107.1
CO2	55500	400488	237762

Because of the induction stove's assumed electrical source, we are able to compare emissions due to both stove types. In all categories the induction stove indirectly produces lower emissions than the gas stove throughout a nineteen year lifespan.

Using the Eco Indicator 99 Annex for heat generation, the eco- indicator for industrial gas combustion is 5.3 millipoints per megajoule (Goedkoop et al: 2000, Annexe 4). Total indicators are shown below.

$I = E^* (1000000MJ/TJ)^*0.0053$

I = *Eco-Indicator for Life time Stove Energy Use*

E = *Life time Stove Energy Use*

Gas Stove Energy Use Indicator $I_G = 7.216(1000000)(0.0053)$

$I_G = 38245$

Induction Stove Energy Use Indicator $I_I = 4.284(1000000)(0.0053)$

$I_I = 22705$

As expected, the Induction Stove has lower indirect emissions than the Gas Stove and thus a lower Indicator score (smaller environmental impact). Based on this data it is our conclusion that choosing induction stove tops is the more favourable option in terms of overall life time environmental impact.

4.0 SOCIAL

4.1 SCOPE

When investigating the social aspect of the comparison between gas and induction stovetops, the analysis is broken down into the stovetop market, employee safety and continuous operations. Examining the current market is crucial in determining the current state of the gas and induction stovetops and how the public perceives each technology. The safety implications of each stovetop are analyzed as the health of the UBC employees cannot be ignored. Finally the operation of the stovetop technology including physiological stresses, maintenance and cooking techniques are examined. With these components analyzed, the best stovetop technology for the new UBC SUB can be determined.

4.2 STOVETOP MARKET

The social aspect of the comparison between gas and induction stovetops is crucial in determining the optimal choice for the UBC SUB. Although economics and environment are contributing factors, the public's perspective and acceptance has a significant impact on the success of new technology. In today's generation, gas stovetops became a commercial appliance since the 1880s with the growth of the gas pipe networks. In the United States, the first long distance natural gas lines began in 1930. These gas transportation pipelines soon extended to large gas fields such as the North Sea, Middle and Siberia (Bizzo et al: 2004, 61). About 30 to 60% of the population in most European and American countries rely on liquefied petroleum gas around the world creating a large market for gas stovetops (Brauer, M et al: 1996, 412).

On the other hand, commercial induction stovetops for cooking are still fairly recent technology with patents of "Wireless Transmissions of Temperature" invented by John Harnden dating back to 1973 (Harnden: 1973). With a century lead in growth, gas stovetops have a deeper impact on the public's views and experiences than the induction stovetop as most North American family's homes are equipped with gas technology. Although induction stovetops are considered a more recent technology, there is a significant growth in the development of this appliance with 28 patents referencing Harden's original filing. These patents evolve the basic induction technology with greater features and efficiency such as grilling units and RFID control chips.

According to Schultheiss' article on "The Power of Induction," manufacturers in Europe and Asian began experimenting with induction technology to cooking uses by the 1970s. In 2008, 65 commercial induction stovetops were introduced in the market from major manufacturers including Bosch, Electrolux, GE and Kenmore. In a commercial business vendor perspective, the purchaser for Sears, Rick Demert, commented on how induction stovetops are an “expanding category” and growing from 3 models to 20 by year-end. The article also observes that mainstream manufacturers such as GE, Kenmore and Viking are marketing induction appliances under their high-end lines (Schulthesiss: 2008, 149). With this marketing approach, the public acceptance of this technology is more settle in entering the market.

As discussed earlier in this research, induction stovetops need a greater capital for implementation. The up-front costs for induction stoves are greater than gas stoves. With a new SUB’s catering kitchen being renovated, this is an opportunity to implement a more efficient solution and help develop a new technology for the mainstream market. Consumers need different choices when selecting a product and new technologies are difficult to surface in a fully developed market. With commercial projects such as the UBC SUB, they can indirectly support new innovations creating a stovetop market with more options.

4.3 WORKER SAFETY

Health and safety of the operators are crucial in the consideration for the most optimal stovetop. The public has a strong perceptive on the safety of the product they will be using. The health hazards associated with gas and induction stovetop will be discussed to determine the safest option of the new UBC SUB.

Gas stovetops require the burning of liquefied petroleum gas which creates a high intensity flame to heat up the cooking element. This generation of heat of around 18000 BTUs causes a high probability of serious burn injuries. A study conducted by Dr. Powell and Dr. Tanz investigated burns of children associated with the use of microwave ovens and conventional stoves. Over a five year period, 41198 burns were associated with gas stovetops and 5160 burns were connected with microwaves which is 73.6% increase. The majority of stove burns (74%) were thermal and seven percent involved a body surface area greater than 25% (Powell et al: 1993, 346). Five percent of gas stovetop injuries required hospital admission. The study concluded that stove burns are more frequent and more severe than microwave ovens and “burn prevention efforts should emphasize the hazards of stoves” (Powell et al: 1993, 348).

A by-product of gas stoves is nitrogen dioxide (NO_2) which has adverse effects on respiratory health. A study conducted by D. Jarvis and the Department of Public Health Medicine of United Medical and Dental Center in London investigates the concerns of gas stoves to respiratory health. Traditional gas stoves can emit pollutants which may cause respiratory infections, chronic lung disease, heart disease and eye irritation after long exposures in confined spaces. Other effects of liquefied petroleum gas include vertigo or dizziness at high concentrations (Bizzo et al: 2004, 65). Using gaseous fuel as a source of energy, the adverse health effects of gas emissions cannot be neglected and may cause long term concerns. These effects are exhibited for long exposures.

In an industrial setting, cooking equipment may accidentally be turned on when not in use. With gas stoves, unintended release of gaseous fuel poses a great risk if an ignition source is present. This can lead to “property damage and/or bodily harm, and possibly an explosion” (Bizzo et al: 2004, 65). Although the situation is exceptionally rare, the danger of gas needs to be considered when comparing different types of stovetops. With induction stovetops, energy is only transfer when in contact with a specialized pot and the risk of any release of energy is improbable.

The effect of induction stovetops is that emission of the time-varying electromagnetic waves due eddy currents in the coils. Electrical interference is common with strong electromagnetic fields and the safety of cooks with artificial medical devices should be considered. A study published in the European Society of Cardiology investigates the effects of induction stovetops on cardiac pacemakers. The study examines eleven induction stovetops and the measures the voltage through the patient’s body for different operating condition including pot position, pot sizes and pot handling. The experimental results concluded that the patient is potentially endangered if they are close to the cooktop and the pot is positioned extremely eccentrically. These situations are rare and may affect 14.8% of the total pacemaker population but the safety implications cannot be ignored (Irnich et al: 2006, 383).

Induction stovetop uses electric and magnetic fields to heat up of the pot and produces no flames or smoke. Due to the physics of vessel’s material properties to heat the content, there is no heat generated on the stove itself. This reduces the probability of direct burns or accidentally contacting the range which significantly decreases the burn injuries compared to gas stoves as the hazard is essentially eliminated by the induction technology. Furthermore the emissions from gas stoves can have adverse respiratory effects under certain conditions. On the other hand, induction stovetops may have negative effects to people with artificial pacemakers. Although, electromagnetic interference is a concern to a small population, the social aspect of equal employment must be considered. UBC can achieve a higher standard of safety for their employees with the implementation of induction stovetops for the SUB catering services.

4.4 OPERATING CONDITION

Although operating quality and operational health goes hand in hand, the conditions that the cook experiences throughout the work shift is a social application that needs to be investigated. This social aspect considers more than the physical conditions but also the physiological responses with working in a kitchen using gas and induction stoves. The environment of the food service industry is considers to the difficult due to long irregular working hours and standing in high temperature conditions.

A comprehensive study was conducted by Dr.Matsuauki and his team of medical experts to examine the stress caused by induction and gas stoves. A controlled experiment was developed featuring a mock kitchen and 12 individuals using an induction stove and a gas stove. Measurement devices were recorded to analyze the physiological responses. Body temperatures, body weight, heart rate, oxygen uptake, blood pressure, posture, and physical activities were monitored for the two stove scenarios (Matsuauki et al: 2008, 361).

Thermal stress is a crucial issue in a kitchen environment as it could lead to increased heart rate causing high stress. The radiant heat index from the gas stove was 10 times higher that the induction stove and over time increased significantly. The physiological response to the gas stove included higher heart rate, blood pressure, oxygen uptake, skin temperature. Furthermore, subjects responded to heat stress significantly more to gas stoves by using avoidance postures and actions, such as turning their body and face away (Matsuauki et al: 2008, 367). Induction stoves yielded better results in terms of physiological responses which lead to a better work environment.

Cooking technique is another social aspect that affects the effectiveness of implementing a new type of stovetop in an industrial setting. The induction stovetop technology utilizes high-frequency electromagnetic waves to transfer energy from the stove to the pot material. This requires direct contact of the cooking pot to the stove in order to produce heat. The use of a wok is common in the food service industry and current induction stovetops are not adequate due to the required contact of the pot to the element. Although, a United States patent for a specialized induction wok has been designed, the complexity of a dual-plate bowl is unfeasible and is currently unavailable in the market (Loong-Chiang: 1992).

The maintenance of the kitchen is important in an industrial environment and lifetime of the stovetops needs to be considered. In order to examine the general maintenance of both gas and induction, the typical patents for both technologies are examined. The “Wireless Transmissions of Temperature” patent discussed earlier and the “Gas Cooktop Appliance” patents are analyzed (Kitabayashi: 2000). Since gas stovetops are more developed and dominant in the market, maintenance troubleshooting and procedures are more mature than induction stovetops.

Cleaning is a crucial factor for health and safety in the food service industry and having an easy to clean system is important. According to the patents of the two technologies, the induction stove patent has a smooth surface counter while the gas stovetop uses heating burner element to contact the pot shown in the figure below. Due to the smooth surface of the induction stove, cleaning is more efficient and the chance of food scarp accumulation is unlikely than the gas stovetop.

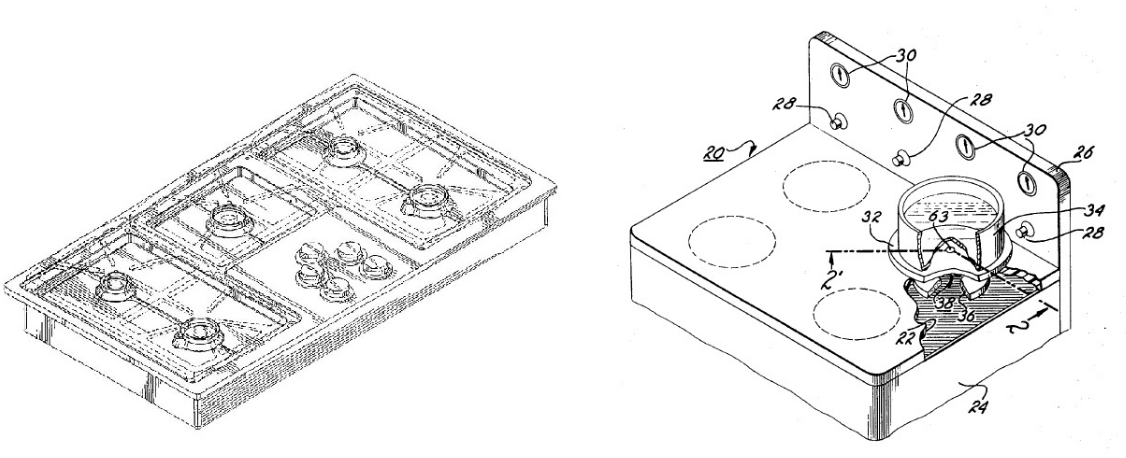


Figure 28 : A common grill gas stovetop (left) and a typical flat induction stovetop (right).

5.0 CONCLUSION

In using the triple bottom line analysis method, our team was able to conduct sufficient research to come to a recommendation in stovetop technology for the food service needs of the new Student Union Building. By breaking down each major area of consideration we were able to see which technology was favourable in each branch of the analysis. While it was concluded through extensive economic modelling that natural gas ranges would be the cheaper technology, the environmental analysis and social analysis both leaned towards induction stovetop technology as the more favourable option. Implementation of Induction technology would yield lower long term emissions when compared to gas range technology, as well as offer significant safety and practicality benefits to cooks. Based on our research it was concluded that the increased costs associated with induction stovetops would be justified by the environmental and social benefits offered by the technology.

6.0 BIBLIOGRAPHY

Adams, A., & Palin, M. (1985). An Investigation into the Efficiency of Induction if Induction Cooking and a Comparison of its Performance with other Cooking Methods: *Department of Hotel Catering and Institutional Management*

Bizzo, W., & Calan, B. (2004). Safety issues for clean liquid and gaseous fuels for cooking in the scope of sustainable development. *Energy for Sustainable Development, 3, 60-67.*

Brauer, M., & Kennedy, S., (1996). Gas stoves and respiratory health. *Lancet. 347. 412-415.*

Cesio, C., & Young, R. (1996). *FTSC Report 5011.95.30 : Garland 2.5kW Induction Range Top.* San Francisco: Pacific Gas and Electric Company.

Engineering Toolbox, The (2010) .*Natural Gas Consumption.* Retrieved January 28, 2011 from http://www.engineeringtoolbox.com/natural-gas-consumption-d_172.html

Goedkoop, M., Effting, S., & Collignon, M. (2000). *The Eco-indicator 99: a damage oriented method for Life Cycle Impact Assessment.* Amersfoort: PRé Consultants B.V.

Harnden, J. (1973). Induction Cooking Appliance including Wireless Transmission of Temperature Data. *United States Patent. 3742179.*

Irnich, W., & Bernstein A. (2006). Do induction cooktops interfere with cardiac pacemakers?. *European Society of Cardiology, 8, 377-384.*

Jungbluth, N. (1997). *Life Cycle Assessment for Stoves and Ovens.* Zurich: Chair of Environmental Natural Sciences and Social Science Interface.

Kitabayashi, J. (2000). Gas Cooktop. *United States Patent. 421694.*

Loong-Chiang, H. (1992). Electric Wok. *United States Patent. 3129314.*

Powell, E., & Tanz R. (1993). Comparison of Childhood Burns Associated With Use of Microwave Ovens and Convectional Stoves. *Paediatrics. 91, 344-349.*

Schultheiss, S. (2008). The Power of Induction. *Money.3. 01494953.*

Manitoba Hydro. (2010) *Utility Rate Comparisons.* Retrieved January 16, 2011, from http://www.hydro.mb.ca/regulatory_affairs/energy_rates/electricity/utility_rate_comp.shtml

Matsuzuki, H., Ayabe, M,. Haruyama, A., Seo, A., Katamoto, S., Ito, A., & Muto, T. (2008). Effects of Heating Appliances with Different Efficiencies on Associations among Work Environments, Physiological Responses, and Subjective Evaluation of Workload. *Industrial Health. 46, 360-368.*

New Sub Project (2010) *75% Schematic Design Report*

Northwest Power and Conservation Council.(2010) *Sixth Northwest Conservation and Electric Power Plan Appendix D*. Retrived February 2, 2011, from http://www.nwcouncil.org/energy/powerplan/6/final/SixthPowerPlan.pdf

Sorensen, G., & Zabrowski, D. (2008). *FSTC Report 5011.08.02 : Diva 10-CT Induction Cooktop Performance Test.* San Francisco: Food Service Technology Center.

TMX. (2010) *NGX Alberta Market Price.* Retrieved February 2, 2010, from http://www.ngx.com/adepenergysum.html

US Energy Information Administration (2010) *Annual Energy Outlook 2010: With Projections to 2035*

Yap, D., Chester, J., Young, R., & Knapp, S. (1998). *FSTC Report 5011.98.64 : Montague Model V136-5 Heavy Duty 30,000 Btu/h Open Top Gas Range.* San Francisco: Pacific Gas and Electric Company.

APPENDIX: CODE FROM ECONOMIC ANALYSIS

<u>**All code is run natively on Mathematica 8**</u>

Inflation Modeling

```
low = 325;
high = 623;
Manipulate[
 Plot[{pgas/((1 + igas)^x), pind/((1 + iind)^x)}, {x, 0, 25}], {pgas, {low,
   high}}, {pind, {851, 1727}}, {iind, -0.02, 0.1}, {igas, -0.02, 0.1}]
```

```
Manipulate[
 Plot[{Piecewise[{{pgas, x < 19}, {pgas + (pgas*((1 + igas)^19)), x >= 19}}],
   Piecewise[{{pind, x < 16}, {pind + (pind*((1 + iind)^16)), x >= 16}}]}, {x,
    0, 25}, PlotRange -> {0, 3000}], {pgas, {325, 480, 635}}, {pind, {850, 1289, 1727}}, {iind, {0.02, 0, -0.05, -
0.1}}, {igas, {0.02, 0, -0.02}}]
```

Dynamic Modeling of Fi and Fg

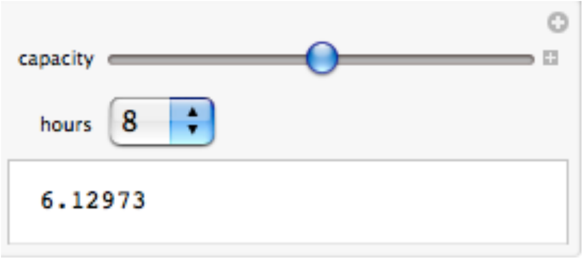
```
Manipulate[
 0.00234692*capacity*hours, {capacity, 0,
  100}, {hours, {7, 8, 9, 10, 11, 12}}]
```

capacity

hours 8

```
0.938768
```

```
Manipulate[
 0.015324329*capacity*hours, {capacity, 0,
  100}, {hours, {7, 8, 9, 10, 11, 12}}]
```



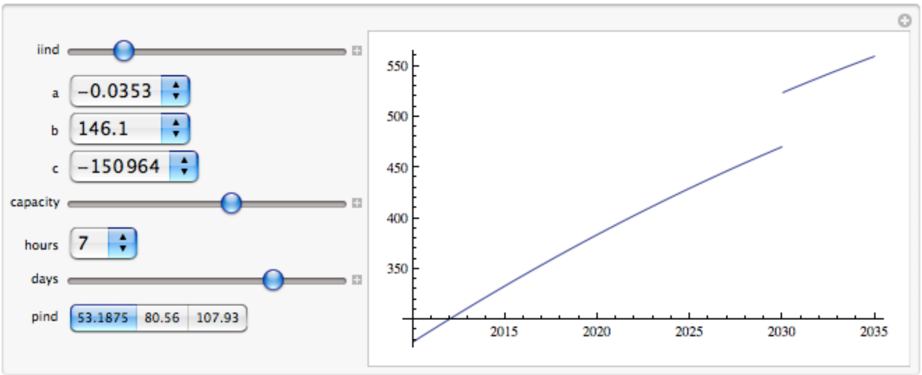
capacity

hours 8

```
6.12973
```

Master Induction Model:

```
a1 = 0.1233;
a2 = -0.0353;
a3 = 0.0691;
a4 = 0.1603;
a5 = -0.0459;
a6 = 0.0898;
b1 = -496;
b2 = 146.1;
b3 = -274.64;
b4 = -644.8;
b5 = 189.3;
b6 = -357.05;
c1 = 49874;
c2 = -150964;
c3 = 273062;
c4 = 64898;
c5 = 196262;
c6 = 354998;
Manipulate[
 Plot[Piecewise[{{(((a*(X^2)) + (b*X) + (c))*0.00234692*capacity*hours*days) +
       pind, X < 2030},
    {pind + (pind*((1 + iind)^19)) + (((a*(X^2)) + (b*X) + (c))*0.00234692*
        capacity*hours*days), X >= 2030}}],
 {X, 2010, 2035}],{iind, 0.02, -0.1}, {a, {a1, a2, a3, a4, a5, a6}}, {b, {b1, b2, b3, b4, b5,
  b6}}, {c, {c1, c2, c3, c4, c5, c6}}, {capacity, 0,
 1}, {hours, {7, 8, 9, 10, 11, 12}}, {days, 0,
 365}, {pind, {53.1875, 80.56, 107.93}}]
```



a −0.0353

b 146.1

c −150964

hours 7

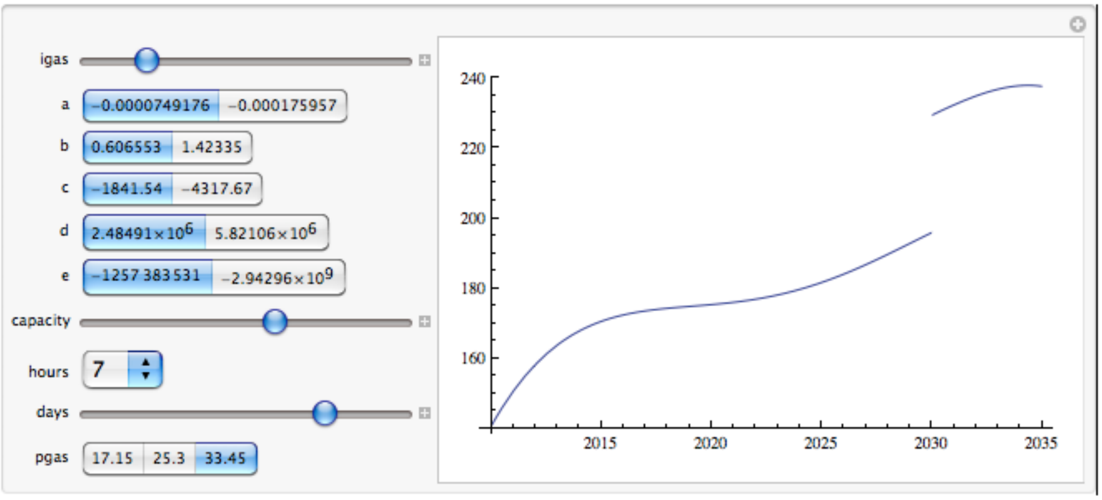
pind 53.1875 80.56 107.93

Master Gas Modeling:

```
a1 = -0.0000749175760025817;
a2 = -0.000175956865979117;
b1 = 0.606552794;
b2 = 1.42335468071715;
c1 = -1841.54427;
c2 = -4317.67271161274;
d1 = 2484909.731;
d2 = 5821061.58089501;
e1 = -1257383531;
e2 = -2942959936.86264;

Manipulate[
 Plot[Piecewise[{{(((a*(X^4)) + (b*(X^3)) + (c*(X^2)) + (d*X) + (e))*0.015325*
       capacity*hours*days) + pgas, X < 2030},
    {pgas + (pgas*((1 + igas)^19)) + (((a*(X^4)) + (b*(X^3)) + (c*(X^2)) + (d*
          X) + (e))*0.015325*capacity*hours*days), X >= 2030}}],
  {X, 2010, 2035}],

 {igas, 0.02, -0.1}, {a, {a1, a2}}, {b, {b1, b2}}, {c, {c1, c2}}, {d, {d1,
   d2}}, {e, {e1, e2}}, {capacity, 0,
  1}, {hours, {7, 8, 9, 10, 11, 12}}, {days, 0,
  365}, {pgas, {17.15, 25.3, 33.45}}]
```



igas
a: −0.0000749176 | −0.000175957
b: 0.606553 | 1.42335
c: −1841.54 | −4317.67
d: 2.48491×10^6 | 5.82106×10^6
e: −1257383531 | -2.94296×10^9
capacity
hours: 7
days
pgas: 17.15 | 25.3 | 33.45