WORKING PAPER

Quantifying the Economic Benefits of Advanced Materials Products and Processes

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The International Center for Research on the Management of Technology

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1 Introduction

This report details efforts of the Materials Systems Laboratory (MSL) to demonstrate a methodology for assessing the economic benefits of developmental materials technologies. The goal of this work was to provide the U.S. Department of Energy, Office of Industrial Technology (OIT) with an approach for evaluating future technology funding opportunities. The framework described herein is designed to be applicable to both initial assessments and detailed case studies. As a screening tool, it serves as a standard basis for evaluating multiple investment opportunities and yields a relevant comparison without requiring significant data collection efforts. For decisions which require additional reflection (e.g., later phase projects), the analysis can be enhanced through the addition of end-user preference data and more detailed market information.

The models delivered in conjunction with this report were built using decision analysis theory as the underlying assessment basis. Utility theory is applied to gauge the position of a developmental technology relative to an incumbent, based on cost and performance characteristics of interest to the end-user. This relative position in turn drives an estimate of market penetration, which ultimately yields forecasts of future sales potential and additional benefits such as energy saved or airborne emissions prevented. By conducting sensitivity analyses, evaluators can thus gauge what must occur, technically, for the new technology to have an appreciable chance of achieving commercial success. Applying these findings, directed technology funding decisions can be made based on the expected likelihood that the required technical and cost objectives can be attained.

To develop an assessment, the evaluator must provide several key items to describe the technology and market under consideration: 1) a list of the critical attributes along which end-users of the technology differentiate products, 2) a relative ranking of the importance of these attributes, 3) a benchmarking of the new and incumbent technology along these dimensions, 4) a description of the market in terms of annual sales dollars. For a screening process, estimates can be employed. For more critical decisions, additional detailing is recommended. The *Methodology* section of this report fully describes this modeling process, and the demonstration case studies provide examples of the information requirements described above.

To demonstrate the methodology, two technologies were evaluated using the model: a continuous fiber ceramic composite (CFCC) radiant burner for industrial steam generation applications and a nickel aluminide (Ni_3Al) intermetallic transfer roll for use in the steel processing industry. While both materials are potentially applicable to a wider array of markets, the results of these case studies provide a solid ground for appreciating the relative level of technical and economic improvement required for commercial success to be likely. The bulk of this report focuses on demonstrating the application of the MSL approach through these cases.

2 Methodology

The major goal of this work was to provide a systematic approach to technology assessment that could be easily implemented by OIT for use in reaching funding decisions. During the early stages of the program, a software package entitled, *DPL (Decision Programming Language)*, was considered as a platform for modeling; however, feedback from OIT during the six month review meeting resulted in a switch to a spreadsheet environment, software with which most analysts would already be familiar.

The MSL framework was developed in *Lotus 123, Release 4.01 for Windows*, but can be converted to other common PC spreadsheets such as *Microsoft Excel*. The model is divided into three distinct regions: user inputs, calculations and outputs. The user inputs section is generally the only section of the model where changes should be made by a technology analyst. The other sections house decision theory and market substitution algorithms or standardized output tables. Use of the model and development of sensitivity analyses similar to those presented in this report require the user have a working knowledge of spreadsheets. Customization of the outputs tables or modification of the calculations section would require a stronger proficiency in spreadsheet programming and the underlying theory embedded in the models. The following section reviews the model structure and theory employed.

2.1 SUBSTITUTIONAL TECHNOLOGY ASSESSMENTS

The MSL modeling methodology is based on the assumption that the new materials technology under consideration will be commercialized as a substitute for an existing market application. An assessment is developed by comparing an existing technology to a developmental effort which potentially offers some form of cost or performance benefit, and estimating what must occur for this new technology to be commercially successful. In cases where an entirely new market is created out of a development, this modeling approach is not an appropriate analysis tool. However, since substitutional implementations are often the focus of technology development, the model is likely to be applicable to many OIT technology funding decisions.

Utility theory provides the mechanism for drawing the comparison, by allowing the combination of cost and performance characteristics offered by each alternative to be translated into an overall metric of end-user preference (i.e., utility). Based on the disparity between incumbent and new technology, in terms of utility, the model then estimates the rate at which the new might be adopted. The substitution rate is obtained from S-curves typified by the work of Fisher and Pry. The greater the advantage, utility-wise, the new technology demonstrates, the more rapid the assumed substitution. In cases where the developmental technology demonstrates a utility disadvantage to the incumbent, some market penetration is still assumed, but the rate of substitution is relatively slow.

The end result is a prediction of market share gained by year, which is then converted to estimated sales dollars, and other impacts of interest, such as energy savings or emissions reductions, where applicable. Sensitivity analysis allows the analyst to examine effects of specific technical or economic changes on the predicted results. Working in this fashion, a list of key technical and economic hurdles can be defined. To apply the modeling results to a funding decision process, an evaluation team must then consider the likelihood that these goals are achievable, and if the implied market potential is sufficient to merit the investment.

2.2 TECHNOLOGY ASSESSMENT USING THE MSL FRAMEWORK

To develop an assessment, the evaluator must provide several key items to describe the technology and market under consideration: 1) a list of the critical attributes along which end-users of the technology differentiate products, 2) a relative ranking of the importance of these attributes, 3) a bench-marking of the new and incumbent technology along these dimensions, 4) a description of the market in terms of annual sales dollars. This section presents an overview of these requirements and discusses the level of detail required for various stages of technology evaluation.

2.2.1 Utility Analysis Inputs

A review of multi-attribute utility analysis (MAUA) was provided with the first *Quarterly Report* for this project, and is not repeated in this document. Essentially, MAUA is a decision analysis methodology for comparing alternatives along multiple dimensions, which can include, but are not limited to, price. Value functions are estimated for each attribute, and scaled according the relative importance in the decision. In this fashion, MAUA aims to assess how an individual or organization values complex alternatives and weighs multiple factors to arrive at a final selection.

To develop an assessment using the MSL model, a list of the key criteria end-users consider when evaluating the technology is required. It is commonplace for an end-user to indicate that almost every descriptive parameter that can be listed about a technology is important, but typically a smaller sub-set represent those which truly drive the decision, especially if all of the alternatives considered meet a specific minimum performance level along several dimensions.

Care must be taken to develop the attribute list using terms that the technology consumers actually consider. While parameters such as tensile strength or Young's modulus might be used to characterize a material, what the user actually cares about is the performance of the product in the application (e.g., life). It is the potential impact of a new material or process on those parameters of interest to the customer that drives the MSL model assessment. Table 1 provides a short example list of attributes which might be important in many technology evaluations.

Table 1. Example Utility Analysis Inputs

Attributes:		**Importance (1=Most, 3=Least) (0=Not In Use)**	**New**	**Incumbent**	**Best Possible**	**Worst Possible (Optional)**
Acquisition Cost	$	1	$10,000	$8,000	$6,000	$15,000
Capacity	tons per hour	3	1,000	900	1,200	800
Product Life	years	2	15	12	20	5

Once the list of key technology attributes is defined, each must be assigned a rank of relative importance. In Table 1, a relative importance scale of 1 (most) to 3 (least) is used to rank acquisition cost, capacity and product life. These rankings are then used by the model to weight differently the impact of each parameter on the overall utility metric.

Next, the new technology must be benchmarked against the incumbent in terms of the specific level of performance each offers for each attribute defined as relevant to the decision. Further, the range over which each attribute is likely to vary (best possible to worst possible occurrence) must be defined. This information is used to derive the individual utility functions in the model, and to develop a comparison of the new to incumbent technology in terms of their overall utility to the end-user.

Figure 1 presents an example utility function that is calculated from the acquisition cost data in Table 1, using the following equation for utility of an attribute, x:

$$U(x) = [(x - x_*)/(x^* - x_*)]^c$$

x^* = the best possible level of x, $U(x^*) = 1$

x_* = the worst possible level of x, $U(x_*) = 0$

c = an exponent which defines the function's risk characteristic, where:

- $c < 1$, implies risk adverse
- $c = 1$, implies risk neutral
- $c > 1$, implies risk positive

For the MSL framework, risk aversity is assumed, and c is calculated from the relative importance ranking. Risk aversity implies diminishing marginal utility, and is typical in most cases of advanced technology implementation.

Total utility (MAU) is calculated from the individual utility functions and relative importance rankings by the following:

$$KU(X) + 1 = \Pi(Kk_i U(x_i) + 1)$$

K = scaling factor for overall utility function, $U(X)$

k_i = scaling factor for individual utility functions, $U(x_i)$

The example presented in Table 1 highlights the rationale behind developing the MSL model: the new technology is better in terms of performance (i.e., capacity and life), but costs more to acquire. It is not intuitive which alternative is better in the eyes of the end-user. While this simplified example could be assessed using some form of cost-benefit analysis to translate increased capacity and life to monetary effects, additional operational and capital information would be required. Further, many attributes, such as pollution emissions, do not translate easily to monetary units. The MAUA methodology utilized by the MSL model avoids these difficulties by instead using relative units to determine the value, or "utility" of the alternatives. The notion of risk, or decisionmaking under uncertainty, is employed to measure (or estimate) the relative intensity of preferences and to reveal the form of the relevant value function. Once the function is determined, measurable properties of the alternatives are taken as inputs to calculate the overall utility, or value.

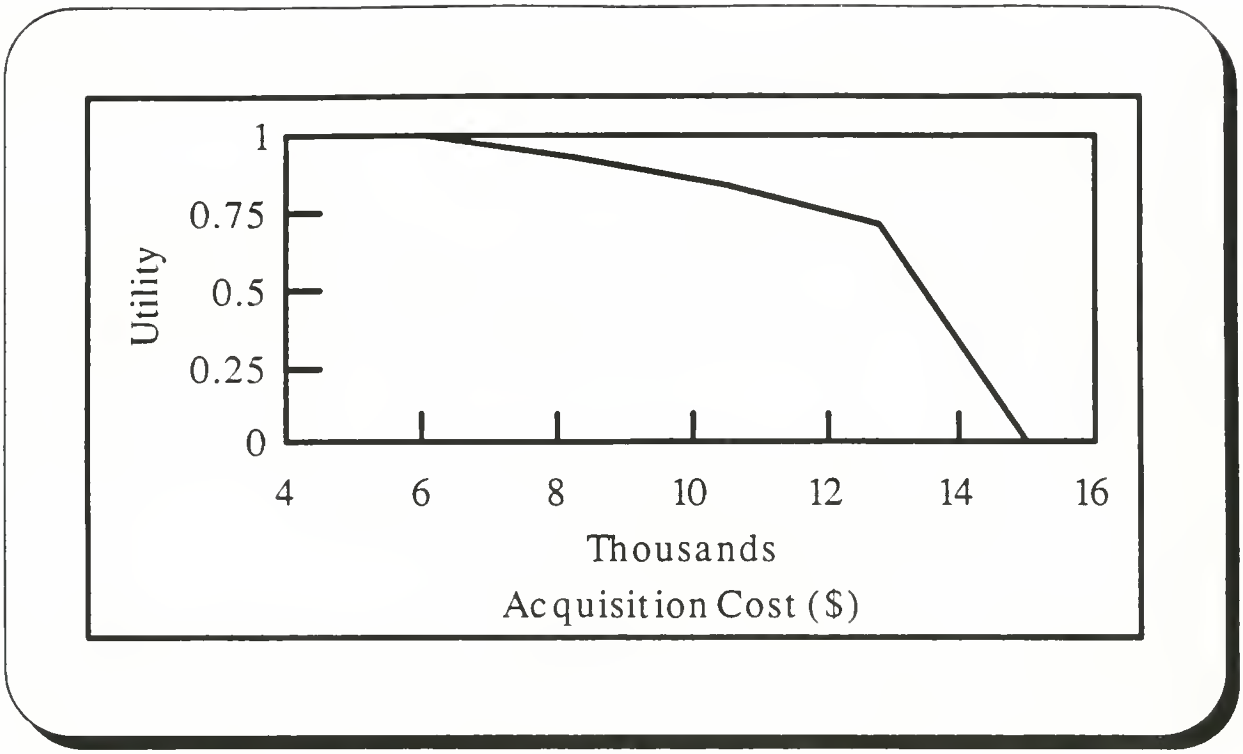

Figure 1. Example Utility Function

2.2.2 Market Data Inputs

A key factor in developing a meaningful assessment with the MSL model is to provide a well focused estimate of the current market for the incumbent technology. Since a comparison of new to incumbent technology drives the overall estimate of market potential, the estimate of current market sales must represent only those products which fit the description developed through attribute benchmarking. Simply phrased, the applicable market segment, and fraction potentially available to a new technology, must be accurately quantified.

Table 2. Example Market Data Inputs

Market Size	$25,000,000	/yr
Discount Rate	10.0%	
Time Before Commercial Sales	2	years
Average Life Incumbent	15	years
Expected Life New Technology	12	years
Estimated Cost (% of Traditional)	125%	

The model requires several additional market related inputs, as shown in Table 2. These include a discount factor, an estimate of the time before commercial sales will begin, the expected useful lives of new and old technologies, and the relative percentage cost premium associated with the new technology. While the cost and life variables might be redundant with the attribute list at times, it is essential that these be included in the market data section because the model requires this data for every case to calculate product life cycle and price impacts on the overall market.

The discount rate and time before sales are initiated are required because the model calculates sales in terms of current dollars (i.e., NPV). Setting both of these inputs to zero yields an undiscounted sales projection.

2.2.3 Substitution Analysis Inputs

The MSL technology assessment model applies two major algorithms to estimate the market potential of a new technology. MAUA provides a basis for comparison of new to incumbent and a substitution model yields an estimate of the rate at which the new technology is adopted. The substitution model utilized is based on the Fisher-Pry S-curve which is described by the following equation:

$$\ln[f/(1-f)] = 2a(t_x - t_{0.5})$$

f =market substitution fraction
a =constant that describes the overall rate of substitution
t_x =time for substitution of fraction x to occur

S-curve models have been widely applied across industry. Cases of materials substitution often require upward of 20 years or more, but can occur much faster if the performance increment is appreciable and the economics are not prohibitive (see Foster, Fisher or Eager). Thus, the MSL model scales an S-curve according to the difference in utility between the incumbent and new technology. The scaling is based on the differential between the expected price of the new technology and the price of the new technology which would render it equal, in terms of utility, with the incumbent. The S-curves are described by the time required to reach a substitution level of ten and fifty percent. Table 3 shows the base case substitution curve data as related to the price differential. Figure 2 presents the resultant curves.

Table 3. Base Case Substitution Curves

% Difference (Price$_{New}$-Utility Equivalent Price$_{New}$)	**$t_{0.1}$**	**$t_{0.5}$**
X >10% (rapid)	2	7
10%>X>5% (regular)	5	13
X<5% (niche)	15	25

While these base case curves are meant to be representative of what has been empirically observed, it is clear that an assessment could be significantly impacted by these assumptions. Therefore, the model is designed to allow sensitivity analysis to be performed by varying the shapes of the S-curves and the percentage factors which determine which curve is used. Two tables appear in the *Inputs* section of the model for this purpose.

2.3 SCREENING VERSUS FORMAL MARKET ANALYSIS

The framework outlined in this report can be applied as both a technology screening tool and for developing more in depth market assessments, depending on the evaluator's needs and resources. Formal utility assessment requires an appreciable amount of fieldwork and time; it is not an inexpensive undertaking. Obviously, developing a full blown MAUA for every technology OIT must evaluate in the course of a funding year would not be feasible.

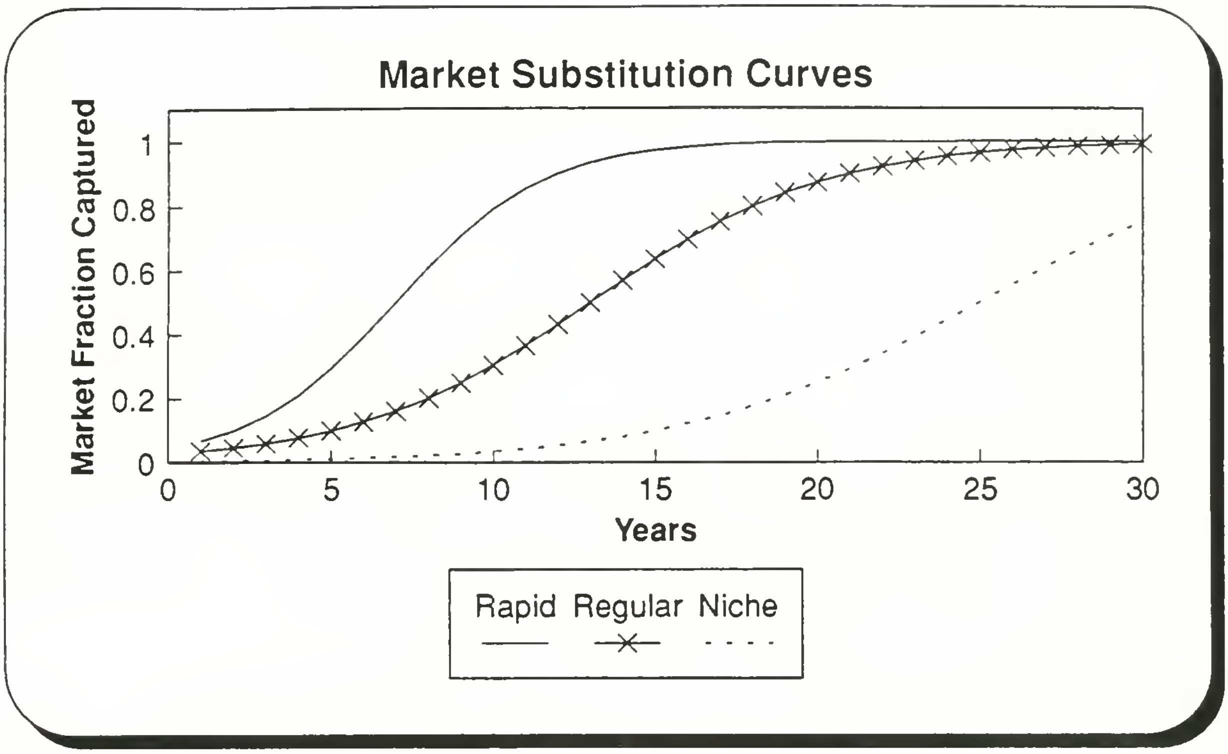

Figure 2. Market Substitution Curves

In developing the two case studies for this project, MSL utilized a an end-user survey which elicited the set of criteria which appeared to matter to end-users of either burners for industrial steam generation or transfer rolls for use in steel processing. This approach was not a true MAUA interview, but was designed to collect approximations of what formal interviews would have yielded. While still end-user based, these interviews were conducted using a simplified, one-page questionnaire and were administered using the telephone. Appendix A presents the materials used in conducting the surveys.

As part of a screening process, an OIT model-user would likely either utilize a similar, phone-based survey technique, or develop the attribute list based on input from the review team, internal experts or others familiar with the technology. MSL expects that formal MAUA assessment might only be conducted for a small number of OIT technology funding decisions.

The two demonstration cases were developed using a less formal survey process to demonstrate that less formal approaches can still yield information useful for examining the likely market potential for new technologies. Assumptions are simply a starting point for analysis. As a tool for assessment, the MSL framework is most powerful when used to perform sensitivity analyses over the set of base assumptions, so that a better understanding of key drivers for market success is obtained. Applied in this manner, the framework is intended to help professionals in the technology field make more informed investment decisions.

3 CFCC Radiant Burner Assessment

Continuous fiber ceramic composites represent a significant advanced materials development effort sponsored by OIT. These materials are being developed for applications ranging from industrial heating to diesel engines. To demonstrate the MSL framework, the application of a CFCC material to industrial boiler burners was examined. The assessment is based on products under development at Alzeta Corporation[1].

Alzeta originally developed ceramic based burners for industrial steam generation as a low NO_x technology. Much of Southern California's industry operates within Air Quality Management Districts (AQMD's) because the area is classified as an ozone non-attainment zone. As a result, industry governed by AQMD's is faced with reducing emissions of combustion products such as NO_x. Alzeta's *Pyrocore*™ technology, based on discontinuous ceramic fiber, enabled radiant burner designs for retrofitting boiler operations. The Alzeta burners significantly reduced NO_x emissions in these operations, but suffered from poor durability. CFCC's are currently being investigated as a solution to this problem. The following assessment presents an estimate of what must occur for the CFCC boiler burner concept to be successful, nationwide.

3.1 POTENTIAL END-USER SURVEY: CALIFORNIA AND OHIO MARKETS

To develop estimates of end-user utility for boiler burners, MSL conducted a survey of industrial sites in Southern California and Eastern Ohio. The California sites faced regulation from AQMD's, while the Ohio participants did not reside in an ozone non-attainment zone. Given that the Ohio businesses were not under severe pressure to reduce NO_x, it was expected that these respondents would demonstrate less utility for advances in low NO_x technologies. Since much of the United States does not comprise non-attainment zones, this segmentation between markets was considered important to defining what must occur for CFCC's to enjoy wide appeal in the boiler burner application.

Appendix B presents the results of the boiler burner technology survey. Eight interviews were conducted over the telephone, three with Ohio participants and five with California participants. Contacts at these sites were provided courtesy of the Southern California Gas Company and East Ohio Gas Company.

In all, twenty-two performance criteria were discussed. However, based on the abilities of the respondents to quantify the criteria and the frequency with which each was mentioned, only five were selected for use as utility attributes. Figure 3 depicts the response rate and relative importance ranking for these attributes: initial cost, energy efficiency, NO_x emissions, expected life, and CO emissions. The data is broken down into regional segments and also presented in aggregate. The total number of responses are indicated by the bar height and the relative importance ranks are listed above each bar (scaled from 1 to 3, 1= most, 3= least important).

The sample size for this survey was small, and student t-tests of the data do not suggest that the California and Ohio responses are statistically separable. Therefore, the initial sensitivity analyses were performed using the aggregate results. However, some analyses were repeated using the regional data to investigate the potential impact on the market assessment.

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[1] For a detailed discussion of CFCC radiant burner markets and Alzeta's CFCC program, see Schweizer

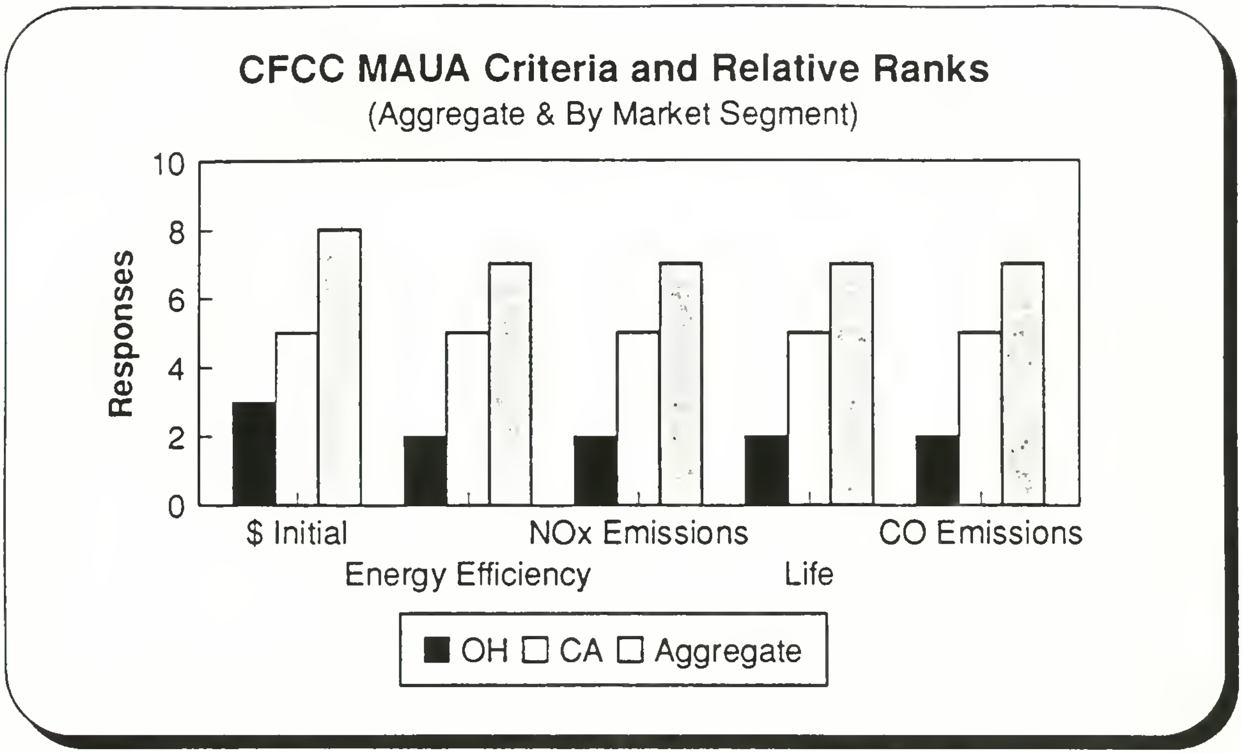

Figure 3. Key Boiler Burner Survey Criteria

3.2 CFCC BASE CASE ASSUMPTIONS

The base case market and product assumptions are shown in Tables 4 and 5, respectively. The replacement burner market is the focus of the analysis, because it vastly out-numbers the market for new installations in the United States. Assuming a capacity utilization of 50 percent, a base of 37,000 industrial boilers, annual energy consumption of 6.5 quadrillion Btu's, a 20 year life of incumbent burners, and a potential two-thirds substitution potential for CFCC's, the annual potential replacement market for which CFCC burners can compete is nearly $50 million[2].

Table 4. CFCC Burner Market Assumptions

Market Size (annual replacement)	$49,000,000	
Energy Consumption	4.3	Quads/year
Energy Savings Potential	2.0%	
Discount Rate	10.0%	
Time Before Commercial Sales	2	
Average Life Incumbent	20	
Expected Life New Technology	10	years
Estimated Cost (% of Traditional)	200.0%	

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[2] Data for this estimate extracted from Schweizer

The incumbent technology that was benchmarked against the CFCC technology was a flue gas recirculation system (FGR), a common approach to combustion emissions reduction. An extension of this study could potentially compare the Alzeta CFCC product to other low NO_x technologies. FGR was selected because it typically meets emission standards for all but the most severely regulated regions and is relatively inexpensive in comparison to other combustion control technologies.

Table 5. CFCC Burner Attribute Assumptions

Attributes	Units	Importance (1=Most, 3=Least) (0=Not In Use)	CFCC Boiler Burner	Incumbent	Best Possible	Worst Possible
Acquisition Cost	$/Mbtu	1.63	$4.00	$2.00	$0.50	$5.00
Energy Efficiency	% convert	1.29	0.82	0.8	0.9	0.6
Product Life	years	1.71	10	20	40	0.01
NOx Emissions	ppm	1.43	9	30	0	45
CO Emissions	ppm	1.86	5	30	0	600

Current boiler burners typically last for twenty years or more, but the *Pyrocore*™ product is highly susceptible to impact and vibration damage. A major goal of the Alzeta CFCC program is to use continuous fibers to increase the durability of these ceramic based, radiant burners. Since the actual life a CFCC burner will yield is uncertain, a conservative base estimate of ten years was assumed, and sensitivity studies over a range of five to twenty years were conducted.

Similarly, the cost of the CFCC product is likely to be more expensive than FGR. Projections from Alzeta provided the base case estimate of $4.00/MBtu, with a sensitivity range of $2.00 to $5.00/MBtu. FGR technology was priced at $2.00/MBtu, as a base case.

3.3 CFCC ANALYSIS RESULTS

The base case projections for CFCC radiant burners in industrial boiler applications are shown in Table 6. Market share, sales (in current dollars), estimated energy savings and NOx reductions by year for five years are included. Given the cost and product life assumptions, it is not surprising that the model predicts only niche level penetration, with less than $1 million in sales annually. The sensitivity analyses which follow are developed to elicit what must occur for a CFCC radiant burner to be more widely accepted in the industrial boiler market. Aggregate survey data is used initially, as in the base case, but the impact of regional survey results are considered later as a potential sensitivity variable.

Table 6. Base Case CFCC Burner Results

Sales Year		1	2	3	4	5
Market Share		0.5%	0.6%	0.8%	1.0%	1.2%
Estimated Sales (NPV)		$379,000	$429,000	$485,000	$548,000	$619,000
Estimated Energy Savings	(quads)	4x10-4	6x10-4	7x10-4	9x10-4	1.1x10-3
Estimated NOx Reductions	(tons)	255	315	395	490	610

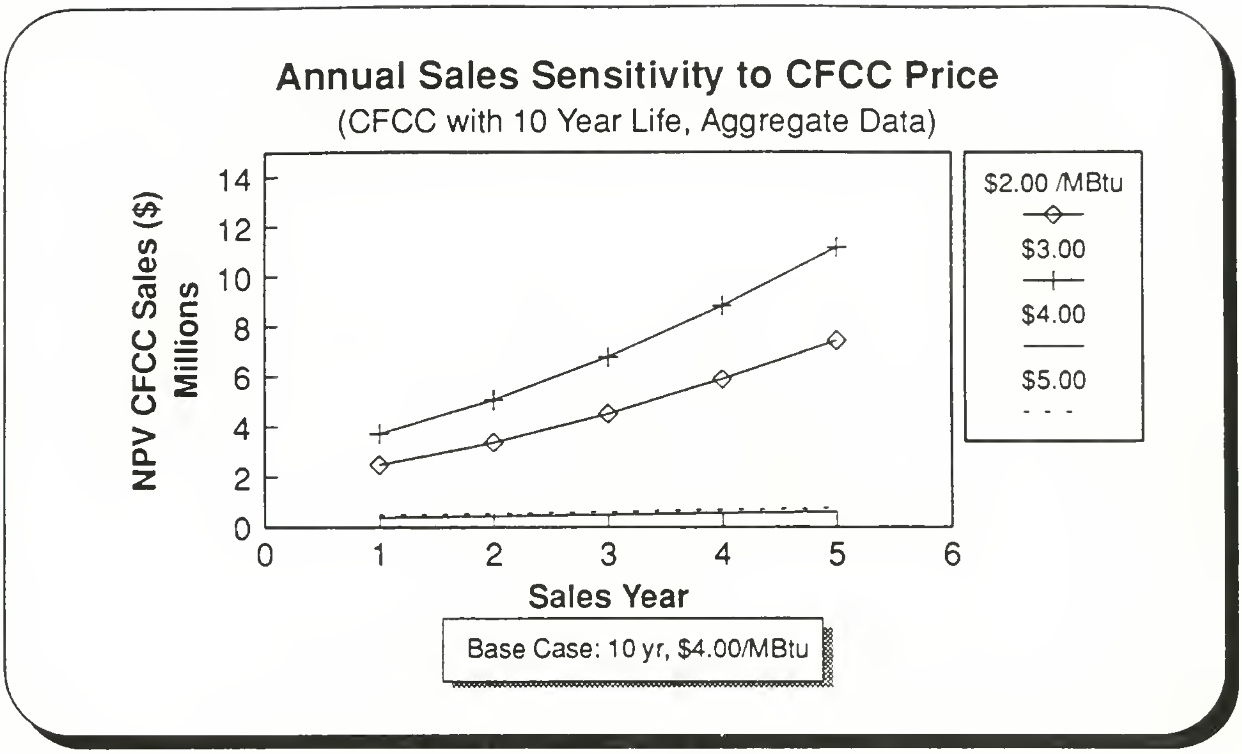


Figure 4. CFCC Price Sensitivity I

Figures 4 and 5 begin to assess the impact reductions in price and increases in the expected life of the CFCC burner could have on market penetration. Figure 4 shows sales by year for different pricing levels of the CFCC burner, under the original assumption of a ten year product life. Figure 5 presents the same analysis using a 20 year life for the CFCC burner. Reductions in prices and increases in life to $3.00/MBtu and 20 years, respectively, lead to sales projections approaching $10 million annually.

The impacts of CFCC price and life are also examined in Figures 6 and 7, as a function of the life of the incumbent technology. The sales results are in terms of current dollars (NPV) for the first five years. At the initial CFCC assumptions, incumbent technology life does not drastically affect the market prediction (Figure 6), but at a price of $3.00/MBtu, the life requirement of the CFCC product is reasonably sensitive to incumbent burner life. Both figures suggest a five year sales level in the $50 million range is possible.

A significant advantage of the Alzeta burner is its ultra-low NO_x capability. Implementations of *Pyrocore*™ have achieved operational levels below nine parts per million (see Gotterba). Alzeta has successfully marketed this technology in the California market based on this capability, which is not attainable through FGR systems. Selective catalytic reduction (SCR) is another ultra-low NO_x alternative that competes for these applications, but is as much as ten times more expensive than FGR. Thus, the Alzeta product has been acceptable in markets where the alternative is more expensive than the base case FGR used in this analysis. Figure 8 examines the sensitivity of CFCC sales to incumbent price. The market value of the CFCC increases rapidly with the price of the incumbent.

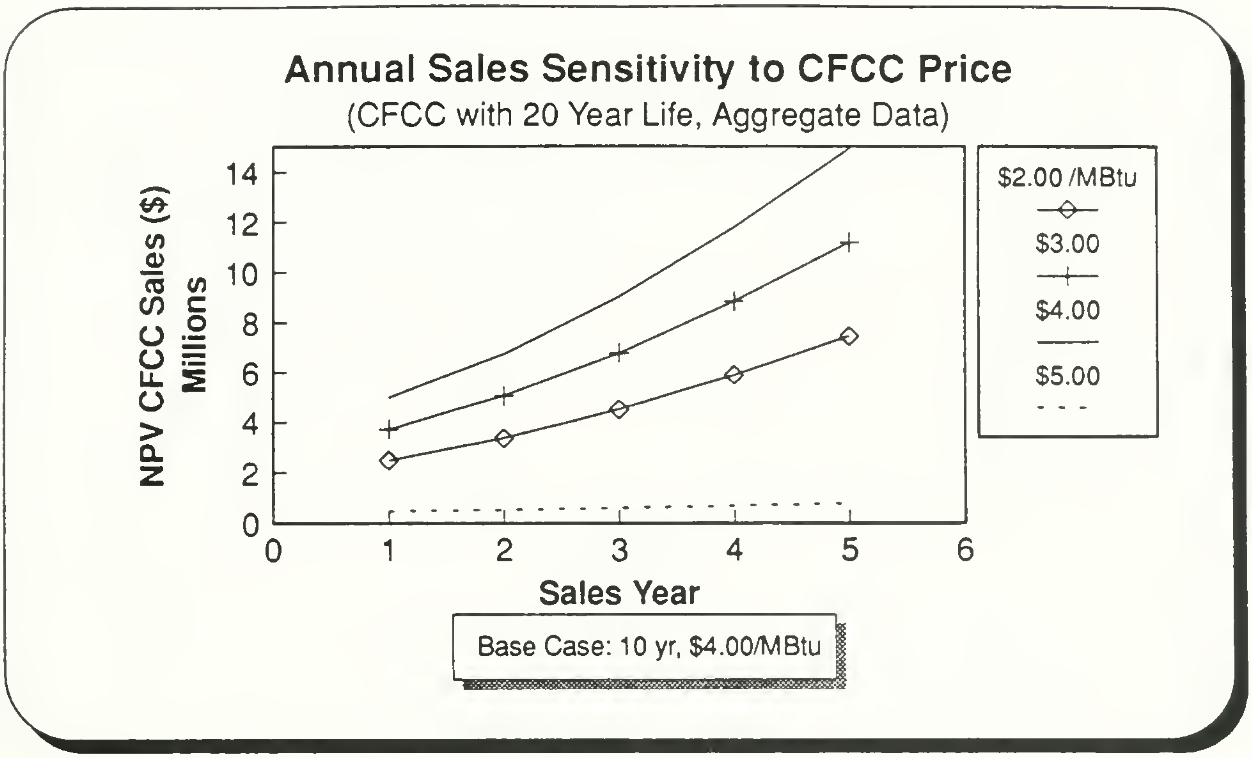


Figure 5. CFCC Price Sensitivity II

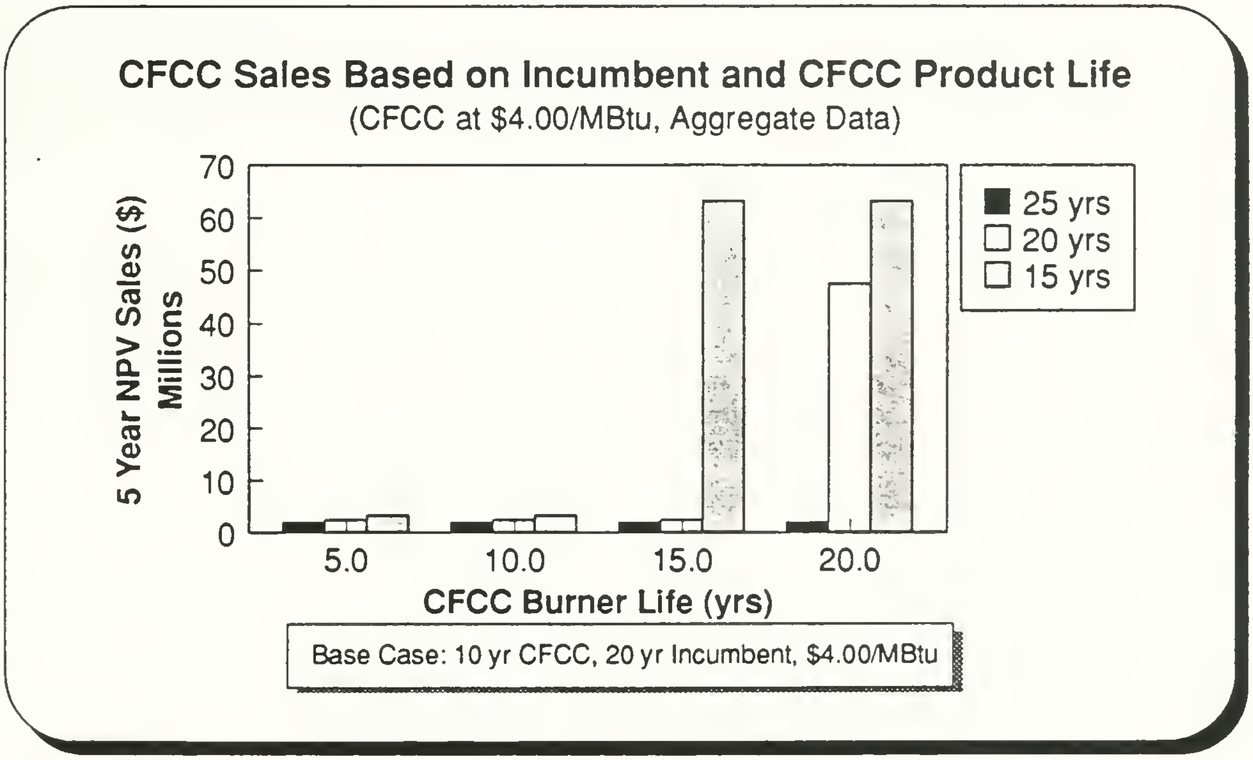
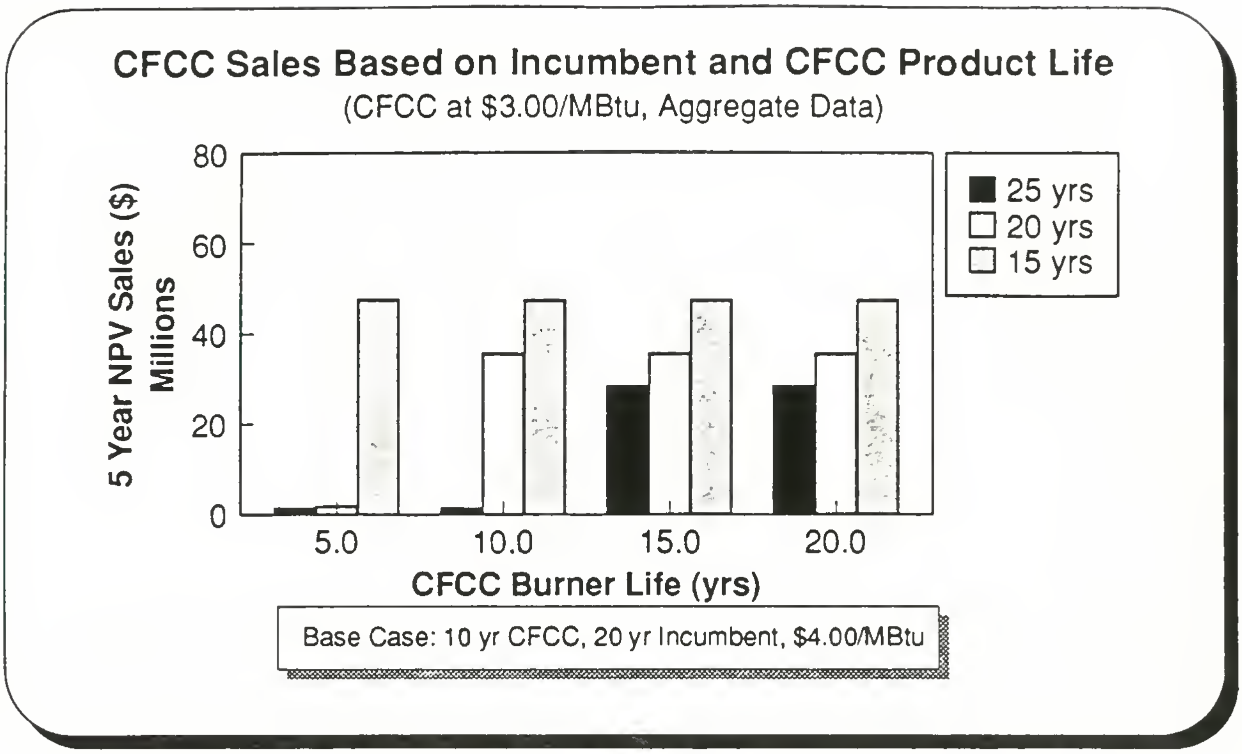


Figure 6. Competing Product Life Sensitivity I

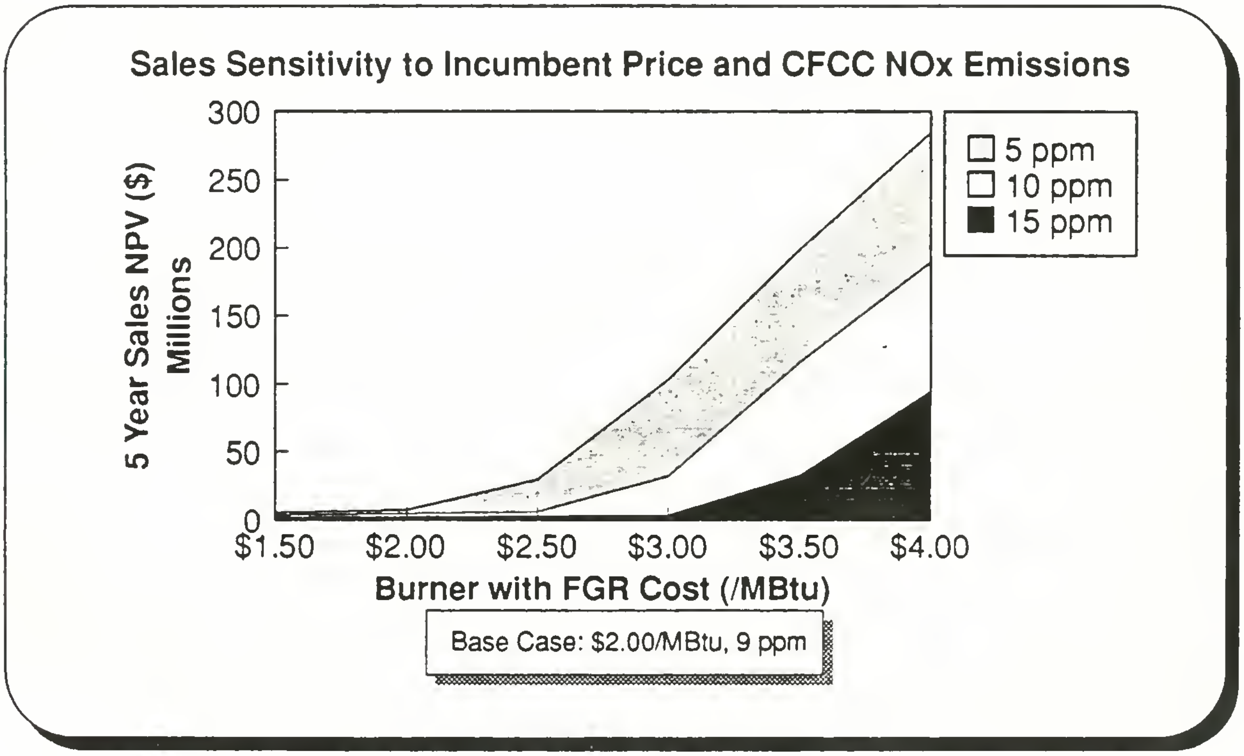


CFCC Sales Based on Incumbent and CFCC Product Life

(CFCC at $3.00/MBtu, Aggregate Data)

Base Case: 10 yr CFCC, 20 yr Incumbent, $4.00/MBtu

Figure 7. Competing Product Life Sensitivity II



Sales Sensitivity to Incumbent Price and CFCC NOx Emissions

Base Case: $2.00/MBtu, 9 ppm

Figure 8. CFCC Market Sensitivity to Incumbent Price

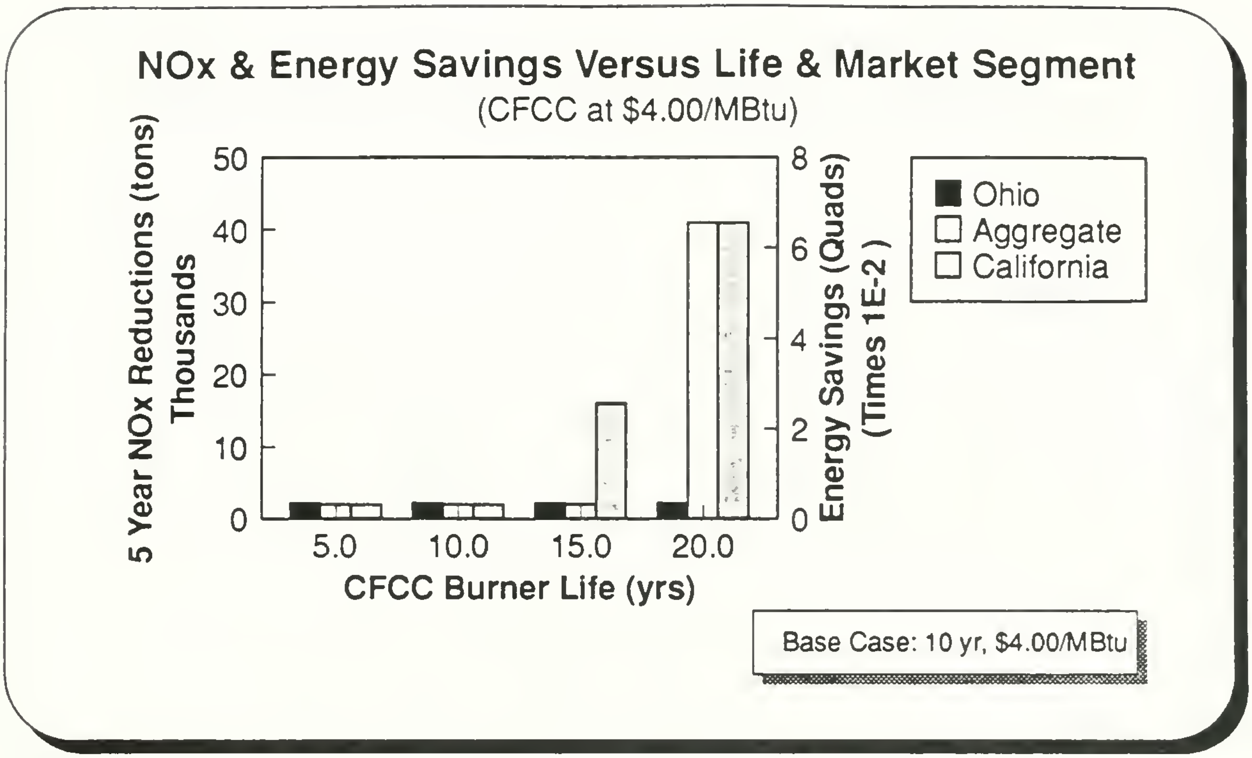


Figure 9. Energy and NO_x Emissions Savings I

In addition to reducing NO_x emissions, CFCC radiant burners offer energy savings potential in many applications. While most industrial steam generation systems are already reasonably efficient (around 80%), it is estimated that a ceramic burner could lead to a two percent efficiency gain. Figures 9 and 10 use the previous sales projections (Figures 6 & 7) to estimate cumulative NO_x and energy savings over the first five years of commercialization, with the assumption of a 20 year incumbent life.

Figures 9 and 10 also draw comparisons between the regional survey responses and the aggregate results, in terms of their impact on CFCC product acceptance. As previously discussed, it was hypothesized that the Southern California market would place a higher value on NO_x reductions than areas of the country which are not considered non-attainment zones, but the survey data was not statistically separable by region. Regardless, the potential impacts of statistically different regional data are interesting and therefore are considered at this stage of the analysis.

The level of NO_x and energy savings shown in Figures 9 and 10 is directly correlated to actual sales: the more CFCC units sold, the greater the reductions. Keeping this relationship in mind, it is clear that the Ohio respondents are less willing to spend additional money or to sacrifice product life to achieve reduced emissions, as compared to the California participants. In particular, Figure 10 suggests that at a selling price of $3.00/MBtu, a ten year burner life would yield appreciable energy and NO_x savings (i.e. sales) in the California market, but the Ohio market would require a life between 15 to 20 years.

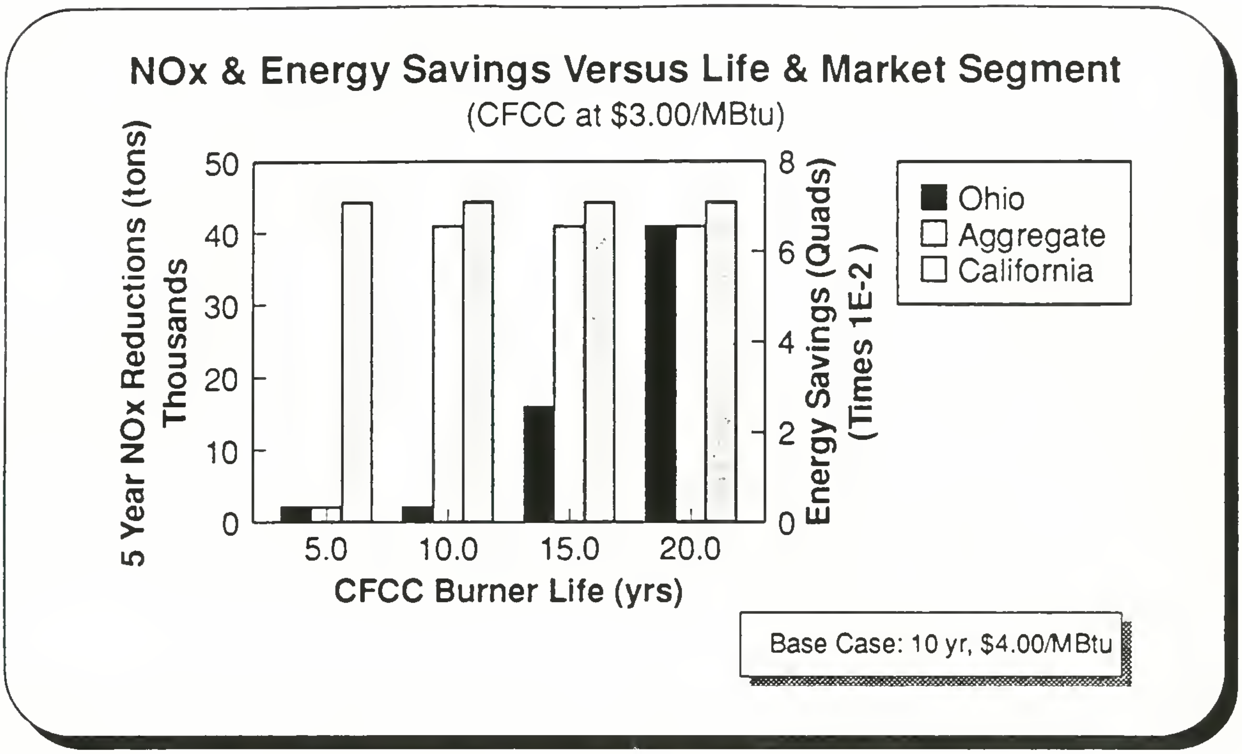


Figure 10. Energy and NO$_x$ Emissions Savings II

3.4 CFCC CASE CONCLUSIONS

The CFCC boiler burner assessment indicated that the base case assumptions of $4.00/MBtu and 10 year operating life (versus $2.00/MBtu and 20 year for incumbent) are likely to result in only niche acceptance of the product, despite the energy and emissions saving potential. The survey data from the California market results in the most optimistic set of requirements for more wide-spread use. Sales projections reach the $10 million annual mark for combinations of life and price of $4.00/Mbtu, 15 years and $3.00/Mbtu, 5 years. If the more pessimistic Ohio responses better represent the market majority opinion, the projected requirements shift closer to $3.00/MBtu, 15 years and $2.00/Mbtu, 10 years.

Alzeta estimates an introductory price near $4.50/MBtu for the CFCC product, with a long-term goal of $3.00/Mbtu. Currently, *Pyrocore*™ lasts about 25,000 hours in the field (5 to 10 years). A major goal of the Alzeta CFCC effort is to significantly increase the life in service. Based on this analysis, it seems likely that the CFCC radiant burner will remain a niche product, unless the most aggressive technical and economic goals are achieved and the overall market attitude is closer to the California and aggregate survey results than the Ohio opinions.

These findings are not inconsistent with opinions expressed by Alzeta. They expect the CFCC boiler burner to be a product which is adopted only in markets where regulations push industrial sites to adopt cleaner burning technology. However, Alzeta expects that their CFCC products will find more extensive use in other applications, such as medical waste incineration. The MSL modeling approach could similarly be applied to evaluate the market potential for these segments as well.

4 Nickel Aluminide Transfer Roll Assessment

DOE has actively funded the development of tri-nickel aluminide (Ni_3Al) intermetallics through the Oak Ridge National Laboratory (ORNL). Ni_3Al is particularly resistant to thermal fatigue, oxidation, and chemical attack, and maintains its strength up to temperatures approaching 1900 Fahrenheit. Potential industrial applications include forging dies, glass casting molds, and furnace tooling or components.

This assessment examines the opportunity for Ni_3Al in transfer roll applications for steel processing. Currently, one U.S. integrated steel manufacturer is testing prototype Ni_3Al rolls in a heat-treat environment for processing plate. Existing steel alloy rolls suffer from poor durability (pitting and wear) and are susceptible to scale formation (pick-up of silicon, carbon and other elements from the plate). Scaled rolls tend to impart damage to the surface of the steel product being transferred through the furnace and must be refurbished or replaced on a relatively frequent basis (roll maintenance related furnace shutdowns occur every one to two months at the prototype site). Ni_3Al potentially could alleviate the scaling problem and extend the wear life of the furnace rolls, leading to less furnace downtime, product scrap and roll maintenance.

Transfer rolls are used widely in steel processing operations; however, wear and scale formation appear to be appreciable problems only in high temperature areas such as heat treating. Even in the roller hearth where the prototype rolls are installed, the line engineers believe that only thirty percent of the rolls exhibit significant wear and scaling problems (i.e., those exposed to the peak heat-treat temperatures and friction loads). While some rolls require multiple annual refurbishments and might only last a few years, others in the same furnace may survive for several decades, virtually unblemished.

Since nickel aluminide is likely to remain a more expensive material than many steel alloys, it is unlikely it would be considered outside of problem areas. Thus, this assessment focuses only on those transfer roll applications which currently suffer from short roll life. Deformation rolls are not considered because the mechanical requirements are appreciably different from those faced by transfer rolls, and it is unclear that Ni_3Al would perform satisfactorily in this application.

For the assessment, two promising application areas were identified: heat-treat and tunnel furnaces. Heat-treat furnaces with rollers are mainly utilized by the integrated steel producers to anneal, harden or quench plate or specialty products. Tunnel furnaces are an integral part of the new thin strip casting (TSC) technologies being implemented by mini-mills such as Nucor and some integrated producers such as ACME. In both cases, roll wear and scaling are considered significant problems.

Another application area that was suggested by the integrated manufacturer involved in prototyping Ni_3Al rolls was re-heat furnaces. However, rolls are not typically used in these environments. Instead, the steel usually slides along coated skids or refractory blocks, or is moved though the furnace using a walking beam. Ni_3Al rolls might potentially be used to upgrade a pusher furnace (skid or block type) without incurring the expense of investing in walking beam technology, but current users of pusher technology were highly skeptical of the concept. For this reason, re-heat furnaces were not considered in this market assessment.

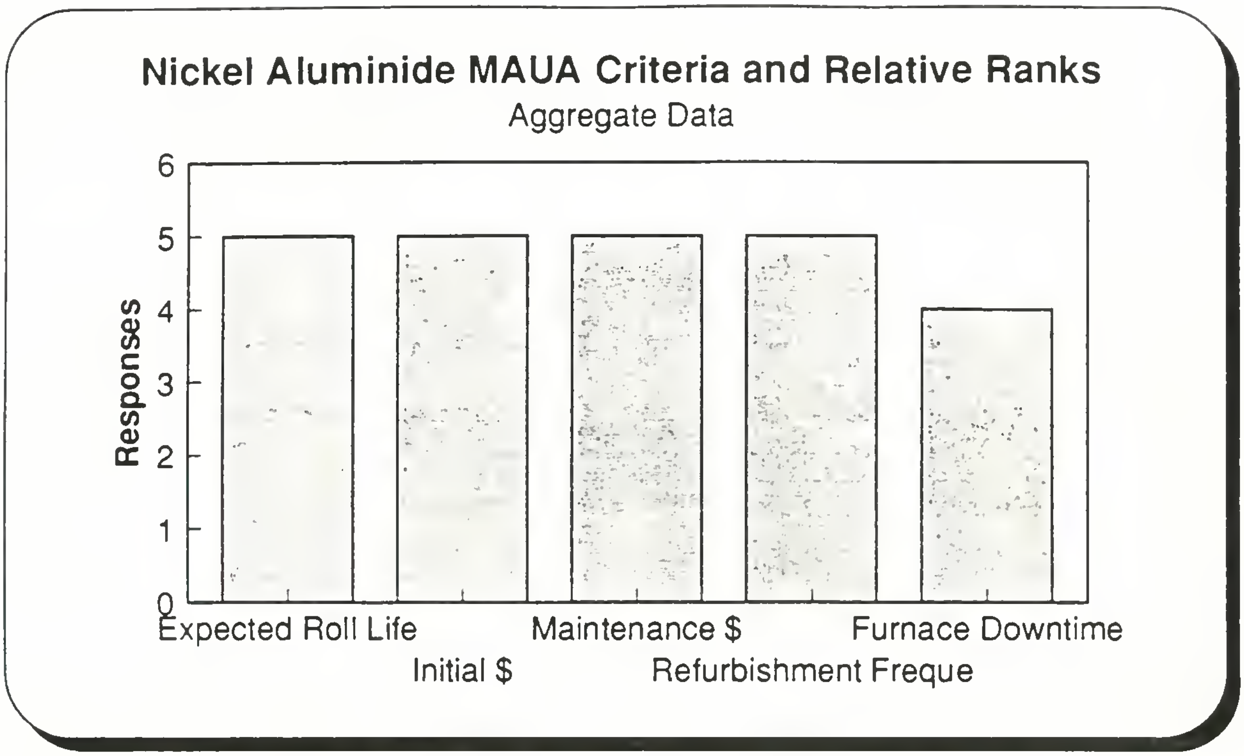


Figure 11. Key Transfer Roll Survey Criteria

4.1 POTENTIAL END-USER SURVEY: HEAT-TREAT & TUNNEL FURNACE ROLLS

A survey of potential end users of Ni_3Al rolls for both heat-treat and tunnel furnaces was conducted in the same fashion as the CFCC radiant burner case. Appendix A presents the questionnaire, Appendix C provides the aggregate results of the furnace roll survey. Five usable responses were obtained and eight potential criteria for evaluating the roll product utility were identified. Based on response frequency and end-user ability to reasonably quantify standards, five of these criteria were used for the assessment: initial and maintenance cost, life, refurbishment frequency and furnace downtime attributable to rolls. Figure 11 shows the respective response rates and relative rankings (scaled from 1 to 3, 1= most, 3= least important). No segmentation of the responses by furnace type was attempted for this case, given the small set of data and the similarities in application areas. Nor was geographic location considered an important part of the Ni_3Al implementation decision, in contrast to the CFCC boiler burner case.

4.2 NI_3AL BASE CASE ASSUMPTIONS

Appendix D contains a detailed list of all of the heat-treat furnaces utilized in the United States steel industry, and separates batch from continuous units[3]. Rolls are only used in continuous furnaces. Assuming that one-third of the rolls in the heat-treat units could be replaced by Ni_3Al, and scaling the number of rolls (based on furnace capacity) to the actual number at the prototype site, the annual roll replacement market for heat-treat furnaces in the steel industry exceeds $2.5 million (see Appendix D for calculations).

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[3] Data extracted from the Directory of Iron and Steel Plants, 1993

Appendix D also provides a list of the major U.S. sites where thin-strip casting technology is being implemented. Currently this amounts to five plants, but each of the associated tunnel furnaces requires nearly 200 rolls. The annual tunnel furnace roll market is similarly estimated to be worth $2.5 million. Both the heat-treat and tunnel furnace market estimates assume a two year life for incumbent rolls.

Table 7. Ni_3Al Roll Market Assumptions

Market Size (annual replacement)	$5,000,000	
Energy Consumption	NA	Quads/year
Energy Savings Potential	NA	
Discount Rate	10.0%	
Time Before Commercial Sales	2	
Average Life Incumbent	2	
Expected Life New Technology	4	years
Estimated Cost (% of Traditional)	150%	

Table 7 provides the combined market data utilized for the roll market evaluation. Table 8 contains the product attribute assumptions. Overall, the Ni_3Al is assumed to provide a two-fold increase in life while quartering the refurbishment requirements, at a cost of 150 percent that of a steel alloy roll. Slight advantages in terms of maintenance cost and associated furnace downtime are also assumed to result from Ni_3Al roll insertion. Initial assumptions were based on conversations with Metallamics Corporation and ORNL, (who are working together to find commercial uses for the intermetallic material) as well as potential end-users.

Table 8. Ni_3Al Roll Attribute Assumptions

Attributes	Units	Importance (1=Most, 3=Least) (0=Not In Use)	Ni_3Al Roll	Incumbent	Best Possible	Worst Possible
Acquisition Cost	$/roller	1.2	$12,000.00	$8,000.00	$5,000.00	$25,000.00
Product Life	years	1	4	2	12	0.01
Maintenance Cost	$/yr	1.8	10.00%	20.00%	0.00%	100.00%
Refurbishment Frequency	/yr	2	0.5	2	0	4
Downtime (from rolls)	%	1.67	0.10%	0.20%	0.00%	2.00%

4.3 NI_3AL ANALYSIS RESULTS

Base case sales estimates (in current dollars) by year for five years are presented in Table 9. These results suggest that, if current problems with welding nickel aluminide can be overcome, it could be readily accepted into these two furnace applications. The base analysis estimates a 30 percent share of the roll applications within five years. Given the assumed performance increase from Ni_3Al, it is not surprising that a rapid transition is predicted. The sensitivity analyses which follow attempt to discern the likelihood of success if technical performance falls short of the base assumptions.

Table 9. Base Case Ni_3Al Roll Results

Sales Year	1	2	3	4	5
Market Share	6.7%	10.0%	14.7%	21.1%	29.3%
Estimated Sales (NPV)	$390,000	$530,000	$660,000	$832,000	$1,000,000

Figure 12 examines the effect of Ni_3Al roll life and cost on estimated sales. With a life of 4 years, a price of 200 percent for Ni_3Al rolls still results in rapid acceptance. At a two year life, equivalent to steel alloy roll assumption, this threshold falls to 150 percent, while expected life in excess of 4 years allows cost to approach 250 percent. Though roll life is clearly an important driver of potential market acceptance, this figure also demonstrates that end-users are likely to consider more expensive technologies that offer equivalent life, but reduced refurbishment requirements.

Figures 13 and 14 continue to examine the sales Ni_3Al roll life relationship, as a function of incumbent roll life. The base case assumed these incumbents lasted an average of two years. In these figures, incumbent lives between one to three years are considered. Figure 13 and 14 assume a Ni_3Al price of 150 and 200 percent, respectively. The most significant effected noted is the overall impact on market value the incumbent life exhibits. The estimated market value is calculated using this input. A reduction from two to one years effectively doubles the market. Regardless of absolute market size, for the incumbent life range considered, a Ni_3Al roll with an expected life of four or more years remains a strong contender for market share.

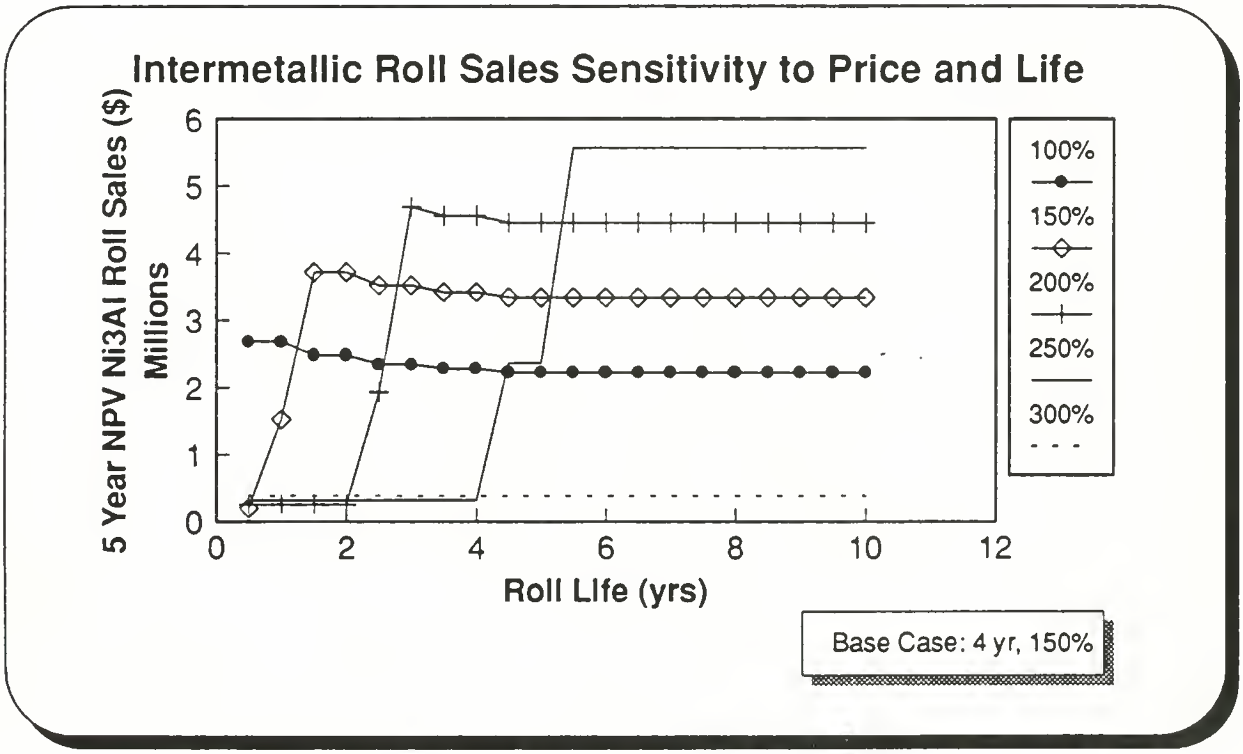

Figure 12. Ni3Al Furnace Roll Price & Life Sensitivity

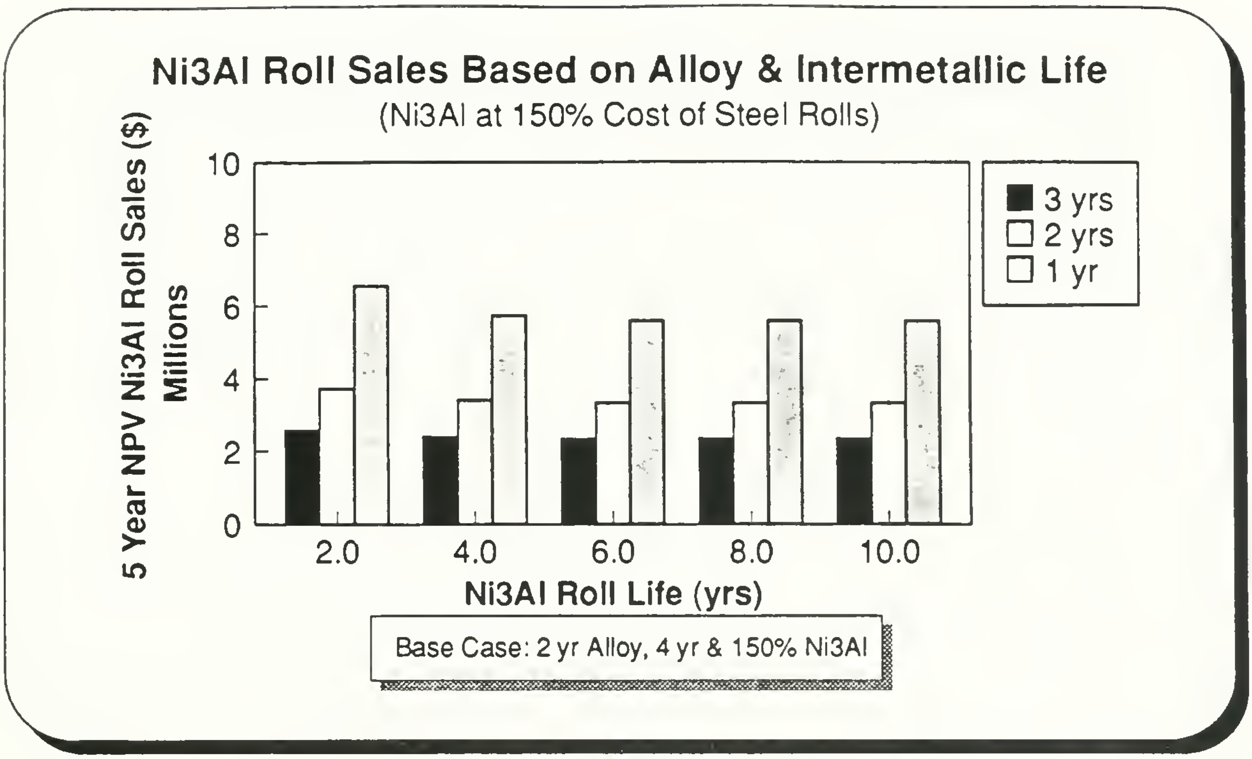

Figure 13. Alloy Roll Life Impacts I

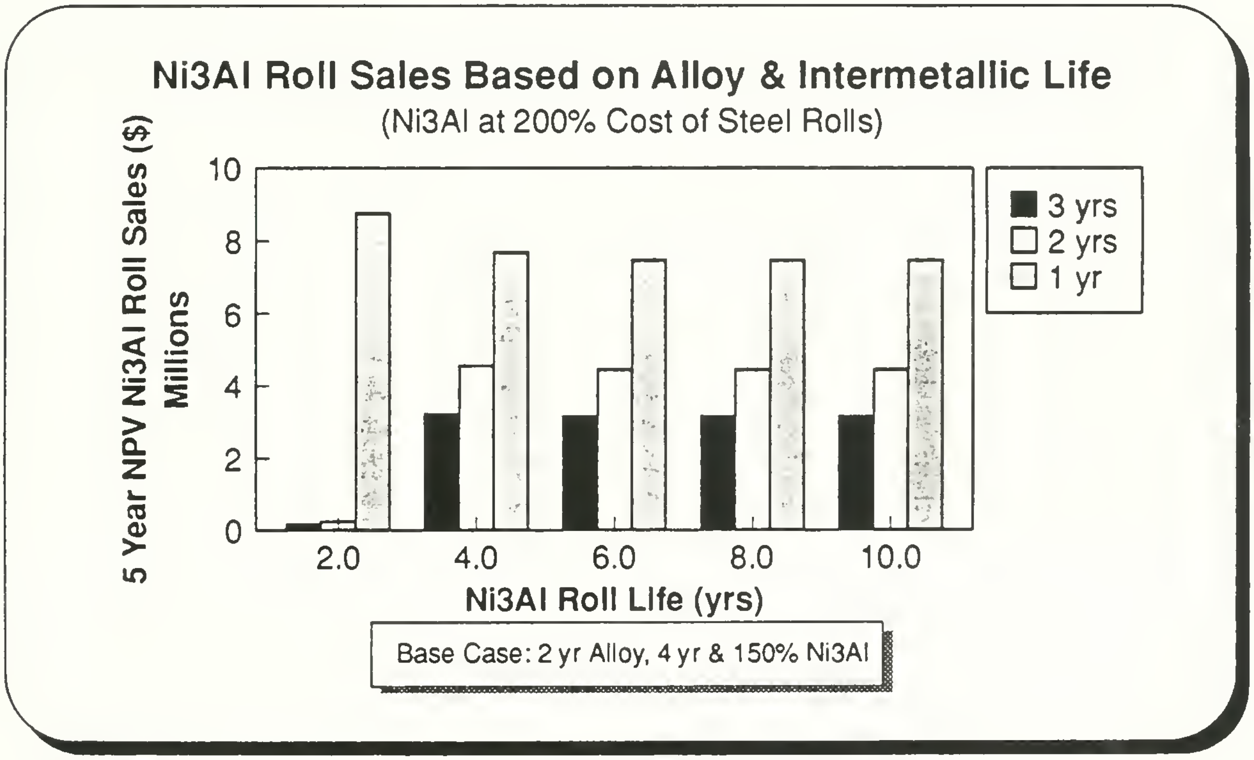

Figure 14. Alloy Roll Life Impacts I

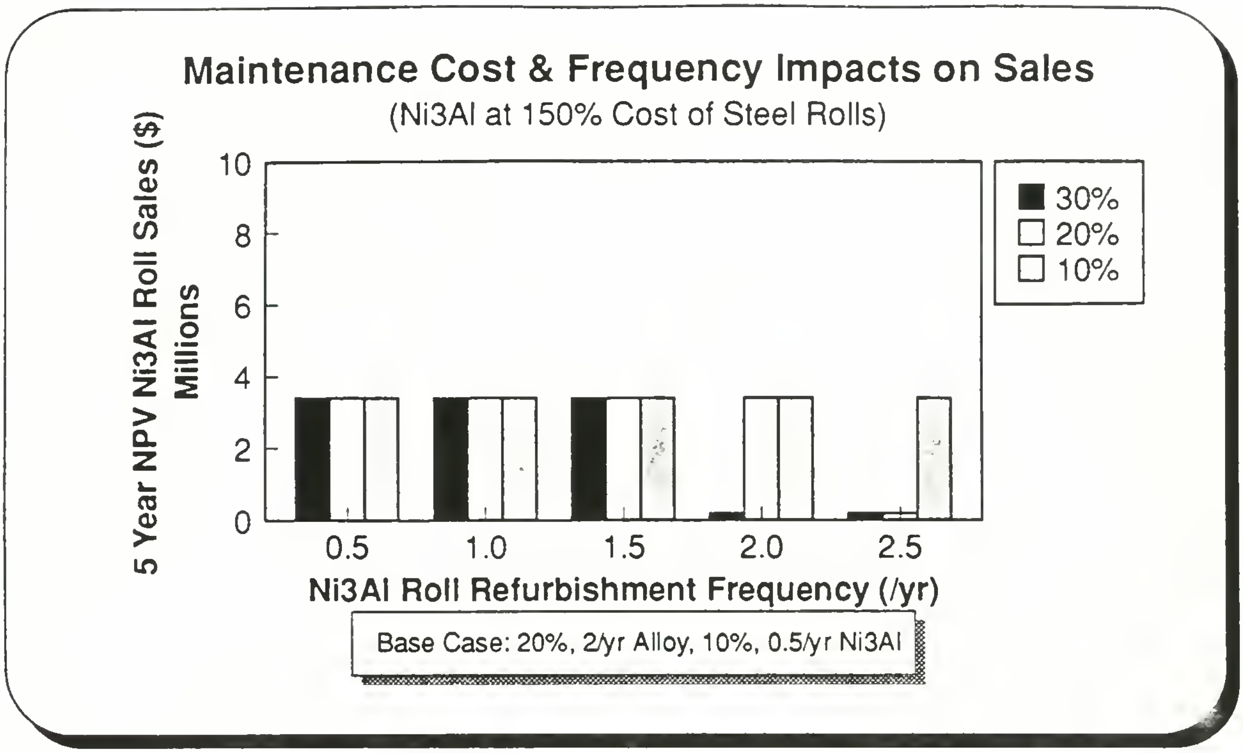

Figure 15. Maintenance Effects on Intermetallic Roll Sales

Figure 15 examines the sensitivity of intermetallic roll sales to maintenance requirements, both cost and frequency. At a price of 150 percent, nickel aluminide rolls remain attractive until refurbishment requirements approach those of alloy rolls (about twice per year). Maintenance cost is expressed as a function of roll cost, and has less of an overall impact for the range considered (10 to 30 percent), except for incidences of frequent refurbishments.

4.4 NI$_3$AL CASE CONCLUSIONS

The Ni$_3$Al furnace roll assessment suggests that intermetallics could be readily adopted in both heat-treat and tunnel furnace applications in the steel industry if the performance and cost projections of Metallamics and ORNL are achieved. In the worst environments, steel alloy rolls currently last as little as two years. This market segment is estimated to be worth over $5 million annually. Using the MSL framework, sales estimates in excess of $1 million (current dollars) annually within five years are projected for Ni$_3$Al rolls. While the absolute dollar sales level is not exceptionally large, it represents a significant portion of the furnace markets considered, and only one potential application. Assessments of other potential Ni$_3$Al markets could also be developed using the MSL framework, and combined to estimate the total global market for the intermetallic material.

5 Conclusion

Decisionmaking under uncertainty is always difficult, especially where advanced technology funding is concerned. Consequences often lie years, if not decades, in the future. Over the last decade, the Materials Systems Laboratory has applied quantitative cost and market analysis to a wide variety of advanced materials technology assessments. For this project, a new framework was developed which draws upon past MSL modeling concepts, decision analysis, and technology forecasting theory to provide a generalized approach to advanced technology project assessment. The goal of the work was to create an analysis tool which OIT could use to screen future technology investment options.

The model developed can be applied to both technology screening and detailed market assessments. As a screening tool, it serves as a standard basis for comparing potential projects. Data requirements for this level of analysis are minimal, and estimates can be employed. Sensitivity analyses provide an understanding of the impacts uncertainties, related to the technology or market, might have on the overall assessment. For more detailed analyses, modeling data can be gathered in a formal fashion. For example, the case studies used to demonstrate the MSL framework employed an end-user survey technique to elicit information about consumer preferences.

The case studies demonstrated both the type of data (collected or estimated) required to run an analysis and typical model outputs that could be applied to assist with technology funding decisions. The major evaluation metric in the MSL framework is product sales in current (NPV) dollars. However, for cases such as the CFCC boiler burner, additional metrics such as energy or NO_x emissions savings were considered.

The CFCC boiler burner assessment suggested that this application of advanced ceramics is likely to remain niche for the foreseeable future, even if aggressive developmental and economic goals are attained. This opinion concurs with that of the company which is developing the technology, but the boiler burner represents only one of the CFCC applications Alzeta hopes to commercialize. Others are expected to demonstrate more appreciable market potential.

In contrast, the assessment of Ni_3Al transfer rolls for steel processing predicted that the intermetallic product stands a reasonable chance of commercialization, assuming several relatively short-term development goals are reached. While the annual total of this market segment is probably less than $5 million in the United States, transfer rolls represent only one potential application of Ni_3Al.

Overall, the MSL modeling framework should be applicable to a significant portion of the advanced technology evaluations OIT must face in the course of a year. Like any model, it is not a panacea for predicting the future, but provides a medium for considering what might occur if certain technical advances are achieved. By understanding what probably must transpire to enable wide-spread commercialization, an evaluation team is better prepared to judge the implicit risk associated with a funding opportunity.

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Appendix A: Telephone Survey Materials

MSL
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Questions for Intermetallic Transfer Roll & CFCC Boiler Burner Study

This fax includes two questionnaires. One is an example of a new car purchase decision. The other is a copy of the furnace roll survey. This investigation simply aims to collect end-user perceptions; there are no right or wrong answers to the questions. On both forms, the major sections are shaded and numbered from 1 to 5. The accompanying questions are as follows.

1. **Are the listed characteristics pertinent to technology selection?** For the characteristics listed, check-off those you consider relevant for evaluating product alternatives. These should be characteristics for which you would be willing to pay for increasing levels of performance or to obtain a certain required level of capability.
2. **For the criteria selected in *Question 1*, how important are specific parameters?** While several characteristics might be pertinent to a decision, some often carry more weight. In the car example, price and expected life are the most significant criteria. Air conditioning, sunroof and cup-holder follow in decreasing levels of importance. Use the table in *Question 2* to indicate the relative importance of each item selected in *Question 1*.
3. **What is the range over which you might expect each parameter to vary?** This is a gauge of what end-users expect is technically or economically feasible. For each parameter, estimate what the best and worst case might be in the foreseeable future. Considering the car example, the respondent believes that prices for the class of car evaluated might range between $11,000 to $17,000, and these cars might last between 70,000 and 150,000 miles.
4. **Is there a minimum or maximum acceptable value for any parameter?** Some product requirements are less flexible than others. For example, government regulations may dictate certain performance requirements for emissions related equipment. Indicate the presence of requirement limits, if they exist. In the automobile example, the customer has indicated that no car with an expected life of less than 100,000 miles is acceptable.
5. **For limits cited in *Question 4*, are additional improvements in performance valued?** If faced with two otherwise equal and acceptable products, would you pay more for one if it were better than the limit while the other simply met this limit? In the car example, the customer will pay for incremental life improvements above 100,000 miles.

Questionnaire Example
New Car Purchase

	1	2				3	4	5
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance**				**Expected Range of Parameter**	**Critical Specification Max or Min? (specify)**	**Value Improvements Beyond Limit? (x if yes)**
		Top Quartile	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**			
		(x indicates ranking)						
General Characteristics								
Acquisition Cost	x	x				$11,000 to $17,000		
Cupholder	x				x	available or not available		
Color								
Expected Life (Reliability)	x	x				70,000 to 150,000 miles	100,000 min	x
Automatic Transmission								
Air Conditioning	x		x			available or not available		
Sunroof	x			x		available or not available		

Boiler Burner Questionnaire

	1	2				3	4	5
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance (x indicates ranking)**				**Expected Range of Parameter**	**Specification Limit? (specify)**	**Value Improvements Beyond Limit? (x if yes)**
		Top Quartile	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**			
Performance/Operation								
Durability (life)						yrs		
On-Off Cycling Speed						sec		
Noise						db		
Temperature Uniformity						max delta F		
Alternative Fuel Capacity						yes or no		
Heat Flux Capacity						MBtu/hr		
Energy Efficiency						%		
Turndown Ratio						x:y		
Cost								
Initial						$/MBtu		
Maintenance						$/Yr/MBtu		
Emissions								
Emissions (NOx)						parts per million		
Emissions (CO)						parts per million		
Emissions (VOC)						parts per million		
Emissions (particulate)						parts per million		
Other								

Furnace Roll Questionnaire

	1	2				3	4	5
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance**				**Expected Range of Parameter**	**Specification Limit? (specify)**	**Value Improvements Beyond Limit? (x if yes)**
		Top Quartile	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**			
		(x indicates ranking)						
Performance/Operation								
Expected Roll Life						yrs		
Roll Refurbishment Frequency						/yr		
Product Yield						%		
Furnace Downtime						%		
Furnace Energy Efficiency						%		
Cost								
Initial						$/roll		
Maintenance						$/roll/yr		
Other								

Appendix B: CFCC Boiler Burner End-User Survey Results

Boiler Burner Questionnaire

Aggregate Data
8 Surveys

	1	2				3	4	5
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance** **Top Quartile**	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**	**Expected Range of Parameter**	**Specification Limit? (specify)**	**Value Improvements Beyond Limit? (x if yes)**
		(x indicates ranking)						
Performance/Operation								
Durability (life)	7	4	1	2		2 to 50 yrs	1(15), 1(25)	2
On-Off Cycling Speed	2		1	1		10 to 120 sec	1 (80)	
Noise	3		1	1	1	30 to 125 db		
Temperature Uniformity	4		3	1		30 to 100 delta F		
Alternative Fuel Capacity	3	1	2			yes or no	1	NA
Heat Flux Capacity	2	2				20 to 80 MBtu/hr		
Energy Efficiency	7	5	2			75 to 100%	2 (80%)	2
Turndown Ratio	5	1.5	2	1	0.5	2:1 to 12:1		
Cost								
Initial	8	4	3	1		$1.00 to ?/MBtu		
Maintenance	8	5	3			NA		
Emissions								
Emissions (NOx)	7	6			1	0 to 30 ppm	4 (AQMD)	3
Emissions (CO)	7	4	1	1	1	0 to 400 ppm	4 (AQMD)	2
Emissions (VOC)	4	2	1	1		0 to <10 ppm	1 (AQMD)	1
Emissions (particulate)	3	2			1	AQMD	1 (AQMD)	1
Other								
manufacturer reputation	2	1	1					
downtime	1	1				0 to 10%		
accessibility/ease of repair	2		2					
training of personnel	1	1						
contractor opinion	1	1						
oil burning capability	1			1				
utility company rebates	1	1						
control complexity	1		1					

Boiler Burner Questionnaire

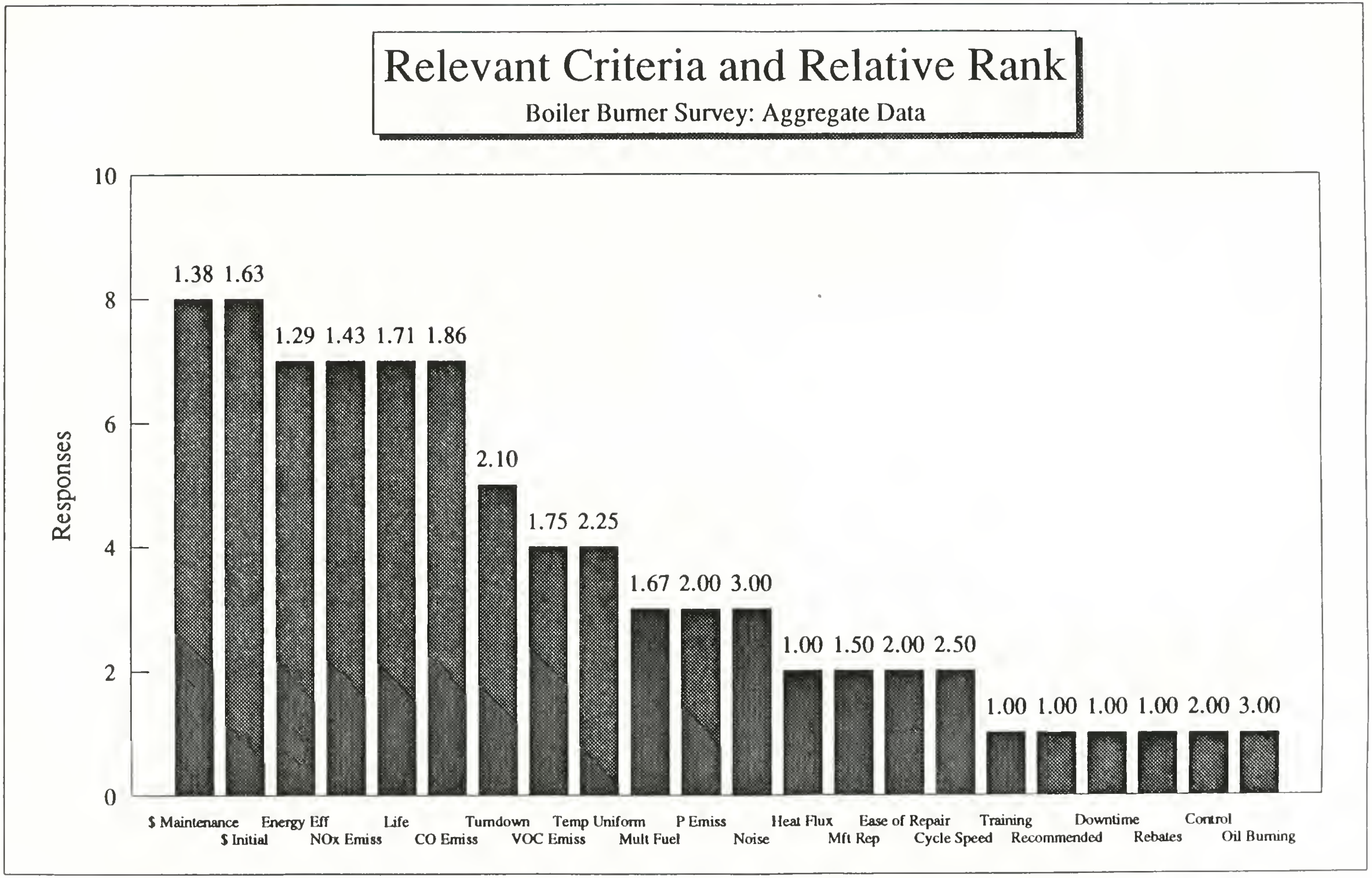
California Data
5 Surveys

Product Characteristics	1	2			
	Pertinent Decision Criteria? (x if yes)	Relative Importance			
		Top Quartile	2nd Quartile	3rd Quartile	Lower Quartile
		(x indicates ranking)			
Performance/Operation					
Durability (life)	5	2	1	2	
On-Off Cycling Speed	2		1	1	
Noise	3		1	1	1
Temperature Uniformity	2		1	1	
Alternative Fuel Capacity	2	1	1		
Heat Flux Capacity	2	2			
Energy Efficiency	5	3	2		
Turndown Ratio	3	1.5		1	0.5
Cost					
Initial	5	2	3		
Maintenance	5	4	1		
Emissions					
Emissions (NOx)	5	5			
Emissions (CO)	5	3	1	1	
Emissions (VOC)	3	2		1	
Emissions (particulate)	2	2			
Other					
manufacturer reputation	2	1	1		
downtime	1	1			
accessibility/ease of repair	1		1		
training of personnel	1	1			
contractor opinion					
oil burning capability	1			1	
utility company rebates	1	1			
control complexity					

Boiler Burner Questionnaire

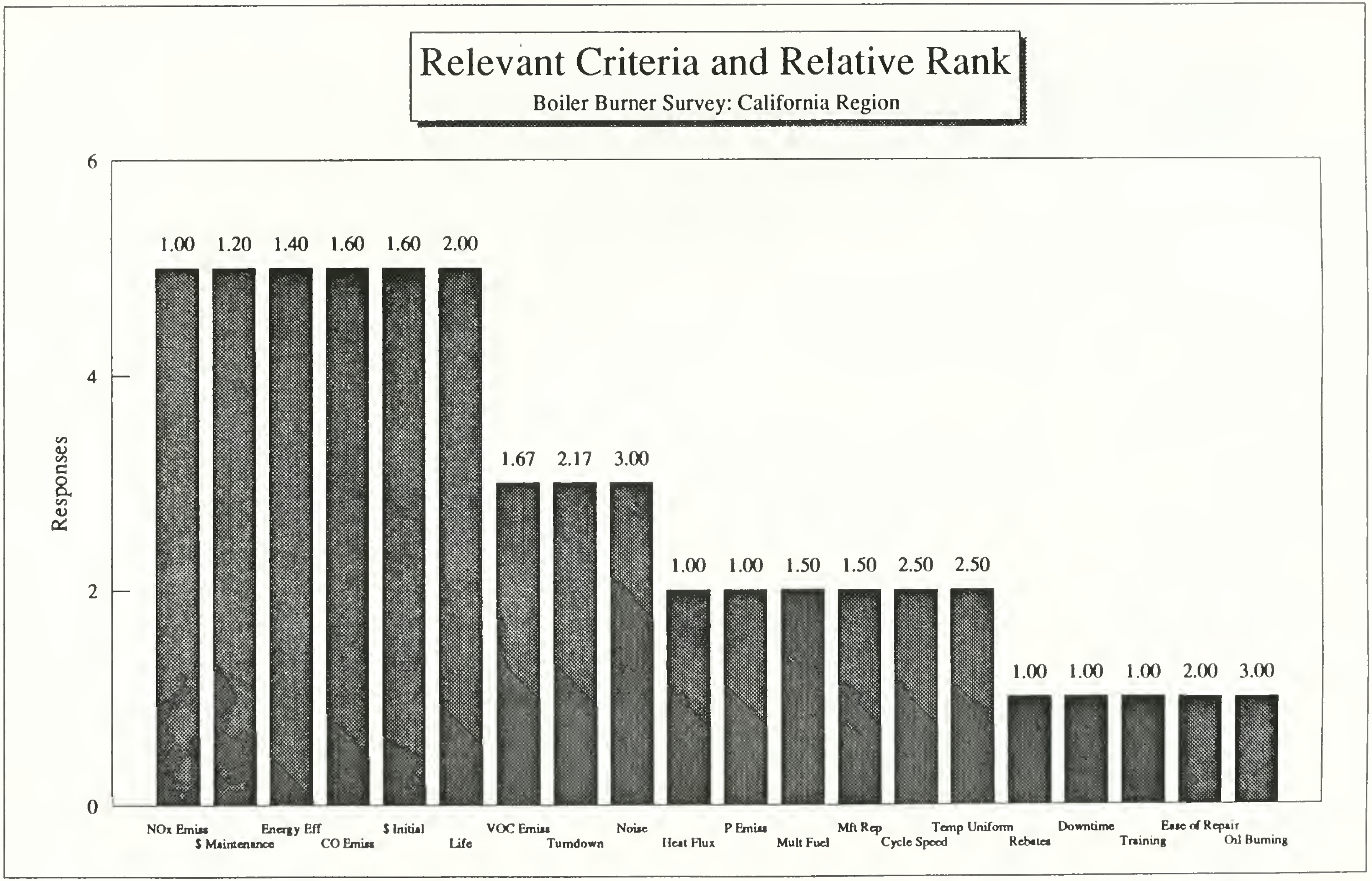
Ohio Data
3 Surveys

	1	2			
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance**			
		Top Quartile	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**
		(x indicates ranking)			
Performance/Operation					
Durability (life)	2	2			
On-Off Cycling Speed					
Noise					
Temperature Uniformity	2		2		
Alternative Fuel Capacity	1		1		
Heat Flux Capacity					
Energy Efficiency	2	2			
Turndown Ratio	2		2		
Cost					
Initial	3	2		1	
Maintenance	3	1	2		
Emissions					
Emissions (NOx)	2	1			1
Emissions (CO)	2	1			1
Emissions (VOC)	1		1		
Emissions (particulate)	1				1
Other					
manufacturer reputation					
downtime					
accessibility/ease of repair	1		1		
training of personnel					
contractor opinion	1	1			
oil burning capability					
utility company rebates					
control complexity	1		1		



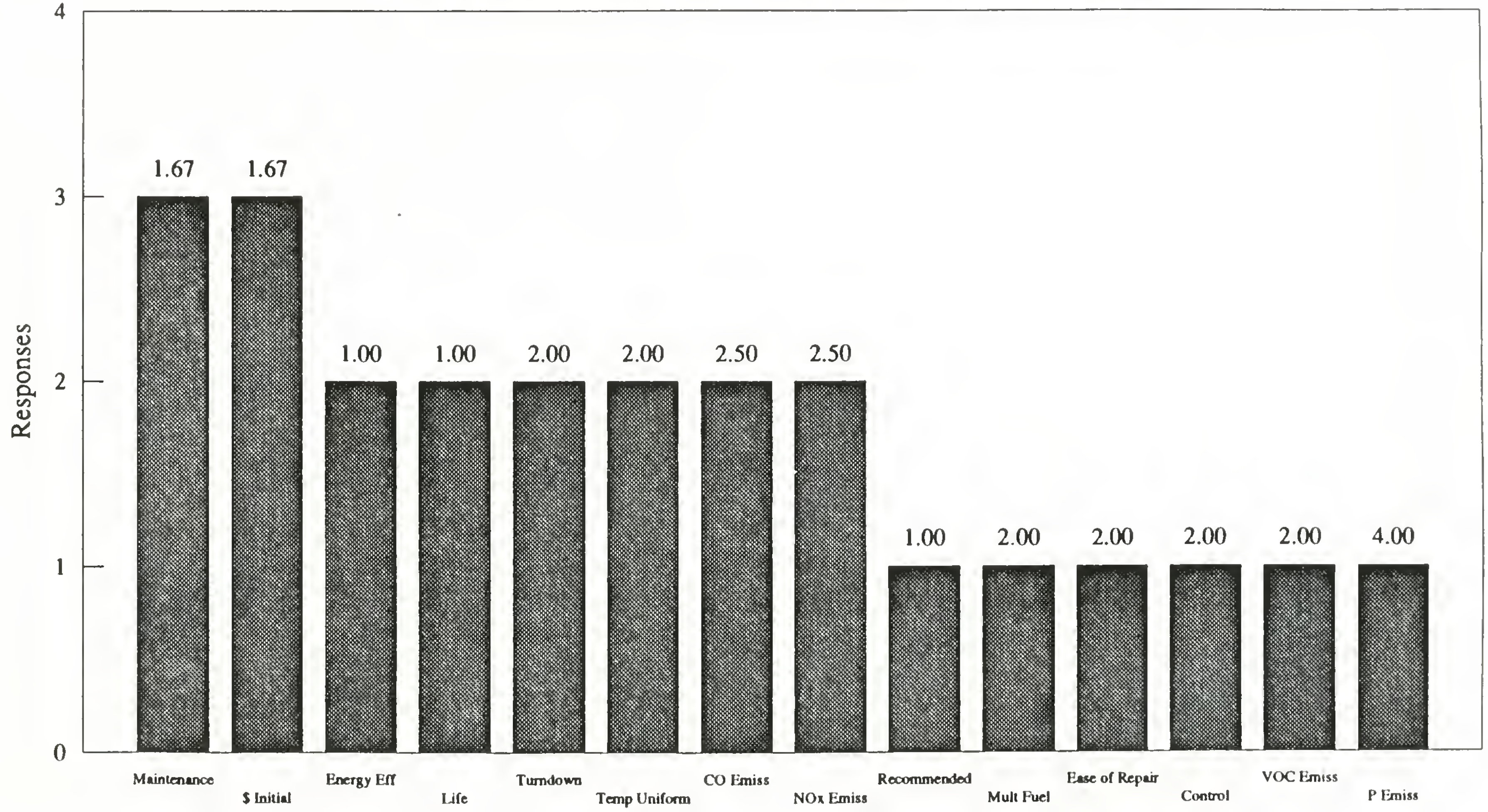
Relevant Criteria and Relative Rank

Boiler Burner Survey: Aggregate Data



Relevant Criteria and Relative Rank

Boiler Burner Survey: Ohio Region



t-Statistics
CFCC Burners

	Maint $		Initial $		Energy Eff		NOx		Life		CO		Turndown		VOC		T Uniform	
Respondant																		
	CA Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile	*CA* Quartile	*OH* Quartile
1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2	2
2	1	2	1	1	1	1	1	4	1	1	1	4	3	2	1	5	3	2
3	1	2	2	3	1	5	1	5	2	5	1	5	2.5	5	3	5	5	5
4	1		2		2		1		3		2		5		5		5	
5	2		2		2		1		3		3		5		5		5	
t-stat (2 tail)	30.5%		93.2%		55.8%		19.2%		83.1%		28.3%		82.3%		49.0%		45.0%	

Appendix C: Ni_3Al Transfer Roll End-User Survey Results

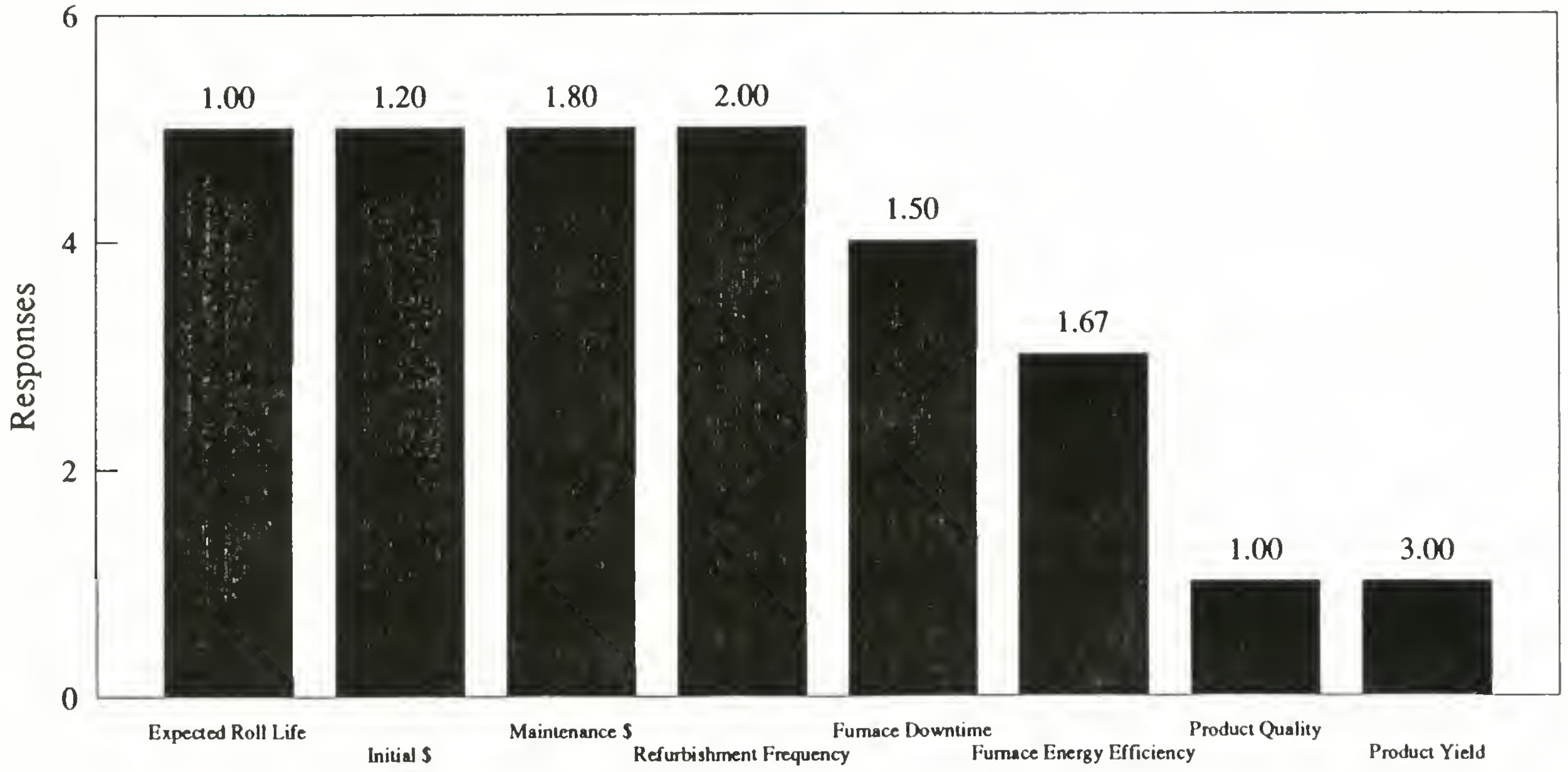
Ni3Al Roll Questionnaire

Aggregate Data
5 Surveys

	1	2				3	4	5
Product Characteristics	**Pertinent Decision Criteria? (x if yes)**	**Relative Importance**				**Expected Range of Parameter**	**Specification Limit? (specify)**	**Value Improvements Beyond Limit? (x if yes)**
		Top Quartile	**2nd Quartile**	**3rd Quartile**	**Lower Quartile**			
		(x indicates ranking)						
Performance/Operation								
Expected Roll Life	5	5				1.5-25 yrs	1.5	3
Roll Refurbishment Frequency	5	2	2		1	0-2 /yr	9 months	1
Product Yield	1			1		0.1-0.3%		
Furnace Downtime	4	2	2			5 %		1
Furnace Energy Efficiency	3	1	2			95 %		1
Cost								
Initial	5	4	1			$4900-9000 /roll		1
Maintenance	5	1	4			$180-6900 /roll/yr	12 months	1
Other								
Product Quality	1	1						1

Relevant Criteria and Relative Rank

Ni3Al Roll Survey: Aggregate Data



Appendix D: Heat Treat & Tunnel Furnace Roll Market Data

HEAT-TREAT FURNACES

FULL LISTING

Assumes 6000 working hours/yr

BA = Batch Annealer
CT = Continuous Tempering
CA = Continuous Annealer
RH = Roller-Hearth
BHT = Batch Heat Treat
N = Normalizing
U = Unspecified

	Company	Site	Furnace Type	Capacity (tons/hr)	Furnace Length (ft)	Product Width (in)	No. of Furnaces	Product	Country
1	ACME Steel	Riverdale	BA	3100			1		USA
2	ACME Steel	Riverdale	BA	49000			16		USA
3	AL Tech Specialty Steel	Dunkirk	BA				7		USA
4	AL Tech Specialty Steel	Watervliet	BA	0.5			18		USA
5	AL Tech Specialty Steel	Watervliet	BA	0.58			1		USA
6	Armco Steel Co	Middletown	BA	95			3		USA
7	Bethlehem Steel	Burns Harbor	BA	8			26		USA
8	Bethlehem Steel	Lackawanna	BA	9			7		USA
9	Bethlehem Steel	Lackawanna	BA	11			5		USA
10	Bethlehem Steel	Sparrows Point	BA	7			19		USA
11	Blair Strip Steel	New Castle	BA	7.3			2		USA
12	Blair Strip Steel	New Castle	BA	2.3			4		USA
13	California Steel Industries	Fontana	BA	2.6			7		USA
14	California Steel Industries	Fontana	BA	6.7			5		USA
15	Cold Metal Products	Hamilton	BA	0.25			4		CAN
16	Cold Metal Products	Hamilton	BA	1.0			2		CAN
17	Cold Metal Products	New Britain	BA				13		USA
18	Cold Metal Products	Youngstown	BA	0.5			1		USA
19	DOFASCO	Hamilton	BA	2.9			3		CAN
20	DOFASCO	Hamilton	BA	2.5			3		CAN
21	DOFASCO	Hamilton	BA	24			4		CAN
22	Greer Steel	Dover	BA	1			17		USA
23	Gulf States Steel	Gadsden	BA				33		USA
24	LTV	Aliquippa	BA	4			10		USA
25	LTV	Cleveland	BA	6			26		USA
26	LTV	Cleveland	BA	1.5			78		USA
27	LTV	Cleveland	BA	12			8		USA
28	LTV	Hennepin	BA	9			16		USA
29	LTV	Indiana Harbor	BA	5.8			19		USA
30	LTV	Indiana Harbor	BA	7.5			4		USA
31	McLouth	Trenton	BA	1.5			68		USA
32	Pittsburgh Flatroll	Pittsburgh	BA				2		USA
33	The Steel Co	Chicago	BA	0.5			4		USA
34	USX	Fairfield	BA	2.8			30		USA
35	USX	Fairless	BA	6.3			21		USA
36	USX	Gary	BA	7.3			25		USA
37	USX	Gary	BA	9.1			15		USA
38	USX	Gary	BA	14			5		USA
39	USX	Mon Valley	BA	5.7			30		USA
40	WCI Steel	Warren	BA	1.5			49		USA
41	Weirton Steel	Weirton	BA	7			12		USA
42	Weirton Steel	Weirton	BA	2.4			15		USA
43	Weirton Steel	Weirton	BA	2.4			15		USA
44	Western Steel	Calegary	BA						CAN
45	Bethlehem Steel	Sparrows Point	BHT						USA
46	Jessop Steel Co	Washington	BHT						USA
47	AL Tech Specialty Steel	Dunkirk	CA	7			1		USA
48	AL Tech Specialty Steel	Watervliet	CA	0.07			1		USA
49	Bethlehem Steel	Burns Harbor	CA	105		60	1		USA
50	Bethlehem Steel	Sparrows Point	CA	58		40	1		USA
51	Cold Metal Products	Hamilton	CA	1.1			1		CAN
52	Cold Metal Products	Hamilton	CA	1.5			1		CAN
53	Cold Metal Products	Hamilton	CA	5.6			1		CAN
54	Cold Metal Products	New Britain	CA			26	1		USA
55	Cold Metal Products	Youngstown	CA	0.7		40	1		USA
56	Cold Metal Products	Youngstown	CA	2.5		58	1		USA
57	Cold Metal Products	Youngstown	CA	1.7		17.5	1		USA
58	DOFASCO	Hamilton	CA	47		40	1		CAN
59	LTV	Aliquippa	CA	50		48	1		USA
60	LTV	Cleveland	CA	150		72	1		USA
61	LTV	Indiana Harbor	CA	58		48	1		USA
62	Republic Engineered Steels	Beaver Falls	CA	1.1			1		USA
63	Republic Engineered Steels	Beaver Falls	CA	1.3			1		USA
64	Republic Engineered Steels	Gary	CA	1.8			1		USA
65	Republic Engineered Steels	Gary	CA	1.2			1		USA
66	Republic Engineered Steels	Gary	CA	1.25			1		USA
67	USX	Fairless	CA	49		38	1		USA
68	USX	Gary	CA	42		38	1		USA
69	USX	Gary	CA	25		37	1		USA
70	USX	Irvin	CA	52		38	1		USA
71	Weirton Steel	Weirton	CA	42		37	1		USA
72	Weirton Steel	Weirton	CA	55		42	1		USA
73	Weirton Steel	Weirton	CA	23		37	1		USA
74	Quanex Corp	Huntington	CT				2		USA
75	Bethlehem Steel	Sparrows Point	RH						USA
76	Geneva Steel	Vineyard	RH		54	127	1		USA
77	Lukens Steel	Coatesville	RH		200				USA
78	Lukens Steel	Coatesville	RH		200				USA
79	Lukens Steel	Coatesville	RH		145				USA
80	Oregon Steel Mills	Portland	RH				3		USA
81	Quanex Corp	Fort Smith	RH				2		USA
82	Quanex Corp	South Lyon	RH				5		USA
83	USX	Mon Valley	U	1.6			12		USA
84	Armco Advanced Materials	Butler	UA	17			1		USA
85	Armco Advanced Materials	Butler	UA	6			1		USA
86	Armco Advanced Materials	Butler	UA	20			1		USA
87	Armco Advanced Materials	Butler	UA	22			1		USA
88	Armco Advanced Materials	Butler	UA	40			1		USA
89	Armco Advanced Materials	Zanesville	UA	21			1		USA
90	LTV	Elyria	UA						USA
91	Republic Engineered Steels	Massillon	UA	1.2			10		USA
92	Electralloy	Oil City	UHT						USA
93	Lone Star Steel	Lone Star	UHT	6		16	5		USA
94	Republic Engineered Steels	Massillon	UHT				3		USA
95	USX	Gary	UN						USA

HEAT-TREAT FURNACES
POTENTIAL NI3AI SITES

Assumes 6000 working hours/yr

BA = Batch Annealer
CT = Continuous Tempering
CA = Continuous Annealer
RH = Roller-Hearth
BHT = Batch Heat Treat
N = Normalizing
U = Unspecified

	Type	Company	Site	Furnace Type	Capacity (tons/hr)	Furnace Length (ft)	Product Width (in)	No. of Furnaces	Product	Country
1	I	Bethlehem Steel	Burns Harbor	CA	105		60	1		USA
2	I	Bethlehem Steel	Sparrows Point	CA	58		40	1		USA
3	I	DOFASCO	Hamilton	CA	47		40	1		CAN
4	I	LTV	Aliquippa	CA	50		46	1		USA
5	I	LTV	Cleveland	CA	150		72	1		USA
6	I	LTV	Indiana Harbor	CA	58		46	1		USA
7	I	USX	Fairless	CA	49		38	1		USA
8	I	USX	Gary	CA	25		37	1		USA
9	I	USX	Gary	CA	62		38	1		USA
10	I	USX	Irvin	CA	52		38	1		USA
11	I	Weirton Steel	Weirton	CA	42		37	1		USA
12	I	Weirton Steel	Weirton	CA	23		37	1		USA
13	I	Weirton Steel	Weirton	CA	55		42	1		USA
14	I	Bethlehem Steel	Sparrows Point	RH						USA
15	I	Geneva Steel	Vineyard	RH		54	127	1		USA
16	I	Oregon Steel Mills	Portland	RH				3		USA
17	I	USX	Mon Valley	U	1.6			12		USA
18	I	LTV	Elyria	UA						USA
19	I	Lone Star Steel	Lone Star	UHT	8		16	5		USA
20	I	USX	Gary	UN						USA
21	S	AL Tech Specialty Steel	Dunkirk	CA	7			1		USA
22	S	AL Tech Specialty Steel	Watervliet	CA	0.07			1		USA
23	S	Cold Metal Products	Hamilton	CA	1.1			1		CAN
24	S	Cold Metal Products	Hamilton	CA	1.5			1		CAN
25	S	Cold Metal Products	Hamilton	CA	5.6			1		CAN
26	S	Cold Metal Products	New Britain	CA			26	1		USA
27	S	Cold Metal Products	Youngstown	CA	0.7		40	1		USA
28	S	Cold Metal Products	Youngstown	CA	2.5		56	1		USA
29	S	Cold Metal Products	Youngstown	CA	1.7		17.5	1		USA
30	S	Republic Engineered Steels	Beaver Falls	CA	1.1			1		USA
31	S	Republic Engineered Steels	Beaver Falls	CA	1.3			1		USA
32	S	Republic Engineered Steels	Gary	CA	1.2			1		USA
33	S	Republic Engineered Steels	Gary	CA	1.6			1		USA
34	S	Republic Engineered Steels	Gary	CA	1.25			1		USA
35	S	Quanex Corp.	Huntington	CT				2		USA
36	S	Lukens Steel	Coatesville	RH		200				USA
37	S	Lukens Steel	Coatesville	RH		200				USA
38	S	Lukens Steel	Coatesville	RH		145				USA
39	S	Quanex Corp.	Fort Smith	RH				2		USA
40	S	Quanex Corp.	South Lyon	RH				5		USA
41	S	Armco Advanced Materials	Butler	UA	20			1		USA
42	S	Armco Advanced Materials	Butler	UA	8			1		USA
43	S	Armco Advanced Materials	Butler	UA	17			1		USA
44	S	Armco Advanced Materials	Butler	UA	40			1		USA
45	S	Armco Advanced Materials	Butler	UA	22			1		USA
46	S	Armco Advanced Materials	Zanesville	UA	21			1		USA
47	S	Republic Engineered Steels	Massillon	UA	1.2			10		USA
48	S	Electralloy	Oil City	UHT						USA
49	S	Republic Engineered Steels	Massillon	UHT				3		USA

Market Model:

BASELINE: HEAT TREAT

Prototype Facility

Capacity (tph)	105.0	
# of Rolls	101.0	
$ New	$12,000	
$ Refurb	$9,000	
Value New Rolls	$1,212,000	if 100% retrofitted

HT ROLL MARKET ESTIMATE

			Market $
Current Roll Life	2.0	yrs	
Expected NI3Al Roll Life	4.0	yrs	
Expected NI3Al Price Premium	150.0%		
HT capacity (reported)	1002	tph	$11,565,943
HT capacity (scaled)	1403	tph	$16,194,629
Potential Substitute Market	33.0%		$5,344,227
Potential Annual Market		@ Incumbent price	$2,672,114

TSC FURNACE MARKET ESTIMATE

		# Rolls	**Estimate $/Roll**	**$ Value Rolls**
Minimills w/ Tunnel Furnaces	Nucor (Crawfordsvill	200.0	$5,000	$1,000,000
	Nucor (Hickman)	200.0	$5,000	$1,000,000
	Gallatin	200.0	$5,000	$1,000,000
	ACME	200.0	$5,000	$1,000,000
	Steel Dynamics	200.0	$5,000	$1,000,000
Potential Substitute Market				$5,000,000

Current Roll Life	2.0	yrs	
Expected NI3Al Roll Life	4.0	yrs	
Expected NI3Al Price Premium	150.0%		
Potential Substitute Market	100.0%		$5,000,000
Potential Annual Market		@ Incumbent price	$2,500,000

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