CONSULTANT REPORT

P I E R
Public Interest Energy Research
CALIFORNIA ENERGY COMMISSION

Industrial/Agricultural/Water
End-Use Energy Efficiency

LOW DROSS ALUMINUM MELTER PROJECT

Gray Davis, *Governor*

STATE OF CALIFORNIA
ENERGY COMMISSION

RESOURCES AGENCY

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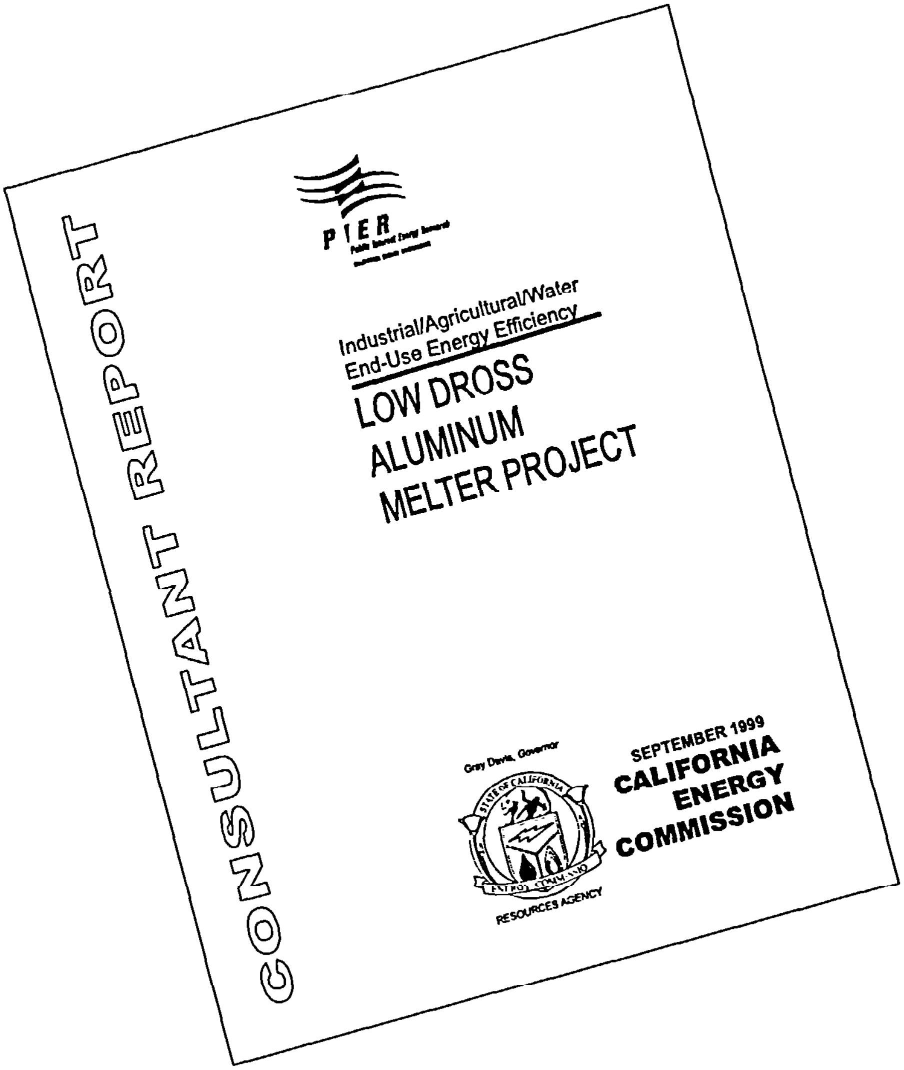

CALIFORNIA ENERGY COMMISSION

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Legal Notice

Acknowledgements

Participating Organizations

The Edison Technology Solutions (ETS) project team included representatives from the user, equipment design and manufacturing, research, utility, and regulatory communities who were each committed to the successful commercialization of the DC plasma arc technology for the secondary aluminum industry. The following summarizes participating organizations and their contributions:

- **ETS** provided project management and contract administration support for the project. ETS staff was instrumental in guiding this research effort to a potentially marketable commercial application.
- **Electrical Power Research Institute (EPRI) Center for Material Production** developed several advanced electro-technologies for the material production industry including the DC plasma arc technology investigated by this project. The EPRI Center for Material Production led the project technical team of participating organizations and industry experts.
- **Process Engineering Dynamics (PED)** developed and engineered the lab prototype and the one-ton demonstration melter including the engineering, testing, and evaluation support for the one ton unit.
- **Paul Wurth, Inc.** managed the design and fabrication of the Prototype One-Ton DC Plasma Arc Melter demonstration and provided the preliminary engineering for the five-ton unit.
- **TIMCO, Division of TST Inc.**, hosted the Prototype One-Ton DC Plasma Arc Melter demonstration, provided the local technical design support, management of installation contracts, and the operators and maintenance staffing required for the startup.
- **Southern California Edison** provided, at cost, the additional electrical infrastructure needed to support the electrical load.

Participating Individuals

Special thanks are extended to the project Technical Advisory Team who ensured that the highest level of current expertise was employed in the development and design of the Prototype One-Ton DC Plasma Arc Melter and in the evaluation of its operational performance. Members of the Technical Advisory Team included:

- Bob Schmidt, Past Associate Director, Center for Material Production
- Dr. Frank Kemeny, President, Process Engineering Dynamics
- Cliff Lotzenhiser, Technical Manager, TIMCO
- Dr. Robert Heart, General Manager Steelmaking, Paul Wurth, Inc.
- William Ebner, Engineer, Paul Wurth, Inc.
- Dr. David Walker, Engineer, Process Engineering Dynamics
- Alex Marr, President, Engineering Resource Associates

- Dr. Jan van Linden, Recycling Technology Services, Inc.

Technology Partners

- Process Engineering Dynamics
- Paul Wurth, Inc.
- TIMCO
- Southern California Edison.

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

Edison Technology Solutions (ETS) is an unregulated subsidiary of Edison International and an affiliate of Southern California Edison Company (SCE). As a result of a corporate restructuring, ETS ceased active operations on September 30, 1999. ETS' remaining rights and obligations were subsequently transferred to SCE.

What follows is the final report for the Low Dross Aluminum Melter project, 1 of 10 projects conducted by ETS. This project contributes to the Industrial/Agricultural/Water End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

Background

In 1995, recycling (secondary recovery) in the United States recovered 3,188 thousand metric tons (3,513 thousand tons) of metal valued at more than $3 billion from both new and old aluminum scrap. New scrap represents shavings and process waste generated by industrial manufacturing and fabrication processes while old scrap is comprised of materials that have been manufactured and used for a specific purpose.

Recycled aluminum has been increasing steadily as a fraction of the United States' total domestic usage since the early 1980's (Figure 1).

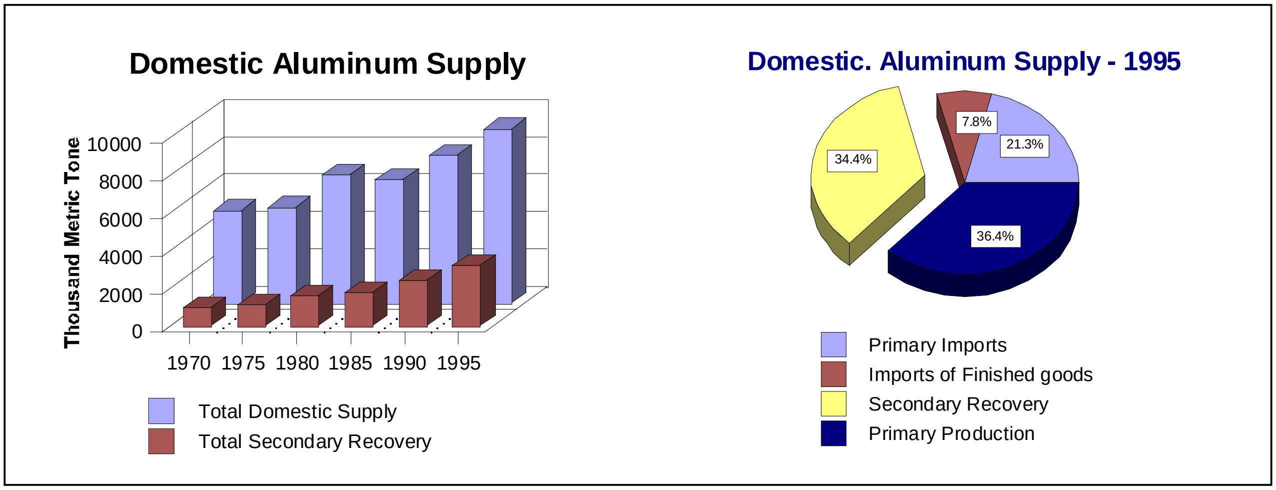

Figure 1. Sources of Domestic Aluminum Production

Of the total materials recycled in 1995, approximately 47 percent (1,505 thousand metric tons) was recovered from old scrap, primarily used beverage cans.

The recovery of aluminum beverage containers has been one of the recycling movement's most impressive success stories. In 1998, Americans returned 64 billion aluminum cans for a recycling rate of 62.8 percent. Recycling of beverage containers alone accounted for almost 2,000 thousand metric tons of the total domestic supply of aluminum available for manufacture and product fabrication this year. Currently, recycled aluminum provides almost 35 percent of the supply for the country's total domestic use. California hosts more aluminum recycling operations than any other state. Almost all are located in the southern part of the State.

The most popular technology used to melt scrap aluminum is the gas-fired reverberatory furnace. These furnaces display relatively low energy efficiencies, have high air pollutant emissions, and generate large waste streams.

Technology Hypothesis

In aluminum melting, a molten aluminum bath accumulates in the furnace as scrap is fed in. The system uses a batch process where the melting of the scrap continues until the furnace is filled. Continuous heating and mixing is required to ensure that the temperature of the molten aluminum in the furnace (the bath) is homogeneous. Alloying and demagging are performed on the molten aluminum bath. Conventional gas-fired, reverberatory furnaces expose the bath to atmospheric oxygen and allow oxidation to take place. Oxidation produces unwanted aluminum oxide, which inhibits the melting process and acts as a sponge absorbing the molten aluminum and reducing process yield. Theoretically, removing or displacing oxygen from the melting environment would inhibit the oxidation process.

A technology that would not need oxygen was proposed—the DC plasma arc. This technology allows use of a plasma blanket of argon gas to create and maintain an oxygen-starved environment, minimizing the process losses attributable to oxidation. In addition, because the technology employs an electrical arc, the air pollutant emissions associated with gas-fired reverberatory furnace technology are avoided.

Program Objectives

The purpose of this program was to demonstrate the commercial viability of the DC plasma arc technology in a controlled atmosphere to melt scrap aluminum for the recycling and reprocessing industries. The program's three main objectives were to:

- Improve the DC plasma arc furnace's competitive performance
- Demonstrate the technology's commercial viability
- Develop strategies to commercialize the DC plasma arc technology.

This program was originally envisioned in two phases. The program's first phase continued work begun on the one-ton Wabash demonstration unit, which validated the theoretical viability of the technology. It also demonstrated the necessity for a durable, efficient, and reliable system to seal the furnace against the intrusion of atmospheric oxygen, for a modified scrap feeding system, and for changes in operational procedures.

This project, the second phase of the program, intended to use the lessons learned to design, install, and operate a one-ton per hour and a five-ton per hour production scale furnace. The project objectives were to:

- Improve furnace sealing integrity to restrict dross formation to 1 percent or less
- Replace electromagnetic stirring devices with mechanical systems to improve melt mixing efficiency
- Optimize the location of stirring and return electrodes to improve process efficiency
- Develop a reliable continuous feed system to increase process throughput.

Program Approach

To demonstrate the competitive performance of the process, a one ton unit was built and tested at Wabash Alloys in Cleveland, Ohio in 1995. Heat transfer to the surface of the bath was fast and efficient; impressive melt rates were observed.

Sealing failures, however, were responsible for the less than ideal, but still good, metal recovery. The sealing system around the electrode repeatedly failed after three to eight hours of operation. The one-ton Wabash demonstration unit was determined to be not reliable enough for commercial viability.

As part of this Public Interest Energy Research (PIER) project, a Prototype One-Ton DC Plasma Arc Melter, with a sealing system designed for longer operation, was built and cold tested at TIMCO, and all components were ready for operation. This unit was never operated, so it was not possible to determine the effectiveness of this sealing system design.

We observed that electromagnetic mixing of the aluminum was not effective: the location of the return electrodes needed to be optimized and a new airtight continuous feed system was required. To improve the competitive performance of the technology, we incorporated the solutions to these problems in a one-ton unit at TIMCO's site in Fontana, California.

Initially, safety concerns stopped the testing of the Prototype One-Ton DC Plasma Arc Melter at TIMCO. We resolved the safety issues on October 23, 1998, but were unable to negotiate an operating agreement with TIMCO acceptable to all parties. This delayed the project and prevented the hot testing of the Prototype One-Ton DC Plasma Arc Melter at TIMCO.

Program Outcomes

We were unable to complete the program, but we did accomplished the following objectives:

- Demonstrated feasibility by:
  - Prepared design requirements for modification of the one-ton demonstration melter.
  - Designed and constructed the Prototype One-Ton DC Plasma Arc Melter adjacent to a comparable gas-fired reverberatory furnace.
  - Integrated power supply, scrap feed systems, and argon gas supply and control system.
  - Performed cold startup of the Prototype One-Ton DC Plasma Arc Melter.
  - Modified the melter as necessary to correct problems discovered during startup.
- Improved the DC plasma arc furnace's competitive performance:
  - At the Wabash site, dross formation rates of only two percent were achieved.
- We were unable to demonstrate the technology's commercial viability because the five-ton unit was never built.
  - The design of the one- and five-ton units and the construction and cold startup of the Prototype One-Ton DC Plasma Arc Melter provided lessons learned to accomplish this in the future.
- We developed and presented a draft commercialization to Electrical Power Research Institute, but a lack of sufficient funds because of the above delays prevented its implementation.

Project Budget

This program had total available funding of $3.1 million, of which $450,000 was provided by Public Interest Energy Research (PIER) transition funding for the Prototype One-Ton DC Plasma Arc Melter demonstration effort at TIMCO.

Table 1 provides the funding by participating agencies.

Table 1. Approved Project Budget by Contributors

Funding Agency	Commitment
Southern California Edison	
Direct Expenditures	$1,300,000
Co-Funding	$400,000
Tailored Collaboration Funding	$250,000
Electrical Power Research Institute	
Matching Tailored Collaboration Funding	$250,000
Base Funding	$50,000
California Energy Commission	
PIER Transition Funding	$450,000
Total Committed Funding	$2,700,000
U.S. Department of Energy National Industrial Competitiveness through Energy, Environmental and Economics (NICE3) Grant (linked to the five-ton unit)	$400,000
Total Available Funding	$3,100,000

Program Schedule

This program was scheduled to extend from the third quarter of 1997 to the last quarter of 2000 (Figure 2). The California Energy Commission funded portion ran from January 1998 through September 1999.

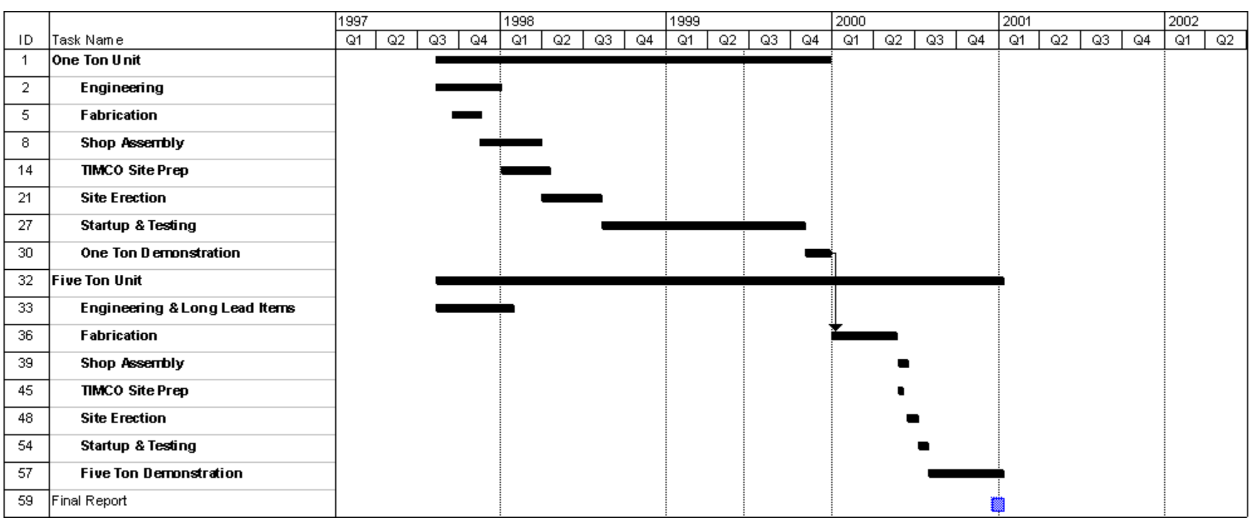

Figure 2. Original Project Schedule

Conclusions

The program demonstrated that DC plasma arc technology and atmosphere control could successfully reduce the formation of dross during the melting scrap aluminum. Unfortunately, the program was concluded before all objectives could be realized.

- The potential economic and environmental benefits of this technology are formidable.
- Widespread deployment of the DC plasma arc scrap aluminum melting technology will significantly improve competitiveness of the Nation's secondary aluminum industry.

Recommendations

A new, committed team is needed to complete the demonstration work and commercialization activities to move the technology forward. This report outlines a proposed plan to continue this program that is estimated to cost $12.5 million and require 7 years to complete.

- The results and findings of this project should be carried forward to the production scale demonstration originally envisioned.
  - Relocate and complete the one ton melter demonstration.
  - Demonstrate the five-ton prototype.
  - Expand low dross melter applications.

Abstract

The Low Dross Aluminum Melter program demonstrated the economic, environmental, energy efficiency and waste reduction benefits of the advanced DC plasma arc low-dross aluminum melter technology compared to existing reverberatory furnace technology. Developing an operating DC plasma arc melting technology would allow the melting of aluminum scrap material for the reuse market within a controlled, oxygen-starved environment that prevents the formation of aluminum oxide (dross) and reduces the volume of process waste materials. Bringing the DC plasma arc melting technology to commercialization will improve the aluminum melting industry's competitiveness, foster energy efficiency, and reduce waste at the source.

Prior to this project, performance of the one ton unit at the Wabash site in Cleveland, Ohio demonstrated the soundness of this process. The heat transfer to the surface of the bath is fast and efficient. Impressive melt rates and fuel efficiencies were observed even under the less than optimal operating conditions caused by furnace sealing failures. Sealing failures were also responsible for the less than ideal, but still good, metal recovery.

In addition, we observed that electromagnetic mixing of the aluminum was not effective, the location of the return electrodes needed to be optimized, and a new airtight continuous feed system was needed. This project was designed to improve the competitive performance of this technology by incorporating the solutions to these problems in the one-ton unit at TIMCO's site in Fontana, California. Some of the equipment from the unit developed at Wabash Alloys was reused at TIMCO. This project was funded by the California Energy Commission, the Electrical Power Research Institute, and Southern California Edison, for the period May 1998 through September 1999.

It appeared that the design and installation of a robust, reproducible sealing method for all potential leaks would verify the feasibility of this technology. However, safety concerns, which were remedied on October 23, 1999, combined with the inability to negotiate a timely operating agreement with TIMCO that was acceptable to all parities, delayed the project and prevented the hot testing of the Prototype One-Ton DC Plasma Arc Melter at TIMCO. A lack of sufficient funds, due to the above delays, effectively stalled work on the remainder of the program.

Keywords: Aluminum recycling, Secondary aluminum, Dross, DC plasma arc, Oxidation, Waste reduction, Energy efficiency, Air pollutant reduction.

1.0 Introduction

The DC plasma arc melting furnace technology has been used successfully to melt scrap steel since 1986. A variation of this technology, the atmosphere-controlled DC plasma arc, has exhibited favorable results in the areas of energy efficiency and environmental friendliness under laboratory conditions. Using a controlled atmosphere and DC plasma arc melting technology was proven feasible at Wabash Allyos in 1996 in the one-ton demonstration melter (Figure 3).

Figure 3. One-Ton Wabash Demonstration Melter

The one-ton demonstration unit displayed both fast and efficient transfer of heat to the surface of the molten aluminum bath. In addition, impressive melt rates and fuel efficiencies were achieved under less than optimal operating conditions. Short test runs returned metal recovery rates regularly exceeding 95 percent, and at times reaching 98 percent, when the aluminum recovered from dross is considered.

Notwithstanding, the one-ton demonstration unit did not reach its full production efficiency potential due to problems associated with leaks that permitted the intrusion of atmospheric oxygen.

1.1. Program Objectives

The purpose of this program was to demonstrate the commercial viability of the DC plasma arc technology in a controlled atmosphere to melt scrap aluminum for the recycling and reprocessing industries. The program's three main objectives were to:

- Improve the DC plasma arc furnace's competitive performance
- Demonstrate the technology's commercial viability
- Develop strategies to commercialize the DC plasma arc technology.

This program was originally envisioned in two phases. The program's first phase continued work begun on the one-ton Wabash demonstration unit, which validated the theoretical viability of the technology. It also demonstrated the necessity for a durable, efficient, and reliable system to seal the furnace against the intrusion of atmospheric oxygen, for a modified scrap feeding system, and for changes in operational procedures.

This project, the second phase of the program, intended to use the lessons learned to design, install, and operate a one-ton per hour and a five-ton per hour production scale furnace. The project objectives were to:

- Improve furnace sealing integrity to restrict dross formation to 1 percent or less
- Replace electromagnetic stirring devices with mechanical systems to improve melt mixing efficiency
- Optimize the location of stirring and return electrodes to improve process efficiency
- Develop a reliable continuous feed system to increase process throughput.

1.1.1. Technology Background

To understand project objectives in demonstrating DC plasma arc technology, it is helpful to review earlier achievements.

- **1990 to 1991**. The Electric Power Research Institute (EPRI) Center for Material Production (CMP) sponsored a program to investigate the feasibility of using DC plasma arc technology to melt aluminum. A laboratory scale furnace with a capacity of 30 pounds (lbs.) demonstrated process metal losses less than half of a comparable reverberatory furnace. This small-scale furnace also demonstrated a 22 percent greater fuel efficiency than that observed for comparable reverberatory furnaces as presented in CMP Report 91-8, "DC Plasma Dross Treatment and Aluminum Chip Making."
- **1995 to 1996**. CMP sponsored the design and operation of a one-ton demonstration melter at Wabash Alloys, Cleveland, Ohio. The furnace achieved 70 percent energy efficiency and 98.2 percent metal recovery in short batch runs.
- **1996**. Production runs at Wabash Alloys revealed weakness in furnace seal and scrap feed systems in the one-ton demonstration melter. It was determined that furnace redesign was required for the successful demonstration of the technology for commercial application.

1.1.2. Program Budget

This program began in December 1996 and was budgeted for total expenditures of approximately $3.1 million. Expenditures to date total $2,668,273 (Table 2). Funding was received from Southern California Edison, the Electrical Power Research Institute, and the California Energy Commission Public Interest Energy Research (PIER) program. Column D of the table provides an estimate of the cost to complete the testing of the Prototype One-Ton DC Plasma Arc Melter at TIMCO. The dismantling and removal of the melter from TIMCO eliminated the need for funding this portion of the work. A new proposed program is described in the Section 3.0 of this report.

Table 2. Program Expenditures by Category

Item	(A) SCE Prior to 1998	(B) ETS Direct After 1/1/98	(C) Total Cost to Date *A+B*	(D) Cost to Finish 1 Ton	(E) Total Phase One *C+D*
Paul Wurth Contract					
1 ton/hour prototype	$743,420	$472,713	$1,216,133	$131,000	$1,347,133
5 ton engineering and long-lead items	$358,789	$133,053	$491,842	$136,863	$628,705
Engineering Resource Association	$5,373	$11,943	$17,316	$5,000	$22,316
TIMCO Site Installation PO	$168,176	$393,217	$561,393	$33,300	$594,693
Travel and Other Direct Costs	Included in PM	$16,203	$16,203	$2,500	$18,703
ETS Project Management	$31,106	$47,418	$78,524	$10,000	$88,524
ETS Labor Adders	$3,110	$30,210	$33,320	$6,673	$39,993
Subtotal Direct Cost	$1,309,974	$1,104,757	$2,414,731	$325,336	$2,740,067
ETS OH	$0	$253,542	$253,542	$74,664	$328,206
Total	$1,309,974	$1,358,299	$2,668,273	$400,000	$3,068,273

PIER funding totaling $450,000 for this project was expended from June to October of 1998 (Figure 4).

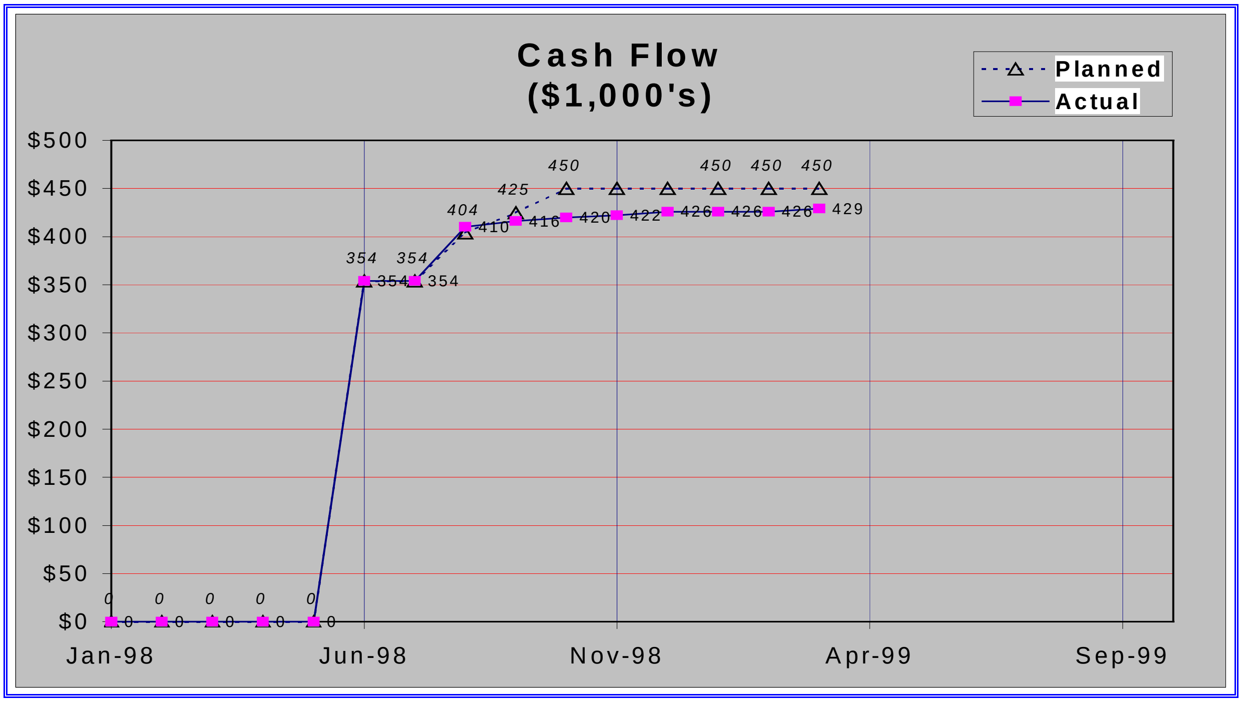

Figure 4. California Energy Commission Funded Expenditures

1.2. Need for the Project

The technology explored in this project will make the processing of scrap aluminum more efficient by reducing process time and process waste generation. Increased process efficiency will allow the industry to produce more products with essentially the same facility and personnel resource requirements presently used. The technology produces less waste, significantly lowering waste management and disposal costs. Finally, this technology employs an environmentally superior melting method that eliminates combustion-related emissions associated with the gas-fired reverberatory furnaces now in common use.

1.2.1. Economic Considerations

Using the five-ton reverberatory furnace as a basis for calculation, dross related process expenditures remove more than $4 million annually from the operator's potential revenue (Figure 5).

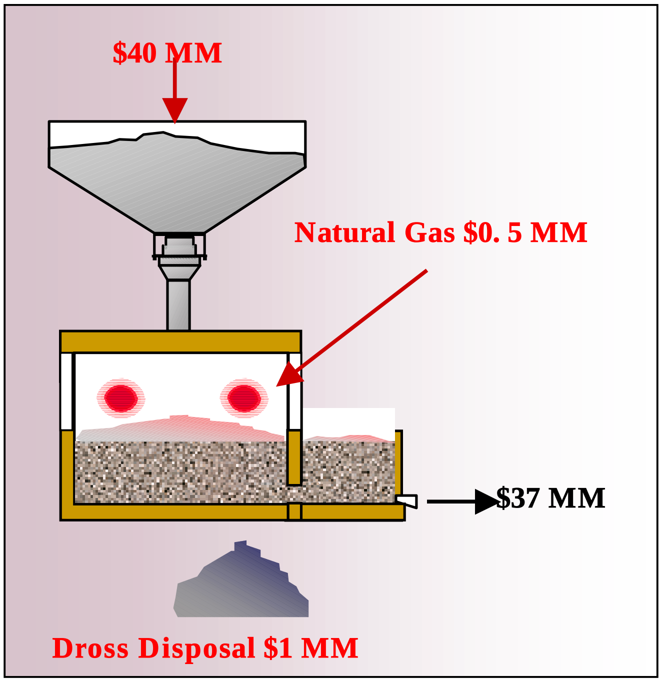

Figure 5. Cost of a Typical Five-Ton Gas Reverberatory Furnace

This revenue loss includes the current cost of metal lost and current dross disposal costs. A typical five-ton gas reverberatory furnace generates dross containing entrapped metal worth $3 million annually ($40 million to $37 million). The disposal cost associated with the annual waste stream typically represents an additional $1 million expenditure. If this calculation were extended to cover all users of gas reverberatory technology for aluminum reprocessing, annual domestic lost revenue would approach $1 billion.

1.2.2. Potential Market

Aluminum is an important component of the Nation's Gross National Product (GNP) and one of the nine "Industries of the Future" targeted by the U.S. Department of Energy (DOE) Office of Industrial Technology (OIT). The Industries of the Future strategy seeks to create partnerships between industry, government, and supporting laboratories and institutions to accelerate technology research, development, and deployment.

OIT's interest is driven by importance of aluminum to the economic interests of the United States. For more than 100 years, the United States' aluminum industry has led the global market. Currently, the industry employs more than 130,000 people and contributes more than $30 billion annually to the U.S. GNP.

The domestic aluminum market processed approximately 9.3 million tons in 1995, the most recent year for which complete statistics are available. The recycled fraction of the domestic supply has been increasing (as a percentage of the total domestic supply) at an annual rate of about 3.2 percent since 1985 (Figure 6).

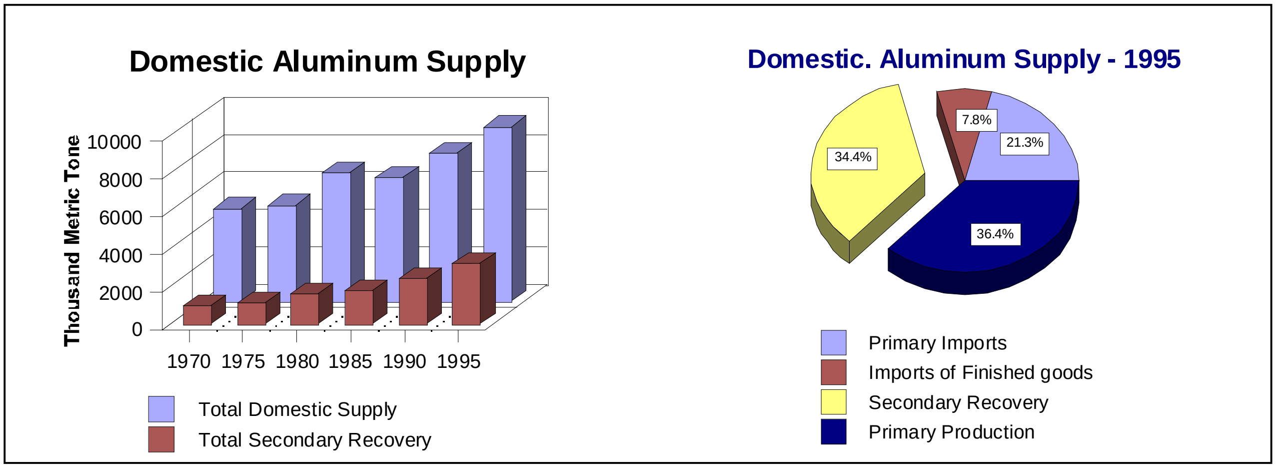

Figure 6. Sources of Domestic Aluminum Production

Currently, recycled aluminum provides almost 35 percent of the country's total domestic use. California hosts more aluminum recycling operations than any other state in the Nation and almost all of these operations are located in the South Coast Air Quality Management District (SCAQMD).

1.3. Commercialization Potential

Objectives for this project include technology transfer and commercialization activities designed to promote and facilitate penetration of the DC plasma arc melting technology within the aluminum reprocessing industry. The commercialization plan developed recognized that the high capital and energy costs associated with introduction of this technology, functioned as a major barrier to its widespread industry penetration. As a consequence, the project's utility partner, Southern California Edison (SCE), investigated ways to subsidize a portion of the high capital cost in exchange for the melter, entering into a long-term agreement to purchase electricity from the utility.

The potential economic and environmental benefit associated with this technology remains valid and should underlie future technology transfer activities if project completion activities are undertaken.

1.3.1. Economic Analysis

An economic analysis was conducted based on the limited test data obtained from the demonstration of the one-ton unit at Wabash Alloys. The analysis results (Figure 7) show the economic benefits of the DC plasma arc technology. Using the results of the Wabash unit, a five-ton commercial unit would save about $4 per ton compared to a gas-fired reverberatory furnace.

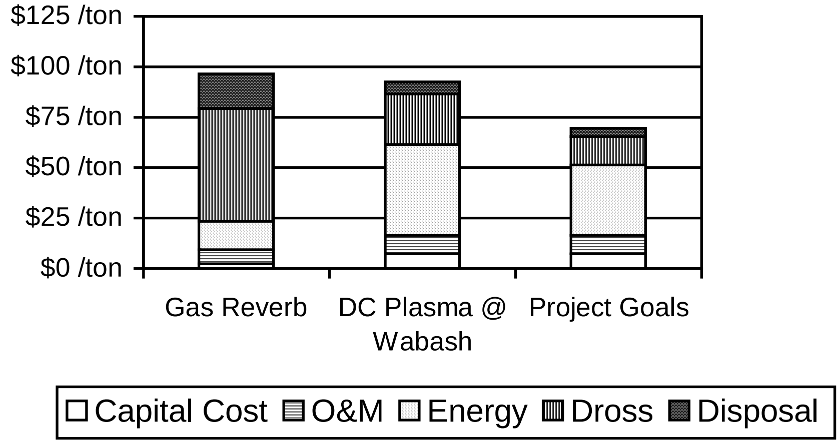

Figure 7. Comparison of Annualized Costs

If a DC plasma arc furnace was able to meet the performance criteria embodied in the project goals, it would save $27 per ton or $1.1 million annually, for each five-ton furnace. Although both capital and energy costs are higher for the technology, these costs are more than offset by the increased product yield and reduced dross management and disposal costs.

1.3.2. Market Penetration Potential

There are more than 1,000 aluminum scrap melters in the Nation and they operate more than 3,000 furnaces. Many of these furnaces are small and are not appropriate targets for technology conversion. If the commercialization effort is focused only on the estimated 100 to 120 large furnaces, it is possible to convert 50 percent of the large, gas-fired reverberatory furnaces in current use by the Year 2010. (Large furnaces produce 40,000 to 100,000 tons / year each, that is, 5 to 12.5 tons / hour each.) To achieve this target, about 50 to 60 large furnaces would need to be converted at an average rate of four to five furnaces per year in the coming 12 years.

If the market penetration goals (Table 3) were realized, a stream of benefits would flow to the U.S. secondary aluminum industry. This analysis is based upon 1996 dollars. Based upon current industry expansion rates, these projected savings could double in the U.S. by the Year 2010. There are additional opportunities for this technology internationally.

Table 3. Commercialization Market

Category (tons)	Current 1995		Future 2010	
	U.S. Market	International (not considered)	U.S. Market	International (not considered)
(a) How many tons will be in operation?	3,600,000	20,000,000	5,800,000	32,000,000
(b) How many tons in (a) use DC Plasma?	0	0	2,900,000	6,400,000
(c) How many tons in (a) will use Conventional?			2,900,000	25,600,000
(d) Define market penetration as (d) = (b)/(a)%.			50%	20%

The DC plasma arc technology will enable the industry to meet current and foreseeable environmental regulations with existing emission and treatment systems. The technology reduces waste and a requirement for disposal management. Finally, the DC plasma arc technology permits an improved shop environment by reducing the production of fine particulates associated with current melting technology. These benefits are discussed in greater detail in the following.

1.3.2.1. Energy Savings

Although more energy is required for scrap melting using the DC plasma arc technology, energy savings result from the reduced treatment, transport, and disposal activities associated with dross management. Estimates of energy requirements to accomplish dross waste treatment and disposal were difficult to obtain. Estimates of the energy savings attributable to salt-cake recycling, appearing in the OIT publication "*Aluminum Industry of the Future*" in July 1997 were used to calculate the energy savings for each ton of aluminum produced. The energy savings for baghouse dust disposal were assumed to be 20 percent of the cost of disposal. The direct reduction in process energy was based on the expected DC plasma energy efficiency for the commercial demonstration.

Table 4 shows projected energy savings for the U.S. market.

Table 4. Energy Savings

Type of Energy	(a) Current Tech Gas Reverb mmBTU/ton	(b) New Tech DC Plasma mmBTU/ton	(c) Energy Savings mmBTU/ton	(d) Number U.S. Tons in Place in 2010	(e) ((e) = (c)x(d)) 2010 Energy Savings mmBTU/year
Oil/Gasoline	0	0	0	2,900,000	0
Natural Gas	5.5	0.12	5.38	2,900,000	15,602,000
Coal	0	0	0	2,900,000	0
Electricity at 10,500 BTU/kWH	0	5.25	-5.25	2,900,000	(15,225,000)
Other Energy (Salt-Cake)	3.75	0.88	2.87	2,900,000	8,316,176
Baghouse Dust Disposal	0.32	0.11	0.21	2,900,000	618,667
Total	9.57	6.36	3.21	2,900,000	9,311,843

1.3.2.2. Greenhouse Gas Emission Savings

The DC plasma arc process melts the aluminum in a stable and inert argon medium. The absence of air reduces the content and volume of gaseous emissions. Contaminants in the scrap are burned or volatilized, without dilution, which allows more efficient emission control and treatment with existing melter's baghouse.

It was not possible to run the Prototype One-Ton DC Plasma Arc Melter to get a better estimate of the reduction in Greenhouse Gas Emission (GGE) realized. Estimates were made based on natural gas combustion emissions compared to electric generation emissions (Table 5).

Table 5. Greenhouse Gas Emission Savings

Type of Greenhouse Gas	(a) Cur. Tech Gas tons/ton Al	(b) New Tech DC Plasma tons/ton Al	(c) ((c) = (a) – (b)) Waste Savings tons/ton Al	(d) 20 Years Direct Effect CO_2 EQ Conv.	(e) ((e) = (c) x (d)) 20 Years Direct Effect CO_2 tons/ton Al	(f) ((f) = (e) x #) Emission Savings in 2010 tons/year
CO_2	0.44	0.27	0.18	1.00	0.18	508,222
Nitrous Oxide	0.00	0.00	0.00	280.00	-0.03	(76,457)
Total					0.15	431,765

1.3.2.3. Waste Management Savings

The DC plasma arc furnace melts aluminum in a non-oxidizing environment, minimizing oxidation and the creation of dross. With this technology, the use of salt fluxes is minimized, reducing or eliminating associated flux treatment and disposal problems. Contaminants in the scrap are burned or volatilized without dilution, allowing more efficient operation of the emission capture and treatment process. Magnesium, a frequent contaminant of scrap aluminum, is well volatilized at the higher DC plasma furnace temperature. As a consequence, the addition of fluoride salts to remove this contaminant by halogenation is eliminated. Halogen emissions must be strictly controlled due to the propensity of this class of chemicals to cause damage to the earth's protective ozone layer.

Table 6 displays preliminary estimates of the savings expected from the cessation of salt use.

Table 6. Salt Waste Savings

Waste Generated	Waste Category	(a) Cur. Tech Gas tons/ton Al	(b) New Tech DC Plasma tons/ton Al	(c) ((c) = (a) – (b)) Waste Savings tons/ton Al	(d) U.S. Tons in 2010	(e) ((e) = (c) x (d)) Annual Waste Savings in 2010 tons/year
Salt-Cake	SXN	0.17	0.02	0.15	2,900,000	435,000
Particulate Emissions	GXN	0.00001	0.0010	-0.0009	2,900,000	(2,735)
NO_X Emissions	GXN	0.00053	0.00140	-0.0009	2,900,000	(2,535)
SO_X Emissions	GXN	0.00000	0.00319	-0.0032	2,900,000	(9,252)

1.3.3. Commercialization/Technology Transfer Prospects

Successful commercialization of the DC plasma arc technology depends on the ability to structure attractive arrangements to finance the high initial capital cost of the furnace and its appurtenances. SCE, the utility member of the project team, is investigating innovative methods to subsidize the capital cost of the furnace in exchange for agreements involving long-term electric supply contracts. The Environmental Pricing Credit (EPC) implemented by SCE in 1999 could be a model for other utilities to follow. Utilities will benefit from this technology, encouraging innovative ways to support widespread conversion.

1.3.3.1. Benefit to California

The DC plasma arc technology is especially attractive to California melters. California has one of the most successful aluminum beverage can recycling programs in the Nation yet most of the cans collected in California must be shipped out of the State for reprocessing. This situation exists because of California's stringent emission regulations.

The DC plasma arc melting technology may make it possible to process used beverage containers (UBC's) within current air pollutant emission limitations. This possibility is viable because there is no oxygen in the furnace and the DC plasma arc volatizes many of the particulates, which are a major pollutant emission associated with aluminum melting.

California's pioneering work in this technology may lead to the creation of new DC plasma manufacturing industry. California manufacturing companies will get the opportunity to convert to this new industry. Table 7 delineates the benefits from State support of the DC plasma arc technology project.

Table 7. California Economic Benefits

California Economic Benefit Assumptions and Calculation			
A. Private Sector			
Direct Benefits to Melters			
Dross management cost savings			
Enhanced product recovery			$18.0 million/year
Additional energy and capital cost			<$9.0 million/year>
Net Private Sector Benefit			$9.0 million/year
Retained Industry Benefits			
Assume out-migration of 10 percent per year due to increased environmental regulation.	Equates to production reduction of 60,000 tons/year at $200/ton		$12.0 million/year
Manufacturing Sector			
Assume California manufacturers command 1/3 world market for new furnaces	World market = 9.0 million tons new production capacity or 21 furnaces/year by 2010 at $2.75 million each $20.0 million/year		
Increased manufacturer benefits	At 10 percent profit		$2.0 million/year
Total Private Sector Benefit			$23.0 million/year
B. Job Market			
Retained Jobs (no out-migration)	20 melters at 10 jobs each	200 jobs	
New Manufacturing Jobs	20 percent of $20.0 million	800 jobs	
Total Job Market Benefit (jobs not lost + new manufacturing jobs)			1,000 jobs
C. Public Sector (Additional California Tax Revenue Benefits)			
Sales Tax on two furnaces/year at $1.3 million/each			$200,000/year
Corporate income tax – additional melter profit at 10 percent			$900,000/year
Corporate income tax on retained melters profit at 10 percent			$1.2 million/year
Corporate income tax new furnace manufacturers at 10 percent			$200,000/year
Personal income tax on new and retained jobs (3 percent of $50 million/year)			$1.5 million/year
Total Additional State Tax Revenues			$4.0 million/year

2.0 Technical Description

2.1. Technology Hypothesis

2.1.1. Current Practices

More than 9.3 million tons of aluminum are melted in the United States each year, mostly in natural gas and air fired reverberatory furnaces (Figure 8). Until now, neither electric resistance nor induction melting furnaces demonstrated sufficiently favorable economic characteristics to convince industry operators to abandon the standard gas-fired reverberatory furnaces. Gas-fired reverberatory furnaces, however, present a variety of operational and environmental challenges.

Figure 8. Gas-Fired Reverberatory Furnace Views

- **Low Energy Efficiency and High Air Pollutant Generation**. Natural gas / air burners produce large volumes of combustion gases including carbon monoxide (CO), reactive organic gases (ROG), and nitrogen oxide (NOX), which are each criteria pollutants of concern throughout California and subject to mandatory controls within the South Coast Air Basin (SCAB).
- **Particulate Matter Control**. The waste feedstock is frequently contaminated with oil, plastic, paint, rubber or other coatings. The gas-fired furnaces partially volatilizes contaminant material and produces fine particulates that must be captured before release of process gas to the atmosphere.
- **Greenhouse Gas Generation**. Scrap aluminum frequently contains feedstock that contains magnesium at levels that are too high for some reuse applications. When this occurs, "demagging" is required. When gas-fired technology is used, demagging is accomplished by the addition of chlorine, aluminum chloride, or aluminum fluoride to the melt. The process releases halogen and halogen-compound gases that are known to have adverse effects on the ozone layer and should not be released, untreated, to the atmosphere. If the facility uses wet scrubbing air pollution control (APC) systems, demagging residuals can be a significant source of waste that must be collected and disposed of under strict guidelines. If electrostatic or dry capture APC processes are

used, the chlorine compounds and other particulate matter generated by the demagging process can marginally increase downstream baghouse maintenance requirements.

- **High Dross Waste Stream**. When aluminum is melted by gas-fired reverberatory furnaces, atmospheric oxygen is allowed to contact the surface of the melt and aluminum oxide is formed. The aluminum oxide, with the demagging salts, form a scum layer (called dross) on the surface of the melt that acts like a sponge trapping pure aluminum and reducing process yield. This mixture of oxides, salts and aluminum is periodically removed and reprocessed to recover the aluminum.

  Typical dross management techniques include the addition of fluxes to the molten metal to limit dross formation and to remove impurities from the melt. Several salts, solvents, and gases may be used as fluxes.

  – **Cover fluxes** contain chemicals such as sodium chloride, calcium chloride, calcium fluoride, borax, aluminum fluoride, and cryolite. Cover fluxes are spread over the top of the melt and react chemically with the oxides on the melt surface where they can be easily skimmed off.

  – **Solvent fluxes** induce melt impurities to float to the surface of the melt, where they combine with the oxide layer and can be easily skimmed off.

  – **Degassing fluxes** are used to remove dissolved hydrogen gas from the molten metal. Gases such as chlorine, nitrogen, helium or argon are forced through the melt from the bottom and bubble through the melt carrying the dissolved hydrogen gas through to the surface.

- **Poor Shop Environment**. The gas-fired reverberatory furnace technology generates large quantities of fumes that are harmful to human and animal systems. In addition, the process is extremely noisy and operators are required to wear earplugs.

2.1.2. DC Plasma Arc Furnace Overview

Most of the research aimed at improving melting techniques for the aluminum reprocessing industry has focused on one problem at a time. Oxyfuel burners, salt cake recycling, and pre-melt drying are all incremental solutions.

DC plasma arc technology melts the aluminum in a stable and oxygen-deprived plasma medium. Because the process inhibits oxidation, there is no need for the addition of salt flux and the associated treatment and disposal problems generated by this process. The absence of air also eliminates the waste energy associated with heating the 80 percent nitrogen fraction of atmospheric air, and reduces the volume of gaseous process emissions.

The technology demonstrated did a superior job of handling contaminants in the raw scrap used to charge the furnace. Contaminants are burned or volatilized by the process being demonstrated, without the need for solvents or magnesium halogenation. This capacity permits a more efficient emission control and treatment strategy to be used and eliminates the production of ozone-depleting halogens.

The DC plasma arc melting furnace has been used for steel scrap since 1986. A discussion of the early investigation of the technology is presented in AIME Electric Furnace Conference Proceedings, Vol. 44, Dallas, 1986, entitled “Single Electrode DC Arc Furnace Operation at

Florida Steel Corporation" by D. Meredith and S. E. Stenkvist. A variation on this furnace, the atmosphere-controlled DC plasma arc furnace, appeared to be ideally suited for melting aluminum scrap. In 1990 – 1991, the Electric Power Research Institute (EPRI) Center for Material Production (CMP) sponsored a program to investigate the feasibility of using such a configuration for melting of aluminum. The investigation led to the development of a pilot-scale furnace to test the technology's concept. The laboratory scale equipment had a processing capacity of 30 pounds (lbs.) and demonstrated metal losses, attributable to oxidation, that were less than half that of a reverberatory furnace. This small-scale furnace also demonstrated an energy efficiency of 57 percent efficient, compared to 35 percent demonstrated by reverberatory furnaces. These results were fully detailed in CMP Report No. 91-8, "DC Plasma Dross Treatment and Aluminum Chip Melting," written by F. L. Kemeny and D. J. Sosinsky.

In 1995, the CMP built a one-ton demonstration melter at Wabash Alloys, Cleveland, Ohio, to verify transferability of the laboratory results to a larger scale production unit. This furnace demonstrated an even greater energy efficiency (70 percent) and comparable (98.2 percent) metal recovery results in short batch runs (Appendix I – Final Wabash Report).

Some of the lessons from the Wabash demonstration were:

- **Furnace Sealing Integrity**. Impressive melt rates and fuel efficiencies were achieved during the few successful tests of the one-ton demonstration melter. These returns were obtained under less than optimal operating conditions created by failure of the furnace sealing system. The design and successful implementation of a robust, reproducible sealing system that addresses all of the melter's potential leaks is the critical factor determining the commercial feasibility of this process. The proposed hardware improvements look promising.
- **Melter Stirring**. Heat transfer from the plasma arc to the surface of the bath is both fast and efficient. Special attention, however, must be given to ensure that heat from the arc does reach the rest of the scrap. The primary issue appears to be conducting the heat from the arc below the electrode to the rest of the scrap melt area. The proposed argon bottom injection to stir the bath is a solution, but might not be the most efficient way to conduct the heat to the rest of the furnace. The current configuration uses argon as a low-melt loss-stirring agent. Flow patterns of the gas through the molten metal, however, are difficult to manipulate and are basically unsympathetic to the stirring objective (vertical and surface disturbing versus horizontal and subsurface mixing).

  Using the injected argon to stir the molten metal may be the only option available for a single vessel furnace design. Notwithstanding, this method presents a number of disadvantages when compared to mechanical stirring; specifically: the gas bubbles constantly break the thin oxide layer on the surface, lowering emissive heat transfer effectiveness, and the stirring pattern is basically vertical. A horizontal, high velocity flow directed straight from the superheated area below the electrode at the submerged scrap area would increase the melt rate, keep the average metal temperature lower, and all but eliminate surface disturbance.

Feed System. Gravity feeding of scrap without adequate (horizontal) molten metal flow to move the melting scrap and its oxides away and expose the new scrap to the superheated metal stream, can inhibit the melting process. It promotes the formation of a mushy, semi-insulating, immobile half-melted mat of metal and skim on the surface of the melt. This condition was not observed during pilot unit tests, but could take place when production rate pressures drive feed rates up. A recommended design improvement, a movable plate, may be used to avoid or eliminate this problem.

The results of the one-ton demonstration melter project were encouraging. The problems identified need to be resolved.

2.2. Project Approach

Originally, the strategy for this project employed a two-phased approach. The approach included correction of the furnace flaws revealed by the one-ton Wabash demonstration melter in the fabrication and operation of a Prototype One-Ton DC Plasma Arc Melter at TIMCO. The approach also included application of the lessons learned to design, fabricate, and demonstrate a commercial-sized five-ton DC plasma arc furnace. Edison Technology Solutions (ETS) assembled a project team to implement the demonstration strategy. The team included a commercial aluminum melter, furnace designer, and furnace fabricator to assist the program management and utility research groups in the commercialization of this technology. ETS, the California Energy Commission and EPRI agreed to address the technology transfer activities cooperatively to promote this technology throughout the secondary aluminum industry. Only phase one was undertaken in this project.

The tasks were:

- **Task 1, Define Required Operational Features**. Paul Wurth, Inc. (PWI), in consultation with the customer, Southern California Edison (SCE), and the project technical team, developed draft requirements for melter operational features of the proposed Prototype One-Ton DC Plasma Arc Melter.
- **Task 2, System Design**. PWI developed the design with Process Engineering Dynamics (PED) and the EPRI CMP. The design incorporated the features identified in the draft requirements, and included innovations developed from operating the one-ton demonstration melter at Wabash Alloys.
- **Task 3, System Fabrication**. The final design was developed. The Prototype One-Ton DC Plasma Arc Melter was constructed at the factory and then shipped to a site at TIMCO, Standard and Tandom, Inc. (TST) for installation. Prototype melter long-lead-time items were ordered.
- **Task 4, Facility Construction**. ETS selected and awarded the balance of the facility construction to local Southern California companies through TIMCO. The goal was to build area contractor experience constructing DC plasma arc furnaces to support future commercialization. Awards included furnace installation, and the provision of power supply, feed system, and argon supply systems.

- **Task 5, Melter Installation**. TIMCO managed the installation and start-up of the Prototype One-Ton DC Plasma Arc Melter at the TST site. The Prototype Melter was located next to a comparable gas-fired reverberatory furnace, to allow comparison of their performance under similar operating conditions and charge materials.
- **Task 6, Melter Operation**. ETS managed the cold startup and testing of the Prototype One-Ton DC Plasma Arc Melter. Modifications were made, as necessary, to correct problems discovered during startup. ETS developed a draft commercialization plan, which was presented to EPRI, owner of the intellectual property rights.

Figure 9 illustrates the schedule for this program.

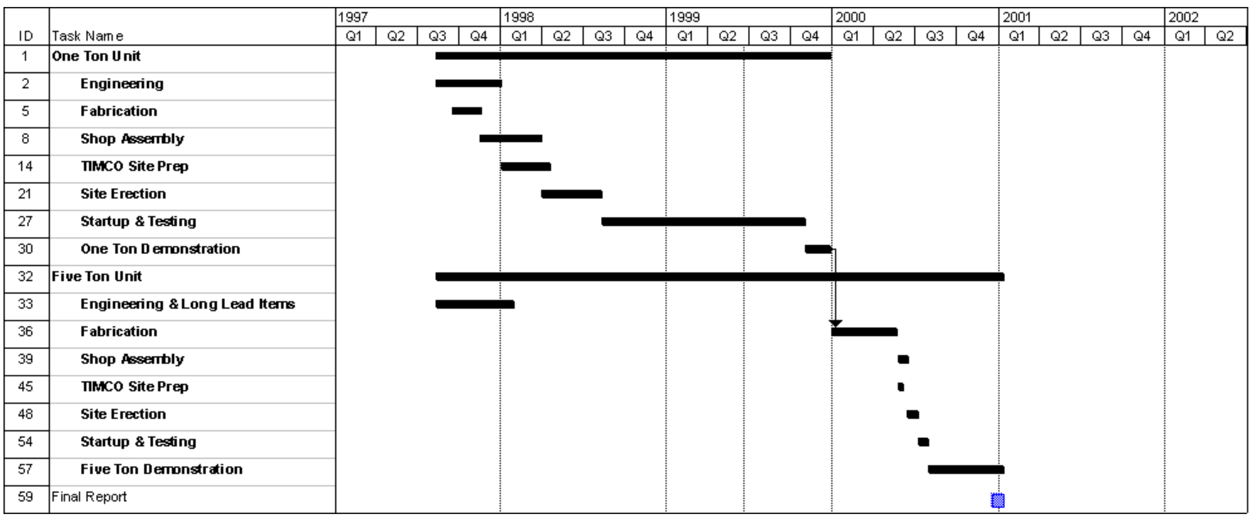

Figure 9. Program Schedule

2.3. Technical Project Description

The one-ton demonstration melter was relocated to the TIMCO facility in Fontana, California, where it was retrofitted and equipped with an advanced scrap feed system. Figure 10 pictures the furnace used for this demonstration project at the TIMCO site.

Figure 10. Prototype One-Ton DC Plasma Arc Melter

2.3.1. Prototype One-Ton DC Plasma Arc Melter

The furnace's refractory lining is composed of 85 percent alumina material that has been keyed or stepped joined between the floor and the sidewalls. A 1/4 inch thick ceramic paper insulation has been inserted against the furnace shell inside the surface, and thermocouples were installed as the walls were formed. The furnace lining is cast at the plant, and cured to 1,000 degrees Fahrenheit (ºF) at the site, after installation. The furnace roof is lined with a cast material having an 85 percent alumina content. The roof lining has been attached with "Y" type anchors.

The furnace was designed to be fed automatically by a pneumatic scrap feed system. A diverter valve and cyclone redirects the feed material into the weigh hopper (Figure 11). Appendix III provides the preliminary drawings for the Prototype One-Ton DC Plasma Arc Melter.

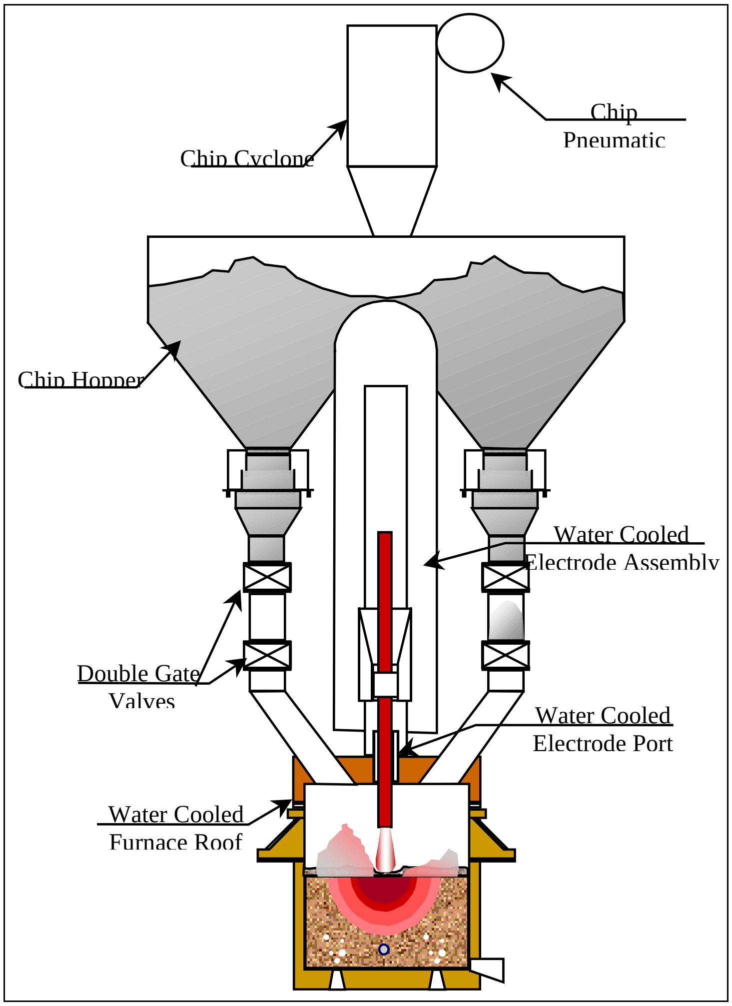

Figure 11. Prototype One-Ton DC Plasma Arc Melter Diagram

2.3.2. Operational Schema

2.3.2.1. Furnace Charging

Although aluminum beverage containers constitute a major fraction of the feedstock for the Nation's aluminum reprocessing activity, this supply stream is not suitable for most Southern California melters because of air quality concerns. Used beverage containers (UBC's) are contaminated with residues of their former contents, and labeling paints and plastics. During the melting process, contaminants are volatized and liberated as fine particulates which are air pollutants of major concern within Southern California's SCAB.

Currently, the feedstock of choice for Southern California melters consists of mill turnings, manufacturing scraps, and heavier items such as motor blocks. The lighter portion of the feedstock is usually shredded to a relatively uniform size to facilitate handling.

The furnace at TIMCO is fed automatically by a pneumatic feed system that has a cyclone and feed tube located above the melter. The operator activates the main feed screw to deliver scrap to the feed tube. A diverter valve redirects fed scrap into the chip hopper. When the chip hopper is approximately 200 lbs. less than its full capacity, the operator can stop the main feed screw.

The feed system is programmed to alternate the release of material, from the weigh hopper, to vibratory feeders associated with each of the furnace's feed legs (Figure 12). The top dump valve of each feed leg is held open until the space between it and the bottom dump valve is filled. When this occurs, feeding is stopped and the top dump valve is closed.

Figure 12. Scrap Feed System at TIMCO

2.3.2.2. Atmosphere Control

After the dump valves have been closed, argon gas is injected into the space between the two dump valves to displace oxygen entrapped by the scrap. After most of the atmospheric air has been displaced, the bottom dump valve opens and the furnace is charged. The feed process alternates until the furnace has been fully charged. Once the furnace is charged with 500 lbs. of scrap, the roof is rotated to the clamped position, and the electrode water cooling system is initiated (Figure 13).

Figure 13. Prototype One-Ton DC Plasma Arc Melter Roof Showing Electrode Opening

The graphite electrode has been drilled to allow injection of argon gas at a rate of 5 to 25 standard cubic feet per minute. Argon is also injected through the molten metal bath by plugs placed in the bottom of the furnace. This bottom-injected argon acts as the furnace's stirring mechanism. The light and relatively buoyant nature of scrap used for this demonstration allowed some material to float on the surface of the melt. Stirring is required because the high temperature of the arc can vaporize the scrap before it can be melted. This is not a desirable outcome.

2.3.2.3. Plasma Generation

An arc is drawn between the central top graphite cathode and the scrap material that is in contact with the anode (return) electrode. Once the graphite electrode is close enough to the conductive scrap, a short circuit will take place, and an arc is formed. The high temperature of the arc ionizes the argon gas around it and converts the gas into a plasma capable of efficiently conveying heat to the molten metal bath. Magnesium and other impurities in the scrap are removed by volatilization and the use of ozone depleting chloride salts is not required.

2.3.2.4. Dross Management

While the furnace is extremely efficient in keeping oxygen out, some dross (approximately one to three percent) will still be produced. Dross is removed when its level exceeds eight inches and the molten metal bath's temperature is uniformly in excess of 1,350 ºF. Assuming a furnace feed rate of 2,000 pounds per hour and a metals recovery rate of 95 percent, dross removal should be accomplished on an hourly basis.

Before the dross is removed, the argon flow from the furnace's bottom is reduced to a level that will gently stir the liquid metal with minimal surface disruption. Dross is then removed, using a conventional dross spoon, and placed in a receiving vessel. Once dross has been removed, the dross cover is lowered onto the furnace to retain heat.

We recommend that process dross be recharged to the furnace, combined with calcium oxide and other oxide fluxes, and the furnace temperature raised to at least 2,500 °F. This furnace will convert the mixture to liquefied calcium aluminate that can be tapped from the furnace, granulated and sold to the steel industry.

2.3.2.5. Product Recovery

Tapping of the furnace is normally done after the dross removal activity. A channel leading to another holding tank is positioned at the end of the tap trough and the tap-hole plug is removed. The molten aluminum runs into the channel by gravity and is combined with molten metal from the three other gas-fired reverberatory furnaces. TIMCO uses an automated casting bed system to produce billets for sale to the commercial aluminum market.

2.4. Problems Encountered

2.4.1. One-Ton Unit Cost Overrun

A number of factors, including parts replacement, contributed to cost overrun for refurbishment of the one-ton demonstration unit. These unforeseen factors limited the ability to provide complete demonstration of the DC plasma arc melting technology during this project timeframe.

2.4.1.1. Unusable Parts

The original project plan and budget assumed that many parts of the one-ton demonstration melter could be reused for the Prototype One-Ton DC Plasma Arc Melter. The one-ton demonstration unit (Figure 14) was shipped to the original fabricators, J. Horst Manufacturing, Dalton, Ohio for inspection and refurbishment. The inspection was completed on August 20, 1997 by PWI. Following the inspection, it was concluded that many items needed to be cleaned, fixed, and replaced. PWI requested approval to issue a time and material purchase order to accomplish the needed repairs, which was granted. By October 1997, it became clear that the cost of refurbishing the one-ton demonstration unit was almost twice the original estimate.

Figure 14. Original One-Ton Demonstration Unit

2.4.1.2. Modified Design

The original work scope for the one-ton demonstration unit modification included a temporary fix for the sealing and feeding systems. Shortly following the commencement of detailed engineering, it was decided to test the proposed five-ton system design on the one-ton demonstration unit. This decision significantly increased the scope of work for both the feed and sealing system. The feed system for the Prototype One-Ton DC Plasma Arc Melter was equipped with the full weighing hoppers, vibrating feeders, and double dump valves to be used for the five-ton commercial prototype. Figure 15 illustrates the one-ton demonstration unit and Prototype One-Ton DC Plasma Arc Melter configurations.

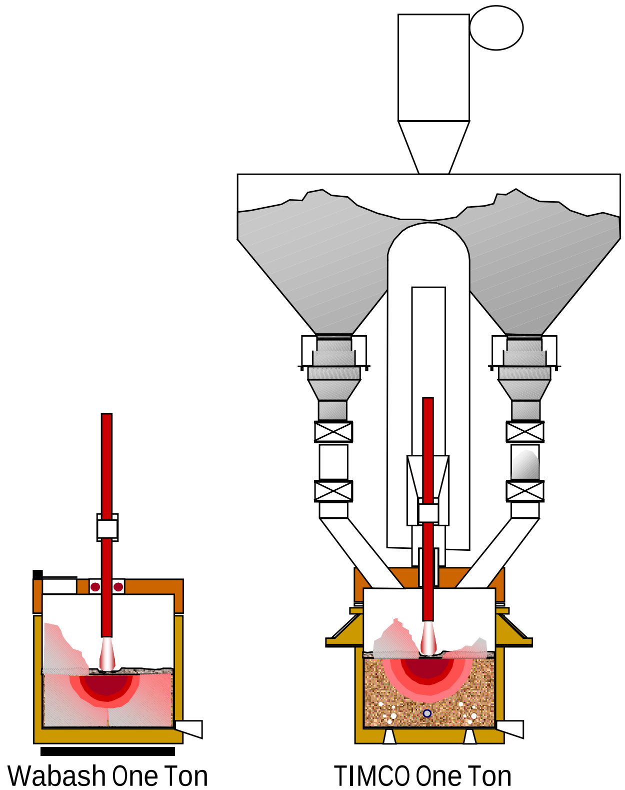

Figure 15. One-Ton Demonstration versus Prototype One-Ton DC Plasma Arc Unit Configurations

The sealing system modification approach for the one-ton demonstration unit was changed from merely sealing the space around the electrode roof opening, to sealing the whole electrode enclosure. These two changes more than doubled the originally estimated costs for these systems.

2.4.1.3. Five-Ton Infrastructure

The original project plan envisioned installation and demonstration of a five-ton commercial prototype following completion of the Prototype One-Ton DC Plasma Arc Melter unit. In an effort to eliminate duplicate lead times, it was decided to install support infrastructure for the Prototype One-Ton DC Plasma Arc Melter that would be adequate for the five-ton commercial prototype unit.

The 4 kV cabling and the electrical transformers were sized to operate the two units. In addition, the electrical board and the water cooling system were all sized for the five-ton unit. Finally the concrete pad was designed to permit removal of the Prototype One-Ton DC Plasma Arc Melter unit and placement of the five-ton unit at essentially the same location.

2.4.1.4. Power Quality Concerns

SCE expressed a concern regarding the potential flicker and harmonics that could be generated by the Spang inverter. Spang was not able to provide test results that were satisfactory to SCE's concerns regarding applicable Institute of Electrical and Electronics Engineers (IEEE) 519 requirements. The utility requested that a 5 kilovolt-ampere (kVA) transformer be used in place of the 2.5 kVA unit specified by the designer. The additional cost associated with this requirement was $50,000.

Based upon an ETS recommendation, two 2.5 kVA transformers were installed to meet the SCE requirement while maintaining the flexibility to operate the facility with one transformer and provide test results to support technology transfer activities associated with commercialization.

2.4.1.5. Extra 4 kV Line

SCE informed the Project Manager that they would only terminate in the pull section of the 4 kilovolt (kV) breaker next to the transformers. Because the TIMCO plant at which the prototype melter is located is congested and space is at a premium, the transformers had to be placed some distance from the melter's location. A contractor was hired to pull the wires from the 4 kV breaker across three buildings, and make the 4 kV terminations into an additional 4 kV breaker located next to the Spang inverter unit. This activity added almost $150,000 to the cost of the project.

2.4.1.6. Permitting

The lack of testing data on emissions from the one-ton demonstration melter tests caused hesitancy on the part of the South Coast Air Quality Management District (SCAQMD) to issue an operating permit for the furnace. A temporary research permit, however, was eventually issued by the agency.

2.4.2. Installation of the Prototype One-Ton DC Plasma Arc Melter

The design, development and installation of the Prototype One-Ton DC Plasma Arc Melter resulted in the accumulation of extensive lessons learned. Lessons which, applied to a next generation DC plasma arc project, would enable the successful build and operation of a five-ton commercial prototype unit. The experiences gained in the installation of the prototype unit are described in the following.

2.4.2.1. Furnace Refractory Curing

Operating temperatures within the interior of a DC plasma arc melter are sufficiently elevated to melt the very steel of the furnace structure. To protect interior surfaces from this heat regime and eliminate potential deformation or melting, a refractory material was used to line interior furnace surfaces.

Curing of the furnace refractory is a long and difficult process. The refractory material needs to have heat applied gradually at a certain rate. After the refractory reaches 1,000 ºF, it must be maintained for several days to expel humidity. Gas reverberatory furnaces include only a few sensitive surfaces that need to be protected during the on-site curing of the refractory. The DC plasma melter, however, has many sensitive parts that should not be exposed to the high heat associated with cure of the furnace refractory.

This curing process delayed startup of the Prototype One-Ton DC Plasma Arc Melter by 1 week, and was suspected of causing damage to many parts. It is conjectured that this damage caused dysfunctional parts, resulting in additional delays. Lessons learned from this effort include the recommendation that the vessel refractory curing process be accomplished at the plant before sensitive system component installation.

2.4.2.2. Enclosure Door Problem

The design, fabrication and installation of the enclosure door for this prototype proved to be a major problem. The enclosure door is the only access to the electrical, water, and argon services leading to the furnace roof or the electrode. The door, however, must be sealable, water cooled, and fit within the small space available around the electrode.

With limited knowledge of the thermal and mechanical forces that would impact the enclosure door, combined with project schedule pressures, a simplified design was used that proved to be inadequate.

The designers provided a curved, double-walled enclosure door that was extremely difficult to fabricate. A specialized shop was contracted to fabricate the enclosure according to its design. Significant difficulties were experienced and field modifications had to be accomplished to fit the door to the furnace. In the end, delivery of the door was accepted, in spite of apparent damage caused from trying to make it fit the opening. This damage to the enclosure door allowed many leaks, and did not permit an airtight seal against the furnace opening. In addition, the enclosure door proved to be too heavy when loaded with cooling water. The enclosure door hinges were stiffened, but this was not adequate to allow easy opening and closing of the enclosure door. As an interim solution, the necessary continuous flow of cooling water through the enclosure door was replaced with a small trickling flow of cooling water. It is hoped that this reduced flow will provide adequate cooling for the enclosure door.

2.4.2.3. Electrode Collar Conductivity Problem

The cathode must be isolated from the anode electrodes. As part of the furnace design, the scrap to be melted is in contact with the anodes arrayed along the bottom of the melting vessel. A short circuit is produced when the cathode is lowered close enough to the scrap, which is in contact with the return electrodes. When close enough, the cathode establishes an arc, which creates the plasma. Just before the start of hot testing, it was discovered that the main electrode was not isolated from the return electrodes.

Initially, damage to the electrode collar isolating kit, caused during the refractory curing process, was suspected to have lowered its effective insulation value. Several attempts to fix the isolating kit failed to fully cure the current leakage problem. Replacement of the electrode isolating kit with a different type reduced conductivity, but leakage remained high enough to prevent formation of the arc needed to create the plasma.

Next, attention was focused on the steel pipe that provides cooling water to the electrode collar, as a possible source of the conductivity. A portion of the steel water-cooling pipe was replaced with non-conductive flexible tubing. Current leakage was reduced, but remained a problem. Subsequent tests revealed that the cooling water itself was conductive, and had to be cleaned. Moreover, a larger portion of steel pipe was replaced with flexible non-conductive pipe.

All of these modifications were necessary to address the conductivity issue. The cleaning of the cooling water, replacement of some steel cooling water pipe portions with flexible non-conductive tubing, and the replacement of the collar isolating kit, contributed to the electrode collar conductivity solution.

2.4.2.4. Furnace Drive Assembly

Initial movement of the furnace caused damage to the variable speed motor and the channel and chains guiding its movement. The control logic did not respond to the signals of the limit switches, causing the furnace to move beyond the guides and cause the damage. After fixing this problem, the variable speed motor produced excessive vibration. The sprockets turned out to be the wrong size, which caused the vibration. Their replacement solved the problem.

2.4.2.5. Fabrication Problems and Delays

Fabrication of the furnace had to be completed before the end of 1997 to qualify for a major portion of SCE funding. This completion requirement required fabrication activity while design engineering continued. This schedule demand increased the cost of fabrication as most of the subcontracts were on a time and materials basis rather than a negotiated fixed price. In addition, fabrication of sub-components was dispersed throughout the United States. When the parts were gathered at TIMCO, lack of coordination resulted in major delays in the installation and startup of the furnace at TIMCO site.

2.4.2.6. Installation Staffing

One of the project management strategies designed to increase commitment to the project was to award TIMCO the major role of managing installation of the prototype One-Ton DC Plasma Arc Melter. Although the staff did their best to fulfill their assigned coordination role, the task proved too complicated for support by part-time personnel. After the surfacing of many installation problems, the project management team concluded that it was necessary to hire a full-time construction manager.

Poor coordination and inspection led to the development of many quality control problems, manifested during the cold starting phase. This caused numerous delays in starting the unit. In addition, the mechanical contractor did not complete the work on time or within budget.

2.4.2.7. Miscellaneous Electrical, Mechanical, and Control Issues

Although the inverter unit was refurbished at Spang, the unit had numerous problems. While few of the electrical, mechanical and control problems delayed the project more than a week, they combined to delay the start of the furnace. In addition, the control problems resulted in a requirement for a Spang engineer to start the inverter.

2.4.2.8. Modifications of Return Electrode Bus Bar

The return electrode bus bar required field modification to permit proper attachment of the water-cooled anode cable to the bus bar. The bar was welded in a vertical position, causing excessive stress on the relatively stiff water-cooled return cable. In addition, the return cable was too short, requiring replacement with a longer one.

2.4.3. Safety Issues

Immediately before the commencement of initial melting tests on the Prototype One-Ton DC Plasma Arc Melter, the furnace developer, Dr. Frank Kemeny of PED, raised safety issues. In a July 1998 letter addressed to the furnace designer PWI, he outlined several concerns regarding the safe operation of the melter. Dr. Kemeny’s concerns and recommended precautions are presented by the following.

2.4.3.1. Possible Water Leakage within Electrode Enclosure

Cooling water flows into and out of the electrode holder, electrode cooler (collar), and electrode housing door. During operation, the electrode housing door is closed, and the inside of the electrode enclosure is not visible. A cooling water leak may go undetected for some time. A significant leak may cause the entry of water into the furnace volume, and reaction with the aluminum and / or the graphite electrode may follow. In most cases, the reactions will form dross, hydrogen, carbon monoxide, carbon dioxide and water vapor. The much less benign scenarios described in the following, however, could develop:

- Some liquid water could become trapped in the aluminum feed and be submerged into the molten aluminum bath. This might result in an explosive release of water vapor from the bath, and possible damage to the furnace.

- The water leak could alter the conduction path for the arc. The arc could attach to the furnace enclosure, possibly causing further damage to the furnace and additional water leakage.
- If the expanding vapor caused by these events could not be safely released from the furnace, an explosion could result, threatening persons and property.

Recommended precautions to protect against a catastrophic electrode enclosure water leak include:

- Installation of water detection instrumentation and logic to warn of a leak. Conductivity and humidity sensors should be installed within the electrode enclosure.
- Installation of a remote camera to provide visual information from within the enclosure.

2.4.3.2. Possible Arcing or Plasma Generation Within the Electrode Cooler

The electrode length is known to the programmable level controller (PLC) logic and the electrode travel is limited by the PLC to prevent arcing close to or within the electrode cooler (collar). It is conceivable that the electrode could break within the furnace due to the impact of scrap or other forces. If this happens, the circuit would become open and the regulator would lower the electrode in an attempt to re-establish the arc. If the broken piece remains vertical within the furnace underneath the electrode, the arc will be re-established between the broken piece and the newly formed electrode tip. The PLC will allow this, since electrode length is determined by calculation within the electrode holder as the measurement point. Under these conditions, the plasma could form close to or within the water electrode collar. Should this take place, damage to the collar is likely and release of cooling water into the furnace could occur.

Some precautions have already been taken to warn of this possibility. Temperature is now monitored at the top and bottom of the electrode collar. Water inlet and outlet temperatures are also monitored.

2.4.4. Project Shut-Down

Safety concerns raised by one of the project subcontractors on August 20, 1998 has caused stoppage of the hot testing work. These safety concerns were remedied by October 23, 1998. Meanwhile, the inability to negotiate a timely operating agreement with TIMCO that was acceptable to all parties delayed the project further. A lack of sufficient funds, due to the above, caused further delays. After more than a year of work suspension, however, TIMCO has decided not to proceed with the project. The equipment at TIMCO was dismantled in September 1999, and delivered to EPRI.

3.0 Conclusions

3.1. Project Outcomes

Problems encountered in the rehabilitation, fabrication, and installation of the Prototype One-Ton DC Plasma Arc Melter resulted in extensive lessons learned that could be easily applied to continuation of this technology demonstration. These issues also resulted in cost overruns and start-up delays of more than 6 months.

Although the California Energy Commission and Edison Technology Solutions (ETS) identified potential sources to complete the Prototype One-Ton DC Plasma Arc Melter project, technology partner TIMCO decided not to proceed. As a consequence, the project was cancelled and the melter was dismantled and removed from the TIMCO facility. The equipment was delivered to the Electric Power Research Institute (EPRI), who have stored it at the Gold Coast Refractory facility in Santa Fe Springs, California.

It was not possible to verify the project objectives, because the Prototype One-Ton DC Plasma Arc Melter was never operated. Even so, there were several accomplishments:

- Preparation of design requirements for modification of the one-ton demonstration melter
- Design and construction of the Prototype One-Ton DC Plasma Arc Melter adjacent to a comparable gas-fired reverberatory furnace
- Successful integration of the power supply, scrap feed systems, and argon gas supply and control system
- Cold startup of the Prototype One-Ton DC Plasma Arc Melter
- Modifications to the melter as necessary to correct problems discovered during startup.

3.1.1. Lessons Learned During Cold Startup at TIMCO

The following design recommendations were developed during the cold startup:

- A new design for the enclosure door to allow access to the electrode and the roof collar
- A new method of seating and cooling the electrode collar to solve the conductivity problem
- Refractory lining and curing of the furnace vessel should be applied and cured at the plant before being shipped to the installation location.

A full-time, experienced construction manager is needed to manage installation of the melter. It is also important that experienced, dedicated installation and maintenance contractors are selected to ensure a high level of quality control.

Operation of the DC plasma arc melter requires some knowledge of and experience in the operation of electronic detection and process control systems. Provisions for training production crews in the proper operation of the system and response to abnormal or emergency situations should be included as part of any installation plan for this technology.

Several concerns have been raised with the potentially devastating effects that could occur if water is allowed to intrude to the furnace’s interior or arcing conditions develop within the furnace's electrode cooler. Design measures are available to minimize the likelihood that these unsafe operating conditions could develop. Measures include:

- Installation of water detection instrumentation and logic to warn of a leak. Conductivity and humidity sensors installed within the electrode enclosure.
- Training on the safe procedures and possible hazards for all operators, maintenance and supervisory personnel.

The DC plasma arc project revealed several problems during startup that suggest the unit may be difficult to maintain. The industry is used to the simple gas reverberatory furnace and, typically, the operation and maintenance (O&M) crew used in secondary aluminum melting operations have limited experience with mechanical, electrical or control systems. This technology requires more experienced O&M staff, that may not currently be employed by most melters.

The TIMCO crew used to help start the unit consisted of the Technical Engineering Manager and his two superintendents. This crew was also needed to run the six production TIMCO furnaces which provide the major cash flow source for this facility. TIMCO management would not commit their most valuable staff to startup activities for the Prototype One-Ton DC Plasma Arc Melter, as their opportunity cost was too high to be compensated by the project team.

3.2. Technology Competitive Performance

The program, based on the results from the one-ton Wabash demonstration unit, demonstrated, that the use of DC plasma arc technology and atmosphere control could successfully reduce the formation of dross while melting scrap aluminum. The reported system "fuel" efficiency of 67 percent is promising, particularly when allowances are made for the use of two and one-half times the theoretical argon gas requirement to overcome the negative effects of poor sealing. If the argon gas requirement were normalized, the system would be able to achieve 85 percent fuel efficiency. Fuel efficiency for the DC plasma arc furnace is significantly higher than the theoretical rate for coreless induction (60 percent) or channel induction (70 percent). On a fuel efficiency basis, the DC plasma arc melter is also competitive with natural gas, assuming a 33 percent power plant efficiency.

The economic and environmental benefits of this technology promise to be formidable and the results and findings should be carried forward to the production scale demonstration originally envisioned for this project.

3.3. Technology Commercialization

Successful commercialization of the technology depends upon the ability of potential customers to finance the relatively high initial cost associated with furnace and ancillary equipment purchase. Subsidies are likely to be required. An initial commercialization plan for the technology was developed, and is presented in the next section.

4.0 Recommendations

Widespread deployment of the DC plasma arc scrap aluminum melting technology will significantly improve competitiveness of the Nation's secondary aluminum industry. The technology should be of particular interest to California melters, currently unable to compete in the recycle market for aluminum used beverage cans (UBC's) because of air quality regulations.

Research projects require a long-term commitment to resolve the many obstacles likely to arise on the path to commercialization. The present team, led by ETS, is unable to proceed with the next phases of the project.

Notwithstanding, the work completed on the DC plasma arc technology has proved viable and should be advanced toward commercialization. For this to take place, a new, committed team is needed to complete the demonstration work and commercialization activities to move the technology forward. The following is provided to help a new team resume work on this project.

4.1.1. Proposed Project Completion and Technology Commercialization Plan

The DC plasma arc technology appears to have a significant potential to improve productive efficiency within the Nation's secondary aluminum industry. It is important that this technology be demonstrated with a variety of different recycle material feed materials. Premature termination of funding at the end of the one-ton or the five-ton melter demonstration tasks, will limit the application of the technology to small feed material only. The successful demonstration of alternatives for this technology will shorten the time needed for its commercialization.

The plan shown on the schedule in Figure 16 is estimated to cost $12.5 million and require 7 years to complete. The plan shows the sequential flow of the proposed phases and how the successful completion of one should lead to the next. A summary description of the activities required for completion of the several phases is presented in the following section.

ID	Task Name	Budget
1	Relocate and Complete One Ton Demonstration	$1,000,000.00
8	Dross Treatment Application	$500,000.00
15	Five Ton Demonstration	$2,500,000.00
24	Commercialization of the LDM Technology	$500,000.00
26	Expand LDM Applications	$500,000.00
30	Five Ton Test Bed	$3,500,000.00
36	Used Beverage Cans Application	$2,000,000.00
41	Sidewell Design for Large Scrap	$2,000,000.00
46	Commercializtion of New LDM Apllications	$500,000.00

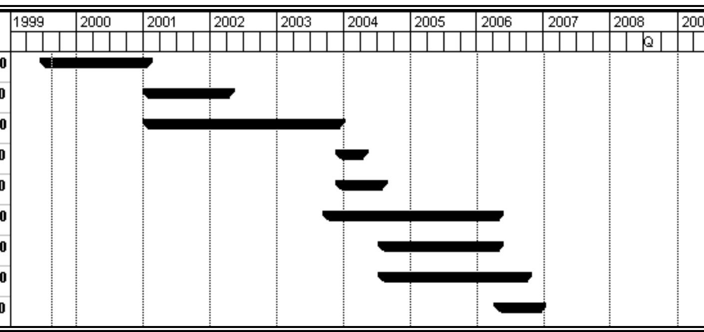

Figure 16. Proposed Project Completion and Technology Commercialization Plan

4.1.2. Detailed Plan Description

4.1.2.1. Relocate and Complete the One-Ton Melter Demonstration

It is critical to complete the demonstration plan for the Prototype One-Ton DC Plasma Arc Melter. Funding for this crucial activity should be provided by one agency to minimize potential distractions of the project management effort and to encourage management's concentration on completion of the testing. The following is the proposed plan for completing the demonstration.

- Develop a new project team capable of resolving prior disputes, and committed to project completion.
- Conduct an independent assessment to certify that the DC plasma arc technology is safe and will work as designed, confirming the economical benefits to melters.
- Resolve testing completion issues before relocation to a new host site. This includes funding and planning to operate and test the melter and address safety concerns and liability issues.
- Obtain a projected $1 million in funding from the California Energy Commission to relocate and complete the Prototype One-Ton DC Plasma Arc Melter demonstration.
- Solicit and select a new host melter.
- Sign project agreements with contractors including the EPRI, host-site owner, Paul Wurth, Inc. (PWI) and Process Engineering Dynamics (PED).
- Inspect Prototype One-Ton DC Plasma Arc Melter at TIMCO to determine the extent of damage from 1 year's neglect. Identify parts for replacement or repair, and cold test the equipment.
- Install the furnace at the new site.
- Complete cold and hot testing as planned to allow optimization of the furnace performance and provide operational test results.
- Demonstrate the Prototype One-Ton DC Plasma Arc Melter for at least 2 months, before the project team returns to conduct further performance testing.
- Develop the final report, documenting the dross and energy efficiency test data. The report will determine the feasibility of the technology and the lessons learned to be incorporated in the next phases.

4.1.2.2. Dross Treatment Application

It is believed that dross (Figure 17) can be converted into a useful steel-making product. This can be done by recharging the dross into the furnace, adding calcium oxide and other oxide fluxes to the dross within the furnace, and elevating furnace temperature to more than 2500°F, causing the mixture to liquefy. The resulting product, liquid calcium aluminate, can be tapped from the furnace, granulated and packaged for sale to the steel industry.

Figure 17. Dross Blocks

TIMCO and other melters have shown great interest in the potential use of the DC plasma arc melter as a dedicated dross treatment unit. This application has the potential to improve yield, reduce dross management cost, and improve the environment.

Testing of the dross management application can be accomplished with a small furnace, and the Prototype One-Ton DC Plasma Arc Melter would be ideal for this use. The furnace refractory, however, would have to be selected to withstand the higher temperature and the handling of different material. To pursue this application, the following plan is proposed:

- Obtain project funding from industry, the California Energy Commission, and environmental agencies, which have the most interest in demonstrating environmentally better ways to dispose of dross.
- Sign project agreements with contractors such as TIMCO and PWI to conduct these tests. Because this demonstration requires re-aligning the Prototype One-Ton DC Plasma Arc Melter, TIMCO might request delay of this phase until the five-ton unit is available for melting regular scrap aluminum.
- Re-align the Prototype One-Ton DC Plasma Arc Melter with different refractory material able to withstand the higher 2,500 F temperature, and the more abrasive calcium aluminate liquid.

- Conduct the startup and test procedures required to prepare the furnace for the dross treatment process demonstration. It is expected that the higher operating temperature of the furnace will present problems to the sensors and the dump valves of the feed system.
- Demonstrate dross treatment for a period of 4 weeks. It is expected that TIMCO will continue to operate the one-ton furnace for treatment of dross if the test results are successful and the five-ton is available for melting scrap aluminum.
- Develop final report documenting the test data, and the economic feasibility of the application of the DC plasma arc technology to the treatment of dross.

4.1.2.3. Five-Ton Prototype Melter Design

Commercialization of the DC plasma arc aluminum melting technology will be enhanced by the successful demonstration of a production unit that is comparable in size to the gas reverberatory furnaces now in widespread use throughout the aluminum reprocessing industry. Completion of the one-ton demonstration program will likely suggest areas of design improvement that can be made part of the design of the five-ton unit.

Based on lessons learned during the brief trial runs with the Prototype One-Ton DC Plasma Arc Melter, the design considerations described in the following should be revisited.

A two-vessel design (Figure 18) may improve the economics of the low dross melter technology. The melting cycle slightly exceeds 30 minutes to load the furnace with the needed five ton of scrap, and melt the scrap. In the remaining 30 minutes, the expensive infrastructure of the furnace is sitting idle waiting for the dross removal and tapping to be completed. A second vessel could be used to melt more scrap, while the first vessel is being de-drossed and tapped.

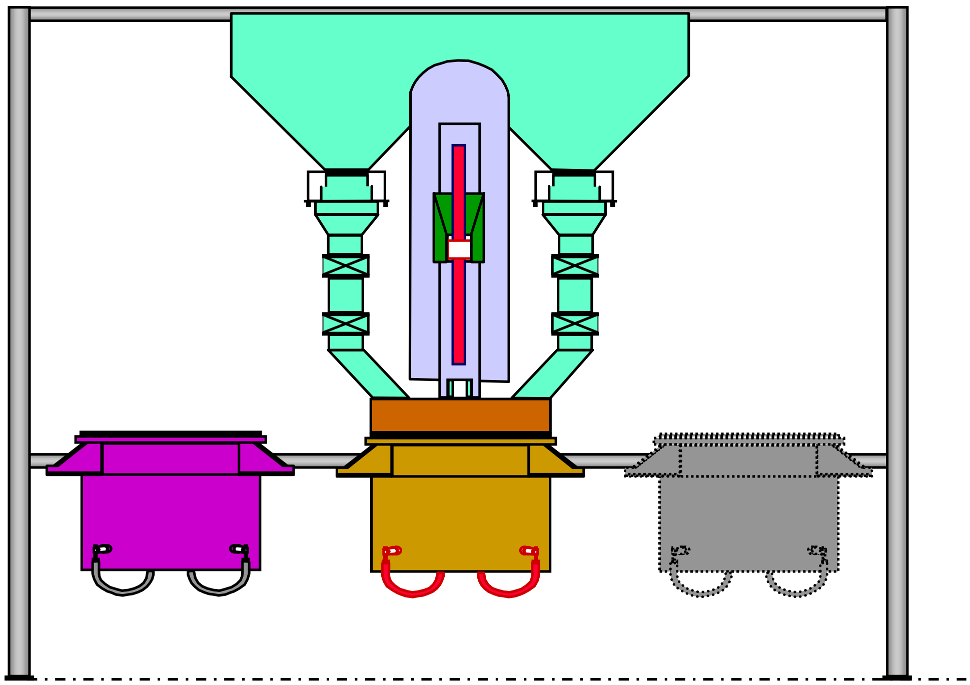

Figure 18. Conceptual Double Vessel Design for Five-Ton Unit

The installation of the Prototype One-Ton DC Plasma Arc Melter took excessive time to complete. This can be avoided by adopting a modular design that allows shop fabrication of three to four major components, connected to all services and instrumentation, and ready to be plugged together on site.

The electrode enclosure was over designed due to lack of operational data. The demonstration of the Prototype One-Ton DC Plasma Arc Melter allows better definition of the minimum thermal, electrical, and mechanical requirements.

The design of the Prototype One-Ton DC Plasma Arc Melter is unnecessarily complicated and over-instrumented. Successful demonstration of the prototype one-ton melter will allow the elimination of features determined unnecessary for the five-ton unit.

4.1.2.4. Five-Ton Melter Demonstration

The following are recommended activities needed to complete a comprehensive demonstration of a five-ton DC plasma arc melter unit.

- **Obtain Project Funding**
  - Obtain project funding from industry, the California Energy Commission, and the U.S. Department of Energy (DOE). Successful completion of the one-ton demonstration program will provide adequate performance history for the furnace manufacturer to confidently extend the kind of performance guarantees that will attract funding. Potential customers should be targeted for a funding contribution ranging from 50 to 100 percent of the equipment five-ton demonstration program. The remaining equipment cost could be funded through utility incentive programs such as Southern California Edison's Environmental Pricing Credit. Federal and state agencies should be approached for funding contributions to cover the initial high cost of engineering, testing, demonstration, and commercialization activities.
  - Negotiate and execute project agreements with participating funding entities, the furnace designer, furnace fabricator, and a production demonstration host.
- **Design Five-Ton DC Plasma Arc Melter**
  - Coordinate and closely supervise the activities of the furnace designer and furnace fabricator. The designer and fabricator should work together to design the five-ton unit incorporating lessons learned from the Prototype One-Ton DC Plasma Arc Melter demonstration, and any other innovations in the technology that may develop from the efforts of other Technology Investigators.
  - Engage a Constructibility Consultant to review preliminary designs for installation appropriateness at the host demonstration site
- **Fabricate Five-Ton DC Plasma Arc Melter**
  - The bulk of the five-ton melter should be fabricated at the factory. In particular, the control and instrumentation devices subject to the application of refectory material should be installed at the factory and the vessel refractory lining should be installed and cured at the factory.
  - The melter should be shipped to the demonstration site in as few pieces as possible.
- **Install Five-Ton DC Plasma Arc Melter**
  - Prepare the facility, install the furnace, the power supply, the feed system, and the argon supply systems.
  - Carefully plan startup and testing activities. Experience with the Prototype One-Ton DC Plasma Arc Melter underscores the importance of correctly estimating the effort needed to cold start and hot start the furnace.
- **Demonstrate Five-Ton DC Plasma Arc Melter**
  - Demonstrate the five-ton unit for at least 6 months before the project team returns to conduct further performance testing.

- **Develop Final Report**

– Develop the final report, documenting the dross and energy efficiency test data. The report will determine the feasibility of the technology, and the lessons learned to be incorporated in the next phases.

4.1.2.5. Commercialization of the Low Dross Melter Technology

The success of the five-ton unit will allow commercialization of the low dross melter technology for small feed material. The industry needs to be informed of the results of the demonstration through seminars, brochures, and other marketing activities.

4.1.2.6. Expand Low Dross Melter Applications

It is important to demonstrate this technology for different feed material. The five-ton demonstration is limited to small feed material only. There are other potential applications of this technology, which will help commercialize the technology within the secondary aluminum industry. The addition of a large scrap feed system and the used beverage feed systems are considered the two most important new applications.

The following is the proposed task to demonstrate these applications:

- Conduct a study of the economic and technical feasibility of the proposed new applications. The study will include a survey of the secondary aluminum challenges, market drivers, and the benefits of these new applications. In addition, the study will assess the alternative technologies available to meet the industry challenges, and establish the relative advantage of using the low dross technology.
- Garner public support for low dross melter technology. The benefits of handling all scrap sizes in the furnace and bringing back the UBC melting industry to California, provide mainly public and not private benefits. Melters are not concerned about melting all types of scrap, as long as there is enough supply of one type of scrap material to keep their furnaces busy. It is expected that most of the funding will need to come from the California Energy Commission, the U.S. DOE, and other public funding agencies.
- Sign project agreements with the identities that have experience in providing ancillary equipment enabling the use of the low dross melter with different feed material.

4.1.2.7. Five-Ton Test Bed

The success of a Five-Ton DC Plasma Arc Melter demonstration will make the five-ton unit an operational unit. It is expected that TIMCO will not allow further development work on their operational five-ton unit. In addition, the procurement of another five-ton test bed unit will allow incorporation of further improvements to the commercial unit design. The following is an outline of the activities needed:

- Negotiate a new test bed host site, that will allow access to contractors, and will provide, at cost, the scrap material and labor needed for the test bed unit.

- Place the five-ton equipment order with the licensed commercial furnace manufacturer. This will allow the identification of commercialization challenges requiring resolution to enable furnace manufacturers to meet customer requirements and provide the right product and service.
- Install the equipment at the test bed host site, complete with the civil and electrical infrastructure needed for a multi-year testing program.
- Operate the test bed five-ton unit while testing modifications and improvements. Form an advisory technical committee to oversee optimization effort on the commercial unit, and plan the addition of new feed systems.

4.1.2.8. Used Beverage Cans Application

California has lost all of the UBC melting operations because of the unacceptable emission levels when UBC's are melted in a gas reverberatory furnace. The final phase of the low dross melter project should demonstrate the economical and environmental benefits of melting UBC's in a DC plasma arc furnace. Steps for this phase are:

- Engineering evaluation of UBC de-lacquer. Options include cleaning the UBC before shredding and feeding using superheated steam. Another option is to use the absence of oxygen to directly feed the UBC into the DC plasma arc furnace, adding control equipment to clean the emissions.
- Install each alternative at the test bed site.
- Demonstrate each alternative as necessary with a projected 6-month completion schedule.
- Identify the UBC de-lacquering option with the greatest economical and environmental benefits.

4.1.2.9. Side-Well Design for Large Scrap

The five-ton demonstration project will design and fabricate a large scrap feed system that allows easy introduction of the scrap without breaking the furnace seal. A plan for demonstration of this technology is provided in the following:

- Engineering evaluation of large scrap material feed. Options include the use of a double lock side-well for the furnace, complete with argon blanketing and electromagnetic re-circulating pump.
- Install each alternative at the test bed site.
- Demonstrate each alternative as necessary with a projected 6-month schedule.
- Identify large scrap feed system with the greatest economic benefit.

Appendix I
Final Wabash Report

Appendix II
Matrix of Equipment Ownership

Appendix III
Preliminary Engineering Drawings for the Prototype One-Ton DC Plasma Arc Melter

Appendix I
Final Wabash Report

Process Engineering Dynamics Inc.
22 Trails End Drive, Grand Island, New York, 14072 (716) 774-1393

Bob Schmitt, CMP EPRI Center for Materials Production
Carnegie Mellon Research Institute
700 Technology Drive, Pittsburgh, Pennsylvania, 15219
Telephone: 412 268 3243, Fax: 412 268 6852

Friday, February 07, 1997

Dear Mr. Schmitt,

During the week ending February 7, we conducted 2 days of trials using the furnace at Wabash Alloys. Despite numerous delays, damaged equipment and labor availability, we collected the following data:

Date	Al charge (lbs)	Al tapped (lbs)	Skim (lbs)	CaF2*** (lbs)	D.C energy (KWh)	A.C. energy (kWh)
February 4, 1997*	1979	1684	250	50	1093	1180
February 5, 1997**	2611	2435	352	100	963	1050

*started with a cold furnace at 40°F
**started with a warm furnace at 500°F
***CaF_2 was added to break up the dross

The aluminum melted during the trial on February 4 was heavily corroded and contained a large amount of oxide powder. As a result, this trial served to test the system and to heat the furnace for the trial on the next day. On February 5, the furnace was started with 1232 lbs of clean dry shot. After melting the initial charge, 1379 lbs of warm dry chips were added and melted.

Yield

Date	Al charge (lbs)	Al tapped (lbs)	Skim (lbs)	Skim-CaF2 (lbs)	Al yield (%)
February 5, 1997	2611	2435	352	252	93*

*yield for combined charge of shot and chips

The yield is a ratio of the charged and tapped aluminum quantities. However, the skimmed dross contained an estimated 50% aluminum. Based on the addition of aluminum contained in the dross the yield may be higher.

Energy Consumption

The following table shows the energy requirements and conversion efficiencies measured during the trial.

Date	Al charge (lbs)	D.C. energy (kWh)	Energy requirement (kWh/ton)	A.C energy (KWh)	Conversion efficiency (%)
February 4, 1997*	1979	1093	1105	1180	93
February 5, 1997**	1232 shot	642	1042		
February 5, 1997***	1379 chips	321	466	1050	92

*shot melted in a cold furnace
**shot melted in a warm furnace
***chips added to a hot furnace

The data shows that as the initial furnace temperature increased, the energy requirement decreased. The A.C. to D.C. conversion efficiency has remained close to 93% for this trial and a previous trial.

Argon Consumption

During the 2 day trial, 8600 cu. ft. (STP) of argon were consumed. The high consumption rate is due to high flow rate to the porous plug and excessive gas purging of the furnace to maintain the inert atmosphere. Improvements in furnace equipment and implementation of an alternative stirring mechanism will reduce the consumption significantly.

Electrode Consumption

The excessive electrode burning experienced during previous trials has been significantly reduced. A packed seal was fabricated and installed on the furnace roof to prevent oxidation of the electrode. As a result there was little evidence of electrode necking. However, the tight seal around the electrode reduced the space for lateral movement causing the electrode to break off on 3 occasions. This can be overcome by better aligning the roof and electrode mast.

Summary

Each successive trial produces better results due to continuous improvement. This trial has shown that yield values better than 93% can be achieved. Also, the energy requirement for melting chips in a hot furnace is lower than previously measured, in this case 466 kWh/ton. The energy conversion efficiency has been shown to be consistent at 93%.

Based on the success of this trial and the experience gained during furnace operation, improvements are recommended before further trials are conducted.

Best Regards

David Walker

approved by Frank Kemeny, 97/02/07

ETS/018b

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Best Regards

D. D. Walker

David Walker

approved by Frank Kemeny, 97/02/07

The energy requirements in addition to the theoretical requirement can be estimated by adding the following losses:

1. Conduction heat losses from the furnace body.
2. Resistive heat loss in the electrode.
3. Conduction heat loss to water cooling on electrode.
4. Emission heat loss (gas and particulate).

Values for these types of losses are difficult to estimate with a limited number of trials. However, it was found that 30 kW (500 A @ 60 V) was required to hold the furnace temperature constant. This value is dependent on the holding temperature and the time since furnace start-up. Lower furnace temperature and longer furnace operation will reduce this value.

Heating Efficiency

The heating efficiency was estimated by comparing the actual rate of temperature rise during heating at a known current and voltage to the theoretical temperature rise assuming 100% efficiency. The following tables contain data collected from 2 separate heats for stirring and non-stirring conditions.

Current Level	Charge Weight (lbs)	Actual (°F/min.)	Theoretical (°F/min.)	Efficiency (%)
2500	1600	9.5	13.2	72
2500	1600	10.7	13.2	81
5000	1600	14.5	26.4	55
5000	1600	18.1	26.4	69
5000	2200	12.9	19.2	67

Factors influencing the heating efficiency are:

1. refractories are not "soaked in",
2. low metal level in the furnace causing radiation heat loss to gas in furnace,
3. long holding times,
4. operating with a high aluminum superheat.

Dross Formation:

Estimating the amount of dross formation in non-steady state conditions is difficult and subject to variability However, an estimate can be made by measuring the mass of dross retrieved from the furnace after melting and tapping the furnace. The following table contains the data from this trial:

Event	Date	lbs melted	lbs of dross skim	%
Initial Trials	April 17/18, 1996	4190	≈75	1.8
Stirring Trials	June 11/13, 1996	3900	≈70	1.8
Melted Shot	December 3, 1996	5020	180	3.6
Melted Shot/Chips	December 4, 1996	2604 (767/1837)	604	23.2
Melted Shot	December 5, 1996	3464	180	5.2

The dross quantity includes contained aluminum, oxides introduced from the feed, and oxidized aluminum. The oxidized aluminum contains approximately 50% aluminum. Thus, the aluminum oxidized in this process is significantly lower than the reported number shown in the table.

Factors influencing the quantity of dross formation are:

1. oxygen infiltration through the feed port,
2. argon gas diffuser on feed port and electrode port were not installed,
3. long holding times and high aluminum superheat,
4. low aluminum level in the furnace (high surface to volume ratio),
5. no stirring causing a high superheat beneath the arc,
6. build-up on inside of furnace.

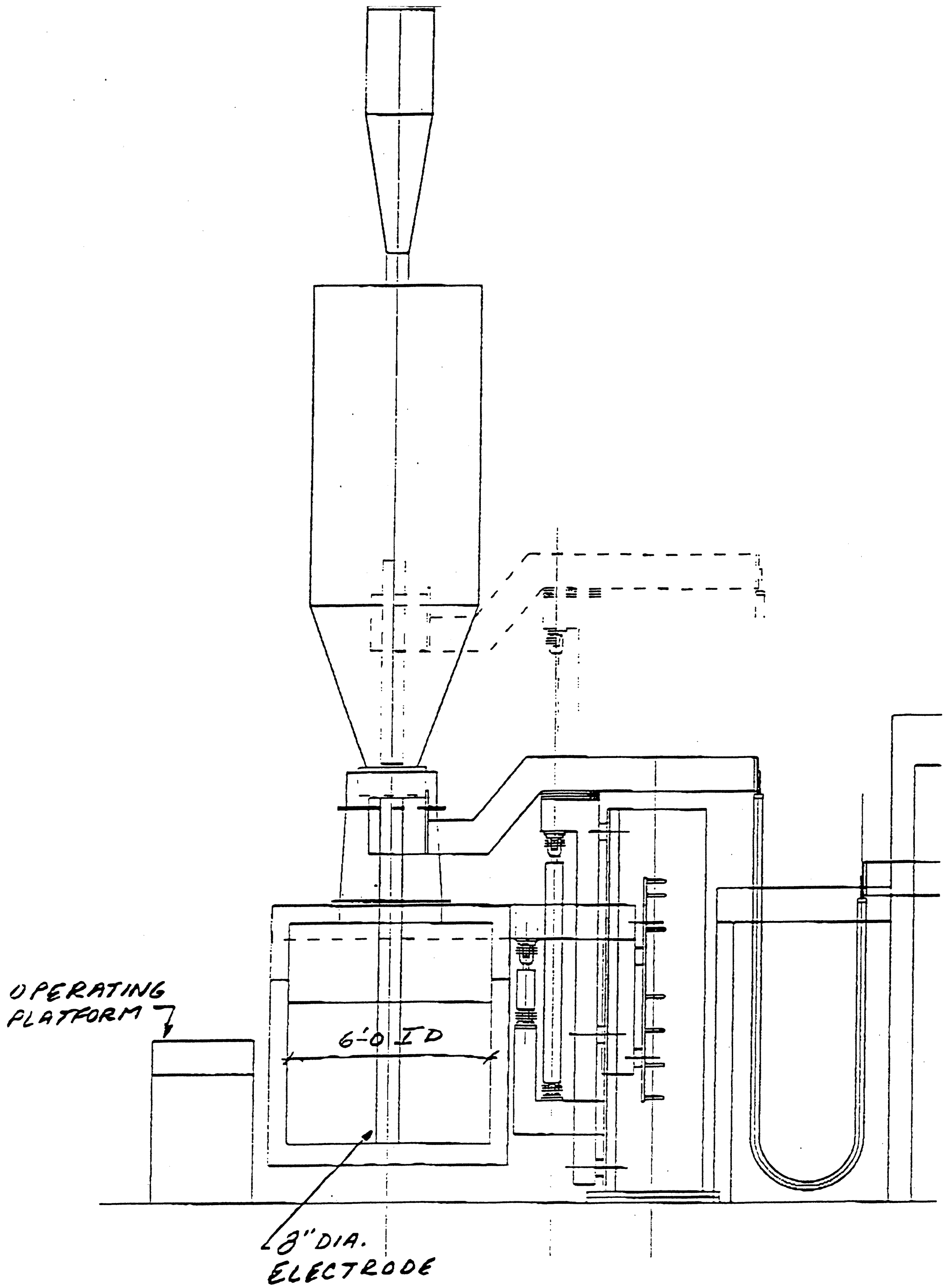
Aluminum recovery

Trials on December 4 & 5 produced aluminum recoveries of 71%, 93%, respectively. The low recovery calculated on December 4 was due to the addition of 1700 lbs of wet chips to the furnace. It is expected that addition of dry chips will produce significantly better recoveries.

Summary

Overall, the energy requirements of this furnace are comprised of the theoretical melting energy (305 kWh/ton), energy conversion efficiency (93%), conduction energy losses from the body (30 kWh), resistive energy losses from the electrode, and energy losses from emissions. Better estimates of the energy losses will be available after further testing.

Modifications to the off-gas system will reduce heat losses through emissions and reduce air aspiration into the furnace. Further trials incorporating 24-hour operation to collect steady-state data will produce values which will better reflect the efficient nature of this furnace.



D.C. Plasma Arc Aluminum Melter

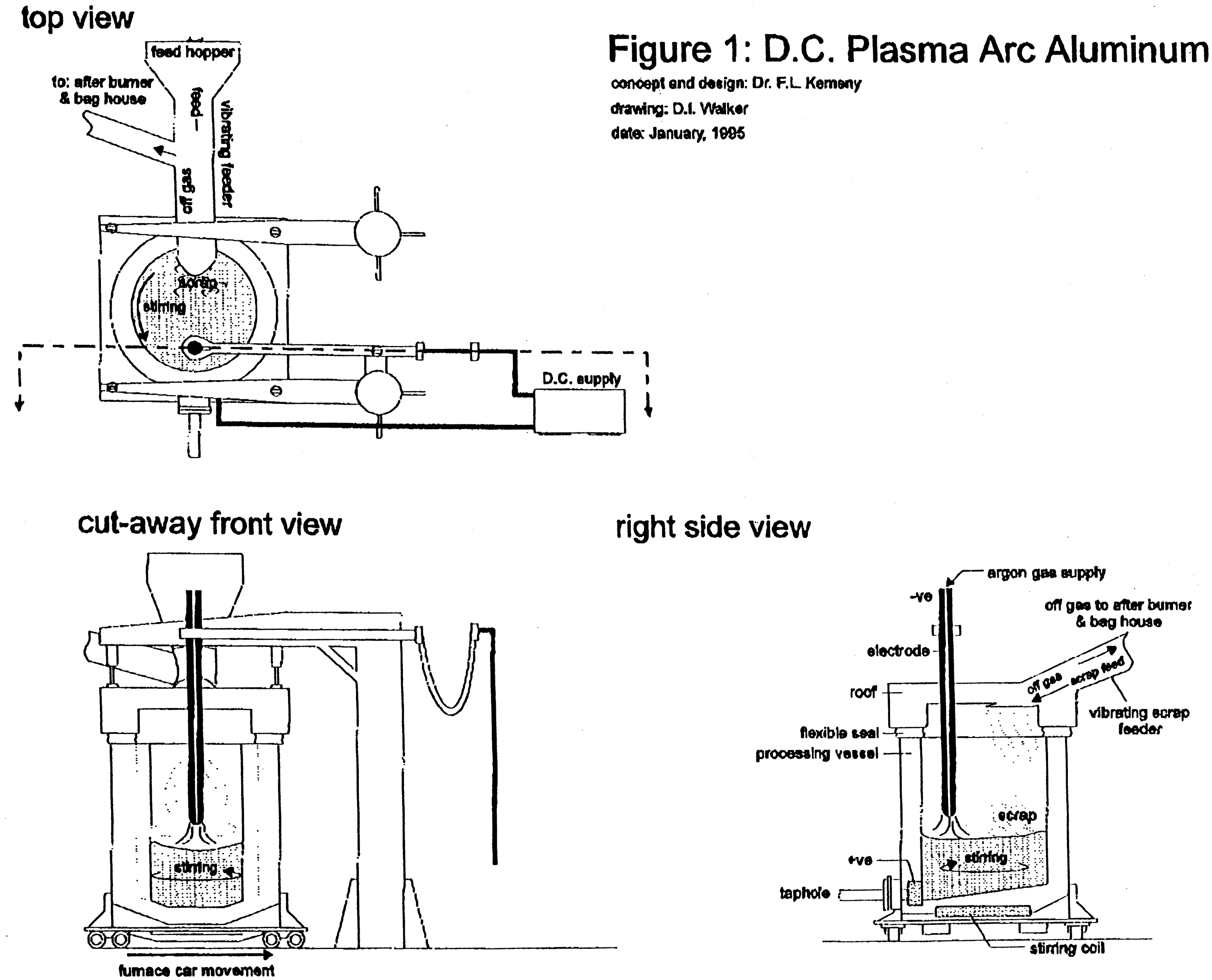
ETS/018f

Figure 1: D.C. Plasma Arc Aluminum Melter

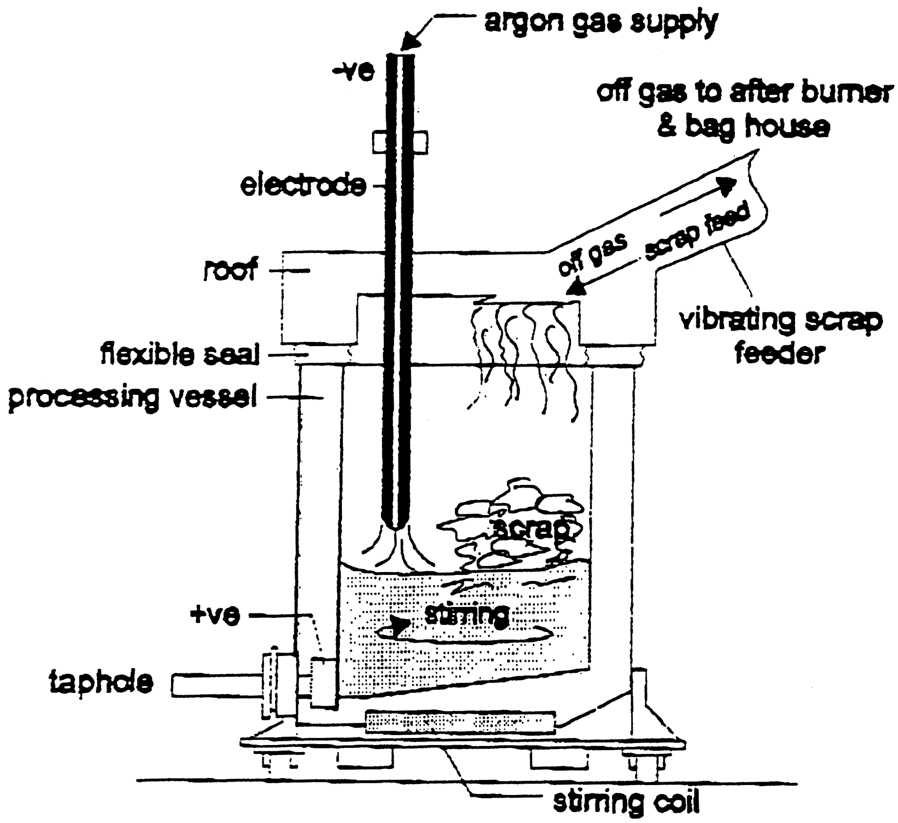
concept and design: Dr. F.L. Kemeny

drawing: D.I. Walker

date: January, 1995

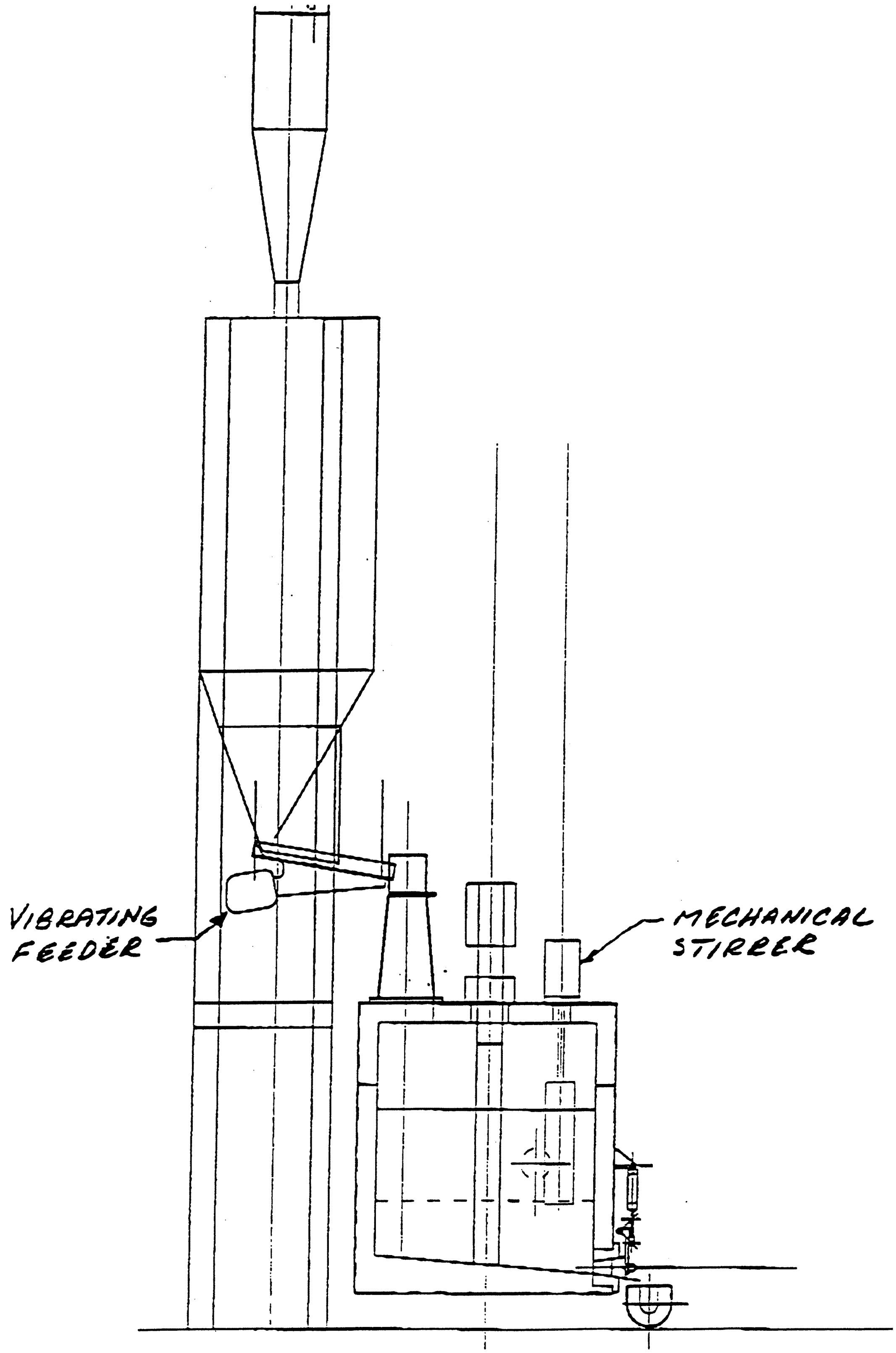


CMP



EPRI/CMP ALUMINUM MELTER

ETS/018h



D.C. Plasma Arc Aluminum Melter

ETS/018i

22 Trails End, Grand Island, NY 14072 (716) 774-1393 Toronto: (905) 569-3962

July 22, 1997

Bob Schmitt, EPRI Center for Materials Production
Carnegie Mellon Research Institute
700 Technology Drive
Pittsburgh, PA 15219
Fax: (412) 268 6852

Re: D.C. Plasma Furnace at Wabash Alloys

Dear Bob,

This is a summary of the latest results from the trials conducted at Wabash, ending in late February, 1997. The objectives during this stage of the project were to determine yield and energy efficiency with minimal cost and effort.

On February 25, 1997, 1650 lb. of aluminum shot with 30 lb. of Mg were melted in the plasma. The purpose of this heat was to soak the furnace refractories and determine the effectiveness of using plasma arc to remove magnesium from aluminum. The heat was left in the furnace overnight. That night, Robert Heard from Paul Wurth delivered the new feeder/feed chute transition pieces.

On February 26, the new transition pieces were installed by early afternoon. Subsequently, the aluminum in the furnace, from the night before, was skimmed. Then, 7.2 lb. of Cu was added to the heal as a tracer to determine the mass of aluminum in the furnace. Next, 1411 lb. of chips were charged to the furnace. After the chips melted, the aluminum was skimmed and tapped to determine the yield of aluminum. During feeding, the transition piece caused the furnace to vibrate violently, breaking the welds on one side of the platform stairs. The vibration caused a breach in the furnace seal, allowing the ingress of air between the furnace and roof. The roof was visibly bouncing up and down on top of the furnace. To avoid further damage to the furnace, this solution was abandoned. Another type of transition piece was designed and fabricated.

On February 27, a new transition piece between the feeder and the feed chute was installed. This design allowed the transition piece to vibrate within the feed chute without translating energy to the furnace. The gap between the transition piece and feed chute was filled with fiber refractory.

The feed hopper was filled with 2477 lb. of chips. Approximately 800 lb. of chips were charged into the furnace and melted. The taper and rough interior surface on the transition piece caused the feeder to jam. The piece was removed and attempts were made to clear the feeder. The trial was eventually terminated due to breech of the inert atmosphere in the furnace, excessive smoking due to the plugged feed chute, and failure of the feeder motor controls. At this point, the molten aluminum level was too low to facilitate skimming. The remaining feed weight could not be determined since there was no way of removing it from the hopper. It was therefore not possible to obtain a yield number. About 800 lb. of molten aluminum was tapped from the furnace, and the interior of the furnace looked fairly clean. The indications are encouraging, and point to a high yield and high energy efficiency, but no quantitative conclusions can be drawn.

Our stopgap solutions were unsuccessful in allowing us to complete a continuous trial run, and thus we still do not have conclusive results with respect to yield. The following table shows the data collected from the 3 days of operation:

Date	*type*	*hopper Al* (lbs)	*Calc. Al* (lbs)	*Al tapped* (lbs)	*Skim* lbs	*total D.C* kWh	*A.C.* kWh	*yield* (%)	*melt D.C.* kWh	*req. D.C.* kWh/t	*Conv. Eff.* (%)
Feb 25	shot	1650 ?	1602	-	80	1544	1660	98†	-	-	93
Feb 26	chips*	1411 ?	1308	2690 ?	148	751	810	95†	350	535	93
Feb 27	chips*	2477	-	~800	-	-	-	-	-	-	-

† including aluminum in skim, estimated at 50%
* clean dry chips, high quality
? uncertain accuracy

Based on the copper addition, the calculated aluminum weight in the furnace was 1602 lbs at the beginning of the trial on Feb 26. After addition of the chips, the calculated weight of metal in the furnace was 2910 lbs. However, only 2690 lbs of aluminum was tapped from the furnace. The discrepancy between calculated and actual metal weights could be a result of inaccuracy in the measurement of sow mold, sow weights and composition of the metal. In general, measured weights at Wabash had limited accuracy. As a result, the yield and required D.C. energy values have been calculated using calculated aluminum weights from the copper dilution data. To minimize the error associated with these measurements, it is again recommended to run the furnace in continuous operation for at least a day, but modifications are required to make this possible.

Magnesium Removal

The following table shows the aluminum composition as a function of time:

Time	*Temp* F	*dT* F	*Mg* (%)	*dMg* (%)	*Zn* (%)
14:13	-	-	2.13	-	0.98
15:32	1500	-	2.12	0.01	1.00
16:35	1686	186	2.16	0.04	0.80
17:42	1950	264	1.89	0.27	0.72
18:33	1940	-10	1.81	0.08	0.66
18:45	-	-	1.77	0.04	0.65
19:15	1934	-	1.73	0.04	0.63
19:27	1927	-7	1.72	0.01	0.63

The greatest change in the magnesium content of the metal corresponds to a large increase in metal temperature due to arcing. Local temperatures near the plasma attachment point are several hundred degrees hotter than the bulk metal temperature, causing magnesium vaporization during intensive arcing. More tests need to be conducted to determine the influence of current, stirring, dross cover and roof position on the magnesium removal rate.

Summary of the trial results

Results from the trials conducted from February 25 to 27 have shown the following:

1. A magnesium removal rate of up to 0.24%/hour was measured.

2. Energy conversion efficiency from A.C. to D.C. is consistently 93%.
3. *Apparent* aluminum recovery from melted shot is near 98%.
4. *Apparent* aluminum recovery from high quality chips is 95%.
5. Makeshift improvements did not provide an adequate furnace seal
6. Further improvements must be made before continuous furnace operation is possible.

The furnace requires extensive modifications before accurate values for yield and energy efficiency can be measured. Unfortunately, our attempts at providing a low cost stopgap solution to obtain representative yield numbers did not succeed.

Project Goals

The project goals have not been completed due to severe underfunding. The project budget was determined based on certain commitments by Wabash Alloys that were not realized. In addition, Wabash imposed physical constraints on the equipment after the engineering phase had been completed. As a result, a great deal of unplanned engineering time was required, and several furnace retrofits were conducted to accommodate the imposed constraints. The following timeline for the project illustrates the areas of difficulty:

Time Line

At the onset of the project, Wabash committed to providing operating staff and a feed system to get chips into the furnace. In addition, construction support and on site modifications and maintenance were offered.

March/96 - Wabash approved location for furnace and preliminary drawings by Paul Wurth. Low dross melter footprint was about 1000 square feet, and head height was well over 30 feet. Wabash agreed to supply buildings for electrical components and control room.

late March/96 - Wabash changed furnace location to a confined space near reverb. furnace. Footprint had to be reduced to 400 square feet, and no buildings were to be provided for electrical components. Also, no control room and work area could be provided. Head height was insufficient, so roof supports had to be modified to make room for the electrode mast.

96/04/16- Furnace Installation complete with additional engineering input from Paul Wurth and PED to accommodate modifications to allow the furnace to fit into the confined space.

April/96 - On commissioning, it was determined that the Praxair designed argon gas curtain was not sufficient to provide an inert atmosphere during continuous feeding of chips. After several attempts to modify the Praxair design, and alter argon flowrates to the furnace, it was decided that a hard furnace seal was required. The building roof over the melter leaked water during a rainstorm, and damaged furnace components. Repairs were made and software had to be reinstalled to the PLC. Further roof leaks occurred during rainy periods, and it was decided that it was too dangerous to operate the furnace at these times.

May/96 - PED, A. Galmarini (Wabash), G. Paul (Paul Wurth), correspond on furnace car, off-gas and feeder system drawings. Wabash agrees to provide in kind labor and several components for the new plan. A budget increase was requested accordingly.

June to November/96 - Feed system design and construction period. Feed system finally installed November 1, about two months late. Furnace car was not built. Wabash financial and in kind support were withdrawn. Load cells were purchased by PED, but not reimbursed by Wabash. PED staff required to operate furnace since Wabash could not supply operators when needed. Stirring coils had insufficient power. University of Toronto recommended installation of additional coils. PED designed a coil support rack and six coils were installed. Defective coil manufacturing caused stirring coils to fail due to faulty insulation. A welding machine was purchased to replace the stirring coil power supply to provide more power to the remaining coils. Finally, a porous plug was installed in the furnace bottom for argon stirring.

January/97 - Several problems remain due to lack of adequate financial and operating support. Off-gas system could not be easily adjusted and caused air infiltration into the furnace. Engineers at Paul Wurth devised solution to electrode necking.

February/97 - Paul Wurth personnel view the furnace in operation and devise solutions to seal the furnace in the short term. The objective becomes to get reliable yield and energy numbers. PED fulfills operating, maintenance and technical functions for the trial period at the end of February. Makeshift solutions are implemented and the final furnace runs are made at the end of the month.

The project goals remain unsatisfied due to:

1. Unclear and insufficient funding
2. Unclear and insufficient participation by Wabash Alloys
3. Frequently changing project constraints

The Keys to Success

The technical success of this furnace depends upon maintenance of the following conditions:

1. Inert melting atmosphere
2. Sufficient metal stirring
3. Sustained plasma arc at the specified voltage and current

If any one of these conditions is not satisfied, then the furnace will not operate in an efficient manner. The inert melting atmosphere is the most difficult condition to maintain. This condition depends upon inert gas supply, and maintenance of furnace body to roof seal, electrode seal, and feed port seal.

For these trials, the furnace body/roof seal consisted of a refractory fiber gasket compressed between the roof and the body. This was not sufficient, especially when vibrations caused the roof to move relative to the furnace body. Either a water-cooled "o-ring" type seal or knife-edge sand seal needs to be installed as a more effective alternative.

The electrode seal was similar to the one used for the trials conducted during the week of February 6, 1997. A stack of 10 refractory fiber rings was added to improve the seal. Electrode necking was observed at the end of the trials, indicating that the solution was not effective. As a result, this seal needs to be improved. Paul Wurth has designed a water-cooled graphite seal, which needs to be tested to determine viability. Other solutions include a telescopic electrode holder, and an encasement housing the entire electrode mast. The latter solution will be used for the TST project in California.

Due to the continuous nature of this process, the feed port cannot be permanently sealed. As a solution, the off-gas from the furnace has been forced through the feeder counter-current to the feed. This practice serves to preheat the feed and remove some of the entrained air. Building an interface between the moving tube feeder and the stationary feed chute has proven difficult. This difficulty can be overcome by changing the feeder design. A double dump valve arrangement has been designed by Paul Wurth and will be implemented in the TST furnace. This arrangement is also suitable for the present furnace, and a retrofit is recommended.

Dross removal is most difficult with a stationary furnace and roof. The gap is less than a foot when the roof is fully lifted, allowing little room for an operator to remove dross. As a result, the drossing operation takes about 20 minutes, and aluminum is oxidized during this operation. In addition, it is difficult not to remove a large quantity of aluminum with the dross. We could not determine how much aluminum is present within the dross that we removed, but we estimated it at about 50%. The furnace needs to be placed onto a car so it can be moved from underneath the roof prior to drossing. The original furnace design called for a car on load cells that moved the furnace body from underneath the roof. It is recommended that the furnace be retrofitted with this design.

Once the recommended modifications are made, the test program should be continued. The furnace has been removed from Wabash and is in storage. We have a number of options for re-installation of the furnace and continuation of the test program. The most promising appears to be in Southern California Edison's territory. Without a review of the site and available resources, it is difficult to provide an accurate cost estimate, but the following can be used as a guideline:

feed system	96,000.00
electrode enclosure and seal	24,000.00
furnace modifications	60,000.00
engineering, expenses and drawings	107,000.00
installation	50,000.00
test program (PED): 10 man-weeks	40,000.00
travel expenses and shipping (to Southern California)	48,000.00
total	$425,000.00

The above cost does not include consumable materials, such as refractory and electrodes. The above cost also assumes that all water requirements can be "flow-through" and no closed loop system is required.

We have learned a great deal from the project experience to date. Indications are that the DC plasma low dross melter is technically sound and provides many advantages over conventional reverberatory melting. With adequate funding and an appropriate new location, we are confident that we can fulfill the project objectives and demonstrate the commercial viability of this electrotechnology for aluminum chip melting.

Best Regards,

Frank L. Kemeny

Nupro Corporation
22 Trails End Drive, Grand Island, New York, 14072 (716) 774-1393 (416) 622-9279

Bob Schmitt, CMP EPRI Center for Materials Production Friday, June 28, 1996

Carnegie Mellon Research Institute
700 Technology Drive, Pittsburgh, Pennsylvania, 15219
Telephone: 412 268 3243
Fax: 412 268 6852

Dear Mr. Schmitt:

Here is a summary of the progress made on the D.C. Arc Melter project at Wabash Alloys in Cleveland to date.

Preliminary "Numbers":

An estimate of the D.C. Plasma Arc Furnace potential as a viable melting tool can be made by evaluating the quantity of dross, heating efficiency and stirring performance during preliminary melting trials. The recommended modifications, outlined at the end of this report, need to be made so that more accurate data can be collected. The modifications and practice changes will have a significant impact on the values presented in this report.

Furnace Operation to Date:

Thus far, the furnace has been used 6 times to melt aluminum. In each case, the furnace was heated from a cold state. Also, the aluminum, once liquid, was held at temperature in the furnace for relatively long periods of time. Both of these practices require more heat when compared to normal continuous operation. The following table contains a list of the data for each heat:

Trial	Date	time (min.)	lbs melted	kWh to melt	kWh/lb
Start-up	April 17, 1996	600	2190	-	-
Wabash Tour	April 18, 1996	450	2000	-	-
E.P.R.I. Tour	April 23, 1996	180	1500	790	0.53
Alumiform Tour	May 14, 1996	270	1539	981	0.63
Stirring Trial	June 11, 1996	480	1500	667	0.44
Stirring Trial	June 13, 1996	480	2400	1062	0.48

Efficient operation of the furnace can only be demonstrated by 24-hour operation.

Dross Formation:

Estimating the amount of dross formation in non-steady state conditions is difficult and subject to variability. However, an estimate can be made by measuring the mass of dross retrieved from the furnace after melting and tapping the furnace. In this case, dross was retrieved from the furnace after 2 heats were melted and tapped. The following table contains the data from this trial:

Number of Heats	Aluminum (lbs)	Dross (lbs)	%
2	4190	≈75	1.8
2	3900	≈70	1.8

Factors influencing the quantity of dross formation are:

1. oxygen infiltration through the feed port,
2. argon gas diffuser on feed port and eléctrode port were not installed,
3. long holding times and high aluminum superheat,
4. low aluminum level in the furnace (high surface to volume ratio),
5. no stirring causing a high superheat beneath the arc.

The quantity of dross formation can be reduced by addressing the preceding factors.

Heating Efficiency:

The heating efficiency was estimated by comparing the actual rate of temperature rise during heating at a known current and voltage to the theoretical temperature rise assuming 100% efficiency. The following tables contain data collected from 2 separate heats for stirring and non-stirring conditions.

Current Level	Charge Weight (lbs)	Actual (°F/min.)	Theoretical (°F/min.)	Efficiency (%)
2500	1600	9.5	13.2	72
2500	1600	10.7	13.2	81
5000	1600	14.5	26.4	55
5000	1600	18.1	26.4	69
5000	2200	12.9	19.2	67

Factors influencing the heating efficiency are:

1. refractories are not "soaked in",
2. low metal level in the furnace causing radiation heat loss to gas in furnace,
3. long holding times,
4. operating with a high aluminum superheat.

The heating efficiency can be improved by changing the preceding factors.

Electromagnetic Stirring:

Preliminary tests of the electromagnetic stirring system showed that a minimum of 400 A supplied to the stirring coil was required to cause a change in the temperature distribution of the aluminum metal at 5000 A supply current.

These results are not conclusive and need to be investigated further because the refractories were not "soaked in" and solid aluminum may have been present in the furnace during the test. In light of these findings, a larger power supply must be purchased, additional copper coils need to be added and the tests repeated.

Summary:

Based on the preliminary results and the factors influencing them, the D.C. Plasma Arc furnace installed at Wabash Alloys has the potential for improved efficiency and reduced dross formation with respect to current levels. Installation of a shot/chip feeder, gas collection system, and furnace car with load cells will enable continuous operation of the furnace and the ability to gather more accurate data regarding the performance of the furnace.

Work In Progress: Facility Tours

A representative of Griffin Wheel visited the facility on June 12, 1996. We demonstrated the operation of the furnace and he was able to view the arc through the newly installed view port. A representative from Beck Aluminum toured the facility on June 13, 1996. As part of the tour we demonstrated the furnace in operation. We melted 2400 lbs of aluminum shot starting with a cold furnace. Our guest was impressed and would like to return for a second tour after a feed system has been installed.

On June 25, 1996, Joe Cogan from Neundorfer toured the facility and was asked to recommend a feed system to supply chips to the furnace. An engineer from Neundorfer will visit the facility to make final recommendations.

Feeder System

Aluminum chips are difficult to convey from a hopper due to their tendency to nest when piled up. In addition, our feed system must supply aluminum chips to the furnace at 2000 lbs/hour. The chips must be moved from a location that a front end loader can easily access. Then the chips need to be elevated to above the furnace roof. Finally, the chips will enter the furnace through the off-gas duct. This will reduce the air entrained in the feed and begin to preheat the feed as it falls through the duct. This type of system is custom fabricated and requires a large amount of engineering support. In addition, many parties are involved in the decision making process with regard to engineering and economics. Thus, ensuring that the correct system is purchased in the most economical manner has proved to be time consuming.

After the recent visit by Joe Cogan, a feeder system salesman, we have specified the components that we require to fulfill our needs. To ensure correct sizing of the feeder, we have sent samples of chips and shot to Joest in Texas and to Neundorfer in Cleveland. By seeing the samples and testing their characteristics, the engineers at these 2 companies who are designing the system will be able to determine the correct method of conveying the chips. Once the drawings for the system are approved, there is a 8-10 week lead time for delivery. We anticipated delivery at the beginning of September.

Off-Gas Collection System

We have decided to extract the off-gas mainly from the feed port. A secondary capture system will be constructed to extract gas from around the electrode. The two ducts will connect into one duct with dampers in each arm. Extracting the gas from the feed port will reduce the air entrainment in the feed.

Furnace Car

The furnace roof, stirring coils and brackets have been removed from the furnace. The furnace body has been lifted out of the cradle and the I-beam rails are in the process of being extended. Load cells have been recommended and are being ordered.

In summary, visitors to the furnace facility are once again impressed with the technology and have expressed interest in repeat visits. Unfortunately, we have encountered some problems that have added a significant amount of time to the modification completion date. However, we expect that furnace car and off-gas collection system improvements will be completed by the middle of August. Thank you for your continued support for this project. Please contact us if you have any questions.

Regards,

David Walker

Approved by Frank Kemeny 96/06/28

Appendix II
Matrix of Equipment Ownership

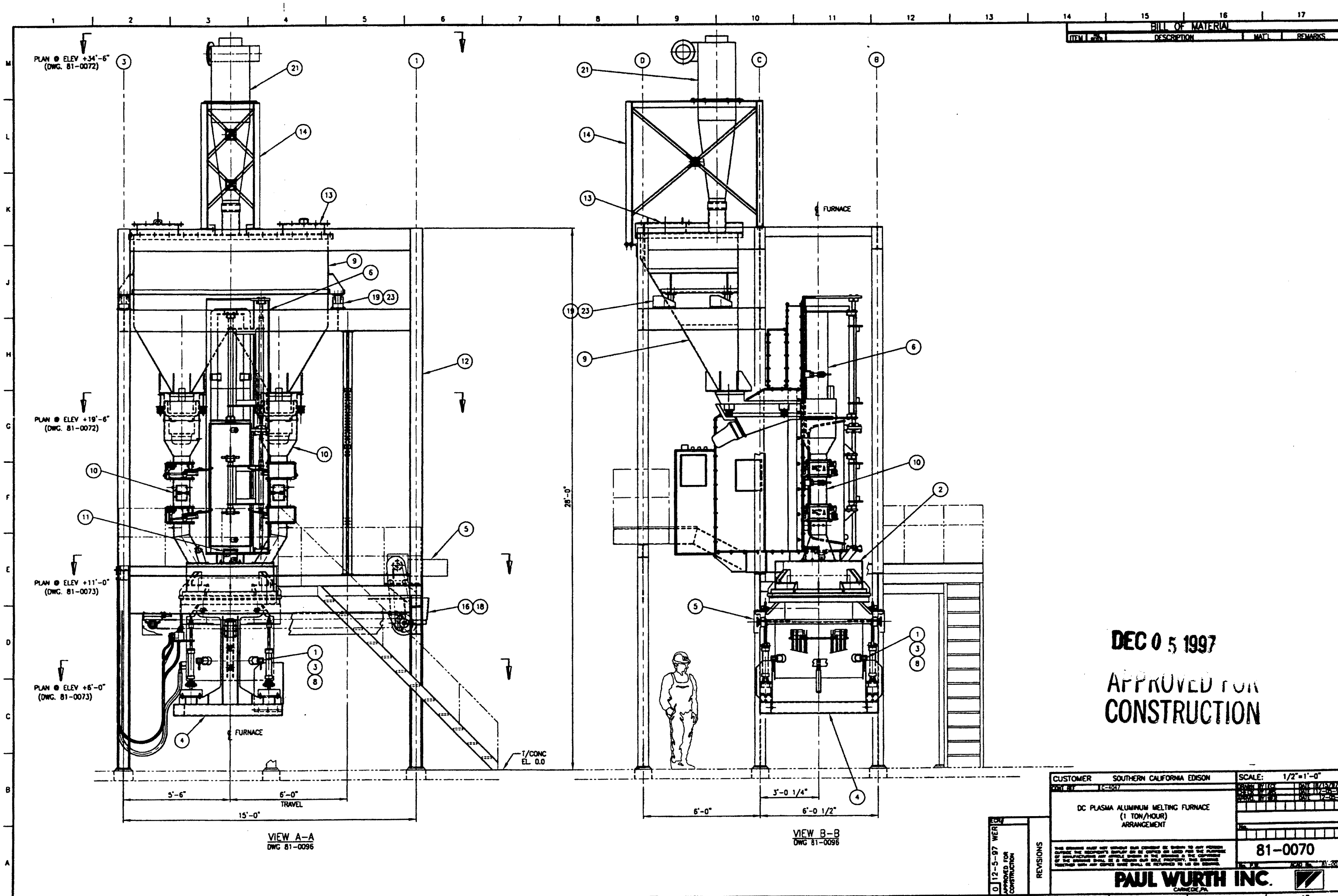
Invoice Date	Phase	Supplier	Item	Cost	Date	Contractor	Vendor Invoice Number
California Energy Commission							
May-98	One	Allegheny Pipe	4 inch Thread Full Port Valve	638.69	05/14/1998	Paul Wurth	4122/98
May-98	One	B&H	Grinder Rod Extension	303.38	05/14/1998	Paul Wurth	4122/98
May-98	One	Baltimore Air Coil	Water Cooling System	26,917.88	05/14/1998	Paul Wurth	4122/98
May-98	One	Brooks Jensen	Slab Boxes	8,452.00	05/01/1998	TST, Inc.	31372
May-98	One	Celesco	Position Transducer	858.43	05/14/1998	Paul Wurth	4122/98
May-98	One	Dell	XPS M200s	3,328.74	05/14/1998	Paul Wurth	4122/98
May-98	One	Endress & Hauser	Promag	2,958.81	05/14/1998	Paul Wurth	4122/98
May-98	Five	ESI	Toshiba 5 kV Switchgear	17,084.04	05/14/1998	Paul Wurth	4122/98
May-98	One	ESI	Toshiba 5 kV Switchgear	17,613.07	05/14/1998	Paul Wurth	4122/98
May-98	One	F.T. Thomas	20 HP Motor	2,268.62	05/14/1998	Paul Wurth	4122/98
May-98	One	Grant Industrial	Interlock Switch	201.18	05/14/1998	Paul Wurth	4122/98
May-98	One	Greentech	Electrode Carriage, Chutes, and Furnace Trolley	21,591.95	05/14/1998	Paul Wurth	4122/98
May-98	One	Harris Industries	Solenoid Valves and Temp Switch	890.82	05/14/1998	Paul Wurth	4122/98
May-98	One	Hiltran	4160/480 Transformer	9,104.88	05/14/1998	Paul Wurth	4122/98
May-98	One	Joest		3,245.00	05/14/1998	Paul Wurth	4122/98
May-98	Five	Joest	Second Invoice Vibratech of $28,350	13,381.20	05/14/1998	Paul Wurth	4122/98
May-98	One	Miscellaneous	Foundation Work	1,022.70	05/01/1998	TST, Inc.	31374
May-98	One	National Instrument	Lookout RunTime Systems 50 I/O, and 100 I/O	4,132.07	05/14/1998	Paul Wurth	4122/98
Aug-98	One	Omega Engineering		473.95	08/28/1998	Paul Wurth	4279/98
May-98	One	OPG	Roof Lift and De-Dross Cylinders	2,057.80	05/14/1998	Paul Wurth	4122/98
May-98	One	Osborn	c/o of Horst	3,909.14	05/14/1998	Paul Wurth	4122/98
May-98	One	Pittsburgh Wire		1,072.44	05/14/1998	Paul Wurth	4122/98
May-98	One	Plattco	2 Sets of Dump Valves	12,603.27	05/14/1998	Paul Wurth	4122/98
May-98	One	Premelt	Cyclone with Divertor Valve	17,370.65	05/14/1998	Paul Wurth	4122/98
May-98	One	Process/Kana	1325 Gal. Poly Tank	3,540.00	05/14/1998	Paul Wurth	4122/98

Invoice Date	Phase	Supplier	Item	Cost	Date	Contractor	Vendor Invoice Number
May-98	One	Ray Dev. & Const. Co	Transformer and Furnace Foundation	10,568.25	05/01/1998	TST, Inc.	31374
May-98	One	Transmission Equip.	Vessel Rail	6,192.82	05/14/1998	Paul Wurth	4122/98
May-98	One	Tri State Supply	6 Proximity Switches	1,793.26	05/14/1998	Paul Wurth	4122/98
May-98	One	UCAR Carbon	Drilled M/F Electrodes	1,834.49	05/14/1998	Paul Wurth	4122/98
May-98	One	UCAR Carbon	Drilled M/F Electrodes	4,719.53	05/14/1998	Paul Wurth	4122/98
Aug-98	One	Wateredge-Uniflex		2,378.88	08/28/1998	Paul Wurth	4279/98
May-98	One	Weigh-Tronix	4 Batching Weigh Bars 10,000 Cap each	7,249.61	05/14/1998	Paul Wurth	4122/98
May-98	One	Wojanis	Hydraulic and Pneumatic Equipment	1,642.43	05/14/1998	Paul Wurth	4122/98
Electric Power Research Institute							
Sep-98	One	B&K	Pneumatic Conveyor Electrical	534.47	09/30/1998	TST, Inc.	33310
Feb-98	One	COMP USA	Digital Camera	444.54	02/13/1998	COMP USA	217375814
Oct-98	One	Ellison Industrial	Liquid Level Probe Holder	558.14	10/19/1998	Paul Wurth	4279/98
Oct-98	One	Endress & Hauser	Promag	2,334.63	10/19/1998	Paul Wurth	4279/98
Oct-98	One	Equipment & Contractors	Single Trip Limit Alarm	295.59	10/19/1998	Paul Wurth	4279/98
Jun-98	Five	Erie Copper Works	Electrode Holder and Other	6,088.80	06/17/1998	Paul Wurth	4188/98
Oct-98	One	Gems Sensors Inc.		569.35	10/19/1998	Paul Wurth	4279/98
May-98	One	General Switchgear	1200 AMP 5 kV switch	11,474.50	05/01/1998	TST, Inc.	31375
Jun-98	One	Gold Coast Fabrication		24,333.96	06/17/1998	Paul Wurth	4188/98
Aug-98	One	Gold Coast Fabrication		13,188.33	08/28/1998	Paul Wurth	4279/98
Dec-98	One	Gold Coast Fabrication	Outstanding balance	31,438.67	12/31/1998	Paul Wurth	4489/98
May-98	One	Gold Coast Installation	Refractory Lining	8,688.33	05/01/1998	TST, Inc.	31375
Sep-98	One	Gold Coast Installation	Structural Steel Installation	42,865.00	09/30/1998	TST, Inc.	33310
Dec-98	One	Gold Coast Installation	Re-install Electrodes and Support Door Completed 7/17/98	2,725.62	12/31/1998	TST, Inc.	34480
Dec-98	One	Gold Coast Installation	Electrode Cable Channel	3,706.22	12/31/1998	TST, Inc.	34480
Dec-98	One	Gold Coast Installation	Install Piping on Furnace	20,543.56	12/31/1998	TST, Inc.	34480
Mar-99	Five	Joest		13,381.20	04/09/1999	Paul Wurth	4572/99

Invoice Date	Phase	Supplier	Item	Cost	Date	Contractor	Vendor Invoice Number
May-98	One	Little John-Rueland	5 kV Cables	27,592.36	05/01/1998	TST, Inc.	31375
Jul-98	One	Little John-Rueland	Installation of 4 kV and Furnace Wiring	90,942.50	07/09/1998	TST, Inc.	32200
Sep-98	One	Little John-Rueland	Electrical Installation	2,477.41	09/30/1998	TST, Inc.	33310
Sep-98	One	Little John-Rueland	Electrical Installation	4,635.00	09/30/1998	TST, Inc.	33310
Sep-98	One	Little John-Rueland	Electrical Installation	10,015.16	09/30/1998	TST, Inc.	33310
Sep-98	One	Little John-Rueland	Electrical Installation	12,610.14	09/30/1998	TST, Inc.	33310
Mar-99	One	McMaster-Carr		431.63	04/09/1999	Paul Wurth	4572/99
Mar-99	One	Omega Engineering		365.09	04/09/1999	Paul Wurth	4572/99
Mar-99	One	Omega Engineering		746.80	04/09/1999	Paul Wurth	4572/99
Mar-99	Five	Plattco	2 Sets of Dump Valves	20,664.16	04/09/1999	Paul Wurth	4572/99
May-98	One	Ray Dev. & Const. Co	Transformer and Furnace Foundation	8,975.00	05/01/1998	TST, Inc.	31375
Sep-98	One	Ray Dev. Const	Trench for Electrical Power	4,782.00	09/30/1998	TST, Inc.	33310
Aug-98	One	Royal Wholesale Electric		677.63	08/28/1998	Paul Wurth	4279/98
Jun-98	One	Tri State Supply		5,347.95	06/17/1998	Paul Wurth	4188/98
Mar-99	One	Trimark	Car/Track/Enclosure Detail	18,868.20	04/09/1999	Paul Wurth	4572/99
Jul-98	One	TST	Furnace Foundation	2,292.67	07/09/1998	TST, Inc.	32200
Jul-98	One	TST	Trench for Electric Power	3,872.00	07/09/1998	TST, Inc.	32200
Sep-98	One	TST	AC Unit and Installation	3,400.00	09/30/1998	TST, Inc.	33310
Oct-98	One	Wojanis	Milwaukee Cylinder	961.43	10/19/1998	Paul Wurth	4279/98
Mar-99	One	Wojanis		3,369.82	04/09/1999	Paul Wurth	4572/99
Southern California Edison							
1997	One	Gold Coast Refractory		$99,378.53		Paul Wurth	3909/97
1997	Five	Hitran		$9,104.88		Paul Wurth	3902/97
1997	One	IBY Corp.		$8,761.50		Paul Wurth	3909/97
1997	One	J. Horst		$16,197.86		Paul Wurth	3902/97
1997	One	Joest		$15,892.33		Paul Wurth	3902/97
1997	One	Omega Engineering		$2,001.26		Paul Wurth	3902/97

Invoice Date	Phase	Supplier	Item	Cost	Date	Contractor	Vendor Invoice Number
1997	Five	SAF		$47,200.00		Paul Wurth	3902/97
1997	Five	Spang Power		$47,790.00		Paul Wurth	3891/97
1997	Five	Spang Power		$247,210.00		Paul Wurth	3891/97
1997	Five	Voyten Electric		$1,770.00		Paul Wurth	3902/97
1997	One	Voyten Electric		$13,334.00		Paul Wurth	3902/97

Appendix III
Preliminary Engineering Drawings for the Prototype One-Ton DC Plasma Arc Melter


BILL OF MATERIAL
ITEM
DESCRIPTION
MAT'L
REMARKS
PLAN @ ELEV +34'-6" (DWG. 81-0072)
PLAN @ ELEV +19'-6" (DWG. 81-0072)
PLAN @ ELEV +11'-0" (DWG. 81-0073)
PLAN @ ELEV +6'-0" (DWG. 81-0073)
FURNACE
T/CONC EL 0.0
28'-0"
5'-6"
6'-0" TRAVEL
15'-0"
VIEW A-A
DWG 81-0096
3'-0 1/4"
6'-0"
6'-0 1/2"
VIEW B-B
DWG 81-0096
DEC 0 5 1997
APPROVED FOR CONSTRUCTION
0 12-5-97 WER APPROVED FOR CONSTRUCTION
REVISIONS
CUSTOMER SOUTHERN CALIFORNIA EDISON
DC PLASMA ALUMINUM MELTING FURNACE
(1 TON/HOUR)
ARRANGEMENT
SCALE: 1/2"=1'-0"
81-0070
PAUL WURTH INC.

ETS/001a