Final Technical Report

Project Title: Cost-Effective Consolidation of Fine Aluminum Scrap for Increased Re-melting Efficiency

Covering Period: October 1, 2003 to March 31, 2005
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Executive Summary

The main objective of this research was to develop a new re-melting process for fine or light gauge aluminum scrap products that exhibits dramatic improvements in energy efficiency. Light gauge aluminum scrap in the form of chips, turnings, and borings has historically been underutilized in the aluminum recycling process due to its high surface area to volume ratio resulting in low melt recovery. Laboratory scale consolidation experiments were performed using loose aluminum powder as a modeling material as well as shredded aluminum wire scrap. The processing parameters necessary to create consolidated aluminum material were determined. Additionally, re-melting experiments using consolidated and unconsolidated aluminum powder confirmed the hypothesis that metal recovery using consolidated material will significantly improve by as much as 20%. Based on this research, it is estimated that approximately 495 billion Btu/year can be saved by implementation of this technology in one domestic aluminum rolling plant alone. The energy savings are realized by substituting aluminum scrap for primary aluminum, which requires large amounts of energy to produce. While there will be an initial capital investment, companies will benefit from the reduction of dependence on primary aluminum thus saving considerable costs. Additionally, the technology will allow companies to maintain in-house alloy scrap, rather than purchasing from other vendors and eliminate the need to discard the light gauge scrap to landfills.

Project Description

1. ***Original project goals and objectives***

For several decades, the aluminum recycling industry has matured both in terms of its technology and efficiency. Despite the progress in increasing yield from recycled aluminum, there still remains a significant issue when loose, light gauge scrap (on the order of less than 15 mm) is processed for re-melting. The main objective of this research was to develop a new recycling process characterized by improved energy efficiency for fine or light gauge aluminum scrap products that cannot be easily re-melted (Figure 1). The root cause of high melt loss for fine aluminum scrap forms is the high surface area to volume ratio of these products, which, upon heating to the melting temperature, results in extensive oxide formation. The primary strategy in this project was to reduce the surface area to volume ratio by consolidating the scrap into a bulk product, making it suitable for re-melting in conventional secondary furnaces.

2. ***Variance from original goals and objectives***

Early in the project, it was decided that partner company Birdsboro Alloying would not be able to perform their assigned task of cleaning wire scrap material because of the large volume of material needed in order to justify running their furnaces. Instead, scrap wire was sent directly to EMV Technologies to be processed for the consolidation experiments. An additional barrier to the technology was realized during the shredding by an independent supplier. Due to the inadequate particle size after shredding, the decision was made that the re-melting experiments would proceed with consolidated and unconsolidated powder only rather than with scrap. The provided scrap after shredding did not represent well the geometrical characteristics required for consolidation experiments.

3. ***Discussion of work performed, hurdles overcome, findings, results and analysis, etc.***

CONSOLIDATION EXPERIMENTS (Tasks 1 and 2)

Two types of starting material were used in the consolidation experiments. These materials included air atomized aluminum powder and industrially shredded aluminum wire scrap. The aluminum powder was used to simulate the consolidation process as a model material and was supplied by Ampal, Inc. The powder was 99.7% pure aluminum with an apparent density of 1.05 - 1.25 g/cm^3, and a surface area of 0.10 - 0.20 m^2/g. The experiments with aluminum powder provided a way to estimate the typical parameters of the extrusion process. Images of the Al material before consolidation experiments can be seen in Figures 2-4. Figure 2 shows the loose Al powder as well as its irregular morphology. New York Wire Co. provided the light gauge wire for the purpose of industrially shredding it into scrap. The wire was 5154 aluminum alloy with a diameter of 0.254 mm (0.010 in.). The cleaned aluminum wire scrap used for the experiments can be seen in Figure 3 in the pre-shredded condition and in Figure 4 in the shredded condition.

The shredded scrap was compacted using a laboratory extrusion press. The experimental results obtained provided an understanding on the differences between an “ideal” material for compacting and the actual materials that would be available for large scale compaction through extrusion.

A laboratory-scale extrusion press was used for compacting both the shredded aluminum scrap and aluminum powder. The apparatus for the direct extrusion die was designed and constructed from hardened steel for use on a 50 ton hydraulic press. The extrusion was a one step process, as opposed to the commonly used two-step process of compacting and then extruding the material. A technique of using a front-pad for compaction allowed for the loose material to be extruded without a separate compaction step, which has been developed elsewhere [1]. Several front pads of varying thickness were used to determine the most effective combination of back-pressure and consolidation to improve extrudability. The front pads were punched from 1100 series aluminum sheet with thicknesses of 0.508 mm (0.020 in.), 0.762 mm (0.030 in.), and 1.016 (0.040 in.). The extrusion ratio of the die was also varied for the same purpose of providing the highest density extrudate. The three extrusion ratios, R, used were 2.5, 3.5, and 4.2, where the extrusion ratio is defined as the ratio between cross section area of the press container divided by the cross section area of the extruded profile.

CHARACTERIZATION OF LAB SCALE EXTRUSIONS (Task 3)

Micrographs of the consolidated wire scrap after extrusion can be seen in Figures 5 and 6 (the extrusion direction is from the left to the right). Figure 5 shows the consolidated scrap material using an extrusion ratio of 2.5 and a front pad thickness of 0.508 mm. The image in Figure 5A shows the deformation that occurred in the extrudate along the surface. The material flow through the die caused some of the particles to deform at the surface while the center particles remained relatively equiaxed as shown in Figure 5B. The extrusion parameters for the extrudate seen in Figures 6A and 6B consisted of an extrusion ratio of 4.2 and a front pad thickness of 0.508 mm. Compared to the images in Figure 5, it can be seen that the higher extrusion ratio promoted better compaction of the aluminum wire scrap as evidenced by the lower amount of porosity. While Figure 6A still shows the deformation of the wire due to the material flow along the edge, the image of the center of the sample (Figure 6B) shows deformation of the particles as well, indicating greater compaction. Due to the porosity distribution, quantitative measurements of porosity were not performed based on the individual micrographs and qualitative representations of the material porosity were used instead.

As a measure of comparison, images were taken of the compacted aluminum powder. The parameters for the extrusion of the sample shown were an extrusion ratio of 3.5 and a front pad thickness of 0.762 mm. Images in Figures 7A and B show the near complete compaction of the powder. These images confirmed the hypothesis that this extrusion process was an effective method of compaction when proper process parameters are chosen. An image of the consolidated powder rod after extrusion is shown in Figure 8, which highlights the good surface finish and durability of an extruded product which is needed for transportation and handling prior to recycling.

The graph in Figure 9 shows the pressure profile of extrusions performed at different parameters for the aluminum wire scrap. By comparison of the pressure profile to the cross-sectional images taken of the extrudates, the proper pressure for effective consolidation was determined. Similarly, the pressure profile of the powder extrudates was recorded, as can be seen in Figure 9.

RE-MELTING EXPERIMENTS (Task 5)

Both unconsolidated aluminum powder and consolidated aluminum rod from the extrusion experiments were used to evaluate the effect of consolidation on the re-melting efficiency. The extrusion parameters used to consolidate the rod used in the re-melting experiments were extrusion ratio of 4.2, and front pad thickness of 0.762 mm due to the higher density achieved. Re-melting experiments were performed at Aleris, Intl. in Morgantown, TN using a lab-scale rotary furnace. The amount of aluminum before and after the melting tests was weighed in order to determine the melt efficiency.

Table I shows the recovery of aluminum using unconsolidated powder and consolidated rod as the feed material in the furnace. It can be seen that the average recovery for the unconsolidated powder and consolidated rod were 75% and 99%, respectively. It should be noted that the values greater than 100% were due to an error in experimental procedure. This error was caused when aluminum powder in the re-melting tests stuck to the furnace wall and was only recovered when the consolidated rod was re-melted. The actual recovery from the rod experiments are likely closer to 95 – 98%. This is a net benefit of greater than 20% in increased efficiency.

4. *Products developed under the award and technology transfer activities*

A paper was presented at the TMS Annual Meeting in San Francisco, CA, in March 2005 titled, "Consolidation of Fine Aluminum Scrap Via the Extrusion Process." This presentation highlighted the technical procedure of consolidating light gauge aluminum scrap and powders by the extrusion process. Additionally, the technology being developed under this grant has been featured at the World's Best Technologies Showcase in Arlington, TX as well as the License Executives Committee Meeting in Boston, MA. These events highlight new technologies in a broad range of industry sectors.

EMV Technologies has been working closely with Vista Ventures, who helped develop a commercialization strategy for the technology being developed under this grant. Additionally, EMV Technologies has received market research help from New Horizons Technologies to understand the potential users of this technology as well as the size of the market for recycled scrap aluminum. The results of this market research study are not available at the time of this report.

5. *Conclusions and recommendations for future work*

The feasibility of light gauge aluminum scrap to be consolidated efficiently was successfully determined in this research and has been compared to the more favorable conditions of powder extrusion. It was seen that the improvement in consolidation of the final rod product was the result of higher extrusion ratio, R, and higher front-pad thickness. This was an important comparison because it highlights the relationship in the pressure profile of the powder compaction and the most successful aluminum wire scrap consolidation. The re-melting tests showed that the consolidated material had a sufficient density to reduce the surface area to volume ratio, thereby increasing the melt recovery.

It is recommended that the technology be migrated to industrial scale by the development of prototype machinery capable of simultaneously shredding and consolidating the light gauge scrap. The technology most likely to accomplish this is by including, as a part of the proposed solution, a continuous extrusion or CONFORM™ technology, which can be tailored to accept irregular particle shapes rather than typical powder as a feedstock. EMV Technologies is in negotiations with manufacturers of CONFORM™ equipment to tailor the machinery to accept scrap metal as a feedstock material. More comprehensive re-melting experiments using consolidated rod from the continuous extrusion machinery can be performed to confirm the melt recovery of the consolidated material. The experimental error in the re-melting tests can be overcome in the future by melting the consolidated rod prior to the unconsolidated aluminum powder.

References

1. M. Galanty, P. Kazanowski, P. Kansuwan and W. Z. Misiolek, "Consolidation of metal powders during the extrusion process", Journal of Materials Processing Technology, Vol. 125-126, September 2002, p. 491-496.

2. R. Kirk, et al, Kirk-Othmer encyclopedia of chemical technology, Wiley, New York, 2000.

3. Energy and Environmental Profile of the U.S. Aluminum Industry report, U.S. Dept. of Energy, July 1997

Appendices

Appendix A. Final Task Schedule
Appendix B. Final Spending Schedule
Appendix C. Final Cost Share Contributions
Appendix D. Energy Savings Metrics

Supplemental Information

Figure 1: Scrap generated during a wire production process.

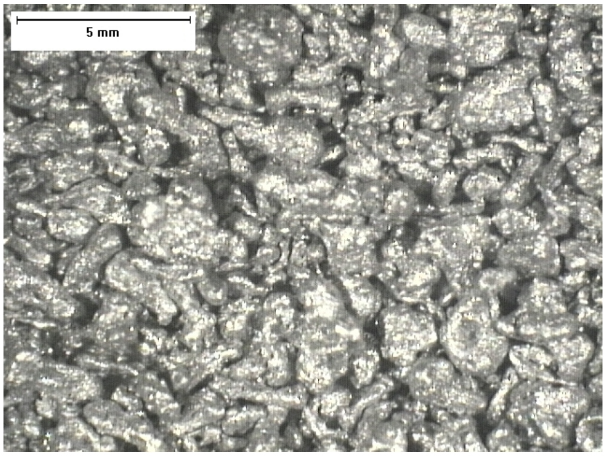


Figure 2: Starting aluminum powder used in consolidation experiments.

Figure 3: Cleaned scrap wire from industrial processing.

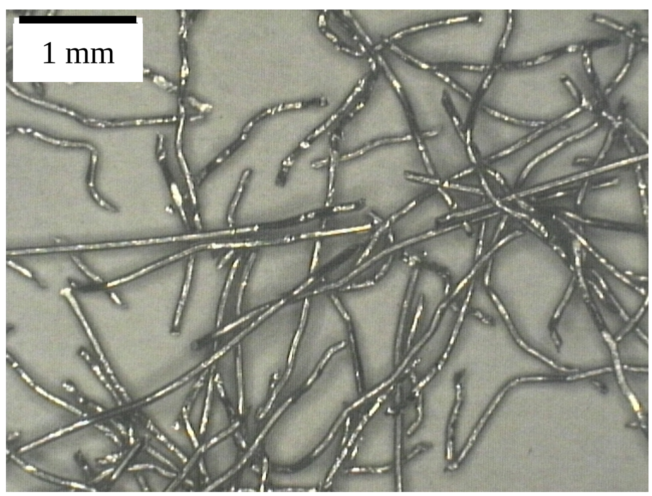
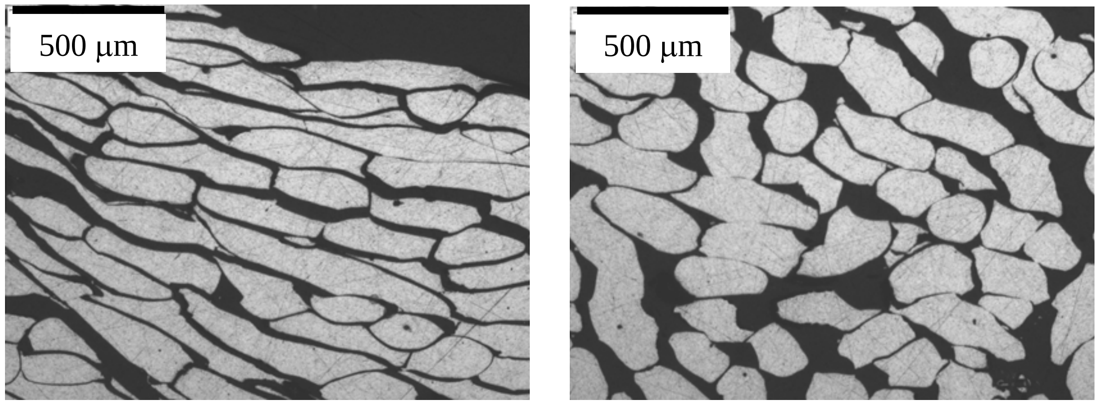
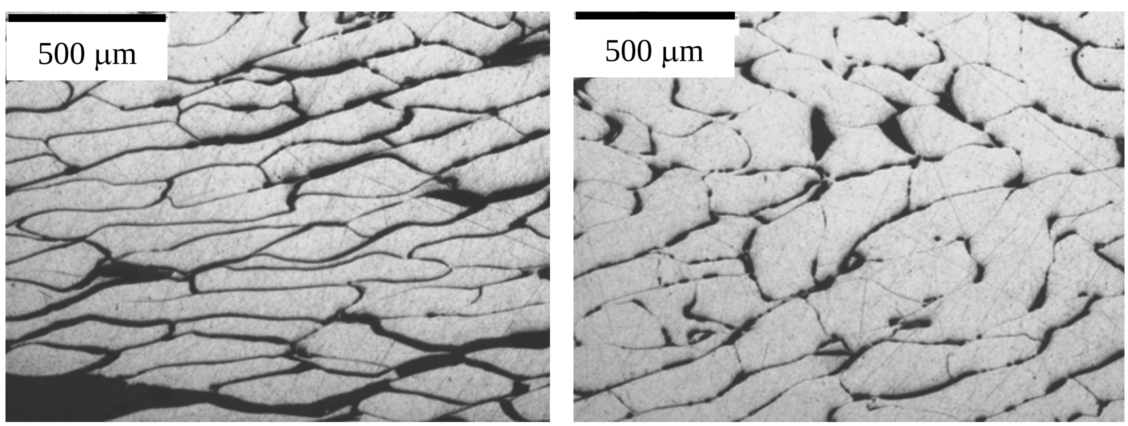


Figure 4: Industrially shredded aluminum wire scrap.



A B

Figure 5: Micrograph from the A) surface and B) center of a rod extruded with an extrusion ratio, 2.5 and front pad thickness of 0.508 mm. The extrusion direction is left to right.



A B

Figure 6: Micrograph from the A) surface and B) center of a rod extruded with an extrusion ratio, 4.2, and front pad thickness, 0.508 mm. The extrusion direction is left to right.

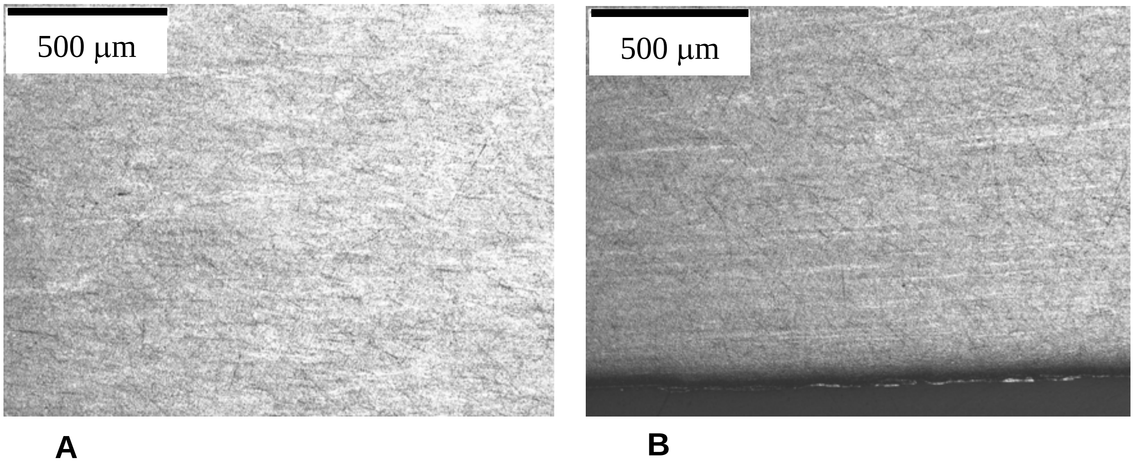


Figure 7: Micrograph from the A) surface and B) center of a rod extruded with an extrusion ratio, 3.5, and front pad thickness, 0.762 mm. The extrusion direction is left to right.

Figure 8: Consolidated rod from aluminum powder after extrusion.

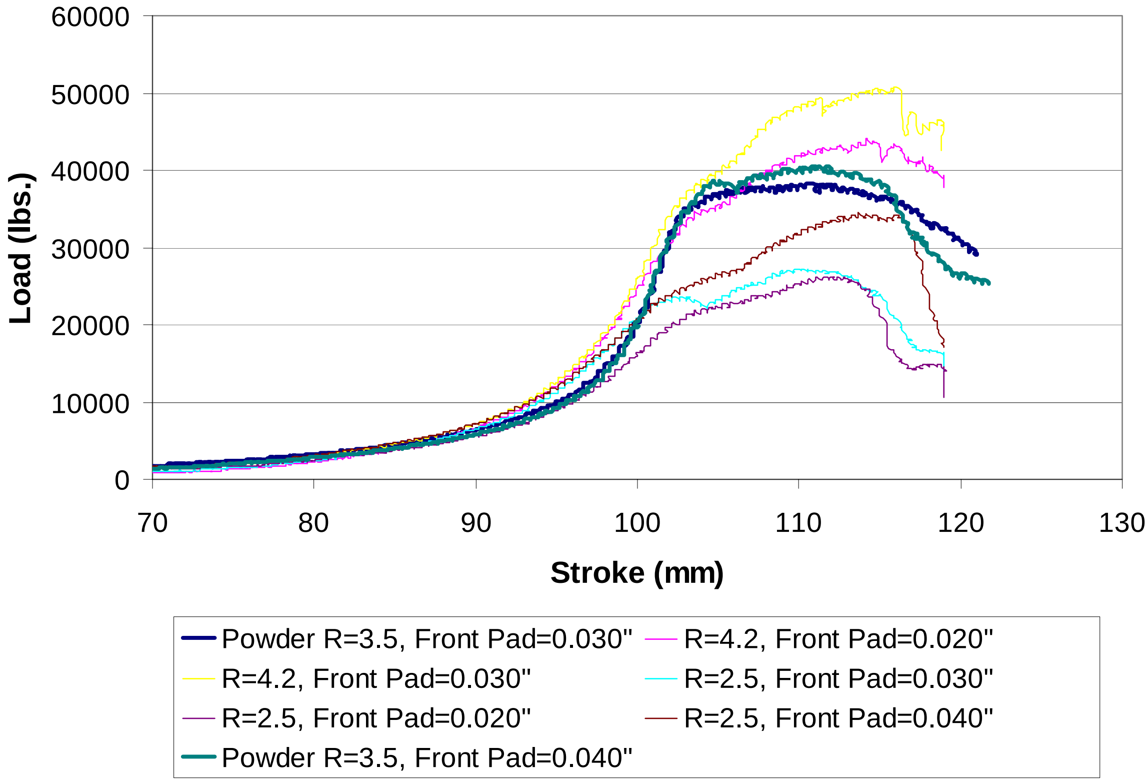


Figure 9: Comparison of load vs. stroke curves for different consolidation parameters.

Table I: Results from re – melt tests on unconsolidated aluminum powder and consolidated aluminum rod.

Material	Starting Weight (grams)	Recovered Weight (grams)	% Recovery
Powder 1	618	469	75.89
Powder 2	572	452	79.02
Powder 3	589	394	66.89
Rod 1	585	647	110.60*
Rod 2	575	576	100.17*
Rod 3	595	579	97.31

* Values greater than 100% were caused by remnant material left over from re-melting the loose powder.

Appendix A

Final Task Schedule

Final Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	Consolidation and flow stress evaluation of fine powders	01/31/04		01/31/04	100%	Completed
2	Consolidation and flow stress evaluation of baseline scrap	04/30/04	09/01/04	09/01/04	100%	Completed
3	Characterization of lab scale extrusions	07/31/04	09/01/04	09/01/04	100%	Completed
4	Review meeting to discuss critical success factors	08/30/2004	12/31/04	12/31/04	100%	Completed
5	Energy, economic, and environmental assessments including lab – scale re-melting testing	12/31/2004	02/28/05	02/28/05	100%	Completed
6	Technical project management, coordination, and reporting	03/31/2005		03/31/05	100%	Completed
7	Project administration, financial accounting, and commercialization support	03/31/2005		03/31/05	100%	Completed

Appendix B

Final Spending Schedule

Final Spending Schedule **Project Period:** 10/01/03 to 03/31/05

Task	Approved Budget	Final Project Expenditures
Task 1: Consolidation and flow stress evaluation of fine powders	24,000	28,000.00
Task 2: Consolidation and flow stress evaluation of baseline scrap	42,000	42,000.00
Task 3: Characterization of lab scale extrusions	16,000	9,000.00
Task 4: Review meeting to discuss critical success factors	1,000	1,000.00
Task 5: Energy, economic, and environmental assessments including lab – scale re-melting testing	6,000	6,000.00
Task 6: Technical project management, coordination, and reporting	7,000	7,000.00
Task 7: Project administration, financial accounting, and commercialization support	3,000	3,000.00
Total	99,000	$96,000.00
DOE Share	75,000	75,000.00
Cost Share	24,000	21,000.00*

* Birdsboro Alloying was not able to participate in the project and therefore could not provide a $3,000 cost share contribution.

Appendix C

Final Cost Share Contributions

Final Cost Share Contributions

Funding Source	Approved Cost Share		Final Contributions	
	Cash	In-Kind	Cash	In-Kind
EMV Technologies	200	9,800	200	9,800
Aleris International		6,000		6,000
Ampal		2,000		2,000
New York Wire		3,000		3,000
Birdsboro Alloying		3,000		*
Total	200	23,800	200	20,800
Cumulative Cost Share Contributions				21,000

* Birdsboro Alloying was not able to participate in the project and therefore could not provide a $3,000 cost share contribution.

Appendix D

Energy Savings Metrics

One Unit of Proposed Technology:

The proposed technology for processing scrap aluminum is fundamentally based on the continuous extrusion process known as CONFORM™. Assuming a standard CONFORM™ equipment operating at 120KW and a throughput of 450 lbs./hr, the equipment would expend 600 kWh to process 1 ton of aluminum for re-melting operations. The energy necessary to consolidate this amount of material would then be approximately 930 Btu/lb. In extruding the 30 million lbs. of aluminum via the proposed technology, approximately 27.9 billion Btus would be expended (see Energy Savings Metrics Table).

One Unit of Current Technology:

The current technology that can be replaced by the continuous extrusion of light gauge scrap is the process to convert bauxite ore to alumina and alumina to primary aluminum metal. According to the recent Kirk-Othmer Encyclopedia of Chemical Technology approximately 206 million Btu is required for the production of 1 ton of primary aluminum (Table II) [2]. By processing 30 million lbs. of primary aluminum, approximately 2.8 trillion Btus will be expended (see Energy Savings Metrics Table). In the United States, a majority of energy used to produce primary aluminum comes from fossil fuel based sources only.

Table II: Energy consumption per metric ton of aluminum produced based on fossil fuel and hydroelectric power sources [2].

Operation	Fossil and Hydro, MJ (Btu)	All Fossil, MJ (Btu)
Mining and Refining	35,200 (33,363,157)	35,200 (33,363,157)
Smelting	146,400 (138,760,407)	182,500 (172,976,600)
Total	*181,600 (172,123,565)*	*217,700 (206,339,758)*

Energy Savings Metrics

Type of Energy Used	A Current Technology (Btu / yr / unit)	B Proposed Technology (Btu / yr / unit)	C=A-B Energy Savings (Btu / yr / unit)	D Estimated Number of Units in U.S. by 2010 (unit)	E=CxD Energy Savings by 2010 (Btu / yr)
Oil / Gasoline					
Natural Gas					
Coal					
Electricity (@ 10,500 Btu / kWh)	2,808,600,000,000	27,840,000,000	2,780,600,760,000	20	55,615,200,000,000

Discussion of Energy Savings:

The developed technology will be able to process aluminum scrap generated by an aluminum processing facility. For example, in the case of a rolling plant alone, the quantity of high surface area scrap generated by a rolling mill with annual sheet production of 500 million pounds/year would be on the order of 6% of the sheet production or approximately 30 million pounds/year. Efficiency in re-melting processes has been addressed in the Energy and Environmental Profile of the U.S. Aluminum Industry report, July 1997 [3]. In this report, it was stated that “turnings and borings and various grades of finely divided scrap are relatively poor materials for recycling purposes because they have a large surface area per unit mass, which increases oxidation during melting.” Using existing aluminum re-melt technologies, very high metal losses, conservatively on the order of 20%, are experienced in processing high surface area scrap. Through implementation of the proposed technology for consolidation of high surface area scrap prior to re-melting, melt losses will be reduced to levels comparable to those achieved processing low surface area scrap between 2 and 5%. Reduced melt loss will lead to a net gain in metal recovery of 4.8 million pounds/year in recycling metal scrap from a unit rolling mill. This net gain preserves the energy investment that had been made in the production of a unit quantity of aluminum that is otherwise lost if a portion of that metal converts to dross. Once converted to dross, the metal values are lost for further applications. Using the proposed technology, the metal values are preserved for re-use.

Compared to conventional scrap re-melting, the proposed light gauge scrap processing method would involve continuous extrusion consolidation. It is estimated that these additional operations could be achieved with energy consumption on the order of 928 Btu/lb. extruded. In extruding 30 million pounds of aluminum, the energy expenditure would be 27.9 billion Btu. The net energy saving related to recovery of an additional 4.8 million lbs./year from an original quantity of light gage scrap of 30 million pounds/year alone would be 4.4 billion Btus.

These savings can be estimated using published figures for the energy required to convert bauxite ore to alumina and alumina to aluminum metal. According to the recent Kirk-Othmer Encyclopedia of Chemical Technology approximately 206 million Btu is required for the production of 1 metric ton of aluminum. For the unit operation described, the savings of 4.8 million pounds/year (2,400,000 tons/year) would lead to energy savings of over 494 billion Btu/year. It is estimated that implementation of the proposed technology for processing all U.S. light gauge scrap (estimated to be about 1 billion pounds/year) would be on the order of 11.6 trillion Btu/year. By assuming 20 units of the proposed technology are introduced by 2010, over 55 trillion Btus are estimated to be saved. These savings will be realized as reduced electrical energy for the production of aluminum metal. Many times the savings from a unit plant will be realized as the new process technology units become adopted throughout the aluminum industry.