The Technology of Recycling Scrap Metal:
An *Advanced Technology Program* Case Study

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I. INTRODUCTION

Many Americans are enthusiastic supporters of recycling. The benefits to recycling are perhaps too well-know to require much elaboration. It is commonly argued that recycling, compared to producing with virgin materials, requires less energy and water, not to mention produces less air and water pollution. “A Recycling Revolution,” an advocacy site, argues that “it takes 95% less energy to recycle aluminum than it does to make it from raw materials” http://www.recycling-revolution.com/recycling-benefits.html. Recycling reduces the need for mining, with its attendant risks and costs. It also reduces the amount of waste being dumped in landfills, conserving valuable landfill space. To paraphrase a famous frog, it is good to be “green.” Recycling is also a major industry. Although many parts of the recycling process are facilitated by the good will of citizens, economic considerations play a role; technology also matters.

Perhaps many Americans are also aware of the role the U.S. government plays in encouraging and supporting the development of “cutting-edge” technologies. These programs are considerably more controversial than environmental programs, even when, as in the case under consideration, many people essentially approve of the goals of the technologies. The focus of this paper is one such technology, one designed to improve the technology of sorting non-ferrous scrap metal, and by doing so increase the amount of such material recycled. In the year 2000, the Advanced Technology Program, ATP, (of the National Institute of Standards and Technology, Commerce Department) funded such a private sector research and development project. ATP paid about 78% of the research and development costs, while the two private firms conducting the research paid the rest. As will be seen, this is a relatively high subsidy rate. The question posed by the paper is whether the subsidy rate was reasonable.

As with any new technology, if the developers of the new technology reap all the benefits of it then it makes little sense to use taxpayer dollars to pay for its development. On the other hand, if some of the benefits of the technology accrue to agents other than the developing firms, then government subsidies may be justified. Benefits the firm does not capture are typically called “spillover benefits.” The major results of the paper suggest that the subsidy was justified in the present case if (1) the benefits of the technology to the firms *using* the new technology are at least half of the profits of the firms *developing* the technology, and (2) there are at least two dollars of additional spillover benefits in other sectors of the economy for every dollar of benefits received by the recycling industry. It should perhaps be mentioned that these results are consistent with the theoretical predictions of Highfill and Scott (2007), although care must be taken in comparing the results of the present paper with that paper because the definitions of the spillover parameters differ.

II. THE INDUSTRY, THE TECHNOLOGY, AND ATP

II.A RECYCLING NON-FERROUS SCRAP METAL

Even for materials for which there is a ready secondary market, recycling is a difficult and expensive activity. Not to belabor the obvious, the materials must be collected, transported to a recycling center, sorted, and then transported to the remanufacturing site. Various aspects of the process have been investigated in the literature: the location of a recycling center, Highfill, McAsey, Mou, (1998, 1997, 1994); recycling productivity; Siebling (1990); transportation logistics Gonzalez-Torre, Adenso-Diaz, and Artiba (2004). There has been some work on metal recycling. Forslind (2008) studies recycling cars in Sweden; van Beukering and Bouman (2001) study lead recycling in a number of countries; and Jee and Kang (1999) consider steel in Korea. As far as I am aware, there is no current study of metal recycling in the United States.

Still, some basic facts about the U.S. industry are readily available. According to an industry association, in 2007 150 million metric tons of scrap material were recycled; the industry employed 50,000 persons and revenue was $71 billion. Non-ferrous metals recycled include aluminum (5 million tons), copper (1.8 million tons), lead (1.3 million tons), and zinc (420,000 tons). Significant amounts of these metals were exported: 1.5 million tons of aluminum, just under a million tons of copper and something over 100,000 tons each of lead and zinc. (See http://www.isri.org/.) According to Wikipedia, in 2006 about 60% of metals and alloys produced in the U.S. were made from recycled materials, and 33% percent of the aluminum. A daily spot market exists for scrap metal, for such items as battery lugs, and plates, lead wheel weights, covered copper cable, and even something called "mixed common babitt." Prices are given for "less than truck load lots" and "truck load lots" and range from about $0.10 per pound for lead dross (less than truck load lot) to $4.36 per pound for lead free solder scrap (truck load lot) as of August 11, 2008. See http://www.recycle.net/Metal-N/Lead/index.html.)

Although all parts of the recycling process have their issues, sorting is especially difficult for non-ferrous scrap metal. The essential problem is to sort metal alloys that are not magnetic and not easily identified by simple inspection. Several sorting methods are in use. Sometimes the metal is held to a grinder because different metals give of different colors and heights of sparks. Another method is to use something like a chemical litmus test. Yet another method uses a liquid bath since different metals have different densities as well.

The key point is that all of these methods are essentially done by hand, by a single worker evaluating the scrap one piece at a time. Sorting is thus very expensive and creates a bottleneck in the recycling process. By the end of the 1990s certain technological advances in optical sensors and their controlling algorithms made it seem possible that this bottleneck might be successfully circumvented. In particular, sorting systems for plastics had been developed and were being used commercially.

Two firms, wTe Corporation of Beford, MA, a commercial recycling firm and National Recovery Technologies Inc. of Nashville TN, a supplier of equipment to commercial recyclers, were seeking funding to support their research and development expenditures on a sorting technology. They were not successful in attracting sufficient venture capital, and thus appealed for governmental support. Their basic argument was that billions of pounds of non-ferrous scrap metal are not being recycled in the United States because the sorting technology is too cumbersome and expensive. If the technology of sorting could be improved, then the U.S. would experience all the benefits of recycling the material that is currently just being dumped in landfills.

II.B THE ADVANCED TECHNOLOGY PROGRAM

The federal government has several programs designed to fund private sector research and development projects. However, the Advanced Technology Program, ATP, (of the National Institute of Standards and Technology) was specifically designed to fund risky projects with potentially high payoffs. Not surprisingly, ATP has been politically quite controversial, and indeed was abolished in 2007, except for projects currently in progress. The scholarly literature has weighed in on both sides of the debate about the wisdom of the government subsidizing private sector R&D; see Gretz, Highfill, and Scott (2009, 2007) and the references therein. There has also been considerable scholarly interest in ATP itself (e.g., Link, Paton, and Siegel, (2005), Powell and Moris (2004), Darby, Zucker, and Wang (2004), Chang, Shipp, and Wang (2002), and Feldman and Kelley, (2003).

Between 1990 and 2007 ATP received 7530 applications for funding, of which 824 were actually funded, making the approval rate slightly under 11%. The sizes of the funded projects ranged from $434 thousand to $31 million. The two firms developing the sorting technology, the wTe Corporation and National Recovery Technologies Inc. applied for funding in the year 2000 funding round. In that year there were some 54 projects funded; the average funded project was \$5.07 million dollars, and the average subsidy rate was 52.55%.

II.C THE ATP PROJECT: HIGH-SPEED SORTING TO RECYCLE SCRAP METAL

The proposal by the wTe Corporation and National Recovery Technologies Inc. was to "develop a high-speed optoelectronic identification system to rapidly and accurately sort non-ferrous scrap metal for recycling." They argued that their laser scanning sorting method could be done in real time on material passing on a conveyor belt, that recycling centers could be smaller (less expensive to build and operate), and perhaps most importantly, that much less scrap non-ferrous metal would escape the recycling virtuous cycle.

The project was funded. ATP was to provide \$1,997,377 of the total \$2,562,805, making a subsidy rate of 78%. Thus comparing this project with the typical project in the same funding round, it was a small project (slightly over half the size of the average project) but well-funded (the average subsidy rate was slightly over 50%). Although the final report on the project has not yet been filed, the wTe Corporation's website, http://www.wte.com/html/new_technologies.html, reports that

> In 2005, wTe commenced commercial operations in the high temperature alloy segment. The "Spectramet Alloy Sorter System" has the ability to process mixed high temperature alloys such as titanium and nickel cobalt alloys at high speeds with 100% accuracy. Spectramet is also able to sort and report up to eight different alloys in a single lot with an automated system which allows us to cost-effectively handle a wide range of sizes and shapes, with weights of less than one ounce up to fifteen pounds.

Their division Spectramet also commercialized the "Spectramet DXRT System" in 2006, which

> converts the mixed non-ferrous concentrates into a high quality aluminum product and a mixed heavies product containing copper, zinc, brass, stainless steel and other non-ferrous metals.

It appears that the project has achieved the first basic milestone of a successful project, the research and development has yielded a commercial project. It remains to be seen, of course, whether the project will be successful in generating profits for the firms and benefits for the firm's customers. And even if it is successful in those terms, it is not self-evident that ATP should have funded the project at the relatively high level that it did. To examine the latter question some theoretical structure may be helpful.

III. THE SUBSIDY RATE VIS-À-VIS SPILLOVERS

As is the case with the ATP project under discussion, suppose the technology produced by the R&D will be commercialized by a single firm, Spectramet. In order to study the question of whether ATP's subsidy rate was optimal, consider a two-stage game where ATP announces its subsidy rate and then Spectramet decides its level of R&D spending. Subgame perfect Nash equilibria are calculated using generalized backward induction. As such, the firm's R&D decision is analyzed first.

Denote variable profits by VP, that is, the firm's total profits except for its expenditure on R&D, the latter being denoted RDE. Typically variable profits depend on price, quantity, and perhaps other variables—the important point for the present analysis it that variable profits also depend on RDE. The higher the expenditure on R&D the better the quality of the product produced, and other things equal, the higher the profits. The profit function for the firm is

$$\Pi = VP - (1 - S)\,RDE$$

Where S is the subsidy rate, the proportion of the R&D expenditure paid by the funding agency. The profit maximizing condition for RDE is

$$\frac{d\,VP}{d\,RDE} = (1 - S)\,.$$

(In general there will be other profit maximizing conditions as well, but this is the only one that is required for the current argument.)

Suppose now the funding agency chooses the subsidy rate to maximize a social surplus function as follows:

$$SS = CS + VP + OB - RDE \ .$$

Variable profits are defined above. Consumer surplus, CS, are the benefits that accrue to the customers of the firm developing the new product. In this case the customers are recycling firms that purchase the sorting equipment. These are a kind of spillover, in that they are benefits that do not accrue to the developing firm, but rather to its customers. OB are "outside of industry benefits," that is benefits that accrue to other agents beside the firm developing the technology and its customers. These benefits are another kind of spillover. Thus the social surplus function includes all the benefits to society of creating the new technology, minus the cost of creating it, the R&D expenditure.

To simplify the analysis, denote the ratio of consumer surplus to variable profits by

$$\alpha \equiv \frac{CS}{VP} \ .$$

It is a straightforward exercise the show that in the familiar case of a monopoly seller with linear demand and constant marginal costs consumer surplus is one half of variable profits so that $\alpha = .5$. Similarly, define the ratio of outside of industry benefits to within industry benefits (i.e., $CS + VP$) by

$$\beta \equiv \frac{OB}{CS + VP} \ .$$

With these assumptions the social surplus can be written

$$SS = (1+\alpha)(1+\beta)VP - RDE \ .$$

The welfare maximizing condition is thus

$$\frac{d\,SS}{d\,S} = (1+\alpha)(1+\beta)\frac{d\,VP}{d\,RDE} - 1 = (1+\alpha)(1+\beta)(1-S) - 1 = 0 \qquad (1)$$

Where the latter equality uses the profit maximizing condition. Recalling the definitions of α and β this equation can be used to evaluate the conditions under which ATP has funded Spectramet at the optimal rate. These results are reported in Figure 1. The actual subsidy rate, $S = 78\%$, has been substituted into the social surplus maximizing condition, and then the equation (1) solved for $\beta \equiv OB/(CS + VP)$.

See Figure 1: Optimal Subsidy Locus

To interpret Figure 1 consider first the standard case where consumer surplus is half of variable profits (i.e., $CS/VP = \alpha = .5$). For a subsidy rate of 78% to be optimal the outside of industry benefits to industry benefits ratio needs to be slightly over 2. In other words, for every dollar of benefit to the firm and its customers there needs to be two dollars of benefits elsewhere in the economy.

Since this project is designed to increase the recycling of non-ferrous metals the spillover benefits include all of the usual benefits to recycling metals. Briefly, it reduces the amount of virgin ore extracted, the energy requirements are less for recycling than for virgin ore processing, and landfill space is conserved. In addition there is one potential spillover benefit to this particular technology that should be mentioned. Since the technology is used to sort alloys on a conveyor belt, some of the researchers involved believe it might also be used "in reverse," so to speak. That is, it might be adapted for mixing metals on a conveyor belt in production processes, rather than separating them. In any event, for this subsidy rate to be optimal in the standard case of linear demand and constant marginal costs (i.e., $CS/VP = \alpha = .5$) the outside of industry benefits need to double the within industry benefits of the technology.

To provide some sensitivity analysis, Figure 1 also considers the case where consumer surplus is 40% of variable profits and the case where consumer surplus is 60% of variable profits. In the former case, industry conditions favor the firm slightly, raising its profits relative to the benefits of customers. In the latter case, industry conditions favor customers a little more. As shown, the outside of industry benefits to industry benefits ratio ranges from about 1.84 to 2.25 for the subsidy rate of 78% to be optimal. Thus, as a rule of thumb, outside of industry spillovers need to be about twice the industry benefits for this rather high subsidy rate (as compared to the average subsidy rate).

Finally, as shown in Figure 1, it is logically possible that ATP funds its projects at too low a rate, as well as too high. Recalling that Figure 1 assumes a subsidy rate of 78%, this rate is too low when the outside of industry benefits and/or consumer surplus are quite high. On the other hand, if the consumer surplus is small compared to variable profits and/or outside of industry benefits are small compared to within industry benefits, then the subsidy rate was probably too high.

A similar analysis could be done for other subsidy rates, although they are not shown graphically. Recalling that the average subsidy rate for ATP projects in 2000 was slightly over 50%, equation (1) implies that for consumer surplus to variable profit ratios in the same range as in Figure 1, the outside of industry benefits need only be from about 25% to something over 40% of within industry benefits. Thus, for the average subsidy rate to be optimal there needs to be positive spillovers, but they could be substantially smaller than that required for the Spectramet project subsidy rate.

CONCLUSION

Government subsidies of private sector R&D are usually justified by the argument that the technologies developed will have applications across many different industries. For the sorting technology of the present case study, the argument would be that the technology development might be useful in other contexts, for example, in quality control applications, or for applications involving material mixing. The subsidy rate in these cases is often about 50%. (There are theoretical arguments in favor of a subsidy rate in this range as well, see Gretz, Highfill, and Scott (2007, forthcoming).) But the sorting technology of this case study has additional benefits—those associated with recycling in general. Presumably it is those “green” benefits that prompted ATP to fund this project at such a high level.

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Figure 2: Optimal Subsidy Locus