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ON-SITE RECYCLING OF HAZARDOUS WASTE SOLVENTS

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ABSTRACT

This article examines the economic desirability of on-site recycling in two situations widely experienced by small and medium-sized firms that generate hazardous waste. We define baseline conditions with and without the recycling device, and calculate the net present value and rate-of-return for the device; we then apply sensitivity analysis and break-even analysis to examine how good the device is under conditions that depart from the baseline. Results show that the device is very profitable for firms generating 100 gallons of solvent per month but for firms using only 20 or 30 gallons per month of solvent (auto repair shops) the device is not economically desirable under some conditions. We examine policy measures for enhancing the desirability of the device–free collection of distillation residuals, grants to reduce the capital cost of the equipment, and an investment tax credit–and find that these measures can make the device an attractive investment in situations where it would not be attractive without incentives.

On-site recycling of hazardous wastes is promising for reducing the threat to the environment and human health from the use and disposal of chemicals. The risks from hazardous wastes, in the form of cancers, birth defects, other health problems, and degradation of aquatic and terrestrial habitats, have been highly publicized. The level of anxiety among the public over toxic risks is high and this anxiety translates into strong support for action to reduce these risks.

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Federal law, particularly the Resource Conservation and Recovery Act (RCRA) and its 1984 amendments, promotes waste minimization and improved treatment methods, and seeks to eliminate land disposal of most hazardous wastes. In the hierarchy of desirable methods, process changes that reduce the amount and toxicity of wastes generated, and on-site recycling, are at the top. When viewed in input-output terms–imagine that a large box encloses the facility–on-site recycling reduces the amount of chemicals going into the box and the amount of wastes leaving it, to be disposed of or recovered outside the facility. However, on-site recycling does not reduce the toxicity of the chemicals, whereas process changes can reduce toxicity. Commercial (off-site) recycling is less desirable because accidents are more likely to occur as a result of the extra transportation and handling of wastes; releases from volatilization also increase.

Small-scale recycling, suitable for on-site use, is promising for solvents, paints, adhesives, and coolants. In addition to its environmental and health benefits, recycling saves firms the cost of new materials and it may reduce disposal costs. Recycling also creates other benefits to society: by reducing the need for virgin resources, it cuts environmental damage due to extracting and transporting resources; also, recovering chemicals from wastes uses less energy than producing them from the raw materials.

Section I of this article examines the hazardous waste management system and identifies the factors that influence the decision of firms to choose on-site recycling or its alternatives. Our emphasis is on small-quantity generators (SQGs) of hazardous waste, most of which are small- and medium-sized firms. There are many SQGs (about one million in the United States), their waste disposal practices are often illegal, and the potential for recycling is considerable [1]. Section II presents a detailed economic analysis of recycling devices suitable for such firms, comparing the rates-of-return to two baseline situations, and applies sensitivity analysis and break-even analysis to examine how good the devices are under different conditions. Section III examines the economic effect of three policy measures, free collection of distillation residuals, grants to reduce the capital cost of the equipment, and an investment tax credit, and presents conclusions and recommendations.

I. THE HAZARDOUS WASTE MANAGEMENT SYSTEM

Definitions

Federal law defines a *small-quantity generator* as a firm or other entity that generates less than 1,000 kg of hazardous wastes in a calendar month at a given site [2]. Firms generating no more than 100 kg per month are conditionally exempt from regulations under federal law. This means that conditionally exempt SQGs can dispose of any hazardous waste, including recycling residuals, at a municipal landfill. California and eight other states do not allow conditional exemptions for generators of 100 kg per month or less, regulating them in essentially the same way as firms that generate between 100 kg and 1,000 kg per month [1].

System Analysis

Commercial recycling – Recycling of solvents is widespread, but most of it is done off-site by commercial recyclers. Between 40 and 70 percent of waste solvents shipped off-site in California are recycled and reused [3]. Most SQGs pay a waste hauler or waste management firm to take recyclable wastes to a commercial recycling facility; in some cases, recycling firms pick up wastes. For wastes that have a high market value, such as chlorinated solvents, or a very high recovery rate (90%), recyclers pay for the waste, the amount depending on the type, quantity, and quality of the waste. Quantity is important. For example, if an SQG sends two drums of 1,1,1-trichloroethane (TCA) to a commercial recycler to be recovered and returned (sold back) to the SQG, the SQG receives a credit of $0.60 for each gallon recovered and they pay $4.10 per gallon for the recycled solvent they buy back, for a net cost of $3.50 per gallon.[1] By comparison, a large generator shipping 1,000 gallons in bulk (tank) to the recycler for recovery, has a net cost of about $2.90 per gallon of recycled solvent.

Recycled solvents generally sell for 75 to 80 percent of the price of new solvent, with paint thinner (at $1.25 per gallon) at the low-price end and Freon-113 at the high price end (price varies from less than $10.00 per gallon to $18.00 per gallon for recycled Freon-113).[2] The demand for recycled solvent is high; about 75 percent of one large recycler's customers buy back the recovered solvent [4].

On-site recycling — In order for a small distillation device used on-site to be economically desirable for solvent wastes, the recovered solvent must be reused on site. Selling the solvent or reusing it at another facility requires an extremely expensive permit, which makes this method uneconomical. The volume of waste recovered, the percentage left as residual, and the cost of disposing of the residual are important factors in determining economic feasibility.

The physical and technical aspects of the waste management system for on-site recycling are quite simple. An employee or automatic feed system must collect the waste and feed it into the recycling device; the recovered chemical is then returned to the production (or service) process.[3] The recovery rate is about 90 percent in

[1] This is the price charged and credit given by one large recycler in Northern California as of August 1989. Prices of new and recycled solvents vary considerably among recycling firms; some recyclers do not give credit for waste solvent, but charge approximately $120 per drum. Information obtained from interviews with Oil and Solvent Processing Company, Ashland Chemical, Van Waters and Rogers, California Solvent Recycling, and Romic Chemical, conducted by Donald R. McCubbin, August 16, 1989.

[2] Freon-113 is the widely used chloroflourocarbon–*trichlorotriflouroethane*. Prices obtained from five recyclers and chemical manufacturers in Northern California, August 16, 1989. The lowest price is for customers of one recycling firm who buy back their recovered solvent.

[3] Continuous (in-line) recovery/reuse is possible for some production processes.

small recycling devices, with 10 percent lost as distillation residuals. Residuals must be removed and transported to a licensed treatment facility (usually an incinerator) unless the SQG generating the waste is in the conditionally exempt category. Losses are made up by purchase of chemicals, but the amount of new chemicals needed and the amount of hazardous wastes that are transported are greatly reduced.

If land disposal of residuals is prohibited by federal law, as is the case with solvent residuals, the availability of treatment capacity becomes an important factor in the system. For example, the principal off-site incinerator in California for disposing of solvent residuals (a cement kiln at Lebec), only accepts shipments of 1,000 gallons or more. Therefore, SQGs need a hauler, transfer station, or route service to pick up small amounts of residuals so they can be accumulated into a truckload shipment.

Organizational factors – The probable success of on-site recycling depends on the costs of purchasing and operating the device, how easy it is to operate, the quality of the recovered chemicals, and the regulations and costs for disposing of the residuals. But success may depend even more on how the organization's reward structure influences investment decisions. Many firms prefer to spend money on increasing production rather than on what they view as "non-productive" activities, such as waste management or energy conservation. In firms that reward managers for growth or total output rather than profits, managers will not invest in waste management *even if it is likely to yield a higher rate-of-return than investing in production* [5, 6]. Rewarding output rather than profitability creates a barrier to investment in recycling technology. Other barriers are: obtaining financing for the device, concerns about handling the hazardous wastes, concern about quality of the recycled solvent (a major problem in the semiconductor industry), resistance to change (organizational inertia), and concern about changes in regulations that would be more costly or increase liability [7].

Regulatory factors – Recycling on-site changes the way waste is counted, and can affect whether a generator is an SQG or is conditionally exempt. Federal regulations, however, are confusing. The wording in the *Federal Register* (March 24, 1985, pp. 10152-10153) explaining the regulation (40 CFR 261.5(d)) is complicated and ambiguous. It is not clear whether the hazardous waste that is recycled and reused is counted only once or once per month before it is recycled. The EPA staff member we asked for clarification interpreted the regulation to mean that waste is counted once each month [8]. For example, if a generator produces 100 gallons of waste solvent from the clean solvent it has at the beginning of the month, and this waste is recycled and reused several times during the month, the generator counts the initial 100 gallons of waste. By the EPA's interpretation, at the beginning of the next month the generator has to start the count over with the recycled (and new) solvent it has at that time. Regardless of the interpretation, by recycling on-site, a generator could be reclassified into a less regulated category, thus reducing its cost of waste disposal. An SQG reclassified as a conditionally exempt SQG could, in forty-one states, legally dispose of its wastes in a municipal landfill. However, nine states require all SQGs, no matter how small, to send their waste to a licensed facility–there are no conditional exemptions. Thus, the benefit from reduced regulatory requirements varies from state to state.

II. ECONOMIC ANALYSIS

We analyze the economic desirability of small-scale distillation devices for recycling hazardous waste solvents on-site. This is the principal category of waste suitable for on-site recycling in SQG industries; it is generated by auto service shops, dry cleaning shops, pain and ink producers, and semiconductor manufacturers. We compare purchase of a recycling device to its two principal alternatives–commercial (off-site) recycling and a route service that collects waste solvents and delivers clean solvent on a regular schedule. This analysis will enable small firms that use solvents to determine if a recycling device is economically desirable for their situation.

Solvent distillation devices suitable for SQGs and some large quantity generators vary in size from five-gallon capacity (tank size), which is capable of processing three to five gallons per shift, to a thirty-five gallon capacity device capable of processing thirty gallons per hour [9]. The smallest and least expensive system costs about $2,300 plus $1,000 for installation, and the thirty-five gallon system costs about $20,000 plus about $4,000 for installation. Running times for a batch differ between manufacturers. One manufacturer states that the average time to process a batch is four to six hours while another lists eight hours. The larger devices can be operated in a continuous mode, and obtain higher processing rates.

Operating costs are in the range of $0.40 to $0.70 per gallon processed. The main costs are labor (about 10 to 15 minutes per batch), electricity ($0.09 to $0.12 per gallon for the low-temperature devices), and liners (bags that collect the residue as filter cake). For the small recycling devices, nylon liners cost $3.50 each and teflon liners $15 each. Liners are emptied and reused–teflon for five to ten batches, nylon for one to three batches. Teflon should be used for chlorinated solvents, as the acid formed will destroy nylon. Continuous feed operation for the larger systems reduces the labor cost per gallon processed; the smallest device requires more handling and has higher labor costs.

Capital cost per gallon depends on the amount processed and the lifetime of the device. Assuming a ten-year lifetime, we calculate the capital cost at $0.45 per gallon (pre-tax) and $0.30 per gallon (after-tax) for both the smallest device processing 100 gallons per month and the medium-sized device processing 300 gallons per month. For auto shops, the small device will suffice; if a shop has three parts-cleaning devices (requiring 30 gallons of solvent per month), the capital cost per gallon for the recycling device will be about $1.00 per gallon (after-tax). We assume that there are no permit costs, as a RCRA permit is not required for on-site recycling if the recovered chemical is reused on-site.

Economic Model for the Calculation

The economic desirability of recycling depends on whether it produces enough economic benefits–the reduced solvent cost and reduced disposal cost–to "pay back" the purchase cost and operating cost of the recycling device. This is a with-project versus without-project comparison, the without project situation being either of the two baseline cases we define below.[4] In technical terms, we calculate the net present value (NPV) and the rate-of-return of the investment in the recycling device compared to the baseline; a firm can then see if the NPV is greater than zero or the rate-of-return is greater than its minimum acceptable rate-of-return [10].

Tax effects – We calculate the effect of federal and state income taxes on the investment (the NPV and rate-of-return calculations are after-tax). The main difference between a before-tax and after-tax calculation is due to depreciation of equipment; we use the accelerated method (200% declining balance) for seven-year property for federal tax calculations and straight-line depreciation for a fifteen-year life for state tax calculations. Using different depreciation methods is appropriate because some states do not allow the accelerated federal appreciation method. Straight-line depreciation gives a very slight underestimate of the rate-of-return if a state allows accelerated depreciation. In considering tax effects, we account for the deduction of state taxes on the federal return.

Cost and benefit items – The principal economic benefits from recycling, compared to Baseline1 (use of a commercial recycling service), are:

1. The reduced cost of buying solvents; and
2. The reduced cost of disposing of the wastes, compared to the baseline case.

For example, if the SQG recovers 50 gallons per month of solvent which it would otherwise pay $4.00 per gallon to buy, it saves $200 per month; reducing its cost creates a positive cash flow. This is the benefit used in the economic analysis.[5] Without the recycling device, the SQG would pay to dispose of its wastes unless it generates high-value wastes; by recycling, it saves the cost of disposal. If the

[4] We also define baseline conditions with the project (recycling device); these include the price the SQG pays for solvent, the price it pays for disposal of the residuals, and the capital and operating costs of the device.

[5] We do not consider the situation where the firm sells part of all of its recycled solvent because doing so would put it into the commercial recycling business, which requires an expensive permit.

SQG generates high-value wastes for which it would receive a credit from a commercial recycler, the SQG will lose this credit by recycling on-site; this reduction in cash flow is a cost of the project. Other costs are the purchase and installation cost, the operating cost (including labor, utilities, materials, and insurance), and the cost of disposing of the distillation residual.

Compared to Baseline2 (use of a route service), the benefit of the recycling device is the amount the SQG saves by not using the route service; its costs (in the without-project situation) are the amount it pays for the solvent it must buy, the amount it pays for disposing of the distillation residual, and the cost of buying and operating the recycling device.

Definition of the baseline situations – Two baseline situations describe our assumptions about the conditions that exist if the firm does not purchase the recycling device–the without-project conditions–and the conditions that exist if it does purchase the device–the with-project conditions. We choose the baseline conditions to illustrate two situations representative of many SQGs and some generators at the lower end of the large-generator category. Baseline1 applies to firms generating close to, or somewhat more than, the 1,000 kg per month limit. Baseline2 applies to the auto maintenance/repair industry, which has the largest number of SQGs–more than two-thirds of the total in California.

- *Baseline1* assumes that the firm (SQG) uses solvents for an operation such as cleaning parts (e.g., in semiconductor manufacture) and buys recycled solvents from a supplier or commercial recycling firm. The SQG has the waste solvents removed by a waste hauler or recycling firm, and pays for disposal or receives a credit depending on the value and quality of the waste solvents. Our data for this baseline condition is from a semiconductor manufacturer that is a large generator. The firm installed a medium-sized device for recycling solvents it uses for cleaning electronic parts [11]. The total cost of the device and installation was $20,000; the device recovers 35 gallons per day (one-shift operation). Estimated operating costs were between $0.30 and $0.30 per gallon (in 1985).
- In *Baseline2*, the SQG–an auto repair shop–uses a route service if it does not purchase a recycling device. We assume that one *unit of service* is 10 gallons per month, the amount of solvent delivered by a route service firm for each parts cleaner the auto repair shop operates.

Assumptions for calculating the net present value and rate-of-return of the recycling device: Baseline1 conditions – We consider both a small device and a medium-sized device for the Baseline1 calculations.

- *Baseline1*–without-project conditions:
  Solvent used = 1,1,1-trichloroethane (TCA)

Unit cost of solvent	=	\$4.10/gallon (recycled solvent)[6]
Amount of waste solvent generated	=	100 gallons per month
Cost of sending solvent to recycler	=	\$0.60 *credit* per gallon 1,1,1-TCA that is recycled for reuse.
Income tax rate of SQG	=	25% federal; 5% state[7]

- *Baseline1*–with-project conditions for small recycling device:

Cost of recycling device	=	\$2,300
Installation cost	=	\$1,000
Operation and maintenance cost	=	\$0.50 per gallon of waste processed (input amount)
Amount of waste solvent	=	100 gallons per month
Amount recovered	=	90 gallons per month (90% recovery rate)
Amount of distillation residual	=	10 gallons per month
Cost of residual disposal	=	\$11.00 per gallon of residual[8]
Life of device	=	10 years

- *Baseline1*–with-project conditions for medium-sized recycling device:

Cost of recycling device	=	\$8,200
Installation cost	=	\$2,000
Operation and maintenance cost	=	\$0.50 per gallon of waste input
Amount of waste solvent	=	300 gallons per month
Amount recovered	=	270 gallons per month (90% recovery rate)
Amount of distillation residual	=	30 gallons per month
Cost of residual disposal	=	\$11.00 per gallon of residual
Life of device	=	10 years

Operating under Baseline1 conditions, the small recycling device produces a benefit of \$369 per month–the reduced cost of buying TCA as a result of

[6] Price charged by Romic Chemical, East Palo Alto, California. Prices for pickup and disposal or recovery of waste solvents from Ron Tressen, Romic Chemical, personal communication with Donald R. McCubbin, January 24, 1989.

[7] The 25 percent federal corporate rate applies to firms having a taxable income of between \$50,000 and \$75,000. We assume that a state tax of 5 percent is an average for this income; high-tax states have maximums of about 10 percent. We did sensitivity calculations for several combinations of federal and state tax rates, and found that the results are not highly sensitive to tax rate.

[8] Romic Chemical charges \$600 per drum for disposal of filter cake residual. The cost to a SQG is higher when a hauler's transportation cost is added (\$100 per drum); if the waste type does not fall into an existing set of categories ("profile sheets") the recycler handles, a charge of \$250 per sample for analysis of the waste could also be added.

recovering 90 gallons. The costs are: loss of the $54 credit on recovery of 90 gallons per month; $110 per month for disposing of residuals; and $50 operating cost (100 gallons at $0.50 per gallon). The net benefit of the device, before considering tax effects, is $155 per month ($1860 per year). The medium-sized device processes three times the amount of solvent, so its net benefit is three times as large–$5580 per year. By a simple payback calculation, both devices have a payback period of less than two years.[9]

Assumptions for comparison to Baseline2 – Using the recycling device, the SQG replaces lost solvent once a month; for each unit of service (parts washer), it purchases mineral spirits, a low-quality solvent, to bring the amount of solvent back up to 10 gallons. There are two ways solvent is lost:

1. In handling and evaporation; and
2. During distillation (as a residual).

The first loss rate determines the amount that goes into the recycling device; the second loss rate determines the amount recovered and the amount of residual. The numerical values we assume for the Baseline2 situation are:

- *Baseline2* conditions–without recycling device:
  The SQG uses 2 parts cleaners (20 gallons per month delivered)

Cost of route service	=	$40 per month (for each parts cleaner)
Tax rate	=	25% federal; 5% state

- *Baseline2* conditions–with recycling device:

Cost of recycling device	=	$2,300
Installation cost	=	$1,000
Operation and maintenance cost	=	$0.50 per gallon of waste (input)
Loss rate (handling)[10]	=	30% (per month)
Loss rate (during distillation)	=	10%
Cost of solvent	=	$2.00 per gallon
Cost of residual disposal	=	$11.00 per gallon of residual
Life of device	=	10 years

Results

Overview of the calculations – Using standard discounted present value methods in a Lotus spreadsheet, we first calculate the net present value (NPV) at

[9] By "simple payback" calculation, we mean the standard calculation which does not take into account the time-value of money. This crude measure of desirability is widely used but can be deceptive.

[10] This is the loss due to parts cleaning–due to "dragout" of the cleaning fluid on the part, and splashing on the mechanic. This loss occurs before the waste solvent is picked up by the route service in the Baseline case, or before the waste solvent is recycled by the SQG if it uses a recycling device.

a discount rate of 10.0 percent (real rate) and the rate-of-return for the baseline conditions described above. We then perform sensitivity calculations by varying the value of one factor at a time from its baseline value and calculating the results (NPV and rate-of-return). We also vary two factors at a time, and for selected cases, three factors at a time. Using the NPV results, we conduct a break-even analysis for the most important pairs of variables. Where we vary three variables at a time, we construct two-variable tables for several different values of the third variable. In effect, we hold one variable constant (not at the baseline) while calculating the NPV for various combinations of two other variables.

From the table of NPVs for different values of the two variables, we interpolate to find the break-even points–the pairs of values for which NPV = 0. We then plot a curve, which is the locus of break-even points (Figure 1); for a three-variable analysis, we get a family of break-even curves–one for each value of the third (parametrized) variable. We illustrate below in the section "Break-Even Analysis."

NPV and rate-of-return of the recycling investment: Baseline1 – Investing in a small or medium-sized solvent recycling device is very desirable under most Baseline1 conditions (see Table 1). For the small device, the rate-of-return is 41.9 percent and the NPV is $5,260; for the medium-sized device the rate-of-return is 41.1 percent and the NPV is $15,700.

A high solvent price favors recycling under Baseline1 conditions, but not under Baseline2 conditions (Table 2).[11] For example, if all other variables stay at their baseline values but solvent price is 50 percent higher, the rate-of-return is 92 percent–more than twice the baseline value. But, all other conditions cannot stay the same–solvent price and the cost of (or credit for) disposing of the waste solvent in the without-project (recycling device) situation are closely linked. The relationship between price of the solvent and the credit paid for it is "erratic" because the price of the solvent and amount of credit paid for the same waste solvent varies considerably among commercial recyclers. The price goes up much faster than the credit. Commercial recyclers pay a larger credit for more valuable waste solvent–$3.00 per gallon for Freon-113 (1,1,2-trichlorotrifluoroethane)–and charge for a lower-value solvent. Thus, the rate-of-return on the recycling device is very sensitive to the combination of these two factors: the amount the SQG pays the commercial recycler (or the amount of credit it gets) for waste solvent (without the device), and the price of solvent the SQG purchases.

In addition to the baseline calculation for 1,1,1-TCA, we calculated the rate-of-return and NPV for a low-priced solvent–mineral spirits (price of $2.00 per gallon; disposal cost of $2.10 per gallon)–and a high-priced solvent–Freon-113 (price of

[11] Under Baseline2 conditions (route service as the alternative), the firm does not buy solvent in the without-project case, so the higher the price of the solvent, the more the with-project case costs. In the Baseline1 situation, the firm buys solvent with or without the project (device), so when the price is higher, the firm saves more money by recycling.

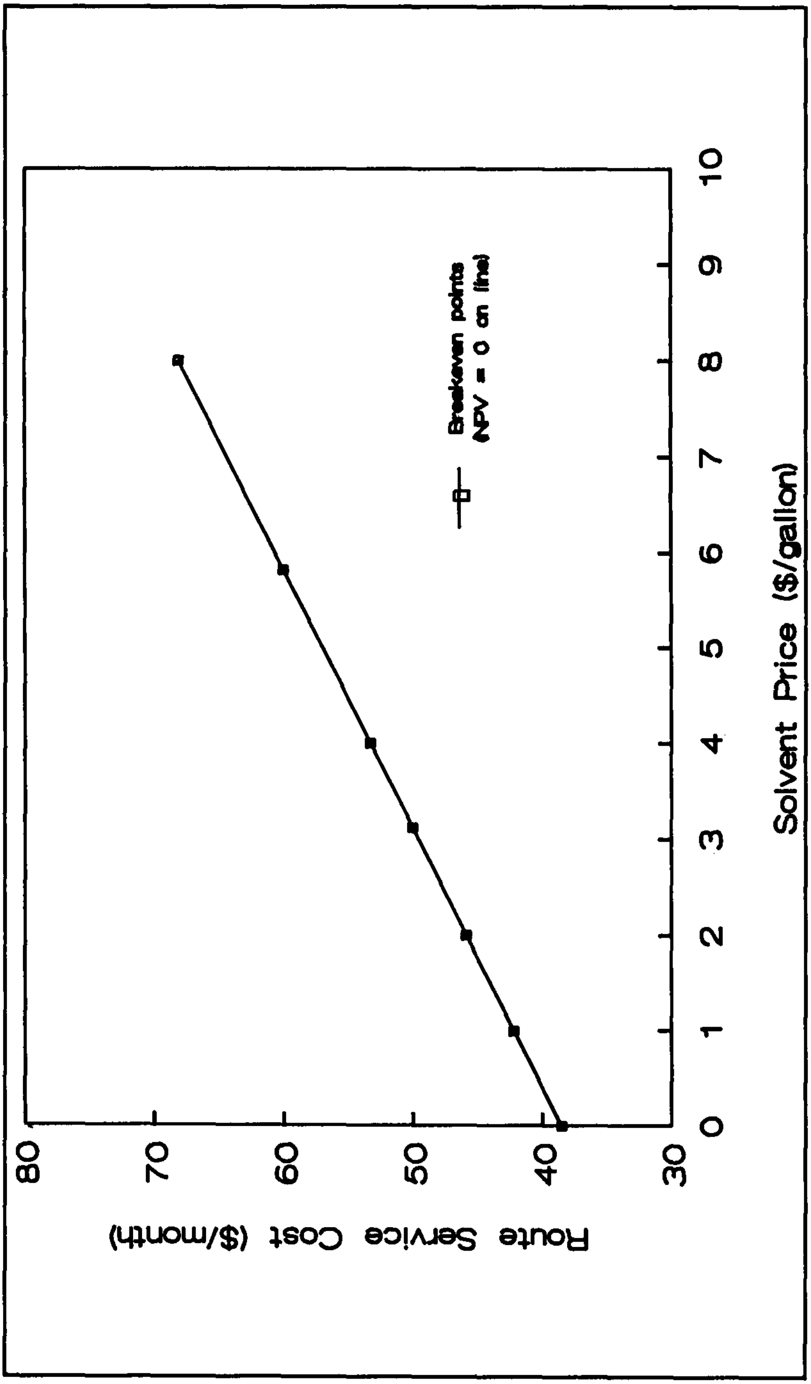

Figure 1. Break-even combinations of solvent price and route service cost.

Table 1. Net Present Value and Rate-of-Return on Small- and Medium-Sized Distillation Devices under Different Conditions, Compared to Baseline1

	Small-Sized Device		*Medium-Sized Device*	
	NPV ($)	*Rate-of-Return[a] (%)*	*NPV ($)*	*Rate-of-Return (%)*
1. Baseline[b]	5,260	41.9	15,700	41.1
2. Residual disposal cost:				
$ 0/gal	11,000	71.6	33,000	70.1
$20/gal	548	13.9	1,590	13.8
3. Amount of waste (input):				
50% of baseline amount	1,200	18.3	3,560	18.1
150% of baseline amount	9.330	63.0	27,900	61.7
4. Solvent price and solvent waste pickup cost:[c]				
Mineral spirits (low-priced)	10,800	70.3	32,200	68.8
1,1,1-TCA (baseline case)	5,260	41.9	15,700	41.1
Freon-113 (high-priced)	50,100	263.0	150,100	256.0
5. Cost of device:				
Small = $4,000[d]	4,700	34.3	–	–
Medium = $12,000	–	–	14,100	34.0
6. Life of device:				
15 years	7,210	42.9	21,600	42.2
20 years	8,390	43.1	25,200	42.4

[a] After-tax rate-of-return.

[b] Baseline1 conditions: Solvent type = 1,1,1-TCA; Price of solvent = $4.10/gal; Residual disposal cost = $11,00 per gallon of residual; Solvent waste pickup cost = $0.60 *credit* to SQG for each gallon recovered; Amount of waste solvent: small device = 100 gal/month, medium device = 300 gal/month; Recycling device cost: small = $3,300 (includes installation), medium = $10,200 (includes installation);Operating cost = $0.50/gal (per gallon of waste input).

[c] Combination of price of solvent and cost (or credit) to SQG for shipping waste solvent to commercial recycler if they do not own recycling device (prices obtained August 16, 1989): Mineral spirits–price = $2.00 per gallon, disposal cost = $120 per drum ($2.10 per gallon); 1,1,1-TCA–price = $4.10 per gallon, disposal credit = $0.60 per gallon recovered; Freon-113–price = $16.00 per gallon, disposal credit = $3.00 per gallon recovered.

[d] For small device, capital cost is $3,000 plus $1,000 for installation; for medium device, capital cost is $10,000 plus $2,000 for installation.

Table 2. Net Present Value and Rate-of-Return on Small Distillation Device under Different Conditions, Compared to Baseline 2 (Auto Repair Shop)

	Number of Parts Cleaners					
	2		*3*		*4*	
Conditions	*NPV ($)*	*R-R (%)*	*NPV ($)*	*R-R (%)*	*NPV ($)*	*R-R (%)*
1. Baseline	-615	5.2	506	13.7	1,630	21.0
2. Solvent price:						
$1.00/gallon	-227	8.3	1,090	17.6	2,400	25.8
$4.00/gallon	-1,390	–	-657	4.8	77	10.6
3. Route service cost:[a]						
$50/month	433	13.1	2,080	23.8	3,720	33.4
$60/month	1,480	20.1	3,650	33.0	5,820	44.8
4. Residual disposal cost:						
$0/gallon of residue	192	11.4	1,720	21.6	3,240	30.7
$20/gallon of residue	-1,280	–	-484	6.2	307	12.3
5. Life of device:						
15 years	-72	9.6	1,320	17.0	2,705	23.6
20 years	260	11.2	1,814	18.0	3,370	24.2

[a] Cost for each parts cleaner.

$16.00 per gallon; credit of $3.00 per gallon for recovery). For mineral spirits, the rate-of-return is about 70 percent for both the small and medium-sized recycling devices compared to 42 percent for the baseline. The result for the low-priced solvent is better than for TCA because the difference in–the saving on–the disposal cost if larger than the difference in price between the two solvents.[12] For Freon-113, the benefits from needing to buy less of the very expensive solvent

[12] Using TCA, the firm pays $4.10 per gallon and receives a credit of $0.60 per gallon for disposal/recovery of the waste. Using mineral spirits, it pays only $2.00 per gallon, but it also pays $2.10 per gallon for disposal. By using a recycling device, the firm saves $2.70 more per gallon on disposal using mineral spirits, and loses @2.10 in benefits of reduced spending on solvents.

boost the rate-of-return to more than 250 percent, a spectacular investment with a payback period of less than three months. (Note that the rate-of-return is nearly the same for the small and medium-sized devices (Table 1) but the net present value is much larger for the medium-sizes device because of its higher initial cost.)

Another important variable is the cost of disposing of distillation residuals. If there is no cost–achieved, for example, by throwing the residual in a dumpster[13]– the rate-of-return is about 71 percent for both size devices, compared to 42 percent when the cost of disposing of the residual is $11 per gallon. At the high-cost end of $20 per gallon of residual (an amount being charged by at least one hauler we know), the investment is barely favorable, returning 14 percent.

Even processing as little as half the capacity–2.5 gallons per day for the small device and 7.5 gallons per day for the medium-sized device–would still be profitable (rate-of-return = 18.3% and 18.1%), but it would not be worthwhile economically to buy the device if much less waste than this is generated.

For the Baseline2 situation, economic desirability is sensitive to the number of parts cleaners the SQG uses, the cost of the route service, and the price the SQG pays for clean solvent if it buys the device; disposal cost of the distillation residual is also important. At the baseline conditions, with two parts cleaners (20 gallons per month delivered), the recycling device is not economically desirable (the NPV is negative); for three or more parts cleaners the device is desirable (see Table 2 for the NPV and rate-of-return numbers).

At a lower solvent price than the $2.00 per gallon baseline, with other conditions at their baseline value, recycling becomes more desirable. At a price of $1.00 per gallon, the rate-of-return is higher by between 3 and 5 percentage points, but the device is still not economically desirable for two parts cleaners.

Price of the route service is very important in determining whether recycling is desirable. An increase in route service cost from the $40 per month baseline to $50 per month causes the device to become economically acceptable for two parts cleaners (rate-of-return = 13%), and very desirable for three or more parts cleaners. At a cost of $60 per month, the device is very desirable even for two parts cleaners (rate-of-return = 20%).

A lower cost of disposing of distillation residuals will make the recycling device more appealing. If there is no disposal cost (other conditions at baseline), the device is just above the minimum rate-of-return (rate-of-return = 11.4%); uncertainty in operating conditions or prices makes this a questionable investment.

[13] One reviewer of this article questions whether a firm that is willing to dispose of its hazardous waste illegally would consider investing in a recycling device. We agree that firms that are disposing of most or all of their waste illegally must first be convinced or coerced to dispose legally before they will consider investing in recycling. The situation we refer to is different; firms that consider purchasing a recycling de vice have been disposing legally by other means; however, when they operate the recycling device they will be tempted to save money by disposing of their residues illegally–all they will need to do is drop a small filter bag (liner) into the municipal trash dumpster. Their chances of getting caught are nil, unless an enforcement agency tracks every owner of a recycling device to see if they have a record of legal disposal of their residuals.

However, for three parts cleaners the device is clearly desirable. Subsidizing the collection of residuals is a legal way of achieving zero disposal cost and making this investment more attractive. Doing so can make a crucial difference for small auto shops facing Baseline2 conditions, but for SQGs at Baseline1 conditions, the argument for a subsidy is weak because the rate-of-return is so high.

Break-Even Analysis

Drawing on the sensitivity calculations for the two variables, *route service cost* and *solvent price*, we illustrate the break-even analysis. Table 3 shows the NPVs resulting from investing in a small recycling device in the Baseline2 situation; we calculate the NPV for twelve combinations of route service cost and solvent price, including their baseline values of $40 per month and $2.00 per gallon, respectively. Other variables are held at their baseline value. To illustrate the break-even calculation, consider route service cost = $50; NPV is positive ($433) at a solvent cost of $2.00 per gallon, but goes negative between that price and $4.00 per gallon. Linear interpolation gives a break-even price of $3.12 per gallon for route service cost of $50; thus we have one break-even point ($3.12, $50). Next, consider solvent price at $4.00 per gallon; NPV is negative (-$343) at a route service cost of $50 per month but is positive at $60. By linear interpolation, we find that break-even point at $53.30 per month. Table 4 shows the set of break-even points obtained from the NPV values in Table 3; Figure 1 shows the locus of break-even points–a straight line with the equation:[14]

Route service cost = $38.50 + $3.70 (solvent price)

From this figure, it is easy to see the combinations of values of route service cost and solvent price for which NPV > 0 (all combinations of the two variables above the line).

Summary of economic analysis – The economic desirability of a small recycling device for solvents depends on the SQG's characteristics, attributes of the device, and prices of solvent and waste disposal. If the situation matches Baseline1, the investment can be highly profitable, and is likely to be a very good investment under most conditions. If the situation matches Baseline2, as it does for a large number of auto service shops, the recycling device may not be a good investment unless the SQG uses at least three parts cleaners (30 gallons per month). If the route service charges $50 a month or more, the recycling device will be a good investment under most conditions, unless the cost of disposing of distillation residuals is much higher than $11.00 per gallon. Some route services now charge $50 per month.

Effectiveness of on-site recycling for reducing environmental and health hazards will depend on the number of firms investing in such devices. This

[14] For some pairs of variables, the locus of break-even points is not a straight line.

Table 3. Sensitivity Analysis for Two-Variable Combinations: Net Present Value for Firm with Two Parts Cleaners, for Different Combinations of Solvent Price and Monthly Route Service Cost[a]

	Net Present Value ($)		
	Route Service Cost[b]		
Solvent Price	$40c	$50	$60
$1.00/gallon	-227	821	1,870
$2.00/gallon[d]	-615	433	1,480
$4.00/gallon	-1,390	-343	705
$8.00/gallon	-2,940	-1,890	-846

[a] Other conditions are at their baseline value; these calculations are for the small recycling device (see Table 1).
[b] Monthly cost per parts cleaner.
[c] Baseline cost for route service.
[d] Baseline cost for solvent price.

Table 4. Break-Even Combinations of Solvent Price and Route Service Cost (Based on Table 3 Results)

Solvent Price	Route Service Cost
$1.00	$42.20
$2.00	$45.90
$3.12	$50.00
$4.00	$53.30
$5.82	$60.00
$8.00	$68.10

number will, in turn, depend on economic desirability–high in situations such as Baseline1–and other factors. Even where economically desirable, on-site recycling will face obstacles: difficulty in obtaining the funds to make the purchase, which could be due to lack of cash or inability to obtain credit from conventional sources; perception of risks in new technology; fear of added liability from managing wastes on-site; and attitudes about doing things in "tried-and-true"

Table 5. Comparison of Four Policy Measures for Baseline1 and Baseline2 Conditions: Free Collection of Distillation Residuals, Grants to Reduce Capital Cost, and a State Investment Tax Credit

	Rate-of-Return (%)	
Policy Measure	*Baseline1*[a]	*Baseline2*[b]
Baseline conditions	41.9	5.2
Policy #1: Free collection of residuals	71.6	11.4
Policy #2: Grant to reduce capital cost:		
By 25%	56.1	11.0
By 50%	83.4	21.0
Policy #3: State investment tax credit[c]		
25% credit	48.6	9.5
50% credit	56.5	15.0
Policy #4: Free collection and 25% grant	94.7	18.4[d]

[a] Baseline1 results are for the small recycling device; see Table 1 for the list of Baseline1 conditions. The rate-of-return for a medium-sized device is within one percentage point of that for the small device.
[b] Baseline2 results are for a SQG using two parts cleaners; see Table 2 for Baseline2 conditions.
[c] Calculation of the rate-of-return for teh state investment tax credit assumes that the firm is in the 25% federal tax bracket (its taxable income is between $50,000 and $75,000.
[d] For three parts cleaners, the rate-of-return is 30.7%.

fashion (i.e., inertia to change). Public policies can help overcome some of the obstacles; we discuss four possibilities next.

III. POLICY OPTIONS AND IMPLICATIONS

Several policy options are available to increase the economic desirability of on-site recycling:

- Policy #1: free collection of distillation residuals;
- Policy #2: grants to reduce the capital cost of the device;
- Policy #3: investment tax credit provided by the states; and
- Policy #4: combination of free collection and grants.

Policy #1

Subsidizing route services to *collect distillation residuals at no cost* greatly enhances the attractiveness of recycling. For the Baseline1 situation (for both the small- and medium-sized device), the rate-of-return increases by about 70 percent from an already desirable baseline level (Tables 1 and 5). For the Baseline2 situation for firms using two parts cleaners, free collection of residuals changes an uneconomic investment (rate-of-return = 5.2%) to one that will be marginally acceptable (rate-of-return = 11.4%) to some firms but not to others. If a SQG faces conditions that are different from our, or it is averse to the risks from changes in conditions, it probably will not invest at this rate-of-return. For firms using three parts cleaners, the rate-of-return increases from an acceptable level (13.7%) to a desirable one (22%) (Table 2). For four or more parts cleaners, this alternative makes a desirable investment considerably more attractive.

Where the rate-of-return is already high, as in Baseline1 situations, the case for a subsidy is not strong. However, offering free pickup of residuals may still make a difference, as firms might worry that the future cost of disposing of residuals could increase, and make the device unprofitable. If that happens, owners of the device will be tempted to dispose of residuals illegally. And, for firms that would dispose illegally at the outset, free pickup will get them to dispose legally. If free pickup causes many firms to invest in recycling devices, route service operators might be able to establish more efficient collection routes, thus lowering their cost and the subsidy cost to government.

Policy #2

Grants to firms for part of the cost of purchasing and installing the device also makes on-site recycling more appealing. This method of subsidy is used in Denmark, apparently with success [12]; it is direct and relatively easy to administer. Grants could, however, cause equipment manufacturers to raise their prices, an outcome that will give them excess profits and reduce the effectiveness of this method (fewer firms will buy the devices). If the benefits of a grant program wind up enriching equipment manufacturers, this method will be undesirable on distributional (equity) grounds.

Economists often object to subsidies because they distort price signals and lead to inefficient levels of consumption–some firms will buy a device that would be unprofitable without the subside, an economically inefficient result if these markets are otherwise efficient. However, where externalities exist, subsidies could promote efficiency by getting firms to invest in devices that reduce health and environmental damages–the externalities firms do not consider in their private investment decisions.

Our economic analysis (Table 5) shows that for Baseline1, a grant of 25 percent of the capital cost (equipment and installation) enhances an already desirable situation (rate-of-return increases from 41.9 % to 56.1%); a 50 percent grant makes this device even more appealing (rate-of-return = 83.4%). For the Baseline2 situation, a 25 percent grant produces similar results to free collection of residuals–for two parts cleaners investing in the device will not be attractive enough for some SQGs (rate-of-return = 11.0%) but for three or more parts cleaners it is desirable. A 50 percent grant makes the device desirable for two parts cleaners as well (rate-of-return = 21.0%).

Policy #3

An investment tax credit (ITC) on federal taxes is similar to a grant from the point of view of the firm, except for the delay between the time of purchase and the time the tax return is filed. The ITC may have a different income distributional (equity) impact, depending on the source of funds for the grant program. If the funds for the grants come from a feedstock tax, rather than from income taxes (as the investment tax credit does), then the users of the chemicals being recycled pay part of the cost–a more equitable outcome. Investment tax credits create possible negative outcomes; the reduction in tax revenues, if not offset by other taxes, could cause cuts in other programs (e.g., education, housing). This means that people other than the users of the products made from the chemicals being recycled will bear the cost–an inequitable result.

Because the Tax Reform Act of 1986 eliminated both general and specific investment tax credits previously available, it is unlikely that specific tax credits will be reinstituted for hazardous waste management in the near future. However, states can offer ITCs. With a state ITC, the firm will have a smaller tax deduction for state taxes on its federal return–its taxable federal income increases by the amount of the tax credit. As a result, the firm will lose (in higher federal taxes) an amount equal to its marginal federal tax rate times the amount of the tax credit. Thus, the state pays for the program and a portion of its lost tax revenue goes to the federal government in the form of higher federal taxes.

A 25 percent state ITC increases the desirability of the device by less than the other two alternatives for Baseline1 conditions, and does not make the device economically acceptable for Baseline2. However, a 50 percent credit does make the device acceptable for Baseline2 (rate-of-return = 15.0%).

Policy #4

Free collection of residuals can be combined with either of the other two alternatives to enhance the recycling device's desirability in situations where it is initially unattractive (Baseline2 for two parts cleaners) or marginally attractive (three parts cleaners). For the Baseline2 situation with two parts cleaners, free collection of residuals, combined with a 25 percent grant for equipment purchase, increases the rate-of-return from an undesirable level (5.2%) to a desirable level (18.4%); for three parts cleaners, the combination of free collection and a 25 percent grant boosts the rate-of-return to a very desirable level (31%). In Baseline1 situations where the rate-of-return is greater than 40 percent initially, there is no need for grants.

Concluding Comments

Firms that approximate Baseline1 conditions should find an investment in on-site recycling highly profitable under most assumptions about future conditions; the result is robust. Firms that approximate Baseline2 conditions–most SQGs do–will find on-site recycling to be uneconomic under most conditions unless they receive subsidies. If policymakers decide to give priority to on-site recycling over competing uses of public funds in the hazardous waste management arena, government programs should target these generators. Stronger enforcement and expanding route service collection of hazardous wastes are prominent alternatives competing for funding [1].

Among the methods to make on-site recycling more attractive economically, grants for purchasing equipment and free pickup of residuals are more appealing than investment tax credits. Because free collection of residuals accomplishes another important objective–assuring legal disposal of residuals–it makes sense to offer this alternative to all SQGs owning on-site recycling devices, and to target a 25 percent grant for purchasing the equipment to SQGs in Baseline2 situations. Such targeting could reduce the overall effectiveness of on-site recycling because some firms in Baseline1 situations will not invest in the device without the grant.

Funding will be a problem in the current climate of massive federal budget deficits and the competing claims of the savings and loan bailout and our military activity in the middle east. If federal funds are not available for subsidies, the most feasible sources appear to be state funds whose source is directly linked to the production of hazardous waste–a feedstock tax on chemicals or taxes on waste disposal. Feedstock taxes have advantages because disposal taxes will create an incentive to dispose illegally, exacerbating a serious problem.

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