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Cost Estimate for Muddy Water Palladium Production Facility at Mound

Ronald K. McAdams

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Abstract

An economic feasibility study was performed on the "Muddy Water" low-chlorine content palladium powder production process developed by Mound. The total capital investment and total operating costs (dollars per gram) were determined for production batch sizes of 1 to 10 kg in 1-kg increments. The report includes a brief description of the Muddy Water process, the process flow diagram, and material balances for the various production batch sizes. Two types of facilities were evaluated -- one for production of new, "virgin" palladium powder, and one for recycling existing material.

The total capital investment for virgin facilities ranged from \$600,000 to \$1.3 million for production batch sizes of 1 to 10 kg, respectively. The range for recycle facilities was \$1 to \$2.3 million. The total operating cost for 100% acceptable powder production in the virgin facilities ranged from \$23 per gram for a 1-kg production batch size to \$8 per gram for a 10-kg batch size. Similarly for recycle facilities, the total operating cost ranged from \$34 per gram to \$5 per gram. The total operating cost versus product acceptability (ranging from 50% to 100% acceptability) was also evaluated for both virgin and recycle facilities. Because production sizes studied vary widely and because scale-up factors are unknown for batch sizes greater than 1 kg, all costs are "order-of-magnitude" estimates. All costs reported are in 1987 dollars.

1. Introduction

A process for preparing low-chlorine content palladium powder ("Muddy Water" process) has successfully been developed by Mound personnel at the request of Los Alamos National Laboratory (LANL). As an extension of this development work, an economic feasibility study was requested to determine the total capital investment and operating costs for various sizes of process scale-ups based on the bench-scale Muddy Water process. This information will be used in the evaluation of the "make versus buy" decision by LANL (i.e., to make the capital investment and produce the palladium powder within the DOE or purchase this material from a commercial manufacturer who will meet LANL's product specifications).

The following report provides cost estimates on the total capital investment and operating expenses for 1- to 10-kg production batch sizes. These estimates have been generated for both virgin and recycle facilities. Because there are many uncertainties involved, (including annual material requirements,

scaling effects on the process above 1-kg batch sizes, an undetermined location, and whether the facility will be dedicated to virgin or recycle material both), these are considered order-of-magnitude estimates with a probable accuracy of -40% to +50%. All cost figures are in 1987 dollars.

2. Summary/Conclusions

2.1 Total Capital Investment Summary

Figure 1 provides a plot of the estimated total capital cost for both virgin and recycle facilities at various production batch sizes. Costs range from approximately \$613,000 to \$1.3 million for virgin facilities, and from approximately \$1.03 million to \$2.3 million for recycle facilities. The major contributors to the higher cost of the recycle facilities are the glovebox, glovebox purge system, and room modification requirements. The itemized costs used to generate the total capital investment estimates are provided on Tables 1 and 2. All tables are found in Appendix A. Details on how the itemized costs were generated are provided in

FIGURE 1 – Palladium production facility -- total capital investment versus batch size.

Section 4, "Total Capital Investment Calculations."

2.2. Operating Costs Summary

Figures 2 and 3 provide plots of total operating costs (\$/g) versus product acceptability for virgin and recycle facility operations, respectively. "Product acceptability" is defined as that quantity of product which meets the required specifications. All costs associated with manufacturing an unacceptable product must be added to the acceptable product costs to realistically represent the total expenses incurred in making a usable final product. Therefore, a process with a 50% product acceptability rate costs essentially twice as much, on a dollars per gram basis, than a process with a 100% acceptability rate (only the palladium costs are not re-incurred). Plots

of acceptability rates in the 50% to 100% range are provided. The individual values used in Figures 2 and 3 are listed in Table 4.

Table 3 provides the itemized costs, in dollars per gram, for various batch sizes and virgin/recycle facilities. Details on how these itemized costs were generated are provided in Section 5, "Total Operating Cost Calculations."

2.3. Conclusions

The total capital investment cost estimates are essentially linear with respect to batch size, with the recycle facility plot having a slightly greater slope than that of the virgin facility. Because of this linear relationship, the total capital costs are minimized by selecting the smallest production batch size that meets the annual material requirements.

FIGURE 2 - Operating cost versus product acceptability -- virgin facility.

FIGURE 3 - Operating cost versus product acceptability -- recycle facility.

The operating cost versus product acceptability plots for both virgin and recycle facilities follow an inverse relationship, where the operating cost differences for the range of product acceptabilities essentially "line-out" at batch sizes of 5 kg (representing 118+ kg annual production) and greater. It is, therefore, recommended, to minimize both capital investment and the effect of product variability/acceptability on operating costs, that a production batch size of 5 kg be selected. This selection assumes that annual production requirements are below the approximately 118 kg which the process can produce under normal operating conditions.

An interesting result of this economic evaluation is provided in Table 3. For a 100% acceptable product, total operating costs are lower for the recycle facility than for the virgin facility at production batch sizes greater than 3 kg. These results provide a real economic incentive to recycle the palladium material.

3. Production Facility Description

3.1. Introduction

The Palladium Production Facility Process Flow Diagram (Figure 4 and Tables 5-14) depicts the Muddy Water process developed by D. R. Grove and others at Mound. This is a nitric acid-based, batch process (most commercial processes are hydrochloric acid-based) which produces a palladium powder product meeting the low-chlorine specifications required by LANL.

The first step of the Muddy Water process involves the dissolution of the palladium sponge (either new, clean sponge in the virgin process or recovered material in the recycle process) in a 70% nitric acid solution. The initial charge of nitric acid is 5 L per 1 kg of sponge. A minute quantity of hydrochloric acid (1 mL per kg sponge) is also added which behaves as a catalyst to initiate the dissolution process. The digester/reactor is heated to 120+°C and agitated to boil down and

concentrate the solution to approximately one-half its original volume. The boil-off and dissolving palladium sponge liberates nitric oxide fumes which must be condensed and scrubbed. The final solution of dissolved palladium in nitric acid is termed "redwine" due to its appearance. The desired redwine concentrations are approximately 2.5 molar palladium and 6-8 molar nitric acid. The solution is filtered before transfer to the neutralization step to remove any insolubles (traces of gold and platinum from the sponge material). This step requires approximately 3 hr.

In the neutralization step, the redwine is slowly charged to a solution consisting of 29.9% ammonium hydroxide (-3.5 L/kg Pd), deionized water (-35 L/kg Pd), and glacial acetic acid (-0.06 L/kg Pd). The slow addition of redwine to the neutralization solution (versus adding solution to the redwine) allows for easy formation of the desired Pd (NH₃)₄(NO₃)₂ solution. The addition of neutralization solution to redwine was found to form Pd(OH)₂ precipitate, which is undesirable. The final neutralization solution has a pH of approximately 8.5 and is termed "vinegar" due to its appearance and odor. This processing step is carried out at essentially room temperature with no intentional temperature control. The solution is agitated during the redwine addition and a minimal amount of ammonia vapors evolve (negligible for processing purposes). The neutralized vinegar solution is filtered before transfer to the reduction step to remove traces of iron hydroxide precipitate which form (from the starting sponge material). This step requires approximately 4 hr.

The primary reduction step is carried out in a third reactor. The reducing agent (88% formic acid) is added to the vinegar at a rate of -0.7 L/kg Pd. The temperature of this step is carefully controlled at 36°C and slight agitation is used while adding the formic acid. Carbon dioxide effervescence is present in a moderate amount, but not to the extent of being a problem. The solution pH is approximately

FIGURE 4 - "Muddy Water" palladium processing facility --- process flow diagram.

3.5 at this stage. As the palladium powder product is generated, the appearance of the reduction solution gradually evolves from a pale yellow color to an olive green and, finally, to a “muddy water” brown. The reduction step may take as long as 8 hr to allow time for complete reduction.

The muddy water solution is then filtered to recover the palladium powder product. The powder is then washed with deionized water at quantities of ~45 L/kg Pd. The remaining waste filtrate may be processed through a second reduction step using a strong reducing agent (such as sodium borohydride) to recover the trace concentrations of palladium remaining in solution. This step would be performed in the same reduction reactor as the primary step and under similar operating conditions.

The wet palladium powder resulting after the above filter wash is then placed in a vacuum tray oven at approximately 80°C and dried for about 6 hr. The dried powder is then run through a centrifugal sifter to break up any clumps. A screen mesh size of 100 is used to recover the final palladium powder product. The total product yield is typically 95+%.

3.2. Process Flow Diagram

The process flow diagram for the palladium processing facility is provided in Figure 4. The process flow sheets for production batch sizes from 1 kg to 10 kg (in 1-kg increments) are provided in Tables 5 through 14. This flow diagram applies to both the cold virgin and recycle processes (only hardware and waste treatment requirements differ for the two facilities).

4. Total Capital Investment Calculations

4.1. Virgin Process Facility

4.1.1. Building/Site/Utilities

Since the facility location is undetermined at this time, several assumptions were required to generate the estimate. For the virgin process,

it was assumed that a grass-roots facility would be constructed at Mound at a location within 800 ft of required site utilities, such as low-pressure steam, deionized water, compressed air, and storm drainage tie-ins. Site work required is assumed to include grading, paving, sidewalks, and curbs.

The production facility building is assumed to be a pre-engineered “Butler-type” building based on the plan view sketch illustrated in Figure 5. The building is assumed to contain a chemical storage area, an office area, and miscellaneous laboratory benches, sinks, etc. to support the process. Electrical, HVAC, and sprinkler system installations are also included.

The floor plan layout in Figure 5 is based on the 10-kg production batch size process. The building cost estimates for the 1- through 9-kg batch sizes are factored from this “full-scale” estimate in the following manner.

General site work, which includes grading, paving, sidewalks, curbs, etc., as well as the utilities installations is considered a fixed cost for all facility sizes, and is estimated at \$102,700. The remaining costs are considered variable with respect to required floor area. The required floor area for the 10-kg batch size is 1125 ft² at a cost of \$99,300. This generates a variable cost of \$88.27 per ft² of floor area required. It is assumed a 1-kg production facility will require approximately one-half the floor area of the 10-kg facility (because much of the floor area needed for storage, office space, access paths, etc. is fixed). This generates a scaling factor of 0.3. The final equation used for the building estimates is:

$$\text{Building/Site/Utilities Cost} = \$102,700 + (\$88.27 \text{ ft}^2)(1125 \text{ ft}^2) \left(\frac{\text{Batch Size}}{10 \text{ kg}} \right)^{0.3}$$

Table 1 provides the total costs for building, site work, and utilities at each of the production batch sizes.

FIGURE 5 - Plan view -- virgin process facility.

Table 1 provides the total costs for building, site work, and utilities at each of the production batch sizes.

4.1.2. Pilot Plant System

The pilot plant system cost estimate was provided by the Pfaudler Company, based on information we provided on process equipment and working capacity requirements for the 10-kg production batch size. Figure 5 provides a rough sketch of the major process equipment involved. The pilot plant system would be of modular construction and includes the following equipment:

1. A 20-gal stainless steel reactor (digester), including an electric heating mantle, a variable speed drive, explosion-proof electric motor, and an impeller agitator.
2. Two 150-gal stainless steel reactors (neutralization and reduction reactors), including carbon steel jackets, variable speed drive/explosion proof electric motors, and an impeller agitator.
3. A jacketed pipe, stainless steel condenser furnished with all required fittings, flanges, nozzles, couplings and gaskets.
4. Three, pilot-scale, stainless steel plate and frame filter presses, including all required nozzles and hardware.
5. Transfer pumps, Teflon wetted parts, complete with electric motors, base plates, couplings, and coupling guards. Three furnished.
6. One lot of instrumentation consisting of temperature transmitters, temperature indicating controllers, recorders, pH probes and control valves. Control panel furnished with instruments mounted, piped, and wired. Pressure and temperature gauges also included.
7. One lot of piping, valves, fittings, flanges and piping accessories, stainless steel and

Teflon construction, to interconnect the Pfaudler furnished equipment.

The estimated cost for this 10-kg production batch-size, pilot plant system was \$300,000. Using the six-tenths factor rule, cost estimates for the remaining batch sizes (listed in Table 1) were generated from the following equation:

$$\text{Pilot Plant System Cost} = \$300,000 \times \left(\frac{\text{Batch Size}}{10 \text{ kg}} \right)^{0.6}$$

4.1.3. Scrubber System

Quotes from several vendors were provided on a fume scrubbing system to scrub the estimated 20 SCFM flow rate of nitric acid vapors generated in the 10-kg batch size digester reactor. The packed scrubbers, using 50% sodium hydroxide solution as the scrubbing medium, were estimated at an average cost of \$13,000. This cost included a draft hood, duct work, blower fan, pH control system with metering pumps, and a control panel with all required switches and alarms.

Again, the six-tenths factor rule was applied to estimate the costs for the smaller batch sizes. These costs are provided in Table 1. The resulting equation is:

$$\text{Scrubber System Cost} = \$13,000 \times \left(\frac{\text{Batch Size}}{10 \text{ kg}} \right)^{0.6}$$

4.1.4. Vacuum Oven

The average estimated cost quotes for using vacuum tray ovens to dry the wet palladium powder were \$2,800 for 1- through 5-kg batch sizes, and \$5,500 for 6- through 10-kg batch sizes.

4.1.5. Centrifugal Sifter

The average estimated cost quote for a centrifugal sifter was \$7,200. This equipment is capable of handling product batch sizes from 1 through 10 kg.

4.1.6. Drum Pumps

Drum pumps are required for transferring the raw material chemicals from their storage drums to the process reactors. Quotes on such pumps are \$500 each, with the number of pumps increasing with increasing production batch sizes.

4.1.7. Installation

The installation cost is estimated at 25% of purchased equipment cost, which includes all items above. This percentage is based on both text book conventions and similar process installations at Mound. This cost includes overhead.

4.1.8. Engineering

Engineering cost is estimated at 25% of the installed equipment cost, the historical average on processing facility installations at Mound. This cost is also burdened (includes overhead).

4.1.9. Contingency

Because of the many uncertainties and unknowns in the production facility at this time, a contingency of 35% of installed equipment plus engineering costs is used. This is consistent with the order-of-magnitude nature of the cost estimates.

4.1.10. Project Management

A project management cost of 5% of the total fixed capital cost is applied to projects of this scale because of administrative, quality assurance, and reporting requirements mandated by the DOE.

4.1.11. Working Capital Costs

Working capital costs are the initial expenses incurred to purchase the raw materials, spare parts, operating supplies, etc. to cover, approximately, the first two production batches. These start-up costs are estimated at 15% of the fixed capital costs.

4.2. Recycle Process Facility

4.2.1. Room Modifications

As with the virgin process facility, the location for the recycle process facility is unknown at this time and, thus, several assumptions are made. It is assumed that the recycle process facility will be located in an existing building which is equipped with the utilities, support facilities, and services required for the process. It is assumed that the location will require complete renovation, including HVAC service. The required floor area of 1150 ft² for the 10-kg batch size (determined by the glovebox layout provided below) is used as the basis for the estimate, along with a cost estimate of \$200/ft² provided by Smith, Stevens, and Young for recent work on a similar lab renovation. A three-tenths factor is again used for scaling the required floor area and resulting cost. The equation is provided below, with the results listed in Table 2.

$$\text{Room Modifications Cost} = (\$200/\text{ft}^2)(1150 \text{ ft}^2) \left(\frac{\text{Batch Size}}{10 \text{ kg}} \right)^{0.3}$$

4.2.2. Gloveboxes

The recycle process facility requires the process equipment to be housed in gloveboxes. The linear feet of gloveboxes required were determined in the following manner:

<u>Item(s)</u>	<u>Glovebox Required (ft)</u>
3 reactors (3 ft ea)	9
3 filters (4 ft ea)	12
4 pumps (1 ft ea)	4
Condenser	3
Scrubber	5
Waste filtrate receiver	5
Drying ovens	6
Centri-sifter	<u>6</u>
TOTAL	50

The configuration and layout of these gloveboxes, as well as the required floor area, are provided in Figure 6.

The gloveboxes purchased equipment costs are estimated at \$6,000/linear ft., based on recent projects. Using a three-tenths factor for required glovebox length at various batch sizes, the following equation was used:

$$\text{Glovebox Costs} = (\$6000/\text{ft})(50 \text{ ft}) \left(\frac{\text{Batch Size}}{10 \text{ kg}} \right)^{0.3}$$

The resulting costs are provided in Table 2.

4.2.3. Glovebox Purge System

The glovebox purge system is required to maintain an acceptable atmosphere within the glovebox by use of monitors, analyzers, and pressure control devices. This system is essentially the same for all glovebox operations, regardless of size, and is estimated at a cost of \$49,300. This cost is fixed for all production batch sizes.

4.2.4. Pilot Plant System

The pilot plant system for the recycle process is assumed identical to that described in the

virgin process, Section 4.1.2 above. An additional \$3,000 is added to the 10-kg batch size estimate to include the cost of a 300-gal stainless steel waste filtrate storage tank. The six-tenths factor rule was again applied.

4.2.5. Scrubber System

The scrubber system is assumed identical to that described in Section 4.1.3. The same costs apply.

4.2.6. Vacuum Oven

This equipment and costs are assumed identical to that described in Section 4.1.4.

4.2.7. Centrifugal Sifter

Assumed identical to that described in Section 4.1.5.

4.2.8. Drum Pumps

Assumed identical to that described in Section 4.1.6.

4.2.9. Installation

Installation costs are again estimated at 25% of purchased equipment costs (includes overhead).

4.2.10. Engineering

Engineering costs (including overhead) are estimated at 25% of installed equipment costs.

4.2.11. Contingency

A contingency of 35% of installed equipment plus engineering is used.

4.2.12. Project Management

A 5% of total fixed capital cost is again applied.

4.2.13. Working Capital Costs

Fifteen percent of fixed capital costs is applied.

FIGURE 6 - Plan view -- recycle process facility.

5. Total Operating Cost Calculations

5.1. Introduction

Tables 3 and 4 provide the operating cost results for both the virgin and recycle facilities. As shown in Table 3, a 95% process yield is assumed for all batch sizes, as well as for both facilities. The Annual Yield results are based on a production rate of 25 batches per year, for all batch sizes. This production rate would allow 2-3 working days for actually manufacturing the product, and 7-8 working days for analytical work to determine the product quality. The analytical results for each batch should be evaluated before proceeding with the next batch. This is the best method of operation because corrections in the manufacturing process can be made, if necessary, to

bring the product within specification before proceeding with successive batches. This will minimize operating costs and eliminate the problem of making several batches of unacceptable product before detecting them.

In Table 4, more than 25 batches will be required, as acceptability decreases, to meet the annual product yields provided in Table 3. For example, at a 50% product acceptability rate, 50 batches of product would have to be manufactured per year to generate 25 batches of acceptable product. The increasing operating costs in dollars per gram account for this increasing production rate.

The following sections describe the calculations used in determining the itemized operating costs listed in Table 3.

5.2. Virgin Process Facility

5.2.1. Raw Materials

Raw material costs include the costs of the original palladium sponge as well as all chemicals used in the manufacturing process. The cost for palladium sponge purchased through the U.S. Dept. of Energy is \$5 per gram, and constitutes 95% of the total raw material costs. Quotes on 55-gal drums of the commodity chemicals used in the process were received from several local distributors and an average cost used in the calculations. The drum deposits on the chemicals are a "one-time" cost which are assumed paid in the Working Capital Costs of the Total Capital Investment (Tables 1 and 2).

Chemical requirements on a volume per gram basis were calculated using the process flow sheets. (Tables 5 through 14). From the known "dollars per 55 gallons", and "gallons per gram" requirements, the total cost of the commodity chemicals used were calculated at 27 cents per gram. Thus a total cost of \$5.27 per gram is generated for raw materials, which is constant at all production batch sizes.

5.2.2. Analytical

The analytical costs are essentially the man-hours used on the 11 analyses required to determine product quality. This manpower is estimated at 6.5 man-days per batch, independent of batch size. The total estimated analytical cost per batch, including overhead costs, is approximately \$5,700. As a fixed cost independent of batch size, the resulting dollars per gram for analytical costs drop considerably as the batch sizes are increased. Thus, the larger the batch size, the more economical the analytical process. Analytical costs are shown to be significant in the smaller batch sizes (Table 3), but are greatly reduced in the larger batches.

The quantity of product consumed and scrapped during the analytical process is less than 5 grams per batch, independent of batch size. This loss is part of the 5% loss described in the production process (i.e., 95% yield per batch).

5.2.3. Labor

The labor costs for operating the manufacturing process are estimated at one man-year of technician time and 0.2 man-year of engineering time for the 1-kg batch size process. This 1.2 man-year includes research and development, and overhead costs. The resulting burdened labor cost for the 1-kg batch size is approximately \$222,400 per year. A conventional scale-up factor of 0.2 is used for labor requirements at increasing batch sizes, thus labor costs are not assumed fixed and independent of batch size. However, as Table 3 illustrates, labor costs also drop significantly as batch size is increased.

5.2.4. Utilities

The utilities costs are the estimated energy requirements for the various production batch sizes, in kilowatt-hours (kWhr) per batch. A portion of these requirements are assumed fixed, such as building utilities, monitors and instrumentation, and single-sized equipment. The remaining energy requirements increase proportionally with increasing equipment sizes (i.e. reactor agitators, pumps, fume scrubbers, reactor heaters, etc.). The total kWhr per batch range from approximately 2,000 for a 1-kg batch size to 3,100 for a 10-kg batch size. The energy cost used in the calculations is 5 cents per kWhr.

5.2.5. Maintenance

A conventional estimate of annual maintenance cost at 10% of Fixed Capital Costs (Tables 1 and 2) is used and divided by the annual yield to generate the cost on a dollars per gram basis.

5.2.6. Operating Supplies

Again, a conventional estimate of 15% of Maintenance costs is used to cover the costs of operating supplies on a dollars per gram basis.

5.3. Recycle Process Facility

5.3.1. Raw Materials

The costs for raw materials is calculated in the same manner as for the virgin facility, except that the palladium sponge cost of \$5 per gram is omitted. In the recycle process, the palladium source material has already been paid for in the initial manufacturing process, thus costing it here again would result in double-counting. The elimination of the palladium sponge cost significantly reduces the overall, total operating costs for the recycle process. As Table 3 illustrates, for a product that is 100% acceptable, the total operating costs are actually lower for the recycle facility than for the virgin facility at batch sizes greater than 3 kg. This is an attractive incentive for recycling the palladium product, regardless of its source.

5.3.2. Analytical

Experience in analyses of similar materials shows that 300% more manpower will be required to generate the analytical results for the recycle product. Thus analytical costs are tripled at all production batch sizes.

5.3.3. Labor

Labor costs are increased by 20% over the virgin process estimate to account for the

differing facilities and hardware, and additional Health Physics support which will be required on occasion.

5.3.4. Utilities

The utilities costs have likewise been increased by 20% over the virgin process to account for differing HVAC requirements and additional instrumentation requirements.

5.3.5. Maintenance

Identical to the virgin process, annual maintenance costs are estimated at 10% of the Fixed Capital Costs.

5.3.6. Operating Supplies

Operating supplies are estimated at 15% of the maintenance costs (identical to the virgin process estimate).

5.3.7. Waste Disposal

Unlike the virgin process, where all waste streams generated can be sent directly to the sanitary sewer, the recycle process requires special treatment of the waste streams. This cost is estimated at \$10 per gallon of waste generated. The cost includes drumming, processing, cement/filler materials, shipment, burial, and overhead costs. Using the process flow sheets of Tables 5 through 14 to determine the total waste generated, a waste disposal cost of 25 cents per gram is calculated.

Appendix A

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TABLE 1

Total Capital Investment -- Virgin Facility (Thousands of Dollars)

	Production Batch Size (Kg)									
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Building/Site/Utilities	152.5	164.0	171.9	178.1	183.4	187.9	191.9	195.6	198.9	202.0
Pilot Plant System	75.4	114.2	145.7	173.1	197.9	220.8	242.2	262.4	281.6	300.0
Scrubber System	3.3	4.9	6.3	7.5	8.6	9.6	10.5	11.4	12.2	13.0
Vacuum Oven	2.8	2.8	2.8	2.8	2.8	5.5	5.5	5.5	5.5	5.5
Centrifugal Sifter	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Drum Pumps	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5
Installation	60.5	73.7	83.8	92.6	100.5	108.2	114.8	121.1	127.0	132.6
Engineering	75.7	92.1	104.8	115.7	125.6	135.3	143.5	151.4	158.7	165.7
Contingency	132.4	161.1	183.4	202.5	219.8	236.8	251.2	265.0	277.8	290.0
Fixed Capital Costs	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	510.7	621.5	707.5	781.0	847.7	913.3	968.9	1022.1	1071.4	1118.4
Project Management	25.5	31.1	35.4	39.1	42.4	45.7	48.4	51.1	53.6	55.9
Working Capital Costs	76.6	93.2	106.1	117.2	127.2	137.0	145.3	153.3	160.7	167.8
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Total Capital Investment	612.8	745.8	849.0	937.2	1017.2	1096.0	1162.7	1226.5	1285.7	1342.1

TABLE 2

Total Capital Investment -- Recycle Facility (Thousands of Dollars)

	Production Batch Size (Kg)									
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Room Modifications	115.3	141.9	160.3	174.7	186.8	197.3	206.7	215.1	222.8	230.0
Gloveboxes	150.4	185.1	209.1	227.9	243.7	257.4	269.6	280.6	290.7	300.0
Glovebox Purge System	49.3	49.3	49.3	49.3	49.3	49.3	49.3	49.3	49.3	49.3
Pilot Plant System	76.1	115.4	147.1	174.9	199.9	223.0	244.6	265.0	284.4	303.0
Scrubber System	3.3	4.9	6.3	7.5	8.6	9.6	10.5	11.4	12.2	13.0
Vacuum Oven	2.8	2.8	2.8	2.8	2.8	5.5	5.5	5.5	5.5	5.5
Centrifugal Sifter	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Drum Pumps	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5
Installation	101.3	127.0	145.9	161.4	175.1	187.8	198.8	209.1	218.7	227.6
Engineering	126.7	158.8	182.4	201.8	218.8	234.8	248.5	261.4	273.3	284.5
Contingency	221.7	277.9	319.1	353.2	383.0	410.9	435.0	457.5	478.3	497.9
Fixed Capital Costs	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	854.9	1071.9	1231.0	1362.2	1477.1	1584.7	1677.7	1764.7	1845.0	1920.6
Project Management	42.7	53.6	61.5	68.1	73.9	79.2	83.9	88.2	92.2	96.0
Working Capital Costs	128.2	160.8	184.6	204.3	221.6	237.7	251.6	264.7	276.7	288.1
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Total Capital Investment	1025.9	1286.2	1477.2	1634.6	1772.6	1901.7	2013.2	2117.6	2214.0	2304.7

TABLE 3

Total Operating Cost -- Virgin Facility

(100% Product Acceptability)

Batch Size (Kg)	Yield Per Batch	Annual Yield (Kg)	\$/g						Total Operating Cost
			Raw Materials	Analytical	Labor	Utilities	Maintenance	Operating Supplies	
1.000	0.950	23.8	5.270	5.971	9.365	0.107	2.150	0.323	23.185
2.000	1.900	47.5	5.270	2.985	5.379	0.058	1.308	0.196	15.197
3.000	2.850	71.3	5.270	1.990	3.889	0.041	0.993	0.149	12.332
4.000	3.800	95.0	5.270	1.493	3.089	0.033	0.822	0.123	10.830
5.000	4.750	118.8	5.270	1.194	2.584	0.027	0.714	0.107	9.896
6.000	5.700	142.5	5.270	0.995	2.233	0.024	0.641	0.096	9.260
7.000	6.650	166.3	5.270	0.853	1.974	0.021	0.583	0.087	8.788
8.000	7.600	190.0	5.270	0.746	1.774	0.019	0.538	0.081	8.428
9.000	8.550	213.7	5.270	0.663	1.615	0.018	0.501	0.075	8.143
10.000	9.500	237.5	5.270	0.597	1.484	0.016	0.471	0.071	7.909

Total Operating Cost -- Recycle Facility

(100% Product Acceptability)

Batch Size (Kg)	Yield Per Batch	Annual Yield (Kg)	\$/g							Total Operating Cost
			Raw Materials	Analytical	Labor	Utilities	Maintenance	Operating Supplies	Waste Disposal	
1.000	0.950	23.8	0.270	17.912	11.238	0.128	3.600	0.540	0.250	33.938
2.000	1.900	47.5	0.270	8.956	6.454	0.070	2.257	0.338	0.250	18.595
3.000	2.850	71.3	0.270	5.971	4.666	0.049	1.728	0.259	0.250	13.193
4.000	3.800	95.0	0.270	4.478	3.707	0.040	1.434	0.215	0.250	10.394
5.000	4.750	118.8	0.270	3.582	3.101	0.032	1.244	0.187	0.250	8.666
6.000	5.700	142.5	0.270	2.985	2.680	0.029	1.112	0.167	0.250	7.493
7.000	6.650	166.3	0.270	2.559	2.369	0.025	1.009	0.151	0.250	6.634
8.000	7.600	190.0	0.270	2.239	2.129	0.023	0.929	0.139	0.250	5.979
9.000	8.550	213.7	0.270	1.990	1.938	0.022	0.863	0.129	0.250	5.462
10.000	9.500	237.5	0.270	1.791	1.781	0.019	0.809	0.121	0.250	5.041

TABLE 4

Operating Costs vs Product Acceptability

- Virgin Facility:

Batch Size (Kg)	\$/g					
	100%	90%	80%	70%	60%	50%
1.000	23.185	25.206	27.731	30.979	35.308	41.370
2.000	15.197	16.330	17.746	19.567	21.995	25.394
3.000	12.332	13.147	14.165	15.474	17.220	19.664
4.000	10.830	11.478	12.288	13.329	14.717	16.660
5.000	9.896	10.440	11.120	11.994	13.160	14.792
6.000	9.260	9.733	10.325	11.086	12.100	13.520
7.000	8.788	9.209	9.735	10.411	11.313	12.576
8.000	8.428	8.809	9.285	9.897	10.713	11.856
9.000	8.143	8.492	8.929	9.490	10.238	11.286
10.000	7.909	8.232	8.636	9.156	9.848	10.818

- Recycle Facility:

Batch Size (Kg)	\$/g					
	100%	90%	80%	70%	60%	50%
1.000	33.938	37.709	42.423	48.483	56.563	67.876
2.000	18.595	20.661	23.244	26.564	30.992	37.190
3.000	13.193	14.659	16.491	18.847	21.988	26.386
4.000	10.394	11.549	12.993	14.849	17.323	20.788
5.000	8.666	9.629	10.833	12.380	14.443	17.332
6.000	7.493	8.326	9.366	10.704	12.488	14.986
7.000	6.634	7.371	8.293	9.477	11.057	13.268
8.000	5.979	6.643	7.474	8.541	9.965	11.958
9.000	5.462	6.069	6.828	7.803	9.103	10.924
10.000	5.041	5.601	6.301	7.201	8.402	10.082

TABLE 5

Palladium Processing Facility Flow Sheet
1.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	1.000	0.167	s	123.0	1.00
2	69.9% Nitric Acid	7.050	5.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.001	0.001	l	123.0	1.00
4	Nitric Oxide	3.525	3,204.814	g	123.0	1.00
5	Unfiltered Redwine	4.525	2.584	l	60.0	1.00
6	Gold/Platinum	0.005	0.000	s	60.0	1.00
7	Redwine	4.520	2.583	l	20.0	1.00
8	29.9% Ammonium Hydroxide	3.230	3.589	l	20.0	1.00
9	Deionized Water	35.885	35.885	l	20.0	1.00
10	100% Acetic Acid	0.063	0.060	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	43.698	42.117	l	20.0	1.00
13	Iron Hydroxide	0.022	0.004	s	20.0	1.00
14	Vinegar	43.676	42.113	l	36.0	1.00
15	88% Formic Acid	0.847	0.718	l	36.0	1.00
16	Carbon Dioxide	0.810	3.208	g	36.0	1.00
17	Unfiltered Muddy Water	44.523	42.830	s/l	36.0	1.00
18	Deionized Water	45.000	45.000	l	20.0	1.00
19	Waste Filtrate	88.098	86.880	l	20.0	1.00
20	Wet Palladium Powder	1.425	0.950	s/l	20.0	1.00
21	Water Vapor	0.475	0.475	g	80.0	1.00
22	Dry Palladium Powder	0.950	0.475	g	80.0	1.00
23	50.0% Sodium Hydroxide	4.476	4.879	l	25.0	1.00

TABLE 6

Palladium Processing Facility Flow Sheet
2.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	2.000	0.333	s	123.0	1.00
2	69.9% Nitric Acid	14.100	10.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.001	0.001	l	123.0	1.00
4	Nitric Oxide	7.051	6,409.627	g	123.0	1.00
5	Unfiltered Redwine	9.051	5.167	l	60.0	1.00
6	Gold/Platinum	0.010	0.001	s	60.0	1.00
7	Redwine	9.041	5.167	l	20.0	1.00
8	29.9% Ammonium Hydroxide	6.459	7.177	l	20.0	1.00
9	Deionized Water	71.770	71.770	l	20.0	1.00
10	100% Acetic Acid	0.126	0.120	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	87.396	84.234	l	20.0	1.00
13	Iron Hydroxide	0.044	0.009	s	20.0	1.00
14	Vinegar	87.352	84.225	l	36.0	1.00
15	88% Formic Acid	1.694	1.435	l	36.0	1.00
16	Carbon Dioxide	1.619	6.416	g	36.0	1.00
17	Unfiltered Muddy Water	89.046	85.661	s/l	36.0	1.00
18	Deionized Water	90.000	90.000	l	20.0	1.00
19	Waste Filtrate	176.196	173.761	l	20.0	1.00
20	Wet Palladium Powder	2.850	1.900	s/l	20.0	1.00
21	Water Vapor	0.950	0.950	g	80.0	1.00
22	Dry Palladium Powder	1.900	0.950	g	80.0	1.00
23	50.0% Sodium Hydroxide	8.952	9.757	l	25.0	1.00

TABLE 7

Palladium Processing Facility Flow Sheet
3.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	3.000	0.500	s	123.0	1.00
2	69.9% Nitric Acid	21.150	15.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.002	0.002	l	123.0	1.00
4	Nitric Oxide	10.576	9,614.441	g	123.0	1.00
5	Unfiltered Redwine	13.576	7.751	l	60.0	1.00
6	Gold/Platinum	0.015	0.001	s	60.0	1.00
7	Redwine	13.561	7.750	l	20.0	1.00
8	29.9% Ammonium Hydroxide	9.689	10.766	l	20.0	1.00
9	Deionized Water	107.656	107.656	l	20.0	1.00
10	100% Acetic Acid	0.188	0.179	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	131.094	126.350	l	20.0	1.00
13	Iron Hydroxide	0.066	0.013	s	20.0	1.00
14	Vinegar	131.028	126.338	l	36.0	1.00
15	88% Formic Acid	2.541	2.153	l	36.0	1.00
16	Carbon Dioxide	2.429	9.624	g	36.0	1.00
17	Unfiltered Muddy Water	133.569	128.491	s/l	36.0	1.00
18	Deionized Water	135.000	135.000	l	20.0	1.00
19	Waste Filtrate	264.294	260.641	l	20.0	1.00
20	Wet Palladium Powder	4.275	2.850	s/l	20.0	1.00
21	Water Vapor	1.425	1.425	g	80.0	1.00
22	Dry Palladium Powder	2.850	1.425	g	80.0	1.00
23	50.0% Sodium Hydroxide	13.428	14.636	l	25.0	1.00

TABLE 8

Palladium Processing Facility Flow Sheet
4.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	4.000	0.667	s	123.0	1.00
2	69.9% Nitric Acid	28.200	20.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.002	0.002	l	123.0	1.00
4	Nitric Oxide	14.101	12,819.255	g	123.0	1.00
5	Unfiltered Redwine	18.101	10.334	l	60.0	1.00
6	Gold/Platinum	0.020	0.001	s	60.0	1.00
7	Redwine	18.081	10.333	l	20.0	1.00
8	29.9% Ammonium Hydroxide	12.919	14.354	l	20.0	1.00
9	Deionized Water	143.541	143.541	l	20.0	1.00
10	100% Acetic Acid	0.251	0.239	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	174.792	168.467	l	20.0	1.00
13	Iron Hydroxide	0.087	0.017	s	20.0	1.00
14	Vinegar	174.704	168.450	l	36.0	1.00
15	88% Formic Acid	3.388	2.871	l	36.0	1.00
16	Carbon Dioxide	3.239	12.832	g	36.0	1.00
17	Unfiltered Muddy Water	178.092	171.321	s/l	36.0	1.00
18	Deionized Water	180.000	180.000	l	20.0	1.00
19	Waste Filtrate	352.392	347.521	l	20.0	1.00
20	Wet Palladium Powder	5.700	3.800	s/l	20.0	1.00
21	Water Vapor	1.900	1.900	g	80.0	1.00
22	Dry Palladium Powder	3.800	1.900	g	80.0	1.00
23	50.0% Sodium Hydroxide	17.904	19.514	l	25.0	1.00

TABLE 9

Palladium Processing Facility Flow Sheet
5.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	5.000	0.833	s	123.0	1.00
2	69.9% Nitric Acid	35.250	25.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.003	0.003	l	123.0	1.00
4	Nitric Oxide	17.626	16,024.068	g	123.0	1.00
5	Unfiltered Redwine	22.626	12.918	l	60.0	1.00
6	Gold/Platinum	0.025	0.001	s	60.0	1.00
7	Redwine	22.601	12.917	l	20.0	1.00
8	29.9% Ammonium Hydroxide	16.148	17.943	l	20.0	1.00
9	Deionized Water	179.426	179.426	l	20.0	1.00
10	100% Acetic Acid	0.314	0.299	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	218.490	210.584	l	20.0	1.00
13	Iron Hydroxide	0.109	0.021	s	20.0	1.00
14	Vinegar	218.380	210.563	l	36.0	1.00
15	88% Formic Acid	4.234	3.589	l	36.0	1.00
16	Carbon Dioxide	4.049	16.040	g	36.0	1.00
17	Unfiltered Muddy Water	222.615	214.151	s/l	36.0	1.00
18	Deionized Water	225.000	225.000	l	20.0	1.00
19	Waste Filtrate	440.490	434.401	l	20.0	1.00
20	Wet Palladium Powder	7.125	4.750	s/l	20.0	1.00
21	Water Vapor	2.375	2.375	g	80.0	1.00
22	Dry Palladium Powder	4.750	2.375	g	80.0	1.00
23	50.0% Sodium Hydroxide	22.380	24.393	l	25.0	1.00

TABLE 10

Palladium Processing Facility Flow Sheet
6.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	6.000	1.000	s	123.0	1.00
2	69.9% Nitric Acid	42.300	30.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.004	0.003	l	123.0	1.00
4	Nitric Oxide	21.152	19,228.882	g	123.0	1.00
5	Unfiltered Redwine	27.152	15.502	l	60.0	1.00
6	Gold/Platinum	0.030	0.002	s	60.0	1.00
7	Redwine	27.122	15.500	l	20.0	1.00
8	29.9% Ammonium Hydroxide	19.378	21.531	l	20.0	1.00
9	Deionized Water	215.311	215.311	l	20.0	1.00
10	100% Acetic Acid	0.377	0.359	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	262.188	252.701	l	20.0	1.00
13	Iron Hydroxide	0.131	0.026	s	20.0	1.00
14	Vinegar	262.056	252.675	l	36.0	1.00
15	88% Formic Acid	5.081	4.306	l	36.0	1.00
16	Carbon Dioxide	4.858	19.248	g	36.0	1.00
17	Unfiltered Muddy Water	267.138	256.982	s/l	36.0	1.00
18	Deionized Water	270.000	270.000	l	20.0	1.00
19	Waste Filtrate	528.588	521.282	l	20.0	1.00
20	Wet Palladium Powder	8.550	5.700	s/l	20.0	1.00
21	Water Vapor	2.850	2.850	g	80.0	1.00
22	Dry Palladium Powder	5.700	2.850	g	80.0	1.00
23	50.0% Sodium Hydroxide	26.856	29.271	l	25.0	1.00

TABLE 11

Palladium Processing Facility Flow Sheet
7.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	7.000	1.167	s	123.0	1.00
2	69.9% Nitric Acid	49.350	35.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.004	0.004	l	123.0	1.00
4	Nitric Oxide	24.677	22,433.695	g	123.0	1.00
5	Unfiltered Redwine	31.677	18.085	l	60.0	1.00
6	Gold/Platinum	0.035	0.002	s	60.0	1.00
7	Redwine	31.642	18.083	l	20.0	1.00
8	29.9% Ammonium Hydroxide	22.608	25.120	l	20.0	1.00
9	Deionized Water	251.196	251.196	l	20.0	1.00
10	100% Acetic Acid	0.440	0.419	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	305.885	294.818	l	20.0	1.00
13	Iron Hydroxide	0.153	0.030	s	20.0	1.00
14	Vinegar	305.733	294.788	l	36.0	1.00
15	88% Formic Acid	5.928	5.024	l	36.0	1.00
16	Carbon Dioxide	5.668	22.456	g	36.0	1.00
17	Unfiltered Muddy Water	311.661	299.812	s/l	36.0	1.00
18	Deionized Water	315.000	315.000	l	20.0	1.00
19	Waste Filtrate	616.686	608.162	l	20.0	1.00
20	Wet Palladium Powder	9.975	6.650	s/l	20.0	1.00
21	Water Vapor	3.325	3.325	g	80.0	1.00
22	Dry Palladium Powder	6.650	3.325	g	80.0	1.00
23	50.0% Sodium Hydroxide	31.332	34.150	l	25.0	1.00

TABLE 12

Palladium Processing Facility Flow Sheet
8.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	8.000	1.333	s	123.0	1.00
2	69.9% Nitric Acid	56.400	40.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.005	0.004	l	123.0	1.00
4	Nitric Oxide	28.202	25,638.509	g	123.0	1.00
5	Unfiltered Redwine	36.202	20.669	l	60.0	1.00
6	Gold/Platinum	0.040	0.002	s	60.0	1.00
7	Redwine	36.162	20.667	l	20.0	1.00
8	29.9% Ammonium Hydroxide	25.837	28.708	l	20.0	1.00
9	Deionized Water	287.081	287.081	l	20.0	1.00
10	100% Acetic Acid	0.502	0.478	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	349.583	336.935	l	20.0	1.00
13	Iron Hydroxide	0.175	0.034	s	20.0	1.00
14	Vinegar	349.409	336.900	l	36.0	1.00
15	88% Formic Acid	6.775	5.742	l	36.0	1.00
16	Carbon Dioxide	6.478	25.664	g	36.0	1.00
17	Unfiltered Muddy Water	356.184	342.642	s/l	36.0	1.00
18	Deionized Water	360.000	360.000	l	20.0	1.00
19	Waste Filtrate	704.784	695.042	l	20.0	1.00
20	Wet Palladium Powder	11.400	7.600	s/l	20.0	1.00
21	Water Vapor	3.800	3.800	g	80.0	1.00
22	Dry Palladium Powder	7.600	3.800	g	80.0	1.00
23	50.0% Sodium Hydroxide	35.808	39.028	l	25.0	1.00

TABLE 13

Palladium Processing Facility Flow Sheet
9.0 Kg Production Batch Size

Stream No. =====	Description =====	Mass (Kg) =====	Volume (l) =====	Phase =====	Temp. (C) =====	Pres. (Atm) =====
1	Palladium Sponge	9.000	1.500	s	123.0	1.00
2	69.9% Nitric Acid	63.450	45.000	l	123.0	1.00
3	37.2% Hydrochloric Acid	0.005	0.005	l	123.0	1.00
4	Nitric Oxide	31.728	28,843.323	g	123.0	1.00
5	Unfiltered Redwine	40.728	23.252	l	60.0	1.00
6	Gold/Platinum	0.045	0.002	s	60.0	1.00
7	Redwine	40.683	23.250	l	20.0	1.00
8	29.9% Ammonium Hydroxide	29.067	32.297	l	20.0	1.00
9	Deionized Water	322.967	322.967	l	20.0	1.00
10	100% Acetic Acid	0.565	0.538	l	20.0	1.00
11	Ammonia Vapors	nil	nil	g	20.0	1.00
12	Unfiltered Vinegar	393.281	379.051	l	20.0	1.00
13	Iron Hydroxide	0.197	0.038	s	20.0	1.00
14	Vinegar	393.085	379.013	l	36.0	1.00
15	88% Formic Acid	7.622	6.459	l	36.0	1.00
16	Carbon Dioxide	7.287	28.872	g	36.0	1.00
17	Unfiltered Muddy Water	400.707	385.472	s/l	36.0	1.00
18	Deionized Water	405.000	405.000	l	20.0	1.00
19	Waste Filtrate	792.882	781.922	l	20.0	1.00
20	Wet Palladium Powder	12.825	8.550	s/l	20.0	1.00
21	Water Vapor	4.275	4.275	g	80.0	1.00
22	Dry Palladium Powder	8.550	4.275	g	80.0	1.00
23	50.0% Sodium Hydroxide	40.284	43.907	l	25.0	1.00