Process, Price, Production (Demand), Reserves, and Applications

When judging an abrasive's overall economic value, components such as abrasive cost, equipment cost, labor cost, cleaning rate, disposal and cleanup expense, and product reusability should be considered.

The following formula was used to determine the total cost of blast cleaning per square foot in a blast abrasive journal article [Better Roads November 1986]:

$$CLEANING\ \ COSTS(\$/SQ.FT.) = \frac{\frac{A(P+D)}{R}+E+L}{X}$$

A = Abrasive flow rate, ton/hr.
P = Delivered price of abrasive, $/ton.
D = Abrasive disposal cost, $/ton.
R = Number of times abrasive is used.
E = Equipment costs, $/hr.
L = Labor costs, including cleanup, $/hr.
X = Abrasive cleaning rate, sq. ft./hr

The same formula was used in another blast journal article for four nonmetallic abrasives without considering recycling capabilities and disposal costs [Seavey 1985]. Performance quality and productivity tests were conducted on the alternative abrasives coal slag, copper slag, and staurolite in comparison to silica sand. Abrasive flow rates, cleaning rates, profiles, and total operating costs were determined for all of these abrasives from tests using 5/16", 3/8", and ½" long venturi nozzles on new millscale-bearing steel at nozzle pressures of 60, 80, 100, 120, and 140 psi. The alternative abrasives had faster cleaning rates and reduced labor and total operating costs as reported in this article by Seavey [Seavey 1985].

End-users may implement available information from their particular blasting operation into this formula to demonstrate that the total cost of their blasting operation involves more than the selling price of their abrasive. Time spent on examining a job from all perspectives can offer significant cost savings. This cost savings can be achieved by determining the nature of the surface to be cleaned, defining the cleanliness required for the coating to be used, choosing the proper abrasive, optimizing the use of equipment and personnel, and taking into consideration the conditions and restrictions under which the work will be done [Better Roads November 1986, Seavey 1985]. Tables 7-8 and 10-13 show productivity and cost comparisons for substitute abrasives versus silica sand. Tables 9 and 14 show cost comparisons for garnet and steel grit versus coal slag. Most of these cost comparisons were produced by abrasive substitute producers who obtained information from their customers, consultants that were hired to perform tests on their products versus silica sand, or from their own personnel. Therefore, potential users of the substitutes abrasives may wish to contact the abrasive substitute producers about the tests that were performed or the information that was gathered to obtain greater detail for the data and results in these tables.

Table 1. Physical Properties of Blasting Abrasives				
Abrasive	**Shape**	**Hardness (MOHS)**	**Bulk Density (lbs/ft^3)**	**No. Uses**
Sand	Rounded Irregular	5.0-7.0	100	1
Staurolite	Rounded Irregular	6.5-7.0	128-148	1* 5**
Garnet	Subangular	7.0-8.0	130-147	3-5* 4-10**
Olivine	Angular	6.5-7.0	90-109	1
Specular hematite	Semi-rounded	6.5-7.0	183.5	6-7**
Coal Slag	Angular	6.0-7.0	75-100	1
Copper Slag	Angular	7.0-8.0	110	1* many**
Nickel Slag	Angular	7.0-8.0	110	1
Crushed Glass	Angular Irregular	5.5-6.5	75	1
Steel Grit	Angular	40-70 Rockwell C	260	50-100* 200-1500**
Aluminum Oxide	Irregular	9.0	120-131	3-5* 15-20**

*Some of the more conservative number of uses that have been listed for steel grit, aluminum oxide, and garnet are 50-100, 3-5, and 4-10 [Austin 1991 and Williams, 1986].

**Abrasive blasting suppliers estimates for the number of times that steel grit, aluminum oxide, and garnet may be reused are: 1500, 20, and 10 times; depending on the grade of material that is used. However the maximum number of uses listed by suppliers often rely on ideal field conditions in abrasive blasting such as low moisture, etc. that do not always exist.

If supplier did not mention abrasive as capable of being recycled in product brochures, it was assumed to be an expendable abrasive which could not be recycled.

Source of data is from [Austin 1991; Williams 1986; company brochures and material safety data sheets from suppliers listed in the Supplemental Reference Section XV].

Table 2. Chemical Composition of Blasting Abrasives* (by Percent Weight)**

Chemical	Sand*	Staurolite	Garnet	Olivine	Specular hematite	Coal Slag	Copper Slag	Nickel Slag	Crushed Glass	Steel Grit	Aluminum Oxide
Silicon Dioxide (SiO_2)**	90-100%	29%	36-38%	39-46%	<1.0%	45-51%	45%	37-51%	72.5%	0.3-1.3%	0.5-1.7%
Crystalline-silica(SiO_2)	49-96%	<5.0%	<.8%	<0.3%	<1.0%	<1.0%	0.1%	<0.1%			
Aluminum Oxide (Al_2O_3)		45%	20-26%	0.2-2.3%	0.34%	14-26%	7.2%	1.5-6.6%	0.16%		92-97%
Specular hematite (Fe_2O_3) or (FeO)		14% (Fe_2O_3)	30-33% (FeO) or (Fe_2O_3)	6-11% (FeO) or (Fe_2O_3)	98.18% (Fe_2O_3)	18-21% (Fe_2O_3)	23.3% (Fe_2O_3)	12-20% (Fe_2O_3)	0.2% (Fe_2O_3)		0.1-1.5% (Fe_2O_3)
Calcium Oxide (CaO)		0.07%	1.0-2.0%	0.2-1.2%	0.060%	4.3-8.2%	19.6%	0.5-2.5%	9.18%		0.14-0.18%
Magnesium Oxide (MgO)		0.75%	1.0-6.0%	39-49%	0.05%	1.0-2.0%	3.7%	4.7-33%	3.65%		0.23-0.30%
Titanium Oxide TiO_2)		4.2%	<=2.0%		0.18%	<1.3%					1.6-4.0%
Potassium Oxide (K_2O)		0.1%				<1.9%		<1.3%	0.12%		0.05-0.08%
Sodium Oxide (Na_2O)		0.18%				<1.1%			13.2%		0.07-0.12%
Manganese Oxide (MnO)		0.1%	1.0%			<0.06%					
Iron (Fe)										>95.0%	
Carbon (C)						<0.4%				0.7-1.3%	
Manganese (Mn)					0.026%					0.5-1.3%	
Sulfur (S)					0.026%			<1.2%		<0.05%	
Sulfur Trioxide (SO_3)						<0.6%			0.39%		
Zirconium (Zr)		3.3%	<0.20%								
Zircon Oxide (ZrO)			<=1%								
Phosphorous (P)					0.011%					<0.05%	
Chromium(Cr)				0.1-0.4%	0.002%					<0.2%	
Nickel (Ni)				0.1-0.3%	0.009%			0.1-0.45%		<0.2%	
Radioactivity Picocuries/gram						15-19.8					
#MSDS's for results	2	1	3	2	1	5	1	2	1	4	8

*The remaining portion of the silica sand abrasive composition consists of water or moisture content and loss on ignition.

**The silicon dioxide chemical includes both non-crystalline and crystalline silica.

***Source of data is from company brochures and material safety data sheets from suppliers listed in the Supplemental Reference Section XV.

Table 3. Range of Values for Elements of Blasting Abrasives (by ug/g)

Element	Sand # (2)	Staurolite # (4)	Garnet # (4)	Olivine # (2)	Specular Hematite # (1)	Coal Slag # (18)	Copper Slag # (7)	Nickel Slag # (3)	Crush Glass # (6)	Steel Grit # (8)	Aluminum Oxide # (6)
Aluminum (Al)*	110-2200	200-860	1400-10000	210-950	270	2600-77000	130-37000	2600-33000	ND-95	ND-500	690-1800
Antimony (Sb)**							ND-500	ND			
Arsenic (As)***	ND	ND	ND	ND	ND	ND-90	ND-1450	ND-180	ND	ND-350	ND
Barium (Ba)***	1-11	ND-10	ND-18	ND-4.8	6.6	13-9900	ND-700	ND-300	ND	ND	ND-33
Beryllium (Be)***	ND	ND	ND	ND	ND	ND-48	ND-180	ND	ND	ND	ND
Calcium (Ca)*	ND-4900	23-490	630-170000	80-970	210	650-41000	650-140000	1500-1700	29-350	ND-2200	10-890
Cadmium (Cd)*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cobalt (Co)*	ND-1.8	ND	ND-4.6	83-110	6.7	ND-31	31-50	24-870	ND-4	40-100	ND
Chromium (Cr)***	ND-4.1	ND-10	ND-6.4	45-370	ND	ND-200	ND-2400	540-3700	ND-2	80-3600	ND-8
Copper (Cu)***	ND-4.4	ND	ND	ND-4.5	3.9	ND-92	1340-6400	17-70	ND	440-1500	ND
Gallium (Ga)**						ND-27					
Iron (Fe)*	360-5300	220-1300	3400-140000	36000-47000	230000	4200-74000	3900-140000	36000-320000	ND-26	840000-100000	30-3500
Lead (Pb)***	ND	4-13	ND	ND-64	ND	ND-20	ND-8900	ND-70	18-220	ND-120	ND-9
Lithium (Li)*	ND-1.8	ND	ND	ND-7.7	ND	ND-100	ND-30	ND	ND	ND	ND-53
Magnesium (Mg)*	ND-3000	4-12	220-820	200000-260000	310	100-5700	1600-24000	22000-56000	ND-49	ND-1700	ND-270
Manganese (Mn)***	2.6-100	10-13	100-700	560-710	190	ND-600	ND-2900	440-1100	ND-1	550-9600	1-230
Molybdenum (Mo)***	ND	ND	ND	ND	ND	ND-11	ND-480	ND	ND	50-700	ND
Nickel (Ni)***	ND	ND	ND	1900-2400	ND	ND-99	ND-2240	830-2400	ND	380-2300	ND
#Samples analyzed by NIOSH 1993-94	2	4	4	2	1	6	2	2	6	8	6
#Samples analyzed by [Stettler 1982]	0	0	0	0	0	12	5	1	0	0	0

*Element data is from bulk samples that were analyzed by NIOSH in 1992-93.

**Antimony data is from one nickel slag and five copper slag bulk samples and gallium is from twelve coal slag bulk samples that were analyzed in a study by Stettler et al in 1982.

***Element data is from bulk samples that were analyzed by NIOSH in 1992-93 and coal, copper, and nickel slag bulk samples that were analyzed in a study by Stettler et al in 1982.

ND stands for Non-Detectable.

#Number of samples analyzed.

Table 3 Continued. Range of Values for Elements of Blasting Abrasives (by ug/g)											
Element	**Sand # (2)**	**Staurolite # (4)**	**Garnet # (4)**	**Olivine # (2)**	**Specular Hematite # (1)**	**Coal Slag # (18)**	**Copper Slag # (7)**	**Nickel Slag # (3)**	**Crush Glass # (6)**	**Steel Grit # (8)**	**Aluminum Oxide # (6)**
Niobium (Nb)**						10-24	ND-24	ND			
Phosphorous (P)*	ND-100	30-60	ND-240	39-130	ND	ND-650	ND-1600	80-470	ND	850-1200	ND-50
Platinum (Pt)*	ND	ND	ND-160	ND-30	280	ND	ND	ND	ND	ND	ND
Rubidium (Rb)**						31-108	ND-10	ND			
Scandium (Sc)**						ND-700	ND-500	ND			
Selenium (Se)***	ND	ND	ND	ND	ND	ND-5	ND-70	ND	ND	ND-570	ND
Silver (Ag)*	ND	ND	ND	ND	ND	ND	ND-6	ND	ND-14	ND	ND
Sodium (Na)*	16-99	90-260	ND-130	ND-360	58	80-2200	280-1000	90-7600	71-640	ND	20-570
Strontium (Sr)**						210-4600	77-208	5			
Tellurium (Te)*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium (Tl)*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tin (Sn)**							ND-1260	15			
Titanium (Ti)***	1.6-230	390-1000	33-570	3-25	66	88-10000	28-2100	47-250	ND-5	ND-140	3-950
Vanadium (V)***	ND-8.9	4-15	2.3-33	ND-12	20	ND-400	ND-160	ND-60	ND	ND-200	ND-14
Yttrium (Y)***	ND-3.4	ND-6	ND-31	ND	ND	ND-65	ND-27	ND	ND	ND	ND-32
Zinc (Zn)***	0.74-8.1	2	3-13	26-46	19	ND-240	133-52000	28-210	2-60	40-90	ND-8
Zirconium (Zr)***	ND-5.0	8-14	ND-22	ND	13	ND-270	ND-850	ND-50	ND	ND	2-430
#Samples analyzed by NIOSH in 1993-94	2	4	4	2	1	6	2	2	6	8	6
#Samples analyzed by [Stettler, 1982]	0	0	0	0	0	12	5	1	0	0	0

* Element data is from bulk samples that were analyzed by NIOSH in 1992-93.

** Element data is from one nickel, twelve coal, and five copper slag bulk samples that were analyzed in a study by Stettler et al in 1982 (tin data came only from the one nickel and five copper slag bulk samples).

*** Element data is from bulk samples analyzed by NIOSH in 1992-93 and one nickel, twelve coal, and five copper slag bulk samples that were analyzed in a study by Stettler et al in 1982.

ND stands for Non-Detectable.

Number of samples analyzed.

Table 4. NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients			
Ingredient	**NIOSH REL**	**OSHA PEL**	**ACGIH TLV**
Aluminum Oxide (Al_2O_3)	NONE ESTABLISHED	15 mg/m^3 total 5 mg/m^3 resp.	10 mg/m^3 total A4
Arsenic (As) metal & inorganic cmpds.	CARCINOGEN 0.002 mg/m^3 [15 min]	0.010 mg/m^3	0.01 mg/m^3 A1
Barium (Ba) soluble cmpds. (except Barium sulfate)	0.5	0.5	0.5mg/m^3 A4
Beryllium (Be) metal & cmpds.	CARCINOGEN 0.0005 mg/m^3[ceiling]	0.002 mg/m^3 [TWA] 0.005 mg/m^3 [ceiling] 0.025 mg/m^3 [30 min max peak]	0.01 mg/m^3 A1
Calcium Oxide (CaO)	2 mg/m^3	5 mg/m^3	2 mg/m^3 A4
Carbon Black (C)	CARCINOGEN 3.5 mg/m^3	3.5 mg/m^3	3.5 mg/m^3
Chromium (Cr) as metal	0.5 mg/m^3	1 mg/m^3	0.5 mg/m^3 A4
Chromium, hexavalent Cr(IV) compounds	CARCINOGEN 0.001 mg/m^3	NONE ESTABLISHED	0.5 mg/m^3
Cobalt (Co) metal, dust & fume	0.05 mg/m^3	0.1 mg/m^3	0.02 mg/m^3 A3
Copper (Cu) dusts & mists	1 mg/m^3	1 mg/m^3	1 mg/m^3
Iron Oxide (Fe_2O_3) dust & fume	5 mg/m^3	10 mg/m^3	5 mg/m^3 A4
Lead (Pb)	0.100 mg/m^3	.050 mg/m^3	0.05 mg/m^3 A3

CARCINOGEN: The RELs for carcinogens listed in Table 4 still reflect the old NIOSH policy for potential occupational carcinogens (described in Section VI), since the NIOSH Pocket Guide to Chemical Hazards still reflects this policy. Changes in the RELs that reflect the new NIOSH policy for potential occupational carcinogens will be included in future editions of the NIOSH Pocket Guide to Chemical Hazards.

A1: ACGIH classified as "Confirmed Human Carcinogen": The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies of, or convincing clinical evidence in, exposed humans.

A3: ACGIH classified as "Animal Carcinogen": The agent is carcinogenic in experimental animals at a relatively high dose, by route(s) of administration, at site(s), of histologic type(s), or by mechanism(s) that are not considered relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence suggests that the agent is not likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.

A4: ACGIH classified as "Not Classifiable as a Human Carcinogen": There are inadequate data on which to classify the agent in terms of its carcinogenicity in humans and/or animals.

Source: American Conference of Government Industrial Hygienists (ACGIH) [1997]
NIOSH [1994a]

Table 4. Continued. NIOSH RELs, OSHA PELs, & ACGIH TLVs for Blasting Abrasive Ingredients			
Ingredient	**NIOSH REL**	**OSHA PEL**	**ACGIH TLV**
Magnesium Oxide (MgO)fume	NONE ESTABLISHED	15 mg/m^3	10 mg/m^3
Manganese (Mn) cmpds. & fume	1 mg/m^3 3 mg/m^3[15 min]	5 mg/m^3 [ceiling]	0.2 mg/m^3
Molybdenum (Mo)	NONE ESTABLISHED	15 mg/m^3	5 mg/m^3 Soluble 10 mg/m^3Insoluble
Nickel (Ni) metal & other compounds	CARCINOGEN 0.015 mg/m^3	1 mg/m^3	1 mg/m^3 Insoluble 0.1 mg/m^3 Soluble
Phosphorous (P)	0.1 mg/m^3	0.1 mg/m^3	0.1 mg/m^3
Platinum (Pt)	1 mg/m^3	NONE ESTABLISHED	1 mg/m^3 metal 0.002 mg/m^3 soluble salts
Selenium (Se)& cmpds	0.2 mg/m^3	0.2 mg/m^3	0.2 mg/m^3
Crystalline Silica (SiO_2): as respirable quartz	CARCINOGEN .05 mg/m^3	$\frac{10\ mg/m^3}{\%\ silica + 2}$	0.1 mg/m^3
Crystalline Silica (SiO_2): as total quartz	CARCINOGEN .05 mg/m^3	$\frac{30\ mg/m^3}{\%\ silica + 2}$	0.1 mg/m^3
Crystalline Silica (SiO_2): as cristobalite	CARCINOGEN .05 mg/m^3	½ x Quartz formula	0.05 mg/m^3
Crystalline Silica (SiO_2): as tridymite	CARCINOGEN .05 mg/m^3	½ x Quartz formula	0.05 mg/m^3
Titanium Dioxide (TiO_2)	CARCINOGEN	15 mg/m^3	10 mg/m^3 A4
Vanadium (V) as V_2O_5 dust	0.05 mg/m^3 [15 min.]	0.5 mg/m^3 (resp.)	0.05 mg/m^3 resp. dust or fume A4
Vanadium (V) as V_2O_5 fume	0.05 mg/m^3 [15 min.]	0.1 mg/m^3 (resp.)	0.05 mg/m^3 resp. dust or fume A4
Yttrium (Yt)& cmpds.	1 mg/m^3	1 mg/m^3	1 mg/m^3
Zirconium (Zr) & cmpds.	5 mg/m^3 10 mg/m^3 [15 min.]	5 mg/m^3	10 mg/m^3 A4

CARCINOGEN: NIOSH has not identified thresholds for carcinogens that will protect 100% of the population. NIOSH usually recommends that occupational exposures to carcinogens be limited to the lowest feasible concentration.

A4: ACGIH classified as “Not Classifiable as a Human Carcinogen”: There are inadequate data on which to classify the agent in terms of its carcinogenicity in humans and/or animals.

Reference: American Conference of Government Industrial Hygienists (ACGIH) [1997]
NIOSH [1994a]

Table 5. 1992 Average U.S. Selling Prices for Other Blasting Abrasives vs Silica Sand	
Blasting Abrasive	**Price per Ton**
Silica Sand	$10-$65
Corn Cob	$225
Nut Shells	$360
Cast Iron Shot	$440
Glass Beads	$500
Sodium Bicarbonate	$900
Sponge	$1,600
Carbon Cut Wire	$2,000
Zirconia Alumina	$2,400
Polymer Carbohydrate	$3,400
Plastic Media	$3,700
Zinc Cut Wire	$4,000
Silicon Carbide	$4,000
Zirconium Silica	$5,000
Aluminum Cut Wire	$6,000
Stainless Steel Cut Wire	$6,500

Source of data is from company brochures from suppliers listed in the Supplemental Reference Section XV, the Paumanock Publications Inc. document entitled "The U.S. Market For Blasting Abrasives - 1992-1997 Analysis" [Paumanock Publications, Inc. 1992].

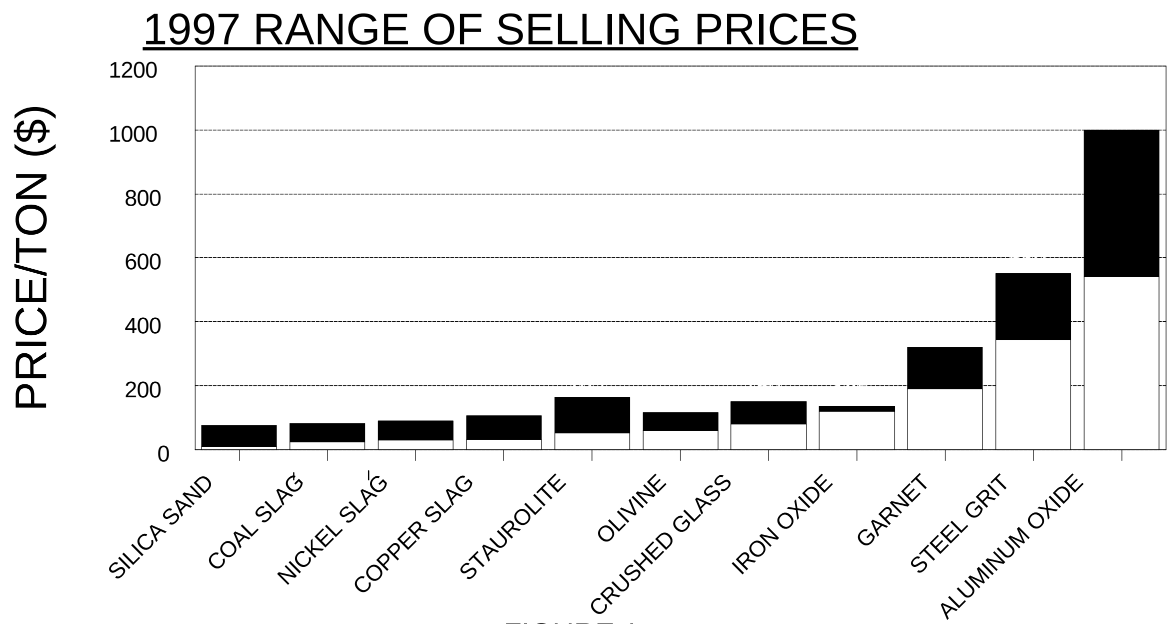

FIGURE 1

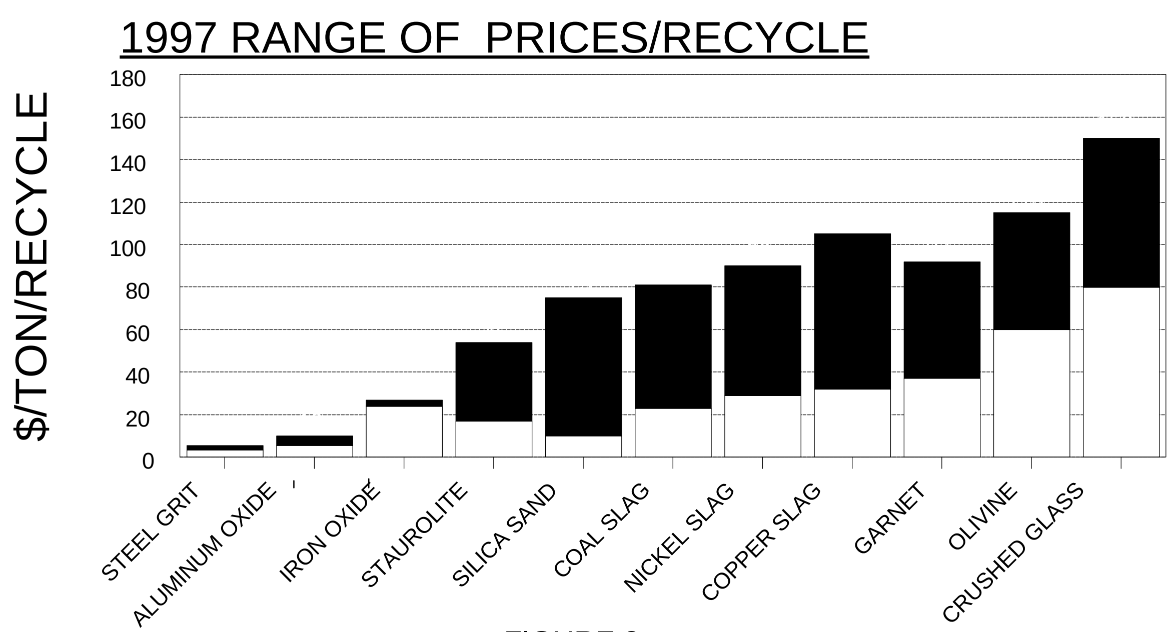

FIGURE 2

Table 6. Location of Major Blasting Abrasive Producers FOB Shipping Points by Abrasive Type	
Blasting Abrasive	**Major Producers FOB Shipping Points**
Sand	**MANY**
Coal Slag	**AL, FL, IL, IN, KS, KY, LA, MD, MN, NH, NJ, OH, SC, TN, TX, VA, WI, WV**
Copper Slag	**AZ, MT, OR, PA, TX**
Steel Grit & Shot	**CANADA, MD, MI, OH, PA**
Staurolite	**FLORIDA**
Nickel Slag	**OR & MID-CANADA**
Crushed Glass	**TN, OH, WA**
Glass Beads	MO, MI, NJ
Aluminum Oxide	**MA, MD, NY**
Garnet	**BC-CANADA, ID, NC, NY**
Specular hematite	**Eastern Canada**
Corn Cob	IL, OH
Sodium Bicarbonate	CT, NJ, SC, TX
Nut Shells	MO, PA
Plastic Media	CT, IN, NY, TN
Olivine	**IN, NC, WA**
Cut Wire Shot	CT, MI, NY
Silicon Carbide	MA, NY
Zirconia Alumina	MA
Polymer Carbohydrate	MN
Zirconium Silica	NJ
Sponge	ME

Silica sand and the primary substitute abrasives for silica sand for abrasive blasting are listed in bold print.

Reference: Price lists/brochures from suppliers listed in the Supplemental Reference Section XV and the Bureau of Mines document entitled "Abrasive Materials 1992" [Austin, 1993].

Table 7. E.I. DuPont De Nemours & Company/Chemicals & Pigments Division Cost Comparison: Silica Sand vs. Staurolite		
	Silica Sand	**Staurolite**
Abrasive Used (lbs.)	2400	900
Blasting Time (min.)	72	43
Delivered Cost ($/ton)	29	120
Disposal Cost ($/ton)	22	22
Total Prep. Cost ($)	61.20	63.90
Labor Savings	None	29 min. or 40% of time

BACKGROUND:

Table 7 shows the results of an evaluation of DuPont's Starblast versus a silica sand blasting media which was used to clean one side of a 10 feet by 22.5 feet piece of new carbon steel that had weathered. Note that the material cost of preparing one side of steel was essentially equal though the delivered cost of Starblast was over four times that of silica sand. When labor savings is considered, Starblast is more economical. The added benefits from Starblast of low dusting, low silica exposure, better profile, etc. are in addition to the monetary savings obtained from reduced abrasive material and labor costs. The abrasives were not recycled in this test. Further savings may be achieved by recycling abrasives.

Although this information is believed to be accurate, Du Pont recommends that all Starblast applications be analyzed individually. Similar results are possible, but final savings may be more or less than this case. Please consult DuPont or one of its authorized Starblast distributors for more information.

Reference: Staurolite - Supplemental Reference Section XV. E.I. DuPont De Nemours & Company. Chemicals & Pigments. Chestnut Run Plaza. P.O. Box 80709. Wilmington, DE 19880-0709.

Table 8. JPCL Journal Cost Comparison: Silica Sand vs. Staurolite		
	Silica Sand	**Staurolite**
Labor Cost to Blast 1000 sq. ft.	$230	$105
Abrasive Cost ($/ton)	$30	$99
Total Cost to Blast 1000 sq. ft.	$310	$190
Abrasive Cost to Blast 1000 sq. ft.	$80	$85
Percent of Total Cost for Labor	74%	55%

BACKGROUND:

Table 8 shows the results of an evaluation of silica sand versus staurolite for a 3/8" nozzle at 120 psi on new millscale-bearing steel, using the formula listed below.

$$CLEANING\ \ COSTS(\$/SQ.FT.) = \frac{\frac{A(P+D)}{R} + E + L}{X}$$

A = Abrasive flow rate, ton/hr.
P = Delivered price of abrasive, $/ton.
D = Abrasive disposal cost, $/ton.
R = Number of times abrasive is used.
E = Equipment costs, $/hr.
L = Labor costs, including cleanup, $/hr.
X = Abrasive cleaning rate, sq. ft./hr

This formula was used in a blast journal article for four nonmetallic abrasives without considering recycling capabilities and disposal costs [Seavey 1985]. Performance quality and productivity tests were conducted on the alternative abrasives coal slag, copper slag, and staurolite in comparison to silica sand. Abrasive flow rates, cleaning rates, profiles, and total operating costs were determined for all of these abrasives from tests using 5/16", 3/8", and ½" long venturi nozzles on new millscale-bearing steel at nozzle pressures of 60, 80, 100, 120, and 140 psi. The nonmetallic alternative abrasives had faster cleaning rates and reduced labor and total operating costs as shown in Figures 8-12 and Tables 6-7 of this journal article [Seavey 1985].

Source is Journal of Protective Coatings & Linings article entitled "Abrasive Blasting Above 100 psi [Seavey 1985].

Table 9. GMA Pty. Ltd./Barton Mines Corporation Garnet Cost Comparison: Garnet vs. Coal Slag @ Shipyard		
	GMA GARNET	**US NAVY COAL SLAG**
AREA CLEANED - SQ. FT.	51	50
TIME - MIN.	11.8	18.5
MATERIAL USED - LBS	177	540
ESTIMATED CONSUMPTION - LB/HR	900	1750
CLEANING EFFICIENCY - LB/SQ.FT.	3.47	10.8
CLEANING RATE - SQ.FT./HR	259	162
ABRASIVE COST - $/TON	300	65
DUST GENERATION	VERY LOW	HIGH
TOTAL COST - $/SQ.FT.	$1.17	$1.78

BACKGROUND:

Table 9 shows the results of an evaluation of GMA garnet blasting media which was completed at a large east coast U.S. shipyard during May, 1992. The GMA garnet and a U.S. Navy approved coal slag were compared for production rate, dust generation, anchor pattern, and total blasting cost. The evaluation was carried out on a newly constructed vessel with 8 - 15 mils of primer and protective coat. Yard air was used and was found to fluctuate between 80 - 85 psi at the blast nozzle. Two blasters were employed. Anchor patterns of about 2.0 Mils (1 Mil = 1/1000th inch) were obtained with the GMA garnet, and the "white metal" surface that was cleaned with the garnet was judged to be superior in all ways. Use of higher pressures would result in proportionally higher cleaning rates and slightly deeper anchor patterns. The following formula was used to calculate the cleaning costs for each abrasive in units of $\$/ft^2$. The cleaning cost calculations are provided.

$$CLEANING\ \ COSTS(\$/SQ.FT.) = \frac{\frac{A(P+D)}{R} + E + L}{X}$$

$$COAL\ \ SLAG = \frac{\frac{.875(\$65+\$150)}{1} + \$50 + \$50}{162} = \$1.78/ft^2$$

$$GARNET = \frac{\frac{.45(\$300+\$150)}{1} + \$50 + \$50}{259} = \$1.17/ft^2$$

A = Abrasive flow rate, ton/hr. Garnet = 0.45. Coal slag = 0.875.
P = Delivered price of abrasive, $/ton. Garnet = $300/ton. Coal slag = $65/ton.
D = Abrasive disposal cost $/ton (assumed $100/ton trucking & disposal + $50/ton cleanup cost = $150/ton total).
R = Number of times abrasive is used = 1 (neither abrasive was reused for this task)
E = Equipment costs, $/hr (assumed to be $50/ton).
L = Labor costs, including cleanup, $/hr (assumed to be $50/ton).
X = Abrasive cleaning rate, sq. ft./hr. Garnet = 259. Coal slag = 162.
Reference: Garnet - Supplemental Reference Section XV. GMA Pty. Ltd./ Barton Mines Corporation.

Table 10. Unimin Corporation Cleaning Rates: Olivine vs. Competitive Abrasives		
	Mill Scale Panel Cleaning Rate (Ft^2/min)	**Painted Panel Cleaning Rate (Ft^2/min)**
GL20x46 olivine	1.00	1.10
GL30 olivine	1.00	0.85
GL40 olivine	1.00	1.30
GL70 olivine	1.20	0.90
staurolite	1.00	0.88
coal slag	0.95	1.10
silica sand	0.66	0.89
nickel slag	0.95	0.74
garnet	1.00	1.20

BACKGROUND:

Unimin Corporation evaluated the performance properties of its olivine versus competitive abrasives when applied on tight mill scale-bearing steel and on polyamide epoxy-coated steel. Table 10 shows the cleaning rates for both mill scale panels and painted panels using a nozzle pressure of 100 psi pressure using various grades of Unimin Corporation's Green Lightning Olivine versus alternative abrasives. A nozzle pressure of 100 psi was used.

Reference: Olivine - Supplemental Reference Section XV. Unimin Corporation.

Table 11. Les Sables Olimag Inc. Efficiency Analysis: Olivine vs. Silica Sand		
ABRASIVE	JJ2 JETMAG 16-60 OLIVINE	SILICA SAND
WEIGHT	200 LBS	200 LBS
COVERED SURFACE (SQ.FT.)	75.2	44.3
TIME	20 MINUTES	20 MINUTES
CLEANING QUALITY	COMMERCIAL	COMMERCIAL
DUST GENERATION	LOW	HIGH
ABRASIVE CONSUMPTION (LB/SQ.FT)	2.7	4.5
ABRASIVE SPEED (SQ.FT/MIN)	3.8	2.2
COST COMPARISON		
TIME (BASIS OF 8 HOURS OF WORK WITH SILICA: 1056 SQ.FT/DAY)	4.6 HRS	8 HRS
LABOR, FUEL, AND ABRASIVE EQUIPMENT COSTS ($60/HR)	$276	$480
LBS OF ABRASIVE FOR 1056 SQ.FT	2,851	4,752
TOTAL ABRASIVE COST (FOB MONTREAL) SILICA: $70/M.T. OLIVINE: $125/M.T.	$162	$151
TOTAL COSTS	$438	$631
DAILY SAVINGS USING OLIVINE	$193	

BACKGROUND:

Table 11 shows an efficiency analysis (Sanivan at Alcan) for daily cost comparisons of Olimag's Jetmag 16-60 synthetic olivine versus silica sand that was printed in an Olimag product brochure. This table shows that other factors besides initial cost can reduce the daily operating costs of a blasting operation. This cost comparison includes reduced labor, fuel and equipment costs along with reduced abrasive material costs.

Reference: Olivine - Supplemental Reference Section XV. Les Sables Olimag Inc.

Table 12. Waupaca Materials/Faulks Brothers Construction, Inc. Cost Comparison: Coal Slag vs. Silica Sand		
	2040 Blackjack COAL SLAG	**2340 SILICA SAND**
MATERIAL COST (100# BAG)	$2.76	$1.43
COVERAGE FOR 100#	32 SQ.FT.	10 SQ.FT.
BLASTING COST/SQUARE FOOT	.09	.14
HOURLY BLASTING COVERAGE	240 SQ.FT./HR	75 SQ.FT./HR

BACKGROUND:

In addition to the data shown in Table 12, Waupaca Materials/Faulks Brothers Construction, Inc. includes a letter from the Wisconsin Compensation Rating Bureau (WCRB)in Milwaukee as part of their reference material. WCRB cites "silica sand abrasive blasters would pay $50 per $100 of payroll under workman's compensation code #5469, whereas coal slag abrasive blasters would pay a rate of $10.30 per $100.00 of payroll under workman's compensation code #5474. The savings realized would be about $39.00 per $100.00 of payroll."

Reference: Coal Slag - Supplemental Reference Section XV. Waupaca Materials/Faulks Brothers Construction, Inc.

Table 13. Clemco, Inc. Annual Cost Comparison: Sand vs. Steel Grit		
	SILICA SAND	**STEEL GRIT**
Consumption Rate	1,000 lb/hr	2,500 lb/hr
Blasting time 4 hrs/day x 5 days/wk x 52 wks/yr	1,040 hrs/yr	1,040 hrs/yr
Abrasive use (No recovery using 3/8" nozzle	520 tons/yr (.5 tons/hr)	1,300 tons/yr (1.25 tons/hr)
Abrasive use (Using Clemco 3x3 hopper recovery system	520 tons/yr (no recovery)	6.5 tons/yr (200 cycles/ton)
Labor use Loading and unloading	346 hrs/yr (40 min/ton)	13 hrs/yr (15 min/wk)
Abrasive material cost based on average price	$20,800 ($40/ton)	$3,900 ($600/ton)
Labor Cost loading/unloading Average of $15/hr	$5,190	$195
Total annual cost	$25,990	$4,095
Total annual savings using Clemco 3x3 hopper recovery system: $21,985		

BACKGROUND:

Table 13 demonstrates why blasting in indoor, enclosed environments should be conducted with a recyclable abrasive such as steel grit. Clemco has a 3x3 hopper recovery system which includes a recessed hopper to collect spent abrasive; a bucket elevator to transport it to an air wash, and a rotary screen abrasive cleaner which returns clean abrasive to the blast machine. It is important to use state-of-the-art blast recovery systems, since leakage of expensive steel grit could cause the abrasive material cost of a blasting operation to increase significantly.

The costs shown in Table 13 decrease as the number of times the abrasive can be recovered increases. Table 13 shows the savings realized by a typical plant after switching from a nonrecoverable abrasive such as silica sand to steel grit, which can be recovered up to 200 times. Using steel grit can be 4 to 5 times less expensive than using silica sand. The figures used in Table 13 are exemplary figures, such as the average price of silica sand of $40/ton. The price of sand varies according to the region of the country where it is sold, but averaged about $24/ton in 1996. However, the selling price range of silica sand is approximately $15-$45/ton. So using $40/ton as the selling price would be using a price from the upper end of the silica sand selling price range.

Note: Exemplary figures only, Clemco Industries Corporation. requests end-users to substitute their own figures to make the above comparison chart applicable to their own blasting operation.

Reference: Steel Grit - Supplemental Reference Section XV. Clemco Industries Corporation.

Table 14. (Materials Performance/Coatings & Linings) Annual Cost Comparison: Nonrecycled Slag vs. Steel Grit		
	SLAG	**STEEL GRIT**
Consumption rate	1500 lb/hr	3500 lb/hr
Blasting time (6 hrs/day x 250 days/yr)	1500 MH/yr/operator	1500 MH/yr/operator
Abrasive use/yr (No recovery)	1500 lb/hr x 1500 man-hr/yr ÷ (2000 tons/lb) = 1125 tons/yr	3500 lb/hr x 1500 man-hr/yr ÷ (2000 tons/lb) = 2625 tons/yr
Abrasive use/yr using SABAR recovery system	1125 tons/yr (No recovery)	17.5 tons/yr (150 cycles/ton)
Abrasive cost/ton (Average price)	$50/ton	$450/ton
Abrasive Materials Cost per operator/yr	1125 tons x $50/ton = $56,250	17.5 tons x $450/ton = $7,875
Total annual abrasive materials cost savings using steel grit: $56,250 - $7,875 = $48,375		
Add $50/ton for reduced handling & disposal costs: $48,375 + (1125 tons - 17.5 tons) x $50/ton = $103,750 Total annual savings.		

BACKGROUND:

Table 14 shows the cost justification for the use of steel grit and a SABAR system (Steel Abrasive Blasting and Recovery System). The SABAR is a portable blast and recovery system that the manufacturer claimed can be used in normal outdoor blasting situations. This comparison is based on blasting operations that use ½ inch nozzles at 100 psi and 330 CFM. Under these conditions, each operator will use approximately 1500 pounds of sand or mineral slag per hour or 3500 pounds of steel grit per hour. The average delivered cost for one ton of each of the following abrasives is: slag, $50; steel grit, $450. This comparison assumes a total blasting time of 6 man-hours(MH)/day x 250 days/yr = 1500 man-hrs (MH)/yr for each operator. It also assumes that the steel grit will be properly contained and recycled. Labor costs were not included in this cost comparison.

Note: Exemplary figures only, please substitute their own figures to make the above comparison chart applicable to their own blasting operation.

Reference: Geise [1988] Materials Performance/Coatings & Linings Journal.

Table 17. Toxicology Ratings for Blasting Abrasives

	Fibrogenic	Carcinogenic	Other
Iron oxide	--	-	In vitro toxicity (+)
Nickel slag	-	+/-	Contains carcinogenic metals (+)
Copper slag	-	+	Contains carcinogenic metals (+)
Aluminum oxide	+	0	Neurotoxicity (++)
Olivine	+	++	Immune effects (+)
Coal slag	++	0	Cytotoxic, inflammatory (+++)
Silica Sand	++++	++	Acute silicosis, cytotoxic, inflammatory (+++)
Crushed glass	0	0	Acute inflammation (+)
Staurolite	0	0	In vitro & in vivo toxicity (++)
Garnet	0	0	In vitro & in vivo toxicity (++)
Treated sand	0	0	In vitro & in vivo toxicity (++)
Steel grit	0	0	0

Scoring:

Highly positive	++++
Highly negative	----
Equivocal data	+/-
Insufficient data	0

Table 18. NIOSH-Recommended Respiratory Protection for Workers Exposed to Respirable Crystalline Silica

Condition	Minimum respiratory protection* required to meet the NIOSH REL for crystalline silica (50 μg/m³)#
≤500 μg/m³† (10 x REL)‡	Any air-purifying respirator with a high-efficiency particulate filter
≤1,250 μg/m³ (25 x REL)	Any powered, air-purifying respirator with a high-efficiency particulate filter, or
	Any supplied-air respirator equipped with a hood or helmet and operated in a continuous-flow mode (for example, type CE abrasive blasting respirators operated in the continuous-flow mode)
≤2,500 μg/m³ (50 x REL)	Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter, or
	Any powered, air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter
≤50,000 μg/m³ (1,000 x REL)	Any supplied-air respirator equipped with a half-mask and operated in a pressure-demand or other positive-pressure mode
≤100,000 μg/m³ (2,000 x REL)	Any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode (for example, a type CE abrasive blasting respirator operated in a positive-pressure mode)
Planned or emergency entry into environments containing unknown concentrations or concentrations ≤500,000μg/m³† (10,000 x REL)	Any self-contained breathing apparatus equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode, ** or
	Any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode**
Firefighting	Any self-contained breathing apparatus equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode**
Escape only	Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter, or Any appropriate escape-type, self-contained breathing apparatus

*Only NIOSH/MSHA-approved equipment should be used.
†≤ is less than or equal to; > is greater than.
‡Assigned protection factor (APF) times the NIOSH REL. The APF is the level of protection provided by each type of respirator.
#These recommendations are intended to protect workers from silicosis; only the most protective respirators are recommended for use with carcinogens.
**Most protective respirators.