A Pollution Prevention Project Report to:

The United State Environmental Protection Agency
EPA Region 2
290 Broadway
New York, NY 10007-1866

On the topic of

Recycling of Two-Stroke Marine Engines

By

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Key Project Information

The major project goals were to develop an understanding of the raw materials that could arise from a two-stroke marine engine recycling program, in an effort to replace two-stroke marine engines with more environmentally friendly four-stroke engines, as well as to identify recycling opportunities that either exist already or that could be easily developed for these materials. The project addressed Region 2 priorities: [1] promoting environmental purchasing and [2] reducing the incidence of chemicals of national concern. The underlying premise is that if there is significant value from a recyclable materials standpoint in older, two-stroke marine engines, then it may be possible to accelerate the retirement of these engines through some type of trade-in program that does not exist at this time.

Recycling of Two-Stroke Marine Engines

Background

The EPA targeted two-stroke marine engines as engines that produce more pollution than four-stroke engines. Consequently, the EPA is interested in the replacement of these engines with four-stroke engines as quickly as possible in order to have the maximum environmental benefit. The goals of the proposed research project were to

1. Perform general characterization of the metals and plastics derived from two-stroke marine engines
2. Identify the best practices for dismantling the engines
3. Process samples of the thermoplastic materials found in the highest percentages to determine the feasibility of incorporating these materials into new products or new and more efficient marine engines
4. Investigate various rebate/turn in programs to develop and outline a system to be applied to two-stroke marine engines

The research team obtained a representative sample of recovered engines from a variety of the largest marine engine manufacturers, dismantled the engines, and determined the materials content. Members of the Marine Trades Association of New Jersey donated engines to the project. The engines covered a range of sizes and were produced over a span covering decades. The two-stroke engines collected for the study were Johnson 6, Johnson 9.9, Yamaha 55, Mercury 50, and Mercury Force 70, and they appear in Figures 1 – 4, respectively.

Figure 1: Johnson 6 two-stroke marine engine

Figure 2: Johnson 9.9 two-stroke marine engine

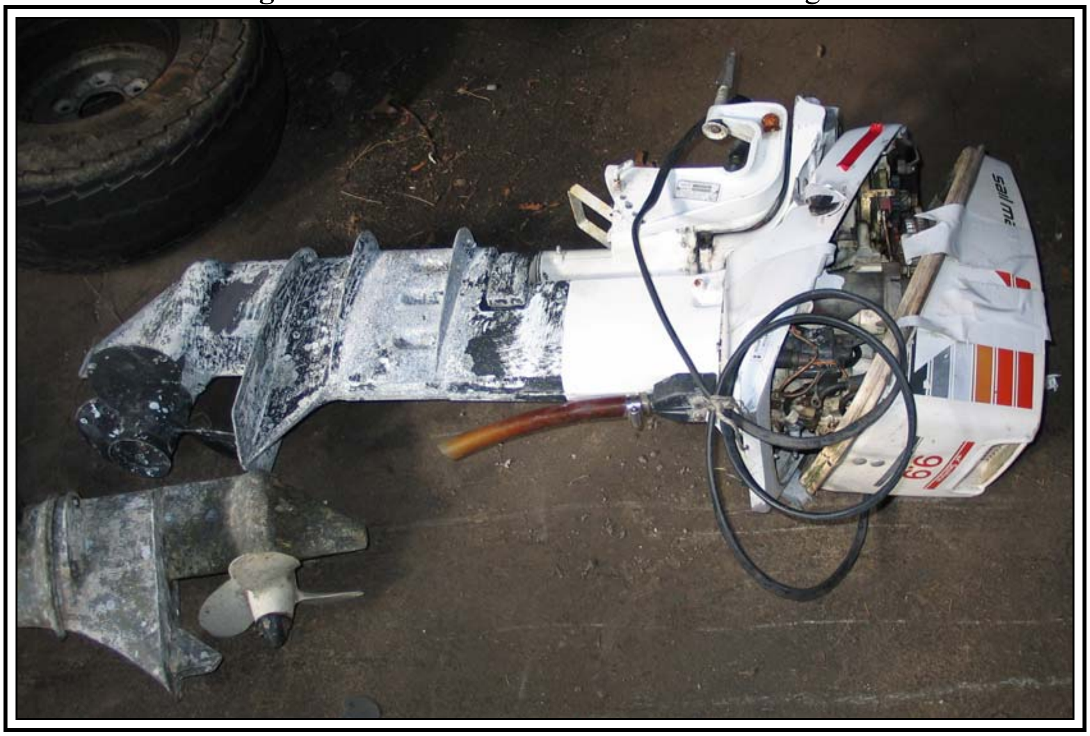


Figure 3: Yamaha 55 two-stroke marine engine

Figure 4: Mercury 50 two-stroke marine engine

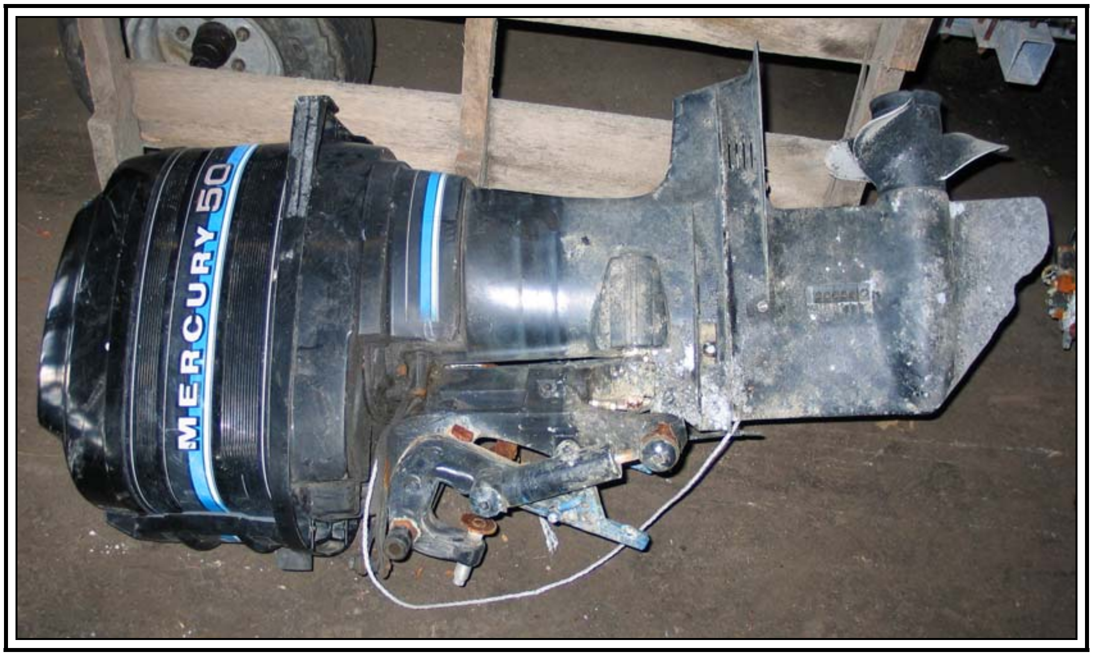


Figure 5: Mercury Force 70 two-stroke marine engine

Results

Each two-stroke marine engine was mounted and dismantled by hand. The recovered materials were separated by type and weighed for each engine. In dismantling the two-stroke marine engines, it was discovered that all of the engines have an aluminum frame, aluminum engine block, steel crankshafts and power output shafts, copper for wiring, and a small quantity of plastic.

The scale used to weigh the various recovered materials appears in Figure 6, an engine mounted for dismantling appears in Figure 7, researchers dismantling an engine is displayed in Figure 8, a dismantled motor appears in Figure 9, recovered aluminum from the Johnson 9.9 two-stroke marine engine appears in Figure 10, and recovered copper is displayed in Figure 11.

Figure 6: Weighing scale

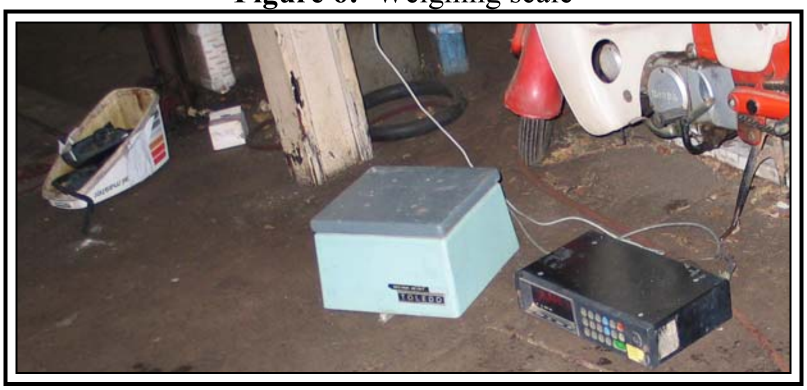


Figure 7: A two-stroke marine engine mounted for dismantling

Figure 8: Researchers dismantling a two-stroke marine engine.

Figure 9: A dismantled two-stroke marine engine motor

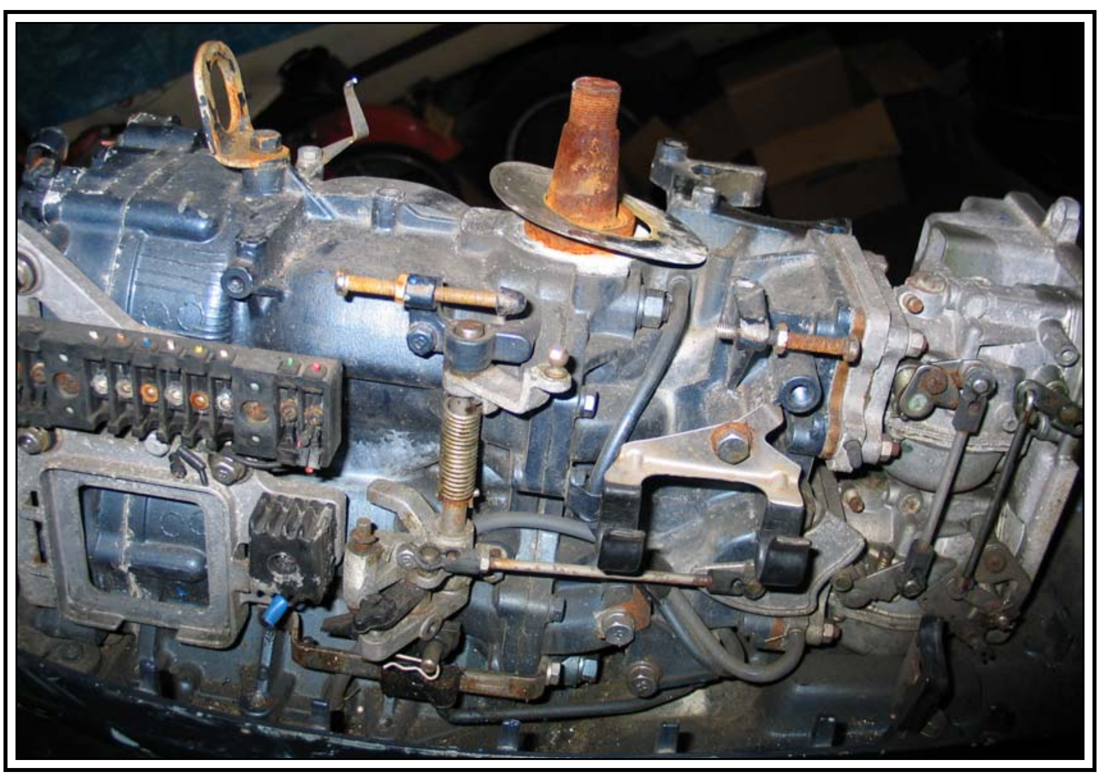
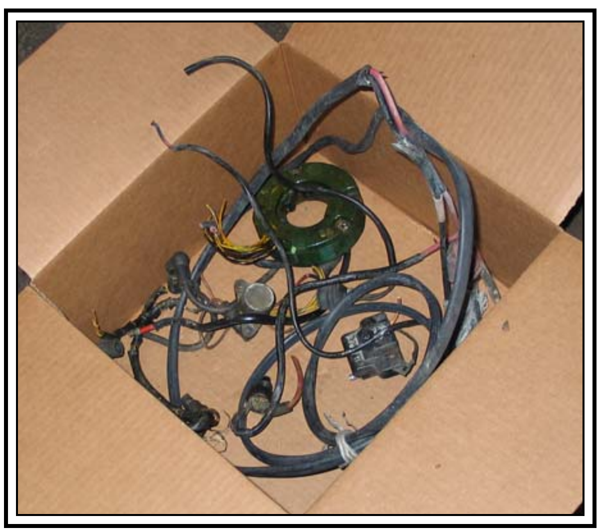


Figure 10: Recovered aluminum from the Johnson 9.9 two-stroke marine engine

Figure 11: Recovered copper



The materials recovered from the two-stroke marine engines are sorted into categories of stainless steel, aluminum, copper, and plastic. The resulting total percentages of each material appear in Figure 12. Differences were observed in the construction and materials of the engines, according to the age of the engines. The older engine, the Mercury 50, has an aluminum hood, while the newer Johnson 9.9 and Mercury Force 70 have plastic hoods. The Mercury 50 most likely dates from the late 1960s while the Mercury Force 70 is most likely less than 5 years old.

The recovered plastics were characterized using a Perkin Elmer Fourier Transform Infrared Spectrometer with photoacoutstic detector and a TA Q1000 Differential Scanning Calorimeter. Results show that the older Johnson 9.9 hood is composed of Sheet Molding Compound (SMC), made of some polyethylene and a variety of fillers, while the newer Mercury Force 70 hood is composed of a thermoset polymer with a high percentage of fiberglass. These types of plastics are not recyclable. The remaining plastics are nylon and rubber with trace amounts of PVC and PP. The percentage of each type of plastic within the total amount of plastics (3.8 % of the total engine weight) is shown in Figure 13. There is little opportunity or value in the plastic portion of two-stroke marine engines.

Figure 12: Percentages of recovered materials from two-stroke marine engines

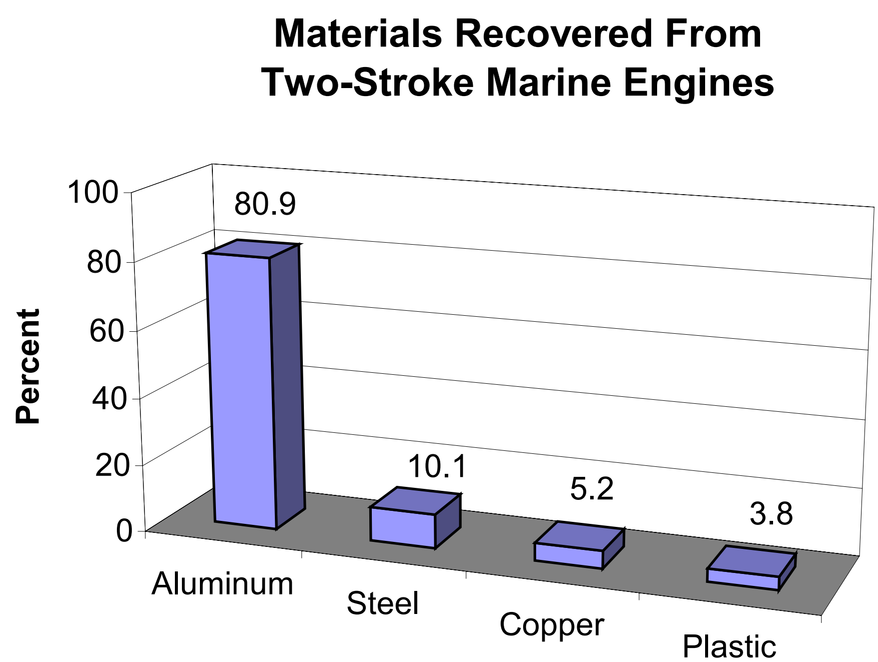
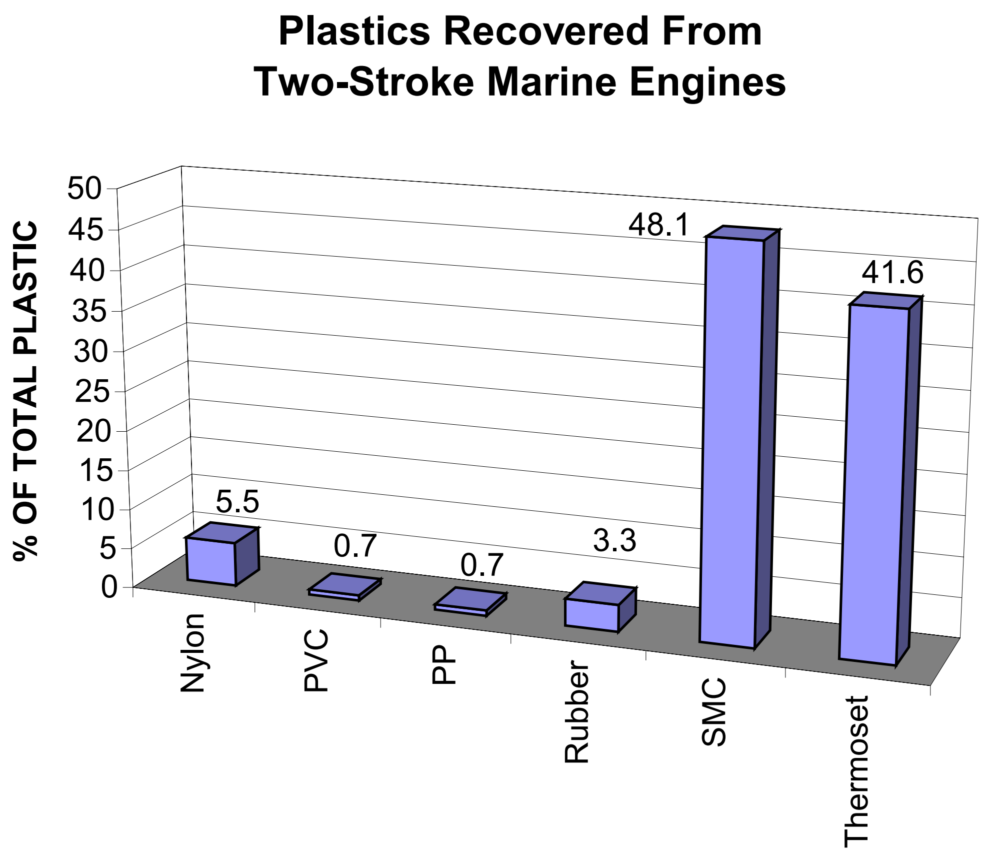


Figure 13: Percentages of each type of plastic within the total amount of plastics Recovered from two-stroke marine engines



Published Engine Weights

The following tables display published engine weights for Evinrude and Johnson, Honda, Mariner, Mercury, Selza, Suzuki, Tohatsu, and Yamaha engines.[i] The labels are defined as: cc - cubic capacity; Cyl - number of cylinders; Inj - fuel injection system (carburettor, EFI, DFI); St - start method (M - manual, E - electric); ET - electric trim/tilt (Yes, No); Wt - weight in kg; Sh - shaft lengths (S - standard, M - medium, L - Long, XL - xtra-long); * - confirmed 1999 prices. Other entries are 1998 rates that may be subject to change. Prices quoted include VAT.

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Evinrude and Johnson								
Johnson 35 2-str	565	3	Carb	E/Man	Y	73	S, L	3646*
Johnson 50 2-str	737	2	Carb	E	Y	86	S, L	3289*
Evinrude 50 4-str	815	3	EFI	E	Y	108	L	3735*
Johnson 70 2-str	920	3	Carb	E	Y	113	L	4601*
Evinrude 70 4-str	1298	4	EFI	E	Y	149	L	6519*
Evinrude 90FICHT 2-str	1726	4	DFI	E	Y	145	L, XL	7094*
Evinrude 115FICHT 2-str	1726	4	DFI	E	Y	145	L, XL	7906*
Evin/John 150FICHT 2-str	2589	6	DFI	E	Y	184	L, XL	9563*

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Honda								
BF30 4-str	499	3	Carb	E/recoil	N	64	L	2889
BF40 4-str	808	3	Carb	E	N	89	L	3800
BF50 4-str	808	3	Carb	E	N	89	L	4259
BF75 4-str	1590	4	Carb	E	Y	163	L	5999
BF90 4-str	1590	4	Carb	E	Y	163	L	6699
BF115 4-str	2254	4	EFI	E	Y	225	L	7799
BF130 4-str	2254	4	EFI	E	Y	229	L	8299

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Mariner								
40 2-str	644	2	Carb	E	Y	75	L	3295
50 4-str	935	4	Carb	E	Y	102	L	4195
60 2-str	967	3	Carb	E	Y	100	L	3995
75 2-str	1386	3	Carb	E	Y	139	L	4995
135 2-str	1998	6	Carb	E	Y	185	L	6995
135 2-str OptiMax	2507	6	DFI	E	Y	200	L	8995

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Mercury								
40 2-str	645	2	Carb	E	Y	75	L	2919*
50 2-str	967	3	Carb	E	Y	99.5	L	3679*
50 4-str	935	4	Carb	E	Y	102	L	4519*
60 2-str	967	3	Carb	E	Y	99.5	L	4079*
75 2-str	1386	3	Carb	E	Y	139	L, XL	5029*
135 2-str	1998	6	Carb	E	Y	185	L, XL	7129*
135 2-str OptiMax	2507	6	DFI	E	Y	200	L	9109*
150 2-str	2507	6	EFI	E	Y	185	L, XL	7939*
150 2-str OptiMax	2507	6	DFI	E	Y	206	L, XL	9529*

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Selva								
Madeira 40 2-str	684	2	Carb	E	Y	72	S, L, XL	2529*
Madeira 50 2-str	684	2	Carb	E	Y	72	S, L, XL	3045*
St Tropez 60 2-str	831	3	Carb	E	Y	104	L, XL	3813*
Teneriffe 70 2-str	831	3	Carb	E	Y	109	L, XL	4019*
Portofino 80 2-str	1025	3	Carb	E	Y	109	L, XL	4098*
Montecarlo 90 2-str	1367	4	Carb	E	Y	136	L, XL	5051*
Montecarlo 100 2-str	1367	4	Carb	E	Y	136	L, XL	5164*
Portocervo 65 2-str twins	2 x 831	2 X 3	Carb	E	Y	2 x 118	L, XL	8724*
Portocervo 80 2-str twins	2 x 1025	2 x 3	Carb	E	Y	2 x 118	L, XL	8890*

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Suzuki								
DT40 2-str	696	2	Carb	E, M	Option	77	L	2399*
DT55 2-str	891	3	Carb	E	Y	103	L	3239*
DF60 4-str	1298	4	EFI	E	Y	152	L	4999*
DT65 2-str	891	3	Carb	E	Y	111	L	3599*
DF70 4-str	1298	4	EFI	E	Y	152	L	5499*
DT75 2-str	1197	3	Carb	E	Y	123	L	4499*
DT90 2-str	1419	4	Carb	E	Y	153	L	5309*
DT100 2-str	1419	4	Carb	E	Y	153	L	5699*
DT115 2-str	1773	4	EFI	E	Y	172.5	L	5939*
DT140 2-str	1773	4	EFI	E	Y	172.5	L	6299*

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Tohatsu								
M40D2 2-str	697	3		E	Y	85	S	3109*
M50D2 2-str	697	3		E	Y	85	S	3184*
M60C 2-str	938	3		E	Y	105	S	3742*
M70C 2-str	938	3		E	Y	105	S	4346*
M90A 2-str	1267	3		E	Y	125	S	5236*
M120A2 2-str	1768	4		E	Y	154	S, L	6218*
M140A2 2-str	1768	4		E	Y	154	S, L	6436*

Model/hp	cc	Cyl	Inj	St	ET	Wt	Sh	Price
Yamaha								
40 Hitec 2-str	698	3	Carb	E	Option	71-88	S, L	From 2699
40 Origin 2-str	703	2	Carb	E, M	Option	72-80	S, L, XL	From 2499
50 Hitec 2-str	849	3	Carb	E	Option	71-102	L	From 2999
55 Origin 2-str	760	2	Carb	E	Option	91-99	L	From 3299
60 Hitec 2-str	849	3	Carb	E	Option	95-105	L	From 3699
70 Hitec 2-str	849	3	Carb	E	Y	105	L	5319
75 Origin 2-str	1140	3	Carb	E	Y	119	L	4899
85 Origin 2-str	1140	3	Carb	E	Y	119	L	5399
90 Hitec 2-str	1140	3	Carb	E	Y	120	L	6599
100 Hitec	1730	4	Carb	E	Y	167	L	6999
F100 4-str	1596	4	Carb	E	Option	104	L	6899
115 Origin 2-str	1730	4	Carb	E	Y	154	L	6799
115 Hitec 2-str	1730	4	Carb	E	Y	167	L, XL	7299
130 Hitec 2-str	1730	4	Carb	E	Y	167	L, XL	7699
150 Hitec 2-str	2596	6	Carb	E	Y	194	L, XL	8299
150 TRP 2-str		6	Carb	E	Y	198	L	10,499

Published Spot Scrap Metal Prices 8/4/04[ii]

RECYCLENET COMPOSITE INDEX:	30890.00	30890.00	+/- 0.00
RECYCLENET SCRAP METALS INDEX:	7965.00	7965.00	+/- 0.00
Benchmark - Average Market Prices	**10:00 AM Fix**	**Current Market** As of: 23:10 EST	**(+/-)**
Scrap Steel Average (US $/ton):	85.00	85.00	0.00
Scrap Copper Average (US $/lbs):	1.02	1.02	0.00
Scrap Brass Average (US $/lbs):	0.52	0.52	0.00
Scrap Aluminum Average (US $/lbs):	0.71	0.71	0.00
Scrap UBC Average (US $/lbs):	0.72	0.72	0.00
Scrap Zinc Average (US $/lbs):	0.51	0.51	0.00
Scrap Lead Average (US $/lbs):	0.19	0.19	0.00
Stainless Steel Scrap Average (US $/lbs):	0.27	0.27	0.00

Sample Scrap Value Calculation For a Two-Stroke Marine Engine

Example: 75 hp. Two-stroke 150 kg = 330 lbs Engine
Value= % of metal X weight of engine X metal reclaim price per pound

Material	Calculation	$
Aluminum	0.809 x 330 x 0.71	189.55
Steel	0.101 x 330 x 0.0425	1.41
Copper	0.052 x 330 x 1.02	17.51
Total Metal Scrap Value Of 150 kg Engine	189.55 + 1.41 + 17.51	208.47

Conclusions and Recommendations

Results indicate that two-stroke marine engines are composed primarily of aluminum (80 % of the total engine weight), and recycling these engines to recover aluminum and other metals could prove to be economical. As shown above, metal scrap prices and typical two-stroke engine weights are readily available. Based on current scrap metal prices, a 150 kg engine is worth more than $200 in scrap value, which is significant. However, the plastics content is low (3.8 % of the total engine weight), and thermosets and sheet molding compound are in the largest quantities. Thus, there are insufficient thermoplastics used in the manufacturing of the two-stroke marine engine for recycling and feasibility of incorporating these materials into new products.

Dismantling the engines using wrenches and screwdrivers is not efficient. The best practice for dismantling two-stroke marine engines is to send the engines to an auto shredder company. There, the engines are granulated and separated into metal types by use of a magnet, and aluminum is separated by eddy current separation. Thus, the aluminum, copper, and steel, the materials present in the largest amounts, are recoverable. A rebate or turn in program is a legitimate solution to offer consumers in order to recover the engines. This type of program could potentially pay for the collection of the engines and provide a margin that could be offered to the owners or repair shops as incentive to remove two-stroke engines from circulation, thereby lowering their environmental impact.

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[i] Appeared in DIVER - February 1999.

[ii] http://www.recycle.net/price/metals.html - Current Market Conditions as of TIME: 23:10 EST - Sunday, Mar 14, 2004