Safer Alternatives to Copper Antifouling Paints: Nonbiocide Paint Options

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EXECUTIVE SUMMARY

Copper antifouling paints have been used routinely for many years to protect the hulls of marine vessels from excessive fouling. The copper in the paints acts as a biocide to deter the marine organisms from attaching to the boat hull. The paints are designed to leach copper gradually over time and this process, together with the practices diving companies use to maintain the paints, has led to a buildup of copper in many basins and marinas in California. Copper is considered a toxic pollutant for water quality purposes and, in some cases, regulations have been adopted that require a reduction in copper loading in California water bodies.

Alternatives to copper antifouling paints (copper paints) are being investigated. They include alternative biocide paints based on zinc or organic biocides and nonbiocide paints which provide a slick surface to prevent marine fouling attachment. From an overall health and environmental standpoint, the nonbiocide paints are the best option and a few of the paints recently introduced to the market have performed well in research projects designed to evaluate their properties. The typical life of a copper paint is two to three years before repainting is required. Some of the nonbiocide paints have much longer lives, ranging from five to more than 10 years. In a research project conducted by the Port of San Diego and the Institute for Research and Technical Assistance (IRTA), 46 alternative biocide and nonbiocide paints were tested on panels and a few of the best performing paints were applied to boats. The results indicated that two of the nonbiocide paints, Intersleek 900 and Hempasil X3, were among the best performing paints. The results also indicated that over the life of the paint, using the nonbiocide paints is comparable in cost to using the copper paints. The cost of a nonbiocide paint job is substantially higher than the cost of a copper paint job, however, and this discourages boaters from selecting the nonbiocide paint alternatives.

Copper paints are generally applied over the old copper paint and the paint is commonly rolled on the boat hull. A typical copper paint job cost for a 30 foot boat is about $1,040. The suppliers of the nonbiocide paints recommend that their paints be applied to a stripped hull the first time they are applied and that the paints be sprayed on the hull rather than rolled. Stripping a 30 foot boat can add as much as $2,500 to the paint job cost and spraying the paint can add an additional $1,000. The nonbiocide paints are generally more expensive than copper paint and they often require more coatings and coating steps during the painting process. The cost of a paint job for a nonbiocide paint for a 30 foot boat can range from $5,500 to $6,400 if spraying the paint and stripping the boat hull are required.

This project was sponsored by U.S. EPA Region IX and Cal/EPA's Department of Toxic Substances Control (DTSC) and it was conducted by IRTA. It involved investigating methods of reducing the cost of using and applying the nonbiocide alternative paints. The project focused on:

- panel testing additional emerging nonbiocide paints
- identifying, testing and demonstrating alternative stripping methods
- avoiding the need for stripping by applying the nonbiocide paints over copper paints
- rolling the nonbiocide paints on the boats rather than spraying them
- investigating the feasibility for copper recycling
- testing new and emerging nonbiocide paints and alternative application methods on boats

The panel testing involved inspecting panels with nonbiocide paints every three weeks for one year. During the inspections, the level of fouling, the ease of cleaning the fouling and the coating condition were noted. The results showed that five of the emerging nonbiocide paints performed very well. IRTA selected four of these paints and one additional emerging paint for testing on boats.

Boatyards currently strip boats using either hand sanding methods or chemical strippers. IRTA investigated three alternative abrasive blasting methods that are better than the current methods from a health and environmental standpoint. The three methods, sodium bicarbonate blasting, volcanic rock blasting and dry ice blasting, were tested on a boat that was slated to be demolished. All three methods hold promise and sodium bicarbonate blasting is used today for stripping boats in the San Diego area. Using these methods in place of the hand sanding and chemical stripping used by boatyards today is somewhat less costly. Using the alternative stripping methods for paint jobs, however, does not lower the overall cost of the paint job significantly.

Two alternative paint application methods investigated by IRTA during the project that are effective in reducing the cost of a paint job for nonbiocide paint are rolling the paint on rather than spraying the paint and applying the paint over the old copper paint rather than stripping the boat hull. Of the 10 boats painted with nonbiocide paints during the project, IRTA arranged for eight of them to have the paint rolled on rather than sprayed on the hulls. IRTA also worked with suppliers to test applying the nonbiocide paints over old copper paint for four of the ten boats that were painted. The cost analysis performed by IRTA indicated that the cost of a paint job can be reduced from about $5,500 for a 30 foot boat to about $4,500 by rolling the paint on and to about $2,300 by applying the paint over old copper paint. Although the paint job cost is still higher than the paint job cost for a copper paint, it reduces the cost by roughly 60 percent. The cost analysis also demonstrates that over the life of the paint, it is less costly to use the nonbiocide paint than it is to use the copper paint.

IRTA worked with a copper recycler called World Resources Company to investigate the feasibility of copper recycling for boatyards. The pilot project involved evaluating several samples of three types of waste streams from boatyards. The streams include the dry sanding dust from surface preparation or hand sanding, the waste from media blasting stripping operations and the clarifier waste from high pressure water spraying the boats and wet sanding during surface preparation and stripping. The highest concentrations of copper were found in the dry sanding dust; it ranged from about 35 to 60 percent. IRTA's cost analysis indicates it is cost effective to recycle the copper stream rather than to dispose of the dust as hazardous waste. It may also be cost effective to recycle the copper in the two other streams depending on their makeup. IRTA worked with two boatyards during the project and both decided to recycle their hand sanding dust.

Ten boats were painted with nonbiocide alternative paints during the project. The boats that were painted were owned by individuals, one port, one city, a diving company, an international transport company and a California state agency. Four of the boats had metal hulls and six had fiberglass hulls. The types of boats included dinghys, inflatables, powerboats and sailboats. Eight of the boats were painted with five emerging paints. These were paints that performed well in the panel testing or were modified modified versions of panel tested paints. Two other paints that had been demonstrated to perform well in the earlier Port/IRTA project were also applied to boats. Two of the boats were stripped using sodium bicarbonate blasting. The paints were rolled on eight boats and paints were applied over old copper paint on four of the boats. The paints had been tested on the boats for between two and twenty months when the project was completed. The boats, the paints applied to them and the application methods that were used are shown in Table E-1.

Table E-1 Boats and Application Methods Tested During Project			
Boat/Owner	Paint Tested	Hull	Application Method
Auerbach	Intersleek 900	Stripped	Sprayed
Port of San Francisco	XZM 480 (E)	Stripped	Rolled
Port of San Francisco	XP-A101 (E)	Unpainted	Rolled
City of Newport Beach	Hempasil X3 XA 278 (E)	Stripped—sodium bicarbonate	Rolled
San Diego Diving Service	BottomSpeed (E)	Half stripped, Half Over Copper	Rolled
Heinem	BottomSpeed (E)	Over Copper	Rolled
Pasha	BottomSpeed (E)	Unpainted	Rolled
Cal. Dept. Fish and Game	XZM 480+ hardener (E)	Over Copper	Rolled
Cal. Dept. Fish and Game	SherRelease (E)	Stripped—sodium bicarbonate	Sprayed
Rhodes	Intersleek 900	Over Copper	Rolled
Note: E signifies emerging paint			

The findings indicate that four of the five new and emerging paints seemed to perform well by the end of the project. These included XP-A101, XA 278, BottomSpeed and SherRelease. The other emerging paint, XZM 480, may be peeling in certain spots from the Fish & Game boat and may also be peeling from the City of Newport Beach boat where it was used under the blocks. In some cases, the paints had been applied only a few months before the project was completed so the boats should be observed for a longer term to verify the coating performance.

The findings also indicate that applying the alternative nonbiocide paints over old copper paint and rolling the paint on can reduce the cost of the paint job significantly. The boats where these methods were used were performing well at the end of the project period. Again, since some of the paints were applied recently, the boats must be observed for a longer timeframe to confirm the performance.

The findings also suggest that some high performing nonbiocide paints may not require as frequent cleaning as previously assumed. IRTA investigated whether two of the boats could be cleaned for the first time five or six months after the paint had been applied. In both cases, although the fouling was very heavy, the boats could be cleaned fairly easily and the coating condition after cleaning was very good. Cleaning the nonbiocide paints less frequently could reduce the cost of using the paints since the maintenance cost is high.

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I. INTRODUCTION

For many years, boaters relied on tributyl tin (TBT) paints to prevent fouling from attaching to the hulls of pleasure craft. Excessive fouling can reduce fuel efficiency, speed and maneuverability and can actually cause hull damage. The TBT paints are toxic to marine organisms and were very effective in preventing fouling attachment to the boat hulls. The TBT entering the water from the paints also caused devastation to many marine species and the paints were eventually phased out worldwide for this reason. Over the last few decades, the marine industry has substituted copper antifouling paints for the TBT paints. The paints passively leach a controlled amount of copper into the water near the hull or they rely on ablation to inhibit fouling.

EPA has established water quality standards for toxic pollutants, including copper. Many basins and marinas in California now have copper concentrations that exceed the water quality standards. In particular, in 1996, the San Diego Regional Water Quality Control Board (RWQCB) placed the Shelter Island Yacht Basin in San Diego on the list of the state's Clean Water Act Section 303(d) list of impaired water bodies. A Total Maximum Daily Load (TMDL) regulation that was adopted for the site requires a 76 percent reduction of copper loading over a 17 year period ending in 2022.

The Institute for Research and Technical Assistance (IRTA) is a nonprofit organization established to identify, develop, test and demonstrate safer alternatives in a range of different applications. In 2008, IRTA partnered with the Port of San Diego on an EPA sponsored project designed to find and test viable alternatives to copper antifouling paints (copper paints). The Port/IRTA project was completed in early 2011. The final report entitled "Safer Alternatives to Copper Antifouling Paints for Marine Vessels" can be accessed on IRTA's website at www.irta.us (SDUPD and IRTA, 2011).

The Port/IRTA project was a landmark study that involved conducting panel tests of 46 new and emerging alternative paints and applying the best performing paints to boats. The project assessed the performance, longevity and cost of the alternative paints and compared them to the performance, longevity and cost of copper paints which were considered the baseline. The alternative paints tested in the project included paints containing zinc biocides or organic biocides or both, paints containing zinc oxide, which is not considered a biocide, and nonbiocide paints. The project results indicated that the best alternative paints, from a health and environmental standpoint, are some of the nonbiocide paints. These coatings perform well and the cost of using them over the life of the paint is comparable to the cost of using a copper paint. Even so, the nonbiocide paints have more complex application procedures and requirements and the cost of the paint job itself is much higher than the cost of a paint job for copper paints.

This project was undertaken by IRTA in May, 2010 and it was sponsored by U.S. EPA and Cal/EPA's Department of Toxic Substances Control (DTSC). The focus of the project was to evaluate methods of simplifying and reducing the cost of applying nonbiocide paints and to test additional newly emerging nonbiocide paints. The next section of this document defines the scope of the DTSC/IRTA project based on a description of the different types of alternative paints, their application procedures and the cost of using them.

II. PROJECT APPROACH AND SCOPE

2.1. Characteristics of Alternative Paints

The alternatives to copper antifouling paints can be classified as:

- zinc biocide paints
- organic biocide paints
- zinc/organic biocide combination paints
- zinc oxide only paints
- soft nonbiocide paints
- hard nonbiocide paints

Zinc biocide paints generally contain zinc pyrithone, a zinc biocide that has emerged over the last few years. These paints also often contain zinc oxide which functions as an adjuvant or a material that aids in the effect of another component. Organic biocide paints often contain Econea, a new organic biocide that has emerged in the last few years; Irgarol, Sea Nine or tolylfluanid are also sometimes used as organic biocides. The organic biocide paints also generally contain zinc oxide. Zinc/organic biocide combination paints most often contain zinc pyrithione and an organic biocide, usually Econea. These paints also often contain zinc oxide as well. Zinc oxide only paints contain no biocides. The zinc oxide only paints encountered in the Port/IRTA project are photoactive; the zinc acts as a catalyst in the formation of hydrogen peroxide which seems to repel fouling. Zinc, like copper, is a heavy metal which has a water quality standard. Soft nonbiocide paints contain no biocides or zinc oxide. Rather they are based on silicon compounds and/or fluoropolymers. These paints function as foul release paints which have a smooth surface that makes it more difficult for fouling to attach. Hard nonbiocide paints contain no biocides; they generally contain epoxy and sometimes ceramic.

2.2. Port/IRTA Project

As mentioned in the Introduction, IRTA and the Port of San Diego conducted a three year project that involved testing a range of different types of paints that could serve as alternatives to copper antifouling paints. The project involved conducting panel and boat tests and performing a detailed cost analysis and comparison of the coatings. The results and findings of that project provided the motivation and focus for the current DTSC/IRTA project. Certain aspects of the earlier project that inform the focus of this project are discussed below.

2.2.1. Port/IRTA Panel Test Results

In the earlier Port/IRTA project, 46 alternative paints were tested on panels using a static immersion testing procedure. Twenty-four of the coatings were either hard or soft nonbiocide paints and three were zinc oxide only paints. Five of the alternative paints were organic biocide paints; at least one of these also contained zinc oxide. Eight of the paints contained zinc either in the form of zinc pyrithione or metallic zinc; many of these paints also contained zinc oxide. Finally, the remaining six paints contained both zinc pyrithione and an organic biocide and also, often zinc oxide. More detail on the protocol used for the panel tests is provided in the next section. The panels were tested in two yacht clubs in the Shelter Island Yacht Basin, together with panels containing standard copper coatings as controls. The panel testing was conducted for a four month period from June through September 2008.

The results indicated that 21 of the coatings performed well in the panel testing. The top performing paints either were effective in repelling marine organisms or preventing fouling growth or were relatively easy to clean or both. Two of the top performing coatings in the panel testing were organic biocide only paints and two were zinc oxide only paints. Twelve of the top performers contained zinc pyrithione or both zinc pyrithione and organic biocides, nearly always Econea. Five of the paints were nonbiocide soft paints. No hard nonbiocide paints were judged to perform well, primarily because they are more difficult to clean and the protocol did not take into account their unique characteristics. In general, the organic biocide, zinc oxide only, zinc biocide paints and zinc biocide/organic biocide combination paints that did well in the panel testing were effective in repelling fouling growth during the four month panel testing period and they were also easy to clean. The best performing soft nonbiocide paints generally were easy to clean.

2.2.2. Port/IRTA Boat Testing

In principle, the boat testing phase should have included all the 21 top performing paints, power and sailboats painted with each paint, a range of boat sizes and duplicates. In practice, however, because of resource constraints, the boat testing phase had to be more limited. Accordingly, the top performing paints were classified into three tiers with Tier 1 coatings having the highest priority. Tier 1 paints were the top performing nonbiocide paints. Tier 2 coatings were zinc oxide only or organic biocide only paints. Tier 3 paints were zinc based biocide paints or zinc biocide/organic biocide combination paints. Preference was given to Tier 1 paints but it was also necessary to ensure that at least one boat with a paint representing each of the different types of paint defined earlier in this section be included in the testing so as much could be learned about the types of paints as possible. There were no hard nonbiocide paints that were in the top performers so the best performing paint of this type in the panel testing was selected for the boat testing. The project team solicited boat owners to participate in the project and boatyards in the San Diego area to help in applying them. The decision as to which coatings to apply to the boats was made through coordination of all involved parties.

Fifteen boats in all were painted with the test coatings. Three of the boats, all with nonbiocide paints, were removed from the testing after three months because they did not perform well. The remaining paints were tested for a duration of between 12 and 20 months. The boat testing protocol involved inspecting and cleaning the boats every three weeks for the period and noting the fouling level, the cleaning effort and the condition of the coating. The 12 boats in the longer term testing included seven boats with three soft nonbiocide paints and one hard nonbiocide paint, two boats with two different zinc oxide only paints, one boat with one organic biocide paint, one boat with a zinc biocide paint and one boat with a combination zinc biocide/organic biocide paint.

The results of the boat testing indicated that two soft nonbiocide paints and one zinc pyrithione/organic biocide paint combination performed well during the testing based on high ratings for cleaning effort and coating condition. The zinc oxide only, organic biocide paints and zinc biocide paints had relatively lower ratings.

2.2.3. Port/IRTA Cost Analysis and Comparison

The project team conducted a cost analysis as part of the project and compared the cost of using the alternative paints to the cost of using a copper paint over the life of the paint. For the nine coatings that were tested on boats over the longer term, cost information on paint jobs was obtained from five San

Diego boatyards and the cost of maintaining (cleaning) the paints was gathered from three diving companies who routinely maintain boats in the area. These costs were compared with comparable costs for copper paints.

The analysis indicated that the cost of paint jobs for all of the alternative paints is higher than the cost of a copper paint job. In general, this is because the alternative coatings are more expensive and many of them require more complex application procedures. Copper paints are commonly rolled on the boat and they can be applied over the old copper paint. Virtually all of the nonbiocide paints must be spray applied and cannot be applied over copper but must be applied to a stripped hull when they are applied the first time. In subsequent paint jobs, the coatings can be applied over themselves. Spraying the paints rather than rolling them can add $1,000 to a paint job for a 30 foot boat. The cost of stripping a 30 foot boat may amount to $2,500 or more. Most of the alternative biocide paints and the zinc oxide only paints can be applied over copper paint and they can be rolled on. The copper paints are commonly cleaned by the divers about 15 times per year. The alternative biocide coatings, zinc oxide only paints and the soft nonbiocide paints can be cleaned on the same schedule as the copper paints. The alternative hard nonbiocide paints require more frequent cleaning in the summer months when the fouling is more prevalent because of higher temperatures.

The project analysis indicated that the cost of using the alternative biocide and zinc oxide only paints is higher than the cost of using the copper paints over the life of the paint. This follows from the fact that copper paints commonly last about two years before they must be repainted whereas the life of the alternative paints is generally shorter, in the range of 1.5 years. The analysis also indicated that the cost of using the soft nonbiocide paints is comparable to the cost of using the copper paints over the life of the paint. The paint job cost for the soft nonbiocide paints is much higher but this higher cost is offset by the much longer life of the coatings which may amount to at least 10 years. The analysis indicate that the cost of using the hard nonbiocide alternative paints is somewhat higher than the cost of using the copper paints. Again, the cost of the paint job for these paints is higher but they do have much longer lives. The hard nonbiocide paints must be cleaned more often than the copper paints, however, so the overall cost of using the paint is somewhat higher.

2.2.4. Port/IRTA Project Conclusions

The project findings are that the nonbiocide paints are regarded as the best option for boaters taking into account the costs over the life of the paint and the environmental issues. Two soft nonbiocide paints, Intersleek 900 and Hempasil X3, performed well during the project and are considered the best alternatives. They are referred to as foul release coatings which provide a smooth surface to which fouling cannot easily adhere. These paints are based on silicon and fluoropolymer compounds and they could be cleaned on a three week schedule or somewhat longer throughout the year.

The hard nonbiocide paints, which are generally based on epoxy or ceramic compounds, are a good option except that many of them require more frequent and aggressive cleaning. Most of these paints should be cleaned periodically with a power brush. The paints that require more frequent cleaning are more costly to use over the life of the paint than copper coatings. Some of these paints may be able to be cleaned with the same frequency as a copper paint. In these cases, the costs of using the paints may be comparable to the cost of using the copper paints over the life of the paint.

The zinc oxide paints and zinc biocide paints contain zinc and this is the disadvantage of using these paints. Zinc is already present in many basins and marinas in California because zinc oxide is used in copper paints and zinc metals are routinely used on the boat hulls. More zinc loading could cause the zinc concentrations to exceed the water quality standard over time.

The organic biocide paints are generally based on Econea, a new biocide. This chemical contains several halogens including fluorine, chlorine and bromine. Nearly all halogenated organic materials pose health and/or environmental problems and there is virtually no way of knowing what kind of problems might emerge from use of the new biocide.

Other conclusions from the project involve boat hull cleaning. Part of the reason for the high copper loading in California basins and marinas is the cleaning practices of the divers. Copper hulls may only require very infrequent cleaning over the life of the paint with a very gentle tool. Most divers clean the hulls 15 times a year regardless of whether significant fouling is present, often with relatively aggressive tools. Thus in addition to the copper that leaches from the paint or ablates from the surface, copper is removed during cleaning. It is likely that, if alternative biocide paints and zinc oxide only paints are used, divers will clean them often and aggressively as well. This is likely to result in a buildup of zinc and organic biocides and it will shorten the life of the coating.

2.3. DTSC/IRTA Project Aims

The DTSC/EPA project was initiated about six months before the Port/IRTA project was completed. At that stage, the alternative nonbiocide paints were recognized as the best option from an overall environmental and health standpoint. Using a soft nonbiocide paint is comparable in cost to using a copper paint over the life of the paint. Even so, the cost analysis indicates that the nonbiocide alternative paints are much more expensive to apply and the cost of a paint job is much higher than the cost of a copper paint job. Many boaters, faced with this much higher up-front cost for using the paints, would be discouraged from using the alternatives. In addition, boatyards are much less or not at all familiar with applying the paints so they do not recommend them to boaters. Divers are also less familiar with the paints and are also reluctant to recommend them.

The DTSC/IRTA project was designed to focus exclusively on nonbiocide paint alternatives to copper antifouling paints. The overall aim of the project was to identify and test additional emerging nonbiocide paint alternatives and to find, test and evaluate methods of making the nonbiocide paints less costly and easier to apply and use. Although the Port/IRTA project identified two viable nonbiocide paints, supplier were developing additional nonbiocide paints and these needed testing and evaluation. The Port/IRTA project identified two cost components for nonbiocide paints that increased the up-front cost of paint jobs substantially. These included the requirement that the alternative nonbiocide paints be spray applied rather than rolled on and that the hull be stripped prior to paint application the first time. After the DTSC/IRTA project was initiated, IRTA identified copper recycling as an additional strategy that could reduce the costs of paint jobs at boatyards.

With these factors in mind, IRTA focused the DTSC/IRTA project on six major tasks. These included:

- conducting panel testing of new and emerging nonbiocide paints
- investigating alternative stripping methods
- testing and analyzing applying nonbiocide paints over copper paints
- testing and analyzing rolling application methods
- initiating, analyzing and implementing copper recycling

- conducting boat testing of alternative application methods and emerging nonbiocide paints

2.4. Document Organization

With the six tasks in mind, this document presents the results of the DTSC/IRTA project. Section III of the document describes the panel testing of new and emerging paints that was conducted during the project. The protocol for the testing is described, the findings are presented and the limitations are clearly identified.

Section IV of the document focuses on the methods of reducing the cost and complexity of the coating application procedures. First, the current stripping methods used by boatyards pose health and environmental problems and alternative stripping methods were evaluated. Second, IRTA investigated and tested methods of applying the alternative paints over copper paints so the high cost of stripping could be avoided. Third, during the Port/IRTA project, a few of the nonbiocide paints were applied using rolling instead of spraying and IRTA pursued this method during the DTSC/IRTA project further. Fourth, IRTA examined the possibility that boatyards could recycle the copper from three processes; this could motivate them to use nonbiocide paints and charge less for the paint job.

Section V of the document describes the new and emerging paints that were applied to boats. Ten boats were painted during the project and nearly all of the boats were painted using an alternative stripping method and/or an alternative application method. Most of the boats were also painted with emerging coatings that had not been tested on boats or on boats in California.

Finally, Section VI of the document describes the outreach materials that were designed as part of the project. It also summarizes the results and conclusions of the project.

III. PANEL TESTING

In the earlier Port/IRTA project, the project team conducted panel testing for a four month period to investigate the alternative paints that were potential substitutes for copper antifouling paints. The team developed a protocol for the panel testing based on input from a large working group of interested stakeholders (SDUPD and IRTA, 2011). IRTA, as part of the DTSC/IRTA project, conducted panel tests with the Port of San Diego using the same protocol developed in the earlier project but extended the testing period to one year. In keeping with the aim of the DTSC/IRTA project, most of the paints included in the testing were nonbiocide paints. This section describes the approach to, the protocol for and the results of the panel testing. It summarizes the best performing nonbiocide paints which were then selected for boat testing during the project.

3.1. Description of Panel Testing

Many recreational boats have hulls that are made of fiberglass. Accordingly, the panels that were constructed for the panel testing phase were made of fiberglass. Boat hulls made of fiberglass are covered with a gel coat before hull paint is applied. The panels that were constructed and used for the panel testing were fiberglass panels with a gel coat. Knight & Carver Yacht Center, a boatyard in the San Diego area, cut and prepared the fiberglass panels and painted them with gel coat. The panels were sanded and cleaned to remove contaminants before painting. The size of the panels that were tested was 12 by 12 inches or one foot square.

Polyvinyl chloride (PVC) frames were constructed to hold the panels in position in the water. One-half inch diameter holes were drilled in the corner of the panels three-fourths inch from each side. The panels were attached to the PVC frames with cable tie wraps in all four corners. Three panels were included in each PVC frame and the frames were attached to floating docks in the water so the top of each panel was 12 inches from the surface of the water. A picture of the three panels in a typical panel frame is shown in Figure 3-1.

Figure 3-1. Typical Panel Frame

IRTA talked to a number of suppliers to identify new and emerging nonbiocide paints that could be included in the panel testing. IRTA coordinated with the suppliers and scheduled the panel painting. The panels were painted over a one day period at Knight & Carver Yacht Center and IRTA staff was involved in the panel painting throughout. No prepainted panels were accepted. Most of the suppliers attended the panel painting and applied their own paint to the panels. A few suppliers shipped their paint and provided instructions for the application; in these cases, a Knight & Carver painter applied the paints to the panels. Some of the paints were sprayed on the panels but most paints were applied with rollers. In all cases, both sides of the panels were painted. Figures 3-2 and 3-3 show the panel painting at Knight & Carver. The painted panels were allowed to cure for a few days and, on August 2, 2010, they were attached to three docks at the San Diego Yacht Club for the static immersion testing.

The frames were attached to floating docks to ensure the panels remained submerged at a constant depth for the testing. The panels were placed in boat slips facing east so all panels would receive the same amount of light exposure. The sides of the panels that were examined were those facing east; the west facing sides were shaded by and facing the docks.

Figure 3-2. Supplier Rolling Paint on Panels

The panel tests were conducted for one year. The longer timeframe provides a better platform for predicting how paints will perform on boats than the shorter timeframe used during the Port/IRTA project. In some cases, for instance, the coating deteriorates but that may not be apparent in the four month timeframe. It may not be necessary to test the panels for as long as a year but a four month period is too short to observe some of these effects.

When a paint performs well in panel testing, it does not necessarily mean it will perform well on boats. The ultimate test of a paint is certainly how it performs on boats. Panel testing is useful, however, for screening which coatings may have a chance of performing well on boats. If coatings perform poorly during panel testing, they almost certainly will not perform well on boats whereas coatings that perform well in panel testing have a better chance of performing well on boats.

Figure 3-3. Supplier Spray Painting Panels

3.2. Panel Testing Protocol

A detailed description of the panel testing protocol is provided in Appendix B of the Port/IRTA study final report (SDUPD and IRTA, 2011). Some of the procedures are described here for reference in the discussion that follows. In general, the protocol included visual assessments and numeric rankings that were used to assess the type and level of fouling, the coating condition and the cleaning frequency and suitability of the cleaning tools.

The panels were inspected every three weeks during the panel testing phase. As figure 3-1 shows, all of the panel frames contained three one foot square panels painted on both sides. The first panel remained untouched throughout the panel testing duration. The second panel was cleaned with a three week frequency with a soft, medium to long shag carpet. This procedure was established to mimic standard hull cleaning practices. Diving companies in the San Diego area generally clean boat hulls every three to four weeks and the standard cleaning tool is the carpet. The third panel was cleaned according to the paint manufacturer's specifications for cleaning tool and cleaning frequency.

During each of the three week inspections, one frame at a time was lifted out of the water and placed on the dock for inspection and cleaning. The frame, composed of three panels with the same paint, included PVC "feet" that could be adjusted to hold the frame upright during the inspection. The project team inspected each of the panels, cleaned the appropriate panels and noted the condition of the coating. While one or two team members cleaned the appropriate panels, another team member made sure the panels remained wet with seawater by using a low flow submersible pump immersed in the water on the side of the dock. The procedures for the inspection are briefly described below.

3.2.1. Fouling Assessment

This assessment focused on the type and density of primary biofouling which is fouling that is directly attached to the panel. Secondary fouling, or fouling attached to primary fouling was noted but not included in the fouling rating. Numeric ratings were used to rank the fouling growth for each paint; these ratings were determined using ASTM method D 3623-78a. A Fouling Rating (FR) was assigned to each paint during each inspection both before and after the panel cleaning. The FR ratings ranged from 1 to 5 where 1 represented little to no fouling and 5 represented high levels of fouling.

3.2.2. Cleaning Assessment

One of the major aims of the panel testing was to evaluate the cleaning effort required for each of the paints. Some paints could have a high level of fouling but, if the fouling were easily cleaned, the coating would serve its purpose. As mentioned earlier, the first panel, Panel A, was not cleaned at all during the year of the inspections. The second panel, Panel B, was cleaned every three weeks with a carpet and the third panel, Panel C, was cleaned using a tool and frequency specified by the paint supplier. Each of the panels was cleaned using the appropriate tool and the cleaning effort was noted using a ranking system. The rankings ranged from 1 to 5, with 1 indicating a light effort where the fouling was easily removed with one wipe and 5 indicating the growth could not be removed.

3.2.3. Coating Condition Assessment

During the inspections, the coating condition was also assessed. The method used was based on ASTM D 6990-05 guidelines. Again, a ranking scheme was used for the coating condition. In this case, a 1 rating indicated a new slick finish and 5 signaled a physical failure detected on over 50% of the panel.

3.3. Characteristics of Panel Tested Paints

Table 3-1 lists most of the paints that were included in the panel testing, the supplier of the paint, the type of paint and the supplier specified third panel cleaning regime. Three of the paints that were tested are not included in the table. Two of these are two 100 percent copper paints and one Econea based biocide paint. The DTSC/IRTA project focus was on nonbiocide paints so the performance of these biocide containing paints is not included here. One copper biocide paint, Trinidad Pro Blue, was used as the copper control paint; it is included in the table. Another paint, XQQ075, a nonbiocide paint that was panel tested earlier, is also included in the table. It was still doing well, so it was also included in the DTSC/IRTA panel tests

In general, the soft nonbiocide paints are most effectively cleaned with very soft cleaning tools. The tools used for cleaning the third panel for soft nonbiocide paints included the soft side of a sponge, microfiber cloths, terry towels and carpet. For the hard nonbiocide paints, more aggressive tools are necessary to remove the fouling. The tools used for cleaning these paints included white pads and green pads.

The California Professional Divers Association (CPDA) Hull Cleaning Best Management Practices Certification Manual describes certain cleaning tools and specifies hull cleaning industry standards. According to the manual, the white pad is the softest of the abrasive pads. Green/blue pads and purple pads are of medium consistency whereas the brown pad is the coarsest of the pads. As Table 3-1 indicates, white pads and green pads were used for cleaning some of the hard nonbiocide paints on the panels.

Table 3-1 Panel Tested Paint Characteristics				
Paint Name	Paint Supplier	Paint Type	Third Panel Cleaning Regime	
			Frequency	Tool
1082 Trinidad ProBlue	Petit	Copper Control	3 months	carpet
Klear N' Klean XP-A100	Petit	Soft Nonbiocide	6 weeks	terry towel
Klear N' Klean Plus XP - A101	Petit	Soft Nonbiocide	6 weeks	terry towel
Sher-Release	Sherwin Williams	Soft Nonbiocide	6 weeks	microfiber cloth
XZM 480	International Paint	Soft Nonbiocide	3 weeks	terry towel
XA 278	Hempel	Soft Nonbiocide	3 weeks	soft sponge
XA 284	Hempel	Soft Nonbiocide	3 weeks	soft sponge
W.A.V.E.	Specialty Marine	Other	3 weeks	microfiber cloth
HullSpeed 3075	Hullspeed	Hard Nonbiocide	3 weeks	green pad
HabraCoat	Xurex	Hard Nonbiocide	3 weeks	white pad
Easy On Bottom Wax	Alex Milne Associates, Lt	Hard Nonbiocide	3 weeks	white pad
HullSpeed 3080	Hullspeed	Hard Nonbiocide	3 weeks	green pad
SmartBottom	Specialty Marine	Other	3 weeks	white pad
Oxilane	Xurex	Hard Nonbiocide	3 weeks	white pad
Crystal Marine Pro	Linlee Marine LLC	Hard Nonbiocide	3 weeks	white pad
Seashell SK9	Seashell Technology	Other	6 months	microfiber cloth
Seashell SK9-S	Seashell Technology	Other	6 months	microfiber cloth
XQQ075	International Paint	Soft Nonbiocide	6 weeks	carpet

3.4. Panel Testing Results

IRTA's major aim in the panel testing was to identify nonbiocide paints that are effective in repelling fouling and/or are easy to clean. Two of the frames were removed with the supplier's approval well before the end of the panel tests, after about five months of testing. These paints were the two provided by Seashell Technology. When the panels were cleaned, the coating was gradually removed and there was very little, if any, coating left on the middle panel when the panels were removed. The International Paint coating called XQQ075, an earlier version of XZM 480, was carried over from the earlier panel tests to the DTSC/IRTA panel tests. The XQQ075 is unstable so the better more viable paint is the XZM 480. One of the Petit Paint formulations, Klear N' Klean Plus XP-A101, contains an ingredient that has been removed from the market. Petit has now reformulated the paint. The two Seashell formulations, the XQQ075 and the Petit formulation are not considered viable candidates for testing on boats.

The data sheets containing the detailed rankings for several of the paints listed in Table 3-1 are provided in Appendix A. The data include most of the information gathered during the inspections for the fouling, cleaning and coating condition assessments for the paints. In some cases, more aggressive tools than those specified by the manufacturer were needed to remove the fouling but this information is excluded from the data sheets provided in the appendix. In what follows, the data are summarized and discussed for the paint categories and specific coatings.

3.4.1. Soft Nonbiocide Paints

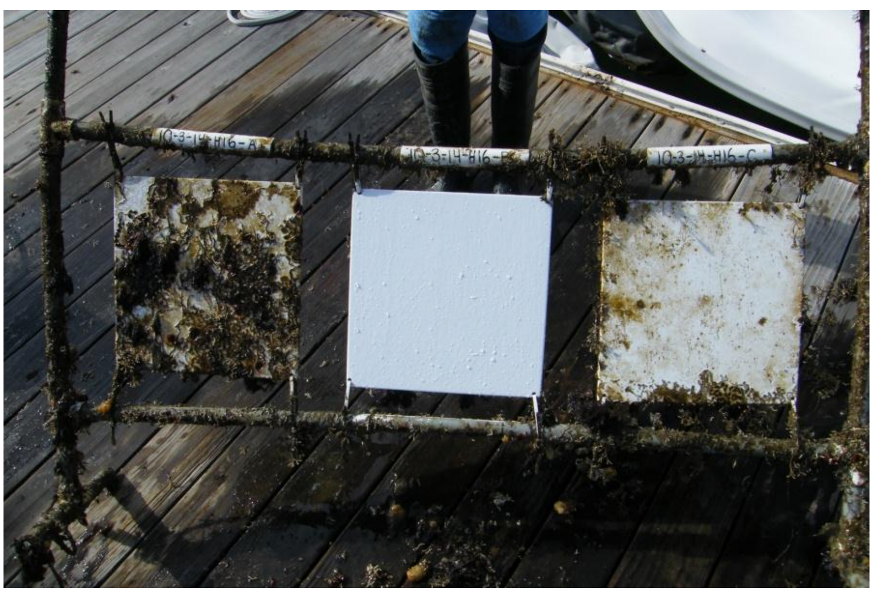
The coatings that performed the best in the panel testing are the coatings that are soft nonbiocide paints. These include Sher-Release, XZM 480, XA 278, XA 280, Klear N' Klean XP-A101 and Klear N' Klean Plus XP-A101. As discussed later in Section V, IRTA arranged for three of these coatings to be applied to boats during the project. IRTA also arranged for a reformulated Petit paint and a version of XZM 480 with a hardener added to be applied to boats. The characteristics and performance on panels of the individual paints is discussed in more detail below for all paints except XQQ075, an earlier version of XZM 480, and the two Seashell Technology coatings which were removed from the testing.

3.4.1.1. Klear N' Klean XP-A100

This paint is a silicon based foul release paint that is classified as a soft nonbiocide paint. The panel testing data sheets show that the two panels (the SC and MC panels) that were cleaned during the panel testing period could be cleaned relatively easily. The panels became stained and had some scratches.

3.4.1.2. Klear N' Klean Plus XP-A101

This paint is also a silicon based foul release paint with a fluoropolymer added. The panel testing sheets indicate that it performed better than the other Klear N' Klean formulation in the panel testing. The two panels that were cleaned were cleaned readily and the coating condition was good until the last inspection when some scratches were noted. A picture of the three panel assembly in January 2011, about halfway through the test period, is shown in Figure 3-4. Again, because the paint includes the ingredient which has been removed from the market, it is not a candidate for boat testing. Petit, the paint supplier, did reformulate the paint with a new fluoropolymer ingredient and the reformulated paint which has the same name was selected for boat testing.

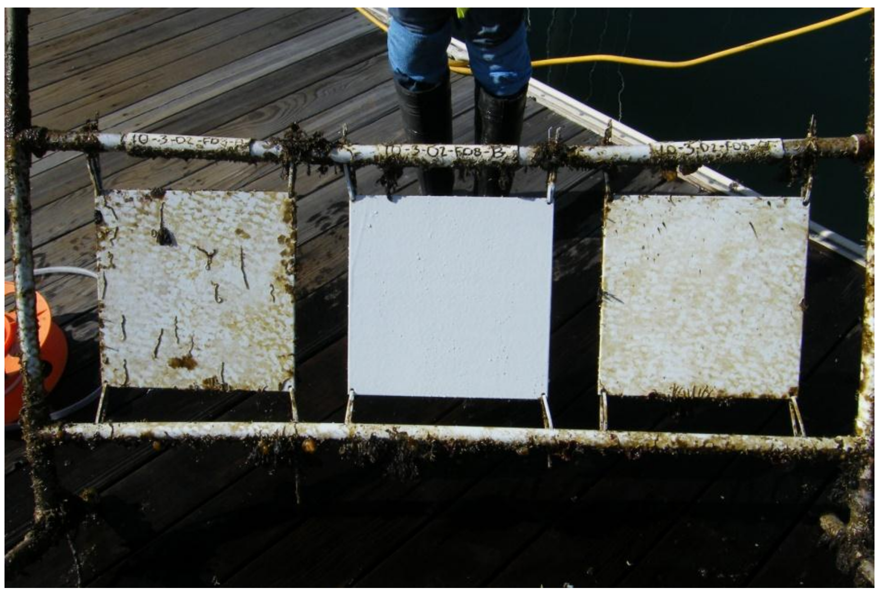


Source: POSD, 2011
Figure 3-4. XP-A101 Paint During Panel Testing

3.4.1.3. Sher-Release

Sher-Release is a silicon based foul release paint and is classified as a soft nonbiocide paint. The Appendix A panel testing data sheets for this paint show that, in general, the first panel (called NC for no clean in the data sheets) had very good results for the fouling ratings and coating condition. The same is true of the values for the panel cleaned using the standard carpet method (called SC in the data sheets). The one exception is that there are 5s in two of the columns for June 21, 2011 inspection. All the other values in the table and all the values for the manufacturer specified cleaning methods panel (called MC in the data sheets) are 1s and 2s. The 5s are likely to be incorrect data input numbers.

This paint did very well in the panel testing. Even the fouling ratings on the no clean panel and the two other panels prior to cleaning are low. The cleaning ratings are all low and the coating condition ratings are all low. A picture of the three panel assembly in January 2011 is shown in Figure 3-5. This paint was selected for boat testing because of its excellent performance in the panel testing. A Material Safety Data Sheet (MSDS) for the product, called Fujifilm Surface Coat Part A-Black, is shown in Appendix B.

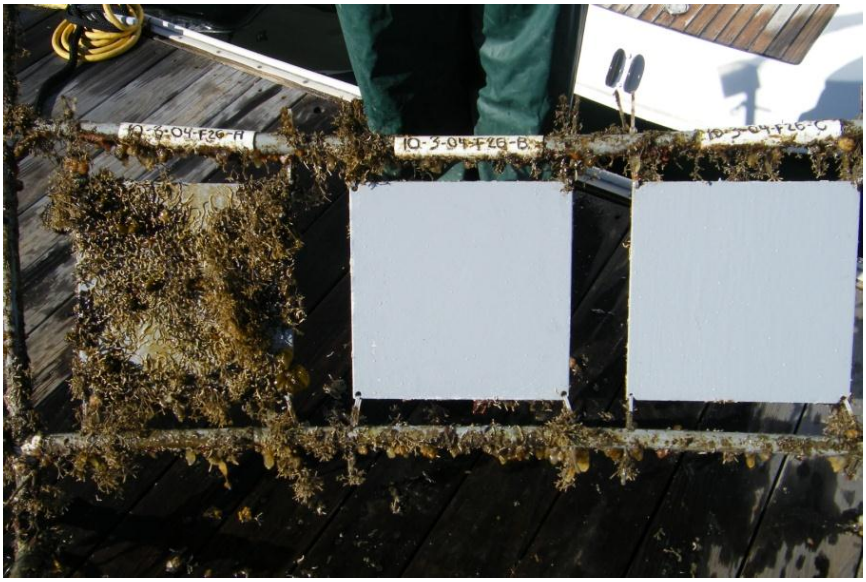


Source: POSD, 2011
Figure 3-5. Sher-Release Paint During Panel Testing

3.4.1.4. XZM 480

This paint is a modified version of Intersleek 900, a paint that was tested on boats in the Port/IRTA project. It is a soft nonbiocide paint based on silicon and fluoropolymer compounds.

The panel testing data sheets in Appendix A show that the fouling ratings on the no clean panel are fairly high whereas the fouling ratings on the other two panels that were cleaned regularly are low. The coating condition on the panels that were cleaned is somewhat high (a few 2s and 3s on the data sheets). The notes indicate that the coating is scratched and this follows from the fact that the coating is very soft and easily removed. A picture of the three panel assembly for the paint in January 2011 is shown in Figure 3-6. This coating was selected for the boat testing phase and an MSDS for the product is shown in Appendix B. As discussed later, the company developed a hardener to add to the paint and it was more durable when it was applied to the boat with the hardener additive.

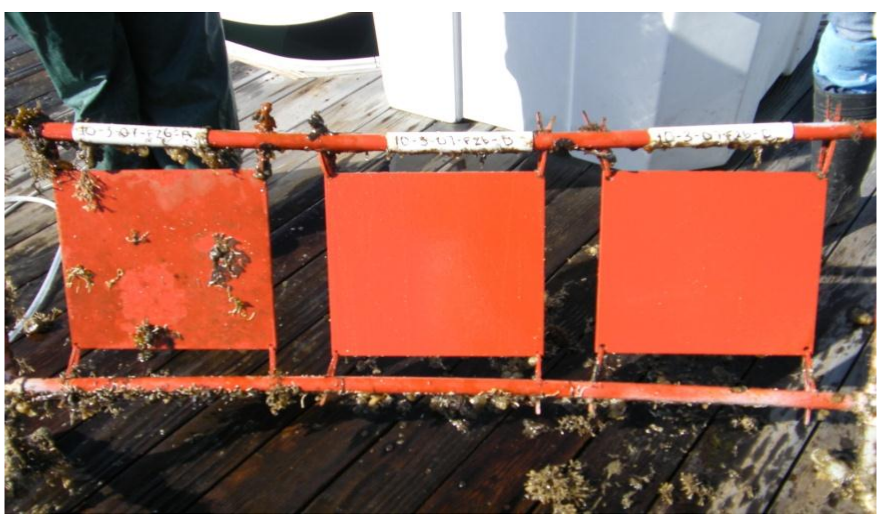


Source: POSD, 2011
Figure 3-6. XZM 480 Paint During Panel Testing

3.4.1.5. XA 278 and XA 284

These two coatings were the best performing paints in the panel testing. Both coatings are silicone foul release paints that are modified versions of Hempasil X3 which was tested on boats in the earlier Port/IRTA project.

The panel testing data show that the fouling ratings on all three panels are very low for XA 278 which means the fouling levels are very good. Cleaning the panels was accomplished easily with soft tools. The company indicated the soft side of a sponge should be used and it readily removed the small amount of fouling that was present. The coating condition of all the panels was good. A picture of the three panel assembly for this paint in January 2011 is shown in Figure 3-7.



Source: POSD, 2011
Figure 3-7. XA 278 Paint During Panel Testing

The data sheets in Appendix A show that the fouling ratings on the no clean panel are high for XA 284. For the other two panels, which were cleaned regularly, the fouling ratings are low. The cleaning ratings are low for the two panels that were cleaned. The coating condition ratings for all three panels are also low.

Both coatings performed extremely well in the panel testing and one of them was selected for boat testing. IRTA selected XA 278 for boat testing and an MSDS for the product is shown in Appendix B.

3.4.2. Hard Nonbiocide Paints and "Other" Paints

The coatings which are classified as hard nonbiocide paints or "other" paints in Table 3-1 did not perform as well as the soft nonbiocide paints under the established protocol, primarily because they are much more difficult to clean. This is expected for the harder coatings because they do not function as foul release paints like the soft nonbiocide coatings. The hard nonbiocide paints and the two "other" paints required more aggressive cleaning tools and greater cleaning effort.

From the earlier panel tests, IRTA became aware of the fact that, in many cases, suppliers did not know what cleaning tools or frequency of cleaning to specify for cleaning the third panel. This was especially true for the hard nonbiocide paints. When the DTSC/IRTA panel test was being planned, IRTA held discussions with each of the suppliers to make sure they specified a more appropriate cleaning tool for this set of panels. As discussed below in the limitations section, the hard nonbiocide coatings really require very aggressive cleaning tools to remove the fouling. If an aggressive tool is not used, the fouling is simply ground into the paint leaving a stain that cannot be removed. If the supplier indicated the paint was hard enough to withstand an aggressive tool, IRTA suggested that a white pad or green pad be used for cleaning the third panel. As indicated in Table 3-1, many of the suppliers did opt to specify the more aggressive tools.

The boat testing in the earlier Port/IRTA project led to two major insights. Hard nonbiocide paints require more frequent cleaning than all other types of paints including alternative biocide and soft nonbiocide paints. During the earlier boat tests, the diving company that worked with IRTA and the Port, San Diego Diving Service, assisted the team in finding the best methods of cleaning the boats. This involved determining both the frequency of cleaning that was necessary and the types of tools that were optimal for each type of paint. One of the boats was painted with a hard nonbiocide paint and the diver periodically needed to clean the boat with a power tool. Cleaning periodically with a nylon bristle power tool prevented a much greater buildup of fouling on the hull and after such a cleaning, the coating was returned to its original smooth condition. Hand cleaning with aggressive tools was then possible again until the fouling built up. The first insight gained from the boat testing was that these types of coatings did require more frequent cleaning in the summer but using the power tool periodically prevented the fouling from building up to unmanageable levels.

The second insight gained from the boat tests with the help of the project diver was that there would be negative results for coatings that are cleaned with a more gentle tool than necessary. In effect, it is better to clean with a more aggressive (and appropriate) tool than with a gentle tool that requires a very long period of aggressive scrubbing. What happens if a gentle tool is used in this way is that there is a good chance the coating will be damaged. The panel testing verified this conclusion. IRTA staff performed much of the panel cleaning for all three sets of panel tests. In some cases, the carpet, which was used in all cases for cleaning the second panel, was not the correct tool for cleaning some of the soft nonbiocide paints. In a few cases, the carpet would "stick" to the paint and substantial scrubbing would be necessary to remove the fouling. The paint was damaged in the scrubbing process. A more effective tool, in these cases, was a terry towel which did not "stick" to the paint and was able to remove the fouling in a very short period of time.

The same situation was apparent in the case of virtually all of the hard nonbiocide paints. Cleaning with the carpet could not adequately remove the fouling no matter how long the cleaning went on. Furthermore, aggressive and prolonged cleaning with the carpet would simply imbed the fouling into the coating rather than remove it. The panels would end up stained with fouling that could not be completely removed. Figures 3-8 and 3-9 show pictures of the three panel assemblies of hard nonbiocide paints with heavily stained middle panels. In addition, some of the coatings had to be scrubbed so hard that the coating was damaged. Cleaning with a more aggressive tool, like an abrasive pad, could remove the paint much more effectively. In some cases, however, even the more aggressive pad did not adequately remove the fouling and a periodic power tool cleaning would have helped considerably.

Source: POSD, 2011
Figure 3-8. Hard Nonbiocide Paint with Stained Middle Panel

Source: POSD, 2011
Figure 3-9. Another Hard Nonbiocide Paint with Stained Middle Panel

Recall that the results of the Port/IRTA panel tests indicated that none of the hard nonbiocide paints performed well on the panels. It later became apparent why these coatings did not do well. The boat testing results from the earlier project clearly indicated that periodic power tool cleanings were necessary for hard nonbiocide paints.

It is difficult to clean panels with a power tool so hand cleaning was part of the protocol from the outset. In the panel protocol the paints were given rankings for ease of cleaning. Because the fouling could not be removed with the hand tools, the hard nonbiocide paints ranked poorly for this category in virtually every case. This is the reason none of the 21 paints selected as the best performers in the panel testing in the Port/IRTA project were hard nonbiocide paints.

The conclusion is that the panel tests are not a good method of evaluating whether or not the hard nonbiocide paints and some of the harder "other" paints would be good candidates for boat testing. Hard nonbiocide paints may have a role, particularly in cases where a very durable coating is needed. They will require more frequent and more aggressive cleaning, however, and for that reason, they will be less cost effective to use than the soft nonbiocide paints which can be cleaned with the same frequency as biocide paints. Even so, some boaters are willing to pay the higher maintenance cost and they may prefer to use a hard nonbiocide paint. The results of the panel tests for some of the hard nonbiocide and "other"coatings are discussed below.

3.4.2.1. Wave

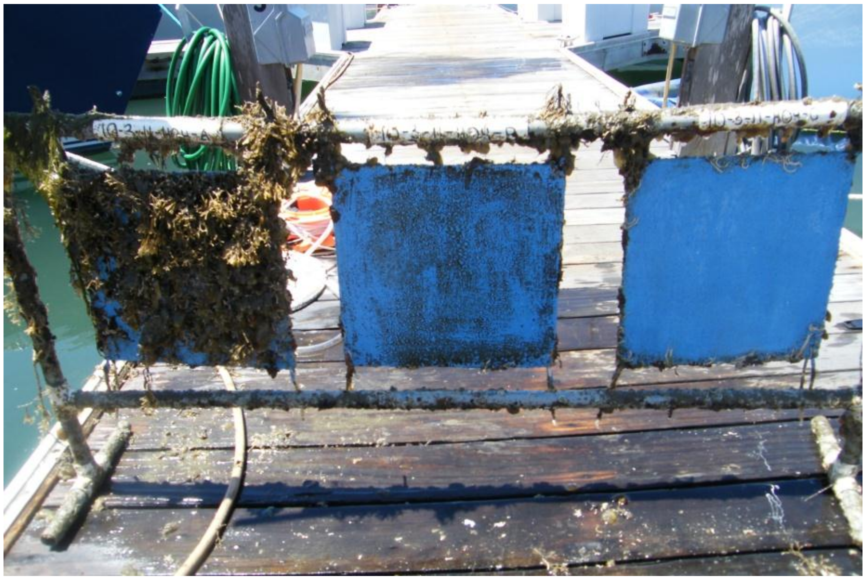
The fouling rating for this paint for the no clean panel is fairly high. The fouling ratings for the other two panels, which were cleaned regularly, are lower. The major problem with this paint, however, is that it was removed during cleaning as indicated by the coating condition ratings. This could be a result of cleaning with a tool that is not aggressive enough.

3.4.2.2. Hullspeed 3080

This paint is a siliconized epoxy. More suppliers are formulating paints of this type. The reason for using some silicon compounds in the formulation is to make the hard epoxy coating easier to clean since the softer silicon based paints have this characteristic. If this sort of combination works effectively, it would be a very durable coating because of the epoxy and it would be easy to clean because of the silicone. In this case, according to the data sheets in Appendix A, the coating on both the standard panel and the manufacturer panel was being removed. Figure 3-10 shows the staining on the paint and some spots where it is being removed. The problem with this coating and others of this type is that an aggressive tool is needed to clean because the coating has heavy soft and hard fouling. Because of the silicon, the coating can be too soft to withstand the aggressive cleaning tool. The third panel, which was cleaned with a green pad, an aggressive tool, has a better unstained appearance than the middle panel which was cleaned with carpet. The data sheets indicate, however, that the coating on the third panel is being removed.

3.4.2.3. HabraCoat

This paint was formulated with epoxy to be as hard as possible. Both panels that were cleaned were heavily stained reflecting the problem with hand tool cleaning. The cleaning tool was not aggressive enough to remove the fouling which was ground into the paint. This coating would require frequent use of a power tool to be cleaned appropriately.



Source: POSD, 2011
Figure 3-10. HullSpeed 3080 Paint During Panel Testing

3.4.2.4. Easy On Botton Wax

This paint is really a wax that is designed to be applied by do-it-yourselfers. The boater is instructed to apply the wax to the boat hull. It is a hard nonbiocide paint. By the end of the testing, it was heavily stained and the paint on the manufacturer's panel was coming off.

3.4.2.5. Hullspeed 3075

This paint, like the other Hullspeed paint described above, is a siliconized epoxy. It became very stained on both of the panels that were cleaned and the coating was being removed on the manufacturer panel. This panel was cleaned with a green pad. The cleaning tool may have been too aggressive for the silicon compound in the paint or the repeated cleaning with a tool that was not aggressive enough may have been the reason for the paint failure.

3.4.2.6. SmartBottom

This paint was difficult to clean and it became very stained on both panels that required cleaning by the end of the testing. Again, this paint could benefit from frequent power tool cleaning.

3.4.2.7. Oxilane

This paint is a hard nonbiocide coating based on epoxy which was designed to be as hard as possible. The coating became stained indicating it was not being cleaned with an aggressive enough cleaning tool. The paint was removed on the panel that was cleaned with carpet but was not removed on the manufacturer panel where a white pad was used for cleaning. This illustrates the issue defined above that paints cleaned with a less aggressive tool than needed. The soft tool may remove the paint because of the need for excess and prolonged scrubbing. This paint would be best cleaned with a power tool frequently.

3.4.2.8. Crystal Marine Pro

This paint, a typical hard nonbiocide paint, was very stained by the end of the testing period. It would likely require frequent cleaning with a power tool to perform well. Figure 3-11 shows the panels containing this paint near the end of the testing.

Source: POSD, 2011

Figure 3-11. Crystal Marine Pro Paint During Panel Testing

3.5. Evaluation of Panel Tested Paints

Several of the soft nonbiocide paints performed well in the panel testing. These included the Klear N' Klean Plus XP-A101, Sher-Release, XZM 480, XA 278 and XA 284. As mentioned earlier, the Klear N' Klean paint contains an ingredient which has been removed from the market so it cannot be offered for sale.

The performance of the hard nonbiocide paints and the "other" paints in the panel testing is much harder to evaluate and judge. Again, the issue is that the hard nonbiocide paints require periodic or routine cleaning with a power tool and are not effectively cleaned with hand tools. Since hand tools were the only cleaning tools used in the panel testing, it is not clear which hard nonbiocide paints might perform well if they could be cleaned with a power tool. Several of the paints were being removed from the panels because it was necessary to hand clean them with sustained pressure with less aggressive tools than required. It is simply not possible to judge from the panel tests how the paints that were being removed would perform if cleaned with a power tool. Two of the coatings were not being removed at all in the panel tests and they could be candidates for further testing. These included Smart Bottom and Crystal Marine Pro. Although the panels that were cleaned were stained, cleaning with a power tool could restore these paints to good unstained condition based on experience in cleaning boats with other hard nonbiocide paints.

IV. ALTERNATIVE APPLICATION PROCESSES AND PROCEDURES

In this section, the cost comparison of using copper and alternative nonbiocide paints is presented. There are two types of costs, the paint job cost and the routine maintenance cost, that contribute to the cost of using a particular paint. This analysis leads to the conclusion that the typical paint job cost for a nonbiocide paint is higher than the paint job cost for a copper paint the first time a nonbiocide paint is applied. The factors that lead to the higher cost are then identified and discussed. The balance of the section discusses the tests, characteristics and costs of the alternative methods of applying the paints that were evaluated in the course of the project.

4.1. Paint Job Costs for Copper and Nonbiocide Paints

Table 4-1 summarizes the copper paint baseline paint job costs and the costs for a few of the alternative nonbiocide paints that went on to boat testing in the earlier Port/IRTA project. The cost of paint jobs was determined by obtaining cost information from five boatyards in the San Diego area. The Port /IRTA final report presents the paint job costs for all five boatyards. The paint job costs for a 30 foot and a 40 foot boat for each paint type were averaged over the five boatyards and only the average paint job cost is presented in Table 4-1. Typical boat sizes for pleasure craft are 30 and 40 foot boats so those were the boat sizes analyzed.

Table 4-1
Average Paint Job Costs for Boats in the San Diego Area

Paint Name	Paint Type	Application Method	Average Paint Job Cost	
			30 Foot Boat	40 Foot Boat
NA	Copper	Rolled, Not Stripped	$1,038	$1,488
Intersleek 900	Soft Nonbiocide	Rolled, Stripped	$4,556	$6,713
		Sprayed, Stripped	$5,512	$7,733
		Rolled, Not Stripped	$2,286	$3,413
		Sprayed, Not Stripped	$2,922	$4,113
Hempasil X3	Soft Nonbiocide	Sprayed, Stripped	$6,358	$8,537
		Sprayed, Not Stripped	$3,858	$4,917
VC Performance Epoxy	Hard Nonbiocide	Rolled, Stripped	$3,915	$4,935
		Rolled, Not Stripped	$1,875	$2,303

Copper paints are generally applied over themselves so only one scenario is presented for the copper paint in Table 4-1. The paint job involves preparing the surface and removing old peeling copper paint, applying epoxy primer on the spots where the coating has deteriorated and then applying copper topcoat over the whole boat. Boats with copper paint should be stripped after three or four paint jobs because the paint builds up on the boat and adds weight. In fact, however, boats with copper paint are infrequently stripped, perhaps every 15 years after seven or eight paint jobs. The stripping cost is high and many boaters are deterred from stripping as frequently as they should for this reason.

For the nonbiocide paints, at least two scenarios, stripping and not stripping, are presented in Table 4-1. The suppliers recommend that the coatings be applied to a stripped hull. After the coatings have been applied to a stripped hull the first time, they can be applied over themselves in subsequent paint jobs. The case where the hull is stripped represents painting a boat that currently has a copper paint and the case where the hull is not stripped represents painting a boat that already has the nonbiocide paint on the hull.

Suppliers of the nonbiocide paints recommend that the paints be applied by spray; since a smooth surface makes it more difficult for fouling to attach to the coating. During the earlier project, Intersleek 900 was applied to two boats; one was applied using spray application and the other was rolled on. The performance of the boat with the coating rolled on did not appear to differ from the performance of the boat with the coating sprayed on. This indicates that Intersleek 900 can be either sprayed or rolled and the cost of both options is specified in Table 4-1. VC Performance Epoxy was rolled on the one boat that participated in the test program and the costs are presented for this coating assuming rolling. Hempasil X3 was only sprayed on the test boats so the table presents the costs assuming spraying.

The values of Table 4-1 illustrate that the paint jobs for the alternative nonbiocide paints are more costly than the paint job for a copper paint. As indicated by the values, the factors that increase the paint job cost substantially for the nonbiocide paints are the requirement for stripping and the requirement for spraying. In addition, the paint itself is much more expensive than copper paint and, in the case of the soft nonbiocide paints, a tiecoat between the primer and the topcoat is required. Taking these factors into account, Table 4-1 demonstrates that even the cost of a paint job for a nonbiocide paint that is rolled on and not put on a stripped hull is more costly than the paint job for a copper paint.

4.2. Maintenance Costs for Copper and Nonbiocide Paints

In the Port/IRTA project, the annual maintenance costs were estimated by obtaining costs from three different diving companies in the San Diego area. The maintenance cost varies based on three factors. First, the maintenance or cleaning cost depends on the size of the boat. Second, the cleaning cost depends on the type of boat; the cost of maintaining a sailboat is less than the cost of maintaining a powerboat. Third, the maintenance cost varies depending on the type of paint on the boat hull. All three of the diving companies had experience cleaning boats with copper paint and hard nonbiocide paint. Only one of the diving companies had experience cleaning the soft nonbiocide paint. The copper biocide paint and soft nonbiocide paints were commonly cleaned by divers 15 times per year, every three weeks in the summer and every four weeks in the winter. All three diving companies agreed that the hard nonbiocide paints needed cleaning more often but the frequency varied. The average of the three annual costs was used for the hard nonbiocide paints. The maintenance cost for the one diver with experience cleaning the soft nonbiocide paints was used in the analysis. Table 4-2 shows the average maintenance cost based on the size and type of boat and the specific paint.

Table 4-2
Average Annual Maintenance Cost

Paint	Annual Maintenance Cost		Annual Maintenance Cost	
	30 Foot Boats		40 Foot Boats	
	Sailboat	Powerboat	Sailboat	Powerboat
Copper	$593	$698	$790	$930
Intersleek 900	$653	$743	$870	$990
Hempasil X3	$653	$743	$870	$990
VC Performance Epoxy	$1,048	$1,242	$1,398	$1,656

The values of Table 4-2 show that the average annual maintenance cost for the two nonbiocide paints, Intersleek 900 and Hempasil X3, is slightly higher than the average maintenance cost for the copper paints. The average maintenance cost for the hard nonbiocide paint, VC Performance Epoxy, is much higher than the cost for the other two types of paints. This follows from the fact that more frequent cleaning is required for hard nonbiocide paints, primarily in the summer months.

4.3. Overall Cost of Using Copper and Nonbiocide Paints

The cost of using a paint takes into account two different types of costs. The first cost is the paint job cost and the second cost is the regular maintenance cost which is the cost of using a diver to clean the hull regularly. Table 4-1 presented the average paint job cost for the copper and three of the nonbiocide paints, two soft nonbiocide paints and one hard nonbiocide paint. To compare the costs of the different paints, the paint job cost can be annualized based on the life of the paint and it can be added to the annual maintenance cost to obtain an annualized cost of using the paint. Employing this procedure allows a comparison of the annualized cost of using a copper and alternative paint.

Copper paint jobs last between about two or three years. The alternative biocide paints, which are generally based on zinc or Econea, have shorter lives ranging from one year to 18 months. Zinc is a softer metal than copper and the paint is depleted more quickly, particularly if divers routinely clean the hull. The alternative nonbiocide paints generally have longer lives than the copper paint. Intersleek 900 and Hempasil X3 have been used on commercial boats; they are smoother and the fuel savings from using them can be as high as six to nine percent compared with using a copper paint. Commercial boats have been using these coatings for five to ten years successfully. In the Port/IRTA report, IRTA analyzed the cost of using Intersleek 900 for five and 10 years. For Hempasil X3, IRTA analyzed the cost of using the paint for 7.5 and 10 years. VC Performance Epoxy has been used on small boats for about five years successfully. Many other hard nonbiocide paints have been on boats for more than 10 years. In the earlier analysis, IRTA analyzed the cost of using VC Performance Epoxy for five and 10 years.

The cost analysis in the Port/IRTA study involved amortizing the one-time paint job cost over the life of the coating. The cost of the paint job was treated as a capital cost. The assumptions were that the cost of capital is four percent and the lives of the paint jobs were those listed above for each of the paints. The annualized cost determined by amortizing the paint job cost over the life of the paint, was then added to the annual maintenance cost to obtain an annual cost of using the paint. Table 4-3 summarizes the total annualized cost of using copper, the two soft nonbiocide paints and the one hard nonbiocide paint.

The values of the table illustrate that the annualized total cost of using the paints with longer lives is lower than the annualized total cost of using the paints with shorter lives, as expected. The paint job cost for copper paint that lasts three years, for instance, is spread over three years rather than two for a copper paint with a two year life so the annualized total cost of using the paint is lower. The cost of using the two soft nonbiocide paints, Intersleek 900 and Hempasil X3, with 10 year lives if the boat is not stripped is lower than the cost of using the copper paint with a two year life. The cost of using Intersleek 900 with a 10 year life when it is not stripped and is rolled on is lower than the cost of using the copper paint with a three year life. The cost of using Intersleek 900 with a 10 year life even when it is stripped but rolled on is comparable to the cost of using the copper paint with a two year life. The cost of using the hard nonbiocide paint, VC Performance Epoxy, with a 10 year life when it is rolled and not stripped is somewhat higher than the cost of using a copper paint with a two year life.

Table 4-3 Total Annualized Cost Over Life of Paint						
Paint	**Life**	**Application**	**Annualized Total Cost**			
	(years)	**Method**	30 Foot Boat		40 Foot Boat	
			Sailboat	Powerboat	Sailboat	Powerboat
Copper	2	Rolled, Not Stripped	$1,133	$1,238	$1,564	$1,704
	3		$953	$1,058	$1,306	$1,446
Intersleek 900	5	Rolled, Stripped	$1,601	$1,691	$2,266	$2,386
	10		$1,127	$1,217	$1,568	$1,688
	5	Sprayed, Stripped	$1,800	$1,890	$2,478	$2,598
	10		$1,226	$1,316	$1,674	$1,794
	5	Rolled, Not Stripped	$1,128	$1,218	$1,580	$1,700
	10		$891	$981	$1,225	$1,345
	5	Sprayed, Not Stripped	$1,261	$1,351	$1,726	$1,846
	10		$957	$1,047	$1,298	$1,418
Hempasil X3	7.5	Sprayed, Stripped	$1,535	$1,625	$2,054	$2,174
	10		$1,314	$1,404	$1,758	$1,878
	7.5	Sprayed, Not Stripped	$1,188	$1,278	$1,552	$1,672
	10		$1,054	$1,144	$1,381	$1,501
VC Performance Epoxy	5	Rolled, Stripped	$1,862	$2,056	$2,424	$2,682
	10		$1,455	$1,649	$1,911	$2,169
	5	Rolled, Not Stripped	$1,438	$1,632	$1,877	$2,135
	10		$1,243	$1,437	$1,638	$1,896

The cost of using the hard nonbiocide paints, in general, is higher than the cost of using copper paints primarily because they need to be cleaned more frequently. The longer life of the hard nonbiocide paints does not offset the increased maintenance cost. One of the diving companies that provided input for the maintenance of the hard nonbiocide paints does not use power tools and the cleaning frequency estimates were based on the need for even more frequent cleaning because less effective hand tools were being used. If the estimates from this diving company are excluded, the cost of using the hard nonbiocide paints with a 10 year life are comparable to the cost of using a copper paint with a two year life.

The cost of using the soft nonbiocide paints with long lives is comparable to the cost of using the copper paint. This is because the maintenance cost for the soft nonbiocide and the copper paints is roughly the same. The cost of the paint job for the soft nonbiocide paints is much higher than the cost of the paint job for the copper paints but this cost is offset by the much longer life of the soft nonbiocide paint. This argument as a reason to adopt the soft nonbiocide paints may convince certain boaters who understand what spreading out the paint job cost means. In general, however, boaters do not want to pay for a paint job that is twice to six times that of a copper paint job even if the paint job lasts longer. Consumers are always sensitive to up-front significantly higher costs and they will avoid them most of the time.

The major components that make the paint job more expensive for the nonbiocide paints is the stripping cost and the spraying cost. In the Port/IRTA project, IRTA analyzed the stripping cost charged by the five boatyards that provided cost information. The results indicated that the average cost of stripping a 30 foot boat for the five boatyards was $76 per foot and the average cost of stripping a 40 foot boat was $85 per foot. This means that the average stripping cost for 30 and 40 foot boats amounts to $2,280 and $3,400 respectively. One boatyard charged a rate as high as $115 per foot. These values demonstrate the high cost charged by boatyards for stripping. During this project, IRTA worked with some boatyards outside the San Diego area and they charge similarly high costs for stripping a boat.

Most of the boatyards currently strip boats using one of two methods. First, some boatyards have workers who strip the boats by hands using abrasive sanding. This is not only costly, labor intensive and time consuming, it also exposes workers to particulate and metal emissions and it generates particulate matter (PM) emissions which are tied to lung disease. Second, some boatyards use chemical strippers. Commonly used strippers are based on methylene chloride which is a carcinogen. This method is also expensive and labor intensive and workers are exposed to a carcinogen in the process. During the Port/IRTA project, IRTA began investigating alternative stripping methods and intensified the effort during this project.

The cost of spraying paint on the boat is much higher than rolling it on the boat as is conventional for copper boats. The difference in cost for spraying rather than rolling the paint on a 30 foot boat may amount to $1,000. Spraying the coating involves tenting the boat with plastic or other material so the paint being sprayed on the boat does not drift to other boats in the boatyard. The workers are not used to spraying so it can actually take longer because of the setup time and effort that is required. All of this adds to the overall cost of a nonbiocide paint job. In the earlier project, some of the alternative paints were rolled on rather than sprayed and there appeared to be little difference in the paint performance.

4.4. Alternative Methods of Application

As the information above indicates, IRTA identified the components that make the cost of using the nonbiocide paints higher than the cost of using copper paints. In particular, two of the cost components, the requirement for stripping and the requirement for spraying, increase the cost of the paint job significantly. During this project, IRTA focused heavily on methods of making it less costly and complex to use the alternative nonbiocide paints. The methods that were investigated are discussed in more detail below.

4.4.1. Alternative Stripping Methods

As discussed above, most boatyards strip infrequently because boaters are reluctant to authorize stripping copper paint because of the expense. When boatyards do strip, they either use chemical stripping methods or hand sanding methods. Both methods have disadvantages and are expensive. During this project, IRTA investigated three alternative methods of stripping, all of which are abrasive blasting methods.

The first method involves using dry sodium bicarbonate at high pressure to remove the coating. A company in San Diego, Advanced Restoration, offers the service of stripping with sodium bicarbonate to boatyards. The company also sells sodium bicarbonate blasting systems. The technique is commonly referred to as soda blasting. A picture of a sodium bicarbonate stripping system is shown in Figure 4-1. When the company strips a boat, the boat is shrouded with plastic sheeting, the hull paint is stripped with sodium bicarbonate and Advanced Restoration collects the media for disposal by the boatyard.

Figure 4-1. Sodium Bicarbonate Stripping System

The second alternative is a blasting method that relies on wet volcanic rock to blast the coating from the boat hull. A company in San Diego called Hawthorne represents a manufacturer of these systems and provides them for rent or for sale. The Farrow system is a self-contained unit with its own air compressor and a 110 gallon water supply. It is mounted on a trailer and it uses volcanic rock as the abrasive medium for stripping. The technology uses low pressure air, heat, water and the media for stripping. The company claims that containment is not necessary because the technology is wet. A picture of the equipment is shown in Figure 4-2.

Figure 4-2. Volcanic Rock Blasting System

The third alternative stripping method is dry ice blasting that uses solid carbon dioxide accelerated at supersonic speeds for blasting the paint from the boat. It is based on a Cold Jet System marketed by Red-D-Arc. The advantage of this method is that the carbon dioxide sublimes or forms a gas and the only waste generated from the process is the paint residue. A picture of the equipment, which can be purchased or rented, is shown in Figure 4-3.

Figure 4-3. Dry Ice Blasting System

IRTA arranged a demonstration of the three alternative stripping methods on a boat that was destined to be demolished. Marine Group, a large boatyard in Chula Vista, California, provided the boat for the testing. Suppliers of the three different technologies attended the testing together so they could all see how the other technologies performed.

The results of the testing are qualitative and limited since the technologies were used to strip patches of a boat with old copper paint rather than an entire boat. Figure 4-4 shows the boat that was used for the stripping tests. All three of the technologies were able to strip the copper antifouling paint from the boat hull. DTSC staff attended the demonstrations and took samples of the spent media and/or coating residue when each of the three methods was tested.

During the demonstrations, a patch of paint approximately two feet by one foot on the boat was stripped by each of the three methods. IRTA wanted to get a rough estimate of the relative stripping rate since a longer time can add to the stripping cost. This was somewhat difficult, however, because the sodium bicarbonate stripping technology supplier is much more experienced in stripping boats than the suppliers of the other two technologies. This means that the former supplier could probably strip faster than the latter two suppliers. This was borne out by the rough times for stripping the patch. The supplier of the soda blast system stripped two patches and each required about 1.5 minutes. The Farrow system supplier required about 2 minutes 15 seconds to

Figure 4-4. Boat Used for Stripping Test

strip the patch. The dry ice blasting system supplier stripped three patches. The first patch required 3 minutes and 10 seconds. The second and third patches required 2 minutes and 10 seconds and 1 minute 50 seconds respectively. For the second and third patches, the supplier tried to strip more quickly and, in fact, he was able to shorten the time considerably when he tried to do so. A more practiced supplier could reduce the time further and the time on the Farrow system stripping might be shortened considerably as well if more effort were made to strip more quickly. Pictures of the stripping are shown in Figure 4-5 and 4-6.

Figure 4-5. Stripping Tests at Marine Group

Figure 4-6. More Stripping Tests at Marine Group

The DTSC laboratory provided the results of the analysis of the spent stripping media/coating residue. The method of analysis that was used is EPA 6010C which involves digesting the samples. High copper concentrations were found in all three of the samples as expected since the paint contains copper. The residue from the dry ice blasting contained the highest copper concentration, at 590,000 milligrams per kilogram. The volcanic rock residue contained 19,700 milligrams per kilogram copper and the sodium bicarbonate residue contained 109,000 milligrams per kilogram copper. These values translate into 59 percent, 1.97 percent and 10.9 percent respectively. A wet sample of the volcanic rock was also analyzed and it contained 280 milligrams per liter. This translates into 0.28 percent.

Many copper paints contain between 50 and 75 percent copper. Although the copper may leach out over time, in most coatings, the matrix in which the copper is held leaches at the same rate. Boats with old copper paint on them, like the boat on which the technologies were tested, would be expected to have a copper concentration of between 50 and 75 percent. The residue of the dry ice blasting does not contain any media. The copper content was 59 percent which is consistent with a 59 percent copper paint. The copper content of the spent volcanic rock media is very low and it is not clear why this is the case. One interpretation might be that a substantial amount of spent media is generated in the stripping process so the copper, as a percent of the total residue, is very small. The copper content of the spent sodium bicarbonate media, at 10.9 percent, is diluted from the original copper content of 59 percent because of the spent sodium bicarbonate material.

The stripping methods used by most boatyards today are chemical stripping or hand sanding. IRTA estimated the cost of stripping a 30 foot boat using each of these technologies as a baseline. Only one boatyard in California has purchased the volcanic rock system and apparently has not yet used it for stripping boats. No boatyard in California has used the dry ice blasting method. Because these two methods have not been used, very little is known about the cost of using them. IRTA did conduct a limited cost analysis for these two technologies but many of the cost factors are simply unknown. In contrast, the sodium bicarbonate method has been used relatively widely. Few sodium bicarbonate systems, if any, have been purchased by boatyards. The analysis conducted here was performed assuming that Advanced Restoration or another similar company would provide the service of stripping to the boatyard.

IRTA compared the cost of using the two baseline technologies with the cost of stripping with sodium bicarbonate blasting. For the cost analysis and comparison, it was assumed that the boatyard would strip a 30 foot boat and the costs were determined through conversations with five boatyards who provided estimates of various components of the cost. Most of the boatyard estimates were in reasonable agreement with one another.

4.4.1.1. Chemical Stripping

Most, if not all, boatyards have at one time used chemical stripping methods to remove the hull paint from boats and many boatyards still use this stripping method. A stripping formulation commonly used at boatyards is called Klean-Strip Aircraft Remover. An MSDS for this stripper is included in Appendix C. The active ingredient in the stripper is methylene chloride, a carcinogen, which accounts for 60 to 100 percent of the stripping formulation. It is listed on the Toxic Air Contaminant (TAC) list in California, it is listed on Proposition 65 and it is a listed RCRA hazardous waste. The stripper also contains methanol and various other ingredients that help the volatile methylene chloride to stay on the surface longer and make it water rinseable.

A tarp, a sheet of plastic or a sheet of cardboard is placed below the boat for the stripping process. The stripper is applied to the boat hull and is allowed to sit for a period of time. When a boat is stripped, there are likely to be five to seven coats of paint that need to be removed; this buildup of paint follows from the fact that boaters are reluctant to pay the high cost of stripping. Because there are multiple coats of paint that need to be stripped, the stripping formulation needs to be applied three to five times. When the paint bubbles up, the workers use a scraper to remove the paint residue and excess stripper which falls to the plastic or cardboard below. Once all the paint is removed, the coating residue is disposed of. The boat is rinsed down with water and is lightly sanded to develop a profile for adhesion of the paint. The water used for the wash down ends up in the clarifier at the boatyard.

The waste from the stripping operation is disposed of by many boatyards in the trash. Actually, the material is classified as hazardous waste for two reasons. It contains methylene chloride which is a listed hazardous waste and it also contains high levels of copper from the paint which would also make it a hazardous waste in California. Although the material is not generally handled as hazardous waste, IRTA's cost analysis assumes the paint residue is disposed of properly as hazardous waste.

Boatyards estimate that a 30 foot boat with multiple coats of paint might require four to seven gallons of stripper for the operation and the yards generally purchase the stripper in gallon quantities. The cost of the formulation, Klean-Strip Aircraft Remover, is $12.79 per gallon. Assuming five gallons are required, the cost of the stripper for the operation would amount to about $64.

The boat would probably be stripped by two workers. Boatyards estimate 20 to 40 labor hours are required to chemically strip a boat with multiple coats of paint. The burdened labor rate at boatyards ranges from about $25 to $36 per hour. Assuming 30 hours are required to strip the boat and that the labor rate is $30 per hour, the labor cost for stripping the 30 foot boat is $900. An additional four hours are required for sanding the stripped boat to create a profile to accept the new coating. Taking this into account, the total labor cost amounts to $1,020.

Boatyards estimate that the amount of waste generated from stripping a 30 foot boat is between five and ten gallons. As discussed earlier, most boatyards do not strip boats that often. Many smaller boatyards would likely be classified as Small Quantity Generators (SQGs). SQGs may accumulate waste for 180 days and must then dispose of it using a hazardous waste hauler. IRTA contacted a hazardous waste hauler to estimate the cost of disposal for the stripping residue. The analysis assumes that 10 gallons of waste are generated in the operation. The hauler estimates the cost of disposal of a 10 gallon pail of the waste, which must be incinerated, at $125. The pick-up fee is $185. In addition, haulers levy a surcharge of between 10 and 16 percent of the disposal cost. Assuming a surcharge of 13 percent, the total disposal cost is $350.

The costs of chemical stripping are summarized in Table 4-4. The values show that the labor cost dominates the total cost of the chemical stripping. Note that this is the cost to the boatyard for the stripping. Boatyards generally mark up the cost of the stripping considerably so the cost of stripping the boater pays is much higher.

Table 4-4
Cost of Chemical Stripping a 30 Foot Boat

Cost Element	Cost
Stripper Cost	$64
Labor Cost	$1,020
Hazardous Waste Disposal Cost	$350
Total Cost	$1,434

4.4.1.2. Hand Stripping

In this case, the workers use sandpaper applied with a dual-action (DA) rotating sander or a vacuum sander to abrade the paint from the surface of the boat hull. For the first few paint layers, the workers may use an aggressive 36 or 40 grit sandpaper and for the lower layers, they will use a less aggressive 64 to 80 grit paper. If a DA sander is used, the boat is generally shrouded with tarp or plastic to prevent the dust from migrating to other boats and destroying other paint jobs. The dust generated in the process needs to be vacuumed up after the operation is complete. When a vacuum sander is used, the boat does not need to be tarped as the dust is collected in the vacuum. The cost of the sandpaper and the electricity for the vacuum is assumed to be negligible.

The labor required for the stripping job is the same as assumed above for the chemical stripping job. Assuming that two workers would be required for the stripping, the total labor cost for the operation is estimated at $1,020.

The amount of waste generated in the hand sanding operation would again be about 10 gallons. It is classified as hazardous waste in California by reason of the copper content which is likely to be as high as 60 percent of the waste. In this case, the waste can be landfilled since it does not contain any solvents and the cost for disposal of the ten gallon pail is $74. There is a transportation fee of $185 and the total cost of disposal will carry a surcharge. Assuming the surcharge is 13 percent, the total disposal cost is $293.

Table 4-5 summarizes the cost of stripping the boat using a hand stripping abrasive method. The cost is somewhat lower than the cost of chemical stripping because no stripper is required and the disposal cost is lower.

Table 4-5
Cost of Hand Stripping a 30 Foot Boat

Cost Element	Cost
Labor Cost	$1,020
Hazardous Waste Disposal Cost	$293
Total Cost	$1,313

4.4.1.3. Sodium Bicarbonate Blasting

As discussed earlier, there are a few companies in California who offer the service of stripping boats with sodium bicarbonate media to boatyards. The service company in San Diego, Advanced Restoration, uses dry sodium bicarbonate. It relies on a food grade baking soda product mixed with air and propelled at 75 to 150 psi pressure to abrade the paint from the boat hull. The equipment used by the company is made by Sodablast Pty Ltd., and it is trailered to the boatyard by Advanced Restoration.

The process involves placing plastic tenting around the boat to restrict migration of the particles created in the process. A tarp is placed on the ground to collect the paint residue and the spent sodium bicarbonate media. The waste material is vacuumed up and put in a drum for the boatyard to handle. The surface left by the blasting process is suitable for accepting paint. A picture of the supplier preparing to strip a boat is shown in Figure 4-7.

Figure 4-7. Sodium Bicarbonate Stripping Vendor Preparing to Strip Boat

Advanced Restoration charges a boatyard about $900 to prepare and strip a 30 foot boat. The spent media, which is classified as hazardous waste, must be shipped off-site by the boatyard. The amount of waste generated through stripping a 30 foot boat is about three-fourths of a drum or about 40 gallons. The cost of waste disposal would be $148 and $185 for the pickup fee. Assuming the surcharge of 13 percent, the cost of disposal would be $376.

According to Advanced Restoration, the waste volume can be reduced significantly by adding water. The sodium bicarbonate reacts with the water, liberating carbon dioxide and the remaining material is about one-fourth of a drum or about 14 gallons of waste. This material is classified as hazardous waste. The hauler estimates the cost of disposal at $74 and $185 for the pickup fee. Again assuming a surcharge of 13 percent, the cost of disposal is $175, the same as the cost of disposal for the hand sanding residue.

According to the California Health and Safety Code, the addition of water to the waste constitutes treatment of hazardous waste (HSC, 25123.5). This means that one of the parties, Advanced Restoration or the boatyard, which is ultimately responsible for the waste, requires a treatment permit to add water to the waste. Some boatyards may already have treatment permits to treat other types of waste. The cost of waste disposal, if a treatment permit is obtained and if the waste volume is reduced, would be $74 and $185 for the pickup fee. Assuming a surcharge of 13 percent, the total cost of disposal would be $175.

Table 4-6 summarizes the cost of using the sodium bicarbonate stripping service for stripping a 30 foot boat including the two different disposal volume costs. Because the fee is lower for the service than the labor cost for hand sanding, the cost of using this technology is lower even assuming the higher disposal cost. It is also better for the workers because the supplier wears a full suit and respirator for the operation so he/she is not exposed to toxic chemicals or dust.

Table 4-6
Cost of Sodium Bicarbonate Blasting a 30 Foot Boat

Cost Element	Cost
Labor Cost	$900
Hazardous Waste Disposal Cost	$175 to $376
Total Cost	$1,075 to $1,276

4.4.1.4. Comparison of Stripping Costs for Chemical Stripping, Hand Stripping and Sodium Bicarbonate Blasting

Table 4-7 compares the cost of the three methods for stripping a 30 foot boat. The cost of using the service of the sodium bicarbonate stripping company is the lowest of the three methods. It is 25 percent lower than the cost of chemical stripping and 18 percent lower than the cost of hand stripping if the lower cost of disposal is used. If the higher cost of disposal is used, the cost of using sodium bicarbonate blasting is slightly lower than the cost of hand sanding.

Table 4-7 Comparison of Stripping Methods for a 30 Foot Boat	
Method	**Total Stripping Cost**
Chemical Stripping	$1,434
Hand Sanding	$1,313
Sodium Bicarbonate Blasting	$1,075 to $1,276

In the earlier Port/IRTA study, IRTA obtained costs of stripping from five boatyards. These costs are the costs charged to the customer by boatyards. For a 30 foot boat, these costs ranged from a low of $1,700 to a high of $3,200 with an average cost of $2,270. This indicates the markup by a boatyard that uses chemical stripping or hand sanding is 58 percent to 73 percent.

4.4.1.5. Abrasive Blasting Methods

The three alternative blasting methods that were tested included Advanced Restoration's sodium bicarbonate blasting system, Hawthorne's Farrow volcanic rock system and Red-D-Arc's Cold Jet dry ice blasting system. There is certainly more experience in using the sodium bicarbonate system for stripping boat hull paint so the costs of using that technology are more definitive. IRTA wanted to draw a rough cost comparison of the three technologies, however, so less certain assumptions are used in the cost analysis below for the Farrow and dry ice blasting system. There is no service provider for the Farrow or dry ice system so that model could not be used in the cost comparison. Rather, IRTA used a daily rental rate for the system which all three companies offer, as the basis for comparison. A 30 foot boat can be stripped in four or five hours. All the technologies have a setup time and cleanup time so assuming a one day rental rate for the units is a reasonable approach. In all cases, the boatyard would be expected to provide two workers to conduct the operations for the eight hour period.

4.4.1.5.1. Sodium Bicarbonate Blasting

Advanced Restoration sells stand alone blasting systems for $40,000 and also provides a system for rent at a rate of $175 per hour. This rate includes a supply of media. Assuming the technology would require only six hours to complete the job, the rental rate would be $1,050. The labor cost for conducting the operation, which would involve laying down a tarp, shrouding the boat, stripping the paint, filling the hopper with media and cleaning up the spent media and paint residue would require two workers. Using the burdened labor rate of $30 per hour, the labor cost amounts to $360. The waste disposal cost for stripping a 30 foot boat ranges from $175 to $376, depending on whether a treatment permit is obtained for adding water to the waste.

Table 4-8 summarizes the cost of using the sodium bicarbonate blasting method based on rental of the system. The total cost of using the system ranges from about $1,600 to about $1,800.

Table 4-8 Cost of Sodium Bicarbonate Blasting a 30 Foot Boat With Rental	
Cost Element	**Cost**
Rental Fee	$1,050
Labor Cost	$360
Hazardous Waste Disposal Cost	$175 to $376
Total Cost	$1,585 to $1,786

4.4.1.5.2. Volcanic Rock Blasting

This technology, called the Farrow System, uses volcanic rock crystals combined with heat and water to abrade the hull coating from the boats. The material is directed to the boat bottom at a pressure of 40 to 60 psi. The cost of a self contained Farrow System with a compressor and trailer is $48,000. The supplier of the technology, Hawthorne, also provides rental units. The daily rental fee is $375 and a transport fee of $75 each way is charged to deliver the system to the user.

IRTA tested the technology but has not seen the technology used for an entire boat. A Farrow Systems representative indicates that the company has stripped a 26 foot single hull boat with two layers of paint in four or five hours. This is somewhat more than the time required to strip a similar boat with sodium bicarbonate blasting.

The system representatives indicate that an advantage of the Farrow System is that the boat does not have to be shrouded to use the technology because it is wet rather than dry and dust is not created. This is similar to wet sanding of a boat instead of dry sanding. A tarp must be put under the boat during the operation. Since the media is wet, it could potentially be hosed down into the clarifier for disposal. It is classified as hazardous waste but so is the wet sanding media boatyards routinely treat in the clarifier. The other option would be to collect the media and dispose of it as hazardous waste.

The cost of using the system to strip a 30 foot boat includes the cost of renting the system for one day. The stripping time would be six hours. The additional time allows for delivery, the setup costs and for cleanup after the operation is completed. The cost of renting the system for one day would be $375 plus the delivery and return fees of $150 for a total cost of $525.

The cost of the media is $32 for a 50 pound bag. The consumption rate is 50 pounds of media in 30 to 45 minutes. For a 30 foot boat, if it is assumed that the stripping time is five hours and that the media consumption rate is 50 pounds in 30 minutes, then 10 bags or 500 pounds of media would be used. The cost of the media amounts to $320.

A 50 pound bag of the media approximately fits easily in a five gallon pail so 500 pounds, together with about 10 gallons of paint residue, would fit roughly in a 55 gallon drum. For the 30 foot boat, about one drum of waste would be generated. The disposal cost of the hazardous waste is $148 for the drum, $185 for the pickup fee and an additional 13 percent surcharge. The total cost of disposal amounts to $376.

Two workers would be involved in the stripping operation for the day. Assuming that 16 labor hours are required and assuming a burdened labor rate of $30 per hour, the cost of the stripping operation is $480.

Table 4-9 summarizes the cost of using the volcanic rock system assuming a daily rental fee. The cost of stripping a 30 foot boat with this technology is about $1,700.

Table 4-9 Cost of Volcanic Rock Blasting a 30 Foot Boat With Rental	
Cost Element	**Cost**
Rental Cost	$525
Media Cost	$320
Labor Cost	$480
Hazardous Waste Disposal Cost	$376
Total Cost	$1,701

4.4.1.5.3. Dry Ice Blasting

The cost of purchasing a dry ice blasting system is about $26,000. This system is not designed in a portable package with the compressor and a trailer. The system requires a larger compressor than the other two technologies, 375 cfm and 200 psi. The cost of such a compressor is about $35,000 and the cost of a trailer is about $2,000. The total cost of a system is about $63,000. This is higher than the cost of purchasing the other two systems.

Red-D-Arc, the distributor for the Cold Jet System, provides systems for rental. The weekly rental rate is $1,108. The compressor rental fee is $800 per week. The weekly rates are for seven days. IRTA could not obtain a daily rate from the company but it could be derived. The rental rate would likely be higher on a per day basis so for purposes of analysis, it was assumed that the daily rental rate is one-seventh of the weekly rate marked up by 30 percent. This amounts to $354 per day for the system and compressor.

The supplier of the system estimated that about 30 percent more time would be required for stripping the 30 foot boat than is required for the sodium bicarbonate blasting technology. Instead of a four hour stripping time, 5.2 hours would be required. The consumption rate of the dry ice is four pounds per minute. At a price of 45 cents per pound, the cost of the media for the 5.2 hour stripping activity is $562.

Two workers would again be required to conduct the operation. Assuming a labor rate of $30, the daily labor cost for stripping the boat would be $480. One disadvantage of this technology is that it leaves a very smooth surface. This is not acceptable for paint adhesion. Three labor hours would have to be devoted to sanding the surface with 80 grit sandpaper. The total labor cost would be $570.

One significant advantage of this technology is that there is not spent media generated as part of the waste. The only waste that is generated is the coating residue. The same amount of waste would be generated as is generated with hand stripping. This is about 10 gallons of paint residue. The disposal cost for a 10 gallon pail is $74. Adding in the additional pickup fee and the 13 percent surcharge, the cost of hazardous waste disposal would be $293.

Table 4-10 summarizes the cost of using the dry ice blasting system for stripping a 30 foot boat. The cost is close to $1,800.

Table 4-10 Cost of Dry Ice Blasting a 30 Foot Boat With Rental	
Cost Element	**Cost**
Rental Cost	$354
Media Cost	$562
Labor Cost	$570
Hazardous Waste Disposal Cost	$293
Total Cost	$1,779

4.4.1.5.4. Summary of Blasting Technology Costs

Table 4-11 summarizes and compares the cost of stripping a 30 foot boat with each of the three blasting methods assuming a system rental. The costs are approximately comparable. It should be noted that the sodium bicarbonate blasting method has been used much more extensively to strip boat hull paint than the other two technologies. The cost of using this technology can be characterized more accurately and there is more uncertainty in the costs associated with the other two technologies.

Table 4-11 Cost Comparison of Blasting Technologies	
Technology	**Cost**
Sodium Bicarbonate Blasting	$1,585 to $1,786
Volcanic Rock Blasting	$1,701
Dry Ice Blasting	$1,779

The costs of using sodium bicarbonate blasting in Table 4-11 can be compared with the cost of providing the service of stripping a boat to a boatyard in Table 4-7. The cost of rental is higher. It could be assumed that, if a supplier provided the stripping service using the volcanic rock or dry ice blasting methods, the cost would be lower as well. The important point is that the costs of using all three abrasive blasting methods in Table 4-11 are comparable. Using any of the three methods is likely to be slightly lower in cost than using chemical or hand stripping and they are also better from an overall health and environmental standpoint.

4.4.2. Applying Nonbiocide Paint Over Copper Paint

Many of the suppliers of the alternative nonbiocide paints are investigating methods of applying the paints over copper paint rather than requiring the boat to be stripped. As discussed in the last subsection, the cost of stripping a boat adds substantially to the cost of a paint job and the suppliers of the nonbiocide paints are aware of this. In general, their investigations involve the use of a so-called sealer or as they call it, a tiecoat primer or primer, on top of the copper paint prior to the application of the topcoat.

During this project, three different paints were applied over copper paint on four different boats. This section compares the paint job cost for a 30 foot boat based on a stripping the hull paint and based on applying the sealer over the copper paint. The cost of the paint job for a boat with an alternative nonbiocide paint is also compared to the cost of a copper paint job. Then based on a life of the copper paint of two years and a life of the nonbiocide paint of five years, the annualized costs of the systems are compared.

4.4.2.1. Copper Paint Job Costs

In the earlier Port/IRTA project, IRTA gathered information on copper paint jobs from five boatyards. For the cost analysis, the costs of the paint jobs at the five boatyards were averaged and the cost used in the analysis was this averaged cost.

Copper painted boats are only stripped infrequently. When the boat is repainted, the procedure involves sanding the places on the hull where the paint is damaged down to the gel coat, applying primer to the gel coat spots and then applying a coat of copper paint over the whole hull. Table 4-12 summarizes the costs obtained for painting a 30 foot boat from the five boatyards in the earlier project. The prices charged by the boatyards range from $870 to $1,110 with an average price of $1,038. They are based on a haulout, hydrowash and one coat of copper paint.

Table 4-12
Paint Job Costs for 30 Foot Copper Boat

Boatyard	Cost/Foot	Total Cost
1	$37	$1,110
2	$36	$1,080
3	$29	$870
4	$36	$1,080
5	$35	$1,050
Average		$1,038

4.4.2.2. Applying Nonbiocide Coatings Over Copper Paint

IRTA estimated the cost of paint jobs for two different coatings that can be applied over copper. As discussed later in the section on the paints applied to boats, the coatings that were applied over copper are a paint called BottomSpeed and Intersleek 900. The other coating applied over copper, XZM 480 with a hardener added, is not yet commercialized so the information on cost and use of paint was not available for analysis.

4.4.2.2.1. BottomSpeed Over Copper Paint

One of the paints tested on boats and described in Section V is a paint called BottomSpeed. This paint was tested on panels in the earlier Port/IRTA project but this version of the paint was not tested on boats.

The procedure for applying BottomSpeed over copper paint on a 30 foot boat involves conducting the same surface preparation operations that are necessary for applying a copper paint over an existing copper paint. After the surface preparation, two coats of the sealer (or tiecoat primer as it is called by the BottomSpeed supplier) are applied to the boat hull. Then one coat of the BottomSpeed topcoat is applied. The operation requires about 1.5 gallons of sealer for each of the two coats for a total of three gallons and one gallon of BottomSpeed. The cost of three gallons of sealer and one gallon of topcoat amounts to $1,774 including a markup of about 25 percent for retail applications. MSDSs for the paint, called BottomSpeed Topcoat Clear, and the sealer, called BottomSpeed TC BaseCoat, are shown in Appendix B.

As part of the analysis, IRTA contacted three boatyards to obtain information on the costs of applying these coatings over copper paints. In this case, two additional coats of paint are required and boatyards add a charge in terms of boat length for additional coats of paint. In addition, they assume a copper paint cost of $150 per gallon. If the price of the paint is higher than that, it must be added to the paint job cost. The markup on the price is about 25 percent. On this basis, the cost of a paint job for the BottomSpeed system using the procedures employed by the three boatyards is $3,694, $3,004 and $3,274 for an average cost of $3,324. Because the paint is more expensive and because additional coats are required, this is still significantly higher than the average cost of a copper paint job, which is $1,038.

Because applying these nonbiocide paints over copper paint is a very new practice and is still in the research phase, there is virtually no data on the life of coatings applied this way. It is not clear whether the paint will last the life of the topcoat or, because it is applied over copper paint, the copper paint may delaminate earlier than the topcoat. Another possibility is that the nonbiocide paint would delaminate from the copper paint earlier than it would from a stripped hull.

As discussed in the next section, BottomSpeed was applied to a diver workboat. Half of the boat was stripped and the other half was not stripped. The BottomSpeed was applied to the stripped hull on one half of the boat and over the copper paint on the other half of the boat. The diver, who has cleaned his own boat with BottomSpeed on it, believes that the life of BottomSpeed should be at least five years. This is based on experience with other soft nonbiocide paints and their lives of as much as 10 years and the performance of the BottomSpeed itself.

Copper paints generally have a life of two years and the BottomSpeed will have an assumed life of five years. The cost of the paint job can be compared based on the life of the paint if the paint job cost is amortized over the life of the paint job. The amortization assumes a cost of capital of four percent and the average values for the copper paint job cost and the nonbiocide paint job cost. On this basis, the annualized cost of the paint job for the BottomSpeed boat is $691 and the annualized cost of the paint job for the copper paint is $540. The annualized cost of the BottomSpeed paint job is about 22 percent higher than the annualized cost of the copper paint job. If the BottomSpeed paint job lasted more than five years and if the life is actually 10 years, then the annualized cost of the BottomSpeed paint job is $345, substantially lower than the annualized cost of the copper paint job. If the life of the BottomSpeed paint job is even six years, the annualized cost of the paint job is $576 which is close to the annualized cost of the copper paint job.

4.4.2.2.2. Intersleek 900 Over Copper Paint

Intersleek 900 was tested on panels and boats in the earlier Port/IRTA project and it was one of the top performing paints on boats. IRTA analyzed the cost of applying Intersleek 900 and a sealer over copper for a 30 foot boat. MSDSs for the Intersleek 900 topcoat, called Intersleek 970 White Part A, and the sealer, called Veridian Tie Coat, are shown in Appendix B. The Intersleek 900 supplier has developed this sealer specifically for applying nonbiocide paints over copper paint.

In this case, the surface is again prepared as for a copper paint job. The boat requires one coat of the sealer and one coat of the Intersleek 900. One gallon of the sealer at $100 per gallon is required. For the topcoat, 1.3 gallons are required at a cost of $475 per gallon. The total cost of the paint is about

$718. Using the same procedure as described above for the three boatyards, the boatyards would charge $2,638, $1,948 and $2,218 for an average cost of $2,268. This is still more than twice the cost of a copper paint job. It is about half the cost of rolling on Intersleek 900 to the stripped hull of a 30 foot boat; referring to Table 4-1, this cost is $4,556. This verifies the cost of applying the nonbiocide paints over copper are lower than if the boat is stripped but they are still higher than the cost of a copper paint job.

Again, the cost of using the Intersleek 900 and the copper paint over the life of the paint can be compared. In this case, the Intersleek 900 is likely to have a life of 10 years since commercial boats have been painted with this coating and the life of the paint job is at least seven or eight years. Two cases were considered, a five year and a 10 year life. The annualized cost of the copper paint job making the assumptions described above is $540. The annualized cost of the Intersleek 900 paint job is $472 assuming a five year life for the paint and $236 assuming a 10 year life for the paint.

4.4.2.2.3. Summary of Paint Job Costs Over Copper

Table 4-13 summarizes and compares the cost of a typical copper paint job and the cost of applying the paint over copper for BottomSpeed and Intersleek 900.

Table 4-13
Cost Comparison of Copper and Alternative Nonbiocide Paint Jobs Over Copper

System	Description	Type of Cost	Cost
Copper paint	Over copper	Average	$1,038
BottomSpeed	Two coats sealer/topcoat	Boatyard 1	$3,694
		Boatyard 2	$3,004
		Boatyard 3	$3,274
		Average	$3,324
Intersleek 900	One coat sealer/topcoat	Boatyard 1	$2,638
		Boatyard 2	$1,948
		Boatyard 3	$2,218
		Average	$2,268

The costs in Table 4-13 can be compared with the costs of applying some of the best performing nonbiocide paints in the Port/IRTA project. Table 4-1 presented the costs of applying Intersleek 900 and Hempasil X3 to 30 and 40 foot boats that were determined by averaging the costs over five boatyards in the San Diego area. The values in the table indicate that the cost of applying the two coatings to a stripped 30 boat hull range from about $4,556 to $6,358, depending on whether the paint was rolled or sprayed on. Comparing these figures with the values of Table 4-13 shows that the cost of applying the paint over copper paint and avoiding the cost of stripping can reduce the cost of the paint job considerably. In particular, the cost of an Intersleek 900 paint job for a 30 foot boat when the paint is applied over copper is $2,268 in Table 4-13. This can be compared with the cost of applying Intersleek 900 to a 30 foot boat with a stripped hull in Table 4-1 of $4,556. Applying the paint over copper instead of stripping the hull can reduce the paint job cost by half.

The major reason the paint job costs are still higher for applying the alternative nonbiocide paints than for copper paint in Table 4-13 is that the cost of the topcoats is much higher than the cost of a copper paint which is about $150 per gallon. If more of the alternative nonbiocide paints are used in the future, production and blending activity would be higher and there would be more competition. As a result, the price of the coatings might be expected to decline. The raw materials cost of the coatings is likely to represent about half to 60 percent of the coating cost, however, so the price will probably remain higher than the price of the copper paint. On that basis, the cost of applying a soft nonbiocide paint over a copper paint might be expected to be about 1.5 to two times the cost of a copper paint job.

Table 4-14 presents the annualized paint job cost averaged over the three boatyards for each of the paint systems. The values assume a life of two years for the copper paint and lives of five and 10 years for the nonbiocide paints. For the 10 year paint life, the annualized cost of the paint job for both alternative paints is lower than the annualized paint job cost for a copper boat. For the five year life, the annualized cost of the paint job for one of the paints is lower than the annualized cost of the paintjob for the copper boat.

Table 4-14
Annualized Paint Job Cost of Copper and Alternative Paints Applied Over Copper

System	Paint Life	Cost
Copper Paint	2 years	$540
BottomSpeed	5 years	$691
	10 years	$345
Intersleek 900	5 years	$472
	10 years	$236

4.4.3. Paint Application by Rolling

The traditional method of applying copper paint is to roll it on. A picture of a paint being rolled on is shown in Figure 4-8. The paint is poured into a tray, the roller is rolled in the tray in the paint and it is then rolled on the bottom of the boat. The transfer efficiency (percent of paint used that is transferred to the surface) of rolling is essentially 100 percent. Spraying the paint is a more complex process. The paint is mixed in the cup of a spray gun and the paint is sprayed onto the surface of the boat. The transfer efficiency of spraying is no more than about 75 percent and can be much lower depending on the type of spray equipment that is used. When boatyards spray paint, they generally use an airless spray gun which has a much lower transfer efficiency.

When a paint is sprayed on, the boat needs to be shrouded in a tarp. Without this protection, the paint could be deposited on other boats in the boatyard or outside the boatyard on other structures, particularly on windy days. Many of the soft nonbiocide paints contain silicon compounds and the material can contaminate other paint jobs if it is not controlled carefully. Inside the shrouding, the worker should wear a respirator while applying the paint.

Spraying a coating is a faster process than rolling. The set-up time, however, is longer because of the need for shrouding in this application. Boatyards have some experience in spraying because racing sailboats, which require a smooth surface for speed, are often sprayed with copper paints. With this exception, however, most boatyards are much less familiar with spraying than rolling and they would much rather roll the coatings on. Boatyards charge a higher price for paint jobs where the paint is sprayed. IRTA analyzed the cost information for the Port/IRTA project and the increased cost of spraying

Figure 4-8. Painter Rolling Paint on Boat.

as estimated by five boatyards for a 30 foot boat ranges from about $218 to $1,000. The average over the five boatyards for a 30 foot boat was an increased cost of about $20 per foot for spraying rather than rolling or about $600.

In the Port/IRTA project, paint was rolled on instead of sprayed on three of the boats that were painted with soft nonbiocide paints. Intersleek 900 was rolled on a 30 foot sailboat and it was assessed for a 12 month period. This boat was heavily used and is a racing sailboat. The boater was pleased with the paint and won several races during the timeframe. Klear N'Klean, another soft nonbiocide paint tested in the previous project, was rolled on two boats. One of the boats was a 32 foot sailboat which was assessed for a 16 month period and the other was a 35 foot sailboat which was assessed for an 18 month period. There was no evidence that rolling instead of spraying made a significant difference in the performance of the paint.

During this project, soft nonbiocide paints of various types were applied to 10 boats. IRTA wanted to investigate rolling so rolling was used for painting eight of the 10 boats that were painted. One of the coatings that was sprayed on cannot be rolled because of its characteristics; a new formulation for the tie coat would have to be developed to allow it. The other coating that was sprayed on was Intersleek 900 which was successfully rolled on another racing sailboat during the Port/IRTA project and on another boat in this project.

Most suppliers of nonbiocide paints are exploring rolling as an alternative to spraying because they are aware that spraying raises the cost of the paint job. From the experience in the Port/IRTA project and this project where a number of paints were rolled on rather than sprayed, there is no evidence that this method cannot be used more widely.

4.4.4. Instituting Copper Recycling

As part of this project, IRTA staff took note of the fact that boatyards have several operations involving hull painting that generate waste streams containing copper. The three types of operations are:

- dry hand sanding during surface preparation and stripping
- wet hand sanding during surface preparation and stripping
- stripping with blasting equipment

Each of these operations is discussed further below. They are of interest because of the high price of copper. If a high enough copper concentration is present in the waste material, then recycling the copper for reuse could be a option.

4.4.4.1. Dry Sanding

As discussed earlier, most repainting operations do not involve stripping the boat. Copper paint is generally applied directly over the old copper paint. When a boat needs to be painted, the old paint is often in bad shape and the workers must prepare the surface to accept the new paint. The workers sand the hull in the spots where the coating is damaged down to the gel coat. They then apply primer to the spots they have sanded. Then the topcoat is applied to the whole boat hull. This same procedure is likely to be used as more boaters adopt alternative nonbiocide paints. There are methods now of applying these paints over copper paint as discussed in the last subsection. The other dry sanding activity occurs during the stripping of paint. As discussed earlier, some boatyards strip copper paint from the hull completely with hand sanding methods.

Many boatyards use DA sanders for sanding the damaged spots and for stripping the paint. Some boatyards use vacuum sanders and the dust is collected in the vacuum. All workers could use vacuum sanders to collect the dust since it is not good policy to emit the dust or deposit it to the ground where it can become airborne and negatively impact other paint jobs. For stripping, in particular, boats are generally shrouded because of the dust.

4.4.4.2. Dry Blasting Stripping Residue

A few boatyards are starting to use sodium bicarbonate blasting for stripping boat hulls either because the copper paint has not been stripped for years or because they intend to apply a nonbiocide coating to the boat hull. Boatyards could also decide to adopt other media stripping operations over the next few years, perhaps including dry ice blasting. Based on the demonstration of the three technologies and the DTSC analysis results, the residue from these operations has fairly high copper content.

4.4.4.3. Wet Sanding and Other Wet Residue

When boats are first removed from the water, they are sprayed with high pressure water to remove the loose patches of fouling and copper paint on the hull. Boatyards generally have clarifiers which treat the water containing the contaminants. Some boatyards use wet rather than dry sanding methods in their surface preparation and for stripping boats. The wet sanding residue is deposited on the ground and is washed into the clarifier at the end of the day. The volcanic rock blasting method is also a wet method and the residue from this operation, should boatyards adopt it, would likely be treated in the same manner. When boatyards strip boats with chemical strippers, after the waste is discarded, the stripping area which likely contains some copper, is hosed down and the water is routed to the clarifier. All of these wet streams contain copper in various concentrations. In the clarifier, the solids are allowed to settle and this material is periodically pumped out, picked up by a hazardous waste hauler in a vacuum truck and the sludge material is disposed of. The water is generally released to the local Publicly Owned Treatment Works (POTW).

4.4.4.4. Analysis of Samples

As discussed earlier, DTSC analyzed samples from the stripping demonstrations of the three blasting technologies. One of these was dry ice blasting. The only waste collected during this process is the coating residue which should have approximately the same copper content as dry sanding dust from surface preparation or stripping. The spent residue did have high copper content, about 60 percent. It is classified as hazardous waste in California by reason of the copper content. Even if sanding dust has somewhat lower copper content, it would still be classified as hazardous waste. Many boatyards do not handle the dry sanding waste properly as hazardous waste; they simply dispose of it in the trash. The DTSC lab results also indicated that the residue from the other two stripping technologies, sodium bicarbonate and volcanic rock blasting, contained copper.

IRTA began working with a copper recycler called World Resources Company, located in Arizona. The company collects copper laden waste streams, processes and consolidates them in various ways and sends them to Canada to a primary copper smelter. IRTA discussed the waste streams from boatyards with the company and they expressed interest in pursuing the possibility of recycling the copper from boatyards.

IRTA worked with several boatyards and Advanced Restoration to obtain samples of various types of waste streams and have them sent to the copper recycling firm for analysis so they could be evaluated for possible recycling. The sanding dust samples contained between about 38 and 60 percent copper and the recycler determined that this stream could be recycled. Because few, if any, boatyards are using volcanic rock and dry ice blasting methods, IRTA did not obtain any spent samples of this material. IRTA did work with Advanced Restoration and sent the recycler several different samples of sodium bicarbonate stripping waste both before adding water to reduce the volume and after. In these cases, the analysis indicated a copper content of about 11 to 13 percent. A few boatyards also sent samples of their clarifier sludge and, generally, this material was low in copper content, containing between about three and five percent.

4.4.4.5. Cost Analysis of Copper Recycling

World Resources assisted IRTA in evaluating each of the streams for their recyclability. As a general rule, if the boatyard generates five to 10 dry tons per year with a 30 percent copper concentration, there would be a net zero cost for disposal or payment for the waste. The boatyard must pay for the pickup, based on the waste material and receives a payment, again based on the recyclability and copper content of the material.

The hand sanding waste (and presumably the dry ice blasting residue, if the technology were used) has the highest concentration of copper of the three waste streams. Smaller boatyards may generate as much as 15 to 50 drums per year of the waste. One boatyard IRTA worked with generated 16 drums per year; another boatyard generated 10 to 12 drums per quarter or about 44 drums per year. The recycler examines the material and calculates the amount of solids and bases the amount the boatyard pays for providing the waste and the payment the recycler remits.

If a boatyard generates about 16 drums per year, for example, that amounts to about four dry tons, based on a density of about nine pounds per gallon for the dry material. If the dry dust contained 60 percent copper, found in one of the boatyard samples, the boatyard would pay $800 to the recycler for pickup and would receive a payment of $800. This would mean there is no net cost for disposal. If the copper content was lower, at about 38 percent, which was found in another sample, the boatyard would pay $800 for the pickup and would receive about $400 back. The net cost of disposal, in this case, would be $400.

If a boatyard used the sodium bicarbonate stripping service offered by Advanced Restoration and generated 16 drums of waste material each year, the boatyard would pay a net fee of about $400 to dispose of the waste with the copper recycler. The copper content of the clarifier sludge analyzed by the recycler was quite low. Two samples which had copper content of about three and five percent, were analyzed. The price the boatyard would pay to send the clarifier sludge to the recycler would vary depending on the copper content and the presence of other recyclable materials.

4.4.4.6. Cost Comparison of Hazardous Waste Disposal and Copper Recycling

The two waste streams that have reasonably high copper content and could potentially be recycled are hand sanding waste and sodium bicarbonate blasting residue. As discussed earlier, the disposal cost for one drum of copper containing hazardous waste, according to PSC, is $148. The pickup cost, regardless of amount is $185 and a surcharge of 13 percent is levied on all pickups.

SQGs are given 180 days or six months to accumulate hazardous waste. Based on a boatyard that generates 16 drums of dry sanding waste per year, it will be assumed that the waste will be picked up twice a year. The hauler charges $1,212 for each pickup of eight drums. The annual cost of disposing of this material as hazardous waste amounts to $2,424. In this case, the material would have to be manifested as hazardous waste in California.

As discussed above, the copper recycler would pay $800 for 16 drums of material with a copper content of 60 percent and the boatyard would receive $800 in payment for a net zero cost. If the 16 drums contained about 38 percent copper, the boatyard would pay $800 and the recycler would remit $400 for a net boatyard cost of $400. In this case, the material sent to the copper recycler would also have to be manifested as hazardous waste because it is so classified in California.

Table 4-15 summarizes the options for the dry sanding dust assuming a boatyard generates 16 drums per year of the material. The values indicate that boatyards generating dry sanding waste, even with only a 38 percent copper content, would benefit from using the copper recycler instead of disposing of the material as hazardous waste.

Table 4-15
Annual Cost of Handling Dry Sanding Dust

Material Characteristic/Destination	Annual Cost
Hazardous Waste Disposal	$2,424
Copper Recycling—38 percent copper	$400
Copper Recycling—60 percent copper	0

The copper recycler tested several different streams IRTA collected from spent sodium bicarbonate boat stripping processes and the copper content ranged from about 11 to 13 percent. The case that was analyzed is that 16 drums per year of dry waste of this type with a 12 percent copper content are generated. A drum contains about one-fourth of a ton and each boat generates about three-fourths of a drum of waste. The boatyard would strip about 21 or 22 boats annually to generate this amount of material. The recycler would pick up the waste four times per year and the cost of recycling would amount to about $240 per drum on this basis. The total cost of recycling the spent stripping media would be $3,840 annually. The hazardous waste disposal cost is $2,424 which is about half this cost so it is more cost effective to dispose of the material as hazardous waste. Table 4-16 summarizes these costs.

Table 4-16
Annual Cost of Handling 16 Drums of Spent Sodium Bicarbonate Blasting Residue

Material Characteristic/Destination	Annual Cost
Hazardous Waste Disposal	$2,424
Copper Recycling—12 percent copper	$3,840

IRTA also examined the cost of recycling clarifier sludge. A few boatyards sent clarifier sludge samples to the copper recycler. One boatyard generates about seven drums or 380 gallons per load. The copper content in the drums was fairly low, in the four percent range. It also contained a small amount of tin and a very small amount of gold and both could also be recycled. The recycler would charge the boatyard between about $125 and $175 per drum for recycling the material.

The clarifier sludge is not RCRA hazardous waste based on the copper content but it is classified as hazardous waste in California. Boatyards often have their clarifiers pumped out and some boatyards pump out the waste themselves and dry it out. The cost of disposal for pickup of 380 gallons of clarifier waste in a vacuum truck includes a four hour minimum pickup and pumpout fee of $95 per hour or a total cost of $380 and a washout fee for the truck of $250 for a total cost of $630 assuming the travel and pumpout time would be four hours or less. In addition, the fee for disposal of the 380 gallons would amount to $1 per gallon or $380. The total disposal cost is $1,010. The recycler indicated he would charge between $125 and $175 per drum for recycling the clarifier waste. Assuming the midpoint, $150, the total cost of recycling the clarifier sludge is $1,050. This is only slightly higher than the cost of disposing of it as hazardous waste.

Table 4-17 summarizes and compares the cost of disposing of the clarifier waste and recycling it. The costs of hazardous waste disposal and recycling are comparable. Some boatyards would be willing to contract with the recycler for the sludge even though it may not be cost effective to do so. The destination for the waste is landfill disposal and many companies have been forced to contribute cleanup costs for land disposal sites that have required cleanup. Some companies, as a result, will pay a higher price to avoid land disposal. In addition, larger companies, like shipyards, may have policies that require recycling where possible regardless of a higher cost to avoid potential liability.

Table 4-17 Annual Cost of Handling 380 Gallons of Clarifier Waste	
Material Characteristic/Destination	**Annual Cost**
Hazardous Waste Disposal	$1,010
Copper Recycling—4 percent copper	$1,050

V. ALTERNATIVE NONBIOCIDE PAINTS ON BOATS

During the project, IRTA was involved in painting ten boats with alternative nonbiocide paints. The purpose of painting the boats was to demonstrate and observe the performance of new and emerging paints and/or to paint the boats using alternative application methods that could result in lower cost paint jobs for the nonbiocide paints. This section describes the boats that were painted, the factors that were investigated and evaluates some of the aspects of the boat performance to date.

Table 5-1 summarizes the information for the ten boats that were painted. The boats that were painted were owned by individuals, one port, one city, a diving company, an international transport company and a California agency. All but two of the boats were painted with a new and emerging paint. The paint was sprayed on only two of the boats. Three of the coatings were put on three and a half boats over copper. Four of the boats had metal hulls and six had fiberglass hulls. The types of boats included dinghys, inflatables, powerboats and sailboats. A more detailed description of each boat and the conditions of the paint application is provided in the table below.

Table 5-1

Characteristics of Boats Painted During Project

Boater/Owner	Paint Name	Boat Description	Factor Investigated
Auerbach	Intersleek 900	25 Foot Catalina Sailboat	Verify Performance
Port of San Francisco	XZM 480	18 Foot Boston Whaler	Emerging paint, rolling
Port of San Francisco	XP-A101	14 Foot workboat, Metal hull	Emerging paint, rolling
City of Newport Beach	Hempasil X3 and XA 278	17 Foot Boston Whaler	Emerging paint, rolling
San Diego Diving Service	BottomSpeed	18 Foot Boston Whaler	Emerging paint, rolling, applied over copper
Heinem	BottomSpeed	32 Foot Bayliner	Emerging paint, rolling, applied over copper
Pasha	BottomSpeed	11 Foot Inflatable Dinghy, Metal Hull	Emerging paint, rolling
Cal Dept. Fish and Game	XZM 480 + hardener	27 Foot Almar Rigid Inflatable, Metal Hull	Emerging paint, rolling, applied over copper
Cal Dept. Fish and Game	SherRelease	24 Foot Almar Rigid Inflatable, Metal hull	Emerging paint
Rhodes	Intersleek 900	42 Foot Sailboat	Rolling, applied over copper

5.1. Auerbach Boat—Intersleek 900

This 25 foot Catalina sailboat is moored in the Balboa Yacht Basin in Newport Beach and the owner often sails the boat to Catalina. The boat was painted at South Coast Shipyard in Newport Beach with Intersleek 900, a soft nonbiocide paint. This paint was one of the two best performing paints in the earlier Port/IRTA project. IRTA collaborated with the Orange County Coastkeeper in painting the boat. The Coastkeeper has an incentive program for boaters in the Balboa Basin to switch from copper paints to nonbiocide paints; the organization provided some of the funding to offset the cost of the paint job.

The boat was painted near the end of June 2010. In this case, the fiberglass boat was stripped and the paint was applied by spray. A picture of the boat, called PiSeas II, at the shipyard during the spray painting is shown in Figure 5-1. A picture of the boat at the boatyard after the application of the topcoat is shown in Figure 5-2.

Figure 5-1. Painter Spraying Paint on Auerbach Boat

Figure 5-2. Boat after Application of Top Coat

IRTA inspected the boat at the end of April, 2011 with the paint supplier when the paint had been on the boat for nine months. The supplier dived in the water and examined the boat hull and its appearance was very good. A picture of the boat during this inspection is shown in Figure 5-3. IRTA and the supplier had provided cleaning guidance to the diving company that maintains the boat. The company was told to clean the boat with gentle tools like a soft carpet and to maintain a schedule of approximately 15

Figure 5-3. Auerbach Boat at One Year Inspection.

cleaning sessions a year. IRTA has remained in contact with the diving company and the company reports the hull is easy to clean and looks very good.

The Intersleek 900 appears to be performing well and is expected to last as long as 10 years before a new paint job is needed. At that stage, the paint can be put over itself without the need for a stripped hull. Because of the experience during the earlier Port/IRTA project and this project, there is no reason that the paint couldn't be rolled on rather than sprayed which should be a savings in the paint job cost.

5.2. Port of San Francisco—XZM 480

XZM 480 is a new coating that was tested on panels during the panel testing phase of the project. The coating is a soft nonbiocide paint. During the panel testing, the paint was cleaned easily with a terry towel but it was noted to be very soft.

The Port of San Francisco wanted to participate in the project and offered to paint one of their boats with an emerging paint. The Boston Whaler fiberglass hulled boat was stripped and it was agreed that the paint, still in the experimental stage, would be rolled on at the Port paint shop. Pictures of the boat during painting are shown in Figures 5-4 and 5-5. The boat was painted during the first week in January 2011. The paint was very soft and the weather was cold and damp; it required a long timeframe to cure. When it was launched, the Port staff was not sure the coating was fully cured.

IRTA's experience with the alternative paints was generally gained in Southern California. The Bay Area is much colder and it is not clear what the fouling patterns would be for the soft nonbiocide paints in that location. As a consequence, IRTA, the supplier and the Port decided to inspect the boat hull in mid-

Figure 5-4. Painter Applying Tiecoat.

Figure 5-5. Painter Applying Topcoat.

Figure 5-6. Port of San Francisco Boat Suspended by Crane


Figure 5-7. Small Barnacles on Port of San Francisco Boat Hull

April, some months after it had been launched. The Port arranged for the boat to be lifted out of the water on a crane so the bottom could be inspected. Figure 5-6 shows the boat suspended by the crane. The boat had not been used during the period and there were small barnacles on the hull. These are shown in Figure 5-7. The boat was usually driven at fairly high speed and it was taken out for a period and the bottom was inspected again to see if the fouling remained. Figure 5-8 shows the hull after the boat was driven at high speed; it shows that nearly all the fouling was removed during normal use. This

Figure 5-8. Port of San Francisco Boat After it was Driven at High Speed

indicated that the boat may not need diver maintenance if it is periodically driven at high speed. The Port agreed to have a diver inspect the boat periodically and perhaps remove any fouling with a soft cloth.

During the boat inspection, there was also evidence that the coating had been damaged at the waterline, particularly on one side of the boat. It may have been damaged by rubbing against the dock. The team decided to pull the boat out of the water again at a later time to touch up the paint on the waterline. The supplier and IRTA decided to use the same coating, this time with an added hardener; this version of the coating had been applied to another boat since the first paint application of the Port boat (see Fish and Game boat description below). Figure 5-8 above shows the Port boat waterline damage and Figure 5-9 shows the boat during the paint/hardener touchup operation. The boat was launched again the first week of August 2011.

<u>5.3. Port of San Francisco—XP-A101</u>

The Port of San Francisco also had a small 14 foot workboat with an aluminum hull that had never been painted. This boat appeared to be a good candidate for testing an emerging paint. One of the paints that performed well in the panel testing was XP-A101, a soft nonbiocide paint based on silicon and fluoropolymer compounds made by Petit. IRTA had contacted the supplier earlier in the project because the panels containing the paint were performing well. The Petit chemist indicated that his supplier of the fluoropolymer component had withdrawn the particular fluoropolymer from the market and that the coating was not available in the form tested on the panels. The company reformulated the paint using a different fluoropolymer ingredient and had begun panel tests. The chemist indicated the behavior of the new formulation seemed very similar to the behavior of the original formulation. An MSDS for the paint is shown in Appendix B. Although it is taking a risk to apply an untested paint to a boat, because the boat is so small, it seemed a reasonable proposition.

Figure 5.9. Port of San Francisco During Paint/Hardener Touchup Operation

The paint was applied to the boat in October 2011 by the Port paint shop. Figure 5-10 is a picture of the boat during the painting process and Figure 5-11 shows the boat with the new paint job. Two coats of a primer, one tiecoat and two topcoats were applied. The boat was launched in mid-October.

Figure 5-10. Port of San Francisco Workboat During Painting

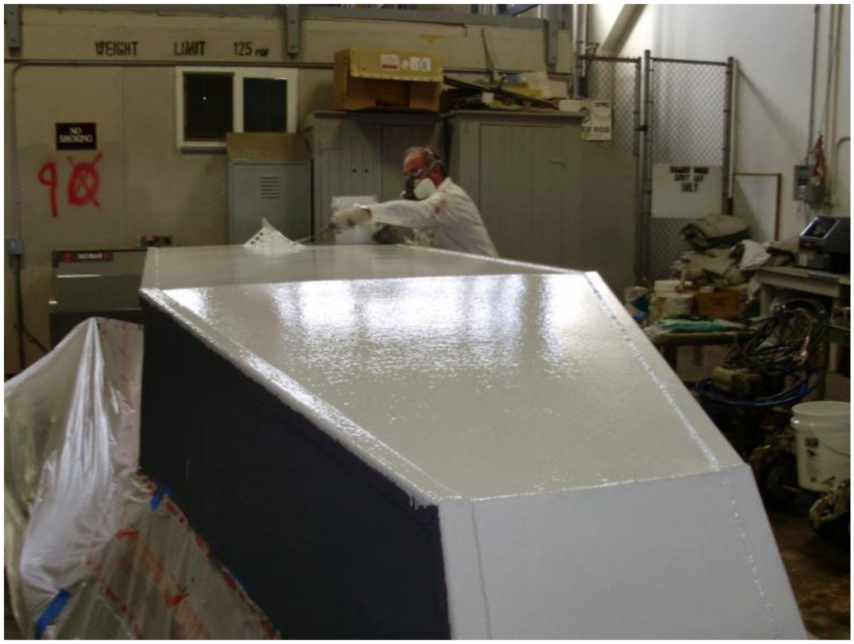


Figure 5-11. Port of San Francisco Workboat with New Paint

5.4. City of Newport Beach—XA 278

IRTA collaborated on this painting project with Orange County Coastkeeper. The Coastkeeper grant applies to boats in Balboa Yacht Basin and the City of Newport Beach boat, which is used as a patrol/observation vessel, is moored there. The Coastkeeper provided some funds to reduce the cost of the paint job. The boat, an 18 foot Boston Whaler, was painted at Basin Marine in Newport Beach in June 2011.

In the earlier Port/IRTA project, one of the best performing paints was a soft nonbiocide paint called Hempasil X3 offered by Hempel. In the panel testing, IRTA tested two new Hempel paints, XA 278 and XA 284. Both sets of panels performed well as discussed in Section III. IRTA wanted to test one of the paints, XA 278, on a boat. Hempel has always recommended that the paint be applied with spraying to keep the surface as smooth as possible. The company wanted to investigate a new method of application by rolling the paint on. IRTA and the company also wanted to compare the new panel tested paint with the Hempasil X3. The team agreed that the Hempasil X3 would be applied to half the boat and the new coating, XA 278, would be applied to the other half of the boat. Both coatings would be rolled and brushed on rather than sprayed to judge the performance of a boat with rolled coatings. An MSDS for Hempasil X3, called Hempasil X387509, is shown in Appendix B.

The supplier wanted the boat to be stripped and IRTA arranged for Advanced Restoration to strip the boat prior to applying the paint. A picture of the boat during the sodium bicarbonate stripping process is shown in Figure 5-12. The boat was first painted with a primer. Then a light red or pink tiecoat was applied. The starboard side of the boat was painted with Hempasil X3 and the port side of the boat was painted with XA 278. The tiecoat and topcoats were rolled on and the rolling was followed by brushing to work in and spread the paints. A picture of the boat after the tiecoat application is shown in Figure 5-13 and a picture of the boat after the topcoat was applied is shown in Figure 5-14.

Figure 5-12. City of Newport Beach Boat Prepped for Sodium Bicarbonate Stripping

Figure 5-13. City of Newport Beach Boat After Tiecoat Application

Boats are generally put on blocks when the bottom paint is applied. These are supports that are removed when the paint job is completed. Figures 5-13 and 5-14 clearly show the blocks in two locations on the boat bottom for this case. When the paint is cured, the blocks are moved and the spots under the blocks must then be painted, often a day or so later. In this case, there was no additional XA

Figure 5-14. City of Newport Beach Boat After Topcoat Application

278 paint to apply to the boat under the blocks. IRTA was involved in painting another boat at the boatyard at the same time (see Fish & Game—XZM 480 Plus Hardener below) and both paints were similar red colors. IRTA did not want the boatyard to apply copper paint to the spots so the XZM 480 plus hardener coating was applied instead.

IRTA discussed the method of maintaining the boat with the owner and with his diving company. The boat was generally cleaned about once a month and IRTA suggested that this schedule be continued. IRTA recommended that the diver use the soft side of a sponge for cleaning the boat. The diver reports on the boat regularly to IRTA. In August, the diver observed a spot where the paint seemed to be coming off. It was on the port side which had been painted with the new coating, the XA 278. In September, the boat had accumulated some hard fouling, including tube worms and bryozoans, and the diver had to clean the boat with a thin white pad. In later cleaning sessions, the diver observed that there were spots where the paint was peeling off on both sides of the boat.

The Orange County Coastkeeper inspected the bottom of the boat and videotaped the hull. There were spots where the paint was peeling and they seemed to be in the same location as the blocks in Figures 5-13 and 5-14. IRTA has been involved in painting several boats with Hempasil X3 and no peeling of the paint was ever observed. The XA 278 is similar to the Hempasil X3 and would not be expected to peel. In contrast, the XZM 480 paint on the Fish & Game boat, as described below, was also peeling in some spots. It seems reasonable to assume that the XA 278 paint is performing well and that the peeling spots on the hull are attributable to the XZM 480 applied under the blocks.

5.5. San Diego Diving Service—BottomSpeed

This boat used by San Diego Diving Service as part of their boat maintenance work is an 18 foot Boston Whaler powerboat. During the earlier Port/IRTA project, a coating used primarily for propellers, called PropSpeed, was one of the paints included in the panel testing. This paint was one of the best performing paints and the project team wanted to test it further on a boat. The supplier was concerned that the coating was too soft, however, and that it would be damaged so it was reformulated to be a harder paint. The new formulation was put on a boat and it was very difficult to clean and had to be removed from the testing within a few months.

During this project, IRTA wanted to revisit the PropSpeed and see if it was available in its original form. The supplier had reverted to the original formulation and reformulated it only slightly, resulting in a paint called BottomSpeed. IRTA and San Diego Diving Service decided to put the paint on the Boston Whaler. The team decided to also test the concept of putting the paint over copper paint (see Section IV). As a consequence, the back of the boat was stripped to gel coat and two coats of black sealer, called a primer/tiecoat by the supplier, were applied and a clear topcoat of BottomSpeed was applied over the sealer. On the front of the boat, the boat was not stripped; the surface was prepared in the same manner as it would be for a copper paint job, where the damaged paint spots are sanded to gel coat. Two coats of black sealer were applied and one coat of clear BottomSpeed was applied over it. The boat was painted at Shelter Island Boatyard and it was launched in mid-February, 2011.

A picture of the boat ready for painting is shown in Figure 5-15. Pictures of the painting operation are shown in Figure 5-16 and 5-17.

Figure 5-15. Diver Workboat Before Painting

The diver has inspected and cleaned this boat for regularly for the last several months. The paint is readily cleaned with a soft tool and there seems to be no difference between the parts of the boat that were stripped or where the paint was applied over copper in terms of cleaning or paint performance. The diver did report that the bottom of the part of the boat that was stripped is smoother and cosmetically more appealing than the other side of the boat that was not stripped. This does not seem to have any impact on boat performance or ease of cleaning, however. The diver, who has significant experience with soft nonbiocide paints, indicates that the paint performs very well compared with other high performing soft nonbiocide paints.

Figure 5-16. Supplier Painting Diver Workboat

Figure 5-17. Another View of Supplier Painting Workboat

5.6. Heinem—BottomSpeed

This boat is a 32 foot Bayliner powerboat and it was painted at the end of May 2011 with BottomSpeed. IRTA wanted to test the concept of putting soft nonbiocide paints over copper paint, and, because the San Diego Diving Services boat was performing well, the supplier and IRTA decided to apply the paint over copper on the entire hull of this boat. The boat was prepared as necessary for a copper paint job. Gray primer was applied to the spots which had been sanded. Then two coats of the black sealer were applied to the hull. Finally, one clear coat of BottomSpeed was applied over the sealer. The boat was painted at Shelter Island Boatyard in late May, 2011 and was launched shortly thereafter.

A picture of the painter applying paint to the boat is shown in Figure 5-18. Figure 5.19 shows the boat after the completed paint job.

Figure 5-18. Painter Applying Paint to Heinem Boat

Figure 5-19. Heinem Boat After Paint Application

IRTA and the diver wanted to test the cleaning needs of the BottomSpeed on this boat and also the cleaning frequency of soft nonbiocide paints in general. Accordingly, the boat was not inspected and cleaned until November 2011, about six months after it was launched. In November, the diver reported that the boat hull had about three to four inches of fouling on the surface, including both soft fouling like algae and silt and hard fouling like tube worms and bryozoans. When he touched the fouling with a gloved hand lightly, the fouling readily came off. He cleaned the boat hull with carpet and a fine, thin gray pad easily and observed that the coating was in excellent condition.

5.7. Pasha—BottomSpeed

The Pasha Group is a transportation and logistics company with one of its operations in San Diego. The company provides port, distribution and a service facility for the movement of automobiles from locations all over the world.

The company had a new 11 foot inflatable boat with an aluminum hull that required painting. Part of the inflatable sides which are made of hypalon, a type of rubber, rest in the water so the hull and these hypalon sections required bottom paint. The boat was intended to serve as a dinghy on another larger boat. A picture of the boat, suspended at Knight & Carver boatyard in San Diego ready for painting, is shown in Figure 5-20.

Figure 5-20. Pasha Boat Ready for Painting

IRTA wanted to test one of the soft nonbiocide paints on an aluminum hull and on a portion of the rubber. The supplier of BottomSpeed offered his coating for testing. The procedure involved painting the hull first with a primer/topcoat and then applying the clear topcoat of BottomSpeed to the aluminum hull. IRTA and the supplier did not think the epoxy primer/tiecoat would stick to the rubber inflatable portion of the boat that is immersed. Epoxy coatings are very hard and when the rubber expands and contracts from temperature changes, it is likely to crack and flake off. In contrast, it is more likely the soft nonbiocide topcoat would tolerate the dimensional change, so IRTA and the supplier decided to paint the rubber inflatable portions with only the clear BottomSpeed topcoat.

A picture of the painter applying paint to the boat is shown in Figure 5-21. Figure 5-22 shows the painter painting the back of the boat.

Figure 5-21. Painter Applying Paint to Pasha Boat

Figure 5-22 Painter Applying Paint to Back of Pasha Boat

Since June, the boat was out of the water for a few months. The diver did indicate that the coating seemed to be flaking from one small spot on the rubber. It appeared that the coating may have failed on this one spot when the inflatable rubber was deflated and inflated again. The BottomSpeed coating may not have been fully cured when the boat was launched and this may have also contributed to the flaking. Overall, both the diver and the boat owner indicated the paint was performing extremely well.

5.8. Fish & Game—XZM 480 Plus Hardener

The California Department of Fish & Game boat is a 27 foot Almar rigid inflatable powerboat with an aluminum hull. The boat is moored in Los Alamitos. XZM 480, the experimental coating that was tested on panels, was applied to the Port of San Francisco boat and the same coating with a hardener added was applied to the Port boat on the damaged waterline. IRTA and the supplier wanted to apply this coating with the hardener to an entire boat and test a sealer system over copper. The boat was painted at Basin Marine in Newport Beach; the paint was applied to the hull but not to the inflatable rubber which is generally not immersed in the water.

The hull was not stripped and the surface of the boat was prepared as it would be if a copper coating were going to be applied. A sealer was applied to the hull, a tiecoat was applied and then two coats of the XZM 480 with the hardener were applied. A picture of the boat with the new paint job is shown in Figure 5-23. After the boat was launched, it was found to be leaking oil. The source of the problem was that certain components of the outboard motor were inadvertently painted with hull paint. The boat was pulled out and the parts were changed out. It was launched again in July 2011.

Figure 5-23. Fish & Game Boat After Paint Application

IRTA and the supplier suggested the boat hull be cleaned with a terry towel and the diver did clean the boat on August 10. At that stage, the hull was observed to be relatively clean. The boat driver did observe that the paint did not adhere well to the rudders of the outboard and was coming off. The rudders are the most highly stressed components on a boat.

The boat was cleaned again in September and the diver observed three spots on the hull where the paint was peeling off. An underwater picture of the hull with the spots where the paint is peeling is shown in Figure 5-24. Another underwater picture of peeling paint in a different hull location is shown in Figure 5.25. According to the diver, one of the spots was a result of wax paper being removed during the paint job; paint was pulled off with the paper. The diver could initially see some wax paper on the

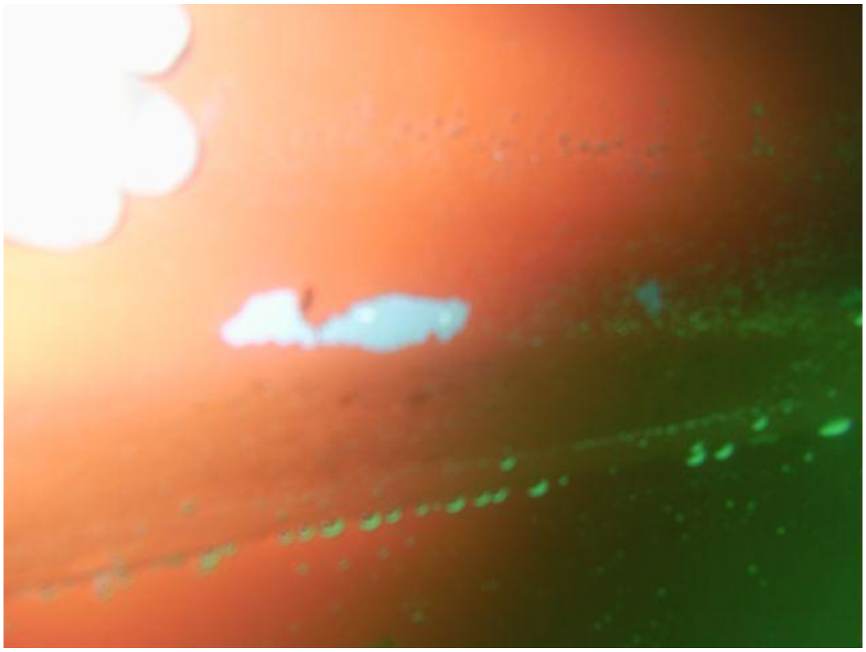


Figure 5-24. Underwater Picture of Peeling Paint

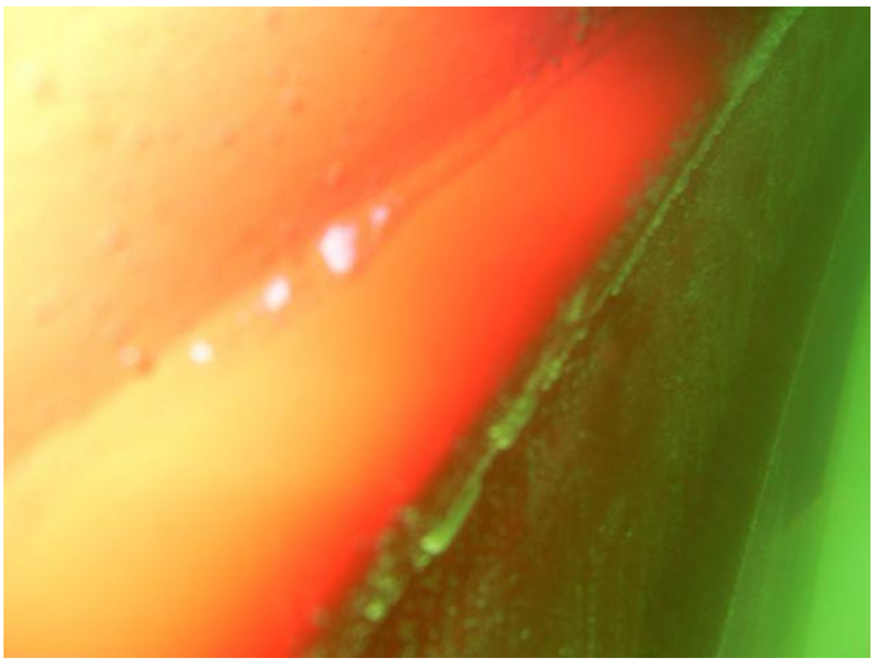


Figure 5-25. Underwater Picture of Paint Peeling in a Different Location

hull at this location. The diver also indicated the boat took a lot of effort to clean because the terry towel was so small. IRTA suggested the diver use a thin white pad for cleaning the boat when it was heavily fouled during the summer months. In October when the boat was cleaned, this time with a thin white pad, the same peeling spots were observed by the diver.

The XZM 480 adhesion appears to be compromised as the pictures of the peeling paint illustrate. The sealer which was applied over the copper was gray, the tiecoat applied over the sealer was white and the topcoat, the XZM 480 was red. From the spots that are peeling in the pictures above, the visible color seems to be white. This indicates that the XZM 480 is likely peeling from the white tiecoat. Because the paint is peeling on this boat, it is likely that the peeling paint on the City of Newport Beach boat discussed earlier is the XZM 480 used under the blocks rather than the Hempel paints used on that boat. The XZM 480 was also applied to one of the Port of San Francisco boats and, when that boat was pulled out of the water in April, the paint was observed to be peeling on the waterline. Whether this was a result of dock damage or adhesion of the paint is not evident. The status of that paint on the Port of San Francisco boat will have to be followed in the future to see if the paint holds up.

5.9. Fish & Game—Sher-Release

This California Department of Fish & Game boat, like the boat described above, is an aluminum hull rigid inflatable Almar 24 foot powerboat with an outboard motor. The boat is used frequently at high speed. IRTA wanted to test one of the coatings, Sher-Release, that performed very well in the panel testing. That paint had never been applied to a boat in California.

The boat was painted at Koehler Kraft in San Diego in June 2011. The hull was stripped by Advanced Restoration using sodium bicarbonate blasting. All of the coatings were applied by spraying. The three step painting process involved first applying a primer, then a tiecoat and then a topcoat. A picture of the boat prior to the painting process is shown in Figure 5-26. The sodium bicarbonate stripping system for stripping the boat is shown in Figure 5-27. Figure 5-28 shows the painter mixing the paint for the spray application to the tarped boat.

Figure 5-26. Fish & Game Boat Before Stripping and Painting

Figure 5-27. Sodium Bicarbonate Stripping System at Boatyard

Figure 5-28. Painter Mixing Paint for Tarped Boat

The boat was launched at the end of June, 2011. In this case, because the paint had performed so well in the panel tests, IRTA and the diver decided to avoid inspecting and cleaning the boat for about five months after launch. When the diver inspected the boat, it did have heavy fouling on it. The fouling was both soft and hard and it was thick on the surface of the hull. The diver cleaned the boat with a thin fine gray pad, the fouling was easy to remove and there was no damage from the cleaning. Most of the fouling was secondary attachment to other fouling and very little was primary attachment fouling. The diver indicated that this coating is performing well, taking into account how easily the paint could be cleaned after such a long fouling season.

During the cleaning, the diver observed that the coating application was somewhat uneven. There were spots on the hull where the coating was thin. Since the coating was sprayed on, this could be a result of the painter having less control over the coating thickness than if it had been rolled on.

5.10. Rhodes—Intersleek 900

This boat, owned by James Rhodes, is a Choate 40, a custom made one-of-a-kind sailboat, called Skysail. The boat is used fairly frequently. The owner was interested in working with IRTA and the paint supplier to test a new experimental process for applying the paint over existing copper paint.

The boat was hauled out on December 6, 2011 at South Coast Shipyard in Newport Beach. It had a copper paint that was about three years old and the paint was in fairly good shape. Figure 5-29 shows the boat after the haulout. The boatyard prepared the surface of the hull as they would if they were to apply a copper paint.

Figure 5-29. Rhodes Boat Before Painting

A gray sealer was applied to the hull the next day. Figure 5-30 shows the painter applying the sealer. The following day, a white topcoat of Intersleek 900 was applied to the boat over the sealer. Figure 5-31 shows the painter applying the topcoat. Both the sealer and topcoat were applied using a roller. The Intersleek 900 was applied generously to achieve eight or nine mils thickness of the paint.

Figure 5-30. Painter Applying Sealer

Figure 5-31. Painter Applying Intersleek 900 Topcoat

The boat was launched on December 10. The owner noticed right away that the boat seemed to move through the water more easily and predicted that he would observe fuel savings in the future. The owner plans to maintain the boat himself and will perform the maintenance with a terry towel.

VI. RESULTS AND CONCLUSIONS

Copper based antifouling paints have been used on boats to prevent marine fouling from attaching to the hulls. Excessive attachment of fouling can lead to hull damage, greater fuel use and loss of maneuverability. Copper is considered a toxic pollutant in the EPA water quality standards. The copper from the antifouling paints on the boat hulls has built up to levels exceeding the water quality standards in many basins and marinas in California.

EPA sponsored a project conducted by the Port of San Diego and IRTA that involved finding and testing alternatives to copper antifouling paints. The three year project, which was completed in January 2011, involved conducting panel and boat testing of a number of alternative biocide and nonbiocide paints. Two of the best performing paints were nonbiocide paints. The project also involved performing cost analysis and comparison of the alternative and copper antifouling paints. The cost analysis indicated that some of the nonbiocide paints are cost effective to use over the life of the paint when compared with the copper paints. Even so, the paint jobs for the nonbiocide paints are significantly more expensive and this makes boaters more reluctant to adopt the alternatives.

This project, which was sponsored by EPA and DTSC, involved investigating, field testing and analyzing methods of making it less costly and easier to apply the nonbiocide alternative paints. The first major factor that makes paint jobs more expensive for nonbiocide paints is that few alternative nonbiocide paints are commercially available and demonstrated today, making them more expensive than copper paints. Furthermore, more coatings need to be applied in the process. The second factor that increases the paint job is that the boat hull needs to be stripped the first time the nonbiocide paint is applied and the stripping cost can be as high as $2,500 for a 30 foot boat. The third factor is that the paints need to be sprayed rather than rolled on the boats and this can increase the paint job cost by as much as $1,000 for a 30 foot boat.

Several methods for reducing the cost and complexity of the application process were evaluated during this project. These included:

- panel testing additional emerging nonbiocide paints
- identifying, testing and demonstrating alternative stripping methods
- avoiding the need for stripping by applying the nonbiocide paints over copper paints
- rolling the nonbiocide paints on the boats rather than spraying them
- investigating the feasibility of copper recycling
- testing new and emerging nonbiocide paints and alternative application methods on boats

6.1. Project Findings

Alternative nonbiocide paints were applied to three panels in a frame which was immersed in the water at floating docks in San Diego for one year. A protocol, developed during the earlier Port/IRTA project, was used to inspect the panels and document the fouling, the ease of cleaning and the coating condition every three weeks for the 12 month duration. There were six soft nonbiocide paints that performed very well in the panel tests. Four of them or a slight variation of one of them, were applied to boats during this project.

When boatyards strip boats today, they either use hand sanding or chemical stripping methods. These methods can lead to worker exposure, can be damaging to the environment and can be expensive. During the project, IRTA investigated and demonstrated three alternative abrasive blasting methods for stripping the boats. These included sodium bicarbonate stripping, volcanic rock stripping and dry ice blasting. The three methods were demonstrated on a boat that was destined to be demolished at Marine Group Boatyard in San Diego and could be potentially used to strip hull paint. All three methods are better from a health and environmental standpoint and the analysis indicates they are slightly less expensive to use than the current stripping methods. One company, Advanced Restoration, offers stripping services using sodium bicarbonate blasting and some boatyards have used the service. The other two methods are available but have not been used by the boatyards.

Although the alternative stripping methods may reduce the cost of a nonbiocide paint job slightly, the stripping cost is still very high. IRTA investigated methods of applying the alternative nonbiocide paints over copper paint the first time they are applied which could effectively eliminate the need for stripping altogether. Two suppliers of alternative paints have developed so-called sealers which can be applied over copper paint and allow the direct application of the nonbiocide paint over the sealer. IRTA arranged for the sealers and three of the alternative nonbiocide paints to be applied to four of the project test boats.

During the earlier Port/IRTA project, the project team applied a few alternative nonbiocide paints to boats using rolling rather than spraying. During this project, IRTA arranged for alternative nonbiocide paints to be applied by rolling to eight of the ten boats that were painted. Using rolling rather than spraying does not appear to change the performance or ease of cleaning the boats. This method can be used in the future to reduce the cost of the paint job for nonbiocide paints substantially.

The best combination of options for reducing the nonbiocide paint job cost is to apply the paint over the existing copper paint instead of stripping the boat and to roll the paints on rather than spraying them. If this proves viable in the longer term as the boats are followed over the next few years, it could lead to significantly lower paint job costs for boaters using nonbiocide paints. In one case, the Rhodes boat, IRTA worked with suppliers to apply Intersleek 900, one of the best nonbiocide paint alternatives to a boat using rolling. IRTA analyzed and compared the cost of applying the Intersleek 900 over copper paint with rolling on the one hand and applying the paint to a stripped hull using spraying on the other hand for a 30 foot boat. The cost of the paint job can be reduced from $5,512 with stripping and spraying to $4,556 for stripping and rolling and to $2,268 for applying the paint over copper paint with rolling. The cost of the paint job can be reduced by about 60 percent by avoiding stripping and spraying.

During the project, IRTA evaluated the feasibility for boatyards to recycle copper which could lead to an overall reduction in paint job costs. IRTA identified three sources of copper that might be recycled from boatyard operations. These include residues of dry sanding waste from surface preparation and hand stripping of boats, spent sodium bicarbonate waste from stripping operations and wet sanding from surface preparation or stripping operations where the residue ends up in a clarifier. IRTA contacted a copper recycler, World Resources Company, and the company worked with IRTA to analyze samples of various types from a variety of boatyards in California. Analysis indicates that the best source of copper is the hand sanding waste which contains between about 35 and 60 percent copper. The sodium bicarbonate waste contains between 11 and 13 percent copper from the analysis and the clarifier waste contains between three and five percent copper. All three waste streams are classified as hazardous waste in California and IRTA's cost analysis indicates that it is cost effective to recycle the hand sanding dust and that it may be cost effective to recycle the other two streams, depending on the makeup of the particular waste. Since the residue from the waste is currently disposed of on land, boatyards may want to recycle the streams to avoid the liability of land disposal even when it is not cost effective to do so.

Ten boats were painted with new and emerging paints during the project and many of the paint jobs involved experimenting with the alternative application methods. Table 6-1 summarizes the boats that were painted and the alternative application methods that were used in each case. The first column provides the identity of the boat owner. The second column identifies the paint that was applied to the boat and indicates whether it is an emerging paint (signified by E) that was either included in the panel testing during this project, reformulated slightly from a panel tested paint or tested for the first time in California. The third column indicates whether the hull was stripped or unpainted or whether the paint was applied over copper paint. The fourth column indicates whether the paint was sprayed or rolled on.

Table 6-1
Boats and Application Methods Tested During Project

Boat/Owner	Paint Tested	Hull	Application Method
Auerbach	Intersleek 900	Stripped	Sprayed
Port of San Francisco	XZM 480 (E)	Stripped	Rolled
Port of San Francisco	XP-A101 (E)	Unpainted	Rolled
City of Newport Beach	Hempasil X3 XA 278 (E)	Stripped—sodium bicarbonate	Rolled
San Diego Diving Service	BottomSpeed (E)	Half stripped, Half Over Copper	Rolled
Heinem	BottomSpeed (E)	Over Copper	Rolled
Pasha	BottomSpeed (E)	Unpainted	Rolled
Cal. Dept. Fish and Game	XZM 480+ hardener (E)	Over Copper	Rolled
Cal. Dept. Fish and Game	SherRelease (E)	Stripped—sodium bicarbonate	Sprayed
Rhodes	Intersleek 900	Over Copper	Rolled
Note: E signifies emerging paint			

The Auerbach boat was painted with Intersleek 900, a paint that performed well in the earlier Port/IRTA project. XZM 480, a paint that was tested on panels during the project, was applied to a Port of San Francisco boat and a Department of Fish & Game boat with a hardener added. For the Fish & Game boat, the paint was applied over copper and, in both cases, the paint was rolled on. A slight modification of another paint tested on the panels, XP-A101, was tested on another Port of San Francisco boat. It was rolled on an unpainted hull. The City of Newport Beach boat was stripped using the sodium bicarbonate blasting method. Hempasil X3, one of the best performing paints in the earlier Port/IRTA project, was applied to half the boat; an emerging paint tested on panels during this project was applied to the other half of the boat. In both cases, the paints were rolled on, the first time this procedure was used for Hempasil X3. Three boats, the San Diego Diving Service, Heinem and Pasha boats, were painted with an emerging paint called BottomSpeed that had not yet been tested in California; in all three cases, the paint was rolled on. The paint was applied over copper paint on half of the San Diego Diving Service boat and the entire hull of the Heinem boat. An emerging paint tested on panels, called SherRelease, was applied to the second Department of Fish & Game boat. The hull was stripped using sodium bicarbonate blasting. Finally, Intersleek 900 was applied over copper paint using rolling to the Rhodes boat.

The project findings indicate that four of the five new and emerging paints appeared to perform well at the end of the project. These included XP-A101, XA 278, BottomSpeed and SherRelease. The other emerging paint, XZM 480, seemed to be peeling in certain spots from the Fish & Game boat and was also peeling from the location on the keel and from under the blocks of the City of Newport Beach boat where it was used. In some cases, the XP-A101, in particular, the paints had been applied only two months before the project end so the coating performance would have to be observed over the longer term for verification.

For two of the boats with nonbiocide paints, IRTA investigated whether the cleaning frequency could be reduced. In these cases, IRTA and the diver waited five to six months after the paint application to clean the boats for the first time. One of the boats was the Heinem boat which was painted with BottomSpeed and the other boat was the Fish & Game boat painted with SherRelease. In both cases, although the boats had a thick layer of fouling, the boat hulls could readily be cleaned with soft tools without damaging the paint. This suggests that the cleaning frequency of some of the nonbiocide paints could be reduced substantially and that this would reduce the overall cost of using the paint over the life of the paint.

6.2. Outreach Materials

IRTA prepared five fact sheets that focus on various aspects of the research performed as part of the project. These focused on:

- the types of alternative nonbiocide paints
- the alternative stripping methods that were investigated during the project
- alternative application methods like rolling instead of spraying and applying the paints over copper paint
- opportunities for copper recycling at boatyards
- methods of cleaning/maintaining nonbiocide paints

These fact sheets can be accessed on IRTA's website at www.irta.us.

VII. REFERENCES

(SDUPD and IRTA, 2011). Unified Port of San Diego and the Institute for Research and Technical Assistance, "Safer Alternatives to Copper Antifouling Paints for Marine Vessels," prepared for U.S. EPA, January 2011.

(POSD, 2011). Port of San Diego, 2011.

(HSC, 25123.5). Health and Safety Code, section 25123.5. Contact the Permit Assistance Centers at 1-800-468-1786 or your local CUPA for more information.