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Commercialization Plan Laser-Based Decoating Systems

**Topical Report
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ABSTRACT

F2 Associates Inc. (F2) is a small, high-technology firm focused on developing and commercializing environmentally friendly laser ablation systems for industrial-rate removal of surface coatings from metals, concrete, and delicate substrates such as composites. F2 has a contract with the U.S. Department of Energy Federal Energy Technology Center (FETC) to develop and test a laser-based technology for removing contaminated paint and other contaminants from concrete and metal surfaces. Task 4.1 in Phase II of the Statement of Work for this DOE contract requires that F2 *"document its plans for commercializing and marketing the stationary laser ablation system. This document shall include a discussion of prospects for commercial customers and partners and may require periodic update to reflect changing strategy. This document shall be submitted to the DOE for review."* This report is being prepared and submitted in fulfillment of that requirement.

This report describes the laser-based technology for cleaning and coatings removal, the types of laser-based systems that have been developed by F2 based on this technology, and the various markets that are emerging for this technology. F2's commercialization and marketing plans are described, including how F2's organization is structured to meet the needs of technology commercialization, F2's strategy and marketing approach, and the necessary steps to receive certification for removing paint from aircraft and DOE certification for D&D applications. The future use of the equipment built for the DOE contract is also discussed.

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EXECUTIVE SUMMARY

F2 Associates Inc. (F2) is a small, high-technology firm focused on developing and commercializing environmentally friendly laser ablation systems for industrial-rate removal of surface coatings from metals, concrete, and delicate substrates such as composites. F2 has a contract with the U.S. Department of Energy Federal Energy Technology Center (FETC) to develop and test a laser-based technology for removing contaminated paint and other contaminants from concrete and metal surfaces. Task 4.1 in Phase II of the Statement of Work for this DOE contract requires that F2 *"document its plans for commercializing and marketing the stationary laser ablation system. This document shall include a discussion of prospects for commercial customers and partners and may require periodic update to reflect changing strategy. This document shall be submitted to the DOE for review."* This report is being prepared and submitted in fulfillment of that requirement.

The laser ablation technology enables selective removal of coatings and is appropriate for a wide variety of applications ranging from precision cleaning on electronic components to the decoating of delicate composite and aluminum aircraft components and airframes, and including decontamination of lead-based paint and radiological contaminants. The dry process uses no chemicals or liquids and cleans out surface pores with no mechanical or thermal damage. It reduces the waste volume by ~80% for hydrocarbon-based coatings by taking advantage of photochemistry. Other advantages are the competitive production rates, low operating costs and waste minimization characteristics.

F2 has developed four basic types of systems to meet the surface cleaning and decoating needs of various government agencies and prospective commercial clients. The four product lines are the small parts decoating workcells, the large parts decoating systems, the hand-held nozzle systems, and the mobile robotic systems. DOE funding has contributed to the development costs of each of these four product lines.

While F2's technology has wide applicability across the \$6 billion worldwide commercial coatings removal industry, F2 is initially targeting three market segments: high value, high volume parts cleaning; radiological decontamination and decommissioning; and aircraft component and airframe depainting.

This report describes the laser-based technology for cleaning and coatings removal, the types of laser-based systems that have been developed by F2 based on this technology, and the various markets that are emerging for this technology. F2's commercialization and marketing plans are described, including how F2's organization is structured to meet the needs of technology commercialization, F2's strategy and marketing approach, and the necessary steps to receive certification for removing paint from aircraft and DOE certification for D&D applications. The future use of the equipment built for the DOE contract is also discussed.

I. Introduction

F2 Associates, Inc., (F2) has a contract with the U.S. Department of Energy Federal Energy Technology Center (FETC) to develop and test a laser-based technology for removing contaminated paint and other contaminants from concrete and metal surfaces. Task 4.1 in Phase II of the Statement of Work for this DOE contract requires that F2 *"document its plans for commercializing and marketing the stationary laser ablation system. This document shall include a discussion of prospects for commercial customers and partners and may require periodic update to reflect changing strategy. This document shall be submitted to the DOE for review."* This report is being prepared and submitted in fulfillment of that requirement.

The primary need for this technology is to address the problem of more effectively removing various contaminated coatings such as paints, epoxies, etc. from concrete and metal surfaces. In the course of a commercialization effort, all possible applications for this technology are being explored.

F2 Associates Inc. has uncovered a large number of applications for this technology. These applications include automotive OEM, durable medical equipment manufacturing, printed circuit board manufacturing, graffiti removal, metal salvage, auto body repair, tire mold cleaning, oxidation removal. There are more applications being uncovered on almost a weekly basis. Proper market penetration techniques will continue to serve us well.

The rest of this introduction will describe the laser-based technology for cleaning and coatings removal, the types of laser-based systems that have been developed by F2 based on this technology, and the various markets that are emerging for this technology.

A. The Technology

F2 Associates Inc. is a small, high-technology firm focused on developing and commercializing environmentally friendly laser ablation systems for industrial-rate removal of surface coatings from metals, concrete, and delicate substrates such as composites. The technology enables selective removal of coatings (hydrocarbon or thin metallics) from structures or parts of various sizes and shapes, with different coatings on the materials. Laser ablation systems are appropriate for a wide variety of applications ranging from precision cleaning on electronic components to the decoating of delicate composite and aluminum aircraft components and airframes. The competitive production rates, low operating costs and waste minimization characteristics of laser-based systems are well suited for a variety of applications, including decontamination of lead-based paint and radiological contaminants. The dry process uses no chemicals or liquids and cleans out surface pores with no mechanical or thermal damage. It reduces the waste volume by ~80% for hydrocarbon-based coatings by taking advantage of photochemistry.

Laser ablation technology uses the unique properties of photons or light energy to instantly vaporize coatings with short, high intensity pulses. Thin layers at a time are instantly transformed from a solid to a gas and particulate mixture, which "explodes" off the substrate. The pulse duration is so short that heat is not able to propagate inward to the substrate, resulting in a cool, dry surface with no thermal or mechanical damage. Pulsed-repetition lasers can be used for efficient bond breaking of specific contaminants or coatings by selecting the wavelength, pulse width, energy per pulse, pulses per second, and the scan rate.

Laser ablation systems can selectively remove individual coating layers without affecting the integrity of the prime coat or damaging the substrate material. Pulsed lasers offer the highest degree of process control for spot-removal of thin layers in cleaning applications such as electronics manufacturing. The key to controlling the ablation process lies in the integration of real-time sensor systems.

F2 uses optical spectral sensors in a process feedback loop to control the scan and laser pulse speed, which maximizes cleaning efficiency. Spectral sensors can also be used in conjunction with F2's patent-pending high speed scanning system for selective decoating on delicate composite materials without damage. No other cleaning, decoating, or decontamination technology on the market today offers this level of sophisticated process control.

Laser ablation is a non-contact technology. No chemicals, blasting media or secondary waste streams are generated for collection and disposal. Many traditional and leading-edge coatings are reduced to their fundamental molecular components. Organic coatings are typically reduced to (pigment) particulates, water vapor, carbon dioxide, and trace amounts of other gases. For hydrocarbon-based coatings such as epoxy and lead-based paint, the waste volume is actually reduced to less than twenty-five percent of the original volume of paint. This waste minimization feature is particularly beneficial for the removal of hazardous coatings, where the cost of disposal is prohibitively expensive.

F2 has been able to develop a major part of the technology for laser-based coatings removal through two government contracts. The first is with the U.S. Department of Energy Federal Energy Technology Center. The objective of this contract is to develop and test a laser-based technology for removing contaminated paint and other contaminants from concrete and metal surfaces. The second government contract is with the U.S. Air Force Wright Laboratories, with funding from the Strategic Environmental Research and Development Program (SERDP). The objective of the Air Force contract is to integrate a laser-based system which can clean and remove various coatings from a variety of substrates on complex-shaped airplane parts. Through these two contracts plus work with Los Alamos National Laboratory (LANL) and Physical Sciences Inc. (PSI), plus in-house funded work, F2's technical staff has several years of experience integrating the appropriate laser, beam delivery system, vacuum filtration unit, sensors, and computer controls with the optimum level of

automation to provide a total laser-based cleaning and decoating system solution.

B. The Systems

The integrated laser ablation system includes a laser, a laser beam delivery subsystem, a workhead, a vacuum-filtration subsystem, a final waste drum, various system sensors and feedback controls, a computer controller, and robotics or parts handling capabilities as appropriate. The actual configuration of a system using these components varies, depending on the application.

Based on numerous interactions with both government agencies and prospective commercial clients, F2 is developing the four basic types of systems as described below to meet their needs for surface cleaning and decoating. Within the DOE weapons complex and the commercial nuclear community, F2 has found the most interest in Items 2 through 4 below. DOE funding has contributed to the development costs of each of these four product lines.

1. Small parts decoating workcells. These are stationary workcells for cleaning and decoating small parts, such as aircraft and manufacturing components as shown in Figure 1). Either the part can be moved around in front of the laser beam or the beam can be scanned over the part. The standard unit can accommodate items up to two feet in any dimension, but workcell dimensions can be readily customized for specific applications. Likewise, the level of automation can be varied to meet customer specific needs. The system can be equipped with spectral sensors for selective stripping. Decoating parameters such as scan speed, pulses per second, and energy per pulse are easily input to the control module. These systems may be equipped with a capture nozzle at the stripping head. The fine tuning and testing of the prototype for these workcells was partly funded by Phase I of our DOE contract.

2. Large parts decoating systems. These are stationary chambers with a completely automated gantry robot as shown in Figure 2. In a sense, they are a large version of the small parts cleaning workcell described above. Components as large as five feet in height by five feet in width by six feet in length can be easily cleaned or decoated. Since the side walls can be removed, components as large as fifteen feet in length can be accommodated. An articulating optical system moves the laser beam around over the part. If necessary, the part can also be moving simultaneously and automated parts handling can be added. All waste effluents are captured at the stripping head and processed through a series of filtration stages. A secondary workcell air curtain with full filtration is available to assure zero release from the operations. All lasing parameters are controlled via a master computer, which integrates a spectral sensor system with a high speed scanner for selective stripping capability. The development of this system is mainly funded through the Air Force Wright Laboratories by the Strategic Environmental Research

and Development Program (SERDP), a cooperative program of the DoD, DOE, and EPA. However, many aspects of the system are based on the work funded by the DOE.

3. Hand-held nozzle systems. These are mobile/transportable systems for detail work as shown in Figure 3. There are a wide variety of applications including component decoating, graffiti removal, decontamination, and boat bottom depainting. A hard optics beam delivery system is used in conjunction with a vacuum filtration system, stand-off safety sensors, and a set of shrouds to conform to various surface geometries. The basic design work is F2 property, but some testing of this is also funded by the DOE.
4. Mobile robotic systems. As shown in Figure 4, the robotic platform contains all the system components and only requires electrical power. This system can be used to remove paint from large surfaces including walls, floors, ceilings, aircraft, storage tanks, and other structures. F2's baseline robotic platform is a variation of the ROSIE robot developed by RedZone Robotics, Inc. under other contracts with the DOE. DOE is funding F2 Associates to design, integrate, and test a laser-ablation-system on a ROSIE robot platform at Florida International University in early 1998.

As appropriate, F2 plans to use a variety of robotic platforms (not only ROSIE) to meet customer defined needs. F2 has developed strategic relationships with several robotic platform suppliers who have spent substantial time with F2, understand our demands and have agreed to customize their equipment to meet our needs. This enables F2 to meet the defined performance and economic objectives of each specific application for our customers. Specifically, F2 has also developed relationships with other well respected robotic suppliers such as PaR Systems (Shoreview, MN) and Berry Engineering (Newport News, VA).

Figure 1
Small Parts Decoating Workcell

Figure 2
Large Parts Decoating System

Figure 3
Hand-held Nozzle System

Figure 4
Mobile Robotic Systems

C. The Markets

1. Overview There is an enormous market potential for the commercial application of laser technology for the cleaning and removal of surface coatings on high value, high volume components. F2 is targeting these types of applications for laser ablation systems. Specifically, we are targeting a variety of applications ranging from precision cleaning on electronic components to the decoating of delicate composite and aluminum aircraft components and airframes. As mentioned, the competitive production rates, low operating costs, and waste minimization characteristics of laser-based systems are well suited for applications involving high value, high volume components in manufacturing and operating plant environments.

Removal of coatings has become an increasingly vexing (and costly) problem for both the government and commercial / industrial complex due to increasing public understanding and concern with environmental issues associated with the use of current processes. Many of the chemicals currently used to strip and decoat, including methylene ketone (MEK) and methylene chloride (MCL), will be severely restricted by both the U.S. Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) regulations that take effect in September 1998^{1,2}. In comparison, the new "environmentally friendly" emerging chemical substitutes for MEK and MCL are slower, less efficient, more costly, and typically contain highly caustic constituents making them only somewhat less harmful to the environment.

Other coatings removal methods involve the use mechanical systems and various blasting media including: water, abrasives, soda, and wheat starch. Blasting technologies typically require costly containment systems, respiratory protection, and generate a secondary waste stream that must be disposed. Blasting methods and mechanical methods such as vacuum shrouded power tools are typically also very labor intensive and costly to deploy. As a result of a stringent regulatory environment and the many other factors discussed, several industries in the United States are now prime for the introduction of a cost-effective technology which substantially reduces labor requirements, as well as, the waste volume typically associated with cleaning and depainting operations.³⁻⁹

For example, the U.S. government has critical needs for low cost, effective clean-up technologies to remove contaminated coatings from concrete and metals without the creation of any secondary hazardous waste. Currently, there are over 18,000 acres of concrete floors and walls in 7,000 DOE's weapons complex facilities that need to be decontaminated and decommissioned (D&D) at an estimated cost of \$275 billion. The DOE has estimated that will require an expenditure of over \$1 billion annually for the next 10 years.¹⁰⁻¹³. Within the DOE complex, laser ablation technology has

been identified as a potential solution for 7 of the 31 D&D national needs. Specifically, the DOE's D&D Needs Assessment Report¹⁴ identified and referenced laser ablation technology as a potential solution for the applications listed below:

<u>Priority</u>	<u>Application</u>
#2	Decontamination on contaminated metal
#5	Material recycle
#6	Decontamination of contaminated concrete
#10	Decontamination of large/complex equipment and structures
#21	Decontamination of lead
#29	Decontamination of graphite reactor components
#31	Characterization and decontamination of construction debris

There are also critical needs in the commercial and industrial complex. For example, the aircraft depainting industry is an \$1.5 billion a year industry currently served by chemical methods which are in the process of being severely restricted for environmental reasons. The cost to chemically depaint a Boeing 747 aircraft is \$11-28 per square foot (depending on the chemical used).¹⁵ This compares with a depainting cost of \$3.50 to \$4.50 per square foot using the F2's laser ablation technology (see Figure 9).

As mentioned above, the chemicals currently used to depaint aircraft are scheduled to be banned or severely restricted for environmental reasons. Both the OSHA and the EPA will begin enforcement of the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations in September 1998. F2 has already received favorable exposure within the marketplace, and several large aircraft maintenance, repair and overhaul (MRO) companies have initiated discussions with F2. In addition to these domestic opportunities, F2 has also received inquiries from international groups such as Lufthansa, Japan Airlines and Air France, as well as, the international MRO community.

In addition to the international aircraft MRO market, there are numerous other market opportunities in the commercial arena. There is an enormous market potential for the commercial application of laser technology for the cleaning and removal of surface coatings on high value, high volume components. For example, laser ablation systems are appropriate for manufacturing applications such as precision cleaning on electronic components. Another important potential market is the use of laser ablation for the decontamination of lead-based paint and radiological contaminants.

The current Department of Defense directives to close and / or privatize many military bases around the world offer numerous opportunities for F2. Facility closings or decommissionings allow easy access to establish laser depainting operation and parts cleaning services at these sites. These military bases

also generally require other remedial clean-up, such as facility cleaning, metal decontamination, and vehicle depainting. These activities, however, are not contingent on the facility being inactive.

2. Initial target market segments While F2's technology has wide applicability across the \$6 billion worldwide commercial coatings removal industry, F2 is initially (year 1 & 2) targeting three market segments: high value, high volume parts cleaning; radiological decontamination and decommissioning; and aircraft component and airframe depainting.

- a. Parts cleaning. This includes the cleaning and removal of coatings on various high value, high volume parts, as well as glass etching and surface preparation in the aerospace, automotive, medical, electronic, and telecommunication industries as well as other general manufacturing applications.

Many manufacturing processes involve the application of some type of coating to components which must then be removed prior to final use or assembly. Another common manufacturing requirement is some type of surface preparation for some or all components. F2's technology provides great advantages over methods currently in use in terms of accuracy, speed, and cost. Companies across these industry groups have expressed excitement about F2's products such that F2 expects to enjoy wide interest and acceptance of its commercial products. Specifically, F2 is targeting applications that involve the depainting of high value, high volume components. The best applications for these types of components are those which have current depainting operations that generate large volumes of hazardous waste, require selective stripping of paint layers, and / or the removal of contaminants from very delicate substrates.

For example, there are approximately 4,500 aircraft maintenance, repair, and overhaul (MRO) operations in the U.S. and double that number worldwide. As new and refurbished parts are delivered to the maintenance facility, they must be thoroughly stripped and cleaned prior to installation on the aircraft. As with aircraft depainting, chemicals currently in use for this purpose are becoming increasingly regulated and many are scheduled to be banned or severely restricted in 1998.

In addition, many aerospace structures and components are increasing being manufactured out of light weight, high strength composite materials. Chemical stripping methods cannot be used on composite substrates because of the potential for corrosion and structural damage. The current baseline method for removing coatings from composite substrates involves the use of vacuum shrouded hand sanders. Hand sanders are very labor intensive and are extremely prone to damage delicate composite materials. Other technologies for depainting composite substrates include wheat starch and soda blasting. These blasting technologies require

containment structures and worker respiratory protection, special facility controls, and they generate a tremendous amount of secondary waste. As a result, F2 is targeting the depainting composite material components for the sale of large and small parts workcell laser systems in the aircraft MRO industry.

F2 offers two different products depending on the size of the parts involved: a stationary small parts workcell and the large parts cleaning system, which is a stationary chamber with a completely automated gantry robot for large parts. These two products will be the primary focus of this report.

- b. Decontamination and decommissioning. Not only is there a need for the removal of radioactively-contaminated paint, but there are a variety of other applications for removing contaminated coatings, such as the removal of lead-based paint and the removal of paint or other coatings contaminated with polychlorobiphenyls (PCBs). For instance, there are 95,000 bridges in the U.S. alone that have lead-based paint.

The mobile robotic system can be used for the removal of paint and other coatings from floors, walls, and ceilings to decontaminate and decommission civilian and military facilities, including government and commercial nuclear facilities.

Disposal costs for low level radioactive waste and mixed low level radioactive waste are approximately \$330 and \$1,200 per cubic foot, respectfully. Laser ablation technology reduces waste volumes by ~75% when compared to the original volume of coating. As a result, the commercial nuclear power industry represents a highly attractive market for F2's technology. As shown in Figure 5, the wave for decommissioning of commercial nuclear reactors is just beginning. Within the next decade, more than five nuclear reactors will begin decommissioning every year. Since decommissioning each nuclear reactor can be expected to cost over \$400 million, this is a large market.

In addition to the use of the mobile robotic system for floors, walls, and ceilings, the large parts cleaning system is also applicable to some other facets of decontamination and decommissioning of nuclear facilities. F2 is particularly interested in targeting the commercialization of laser ablation technology for the decontamination of the DOE's inventory of radiologically contaminated scrap metal (priority #5). The Department of Energy facilities have a large inventory of metal with surface contamination. According to the DOE's 1995 Scrap Metal Inventory Report (DOE/HWP-167)¹⁶, the DOE has approximately 203,000 tonnes of radiologically contaminated scrap metal. This material can be decontaminated and sold as scrap metal at a considerable cost savings over disposal costs for radioactive waste. The 1.5 to 2 kilowatt laser ablation system F2 is currently developing and

testing for the DOE is well suited for such stationary applications as scrap metal decontamination and characterization, where the various metal components would be brought to the system.

Laser ablation technology is suitable for removing a variety of coatings other than paint. Therefore, there are a variety of maintenance applications at commercial nuclear power plants that represent an additional market beyond decommissioning.

- c. Aircraft depainting. Per a study performed by Frost and Sullivan¹⁵, the depainting of U.S. commercial aircraft is estimated to be a \$1.15 billion per year industry in 1995 with additional revenue associated with U.S. military aircraft. Growth factors include increasing demand for air travel in emerging countries, extended useful lives of commercial airplanes (since older aircraft require more frequent repainting), and expansion of the commercial / industrial complex worldwide. Currently 90% of aircraft paint removal is achieved through chemical stripping. However, new regulations have severely limited the use of specific chemicals such as methylene chloride, and the remaining chemical alternatives are significantly less effective and more expensive. Other new technologies are used only in very specific applications and are not considered widely viable due to substrate damage, secondary waste generation or slower production rates. F2's technology represents a solution superior in both performance and cost to existing chemical stripping as well as emerging environmentally-friendly alternatives.

All four of F2's product lines are applicable to aircraft depainting. As mentioned above, the small parts cleaning workcell and the large parts cleaning system would be used for detachable components of the aircraft. The mobile robot system would depaint the main body of the aircraft, and the hand-held system would be used for detail work.

Although the U.S. is the initial target market for F2's product lines, there clearly is a international market for the technology. Furthermore, although they are not part of F2's initial focus, areas for future market expansion include the shipping industry, scrap metal processing, precious metal remediation, graffiti removal, and environmental clean-up.

3. The general markets:

The general markets can be described in a matrix that cuts three ways.

a. By type of coating:

- i. Radioactively-contaminated hydrocarbon-based coatings that may or may not also contain hazardous materials such as lead-based paints.

- ii.* Coatings that contain hazardous materials but are not radioactively-contaminated: lead-based paint and other coatings containing heavy metals, PCBs, etc.
- iii.* Coatings that contain neither hazardous materials nor radioactively-contamination.
- iv.* Metallic coatings (on metals).

For the DOE contract, the focus has been on radioactively-contaminated lead-based paint and two-part epoxy paint. For the radioactively-contaminated lead-based paint in DOE facilities, 99% of the heavy metal atoms are lead and the other 1% are uranium or plutonium atoms. Thus, given the dynamics of laser ablation, by funding the development of the technology to remove radioactively-contaminated lead-based paint, the DOE has simultaneously funded technology for lead-based paint abatement. The steel structures lead-based paint abatement market in the U.S. (i.e., bridges, storage tanks, and industrial structures) is a substantial market (over \$800M) by itself and offers a lot of potential for laser ablation technology.

b. By type of substrate:

- i.* Concrete.
- ii.* Thick metals.
- iii.* Delicate substrates like thin metals, composite materials, and wood.

The focus of the DOE contract is on concrete and thick metals, with an emphasis on the metals.

c. By type of system:

- i.* Small parts decoating workcells: Applications for this system include glass etching, surface preparation, and coatings removal in the manufacturing process across a variety of industries including electronics, automotive, medical, general manufacturing, and telecommunications as well as military and commercial aviation.
- ii.* Large parts decoating systems: Applications for this system include larger aircraft parts (rudders, ailerons, flaps, landing gear, engine cowlings, etc.), decontamination of radioactively-contaminated parts, and scrap metal recovery.
- iii.* Hand-held nozzle systems: Applications for this system include large component decoating, graffiti removal, boat bottom depainting, and decontamination.

- iv. Mobile robot systems: Applications for this system include depainting and decontamination of large surfaces including walls, floors, ceilings, aircraft, storage tanks, and other structures.

D. Focus of this Report

The DOE has contributed towards the technology development of all four types of systems, and has greatly contributed towards our database regarding the lasing parameters for various coatings on different substrates. However, as required under our contract Statement of Work for Task 4.1, the focus of this report is on the "stationary laser ablation systems", that is the small parts workcell and the large parts decoating system.

II. Commercialization and Marketing Plans

A. Organization

F2's organization structure is shown in Figure 6. For a new application, the process starts in F2's Applications Science Laboratory where F2 has a variety of lower-power lasers covering the spectrum of laser light wavelengths from ultraviolet through visible and the near infrared on into the far infrared. Tests are done in the Applications Science Laboratory to determine the best combination of parameters for the customer's application. These parameters include wavelength, power density, energy density, repetition rate, and scan speed.

After testing, F2's technical staff does the necessary customizing design for the customer's needs. Many of the components that make up a laser-based system are standardized, but the specific configuration, such as special parts handling capabilities, tend to be unique for a given customer. F2's technical staff designs a prototype system, and any necessary iterations with the customer regarding the final design. The technical staff also works with the Marketing, Sales, and Service Department to assure that designs meet the customers needs and are user friendly and easily serviceable in the field.

As commercial sales increase, F2 will add a Production Manager, who will be responsible for: (1) working with the technical staff on designs of components to assure that they can be mass manufactured in the most cost-effective ways without sacrificing quality, and (2) managing production operations.

F2 has long-term trade relationships with stable companies on a world-wide basis. F2 has investigated which suppliers have the ability to meet our standards and specifications for the components to our products. Initially, F2 plans to outsource manufacture of product components to specialty fabricators and

perform final assembly at our facilities. Once volumes increase, F2 will integrate some of its manufacturing requirements in-house.

The Marketing, Sales & Service Department performs the obvious and usual Marketing and Sales functions, and also stays in touch with the customer after a sale in order to acquire feedback on how well the system is working and what improvements might be made in future versions.

The heads of the four departments described above function as a team. As outlined, F2 has been organized from the beginning to be production and commercialization oriented.

B. Strategy

F2's strategy has been to proceed in two phases: first secure government contracts to develop the necessary laser-based technology and then (second) to secure private funding to develop prototypes and adapt the technology to commercial requirements. F2 has largely completed phase one of its strategy, having successfully developed the technology under the government contracts. During the past year, F2 has been working to secure the funding to develop the prototypes as well as to expand its marketing efforts and production capability. In addition, F2 has begun to pursue commercial markets in parallel with its government contract work. F2 currently has an abundant backlog of sales opportunities, such that our current marketing and sales staff will be increased once revenues are sufficient to support it. F2 is currently working with over a dozen commercial customers for a total of over \$6 million in pending commercial sales within the next year.

In addition to our efforts to secure the funding for the next steps in commercialization, F2 is working to establish strategic relationships with the key firms that dominate the different market segments. Thus, we are establishing strategic relationships with the key aerospace firms and with key firms in the nuclear D&D market. To target the commercial nuclear D&D market, F2 has forged a formal teaming agreement with a very well respected international nuclear plant original equipment manufacturer and maintenance service provider. We are in the process of developing similar relationships in the aircraft MRO market. We are also seeking to establish strategic relationships with the suppliers of the key components for our systems.

While F2 owns all the intellectual property rights to the technologies comprising their product lines, the majority of the currently existing physical equipment is owned by the government agencies who funded their creation. In addition, there is an extensive inventory of equipment that is on loan to F2 through the DOE FETC and Sandia National Laboratories. For these reasons, F2 is aggressively seeking private funding to build the prototypes for each product as well as to expand our marketing efforts and production capability.

Figure 6
F2 Associates Inc.
Organization

C. Certification

For certain market areas, the technology must be certified. For example, any process to remove paint and other coatings from aircraft parts must be certified by the original manufacturer of the aircraft. Thus, Boeing certifies processes to depaint or clean the body and parts for their aircraft used by the commercial airlines, and Northrop certifies processes to depaint or clean the body and parts for their aircraft used by the U.S. military. Likewise, any process to remove paint from DOE facilities that are undergoing decontamination and decommissioning must be scrutinized by the DOE.

1. Aircraft Certification

Any depainting or coating removal process involving commercial aircraft is required to complete a lengthy certification process. However, this certification is greatly expedited if the process has been cleared and used for military aircraft. Therefore, F2 believes that its continuing involvement with the Air Force and other government agencies will minimize the cost and delay in achieving certification. Furthermore, F2's strategy is to first achieve certification for cleaning small aircraft parts, then large aircraft parts, and finally aircraft body depainting. In addition to working with the U.S. Defense Department, F2 is working with the U.S. manufacturers of military and commercial aircraft to achieve the necessary certifications. Specifically, F2 is working with one of our laser suppliers and Boeing on a formal commercial aircraft depainting certification program (SAE-ISO-MA 4872).

2. DOE Certification

For the DOE D&D market there are two ways for a technology to be certified:

The first is to work through the usual four steps of DOE EM-50:

- a. Laboratory research, development, testing, and evaluation (RDT&E).
- b. Tests at FIU to get into the "Green Book." These tests are conducted with non-radioactive, non-hazardous materials.
- c. Participate in a Large Scale Demonstration.
- d. Be part of a Technology Deployment Initiative.

The second is to have a qualified third party certify your technology:

- a. Demonstrate the technology to the point where enough data is collected to fill out very detailed cost and performance evaluation sheets.

- b. The data is then verified by a reputable third company and an EPA regulatory official.
- c. When verified, then the technology is included in the "preferred alternatives matrix" used by DOE EM-40 and the DoD.

F2 is pursuing both approaches. We are working through EM-50's four steps, and are also working with firms like Framatone Technologies Inc. to become part of commercial nuclear D&D jobs.

It is F2's plan to bid and participate in the Hanford Large Scale Demonstration Project in 1998. Provided F2 is able to participate and the Large Scale Demonstration is successful, F2 then plans to submit a Technology Deployment Initiative proposal that would involve the use of a 2 kilowatt DOE laser system for scrap metal decontamination and characterization at the Paducah, Oak Ridge, Portsmouth, and Fernald Sites. F2 has already made a presentation to the DOE and site management at the Paducah Site on the use of laser ablation technology for the scrap metal at those sites. The feedback on the technology and the application from the attendees of the presentation was very favorable.

D. Marketing

Historically, F2's primary marketing efforts had been directed at agencies of the U.S. Government. As mentioned above, F2 has begun to pursue commercial markets in parallel with its government contract work. F2's initial approaches to the commercial sectors have been positively received. F2's marketing strategy is to offer potential customers free or low cost application feasibility and economic comparison testing. There is already a strong customer base for the small parts cleaning workcell through the use of this strategy. F2 currently has an abundant backlog of sales opportunities. F2 is currently working with over a dozen commercial customers for a total of over \$6 million in pending commercial sales within the next year.

F2 has advertised our four product lines in F2 literature (example in Appendix A), in trade magazine ads, at trade shows, and through mailings and site visits. A list of recent and forthcoming trade shows where F2 is exhibiting is given in Figure 7. We are now developing video and web site mediums as well.

To assist in its sales efforts, F2 has designed a trailer-mounted laser demonstration unit (Figure 8). The trailer contains a 250 Watt laser, which will be the operating system for a small parts cleaning module. Once this mobile demonstration unit is built, F2 plans to take it to aircraft maintenance facilities, tradeshow, and potential customers facilities to demonstrate its superior technical capabilities.

In the short term, F2 plans to use an internal sales force to support our marketing efforts. However, due to the number of marketing niches where F2's products are

applicable, F2 plans to eventually develop and use a network of independent sales representatives. These representatives would have expertise in a particular market segment or industry and would market a number of non-competing products in exchange for commissions.

E. Competition

There are four basic methods to remove surface coatings. Briefly, those methods are:

1. Mechanical

Scabbling - the use of metal beaters and vacuum shrouded power tools

Solid abrasives - sand, walnut shell, plastic beads and CO₂ ice pellets

Liquids - water and water with suspended abrasives

Figure 7
Trade Show and Conference Attendance

Trade Shows Attended			
<u>Conference</u>	<u>City</u>	<u>Dates</u>	<u>Exhibit/Paper</u>
Naval MRO	Jacksonville, FL	Dec 5-7, 1996	Exhibit Booth
MRO '97	Dallas, TX	April 14-15, 1997	Exhibit Booth
Precision Cleaning	Cincinnati, OH	April 16-18, 1997	Exhibit Booth
DoD Coatings	Las Vegas, NV	May 13-15, 1997	Exhibit Booth
SAE	Vancouver, B.C.	August 4-7, 1997	Paper
Paint / Depaint	Johnstown, PA	Sept. 9-10, 1997	Poster Session
Powder Coating	Charlotte, NC	Oct. 7-9, 1997	
MEK / Defense Cleanup	Pittsburgh, PA	Oct. 22-23, 1997	
Industry Partnerships	Morgantown, WV	Oct. 21-23, 1997	Presentation
X-Change '97	Miami, FL	Nov 30 - Dec 5, 1997	Exhibit Booth
Solvent Substitution	Phoenix, AZ	Dec. 2-5, 1997	Vendor Presentation

Trade Shows Planned			
<u>Conference</u>	<u>City</u>	<u>Dates</u>	<u>Exhibit/Paper</u>
Waste Management '98	Tucson, AZ	March 1-5, 1998	
CleanTech	Rosemount, Ill	May 19-21, 1998	Exhibit Booth
MRO '98	Ft. Lauderdale, FL	April 1-3, 1998	Exhibit Booth
1998 DOD/Industry Aerospace Coatings	Atlanta, GA	June 9-11, 1998	Exhibit Booth
Spectrum '98	Denver, CO	Sept. 13-18, 1998	Paper

Figure 8
Trailer Mounted Laser Demonstration Unit

2. Thermal

Incineration

Cryofracture - freeze cracking with liquefied nitrogen

3. Chemical

Wet paint strippers

Dry strippable coatings

4. Radiation

Microwaves

Lasers

For each of the above applications, there are factors which must be considered that ultimately determine the effectiveness and cost efficiency of the process used. Those factors to be considered are:

1. Waste volume reduction: F2's technology reduces waste volume (which includes the coating being removed) by 75% and adds no other waste volume. Most other technologies increase the waste volume by adding a secondary waste stream. This becomes extremely important when removing radioactive materials as costs to store contaminated material is in excess of \$350 per cubic foot. The other methods described above using removal type mediums (sand, plastic, other) must add the volume of the removal medium used to the removed coating residual volume, which results in higher net costs.
2. Cleaning thoroughness: The effectiveness of the first round of cleaning determines the cost efficiency of the process. F2's process is the only process available that completely cleans the first time, including the surface pores where contamination (such as radioactive materials, lead, or PCBs) is a critical issue.
3. Damage to substrate: F2's system is designed to remove coatings without any mechanical or thermal damage. Other processes are severely limited in removing coatings completely, or risk mechanical and/or thermal damage.
4. Use of hazardous chemicals: The use of hazardous chemicals, at times, requires the operator to wear a 60 pound breathing apparatus. The chemical waste generated is typically more toxic and greater in volume than the original material to be removed. Also, the use of chemicals can create a secondary mixed waste stream which can be prohibitively expensive to dispose of.
5. Use of liquids: Liquids used in the cleaning and removal process are highly undesirable because of clean-up time and the interruption of other on-going maintenance and the waste volume created.

6. Worker safety: Any technology that increases worker safety is important. Reducing the level of dress increases the production rates of the worker since the dress paraphernalia can be cumbersome, slowing functions and limiting movement. Working with radioactive coatings and waste, worker concerns escalate greatly. F2 addresses these concerns by its proprietary system through the "capture nozzle". The lowest level of worker dress is necessary while providing the highest degree of safety within the industry.
7. Environmental Protection. Many blasting and mechanical technologies require the use of costly secondary containment structures to capture the blast media and / or contaminants. The cost of containment can range between \$2 up to \$15 per square foot alone. In addition, a significant amount of time and labor is necessary to construct containment structures. The waste effluents that are generated during the laser ablation process are easily captured by a primary vacuum and containment engineering controls such that no secondary containment structures are necessary.
8. Cleaning rate and costs: Costs must be calculated considering the entire cycle of the cleaning operation. The speed at which an airplane can be de-coated is a major consideration. The de-painting of a 747-400 by chemical process takes almost one week at a cost of \$400,000. F2's process takes less than 36 hours and can compete profitably at less than half of market price charged (Figure 9).

In short summary, F2 has significant advantages over its competition with pulsed repetition lasers.¹⁷ In addition to waste volume reductions not experienced by the competition, the laser process is designed to remove various coatings from the most delicate of substrates. This laser technology is the only technology that removes coatings imbedded within the surface pores of the substrate. No other system has this level of cleanliness. (Figure 9A)

The Department of Energy has published the following needs and requirements for technical improvement of its D&D:¹⁴

- reduce health and safety risks
- provide a system that is easily installed and operated
- less expensive and lower maintenance costs
- reduce D&D time and reduce labor intensity
- reduce waste volumes
- produce reusable or recyclable materials
- provide accepted technology
- remove and destroy higher levels of contaminants
- minimize spread of contaminants

F. Commercialization of the Technology

As discussed in the Appendix, our technology is well postured for commercialization. F2 has begun to pursue commercial markets in parallel with its government contract work. F2 currently has an abundant backlog of sales opportunities. F2 is currently working with over a dozen commercial customers for a total of over \$6 million in pending commercial sales within the next year.

1. Small Parts Decoating Cells We are already offering these as a commercial product. We have received a lot of interest from non-nuclear industries, including applications regarding the removal of hazardous coatings. We are working with major manufacturing companies to build units for them to replace the chemicals presently used in decoating, with the advantages shown in Figure 10. Commercial sales of units for non-nuclear decoating applications are expected in 1998. In addition, we have entered into negotiations with firms that provide maintenance and support services to commercial nuclear power plants internationally. F2 will build the systems that will be used for commercial nuclear maintenance and decontamination.
2. Large Parts Cleaning Cells For nuclear decontamination, these will be a cross of the technology developed under our DOE contract (minus gantry robot), and our USAF/SERDP contract ("LCCRS" with gantry robot). We are already marketing the potential of this system. For example, there is strong interest expressed from DOE Paducah in using such a system for some of their nuclear decontamination needs. Paducah could also serve as a "beta-site" for demonstrations of such systems. Paducah has over 33% of the DOE's surface-contaminated metals, an ideal fit with this technology. Since most U.S. D&D contractors are reluctant to experiment with new technology, we appreciate the efforts of DOE EM-50 with the Large Scale Demonstration and Technology Deployment Initiative programs.
3. Hand-Held Units. The DOE has funded some testing of F2's hand-held units for doing corner work, nooks-and-crannies, grid work, etc. We are getting a tremendous amount of interest in these hand-held, particularly from the aerospace industry. With successful demonstrations in the fall of 1997 in our laboratory, F2 expects to see first commercial sales of such units in mid 1998.
4. Mobile Robotic Systems. The demonstration at FIU in mid 1998 will use a 2 kW laser and a ROSIE Robot furnished through our government contracts. This demonstration will be videotaped and used as part of our marketing efforts. In addition, many of the potential customers for this system have been invited to attend the demonstration. Since we have already received strong interest from commercial customers, including firms in the aerospace, petroleum, and bridge painting industries, we expect that there will be a strong attendance.

Figure 9
Comparison of Aircraft Depainting Costs

(Costs include materials, labor, waste disposal, training,
safety compliance, and equipment amortization)

Figure 9A

Example of a Coatings Removal Technology Matrix

	Waste Volume		Cleans out surface pores	No thermal damage	No mechanical damage	No hazardous chemicals	No liquids	Level-D dress
	Increase	Same	Decrease					
Mechanical scabbling		✓		✓		✓	✓	
Solid abrasives or air blasting	✓			✓		✓	✓	
Dry ice pellet blasting		✓		✓	✓	✓	✓	CO2 atmos
Water blasting	✓			✓				
Liquid nitrogen cryofracture		✓		?	✓	✓	✓	N2 atmos
Wet chemical strippers	✓			✓	✓			?
Dry strippable coatings	✓			✓	✓		✓	?
CW lasers		✓	✓			✓	✓	✓
Pulsed-repetition lasers			✓	✓	✓	✓	✓	✓

Pulsed Repetitive Lasers are the Best

G. Future Use of the DOE Equipment

One remaining aspect of the commercialization of the laser ablation technology is the future use of the hardware that F2 has built for the DOE as shown in Figure 11. We recommend transitioning the hardware to a DOE site for testing, demonstration, and validation, and possibly even limited production use for D&D.

These applications would be the removal of radioactively-contaminated hydrocarbon-based coatings from metals using a fixed (not mobile) robotic system.

F2 has built for the following equipment for DOE contract (Figure 11):

- Large transportable (but not mobile) laser
- Beam delivery system (BDS)
- X,Y,Z raster scanner decoating workhead
- VAC-PAC vacuum and filtration unit
- Certain on-line sensors
- Computer controller

As part of the DOE contract, this DOE equipment is being tested and demonstrated in F2's laboratory facilities. Also as part of the DOE contract, F2 will demonstrate the mobile robotic system using a more mobile 2 kW laser and the DOE's ROSIE Robot. This demonstration is scheduled to take place in Miami, FL, in early 1998. Both the 2 kW laser and the ROSIE Robot are borrowed equipment.

The options for use of the hardware built for the DOE contract are somewhat limited, since that hardware lacks mobility. Aside from the X,Y,Z scanner, the DOE system has no other robotics. The laser built for the DOE is too large to be used for the mobile robotic platform. That is why a smaller laser is being used for the Miami demonstration. However, the DOE laser is suitable for stationary applications. For example it could readily be used in the large parts cleaning system, although that would require purchase of a gantry robot.

One option is to use the DOE hardware plus some manual or automatic parts handling to move relatively flat parts under the 12-inch by 32-inch raster-pattern area. Larger flat parts can be handled, because the articulating beam delivery system permits the scanner to be moved around to cover several adjacent one foot by three feet rectangles in both X and Y dimensions without having to move the laser or the first pedestal of the beam delivery system.

Figure 10
Comparison of Chemical and Laser Decoating Processes

Decoating with Chemicals

Decoating with Lasers

We calculate that the hardware "as is" operated in the mode described above should be able to cover at least 150 square-feet of surface area (see Figure 12) in less than a semi-circle without placing undue stresses on the pedestal joint of the BDS or the joint where the BDS enters the scanner assembly (see Figure 12). In addition, larger parts can be handled if placed onto and moved around with a roller-ball table. Longer, narrower parts can be handled by moving them in steps on a conveyor under the scanner's rectangle.

At present, F2 is working with both Jacobs Engineering and Lockheed Martin at the DOE's Paducah site to pursue installation of the laser-ablation equipment at Paducah to address one of two issues:

1. Surface decontamination of the vast amount of metals (steel and aluminum) that they have. For example, Paducah has a number of surface-contaminated circular thick aluminum plates about eight feet in diameter. As can be seen from Figure 12, these can be handled with the existing DOE equipment; so can a lot of other larger items.
2. Removal of the rust and lead-based paint from the UF6-tailings storage cylinders. They have about 46,000 of the thick-wall cylinders, most four feet in diameter by six feet long. These cylinders need to be periodically decoated, inspected, and repainted. In addition, more are being generated each month from this active (fully operational) enrichment plant.

The Paducah personnel are very interested in this approach. The issue is funding. This includes the question of which part of DOE would provide the funding and when these funds would be available.

F2 is also exploring ways to become part of a Large Scale Demonstration and Technology Deployment Initiative once we have completed the demonstration at FIU and the laboratory tests at F2 early in 1998.

Though the emphasis is to be on decoating metals, another possible application is the removal of lead-based paint from concrete shielding blocks as part of the Large Scale Demonstration Program at Argonne National Laboratory's CP-5 reactor. At present, because of the lead-based paint, the in-depth contaminated concrete blocks are considered as mixed waste. By removing the lead-based paint, the blocks would then no longer be considered as mixed waste, just radioactive waste. To do this work with the existing equipment built by the DOE, only a fork lift to bring the blocks to the laser-ablation equipment would be required.

We previously had interactions with Fernald and RMI personnel who both expressed real interest in the technology. Unfortunately, delays in the laser fabrication meant that F2 could not meet Fernald's schedule. F2 intends to revisit those applications with Fernald.

Figure 11
Hardware Built for the DOE Contract

6kW CO₂ Pulsed-Repetition Laser

- On-line real-time feedback and control of scan rate and laser pulse rate
- May also lead to on-line assay capability as material is being ablated and deposited into on-line final disposal drum.

III. Conclusion

Laser ablation is an extremely promising technology with many technical and cost benefits for a wide variety of cleaning and depainting applications. F2's plan is to provide system integration services to fully develop and commercialize laser ablation technology to industry in the United States and eventually internationally. Clearly, there is a defined need for advanced cleaning and depainting technology that is more environmentally friendly and cost effective. F2 firmly believes laser ablation is that technology and that we will be successful in our commercialization efforts in multiple industries.

Figure 12
Operating Range for Existing DOE Hardware

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LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

CO ₂	Carbon dioxide
D&D	Decontamination and decommissioning
DOE	U.S. Department of Energy
DoD	The U.S. Department of Defense
EPA	The U.S. Environmental Protection Agency
F2	F2 Associates, Inc.
Fernald	Fernald Environmental Restoration and Management Corporation (FERMCO), their facilities are located in Fernald, OH, near Cincinnati.
FETC	Federal Energy Technology Center
kW	Kilowatts
LANL	Los Alamos National Laboratory
Laser ablation	Removal by vaporizing; that is intense heating of solid material using laser energy such that the solid material goes directly to the gaseous state, resulting in a partially ionized gas (plasma).
MCL	Methylene chloride, a chemical currently used for removing paint and other coatings whose use is being severely restricted under federal regulations that go into effect in September 1998.
MEK	Methylene ketone, a chemical currently used for removing paint and other coatings whose use is being severely restricted under federal regulations that go into effect in September 1998.
MRO	Maintenance, Repair and Overhaul companies for aircraft
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PCBs	Polychlorobiphenyls

LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS
(continued)

PSI	Physical Sciences Inc.
RDT&E	Research, development, testing, and evaluation
ROSIE	A mobile robot developed by RedZone Robotics, Inc. under other contracts with the DOE
SAE- ISO-MA 4872	A formal commercial aircraft depainting certification program
SERDP	The Strategic Environmental Research and Development Program
UF6	Uranium hexafluoride
W	Watts

APPENDIX

Technology Assessments:

The Westinghouse Model,

The A.D. Little Model, and

The "S"-Shaped Learning Curve

March 1997

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