

# **IPRO 323: Laser and Waterjet Technology**

## **Final Report**

**Spring 2006**

Objective .....	3
Background .....	3
Waterjet Cutting.....	4
Introduction.....	4
History.....	4
How They Work .....	5
Why Use A WaterJet?.....	6
Who Uses Waterjets?.....	6
Summary of Characteristics .....	7
Pure WaterJet Attributes .....	7
Abrasive WaterJet Attributes .....	8
Orifice Attributes .....	8
Laser Cutting.....	9
Introduction.....	9
Creating a Laser Beam.....	9
Laser Properties .....	10
Laser Types.....	11
Laser Uses .....	11
Materials Lasers Can Cut:.....	12
Examples.....	12
Current Market Trends.....	13
Comparison.....	14
Laser.....	15
Water Jet .....	15
Basics .....	15
Costs.....	15
Operating Environment.....	15
Conclusion .....	16
References.....	16
Waterjet.....	16
Laser.....	16

## **Objective**

The objective of IPRO 323 is to analyze the role that laser and waterjet technologies have in current industrial and manufacturing processes. Specifically, this IPRO seeks to gain a better understanding of how these two technologies work in practice. In addition, the IPRO will offer a comparison of the advantages of each technology as well as determine where these tools can be implemented in small manufacturing companies to assist their product development and construction. In order to accomplish these goals, the team conducted extensive research to gain background information on laser and waterjet technologies. Further knowledge was gained through on-site demonstrations of these machines to determine their practicality. Conclusions were then drawn from the data collected to determine the best placement of these machines in current industries.

## **Background**

Both lasers and waterjets have been used as tools in manufacturing processes for several decades. Lasers have generally gained more renown for their variety of uses including medical procedures such as surgery, therapeutic applications, and the popular Lasik eye surgery. They are also featured in a variety of entertainment platforms providing spectacular light shows, as well as research applications involving biological instruments and general university research. Despite these high profile applications, lasers have made a significant contribution to the world of manufacturing, specifically for their use in cutting applications. Accordingly, lasers have allowed many companies to streamline their production processes, instead of using more traditional methods such as material stamping and die-casting.

In a similar light, waterjets have also provided companies greater flexibility in choosing a method of metal and ceramic shaping. While not as widely known or publicized as lasers, waterjets have been used commonly for cutting materials such as glass, concrete, and steel since the early 1980's. Operating on a simple principle, they cut a variety of materials simply with an ultra high pressure stream of water. After a few years of development, abrasives were added commercially to waterjets, increasing their cutting power even more, thus making them more versatile.

Despite the fact that these machines have been in existence for several decades, it has not been until relatively recently that their potential has truly been discovered in the world of manufacturing. Originally, this technology was more of a novelty than a practical investment. Even large-scale companies with large amounts of capital either were not aware of these machines or generally did not operate any of them in-house.

When most manufacturers need to employ the use of laser or waterjets, their materials and plans are sent to large scale machine shops. These shops specialize in hosting a variety of laser and waterjet equipment, and are designed to handle nearly any material or part design that is given to them. The machine

shops will take these designs, do the necessary work on the parts, and then send the finished product back to its original manufacturer.

What makes lasers and waterjets unique today is that they are just recently becoming mainstream manufacturing tools. As technology has advanced, lasers and waterjets have become far smaller and much easier to maintain and operate. With lasers and waterjets just recently being discovered for commercial use, it is possible that a trend will start soon in which it will become economically feasible for a company to purchase their own laser or waterjet equipment and do all necessary material cutting and shaping in their own shop. While most small businesses have not ventured to invest the capital necessary to purchase these machines for themselves, this IPRO believes it is becoming an increasingly cost effective option to do all work in house, thus saving the manufacturer both time and labor costs in the long run.

## **Waterjet Cutting**

### ***Introduction***

Waterjets are instruments that are primarily used for cutting materials. Waterjet cutting has been used in a wide variety of industries since about 1970. Around 1990, the waterjet cutting technology became very popular for machine shops because major advances in the technology, such as advanced software tools, were introduced. In fact, during this time, a market research company named Frost and Sullivan mentioned that "The waterjet machine tool market has emerged as the fastest growing market segment, with a growth rate forecast at 9.1 percent for the forecast period [1997-2004]." Today, more and more companies are saving a great deal of money by replacing or complimenting conventional machining with waterjet cutting methods.

### ***History***

The idea of the waterjet can be traced to Dr. Norman Franz, who in the 1950's wanted to find new ways to cut thick trees into lumber. In his experiment, Franz dropped heavy weights onto columns of water and forced this water through a tiny orifice. Consequently, Franz obtained short bursts of water at very high pressures, which was easily able to cut wood and other materials. Although Franz did not have too much success in obtaining high pressure water continually, he demonstrated with his experiment a very important point: a beam of high pressure water at very high velocity could have a tremendous amount of cutting potential. Dr. Franz introduced the waterjet; other researchers then tried to find ways to make it more powerful.

Perhaps the researcher whose contributions were most significant in this regard was Dr. Hashish, who in 1979 invented the process of adding abrasives to the plain waterjet to increase its cutting power. Dr. Hashish's experiment had a profound result: the abrasive-filled waterjet could cut almost any material, including steel, glass, and concrete. In 1983, the first commercial abrasive-waterjet was sold for cutting automotive glass. Soon, the aviation and space industries also realized the profits they could gain with abrasive waterjets and

bought them to cut hard materials such as steel and titanium. Since then, several other industries -- including job-shop, stone, tile, glass, jet engine, and construction -- have all followed in their footsteps and have acquired huge financial benefits by purchasing and using abrasive-waterjets rather than employing traditional cutting methods.

### ***How They Work***

Today's waterjets are more complex than those built by researchers such as Dr. Hashish in the 1970's. However, their operation is essentially the same: water flows from a pump, through plumbing, and out of a cutting head. Each of these three components is vital for the waterjet to function properly.

The pump is responsible for creating the high-pressure water and delivering it continuously. There are two types of pumps available today: intensifier based and direct drive based. The difference between the two is that the direct drive pumps are much simpler (both in design and in operation) than the intensifier pumps. But with this simple design also comes a price: direct drive pumps can only deliver maximum continuous pressure that is 10 to 25% lower than intensifier pumps. This is exactly why the majority of industries today utilize intensifier-based pumps, which are capable of raising the water pressure up to 60,000 psi.

Once the high-pressure water is created by either the intensifier pump or the direct drive pump, it needs to be delivered to the cutting head. This transporting of water is accomplished by high-pressure plumbing. The most common type of plumbing is stainless steel tubing. There are at least three different types of tubing available (1/4 inch, 3/8 inch, 9/16 inch), each used for a different purpose. For example, while the 1/4 inch steel tubing provides great flexibility over short distances, the 9/16 inch steel tubing is used to transport high-pressure water over long distances.

The plumbing delivers the high-pressure water to the cutting head, a small jewel attached to the end of the plumbing tubing. The jewel has a very tiny hole in it. The purpose of this hole is to convert the high water pressure created by the pump to high water velocity because it is precisely this velocity (and not the pressure) that can tear away minute pieces of material. As an example of how fast and powerful the resulting stream of water can be, at about 60,000 psi, the stream of water passing out of the orifice travels at speeds over Mach 3!



*Smaller – high precision*



*Advanced, high production system*

(source: [www.flow.com](http://www.flow.com))

### ***Why Use A WaterJet?***

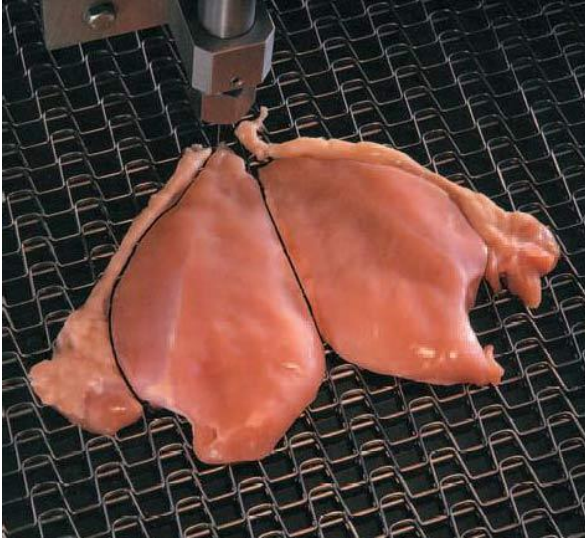
Waterjets are excellent cutting tools for many reasons. With the addition of an abrasive, as discussed above, they are very powerful and can cut through any material. Though this cutting is a mechanical operation, the wear is on the disposable abrasive, not expensive machine tools. Additionally, because it is a "cold" i.e. mechanical cut, the properties of the material are not altered in any way. This also means that no cooling or other processing is required after cutting-- a major time-saver.

### ***Who Uses Waterjets?***

Waterjets fulfill many roles, from specialized applications in assembly lines to the primary tools of smaller shops; their flexibility is one of their primary benefits.

Abrasive-less waterjets are often used in the food industry for rapid cutting of food products. Even an abrasive-less jet can cut food much faster than traditional blades. Since the water is purified before use, there is no need for

additional sterilization; the high-pressure even helps eliminate bacteria. In comparison to traditional blades, there is no downtime for sharpening and sterilization, and a waterjet cuts much faster; for the food industry they are an improvement over blades in every way.



(source: <http://www.foodprocessing-technology.com/projects/wayne/wayne7.html>)

The aerospace industry uses waterjets almost exclusively for some materials. This is because waterjets are the only efficient way to cut some of the alloys and composites they use. Waterjets have no problem on very hard or strong materials; likewise they have no problems on composites of different materials. This makes waterjets the only choice for many aerospace applications.

Smaller custom shops also find waterjets to be ideal. One waterjet nozzle is used for all cutting jobs, so no tool swapping is required. There is also little fixturing required; a few pieces of heavy material are usually enough to secure the cutting material. After quickly drafting up the required part in a CAD program, it is ready to be cut. This quick turnaround between initial design and finished product means that short or one-part runs can be profitable for custom shops.

### ***Summary of Characteristics***

The following three tables (“Two Types of WaterJets,” Flow Corporation) highlight the major characteristics of pure and abrasive waterjets and the types of orifice materials that can be used for each:

#### **Pure WaterJet Attributes**

- Very thin stream (0.004 to 0.010 inch in diameter)
- Extremely detailed geometry
- Very little material loss due to cutting
- Non-heat cutting

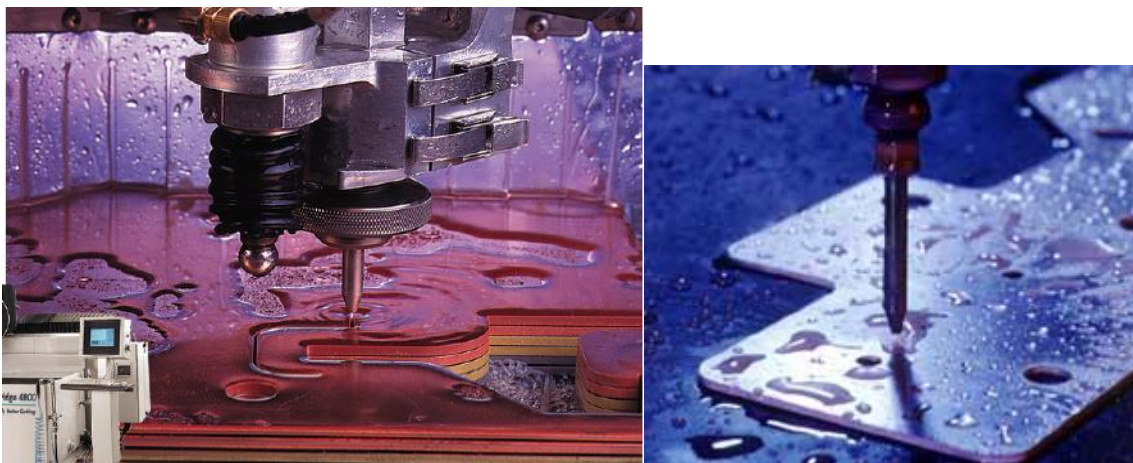
- Able to cut soft, light materials
- Usually cuts very quickly
- Extremely low cutting forces

### Abrasive WaterJet Attributes

- Thin stream (0.020 to 0.050 inch in diameter)
- Extremely detailed geometry
- Some material loss due to cutting
- No Heat Affected Zones
- Extremely versatile process
- Thin material cutting
- 10 inch thick cutting
- No mechanical stresses
- Low cutting forces (under 1 lb. while cutting)

### Orifice Attributes

Orifice Material	Life (in hours)	Use	Highlights
Sapphire	50-100	Pure WaterJet	-General Purpose -Most Common
Ruby	50-100	Abrasive WaterJet	-Stream not suited for pure waterjet
Diamond	800-2,000	Pure/Abrasive WaterJet	-Very Long Life -10 to 20 times more expensive than Ruby/Sapphire



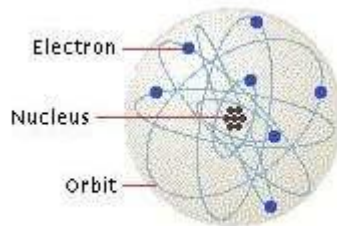
(source: [www.flow.com](http://www.flow.com))



# Laser Cutting

## *Introduction*

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers are formed by the interaction of light with electrons. Electrons exist at specific energy levels or states characteristic of that particular atom or molecule. The energy levels are called orbitals and they form a ring around the nucleus. Electrons in outer rings are at higher energy levels than those in inner rings. Electrons can be raised to higher energy levels by the injection of energy- for example, by a flash of light. When an electron drops from an outer to an inner level, "excess" energy is given off as light. Depending on the particular lasing material being used, specific wavelengths of light are absorbed (to energize or excite the electrons) and specific wavelengths are emitted (when the electrons fall back to their initial level). These photons of the same wavelength form a laser beam.



**Figure 1 - Simple Atom Model**  
(Source: University of Liverpool)

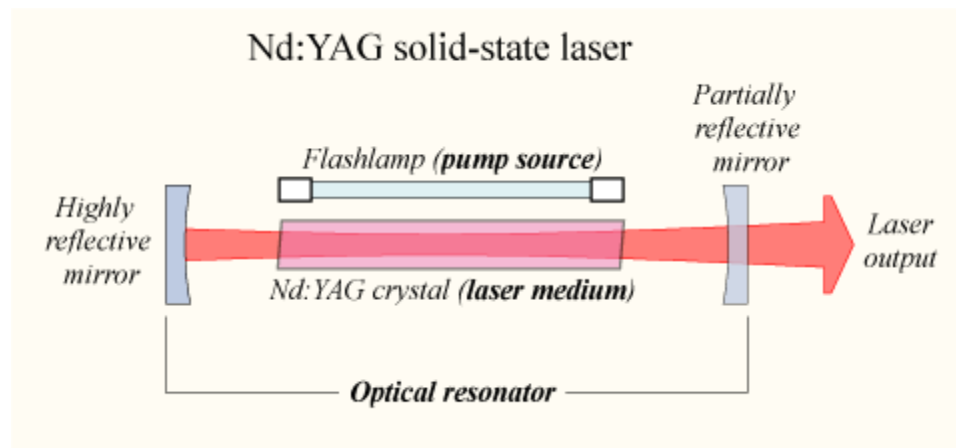
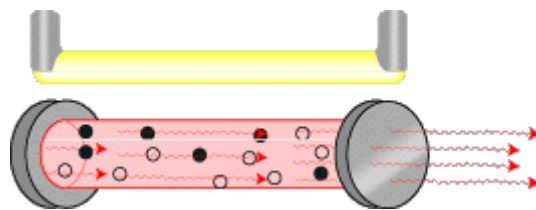
## *Creating a Laser Beam*

A laser is a device that controls the way in which energized atoms release photons. There are many different types of laser available; all the different types of laser rely on the same basic elements. In all types of laser there is a lasing medium, which is pumped to get the electrons within the atoms to a higher-energy orbital i.e. to get the atoms excited. Typically, very intense flashes of light or an electrical discharge pump is used as a lasing medium and they create a large number of excited-state atoms that result in a high degree of population inversion (the number of excited state atoms versus the number of atoms at ground-state energy level). At any stage the excited state atoms can release some of the energy and return to a lower-energy orbital. The energy released, which comes in the form of photons, has a very specific wavelength that is dependant on the level of energy or excitation of the electron when the photon is released. Two identical atoms with electrons in identical states will release photons with identical wavelengths. This forms the basis for laser light.

Any photon that has been released by an atom, (which therefore has a wavelength, phase and energy level dependant on the difference between the excited atom state and the ground-state energy level) should encounter another atom that has another electron in the same excited state resulting in stimulated

emission. The first photon can stimulate or induce atomic emission so that the emitted photon vibrates with the same frequency and direction.

To produce laser light it is necessary to have a pair of mirrors at either end of the lasing medium. These mirrors are often known as an optical oscillator due to the process of oscillating photons between the two mirrored surfaces. The mirror positioned at one end of the optical oscillator is half-silvered; therefore it reflects some light and lets some light through. The light that is allowed to pass through is the beam that is emitted from the laser. During this process photons are constantly stimulating other electrons to make the downward energy jump, hence causing the emission of more and more photons and an avalanche effect, leading to a large number of photons being emitted of the same wavelength and phase.



**Schematic Showing Column of Laser Light Leaving Optical Oscillator**

### ***Laser Properties***

- Laser light is monochromatic. It contains one specific wavelength of light that is determined by the amount of energy released when the electron drops to a lower-energy orbital.
- Laser light is coherent. Each photon moves in step with the other and the wavelengths are in phase with each other.
- Laser light is highly directional.
- Light possesses high radiant power per unit area (i.e. high irradiance)

## ***Laser Types***

There are hundreds of different lasers available in the market. However, only a few types are in regular use in engineering because of their cost and effectiveness. Some of the most frequently used lasers in engineering are:

1. Solid state lasers
2. Gas lasers
3. Semiconductor lasers
4. Molecular or Eximer lasers
5. Dye laser



**Description: Sealed laser cutting machine for light industrial equipment**

**(source: google images)**

## ***Laser Uses***

Lasers have many advantages over other conventional metal cutting and metal fabricating processes. Laser cutting can produce very complex parts while cutting materials from 0.005" to 0.750" thick. Lasers can cut the hardest materials and leave burn-free edges. The laser cutting process is extremely repeatable and produces parts with virtually no distortion. Laser cutting is well suited for rapid prototyping and provides a cost effective solution for short run production, making it a good alternative to metal stamping.

The narrow laser cut width created by material removal, provides for the efficient layout of parts (and more parts per sheet), with less material scrap waste than most other cutting methods.

Lasers are capable of cutting steel, stainless steel, alloys, copper, aluminum, and brass. They are capable of cutting non-metallic materials like plastics, ceramics, rubber, quartz, wood and even some composite structures. Overall, laser cutting out-performs plasma, NC milling, and conventional saws in nearly every cutting process. However, for some materials, thickness requirements, or tolerances, other metal cutting processes may be more efficient.

**Materials Lasers Can Cut:**

Organic	Inorganic	Metals
Acrylic	Glass	Steels
Polyethylene	Ceramics	Iron
Polypropylene	Quartz	Nickel
Polycarbonate	Alumina	Tin
Rubber	Asbestos	Lead
PVC	Mica	Aluminum
Wool	Rocks	Titanium
Cotton		Copper
Wood		Brass
		Bronze
		Tungsten

**Examples**



High speed laser machining of composite plastic, fiberboard, rubber, paper, etc.



**Laser trimming and cutting packaging and molded components for production or prototype.**



**Laser cut foam components to verify design prior to expensive die procurement.**



**Wooden box precisely cut and decorated from one flat piece of wood using one simple graphics file.**

### ***Current Market Trends***

In recent years there has been an explosive growth in the production and distribution of laser machines. While lasers are employed in a wide variety of applications, the materials processing sector that focuses on manufacturing and industry has the largest volume of sales compared to all other types of lasers. In a single year between 2003 and 2004, laser sales grew by 22%, and in 2005, it is estimated that sales of lasers will increase another 3%. This means that currently, over \$1.5 billion in laser sales are being conducted per year. Also, between 2004 and 2005 there was an increase of over 1600 units sold. The exciting prospect is that in addition to rapid sales growth, the prices of materials processing lasers are slowly dropping as well. The following chart displays the current pricing trends of the laser market.

## MATERIALS PROCESSING

*Includes lasers used for all types of metal processing (such as welding, cutting, annealing, drilling); semiconductor and microelectronics manufacturing (such as lithography, inspection, control, defect analysis and repair, via drilling, but excludes marking); marking of all materials including plastic, metals, silicon; other materials processing such as rapid prototyping, desk-top manufacturing, micromachining, embossed holograms, grating manufacture.*

Sales	2001	2002	2003	2004	2005
Units (K)	26	29.6	30.3	38.7	40.3
\$ (M)	1225	1267	1206	1467	1503



Boosted by near-record annual growth in the semiconductor equipment sector combined with strong sales of lasers for marking, overall materials-processing revenues jumped 22% in 2004 (vs. 2003). A very modest 2% gain is forecast for 2005 as a moderate cyclic decline expected in the semiconductor segment takes its toll on laser revenues.

While this table indicates a slowing trend for the growth of laser sales, it is important to note that the majority of this trend is due to a slump in the semiconductor industry. However, most predictions indicate that this is a temporary slump and within a few business quarters, growth will be seen again with minimal damage to the laser market in the meantime. With sales holding steady, small businesses are at an advantage to begin investing in this type of equipment. Prices are at a level point which will allow them to purchase a laser without fear of losing money in a few quarters due to a significant price drop. In addition, the ability to cut and weld materials in house will allow many businesses to recover their initial investment over time due to savings from not having to send their materials to larger machine shops.

## Comparison

Lasers and waterjets can both be used as cutting tools. Their methods of cutting are completely different, however; one uses a beam of focused light, while the other uses high pressure and mechanical force. This results in some important differences that should be considered before choosing to use either of these technologies.

In general, waterjets can be considered the "lower tech" option. This does not imply that they are less useful, but that the technology behind creating high-

pressure water is simpler, and easier to understand. However, some negative aspects go along with less technology; waterjets are noisy and (if using abrasive) produce a lot of waste, putting them at a disadvantage to lasers' quiet operation and low waste.

The biggest contrast, however, is in waterjets' "cold cut" with lasers' high heat. A cold cut has several advantages; it can be used on almost any material without worrying about the heat sensitivity or whether the material is flammable. However, lasers' heat generation may be desirable in some situations.

In other areas, the two technologies are very similar. As far as preparing the equipment, the process is almost identical; the cutting path is drafted, machine parameters are varied, and the material is secured to the cutting table. A good waterjet and a laser will have similar cutting tolerances, so in many cases, the final product will be very similar. As far as costs, the initial price of each is generally similar to the price of comparably-sized machine tools, though lasers are generally more expensive. The price varies greatly, of course, based primarily on size and power. Power consumption is similar. Operating costs for waterjets are higher in most applications because of the cost of disposable abrasive.

This final table summarizes the differences discussed above, as well as providing numerical comparisons where appropriate.

	<b>Laser</b>	<b>Water Jet</b>
<b>Basics</b>		
Cutting Method	Light (heat)	Water (abrasive/mechanical)
Materials	Metals, Plastics, Wood, Glass	Any material
Precision	CO2: 0.005" - 0.015" Yag: 0.0015" - 0.012"	Water: 0.001" - 0.014" Abrasive: 0.016" - .045"
Energy Source	Gas Laser	Water Pump
<b>Costs</b>		
Initial Costs	125,000 – 750,000+	75,000 – 500,000+
Energy Consumption	1500W Laser: 24-40kW	20kW pump: 22-35kW
Operating Cost	Laser: ~15 / hour	Water: 12-13 / hour Abrasive: 25-28 / hour
<b>Operating Environment</b>		
Noise	Low	High
Waste	Low	High

Waterjets and lasers are different, and one or the other will be preferable in different situations. They can even be complementary; many companies use both. However, choosing whether one or the other will be better for a certain situation must be done on a case-by-case basis.

## **Conclusion**

Both laser and waterjet technologies can give companies a significant improvement for methods in large scale cutting and welding of the materials they use in manufacturing. They can be time saving and cost effective alternatives to common material processing options available on the market today. The option for small businesses to invest in laser and waterjet machines continues to be very promising. Many man-hours and labor costs can be reduced with these machines, without sacrificing product quality. It can be expected that lasers and waterjets will continue to benefit the manufacturing industry as new models are developed and marketed. In that light, this IPRO would strongly recommend that companies evaluate how they can utilize this technology. Our recommendation further calls for companies to consider purchasing this equipment for use in their own shops where feasible. If not cost effective it is suggested that companies seek out larger machine shops as resources for processing materials in a more timely and cost effective manner than they currently employ. As an additional conclusion, it would be ideal for a follow-up IPRO to continue the work done by this current team. Future IPRO teams could use this research to seek out companies that are top candidates for these machines and present this information to them. These efforts could help companies make informed decisions about the options they have for manufacturing equipment.

## **References**

### ***Waterjet***

Courtesy of OMAX corporation: [www.waterjets.org](http://www.waterjets.org)

Flow corporation: [www.flowcorp.org](http://www.flowcorp.org)

Wikipedia Encyclopedia: [www.wikipedia.com](http://www.wikipedia.com)

### ***Laser***

[http://en.wikipedia.org/wiki/Laser\\_cutting](http://en.wikipedia.org/wiki/Laser_cutting)

[http://www.thefabricator.com/LaserCutting/LaserCutting\\_Article.cfm?ID=827](http://www.thefabricator.com/LaserCutting/LaserCutting_Article.cfm?ID=827)

[http://www.online-inc.com/application\\_examples.htm](http://www.online-inc.com/application_examples.htm)

<http://www.teskolaser.com/lasercuttingfaqs.html#q2>

<http://www.cmslaser.com/cdw/>

[http://lfw.pennnet.com/Articles/Article\\_Display.cfm?Section=ARCHI&ARTICLE\\_ID=219847&VERSION\\_NUM=2&p=12](http://lfw.pennnet.com/Articles/Article_Display.cfm?Section=ARCHI&ARTICLE_ID=219847&VERSION_NUM=2&p=12)