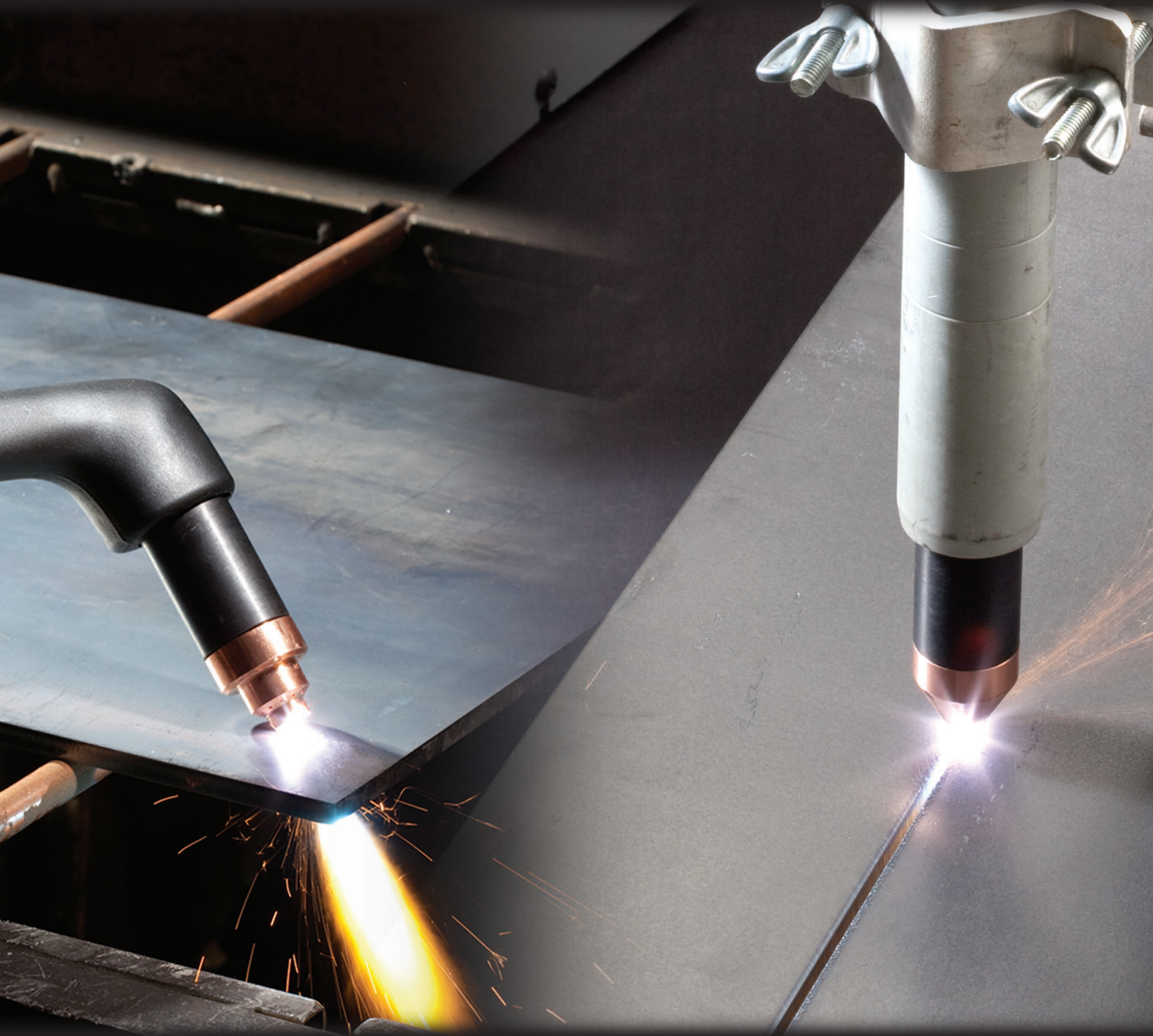
# *Plasma Cutting Technology: Theory and Practice*

Facilitator guide



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893400 – Revision C

# Introduction

Welcome to the ***Plasma Cutting Technology: Theory and Practice*** course.  This Facilitator's Guide, along with the accompanying PowerPoint slides, activity worksheets, and hands-on materials, are the tools you need to conduct a 10-session course.  Each session is designed to be 50 to 60 minutes in length, and all of them include activities to keep your students engaged and motivated to learn.

***About the designers of this course:*** Hypertherm designs and manufactures the world's most advanced plasma cutting systems for use in a variety of industries such as shipbuilding, manufacturing, and automotive repair. Its product line includes handheld and mechanized plasma systems and consumables, as well as CNC motion and height controls. Hypertherm systems are trusted for performance and reliability that results in increased productivity and profitability for tens of thousands of businesses. The New Hampshire based company's reputation for plasma innovation dates back over 40 years, to 1968, with Hypertherm's invention of water injection plasma cutting. The company, consistently named one of the best places to work in America, has more than 1,000 associates along with operations and partner representation worldwide. To learn more, please visit www.hypertherm.com.

## Course Overview

Session 1: What is Plasma?

Session 2: Using Plasma Systems in Industry

Session 3: Overview of a Plasma System

Session 4: Using Your Plasma System Operator's Manual

Session 5: Operation of the Plasma System

Session 6: Evaluating Cut Quality and Troubleshooting

Session 7: Theory Exam

Session 8: Freehand and Template Cutting

Session 9: Hole Piercing and Gouging Part One

Session 10: Gouging Part Two and Final Evaluations

- **Starting Each Session.** This guide provides an overview of each session, including an outline of the material to be covered along with recommended timing, and a section called "Before You Begin." Be sure to read the steps that you should take before each class session to make sure that you are prepared before students arrive for class.

- **PowerPoint Slides.** This course uses PowerPoint slides that are projected in front of the class. You will need to make sure that you have a computer and projector available for each of the six theory lessons in order to make the most out of these course materials.

The PowerPoint slides are provided on the CD-ROM that is included in this kit and are named according to the session number:

- Session1 – What is Plasma.ppt
- Session 2 – Using Plasma Systems in Industry.ppt
- Session 3 – Overview of a Plasma System.ppt
- Session 4 – Using Your Plasma System Operator Manual.ppt
- Session 5 – Operation of the Plasma System.ppt
- Session 6 – Evaluating Cut Quality and Troubleshooting.ppt

To run each slide deck, double-click on the appropriate filename to open the file. Once the file is displayed, you will need to switch the program to "Slide Show" mode. You can do that by pressing the F5 key, clicking on "View" from the top menu and then selecting "Slide Show" from the dropdown choices, or clicking on the icon of the screen in the lower left corner of the screen.

Once the slide deck is displayed, use the space bar or the right arrow to advance through the slides. There are some interactive screens within the course that require you to click on menus within the PowerPoint slides. Instructions for these types of interactions are included within this Facilitator's Guide and/or on the PowerPoint slide.

To end a slide show, press the "Esc" key on your keyboard. You can then close PowerPoint by clicking on the "X" in the upper right corner of the screen or by selecting "File" from the top menu bar and then "Exit" from the dropdown menu.

- **Minimum System Requirements.** The PowerPoint slides associated with this course contain videos that require a computer with adequate processor speed to function properly. Please make sure that your computer meets the following specifications before you attempt to run the course:
  - Processor: Intel Core2Duo 2.2 GHz with 2 GB RAM
  - Disk storage: 160 gigabyte hard disk drive and combo DVD-RW/CD-RW drive
  - Video: 256 MB dedicated video RAM & LCD monitor
  - Operating System: Microsoft Windows XP Professional, Microsoft Windows Vista Business*, or Microsoft Windows Vista Ultimate*
  - Flash Player Version 9 or higher, Adobe Acrobat Reader, and Windows Media Player 10
- **Student Activities.** This facilitator's guide includes all of the activity worksheets with the correct answers identified, followed by student versions of each worksheet. The activity worksheets are placed within the flow of each session.
- **Homework Activities.** You will notice that there are homework questions included with each of the theory lessons (Sessions 1 – 6). These questions review the material covered in the previous class session and prepare students to move on to new content.
- **Theory Assessment.** There is a 30-question theory assessment planned for Session 7. This assessment tests students on the key concepts presented during the theory portion of the course. Note that the questions in the homework activities cover the same learning objectives as the questions on the theory assessment. Therefore, they serve as good review activities as students prepare for the assessment. This assessment and the answer key are provided within this facilitator's guide.

# Session 1: What is Plasma?

This session provides an overview of the course as well as an introduction to the plasma system, including an instructor-led demonstration of the plasma system to actively engage students at the beginning of this 10-session course.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction | 5 minutes |
| What is a Plasma System? | 5 minutes |
| Plasma System Demonstration | 15 minutes |
| What is Plasma? (including worksheet and discussion) | 10 minutes |
| How is Plasma Created in a Plasma System? (including discussion) | 10 minutes |
| History of Plasma Systems | 5 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Set up the plasma system and make sure that you are comfortable demonstrating a drop cut.
2. Gather safety glasses for all of the students in the class for use during the cutting demonstration.
3. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
4. Make a copy of the homework sheet for every student in the class.

## Introduction

*Purpose: Cover the learning objectives and overall course structure.*

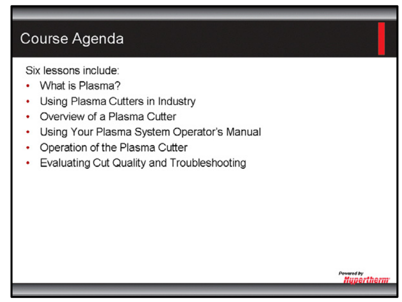
*Time: 5 minutes*


**Slide 0: Lesson Title**

**Slide 1: Course Agenda**

The course includes six lessons, each of which includes in-class activities:

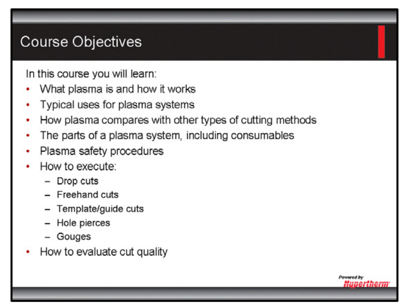
1. What is Plasma?
2. Using Plasma Systems in Industry
3. Overview of a Plasma System
4. Using Your Plasma Cutter Operator's Manual
5. Operation of the Plasma System
6. Evaluating Cut Quality and Troubleshooting



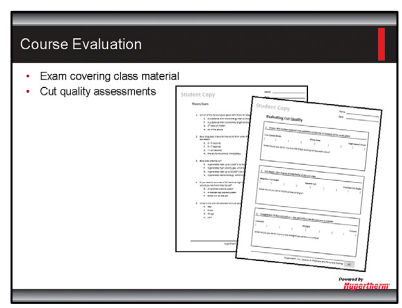

**Slide 2: Course Objectives**

Upon completion of this course, you will be able to:

- Demonstrate understanding of what plasma is and how it works.
- Identify industrial uses for plasma systems.
- Compare and contrast plasma with other cutting methods, including oxy-fuel and laser.
- Identify the parts of a plasma system, including consumables.
- Demonstrate understanding of plasma safety procedures.
- Demonstrate the ability to execute:
    - Drop cuts
    - Freehand cuts
    - Template/guide cuts
    - Hole pierces
    - Gouges
- Demonstrate the ability to evaluate the quality of cuts.




**Slide 3: Course Evaluation**




Students will be evaluated based on two criteria:

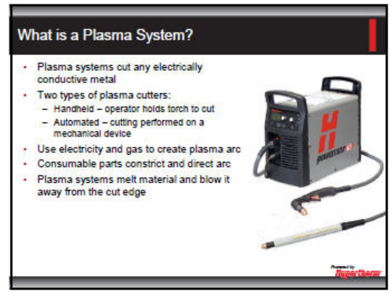
- A 30-question assessment based on the materials covered within the six lessons.
- Self- and instructor-evaluations of the cuts made with the plasma system.

*Note: Communicate to your students that the self-evaluation is as important as the instructor evaluations. Even though cuts are not expected to be perfect the first time, students will learn proper technique and should be able to identify the good and bad points of cuts.*

## What is a Plasma System?

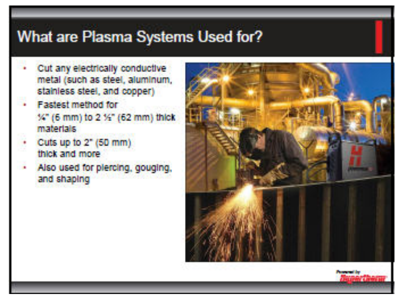
*Purpose: Provide an overview of plasma cutter systems*

*Time: 5 minutes, including demonstration*




**Slide 4: What is a Plasma System?**

- Plasma systems are machines designed to cut various thicknesses of electrically-conductive metal.
- They range from handheld portable units to automated, table-mounted units.
- A plasma system uses electricity and gas to create a very high temperature (20,000° C) arc, also known as plasma.
- The consumable parts held by the torch work to constrict and direct the arc, which maximizes its efficiency at cutting metal.
- Plasma systems use the arc and the gas flow that shapes the arc to melt material and blow it away from the cut edge, respectively.



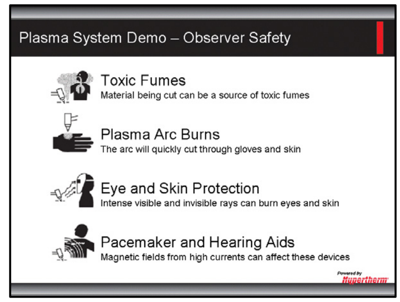

**Slide 5: What Are Plasma Systems Used For?**

- Plasma systems can cut ***any*** electrically conductive metal; common materials include carbon steel, aluminum, stainless steel, and copper.
- Plasma cutters are generally the fastest method for cutting materials between ¼" (6 mm) and 2 ½" (32 mm) in thickness.
- Typical plasma cutters can cut plate up to 2" (50 mm) thick. However, specialized industrial machines are available to cut even thicker materials.
- Plasma cutters are also used for piercing, gouging, and shaping (for example, bevel cuts).


**Slide 6: Types of Plasma Systems**

- Manual – readily portable units often with a hand-held torch, with typical capacity of cutting up to 2" (50 mm) thick plate. Special straight torches allow these systems to be used on CNC cutting tables for certain applications.
- Mechanized – typically installed in a factory setting for high duty cycle use. Usually optimized for very high quality or high speed cutting, and some systems capable of cutting extremely thick materials.

## Plasma System Demonstration




*Purpose:* *Generate interest in the plasma cutting process by demonstrating a cut for the class.*

*Time:* *15 minutes, including demonstration.*

*Facilitator Notes: Before you cut, you must go over some of the most important safety information. Note that this information will be covered in greater detail later in the course, before students do any independent cutting.*

**Slide 7: Safety for Observers**

- **Toxic Fumes** – The material being cut can be a source of toxic fumes or gases that deplete oxygen. Metals that may release toxic fumes include, but are not limited to, stainless steel, carbon steel, zinc (galvanized), and copper. Metal can also be coated with substances that can release toxic fumes; they may include, but are not limited to lead, cadmium, and beryllium.
- **Plasma Arc Burns** – The plasma arc forms immediately when the torch switch is activated and will cut quickly through gloves and skin. Keep clear of the torch tip and cutting path, and never point the torch toward yourself or others.
- **Eye and Skin Protection** – Plasma arc rays produce intense visible and invisible (ultraviolet and infrared) rays that can burn eyes and skin. Use eye protection with appropriate lens shading and wear protective clothing, including gauntlet gloves, safety shoes, hat, flame-retardant clothing, and cuff-less trousers to prevent entry of sparks and slag. Remove any combustibles from your pockets before cutting.
- **Pacemaker and Hearing Aids** – Pacemakers and hearing aid operation can be affected by magnetic fields from high currents. Wearers of either device should consult a doctor before going near any plasma arc cutting and gouging operations.

### Instructor/Operator Safety Information

- **Fire Hazards** – make sure there is a fire extinguisher in the area and that all flammables are at least 35 feet away from the cutting area.
- **Electrical Shock** – touching live electrical parts can cause a fatal shock or severe burn. Operating the Plasma System completes an electrical circuit between the torch and the workpiece; the workpiece and anything touching the workpiece are part of the electrical circuit. Never touch the torch body, workpiece, or the water in a water table when the Plasma System is operating. Wear insulated gloves and boots, and keep your body and clothing dry.
- **Grounding** – Attach the work cable securely to the workpiece or the work table with good metal-to-metal contact. Do not connect it to the piece that will fall away when the cut is complete.
- **Compressed Gas Equipment** –use only gas cylinders, regulators, hoses, and fittings designed for the specific application
- **Noise** – On some large plasma systems, prolonged exposure to high levels of noise can damage hearing. If necessary, use approved ear protection when using a plasma system and warn others nearby about the noise hazard.
- **Only trained and authorized personnel may open this equipment**. Always follow the instructions for disconnecting power before inspecting or changing torch consumable parts.

## How to Make Your First Cut

*Facilitator Notes: Make sure that you have the plasma system hooked up with all of the necessary inputs (air, power, and ground). Provide protective eye-wear for everyone in class. We suggest that you use a piece of carbon steel for the demonstration cut. The following pages show the Quick Setup Card for the Powermax65 and Powermax85 and then the Quick Setup Card for the Powermax45. Reference the Quick Setup Card for the system most similar to yours for instructions on how to set-up and operate the plasma system.*

**Directions:**

- Bring the plasma system to the cutting area of the workshop.
- Demonstrate the **Machine Startup** activity using the Quick Setup Card
- Review drop cut technique for group, demonstrating cut speed and torch angle WITHOUT actually cutting.
- Put on full Personal Protective Equipment (PPE) and check that the system is ready for cutting.
- Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, etc.).
- Class observes as you cut.
- After the cut, stop and review technique with entire class.

If time allows, you may want to allow a student to make a cut at this point in the class. If you do, make sure that they wear the full PPE and follow all safety procedures.

# Hypertherm

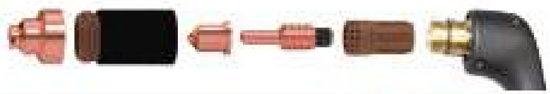
## powermax65® / powermax85®

**Warning: Read the Operator Manual thoroughly. Follow the safety instructions.**

Avertissement : Lire attentivement le manuel de l'opérateur. Suivre les instructions de sécurité.

Advertencia: Leer el Manual del operador con detenimiento. Cumpla con las instrucciones de seguridad.

**1.**



**See reverse for options.**
Voir les options au dos.
Vea el reverso para ver las opciones.

**2.**

**3.**

**4.**

**Do not attach clamp to a portion of the workpiece that will fall away.**
Le connecteur ne doit pas être fixé à la partie de la pièce qui doit tomber.
No fije la pinza a la parte de la pieza a cortar que caerá.

**5.**

**6.**

Expanded metal
Métal déployé
Metal expandido

Plate cutting
Coupage de tôle
Corte de placas

Gouging
Gougeage
Ranurado

Lock
Verrouillage
Bloqueo

**Ready to cut.**
Prêt à couper.
Listo para el corte.

## Cutting / Coupage / Corte

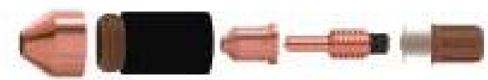
**No standoff.** Aucune distance torche-pièce. No alejar.

| | | | | | |
|---|---|---|---|---|---|
| 45 A | 220818 | 220854 | 220941 | 220842 | 220857 |
| 65 A | 220818 | 220854 | 220819 | 220842 | 220857 |
| 85 A | 220818 | 220854 | 220816 | 220842 | 220857 |

## Piercing / Perçage / Perforando

**Roll torch to 90°.** Déplacer la torche à 90°. Ponga la antorcha a 90°.

## Gouging / Gougeage / Ranurado



| | | | | |
|---|---|---|---|---|
| 220798 | 220854 | 220797 | 220842 | 220857 |

## FineCut™

| | | | | |
|---|---|---|---|---|
| 220931 | 220854 | 220930 | 220842 | 220947 |

*Need help?* ***Avez-vous besoin d'aide?***
*¿Necesita ayuda?*

**First contact your distributor.**

If you need additional assistance, you can contact Hypertherm Technical Service.

**Contacter d'abord votre distributeur.**

Pour toute aide supplémentaire, communiquez avec le service technique d'Hypertherm.

**Primero contacte su distribuidor.**

Si necesita mas ayuda, puede ponerse en contacto con el Servicio Técnico de Hypertherm.


Hypertherm

**Technical Service**
technicalservice@hypertherm.com

USA
800-643-9878 (USA only)
603-643-3441 Ext. 1770 Tel
603-643-4609 Fax

Brazil
55 11 6482 1087 Tel
55 11 6482 0591 Fax

**European Technical Support Organization**
euroservice@hypertherm.com

Germany
49 6181 58 2123 Tel
49 6181 58 2134 Fax

Italy
39 02 725 46 314 Tel
39 02 725 46 400 Fax

The Netherlands
00 800 49 73 7843 Toll free
31 165 596900 Tel
31 165 596901 Fax




# Hypertherm
## powermax45

# Quick Setup Card
## *Fiche de préparation rapide*
## *Tarjeta de establecimiento rápido*

**806100 – Revision 0**

Hypertherm
powermax45

*Quick Setup Card*
*Fiche de préparation rapide*
*Tarjeta de establecimiento rápido*

**Warning: Read the Operator Manual thoroughly.**

**Follow the safety instructions.**

**Do not connect the power until indicated in Step 4.**

The Operator Manual contains detailed information about your machine's features and important warnings about operation and maintenance safety.

This card gives you a brief overview of your system's setup requirements. It does not contain all the information needed to operate your machine safely and it is not a substitute for the Operator Manual.

**Avertissement : Lire entièrement le manuel de l'opérateur.**

**Suivre les instructions relatives à la sécurité.**

**Ne pas brancher tant que cela n'est pas indiqué à l'étape 4.**

Le manuel de l'opérateur contient des renseignements détaillés sur les fonctions de votre système et des avertissements importants relatifs à la sécurité du fonctionnement et de l'entretien.

Cette fiche donne une vue globale brève des exigences d'installation de votre système. Elle ne contient pas tous les renseignements nécessaires pour faire fonctionner votre machine en toute sécurité et elle ne remplace pas le manuel de l'opérateur.

**Advertencia: Lea el Manual del Operario completamente.**

**Siga las instrucciones de seguridad.**

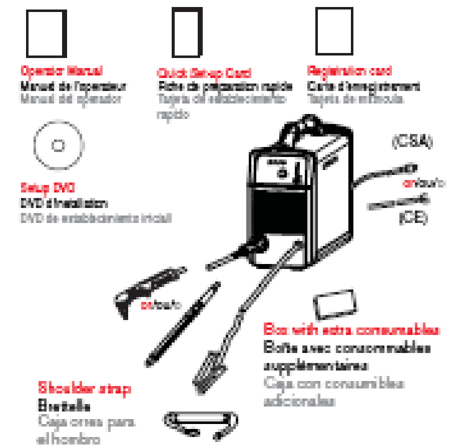
**No conecte a la potencia primaria hasta lo indicado en el paso 4.**

El Manual del Operario contiene información detallada acerca de las características de su sistema y advertencias importantes acerca de la seguridad de operación y mantenimiento.

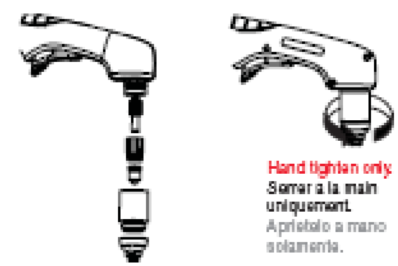
Esta tarjeta da una visión total breve de los requisitos de establecimiento inicial de su sistema. No contiene toda la información necesaria para operar su máquina con seguridad y no es un substituto para el Manual del Operario.



## 1 Check the contents
***Vérifier le contenu***
***Verifique el contenido***




## 2 Check the consumables
***Vérifier des consommables***
***Verifique los consumibles***




## 3 Connect the torch lead
***Connecter le faisceau de la torche***
***Conecte el cable de la antorcha***

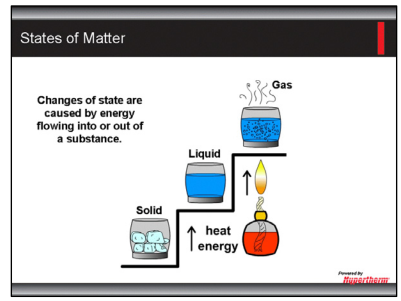
## What is Plasma?

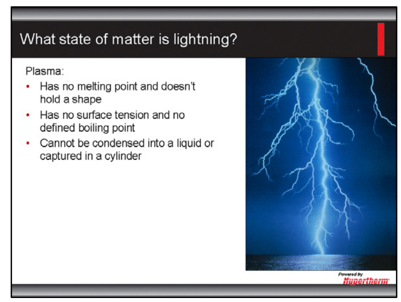
*Purpose:* *Overview of plasma from a scientific perspective to provide foundational knowledge necessary for upcoming lessons.*

*Time:* *10 minutes, including worksheet and discussion.*

**Slide 8: Plasma is a State of Matter**

- Engineers use the term "state" to describe the physical form of a substance. Familiar examples of "states" are solid, liquid, or gas. Under the proper conditions, every element or chemical compound is capable of existing in these three standard states.
- When a substance changes state, the chemical make-up of the substance doesn't change, only its physical form changes.
- Changes in state are always caused by energy flowing into or out of a substance. Adding heat energy to a substance can increase its temperature and eventually cause it to change state.
- When heat energy is added to ice, the temperature increases, and it changes from a solid (ice) to a liquid (water). Add even more heat energy, and eventually the liquid will become a gas (steam).
- For most substances, lower energy states (solids) tend to be more dense and rigid than higher energy states (gases).

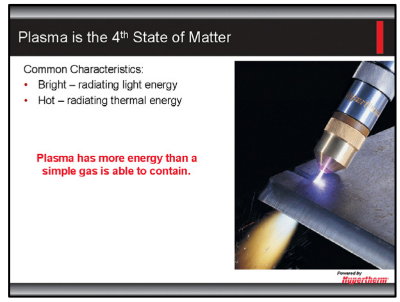



**Slide 9: What state of matter is lightning?**

- Display the photo of lightning and ask students, what state does lightning fit into? *The correct answer is "none of the above;" lightning is a form of plasma.*
- Discuss the students' responses in the context of the characteristics listed below:
  - Plasma can't be solid because it has no melting point and doesn't hold a shape.
  - Plasma can't be liquid because it has no surface tension and no defined boiling point.
  - This only leaves gas, but unlike other gases, one cannot condense lightning or flame into a liquid or capture a sample of pure flame or lightning in a cylinder.

**Slide 10: Plasma is the $4^{th}$ State of Matter**




- The common characteristics of lightning and other plasmas are that they are bright (radiating light energy) and they are generally hot (radiating thermal energy).
- Plasma has more energy than a gas is able to contain – the molecules in plasma are breaking down; they are excited to a point beyond being a gas.
- This is why plasma is called the "$4^{th}$ State of Matter."

## Plasma Worksheet

*Facilitator Notes: This worksheet challenges students to identify instances of plasma in the world around them using the characteristics just discussed.*

*Review the following points:*

- *Plasma is a substance that has more energy in it than can be contained in a simple gas.*
- *Key characteristics of plasma include brightness and high heat when at normal atmospheric pressure.*

*Then, distribute the handouts to students and ask them to take a few minutes to complete them. Give them 3 to 5 minutes to complete the activity, and then lead a discussion reviewing the correct answers.*

*The student handout with answers indicated is provided on the following page. The correct answers and teaching points are provided below.*

**Substances that ARE Plasma:**

| | |
|---|---|
| Stars | A star is a ball of plasma held together by its own gravity. |
| Auroras | Also known as the "Northern Lights" or the "Southern Lights," auroras are light displays in the sky; they originate when solar wind (which is a stream of charged particles from the Sun) interacts with the magnetic field surrounding the Earth and impacts gas molecules high in the atmosphere. |
| Lightning | A spark occurs when the number of free electrons and ions in the air rises rapidly, causing the air to become an electrical conductor; lightning is the best example of a natural spark. Discharges of **static electricity** are another naturally occurring spark. |
| Neon Lights | A neon light consists of an electric current being conducted through a tube of neon gas. The excited gas glows orange-red. |
| Fluorescent Bulbs | Bulbs with an electrical current that flows from the ballast through the gas, causing it to emit ultraviolet light, which then excites a phosphor coating on the inside of the tube. The coating emits visible light. |
| Plasma Televisions | Two plates of glass have thousands of noble gas cells sandwiched between them. Embedded electrodes can cause gas in individual cells to ionize, forming plasma. UV light emitted by the small plasma cell excites a phosphor coating, which then glows in a controlled combination of reds, greens, and blues to produce a television picture. |

**Substances that ARE NOT Plasma:**

| | |
|---|---|
| Steam | Steam is a gas produced by heating water. |
| Electric Stove | Electric stoves use an electric heating element that creates heat through a resistance coil. |

| | |
|---|---|
| LEDs | LEDs, or light emitting diodes, produce *light* through electroluminescence; when current flows through the device, energy is released in the form of visible light. |
| Standard Light Bulbs | An incandescent light bulb creates light by passing current through a thin element, heating it until it produces visible light. |
| Aerosol Sprays | Aerosol spray occurs when a pressurized liquid is released into the atmosphere, where the lower pressure allows the liquid to vaporize into tiny suspended particles. |
| Smoke | Smoke is a vapor coming from the products of combustion, containing small particles of liquids and solids. |

# Plasma Worksheet

**Circle the real world substances that contain plasma.**

| | |
|---|---|
| Stars | Element on Electric Stove |
| Plasma Televisions | Aerosol Sprays |
| LEDs | Lightning |
| Steam | Fluorescent Bulbs |
| Smoke | Neon Lights |
| Auroras | Standard Light Bulbs |

Student Copy

Name: ______________________

Date: ______________________

# Plasma Worksheet

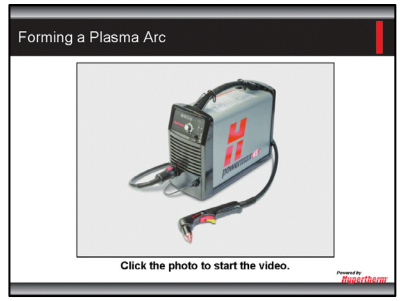
**Circle the real world substances that contain plasma.**

| | |
|---|---|
| Stars | Element on Electric Stove |
| Plasma Televisions | Aerosol Sprays |
| LEDs | Lightning |
| Steam | Fluorescent Bulbs |
| Smoke | Neon Lights |
| Auroras | Standard Light Bulbs |

## How is Plasma Created in a Plasma System?

*Purpose: Illustrate how plasma arc is formed in a plasma system*

*Time: 10 minutes*




*Facilitator Notes: Distribute a set of parts to each table, including a torch body and consumables. Students can look at the parts as this portion of the class is discussed.*

*Note that this section of the PowerPoint deck links to an animation which illustrates how the plasma arc is created. You may pause the animation to explain each step in the process. Use the animation control bars to pace the presentation. The narration script for the animation is provided below.*

**Slide 11: Forming a Plasma Arc (animation)**

Handheld plasma torches receive gas and current flow from the power supply. They also hold consumable parts like the ones shown here, which help shape and maintain the plasma arc. At rest, the electrode and nozzle are in contact. Gas “blows back” the electrode, creating a separation in the current path. Electrons flow from the electrode and collide with neutral gas molecules. Each collision frees more electrons and creates positively charged gas molecules (ions). A cascading column of collisions is created; this column radiates thermal (or heat) energy and light energy (brightness) – this is plasma. The swirling gas inside the torch positions the arc precisely in the center of the electrode and pushes it out of the nozzle, where it can be used to cut or gouge metal.

A plasma arc cutter consists of a power supply and a torch. The power supply is very similar to a battery: it can provide a DC electrical current. The ‘carriers’ of this electrical current are called electrons, and electrons carry a negative charge. The electrons will flow from the negative terminal, around the circuit, and back to the positive terminal, forming a circuit.

There are two “consumable” parts connected into the circuit; they are called the electrode and the nozzle. “Consumable” simply means that they are slowly damaged by contact with the arc and by the heat of the plasma arc; they eventually wear out and need to be replaced. Other consumable parts on a torch include the swirl ring, the retaining cap, and the shield. The consumable parts control the size and shape of the plasma arc, and they can be optimized for specific applications or to emphasize a particular attribute like cut speed or cut quality. Some consumable sets are intended for cutting thin metal as artwork. These consumables are used with minimal standoff and cut a very narrow kerf. Other consumables are intended for making fast cuts in thicker material or gouging; these sets create a larger, wider arc.

In a plasma arc cutter, the torch is connected into the circuit with the electrode at the negative terminal and the nozzle at the positive terminal. When the electrode and the nozzle are conductive and are touching each other current flows through them unimpeded; we need to create a gap in that circuit in order to make an electric arc. The power supply of a plasma arc cutter provides process gas (usually compressed air for handheld systems) to the torch. One way of creating an electric arc involves using the pressure of the process gas to separate the electrode and the nozzle from each other. Starting a plasma arc cutting torch by separating a shorted electrode and nozzle to form an arc is called “contact starting,” because the electrode and nozzle started in contact with each other.

When the electrode and nozzle separate while already conducting current, the electrode emits a stream of electrons from its hafnium tip. As the electrons accelerate across the gap, they contact neutral gas molecules with enough force to strip more electrons free. Then the free electrons are re-accelerated toward the nozzle by the electric field and the positive ions are accelerated toward the electrode, making even more collisions possible. These collisions create more and more positive ions and free negative ions.

A cascading column of collisions forms; it radiates thermal energy and light energy – this is plasma – resulting in the formation of a spark. This spark is similar to the spark that is created by pulling the toaster plug from the wall when the toaster is running. The difference is that the spark from the toaster plug is momentary, but the plasma arc power supply is designed to feed power to the spark, instantaneously enlarging the spark into an arc. The arc that forms between the electrode and the nozzle is called the "pilot arc." Gas from the power supply is used to force the pilot arc out of the nozzle orifice.

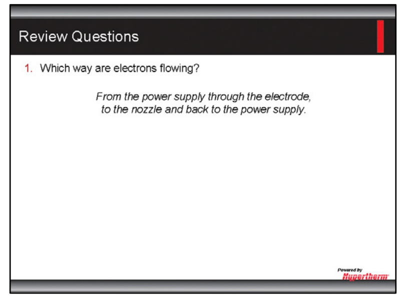
Once the pilot arc has been established, the workpiece needs to be brought into the circuit. The important step is converting the pilot arc (between the electrode and nozzle) into a "transferred arc" between the electrode and the workpiece. As the torch approaches the workpiece and the pilot arc contacts the plate, the nozzle and workpiece start to share the plasma current. The power supply forces all the current to go through the workpiece. The power supply increases the current to the cutting level and metal cutting begins.

## Slides 12 - 16: Review and Discussion

*Facilitator Notes: Review the arc creation process with students by displaying stills from within the animation (in the next several slides) and then ask students to answer several questions.*

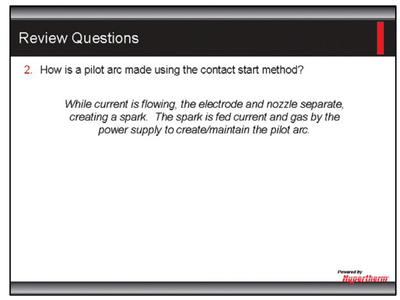
### Slide 12: Which way are electrons flowing?

*From the power supply through the electrode, to the nozzle and back to the power supply.*



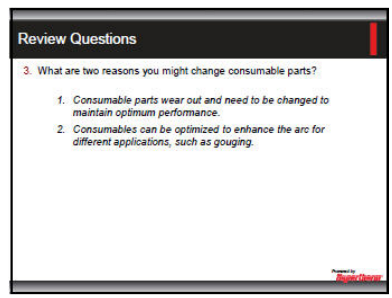

### Slide 13: How is a pilot arc made using the contact start method?

*While current is flowing, the electrode and nozzle separate, creating a spark. The spark is fed current and gas by the power supply to create/maintain the pilot arc.*



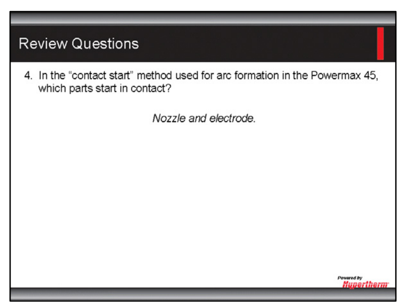

### Slide 14: What are two reasons you might change consumable parts?

1. *Consumable parts wear out and need to be changed to maintain optimum performance.*
2. *Consumables can be optimized to enhance the arc for different applications, such as gouging.*



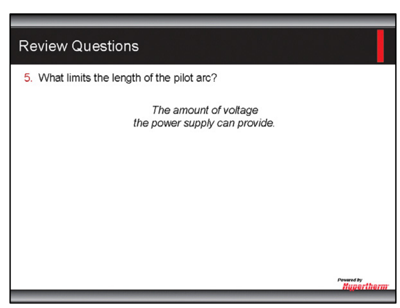

### Slide 15: In the "contact start" method used for arc formation in Powermax systems, which parts start in contact?

*Nozzle and electrode.*




### Slide 16: What limits the length of the pilot arc?

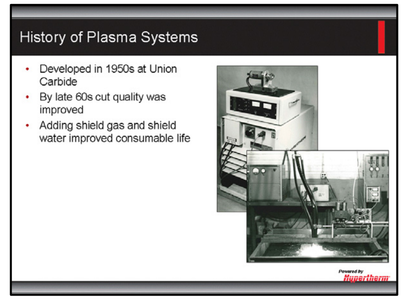
*The amount of voltage the power supply can provide.*



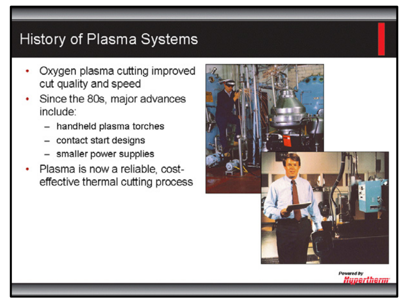
## History of Plasma Systems

*Purpose:* *Provide an overview of history of plasma cutting.*

*Time:* *5 minutes*




*Facilitator Notes: Use the write-up below to learn more about the history of plasma, and then use the PowerPoint slides to cover the key concepts. Although you may choose to review this information quickly, it is important for students to understand the origin of the technology.*




**Slides 17 and 18: History of Plasma Systems**

Plasma cutting was developed in the mid 1950s by a Union Carbide development engineer named Bob Gage. Union Carbide had developed a helium TIG welding torch called Heliarc for welding stainless steel and exotic alloys. Gage constricted the welding arc with a nozzle and increased the gas flow. By doing this, he created enough gas momentum and heat from the arc to cut through material. Gage got a patent for plasma arc cutting in 1957. Originally, plasma was used to cut stainless steel, which cannot be cut with oxyfuel. Stainless steel is a very small subset of the total steel production in the world; the vast majority is carbon steel and alloy steels. The cut quality and the reliability of the first plasma systems were poor, and in the late 50s and early 60s they met a very specific need for a relatively small market. Most customers would only purchase a plasma cutting system out of necessity.

By the late 60s, there were several companies researching plasma cutting. Stainless steel wasn't the only cutting possibility for plasma; it also offered a significant cut speed advantage over oxyfuel on carbon steel. Cut quality on carbon steel was not good, but if plasma ever became a viable option for cutting carbon steel the market for plasma would multiply quickly. Researchers needed to provide an answer to this question: why would someone buy plasma instead of oxyfuel to cut carbon steel? The solution was to focus research on improving cut quality.

One advance led to another. Addition of a shield gas improved the life of consumable parts. Switching that shield gas to shield water made consumable life still better. The use of water paved the way for water injection plasma cutting – swirling the shield water improved cut speed, cut quality, and consumable life. Though there were still significant challenges with dross formation, it appeared that plasma would be an alternative to oxyfuel for cutting carbon steel as well.

The next challenge was to make *consistently* high quality cuts with plasma. Even into the 70s plasma systems were expensive, unreliable, and specialized for cutting stainless steel. Consumable parts lasting more than 100 starts were rare. Operators were never certain what would happen when they pushed the start button. Differences in metal composition greatly affected cut quality. Plasma system manufacturers needed to find a cutting method that worked well on all varieties of carbon steel.

The solution was oxygen plasma cutting, which uses oxygen to create an additional chemical reaction with carbon steel. Cut quality improved, and operators were able to produce cuts with little or no dross. There was a tradeoff, however; oxygen made a hotter arc, which used up consumables very quickly. Customers liked the faster cut speeds and improved cut quality, but were frustrated with the loss of production time caused by constantly changing consumables. In 1983, that problem was addressed by water injection, which cooled the nozzle and made the consumables last longer.

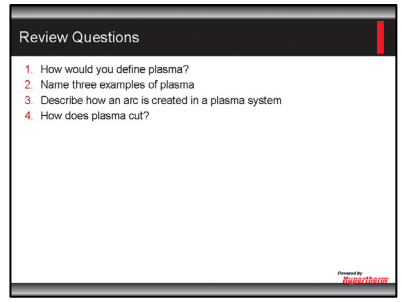
Since the 80s, there have been major advances in plasma cutting technology. Handheld plasma torches that used air as the plasma gas made plasma available to shops that did not have access to bottled gases. Shortly thereafter, the start mechanism for handheld plasma systems was redesigned, removing the need for high frequency starting. The new contact start design allowed for smaller parts. Reducing the size and number of parts in the power supplies made a huge difference in weight. By comparison, a handheld power supply in 1985 weighed nearly 400 pounds; today, there are handheld systems that only weigh 20 pounds!

25 years ago, some people thought there would be no more major improvements to the plasma cutting process. Now, over 50 years after its initial development, we know that plasma manufacturers are not close to exhausting the capability of plasma. While there has not been a significant technological development in the field of oxyfuel cutting in many years, plasma cutting continues to expand. The last 10 years alone have seen rapid advances in cut quality, consumable life, and versatility. Plasma is now a reliable, cost effective thermal cutting process. Current research is expected to further improve the capability of plasma.

## Wrap-Up

*Purpose:* *Lesson recap and review*

*Time:* *5 minutes*




*Facilitator Notes: There is a homework sheet provided on the following page that will challenge students to practice what they have learned. A homework answer key and review discussion is built into the beginning of the next lesson.*

**Slide 19: Wrap-Up and Review Question Overview**

This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Instructor Copy

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
## Homework #1: What is Plasma?

1. How would you define plasma?

   Good answers include: "the 4th state of matter" or "a substance with more energy than a simple gas can contain."

2. Name three examples of plasma.

   Possible answers include: stars, auroras, static electricity, lightning, neon lights, fluorescent bulbs, and plasma televisions

3. Describe how an arc is created in a plasma system.

   Under current, the electrode emits a stream of electrons from its hafnium tip, making it possible for the current to flow across the gap between the electrode and the nozzle. As the electrons accelerate across the gap, they contact neutral gas molecules with enough force to strip more electrons free. Then the free electrons are re-accelerated toward the nozzle by the electric field, making even more collisions possible. These collisions create more and more positive ions and free negative ions. A cascade is created, resulting in a plasma arc.

4. How does plasma cut?

   The heat from the plasma arc can reach more than 20,000° C, which melts the metal workpiece. The high velocity gas flow removes the molten material from the bottom of the cut kerf.

Student Copy

Name: ______________________

Date: ______________________

# Plasma Cutting Technology: Theory and Practice
## Homework #1: What is Plasma?

1. How would you define plasma?

______________________

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2. Name three examples of plasma.

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3. Describe how an arc is created in a plasma system.

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4. How does plasma cut?

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# Session 2: Using Plasma Systems in Industry

This session provides information on the use of plasma systems in industry, including an overview of typical applications, the types of plasma systems available (with a pros and cons discussion of each), a discussion of how cost/benefit can be calculated and a case study activity.

The recommended timing for this session is as follows:

| **Topic** | **Estimated Time** |
|---|---|
| Introduction/Review | 5 minutes |
| Suitable Applications for Plasma Cutting | 10 minutes |
| Mechanized Cutting Comparisons | 10 minutes |
| Cost/Benefit Analysis (including discussion and case study activity) | 25 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

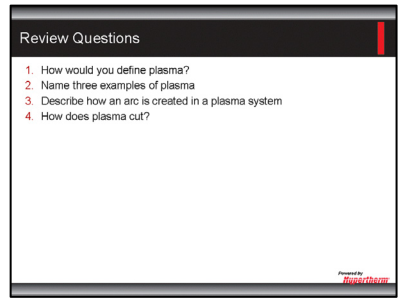
1. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
2. Make a copy of the "Pros and Cons" activity sheet for every student in the class.
3. Make a copy of the "Calculating Labor Costs" activity sheets. Note that there are two activity sheets – half of your students will complete one sheet and the other half will complete the second sheet.
4. Make a copy of the homework sheet for every student in the class.

## Introduction

*Purpose:* *Review and reinforce previous lesson content.*

*Time:* *5 minutes*


The homework questions from Session 1, along with the correct answers, are provided below:




1. How would you define plasma?

   *Good answers include: "the 4th state of matter" or "a substance with more energy than a simple gas can contain."*

2. Name three examples of plasma?

   *Possible answers include: stars, auroras, static electricity, lightning, neon lights, fluorescent bulbs, and plasma televisions.*

3. How is an arc created in a plasma system?

   *Under current, the electrode emits a stream of electrons from its hafnium tip, making it possible for the current to flow across the gap between the electrode and the nozzle. As the electrons accelerate across the gap, they contact neutral gas molecules with enough force to strip more electrons free. Then the free electrons are re-accelerated toward the nozzle by the electric field, making even more collisions possible. These collisions create more and more positive ions and free negative ions. A cascade is created, resulting in a plasma arc.*

4. How does plasma cut?

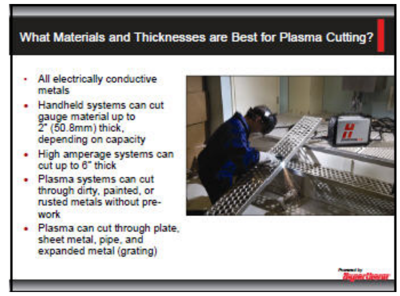
   *The heat from the plasma arc can reach more than 20,000° C, which melts the metal workpiece. The high velocity gas flow removes the molten material from the bottom of the cut kerf.*

## Suitable Applications for Plasma Cutting

*Purpose: Present an overview of applications and industries in which plasma systems are used.*

*Time: 10 minutes*

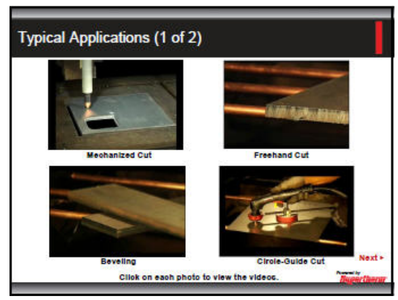
**Slide 2: What Materials and Thicknesses are Best for Plasma Cutting?**

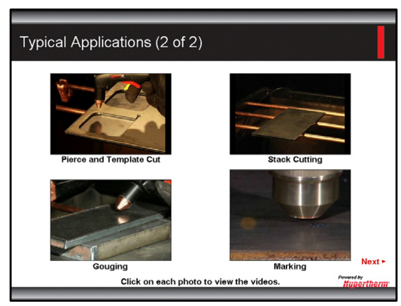



- All electrically conductive metals – most frequently carbon steel, stainless steel, and aluminum.
- Handheld plasma systems can cut gauge material up to 2" (50 mm) thick, depending upon capacity.
- High amperage mechanized plasma systems are capable of cutting materials over 6" (15 cm) thick.

Plasma can cut through dirty, painted, or rusted metals without "pre-work" – preparation of the workpiece (the material being cut) before any cuts are made. Other cutting methods often involve prework, but with plasma all you need is good contact for grounding. Typical material forms cut with plasma include:

- Plate
- Sheet metal
- Pipe
- Expanded metal (grating)




**Slides 3 and 4: Typical Applications**

*These slides show videos of different types of cutting. Click on each photo to play the video; descriptions of each cut type are provided below.*

- Cutting – typical cutting through a conductive workpiece with a hand held or machine (automated) torch:
  - Stack cutting – cutting through several pieces of plate stacked on top of one another.
  - Template cutting – cutting a workpiece using a shape or template as a guide.
  - Beveling – a cutting technique that produces an angle on the edge of the material being cut (such as for joining pieces of pipe).
- Piercing – starting a cut by plunging the arc into and through the workpiece (as compared to starting a cut at the edge of the work piece).
- Gouging – removing metal from the surface of the work piece without severing the piece in two (such as for weld preparation or removing an old weld).
- Marking – a low amperage process typically used to "write" part numbers or words on a part by removing a thin layer of the workpiece.

### Slide 5: Typical Industries Where ***Handheld*** Plasma Systems are Used

*Facilitator Notes: Ask students for examples of industries and applications where a handheld plasma system could be used.*


Some common uses for manual plasma systems include:

- General fabrication (pressure vessels, etc.) and manufacturing – food processing equipment, highway equipment, sign manufacturing, tank fabrication, and so on.
- Facility and equipment maintenance – railway maintenance, sawmill maintenance, for example.
- Structural steel building construction – wall and ceiling framing, floor and roof truss fabrication, roofing, siding, and decking installation.
- Shipbuilding.
- Container fabrication and repair.
- Energy – oil and gas, offshore rigs, pipelines.
- Vehicle repair and restoration – body and floor panel replacement, exhaust repair, frame repair, bracket removal.
- HVAC / mechanical contractors– duct fabrication and alteration, suspension bracket fabrication.
- Agricultural equipment repair – remove rusted panels, bevel cuts, gouging out of old welds for replacements, expanded metal fabrication.
- Ornamental metal fabrication – free-form cutting, piercing and gouging, working with aluminum, ornamental fabrication.


### Slide 6: Typical Industries Where ***Mechanized*** Plasma Systems are Used

*Facilitator Notes: Remind students that mechanized systems are capable of cutting a wider range of thicknesses because they range in amperage from less than 45A to over 400A. Mechanized plasma is ideal for jobs requiring high levels of precision and repeatability. Most of these systems are used with a CNC-controlled XY table, track cutter, or robot to gain greater precision and efficiency.*

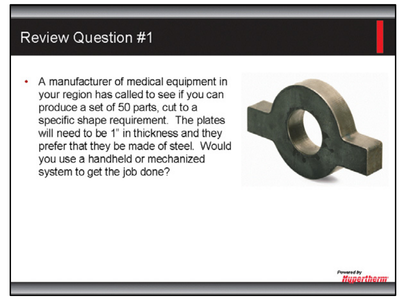
Ask students for examples of applications where a mechanized plasma system could be used. Some common uses for mechanized plasma systems include:

- Steel Service Centers
- Job Shops (Fabrication Shops)
- Industrial Manufacturers – heavy equipment for farming, agriculture, construction
- Transportation – trailer bodies, railway cars
- Vehicle Fabricators –panels, chassis parts

- Shipbuilder – thick panels, brackets
- Mining
- Energy (Windmills)
- Defense – nuclear, subs

**Slides 7 - 9: Review and Discussion**

*Facilitator Notes: The following slides contain three different business scenarios. Present each scenario and ask the student to assess the job requirements received by different customers, and then decide whether to use a handheld or mechanized plasma system to get the job done. For each question, ask a student to explain to you (the "boss") why they made their selection. Correct answers are shown below.*

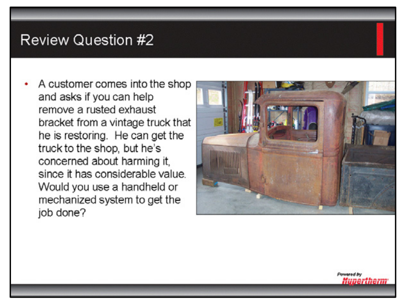



**Slide 7: Review Question #1**

A manufacturer of medical equipment in your region has called to see if you can produce a set of 50 parts, cut to a specific shape requirement. The plates need to be 1" (25 mm) carbon steel. How would you do it?

*Correct answer:*

*Use a mechanized system, because of the precision and repeatability required.*

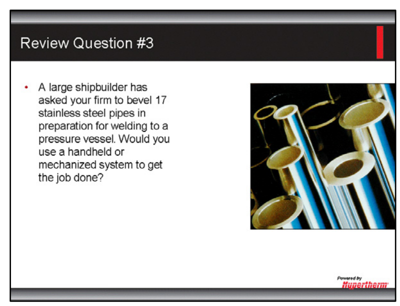



**Slide 8: Review Question #2**

A customer comes into the shop and asks if you can help remove a rusted exhaust bracket from a vintage truck that he is restoring. He can get the truck to the shop, but he's concerned about harming it, since it has considerable value. How would you do it?

*Correct answer:*

*Use a handheld system, because the truck can't be mounted in a mechanized system.*




**Slide 9: Review Question #3**

A large shipbuilder has asked your firm to bevel 17 stainless steel pipes in preparation for welding to a pressure vessel. How would you do it?

*Correct answer:*

*Use a mechanized system, because of the greater precision and repeatability required.*

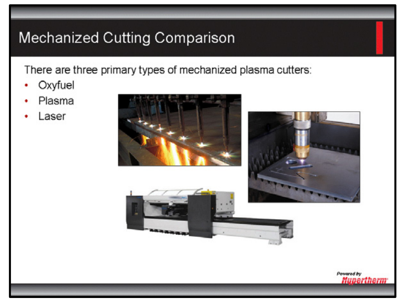
## Mechanized Cutting Comparison

*Purpose: Compare oxyfuel, plasma, and laser cutting systems.*

*Time: 10 minutes*

*Say to Class: There are many different cutting options to choose from, including plasma, oxyfuel, laser, water jets, shears, and saws. For high rate, large volume production of shaped parts, the three most common cutting methods are plasma, oxyfuel, and laser.*

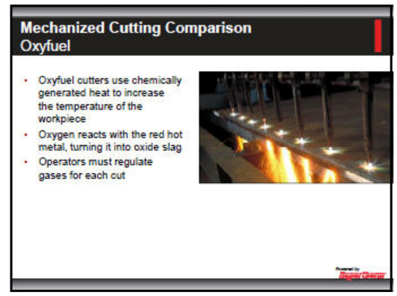
*It is important to note that not all systems are equal – especially when considering laser and plasma. There is a huge variety in cut capacity and speed from one manufacturer to another. The comparisons made in this lesson are general, used to explain the basic pros and cons or each system, and are not tied to specific manufacturers or numbers.*




**Slide 10: Mechanized Cutting Comparison**

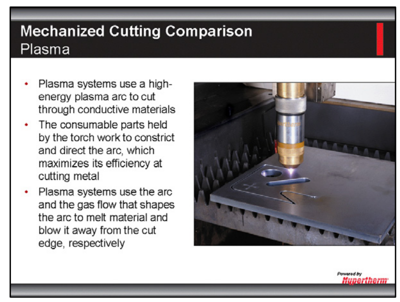
There are three primary types of mechanized plasma cutters:

- Oxyfuel
- Plasma
- Laser




**Slide 11: Oxyfuel**

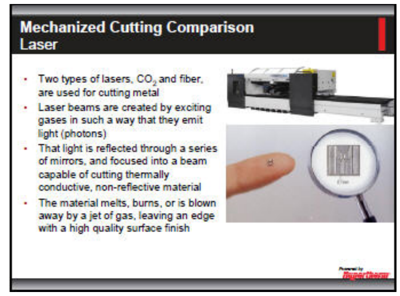
- Oxyfuel cutters use chemically generated heat to increase the temperature of the workpiece.
- Oxygen reactss with the red hot metal, turning it into oxide slag.
- Operators must regulate gases for each cut.




**Slide 12: Plasma**

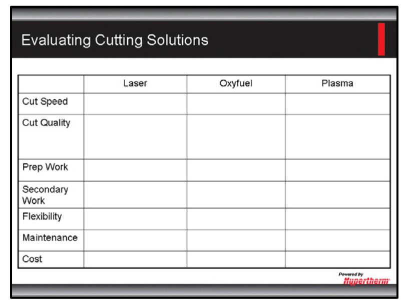
- Plasma systems use a high-energy plasma arc to cut through conductive materials.
- The consumable parts held by the torch work to constrict and direct the arc, which maximizes its efficiency at cutting metal.
- Plasma systems use the arc and the gas flow that shapes the arc to melt material and blow it away from the cut edge, respectively.

**Slide 13: Laser**



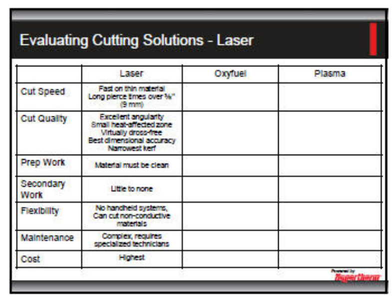

- Two types of lasers, $CO_2$ and fiber, are used to cut metal.
- Lasers transmit energy in the form of coherent photons. High intensity lasers transmit enough energy to cut non-reflective metal. Fiber laser can be used on some reflective metals as well.
- The material melts, burns, or vaporizes and is blown away by a jet of gas, leaving an edge with a high quality surface finish.
- The tightly-focused energy of a laser can produce very narrow kerf widths, especially on thin material.

**Slide 14: Evaluating Cutting Solutions**




*Facilitator Notes: The comparison chart within the PowerPoint deck will build from one slide to the next. As you go, compare the different solutions with the class. The first slide shows only the criteria for evaluation, giving you time to discuss what each criteria means before going into the specifics of each system.*

When trying to decide what cutting solution to choose, look at several factors, including:



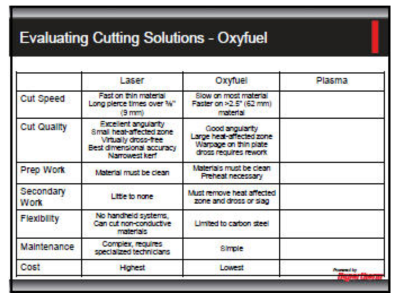

- Cut Speed – How fast is the actual cutting process?
- Cut Quality – How clean and square is the finished cut? How much dross remains following the cut? Is any secondary grinding required?
- Prep Work – How much cleaning and pre-work is needed before a material can be cut?
- Secondary Work – What is required after the cut is made and how much time does that take?
- Flexibility – Can the cutter accommodate different types of materials, types of cuts, and different material thicknesses?
- Maintenance – How hard is it to maintain/repair the system and can operators do it in-house?
- Cost – How much do the cutter and consumable parts cost?

**Slide 15: Evaluating Cutting Solutions – Laser**

- Cut Speed: Very fast on thin material and slower on thicker materials; long pierce times material over ⅜" (9 mm).
- Cut Quality: Excellent angularity, small heat-affected zone, virtually dross-free, and excellent dimensional accuracy with the narrowest kerf.
- Prep Work: Material has to be clean for the laser to work.

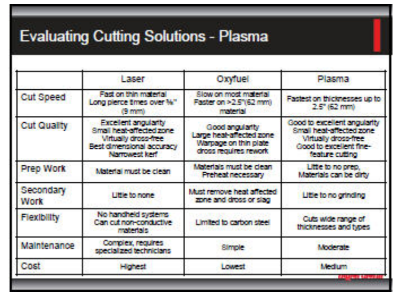
- Secondary Work:  Little to none.
- Flexibility:  Pro: Laser is best at cutting thin carbon steel. Laser can do “common line cutting” – that is, it can produce final cuts in both directions with a single cut. This reduces/eliminates “skeletons”, which are the parts of metal sheets which are thrown away after parts are cut from them. Con: there are no hand-held laser systems, so the workpiece must lie on a table to be cut. Fiber laser can cut other metals. Cutting reflective material (aluminum) with $CO_2$ laser requires pre-work to cover the material surface.
- Maintenance:  Complex maintenance tasks require specialized technicians.
- Cost:  Laser has the highest initial cost of the three – there are laser systems that cost over $1M.

**Slide 16: Evaluating Cutting Solutions – Oxyfuel**




- Cut Speed:  Slow cutting speeds across a wide range of thicknesses (faster than other systems on carbon steel over 2.5" or 62 mm);  the pre-heat time increases pierce times significantly, decreasing overall cutting speed.
- Cut Quality:  Good angularity, large heat-affected zone, warpage on thin plate, dross levels require rework.
- Prep Work:  Oxyfuel cutters have to preheat the work piece prior to cutting. The cut area must be free of rust/dirt/paint before cutting. Operator must regulate gas flow for each torch, and oxyfuel tables often run multiple torches to compensate for slower cut speeds.
- Secondary Work:  Operators may have to grind off the heat affected zone, which is larger than with other systems; this process can be time-consuming and difficult.
- Flexibility:  Oxyfuel is limited to carbon steel and is not effective on stainless steel or aluminum.
- Maintenance: Simple maintenance requirements can often be performed by in-house maintenance groups.
- Cost:  Oxyfuel has the lowest initial cost of the three.

**Slide 17: Evaluating Cutting Solutions – Plasma**

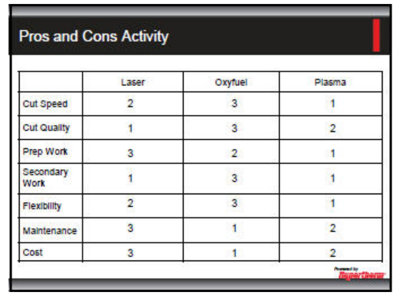



- Cut Speed:  Fastest on a wide range of thicknesses, up to 2.5" (62 mm).
- Cut Quality: Good to excellent angularity, small heat-affected zone, virtually dross-free, and good to excellent fine-feature cutting.
- Prep Work: Little to no prep required. Tolerant of paint/dirt/rust/oil on the work piece.
- Secondary Work: Little to no grinding; typically less than oxyfuel.
- Flexibility:  Cuts a wide range of material thicknesses and types.
- Maintenance:  Moderate maintenance requirements; many components are serviceable by in-house maintenance groups.
- Cost:  Initial cost is typically between oxyfuel and laser, ranging from less than $2,000 up to $55,000.

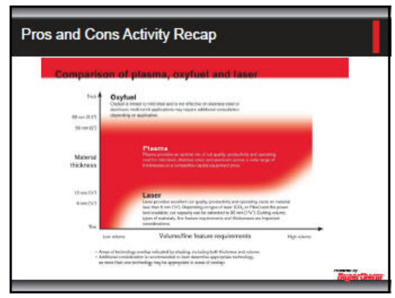
## Pros and Cons Activity

**Slide 18: Pros and Cons Activity**

*Facilitator Notes: Display the blank chart, which matches the blank chart in the student's handbook (as shown on the next page). Ask students to pair up and then fill in the chart by placing a "1" to show the best, "2" to indicate medium, and "3" to indicate the worst for each block. When completed, the chart should look like this.*




| | Laser | Oxyfuel | Plasma |
|---|---|---|---|
| Cut Speed: | 2 | 3 | 1 |
| Cut Quality: | 1 | 3 | 2 |
| Prep Work: | 3 | 2 | 1 |
| Secondary Work: | 1 | 3 | 1 |
| Flexibility: | 2 | 3 | 1 |
| Maintenance: | 3 | 1 | 2 |
| Initial Cost: | 3 | 1 | 2 |




*Discuss the chart with the class, revealing the correct answers on the PPT screen. When necessary, review the previous discussion to make sure that students understand and can recall the pros and cons of various cutting methods.*

*Note that if students have different answers than those provided here, there may be justification for them. For example, cut speed is dependent upon material thickness, so a student may choose any of the three options as having the advantage at a given thickness. Use differences on this review sheet to continue the discussion.*

**Slide 19: Pros and Cons Activity Recap**

*This slide provides a recap of the pros and cons of each cutting method. Key points to discuss include:*

- Oxyfuel has a low initial cost, but is limited to carbon steel and is not effective on stainless steel or aluminum.
- Plasma provides optimal mix of cut quality, productivity, and operating cost, for carbon steel, stainless, and aluminum across a wide range of thicknesses at a competitive capital and equipment price.
- Laser provides excellent cut quality and productivity on thin material. Laser technology has high capital equipment, running, and maintenance costs, therefore a high level of business volume is required to pay back the cost of the equipment.

Student Copy

Name: ______________________

Date: ______________________

# Pros and Cons Activity

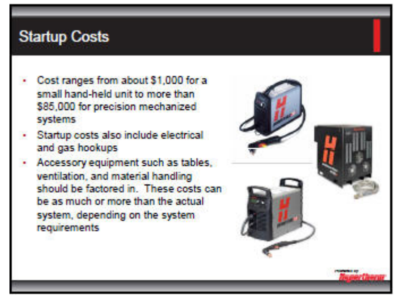
**Fill in the chart below by rating each cutting technology for each criteria with a 1, 2, or 3, where 1 is the best of the three, 2 is medium, and 3 is the worst.**

| | Plasma | Oxyfuel | Laser |
|---|---|---|---|
| **Cut Speed** | | | |
| **Cut Quality** | | | |
| **Prep Work** | | | |
| **Secondary Work** | | | |
| **Flexibility** | | | |
| **Maintenance** | | | |
| **Initial Cost** | | | |

## Cost/Benefit Analysis

*Purpose:* *Present an analysis of the costs and benefits of common cutting systems.*

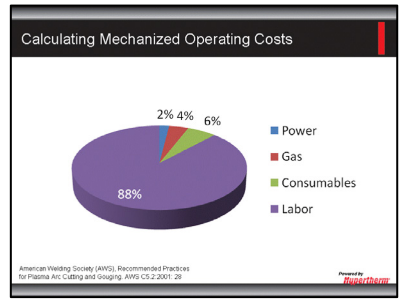
*Time:* *25 minutes*




**Slide 20: Startup Costs**

Review the startup costs associated with plasma systems:

- Plasma systems range in cost from about $1,000 for a small hand-held unit to more than $85,000 for precision mechanized systems.
- Startup costs also include electrical and gas hookups.
- In addition, accessory equipment such as tables, ventilation, and material handling should be factored in. These costs can be as much or more than the actual system, depending on the system requirements.




**Slide 21: Calculating Operating Costs**

The total cost to operate any type of cutting equipment (following the initial equipment cost) is comprised of four primary costs:

- Power to run the equipment (2%).
- Gas to produce the plasma (4%).
- Replacement parts, including torch consumables (6%).
- Labor required to operate and maintain the equipment, do required prep work, and complete any necessary secondary work (88%).


**Slide 22: Labor Cost**

Since we know that labor is by far the largest factor in calculating operating costs, ask students to list the features of plasma systems that they think help to reduce labor time required.

Possible answers include:

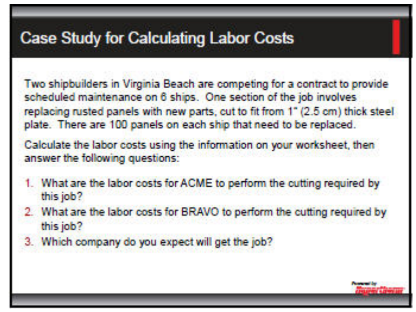
- Higher cut speeds reduce the actual cutting time.
- Prep work is minimal, since plasma can cut through painted, dirty, oily, and rusty material. Also no pre-heat required. Setup time is lower because there is no need to regulate gases – operator can use charts in the manual to set up the gas flow quickly.
- Secondary work is minimal. Little to no grinding is required following cuts because of the smaller heat-affected zones.
- Flexibility to cut through different metals and thicknesses; operators can use plasma systems for different applications.

## Case Study for Calculating Labor Costs

*Facilitator Notes: This activity challenges students to do the math required to compare labor costs for plasma versus oxyfuel. Hand out the worksheets and ask students to do the calculations required to answer the three questions at the bottom of the page. Note that you may need to support your students by walking through the calculations as a group.*

**Slide 23:**

Two shipbuilders in Virginia Beach are competing for a contract to provide scheduled maintenance on a large container ship. One section of the job involves removing rusted panels from the ship's hull and replacing them with new panels cut to fit from 1" (2.5 cm) thick steel plate. There are 100 panels on the ship that need to be replaced.




- ACME Incorporated uses a reliable oxyfuel cutter that they've had in the shop for years. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels............................................10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate .....25 minutes per panel

  Grind the replacement panels prior to welding.............10 minutes per panel

  Weld Replacement Panels............................................15 minutes per panel

- BRAVO Industries uses a plasma cutter. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels............................................10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate .......5 minutes per panel

  Weld Replacement Panels............................................15 minutes per panel

Calculate the labor costs required to perform this job and then answer the following questions:

1. What are the labor costs for ACME to perform the cutting required by this job? *[$10,000]*
2. What are the labor costs for BRAVO to perform the cutting required by this job? *[$5,000]*
3. Which company do you expect will get the job? *BRAVO Industries*

*Facilitator Note: This example shows how plasma's speed and cut quality advantages can translate into profitability, and it only considers 100 repair parts; large container ships are often constructed of over 20,000 steel parts!*

Student Copy

Name: ______________________

Date: ______________________

## Case Study for Calculating Labor Costs

Two shipbuilders in Virginia Beach are competing for a contract to provide scheduled maintenance on a large container ship. One section of the job involves removing rusted panels from the ship's hull and replacing them with new panels cut to fit from 1" (2.5 cm) thick steel plate. There are 100 panels on the ship that need to be replaced.

- ACME Incorporated uses a reliable oxyfuel cutter that they've had in the shop for years. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels..............................................10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate .....25 minutes per panel

  Grind the replacement panels prior to welding.............10 minutes per panel

  Weld Replacement Panels..............................................15 minutes per panel

- BRAVO Industries uses a plasma cutter. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels..............................................10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate .......5 minutes per panel

  Weld Replacement Panels..............................................15 minutes per panel

Calculate the labor costs required to perform this job and then answer the following questions:

1. What are the labor costs for ACME to perform the cutting required by this job?

2. What are the labor costs for BRAVO to perform the cutting required by this job?

3. Which company do you expect will get the job?

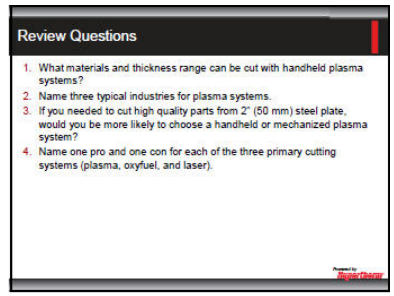
## Wrap-Up

*Purpose: Lesson recap and review*

*Time: 5 minutes*

*Facilitator Notes: There is a homework sheet provided on the following page that will challenge students to practice what they have learned. A homework answer key and review discussion is built into the beginning of the next lesson.*

**Slide 23: Wrap-Up and Review Question Overview**




This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Instructor Copy

Name: ______________________

Date: ______________________

# Plasma Cutting Technology: Theory and Practice
# Homework #2: Using Plasma Systems in Industry

1. What materials and thickness range can be cut with handheld plasma systems?

   Cutting metal and other conductive materials between ¼" (6 mm) and 1¼" (32 mm) in thickness.

2. Name three typical industries for plasma systems.

   Possible answers include: general fabrication, manufacturing, facility and equipment maintenance, agricultural equipment repair, car and truck repair, structural steel building construction, shipyard, container fabrication and repair, energy, HVAC/mechanical contractors, metal artwork

3. If you needed to cut high quality parts from 2" (50.8 mm) steel plate, would you be more likely to choose a handheld or mechanized plasma system?

   Mechanized – although some handheld systems are capable of cutting 2" (50 mm), "high quality" is the key phrase. Mechanized plasma offers higher cut quality and repeatability.

4. Name one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser).

   **Correct answers include the following (also refer to the complete lists from Session 2):**

| | |
|---|---|
| Plasma Pros: | Cuts any conductive material, cut speed and quality advantage on a wide range of thicknesses, little to no prep and secondary work, ease of use |
| Plasma Cons: | Initial cost higher than oxyfuel, cut quality less than laser, moderate maintenance requirements |
| Oxyfuel Pros: | Low initial cost, cut speed advantage at larger thicknesses, low maintenance costs, fewest parts |
| Oxyfuel Cons: | Only cuts ferrous metals, slow cut speed on thin material, poor cut quality, greater prep and secondary work, considerable skill required, flammable gas |
| Laser Pros: | Best cut quality and speed advantage on thin materials |
| Laser Cons: | High initial cost, no manual cutting, greater prep work, expensive maintenance |

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
# Homework #2: Using Plasma Systems in Industry

1. What materials and thickness range can be cut with handheld plasma systems?

2. Name three typical industries for plasma systems.

3. If you needed to cut high quality parts from 2" (50 mm) steel plate, would you be more likely to choose a handheld or mechanized plasma system?

4. Name one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser).

# Session 3: Overview of a Plasma System

During this session, you'll discuss the parts of the plasma system, plasma cutting variations, and how operators select the best consumable parts for a specific application.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| Parts of a Plasma System | 5 minutes |
| Plasma Cutting Torch Variations | 10 minutes |
| Consumable Sets (including consumable set build activity) | 20 minutes |
| Gas Considerations | 10 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
2. Print Operator Manuals and the appropriate language sections from the Safety and Compliance manuals for students to use to complete the class exercises.
3. Gather the consumable sets (consumables connected by a string) so that you can pass them among the students.
4. Make a copy of the "Building a Consumable Set" worksheet for every student in the class.
5. Make a copy of the homework sheet for every student in the class.

## Introduction

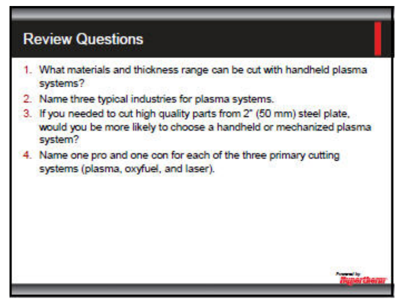
*Purpose:* *Review and reinforce previous lesson content.*

*Time:* *5 minutes*


The homework questions from Session 2, along with the correct answers, are provided below:

1. What materials and thickness range can be cut with handheld plasma systems?

   *Cutting metal and other conductive materials between ¼" (6 mm) and 1¼" (32 mm) in thickness.*




2. Name three typical industries for plasma systems.

   *Possible answers include: general fabrication, manufacturing, facility and equipment maintenance, agricultural equipment repair, car and truck repair, structural steel building construction, shipyard, container fabrication and repair, energy, HVAC/mechanical contractors, metal artwork*

3. If you needed to cut high quality parts from 2" (50 mm) steel plate, would you be more likely to choose a handheld or mechanized plasma system?

   *Mechanized – although some handheld systems are capable of cutting 2" (50 mm), "high quality" is the key phrase. Mechanized plasma offers higher cut quality and repeatability.*

4. Name one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser).

   *Correct answers include [refer instructor to complete lists from Session 2]:*

   *Plasma Pros:* *cuts any conductive material, cut speed and quality advantage on a wide range of thicknesses, little to no prep and secondary work, ease of use*

   *Plasma Cons:* *initial cost higher than oxyfuel, cut quality less than laser, moderate maintenance requirements*

   *Oxyfuel Pros:* *low initial cost, cut speed advantage at larger thicknesses, low maintenance costs, fewest parts*

   *Oxyfuel Cons:* *only cuts ferrous metals, slow cut speed on thin material, poor cut quality, greater prep and secondary work, considerable skill required, flammable gas*

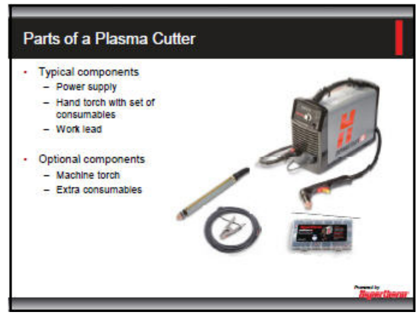
   *Laser Pros:* *best cut quality and speed advantage on thin materials*

   *Laser Cons:* *high initial cost, no manual cutting, greater prep work, expensive maintenance*

## Parts of a Plasma System

*Purpose: Review the parts of a plasma system.*

*Time: 5 minutes*




**Slide 2: Parts of a Plasma System**

A plasma system will typically have the following components:

- Power supply
- Hand torch with set of consumables
- Work lead

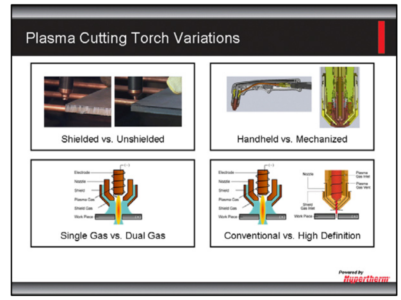
It may also have these optional components, depending upon the manufacturer:

- Machine torch
- Extra consumables

# Plasma Cutting Torch Variations

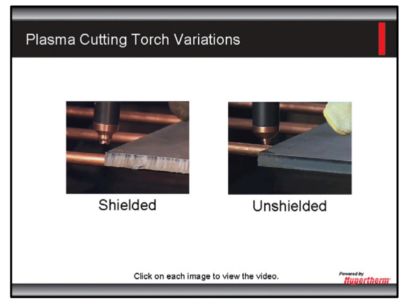
*Purpose:* *Discuss torch variations for different cutting applications.*

*Time:* *10 minutes*



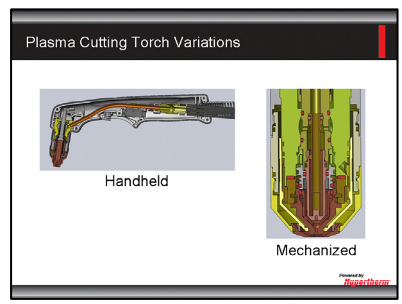

**Slide 3: Plasma Cutting Torch Variations**

- Shielded versus Unshielded
- Handheld versus Mechanized
- Single Gas versus Dual Gas
- Conventional versus High Definition




**Slide 4: Shielded versus Unshielded**

- The original plasma cutting consumable set-up was unshielded; gas flowed between the electrode and nozzle forming a plasma arc.
- The nozzle shaped the plasma to cut through metal.
- Standoff is required when using unshielded consumables. The operator holds the nozzle approximately 1/8" (3 mm) off the plate. If the torch touches the plate, the consumables can be damaged or ruined.

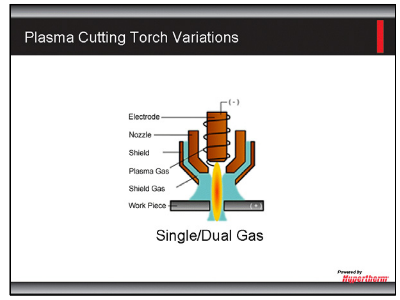



- Some operators use unshielded consumables because they allow greater arc visibility in tight spaces.
- The shield serves several purposes:
    - Drag-tip shields allow the torch to rest directly on the work by setting the proper standoff distance.
    - Protects the consumables by keeping the nozzle electrically neutral.
    - Provides some secondary arc restriction.

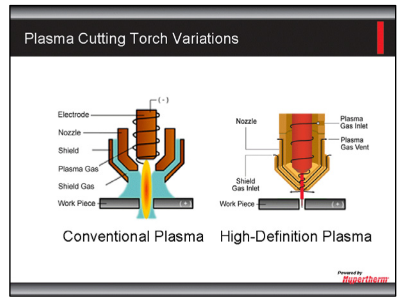
**Slide 5: Handheld versus Mechanized**

- Different starting mechanisms – handheld torches often have contact start designs, while mechanized torches may use either contact or high frequency starting.
- Hand torches are air cooled; mechanized torches may be water cooled.

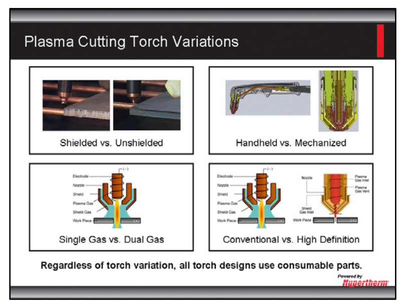
**Slide 6: Single Gas versus Dual Gas**




- Most single gas and dual gas torches have a shield protecting the nozzle as well as a secondary flow of gas around the nozzle; the secondary flow is called “shield gas.” The difference between single and dual gas designs is simple: if the plasma and shield gas are the same, it is single gas. If they differ, it is a dual gas.
- The selection of shield gas depends on the specific cutting application.
- Shield gas serves 3 purposes:
  - Cools the nozzle.
  - Keeps heat from radiating back up to the nozzle.
  - Helps remove molten material.




- In handheld systems, the plasma gas and shield gas usually flow from a single source; commonly, the gas will be compressed air or nitrogen. This is because:
  - Cut quality is less important than with mechanized systems.
  - Multiple gas cylinders and leads affect the portability of the system.




Many gas combinations are available, and are selected based on the equipment and the specific application; gas considerations are discussed in greater detail later in this session.

**Slide 7: Conventional Plasma vs. High Definition Plasma**

- Also called “Precision Plasma Cutting,” high definition is the state-of-the-art mechanized arc constriction method
- High definition provides extremely constricted plasma arcs that have increased energy density.
  - Energy density is achieved by high-flow vortex nozzles, high-velocity mixing chambers, magnetic fields, and other evolving technology.
  - High definition can be similar to laser cut quality in terms of angularity and dross.
  - High definition is used only in mechanized applications.

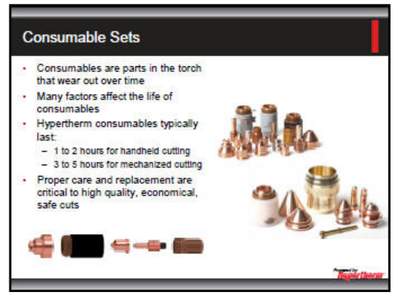
**Slide 8: Plasma Cutting Torch Variations**

- The common tie between all torch variations is their consumable parts.

## Consumable Sets

*Purpose:* *Learn the parts in consumable sets for various applications.*

*Time:* *10 minutes*




**Slide 9: Consumable Sets**

- Consumable sets are the parts in the torch that wear out over time.
- How often you need to change the consumables depends on a number of factors, including:
  - Thickness and type of material being cut
  - Length of the average cut
  - Air quality (the presence of oil, moisture, or other contaminants)
  - Whether you are piercing or edge-starting
  - How well the proper torch-to-work distance is maintained with unshielded consumables
  - Proper pierce height
  - Which consumables you are using
- For Hypertherm systems, a set of consumables lasts approximately 1 to 2 hours of actual "arc-on" time for handheld cutting and as much as 3 to 5 hours for mechanized cutting.
- Proper care and replacement of these parts are critical to high quality, economical, safe cuts.
- Always follow instructions for disconnecting power before inspecting or changing torch consumable parts.

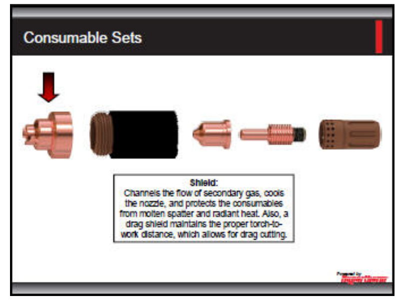
*Facilitator Notes: Some manufacturers have unique names for their parts; there is no industry "standard" when it comes to consumable names. To make this section easier for your students, we have chosen to present the consumable names as they will see them in Powermax operator manuals.*

*Because consumable technology is constantly evolving and because of patented consumable designs, some consumables sets will look different from the Powermax45 and Powermax65 consumables we have provided. Sometimes pieces are combined (retaining cap and shield together as one piece, for example), or have different features (nozzle and electrode shapes). For clarity, we have chosen to present the consumables your students will need to operate Powermax plasma system. Remember: regardless of design, consumables on a plasma torch are designed to create, shape, and maintain the plasma arc.*

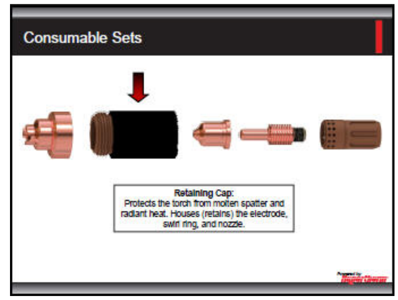
*We have provided Powermax45 consumable sets for students to view during this section of the class – they are held together on a wire. The Powermax65 consumables are in the spare parts box. If you compare them, you will see very obvious differences in the electrodes and shields. The patented electrode for the Powermax65 has a spring designed into it to allow the electrode to move. For the Powermax45, this movement is controlled by a plunger in the torch. Distribute the consumable sets evenly amongst your students, and then proceed with the rest of this section.*

*Ask students to open the consumable set by loosening the fastener and unscrewing the shield from the retaining cap. They can follow along with their model as each part is described below.*

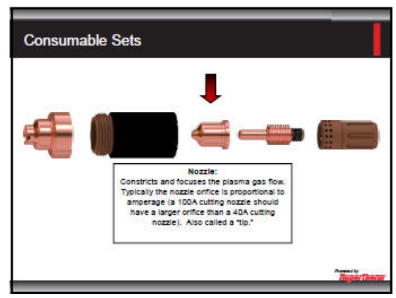
The main parts of a consumable set include:



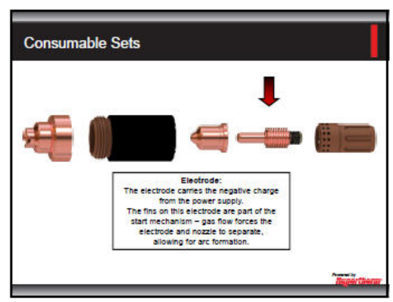

- **Shield (slide 10)** – Channels the flow of secondary gas, cools the nozzle, and protects the consumables from molten spatter and radiant heat. This shield maintains the proper torch-to-work distance, which allows for drag cutting. The grooves in the tip of the shield allow the gas flow to blow molten material (and heat) away from the consumable set.



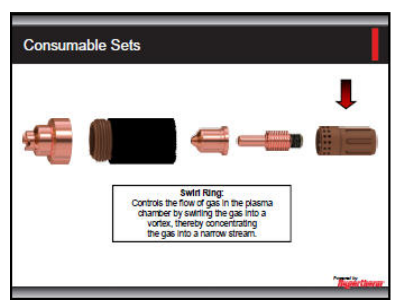

- **Retaining Cap (slide 11)** – Protects the torch from molten spatter and radiant heat. Houses (retains) the electrode, swirl ring, and nozzle.




- **Nozzle (slide 12)** – Constricts and focuses the plasma gas flow. Typically the nozzle orifice is proportional to amperage (the nozzle on the wire has been bored out to fit). The nozzle of a 100A machine will have a larger orifice than the Powermax45 (45A). Also called a "tip." *Also make students aware that there are special gouging nozzles, which have a larger orifice. Gas pressure is lowered for gouging, which produces less concentrated, wider plasma arc. Compare a Powermax65 shielded nozzle to a gouging nozzle – there is a visible difference in orifice size that would be a good visual comparison for this section.*




- **Electrode (slide 13)** – Copper with a conductive insert (hafnium); the electrode carries the negative charge from the power supply. The fins on this electrode are part of the start mechanism – gas flow forces the electrode and nozzle to separate, allowing for arc formation. *The Powermax45 electrode on the wire depends on the plunger in the torch to hold it in contact with the nozzle prior to arc formation. The Powermax65 electrode has a spring built into the top. This takes a moving part, which can break, out of the torch, increasing the reliability of the torch.*




- **Swirl Ring (slide 14)** – Controls the flow of gas in the plasma chamber. Notice that the holes in the swirl ring are slanted to swirl the gas into a vortex (tornado), thereby concentrating the gas into a narrow stream.

  Point out that when assembled, the holes in the swirl ring are below the fins on the electrode. When gas is forced through those holes, it pushes against the fins on the electrode, forcing it apart from the nozzle. This motion, called "blowback," is what allows for arc formation in the Powermax45 and Powermax65 contact start method.

***Review Question:***

After you have finished reviewing all of the parts, ask students which consumables they would expect to wear out first? Do they think that they will all need to be changed at once?

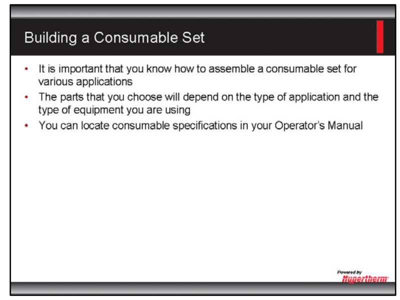
> ***The correct answer is:***
>
> The electrode and nozzle will need more frequent replacement and should be changed at the same time. Mixing new and used electrodes and nozzles can significantly lower the life of both parts. As we learned in Session 1, they carry current and form the arc. They are also closest to the heat of the arc. Expect the pair to last approximately 1-2 hours of arc-on time for handheld cutting.
>
> The shield is subject to heat and molten spatter build-up. Shields can be cleaned by hand, but should be replaced once the molten material clogs the grooves of the drag tip or changes the torch-to-work distance.
>
> Swirl rings and retaining caps can last much longer. Swirl rings need to be replaced if their holes cannot be unclogged. Both swirl rings and retaining caps need to be replaced if they become cracked/warped.

## Building a Consumable Set

*Purpose:* *Learn to build consumable sets for various applications.*

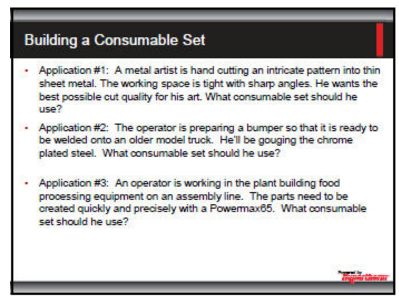
*Time:* *10 minutes*

**Slide 15: Building a Consumable Set**




- It is important that students know how to assemble a consumable set for various applications.
- The parts that you choose will depend on the type of application and the type of equipment you are using.
- You can locate the consumable specifications in your Operator's Manual.

**Slide 16: Building a Consumable Set**




- Ask students to work in teams of 3. One student works in the manual to identify the appropriate parts, one student assembles the parts, and the third student checks their work to make sure it is correct. They will rotate roles for each of the three activities below.
- Ask students to open their Powermax65 manual to Section 3. This section includes the consumable options they will need to use to build an appropriate consumable set.
- Give students 3 or 4 minutes to build an appropriate consumable set for each of these scenarios. Students should fill out the worksheet (provided on the following page) for each scenario. Stop after each scenario and make sure that each group has selected the appropriate consumables.

The correct answers are provided on the following page.

# Plasma Cutting Technology: Theory and Practice
## Building a Consumable Set

**Application #1:** A metal artist is hand cutting an intricate pattern into thin sheet metal. The working space is tight with sharp angles. He wants the best possible cut quality for his art. What consumable set should he use?

Consumable Set: FineCut® consumables

| Consumables: | Part: | Number: |
|---|---|---|
| | Electrode | 220842 |
| | Swirl Ring | 220947 |
| | Retaining Cap | 220854 |
| | Nozzle | 220930 |
| | Shield | 220931 |

**Application #2:** The operator is preparing a bumper so that it is ready to be welded onto an older model truck. He'll be gouging the chrome plated steel. What consumable set should he use?

Consumable Set: Gouging consumables

| Consumables: | Part: | Number: |
|---|---|---|
| | Electrode | 220842 |
| | Swirl Ring | 220857 |
| | Retaining Cap | 220854 |
| | Nozzle | 220797 |
| | Shield | 220798 |

**Application #3:** An operator is working in a plant, building food processing equipment on an assembly line. He needs to cut parts quickly, but precisely, with a Powermax65. What consumable set should he use?

Consumable Set: Drag-cutting consumables

| Consumables: | Part: | Number: |
|---|---|---|
| | Electrode | 220842 |
| | Swirl Ring | 220857 |
| | Retaining Cap | 220854 |
| | Nozzle | 220819 (65 amp) |
| | Shield | 220818 |

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
## Building a Consumable Set

**Application #1:** A metal artist is hand cutting an intricate pattern into thin sheet metal. The working space is tight with sharp angles. He wants the best possible cut quality for his art. What consumable set should he use?

Consumable Set: ________________________________________

Consumables: Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

**Application #2:** The operator is preparing a bumper so that it is ready to be welded onto an older model truck. He'll be gouging the chrome plated steel. What consumable set should he use?

Consumable Set: ________________________________________

Consumables: Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

**Application #3:** An operator is working in a plant, building food processing equipment on an assembly line. He needs to cut parts quickly, but precisely, with a Powermax65. What consumable set should he use?

Consumable Set: ________________________________________

Consumables: Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

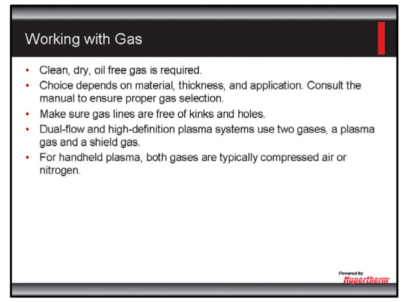
Part: ________________________ Number: ________________________

## Gas Considerations

*Purpose: Review the gas options and the criteria for selecting different gases for various applications.*

*Time: 10 minutes*

**Slide 17: Working with Gas**

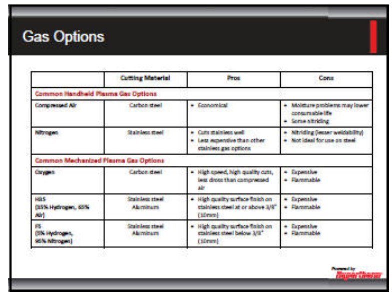



Review the following important considerations when working with gas in a plasma system:

- Clean, dry, oil free gas is required.
- Mechanized plasma operators use a variety of gases; their choice depends on material, thickness, and application. Consult the operator manual to ensure proper gas selection.
- Make sure gas lines are free of kinks and holes. A drop in gas pressure may affect cut quality or cause a loss of start.
- Dual-flow and high-definition plasma systems use two gases, a plasma gas and a shield gas, to provide better cut quality and consumable life. For handheld plasma, both gases are typically compressed air or nitrogen.

**Slide 18: Gas Options**

The table shows the four most common gases used in plasma systems, along with general pros and cons for each. Review the chart with the class.




| | Cutting Material | Pros | Cons |
|---|---|---|---|
| **Common Handheld Plasma Gas Options** | | | |
| **Compressed Air** | Carbon steel | • Economical | • Moisture problems may lower consumable life<br>• Some nitriding |
| **Nitrogen** | Stainless steel | • Cuts stainless well<br>• Less expensive than other stainless gas options | • Nitriding (lesser weldability)<br>• Not ideal for use on steel |
| **Common Mechanized Plasma Gas Options** | | | |
| **Oxygen** | Carbon steel | • High speed, high quality cuts, less dross than compressed air | • Expensive<br>• Flammable |
| **H35**<br>**(35% Hydrogen, 65% Air)** | Stainless Steel<br>Aluminum | • High quality surface finish on stainless steel at or above 3/8" (10 mm) | • Expensive<br>• Flammable |
| **F5**<br>**(5% Hydrogen, 95% Nitrogen)** | Stainless Steel<br>Aluminum | • High quality surface finish on stainless steel below 3/8" (10 mm) | • Expensive<br>• Flammable |

Ask the class the following questions and discuss their answers.

1. Which is the least expensive gas you could use in a handheld plasma system to cut carbon steel?

   *Correct answer: Compressed Air*

2. Which gas will produce the best cut on carbon steel in a dual-flow, mechanized system?

   *Correct answer: Oxygen*

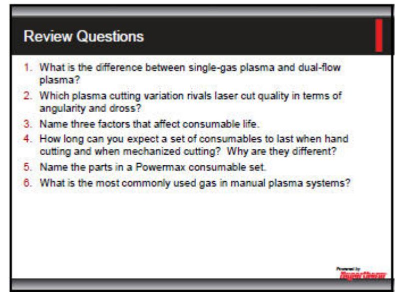
3. For a high-quality surface finish on stainless steel, which two gas mixtures might you use? How would you decide which was the better option?

   *Correct answer: H35 and F5; decide which to use based on material thickness (±3/8" or 10 mm).*

## Wrap-Up

*Purpose:* *Lesson recap and review.*

*Time:* *5 minutes*




*Facilitator Notes: There is a homework sheet provided on the following page that will challenge students to practice what they have learned. A homework answer key and review discussion is built into the beginning of the next lesson.*

**Slide 19: Wrap-Up and Review Question Overview**

This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
## Homework #3: Overview of a Plasma System

1. What is the difference between single-gas plasma and dual-flow plasma?

   *Just like the name says, dual-flow has two gases – a plasma gas and a shield gas. The addition of a shield protects the consumables from radiant heat and molten spatter. Shield gas provides some additional arc restriction and helps remove molten material.*

2. Which plasma cutting variation rivals laser cut quality in terms of angularity and dross?

   *High-definition.*

3. Name three factors that affect consumable life.

   *Possible answers include: thickness of the metal being cut, Length of the average cut, whether you're doing machine or hand cutting, air quality, whether you are piercing or edge-starting, proper torch-to-work distance with unshielded consumables, proper pierce height, and which consumables you are using.*

4. How long can you expect a set of consumables to last when hand cutting and when mechanized cutting? Why are they different?

   *Typically 1 to 2 hours of actual "arc on" time for hand cutting; 3 to 5 hours for mechanized cutting. The pilot arc "on time" is greater for hand-held systems.*

5. Name the parts in a Powermax consumable set.

   *Electrode, nozzle, swirl ring, retaining cap, shield.*

6. What is the most commonly used gas in manual plasma systems?

   *Compressed or bottle air.*

Student Copy

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
## Homework #3: Overview of a Plasma System

1. What is the difference between single-gas plasma and dual-flow plasma?

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

2. Which plasma cutting variation rivals laser cut quality in terms of angularity and dross?

_______________________________________________

3. Name three factors that affect consumable life.

_______________________________________________

_______________________________________________

_______________________________________________

4. How long can you expect a set of consumables to last when hand cutting and when mechanized cutting? Why are they different?

_______________________________________________

_______________________________________________

_______________________________________________

5. Name the parts in a Powermax consumable set.

_______________________________________________

6. What is the most commonly used gas in manual plasma systems?

_______________________________________________

# Session 4: Using Your Plasma System Operator's Manual

This lesson starts with a review of the manual and then moves into safety procedures and an activity on proper safety equipment. You'll discuss the importance of safety when working with plasma systems.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| The Plasma System Manual (including Reference Manual activity) | 20 minutes |
| Safety Procedures | 15 minutes |
| Safety Equipment Activity | 5 minutes |
| Wrap Up | 5 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

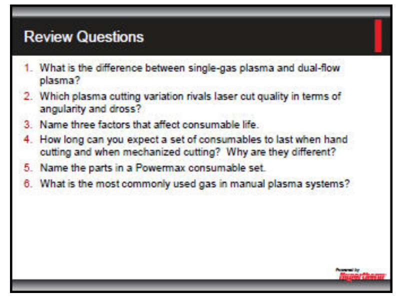
1. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
2. Make sure you have enough copies of the Powermax65 manual and the appropriate language section of the Safety and Compliance manual for students to use.
3. Make copies of the "Reference Manual Activity Sheets." Note that there are 3 different activities, and each student will complete just one of the three activities.
4. Make a copy of the homework sheet for every student in the class.

## Introduction

*Purpose: Review and reinforce previous lesson content.*

*Time: 5 minutes*


The homework questions from Session 3, along with the correct answers, are provided below:




1. What is the difference between single-gas plasma and dual-flow plasma?

   *Just like the name says, dual-flow has two gases – a plasma gas and a shield gas. The addition of a shield protects the consumables from radiant heat and molten spatter. Shield gas provides some additional arc restriction and helps remove molten material.*

2. Which plasma cutting variation rivals laser cut quality in terms of angularity and dross?

   *High-definition.*

3. Name three factors that affect consumable life.

   *Possible answers include: thickness of the metal being cut, Length of the average cut, whether you're doing machine or hand cutting, air quality, whether you are piercing or edge-starting, proper torch-to-work distance with unshielded consumables, proper pierce height, and which consumables you are using.*

4. How long can you expect a set of consumables to last when hand cutting and when mechanized cutting?

   *Typically 1 to 2 hours of actual "arc on" time for hand cutting; 3 to 5 hours for mechanized cutting. The pilot arc "on time" is greater for hand-held systems.*

5. Name the parts in a Powermax consumable set.

   *Electrode, nozzle, swirl ring, retaining cap, shield.*

6. What is the most commonly used gas in manual plasma systems?

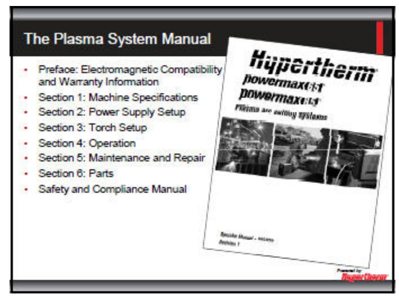
   *Compressed or bottle air.*

## The Plasma System Manual

*Purpose: Discuss the sections of the manual and learn to locate important information quickly.*

*Time: 20 minutes, including the activity*

*Facilitator Notes: Distribute Powermax65 manuals amongst the students. The Operator Manual is your best resource for the safe and effective use of a plasma system. In this lesson, you will be using Powermax65 manuals, but the lesson about Operator Manuals is intended to apply generically to all plasma manufacturers. Each manufacturer's manual will be different, but similar content should be covered.*




**Slide 2: The Plasma System Manual**

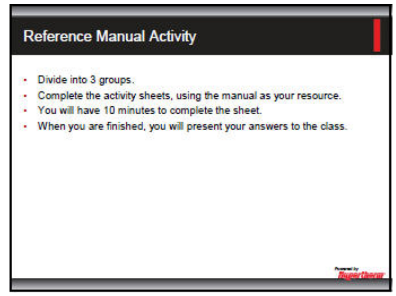
Ask students to open the manual to Page vii – Table of Contents.

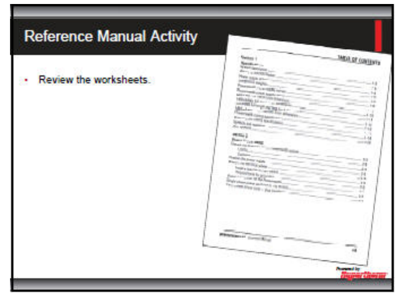
The manual should serve as the operator's first resource for information on the plasma system.

Rather than reading the outline to the class, ask them some lead-in questions to get them thinking about where they would look for certain information.

- Where would you look to locate instructions for proper usage? (Section 4: Operation)
- Where would you look for information on troubleshooting typical problems? (Section 5: Maintenance and Repair)
- Where would you find the weight and dimensions of a plasma power supply? (Section 1: Specifications)
- Where would you look for factory part numbers? (Section 6: Parts)
- Where would you look to determine the consumable requirements for different types of cutting? (Section 3: Torch Setup)
- Where would you find information about connecting the gas supply? (Section 2: Power Supply Setup)

**Slide 3 - 4: Reference Manual Activity**




The activity challenges students to use the Powermax65 manual to answer a series of questions.

- Divide the class into 3 groups. Pass out the three activity worksheets – one to each group.
- Make sure each group has at least one copy of the Powermax65 manual and a copy of the Safety and Compliance Manual.
- Ask students to complete the activity sheets, using the manual and the Safety and Compliance Manual as resource tools.
- Give students 10 minutes to complete the sheet. Depending on class size and the number of manuals available, you may have students work individually or in pairs.
- When they are finished, ask each group to present their questions and answers to the class.

During the student presentations, use your answer key to help guide the discussion. Encourage students to follow along with the presentation by finding the relevant pages within their manuals. The activity sheets, with answers included, are provided on the following pages.

Instructor Copy

## Reference Manual Activity Sheet #1

You are working in an auto body shop in which a variety of jobs are required on a daily basis. The shop just purchased a Powermax65, and they intend to use it for all types of handheld cuts. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Section 1: Machine Specifications – What types of gas input does the Powermax65 take? — p. 1-6

   *Air or Nitrogen (p. 1-6)*

2. Section 3: Torch Setup – Choose the appropriate drag-cutting (shielded) consumables for hand-cutting carbon steel. — p. 3-6

   *Shield (220818), retaining cap (220854), nozzle (220619), swirl ring (220857), and electrode (220842)*

3. Section 5: Maintenance and Repair – When you turn on the cutter, the fault LED illuminates and the fault code 0-50 displays on the LCD screen. What does that mean? — p. 5-8

   *The consumables are loose, improperly installed, or missing.*

4. Section 4: Operation – The first cut you'll try is a piece of 5 mm plate. Where should the mode switch be set and what is this mode called? — p. 4-4

   *In the second position; "non-continuous pilot arc."*

5. Section 3: Torch Setup – You're asked to remove an existing weld. What shield part number would you use? — p. 3-6

   *Part number 220798 for gouging*

6. Section 5: Maintenance and Repair – The arc doesn't transfer to the work piece when you make a cut. What should you do? — p. 5-4

   *Check the work clamp; make sure you are not holding the torch too far away from the work piece.*

## Reference Manual Activity Sheet #2

You are working in an HVAC shop, primarily fabricating and altering duct work. Your boss just asked you to look over a new Powermax65 and be prepared to show your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Preface – How long is the warranty on the power supply? — p. iii

   *Three years*

2. Safety and Compliance Manual – For eye protection, what is the minimum protective shade number for the Powermax65? — p. S-5

   *Eight*

3. Safety and Compliance Manual – Should you turn the power off before disassembling the torch? — p. S-2

   *Yes*

4. Section 1: Machine Specifications – How much does a CSA Powermax65 weigh? — p. 1-5

   *54.1 pounds (or 24.5 kg)*

5. Section 3: Torch Setup – What is the Best Quality cut speed (mm/min) for cutting 10 mm aluminum with shielded consumables at 65 amps? — p. 3-35

   *1200 mm/min*

6. Section 5: Maintenance and Repair – When would you replace the electrode? — p. 5-3

   *If the surface is worn or if the pit depth is more than 1.6 mm deep.*

## Reference Manual Activity Sheet #3

You are working for a custom metal fabricator that makes all types of parts to be used in manufacturing. They recently purchased a new Powermax65 plasma system and intend to use it for both mechanized and hand cutting. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Preface – How long are the factory supplied torch parts warranted? — p. iii

   *One year from date of delivery*

2. Section 1: Machine Specifications – What is the mechanized pierce capacity of the Powermax65? — p. 1-12

   *5/8" (or 16 mm) with automatic torch height control, 1/2" without torch height control.*

3. Section 4: Operation – Which is easier when hand cutting – pushing the torch or pulling/dragging it? — p. 4-17

   *Pulling or dragging the torch along the cut is easier than pushing it*

4. Section 4: Operation – You are asked to remove an existing weld. What is the recommended angle for gouging? — p. 4-21

   *35 - 40 degrees*

5. Section 4: Operation — What do you do with the hand clamp? — p. 4-11

   *The hand clamp must be attached to the workpiece while you are cutting, but not to the piece to be cut away.*

6. Section 5: Maintenance and Repair – The power LED is blinking and fault code 0-13 shows on the screen. What does this mean? — p. 5-8

   *The input voltage is unstable, either too high or too low.*

Student Copy

Name: ______________________________

Date: ______________________________

## Reference Manual Activity Sheet #1

You are working in an auto body shop in which a variety of repairs are required on a daily basis. The shop just purchased a Powermax65, and they intend to use it for all types of handheld cuts. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Section 1: Machine Specifications – What types of gas input does the Powermax65 take? __________

   ______________________________________________________________

2. Section 3: Torch Setup – Choose the appropriate shielded consumables for hand-cutting carbon steel. __________

   ______________________________________________________________

3. Section 5: Maintenance and Repair – When you turn on the cutter, the fault LED glows yellow and the fault code 0-50 displays on the LCD screen. What does that mean? __________

   ______________________________________________________________

4. Section 4: Operation – The first cut you'll try is a piece of 5 mm plate. Where should the mode switch be set and what is this mode called? __________

   ______________________________________________________________

5. Section 3: Torch Setup – You're asked to remove an existing weld. What shield part number would you use? __________

   ______________________________________________________________

6. Section 5: Maintenance and Repair – The arc doesn't transfer to the work piece when you make a cut. What should you do? __________

   ______________________________________________________________

Student Copy

Name: ______________________________

Date: ______________________________

## Reference Manual Activity Sheet #2

You are working in an HVAC shop, primarily fabricating and altering duct work. Your boss just asked you to look over a new Powermax65 and be prepared to show your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Preface – How long is the warranty on the power supply? __________

   ______________________________________________________________________

2. Safety and Compliance Manual – For eye protection, what is the minimum protective shade number for the Powermax45? __________

   ______________________________________________________________________

3. Safety and Compliance Manual – Should you turn the power off before disassembling the torch? __________

   ______________________________________________________________________

4. Section 1: Machine Specifications – How much does a CSA Powermax65 weigh? __________

   ______________________________________________________________________

5. Section 3: Torch Setup – What is the Best Quality cut speed (mm/min) for cutting 10 mm aluminum with shielded consumables at 65 amps? __________

   ______________________________________________________________________

6. Section 5: Maintenance and Repair – When would you replace the electrode? __________

   ______________________________________________________________________

Student Copy

Name: ______________________

Date: ______________________

## Reference Manual Activity Sheet #3

You are working for a custom metal fabricator that makes all types of parts to be used in manufacturing. They recently purchased a new Powermax65 plasma system and intend to use it for both mechanized and hand cutting. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

**Page #**

1. Preface – How long are the factory supplied torch parts warranted? __________

   ______________________________________________

2. Section 1: Machine Specifications – What is the mechanized pierce capacity of the Powermax65? __________

   ______________________________________________

3. Section 4: Operation – Which is easier when hand cutting – pushing the torch or pulling/dragging it? __________

   ______________________________________________

4. Section 4: Operation – You are asked to remove an existing weld. What is the recommended angle for gouging? __________

   ______________________________________________

5. Section 4: Operation – What do you do with the hand clamp? __________

   ______________________________________________

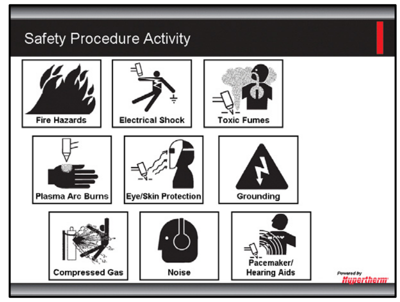
6. Section 5: Maintenance and Repair – The power LED is blinking and fault code 0-13 shows on the screen. What does this mean? __________

   ______________________________________________

## Safety Procedures

*Purpose: Review important safety procedures.*

*Time: 20 minutes, including the activity*




**Slide 5: Safety Procedure Activity**

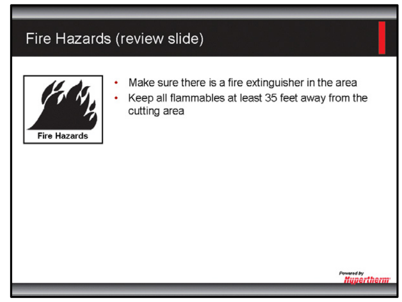
There are 9 main safety topics covered in the Safety and Compliance Manual, including the following:

| | | |
|---|---|---|
| Fire Hazards | Electrical Shock | Toxic Fumes |
| Plasma Arc Burns | Eye and Skin Protection | Grounding |
| Compressed Gas | Noise | Pacemaker/Hearing Aids |

- Split the class into small groups and assign each group one safety topic. If you have a small class you may want to combine topics as follows:
  1. Fire Hazards
  2. Electrical Shock
  3. Toxic Fumes
  4. Compressed Gas
  5. Grounding, Noise, and Pacemaker/Hearing Aids
  6. Plasma Arc Burns and Eye/Skin Protection

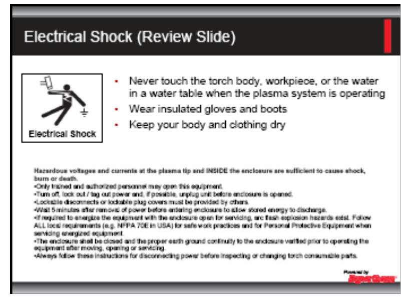
- Ask each group to take 5 minutes to review the safety information for their topic(s) and then be ready to present their findings to the class.
- PowerPoint summaries are provided for each topic. After each group presents their findings, display the appropriate PPT slide and review the key points to make sure that they have been covered completely.

**Slide 6: Fire Hazards (Review Slide)**




- Make sure there is a fire extinguisher in the area.
- Keep all flammables at least 35 feet (10.5 meters) away from the cutting area.

**Slide 7: Electrical Shock (Review Slide)**



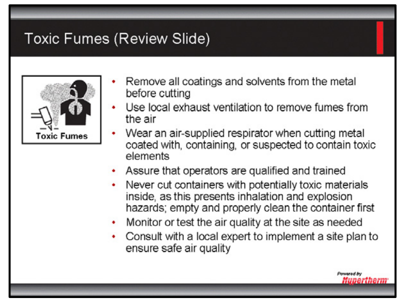

Touching live electrical parts can cause a fatal shock or severe burn. Operating the plasma system completes an electrical circuit between the torch and the workpiece; the workpiece and anything touching the workpiece are part of the electrical circuit.

- Never touch the torch body, workpiece, or the water in a water table when the plasma system is operating.
- Wear insulated gloves and boots.
- Keep your body and clothing dry.

Hazardous voltages and currents at the plasma tip and INSIDE the enclosure are sufficient to cause shock, burn or death.

- Only trained and authorized personnel may open this equipment.
- If power source is cord & plug connected, turn off power and unplug power source before opening the enclosure.
- If power source is permanently connected, turn off and lockout / tagout power before opening enclosure.
- Wait 5 minutes after removal of power before entering enclosure to allow stored energy to discharge.
- If required to energize the equipment with the enclosure open for servicing, arc flash explosion hazards exist. Follow ALL local requirements (e.g. NFPA 70E in USA) for safe work practices and for Personal Protective Equipment when servicing energized equipment.
- The enclosure shall be closed and the proper earth ground continuity to the enclosure verified prior to operating the equipment after moving, opening or servicing.
- Always follow these instructions for disconnecting power before inspecting or changing torch consumable parts.

**Slide 8: Toxic Fumes (Review Slide)**

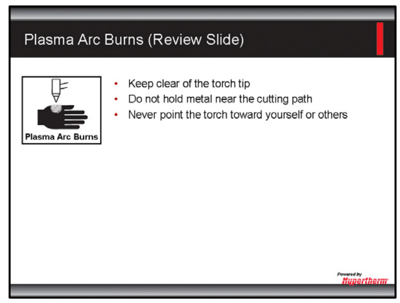



The material being cut can be a source of toxic fumes or gases that deplete oxygen. Metals that may release toxic fumes include, but are not limited to, stainless steel, carbon steel, zinc (galvanized), and copper. Metal can also be coated with substances that can release toxic fumes; they may include, but are not limited to lead, cadmium, and beryllium.

To reduce the risk of exposure to fumes:

- Remove all coatings and solvents from the metal before cutting.
- Use local exhaust ventilation to remove fumes from the air.
- Wear an air-supplied respirator when cutting metal coated with, containing, or suspected to contain toxic elements.
- Assure that operators are qualified and trained.
- Never cut containers with potentially toxic materials inside, as this presents inhalation and explosion hazards; empty and properly clean the container first.
- Monitor or test the air quality at the site as needed.
- Consult with a local expert to implement a site plan to ensure safe air quality.

**Slide 9: Plasma Arc Burns (Review Slide)**




The plasma arc forms immediately when the torch switch is activated and will cut quickly through gloves and skin.

- Keep clear of the torch tip.
- Do not hold metal near the cutting path.
- Never point the torch toward yourself or others.

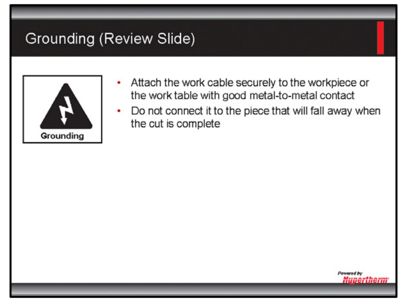
**Slide 10: Eye and Skin Protection (Review Slide)**


Plasma arc rays produce intense visible and invisible (ultraviolet and infrared) rays that can burn eyes and skin.

- Wear insulated gloves and boots.
- Wear eye protection (safety goggles or goggles with side shields, and a welding helmet) with appropriate lens shading to protect eyes from the arc's ultraviolet and infrared rays.
- Wear flame retardant clothing to cover all exposed areas.
- Wear cuff-less trousers to prevent entry of sparks and slag.
- Remove any combustibles, such as lighters or matches, from pockets before cutting.

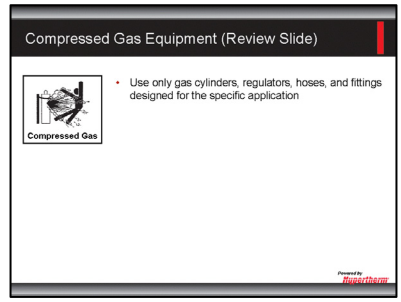
**Slide 11: Grounding (Review Slide)**

- Attach the work cable securely to the workpiece or the work table with good metal-to-metal contact.
- Do not connect it to the piece that will fall away when the cut is complete.




**Slide 12: Compressed Gas Equipment (Review Slide)**

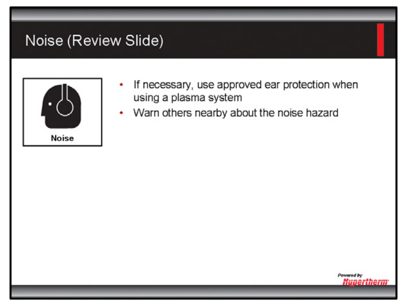
- Use only gas cylinders, regulators, hoses, and fittings designed for the specific application.




**Slide 13: Noise (Review Slide)**

Prolonged exposure to high levels of noise can damage hearing.

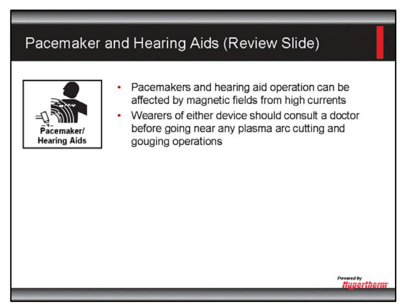
- If necessary, use approved ear protection when using a plasma system .
- Warn others nearby about the noise hazard.




**Slide 14: Pacemaker and Hearing Aids (Review Slide)**

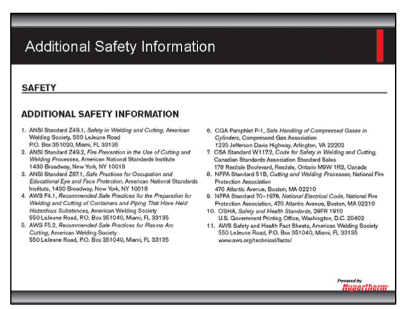
Pacemakers and hearing aid operation can be affected by magnetic fields from high currents.

- Wearers of either device should consult a doctor before going near any plasma arc cutting and gouging operations.




**Slide 15: Additional Safety Information**

- Additional safety information can be found in the resources shown on this slide.



## Safety Equipment Activity

*Purpose: Confirm understanding of important safety procedures, reinforce the value of Personal Protective Equipment (PPE), and a "safety first" mentality.*

*Time: 5 minutes*


*Facilitator Notes: Show each slide and ask students to not only identify "What's wrong in this picture?" but also "Why?" The correct answers are shown below.*

**Slide 16: Safety Equipment Activity (Photo #1) -** *Cutting near flammable materials = compressed gas/explosion hazard.*

**Slide 17: Safety Equipment Activity (Photo #2) -** *Face in fume and spark zone = inhalation and spark hazard.*

**Slide 18: Safety Equipment Activity (Photo #3) -** *Gloves are not adequate eye protection! = eye hazard.*

**Slide 19: Safety Equipment Activity (Photo #4) -** *The ground clamp is on the piece being removed = grounding hazard. Teaching point: the ground clamp gives the current in the workpiece a place to go – if the ground clamp is attached to the piece that falls away from the work, you may be left with a highly charged piece of metal on the table.*

**Slide 20: Safety Equipment Activity (Photo #5) -** *Holes in gloves = ability for operator to become part of the electrical circuit.*

**Slide 21: Safety Equipment Activity (Photo #6) -** *The operator is holding the wrong piece and not wearing gloves = electrical shock hazard.*

**Slide 22: Safety Equipment Activity (Photo #7) -** *Poor ground connection.*

**Slide 23: Safety Equipment Activity (Photo #8) -** *The system cover is off = electric shock hazard.*

**Slide 24: Safety Equipment Activity (Photo #9) -** *The operator isn't wearing gloves.*

**Slide 25: Safety Equipment Activity (Photo #10) -** *The operator isn't wearing a jacket = plasma arc burns/skin protection hazard.*

**Slide 26: Safety Equipment Activity (Photo #11) –** *The operator's face shield is up = eye and skin protection hazard.*

**Slide 27: Safety Equipment Activity (Photo #12) -** *Face shield on, but shade is up = eye hazard.*

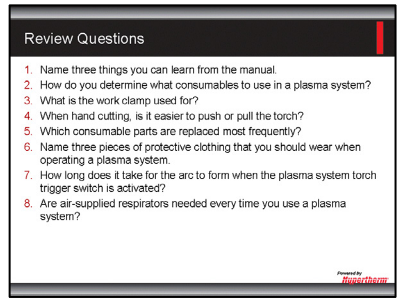
**Slide 28: Safety Equipment Activity (Photo #13) -** *The operator isn't watching the cut.*

**Slide 29: Safety Equipment Activity (Photo #14) -** *Nearly everything is wrong with this picture! = fire hazard (cutting propane tank), electrical shock, toxic fumes, plasma arc burns, eye and skin protection.*

## Wrap-Up

*Purpose: Lesson recap and review.*

*Time: 5 minutes*




*Facilitator Notes: There is a homework sheet provided on the following page that will challenge students to practice what they have learned. A homework answer key and review discussion is built into the beginning of the next lesson.*

**Slide 30: Wrap-Up and Review Question Overview**

This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Instructor Copy

Name: ______________________

Date: ______________________

# Plasma Cutting Technology: Theory and Practice
# Homework #4: Using a Plasma System Safely

1. Name three things you can learn from the manual.

   *Possible answers include: warranty information, machine specifications, utility requirements, torch set-up and consumables, operation instructions, maintenance and repair, and parts.*

2. How do you determine what consumables to use in a plasma system?

   *Reference the charts in the manual.*

3. What is the work clamp used for?

   *To properly ground the work piece*

4. When hand cutting, is it easier to push or pull the torch?

   *It is easier to pull or drag the torch across the work piece.*

5. Which consumable parts should be replaced most frequently?

   *Electrode and nozzle.*

6. Name three pieces of protective clothing that you should wear when operating a plasma system.

   *Possible answers include: insulated gloves and boots, eye protection, and flame retardant clothing.*

7. How long does it take for the arc to form when the plasma system torch trigger switch is activated?

   *The plasma arc forms almost immediately*

8. Are air-supplied respirators needed every time you use a plasma system?

   *No – the plasma itself does not produce toxic gas. However, the material you are cutting may be a source of toxic fumes or gases that deplete oxygen. Monitor or test the air quality at the site as needed and wear an air-supplied respirator when cutting metal coated with, containing, or suspected to contain toxic elements.*

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
## Homework #4: Using a Plasma System Safely

1. Name three things you can learn from the manual.

_______________________________________________

_______________________________________________

_______________________________________________

2. How do you determine what consumables to use in a plasma system?

_______________________________________________

3. What is the work clamp used for?

_______________________________________________

_______________________________________________

4. When hand cutting, is it easier to push or pull the torch?

_______________________________________________

5. Which consumable parts should be replaced most frequently?

_______________ _______________

6. Name three pieces of protective clothing that you should wear when operating a plasma system.

_______________ _______________ _______________

7. How long does it take for the arc to form when the plasma system torch trigger switch is activated?

_______________________________________________

8. Are air-supplied respirators needed every time you use a plasma system?

_______________________________________________

# Session 5: Operation of the Plasma System

During this session, you'll discuss the importance of safety when working with plasma systems. The lesson starts with a review of the manual and then moves into safety procedures and an activity on proper safety equipment.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
| --- | --- |
| Introduction/Review | 5 minutes |
| Common Terminology | 5 minutes |
| Machine Startup and Operation | 15 minutes |
| Execute a Drop Cut | 20 minutes |
| Wrap Up | 5 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

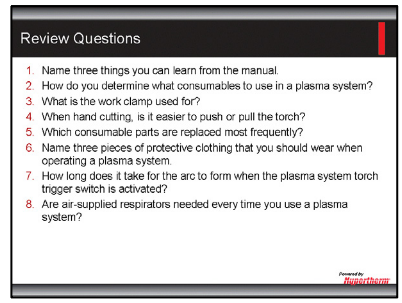
It is recommended that you prepare for this session by completing the following tasks:

1. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
2. Students will be executing a drop cut during this session, so make sure that you have the following materials ready before the class session begins:
    - Plasma system with all necessary hookups (air, power, ground).
    - Protective eye-wear for everyone in the class.
    - At least one complete set of PPE (preferably two or more).
    - A copy of the "Quick Setup Guide" provided with this course.
    - Enough carbon steel for 50+ straight cuts (recommended: at least 3 feet (90 cm) by 1 foot (30 cm)).
3. Make a copy of the homework sheet for every student in the class.

## Introduction

*Purpose:* *Review and reinforce previous lesson content.*

*Time:* *5 minutes*


The homework questions from Session 4, along with the correct answers, are provided below:

1. Name three things you can learn from the manual.

   *Possible answers include: warranty information, machine specifications, utility requirements, torch set-up and consumables, operation instructions, maintenance and repair, and parts.*

2. How do you determine what consumables to use in a plasma system?

   *Reference the charts in the manual.*

3. What is the work clamp used for?

   *To properly ground the work piece.*

4. When hand cutting, is it easier to push or pull the torch?

   *It is easier to pull or drag the torch across the work piece.*

5. Which consumable parts should be replaced most frequently?

   *Electrode and nozzle*

6. Name three pieces of protective clothing that you should wear when operating a plasma system.

   *Possible answers include: insulated gloves and boots, eye protection, and flame retardant clothing.*

7. How long does it take for the arc to form when the plasma system torch trigger switch is activated?

   *The plasma arc forms almost immediately.*

8. Are air-supplied respirators needed every time you use a plasma system?

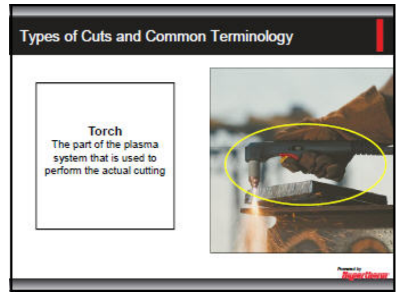
   *No – the plasma itself does not produce toxic gas. However, the material you are cutting may be a source of toxic fumes or gases that deplete oxygen. Monitor or test the air quality at the site as needed and wear an air-supplied respirator when cutting metal coated with, containing, or suspected to contain toxic elements.*

## Common Terminology

*Purpose: Review and common plasma cutting terminology.*

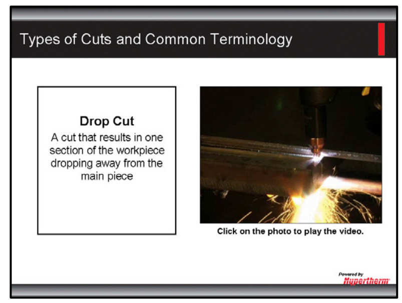
*Time: 5 minutes*

*Facilitator Notes: During the remainder of the course, students will be asked to complete a series of cuts. They will be expected to know the terminology associated with each type of cut, as well as some of the common terms used in cutting and welding. Because many of your students will already know this information, present this segment of the lesson as a fun and challenging review, rather than a lecture-based format.*




In this activity, display each slide and ask the class to name the term being illustrated or described in the photo. When they do, click the mouse to display the term on the screen. Then, go on to the next term.

The terms and definitions included in this review (in order of appearance within the PowerPoint deck) are provided below:

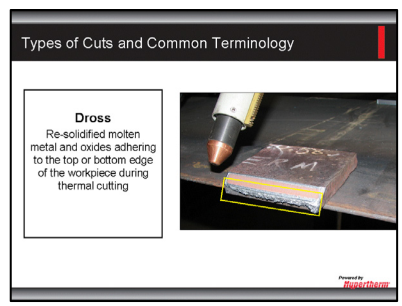



**Slide 2: Torch**

*The part of the plasma system that is used to perform the actual cutting.*

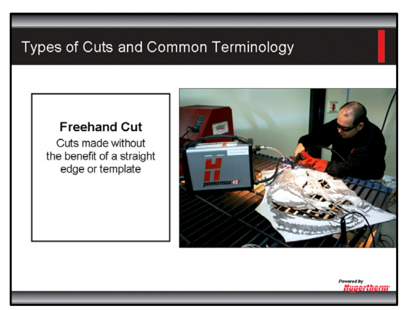
**Slide 3: Drop Cut**

*A cut that results in one section of the workpiece dropping away from the main piece.*




**Slide 4: Dross**

*Re-solidified molten metal and oxides adhering to the top or bottom edge of the work piece during thermal cutting.*



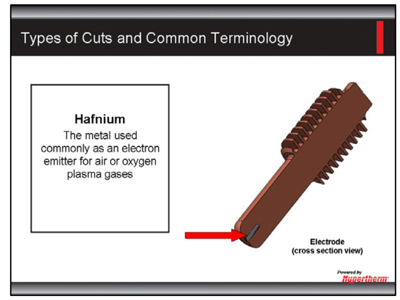

**Slide 5: Freehand Cut**

*Cuts made without the benefit of a straight edge or template*

*Teaching point: ask the class to point out the safety issue with this image (no glove).*

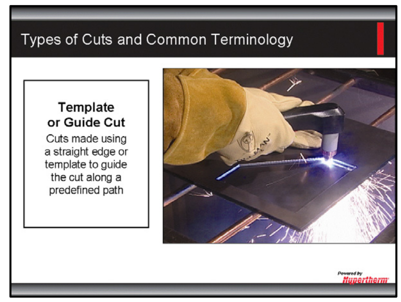
**Slide 6: Hafnium**

*The metal used commonly as an electron emitter for air or oxygen plasma gases.*



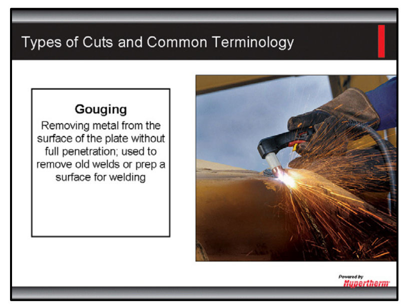

**Slide 7: Template or Guide Cut**

*Cuts made using a straight edge or template to guide the cut along a predefined path.*



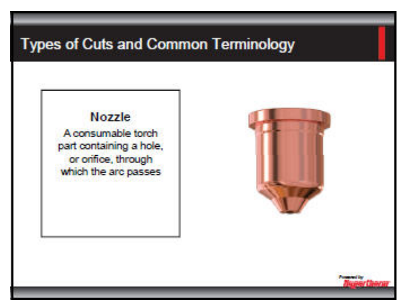

**Slide 8: Gouging**

*Removing metal from the surface of the plate without full penetration; used to remove old welds or prep a surface for welding.*



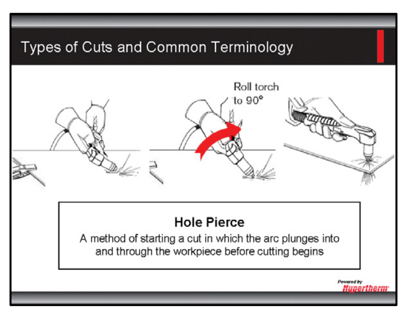

**Slide 9: Nozzle**

*A consumable torch part containing a hole, or orifice, through which the arc passes.*



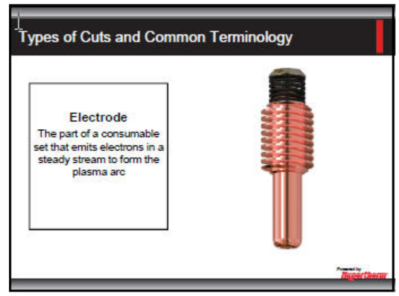

**Slide 10: Hole Pierce**

*A method of starting a cut in which the arc plunges into and through the workpiece before cutting begins.*



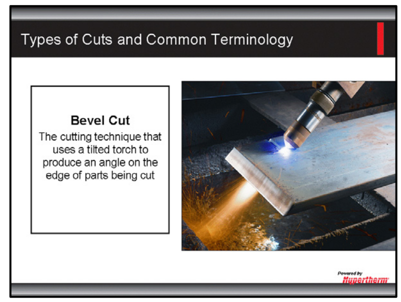
**Slide 11: Electrode**

*The part of a consumable set that emits electrons in a steady stream to form the plasma arc.*



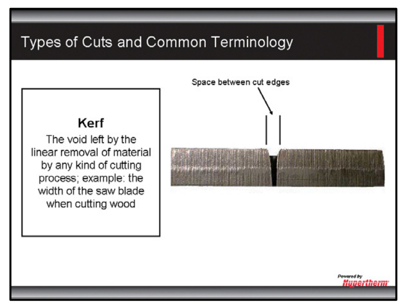

**Slide 12: Bevel Cut**

*The cutting technique that uses a tilted torch to produce an angle on the edge of the parts being cut.*




**Slide 13: Kerf**

*The void left by the linear removal of material by any kind of cutting process; example: the width of the saw blade when cutting wood.*



## Machine Startup

*Purpose:* *Illustrate proper set-up and startup of a Powermax.*

*Time:* *20 minutes*


*Before you start the video, hand out the Quick Setup Card that provides step-by-step instructions for starting and operating the plasma system. These cards provide a summary of the information presented within the video. Ask students to follow along as the video plays.*

**Slide 14: Machine Startup**

A summary of the information presented within the video is provided on the following pages.

Verify the power is disconnected and, if cord & plug type power source, verify the power plug is unplugged prior to Step 1.

**Step 1: Check the proper installation of the torch consumables**

- Unscrew the retaining cap to remove the parts within.
- Replace the parts by first inserting the nozzle, then the electrode, followed by the swirl ring.

  Screw the retaining cap on until finger tight; do not over-tighten as the consumables may become damaged.

**Step 2: Connect the torch lead to the front of the power supply**

**Step 3: Connect the gas**

- Pull back the quick release collar on the gas hose and insert on the quick disconnect fitting.
- The gas can be either bottled nitrogen, bottled air, or compressed air.
- Air should be filtered to remove all dirt, water, and oil because contaminants can damage the power supply, torch, and consumables.
- Check the system for gas pressure requirements. The Powermax65 has a recommended gas pressure of 85 psi or 5.5 bar and a maximum gas pressure of 135 psi or 9.3 bar.

**Step 4: Attach the work clamp**

- Check to see that the work lead is attached to the power supply. (Some systems do not have a quick disconnect on the work lead.) For the Powermax65, push the connector into the receptacle and turn clockwise ¼ turn, making sure that the connector is fully seated against the stop to achieve an optimal electrical connection.
- Attach the work clamp securely to the work piece or the cutting table near the cut.
- Rust, paint, or coatings must be removed to be sure that the clamp has a good electrical contact.

  The clamp should never be attached to the portion of the metal that will fall away.

**Step 5: Power on the system**

- Plug the power cord into the proper receptacle.
- Power on the system.
- The power lamp on the front of the system will illuminate.

  For input voltage requirements, look at the data plate on the bottom or back of the power supply or in the operator manual.

**Step 6: Set the mode switch**

- Set the switch to plate cutting. The position may vary. On the Powermax45, for example, it is the middle position. On the Powermax65, it is the second position.

**Step 7: Check the gas pressure**

- Systems such as the Powermax65 have automatic gas adjustment. Unless there is a fault light illuminated and a gas pressure fault code on the LCD screen, the gas pressure is correct. Other systems, like the Powermax45, may require that you adjust the pressure:
  - If the LED bar in the pressure gauge is green, the gas pressure is set correctly.
  - If the LED is yellow, the gas pressure needs adjustment.
  - To adjust the gas pressure, turn the amperage knob all of the way counter-clockwise to the “gas test” position.
  - Then, pull the regulator knob to unlock it.
  - Turn the knob until the green LED appears in the center of the pressure bar.
  - Then, push the regulator knob to lock it.

**Step 8: Adjust the amperage**

- Adjust the amperage knob to the top amperage setting for full cutting power (65 amps for the Powermax65).
- If cutting thinner metal, the amperage may be lowered for improved consumable life and cut quality.

**Step 9: Operate the safety trigger**

- Avoid unnecessary starts, because they reduce the nozzle and electrode life.

**Performing an Edge Start and Drop Cut**

- Hold the torch vertically (perpendicular to workpiece), just off the edge of the workpiece.
- The shield may be placed on the workpiece for ease of cutting.
- Flip the safety trigger forward and press the red torch trigger.
- The pilot arc transfers to the workpiece and becomes the cutting arc.
- Pause at the edge, allowing the arc to cut completely through the workpiece before proceeding with the cut.

- Pull torch steadily to cut.

  When nearing the end of the cut, roll your torch hand forward slightly, lifting your wrist. This will angle the torch into the direction of the cut, allowing the arc to completely sever the material.

**Proper Travel Speed**

- Maintaining proper travel speed is key to successful cutting.
- Watch the arc beneath the plate; sparks should lag 15° to 30° degrees behind the cut.
- If the sparks are vertical, then the speed is too slow.
- If the sparks are perpendicular to the cut or are spraying up from the workpiece, then the speed is too fast or the system does not have sufficient power. Lag lines on the finished cut edge should also be about 15° to 30°.

**Template Cutting**

- A plasma cutting guide, straight edge, or template can be used to guide the torch.

  The distance from the shield's center to the edge must be factored in when creating a template or placing the straight edge.

**Bevel Cuts**

If you are beveling using a plasma cutting guide or free hand, remember that the material thickness increases proportionally with the bevel angle.

**Piercing**

- The piercing capability of the system is roughly half of the maximum cut capacity.
- Depending on the thickness of the metal being pierced and the system being used, there are two methods of piercing:
  - If piercing thin metal, hold the torch perpendicular to the workpiece and pull the trigger to transfer the arc.
  - If piercing thick metal, hold the torch at a 45° angle so that the nozzle is within 1/8" (3 mm) from the workpiece; pull the trigger to transfer the arc, then slowly rotate it to an upright position.
- In both methods, when sparks are exiting from the bottom of the workpiece the metal has been pierced and then cutting can begin.

  To prolong the life of the consumables, it is recommended that the second method be used to minimize damage to the consumables caused by molten metal blowback.

**Cutting Expanded Metal**

- To cut expanded metal (grating), or an application with interrupted cuts, set the mode switch to "Expanded Metal Cutting," which is the top position.
- This enables the system to automatically reinitiate the pilot arc without retriggering.

  To cut, simply follow the same procedures as outlined for plate cutting.

**Gouging**

- To gouge, first turn off the system, install the gouging consumables, then restart the system.
- Set the mode switch to gouging. On the Powermax45, this is the bottom position. On the Powermax65, it is the third position.
- Depending on the system you are using, you may need to adjust the gas pressure to get a wider, diffused arc for gouging. The Powermax65 does this for you. If you are using a Powermax45 or other non-autogas system:
  - Turn the current knob all of the way counter-clockwise to the “gas test” position.
  - Then pull the regulator knob to unlock it, turn the knob until the green LED appears in the center of the pressure bar, and push the knob back down to lock it.
- Adjust the amperage to full output for full gouging power.
- Hold the torch at approximately a 40° angle from the workpiece, with a small gap between the torch tip and the workpiece, then pull the trigger to transfer the arc.
- Maintain this angle and slowly move the torch along the workpiece to remove unwanted metal or weld.
- If a shallower gouge is desired, decrease the angle of the torch.

  For a deeper gouge, increase the angle of the torch or make additional passes.

**System Optimization**

- Cut quality and consumable life are two very important factors for operators.
- To ensure that the torch consumables last as long as they are designed to last and perform to manufacturer’s specifications, follow the instructions in this video, refer to the supplied cut charts for proper set-up, and follow proper maintenance procedures.
- A number of factors determine how long consumables last, including air quality, piercing technique, length of average cut, operator skill, material thickness, and material type.
- Reduced system performance and cut quality are often caused by poor air quality, so be sure to maintain clean, dry, oil-free air.

**Accessories**

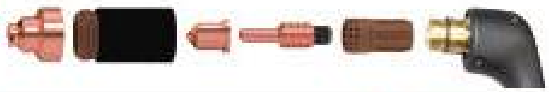
Manufacturers offer a variety of accessories, including:

- Air filters
- Plasma cutting guides
- Leather torch sheathing
- System dust covers
- Face shields
- Gloves

# Hypertherm powermax65 / powermax85

**Warning: Read the Operator Manual thoroughly. Follow the safety instructions.**
Avertissement : Lire attentivement le manuel de l'opérateur. Suivre les instructions de sécurité.
Advertencia: Lea el Manual del operador con detenimiento. Cumpla con las instrucciones de seguridad.

**1.**



**See reverse for options.**
Voir les options au dos.
Vea el reverso para ver las opciones.

**2.**

**3.**

**4.**

**Do not attach clamp to a portion of the workpiece that will fall away.**
Le connecteur ne doit pas être fixé à la partie de la pièce qui doit tomber.
No fije la pinza a la parte de la pieza a cortar que caerá.

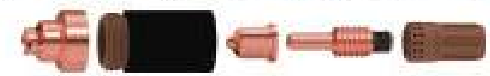
**5.**

**6.**


**Ready to cut.**
Prêt à couper.
Listo para el corte.

## Cutting / Coupage / Corte

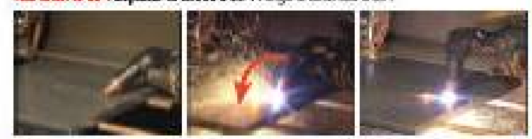
**No standoff.** Aucune distance torche-pièce. No alejar.



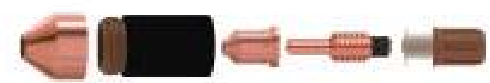
| | | | | | |
|---|---|---|---|---|---|
| 45 A | 220818 | 220854 | 220941 | 220842 | 220857 |
| 65 A | 220818 | 220854 | 220819 | 220842 | 220857 |
| 85 A | 220818 | 220854 | 220816 | 220842 | 220857 |

## Piercing / Perçage / Perforando

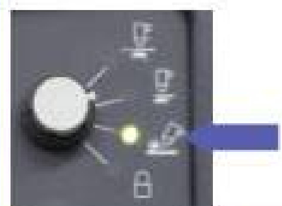
**Roll torch to 90°.** Déplacer la torche à 90°. Ponga la antorcha a 90°.



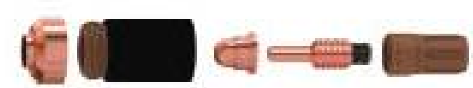
## Gouging / Gougeage / Ranurado



| | | | | |
|---|---|---|---|---|
| 220798 | 220854 | 220797 | 220842 | 220857 |




## FineCut™



| | | | | |
|---|---|---|---|---|
| 220931 | 220854 | 220930 | 220842 | 220947 |

*Need help?* ***Avez-vous besoin d'aide?***
*¿Necesita ayuda?*

**First contact your distributor.**

If you need additional assistance, you can contact Hypertherm Technical Service.

**Contacter d'abord votre distributeur.**

Pour toute aide supplémentaire, communiquez avec le service technique d'Hypertherm.

**Primero contacte su distribuidor.**

Si necesita mas ayuda, puede ponerse en contacto con el Servicio Tecnico de Hypertherm.


Hypertherm

**Technical Service**
technical.service@hypertherm.com

USA
800-643-9878 (USA only)
603-643-3441 Ext. 1770 Tel
603-643-4609 Fax

Brazil
55 11 6482 1087 Tel
55 11 6482 0591 Fax

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39 02 725 46 400 Fax

The Netherlands
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31 165 596900 Tel
31 165 596901 Fax




# Hypertherm powermax45

## *Quick Setup Card*
## *Fiche de préparation rapide*
## *Tarjeta de establecimiento rápido*

***806100 – Revision 0***

# Hypertherm powermax45

*Quick Setup Card*
*Fiche de préparation rapide*
*Tarjeta de establecimiento rápido*

**Warning: Read the Operator Manual thoroughly.**

**Follow the safety instructions.**

**Do not connect the power until indicated in Step 4.**

The Operator Manual contains detailed information about your machine's features and important warnings about operation and maintenance safety.

This card gives you a brief overview of your system's setup requirements. It does not contain all the information needed to operate your machine safely and it is not a substitute for the Operator Manual.

**Avertissement : Lire entièrement le manuel de l'opérateur.**

**Suivre les instructions relatives à la sécurité.**

**Ne pas brancher tant que cela n'est pas indiqué à l'étape 4.**

Le manuel de l'opérateur contient des renseignements détaillés sur les fonctions de votre système et des avertissements importants relatifs à la sécurité du fonctionnement et de l'entretien.

Cette fiche donne une vue globale brève des exigences d'installation de votre système. Elle ne contient pas tous les renseignements nécessaires pour faire fonctionner votre machine en toute sécurité et elle ne remplace pas le manuel de l'opérateur.

**Advertencia: Lea el Manual del Operario completamente.**

**Siga las instrucciones de seguridad.**

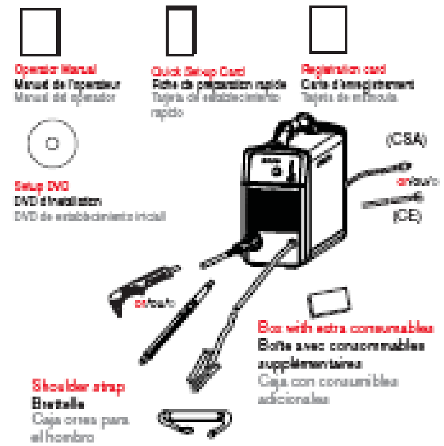
**No conecte a la potencia primaria hasta lo indicado en el paso 4.**

El Manual del Operario contiene información detallada acerca de las características de su sistema y advertencias importantes acerca de la seguridad de operación y mantenimiento.

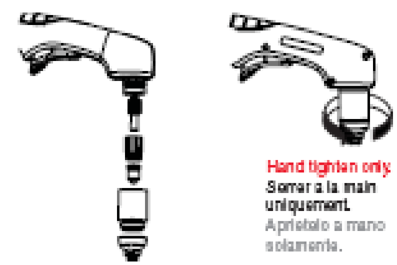
Esta tarjeta da una visión total breve de los requisitos de establecimiento inicial de su sistema. No contiene toda la información necesaria para operar su máquina con seguridad y no es un substituto para el Manual del Operario.



## *1 Check the contents*
***Vérifier le contenu***
***Verifique el contenido***




## *2 Check the consumables*
***Vérifier des consommables***
***Verifique los consumibles***




## *3 Connect the torch lead*
***Connecter le faisceau de la torche***
***Conecte el cable de la antorcha***

## Execute a Drop Cut

*Purpose:* *Build confidence with freehand plasma cutting by experimenting with technique, cut speed changes, torch angle changes, etc. Also, review and practice machine set-up and proper use of PPE.*

*Time:* *25 - 30 minutes*

**Materials:**

1. Plasma system with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for 50+ straight cuts [recommended: at least 3 feet (90 cm) x 1 foot (30 cm)].

- *Note that we also recommend giving your students the opportunity to practice making cuts on aluminum and stainless steel, if possible.*

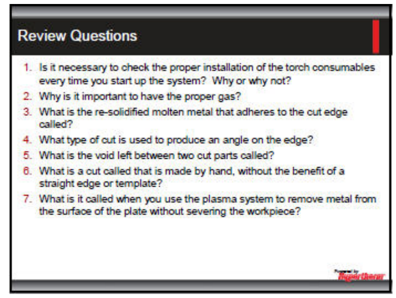
**Directions:**

- Bring system to cutting area of the workshop.
- Mimic the **Machine Startup** activity; students take turns using the "Quick Setup Guide" to prepare the plasma system for cutting.
- Review drop cut technique for group, demonstrating cut speed and torch angle WITHOUT actually cutting – leave the fun part for your class this time!
- First student puts on full PPE and checks that system is ready for cutting.
- Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on.)
- Each student will get the opportunity to perform 2-3 drop cuts.
- Class observes the student cutting to provide constructive feedback.
- After each cut, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments.

## Wrap-Up

*Purpose:* *Lesson recap and review.*

*Time:* *5 minutes*




*Facilitator Notes: There is a homework sheet provided on the following page that will challenge students to practice what they have learned. A homework answer key and review discussion is built into the beginning of the next lesson.*

**Slide 15: Wrap-Up and Review Question Overview**

This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Instructor Copy

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
# Homework #5: Operation of the Plasma System

1. Is it necessary to check the proper installation of the torch consumables every time you start up the system? Why or why not?

   *Yes – especially in situations where operators share machines, consumables may have been swapped in/out incorrectly. Also, consumables need to be checked for wear regularly.*

2. Why is it important to have the proper gas pressure?

   *An improper gas setting affects cut quality and the life of your consumables. Check the pressure gauge if the system has one or watch for fault indicators on auto-gas systems.*

3. What is the re-solidified molten metal that adheres to the cut edge called?

   *Dross*

4. What type of cut is used to produce an angle on the edge?

   *Bevel cut*

5. What is the void left between two cut parts called?

   *Kerf*

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?

   *Freehand cut*

7. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?

   *Gouging*

Student Copy

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
# Homework #5: Operation of the Plasma System

1. Is it necessary to check the proper installation of the torch consumables every time you start up the system? Why or why not?

   ______________________________________________________________________

   ______________________________________________________________________

   ______________________________________________________________________

2. Why is it important to have the proper gas pressure?

   ______________________________________________________________________

   ______________________________________________________________________

   ______________________________________________________________________

3. What is the re-solidified molten metal that adheres to the cut edge called?

   ______________________________________________________________________

4. What type of cut is used to produce an angle on the edge?

   ______________________________________________________________________

5. What is the void left between two cut parts called?

   ______________________________________________________________________

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?

   ______________________________________________________________________

7. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?

   ______________________________________________________________________

# Session 6: Evaluating Cut Quality

During this session, you'll discuss the criteria used to evaluate cuts and then start to apply those criteria to assess the quality of the cuts made during the previous class session. These criteria will also be used in upcoming class sessions to evaluate the quality of student cuts throughout the remainder of the course.

The recommended timing for this session is as follows:

| **Topic** | **Estimated Time** |
| --- | --- |
| Introduction/Review | 5 minutes |
| Primary Factors Affecting Cut Quality | 10 minutes |
| Evaluating Cut Quality Activity | 20 minutes |
| Other Troubleshooting Tips (including review) | 10 minutes |
| Wrap Up | 5 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

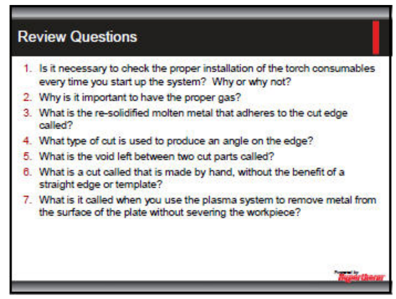
1. Load the PowerPoint slides in the computer and make sure that the images are projected so that all of the students in the class can see them.
2. Make a copy of the "Evaluating Cut Quality" worksheet for every student in the class.
3. Make a copy of the "Troubleshooting Activity" worksheet for every student in the class.
4. Make a copy of the homework sheet for every student in the class.

## Introduction

*Purpose: Review and reinforce previous lesson content.*

*Time: 5 minutes*


The homework questions from Session 5, along with the correct answers, are provided below:




1. Is it necessary to check the proper installation of the torch consumables every time you start up the system? Why or why not?

   *Yes – especially in situations where operators share machines, consumables may have been swapped in/out incorrectly. Also, consumables need to be checked for wear regularly.*

2. Why is it important to have the proper gas pressure each time?

   *An improper gas setting affects cut quality and the life of your consumables. Check the pressure gauge if the system has one or watch for fault indicators on auto-gas systems.*

3. What is the re-solidified molten metal that adheres to the cut edge called?

   *Dross*

4. What type of cut is used to produce an angle on the edge?

   *Bevel cut*

5. What is the void left between two cut parts called?

   *Kerf*

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?

   *Freehand cut*

7. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?

   *Gouging*

## Primary Factors Affecting Cut Quality

*Purpose:* *Discuss the three primary factors that affect cut quality: dross, cut angle, and cut surface.*

*Time:* *10 minutes, including activity*

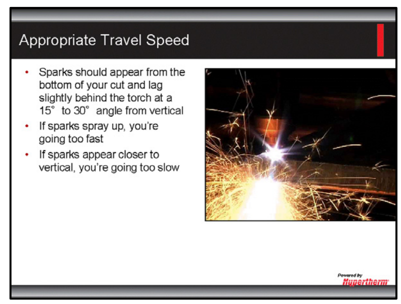

**Slide 2: Evaluating Cut Quality**

There are three primary factors to consider when assessing cut quality:

- Dross – the molten material that solidifies on the top or bottom of the work piece.
- Cut Angle – the degree of angularity of the cut edge.
- Cut Surface – the cut surface can be concave or convex, and may have varying surface finish (both in terms of straightness and texture); handheld plasma cutting typically produces a rougher cut surface than mechanized plasma.


**Slide 3: Dross**

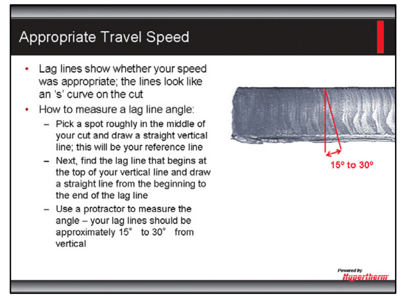
- Dross is re-solidified molten metal and oxides that adhere to the top or bottom edge during thermal cutting.
- Some amount of dross will always be present when cutting with air plasma.
- Excessive dross is primarily caused when the travel speed is too fast or too slow for the material being cut.




**Slide 4: Appropriate Travel Speed**

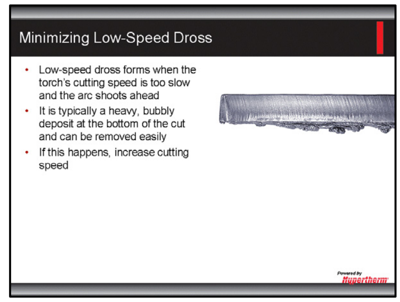
- When you are cutting at the correct speed, the sparks should appear from the bottom of your cut and lag slightly behind the torch at a 15° to 30° angle from vertical; this is hard to see for yourself – you may want to have someone watch and provide feedback as you cut.
- If sparks spray up, the torch is moving too fast; this is sometimes called a "rooster tail."
- If sparks appear closer to vertical from the bottom of the cut, the torch is moving too slow.

**Slide 5: Appropriate Travel Speed (cont.)**



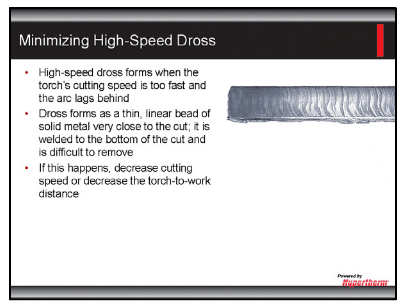

- The lag lines on the edge of the cut show whether your speed was appropriate; the lag lines look like an 's' curve on the cut.
- How to measure a lag line angle:
  - Pick a spot roughly in the middle of your cut. Draw a straight vertical line. This will be your reference line.
  - Next, find the lag line that begins at the top of your vertical line. Draw a straight line from the beginning to the end of the lag line.
  - Use a protractor to measure the angle. Your lag lines should be approximately 15° to 30° from vertical.

**Slide 6: Minimizing Low-Speed Dross**




- Low-speed dross forms when the torch's cutting speed is too slow and the arc shoots ahead.
- It is typically a heavy, bubbly deposit at the bottom of the cut and can be removed easily.
- If this happens, increase cutting speed.

**Slide 7: Minimizing High-Speed Dross**

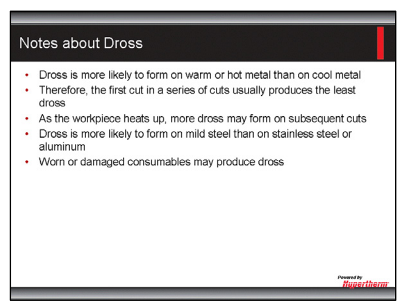



- High-speed dross forms when the torch's cutting speed is too fast and the arc lags behind.
- Dross forms as a thin, linear bead of solid metal very close to the cut; it is welded to the bottom of the cut and is difficult to remove.
- If this happens, decrease cutting speed or decrease the torch-to-work distance.

**Ask the class:**

*Which would you prefer to have:  low- or high-speed dross?*

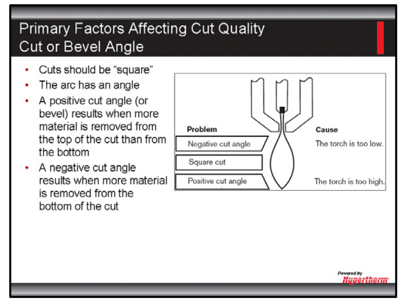
*Answer:  Low-speed dross, because you can remove it easily without grinding.*




**Slide 8: Notes about Dross**

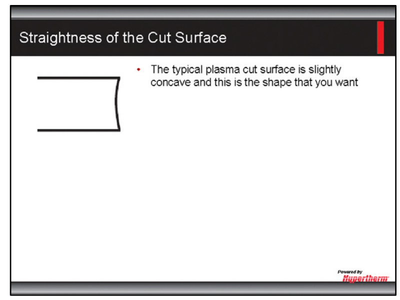
- Dross is more likely to form on warm or hot metal than on cool metal.  Therefore, the first cut in a series of cuts usually produces the least dross.  As the workpiece heats up, more dross may form on subsequent cuts.
- Dross is more likely to form on carbon steel than on stainless steel or aluminum.
- Worn or damaged consumables may produce dross.

**Slide 9: Cut or Bevel Angle**



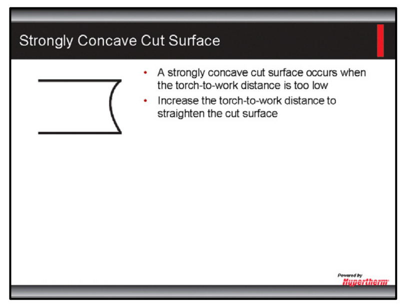

- You want the cuts that you make to be "square," which means that there is no bevel on the sides of the cut.
- We have mentioned several times that "the drag shield allows you to drag the torch along the surface of the workpiece, keeping the arc at the proper distance from the workpiece." Here is another illustration of how that works: it makes sure the arc shape that does the cutting is as close to square as possible.
- The arc itself has an angle as shown in the slide.
- A positive cut angle (or bevel) results when more material is removed from the top of the cut than from the bottom.
- A negative cut angle results when more material is removed from the bottom of the cut.
- Note that the highest quality cuts are always on the right with respect to the forward motion of the torch – this is because the arc swirls clockwise (when viewed from overhead), so it is actually hottest and the most dense where it exits the right cut edge.

**Slide 10: Straightness of the Cut Surface**



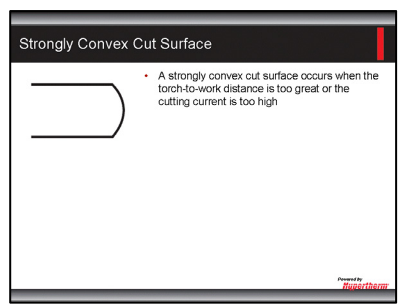

- The typical plasma cut surface is slightly concave and this is the shape that you want.

**Slide 11: Strongly Concave Cut Surface**




- A strongly concave cut surface occurs when the torch-to-work distance is too low.
- Increase the torch-to-work distance to straighten the cut surface.

**Slide 12: Strongly Convex Cut Surface**




- A strongly convex cut surface occurs when the torch-to-work distance is too great or the cutting current is too high.

## *Evaluating Cut Quality Activity*

*Purpose:* *Familiarize students with the measurement tools used to determine relative cut quality, as well as methods of optimization. Students will become more comfortable with self-assessment and will become familiar with how to recommend adjustments.*

*Time:* *15 – 20 minutes*

**Materials:**

1. Cut Evaluation Worksheet – includes definitions of cut assessment terminology.
2. Student cuts from Session 5.

**Directions:**

- Gather the students' cuts from Session 5 and look at them as a group.
- Pick three or four cuts that show examples of variations such as high- or low-speed dross, good or bad cut angles, and/or convex or concave cut surfaces.
- Give each student a cut evaluation worksheet and ask them to evaluate each cut based on what they learned within this lesson.
- When they are finished, discuss each cut as a group to provide feedback and reinforcement for student selections.
- Make sure that students understand the different factors influencing cut quality and that they are able to accurately identify them on each selected cut.

Student Copy

Name: ______________________

Date: ______________________

Cut: ______________________

# Evaluating Cut Quality

**1. Dross – the molten material that solidifies on the top or bottom of the work piece**

| **Low Speed Dross** | | | | **Dross Free** | | | | **High Speed Dross** |
|---|---|---|---|---|---|---|---|---|
| \| | \| | \| | \| | \| | \| | \| | \| | \| |

What would you do to improve the dross buildup on the work piece?

**2. Cut Angle – the degree of angularity of the cut edge**

| **Negative Cut Angle** | | | | **Square Cut** | | | | **Positive Cut Angle** |
|---|---|---|---|---|---|---|---|---|
| \| | \| | \| | \| | \| | \| | \| | \| | \| |

What would you do to improve the cut angle?

3. **Straightness of the Cut Surface – the cut surface can be concave or convex**

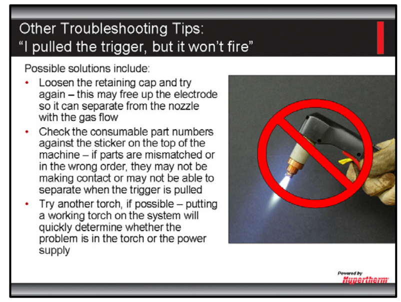
| **Concave** | | | | **Straight** | | | | **Convex** |
|---|---|---|---|---|---|---|---|---|
| \| | \| | \| | \| | \| | \| | \| | \| | \| |

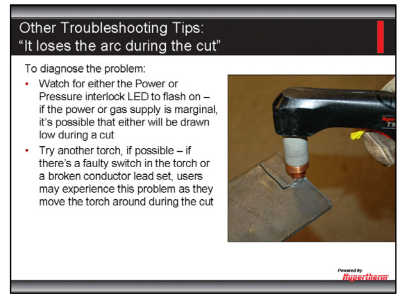
What would you do to improve the straightness of the cut surface?

## Other Troubleshooting Tips

*Purpose: Present primary cut quality factors and common troubleshooting issues.*

*Time: 10 minutes, including activity*




*Facilitator Notes: Remind your audience that the Operator Manual is the best place to start with any troubleshooting issue. These troubleshooting tips were developed by the Hypertherm team, based on the most common calls received at the help desk.*

**Slide 13: I pulled the trigger, but it won't fire**

A plasma torch is designed to initiate an arc by running a current through the electrode and nozzle, which are touching when the torch is idle. When the trigger is pulled while current is flowing, the gas flow pushes the two pieces apart and produces the initial plasma. Without this separation or initial arc, a cutting arc will not form.

Possible solutions include:

- Loosen the retaining cap slightly and try again – this may free up the electrode so it can separate from the nozzle with the gas flow.
- Check the consumable part numbers against the sticker on the top of the machine – if parts are mismatched or in the wrong order, they may not be making contact or may not be able to separate when the trigger is pulled.
- Try another torch, if possible – putting a working torch on the system will quickly determine whether the problem is in the torch or the power supply.

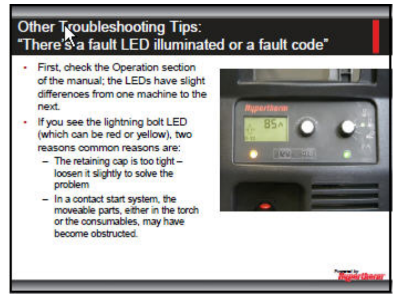
**Slide 14: It loses the arc during the cut**

If this happens only occasionally, it may be due to marginal power or a contaminated air supply. If it happens always or if substituting a working torch doesn't solve the problem, then it needs to go back to the manufacturer for repair.

To diagnose the problem:

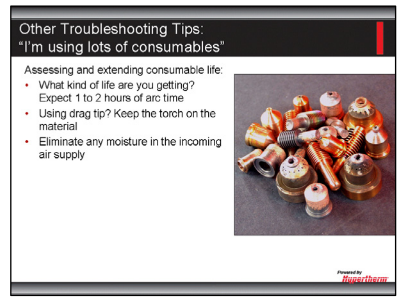
- Watch for either a fault LED or a fault code to flash on – if the power or gas supply is marginal, it's possible that either will be drawn low during a cut.
- Try another torch, if possible – if there's a faulty switch in the torch or a broken conductor in the torch lead users may experience this problem as they move the torch around during the cut.

**Slide 15: There's a fault LED illuminated or a fault code displaying on the LCD screen.**




- First, check the Operation section of the manual; the LEDs have slight differences from one machine to the next. The manual should help solve the problem.
- If you see the lightning bolt LED (which can be red or yellow), two common reasons are:
    - The retaining cap is too tight – loosen it slightly to solve the problem.
    - In a contact start system, the moveable parts, in either the torch or the consumables, may have become obstructed.

**Slide 16: I'm using lots of consumables**

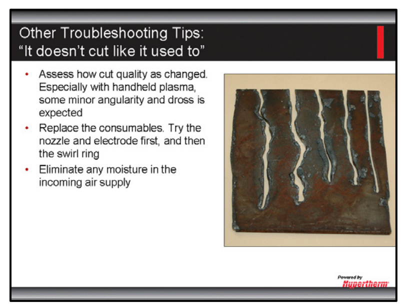



Consumable life depends on many variables, including amperage (more amps = shorter consumable life), material thickness (greater thickness = shorter life), feed rate (faster cuts = shorter life), and piercing (edge-starting helps preserve consumables).

Some tips for assessing and extending the life of your consumables include:

- What kind of life are you getting?  Expect 1 to 2 hours of arc time for manual cutting.
- Using a drag tip?  Keep the torch on the material.
- Eliminate any moisture in the incoming air supply.

**Slide 17: It doesn't cut like it used to**




Cut quality is greatly influenced by the user's technique.  Therefore, the first step is to assess how the cut quality has changed (if at all).

Some tips for assessing and improving cut quality include:

- Assess how cut quality as changed.  Especially with handheld plasma, some minor angularity and dross is expected.
- Replace the consumables. Try the nozzle and electrode first, and then the swirl ring.
- Eliminate any moisture in the incoming air supply.
- Change in the composition of the workpiece can affect cut quality.

Instructor Copy

## Troubleshooting Activity

*Facilitator Notes: Ask students to complete the Troubleshooting Worksheet (shown below with answers) to demonstrate that they understand the relationship between the most common problems and the most likely solutions. The student worksheet can be found in their workbook.*

*Give students 5 minutes to complete the activity and then discuss, asking students to provide the correct answers.*

| Problem | Most Likely Cause |
| --- | --- |
| __G__ Short consumable life | A. Cutting speed too fast |
| __E__ Arc won't fire when the trigger is pulled | B. Torch-to-work distance is too low |
| __A__ Thin, linear dross formation on the bottom of the cut | C. Cutting speed too slow |
| __F__ Positive cut angle | D. Power or gas supply is marginal |
| __B__ Negative cut angle | E. Mismatched consumables |
| __C__ Heavy, bubbly dross deposit at bottom of the cut | F. Torch-to work distance is too high |
| __D__ Torch loses the arc during cutting | G. If using a drag tip, keep the torch on the work plate |

Student Copy

Name: ____________________________

Date: ____________________________

# Troubleshooting Activity

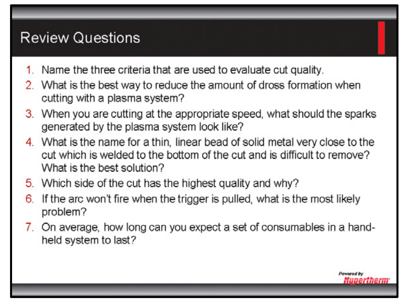
Match the problem with the most likely cause by writing the appropriate letter in the blanks on the left.

| Problem | Most Likely Cause |
|---|---|
| _____ Short consumable life | A. Cutting speed too fast |
| _____ Arc won't fire when the trigger is pulled | B. Torch-to-work distance is too low |
| _____ Thin, linear dross formation on the bottom of the cut | C. Cutting speed too slow |
| _____ Positive cut angle | D. Power or gas supply is marginal |
| _____ Negative cut angle | E. Mismatched consumables |
| _____ Heavy, bubbly dross deposit at bottom of the cut | F. Torch-to work distance is too high |
| _____ Torch loses the arc during cutting | G. If using a drag tip, keep the torch on the workplate |

## Wrap-Up

*Purpose: Lesson recap and review.*

*Time: 5 minutes*




*Facilitator Notes: This completes the sixth session and all of the theory instruction in the course The remainder of the sessions are all hands-on, where the students will be using the plasma system to make various cuts and evaluate their work.*

*Before ending the session, remind students that the final exam for the theory portion of the course is scheduled for the next class session. The best way to prepare is to review the homework assignments associated with each session – the exam questions are based on the homework. Review what you discussed during this class and take a minute to answer any remaining questions that the students may have.*

*There is a final homework sheet provided on the following page that will allow students to review what they learned during this session. You should plan to review this homework at the beginning of the next lesson (before the final exam). The correct answer key is provided in Lesson 7.*

**Slide 18: Wrap-Up and Review Question Overview**

This slide displays the homework questions for this session. If you choose not to assign homework, you may want to quickly review these questions at the end of the class.

If you do choose to assign homework, hand out the review questions and ask students to complete the worksheet before the next class session.

Instructor Copy

Name: ____________________

Date: ____________________

# Plasma Cutting Technology: Theory and Practice
## Homework #6: Evaluating Cut Quality

1. Name the three criteria that are used to evaluate cut quality.

   *Dross, cut angle, straightness of the cut surface*

2. What is the best way to reduce the amount of dross formation when cutting with a plasma system?

   *Appropriate travel speed*

3. When you are cutting at the appropriate speed, what should the sparks generated by the plasma system look like?

   *Shooting out the bottom of the cut at a 15° - 30° angle.*

4. What is the name for a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove? What adjustment can be made to reduce this formation?

   *High-speed dross – decrease cut speed.*

5. Which side of the cut has the highest quality and why?

   *The right side, because the arc swirls clockwise when viewed from overhead, so it is hottest and most dense when it exits the right cut edge.*

6. If the arc won't fire when the trigger is pulled, what is the most likely problem?

   *Mismatched consumables*

7. On average, how long can you expect a set of consumables in a hand-held system to last?

   *1 – 2 hours*

Student Copy

Name: ______________________________

Date: ______________________________

# Plasma Cutting Technology: Theory and Practice
# Homework #6: Evaluating Cut Quality

1. Name the three criteria that are used to evaluate cut quality.

   ______________________ ______________________ ______________________

2. What is the best way to reduce the amount of dross formation when cutting with a plasma system?

   ________________________________________________________________

3. When you are cutting at the appropriate speed, what should the sparks generated by the plasma system look like?

   ________________________________________________________________

4. What is the name for a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove? What adjustment can be made to reduce this formation?

   ________________________________________________________________

5. Which side of the cut has the highest quality and why?

   ________________________________________________________________

   ________________________________________________________________

6. If the arc won't fire when the trigger is pulled, what is the most likely problem?

   ________________________________________________________________

7. On average, how long can you expect a set of consumables in a hand-held system to last?

   ________________________________________________________________

# Session 7: Theory Exam

During this session, you'll deliver the written exam that assesses students on all of the theory content discussed during the first 6 sessions. The exam has 30 questions, which are largely based on the review questions from each session. It should take students no longer than 45 minutes to complete the exam.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| Theory Exam | 45 minutes |
| **Total Time:** | **50 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Make a copy of the "Theory Exam" for every student in the class

## Introduction

*Purpose: Review and reinforce previous lesson content.*

*Time: 5 minutes*

The homework questions from Session 5, along with the correct answers, are provided below:

1. Name the three criteria that are used to evaluate cut quality.

   *Dross, cut angle, straightness of the cut surface*

2. What is the best way to reduce the amount of dross formation when cutting with a plasma system?

   *Appropriate travel speed*

3. When you are cutting at the appropriate speed, what should the sparks generated by the plasma system look like?

   *Shooting out the bottom of the cut at a 15° - 30° angle.*

4. What is the name for a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove? What adjustment can be made to reduce this formation?

   *High-speed dross – decrease cut speed.*

5. Which side of the cut has the highest quality and why?

   *The right side, because the arc swirls clockwise when viewed from overhead, so it is hottest and most dense when it exits the right cut edge.*

6. If the arc won't fire when the trigger is pulled, what is the most likely problem?

   *Mismatched consumables*

7. On average, how long can you expect a set of consumables in a handheld system to last (in "arc-on time")?

   *1 – 2 hours*

## Plasma Theory Assessment

*The theory assessment consists of 30 questions that correspond to the learning objectives and the review homework throughout the theory section of the course (Sessions 1-6). The assessment, with answer key included, is provided on the following pages.*

1. Which of the following are good definitions for plasma? **Circle all that apply.**
   - A. A substance with more energy than a simple gas can contain.
   - B. A substance that is extremely bright and extremely hot.
   - C. $4^{th}$ state of matter.
   - **D. All of the above**

2. How long does it take for the arc to form when the plasma system torch trigger switch is activated?
   - A. 3 – 5 seconds
   - B. 5 – 7 seconds
   - C. 7 – 10 seconds
   - **D. The arc forms almost immediately**

3. How does plasma cut?
   - A. It generates heat up to 2,000° C to melt the workpiece.
   - B. It generates high velocity gas, which blows away the workpiece.
   - **C. It generates heat up to 20,000° C to melt the workpiece.**
   - D. It generates radiant energy, which creates a gap in the workpiece.

4. If you need to cut a set of 20 identical high quality parts from 2" (50 mm) steel plate, which would you be more likely to use?
   - A. A handheld plasma system
   - **B. A mechanized plasma system**
   - C. Either will do the job

5. What is the void left between two cut parts called?
   - A. Gap
   - B. Dross
   - C. Gouge
   - **D. Kerf**

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?
   **A. Freehand cut**
   B. Drop cut
   C. Bevel cut
   D. Gouge

7. In a dual-flow plasma system, what function does the second gas serve?
   A. It shields the consumables from radiant heat and molten splatter.
   B. It provides additional arc restriction.
   C. It helps remove molten material.
   **D. All of the above.**

8. How long can you expect a set of consumables on a mechanized system to last?
   A. 1 to 2 hours of "arc on" time.
   **B. 3 to 5 hours of "arc on" time.**
   C. 7 to 10 hours of total cutting time.
   D. It is impossible to predict because there are too many variables.

9. What is the most commonly used gas in handheld plasma systems?
   A. Oxygen
   B. Nitrogen
   C. H35
   **D. Compressed Air**

10. Which of the following are examples of plasma found in the world around you? **Circle all that apply.**
   **A. Auroras**
   B. LEDs
   **C. Lightning**
   D. Steam
   E. All of the above

11. What do you call a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove?

   **A. High speed dross**

   B. Low speed dross

   C. Molten scrap

12. Which consumable parts are replaced most frequently?

   A. Shield and Nozzle

   **B. Electrode and Nozzle**

   C. Shield and Retaining Cap

   D. Electrode and Swirl Ring

13. Which of the following best describes "contact starting?"

   **A. Consumable parts separate under current, creating a plasma pilot arc; gas flow maintains and forms the cutting arc.**

   B. A spark generated by the swirl ring ignites gas as it flows through the consumables, lighting the arc used for cutting.

   C. The operator uses the trigger to light the pilot gas, creating the initial arc; the shield gas feeds the flame and maintains the cutting arc.

14. Why is it necessary to check the proper installation of the torch consumables every time you start up the system? Check all that apply.

   **A. Consumables may be installed incorrectly.**

   **B. They need to be checked regularly for wear.**

   C. They need to be replaced before every use.

   **D. Someone else may have used the system.**

15. What is the re-solidified molten metal that adheres to the cut edge called?

   A. Kerf

   **B. Dross**

   C. Gouge

   D. Scrap

16. What type of cut is used to produce an angled cut on the edge?
    A. Freehand cut
    B. Drop cut
    **C. Bevel cut**
    D. Gouging

17. Which of the following are typical applications for plasma systems? **Circle all that apply.**
    **A. Shipyard maintenance**
    **B. HVAC manufacturing and repair**
    **C. Agricultural equipment repair**
    **D. General fabrication**

18. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?
    **A. Gouging**
    B. Soldering
    C. Brazing
    D. Beveling

19. What is the best way to reduce the amount of dross formation when cutting with a plasma system?
    **A. Use appropriate travel speed.**
    B. Use shielded consumables.
    C. Increase gas pressure.
    D. Cut on metal that is already warm.

20. When you are cutting at the appropriate speed, at what angle should the sparks fly out of the bottom of the cut?
    A. 5° - 10°
    **B. 15° - 30°**
    C. 45°
    D. 90°

21. If you pull the trigger and the torch does not fire, which of the following is most likely the problem?
    A. Torch-to-work distance is too low.
    B. Cutting speed is too fast.
    C. Torch-to-work distance is too high.
    **D. Power or gas supply is marginal.**

22. On average, how long can you expect a set of consumables in a handheld system to last?
    **A. 1 to 2 hours of "arc on" time.**
    B. 3 to 5 hours of "arc on" time.
    C. 7 to 10 hours of total cutting time.
    D. It is impossible to predict because there are too many variable factors.

23. When hand cutting, is it better to push or pull the torch?

    *Correct answer: Pull*

24. Name three pieces of protective equipment that you should wear when operating a plasma system.

    *Correct answers include: insulated gloves and boots, eye protection, and flame retardant clothing.*

25. What is the work clamp used for?

    *Correct answer: To properly ground the work piece.*

26. How do you determine which consumable sets to use in a plasma system?

    *Correct answer: Reference the charts in the manual.*

27. List one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser).

*<u>Correct answers include:</u>*

*Plasma Pros:* *cuts any conductive material, cut speed and quality advantage on a wide range of thicknesses, little to no prep and secondary work, ease of use.*

*Plasma Cons:* *initial cost higher than oxyfuel, cut quality less than laser, moderate maintenance requirements.*

*Oxyfuel Pros:* *low initial cost, cut speed advantage at larger thicknesses, low maintenance costs, fewest parts.*

*Oxyfuel Cons:* *only cuts ferrous metals, slow cut speed on thin material, poor cut quality, greater prep and secondary work, considerable skill required, flammable gas.*

*Laser Pros:* *best cut quality and speed advantage on thin materials.*

*Laser Cons:* *high initial cost, no manual cutting, greater prep work, expensive maintenance.*

28. Name three factors that affect consumable life.

*Correct answers include: thickness of the metal being cut, Length of the average cut, whether you're doing machine or hand cutting, air quality, whether you are piercing or edge-starting, proper torch-to-work distance with unshielded consumables, proper pierce height, and which consumables you are using.*

29. Name the three criteria that are used to evaluate cut quality.

*Correct answer: Dross, cut angle, straightness of the cut surface.*

30. Name the five parts in a shielded consumable set.

*Correct answers: Electrode, nozzle, swirl ring, retaining cap, shield.*

Name: ______________________________

Date: ______________________________

## Theory Exam

1. Which of the following are good definitions for plasma? **Circle all that apply.**
   - E. A substance with more energy than a simple gas can contain.
   - F. A substance that is extremely bright and extremely hot.
   - G. $4^{th}$ state of matter.
   - H. All of the above.

2. How long does it take for the arc to form when the plasma system torch trigger switch is activated?
   - E. 3 – 5 seconds
   - F. 5 – 7 seconds
   - G. 7 – 10 seconds
   - H. The arc forms almost immediately.

3. How does plasma cut?
   - E. It generates heat up to 2,000° C to melt the workpiece.
   - F. It generates high velocity gas, which blows away the workpiece.
   - G. It generates heat up to 20,000° C to melt the workpiece.
   - H. It generates radiant energy, which creates a gap in the workpiece.

4. If you need to cut a set of 20 identical high quality parts from 2" (50 mm) steel plate, which would you be more likely to use?
   - D. A handheld plasma system.
   - E. A mechanized plasma system.
   - F. Either will do the job.

5. What is the void left between two cut parts called?
   - E. Gap
   - F. Dross
   - G. Gouge
   - H. Kerf

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?
    E. Freehand cut
    F. Drop cut
    G. Bevel cut
    H. Gouge

7. In a dual-flow plasma system, what function does the second gas serve?
    E. It shields the consumables from radiant heat and molten splatter.
    F. It provides additional arc restriction.
    G. It helps remove molten material.
    H. All of the above.

8. How long can you expect a set of consumables on a <u>mechanized</u> system to last?
    E. 1 to 2 hours of “arc on” time.
    F. 3 to 5 hours of “arc on” time.
    G. 7 to 10 hours of total cutting time.
    H. It is impossible to predict because there are too many variables.

9. What is the most commonly used gas in handheld plasma systems?
    E. Oxygen
    F. Nitrogen
    G. H35
    H. Compressed Air

10. Which of the following are examples of plasma found in the world around you? **Circle all that apply.**
    F. Auroras
    G. LEDs
    H. Lightning
    I. Steam
    J. All of the above

11. What do you call a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove?
    D. High speed dross
    E. Low speed dross
    F. Molten scrap

12. Which consumable parts are replaced most frequently?
    E. Shield and Nozzle
    F. Electrode and Nozzle
    G. Shield and Retaining Cap
    H. Electrode and Swirl Ring

13. Which of the following best describes “contact starting?”
    D. Consumable parts separate under current, creating a plasma pilot arc; gas flow maintains and forms the cutting arc.
    E. A spark generated by the swirl ring ignites gas as it flows through the consumables, lighting the arc used for cutting.
    F. The operator uses the trigger to light the pilot gas, creating the initial arc; the shield gas feeds the flame and maintains the cutting arc.

14. Why is it necessary to check the proper installation of the torch consumables every time you start up the system? **Check all that apply.**
    E. Consumables may be installed incorrectly.
    F. They need to be checked regularly for wear.
    G. They need to be replaced before every use.
    H. Someone else may have used the system.

15. What is the re-solidified molten metal that adheres to the cut edge called?
    E. Kerf
    F. Dross
    G. Gouge
    H. Scrap

16. What type of cut is used to produce an angled cut on the edge?
    E. Freehand cut
    F. Drop cut
    G. Bevel cut
    H. Gouging

17. Which of the following are typical applications for plasma systems? **Circle all that apply.**
    E. Shipyard maintenance
    F. HVAC manufacturing and repair
    G. Agricultural equipment repair
    H. General fabrication

18. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?
    E. Gouging
    F. Soldering
    G. Brazing
    H. Beveling

19. What is the best way to reduce the amount of dross formation when cutting with a plasma system?
    E. Use appropriate travel speed.
    F. Use shielded consumables.
    G. Increase gas pressure.
    H. Cut on metal that is already warm.

20. When you are cutting at the appropriate speed, at what angle should the sparks fly out of the bottom of the cut?
    E. 5° - 10°
    F. 15° - 30°
    G. 45°
    H. 90°

21. If you pull the trigger and the torch does not fire, which of the following is most likely the problem?
    E. Torch-to-work distance is too low.
    F. Cutting speed is too fast.
    G. Torch-to-work distance is too high.
    H. Power or gas supply is marginal.

22. On average, how long can you expect a set of consumables in a handheld system to last?
    E. 1 to 2 hours of "arc on" time.
    F. 3 to 5 hours of "arc on" time.
    G. 7 to 10 hours of total cutting time.
    H. It is impossible to predict because there are too many variable factors.

23. When hand cutting, is it better to push or pull the torch?

24. Name three pieces of protective equipment that you should wear when operating a plasma system.

25. What is the work clamp used for?

26. How do you determine which consumable sets to use in a plasma system?

27. List one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser).

28. Name three factors that affect consumable life.

29. Name the three criteria that are used to evaluate cut quality.

30. Name the five parts in a shielded consumable set.

# Session 8: Straight Edge and Template Cuts

During this session, students will use the plasma cutter to practice both freehand and template cutting. There are no PowerPoint slides for this session. Instead, the instructor will guide students through the activities using the directions provided on the following pages.

When students have finished making their cuts, encourage them to evaluate their work using the student evaluation sheets provided. Although student cuts are not expected to be perfect, it is important that students understand what they are doing right and wrong, and be able to articulate their understanding on the evaluation sheet.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| Freehand Cutting | 25 minutes |
| Template Cutting | 25 minutes |
| Review Student Evaluations and Wrap Up | 5 minutes |
| **Total Time:** | **60 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Set up the plasma system and make sure that you have material to cut for every student in the class.
2. Gather safety glasses for all of the students in the class for use during the cutting demonstration.
3. Gather at least one complete set of PPE (preferably 2 or more).
4. Make sure that every student has access to a copy of the "Quick Setup Guide."
5. Gather enough carbon steel for 50+ straight cuts (recommended: at least 3 feet (90 cm) x 1 foot (30 cm)).
6. Gather enough carbon steel for two straight cuts and two 3" (7.5 cm) squares per student (recommended: 6 - 7" (15 – 17.5 cm) x 12" (30 cm) of plate per student).
7. Make sure you have a straight edge and shape template for the template cutting exercise.
8. Print or copy "Evaluating Cut Quality" sheets for every student in the class (two sheets per student).

## Freehand Drop Cut

*The goal of this exercise is to build confidence with freehand plasma cutting by experimenting with technique, cut speed changes, torch angle changes, etc. In addition, students will be able to review and practice machine set-up and the proper use of personal protective equipment (PPE).*

**Timing:** 25-30 minutes

**Materials:**

1. Plasma cutter with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for 50+ straight cuts (recommended: at least 36" (90 cm) x 12" (30 cm)).

- *Giving your students the opportunity to practice making cuts on aluminum and stainless steel is recommended.*

**Directions:**

1. Bring the plasma system to cutting area of the workshop.
2. Mimic the **Machine Startup** activity; students take turns using the "Quick Setup Guide" to prepare the plasma system for cutting.
3. Review drop cut technique for group, demonstrating cut speed and torch angle WITHOUT actually cutting – leave the fun part for your class this time.
4. First student puts on full PPE and checks that system is ready for cutting.
5. Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on).
6. Each student will get the opportunity to perform 2-3 drop cuts.
7. Class observes the student cutting to provide constructive feedback.
8. After each cut, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments.

## Template Cut

*The goal of this exercise is to use a straight edge and template to cut with plasma. Students will practice technique, proper cut speed and torch angle, etc. In addition, students will be able to review and practice machine set-up and the proper use of personal protective equipment (PPE).*

**Timing:** 25-30 minutes

**Materials:**

1. Plasma cutter with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for two straight cuts and two 3" (7.5cm) squares per student (recommended: 6 - 7" (15 – 17.5 cm) x 12" (30 cm) x 3/8" (10 mm) thick plate per student).
6. Straight edge and an "H" shaped template.

- *Giving your students the opportunity to practice making cuts on aluminum and stainless steel is recommended.*

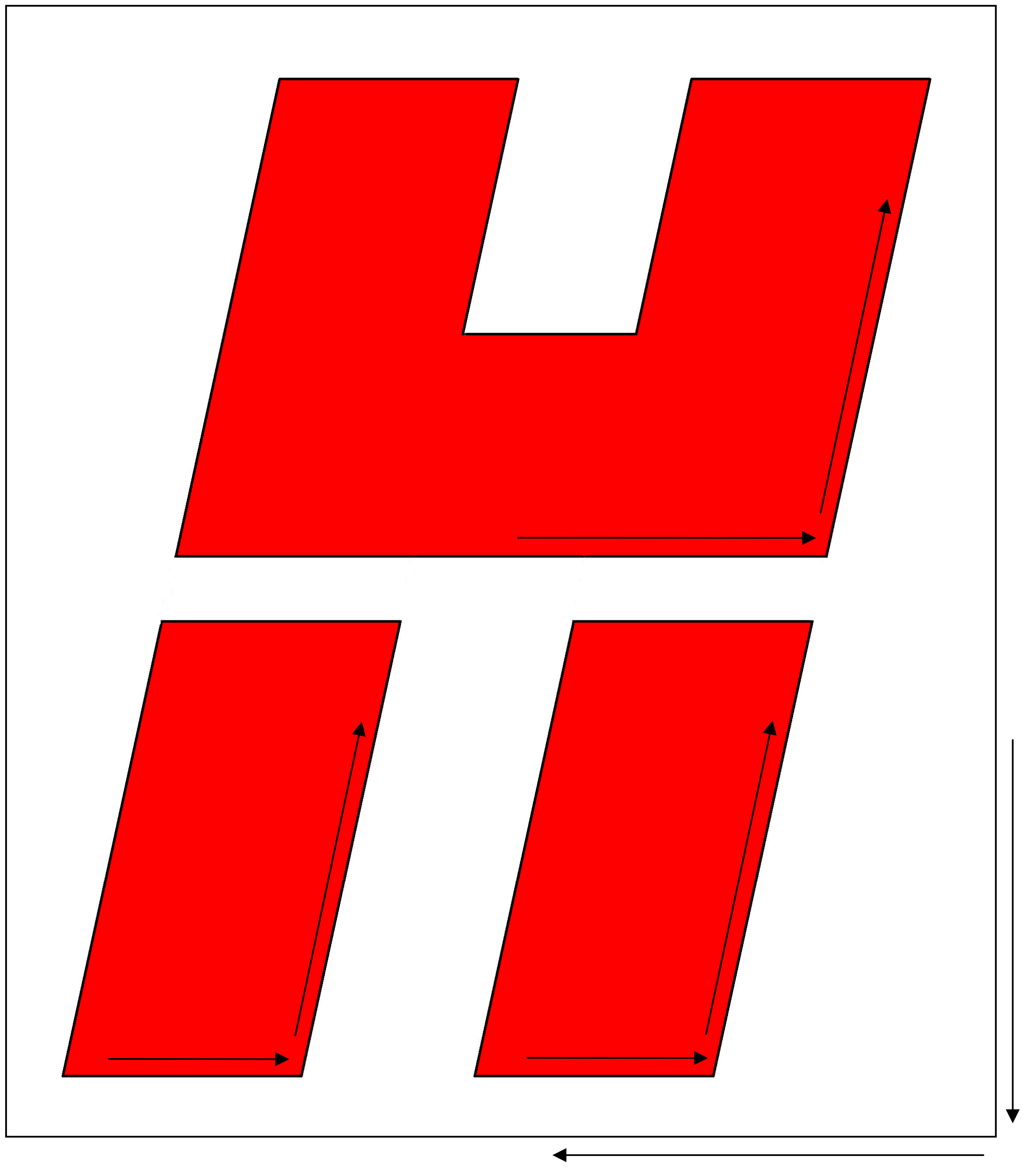
**Directions:**

1. Bring system to cutting area of the workshop.
2. Take turns using the "Quick Setup Guide" to prepare the plasma system for cutting.
3. Review straight edge and template cut techniques for group. Focus on consistent cut speed and torch angle. Be sure to point out **good side vs. bad side** of the cut – template cutting should be done **clockwise** if the finished piece is inside the template, and **counter-clockwise** if you are keeping the exterior and removing the piece within the template.
4. First participant puts on full PPE and checks that system is ready for cutting.
5. Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on).
6. Each learner will get the opportunity to perform 2 straight edge drop cuts and one template cut. A template is provided on the following page.
7. Class observes the person cutting to provide constructive feedback.
8. After each cut, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments.

Option #1: There is a sample template design provided on the next page of this Guide.

**Instructor Directions:**

1. Trace all lines onto plate.
2. Remove interior "H" pieces by cutting counter-clockwise.
3. Remove large rectangle by cutting clockwise.



## Review Student Evaluations and Wrap Up

*As students complete their cuts, ask them to complete a Cut Evaluation Sheet (as shown on the next page). Students should be able to assess their cuts and use instructor feedback to evaluate what they did right and wrong. These evaluation sheets should be turned in at the end of class. The instructor will use the student's evaluation sheets to help evaluate the "practice" portion of the course.*

As you conclude this class session, ask your students:

- Do you have any questions on the materials that were covered today?
- What information surprised you or was different than you expected?

Student Copy

Name: ______________________

Date: ______________________

# Evaluating Cut Quality

**1. Dross – the molten material that solidifies on the top or bottom of the work piece**

**Low Speed Dross** | **Dross Free** | **High Speed Dross**

| | | | | | | | |

What would you do to improve the dross buildup on the work piece?

**2. Cut Angle – the degree of angularity of the cut edge**

**Negative Cut Angle** | **Square Cut** | **Positive Cut Angle**

| | | | | | | | |

What would you do to improve the cut angle?

3. **Straightness of the Cut Surface – the cut surface can be concave or convex**

**Concave** | **Straight** | **Convex**

| | | | | | | | |

What would you do to improve the straightness of the cut surface?

# Session 9: Hole Piercing and Gouging

During this session, students will use the plasma cutter to practice hole piercing and gouging. There are no PowerPoint slides for this session. Instead, the instructor will guide students through the activities using the directions provided on the following pages.

When students have finished making their cuts, encourage them to evaluate their work using the student evaluation sheets provided. Although student cuts are not expected to be perfect, it is important that students understand what they are doing right and wrong, and be able to articulate their understanding on the evaluation sheet.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| Hole Piercing | 25 minutes |
| Gouging | 25 minutes |
| Review Student Evaluations and Wrap Up | 5 minutes |
| **Total Time:** | **60 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Set up the plasma system and make sure that you have material to cut for every student in the class.
2. Gather safety glasses for all of the students in the class for use during the cutting demonstration.
3. Gather at least one complete set of PPE (preferably 2 or more).
4. Make sure that every student has access to a copy of the appropriate “Quick Setup Guide.”
5. Gather enough carbon steel for three holes 2-3" (5 cm – 7.6 cm) in diameter per student (recommended: 4" (10 cm) x 12" (30 cm) of plate per student).
6. Gather enough carbon steel for two 6" (15 cm) x 1" (2.5 cm) gouges per student (recommended: 4" (10 cm) x 12" (30 cm) of plate per student).
7. Gather a ruler and 2 permanent markers .
8. Print or copy “Evaluating Cut Quality” sheets for every student in the class (two sheets per student).

## Hole Piercing

*The goal of this exercise is to practice the technique of hole piercing and circle cutting. In addition, students will be able to review and practice machine set-up and the proper use of personal protective equipment (PPE).*

**Timing:** 25-30 minutes

**Materials:**

1. Plasma cutter with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for three holes 2-3" (5 cm – 7.6 cm) in diameter per student [recommended: 4" (10cm) x 12" (30cm) x 3/8" (10mm) thick plate per student].
6. Chalk or paint marker.

- *Giving your students the opportunity to practice making cuts on aluminum and stainless steel is recommended.*

**Directions:**

1. Draw three circles per student, each with a diameter of 2 - 3" (5 cm – 7.6 cm).
2. Bring system to cutting area of the workshop.
3. First student will begin by using the "Quick Setup Guide" to prepare the plasma system for cutting.
4. Review hole pierce techniques for group. Focus on pierce angle, torch rollover to vertical, and freehand circle cutting. Be sure to point out **good side vs. bad side** of the cut – hole cutting should be done **clockwise** if the finished piece is inside the hole, and **counter-clockwise** if you are keeping the exterior and removing the piece within the hole!
5. First student puts on full PPE and checks that system is ready for cutting.
6. Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut).
7. Each student will get the opportunity to perform 3 hole pierces and circle cuts.
8. Class observes the student cutting to provide constructive feedback.
9. After each cut, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments.

Option #1: Write each student's name above their three hole pierce attempts. Use a straight edge to cut the finished plate into sections for each student. Have them write a short paragraph assessing their hole pierces, their progress from 1$^{st}$ try to 2$^{nd}$, and what they would do differently next time.

Option #2: Same as above, but hand out the hole pierces to different students.

## Gouging – Part One

*The goal of this exercise is to practice weld preparation by plasma gouging. In addition, students will be able to review and practice machine set-up and the proper use of personal protective equipment (PPE).*

**Timing:** 25-30 minutes

**Materials:**

1. Plasma cutter with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for two 6" (15 cm) x 1" (2.5 cm) gouges per student [recommended: 4" (10 cm) x 12" (30 cm) x 3/8" (10 mm) thick plate per student].
6. Ruler and chalk or paint marker.
7. Gouging consumables.

**Directions:**

1. Using chalk or paint marker, make two vertical lines ½" (12 mm) to ¾" (19 mm) apart.
2. Bring system to cutting area of the workshop.
3. First student will begin by using the "Quick Setup Guide" to prepare the plasma system for gouging – requires consumable set change.
4. Review gouging techniques for group. Focus on smooth motion and correct torch angle. Be sure to point out how gouge speed and torch angle affect the size and shape of the gouge.
5. First student puts on full PPE and checks that system is ready for gouging.
6. Check that everyone has protective eyewear on before gouging begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on).
7. Each student will get the opportunity to perform 2 gouges.
8. Class observes the student gouging to provide constructive feedback.
9. After each gouge, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments. Rate overall gouge on staying close to the edges of the lines without going through them, complete removal of material (off the edge of the plate), and consistent gouge depth (the depth can vary, but they should not sever the workpiece).

Option #1: Write each student's name above their two gouging attempts. Use a straight edge to cut the plate into sections for each student. Have them write a short paragraph assessing their gouges, their progress from 1st try to 2nd, and what they would do differently next time.

Student Copy

Name: ______________________________

Date: ______________________________

# Evaluating Gouge Quality

**4. Depth – vertical measurement from the base of the gouge to the top of the workpiece**

| **Too Shallow** | | | | **Preferred depth** | | | | **Too Deep** |
|---|---|---|---|---|---|---|---|---|
| \| | \| | \| | \| | \| | \| | \| | \| | \| |

What would you do to improve the gouge depth?

**5. Width – horizontal measurement from across the gouge**

| **Too Narrow** | | | | **Preferred width** | | | | **Too Wide** |
|---|---|---|---|---|---|---|---|---|
| \| | \| | \| | \| | \| | \| | \| | \| | \| |

What would you do to improve the gouge width?

## Review Student Evaluations and Wrap Up

*As students complete their gouging, ask them to evaluate their work. Students should be able to assess their gouges and use instructor feedback to evaluate what they did right and wrong.*

As you conclude this class session, ask your students:

- Do you have any questions on the materials that were covered today?
- What information surprised you or was different than you expected?

# Session 10: Gouging and Final Evaluations

During this session, students will use the plasma cutter to practice gouging one more time and then the facilitator will provide final evaluations to students. There are no PowerPoint slides for this session. Instead, the instructor will guide students through the activities using the directions provided on the following pages.

When students have finished making their cuts, encourage them to evaluate their work using the student evaluation sheets provided. Although student cuts are not expected to be perfect, it is important that students understand what they are doing right and wrong, and be able to articulate their understanding on the evaluation sheet.

The recommended timing for this session is as follows:

| Topic | Estimated Time |
|---|---|
| Introduction/Review | 5 minutes |
| Gouging | 25 minutes |
| Instructor Final Evaluations | 25 minutes |
| Wrap Up | 5 minutes |
| **Total Time:** | **60 minutes** |

## Before You Begin

It is recommended that you prepare for this session by completing the following tasks:

1. Set up the plasma system and make sure that you have material to cut for every student in the class.
2. Gather safety glasses for all of the students in the class for use during the cutting demonstration.
3. Print or copy “Evaluating Cut Quality” sheets for every student in the class (one sheet per student).
4. Gather enough carbon steel for two 6" (15 cm) x 1" (2.5 cm) gouges per student (recommended: 4" (10 cm) x 12" (30 cm) of plate per student).
5. Print or copy “Evaluating Cut Quality” sheets for every student in the class (two sheets per student).

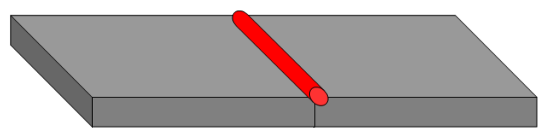
## Gouging – Part Two

*The goal of this exercise is to practice weld removal by plasma gouging. In addition, students will be able to review and practice machine set-up and the proper use of personal protective equipment (PPE).*

**Timing:** 25-30 minutes

**Materials:**
1. Plasma cutter with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Setup Guide."
5. Enough carbon steel for two 6" (15 cm) x 1" (2.5 cm) gouges per student (recommended: 4" (10 cm) x 12" (30 cm) x 3/8" (10 mm) thick plate per student).
6. Gouging consumables.

**Directions:**



1. Prior to activity, butt weld two pieces of steel (180° angle).
2. Bring system to cutting area of the workshop.
3. First student will begin by using the "Quick Setup Guide" to prepare the plasma system for gouging – requires consumable set change.
4. Review gouging techniques for group. Focus on smooth motion and correct torch angle. Be sure to point out how speed and torch angle affect the size and shape of the gouge.
5. First participant puts on full PPE and checks that system is ready for cutting.
6. Check that everyone has protective eyewear on before gouging begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on).
7. Each student will get the opportunity to perform 2 gouges.
8. Class observes the student gouging to provide constructive feedback.
9. After each gouge, stop and review technique with entire class. Point out what was done well BEFORE providing any suggestions/adjustments. Rate overall gouge on complete removal of material, condition of separated pieces, and consistent gouge depth.

If possible, you may wish to re-weld the gouged pieces to save material; use caution, as multiple cuts and gouges can make the plate very hot.

Option #1: Have the students practice the butt weld as well as gouging steps.

Student Copy

Name: ______________________

Date: ______________________

## Evaluating Gouge Quality

**6. Depth – vertical measurement from the base of the gouge to the top of the workpiece**

**Too Shallow** **Preferred depth** **Too Deep**

| | | | | | | | |

What would you do to improve the gouge depth?

**7. Width – horizontal measurement from across the gouge**

**Too Narrow** **Preferred width** **Too Wide**

| | | | | | | | |

What would you do to improve the gouge width?

## Review Student Evaluations and Wrap Up

*As students complete their gouging, ask them to evaluate their work.  Students should be able to assess their gouges and use instructor feedback to evaluate what they did right and wrong.*

As you conclude this class session, ask your students:

- Do you have any questions on the materials that were covered today?
- What information surprised you or was different than you expected?

## Final Practice Evaluations and Course Grading

As students complete the final gouging activity, speak with each student individually to review their cuts and evaluation sheets and provide personalized feedback and remediation.

For each student, you should have cut samples for each of the following activities:

1. Freehand Cut............................................................ 20%
2. Template Cut............................................................ 20%
3. Hole Pierce ............................................................... 20%
4. Gouging to prepare for welding................................ 20%
5. Gouging to remove a weld........................................ 20%

Review the student's cut and evaluation sheet for each of the 5 cuts. It is recommended that you provide verbal feedback in class and then review the cuts in greater detail when you have more time after class to assign "practice" grades for each of the cuts. Recall that you should not be grading on final cut quality, but rather on the student's ability to understand what he or she did right and wrong, and their ability to articulate their understanding on the cut evaluation sheets.

When you calculate the final grades for this course, it is recommended that you use the following weighting:

Grade on Theory Exam ............................................ 50%
Grade on Practice Cuts ............................................ 50%

# Glossary

| | |
|---|---|
| Bevel Cut | The cutting technique that uses a tilted torch to produce an angle on the edge of parts being cut. |
| Drop Cut | A cut that results in one section of the workpiece dropping away from the main piece. |
| Dross | Re-solidified molten metal and oxides adhering to the top or bottom edge of the workpiece during thermal cutting. |
| Electrode | The part of a consumable set that emits electrons in a steady stream to form the plasma arc. |
| Freehand Cut | Cuts made without the benefit of a straight edge or template. |
| Gouging | Removing metal from the surface of the plate without full penetration; used to remove old welds or prepare a surface for welding. |
| Guide Cut | Cuts made using a straight edge or template to guide the cut along a predefined path. |
| Hafnium | The metal used commonly as an electron emitter for air or oxygen plasma gases. |
| Hole Pierce | A method of starting a cut in which the arc plunges into and through the workpiece before cutting begins . |
| Kerf | The void left by the linear removal of material by any kind of cutting process; example: the width of the saw blade when cutting wood. |
| Nozzle | A consumable torch part containing a hole, or orifice, through which the arc passes. |
| Template Cut | Cuts made using a straight edge or template to guide the cut along a predefined path. |
| Torch | The part of the plasma system that is used to perform the actual cutting. |