



**GREEN
WELD**

Greenweld Impact Measurement

CU_GW_02

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Introduction

This document has been prepared to unify all contents that belong to the second competence unit (**CU_GW_02: GreenWeld Impact measurement**) in order to facilitate the study of the contents for the students. The teaching contents are separated into three parts, Part A and Part B, and Part C.

Part A

1. Parameters to measure the impact of welding work

Welding industry is making efforts to adopt more environmentally friendly practices, such as reducing energy consumption, using eco-friendly materials, and minimizing waste. This aligns with the broader trend of incorporating sustainable practices into various industries.

Measuring the **environmental impact of welding work** is crucial for promoting sustainability and minimizing negative effects on the environment.

The **key parameters** to consider:

Emissions

Welding processes can generate various harmful emissions and by-products that may have environmental and health impacts. The specific emissions depend on the welding method used, materials welded, and operating conditions. Here are some common environmental harmful emissions associated with welding:

Fumes and Particulate Matter:

Metal Fumes: Welding processes often produce metal fumes, such as manganese, chromium, nickel, and other alloying elements, which can be harmful if inhaled.

Particulate Matter (PM): Fine particulates can be released into the air during welding, contributing to air pollution.

Gases:

Ozone: Ozone can be formed as a by-product of welding, especially in processes involving high temperatures.



Nitrogen Oxides (NO_x): Welding at elevated temperatures can lead to the formation of nitrogen oxides, contributing to air pollution and respiratory issues.

Volatile Organic Compounds (VOCs): Hydrocarbons: Some welding processes release hydrocarbons, contributing to VOC emissions, which can have negative effects on air quality and contribute to air pollution.

Carbon Dioxide (CO₂): CO₂ Emissions: Welding processes that involve burning or combustion can release carbon dioxide, contributing to greenhouse gas emissions.

Welding Shielding Gases: Fluorinated Gases: Certain welding processes use shielding gases that contain fluorinated compounds, which can have a high global warming potential.

Oxides of Sulfur (SO_x): Sulfur Dioxide (SO₂): Welding activities can produce sulfur dioxide, especially if the materials being welded contain sulfur.

Noise Pollution (safety): Noise Emissions: Welding operations, particularly those involving heavy machinery, can contribute to noise pollution, affecting both the environment and the health of nearby individuals.

UV and Infrared Radiation: Radiation Emissions: Welding processes can emit ultraviolet (UV) and infrared (IR) radiation, which can be harmful to the eyes and skin of welders and can also contribute to heat buildup in the immediate environment

Efforts to mitigate these harmful emissions include using proper ventilation systems, adopting welding processes with reduced fume generation, implementing effective local exhaust ventilation (LEV), and utilizing personal protective equipment (PPE) for welders. Additionally, advancements in technology, such as the development of low-emission welding processes and the use of eco-friendly consumables, contribute to reducing the environmental impact of welding operations.

Welding operators should be aware of potential emissions and employ best practices to minimize their impact on both the environment and the health of workers. Compliance with environmental regulations and industry standards is also crucial in managing and reducing harmful emissions from welding activities.

Energy Consumption



Environmentally friendly welding aims to reduce the overall environmental impact, including energy consumption. Here are several strategies and technologies employed in welding to make the process more energy-efficient. **Energy Consumption is also mentioned in a previous chapter, as it is a critical parameter in terms of environmentally friendly processes.**

Power Consumption

Assess the energy consumption of welding equipment and processes to identify opportunities for energy efficiency

Inverter Technology: Inverter-based welding machines are more energy-efficient than traditional transformer-based machines. They convert AC power to DC power more efficiently, reducing energy consumption.

Pulse Welding: Pulse welding processes, such as pulsed MIG (Metal Inert Gas) or TIG (Tungsten Inert Gas) welding, allow for precise control of the heat input. This can lead to reduced energy consumption and improved efficiency.

High-Frequency Start Systems: Some welding processes, like TIG welding, use high-frequency start systems, which consume less energy during the starting phase compared to traditional methods.

Advanced Welding Processes: Certain advanced welding processes, such as laser welding or electron beam welding, can be more energy-efficient compared to traditional arc welding methods.

Efficient Power Sources: Selecting energy-efficient welding power sources can contribute to reducing overall energy consumption. Look for machines with high power factor and efficiency ratings.

Energy Recovery Systems: Some modern welding equipment incorporates energy recovery systems, capturing and reusing energy that would otherwise be wasted, thus increasing overall efficiency.

Energy-Efficient Lighting: Implementing energy-efficient lighting in welding shops can contribute to reducing overall energy consumption (LED lighting).

Automated Welding Systems: Automation and robotic welding systems are designed for precision and efficiency, reducing the need for human intervention and minimizing energy waste.



Welding Parameter Optimization: Ensuring that welding parameters such as **voltage, current, and travel speed are optimized** for the specific application can contribute to energy efficiency.

Energy Management Practices: Implementing energy management practices, such as scheduling welding operations during non-peak hours or shutting down equipment when not in use, helps reduce unnecessary energy consumption.

Use of Renewable Energy: Consider the use of renewable energy sources. Where feasible, consider powering welding operations with renewable energy sources such as solar or wind power. This can significantly reduce the environmental impact associated with energy consumption.

Material Usage and Waste

Minimizing material usage and waste is a key aspect of environmentally friendly welding. Waste of materials may be categorized in

Consumable Waste: Minimize the generation of consumable waste such as welding electrodes, wires, and shielding gases.

Base Metal Waste: Manage and recycle scrap metal generated during welding to reduce overall material waste.

Several **strategies and practices to reduce material consumption** and manage waste effectively are presented to Part C | Chapter 4 . Waste and material reduction.

Hazardous Substances

While environment-friendly welding practices aim to minimize environmental impact, it's important to consider potential hazardous substances associated with welding activities, which can easily be categorized in general on:

Hazardous Fumes: Hazardous fumes and gases produced during welding.

Chemical Substances: Harmful chemicals and substances in welding processes.

Key considerations for handling hazardous substances in an environmentally friendly welding setting



Low Emission Processes: Choose welding processes that emit fewer hazardous substances. For example, processes like gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW) typically produce fewer fumes compared to some other welding methods.

Emission Capture and Ventilation: Implement effective local exhaust ventilation (LEV) systems to capture and remove welding fumes at the source, reducing exposure to hazardous airborne particles.

Substitute Hazardous Materials: Explore alternatives to hazardous welding materials. For instance, consider low-emission or non-toxic shielding gases, and choose consumables with reduced levels of hazardous elements.

Hexavalent Chromium Alternatives: Hexavalent chromium, often present in stainless steel welding, can be hazardous. Explore alternatives, such as using stainless steel with lower chromium content or employing processes that produce less hexavalent chromium.

Flux and Coating Selection: Choose welding fluxes and coatings that contain fewer hazardous substances. Some fluxes may contain compounds that release harmful emissions during welding.

Welding Wire and Electrode Composition: Choose welding wires and electrodes with compositions that minimize the emission of hazardous elements. Look for products with reduced levels of substances like manganese, nickel, or other potential irritants.

Waste Management: Properly manage and dispose of hazardous waste generated during welding operations. This includes used welding consumables, contaminated protective equipment, and other materials that may pose a risk.

Regular Monitoring and Testing: Conduct regular air quality monitoring and testing to assess the concentration of hazardous substances in the workplace.

Material Safety Data Sheets (MSDS): Maintain up-to-date MSDS for all welding materials used. These sheets provide information on the properties, hazards, and safe handling of substances used in the welding process.

Welding in Controlled Environments: Consider conducting welding activities in controlled environments, such as welding booths or enclosures, to better manage and control exposure to hazardous substances.



Environmental Management Systems (EMS): Implement an EMS to systematically identify, monitor, and manage the environmental aspects, including the use of hazardous substances, associated with welding operations.

By integrating these measures into environmentally friendly welding practices, it is possible to minimize the impact of hazardous substances on both the environment and the health and safety of welding personnel. Regular risk assessments and ongoing efforts to identify and adopt safer alternatives contribute to a more sustainable approach to welding

Water Usage

Water Consumption: Evaluate the amount of water used in cooling systems and other aspects of the welding process. Implement water-saving measures where applicable.

Managing water usage in welding processes is an important aspect of environmentally friendly practices. While welding operations may not be as water-intensive as some other industrial processes, evaluation of the amount of water used in cooling systems and other aspects of the welding process may be considered. Here are some considerations for minimizing water usage in environmentally friendly welding:

Cooling Systems: Implement efficient and closed-loop cooling systems for welding equipment to reduce water consumption. Closed-loop systems recirculate water, minimizing the need for fresh water.

Water Recycling: Explore water recycling and reuse systems where feasible. Some water used in cooling systems can be treated and recycled, reducing the demand for new water.

Low-Flow Water Cooling: Choose low-flow water cooling systems that use water more efficiently without compromising the cooling effectiveness. This helps minimize the overall water consumption.

Process Optimization: Optimize welding processes to reduce the need for excess water. For example, adjusting parameters to minimize spatter and splatter can result in less need for water-based clean-up processes.



Water-Efficient Cutting Methods: Choose water-efficient cutting methods, such as waterjet cutting, which uses water more efficiently compared to traditional cutting methods.

Weld Joint Design: Optimize weld joint designs to minimize the need for water-intensive post-welding cleaning processes. Efficient joint designs can reduce the amount of material and cleaning required.

Use of Eco-Friendly Coolants: When water is used as a coolant, consider using eco-friendly coolants that are less harmful to the environment.

Water Management Plans: Develop water management plans that outline strategies for reducing water consumption, recycling, and minimizing environmental impact.

Regular Monitoring and Auditing: Conduct regular monitoring and audits of water usage in welding processes. This helps identify areas for improvement and ensures compliance with water efficiency goals.

Technology Upgrades: Invest in modern welding equipment that incorporates water-efficient technologies. Newer technologies may offer improved efficiency and reduced water consumption compared to older equipment.

Drip Pans and Containment Systems: Use drip pans and containment systems to capture water and prevent it from being wasted or contaminating the surrounding environment.

Water Quality: Maintain good water quality to prevent corrosion and scaling in cooling systems, which can affect efficiency and increase water usage.

Rainwater Harvesting: Consider incorporating rainwater harvesting systems to collect and utilize rainwater for non-critical water needs in the welding facility.

By adopting these measures, welding operations can contribute to water conservation and minimize their environmental impact. Integrating water-efficient practices into welding processes aligns with broader sustainability goals and helps ensure responsible resource management.

Environmental Compliance

Ensure compliance with local, regional, and national environmental regulations related to welding activities. Environmental compliance in welding involves adhering to regulations and standards



designed to minimize the environmental impact of welding activities. Compliance ensures that welding operations are conducted in a manner that protects the environment, surrounding communities, and the health and safety of workers. Key aspects of environmental compliance for environmentally friendly welding:

Regulatory Knowledge: Stay informed about local, regional, and national environmental regulations that apply to welding operations. Regulations may include emission standards, waste management requirements, and water usage guidelines.

Permitting and Reporting: Obtain any necessary permits for welding activities and ensure timely and accurate reporting to regulatory authorities as required. This may include air quality permits, water discharge permits, or hazardous waste permits.

Air Quality Compliance: Monitor and control air emissions from welding processes to comply with air quality standards. This may involve the use of ventilation systems, emission capture technologies, and regular emission testing.

Hazardous Material Management: Manage hazardous materials used in welding processes in accordance with regulations. This includes proper storage, handling, labeling, and disposal of materials such as welding consumables, gases, and chemicals.

Waste Management and Recycling: Implement proper waste management practices, including the recycling or proper disposal of welding-related waste. Ensure compliance with regulations regarding the handling and disposal of hazardous and non-hazardous waste.

Water Quality Compliance: Adhere to regulations related to water usage and discharge. Ensure that water used in welding processes and associated cooling systems meets quality standards and is managed responsibly.

Record Keeping: Maintain accurate and up-to-date records related to environmental compliance. This includes documentation of emissions testing, waste disposal records, and any other information required by regulatory authorities.

Environmental Management Systems (EMS): Implement an Environmental Management System to systematically identify, manage, monitor, and continuously improve environmental performance. This may involve setting environmental objectives, conducting regular audits, and ensuring compliance with relevant standards.



Community Engagement: Engage with the local community and stakeholders to address concerns, provide information about environmental initiatives, and foster positive relationships. Transparent communication can contribute to community support and compliance with regulatory expectations.

Continuous Improvement: Regularly review and update environmental management practices to ensure they remain effective and aligned with changing regulations. Seek opportunities for continuous improvement in environmental performance.

By prioritizing environmental compliance in welding operations, businesses can contribute to sustainable practices, maintain a positive relationship with regulatory authorities, and demonstrate a commitment to environmental stewardship.

Green Welding Technologies

Green welding technologies, also known as environmentally friendly or sustainable welding technologies, aim to reduce the environmental impact of welding processes. These technologies focus on minimizing energy consumption, emissions, and waste while maintaining or improving the quality and efficiency of welding operations. Green welding technologies may be categorized to processes and equipment, **and they are also included in a previous chapter, highlighting the importance as a green parameter.**

Here are some examples of green welding technologies

Advanced Welding Processes

Explore and implement advanced welding technologies that are designed to be more environmentally friendly, such as processes with reduced emissions.

Friction Stir Welding (FSW): FSW is a solid-state welding process that generates less heat and produces minimal fumes compared to traditional welding methods.

Electron Beam Welding (EBW): EBW is a high-energy welding process that uses an electron beam to create precise and efficient welds, reducing the need for filler materials.



Pulsed Welding: Pulsed MIG (Metal Inert Gas) and TIG (Tungsten Inert Gas): Pulsed welding processes allow for better control of heat input, reducing energy consumption and minimizing distortion while improving weld quality.

Cold Metal Transfer (CMT): CMT is a welding process that operates at lower temperatures, reducing heat input and energy consumption. It is particularly suitable for joining dissimilar materials.

Plasma Arc Welding (PAW) and Cutting (PAC): Plasma processes can be more energy-efficient compared to traditional welding methods. PAC, in particular, is known for its precision and reduced heat input.

Efficient Equipment

Use energy-efficient welding equipment and technologies that contribute to lower environmental impact.

High-Efficiency Power Sources: Inverter Technology: Inverter-based welding machines are more energy-efficient compared to traditional transformer-based machines. They convert power more efficiently and can contribute to overall energy savings.

Efficient Cooling Systems: Water-Cooling Systems: Implementing water-cooling systems for welding equipment can improve energy efficiency by reducing the need for excess cooling.

Robotics and Automation: Robotic Welding: Automation can lead to more consistent and precise welds, reducing the need for rework and optimizing material usage. It can also contribute to energy efficiency by optimizing welding parameters.

Lightweight Materials and Thin-Section Welding: Using lightweight materials and welding thin sections can reduce material consumption and energy requirements.

Energy Recovery Systems: Some modern welding equipment includes energy recovery systems that capture and reuse energy, improving overall efficiency and reducing energy consumption.

Low-Emission Consumables: Using consumables with low emissions, such as low-fume welding wires and electrodes, can help minimize air pollution and improve the working environment for welders.



Welding Simulation Software: Welding simulation software allows for virtual testing and optimization of welding parameters, reducing the need for physical trial and error. This can lead to more efficient and resource-friendly welding processes.

Green Coating Technologies: Implementing eco-friendly coatings that reduce the need for pre-welding cleaning processes can contribute to a more sustainable welding operation.

Carbon Footprint Analysis: Conducting carbon footprint analyses for welding processes to identify areas for improvement and implement strategies to reduce overall environmental impact.

By incorporating these technologies and practices, industries can move towards more sustainable and environmentally friendly welding operations. The goal is to strike a balance between meeting welding requirements and minimizing the ecological footprint of these processes.

Transportation Impact

Logistics and Transportation: Consider the environmental impact of transporting materials, equipment, and finished products associated with welding activities.

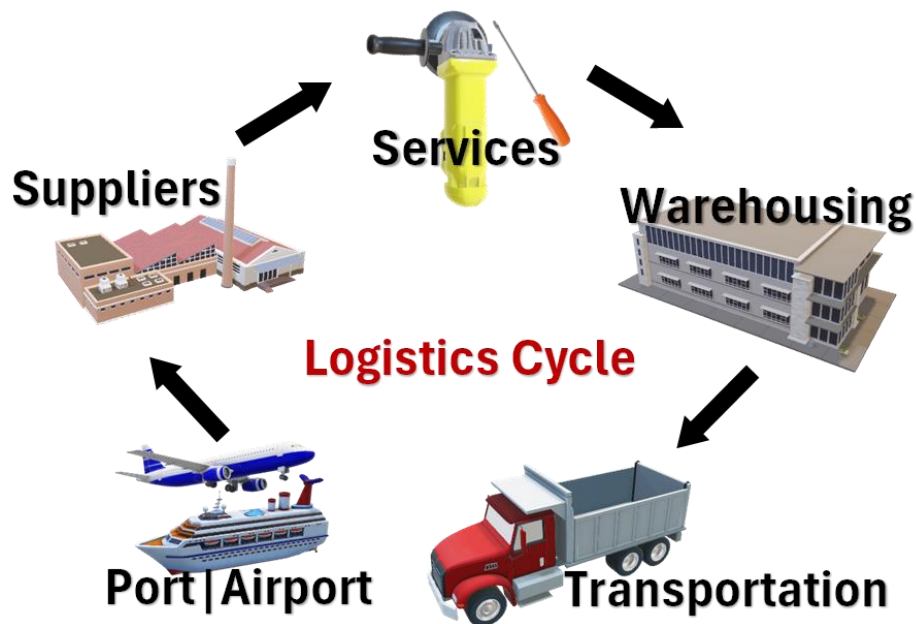


Figure 1 – Illustration of the logistics cycle.

Carbon Footprint



Carbon Emissions: Calculate and monitor the carbon footprint of welding activities, considering the overall greenhouse gas emissions associated with the process, by analysing the carbon footprint of welding involves assessing the environmental impact of the entire welding process, from raw material extraction to the end of the product's life cycle.

During Welding process a lot of other activities **before, during and after** welding are taking place. Per example:

The welding procedure that is going to be performed is MAG Welding procedure on Carbon Steel plate with 6mm thickness. To implement this activity **Before**: someone purchase the welding power source, **during**: Corgon as Shielded gas is going to be used **After**: Start and Stop locations of the weld seam are going to be removed.

Meaning:

Before: The power Source that is purchased by the company shall be energy efficient power source. Responsible Party: Purchase Department

During: Shielded gas rate shall be measured with appropriate equipment, Responsible Person: Welder to know how to use the equipment, Company to provide the equipment

After: Metal Scrap after the welding process is completed. Responsible: Company to implement collecting, recycling procedures.

From the above example, we understand that the footprint of a procedure is depending to a lot of other activities connected to this procedure. Meaning, that it is depended on more that one person, responsible for each activity.

Welders and Welder operators are responsible for the welding procedure and have to do their part on each connected activity.

It is estimated that the construction sector, which includes welding procedures, is responsible for over 35% of the EU's total waste generation. This why European Rules and Norms are getting more and more strict regarding environment and construction.

Environmental Management Systems (EMS)

EMS Implementation: Adopt an environmental management system to systematically manage and improve the environmental performance of welding operations.



Green welding technologies and sustainable practices can contribute to minimizing the overall environmental impact of welding work.

2. Measurement Types and Techniques for Green Welding

Measuring and monitoring environmental performance in welding operations is crucial for assessing the effectiveness of environmentally friendly practices. Various types of measurements and techniques can be employed to evaluate different aspects of the welding process.

Following, are presented some measurement types and techniques for environment-friendly welding:

Emissions Monitoring

Emissions monitoring in welding involves the measurement and assessment of various pollutants and airborne contaminants released during the welding process. Monitoring emissions is crucial for ensuring workplace safety, compliance with environmental regulations, and promoting environmentally friendly practices.

Type of measurement:	Air quality monitoring for particulate matter, metal fumes, and gases
<i>Measurement Techniques</i>	Direct Sampling: Collect air samples during welding activities and analyze them for pollutants
	Continuous Emissions Monitoring Systems (CEMS): Install CEMS to continuously measure emissions during welding processes

Particulate Matter (PM):	Particulate matter is measured in terms of particle size and concentration
Instrumentation:	Particulate matter (PM) emission measuring equipment in welding is designed to quantify the concentration and characteristics of airborne particles generated during welding processes. These measurements are essential for assessing worker exposure, ensuring compliance with



	<p>environmental regulations, and implementing effective control measures to minimize the impact of welding emissions</p> <ul style="list-style-type: none">• Real-Time Particle Counters: These devices provide real-time measurement of particle concentrations in different size ranges, with continuous monitoring of particulate matter during welding operations. They are portable and easy to use, with the capability to measure particle counts and size distributions in the nanometer to micrometer range.• Gravimetric Samplers: They collect particulate matter on a filter over a specified period, and the filter is then weighed to determine the mass concentration. It is often used for regulatory compliance monitoring, but requires laboratory analysis for accurate results and adherence to specific sampling protocols.• Personal Dust Monitors: Portable devices worn by workers to measure personal exposure to airborne particulate matter. Provides real-time data on a worker's exposure to dust during welding activities. Lightweight, easy to wear, and offers immediate feedback on exposure levels.• High-Volume Air Samplers: It draws a large volume of air through a filter, collecting particulate matter for subsequent analysis. It is used for collecting bulk samples over an extended period for detailed analysis. It is also suitable for both indoor and outdoor air sampling, but not as portable as real-time counters.• Direct-Reading Dust Monitors: They are categorized as Real-time monitors that use light scattering or other technologies to measure particulate concentrations, offering continuous monitoring of airborne dust levels during welding activities. They provide immediate feedback on particulate concentrations, helping to assess the effectiveness of control measures in real time.• Cascade Impactors: They separate particles based on size using a series of stages with different aerodynamic cutpoints. They are used for determining the particle size distribution of welding fumes.
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	<ul style="list-style-type: none"> • Nephelometers: Measures the light scattering caused by airborne particles to determine their concentration, in Real-time monitoring. They are portable and provides continuous, immediate results. • Indoor Air Quality (IAQ) Monitors: Monitors designed to assess indoor air quality, including particulate matter, suitable for monitoring welding emissions in indoor environments. • Dust Trak Monitors: Real-time monitors that use light scattering to measure particulate matter concentrations, providing continuous monitoring of airborne dust levels during welding activities. They are portable and provides real-time data on particulate concentrations.
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Fume Composition:	Fume composition measurement in welding involves the identification and quantification of specific metal fumes and gases generated during welding processes.
Instrumentation:	<p>Measuring the composition of welding fumes is essential for assessing potential hazards and implementing effective control measures. Various types of equipment and analytical techniques are used for fume composition measurement in welding.</p> <ul style="list-style-type: none"> • Elemental Analysis Techniques determine the elemental composition of fumes by analyzing the presence and concentration of specific metals. <ul style="list-style-type: none"> • X-ray Fluorescence (XRF): Excite atoms in the sample with X-rays and measure the resulting fluorescence to identify and quantify metals in welding fumes. Portable XRF analyzers are available for on-site analysis. • Inductively Coupled Plasma Mass Spectrometry (ICP-MS): Ionize the sample in a plasma torch and measure the mass-to-charge ratio of ions for elemental analysis. It quantifies trace metals in welding fumes and provides high sensitivity and accuracy. • Gas Chromatography-Mass Spectrometry: Separates and analyzes the components of gaseous fumes, by identifying and quantifying volatile



	<p>organic compounds (VOCs) and other gases released during welding, it is useful for analyzing complex gas mixtures.</p> <ul style="list-style-type: none"> • X-ray Diffraction (XRD): Analyzes and identifies the crystal structure of particulate matter to identify specific compounds. It provides information on the crystalline phases present in the fumes. • Fourier Transform Infrared Spectroscopy (FTIR): Measures the absorption of infrared light by different chemical bonds, allowing for identification of specific compounds (organic and inorganic) It is really effective for analyzing a wide range of chemical species. • Energy-Dispersive X-ray Spectroscopy (EDS): Analyze the X-rays emitted by a sample when bombarded with electrons to determine elemental composition. It is often integrated into scanning electron microscopes. • Total Carbon and Nitrogen Analysis: Measure the total carbon and nitrogen content in fume samples, by assessing the total organic content of welding fumes. Combustion-based methods are commonly used for total carbon and nitrogen determination. • Mass Spectrometry (MS): Ionize and separate ions based on their mass-to-charge ratio for identification and quantification. It is used for analyzing the composition of gases and volatile compounds in welding fumes, with high sensitivity and specificity.
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Volatile Organic Compounds (VOCs):	Detection and quantification of organic compounds, as VOCs can be released during welding processes from various sources, including the use of coatings, solvents, and consumables.
Instrumentation:	<p>The selection of equipment and methods depends on factors such as the specific VOCs of interest, the complexity of the sample matrix, and the analytical requirements, with various types of equipment and instruments available.</p> <ul style="list-style-type: none"> • Gas Chromatography (GC): Separates and quantifies individual VOCs based on their chemical properties, by identifying and quantifying specific VOCs emitted during welding. They provide high precision and sensitivity and they are suitable for laboratory analysis.



	<ul style="list-style-type: none"> • Gas Chromatography-Mass Spectrometry (GC-MS): It combines GC with mass spectrometry for enhanced identification and quantification of VOCs., providing both separation and identification of VOCs. • Flame Ionization Detector (FID): Measures the ionization of organic compounds in a flame to quantify VOC concentrations, by continuous monitoring of total VOC levels in welding environments, providing high sensitivity to a broad range of organic compounds. • Photoionization Detector (PID): Measures ionization of VOCs when exposed to ultraviolet light, in • Real-time monitoring of specific VOCs in welding fumes. It is portable and provides immediate readings. • Infrared (IR) Spectroscopy: Analyzes the absorption of infrared light by VOCs for identification and quantification of specific VOCs. It can be used for real-time monitoring and laboratory analysis. • Ion Mobility Spectrometry (IMS): Measures the mobility of ions in a gas for rapid detection of VOCs in welding environments, with high sensitivity and quick response. • Total VOC (TVOC) Analyzers: Measures the overall concentration of VOCs without identifying individual compounds, with continuous monitoring of total VOC levels in the air. It provides a comprehensive assessment of the total VOC burden. • Direct-Reading Instruments: It is a portable instrument that provides immediate readings of specific VOCs, compact, easy to use, and suitable for on-site measurements. • Canister Sampling: Collects air samples in canisters for subsequent analysis at specific times and it is useful for detailed laboratory analysis of VOCs.
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<p>Gaseous Emissions</p>	<p>Monitoring of specific gases such as nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3), and other gases produced during the welding process.</p>
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Instrumentation:	<p>To measure gaseous emissions in welding, various types of equipment and instruments are available. The choice of equipment depends on the specific gases of interest, the measurement accuracy required, and the conditions of the welding operation.</p> <ul style="list-style-type: none">• Gas Analyzers: Measure the concentration of specific gases in the air, such as CO, NO_x, SO₂ during welding activities. It is portable or stationary and can provide real-time data.• Infrared Gas Analyzers (IRGA): It utilizes the absorption of infrared light by gases to measure their concentration, by quantifying gases like CO and CO₂ emitted during welding. Provides high sensitivity and selective for specific gases.• Electrochemical Sensors: It uses chemical reactions to generate an electric current proportional to the gas concentration, providing in Real-time monitoring of gases such as CO and NO_x. It is portable, cost-effective, and suitable for on-site measurements.• Flame Ionization Detector (FID): Measures the ionization of organic compounds in a flame to quantify total hydrocarbons, and monitors the total hydrocarbons released during welding. It is sensitive to a broad range of organic compounds.• Chemiluminescence Analyzers: It exploits the light emission resulting from a chemical reaction to measure NO and NO₂, by monitoring nitrogen oxides (NO_x) in welding emissions. Provides high sensitivity and specificity for NO_x gases.• Tunable Diode Laser Absorption Spectroscopy (TDLAS): Measures the absorption of specific wavelengths of laser light by gases, with high precision on specific gases like CO, CO₂, and methane. Gives high sensitivity, suitable for research and detailed analysis.• Gas Chromatography (GC): Separates and quantifies individual gases based on their chemical properties, but it is a laboratory-based technique.• Photoacoustic Spectroscopy (PAS): Measures the sound waves generated by the absorption of laser light to quantify gases, and it is sensitive and selective for certain gases.
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	<ul style="list-style-type: none"> • Cavity Ring-Down Spectroscopy (CRDS): it measures the time it takes for light to decay in a cavity to quantify gas concentrations, giving high-precision measurement of gases like CO2. It is extremely high sensitivity and accuracy
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Gas Flow Rates	<p>Measuring gas flow rates (volume of gases) in welding processes is essential for ensuring the proper shielding of the weld area and achieving high-quality welds. The flow rates of shielding gases, such as argon, carbon dioxide, or a mixture of gases, are critical parameters that impact the stability of the arc, weld bead formation, and overall weld quality.</p>
Instrumentation:	<ul style="list-style-type: none"> • Flowmeters: Measure the volumetric flow rate of a gas passing through a tube or pipe, and monitoring and controlling the flow of shielding gases. Provides direct reading of flow rates, available in various designs (rotameter, ball float, or digital). • Rotameters: They use a tapered tube and a float to indicate the flow rate of a gas, commonly used in welding. It is simple, cost-effective, and easy to read equipment. • Mass Flow Meters: It's direct Measure the mass of a gas flowing through a sensor for better accuracy. It is suitable for various gases, with high accuracy, and can provide direct digital readings. • Thermal Mass Flow Meters: Measures the convective heat transfer from a heated sensor in contact with the flowing gas, providing an accurate measurement of mass flow rates for gases. It is suitable for a wide range of gases, giving high accuracy, and digital output. • Differential Pressure Flowmeters: Measure the pressure drop across a constriction in the flow path to determine flow rate, and it is suitable for gases and liquids in various industries, including welding. It is available in different types, such as orifice plates, venturi tubes, and flow nozzles. • Variable Area Flowmeters: Use a tapered tube and a float, but the float position varies based on flow rate so it can monitor the gas flow rates in welding applications. It is easy to read available in different materials.



	<ul style="list-style-type: none"> • Ultrasonic Flowmeters: Measure the transit time of ultrasonic signals across a flowing gas, it is suitable for non-intrusive flow measurement of gases, but has no moving parts, it is good for clean gases, and minimal pressure drop.
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Energy Consumption

<p><u>Type of measurement:</u></p>	<p>Measurement of energy usage during welding operations. We choose the method that best fits our specific needs and the type of welding process. Combining multiple measurement techniques may offer a more comprehensive understanding of energy consumption during welding</p>
<p><u>Measurement Techniques</u></p>	<ul style="list-style-type: none"> • Utility Bills: Track energy consumption through utility bills and assess trends • Power Meters directly measure electrical power consumption by connecting them between the welding machine and the power source. This method provides a direct measurement of electrical power but may not account for other forms of energy consumption, such as gas usage. • Specialized welding Process Monitors can be used to measure and analyze various parameters during welding, including energy consumption. These devices typically monitor voltage, current, and other relevant parameters to calculate energy consumption. Some advanced monitors can be directly integrated into welding equipment, providing detailed data on the welding process, allowing for more comprehensive energy analysis.

Material Efficiency

<p><u>Type of measurement:</u></p>	<p>Measurement of material usage and waste generation, to optimize resources usage. We may use a combination of equipment and techniques to monitor and optimize material usage, by weighing and Recording: (Weight materials before and after welding to track consumption and waste) and/ or by Material Flow Analysis (assess the flow of materials through the welding process to identify opportunities for efficiency improvements)</p>
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<p><u>Measurement Techniques</u></p>	<ul style="list-style-type: none">• Weighing Scales: Weigh raw materials before welding and weigh the finished product after welding to calculate the material used. Compare this to the weight of the final product to determine material efficiency.• Volume Measurement Devices: For materials in bulk or in liquid form, measure the volumes before and after welding to assess the amount of material used.• Waste Collection and Analysis: (Bins or containers for collecting waste materials), collect and segregate waste generated during welding. Weigh or measure the waste to determine the percentage of material that becomes scrap.• Cutting Pattern Optimization Software: Utilize software tools to optimize cutting patterns for flat materials, minimizing waste during the cutting process.• Welding Consumable Monitoring Devices which are integrated with welding machines. Monitor the consumption of welding consumables (electrodes, welding wire) during welding operations. Some welding machines have integrated counters or sensors for this purpose.• Gas Flow Meters: Measure and monitor the flow rates of shielding gases to ensure optimal usage during welding. This helps in minimizing waste and improving gas efficiency.<ul style="list-style-type: none">• Welding Wire Deposition Monitoring: These systems measure the actual deposition of welding wire into the welding joint, providing insights into the efficiency of wire usage.• Material Traceability Systems: Barcode scanners, RFID systems, or other traceability tools to implement traceability systems to track the origin and usage of materials throughout the welding process. This helps in identifying inefficiencies and areas for improvement.• Real-Time Monitoring Systems: Sensors, data loggers, or IoT devices to implement real-time monitoring systems to track material usage during welding operations. This provides instant feedback for process optimization.
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	<ul style="list-style-type: none"> • Lean Manufacturing Tools for implementing lean manufacturing principles, by applying lean methodologies to identify and eliminate waste in the welding process, promoting efficient material usage. • Environmental Performance Software: Environmental performance tracking software to be used as tool to track key performance indicators (KPIs) related to material efficiency and environmental impact.

Water Usage

<i>Type of measurement:</i>	Measurement of water consumption in welding operations
<i>Measurement Techniques</i>	<ul style="list-style-type: none"> • Install flow meters in the water supply lines of water-cooled welding systems, which are measuring the volume of water passing through, providing real-time data on water consumption. • Water Quality Sensors to monitor the condition of the water in the cooling system (parameters like pH, conductivity, and impurity levels) to ensures that the water used in welding processes remains within specified quality parameters, reducing the need for frequent replacements. • Implement data logging systems to record water consumption over time. It provides historical data for analysis, helping identify patterns and potential areas for improvement. • Drip Pans and Collection Systems under welding equipment that collects water runoff for measurement.

Weld Quality and Defects

<i>Type of measurement:</i>	Measurement of weld quality and defects.
	Visual Inspection: Regularly inspect welds for quality and identify defects



<i>Measurement Techniques</i>	Non-Destructive Testing (NDT): Use NDT methods such as ultrasonic testing or radiography to assess weld quality without damaging the material. Each NDT method needs different equipment
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Greenhouse Gas Emissions

<i>Type of measurement:</i>	Measurement of greenhouse gas emissions associated with welding processes.
<i>Measurement Techniques</i>	Emission Factors: Use emission factors for different welding processes to estimate greenhouse gas emissions
	Carbon Footprint Analysis: Conduct a comprehensive analysis to quantify the carbon footprint of welding operations.

Waste Generation and Recycling

<i>Type of measurement:</i>	Measurement of waste generation and recycling rates
<i>Measurement Techniques</i>	Waste Audits: Conduct regular waste audits to assess the types and quantities of waste generated
	Recycling Tracking: Monitor the amount of materials recycled, such as metal scrap
	Regular monitoring and measurement, combined with effective data analysis, enable organizations to make informed decisions, identify areas for improvement, and track progress toward environmental sustainability goals in welding operations



3. International Standard, European Legislation and Acceptance criteria

International standards, European legislation, and acceptance criteria related to environmentally friendly welding are subject to change nowadays due to the high need for sustainability.

International Standards

ISO 14001: Environmental Management Systems: ISO 14001 is an international standard specifying the requirements for an environmental management system (EMS). It provides a framework for organizations to manage their environmental impact, including those related to welding processes.

ISO 3834: Quality Requirements for Fusion Welding of Metallic Materials: ISO 3834 outlines quality requirements for fusion welding of metallic materials. While it primarily focuses on quality aspects, adherence to these standards can indirectly contribute to environmental considerations. EWF 639 and EWF 637, provide detailed guidance for Assessment of Manufacturers of Welded Products in accordance with ISO 3834

European Legislation

REACH Regulation (EC) No 1907/2006: Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) is a European Union regulation that addresses the production and use of chemical substances. Compliance with REACH is essential for managing the environmental impact of welding consumables and chemicals used in the process.

RoHS Directive (2011/65/EU): The Restriction of Hazardous Substances (RoHS) Directive restricts the use of certain hazardous substances in electrical and electronic equipment. While not specific to welding, it may impact the selection of materials and components used in welding equipment.

European Waste Framework Directive (2008/98/EC): This directive sets out the legal framework for waste management in the European Union. It emphasizes waste prevention and the promotion of recycling, which can be relevant for managing waste generated during welding processes.



Acceptance Criteria

Environmental Performance Indicators: Organizations may establish specific environmental performance indicators as acceptance criteria. These can include metrics related to energy efficiency, emissions reduction, and waste minimization in welding operations.

Adherence to Industry Standards: Industries may have specific standards or guidelines that set acceptance criteria for environmentally friendly welding practices. These could cover aspects such as emissions control, waste management, and energy efficiency.

Customer Requirements: Customers may specify environmental criteria in contracts or procurement agreements. Adherence to these criteria becomes a condition for acceptance.

Certification to Environmental Standards: Certification to recognized environmental standards, such as ISO 14001, may serve as acceptance criteria, demonstrating a commitment to environmental management in welding operations.

Performance Benchmarking: Organizations may establish acceptance criteria based on benchmarking against industry best practices. This could include comparisons with similar operations or adherence to recognized environmental benchmarks.

Legal Compliance: Compliance with applicable environmental laws and regulations serves as a fundamental acceptance criterion. Meeting legal requirements ensures that welding processes align with environmental standards.

4. The influence of novel approaches on overall emission for environmentally friendly welding

Novel approaches in welding technologies and practices have the potential to significantly influence overall emissions, contributing to more environmentally friendly welding processes. These approaches aim to reduce energy consumption, emissions, and waste while maintaining or improving the quality and efficiency of welding operations. Here are several novel approaches that can influence overall emissions in environmentally friendly welding:



Influence on Emissions of Advanced Welding Processes

Friction Stir Welding (FSW): FSW is a solid-state welding process that generates less heat compared to traditional methods. This reduces the need for shielding gases and minimizes fume emissions.

Electron Beam Welding (EBW): EBW operates in a vacuum, minimizing the need for shielding gases and reducing atmospheric contamination. This can lead to lower emissions compared to some traditional welding methods.

Influence on Emissions of Pulsed Welding Technologies

Pulsed MIG/TIG Welding: Pulsed welding processes allow better control of heat input, resulting in reduced energy consumption and less spatter. This can contribute to lower emissions and improved efficiency.

Cold Metal Transfer (CMT) Technology: CMT is a welding process that operates at lower temperatures, reducing heat input and minimizing emissions. It is particularly effective for welding thin sections and dissimilar materials.

Influence on Emissions of Efficient Power Sources

Inverter Technology: Inverter-based welding machines are more energy-efficient compared to traditional transformer-based machines. This can lead to overall energy savings and a reduction in emissions.

Influence on Emissions of Low-Emission Consumables

Low-Fume Welding Wires and Electrodes: The use of low-fume welding consumables can help minimize airborne particulate matter and fumes, improving air quality and reducing overall emissions.

Influence on Emissions of Green Coating Technologies

Eco-Friendly Coatings: Applying environmentally friendly coatings can reduce the need for pre-welding cleaning processes, decreasing the use of solvents and chemicals that contribute to emissions.



Influence on Emissions of Robotics and Automation:

Automated Welding Processes: Robotics and automation can optimize welding parameters, leading to more consistent and efficient processes. This can result in reduced energy consumption and emissions.

Influence on Emissions of Welding Simulation Software

Virtual Testing and Optimization: Simulation software allows for virtual testing and optimization of welding parameters, reducing the need for physical trial and error. This can lead to more efficient processes, minimizing emissions during experimentation.

Influence on Emissions of Material and Process Optimization

Lightweight Materials and Thin-Section Welding: Using lightweight materials and welding thin sections can reduce material consumption, energy requirements, and overall emissions.

Influence on Emissions of Energy Recovery Systems

Energy Recovery Systems: Some modern welding equipment includes energy recovery systems that capture and reuse energy, improving overall efficiency and reducing emissions.

Influence on Emissions of Carbon Footprint Analysis and Management

Continuous Improvement Strategies: Regularly conducting carbon footprint analyses and implementing continuous improvement strategies can identify opportunities to further reduce emissions throughout the welding process.

These novel approaches collectively contribute to more environmentally friendly welding practices by addressing various aspects such as energy efficiency, emission reduction, and waste minimization. Implementing these technologies and practices aligns with the broader goal of achieving sustainability in welding operations. Keep in mind that the effectiveness of these approaches may vary depending on the specific welding application and materials used.



5. Evaluation of Welding Techniques: Emissions and Quality for a more Eco-Friendly Welding

The performance of various welding techniques in terms of emissions and welding quality is crucial for evaluating environmental friendliness. Different welding processes have varying impacts on the environment, and the quality of the weld produced. Below, an overview of some common welding techniques, considering their emissions and welding quality:

Gas Metal Arc Welding (GMAW) / MIG Welding		
	Advantages	Consideration
Emissions	Generally, produces lower emissions compared to some other processes.	Use of shielding gases and consumables can contribute to environmental impact
Weld Quality	High deposition rates, good quality welds.	Sensitive to wind and atmospheric conditions.
Gas Tungsten Arc Welding (GTAW) / TIG Welding		
	Advantages	Consideration
Emissions	Generally, produces fewer emissions due to the use of inert shielding gases.	Tends to be a slower process compared to some others
Weld Quality	High-quality welds with precise control.	Requires a high skill level, slower deposition rates
Shielded Metal Arc Welding (SMAW) / MMA Welding		
	Advantages	Consideration
Emissions	Simple process with minimal equipment, lower emissions.	Flux coating may contain certain elements impacting emissions
Weld Quality	Versatile, suitable for outdoor and adverse conditions	Slower compared to some other processes.



Flux-Cored Arc Welding (FCAW)		
	Advantages	Consideration
Emissions	Can be designed as a low-emission process.	Gas shielding or self-shielding options impact emissions.
Weld Quality	High deposition rates, suitable for thick materials.	May produce more spatter compared to other processes.
Submerged Arc Welding (SAW)		
	Advantages	Consideration
Emissions	It can be a low-emission process when automated.	High heat input, potential for fume emissions.
Weld Quality	High deposition rates, efficient for thick sections	Typically used in heavy fabrication
Friction Stir Welding (FSW)		
	Advantages	Consideration
Emissions	Low emissions due to the solid-state nature of the process.	Limited to certain materials and geometries.
Weld Quality	Excellent for joining dissimilar materials, no melting.	Requires specialized equipment
Electron Beam Welding (EBW)		
	Advantages	Consideration
Emissions	Minimal emissions as it operates in a vacuum.	Requires high-vacuum conditions.
Weld Quality	Precise and high-quality welds.	Limited to specific applications
Plasma Arc Welding (PAW)		
	Advantages	Consideration
Emissions	Generally low emissions.	Requires the use of plasma gas.



Weld Quality	High energy concentration, good for precision welding.	Similar to TIG but with higher energy.
Resistance Spot Welding (RSW)		
	Advantages	Consideration
Emissions	Low emissions as no consumables are used.	Limited to specific applications.
Weld Quality	High-speed process, suitable for mass production.	Limited to certain material thicknesses.

6. The impact on Welding gasses: Emissions and Quality for a more Eco-Friendly Welding

The choice of shielding gases in welding has a significant impact on both emissions and welding quality. Different gases serve specific purposes during welding processes, affecting the stability of the arc, the quality of the weld, and the environmental impact. An overview of the impact of various gases on emissions and welding quality in the context of environmentally friendly welding is presented below:

Common Shielding Gases

Argon (Ar):		
	Advantages	Consideration
Emissions Impact	Argon is inert and does not react with molten metal. It typically results in low emissions during welding	Argon is more commonly used in processes like TIG welding, which tend to have lower emissions compared to some other methods
Weld Quality	Provides a stable arc and good penetration. Often used for high-quality welds in applications such as stainless steel and aluminum	Relatively more expensive than some other gases



Helium (He):		
	Advantages	Consideration
Emissions Impact	Helium can provide increased heat input and deeper penetration, but it can also increase emissions.	Helium is often used in conjunction with other gases to balance performance and emissions.
Weld Quality	High thermal conductivity, suitable for deep-penetration welding.	Can result in a wider bead and increased spatter.
Carbon Dioxide (CO2):		
	Advantages	Consideration
Emissions Impact	CO2 is economical and widely used, but it can contribute to higher emissions.	May produce more fumes compared to inert gases.
Weld Quality	Provides good penetration and is commonly used in GMAW (MIG) welding	Increased spatter and potential for porosity
Oxygen (O2):		
	Advantages	Consideration
Emissions Impact	Oxygen is not commonly used as a shielding gas due to its oxidizing nature, which can lead to increased emissions	In certain processes, small amounts of oxygen may be added for specific benefits.
Weld Quality	Can improve arc stability and reduce the risk of undercut	Oxygen is generally avoided in processes where oxide formation is a concern.
Nitrogen (N2):		
	Advantages	Consideration
Emissions Impact	Nitrogen is not commonly used as a primary shielding gas, but it may be present in the atmosphere and contribute to emissions.	Nitrogen can react with molten metal, leading to nitride formation



Weld Quality	Generally, not used as a primary shielding gas due to potential issues with arc stability and weld quality.	May be used in some processes in small quantities for specific benefits.
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7. The impact on Welding gasses: Emissions on production time for a more Eco-Friendly Welding

The impact of various gases and emissions on production time in environmentally friendly welding is influenced by several factors, including the welding process, the specific gases used, and the overall efficiency of the operation. While certain gases and emission levels can contribute to a more environmentally friendly welding process, it's essential to consider how these factors might affect production time.

Choice of Shielding Gases

Argon (Ar):		
	Advantages	Consideration
Impact on Production time	Argon is inert and generally results in stable welding arcs with good penetration. This can contribute to efficient welding processes	While argon is associated with stable welding, the choice of gas alone may not significantly impact production time compared to other process-related factors.
Carbon Dioxide (CO2):		
	Advantages	Consideration
Impact on Production time	CO2 is often used in GMAW (MIG) welding due to its affordability and good penetration	CO2 may contribute to increased spatter, which could require additional time for post-weld cleanup.



Helium (He):		
	Advantages	Consideration
Impact on Production time	Helium can provide increased heat input and penetration, potentially reducing welding time for certain applications.	The cost of helium may be a consideration, and adjustments to welding parameters are needed for optimal results.
Gas Mixtures (Ar/CO2, Ar/O2, etc.):		
	Advantages	Consideration
Impact on Production time	Gas mixtures are often used to balance performance and emissions. Optimal gas mixtures can contribute to efficient welding.	Fine-tuning gas mixtures may be required, impacting setup time

Emissions and Environmental Considerations

Low-Emission Gases		
	Advantages	Consideration
Impact on Production time	Choosing low-emission gases aligns with environmentally friendly practices but may not have a direct impact on production time.	The environmental benefits may justify any potential minor adjustments in welding parameters.
Emission Monitoring and Compliance		
	Advantages	Consideration
Impact on Production time	Regular emission monitoring ensures compliance with environmental standards and regulations.	: Periodic monitoring may have a minimal impact on production time, but it is a necessary aspect of environmentally friendly practices.



Efficiency and Process Optimization

Efficiency Improvements:		
	Advantages	Consideration
Impact on Production time	Implementing efficient welding practices, such as using advanced welding processes or automation, can reduce production time	Initial setup and training may be required for the adoption of new technologies, impacting production initially.
Process Optimization for Emission Reduction:		
	Advantages	Consideration
Impact on Production time	Optimizing welding parameters to reduce emissions can contribute to environmentally friendly welding	Fine-tuning parameters may be necessary, potentially affecting initial setup time.



Part B

Energy performance, specifically energy efficiency, plays a crucial role in developing a greener skill set for welders. When assessing the environmental impact of a welding process in terms of emissions, two main categories should be taken into account. Firstly, material consumption and usage, where reducing, reusing, and recycling become important parameters toward a greener future. Secondly, the energy consumed during the process emphasizes the significance of energy efficiency as a crucial parameter for improvement.

This section focuses on the energy performance in the welding process, outlining how individual welders can impact it through welding techniques, methods, and machine settings. Additionally, it highlights the role companies play in providing welding equipment and making sustainable choices related to energy sources and materials used.

1. Energy Consumption and Efficiency Measures

Overview of Welding Energy Consumption

Understanding the overall energy consumption within a welding process is crucial for the refinement of welding skills, aiming to achieve more efficiency and minimizing the environmental emissions associated directly with the welding process.

The individual welders play a major role in influencing the energy efficiency of the welding process and reducing its emissions through several key parameters. These parameters primarily include the utilization of welding wire, gas consumption, and electricity. The impact of the individual welder on these three parameters is significantly contingent upon how they configure their machines, specifically adjusting voltages (V), amperage (A), wire feed speed (WFS), and gas usage (G), (Sangwan, Herrmann, Egede, Bhakar, & Singer, 2016).

In addition to machine settings, welding techniques likewise impact both the energy performance and CO₂ emissions of the welding process. Beyond their impact on energy performance, machine settings, and techniques, also play a crucial role in determining welding quality and the overall aesthetics of the weld. These factors should be carefully considered, as reducing post-welding processes positively contributes to the overall efficiency and emission reduction of the entire production flow.



Beyond the individual's impact on welding, production companies or welding facilities also significantly influences energy performance. This is closely tied to investing in the right equipment, providing welders with the best possibilities for performing more energy-efficiently. Moreover, ensuring access to greener electricity and maintaining a stable electricity distribution network is essential. Challenges such as an under dimensioned distribution network or lengthy supply lines can lead to process instability and should be addressed to uphold efficient and stable welding operations (Børgesen, 2022).

Key Performance Indicators for Energy Efficiency

When choosing Key Performance Indicators (KPIs) for measuring energy efficiency in the welding process, it is recommended to clearly define which aspects of the welding process you are aiming to optimize to improve energy efficiency. Below are some KPIs that can be considered:

- **Energy/gas consumed per unit of welding output**

The amount of energy / gas consumed for each unit of welding output (could be related to length or time). This type of KPI works as a direct indicator of how efficiently energy is utilized in the welding process. However, if the KPI is used to compare or track progress, the most accurate comparisons are when the welding process is performed with the same material and the same thickness of material.

- **The entire welding process time**

Tracking the entire process time to complete the welding process, from setup to completion, can indicate process efficiency. As the machines are still consuming energy while on standby, preparing the welding stations in between tasks can reduce the overall process time. Optimizing this, without compromising quality, contributes to energy savings.

- **Energy consumption during Standby time.**

Standby time refers to the periods when the welding equipment is not actively welding. Reducing the standby time throughout an entire workday enhances operational efficiency and optimizes energy utilization. If one of the initiatives is to turn off the machine during standby times, it is recommended to test whether this saves energy or if it is more consuming due to the machine having to start and stop several times. This might depend on the machine type.

- **Utilizing welding materials**



Evaluating the welding materials as a KPI assesses how efficiently materials are used in the welding process. This parameter is mainly related to the consumption of welding wire. As the welding wire has a significant impact on the total emissions of the welding process, using the right wire consumption makes a difference. Furthermore, this might lead to reducing the amount of rework needed, saving energy in post-welding processes.

- **Machine settings and machine capabilities**

On a company level, evaluating various machine settings and capabilities allows for comparisons and can serve as a foundation for potential investments to transition towards a greener and more energy-efficient machine setup.

- **Percentage of Energy from Renewable or Low-Carbon Sources**

Another company, KPI, could assess the percentage of energy sourced from renewable or low-carbon alternatives within the total energy composition for welding. It indicates the environmental sustainability of the utilized energy sources.

2. Low Carbon Welding techniques and Quality

Balancing Energy Efficiency and Welding Quality

It is feasible to categorize emissions in a welding process into two main segments: Material consumption (both the material used in the welded product and the material consumed as part of the welding process), and the energy consumed during the process. In most cases, the predominant emissions are associated with overall material consumption. Thus, the quality and strength of the welds emerge as the most critical parameters for enhancing the sustainability of welding. Ensuring that welding lasts as long as possible, utilizing precisely the needed welding wire that requires no post-welding removal, stands out as the area where welders can have the most significant impact.

In conclusion, welding quality is closely intertwined with sustainability and environmentally friendly welding, and should not be compromised.

Nonetheless, placing a focusing on optimizing energy efficiency in the welding process becomes an integral aspect in the transition towards more environmentally welding practices. This pursuit of energy efficiency is intricately intertwined with the overall quality of welding. As highlighted in the earlier section, a comprehensive examination of emission parameters in a welding process emphasizes three primary contributors:



- 1) Welding material consumed (primarily welding wire)
- 2) The gas consumption
- 3) The electricity consumption

Considering these three key parameters concurrently with welding strength and quality is crucial when you start working to make welding more energy efficient. Therefore, balancing the energy efficiency and welding quality makes sure that we think about the environment in the heart of welding activities, creating a balance between being eco-friendly and maintaining high-quality welding work.

Energy-saving actions

Energy-saving actions related to the individual welder are closely linked to welding techniques and the welding pace. The welding pace doesn't necessarily have to be as fast as possible if it compromises welding quality. The other parameter is the machine settings. However, there is a significant connection between the technique and how the welding machine should be set, meaning that these two parameters should always be seen in close collaboration. The aim should be to find the right balance, choosing a technique most suitable for the given task in terms of the lowest energy consumption and wire usage, without compromising quality. This highly depends on specific cases, which is why Green Welders should be trained to make these kinds of decisions depending on their given task.

Welding techniques

Choosing the appropriate welding techniques for specific tasks involves considering various parameters. This relates not only to the welding method, such as SMAW (Stick Welding), GMAW (MIG Welding), GTAW (TIG Welding), FCAW (Flux-cored Arc Welding), SAW (Submerged Arc Welding), and Laser and Ultrasonic Welding.

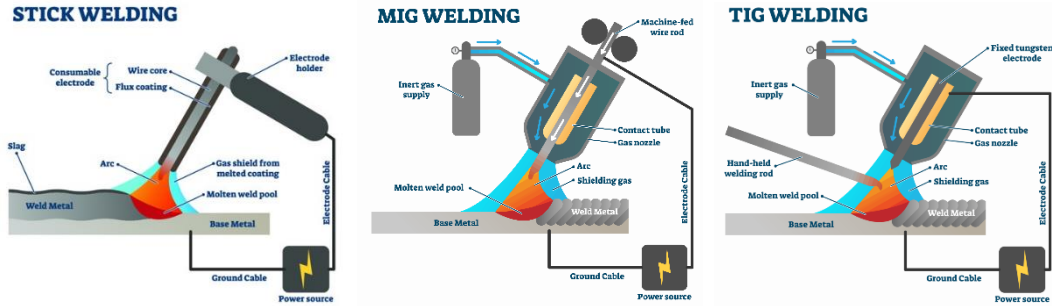
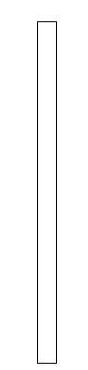


Figure 2 – Illustration of different welding methods.

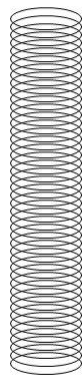
Furthermore, specific techniques, like stringing and weaving welding techniques. By changing the method, the average power consumption is reduced, and thus energy loss is minimized when stringing a weld instead of weaving, as a lot of heat is generated in the material during weaving.

Stringer



Narrow and No Motion

Weave Beads



A. Circles



B. Crescent



C. zig zag



D. Box Weave



E. Double J ⁵⁸

Figure 3– Illustration of different welding techniques.

In business cases, certain fundamental requirements for welding often exist, primarily linked to strength, process time, and the visual appearance of the weld. For a more environmentally friendly welding process, welders need to consider an additional aspect to these parameters. This involves balancing the fulfillment of main business



requirements while utilizing skills to select methods and techniques that contribute to minimal energy and material consumption.

Machine setting

Ensuring that the settings on the welding machines align with the specific task, including the materials used, task requirements, and welding technique, is critical for improving energy efficiency. Regarding welding techniques, these parameters vary based on different factors that welders must consider, depending on the specific task and machine type. Below are some machine settings that could be taken into consideration.

- **Voltage (V):** Voltage impacts the energy input and heat generated during the welding process.
- **Amperage (A):** Amperage regulates the welding current, affecting the heat produced. Optimizing amperage settings can contribute to energy efficiency.
- **Wire Feed Speed (WFS):** Managing the speed at which the welding wire is fed into the weld pool influences the overall energy consumption and efficiency of the process, as well as the material usages.
- **Gas Flow Rate:** Adjusting the flow rate can impact the efficiency of gas usage, contributing to energy savings.
- **Pulse Settings:** Utilizing pulse settings can enhance control and reduce overall energy consumption. However, not all welding machines allow the welder to adjust the pulse.
- **Arc Length:** The optimal arc length is essential for efficient welding. Adjusting this parameter can impact energy efficiency and the quality of the weld.

It is crucial to emphasize that any adjustments to techniques or settings should not compromise the overall welding quality and strength.



3. Energy efficiency policies and industrial equipment

In addition to the individual welder, companies and welding institutes play a crucial role in embracing greener welding processes by offering appropriate facilities and equipment. Individual welders might not directly influence parameters related to their companies. Nevertheless, by staying informed and undergoing training in green awareness, understanding which parameters can be tracked for improvements in transitioning to greener practices, they can contribute to their respective companies when making new equipment investments.

Optimizing industrial welding equipment

There are various types of welding machines, each with different specifications, capabilities, and quality, all of which must be taken into account when investing in new equipment. When evaluating welding equipment from a sustainability standpoint, the key is to find a machine with optimal performance based on energy consumption.

One parameter to assess is the efficiency of electricity usage and how flexibly and effectively the welding machine controls the transition from the welding process.

Another parameter to evaluate in terms of energy efficiency is how well the power source of the welding machine performs. This aspect is crucial to ensuring a minimum of "Reactive Power," meaning the energy not absorbed by the power source in the welding machine and consequently sent back to the circuit. High reactive power in machines implies greater energy loss (Roderick, 2021).

Renewable energy resources and welding materials

Renewable resources, whether it is an energy supply from renewable sources, more sustainable gas compositions, or eco-friendly welding materials, are all parameters that production companies or welding institutes can improve to support their welders and move towards a greener future.

Even though individual welders might not necessarily have a direct impact on the choice of energy resources or materials used, being aware that these decisions affect the sustainability of their jobs enables them to support their companies and move them in a greener direction.



4. Conclusions

In conclusion, Welding Energy Performance represents a mixture of insight and actions involving both individual welders and the welding industry as a whole. The key takeaways are outlined below:

- **Quality Equals Sustainability:** It is essential to emphasize that sustainability should be viewed holistically and not solely confined to energy performance. Ensuring strength and quality throughout the entire welding process is a critical factor.
- **Welding Skills and Machine Settings Matter:** Individual welders can impact energy efficiency by making informed choices in welding techniques, methods, and machine settings that best suit the specific task at hand.
- **Role of Welding Institutes and Companies:** The welding industry collectively plays a critical role in providing optimal setups and technologies for their students or employees, contributing to the improvement of energy performance. The same goes for the training provided for the welders.
- **Embracing Sustainable Resources:** Actively choosing more sustainable resources, such as renewable energy, eco-friendly gas compositions, or enhanced welding materials, is also a crucial factor in steering the entire welding process towards a more sustainable future.



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Part C

The present document ensures the accumulation of digital skills necessary for the use of digital devices that create virtual and augmented reality. The implementation of the virtual environment and augmented reality in the practical training of future welders ensures the access of the new generation to a training mode close to the reality in which they live and carry out their daily activities.

The module deals with aspects regarding the methodology and tools used in digital training, learning management systems and a brief presentation of welding simulators.

The first unit covers subjects related to digital tools used in welding training and which are the advantages and disadvantages of using digital tools in welding.

The second unit introduces the trainees in the virtual learning environments where they can learn and interact with digital tools or with other trainees. The learning management systems (LMS) are the best digital tools to register users, to provide content and to assess the performance of the trainees. How an LMS can be defined, set up and which are the functionalities of a LMS as well as the advantages and disadvantages of a LMS are presented in this module. The trainees will also learn about available solutions for developing their own LMS.

The third unit deals with welding simulators. Typical welding simulator system are presented in the introduction of the module. The virtual reality (VR) and augmented reality (AR) are explained in order to provide to the trainees the necessary knowledge in order to be able to understand and to use how these technologies work. At the end of the module a brief presentation of the difference between welding simulator and real welding system as well as a short example regarding the setting of a welding simulator.

1. Training Digital Tools and Methodology

This topic covers subjects related to digital tools used in welding training and which are the advantages and disadvantages of using digital tools in welding. Several software applications used in welders training are presented in order to show the importance and the relevance of digital tools in learning process.

There are two ways in which information is transmitted to trainees: the first refers to the teacher being at the center of the learning activity, and the second one puts the student in the middle of all activities. The use of digital tools in the learning activity can be successfully applied to the second



option, considering the affinity of young people for everything that means connectivity and making information available in any place, time and way.

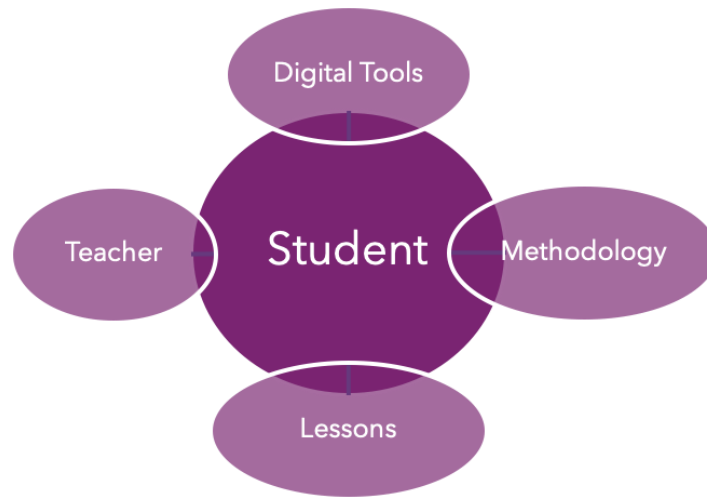


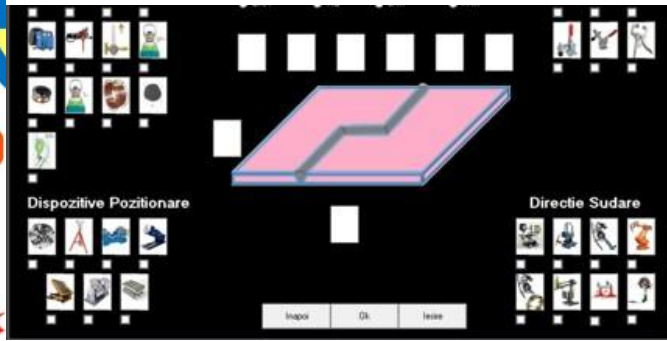
Figure 4– Student-centered Learning

Student-centered learning can be achieved if a few rules are followed:

- Being clear about how you will promote, measure, and celebrate understanding.
- Modeling how to think for trainees.
- Helping trainees understand what's worth understanding.
- Diversifying what you accept as evidence of understanding.
- Creating curriculum and instruction around a need to know.
- Collaborating with trainees to create the rubric or scoring guide.
- Letting trainees choose the project's purpose.
- Letting trainees choose their own media form that reflects the purpose of the reading.
- Using the on-demand writing prompt as the summative assessment.
- Framing learning in terms of process and growth and purpose.

Digital tools used in welding training:

The digital tools used mainly in the training of people in the welding profession are largely dedicated to the theoretical aspects presented in digital format (doc., pdf., ppt., Images and videos) as well as the evaluation process related to the subjects taught. Newly, the information is incorporated into applications dedicated to learning that include both electronic documents and video images and animations all being compiled in an interactive way.



a. FutureWeld learning app

b. FutureWeld assessment app



c. Microbond learning app

d. Microbond assessment app

Figure 5 – Example of digital tools used in welding training.

The next step is to combine theoretical and practical training, and this can be achieved through welding simulators. Welding simulators can support both theoretical, practical and online or offline assessment of the student.



Figure 6 – Welding Simulators



➤ TIPS:

- Digital tools mean any software application or electronic device which is used in training.
- Software applications are mostly used for theoretical training and examination of the trainees knowledge.
- Welding simulators can be used both for theoretical and practical training in welding, as well as in examination process.

Advantages and disadvantages of digital tools in welding:

The use of welding digital tools presents both advantages and disadvantages for the process of learning and training future welders. The main advantages of simulated welding are:



Figure 7 – Advantages of the use of digital tools in learning process

➤ Economical:

- Reduced costs with energy and simulator servicing.
- Reduced costs with teachers/trainers.
- Reduced costs with preparation of base materials and increasing the time on arc of the trainees.
- Specific industrial components for welded structures can be simulated.

➤ Ecological:

- No emissions taking into consideration that all welding operations are simulated.
- No waste materials which can affect the environment.
- Low carbon footprint taking into consideration the low energy consumption.

➤ Safety:

- Training takes place in a safe environmental without dangers from heat, radiation and gas.



- No risks regarding 3 phases electrical power.
- Educational:
 - Easy user interface in VR/AR environment.
 - Increased potential for self-learning and self-assessment.
 - Development of competition scoring system which will lead to increase the learning readiness of the trainees.
 - Different levels of the difficulty for practical exercises.
 - Cover of the main arc welding processes.
 - Distance learning using internet connection between servers and welding simulators.
 - In-depth analysis of the welds and welding processes performed by trainees.

In terms of disadvantages, the simulation of welding processes cannot substitute the real welding. There two categories of disadvantages identified:



Figure 8 – Disadvantages of the use of digital tools in learning process

- Human Resource:
 - Lack of digital skills of the teachers/trainers regarding the integration of welding simulators into the learning process.
 - Lack of digital skills of the teachers/trainers regarding the integration of welding software applications into the learning process.
- Limited Technology:
 - The welding simulators allow the practical training in order to improve the skills of the trainees, but it doesn't cover the other aspects related for instance to base material preparation.
 - There are some technological limitations regarding the arc ignition which are different by the real welding.
 - Not all welding processes can be digitalized in welding simulator.



2. Learning Management System (LMS)

Digital tools can be defined as any devices and technologies of transmitting knowledge from teacher to student with computer applications, online course media or practical training through devices that use augmented reality, virtual reality, etc.

Digital tools are designed to help the trainees and teacher in the learning process. This sub-chapter contains basic information regarding digital tools and specific methodologies for learning process in a digital environment.

Virtual Learning Environments:

Virtual Learning Environment (VLE) consists of a digital system that provides educational materials (courses, presentations, videos, animations and software applications) to the trainees using online webpages. Using an Internet connection on their own digital tools (computers, tablets, smartphones, etc.) the users can access the information both on and off school 24 hours a day and 7 days a week. A VLE supports student's registration, tracking of their activities, collaboration and communication between trainees, trainers, and assessment. There are three different types of VLEs.

- Open source: are offered free of charge for use and adapt but in most cases some fee are required for support activities.





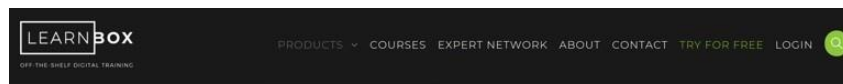
Figure 9 – Open source VLE

- Bespoke: are developed by educational and training institutes in order to comply with their own needs.



Figure 10 – Bespoke VLE

- Of-the-self: products are packaged solutions that are then adapted to satisfy the needs of the purchasing organization, rather than the commissioning of custom-made.



OFF-THE-SHELF LMS



Figure 11 – Off-the-shelf LMS product

Definition and characteristics of LMS:



A Learning Management System (LMS) is the same thing as Virtual Learning Environment (VLE). Another name for LMS is Course Management System (CMS). As a general definition, the Learning Management System is a software application or web-based technology for planning, implementing and assessing a specific learning process. The main characteristics of LMS are:

- Possibility to upload or create and deliver content related to educational materials.
- Monitor the student participation and continuous assessment for improvement the learning process and student performance.
- Tool for interactive features such threaded discussions, video conferencing, forums, etc.

Setting and functionalities of LMS:

The functionalities of a LMS are defined in most cases by the developer. However, minimal functionalities should be provided by any LMS.

- Reports: The teachers can benefit from LMSs reports in order to assess the student performance. Information regarding the individual study time, modules used during learning process, case studies and any other activities performed by the trainees will represent inputs for analysis.
- Analysis: This feature will allow the teacher to evaluate the student performance as well as to find the best solution for filling the knowledge gaps.
- Customization: The LMS support platforms allow the developer to customize the e-Learning experience. Starting with company logo and embedding all educational materials in one consolidated structure will increase the performance of the learning management system. The developer can also create customized learning path for each student in order to improve the learning process. In case of use of digital tools like simulators for practical training, the teacher/trainer can decide which assessment, method can be used for evaluation of the student's competences and skills. Another important component is related to types and formats of the educational materials. The LMS should accept at least documents in doc and pdf format, presentations and the common video types such as avi, mp4, etc.
- Assessment: Represents one of the most important features of the LMS. The system allows the evaluation during course through multiple choice tests in order to determine how well the trainees know it, as well as how they are able to apply the information in real world settings.



- **Communication:** This feature allows the participants to share knowledge and experience in order to improve the learning process. Moreover, trainees can work together at the same projects and case studies at the same time.

LMS – challenges and advantages:

The advantages of LMS in learning process are well known by the institutions, which are using the system. At least three major benefits can be identified when a LMS is implemented and use in learning process.

The challenges are also high when a LMS is implemented for more than one programme study. The digital templates for courses, presentations, videos and software applications must cover all aspects related to the development of educational materials. One major challenge is related to harmonization and exchange of information between two learning management systems. Trainees from different school should be able to exchange information with other colleagues using the features of the LMS.

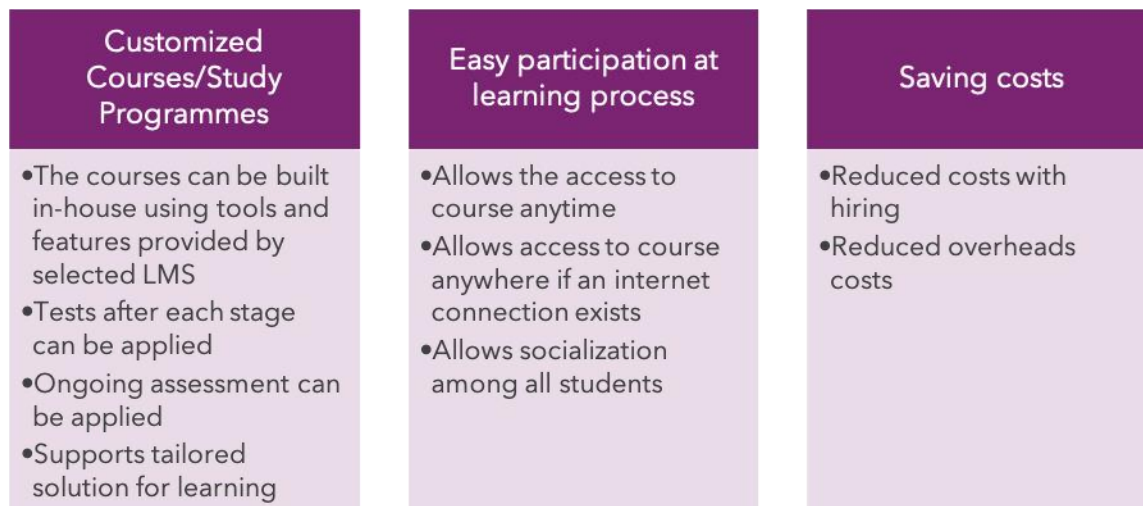


Figure 11 – Benefits of using LMS in learning process.



Available solutions for developing LMS:



Figure 12 – LMS – development options

- Installed vs Webbased: There is a big difference between LMS installed in your own computer / server as a dedicated application and a learning management system developed on a web platform. Adopting a solution installed on your own server means both the need for adequate technical support and higher costs for installing the application. The technical support and maintenance of the application will be realized by the own personnel, and the financial costs are mainly related to the actual cost of the application. If this application is a customized one, then the acquisition costs will be higher. The second option is also the most recommended. Implementing an online LMS will reduce acquisition costs, and the IT staff of the online platform support maintenance. Moreover, LMS is in continuous development and updating, and the costs are borne by those who support the online platform.
- Cloud vs Hosted: These options are also important when implementing an LMS. If the HOST variant is adopted, then the LMS control is exclusively available to the developer. The advantage of this option is that the LMS developer will have full control over the application and can make all the changes it deems appropriate. However, full control also comes with responsibilities regarding data security and updates available to the server. The second variant, CLOUD, does not provide full control over the application but only its use. From the point of view of the learning process and of the teachers / trainers this option is the best considering that all the attention will be given to the development of the courses, presentations, videos and practical case studies that the users are going to use.
- Free vs Comercial: Free LMS are available in a variety of software solutions. If the budget allocated to the development of LMS is a small one, then this option is the best one to consider. However, there is a major disadvantage, namely that the installation of the platform and its maintenance will be the responsibility of its own staff. It is recommended to purchase an LMS platform that offers a very good experience in terms of appearance, interface, access to documents, performance evaluation, etc.



- Open-Source vs Closed Source: Open-source software (OSS) is distributed under a licensing agreement which allows computer code to be shared, viewed and modified by other users and organizations. Open-source software is available for the general public to use and modify from its original design free of charge. What it means is that a piece of software can evolve and be iterated upon by other developers anywhere in the world. Ideally, this means that the software is improved over time, but it can often take plenty of interesting twists and turns with all of that evolution and can change form and shape entirely. However, the open-source software is vulnerable to rogue developers who choose to break things for their own benefit.

Closed source software (CSM) can be defined as proprietary software distributed under a licensing agreement to authorized users with private modification, copying, and republishing restrictions. Generally, the key differentiators between open and closed come down to a few factors:



Figure 13 – Key differentiators between OSS and CSM



3. Welding Simulators

The technological evolution has allowed the use of simulators for the training of welded apprentices in order to obtain the necessary skills for insertion in the labour market. Most modern simulators are run by a personal computer and employ software, which enables a variety of processes. These include setting up (i.e. selection of materials, weld type and weld settings), performance assessment, and provision of feedback, in line with the second and third training principles.

Welding simulators systems:

Welding simulators are built using modern technologies like Virtual Reality (VR) or Augmented Reality (AR). These technologies provide the simulator display and visual feedback. In VR systems, a Head Mounted Display (HMD) creates the LVE. The welder cannot see the actual gun and welding surfaces; instead, they see a virtual representation of these projected onto the HMD. In AR systems, a digital image or animation is superimposed on the real image that can be viewed through monitors. Unlike the VR systems, in the AR systems, the welder can see the gun and welding surfaces they are interacting with. In both VR and AR systems, virtual imagery is used to provide visual feedback. A separate monitor is also generally included to allow instructors to view student performance and review feedback after welding completion.



a. AR welding simulator



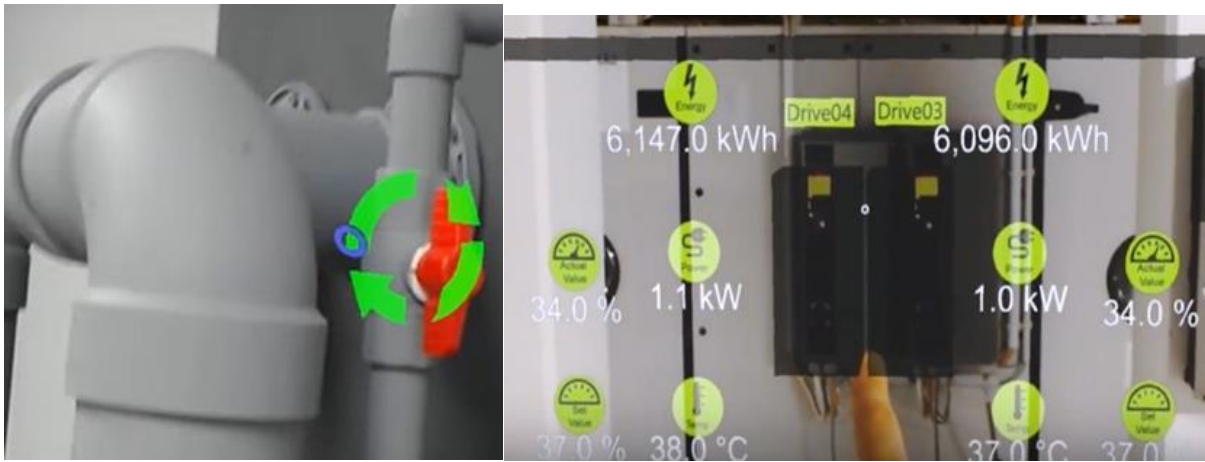
b. VR welding simulator

Figure 14 – AR and VR welding simulators



Augmented Reality:

Augmented Reality (AR) technology allows the blending the real and virtual worlds. AR applications can translate that particular coded image into a virtual item on the screen. Some camera apps even include the option to add virtual elements to a photo, along with some measure of 3D sensing that allows them to move around the picture as if they were part of the scene. AR is a live direct or composite view of a physical, real-world environment superimposed with virtual elements, which have augmented (enhanced) by computer-generated sensory input such as sound, video, graphics or GPS data. The most common applications known by users are related to QR scanning codes and games such Pokemon Go.



a. HoloLens Plant Maintenance, BEApplied Research

b. Phoenix Contact -
Augmented reality in use for industry
4.0 and building technology

Figure 15 – Applications of AR technology



The three major components of the AR technology are: hardware, software and a remote server.



Figure 16 – Basic architecture of AR system

- Hardware: Hardware components of an AR system consist of a processor for computational purposes, a display device such Head Mounted Displays (HMD), Smartphone Screen (SS), Eyeglass (EG), an input device which can be a webcam and position sensors such GPS, gyroscope, accelerometer. Also, for better interactivity, the AR systems have sensors.



Figure 17 – Displays for AR applications

- Software: Virtual images, used for overlapping over the real live image, can be generated using 3D software. Software can be AutoCad3D, StudioMax or Cinema4D. CT and MRI data can also be added to the real world. Also, to experience Augmented reality, the end-user has to download a software application or browser plug-in.
- Remote Server: The remote server is required for storing the virtual images created using software. The remote server can provide virtual images stored from web or cloud server.



Virtual Reality:

Virtual Reality (VR) technology aims to create realistic 3D environment that user can perceive as real. The user can even interact with in realistic way. The LVE can be created on a display computer or on VR headset (HMD). A VR headset can integrate both hardware and software components and can include only software components but, in this case, a computer is required. A complete VR device should contain the necessary components in order to provide best experience.

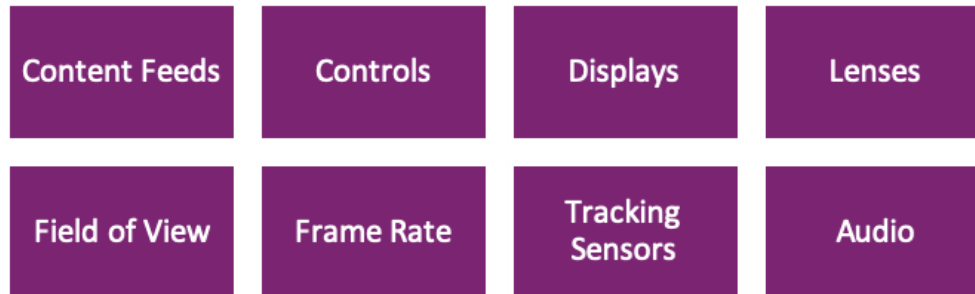


Figure 18 – Complete VR system

- **Content Feeds:** Content feeds are supplied by hardware, typically the hardware in a computer, console, or phone. This is data that makes up the digital world, and it needs to come from somewhere. The VR training experience can be achieved within a single app or game. Also, by using VR technologies, trainees can communicate and share their projects or study cases. According to Google, VR content means a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.

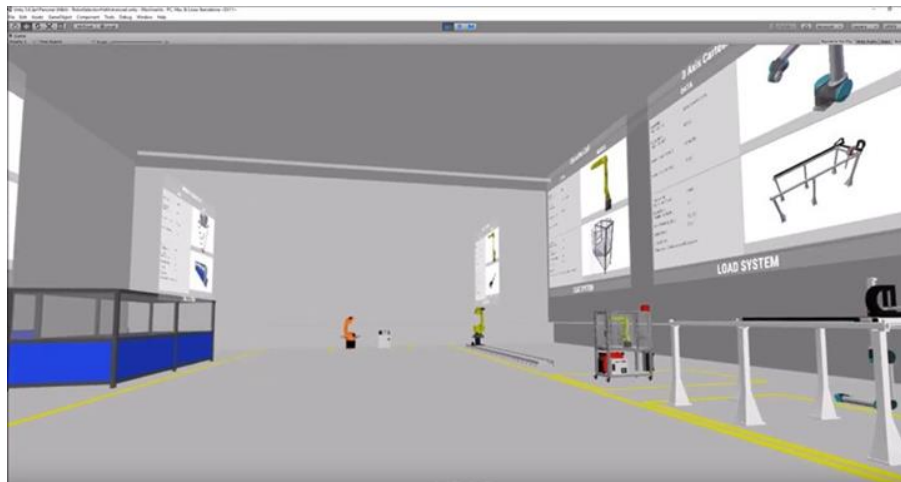




Figure 19 – VR Content

- Controls: Very simple VR headsets allow basic exploration and interaction with a few buttons located on the headset. More advanced headsets offer handheld controllers (Nintendo Wii). The most advanced offer controllers that mimic real devices, such as welding gun and electrodes. They interact directly with the hardware that sends the feed.



Figure 20 – VR Controles

- Displays: The display is where the VR image is pushed out to your eyeballs. In the old days, two separate displays, one for each eye, were included in the goggles, and this remains a popular approach for headsets like the Oculus Rift. But because of the extra cost and components, this is less common these days. Many inexpensive headsets simply use the full smartphone screen as a display, or a single OLED screen. Actually, VR welding simulators use displays embedded in welding helmet in order to be closer to real welding.



a. Simple smartphone



b. VR helmet

Figure 21 – Displays for VR welding simulators



- Lenses: The role of the lenses in human eyes is to alter the incoming light in a way that it gets focused on our receptors on the back of eyes. The lens bends depending on the distance between eyes and the thing the eye is focusing on. If the user looks at something really close his lenses have to bend a lot to give you a sharp image. If the user looks at something in the distance the lens does not need to bend a lot. Many headsets include lenses that help focus the eyes on the screen so that it appears the user is looking into a real environment. This is what allows VR to work on single screens like smartphones have. More advanced versions also allow for lens adjustment, which is very important for both eyestrain and realism.
- Field of view: A perfect field of view would, of course, be 360 degrees. Since this isn't possible on a headset, most VR headset creators settle for around 100 to 120 degrees, which helps improve immersion. However, if the virtual images are generated on monitors, the 360 degrees view can be achieved.
- Frame rate: The higher the frame rate, the better the immersion, so the goal here is frequently 60 FPS to 120 FPS and powerful hardware to back it up. Less ambitious experiences may not worry much about frame rate, but if it starts slowing down then all immersion is lost and headaches often result.
- Tracking Sensors: Advanced headsets need to know when the user moves his head, hands, and even body, so they can move the content feed in a similar fashion. So, headsets also come with movement sensors on the headset – and sometimes also on additional hardware to map out your space. Most tracking sensors are using magnetic fields which requires an additional power source to generate the current required for operation.
- Audio: Audio is either supplied as part of the content feed in the headset itself, or as a separate feed that uses an additional speaker headset that the user needs to wear.

Difference between welding simulator and real welding system:

The use of welding simulation presents many differences from real welding system. The following table shows you the most relevant ones:



Welding Simulator	Real Welding System
<ul style="list-style-type: none"> •Practices in an Augmented lab •Less pollutant •More safe - Less accidents •Less costs •Unlimited AR/VR practices •Less time •Reduce the environmental impact 	<ul style="list-style-type: none"> •Practices in small space •Gas emission •Burn risks •Expensive - More money •Numerous repetitions •More time •More emissions

Figure 22 – Differences between welding simulator and real welding system

Set-up of welding simulators:

We can find different configurations depends on the manufacturer that we choose. In all cases, the welding simulator includes a complete user manual (pdf-doc, online or both). These tend to be more or less extensive depending on the benefits they offer. The following settings are normally allowed to be changed in the simulator:

<p>General</p> <ul style="list-style-type: none"> •Language •Mode •Date and Time •Units •Standards 	<p>Login</p> <ul style="list-style-type: none"> •Username •Password 	<p>SOLDAMATIC homepage</p> <ul style="list-style-type: none"> •Courses •Predefined welding practices •User guides and tutorials •Open practices for demos 	<p>Course selection</p> <ul style="list-style-type: none"> •General courses •Specific courses 	<p>Welding parameters</p> <ul style="list-style-type: none"> •Welding process •Joint type •Position •Base material •Thickness •Filler material type •Filler metal diameter •Gas
<p>Welding passes design</p> <ul style="list-style-type: none"> •Length of weld •Number of passes •Weave pattern •Welding sequence •Welding technique 	<p>Lighting calibration</p> <ul style="list-style-type: none"> •More light •Less light 	<p>Analysis module</p> <ul style="list-style-type: none"> •View results •Clear weld and restart •Continue weld •Back to activity selection 		

Figure 23 – Set-up of a welding simulator



4. Green Weld Good Practices

Let's Work on our Skills!

Green welding refers to environmentally friendly and sustainable welding practices aimed at minimizing the environmental impact of welding processes.

Welding Green Practices

Green Actions and Strategies to control energy consumption during welding

- **Process Selection:** Choose welding processes that are inherently more environmentally friendly. For example, processes like GMAW and laser or stir welding may have lower environmental impact compared to traditional methods and be more energy-efficient for certain applications
- **Pulse Welding:** Use pulse welding techniques, where the power source alternates between high and low energy pulses. Pulse welding can reduce heat input, minimize distortion, and can reduce overall energy consumption.
- **Welding Procedures:** Develop and adhere to optimized welding procedures. Make use of standardized procedures that focus on achieving the desired weld quality with the least energy consumption.
- **Optimized Welding Parameters:** Adjust welding parameters such as voltage, current, and travel speed to optimize energy consumption while maintaining weld quality. Use the minimum power necessary for the specific application. Avoid excessive heat input, which can lead to energy waste and increased consumption.
- **Advanced Power Sources:** Invest in advanced welding machines with inverter technology and high energy efficiency with reduced overall power consumption. Modern inverter-based welding machines are generally more energy-efficient than traditional transformer-based models.
- **Scheduled Maintenance:** Maintain welding equipment regularly to ensure optimal performance, for operating more efficiently, reducing the risk of energy wastage.
- **Use Power Factor Correction:** Power factor correction devices can be used to improve the efficiency of electrical systems, reducing reactive power consumption, and optimizing energy use.



- **Idle-Time Reduction:** Minimize idle time for welding equipment. Turn off welding machines and related equipment when are not in use to prevent unnecessary energy consumption
- **Energy Recovery Systems:** Install energy recovery systems that save and reuse energy generated during the welding process, which may improve the total efficiency and reduce energy consumption
- **Cold and Micro - Welding:** Choose cold welding methods that require less heat input, reducing energy consumption and minimizing thermal impact or micro-welding techniques for precision welding of small components, which reduces the total amount of material and energy required for the welding process.
- **Lightweight Materials:** Consider using lightweight materials and advanced alloys, which may require less energy to weld compared to heavier materials.
- **Material Efficiency:** Optimize material usage to reduce the overall energy footprint. Minimizing material waste through precise cutting and fitting contributes to energy efficiency.
- **Energy-Efficient Consumables:** Choose welding consumables, such as electrodes and welding wires, with high deposition rates and low environmental impact. Consumables with lower resistance and improved conductivity can contribute to energy savings.
- **Water-Based Fluxes:** Explore water-based fluxes as alternatives to traditional fluxes. They are often more environmentally friendly and produce fewer emissions.
- **Green Filler Materials:** Select environmentally friendly filler materials, made from recycled or sustainable materials with high deposition rate and minimal environmental impact.
- **Reduced Gas Emissions:** Choose shielding and protective gases with lower global warming potentials (GWPs) to reduce greenhouse gas emissions associated with welding.
- **Recycling and Reusing Materials:** Recycle the scrap materials generated during welding. Reusing materials reduces the need for new production and minimizes the environmental impact.
- **Energy-Efficient Facility Designation:** Design the welding work shop facilities with energy efficiency in mind. Proper insulation, natural lighting, and ventilation can contribute to the total energy savings.



- **Energy-Efficient Lighting:** Ensure that the welding area is well-lit with energy-efficient lighting systems. LED lighting may provide adequate illumination with lower energy consumption.
- **Energy Management Systems:** Use energy management systems to monitor and control energy usage during welding operations.
- **Regulatory Compliance:** Stay informed about and comply with energy efficiency regulations and standards applicable to welding operations.
- **Continuous Improvement:** Continuous improvement with regularly assessments and implementation of new technologies and practices increasing energy efficiency.
- **Monitor and Rate Energy Usage:** Implement energy monitoring systems to track energy usage during welding processes. Performance rating helps identify areas for improvement and sets targets for energy reduction.
- **Life Cycle Assessment (LCA):** Conduct life cycle assessments to evaluate the environmental impact of welding processes from raw material extraction to end-of-life disposal.
- **Automation and Robotics:** Use automation and robotics into welding processes when possible. Automated systems can optimize welding parameters, reduce errors, and improve the total efficiency.
- **Renewable Energy Sources:** When applicable, powering welding operations by using renewable energy sources such as solar or wind power. By this you may significantly reduce the environmental impact of energy consumption.

By combining these actions and strategies, welding procedures may effectively control energy consumption, promoting sustainability and reducing operational costs

Extra Tip!

Choosing Gases for Environmentally Friendly Welding

- **Low-Emission Gases:** Choose shielding gases that contribute to lower emissions, such as inert gases like argon.
- **Gas Mixtures:** Use gas mixtures that balance the need for good welding quality with environmental considerations.



- Efficiency and Cost: Consider the overall efficiency and cost-effectiveness of the chosen shielding gas, taking into account both welding quality and environmental impact.
- Advanced Gas Mixtures: Explore advanced gas mixtures designed for specific applications, which may offer improved performance and reduced environmental impact.
- Gas Recycling: Implement gas recycling systems to reduce overall consumption and waste.
- Emission Monitoring: Regularly monitor emissions and assess the environmental impact of the chosen shielding gases.
- Process Optimization: Optimize welding parameters and processes to minimize the environmental impact while maintaining welding quality

The impact of gases on emissions and welding quality is highly dependent on the specific welding process, material, and application. Choosing the right shielding and protective gas and optimizing welding parameters are essential steps in achieving environmentally friendly welding practices without compromising on the quality of the weld.





Let's go Technical!

More good practices to consider for energy-saving during welding:

Joint Preparation and Fit-Up: Ensure proper joint preparation and fit-up to reduce the amount of filler material required. Well-prepared joints minimize the need for excessive welding and reduce energy consumption.

Preheating and Interpass Temperature Control: Implement preheating and control interpass temperatures appropriately to reduce the energy needed for welding thicker materials. Controlled heating can enhance the welding process efficiency.

Gas Efficiency: Optimize shielding gas selection and flow rates. Using the right gas mixture and controlling the flow can contribute to energy savings and improved welding performance.

Travel Speed: Adjust the welding travel speed to achieve optimal deposition rates while maintaining quality. A consistent travel speed helps control the heat input and energy consumption.

Cooling Systems: Optimize the cooling systems for welding equipment. Ensure that water-cooled systems are efficient and that the cooling requirements match the application.

Extra Tip!

Green Welding and productivity

Considerations for Environmentally Friendly Welding:

- **Balancing Efficiency and Environmental Impact**: Striking a balance between environmentally friendly practices and production efficiency is crucial. Evaluate the overall impact on both aspects when choosing gases and implementing emission reduction measures.



- **Continuous Improvement:** Regularly assess and improve welding processes to enhance efficiency and reduce environmental impact. This may involve adopting new technologies or fine-tuning existing practices.
- **Training and Skill Development:** Proper training and skill development for welders are essential when introducing new gases or optimizing processes. This may have an initial impact on production time but can lead to long-term efficiency gains.
- **Technology Adoption:** Embrace advanced technologies and automation to streamline welding processes. While initial implementation may require time and investment, the long-term benefits can include increased production efficiency.
- **Emission Monitoring and Compliance:** Allocate time for periodic emission monitoring and compliance checks to ensure adherence to environmental standards. This is essential for maintaining an environmentally friendly operation.
- **Collaboration and Expert Consultation:** Work with experts in environmental and welding technologies to identify the most suitable gases and practices for your specific application. Collaboration can lead to informed decisions that balance environmental considerations and production efficiency.

In summary, the impact of various gases and emissions on production time in environmentally friendly welding is multifaceted. While certain choices, such as adopting low-emission gases or optimizing processes, may require initial adjustments, the long-term benefits include both environmental sustainability and production efficiency. Balancing these factors requires careful consideration of the specific welding application, technology adoption, and ongoing process optimization efforts.

Things to Think!!

Crucial for **environmentally Friendly Welding in respect to emissions**, should be considered the

- **Consumable Selection:** Choose low-emission consumables and filler materials.
- **Energy Efficiency:** Optimize welding parameters for energy efficiency.
- **Waste Reduction:** Implement strategies to reduce waste generation and promote recycling.
- **Automation:** Consider automation to improve efficiency and reduce emissions.
- **Advanced Processes:** Explore advanced processes like friction stir welding for specific applications.



- Material Efficiency: Choose processes that maximize material efficiency and minimize distortion.
- Emission Monitoring: Regularly monitor and assess emissions to identify improvement opportunities

The environmental impact of welding is a complex interplay of process, material, and operational factors. Selecting the most suitable welding technique depends on the specific application, material requirements, and environmental goals.