



Project title:

Creating knowLedge and skillS in Additive Manufacturing



## Metal AM Operator PBF-EB

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3.1 European AM Designer, Specialist, Operator and European AM Inspector's Occupational Standards

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3.2 LOs' Guideline for the AM Qualifications

Guideline - General information for the public and organizations that implement these qualifications

Metal AM Profiles

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## 1. Preface

The present document consists in European Guideline for Metal AM Operator PBF-EB, developed in the framework of the European project “Creating KnowLedge and SkillS in Addlitive Manufacturing / CLLAIM“.

This guideline, for the European education, training, examination and qualification of additive manufacturing personnel, has been developed and approved by all partners involved in the project: EWF, CESOL, DVS, FhG, LZH, Lloyd’s Register, IDONIAL, TWI. Contains general information for the public and organisations that implement this qualification.

This guideline was developed with a close relation to industry and standardization bodies. The guideline was validated in workshops directed to industry and education centres. Moreover, the guideline was validated by experts from EWF’s International Additive Manufacturing Qualification Council and was built with close relation to ISO and ASTM.

Furthermore, this guideline englobes Occupational Standards and Learning Outcomes for the qualifications identified by the Industry as more relevant: Operator, Designer, Supervisor and Inspector.

Copies of this document can be downloaded from CLLAIM website: [cllaimprojectam.eu](http://cllaimprojectam.eu) or requested from European Union dissemination platform.

## 2. Routes to Qualification

Three distinct routes to gaining the qualifications described in this document have been agreed to all AM profiles developed under project CLLAIM scope.

1. The Standard Route
2. Blended Learning Route
3. Alternative Route

### 2.1 The Standard Route

The Standard Route requires successful completion of AM approved courses which are designed to meet all the requirements in this Guideline. This is the route recommended, as offering the fastest, most comprehensive manner in which the detailed knowledge may be covered.

### 2.2 Blended Learning Route

The Cross-Cutting Competence Units (theoretical knowledge and skills) may be taught using Distance Learning Programs under the control of European harmonized system and all the Functional Competence Units (practical knowledge and skills) must be taught at the facilities of a Training Centre that has the capacity to do so.

### 2.3 Alternative Route

The alternative route allows those who have gained relevant knowledge and skills in a particular job function through formal, informal and non-formal means of education to proceed to examination without a compulsory attendance of an approved training course or specific Competence Unit addressed by it. The alternative route encompasses two possibilities for the validation of knowledge and skills, through: the direct recognition of the Competence Unit.

### 3. Guideline for Metal AM Operator PBF - EB

#### 3.1 Introduction to Metal AM Operator PBF - EB

This guideline covers the minimum requirements for education and training, in terms of Learning Outcomes (Knowledge and Skills) and the recommended contact (teaching) hours to be devoted to achieving them.

Students successfully completing examinations will be expected to be capable of applying the achieved learning outcomes at a level consistent with the qualification diploma level. The modular course contents are given in the following structure (overview):

COMPETENCE UNITS	EO-PBF-EB	
	Recommended Contact Hours*	Expected Workload**
CU 00: Additive manufacturing Process Overview	7	14
CU 22: PBF-EB Process	14	28
CU 23: Quality Assurance (QA) in PBF-EB	7	14
CU 24: Health, Safety and Environment (HSE) in PBF-EB	3,5	7
CU 50: Hardware, software and build file set-up for PBF-EB	14	28
CU 51: Monitoring and managing the manufacturing of PBF-EB parts	3,5	7
CU 52: Post-processing of PBF-EB parts	7	14
CU 53: Maintenance of PBF-EB systems	7	14
<b>Subtotal (without optional CUs)</b>	<b>63</b>	<b>126</b>
CU 48: Powder Handling	14	28
<b>Total</b>	<b>77</b>	<b>144</b>

\* Recommended Contact Hours are the minimum recommended teaching hours for the Standard Routes. A contact hour shall contain at least 50 minutes of direct teaching time.

\*\* Expected Workload is calculated in hours, corresponding to an estimation of the time students typically need to complete all learning activities required to achieve the defined learning outcomes in formal learning environments plus the necessary time for individual study.

Although the hours indicated in the above table are merely recommended, it is mandatory that in total the qualification has a minimum of 40 contact hours.

Within CLLAIM project’s qualifications, there are two types of Competence Units:

Cross-cutting Competence Unit - A competence unit whose learning outcomes are not directly linked with one job function since the knowledge and skills achieved will be mobilized in several job functions and activities.

Functional Competence Unit - A competence unit whose learning outcomes are directly linked with at least one job function and in which the knowledge and skills achieved will be mobilized in specific job functions and related activities.

The expected learning outcomes are described in two ways: generic outcome descriptors organized in knowledge, skills, autonomy and responsibility; and in detail for each competence unit, organized in job functions and related activities, knowledge and skills corresponding to a specific proficiency level within EWF’s Sectoral Systems Framework levels (see Appendix I). On each Competence Unit, objectives and scope are defined for a specific depth of knowledge and skills. Recommended contact hours are distributed between theoretical (A), assigned projects/exercises (B), practical workshop training (C), etc., as shown in the following example:

Qualification: Example 1	
RECOMMENDED CONTACT HOURS	X = SUM (A:C)
Subject Contents	A + B + C

### 3.2 Occupational Standard

EO PBF-EB is the professional with the specific knowledge, skills, autonomy and responsibility to operate metal AM machines using PBF-EB Process. His/her main tasks are to:

- Operate electron beam powder bed fusion machines for AM, including fitting and setting up, maintenance and repair.

He/She will be able to:

- Remove parts and prepare them for post-processing steps;
- Self-manage the handling of powder (approval, storage, contamination, traceability);
- Develop solutions on basic and specific problems related with electron beam powder-bed fusion machines



### 3.3 General Access Conditions

The defined access conditions are given in detail for all training institutions participating in the European AM Qualification System.

The access conditions to European Operator Qualification admission are the following:

- National compulsory school diploma

### 3.4 Qualification Outcome Descriptors

QUALIFICATION	EFW LEVEL	KNOWLEDGE	SKILLS	AUTONOMY AND RESPONSIBILITY
EO PBF-EB	INDEPENDENT	Factual and broad concepts in the field of PBF-EB metal additive manufacturing process.	Fundamental cognitive and practical skills required to develop proper solutions and application of procedures and tools on simple and specific of PBF-EB manufacturing problems	Self-manage of professional activities and simple standard applications of PBF-EB manufacturing in predictable contexts but subject to change.

### 3.5 Mandatory Competence Units Learning Outcomes

Each of the Competence Units that compile the Guideline for Metal AM Operator DED-Arc is listed below.

#### 3.5.1 Competence Unit 00: Additive Manufacturing Processes Overview

CU 00: Additive Manufacturing Processes Overview	RECCOMM ENDED CONTACT HOURS
SUBJECT TITLE	
Directed energy deposition	1
Powder bed fusion	1
Vat photopolymerization	1
Material jetting	1
Binder jetting	1
Material extrusion	1
Sheet lamination	1
<b>Total</b>	<b>7</b>
<b>WORKLOAD</b>	<b>14</b>

Learning Outcomes – CU 00: Additive Manufacturing Processes Overview	
<b>KNOWLEDGE</b>	Factual and broad knowledge of theory, principles and applicability of: <ul style="list-style-type: none"> <li>– Directed ernaly energy deposition</li> <li>– Powder bed fusion</li> <li>– Vat photopolymerization</li> <li>– Material jetting</li> <li>– Binder jetting</li> <li>– Material extrusion</li> <li>– Sheet lamination</li> </ul>
<b>SKILLS</b>	Distinguish parts produced by different AM processes Recognise the advantages and limitations of AM processes from a manufacturing process chain point of view Identify the applicability of different AM processes, according to the characteristics of each process

**3.5.2 Competence Unit 22: PBF-EB Process**

CU 22: PBF-EB Process	RECOMMENDED CONTACT HOURS
<b>SUBJECT TITLE</b>	
Introduction to Additive Manufacturing (AM)	1,5
Applications	1
Process Principles	1
System – Hardware and Software	3
Parameters	3
System – Software	0,5
Feedstock	2
Consumables	1
Post Processing	1
<b>Total</b>	<b>14</b>
<b>WORKLOAD</b>	<b>28</b>

<b>Learning Outcomes – CU22: PBF-EB Process</b>	
<b>KNOWLEDGE</b>	<p>Factual and broad knowledge of:</p> <ul style="list-style-type: none"> <li>– EB systems</li> <li>– EB characteristics</li> <li>– Build platform</li> <li>– Wire /Powder</li> <li>– Vacuum pressure</li> <li>– Advantages and limitations of the process</li> <li>– Processable materials with EB</li> </ul>

Learning Outcomes – CU22: PBF-EB Process	
<b>SKILLS</b>	<p>Describe the EB systems, including the components and their functions</p> <p>Outline the main advantages and limitations of EB over conventional and other AM processes, namely based on Electron beam</p> <p>Recognise the characteristics of the EB build platform, feedstock and other consumables</p> <p>Recognise the EB parameters and the influence of their adjustment on the as built part</p> <p>Recognise the interaction of the process heat source with the feedstock</p> <p>Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock used in EB</p>

### 3.5.3 Competence Unit 23: Quality Assurance (QA) in PBF-EB

CU 23: Quality Assurance (QA) in PBF-EB	RECOMMENDED CONTACT HOURS
<b>SUBJECT TITLE</b>	
General QA principles	2,5
AM Machine QA	1,5
AM Parts QA	1
Visual Inspection Overview	2
<b>Total</b>	<b>7</b>
<b>WORKLOAD</b>	<b>14</b>

Learning Outcomes – CU23: Quality Assurance (QA) in PBF-EB	
<b>KNOWLEDGE</b>	<p>Factual and broad knowledge of:</p> <ul style="list-style-type: none"> <li>- Quality Assurance in PBF-EB</li> <li>- Visual Inspection</li> </ul>

<b>Learning Outcomes – CU23: Quality Assurance (QA) in PBF-EB</b>	
<b>SKILLS</b>	<p>Recognise the broader use of QA within engineering</p> <p>Recognise the scope of the PBF-EB operator qualification within the AM industry</p> <p>Support the qualification and requalification procedures of PBF-EB equipment</p> <p>Identify the main procedures, equipment and their role</p> <p>Prepare test reports based on the requirements specified by the manufacturer</p> <p>Read a manufacturing plan</p> <p>Compare geometry and dimensions specified in the technical drawings with the as built parts</p> <p>Use simple measurement devices and techniques to carry out a basic visual inspection of the as built part</p> <p>Identify problems in the as build parts distinguishing between imperfections and defects</p> <p>Report defects suggesting either their removal with post processing operations, further inspection or part disposal</p>

**3.5.4 Competence Unit 24: Health, Safety and Environment (HSE) in PBF-EB**

CU24: Health, Safety and Environment (HSE) in PBF-EB	RECOMMENDED
SUBJECT TITLE	CONTACT HOURS
Health, Safety and Environment	3,5
Total	3,5
WORKLOAD	7

Learning Outcomes – CU24: Health, Safety and Environment (HSE) in PBF-EB	
<b>KNOWLEDGE</b>	Factual and broad of: <ul style="list-style-type: none"> <li>– Health, Safety and Environment related to PBF-EB</li> </ul>
<b>SKILLS</b>	Identify the main hazards and safety measures associated with PBF-EB systems

### 3.5.5 Competence Unit 50: Hardware, software and build file set-up for PBF-EB

CU 50: Hardware, software and build file set-up for PBF-EB	RECOMENDE D CONTACT HOURS
SUBJECT TITLE	
PBF-EB machine set-up requirements	4
Pre-build check list	3
Consumables, feedstock & substrate	3
Build files	1
Work documentation	2
Practical implementation of HSE procedures (while fit and set up the machine)	1
<b>Total</b>	<b>14</b>
<b>WORKLOAD</b>	<b>28</b>

CU	EQ/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Hardware, software and build file set-up for PBF-EB	4 Independent	Hardware, software and build file set-up for PBF-EB	Verifying the PBF-EB system set-up according to the procedure determined by the machine manufacturer and required operational conditions	14	28
			Preparing and verifying the build substrate and feedstock conditions		
			Performing: build file loading, process preparation, process starts, in process observation and mal function detection and mitigation		
			Build observation		



			Following HSE procedures during machine and build file set-up		
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Learning Outcomes – CU 50: Hardware, software and build file set-up for PBF-EB	
<b>KNOWLEDGE</b>	<p>Factual and broad knowledge of:</p> <ul style="list-style-type: none"> <li>– Variables of PBF-EB and related operational conditions parameters</li> <li>– PBF-EB equipment requirements</li> <li>– Materials used for PBF-EB</li> <li>– Type of files and work documentation</li> <li>– HSE procedures under PBF-EB</li> </ul>
<b>SKILLS</b>	<p>Prepare the machine for operation, according to the AM procedure specification</p> <p>Prepare the feedstock, build platform and the machine in accordance to the material being used</p> <p>Verify if the PBF-EB machine complies with the machine manufacturer and/or internal specifications</p> <p>Load files to PBF-EB machines</p> <p>Verify if the PBF-EB machines are working in accordance with the job specification, in terms of process parameters</p> <p>Comply with HSE procedures associated to PBF-EB machines</p> <p>Interpret technical information related to the PBF-EB process and machines</p>

**3.5.6 Competence Unit 51: Monitoring and managing the manufacturing of PBF-EB parts**

CU 51: Monitoring and managing the manufacturing of the PBF-EB parts	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Machine functionalities and monitoring systems	2
HSE Procedures	0,5
Documentation	1
Total	3,5
WORKLOAD	7

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Monitoring and managing the manufacturing of PBF-EB parts	4 Independent	Monitoring and managing the manufacturing of PBF-EB parts	Following HSE procedures when printing AM parts	3,5	7
			Following and completing work documentation according to quality/parts requirements		
			Reporting issues and implementing corrective or preventive actions based on parts' requirements feedback from the Engineer		

<b>Learning Outcomes – CU 51: Monitoring and managing the manufacturing of the PBF-EB parts</b>	
<b>KNOWLEDGE</b>	Factual and broad of: <ul style="list-style-type: none"> <li>– Manufacturing of PBF-EB parts</li> <li>– Machine functionalities and monitoring systems</li> </ul>
<b>SKILLS</b>	Load powder following mandatory safety procedures Apply HSE procedures when manufacturing parts Interpret technical documentation related to the requirements of the as built parts Identify the main reasons for failure during the manufacturing process Prepare reports on the manufacturing process, including identified issues

**3.5.7 Competence Unit 52: Post processing of PBF-EB parts**

CU 52: Post processing of PBF-EB parts	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Powder and parts removal processes	4
Manual tools and methods for post-processing operations	3
Total	7
WORKLOAD	14

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Post processing of PBF-EB parts	4 Independent	Prepare PBF-EB parts for post processing	Providing information from monitoring data about critical areas for extended testing	7	14
			Applying simple manual operations to parts (cleaning, subtractive & post processing)		
			Handing parts for post processing operations		
			Following applicable HSE procedures		

Learning Outcomes – CU 52: Post processing of PBF-EB parts	
KNOWLEDGE	Factual and broad of: <ul style="list-style-type: none"> <li>– Powder removal processes</li> <li>– Manual Tools and Methods for subtractive operations</li> <li>– Procedures for different post-processing methods and materials</li> </ul>

<b>Learning Outcomes – CU 52: Post processing of PBF-EB parts</b>	
<b>SKILLS</b>	<p>Remove the as build parts and base plates from the machine applying the necessary HSE procedures</p> <p>Carry out simple manual preparation of the as built part for different post-processing methods</p> <p>Remove powder from the powder bed and parts following mandatory safety procedures</p> <p>Separate the as built parts from base plates distinguishing the base plate from the part based on the technical drawing and specifications using simple manual processes</p>

**3.5.8 Competence Unit 53: Maintenance of PBF-EB systems**

CU 53: Maintenance of PBF-EB systems	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
General maintenance aspects	2
Optical elements	0,5
Parts maintenance	1,5
Auxiliary elements maintenance	0,5
Application driven material change	1,5
HSE procedures	1
<b>Total</b>	<b>7</b>
WORKLOAD	14

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Maintenance of PBF-EB systems	4 Independent	Maintain and repair the PBF-EB system	Implementing equipment manufacturer's maintenance routines Cleaning and replacing materials components (e.g. powder bed, cleaning agent, filters) Reporting problems to the Engineer Following applicable HSE procedures	7	14

Learning Outcomes – CU21: Maintenance of PBF-EB systems	
KNOWLEDGE	Factual and broad of: – Maintenance aspects associated with PBF-EB systems

<b>Learning Outcomes – CU21: Maintenance of PBF-EB systems</b>	
<b>SKILLS</b>	<p>Clean the nozzle</p> <p>Assess the need to perform maintenance operations in PBF-EB system</p> <p>Perform maintenance operations in PBF-EB system</p> <p>Identify the consumables for the different machine parts</p> <p>Report the need to execute specific maintenance</p> <p>Support other technicians during system maintenance</p> <p>Verify the cleanliness of the system</p> <p>Monitoring and calibration status</p> <p>Verify the level of wear of a mechanical component</p> <p>Verify the system gas flow</p> <p>Adequate maintenance routines to the material type</p> <p>Verify the condition and make use of the personal protective equipment</p>

### 3.5.9 Competence Unit 48: Powder Handling

CU 48: Powder Handling	RECOMENDED CONTACT HOURS
SUBJECT TITLE	
Overview of Powder Manufacturing Processes	3
Chemical Composition and Physical Properties	4
Particle Size Distribution	2
Powder storage, handling, ageing and documentation	3
Powder reusability	1
HSE procedures	1
<b>Total</b>	<b>14</b>
<b>WORKLOAD</b>	<b>28</b>

CU	EQF/ EWF LEVEL	JOB FUNCTIONS	JOB REQUIRED ACTIVITIES	CONTACT HOURS	WORKLOAD
Power Handling	4 Independent	Manage powders for Metal AM	Implementing procedures for powder delivery and storage	14	28
			Preparing and analysing powder according to technical documentation		
			Performing powder reconditioning (e.g. sieving) after build cycle		
			Following HSE procedures		

Learning Outcomes – CU 48: Powder Handling	
KNOWLEDGE	Factual and broad of:  – Powder handling, storage and reconditioning



<b>Learning Outcomes – CU 48: Powder Handling</b>	
<b>SKILLS</b>	Complete technical documentation related to powders for metal AM Characterise powders according to instructions from the engineer Ensure powder conditioning according to the AM Procedure Specification Control the reusability of powders Handle powders according to HSE procedures