

# AM INTERACTION DAYS



David Hardacre, Lloyd's Register

*Certification of AM products*



**EU Industry Week**  
2021  
#EUIndustryWeek



# About LR



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ARE YOU—  
**AM**  
— READY?

## Lloyd's Register Foundation & Group

1. LR Foundation is a charity
2. Its mission is to enhance safety of life and property, and advance public education
3. It is based in the UK but gives grants globally
4. It is the sole shareholder of the Lloyd's Register Group
5. Impact and excellence are the major grant-giving criteria
6. >\$27M donated to LR Foundation to support science & engineering research and education



The background features a repeating pattern of pink 3D cubes, each outlined with a dashed yellow hexagon. A large teal rectangle is positioned on the right side of the image, containing the text "Why certify?".

# Why certify?

# Why certify?

## Safety

- Consumers
- Operators
- Members of the public
- Assets
- Environment



Flixborough disaster – 1974  
28 lives lost, 36 non-fatal injuries



Concorde – 2000  
113 lives lost



Piper Alpha – 1988  
167 lives lost



Bhopal disaster – 1984  
>3787 lives lost, >500,000 non-fatal injuries



# Why certify?

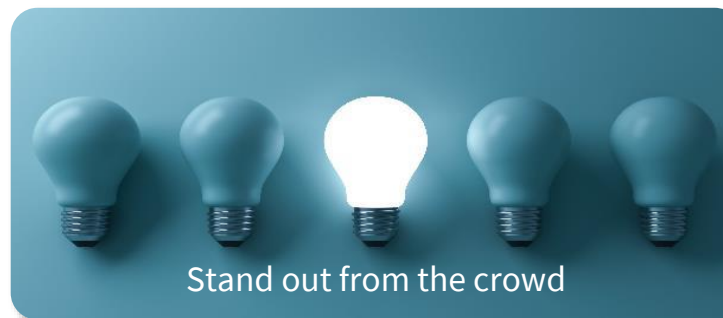


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## Product assurance

- Industry & market acceptance (safety of product for intended application)
- Confirms legal requirements are met
- Provides assurance of quality and capability to manufacturers, clients and users



Benchmarking



# Why certify?



## Safety

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## Self-certification

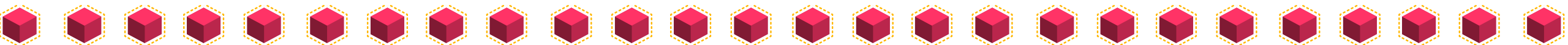
- Aerospace: CAA
- Medical: FDA
- Mining: Country specific (e.g. Indian Bureau of Mines)
- Automotive

## Product assurance

- Industry & market acceptance (safety of product for intended application)
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## 3rd party certification

- Oil & gas
- Marine
- Energy
- Construction



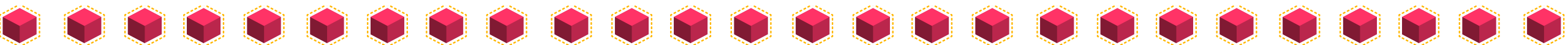


# Qualification & Certification



LR provides material and part **certification** but facility **qualification**

- To understand the difference, we first need to understand the difference between **verification** and **validation**
- Very simplistically:
  - **Verification**: are all the right things in there?
  - **Validation**: are all the things in there, right?
- For example, if assessing a spreadsheet, then:
  - verification would involve checking that all required formulas were entered correctly in order to calculate the required outputs (i.e. auditing)
  - validation would involve checking that the values were calculated correctly, usually by use of specific test cases (i.e. testing)



# Why certify?

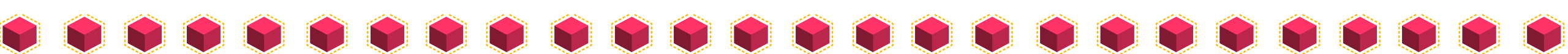


So, in terms of additive manufacturing...

- A **qualified facility** is one that has been **verified** as having the necessary equipment, personnel, processes, etc. to produce the outputs that they have been qualified for
- **Certified materials & parts** are the outputs from a qualified facility that have been **validated** as satisfying the requirements of a specific regulation, code, standard or specification

*“Qualification is possible without certification  
but certification requires qualification”*

- Confusion sometimes arises since a **certificate** is issued for both certification and qualification - unfortunately, there is no such thing as a **qualificate**!



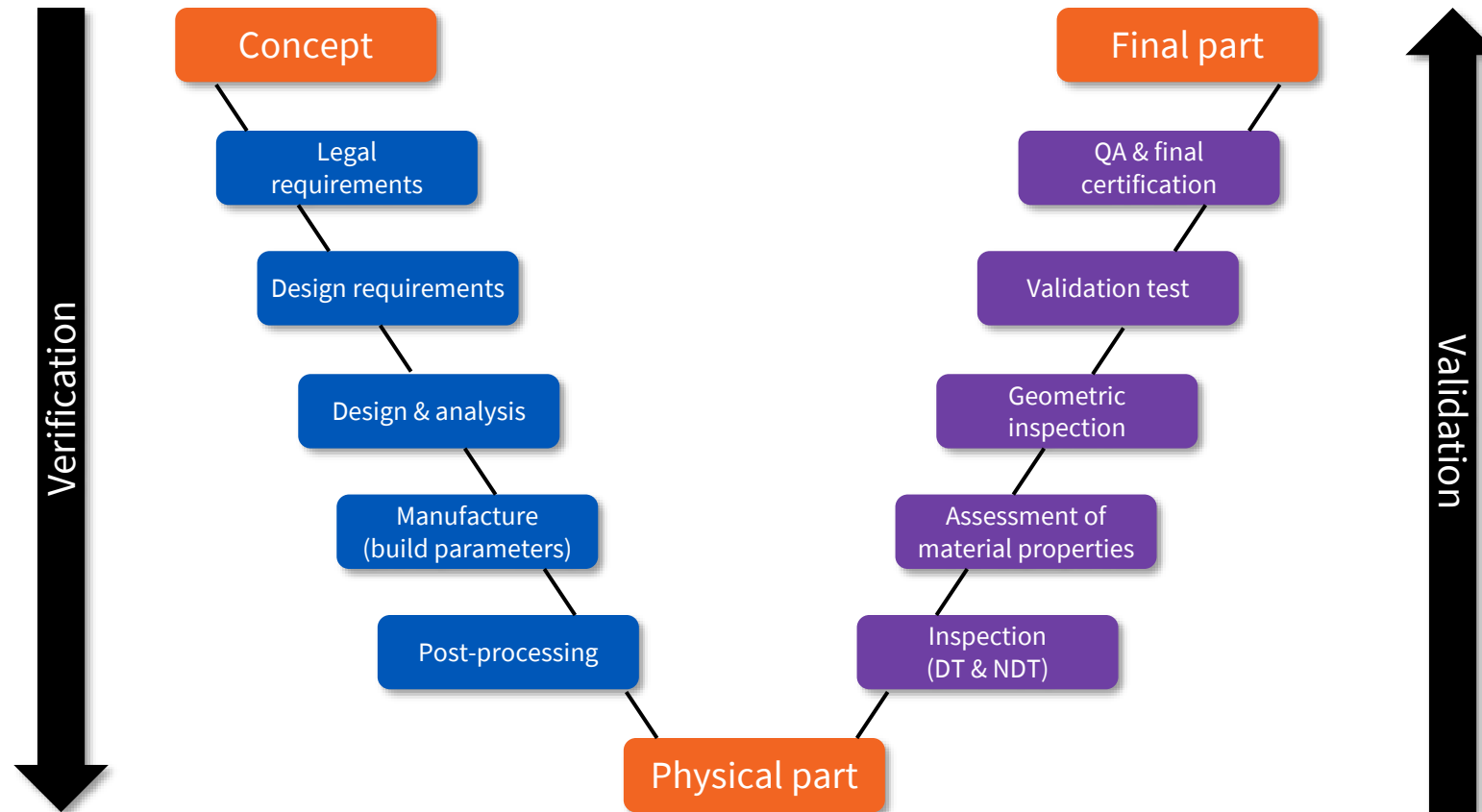


# Project stages



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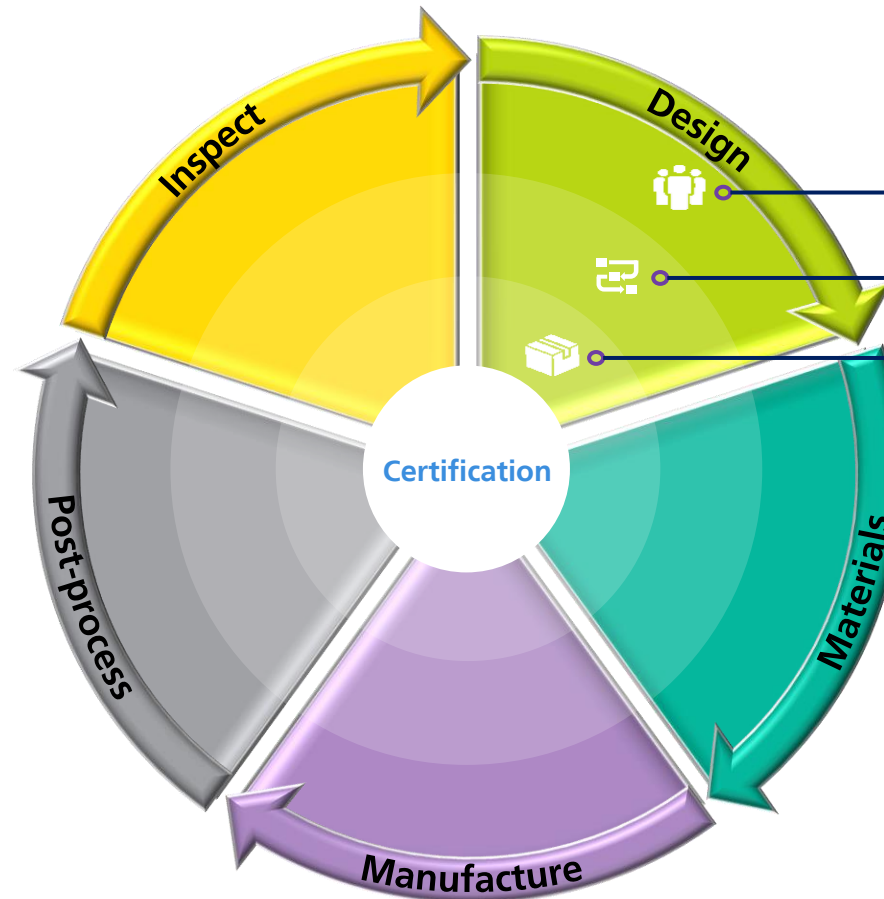
# Functional stages for certification



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Within each area of activity, the tasks can be further sub-divided into:



**People**  
**Process**  
**Product**

...and of course, quality control needs to be applied throughout each functional stage.



# Functional stages for certification

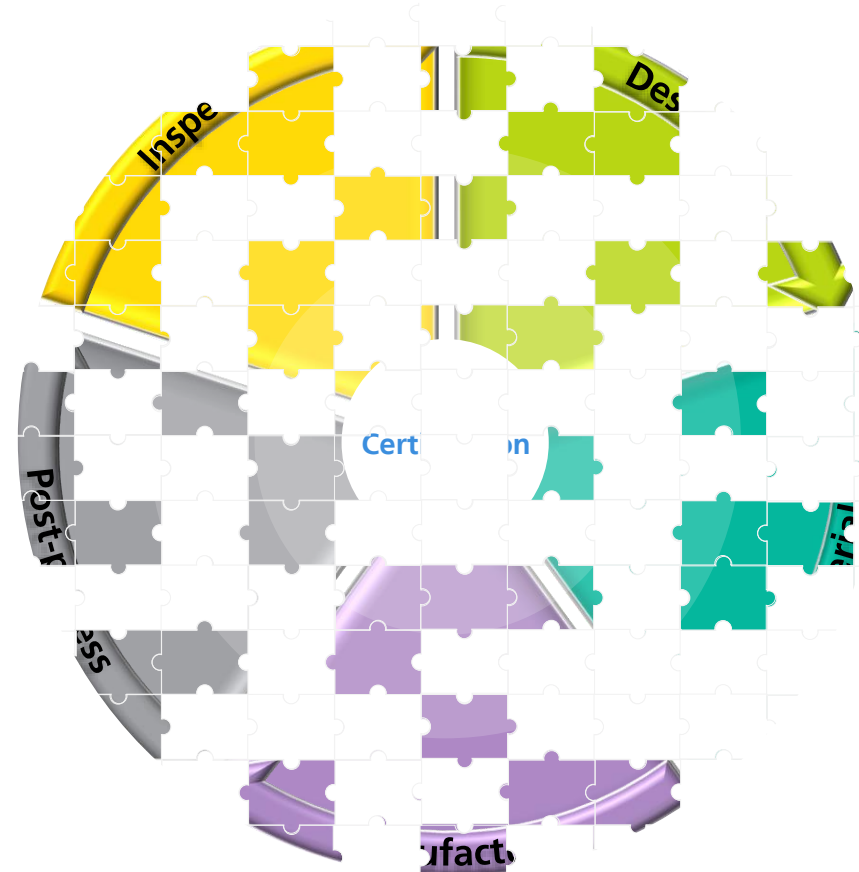


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## Application specific standards

- Aspects of these can be used for AM, where relevant
- AM-specific information is not typically provided in these standards at the moment
- Questions arise, for example:
  - What material properties to use?
  - Is a design factor required?
  - Are existing fatigue curves applicable for AM?
  - Are current inspection techniques capable of detecting AM-specific flaws?
  - Are AM builds repeatable? What are the causes of variation?



# Functional stages for certification

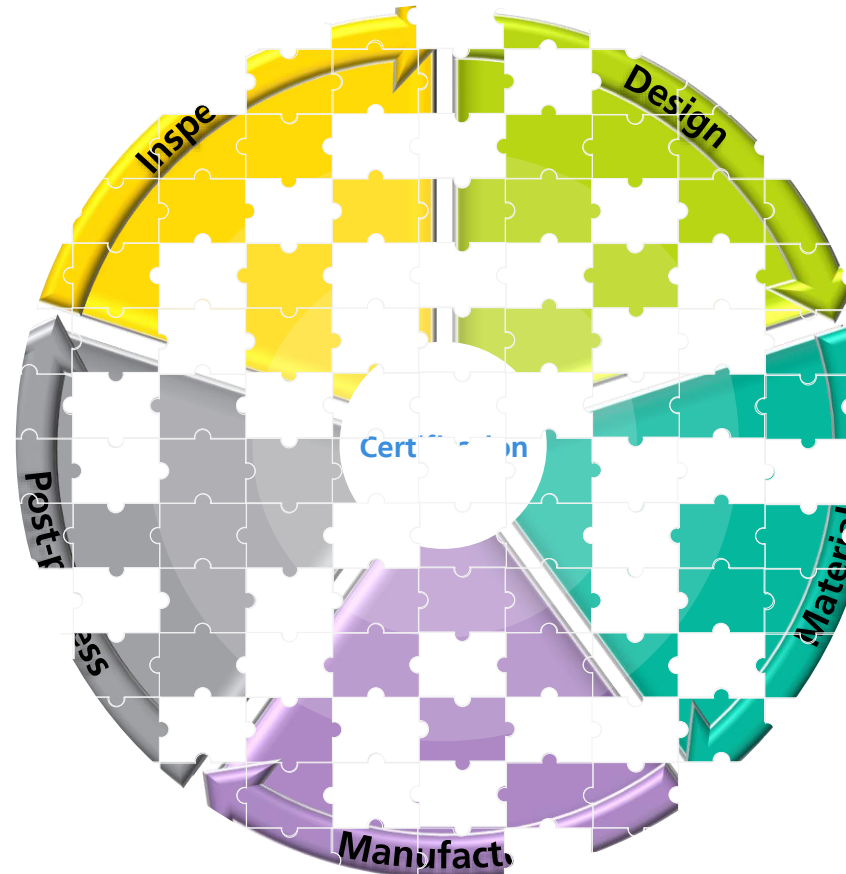


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## AM specific standards

- Fills the gaps within the industry standards for AM
- Not many AM-specific standards available yet



# Functional stages for certification

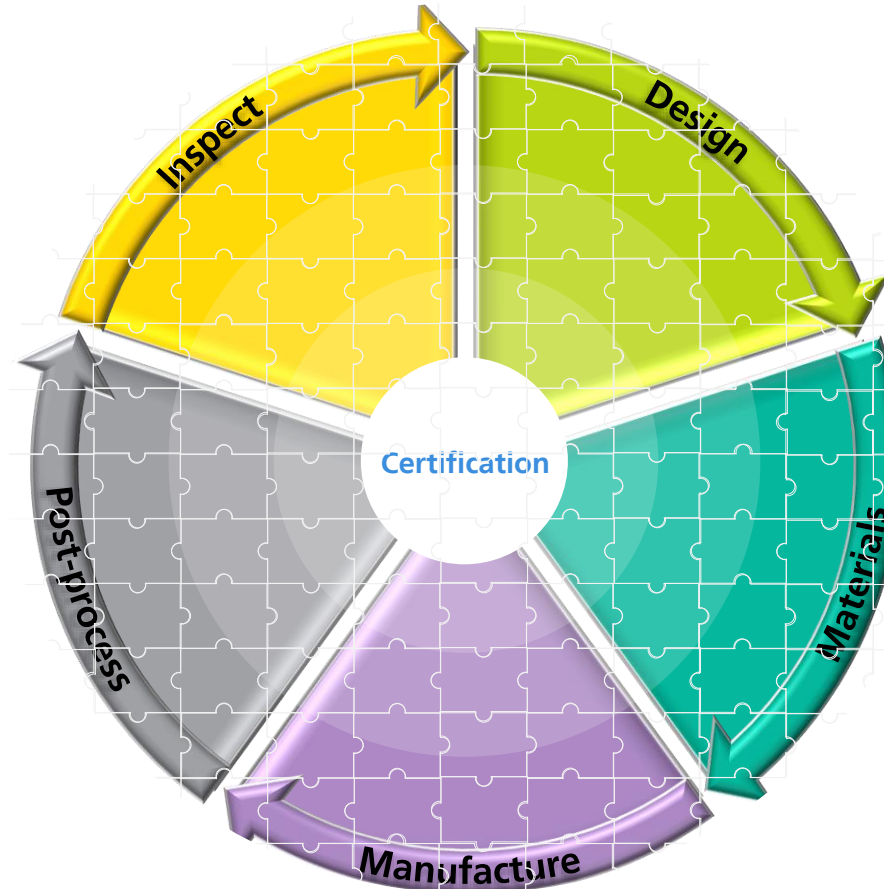


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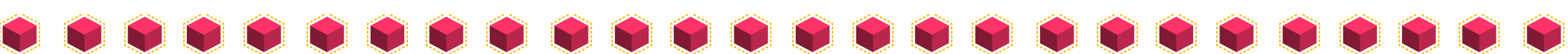


## AM specific standards

- Fills the gaps within the industry standards for AM
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## Technology Qualification

- Used where neither industry-specific nor AM-specific standards are available
- Guidance provided by Regulator or Inspection Authority



# Application-specific standards

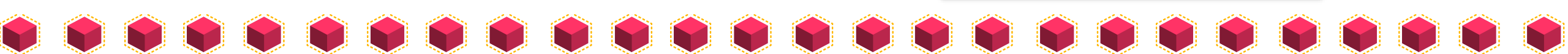


## API 20S: AM metallic materials for use in the petroleum & natural gas industries

- The API 20S Standard is designed to play a crucial role in leveraging Additive Manufacturing (AM) to foster innovation in the oil and gas industry and encourage a safer, broader, and faster adoption of AM technologies in the mainstream oil and gas applications.
- Initial draft is complete and is currently progressing through the review & ballot stage:  
API Ballot: 5386-API 20S, 1st Edition
- Ballot closes 24<sup>th</sup> March 2021

### Additively Manufactured Metallic Materials for use in the Petroleum & Natural Gas Industries

API SPECIFICATION 20S  
FIRST EDITION (CURRENTLY DRAFT STATUS)





# Application-specific standards

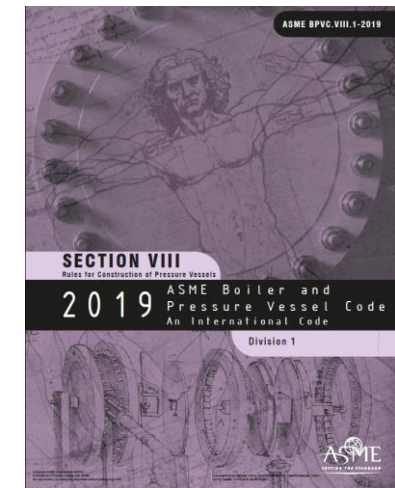
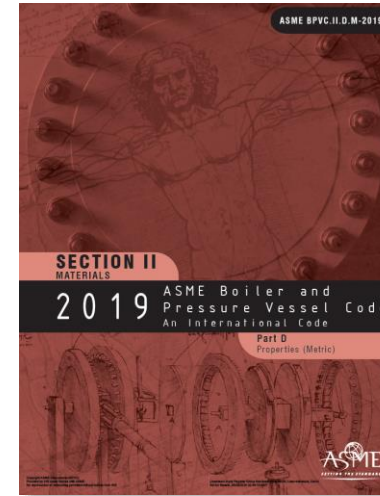


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## ASME BPTCS/BNCS Special Committee

- Charter: to develop a technical baseline to support development of a proposed BPTCS standard or guideline addressing the pressure integrity governing the construction of pressure retaining equipment by additive manufacturing processes. Construction, as used in this Charter, is limited to materials, design, fabrication, examination, inspection, and testing.
- This Committee has now produced the final draft of “ASME Criteria for Pressure Retaining Metallic Components Using Additive Manufacturing” which is currently being balloted (Ballot #21-179).
- Scope is limited to powder bed fusion (laser and electron beam energy sources) at the moment (DED-Arc to follow).
- Once approved, the criteria will be published as a Pressure Technology Book (PTB) and used as a reference document for proposals for AM Code Cases or incorporation of AM into construction codes.

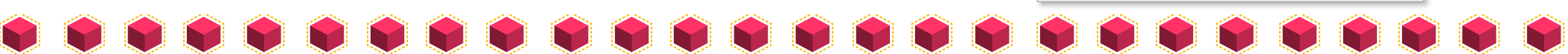
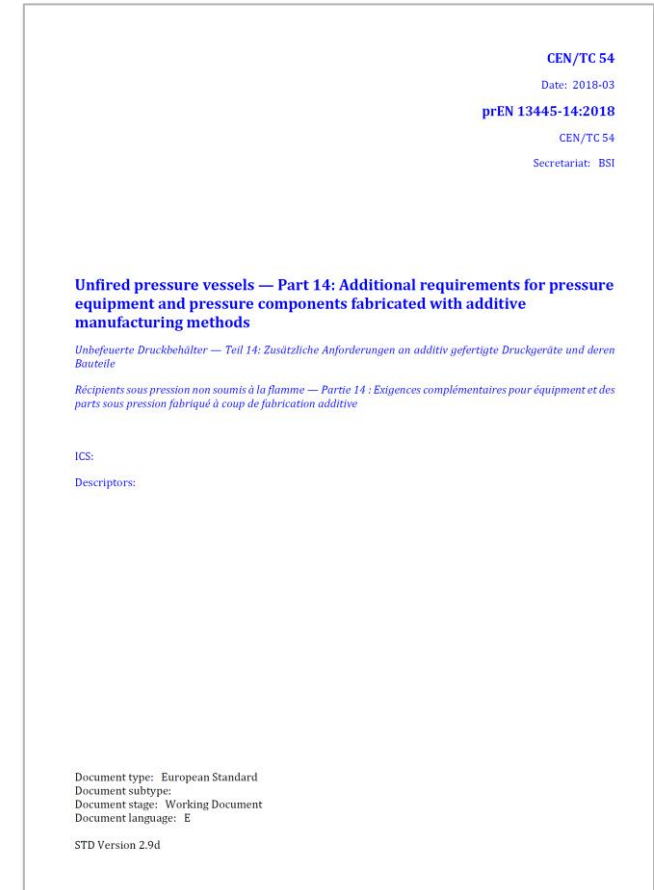


# Application-specific standards



## CEN/TC 54: Unfired pressure vessels

- **EN 13445 Part 14** has been drafted a new to incorporate requirements for pressure components by AM
- Includes sections on:
  - Materials (including nominal design stress rules)
  - Design & fabrication rules (including documentation & identification)
  - Inspection & testing (including Quality Factor for different levels of NDE)
  - Separate annexes for different AM processes (e.g. Annex A for powder bed fusion; Annex B for direct energy deposition with wire; etc.)
  - Each annex further sub-divides by specific material requirements (e.g. B.1 General requirements for DED-wire; B.2 DED-wire and steel; B.3 DED-wire and aluminium; etc.)



# AM-specific standards



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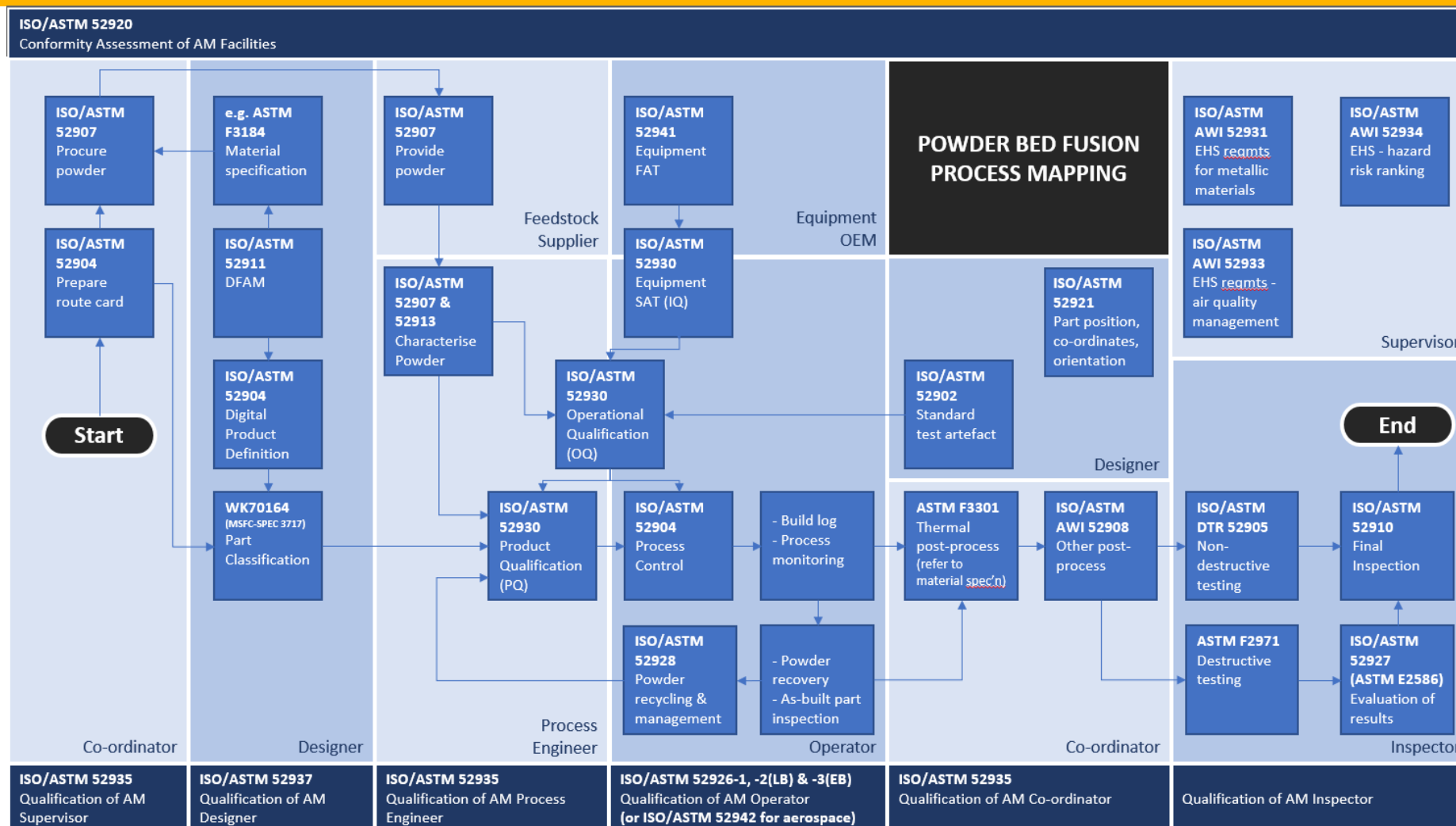
| WG1<br>Terminology   | WG2<br>Methods, process & materials   |  |   | WG3<br>Test methods  | WG4<br>Data & design   |   |  | WG6<br>Environmental,<br>health & safety   | JWG10<br>AM in aerospace applications  |   |  | JWG11<br>AM for plastics  |  |
|--|---|--|---|--|--|---|--|--|--|---|--|---|--|
| ISO/ASTM 52900:<br>Terminology   | ISO 17296-2:<br>Overview of process categories and feedstock  |  |   | ISO 17296-3<br>Main characteristics and<br>corresponding test methods            | ISO 17296-4<br>Overview of data<br>processing  |   | ISO/ASTM 52910:<br>Standard Guidelines for<br>Design for AM  | ISO/ASTM CD 52931:<br>Standard guideline for<br>use of metallic materials  | ISO/ASTM CD 52926-1:<br>Qualification of<br>machine<br>operators for<br>metallic parts<br>production               | ISO/ASTM CD 52926-2:<br>Qualification of<br>machine<br>operators for<br>metallic parts<br>production for<br>PBF-LB  | ISO/ASTM CD 52926-3:<br>Qualification of<br>machine<br>operators for<br>metallic parts<br>production for<br>PBF-EB | ISO 27547-1:<br>Plastics — Preparation<br>of test specimens of<br>thermoplastic materials<br>using mouldless<br>technologies: General<br>principles & laser sinter<br>of test specimens |  |
| ISO/ASTM 52921:<br>Standard practice for<br>part<br>positioning,<br>coordinates &<br>orientation | ISO/ASTM 52903-1:<br>Material<br>extrusion<br>based AM of<br>plastics:<br>Feedstock<br>materials              | ISO/ASTM 52903-2:<br>Material<br>extrusion<br>based AM of<br>plastics:<br>Process/<br>Equipment                | ISO/ASTM CD 52903-3:<br>Material<br>extrusion<br>based AM of<br>plastics: Parts | ISO/ASTM 52901:<br>Requirements for purchased<br>AM parts                        | ISO/ASTM 52911-1:<br>Technical<br>Design<br>Guideline for<br>PBF: PBF-LB of<br>metals                | ISO/ASTM 52911-2:<br>Technical<br>Design<br>Guideline for<br>PBF: PBF-LB of<br>polymers     | ISO/ASTM AWI 52911-3:<br>Technical<br>Design<br>Guideline for<br>PBF: PBF-EB of<br>metals          | ISO/ASTM CD 52932:<br>Determination of<br>particle emission rates<br>from desktop 3D<br>printers using material<br>extrusion | ISO/ASTM CD 52926-4:<br>Qualification of<br>machine<br>operators for<br>metallic parts<br>production for<br>DED-LB | ISO/ASTM CD 52926-5:<br>Qualification of<br>machine<br>operators for<br>metallic parts<br>production for<br>DED-Arc | ISO/ASTM AWI 52935:<br>Qualification of<br>coordinators<br>for metallic<br>parts<br>production                     | ISO/ASTM DIS 52924:<br>Quality grades for AM of<br>polymer parts  |  |
|  | ISO/ASTM 52904:<br>Standard<br>Practice for<br>metal PBF<br>process to<br>meet critical<br>applications       | ISO/ASTM CD TR 52906:<br>Standard<br>practice for<br>intentionally<br>seeding replica<br>into AM<br>structures | ISO/ASTM 52907:<br>Technical<br>specification<br>on metal<br>powders            | ISO/ASTMAWI TR 52905:<br>NDT of AM products                                      | ISO/ASTM TR 52912:<br>Technical<br>report for the<br>design of<br>functionally<br>graded AM<br>parts | ISO/ASTM PWI 52914:<br>Design —<br>Standard guide<br>for material<br>extrusion<br>processes | ISO/ASTM 52915:<br>Standard<br>specification<br>for AM file<br>format (AMF)<br>v1.2                | ISO/ASTM WD 52933:<br>Standard specification<br>on indoor air quality<br>management  | ISO/ASTMAWI 52937:<br>Qualification of designers   |   |  | ISO/ASTM DIS 52925:<br>Qualification of polymer<br>materials for PBF-LB   |  |
|  | ISO/ASTMAWI 52908:<br>Post-processing -<br>Specification for QA &<br>post processing of PBF<br>metallic parts |  |   | ISO/ASTMAWI 52913:<br>Characterization of powder<br>flow properties              | ISO/ASTMAWI 52917:<br>Guideline for conducting<br>round robin studies                                | ISO/ASTM DTR 52916:<br>Optimized<br>medical image<br>data for AM                            | ISO/ASTM CD TR 52918:<br>Data formats --<br>File format<br>support,<br>ecosystem and<br>evolutions | ISO/ASTM PWI 52922:<br>Design —<br>Directed<br>Energy<br>Deposition  | ISO/ASTM PWI 52934:<br>Standard guideline for<br>hazard risk ranking &<br>safety defense                           | ISO/ASTM 52941:<br>Standard test<br>method for<br>acceptance of<br>PBF machines<br>for metallic<br>materials for    | ISO/ASTM 52942:<br>Qualifying<br>machine<br>operators PBF-<br>LB machines in<br>aerospace<br>applications          | ISO/ASTM PWI 52944:<br>Specification<br>for PBF<br>processes in<br>aerospace<br>applications  |  |
| Working Document<br>[10,20,30]   |   |  |   | ISO/ASTMAWI 52919-1:<br>Test method of sand mold<br>for metalcasting: mechanical |  |   |  | ISO/ASTM PWI 52938-1:<br>Safety requirements for<br>PBF-LB machines  |  |   |  |   |  |
| Available<br>As Draft<br>{40,50}   |   |  |   |  |  |   | ISO/ASTM 52950:<br>General<br>principles --<br>Overview of<br>data<br>processing                   |  |  |   | ISO/ASTM PWI 52943-1:<br>Specification<br>for DED using<br>wire and beam<br>in aerospace<br>applications           | ISO/ASTM PWI 52943-2:<br>Specification<br>for DED using<br>wire and arc in<br>aerospace<br>applications   | ISO/ASTM PWI 52943-3:<br>Specification<br>for DED using<br>laser blown<br>powder in<br>aerospace<br>applications |
| Published<br>ISO/ASTM<br>[60]  | ISO/ASTM CD 52920:<br>Qualification<br>principles — QA<br>requirements<br>for production                      | ISO/ASTMAWI 52928:<br>Powder life<br>cycle<br>management   | ISO/ASTM PRF TS 52930:<br>Guideline for<br>IQ/OQ/PQ of<br>PBF-LB<br>equipment   | ISO/ASTMAWI 52919-2:<br>Test method of sand mold<br>for metalcasting: physical   | ISO/ASTM PWI 52923:<br>Design decision<br>support  | ISO/ASTM PWI 52951:<br>Data packages<br>for AM parts  |  |  |  |   |  |   |  |
| Withdrawn<br>/Cancelled  |   |  |   | ISO/ASTM PWI 52927:<br>Process characteristics and<br>performance - Test methods |  |   |  |  |  |   |  |   |  |

# AM-specific standards

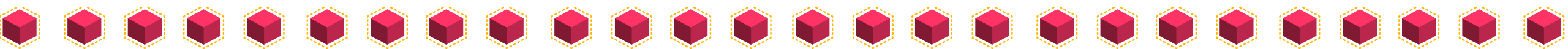
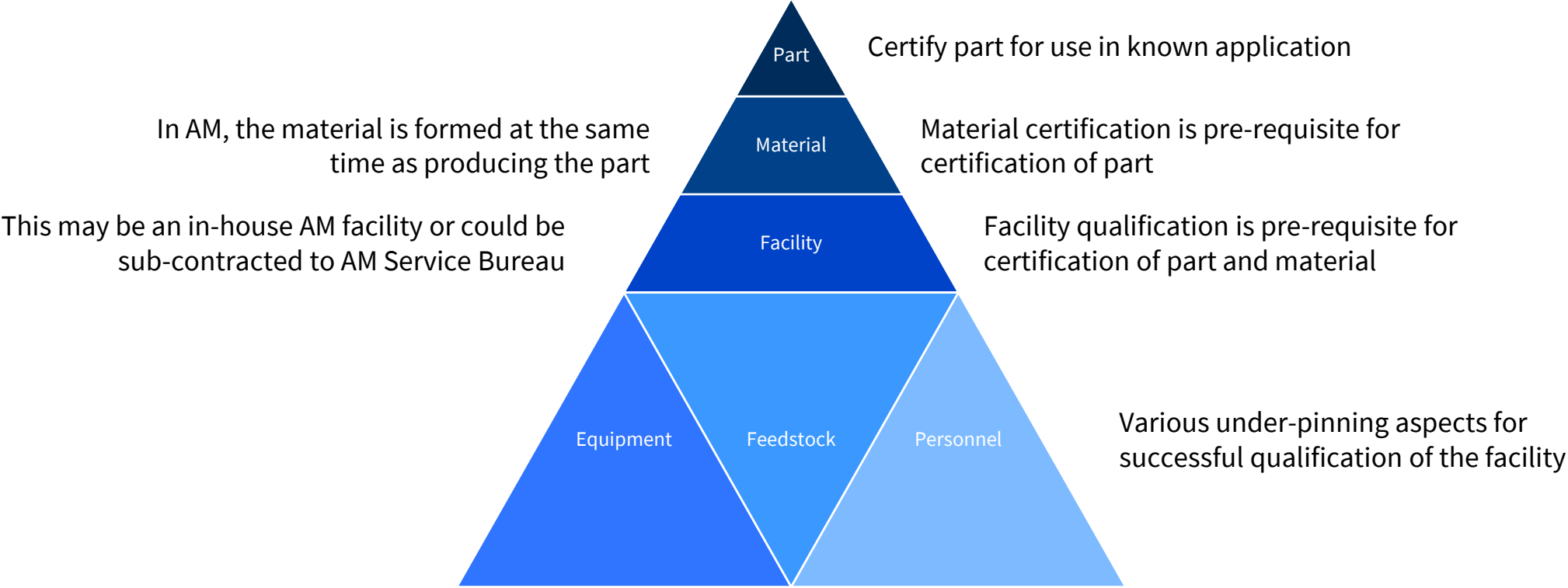


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# Certification hierarchy





# Certification hierarchy



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## Why do we need personnel qualifications for AM?

### Material specifications require it:

- EN 764-5 (metallic materials for pressure equipment)
  - e) The competent body shall evaluate by interviews or by the examination of documents:
    - 1) that the manufacturing equipment and the equipment controlling the essential parameters are available. They shall be capable of permitting the consistent delivery of products in the required quality;
    - 2) that competent personnel are available for operating and maintaining the equipment and supervising the manufacturing and inspection and testing activities;



### Product standards require it:

- EN 13445-1 (unfired pressure vessels - general)
  - the welder or welding operator shall be qualified, see 7.4 of EN 13445-4:2009.
- EN 13445-3 (design)

Due to the advanced methods applied, until sufficient in-house experience can be demonstrated, the involvement of an independent body, appropriately qualified in the field of DBA, is required in the assessment of the design (calculations) and the potential definition of particular NDT requirements.

- EN 13445-5 (inspection)

All inspections shall be carried out by qualified personnel.





# Certification hierarchy



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- EN 764-5 (metallic materials for pressure equipment)

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2) that competent persons  
manufacturing and in

*Additive Manufacturing cannot offer a loophole  
against existing regulations and requirements for  
conventionally-produced materials and parts*

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— the welder or welding operator

- EN 13445-3 (design)

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# Certification documentation



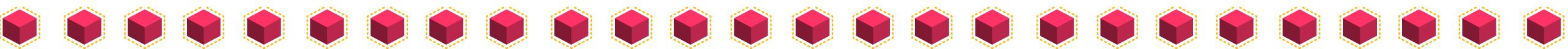
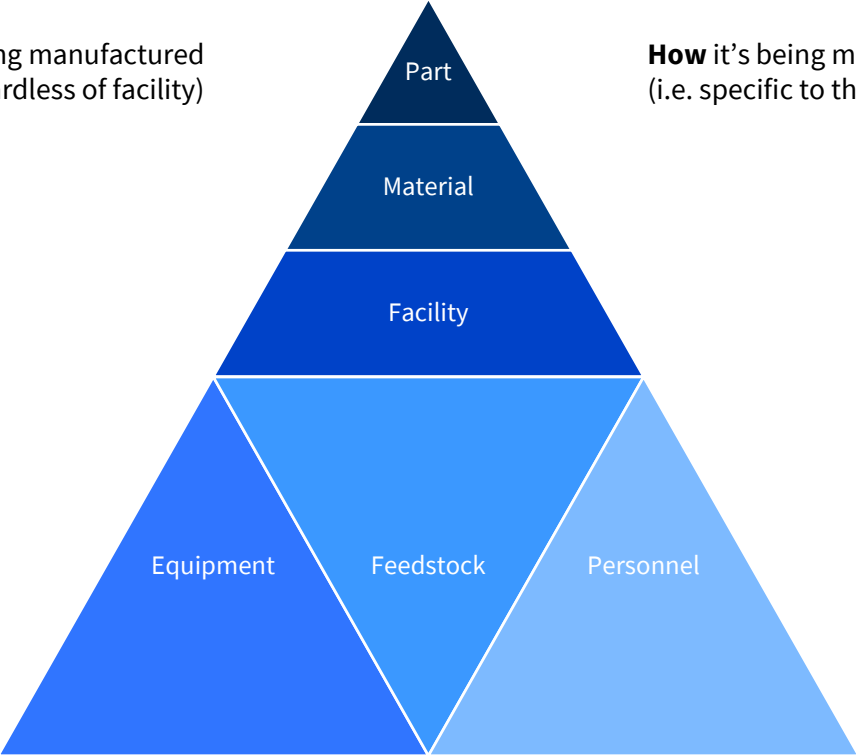
## MANUFACTURING PLAN

**What** is being manufactured  
(i.e. specific to the part, almost regardless of facility)



## FACILITY PROCEDURES

**How** it's being manufactured  
(i.e. specific to the facility, regardless of what is being made)



# Certification documentation



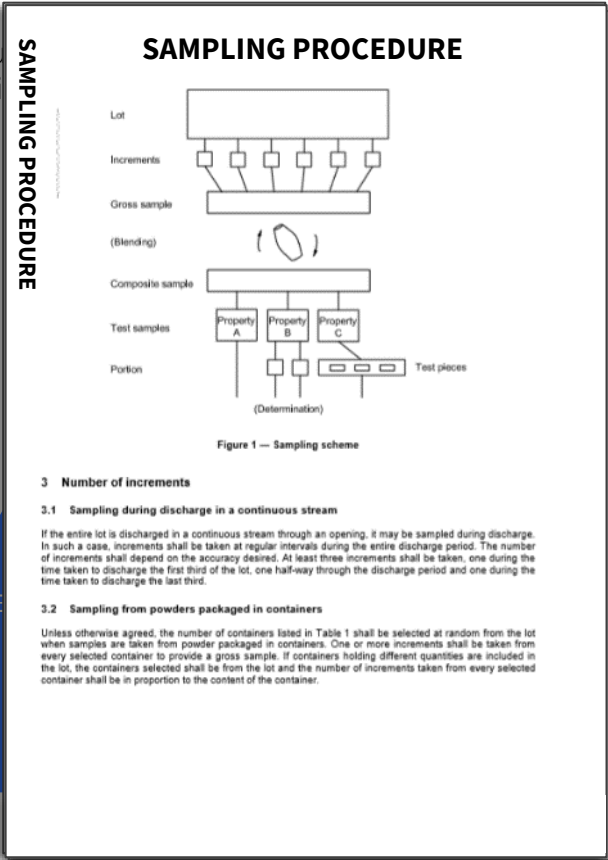
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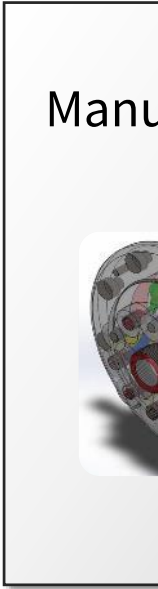
# Certification documentation



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## MANUFACTURING PLAN

## FACILITY PROCEDURES



MANUFACTURING PLAN

**JOB CONTROL CARD**

**MATERIAL SAFETY DATASHEET**

**BUILD LOG**

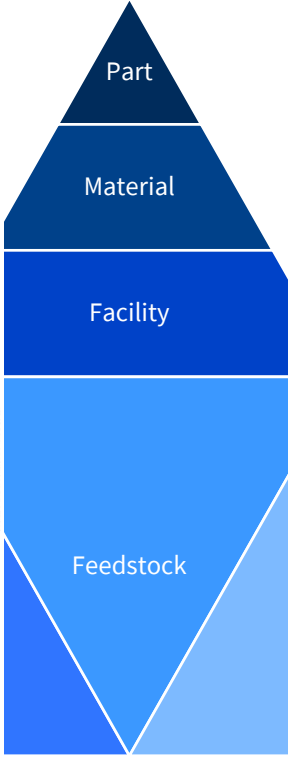
**METALLURGICAL TESTING**

**MECHANICAL TESTING**

**HEAT TREATMENT RECORD**

**NDE REPORTS**

**FEEDSTOCK TEST REPORT**



FACILITY PROCEDURES

**DIGITAL FILE & VERSION CONTROL**

**HSE EQUIPMENT & PROCEDURES**

**TRAINING RECORDS**

**OPERATOR PROCEDURES**

**MAINTENANCE**

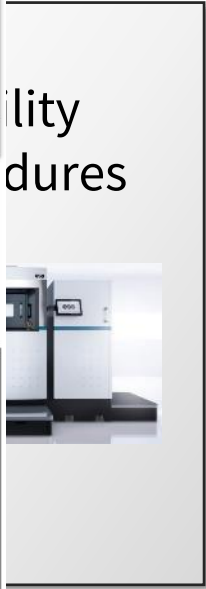
**SAMPLING PROCEDURE**

**PRE- & POST-BUILD CHECKS**

**POWDER & SUPPORT STRUCTURE REMOVAL**

**APPROVED CLEANING SOLUTION**

**CLIMATE CONTROL**

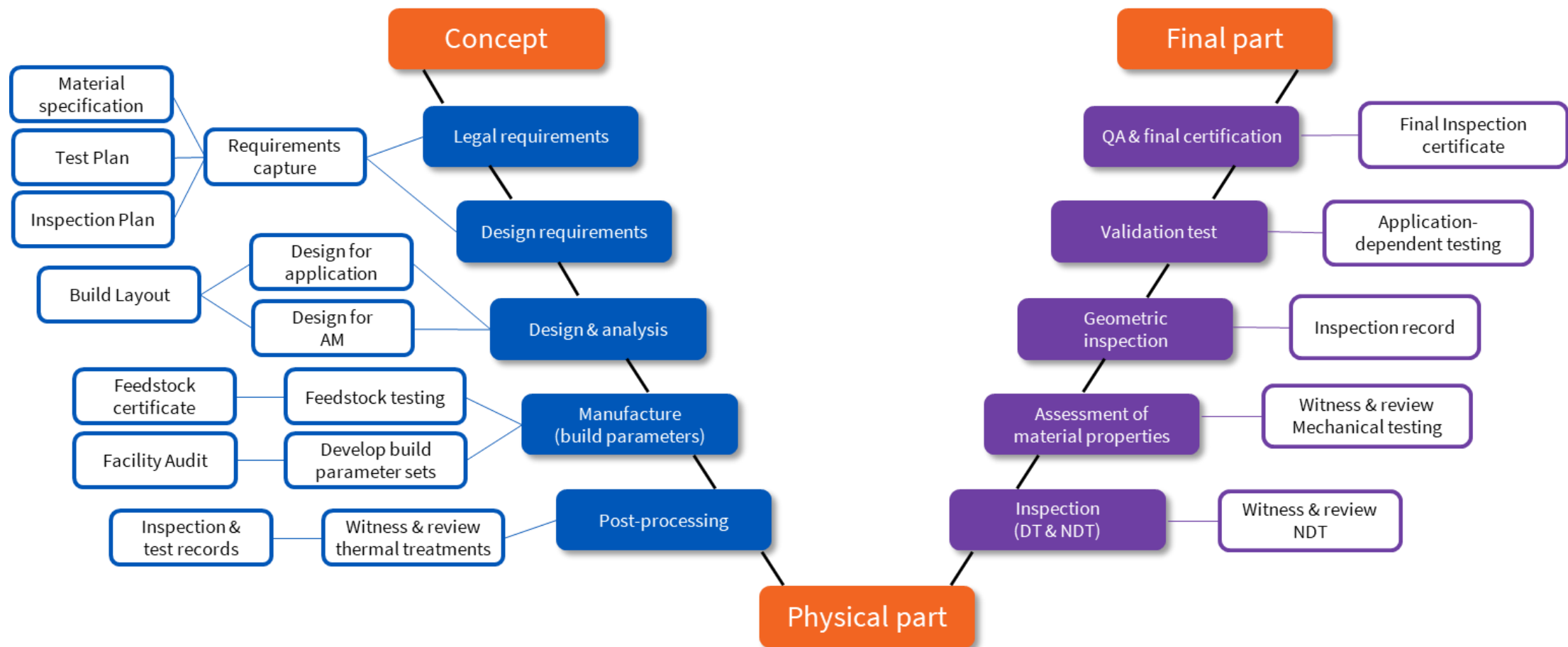


# Certification project



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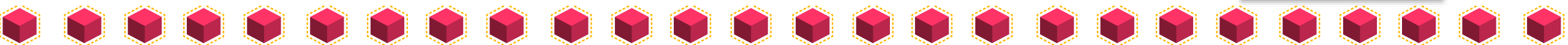


# Certification project



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- Design Appraisal Document
  - Assessment of design against required regulatory, code and/or standards requirements
  - Independent calculations and assessment of build layout
  - Statement of Endorsement can be issued prior to progressing with build
- Material (powder, wire) certification
  - Witnessed material testing
  - Inspection report issued (to powder vendor or manufacturer, depending who performs the required testing)
- Additive manufacturing facility certification
  - Facility audit
  - Review of existing approvals, processes & procedures
  - Issue AM Quality Scheme Approval Certificate
- Post-process & inspection facility
  - Witnessed material testing
  - Material certification (formed material)
  - Inspection report issued
- Part certification
  - Limited in scope to the design, material, facility & manufacturing instructions used
  - Changes to any part of the process would require re-validation of the part certification





# Certification project

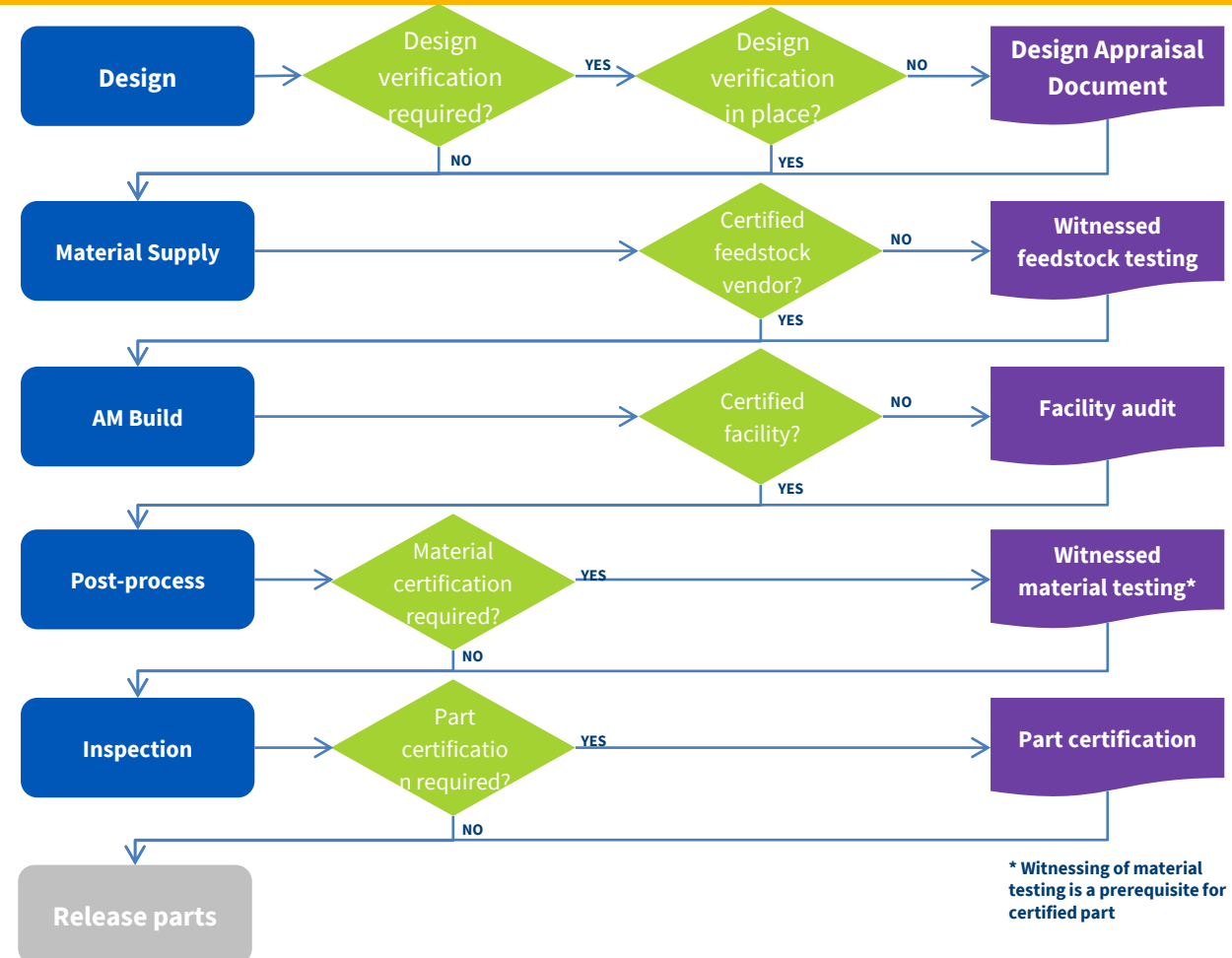


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## Modular approach

- Different organisations within the supply chain may perform activities within each functional stage
- Specific certification can be provided for each stage, which can then reduce the effort required for subsequent part design
- Using pre-qualified facilities can enable part manufacturers to reduce cost and lead times for part certification



# Examples of Projects & Activities



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**Certification of Laser Powder Additive Manufactured Components for Industrial Adoption in the Energy and Offshore Sectors**

JOINT INDUSTRY PROJECT OUTLINE

**Summary**

Additive Manufacturing (AM), widely known as 3D printing, is a direct digital manufacturing process in which a component is produced layer by layer directly from 3D digital data without the use of machining, moulding or casting. AM has developed rapidly in the last ten years and has demonstrated significant potential for reducing the cost of aerospace components and unique opportunities in the medical sector. Benefits can be realised through improved design freedom, weight reduction and lower tooling costs, complemented by reductions in carbon footprint and waste during manufacture.

This Joint Industry Project (JIP) will:

- Identify potential applications of AM in the Energy, Oil & Gas and Marine sectors.
- Undertake practical work to determine optimum build parameters and produce components.
- Determine required inspection activities to certify components.
- Generate AM Certification Guidelines, based on certification of the selected components.

Selective Laser Melting (SLM) and Laser Metal Deposition (LMD) are the processes that will be applied in the JIP, leading to qualification of components defined by the Sponsors.

**Suzhou Nuclear Power Research Institute**

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Joint Industry Projects



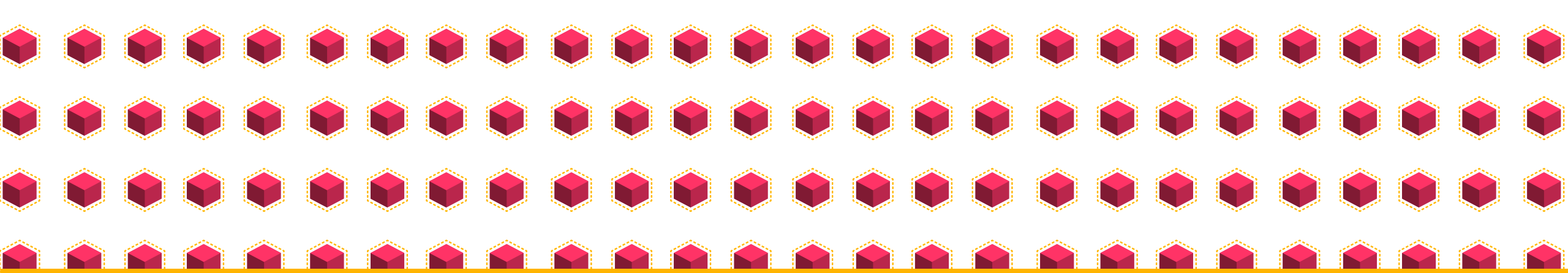
EOS Singapore Pte Ltd

AM Facility Qualification

Consultancy & Training

SETTING THE STANDARD

Knowledge Sharing



# Thank you!



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