Additive Manufacturing

Justification and Implementation

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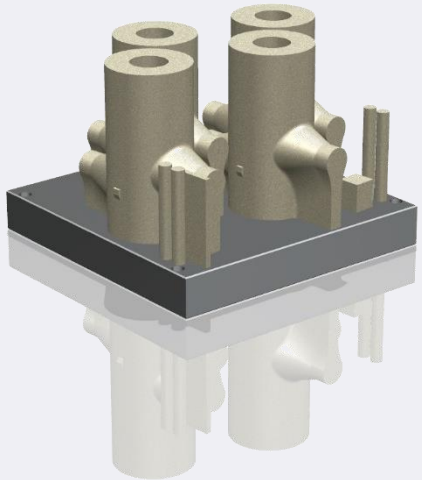


Agenda

01 **Implementation Strategy**
Substitution > Enhanced Substitution > One-way-choice

02 **The Lead Application**
Primary Circuit Manual Globe Valve

03 **Justification Strategy**
‘Beyond code’ multi-legged TAGSI approach

04 **Where next?**
Robust production, new applications and R&T

05 **Questions**
and discussions

01

Implementation Strategy

"The Additive Manufacturing Team will be the Rolls-Royce Nuclear and Defence centre of competence for additive manufacture; delivering improvements to cost, quality & delivery through innovative & effective implementation of additive manufacturing technology"

Background

In the beginning...

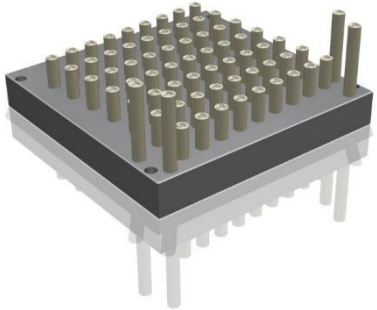
- Ist EOS M2xx Series LPBF system (single laser) installed in 2008.
- Single engineer part-time only
- Rig parts, visualisation assemblies, rapid tooling
- Developing knowledge and experience of LPBF
- Materials development and laser parameter DoEs
- A lot of internal marketing, demonstrations and commodity discussions!

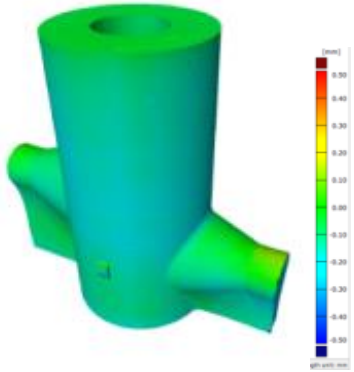
Capability Development...

- Technology readiness levels – manufacturing and materials
- Increasing experience of parts on rigs in representative environments
- Significant materials testing programmes – predominantly 316L and A625.
- Increased capacity (people and machines) as demand rose quickly.
- Lead application identified and taken through formal gated review process.

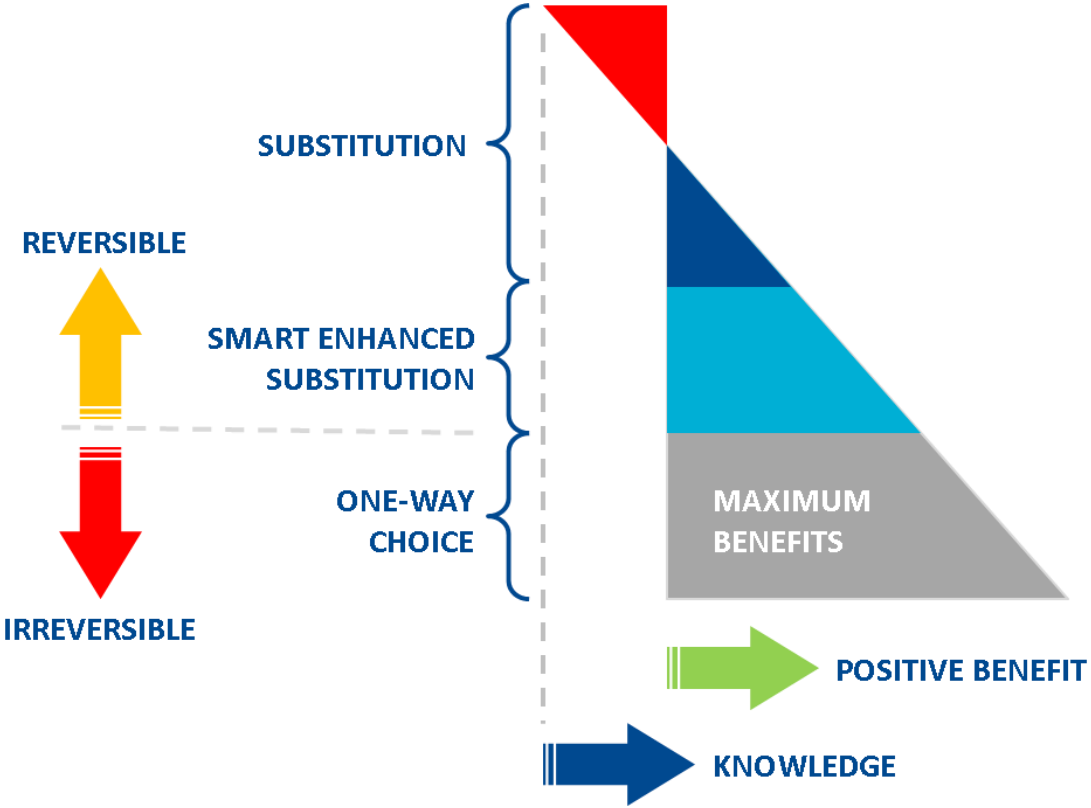
Current state...

- 7x EOS M2xx Series LPBF systems supported by two teams – Manufacturing Engineering and Operations.
- Lead applications in full production.
- Focussed AM teams also in Materials and Design Engineering departments.
- 1st single laser replacement in 2021 - NEW multi-laser system.
- New facility to be commissioned in 2021 including post-processing capability.
- Focussed R&T programmes.





Implementation Strategy



02

The Lead Application

High volume manual globe valve

Safety critical

Pressure boundary

Manual Globe Valve (15, 25 & 50mm NB)

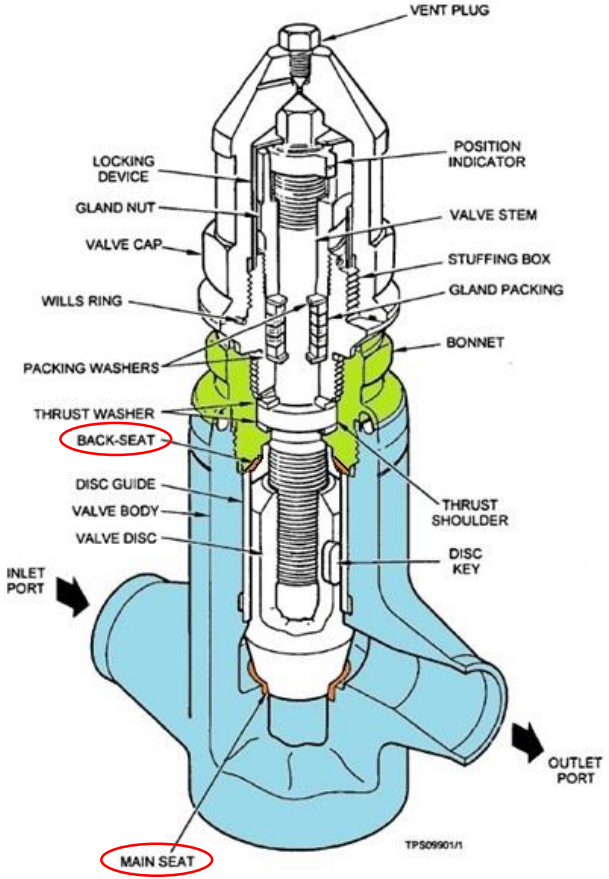
316 Stainless Steel Body & Bonnet

Tristelle 5183 Main and Back Seats (hard facings)

High Production Volume

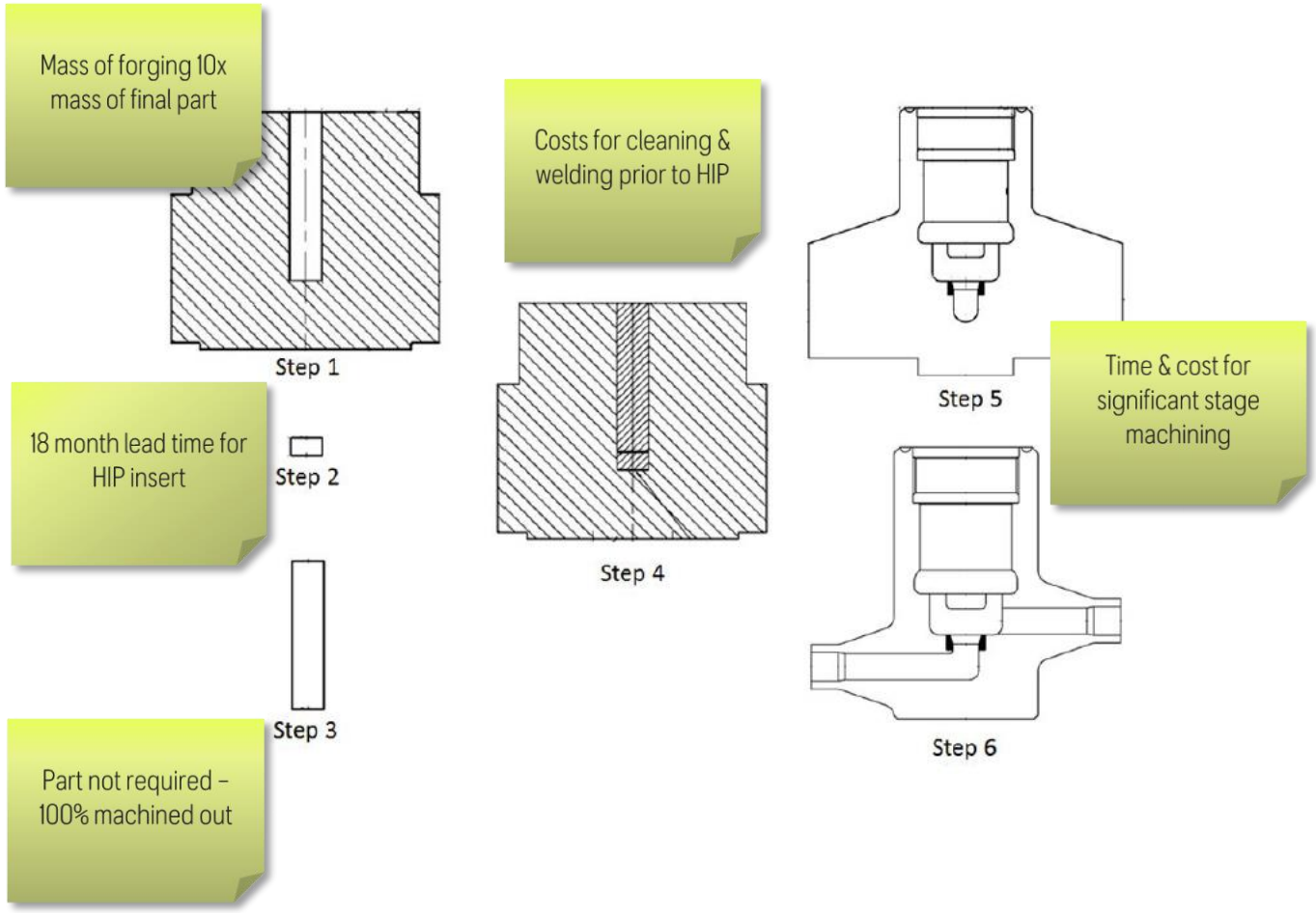
Pressure Boundary

Safety Critical



Traditional MoM

1. Rough Machine Wrought Billet
2. Tristelle 5183 Insert (Hot Isostatic Press (HIP) bar)
3. Stainless Steel Plug
4. Assemble & HIP Bond Insert to Body
5. Rough Machine to Form Valve Seat
6. Machine to Complete Final Form



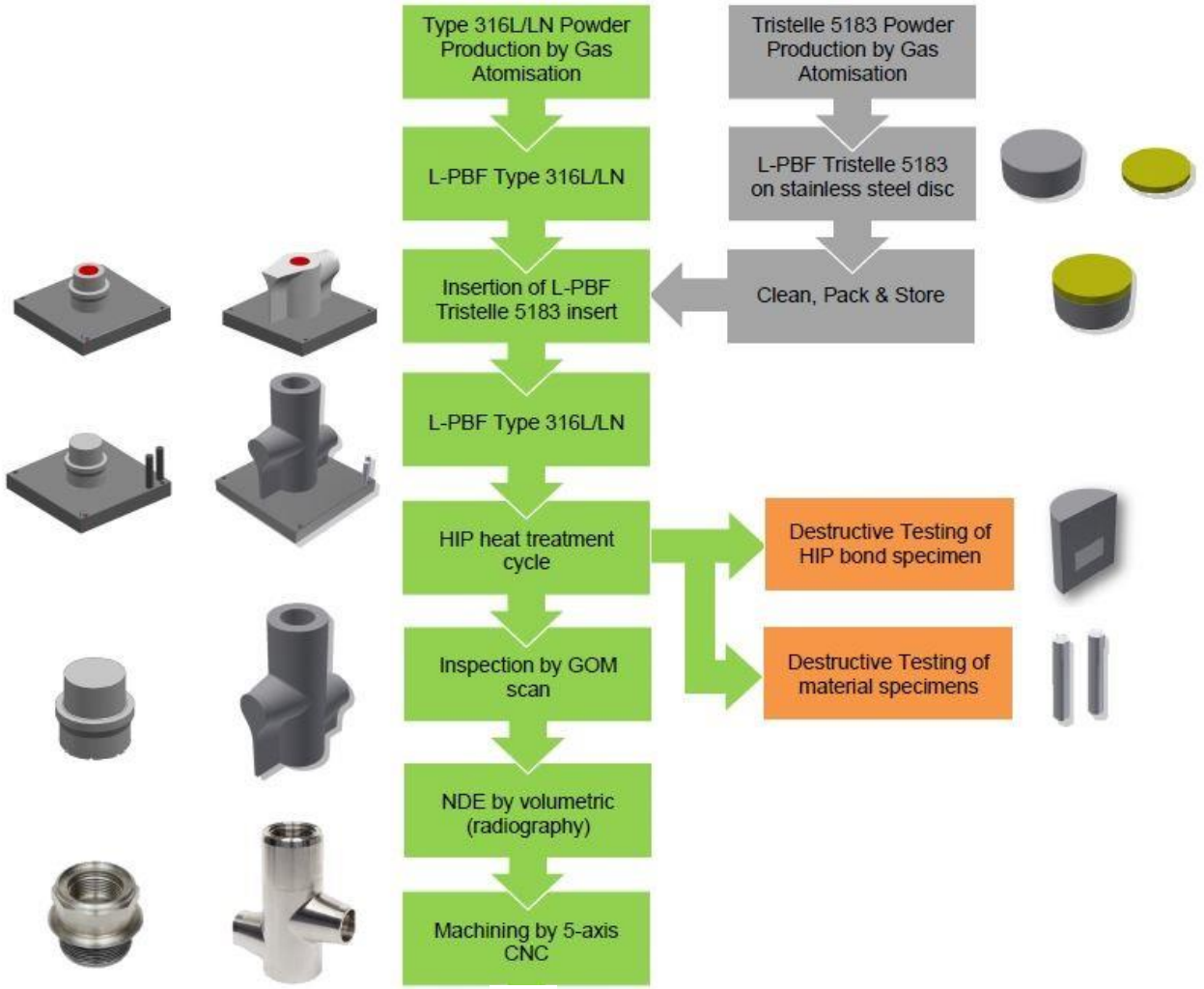
LPBF MoM

Laser-Powder Bed Fusion (L-PBF) Technology produces 316 body near net shape and Tristelle insert.

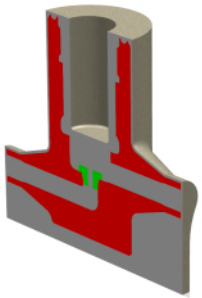
Post AM, single HIP cycle bonds insert, forms properties of both alloys and stress relieves.

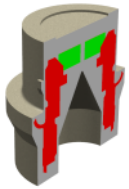
Phase 1 – Substitution only

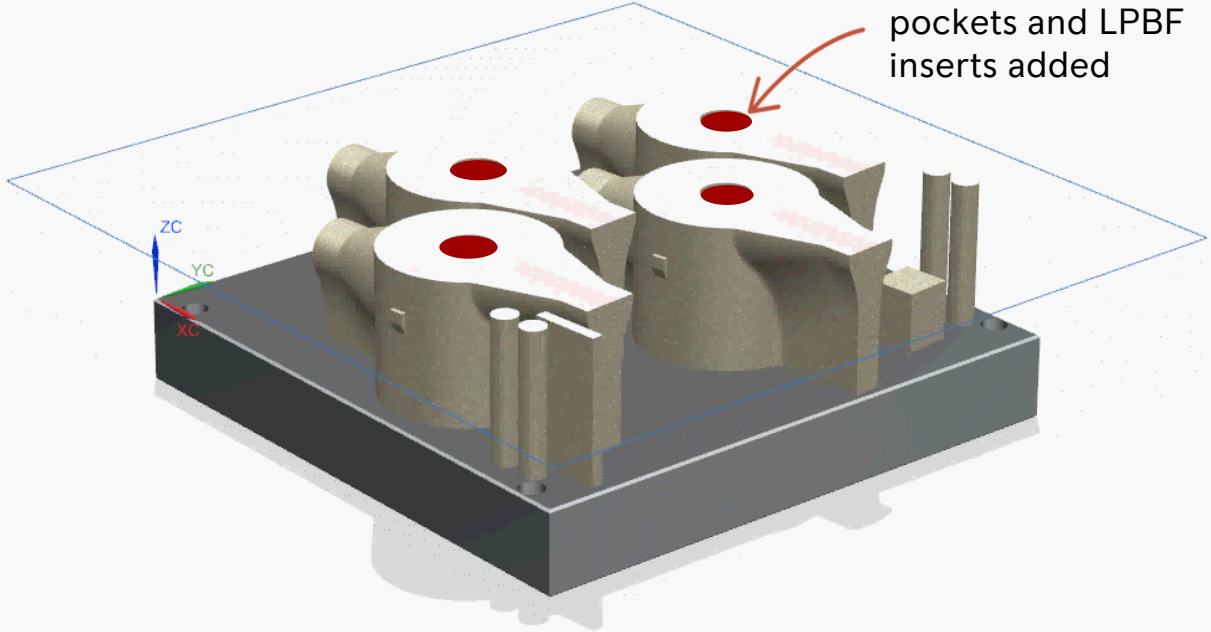
- No change to design configuration/geometry
- No change to material types
- No change to product finish (all surfaces machined)



Method of Manufacture







What are the benefits?

Still at Phase 1 – simple substitution only.

Phase 2 – Enhanced substitution programmes will deliver further benefits to cost and delivery.

- In-process monitoring
- Justification of as-built surfaces

Leadtime Reduction

- Removal of a HIP cycle
- Reduced machining steps and timescales

Cost Reduction

- Simplification of manufacturing method
- Removal of extensive machining operations
- Reduced raw material inventory

Collaboration

Rolls-Royce leading on AM with key partners across exchange programme

Materials

- AM material properties meet specification requirements
- Materials types applicable to broad product range

Quality Assurance

Quality assurance of metallic powder and product (control samples/HIP bond specimens)

Innovation

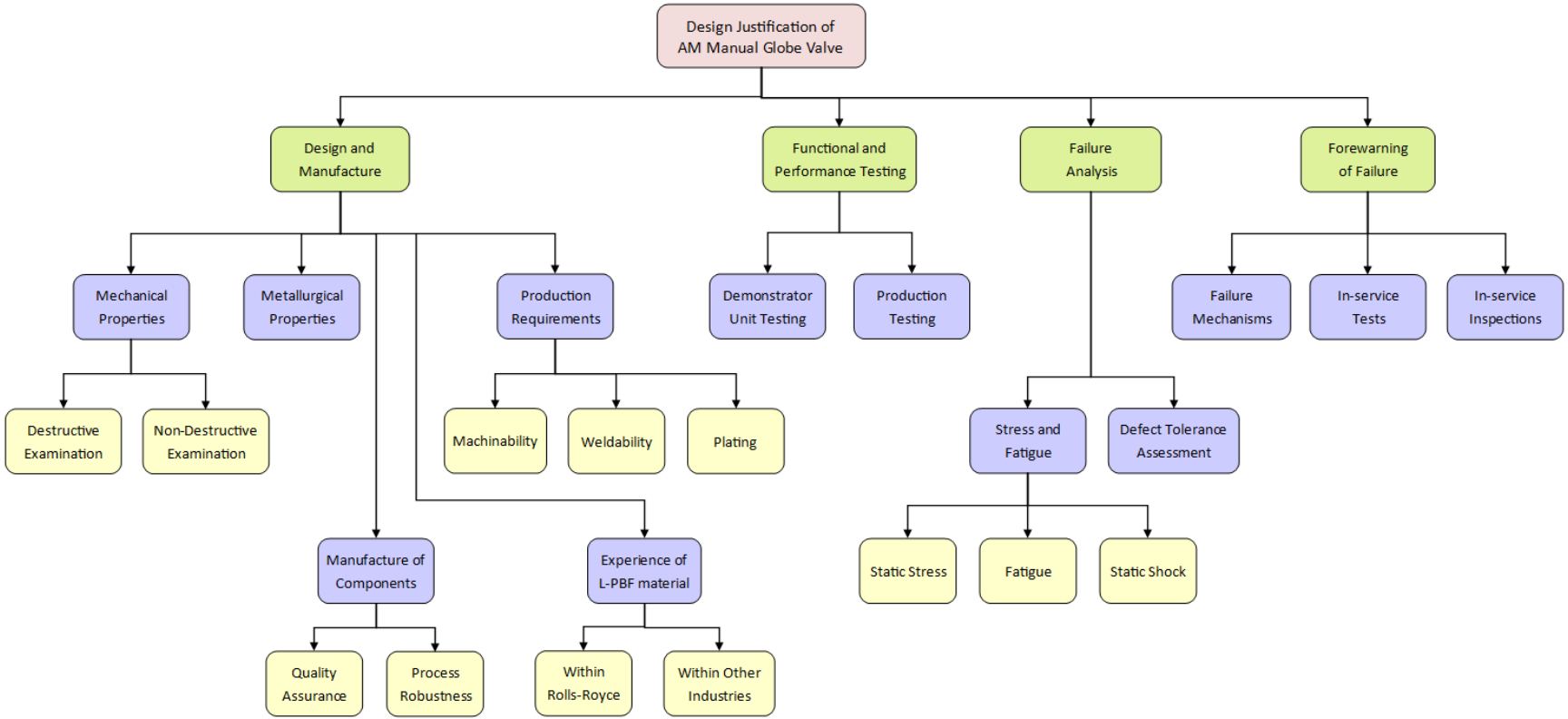
Encapsulation principle patent – exploitation opportunities against broad product range

03

Justification Strategy

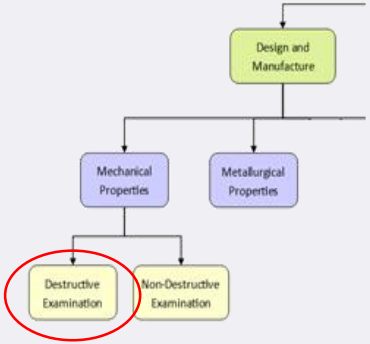
Beyond-code approach to justification based on TAGSI multi-legged structure: design and manufacture, functional testing, failure analysis & forewarning of failure.

Design Justification Strategy

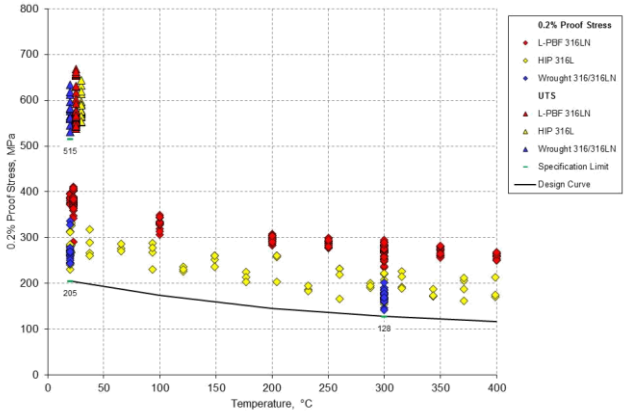


Leg 1 - Design & Manufacture

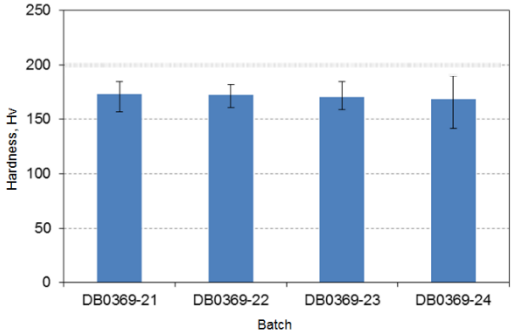
Mechanical, metallurgical & corrosion testing



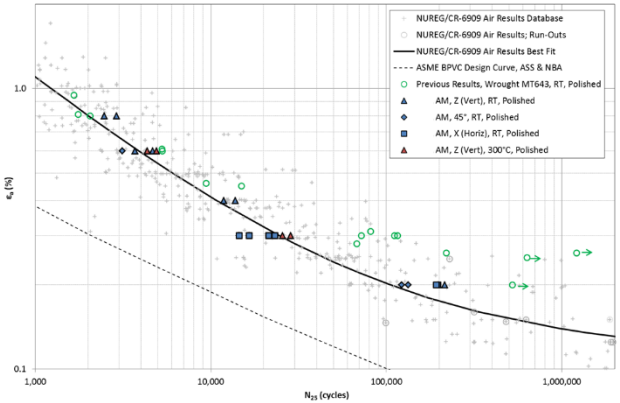
UTS and Proof Stress



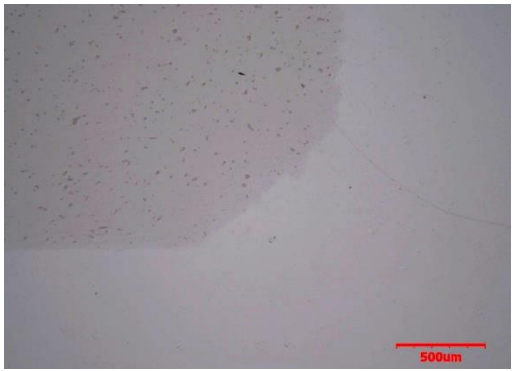
Hardness



Fatigue



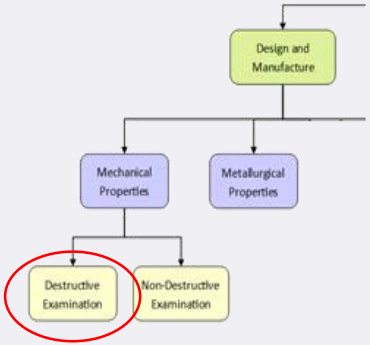
Tristelle 5183 to 316 St St Bond Line

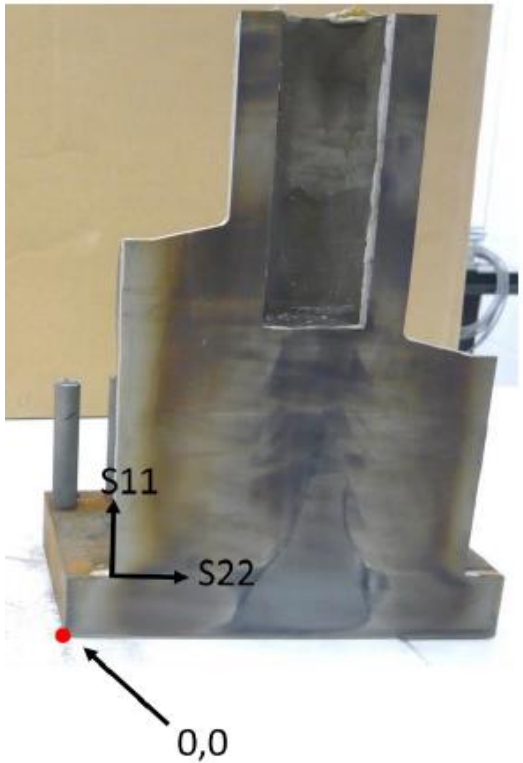


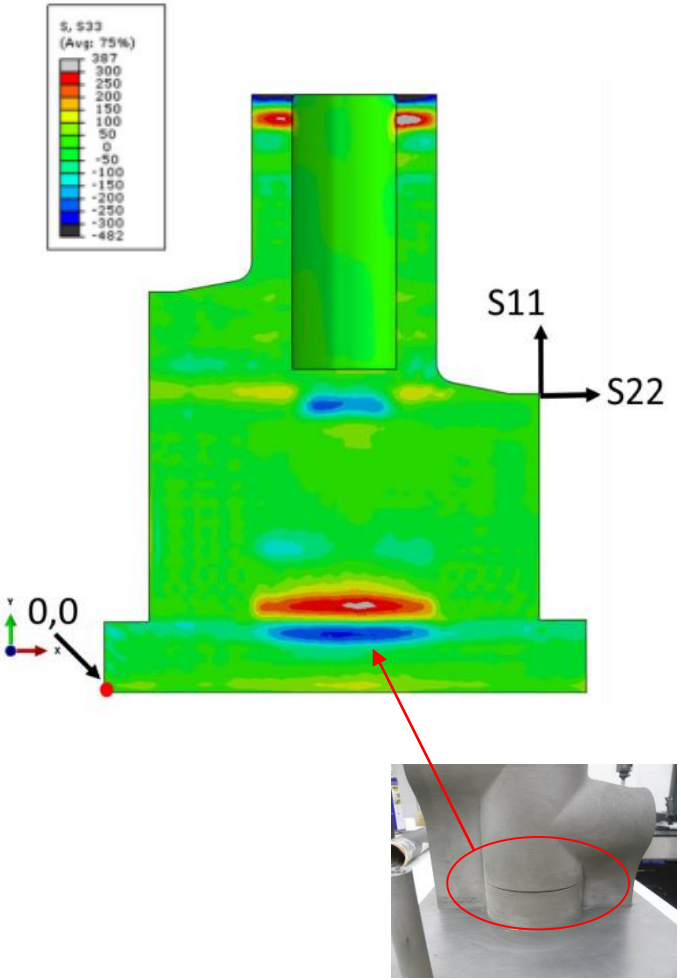
Leg 1 - Design & Manufacture

Contour residual stress measurement of valve body

Destructive mechanical strain relief technique



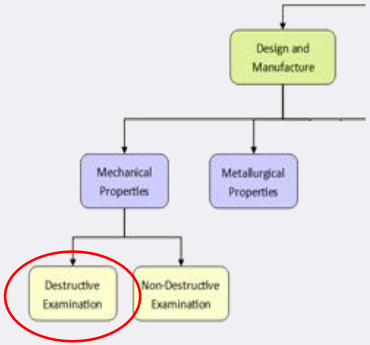




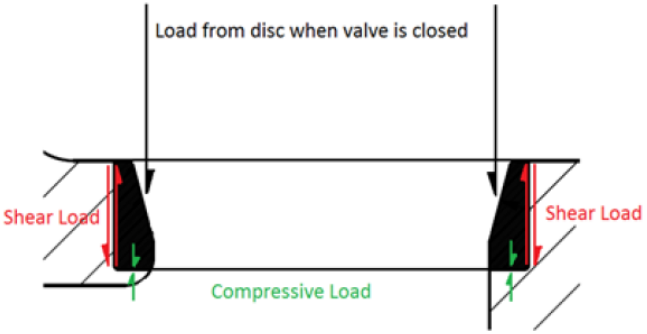
Leg 1 - Design & Manufacture

Shear load test - 316 St St to Tristelle 5183 bond line.

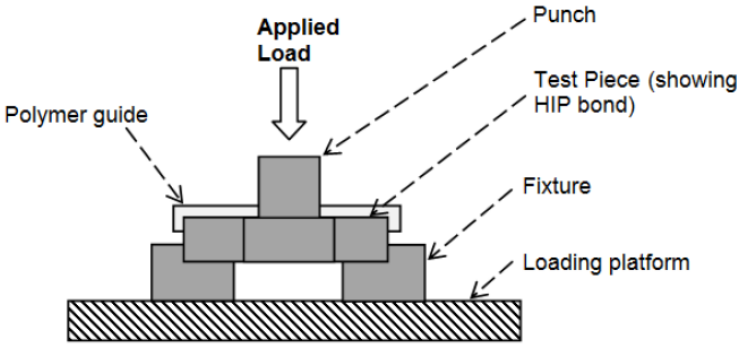
Withstand beyond highest in-service loadings applied.



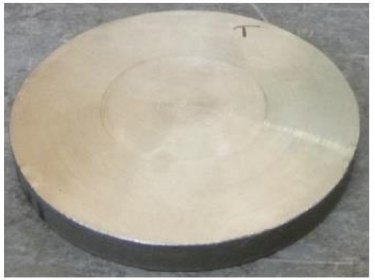
Valve Seat Geometry



Test Set-up



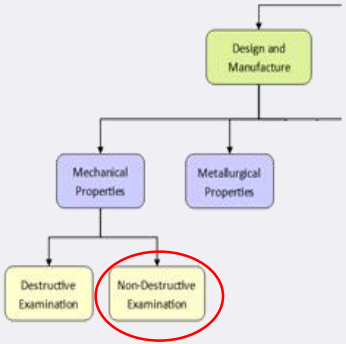
Test Piece Geometry



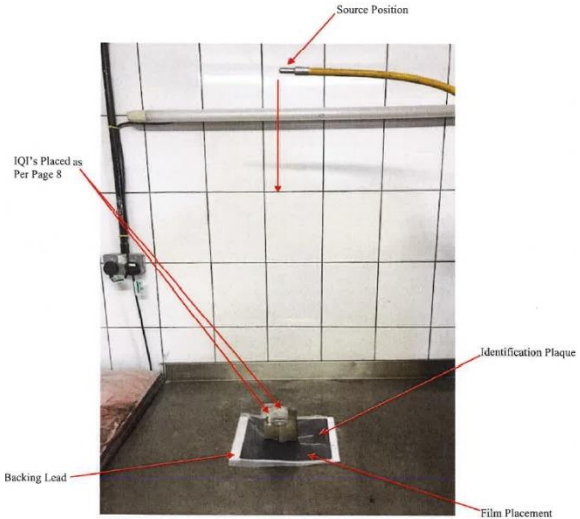
Leg 1 - Design & Manufacture

Volumetric on-destructive testing – radiography

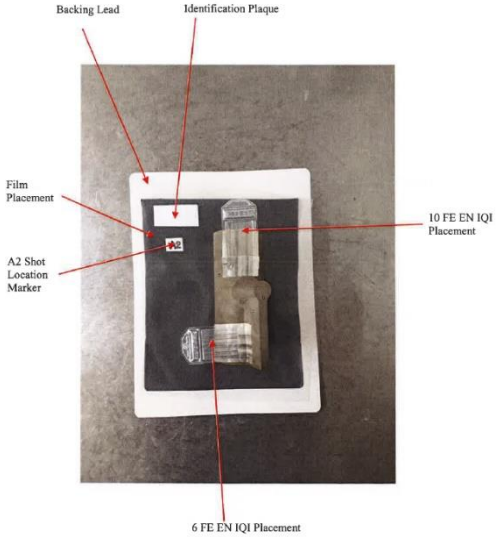
Surface visual examination



50mm MGV Bonnet



15mm MGV Body

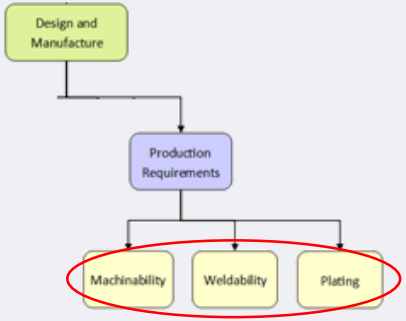


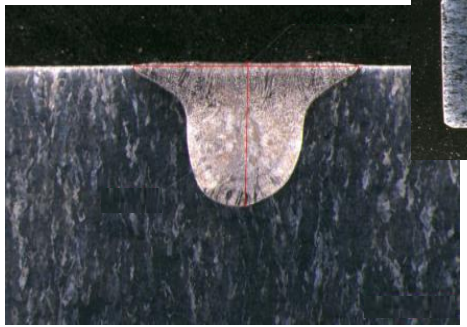
- Current Method – Wrought/HIP bar examined using Ultrasonic Testing
- AM Method – Radiographic Testing based on near-net-shape and start-of-Life defect characterisation
- Defect characterisation by expert elicitation used to guide inspection technique and inspection acceptance criteria
- Future expectation for though-process melt pool monitoring to remove traditional volumetric examination

Leg 1 - Design & Manufacture

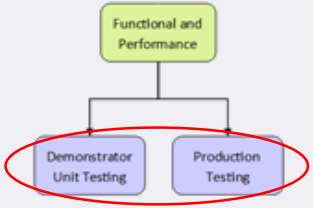
Production Requirements:

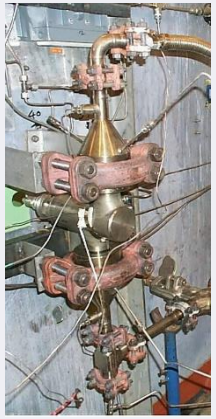
- Weldability Trials
- Canopy Weld Trials
- Pipework Stub Trials
- Machining, grinding, plating methods trialled





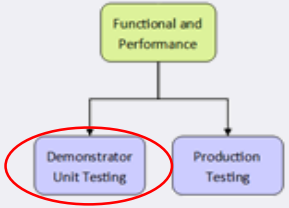
Leg 2 – Functional & Performance Testing





Test Type	Description	Component	Size	Comparison Wrought Valve	Production Test
Hydrostatic	Standard Hydro	Body only	15mm✓ 25mm✓ 50mm✓	No	Yes
	Valve Half Open	Full Assembly	15mm✓ 50mm✓	No	Yes
	Valve Closed	Full Assembly	15mm✓ 50mm✓	No	Yes
Ultimate Hydrostatic	Ultimate Pressure Test	Body only	50mm only✓	Yes	No
Performance	Cold	Full Assembly	15mm✓ 50mm✓	No	Yes
	Hot	Full Assembly	15mm✓ 50mm✓	No	No
	Repeat Cold	Full Assembly	15mm✓ 50mm✓	No	No
Endurance	Hot	Full Assembly	15mm only✓	No	No
Shock	Cold	Full Assembly	50mm only✓	Yes	No
Fatigue	Thermal Shock	Full Assembly	50mm only✓	Yes	No

Leg 2 – Functional & Performance Testing



Ultimate Pressure Tests

Explore full capability of AM pressure boundary on MGV body

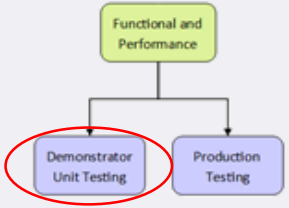
>2000bar applied without failure

Representative material strain rates

Wrought and AM MGV Bodies Pre-burst Test

Wrought and AM MGV Bodies Post-burst Test

Leg 2 – Functional & Performance Testing



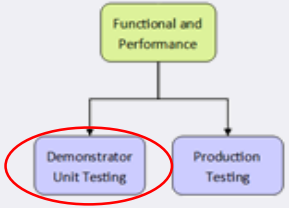
Shock Loading Tests

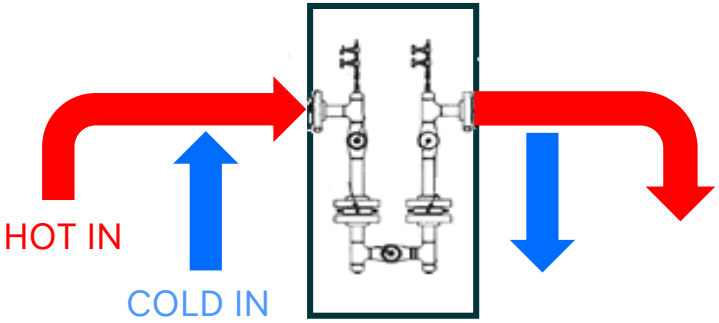
Shock test to assess integrity of key MGV regions during shock event

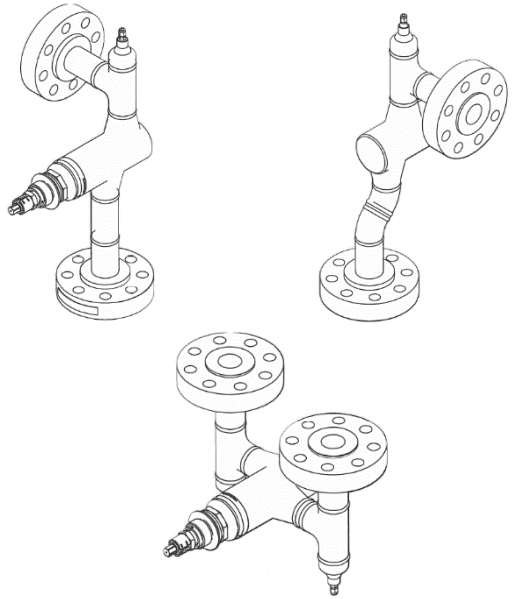
Three test orientations on both AM and Wrought MGVs

Pre and post test functional checks successful on each MGV

Leg 2 – Functional & Performance Testing





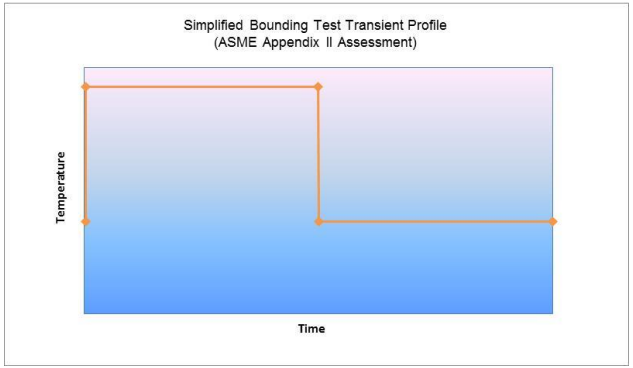


Thermal Fatigue Test

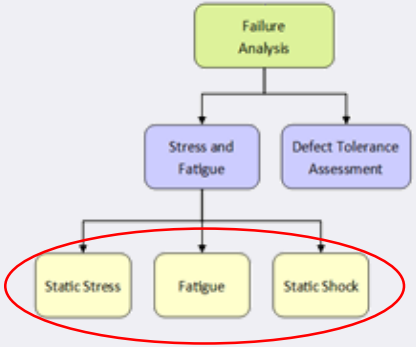
ASME III, Appendix II assessment used to specify extended thermal cycle test

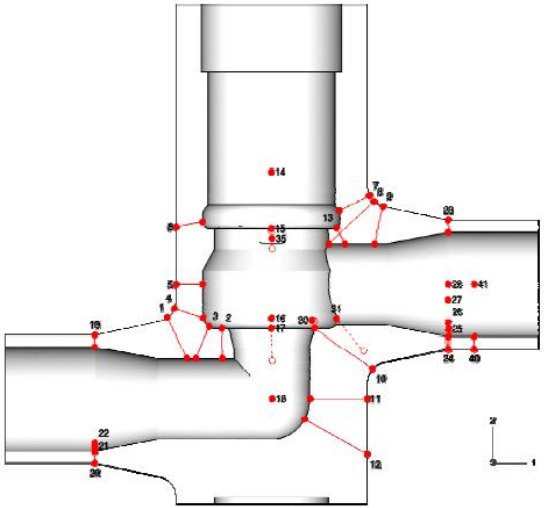
2 x AM and 1 x Wrought MGV tested

Valves functionally tested after extended life simulation

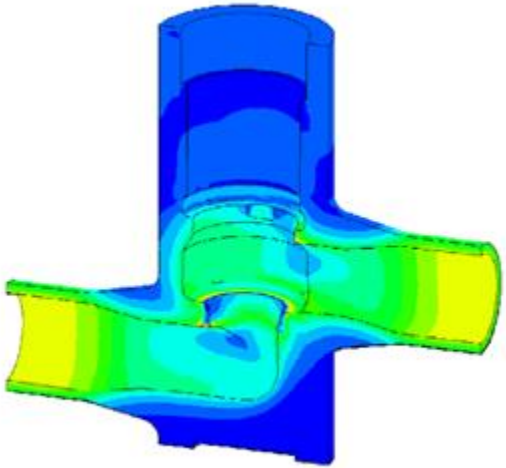


Leg 3 – Failure Analysis



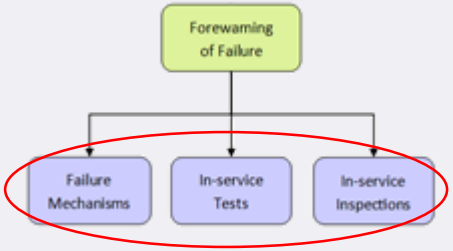


Location of Stress Classification Lines for ASME Assessment



- Design, hydrostatic and level A conditions assessed for limiting valve location
- Fatigue assessment using cycling counting method and static shock assessment
- Leg 1 – Material test data confirms analysis inputs remain appropriate
- Leg 2 – Functional/performance testing provides further assurance in theoretical analysis

Leg 4 – Forewarning of Failure



- FMEA Review
- System Hydrostatic and Valve Functional Tests
- In-service Inspections
  - External for evidence of corrosion/EAC
  - Internal for evidence of bond line corrosion and condition of seat contact line
- Potential for additional volumetric NDE in-service (Remote RT, Phased Array UT)
  - Development of Techniques
  - ALARP study

04

Where Next?

Increasing applications across plant

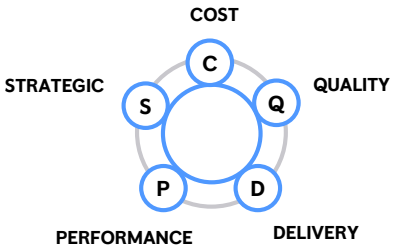
Strategic alloy development

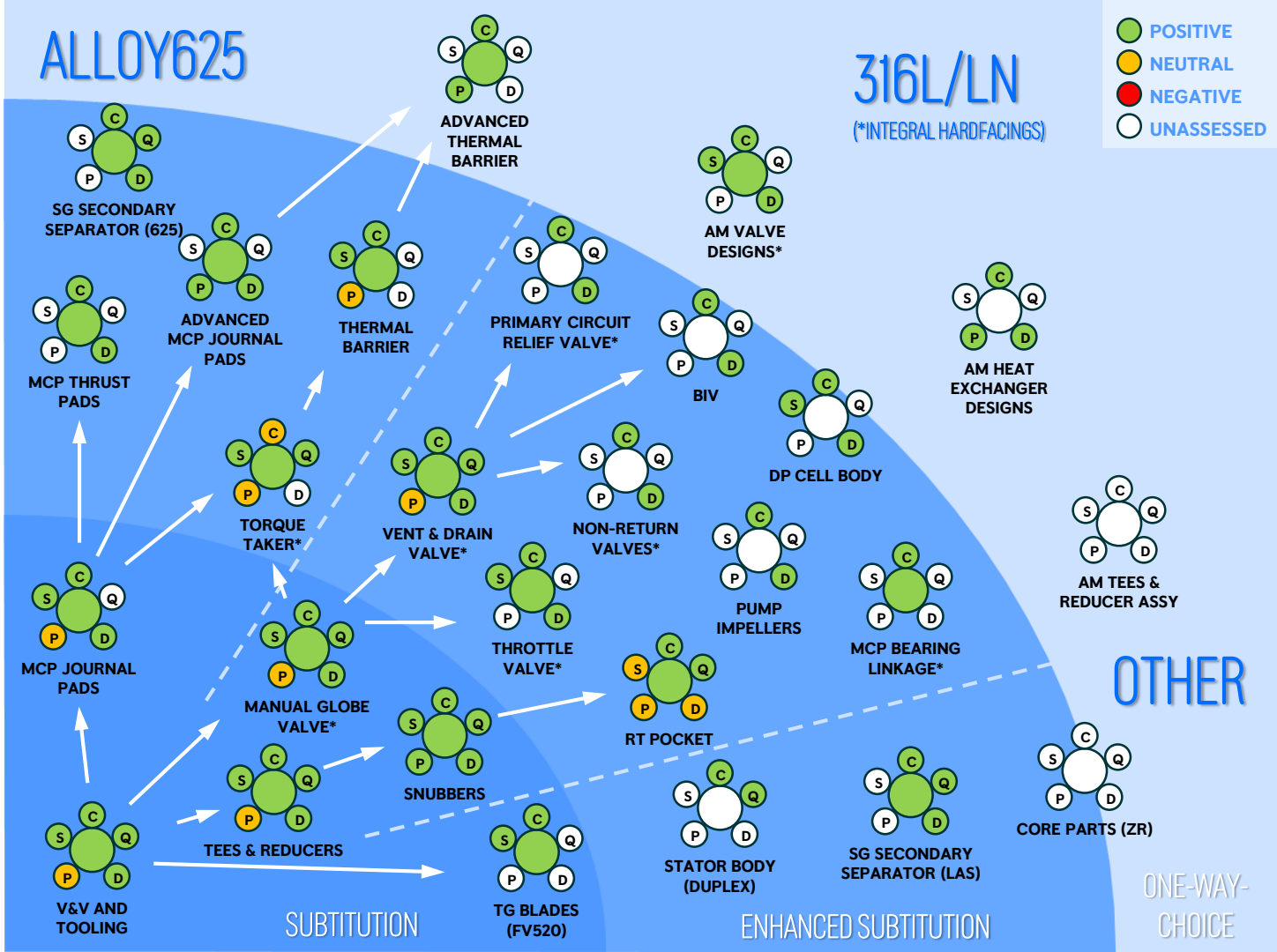
Facility commissioning

Increased size, capacity and build speed

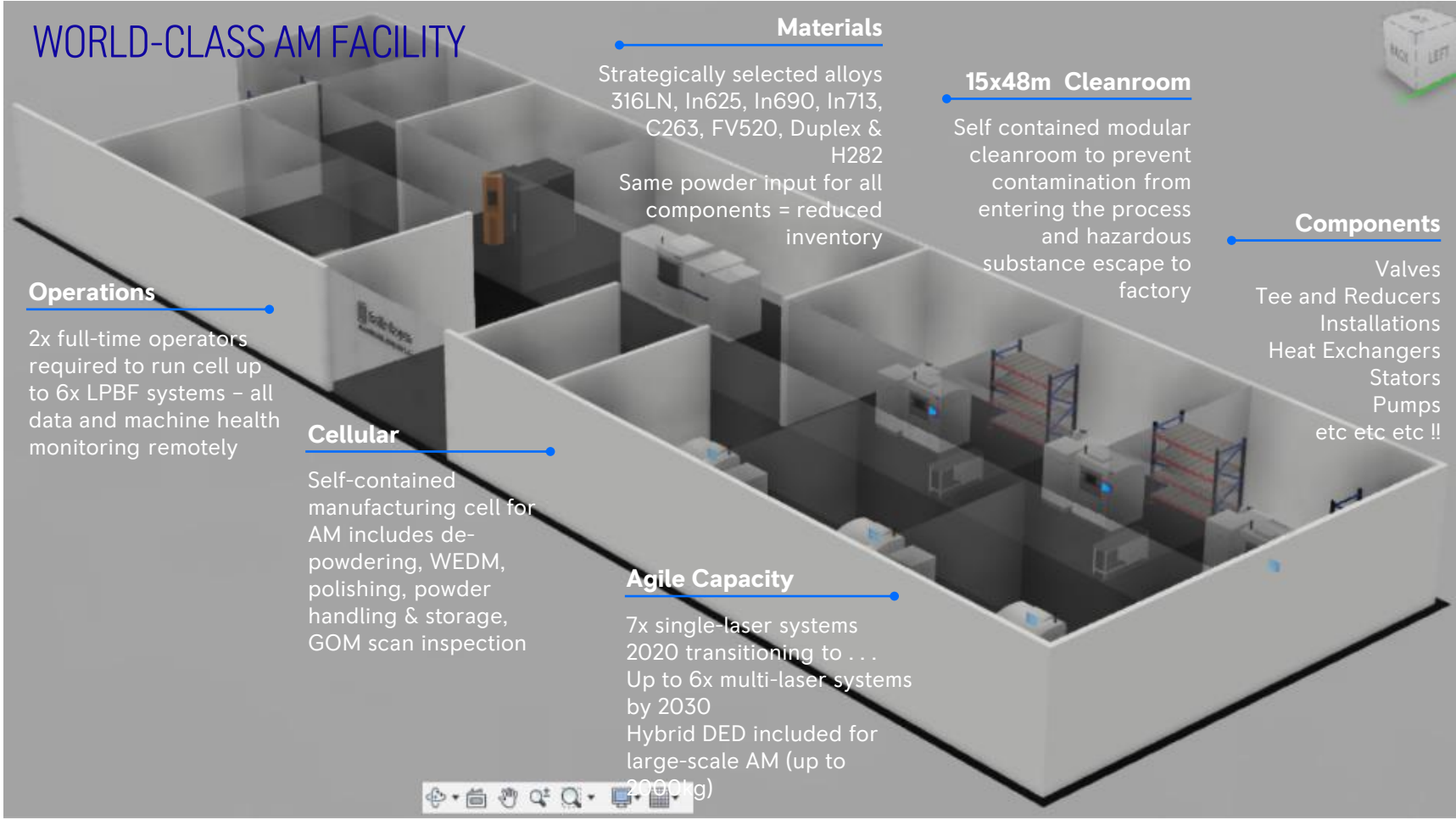
LPBF Component Strategy

Commodities engaged on opportunities for AM to deliver benefits





WORLD-CLASS AM FACILITY



Materials

Strategically selected alloys 316LN, In625, In690, In713, C263, FV520, Duplex & H282
Same powder input for all components = reduced inventory

15x48m Cleanroom

Self contained modular cleanroom to prevent contamination from entering the process and hazardous substance escape to factory

Components

Valves
Tee and Reducers
Installations
Heat Exchangers
Stators
Pumps
etc etc etc !!

Operations

2x full-time operators required to run cell up to 6x LPBF systems – all data and machine health monitoring remotely

Cellular

Self-contained manufacturing cell for AM includes de-powdering, WEDM, polishing, powder handling & storage, GOM scan inspection

Agile Capacity

7x single-laser systems 2020 transitioning to . . .
Up to 6x multi-laser systems by 2030
Hybrid DED included for large-scale AM (up to 2000kg)

05

Questions & Discussion

Thank you