

Webinar



# ENGIE Journey to qualified AM manufacturer

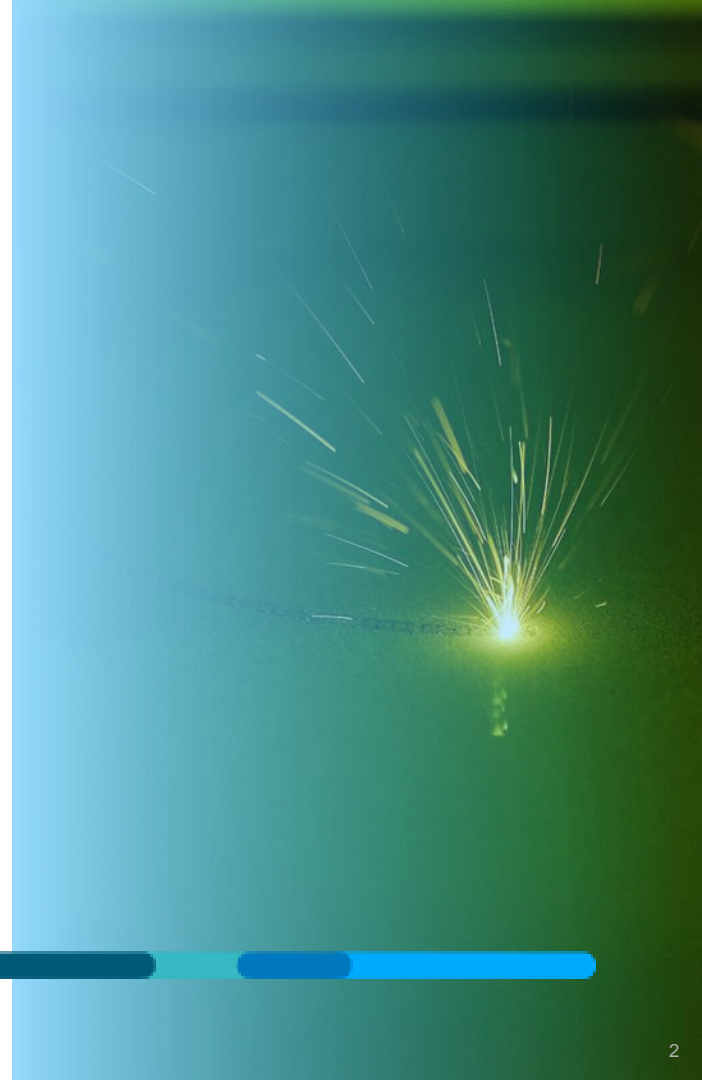
Ensuring and validating selective laser process stability for qualification purposes

Energifosk— 23 September 2020  
[3dprinting.laborelec@engie.com](mailto:3dprinting.laborelec@engie.com)

Steve NARDONE

SLM  
Solutions GmbH

# Additive Manufacturing @ ENGIE



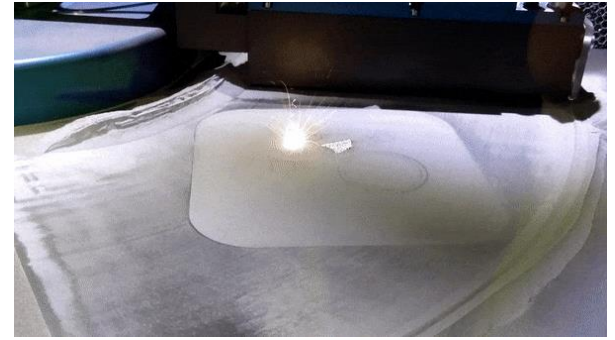
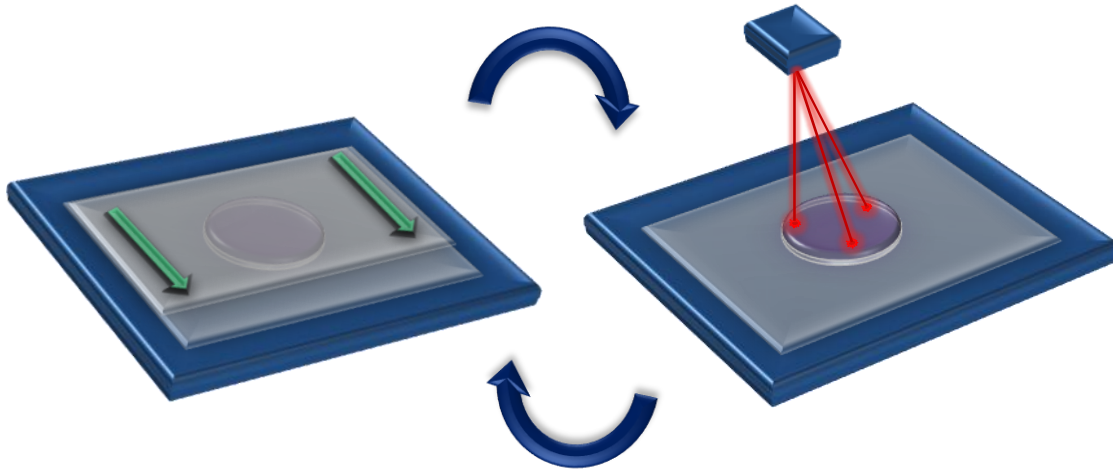
# ENGIE Laborelec

## In a nutshell

- ENGIE Laborelec is a leading **expertise** and **research** center in **electrical power technology**.
- Founded in 1962, the company has **over 55 years** experience in the power sector.
- ENGIE Laborelec is a **cooperative company** with ENGIE and independent grid operators as shareholders.
- Our competencies cover the **entire electricity value chain**: generation, transmission & distribution, RES, storage, usage of the energy for the industry and other end-users.
- We put a strong focus on the **energy transition** and the 3D's : **decentralization**, **decarbonization** and **digitalization**.
- We offer **specialized services**, R&D and **global solutions** in each of these domains, to companies in **all parts of the world**.

# This webinar deals exclusively with the Laser Powder Bed Fusion process

Local fusion of successive metal powder layers using a high energy laser.



## Simple facts

Production of 10mm-cube using 50 $\mu$ m-layer thickness requires:

- 200 meters of scanned lines !
- 200 layers !
- Fast and local welding process with high heating/cooling cycles

# Additive Manufacturing as key enabler for operational excellence

## Launch of ENGIE AM Expertise Centre in late 2015



- Fe-, Ni-, Al-based AM powders (Ti)

### Foster industrialization

- > Tackle obsolescence issues
- > Functionality-driven approach
- > Validation & Implementation of **high-end applications with high qualification standards**

AM Machine Capabilities

Material Expertise

### Laboratories

- > Materials laboratories
- > Non-destructive testing (inspection & qualification)
- > AM Powder lab

### Materials Technology

- > QA/QC of inspection campaigns
- > Multidisciplinary projects for thermal/nuclear power plants
- > Maintenance plan optimisation and revision

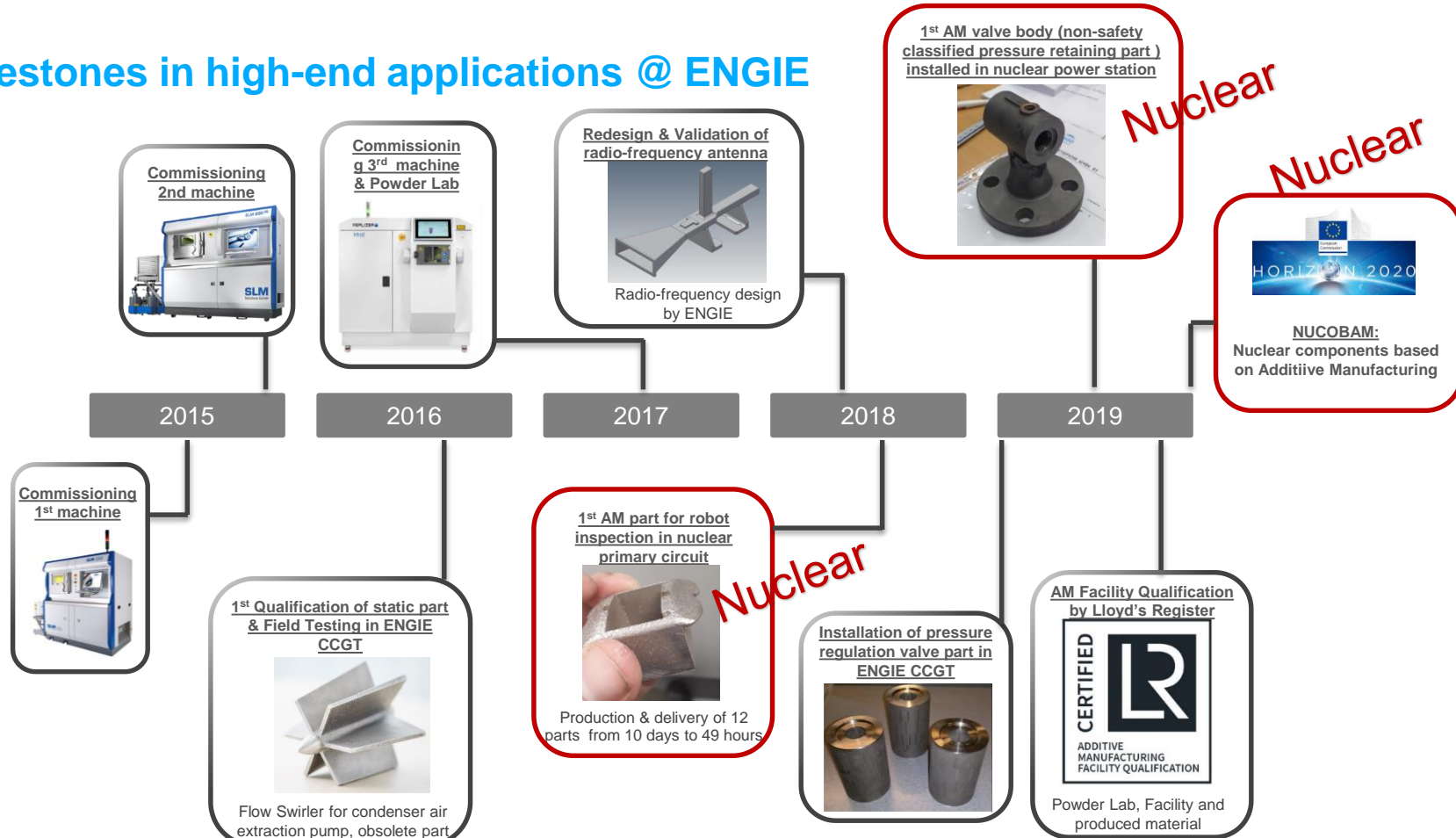
Industry-driven approach

Certification

### Certification Project

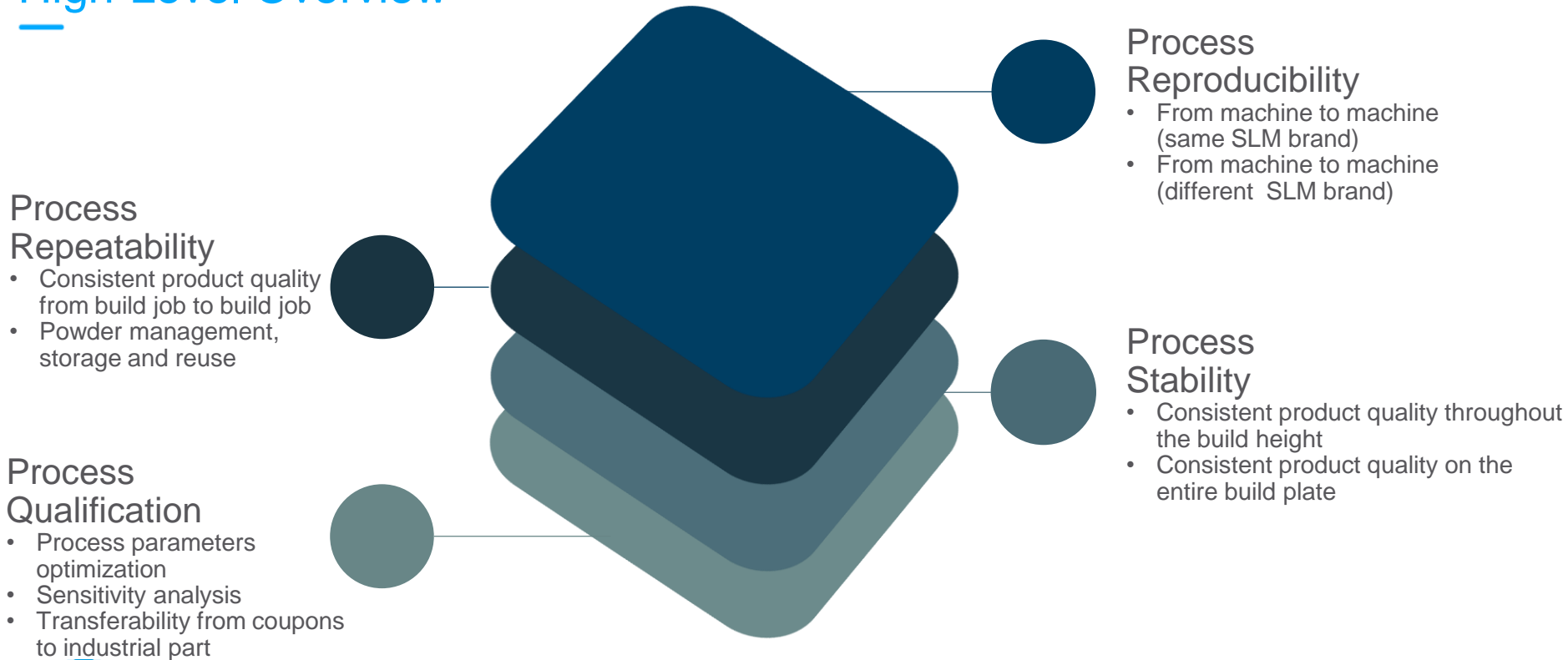
- > Technological bricks: feedstock / Process / AM Material Performance
- > Materials certificates 3.1 & 3.2
- > Proactive approach before release of future EN 13445 Part 14

# Key milestones in high-end applications @ ENGIE

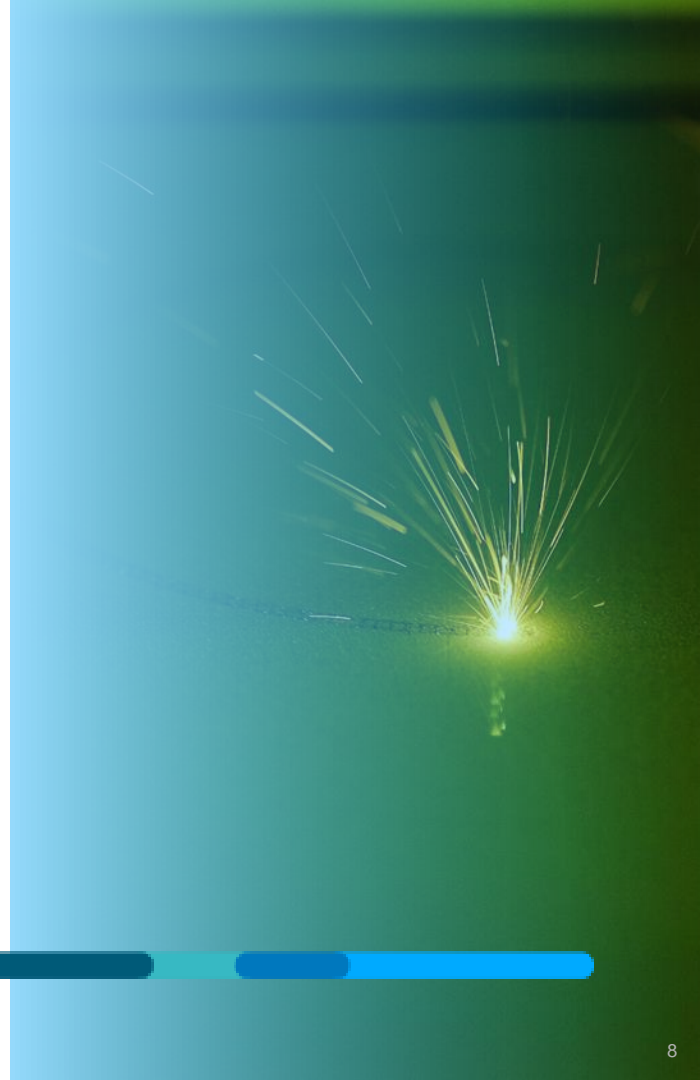


# Additive Manufacturing Product Quality

## High-Level Overview



# ENGIE Qualification Approach for Laser Powder Bed Fusion Process



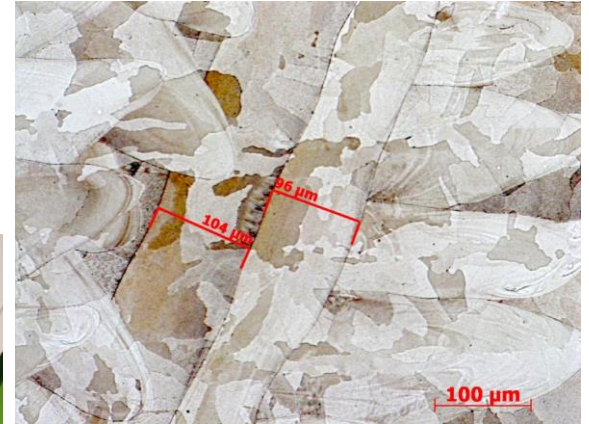


# Assumptions for this Webinar

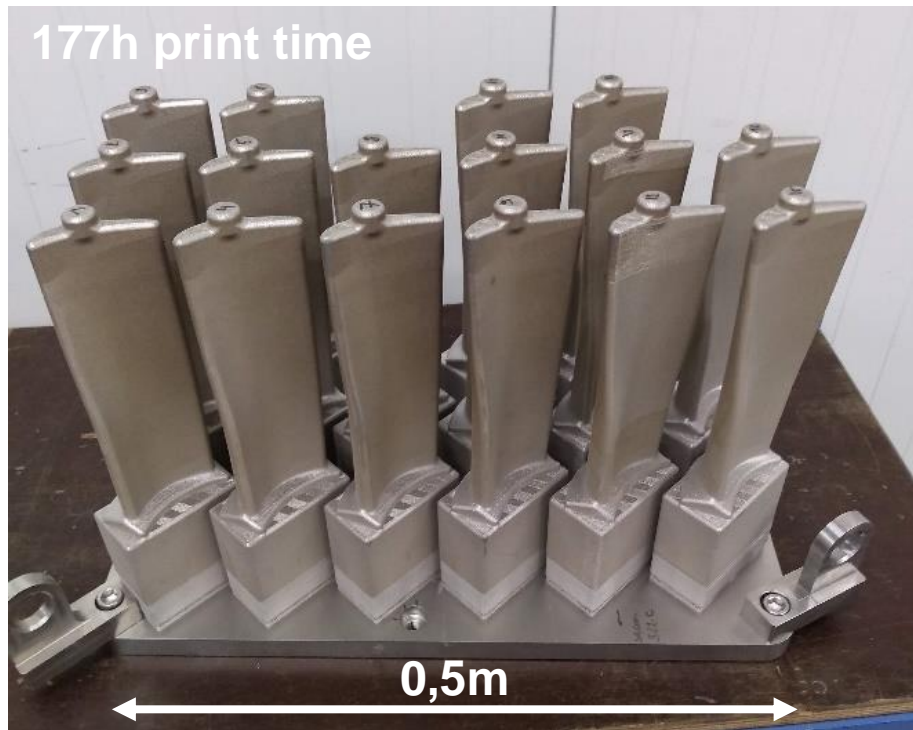
- Optimized laser process parameters already implemented during fabrication



Microstructure ✓  
Relative density ✓  
Key mechanical properties ✓



# Challenges for production of high-end components and large productions runs



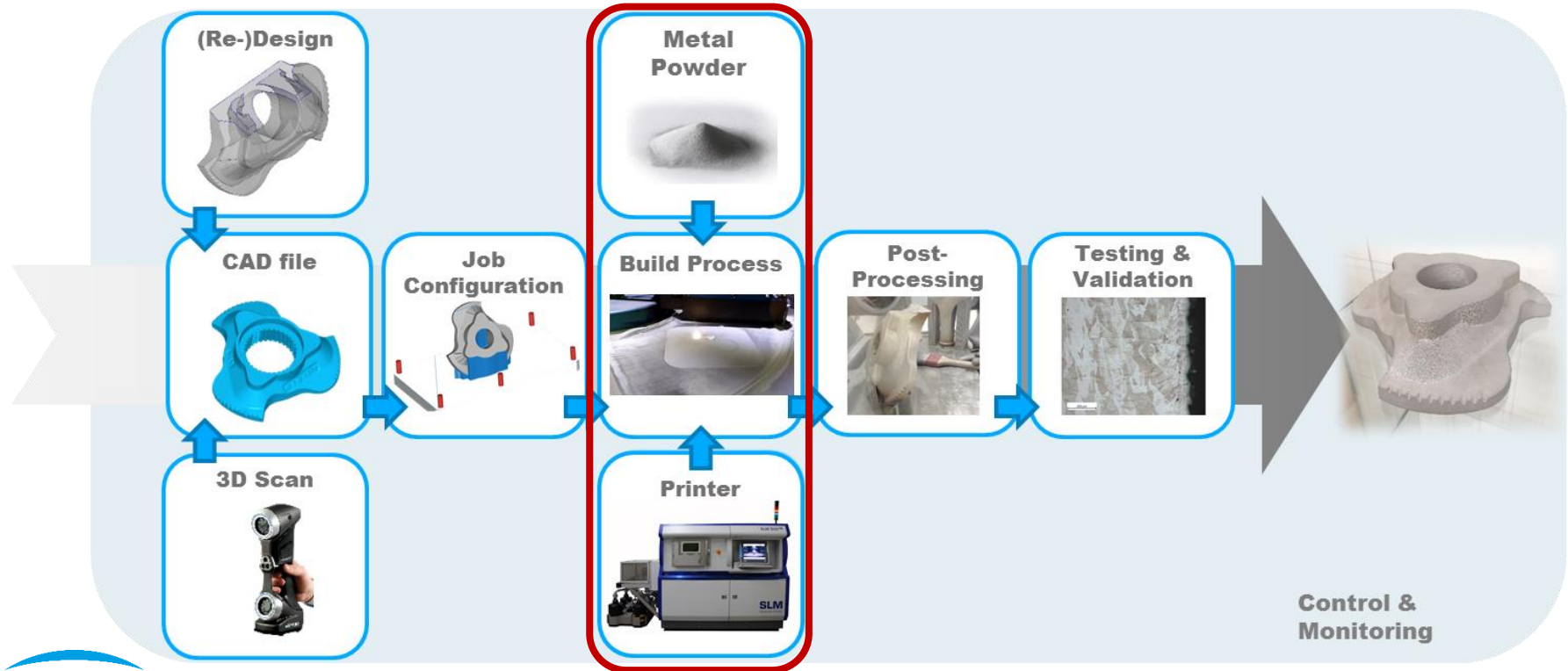
Ensuring process stability, quality & reproducibility over the long term for large production runs:

- Large components
- Heavily-loaded build platform

# Challenges for production of high-end components and large productions runs



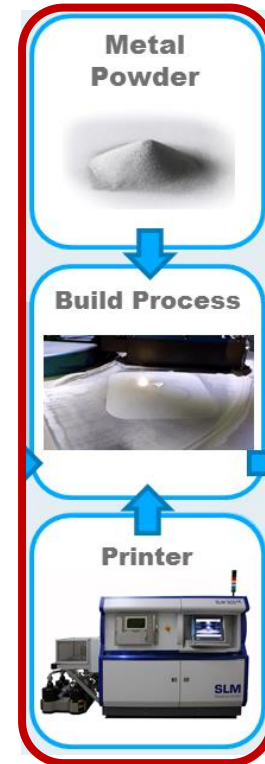
# What can go wrong along the whole value chain ?



# What can go wrong along the whole value chain ?

Ensuring process stability, quality & reproducibility over the long term for large production runs :

- Influence of powder batch
- Powder storage & recycling
- Influence of build location
- Influence of build height
- Transferability from coupons to industrial part
- From build job to build job



# Material Feedstock for Laser Powder Bed Fusion

## Standardization & acceptance criteria

### **ISO/ASTM 52904-19**

Additive Manufacturing –  
Process Characteristics and  
Performance: Practice for Metal  
Powder Bed Fusion Process to  
Meet Critical Applications

### **ASTM F2924-14**

Standard Specification for AM  
Ti6Al4V with L-PBF

### **ASTM WK62190**

AM Feedstock materials Technical  
specifications on metal powder

### **ASTM F3049-14**

Standard Guide for  
Characterizing Properties of  
Metal Powders Used for Additive  
Manufacturing Processes

### **ASTM F3055-14a**

Standard Specification for AM  
Ni Alloy UNS N07718 with L-PBF

But also AMS, AWS, MPFI...

### **AMS7024**

IN718 L-PBF Material Specification

### **ASTM F3184-16**

Standard Specification for AM  
Stainless Steel UNS S31603  
with L-PBF

### **MPIF Standard 28**

Method for Determination of Apparent  
Density of Non-Free-Flowing Metal  
Powders Using the Carney Apparatus

...

...

...

No quantitative acceptance criteria in ASTM standards for L-PBF powder feedstock, except chemical composition



# Material Feedstock for Laser Powder Bed Fusion

## Standardization & acceptance criteria



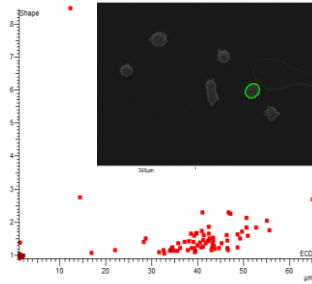
Sample Thief



Sample Divider



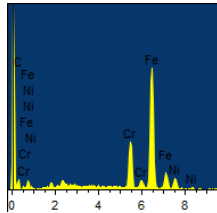
Particle Size Distribution by Laser Diffraction



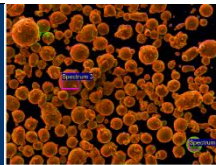
Particle Morphology by Scanning Electron Microscopy



Mechanical Sieving



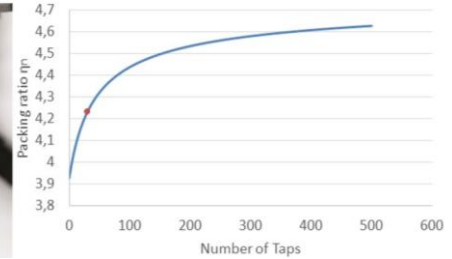
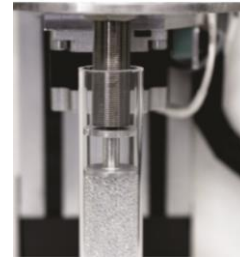
Semi-quantitative chemical analysis by Scanning Electron Microscopy



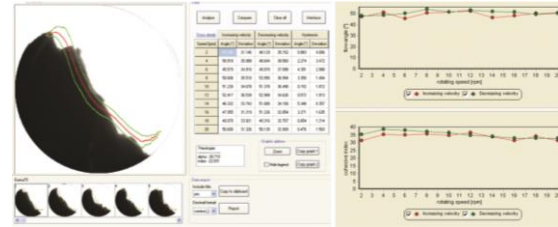
Archimedes density testing



Hall flow, Carney flow and apparent density



Semi-automatized tapped density method producing compaction curve as a function of number of taps for a SLM metal powder



Automated measurements of dynamic angle of repose, providing cohesive index and flowing angles for different shearing stresses



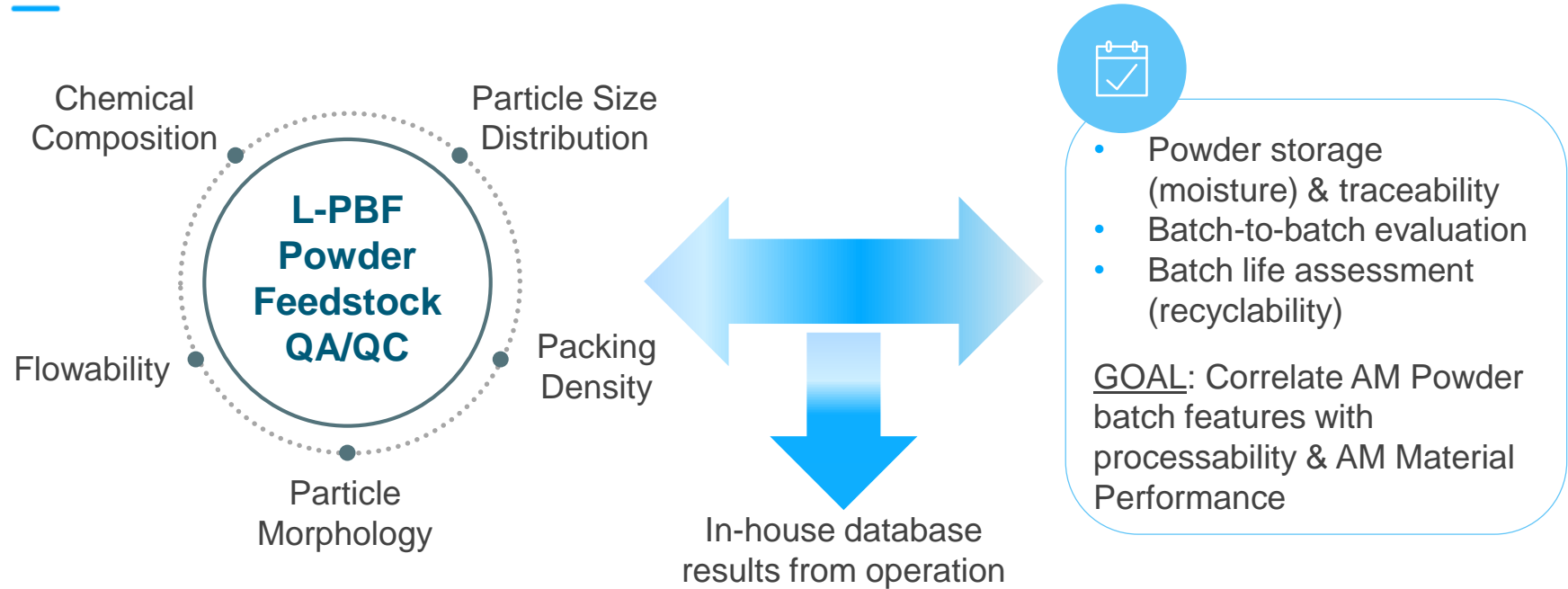
Rheometer, shear cell, wall friction

**Metal Powder Characterization based on ASTM F3049-14**

**New Metal Powder Characterization Methods**

# Material Feedstock for Laser Powder Bed Fusion

## Standardization & acceptance criteria

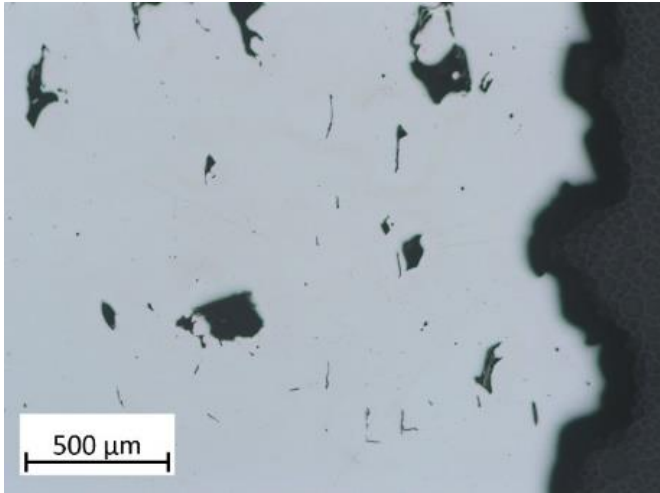


**Formulation of Acceptance Criteria / Quality Indicators /  
Process Window for L-PBF Powders**



# What can go wrong along the whole value chain ?

## Influence of build location & build height

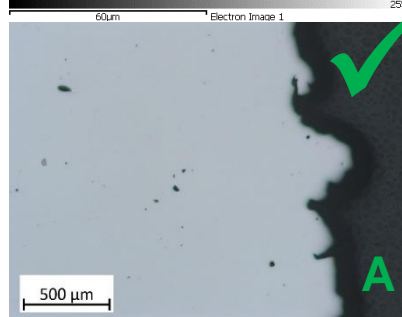
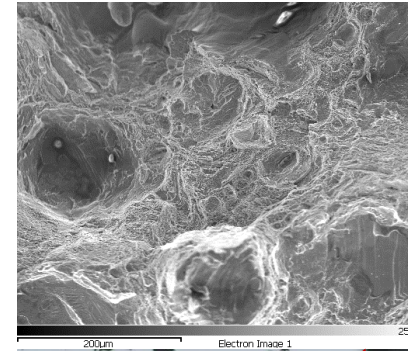
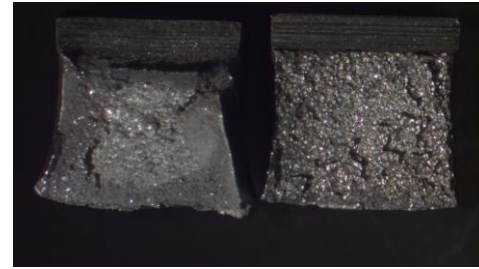
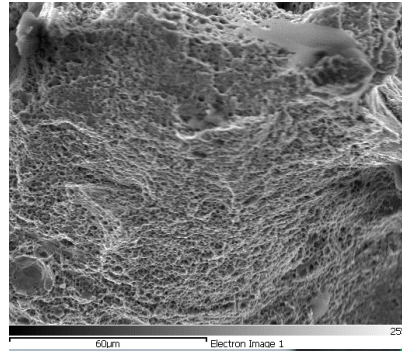
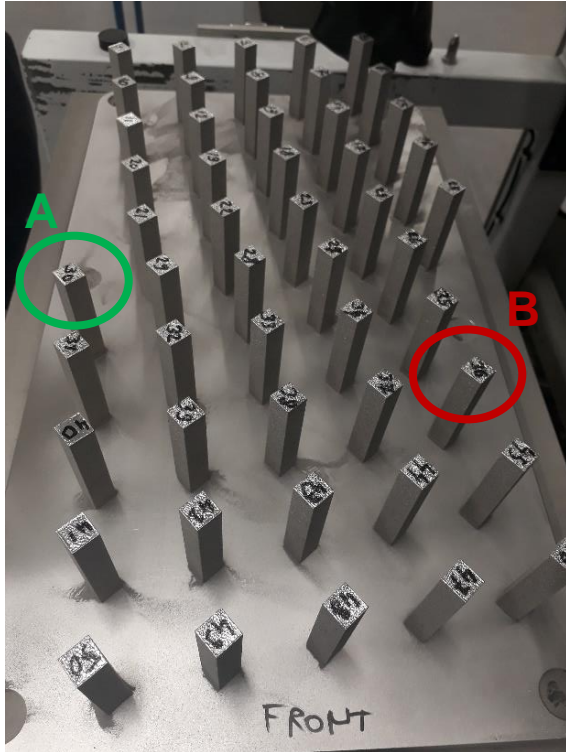


Large quality discrepancy for heavy-loaded platform without careful machine fine-tuning, even with **optimal laser process parameters**

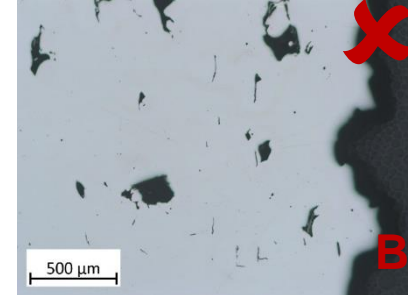
# Process Stability

Challenge: Homogeneous properties over the platform !

Large quality discrepancy for heavy-loaded platform without careful machine fine-tuning, even with optimal laser process parameters

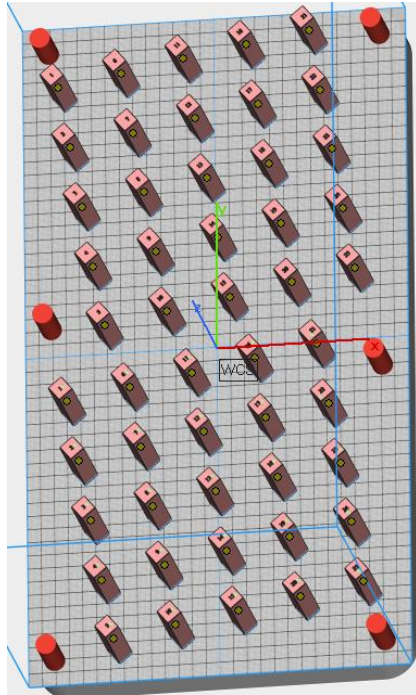


Impact testing  
136 J vs. 16 J



# Process Stability

Challenge: Homogeneous properties over the platform !



Charpy V-notch toughness values over the build platform using optimized laser process parameters

	87	70	61	66	32
	54	74	49	75	47
	79	76	69	54	61
	73	77	89	47	35
	73	33	52	60	45
76	71	85	78	49	
65	65	92	64	39	
61	82	56	35	42	
58	47	50	25	27	
40	49	33	23	24	

Charpy V-notch toughness in Joule

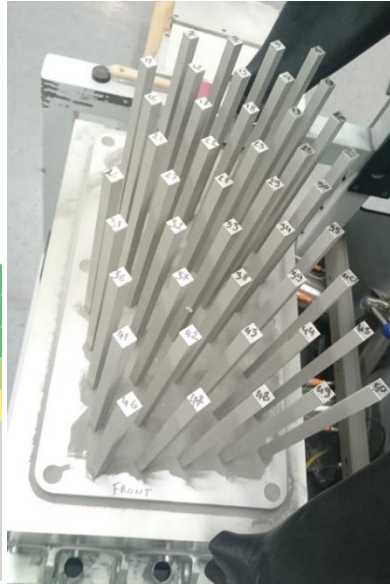
# Process Stability over build height & Process Transferability

## Full height samples

### Process Stability

- ❖ Consistent product quality throughout the build height

	107	108	104	109	108
	110	109	103	115	128
	104	111	104	135	140
	100	102	114	133	76
	113	106	87	121	55
112	111	109	112	118	
107	106	97	118	99	
111	118	112	142	85	
106	108	111	114	132	
104	102	110	116	130	



## Big blocks

### Process Qualification

- ❖ Transferability from coupons to industrial part



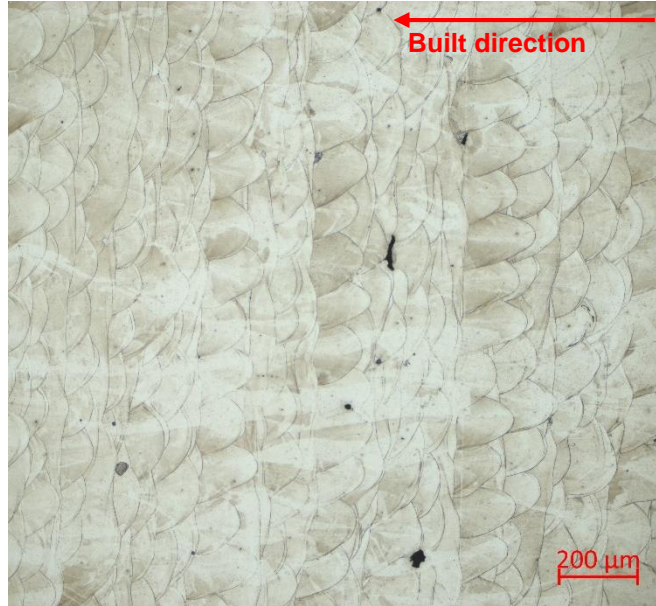
	yield strength (MPa)	tensile strength (MPa)	elongation (%)	reduction of area (%)
average	434	571	45.8	59.9
stdev	18	26	6.5	11.1



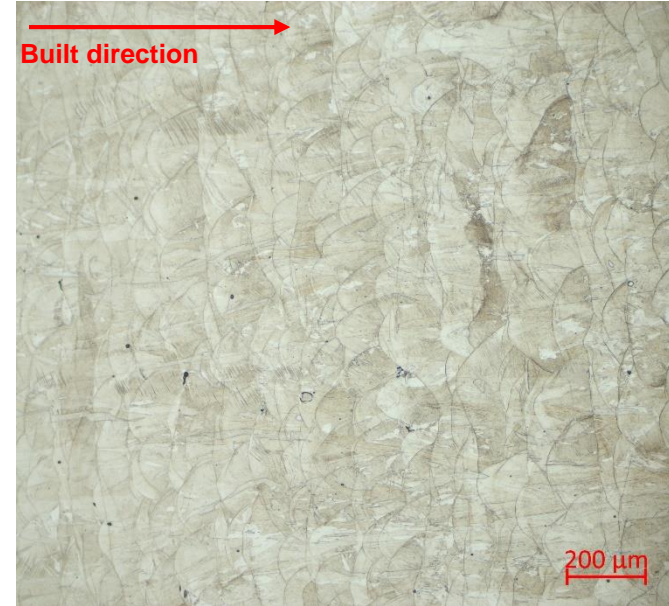
# Process Stability over build height & Process Transferability

## Microstructure

Before gas flow upgrade



After gas flow upgrade



After gas flow upgrade and corresponding parameter optimisation, the visible melt pools after etching seem to be less pronounced and more homogeneous in size

# ENGIE Certification Project

## Successful ENGIE Facility and Powder Lab Certification by Lloyd's Register on 10.09.2019

### ❖ Technological bricks:

- Feedstock
- Process
- AM Material Performance

### ❖ Material certificates 3.1 & 3.2

### ❖ Proactive approach before release of future EN 13445-14

Relative Archimedes Density – Laborelec Procedure LBE04113339							
		Average	Standard deviation		Comments		
Results		99,43%	0,13%		8 measurements of 15mmx15mmx15mm cubes from qualification platform		
Tensile properties							
		Condition	Yield Strength 0.2%	Ultimate Tensile Strength	Elongation at break A5	Reduction of Area	Comments
ASTM F3184-16	Min.	Solution annealed	205 MPa	515 MPa	30%	30%	In all build directions
Results – XY build direction		Solution annealed	379 ± 8 MPa	614 ± 3 MPa	48 ± 2 %	60 ± 3 %	Based on 5 specimens for each build direction, as per ASTM E23 with Ø6mm
Results – 45° build direction			382± 3 MPa	606 ± 3 MPa	52 ± 2 %	63 ± 3 %	
Results – Z build direction			370± 7 MPa	586 ± 9 MPa	57 ± 3 %	65 ± 3 %	
Hardness							
		Condition	Measurement		Comments		
ASTM F3184-16		Not mentioned					
ASTM A240/A240M–06b	Max.	Solution annealed	217 HB				
Results		Solution annealed	185 ± 8 HV0,5		16 measurements per cube on 2 cubes		
Charpy V-notch impact testing							
		Condition	Charpy Impact Energy		Lateral expansion		Comments
ASTM F3184-16		Not mentioned					
Results – XY build direction		Solution annealed	122J / 130J / 132J		1,78mm / 1,82mm / 1,88mm		Based on 3 specimens for each build direction, as per ASTM E23



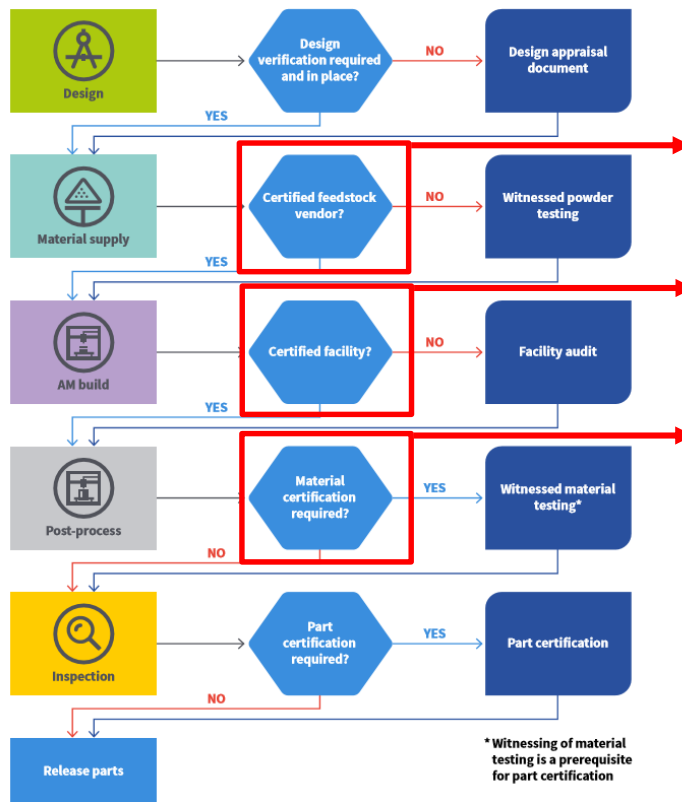
# ENGIE Certification Project

- **Our Main Goal**

- Achieving ENGIE AM Facility Qualification & Material Certification

- Material Certificate linking Powder Batch, Machine/Process & Formed Material

- Delivery of material certificate 3.1 or 3.2 for 316L material under Lloyd's Register label



**Certification of stainless steel 316L powder feedstock & our Laborelec Powder Lab**

**Validation of SLM500 equipment at ENGIE Fabricom Zwijndrecht**

**Certification of produced stainless steel (mechanical performance)**

\*Witnessing of material testing is a prerequisite for part certification

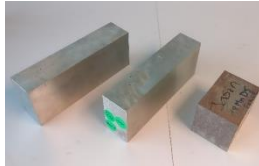
# Additive Manufacturing Product Quality and Control

Off-line / non-destructive

- Material properties determine inspectability for UT and EC
  - New manufacturing technology leads to unique challenges and material properties
  - Codes and regulations require inspection of critical components
  - Benchmark AM material against industry-standard materials (forging and casting)



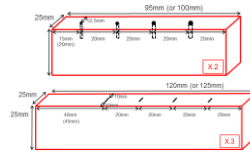
Industry-standard material



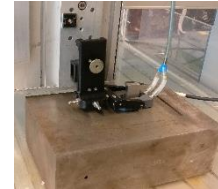
AM material



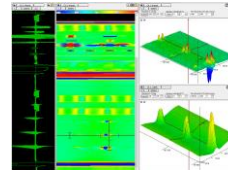
Fabrication of standardized blocks with reference defects



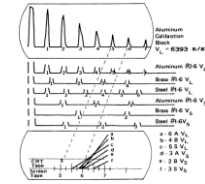
Ultrasound testing



Eddy current testing



Calculate material properties

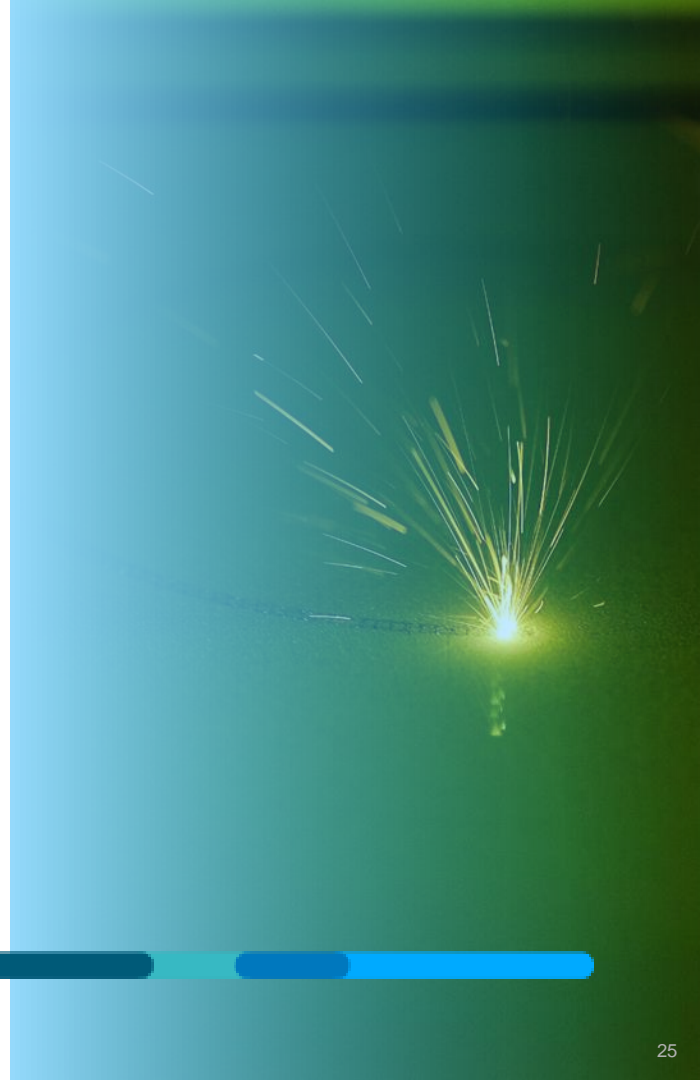


Benchmark against industry standard

Young modulus  
Signal to noise  
Absorption  
Sound velocity  
Anisotropy  
Electrical conductivity



# Implementation of qualification approach to tackle ENGIE obsolescence challenges



# Reverse Engineering incorporating Metal Additive Manufacturing

Reverse engineering	
ORIGINAL ITEM INFORMATION	
Component ID	PC001 - C01-500902
Component ID	PC001 - C01-500902
Item short name	
Manufacturer	
Manufacturer Part Number	
Material name (if functional location)	
Item description	
REVERSE ENGINEERING SUMMARY	
Studied registered item	3D printed valve body
Component ID	
Manufacturer	
Manufacturer Part Number	
Material name (if functional location)	
Item description	

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TRACTEBEL ENGINEERING S.A.  
Rue de la Vallée 100-101-102-103-104-105-106-107-108-109-110-111-112-113-114-115-116-117-118-119-120-121-122-123-124-125-126-127-128-129-130-131-132-133-134-135-136-137-138-139-140-141-142-143-144-145-146-147-148-149-150-151-152-153-154-155-156-157-158-159-160-161-162-163-164-165-166-167-168-169-170-171-172-173-174-175-176-177-178-179-180-181-182-183-184-185-186-187-188-189-190-191-192-193-194-195-196-197-198-199-200-201-202-203-204-205-206-207-208-209-210-211-212-213-214-215-216-217-218-219-220-221-222-223-224-225-226-227-228-229-230-231-232-233-234-235-236-237-238-239-240-241-242-243-244-245-246-247-248-249-250-251-252-253-254-255-256-257-258-259-260-261-262-263-264-265-266-267-268-269-270-271-272-273-274-275-276-277-278-279-280-281-282-283-284-285-286-287-288-289-290-291-292-293-294-295-296-297-298-299-300-301-302-303-304-305-306-307-308-309-310-311-312-313-314-315-316-317-318-319-320-321-322-323-324-325-326-327-328-329-330-331-332-333-334-335-336-337-338-339-340-341-342-343-344-345-346-347-348-349-350-351-352-353-354-355-356-357-358-359-360-361-362-363-364-365-366-367-368-369-370-371-372-373-374-375-376-377-378-379-380-381-382-383-384-385-386-387-388-389-390-391-392-393-394-395-396-397-398-399-400-401-402-403-404-405-406-407-408-409-410-411-412-413-414-415-416-417-418-419-420-421-422-423-424-425-426-427-428-429-430-431-432-433-434-435-436-437-438-439-440-441-442-443-444-445-446-447-448-449-450-451-452-453-454-455-456-457-458-459-460-461-462-463-464-465-466-467-468-469-470-471-472-473-474-475-476-477-478-479-480-481-482-483-484-485-486-487-488-489-490-491-492-493-494-495-496-497-498-499-500-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000-1001-1002-1003-1004-1005-1006-1007-1008-1009-1010-1011-1012-1013-1014-1015-1016-1017-1018-1019-1020-1021-1022-1023-1024-1025-1026-1027-1028-1029-1030-1031-1032-1033-1034-1035-1036-1037-1038-1039-1040-1041-1042-1043-1044-1045-1046-1047-1048-1049-1050-1051-1052-1053-1054-1055-1056-1057-1058-1059-1060-1061-1062-1063-1064-1065-1066-1067-1068-1069-1070-1071-1072-1073-1074-1075-1076-1077-1078-1079-1080-1081-1082-1083-1084-1085-1086-1087-1088-1089-1090-1091-1092-1093-1094-1095-1096-1097-1098-1099-1100-1101-1102-1103-1104-1105-1106-1107-1108-1109-1110-1111-1112-1113-1114-1115-1116-1117-1118-1119-1120-1121-1122-1123-1124-1125-1126-1127-1128-1129-1130-1131-1132-1133-1134-1135-1136-1137-1138-1139-1140-1141-1142-1143-1144-1145-1146-1147-1148-1149-1150-1151-1152-1153-1154-1155-1156-1157-1158-1159-1160-1161-1162-1163-1164-1165-1166-1167-1168-1169-1170-1171-1172-1173-1174-1175-1176-1177-1178-1179-1180-1181-1182-1183-1184-1185-1186-1187-1188-1189-1190-1191-1192-1193-1194-1195-1196-1197-1198-1199-1200-1201-1202-1203-1204-1205-1206-1207-1208-1209-1210-1211-1212-1213-1214-1215-1216-1217-1218-1219-1220-1221-1222-1223-1224-1225-1226-1227-1228-1229-1230-1231-1232-1233-1234-1235-1236-1237-1238-1239-1240-1241-1242-1243-1244-1245-1246-1247-1248-1249-1250-1251-1252-1253-1254-1255-1256-1257-1258-1259-1260-1261-1262-1263-1264-1265-1266-1267-1268-1269-1270-1271-1272-1273-1274-1275-1276-1277-1278-1279-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2280-2281-2282-2283-2284-2285-2286-2287-2288-2289-2290-2291-2292-2293-2294-2295-2296-2297-2298-2299-2300-2301-2302-2303-2304-2305-2306-2307-2308-2309-2310-2311-2312-2313-2314-2315-2316-2317-2318-2319-2320-2321-2322-2323-2324-2325-2326-2327-2328-2329-2330-2331-2332-2333-2334-2335-2336-2337-2338-2339-2340-2341-2342-2343-2344-2345-2346-2347-2348-2349-2350-2351-2352-2353-2354-2355-2356-2357-2358-2359-2360-2361-2362-2363-2364-2365-2366-2367-2368-2369-2370-2371-2372-2373-2374-2375-2376-2377-2378-2379-2380-2381-2382-2383-2384-2385-2386-2387-2388-2389-2390-2391-2392-2393-2394-2395-2396-2397-2398-2399-2400-2401-2402-2403-2404-2405-2406-2407-2408-2409-2410-2411-2412-2413-2414-2415-2416-2417-2418-2419-2420-2421-2422-2423-2424-2425-2426-2427-2428-2429-2430-2431-2432-2433-2434-2435-2436-2437-2438-2439-2440-2441-2442-2443-2444-2445-2446-2447-2448-2449-2450-2451-2452-2453-2454-2455-2456-2457-2458-2459-2460-2461-2462-2463-2464-2465-2466-2467-2468-2469-2470-2471-2472-2473-2474-2475-2476-2477-2478-2479-2480-2481-2482-2483-2484-2485-2486-2487-2488-2489-2490-2491-2492-2493-2494-2495-2496-2497-2498-2499-2500-2501-2502-2503-2504-2505-2506-2507-2508-2509-2510-2511-2512-2513-2514-2515-2516-2517-2518-2519-2520-2521-2522-2523-2524-2525-2526-2527-2528-2529-2530-2531-2532-2533-2534-2535-2536-2537-2538-2539-2540-2541-2542-2543-2544-2545-2546-2547-2548-2549-2550-2551-2552-2553-2554-2555-2556-2557-2558-2559-2560-2561-2562-2563-2564-2565-2566-2567-2568-2569-2570-2571-2572-2573-2574-2575-2576-2577-2578-2579-2580-2581-2582-2583-2584-2585-2586-2587-2588-2589-2590-2591-2592-2593-2594-2595-2596-2597-2598-2599-2600-2601-2602-2603-2604-2605-2606-2607-2608-2609-2610-2611-2612-2613-2614-2615-2616-2617-2618-2619-2620-2621-2622-2623-2624-2625-2626-2627-2628-2629-2630-2631-2632-2633-2634-2635-2636-2637-2638-2639-2640-2641-2642-2643-2644-2645-2646-2647-2648-2

# Reverse Engineering incorporating Metal Additive Manufacturing



# Any Questions ?

