

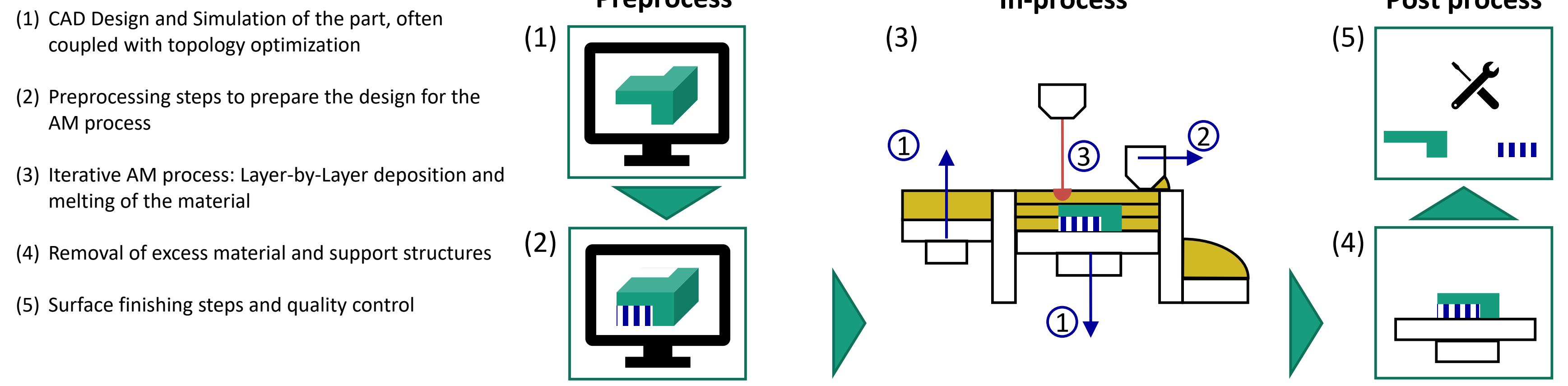
Development of a Hydrogen Metal Hydride Storage Produced by Additive Manufacturing

Motivation

Metal hydride storage systems (HMHS) can store hydrogen in a compact space at low pressures, but are comparatively heavy due to the use of the metal hydride. This makes them particularly suitable for stationary systems. Away from these, fuel cell powered forklifts are suitable vehicles for an HMHS as they require a counterweight to balance the load carried. However, to ensure efficient operation, the loading times of the HMHS must be reduced. A critical factor here is heat dissipation out of the tank, since loading is an exothermic process. In addition, the tank should have a rectangular design so that it can be installed in the forklift in a space-saving manner.

Additive manufacturing (AM) offers great potential for the simple and direct production of complex and functional components made of polymers and metals. Due to the freedom of design, AM offers great innovation potential compared to conventional manufacturing processes. In many cases, component designs that exploit the possibilities of AM show higher technical performance or functionality compared to components manufactured by conventional processes. In this work we assessed the freedom of design due to AM and focused the optimization on fast loading times and customized the outer dimensions to allow more flexibility in the overall system design.

Manufacturing steps and flow diagram of an PBF-LB/M process



Concept Phase

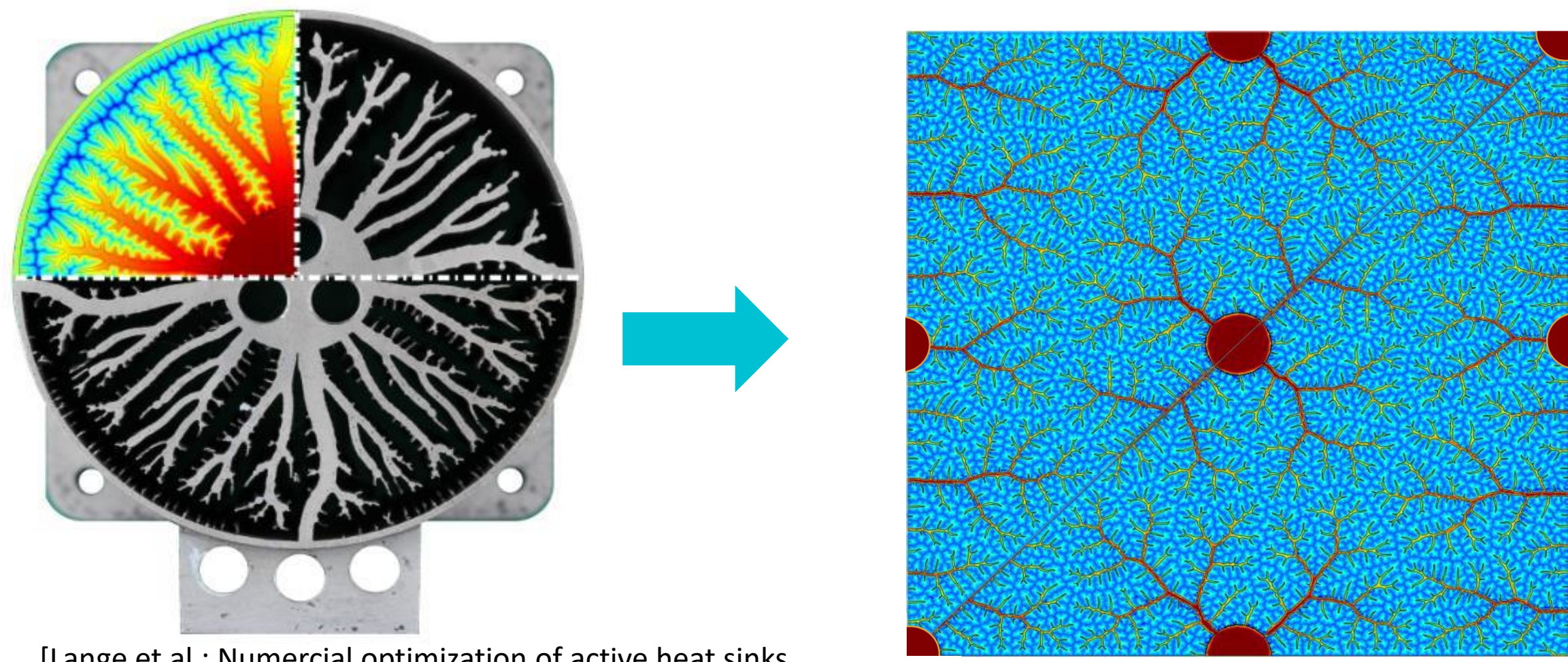
Identification of the main functions of the HMHS that can be enhanced through AM:

- Cooling Jacket:
 - Outer shell that enhances heat dissipation
- Cooling Channels:
 - Choice depends on Manufacturing constraints and desired heat dissipation
 - Variation of the design and arrangement
- Heat Exchanger (HE) structure:
 - Used to transfer heat out of the metal hydride
 - Key parameter of a HMHS
 - AM offers the possibility to greatly increase the surface area of the heat exchanger structure
- Reinforcements to withstand the load of the HMHS:
- Splitting of the tank

Morphological Chart Hydrogen storage of a metal hydride tank manufactured by laser powder bed fusion

Functions ↓		Elements								
		1	2	3	4	5	6	7	8	
1	cooling jacket	existent	non existent							
2	cooling channels	leaf structure	axial	radial	zigzag	spiral	grid	from jacket to core	no cooling channels	
3	heat exchanger	metal foam	adding substance to the metal hydride	fins	tree-like structure	honeycomb	grid	no heat exchanger		
4	reinforcement	reinforcements outside	braces inside the tank	in the cooling jacket	no reinforcement					
5	splitting the tank	one big tank	single housing, several tanks inside	several small tanks						

HE Design Phase



[Lange et al.: Numerical optimization of active heat sinks considering the restrictions of selective laser melting, Lausanne, COMSOL Conf., October 2018, pp. 0-7]

Adaptation of a topology optimized heat exchanger design to a rectangular metal hydride tank

Topology optimized HE structures have superior heat dissipation properties:

- Branching creates large surface area that is in contact with the metal hydride

Lange et al. developed such a HE design that outperforms conventional designs by a factor of 5

This design was used and adapted for the rectangular HMHS

Highlights the advantages of AM in contrast to conventional manufacturing methods:

- Geometries that were inconceivable become feasible with AM
- Bionic designs can enhance the functionality of technical parts

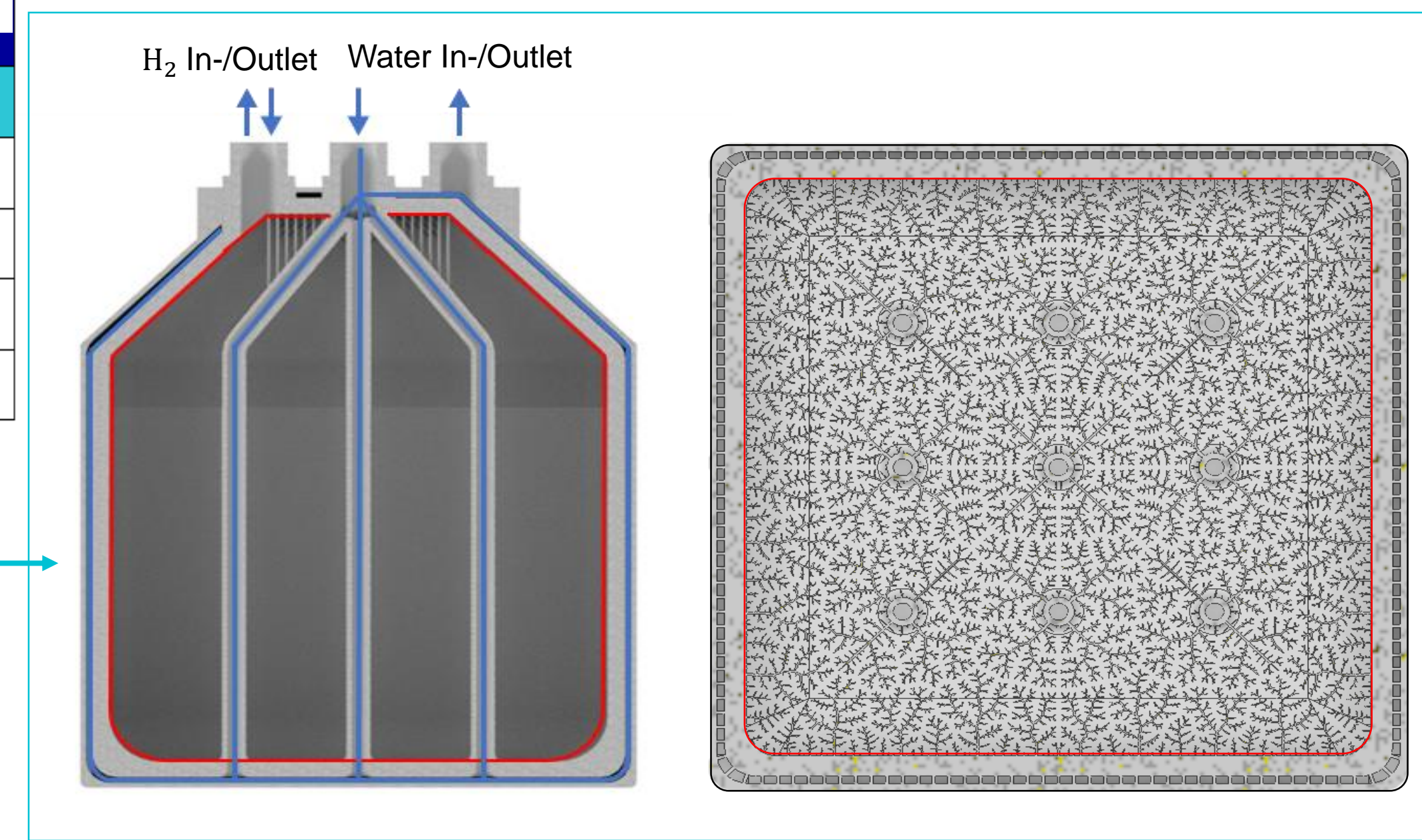
Tank Design Phase

criteria	weighting	solution 1		solution 2		solution 3		solution 4		solution 5		solution 6		solution 7	
		rating	weighting	rating	weighting	rating	weighting	rating	weighting	rating	weighting	rating	weighting	rating	weighting
heat exchange	30%	3	0,9	6	1,8	4	1,2	6	1,8	8	2,4	10	3	3	0,9
metal hydride content	40%	3	1,2	7	2,8	8	3,2	6	2,4	2	0,8	6	2,4	9	3,6
integrability	30%	9	2,7	5	1,5	6	1,8	4	1,2	7	2,1	9	2,7	9	2,7
sum	100%	15	4,8	18	6,1	18	6,2	16	4,8	17	5,1	25	7,5	21	6,3

With the help of an evaluation matrix different designs were rated. The focus here was set on the heat exchanging properties, the metal hydride content inside the tank and the integrability of the functions.

Designvariation #6 has achieved the highest score, it is designed with the following functions:

- An existing Cooling Jacket
- Axial Cooling Channels that connect to the outlying cooling jacket and the tree-like HE
- Tree-like heat exchanging structures: These can not be manufactured by conventional methods and have a very high surface area to transfer heat out of the metal hydride
- Reinforcement ribs inside the cooling jacket
- One big tank without any separations



Demonstrator and Outlook

Validation of the design

FEA simulation with an expected pressure of 50.05 bar resulted in a desired wall thickness of 7 mm.

Advantages and features of the design:

Optimized heat dissipation structures that reduce the loading times

The design is well-suited to prevent damages due to contraction and expansion of the metal hydride

- Mainly due to the accumulation of bigger metal hydride particles in the branches of the tree-like structure, rather than the bottom of the tank

The tank consists only of one component:

- Outer cooling jacket, rib reinforcements, inner shell and HE structures are print in one step

Outlook

Combination of mechanical and heat related topology optimization

- Can further increase the capabilities of the design
- Main HMHS functions of fast charging and burst prevention coupled

Manufacturing of the design out of 316 L by Laser Powder Bed Fusion

Experimental validation of the design

Adaptation of the design for a luggage cart used at an airport

- Research project at iLAS aims to improve a tank of such a cart through AM

Demonstrator

On the right a demonstrator is presented. This was manufactured out of PLA in the MEX-P-process to show the inner design of the tank.

