From Organic Waste to Ink for 3D Printing Within the MELiSSA Loop

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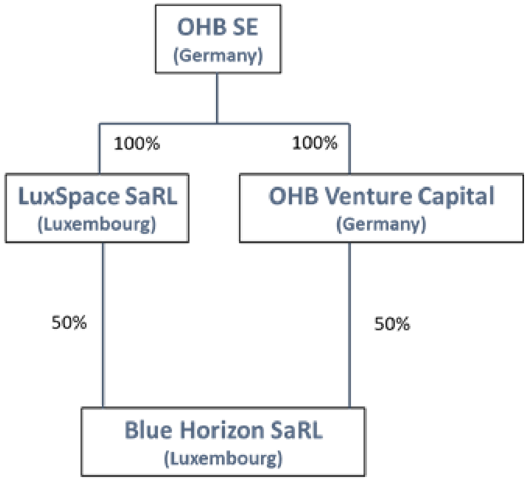
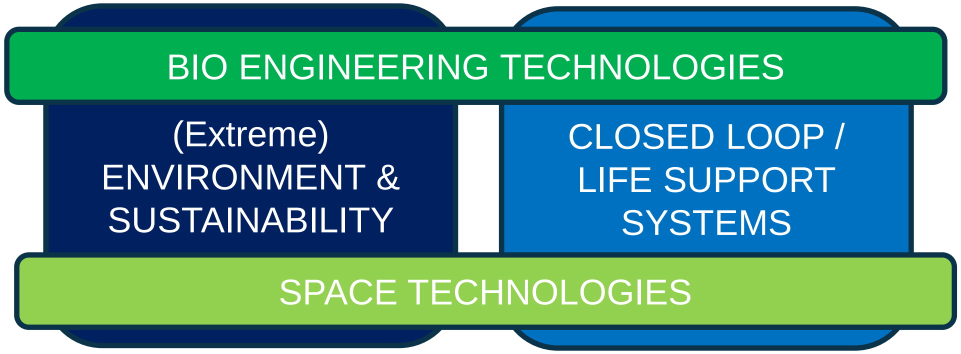
Blue Horizon SarL – introduction

- Implemented in Betzdorf, Luxembourg in 2017
- Operational since 2018
- Ownership: 100% OHB SE
- 7 crew members



- Mission
  - Life sciences for Earth and Space
  - Offer biotechnological solutions
- Core competences
  - Microbiology
  - Bioprocess engineering
  - Systems engineering
  - Earth observation



Motivation

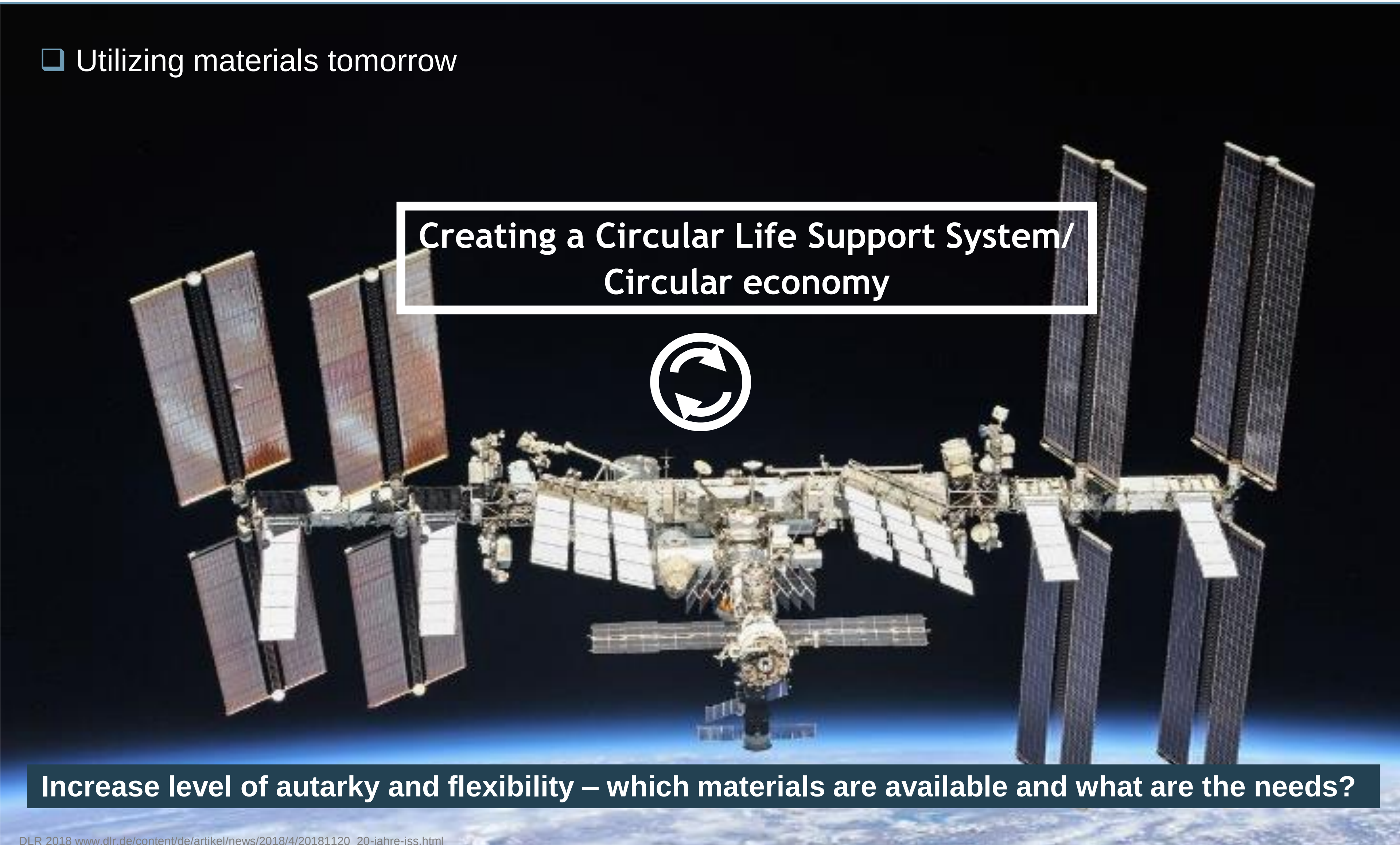
- Utilizing materials today

DLR 2018 www.dlr.de/content/de/artikel/news/2018/4/20181120_20-jahre-iss.html

Linear way of material utilization

Motivation

- Utilizing materials tomorrow



Increase level of autarky and flexibility – which materials are available and what are the needs?

DLR 2018 www.dlr.de/content/de/artikel/news/2018/4/20181120_20-jahre-iss.html

Biological Life Support System

Inputs:
O_2
Water
Food

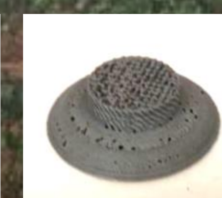
Outputs:
CO_2
Transpiration
Organic waste (OW)
Liquid: urine
Solid (sOW): feces
microbes
plant residues

WASTE & PROCESSING

Feedstock:
for *in-space* processing and
Additive manufacturing (AM)

APPLICATIONS

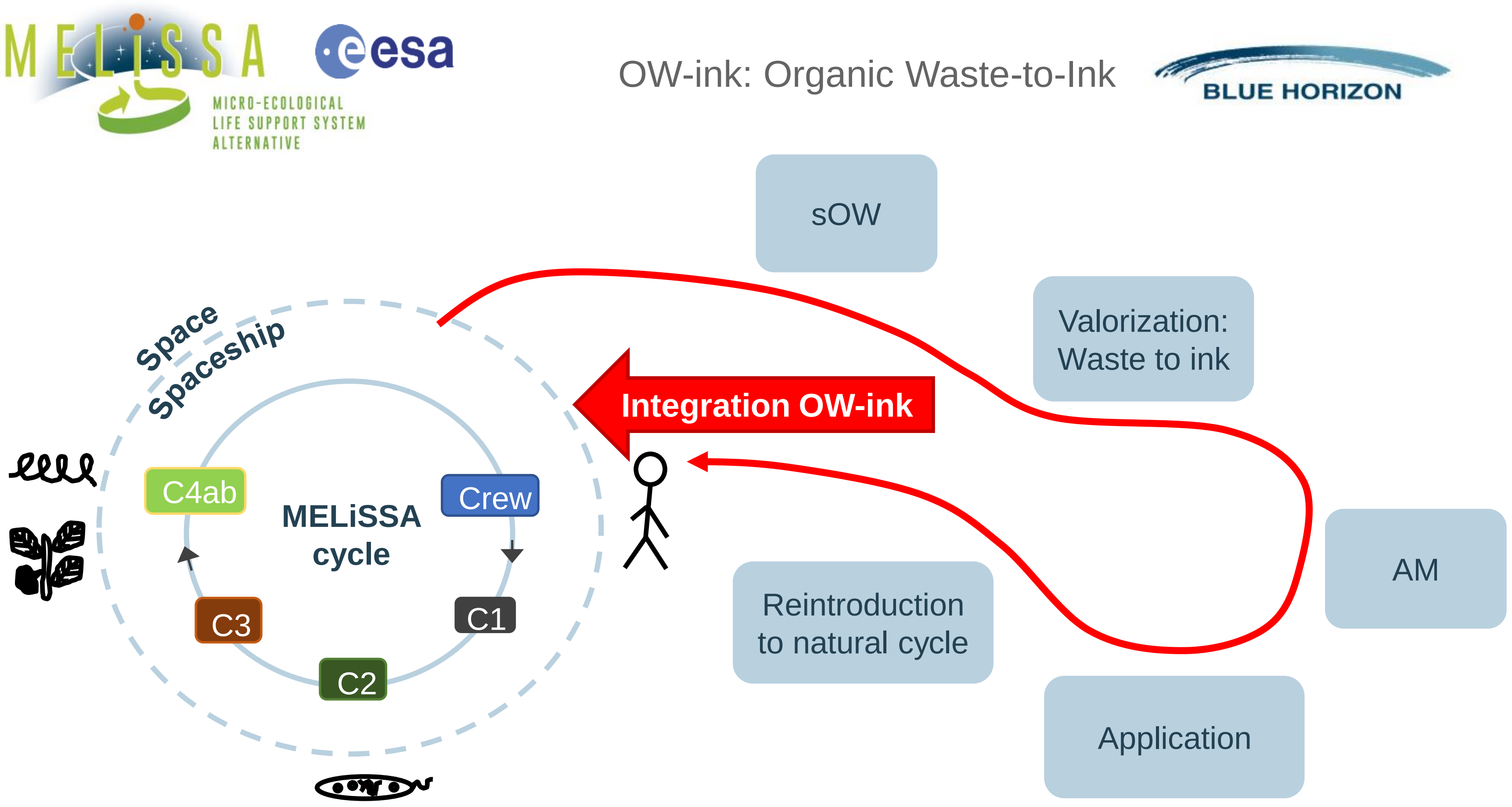
Spare Parts ?
Tools ?
Everyday objects ?
Structural material ?



Solid organic waste (sOW): just waste or an opportunity?

Adapted from www.inhabitat.com
„The Martian““ (20th Century Fox)
Filament: https://www.amazon.de/Filament-SUNLU
Wrench: www.NASA.gov
Foil: Bayer 2014 dx.doi.org/10.1021/ma5008557
Bowl: Wösten, Montalti et al. (2018) ESA RFP/NC/IPL- PTE/LF/as/518.2016
Part: Putman 2015, www.nasa.gov

Add-on subsystem to MELiSSA

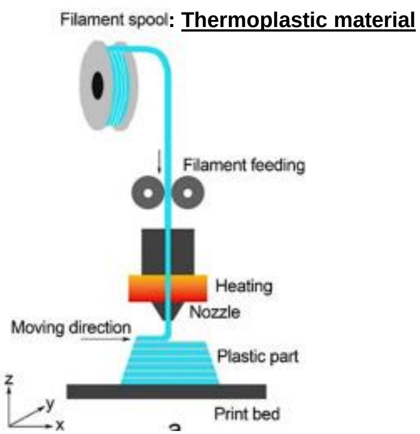


Identification of waste and valorization processes

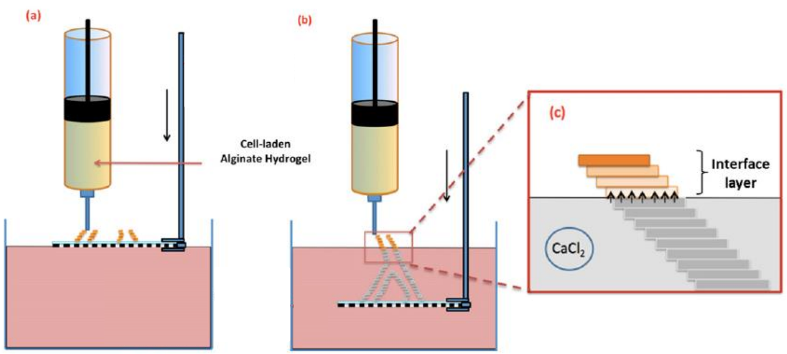
Additive manufacturing (AM)

- 3D-printing: Subsequent layer-wise addition of ink (compound material) to obtain 3D objects

Fused Deposition Modeling (FDM)

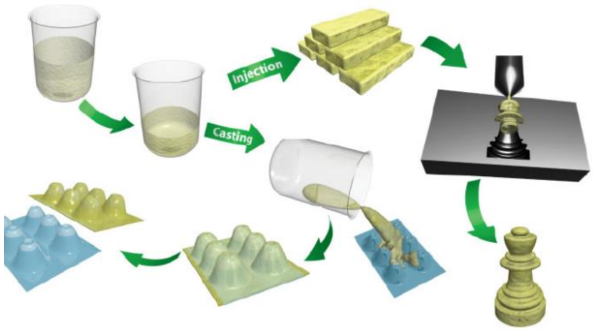


Inkjet bioprinting



Paste extrusion

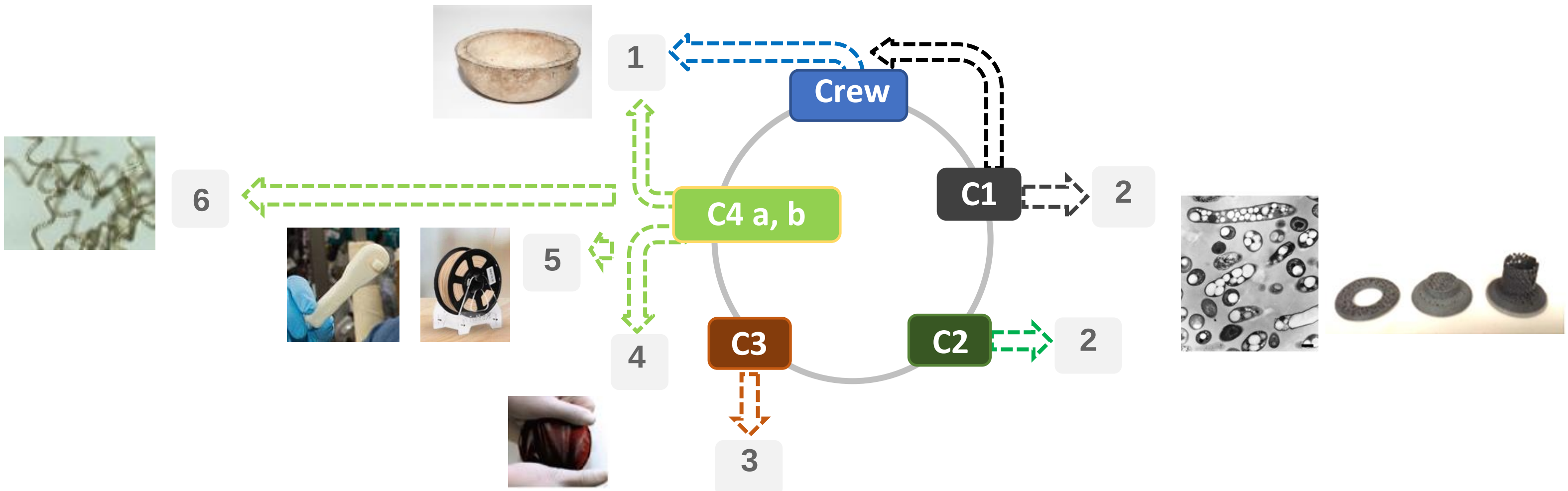
- (Injection) molding
- Solvent casting



FDM: Tao 2021 doi.org/10.1016/j.jmrt.2021.10.108
Gel: Tabriz 2015: doi:10.1088/1758-5090/7/4/045012
Paste: Wösten, Montalti et al. (2018) ESA RFP/NC/IPL- PTE/LF/as/518.2016
Mold, cast: Fernandez 2014: doi 10.1002/mame.201300426

Screening: waste and valorization processes

- Baseline: sOW derived from MELiSSA (concept status: 2020)



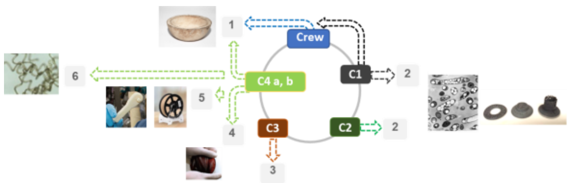
#	sOW	Processing	Ink-precursor	Processing	Ink (POLYMER)
1	Plant residues, feces		Living fungus on sOW		Entangled mycelium (chitine)
2	Microbial biomass		Volatile fatty acids (VFA)		Polyhydroxy-butyrate (PHB)
3	Microbial biofilm		Unfractionated biomass		Protein, polysaccharides
4	Plant residues		Solubilized sOW		Lignocellulose
5	Plant residues		Fermentable sugars		Polylactic acid (PLA)
6	Microbial biomass		Unfractionated biomass		Protein, polysaccharides

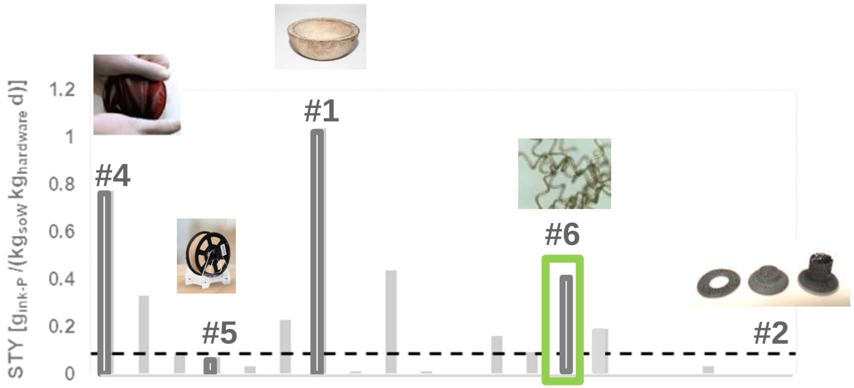
1: Cerimi 2019 doi.org/10.1186/s40694-019-0080-y; Wösten, Montalti et al. (2018) ESA RFP/NC/IPL- PTE/LF/as/518.2016; 2: PHB: Putman 2015, www.nasa.gov; Chen 2018 :: doi.org/10.1101/288746; Ryu 1997 CCC 0006-3592/97/010028-05; 3: not evaluated; 4: Bayer 2014 dx.doi.org/10.1021/ma5008557; 5: Gupta 2007 doi:10.1016/j.progpolymsci.2007.01.005; 6. Cinar 2020 doi:10.3390/ijerph17113842; Fredericks 2021 doi.org/10.1002/pol.20210683

sOW and process selection

- Order-of-magnitude analysis (space-time-yield, STY)
  - Mass of produced ink
  - Mass of input sOW
  - Estimate on hardware mass
  - Ink production time
- ALiSSE criteria
  - Safety aspect
  - Performance

  Thermoplastic material for FDM 3D Printer @ISS





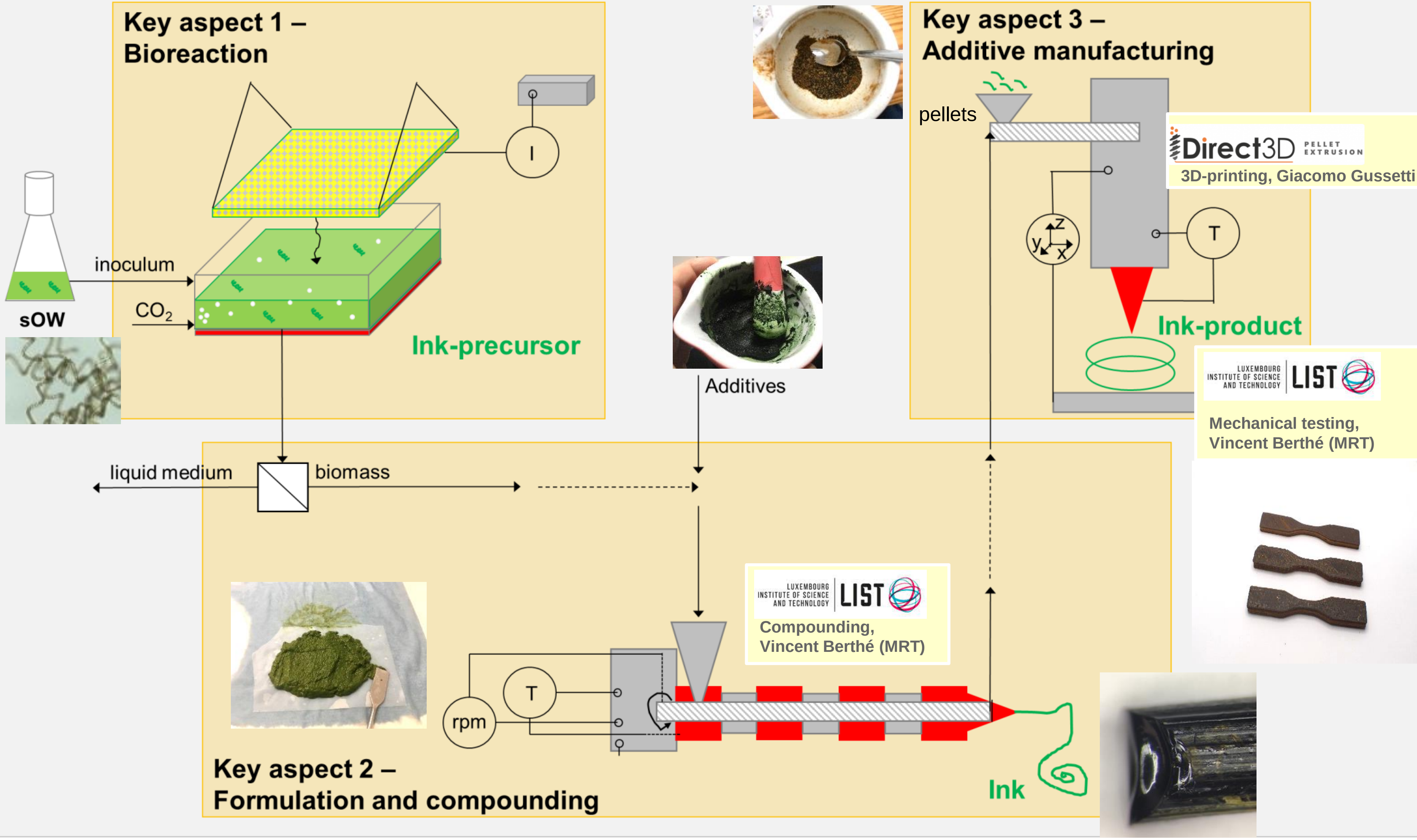
Process	STY	Safety	Thermoplastic/FDM
1	✓	(✓)	✘
2	✘	✘	✓
3	-	-	-
4	✓	✘	✘
5	✘	✘-o	✓
6	o	✓	?

FDM: Tao 2021 doi.org/10.1016/j.jmrt.2021.10.108
Printer at ISS:built and operated by Made In Space, Inc., from the 3D Printing in Zero G Technology Demonstration Mission. In Prater 2019, https://doi.org/10.1007/s00170-018-2827-7

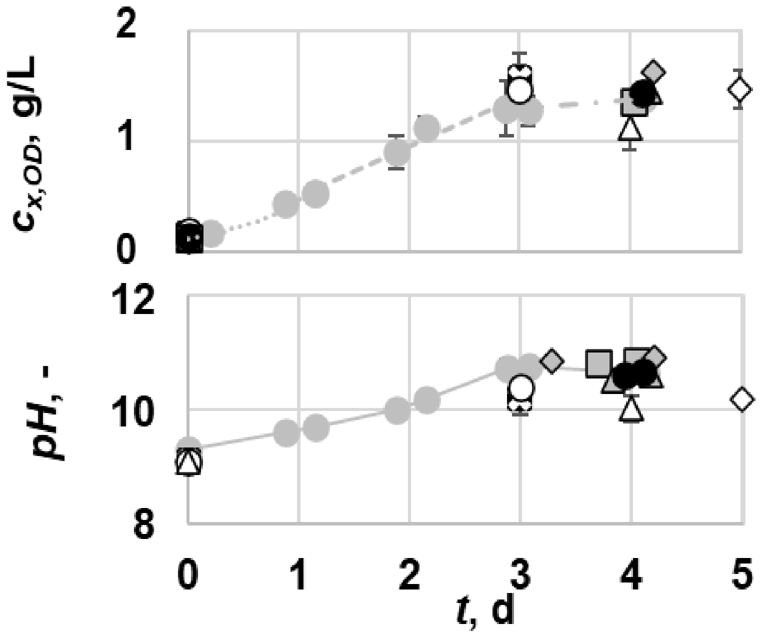
TN4100 Elaboration of a consolidated concept; OW-ink project

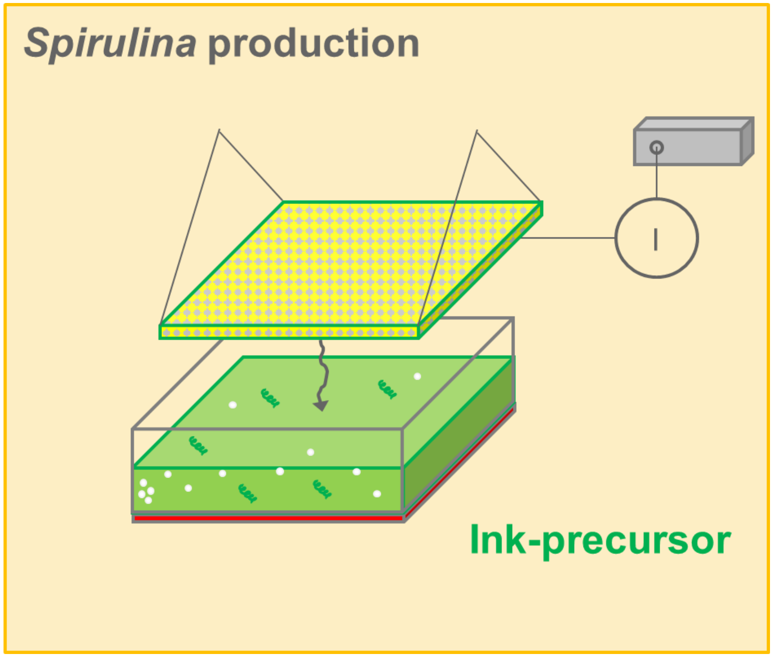
Current work: focus on *Limnospira/Spirulina* biomass

Testing: Lab breadboard model



Results: Ink-precursor production

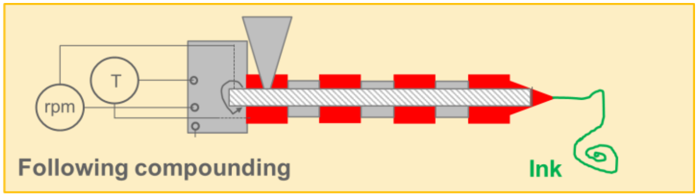


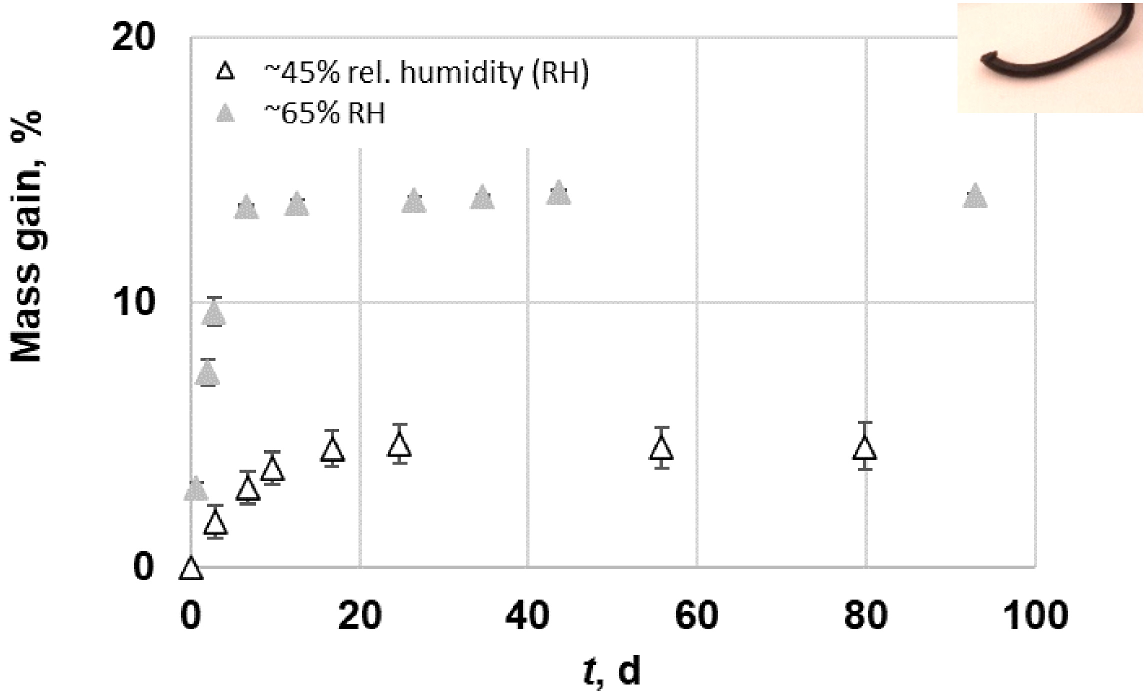


Production of >100 g *Spirulina* (dry) biomass containing mix of biopolymers (proteins, polysaccharides, polynucleotides, …)

Results: Ink characterization

- ❑ Absorption of water at different humidity
  - ❑ Starting point: dried ink
  - ❑ Determine mass gain by weighing
  - ❑ Strands ~0.5-1 cm x 1-2 mm [LxD]

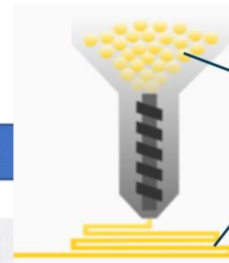




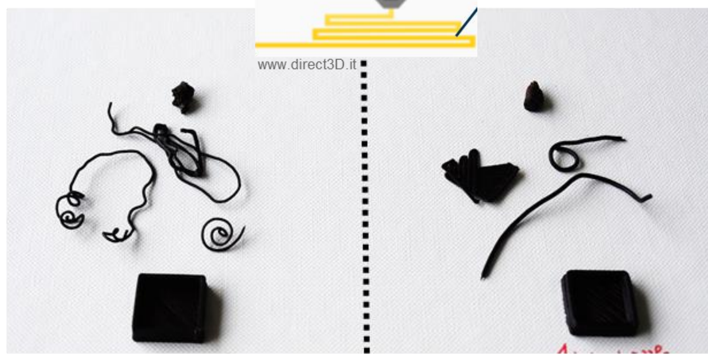
5-15% weight gain due to humidity absorption within ~10 d

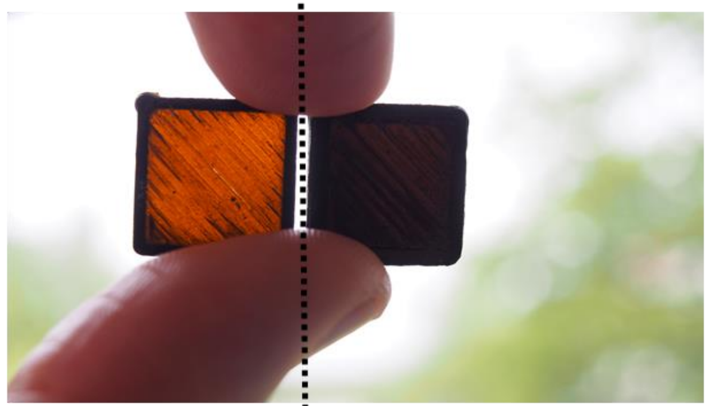
Results: Demonstration of 3D-printability

0.6 mm nozzle



1 mm nozzle

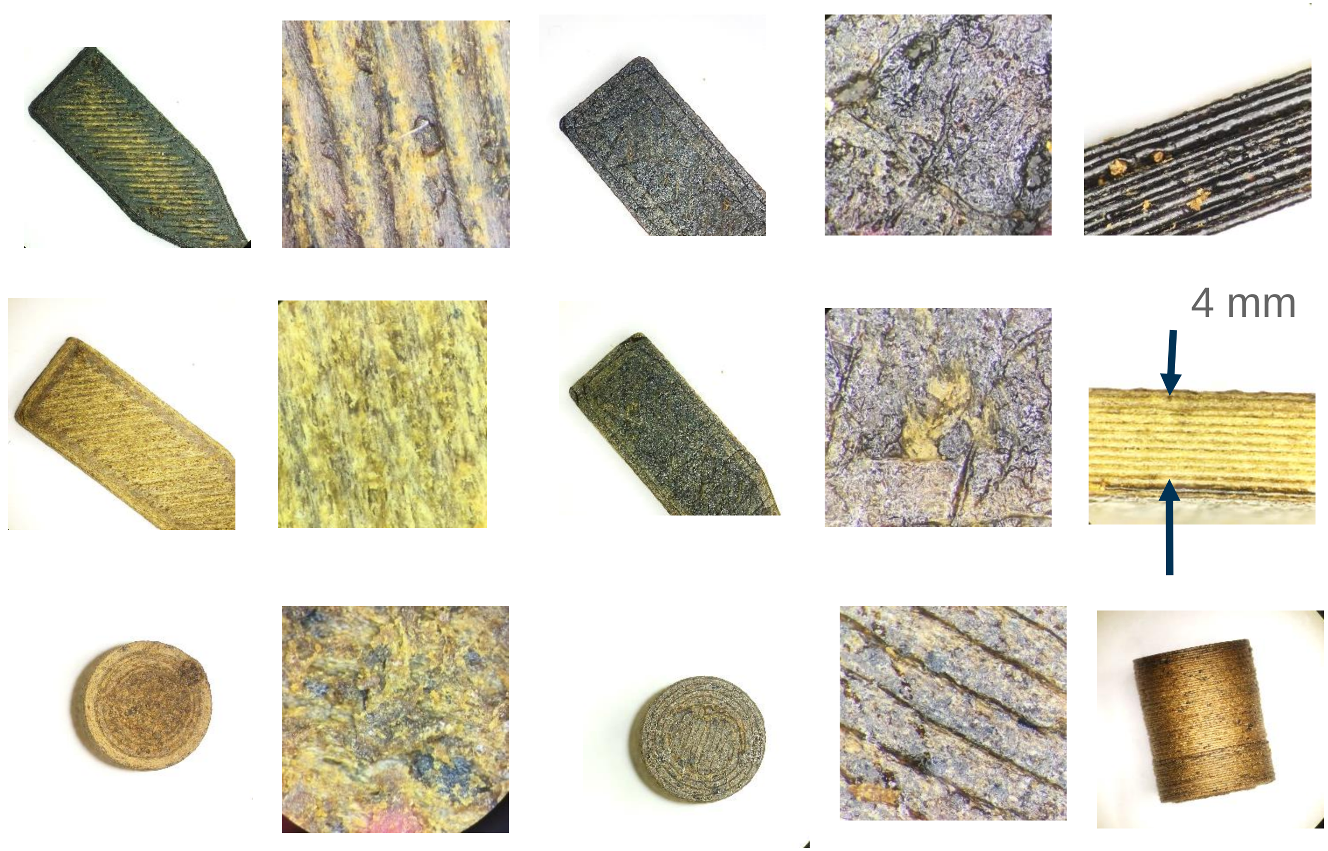




Layer adhesion after deposition is observed

Results: 3D printing of test specimens

- Type-V tensile bars (ASTM 638)
- Compression cylinders (ASTM 695)

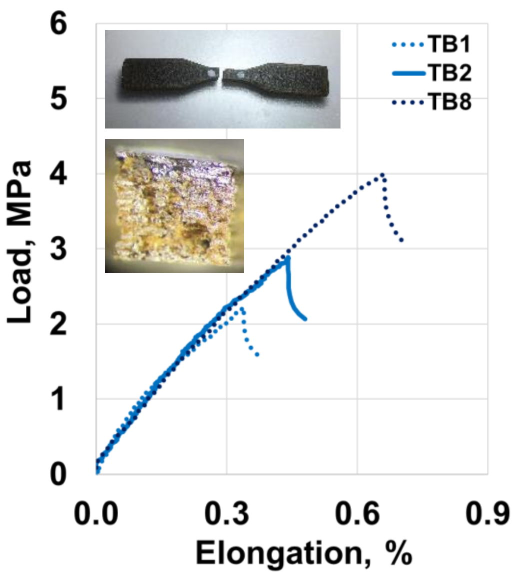


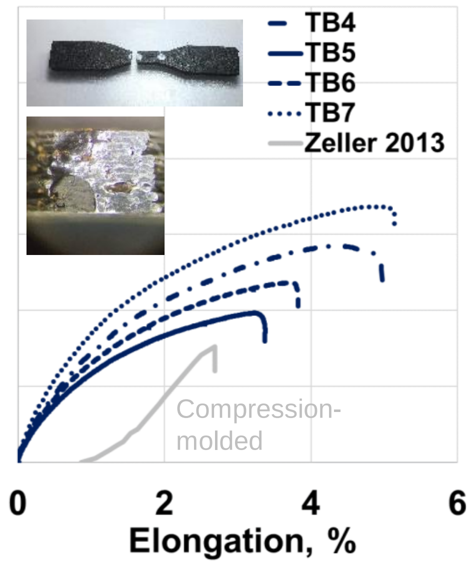
Detailed printing was possible to obtain test specimens

Mechanical testing of 3D-printed tensile bars

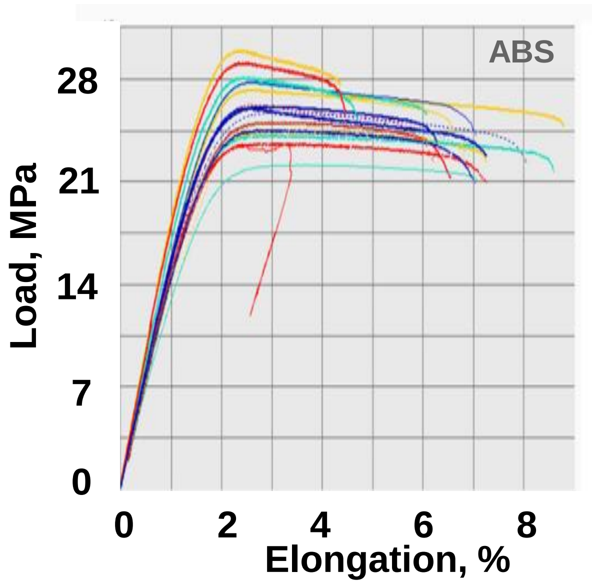
BLUE HORIZON

ABS=Acrylonitrile butadien styrene





Zeller 2013, DOI: 10.1002/APP.39559



Prater 2019, https://doi.org/10.1007/s00170-018-2827-7

Elastic modulus [GPa]:

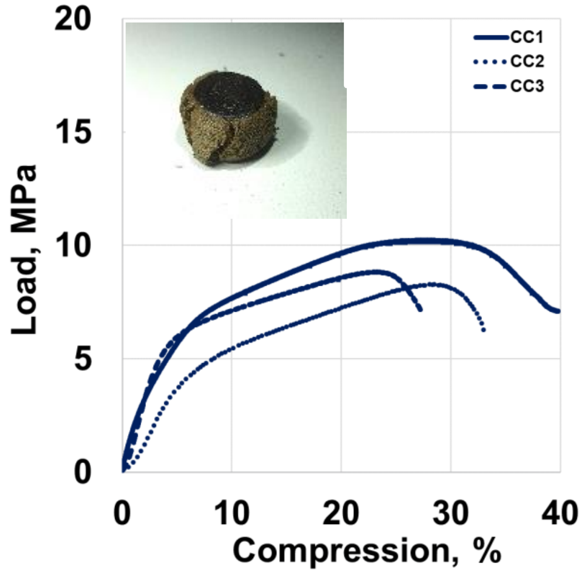
0.76 ± 0.05	**0.20 ± 0.04** (~0.10)	**>1.4**

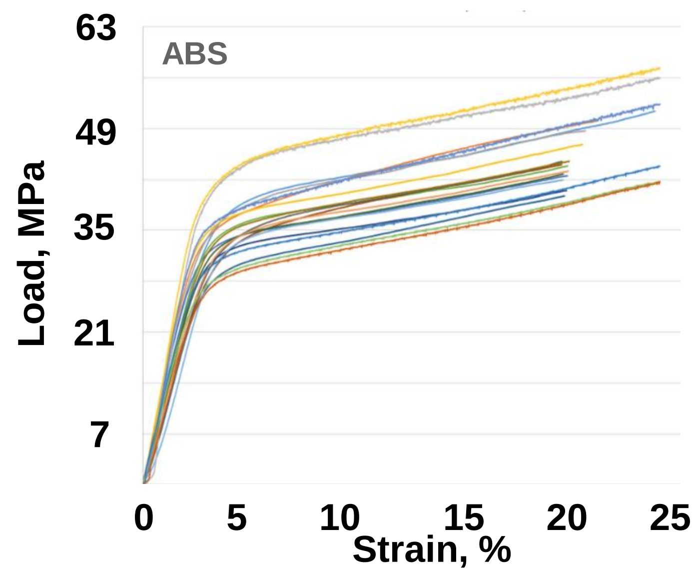
Ultimate tensile strength and modulus ~10x lower compared to 3D-printed ABS

Additional moisture weakens mech. strength and increases elongation (TB 4-7)

Mechanical testing of compression cylinders

BLUE HORIZON





Prater 2019, https://doi.org/10.1007/s00170-018-2827-7

Elastic modulus [GPa]:

~0.1	**~1.3**

Ultimate compressive (yield) strength and modulus 5-10x lower compared to 3D-printed ABS

Summary and next steps

BLUE HORIZON

- ❑ MELiSSA concept: identified sOW suitable for AM
- ❑ *Spirulina* biomass as bioplastic precursor
- ❑ Developed process chain to obtain compounded thermoplastic (ink) material
- ❑ Proof-of-concept: 3D-FDM (pellet) printing of the material
- ❑ Limitations material properties: sensitive to humidity and dissolution in water
- ❑ Tensile and compressive load ~ 1 OM below printed ABS

- ❑ Extend the production of the precursor biomass
- ❑ Improve processes to produce ink material of constant quality
- ❑ Characterize materials in more depth
- ❑ Test for recyclability and biodegradability
- ❑ Design, manufacture and test applications
- ❑ Elaborate on the potential integration of the OW-ink subsystem into MELiSSA

Acknowledgements

BLUE HORIZON

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esa

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