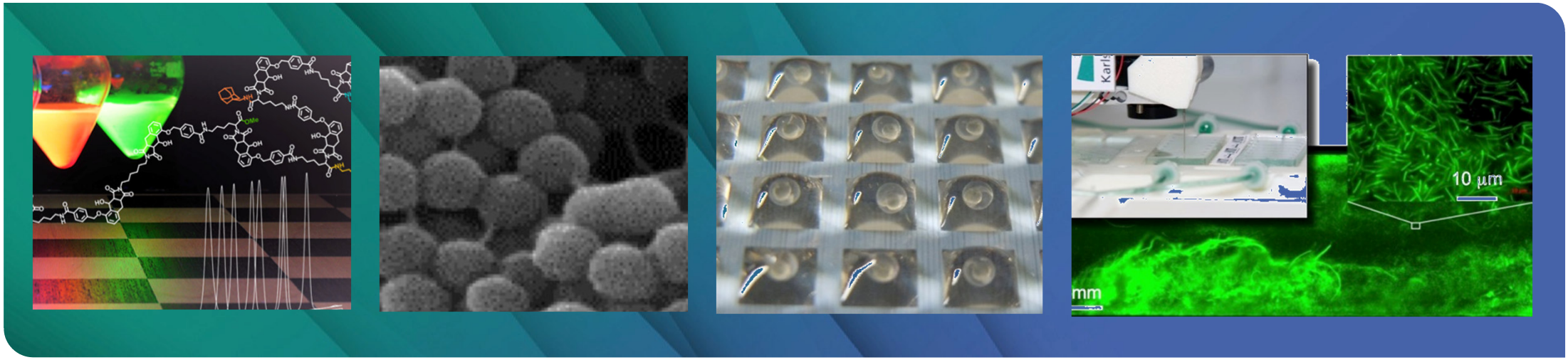
Karlsruhe Institute of Technology

Information-based biohybrid materials design - Future perspectives and current activities

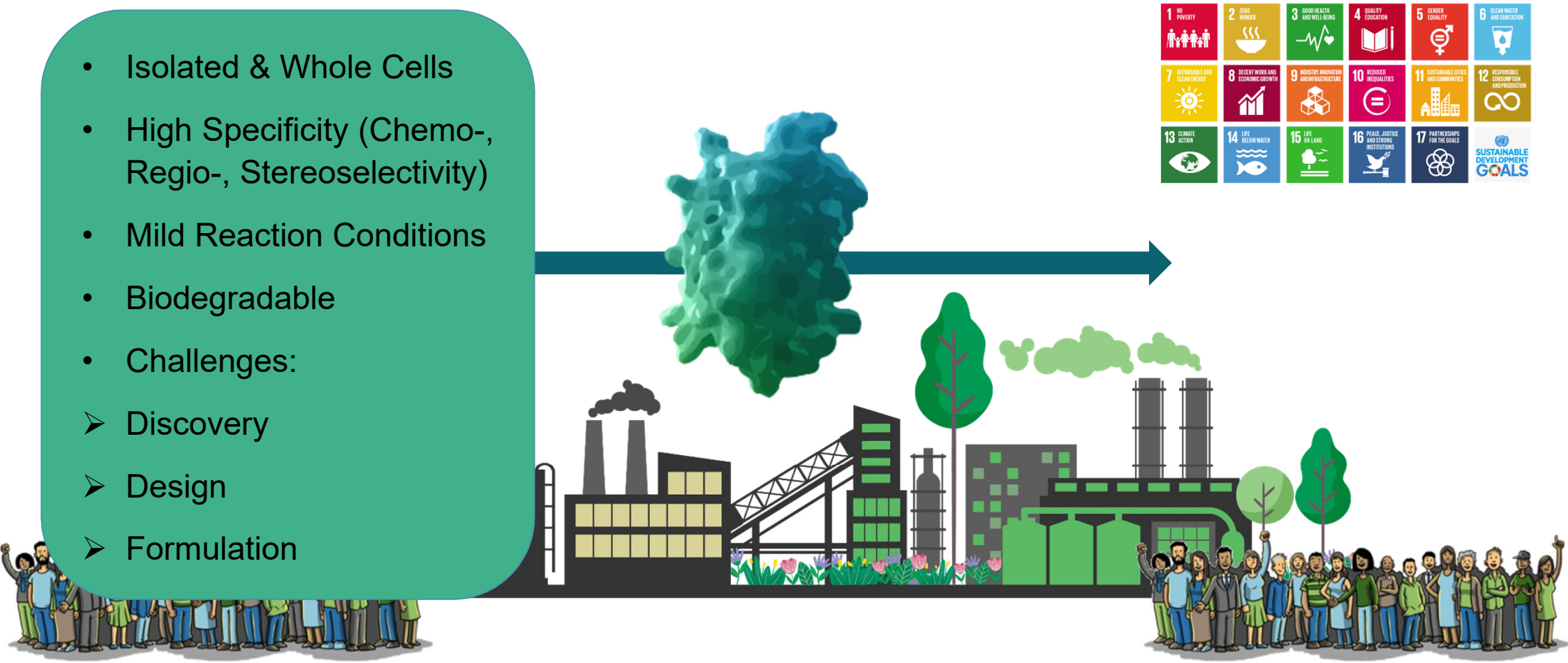
Christof M. Niemeyer



Biocatalysts - Key to Sustainable Industrial Processes

Biocatalysts - Key to Sustainable Industrial Processes

- Isolated & Whole Cells
- High Specificity (Chemo-, Regio-, Stereoselectivity)
- Mild Reaction Conditions
- Biodegradable
- Challenges:
  - ➢ Discovery
  - ➢ Design
  - ➢ Formulation

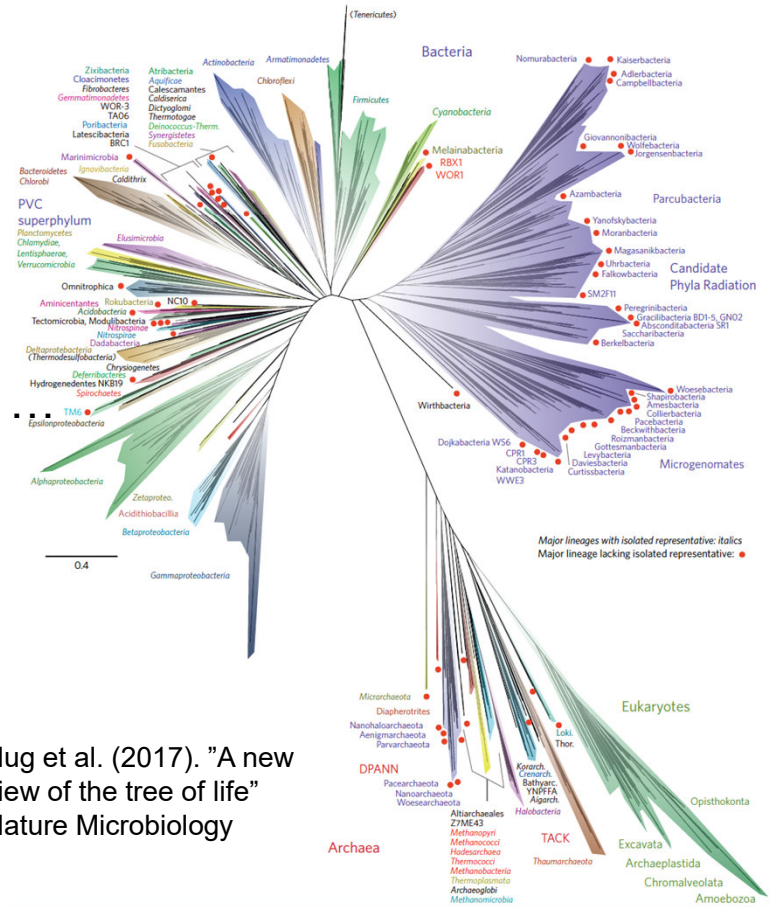


Information brings biology to application

Untapped microbial diversity in natural biofilms

- **Eukaryotes (~ 9 mio species, ~ 2 mio described)**
- **Prokaryotes (2 million - 2 trillion species, < 100.000 are described**
- „Microbial Dark Matter“
- Hidden Biotechnological Potential for Biocatalysis, Bioremediation, Discovery of Biocatalysts, Natural Products, …
- Deep Sequencing
- Metagenomes, Single-Amplified Genomes
- Single Cell Omics Pipelines (only 3 world-wide)

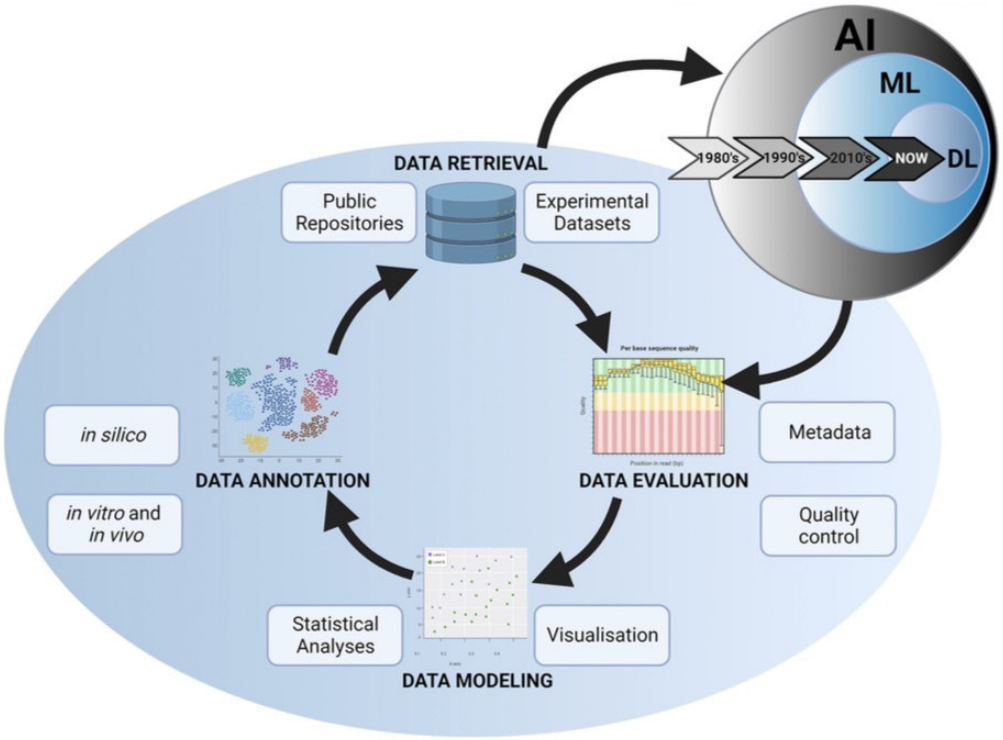
- Joint Genome Institute (DOI), CA
- Bidelow Laboratory, Maine, US
- Kaster Laboratory (KIT), DE

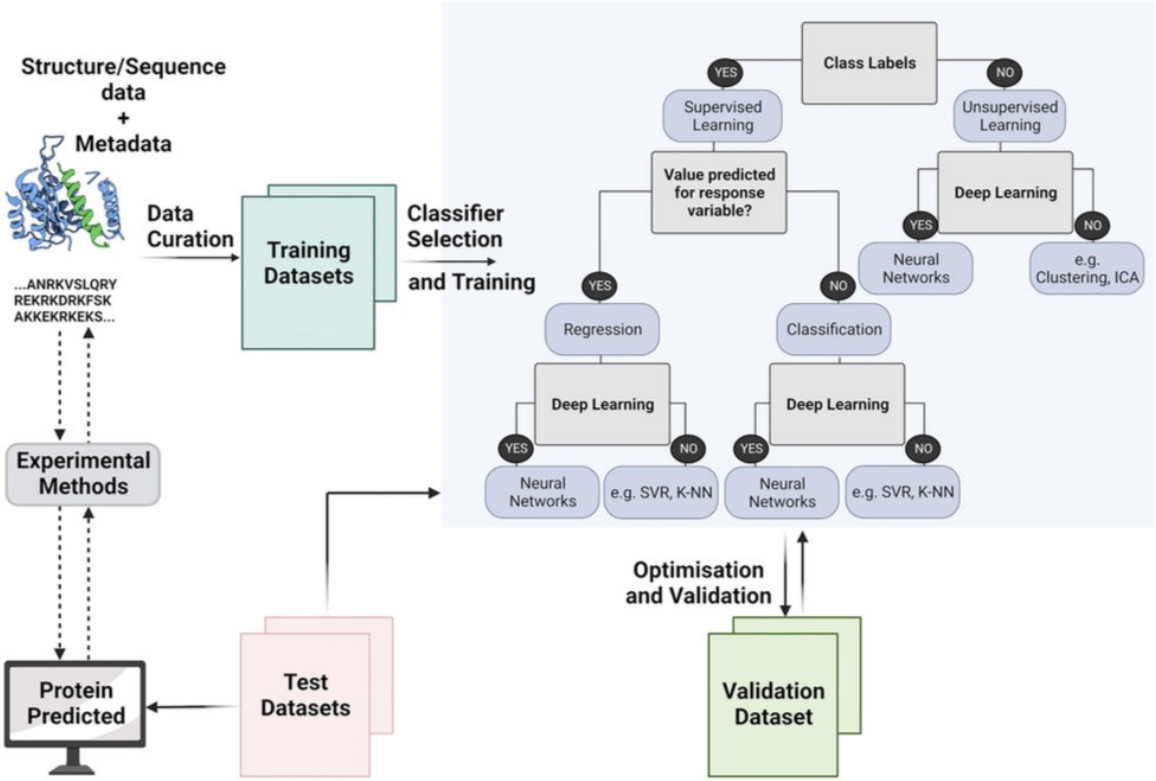


Hug et al. (2017). ”A new view of the tree of life” Nature Microbiology

Elucidating protein functionality using Big Data & AI

Kaster Laboratory (KIT)

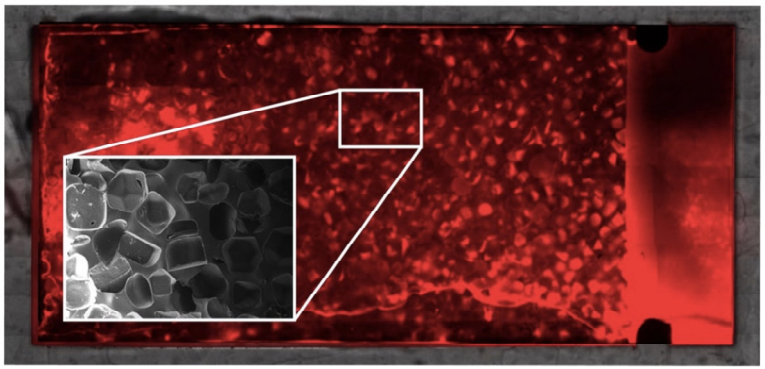




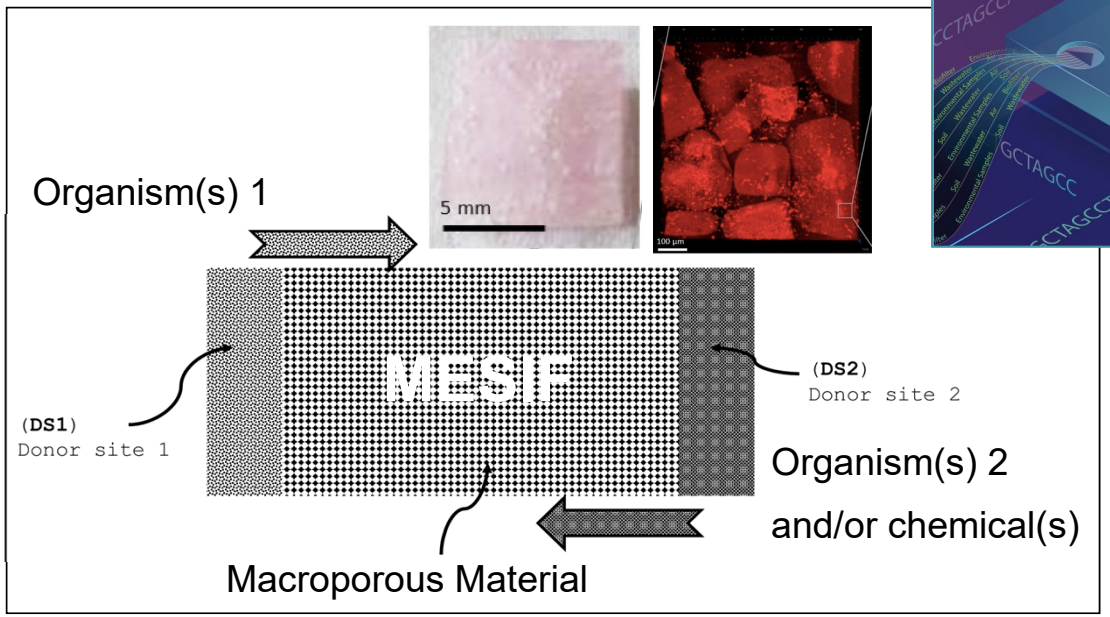
Ardern, FEMS Microbiol. Rev. **2023**, fuad003

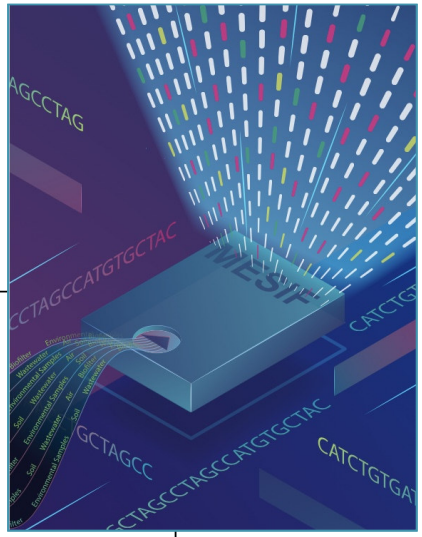
Novel materials for hunting microbial dark matter

- Macroporous Silicone Foam (MESIF)
- Adjustable form, pore size, surface chemistry
- Double gradient for microbial adaptation
- Stable communities, near axenic cultivation
- Enable community analyses & Enzyme discovery



Zoheir et al., ACS-AMI **2022**, 49592

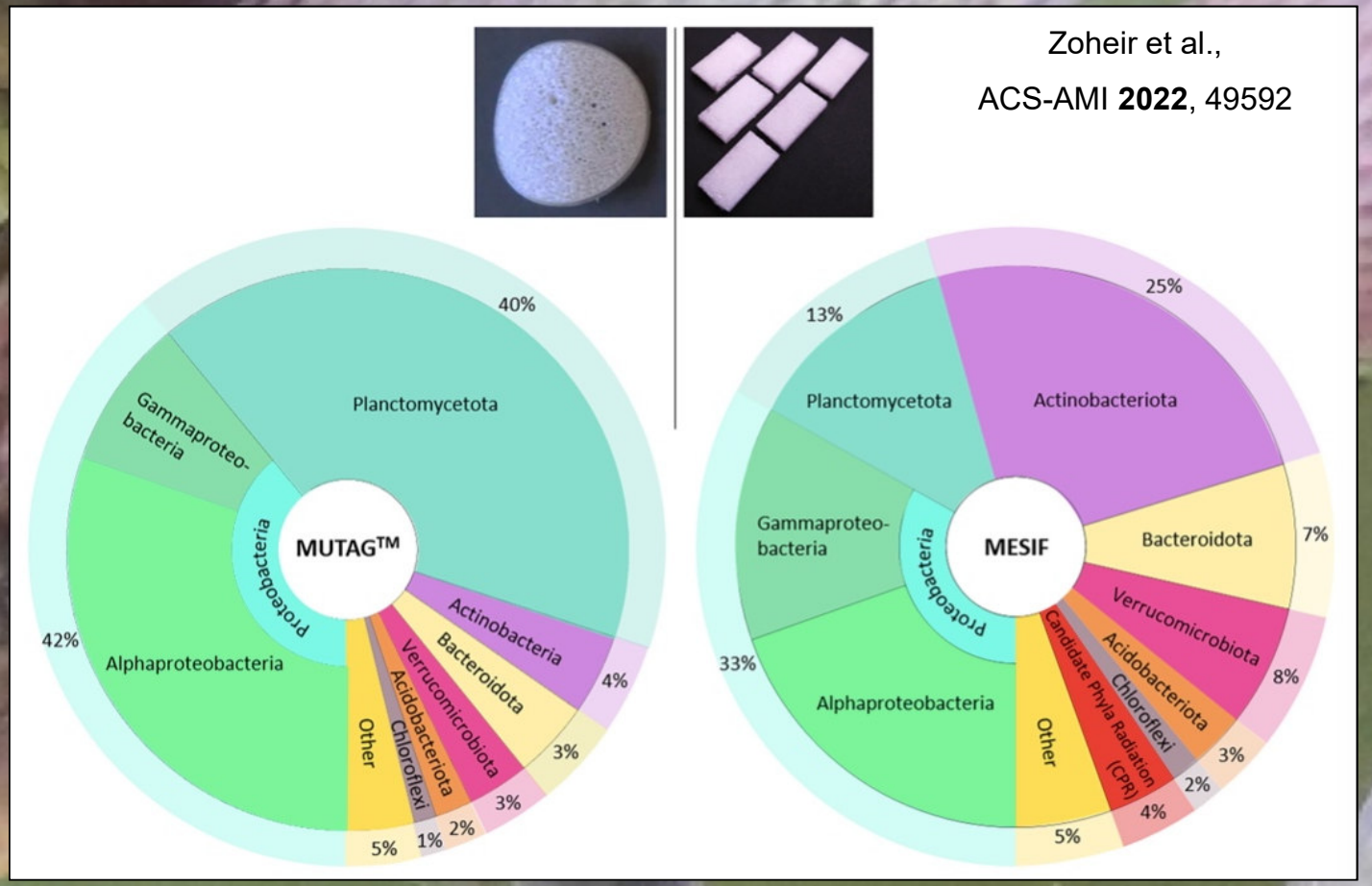




Novel materials for hunting microbial dark matter

Example:

Community analysis from fish farm biofilter

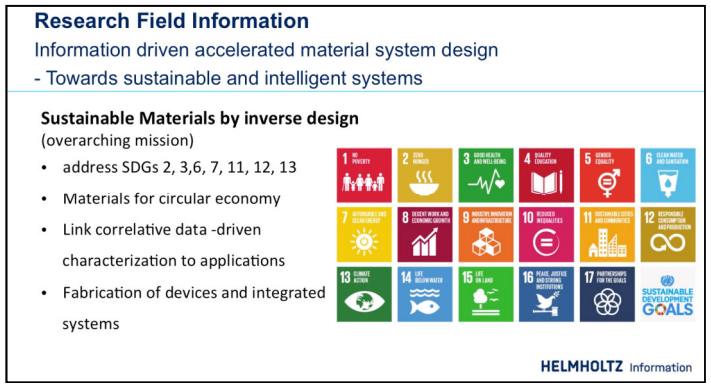


Information-driven accelerated materials systems design

- Over-arching goal

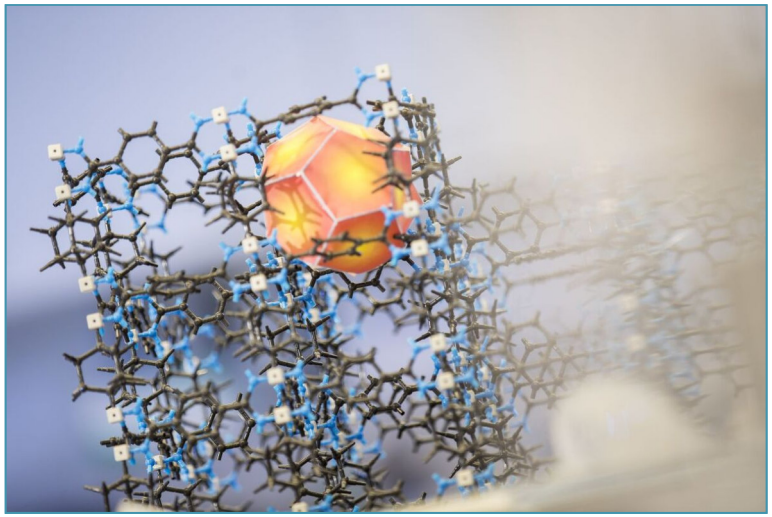
VIRTUAL MATERIALS DESIGN

Virtual, information-driven design of materials and devices



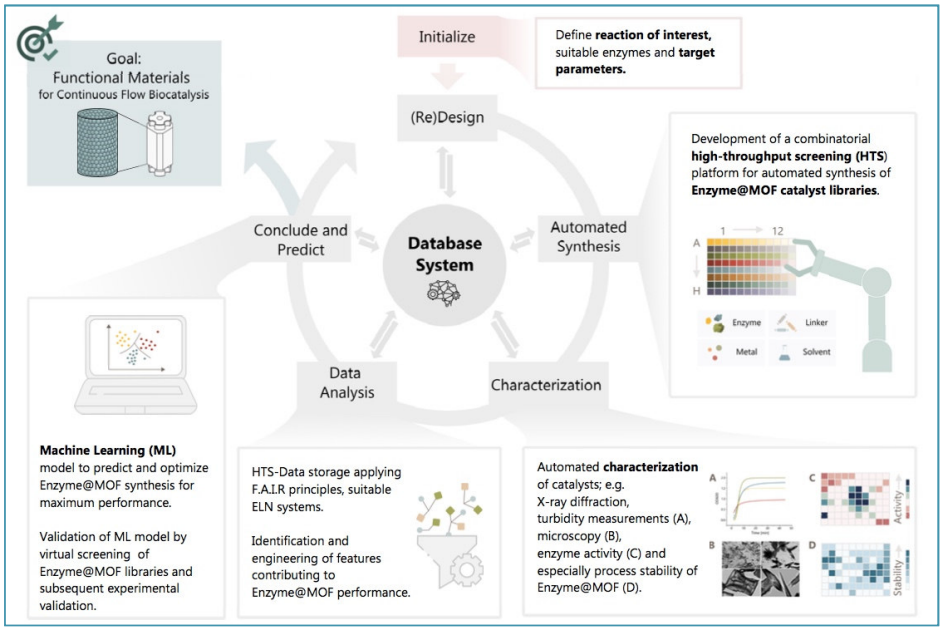
- Data science for Design, Synthesis & Characterisation
- Metal-organic framework (MOF) materials
- Artificial intelligence accelerates MOF syntheses
- Trained and optimized ML algorithms demonstrate superior prediction capabilities, outperforming human experts

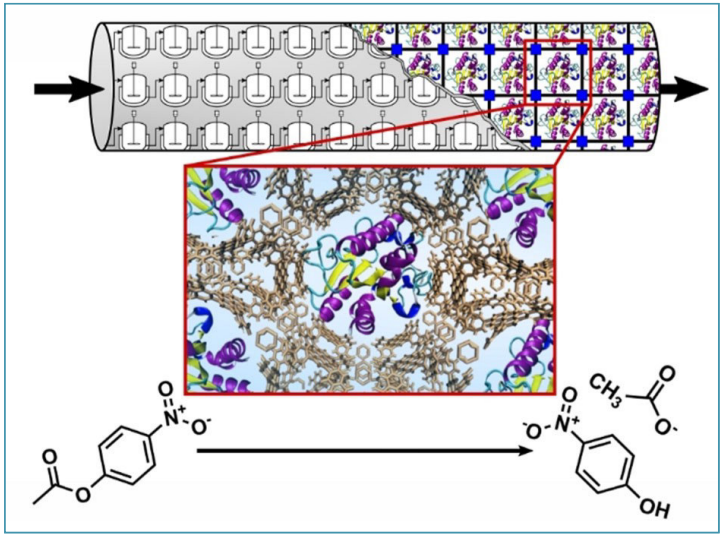
Luo et al., ACIE **2022**, e202200242



MOF-hosted enzymes for biocatalysis

- MOFs can stabilize enzymes against harsh process conditions (e.g., organic solvents)
- Requires extensive screening of MOF compounds and synthesis conditions to meet enzyme demands

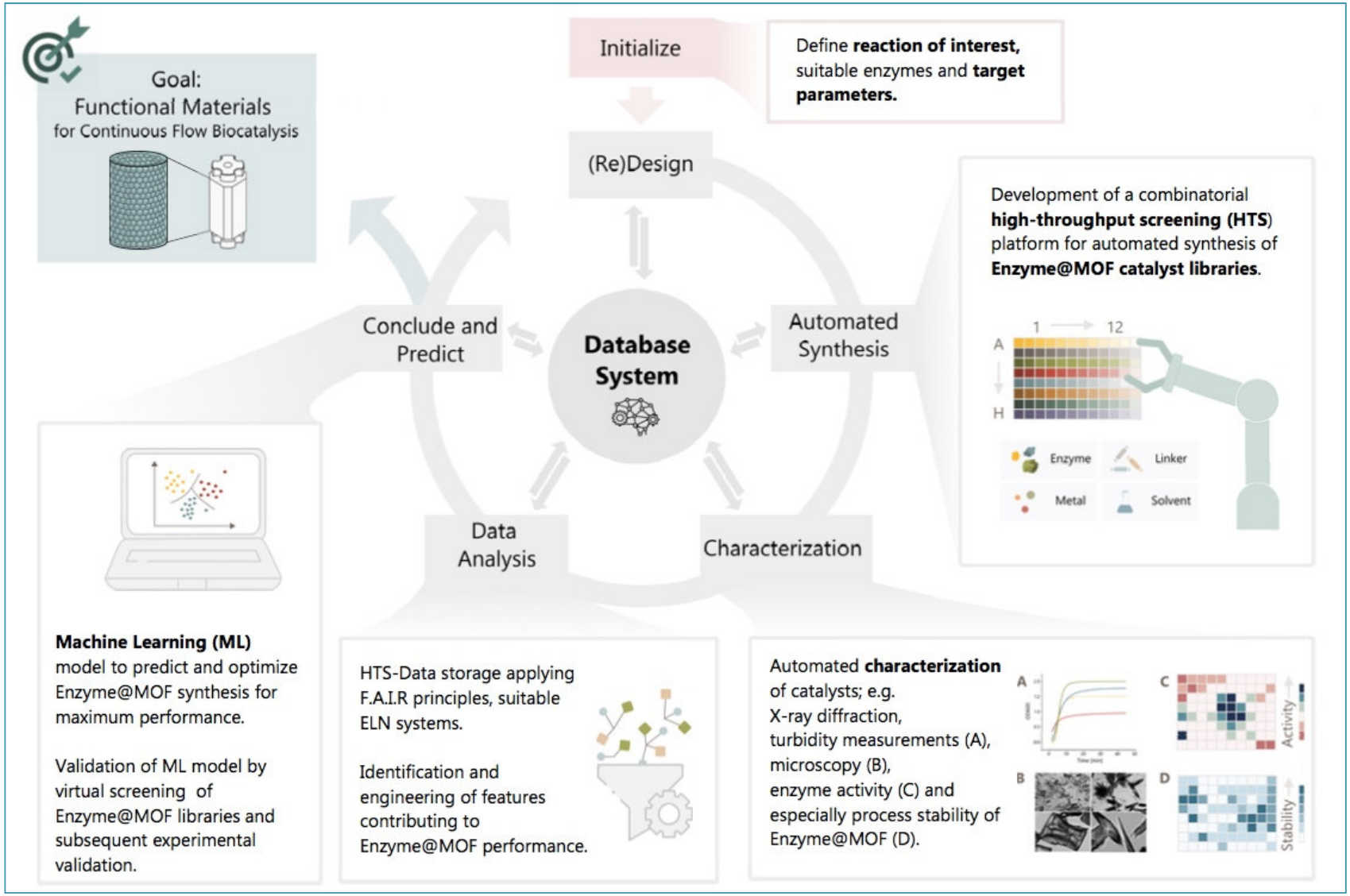




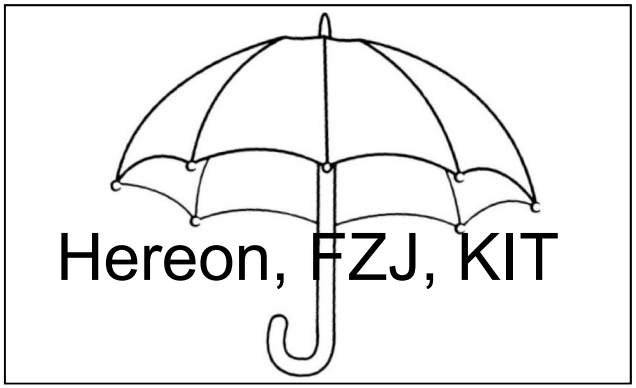
Greifenstein et al., ACIE **2022**, e202117144

- Combinatorial high-throughput screening (HTS) platform for automated synthesis
- Automated characterization (e.g. X-ray diffraction, turbidity, UV/vis, microscopy, enzyme activity, process stability
- HTS-Data storage applying ELN systems & F.A.I.R principles
- Machine Learning (ML) to optimize and predict Enzyme@MOF performance

Pipeline


Goal:
Functional Materials
for Continuous Flow Biocatalysis
Initialize
Define **reaction of interest,** suitable enzymes and **target parameters.**
(Re)Design
Development of a combinatorial **high-throughput screening (HTS)** platform for automated synthesis of **Enzyme@MOF catalyst libraries.**
1
12
A
H
Enzyme
Linker
Metal
Solvent
Automated Synthesis
Characterization
Data Analysis
Conclude and Predict
Database System
Machine Learning (ML) model to predict and optimize Enzyme@MOF synthesis for maximum performance.
Validation of ML model by virtual screening of Enzyme@MOF libraries and subsequent experimental validation.
HTS-Data storage applying F.A.I.R principles, suitable ELN systems.
Identification and engineering of features contributing to Enzyme@MOF performance.
Automated **characterization** of catalysts; e.g. X-ray diffraction, turbidity measurements (A), microscopy (B), enzyme activity (C) and especially process stability of Enzyme@MOF (D).
A
B
C
D
Activity
Stability

Wrap-up



- **Instructive Materials and Devices for Red and White Biotechnologies**

- Bio-instructive materials for health- & production-technologies (biocatalysis, implants, medical devices…)
- Includes structural and molecular biology, microbiology, biohybrid materials
- R&D in White Biotech is at the heart of "Information“

Focus @ KIT

- KIT Health Technologies (Lecture Ute Schepers)
- White (industrial) Biotechology
- Materials for Chemical Production Processes
- Materials for Bioremedation
- Materials & Innovation for Sustainable Agriculture

SDGs


1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS