MICRO4 BIOGAS

Task 7.5 - Professional training

Module 2

2.5 Scale-up of bioaugmentation

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Participants: DARWIN

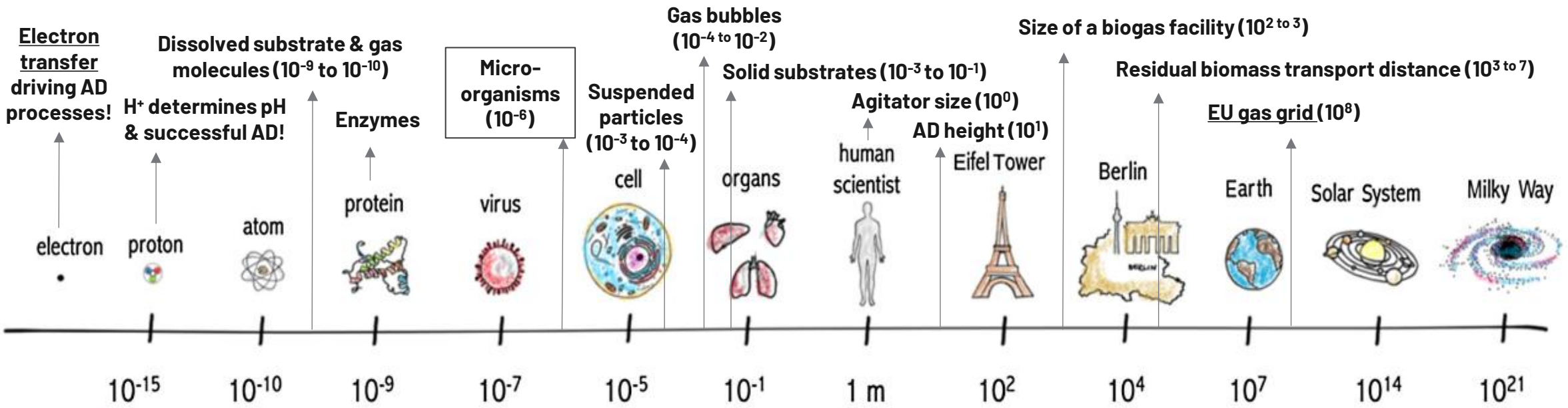
University of Valencia, UVEG

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement **No 101000470**

❑ Anaerobic digestion across scales

- **All scales imaginable are involved in AD, from small to big.**

→ Which are the scales that are relevant to your scale-up project?



Scales relevant to the anaerobic digestion sector → 23 orders of magnitude!

Typical scales subject to AD scale-up studies: 'only' 7 orders of magnitude…

Figure adapted from DOI: 10.1103/PhysRevLett.132.090001

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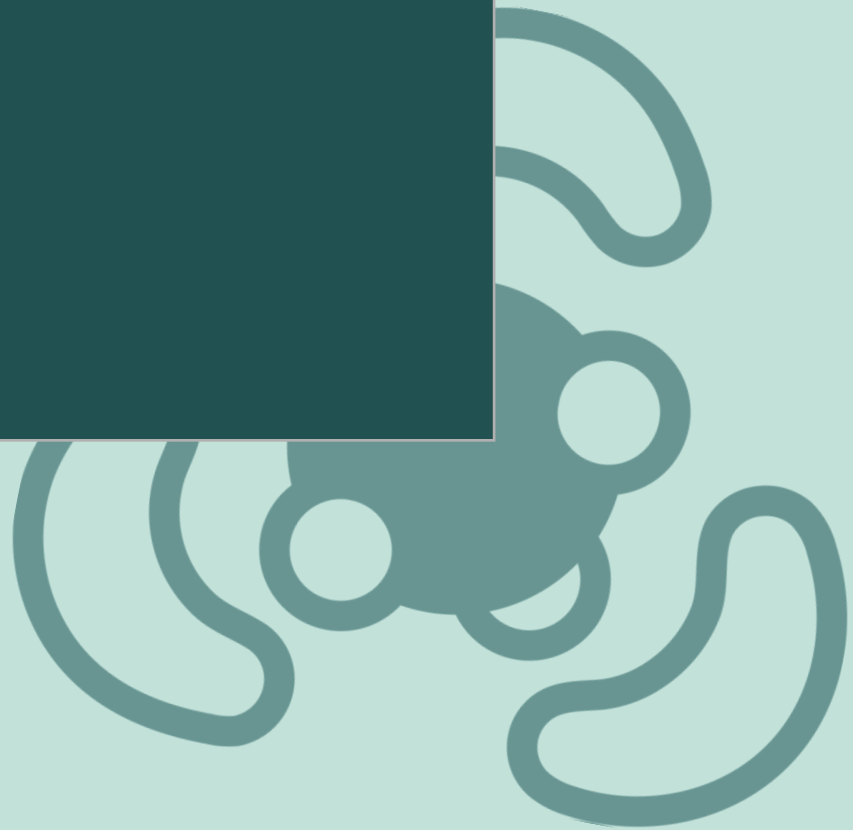
Learning goals

Scale-up of bioaugmentation

- ❑ What is scale-up?
- ❑ Why is it important?
- ❑ How is scale-up done?
- ❑ What are the specifics for bioaugmentation?



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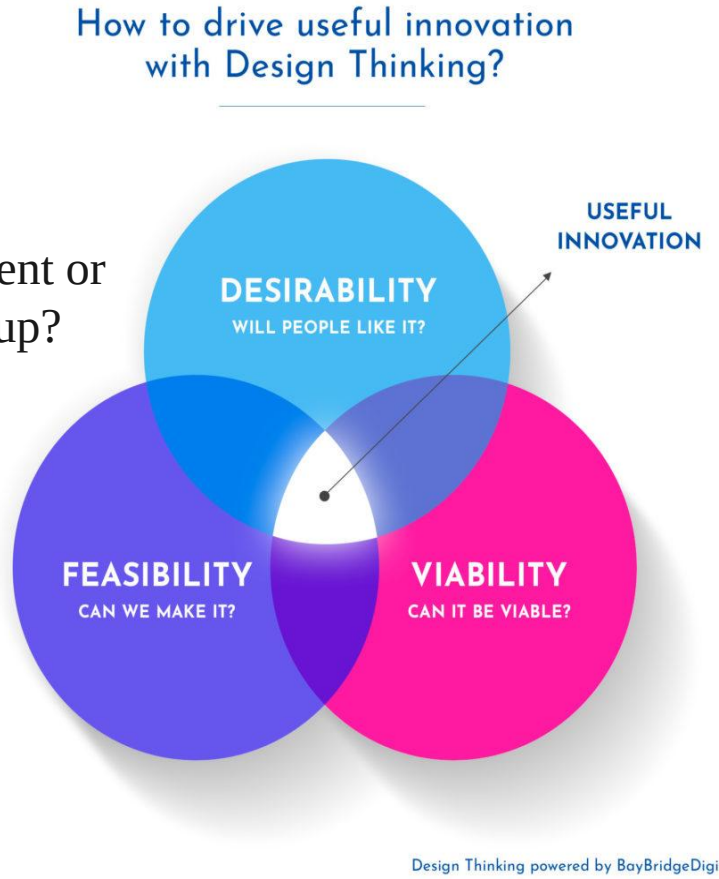
❑ Design thinking framework

- **Scale-up can be costly and time-consuming.**

→ Does the innovation have sufficient potential to become successful?

Is there actually a need (current or future) to put effort in scale-up?

This is the typical focus of technical scale-up activities



- Is there sufficient reason to invest time and money in scale-up?
- How are desirability and viability impacting your product design?
- If so, how are they changing the scope of your scale-up activities?

In case successful, can it be affordable?

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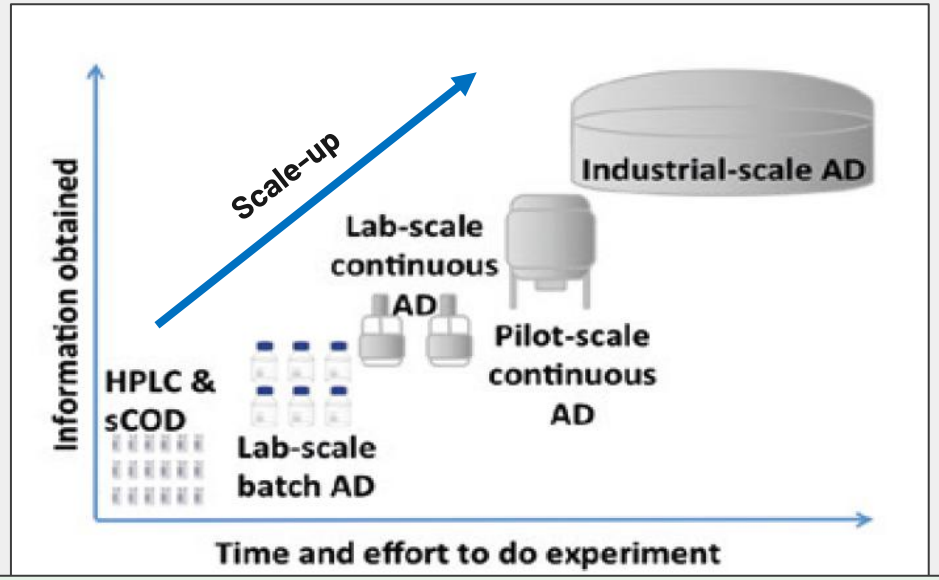
❑ From laboratory to industry

- **The various stages of scale-up.**

→ Which insight do you need to get next?

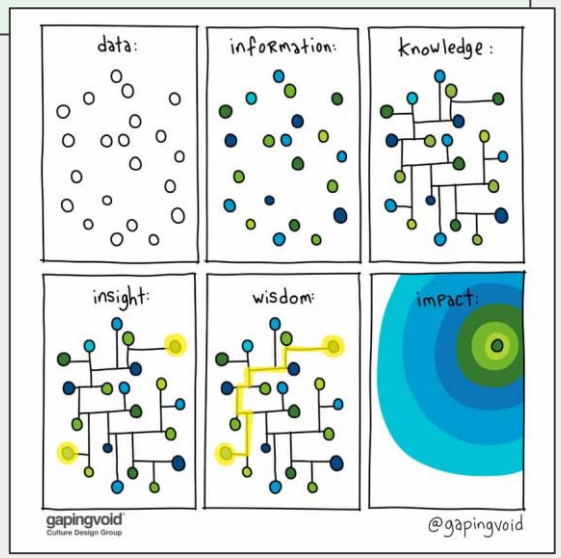


Objective to advance the process from concept towards practice

- Validate working principles across scales
- Advance the development and design
- Determine critical control parameters

→ Improved understanding & reduced risk

→ Towards successful application & sustainable impact!



Important aspects of scale-up:

- Mode: Batch → Continuous
- Scale: 0,03L → 3.000m3 (factor of 10^8!!!)
- Setting: Lab → Pilot → Industry
- Experiments: High-throughput screening → multiple scale-up tests → few validation runs

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Figure adapted from: http://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/pretreatment_web.pdf

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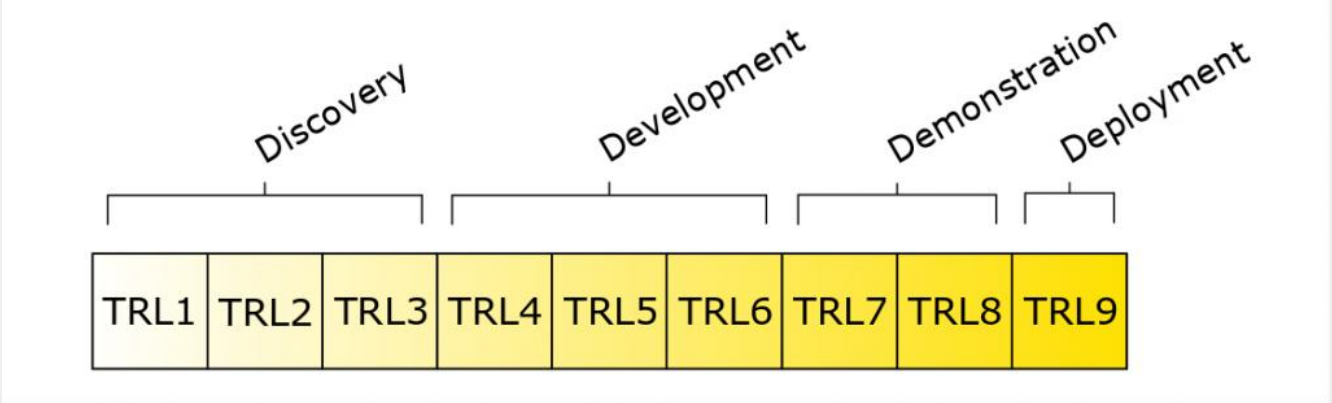
❑ Technical Readiness Level

- **The various stages of scale-up.**

→ Which stage are you now? And where to go?



Technology Readiness Levels in the European Commission (EC)[5]

Technology Readiness Level	Description
TRL 1.	basic principles observed
TRL 2.	technology concept formulated
TRL 3.	experimental proof of concept
TRL 4.	technology validated in lab
TRL 5.	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6.	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7.	system prototype demonstration in operational environment
TRL 8.	system complete and qualified
TRL 9.	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

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EU TRL levels h2020-wp1820-annex-g-trl_en.pdf

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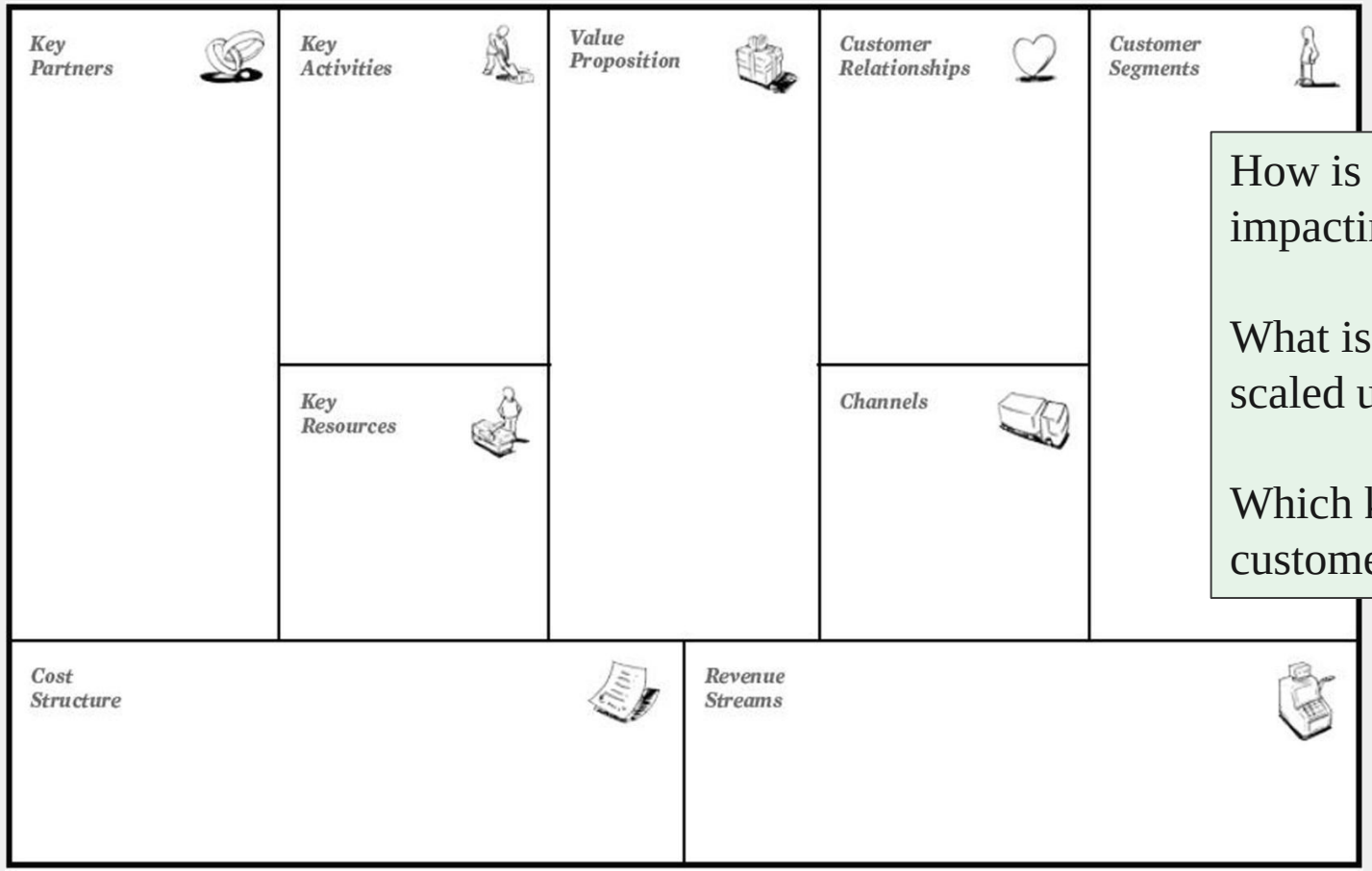
❑ Business model canvas

- **Assuming the technical scale-up will be successful.**

→ Which stakeholders need to be involved in the scale-up process?



How is the business model canvas impacting your scale-up activities?

What is the value proposition to be scaled up?

Which key partners (suppliers, lead-customers) need to be involved?

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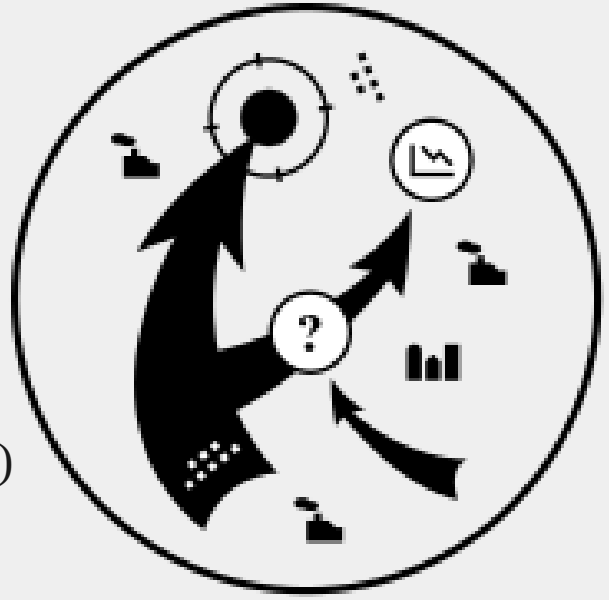
❑ Important scale-up metrics

- **A list of important attention points (non-comprehensive).**

→ be sure to define the key inputs & outputs as first step in the scale-up!

Prerequisites:

- Defined working principle (first principles)
- Key performance indicators identified (speed, yield, robustness)
- Objectives & success criteria established (target & minimum)



Preparation:

- List of key unknowns (questions to be answered)
- Planning of scale-up activities (including key resources needed)
- Test & monitoring plan (key inputs & outputs, sampling → proper controls)
- Mitigation plan (addressing key issues and risks)

Objectives / outputs:

- Improved understanding: functional benefits reproducible & validated across scales (small, medium, large)
- Development advanced: from lab environment to pilot & industry relevant environment
- Design advanced: from blueprint product, to mock-ups, to initial prototypes to final version for application
- Protocols established and validated.

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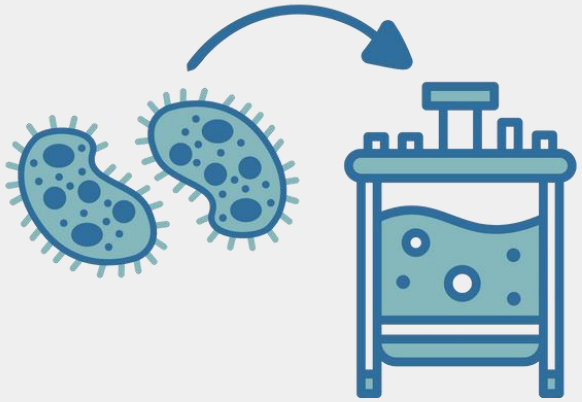
❑ Bioaugmentation strategies

- **Various bioaugmentation strategies were defined in Micro4Biogas.**
- **Each strategy having its own characteristics.**

→ Scale-up activities are specific for each strategy.

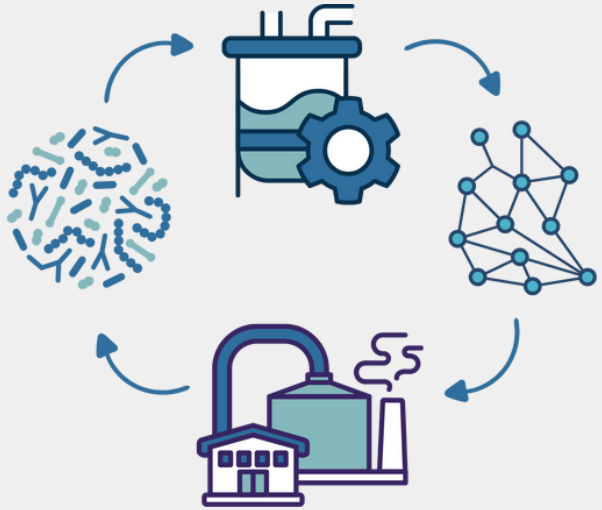
1. Additive

Single-strain or mixed-strains additives



2. Technology

On-site enrichment of microbial consortia



3. Service

Inter-site full microbiome transplantation

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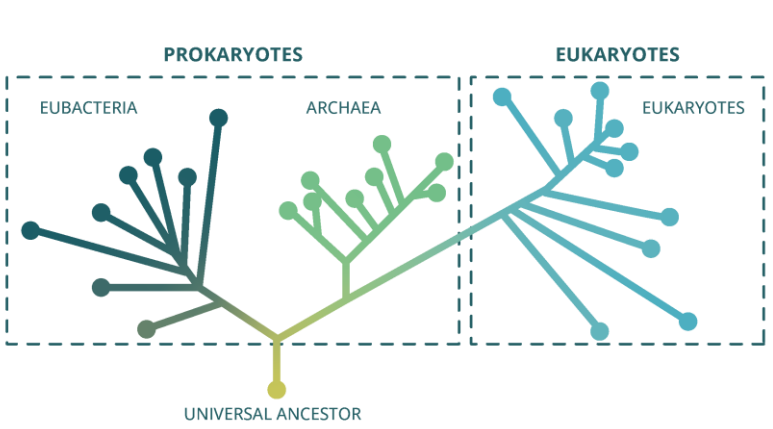
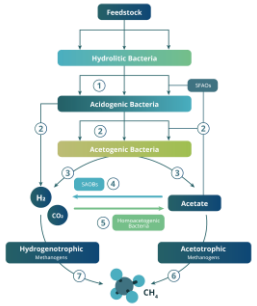
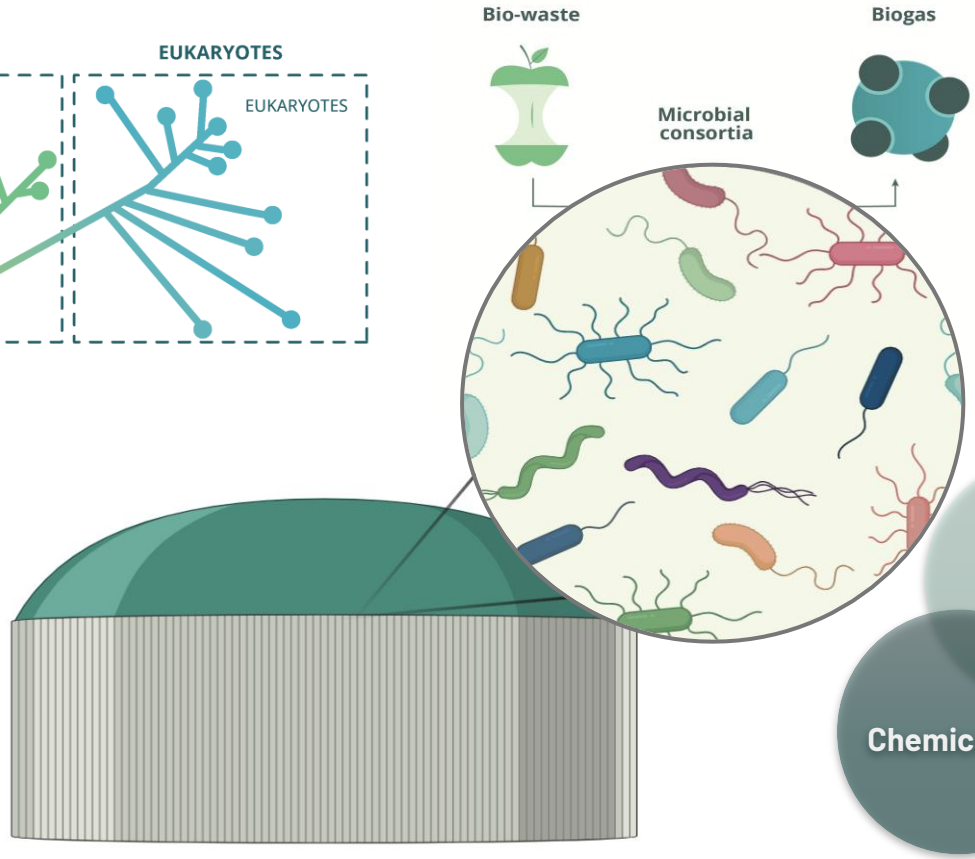
❑ Microbiome identification @ the core of validation

- **Traditional AD scale-up is based on monitoring physico-chemical parameters.**
- **Micro4Biogas now added biological parameters via the 'microbiome' approach.**

→ By adding taxonomy monitoring (abundance, diversity, species) to scale-up activities, a direct measure for validating bioaugmentation strategies becomes available!

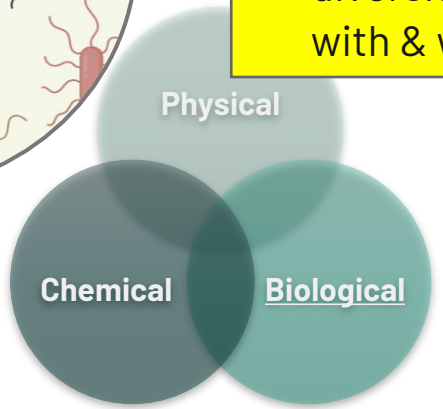






Top-tips from practice:

- Preferred validation setting has an identical reference digester & biogas measurement on each tank.
- Take your time to establish a baseline, rather than rushing the experiment.
- During validation, put emphasis on tracking the microbiome (abundance, diversity, functionality, key-species) with & without bioaugmentation!



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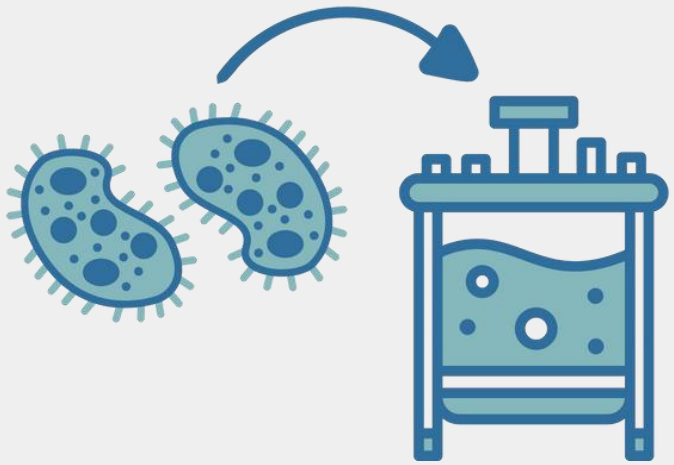
❑ Strategy 1 – scale-up of microbial additives

- **Pure cultures or a mixture of various strains sourced externally.**

Microbial additive products based on single-strains or mixed-strains boosting AD



Key aspects:

1) Design & develop optimum additive proposition:

- Strains & mixtures (safe, effective & scalable)
- Product type (lyophilized, spores, cooled, ..)
- Cultivation & downstream processing protocols
- Quality control protocol, storage & handling protocols
- Protocol for addition to digester (amount, frequency, ..)

2) Scale-up to validate the proposition:

- Scale-up of strain production is feasible (lab → pilot plant → full-scale)
- Positive impact of strains on AD is reproducible and meets KPI (batch screening, continuous validation, mesophilic / thermophilic, various digestates, various feedstocks, various scale including product from pilot production successfully tested in full-scale operational environment)
- All supply-chain aspects are tackled (regulatory, safety, viability, stability, shelf-life, storage conditions, quality control, key partners)
- Full-scale testing & validation complete.

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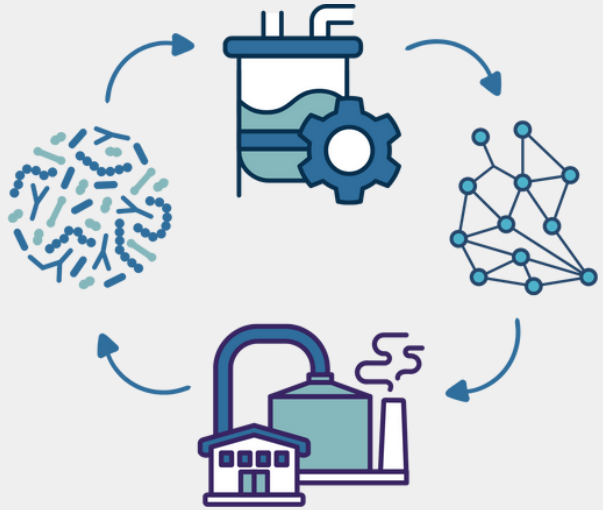
❑ Strategy 2 – scale-up of enriched consortia

- **Enrichment cultures with specific functionality produced on-site.**

Enriched microbial consortia having specific functionality boosting AD processes



Key aspects:

1) Design & develop optimum enrichment proposition:

- Define enrichment protocols (inoculum, nutrient medium, process conditions, cycle time, quality control, ..).
- Validate output composition (abundance, diversity, key species and functionality, viability, reproducibility of protocol, …).
- Design and operation of prototype bioreactor
- Protocol for addition to digester (amount, frequency, ..)

2) Scale-up to validate the proposition:

- Reproducibility of enrichment protocols across scales validated
- Bioreactor design successfully scaled-up, output meeting criteria
- Positive impact of enrichment on AD is reproducible and meets KPI (batch screening, continuous validation, mesophilic / thermophilic, various digestates, various feedstocks, various scales)
- Full-scale testing & validation complete (product from full-scale enrichments successfully tested in full-scale operational environment)

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❑ Strategy 3 - scale-up of transplantation

- **Inter-site distribution of fully functional microbiomes.**

Inter-site transplantation of full AD microbiomes for fast recovery of compromised processes

Key aspects:

1) <u>Develop optimum transplantation proposition:</u>
   - Define protocols (when applicable?, type & amounts needed for transplantation, quality control of transplant, monitoring of transplantation success)
   - Include regulatory aspects (no cross-border transport of digestate, not possible to mix waste with fertilizer, not possible to mix manure with plant-based digesters)
   - Validate protocols in lab-based (batch) and pilot-plant (continuous) test settings on various compromised digestates with various feedstocks.

<u>2) Scale-up to validate the proposition:</u>
   - Straight to full-scale testing & validation (preferred setting has a reference digester & biogas measurement on each tank)
   - Special focus to tracking of microbiome with & without transplant (abundance, diversity, functionality, key-species)
   - Define optimum sources (EU AD microbiome map, big-data)

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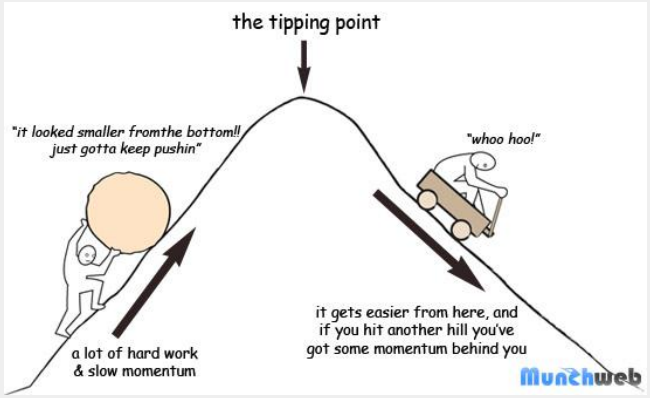
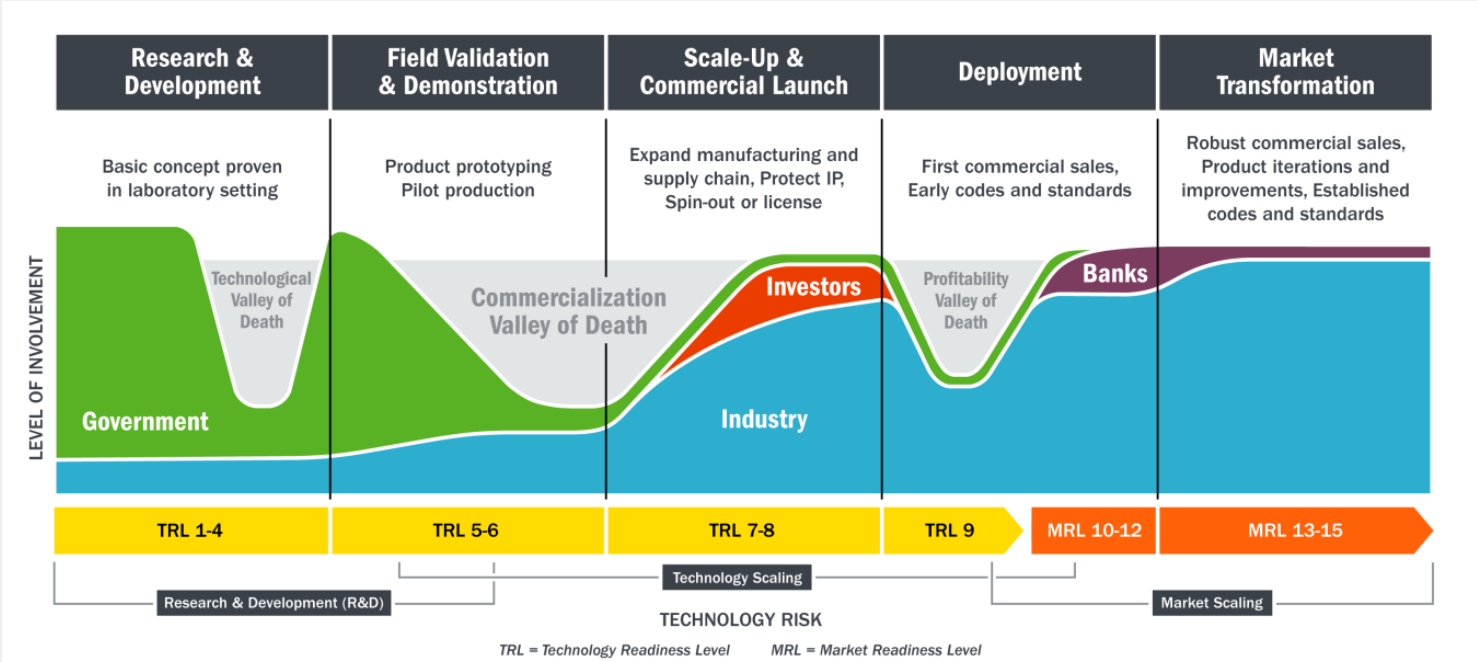
❑ Some final advice

- **Scale-up is a lot of hard work & there will be many setbacks…**

→Don't be discouraged and remember to also enjoy the process!





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❑ Further reading

- **Some suggestions for further reading.**
- **Putting focus on defining the right approach for your scale-up activities.**

→ Please don't not forget to talk with experts!

- Introduction to scale-up approach for biogas (pre-treatment example case-study) http://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/pretreatment_web.pdf
- Introduction to Technical Readiness Levels as key metric for development stage and project funding: https://en.wikipedia.org/wiki/Technology_readiness_level
- Overview of steps in bringing new technologies to market by the US department of energy https://www.energy.gov/eere/buildings/technology-market including the typical funders per development stage
- Clayton Christensen 'the innovators solution' a 2003 book on innovation types (sustaining, transformational, disruptive) creating and sustaining succesful growth of businesses
- Gartner hype cycle distinguishing typical phases encountered during the development and maturation of new technologies: https://en.wikipedia.org/wiki/Gartner_hype_cycle
- Blog on design thinking. How to focus on core product benefits and on how to continuously iterate in the design and development process https://simplyvoyce.com/blog/tackling-product-feature-bloat-with-design-thinking

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Scale-up of bioaugmentation

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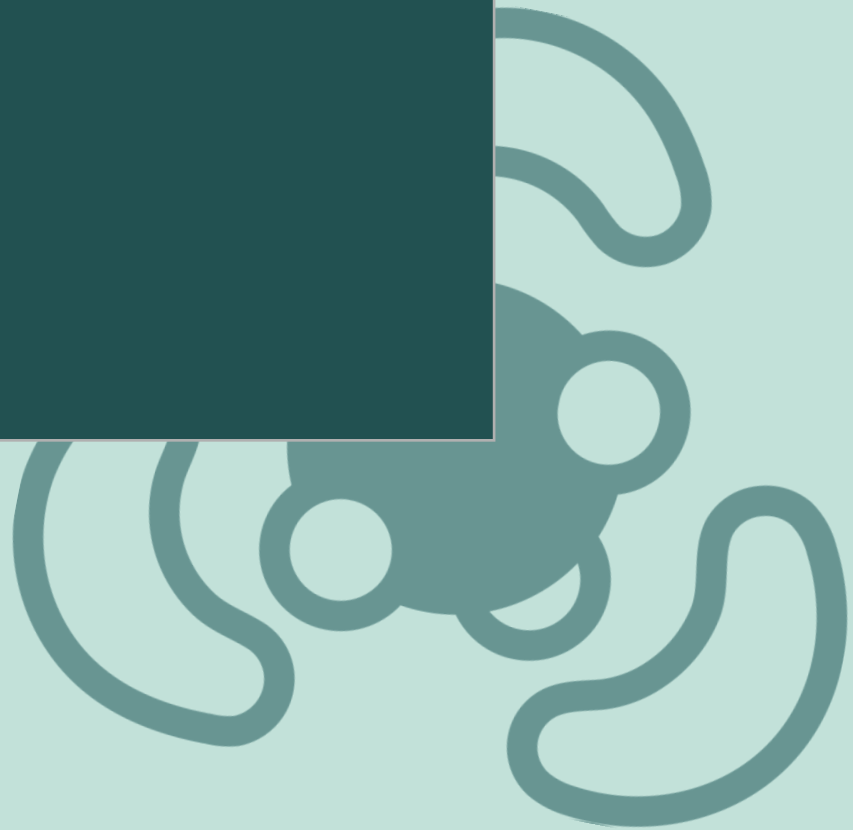

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