

# Formulation and Processing: Manufacturability

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# What is formulation?

- ❑ Chemical composition the same
- ❑ Microstructure controls delivery
- ❑ Common across industry sectors



# Matrix of skills and industry sectors

	Food, Health and Nutrition	Bioindustries	Home and Personal Care, Pharma	Energy and Chemical Industries
Structured Liquids	Gels and creams	Fermentation broths	Shampoos and creams	Supercritical fluid techniques, paints
Soft Solids	Spreads, emulsions and confectionery	Soft tissue engineering	Crystals, creams and foams	Paints and coatings
Structured Solids	Breads and starch products	Hard tissue engineering	Tablets and capsules	Fuel cells and catalysts: control of interface and structure
Particulate materials	Grains	Separation and delivery systems	Granules and powders	Fuel cells and catalysts



# Formulation CDT



**PEPSICO**



Johnson Matthey



Unilever

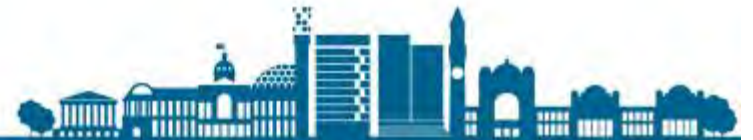


**P&G**



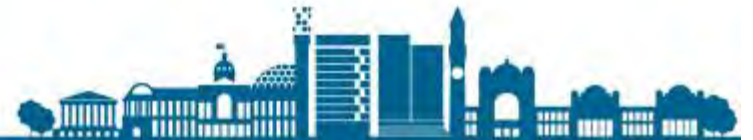
# Processing and formulation

- First understand the sequence of events in processes
- To build new processes that are inherently more efficient – what are the boundary conditions set by the physics, the biology, and the consumer?
- Do you understand the process? The equipment? The usage?



# Manufacturability

- First understand the sequence of events in processes
- Can you scale it up? No: *really*.
- Do you understand the process?
- Can you make it
  - Efficiently
  - To cost
  - Sustainably

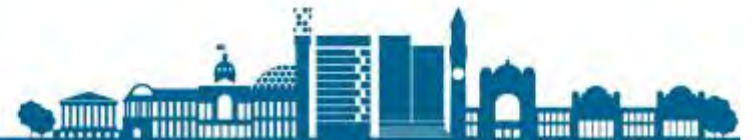


# Can you scale it up?



## Constraints:

- Microbial
- Quality
- Cost



# Need to save water (=heat) ...

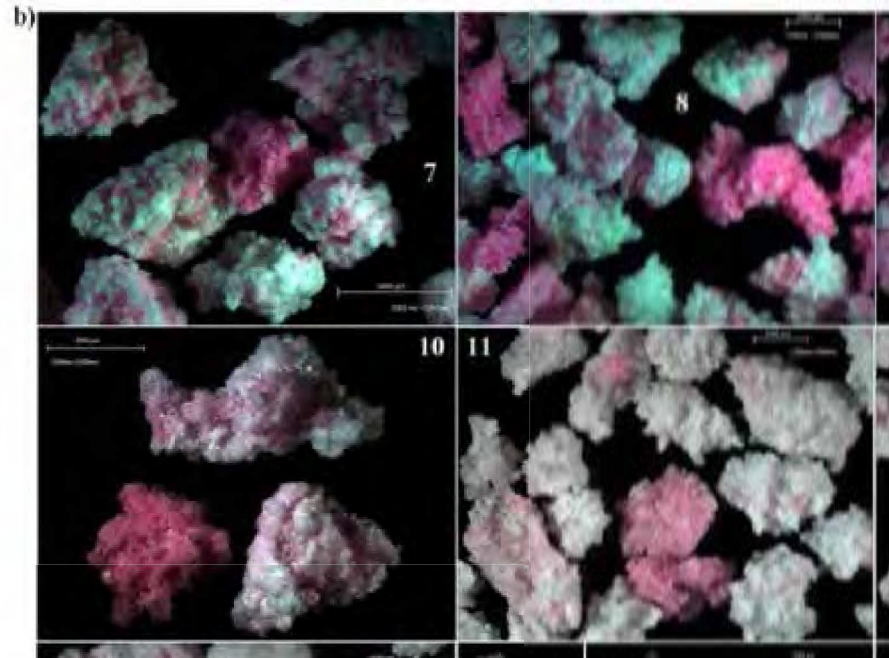
- Final structure controls disssolution
- Constraint on drying method
- But all water added has to be evaporated



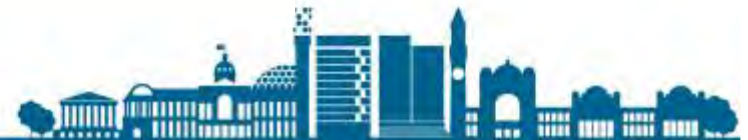


# Scale up: spray drying

- Everything structured in the tower, right?
- So paint the wall layer
- And count the coloured particles that come out...

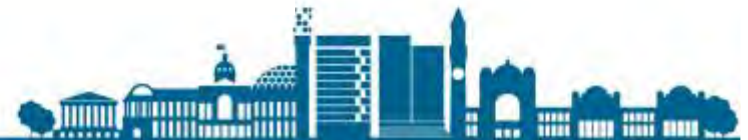
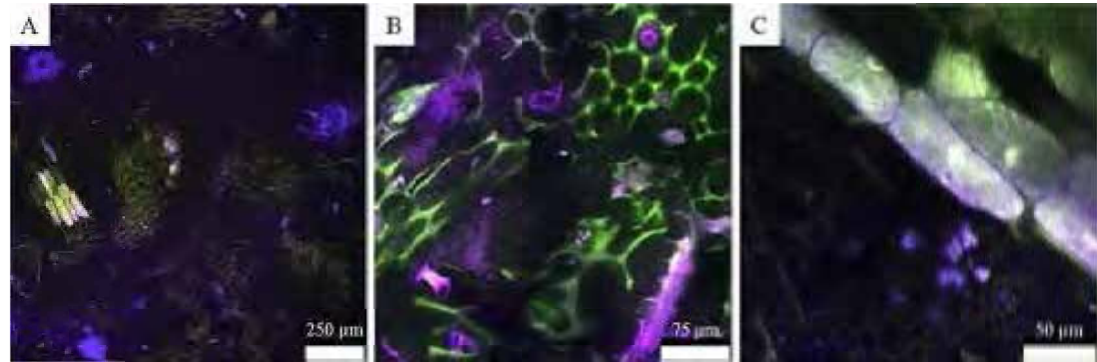
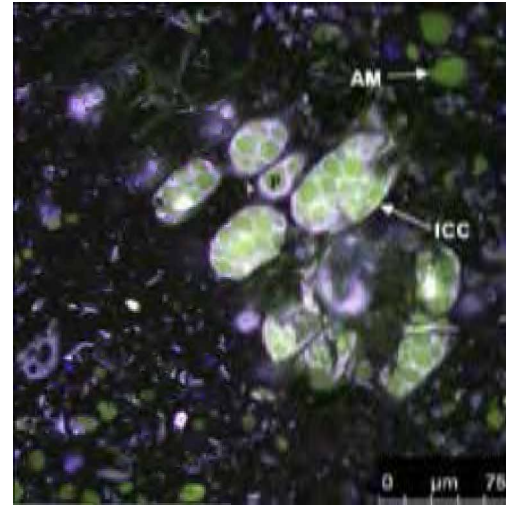


*AIChE J*, 61: 1804–1821, 2015

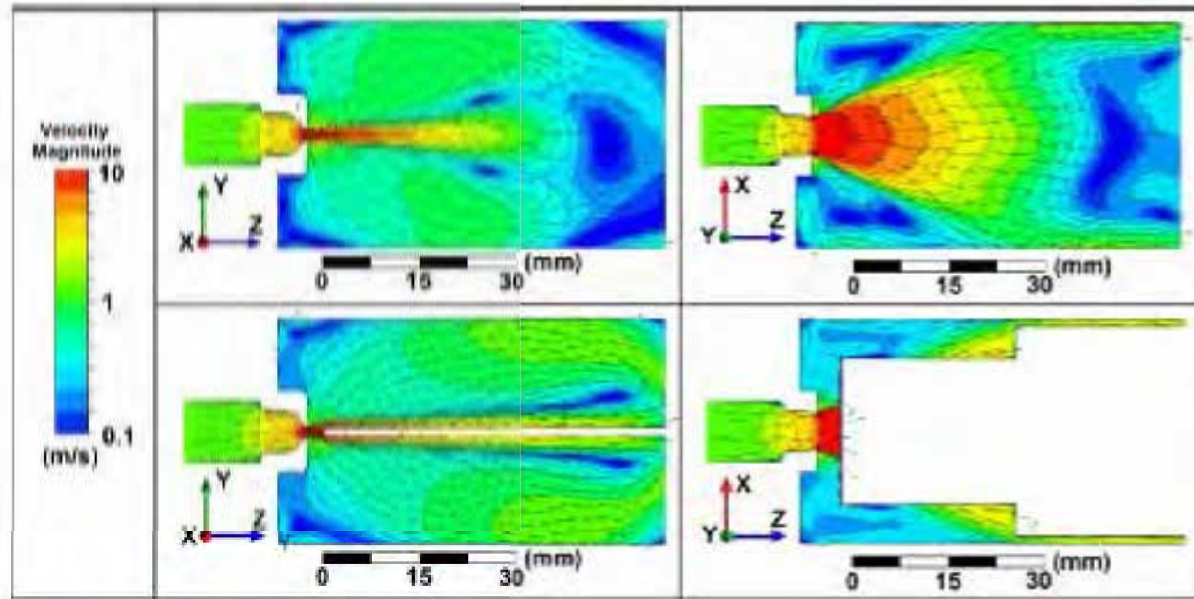


# Scale up: grinding, ultrasound

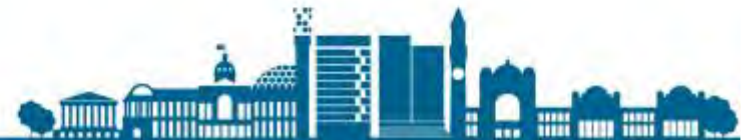
- Ultrasound proposed as process intensification
- Works at lab but not pilot scale...



# Understand the equipment: liquid whistles

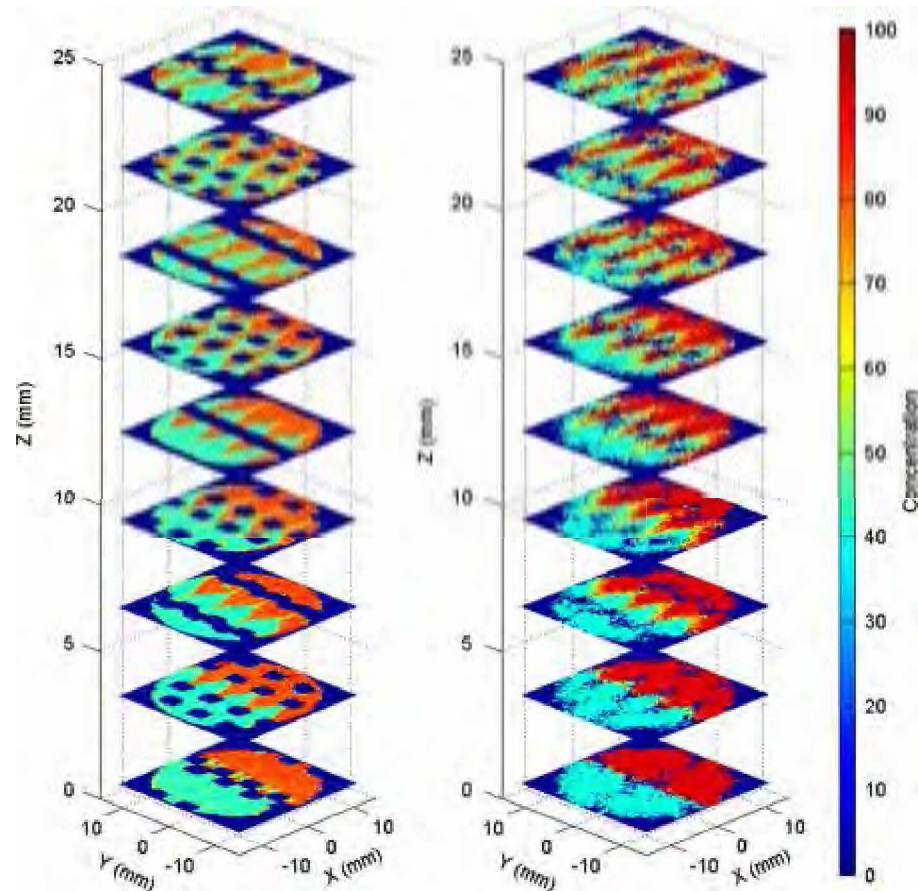


*D.J. Ryan et al / Chemical Engineering Science 163 (2017) 123–136*



# Understand equipment: static mixers

- PEPT follows individual particle paths
- MRI measures concentration of doping agent
- Do they agree?...

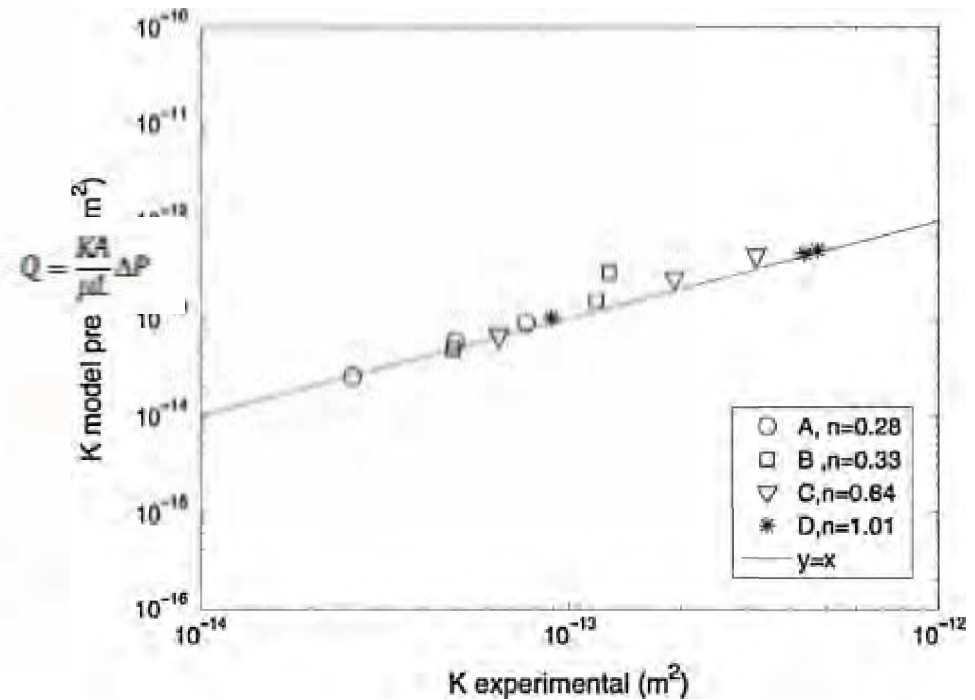


*O. Mihailova et al. / Chemical Engineering Science 137 (2015) 1014–1023*



# Understand the equipment

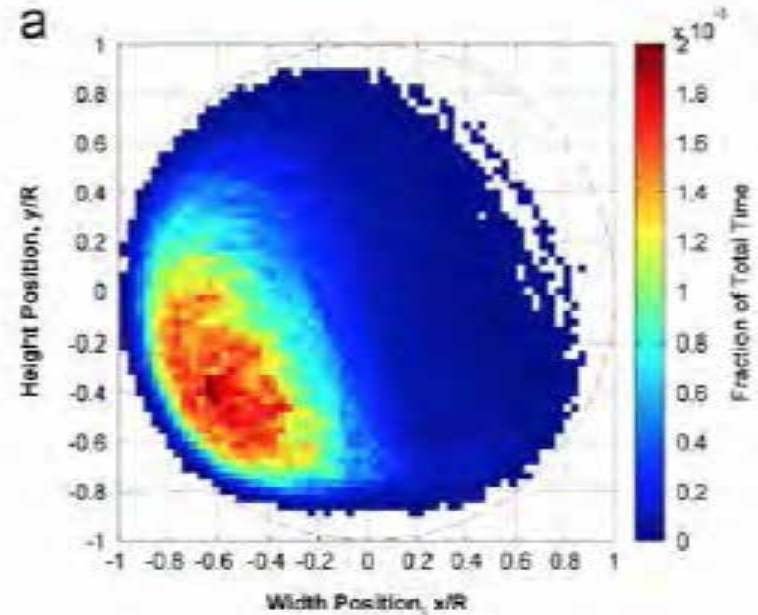
$$Q = \frac{KA}{\mu L} \Delta P$$



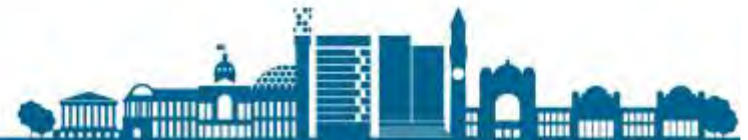
J.Food Eng., 150, 106-116, 2015



# Understand the equipment

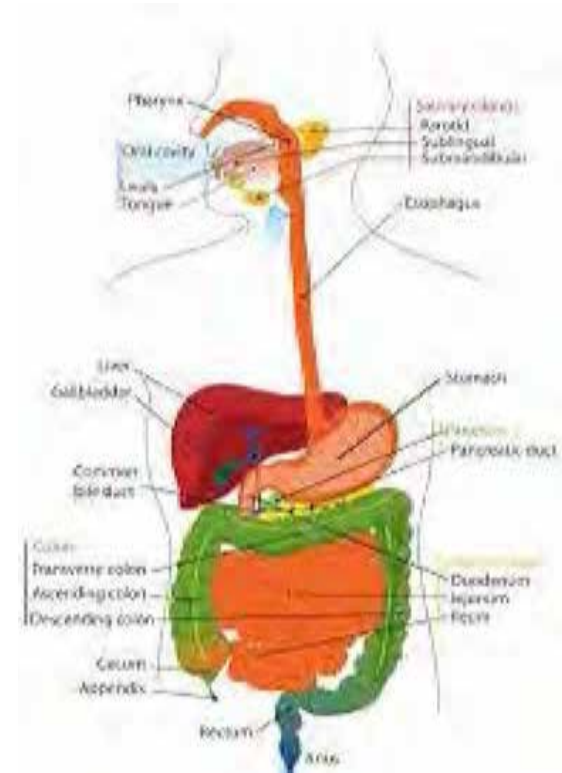


*C. Mac Namara et al. / Chemical Engineering Science 75 (2012) 14–27*



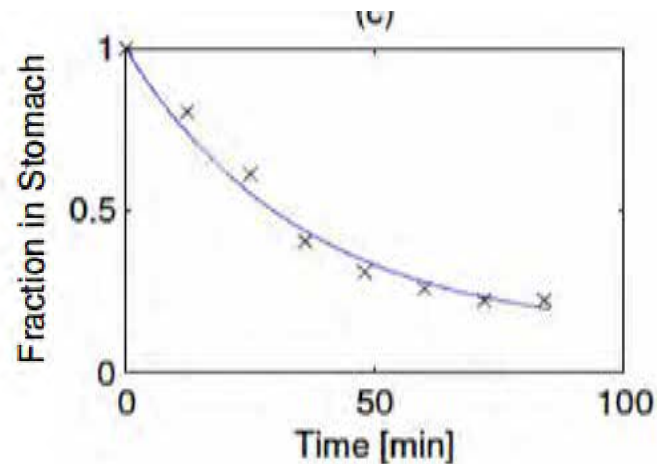
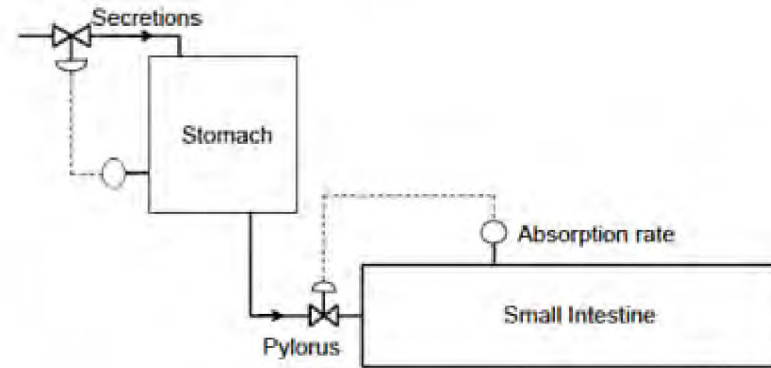
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- Dry food is hydrated and acidified
- Then mixed and reacted
- Water is then removed...



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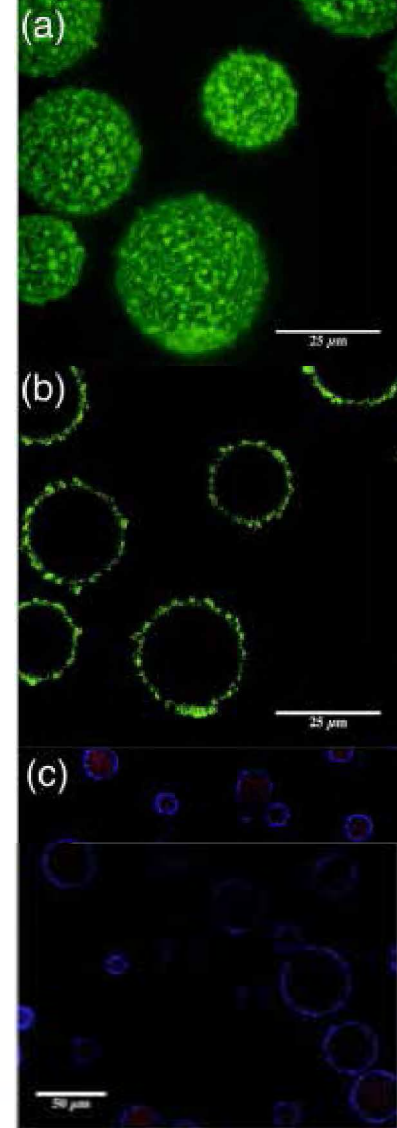




# Make new structures

- Fluid gels for encapsulation
- Whey protein encapsulating fat
- New delivery
- Applicable to pharma, foods, HPC

*RSC Adv.*, 2015, **5**, 60786-60795

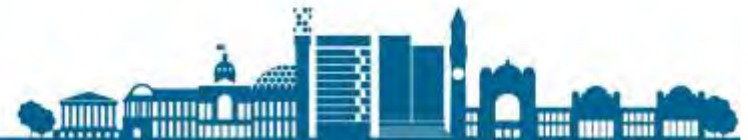


# Stop new structures

- ❑ Heterotopic ossification (HO)
- ❑ Dissolve hydroxyapatite
- ❑ New delivery
- ❑ This is inverse dentistry



Eisenstein N, Stapley SA and Grover LM (2016). A novel treatment strategy in preventing and treating heterotopic ossification. *Front. Bioeng. Biotechnol. Conference Abstract: 10th World Biomaterials Congress*. doi: 10.3389/conf.FBIOE.2016.01.01939



# Manufacturability

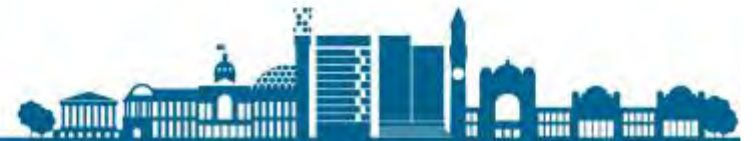
- How do we make sustainable supply chains?
- Minimise transport costs?
- New sustainable feedstocks
- Distributed manufacture
- Where is waste in process and after?



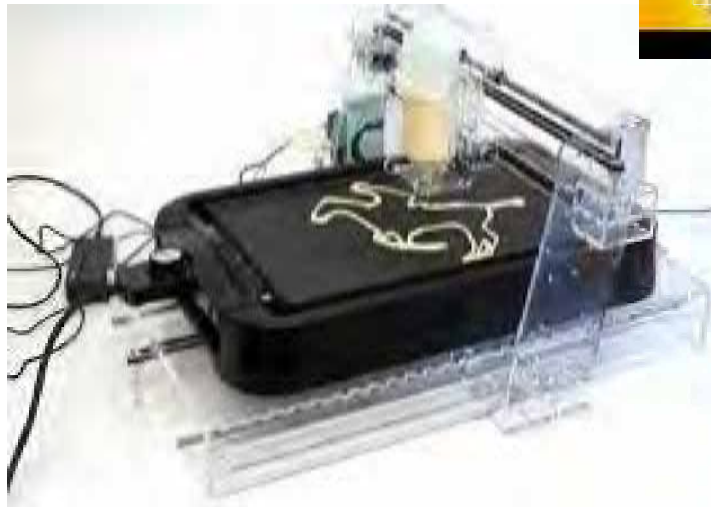
# Formulate replacements



# Local and global manufacture

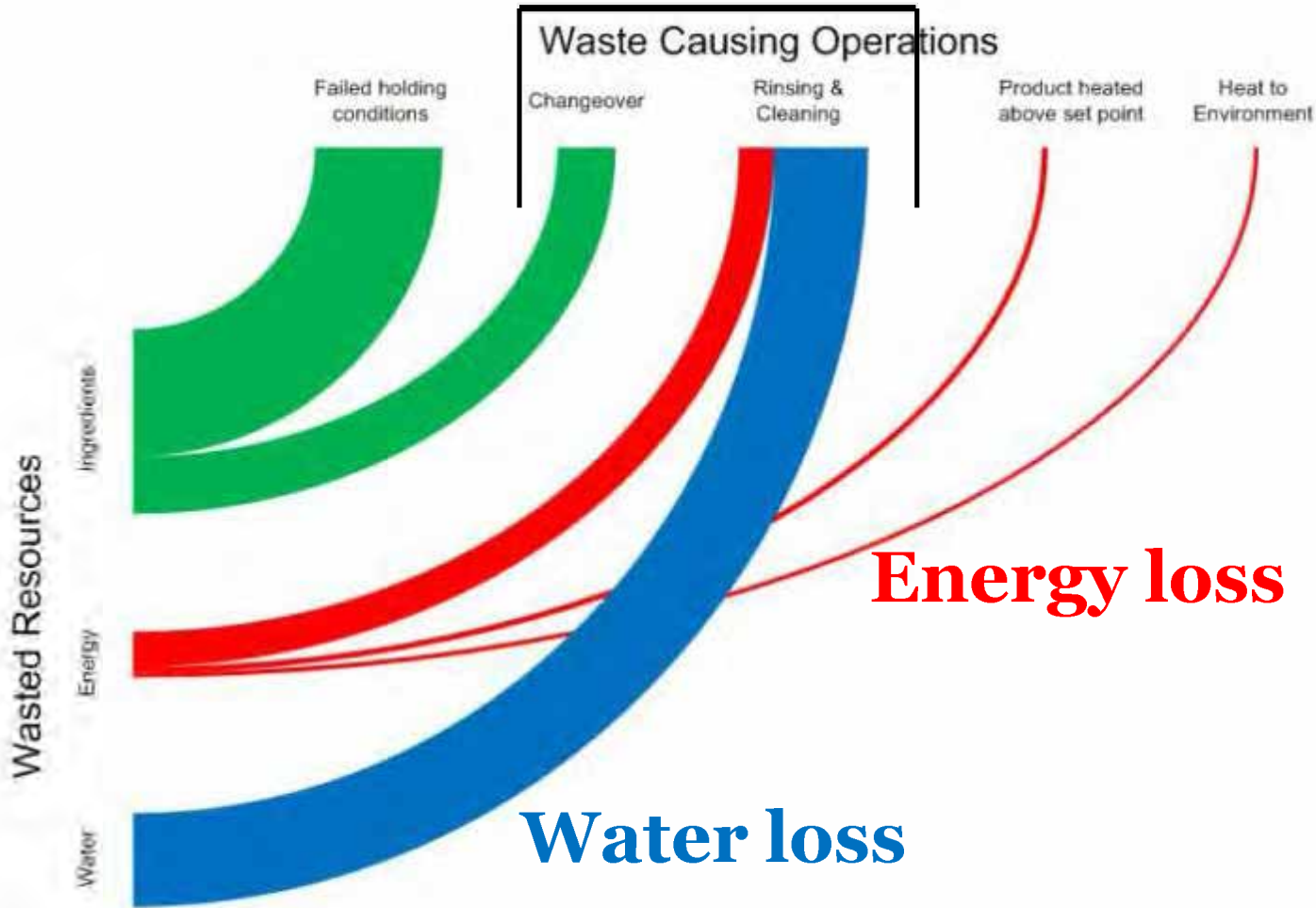


# Local and global manufacture



# What do you waste?

**Changeover and cleaning**



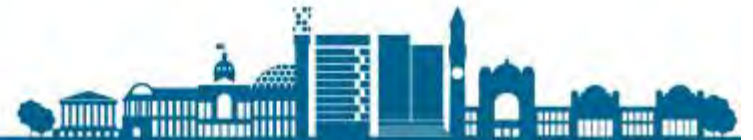
**Energy loss**

**Water loss**



# How does cleaning work?

- Everyone does it... nobody knows how
- Tend to be two problems:
  - Product recovery: at the end of a run, the plant is full of product;
  - Cleaning: at the end of product recovery, there is still stuff to remove
- Efficient measures of cleaning time at plant scales
- To know what *not to do*...





# Cleaning with an impinging jet

8mm thick  
deposit of  
Carbopol®  
solution

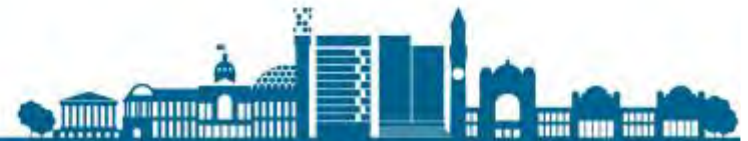


$1000 \text{ ml min}^{-1}$   
 $16.7 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$



$1500 \text{ ml min}^{-1}$   
 $25.0 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$

COFE: Ohio State, Sept 2016



3 seconds later

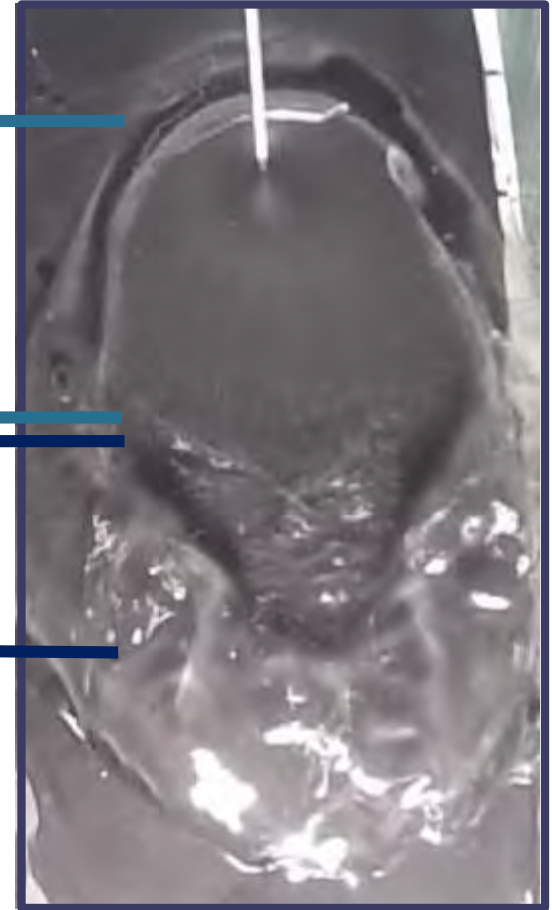
1000 ml min<sup>-1</sup>



Adhesive  
cleaning

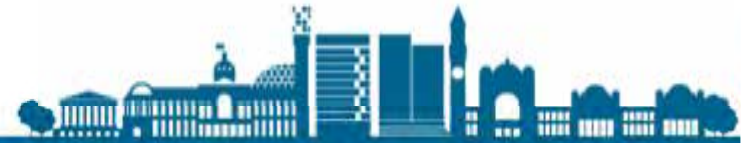
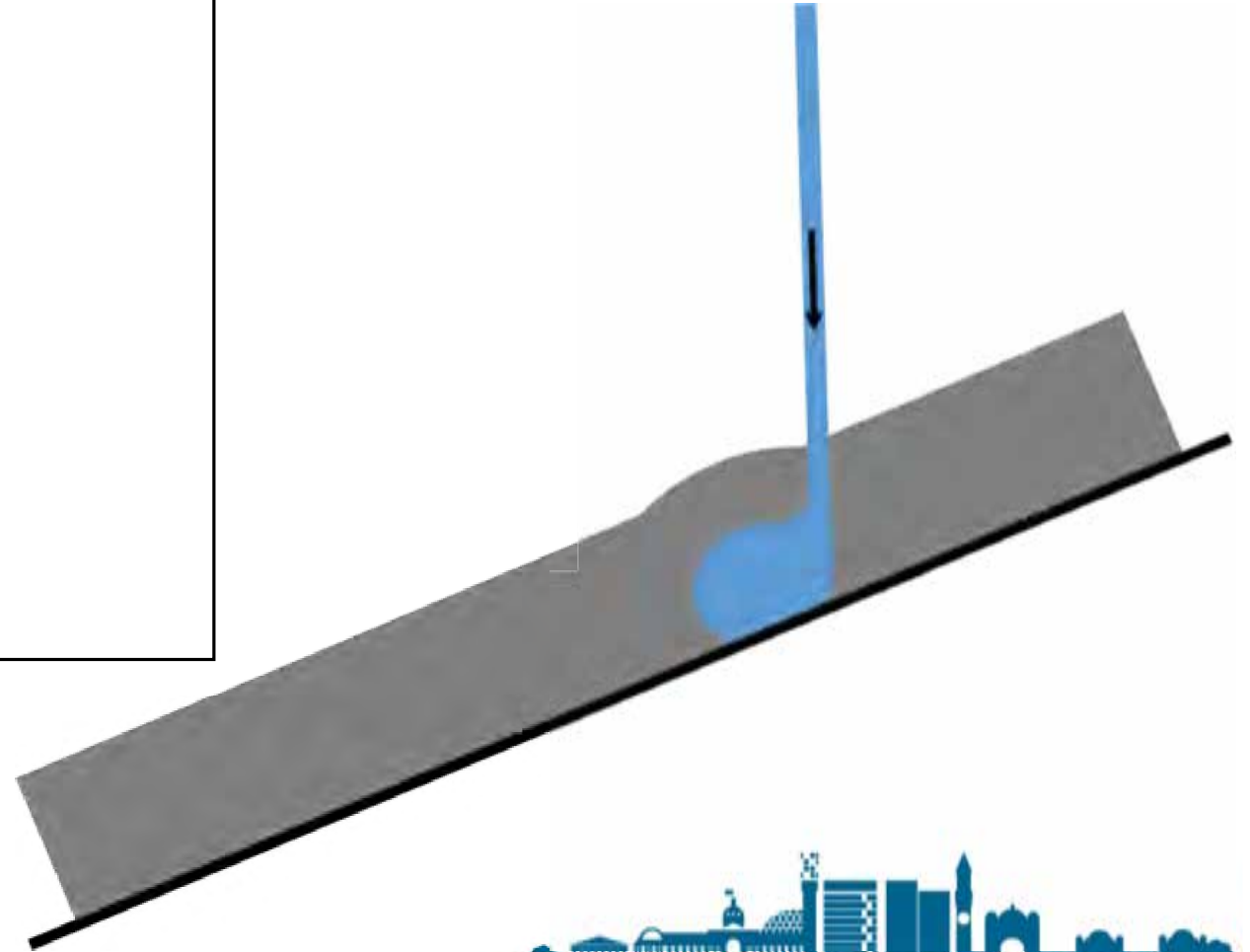
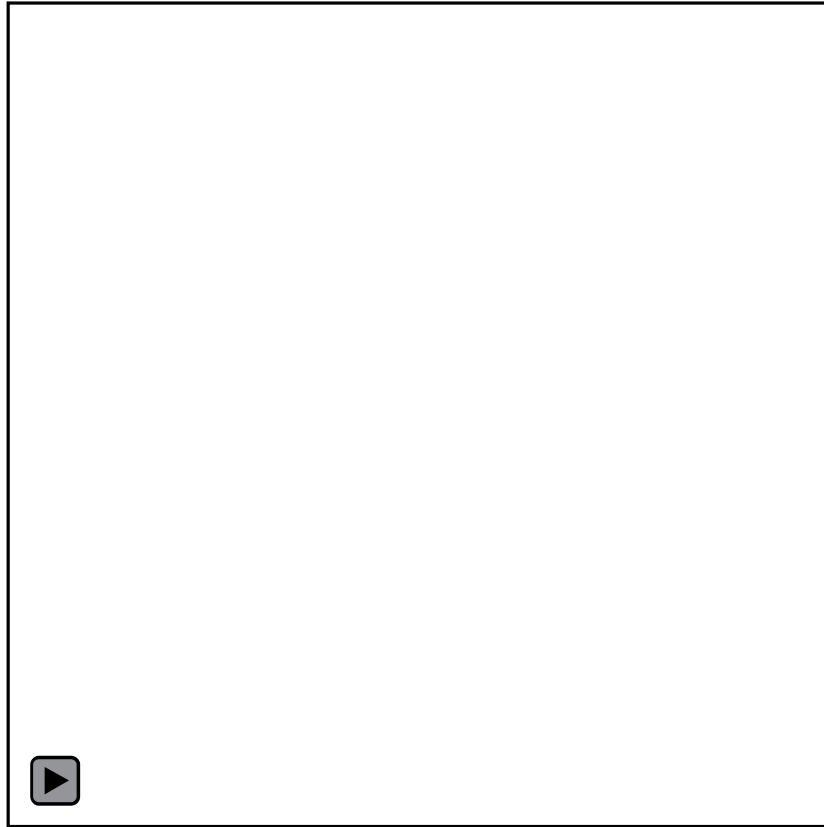
Cohesive  
cleaning

1500 ml min<sup>-1</sup>

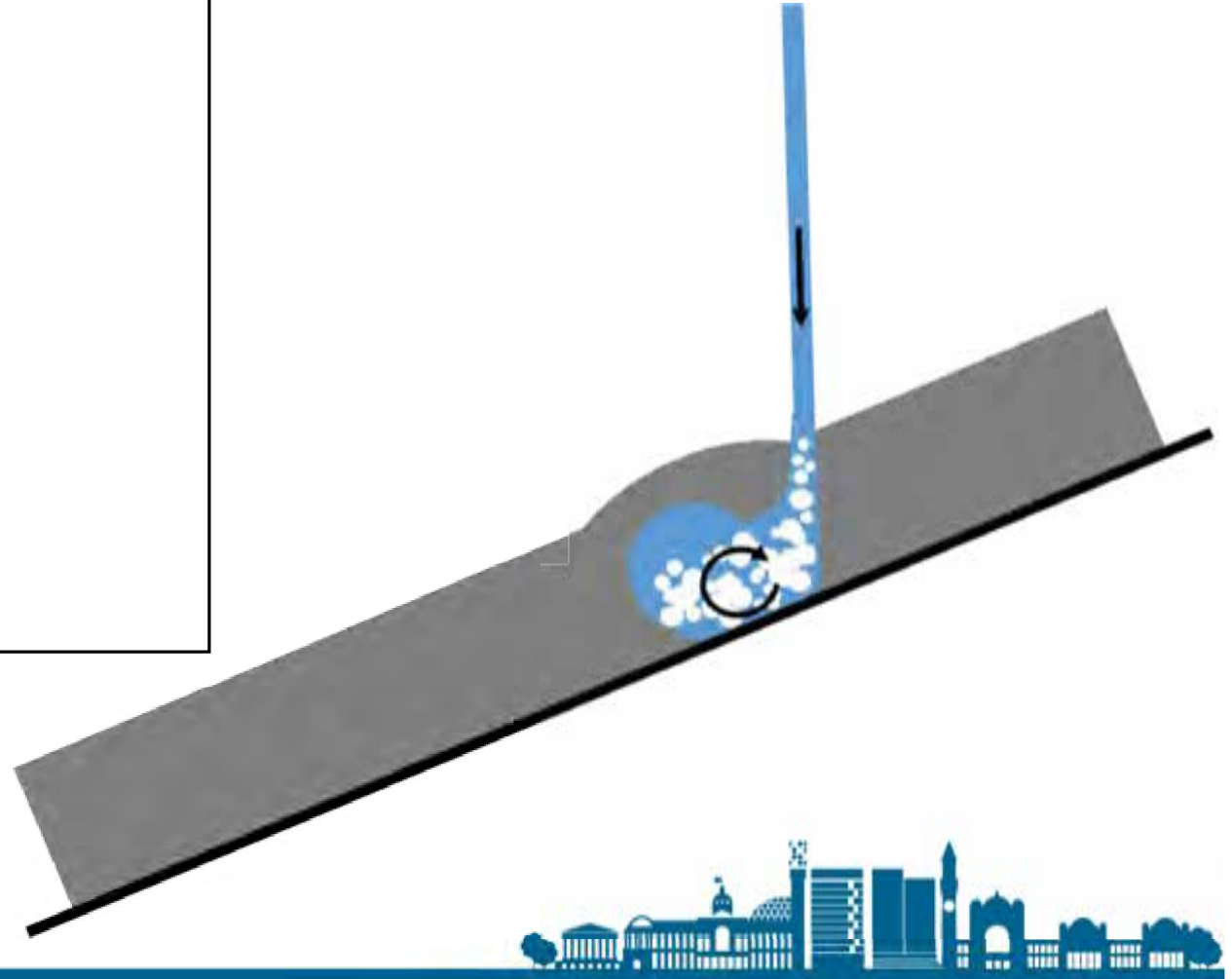
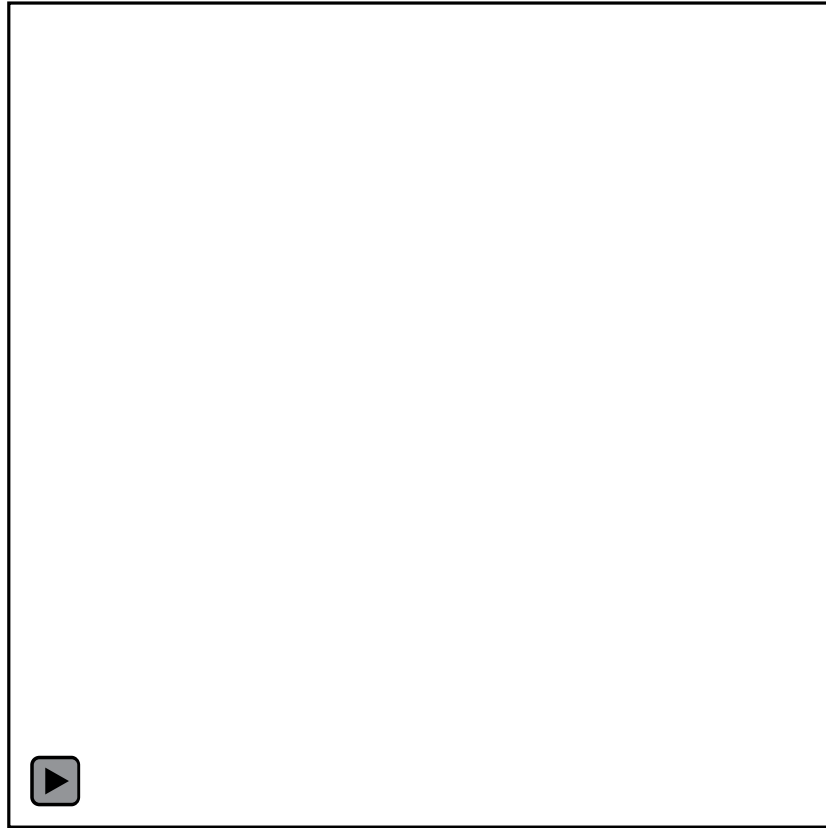




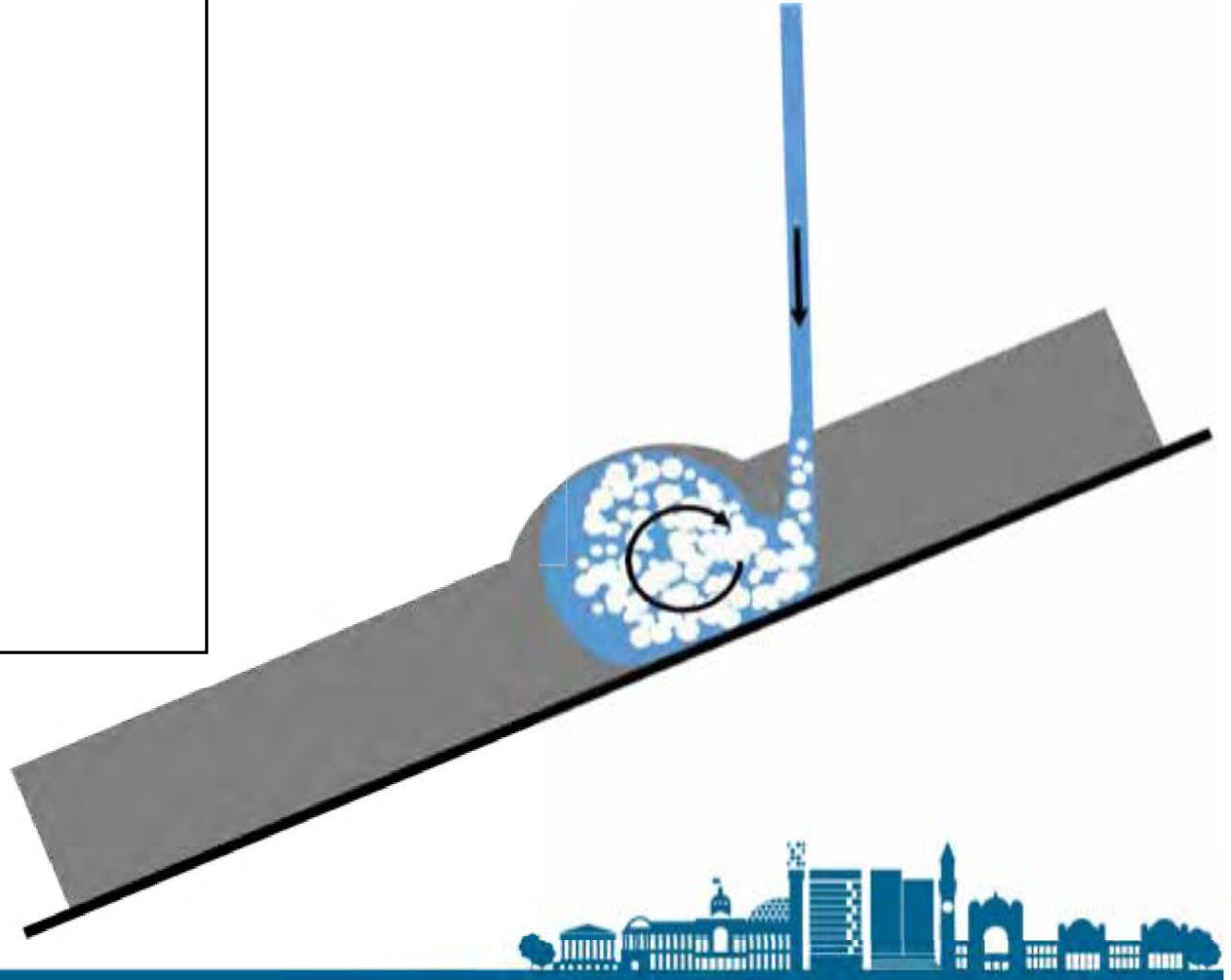
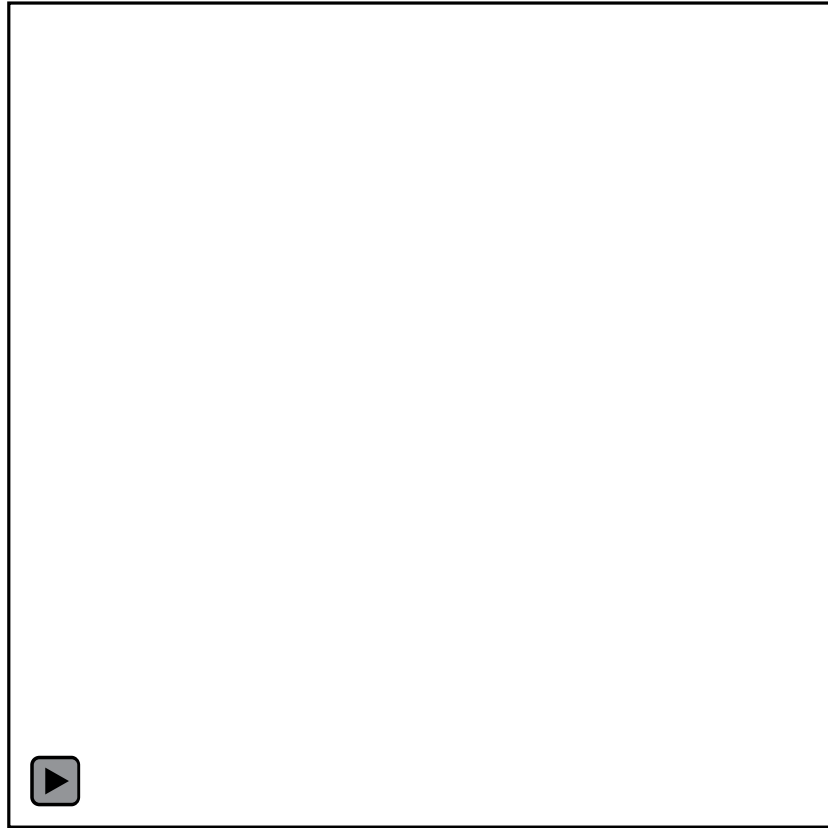
# Impingement of deposit



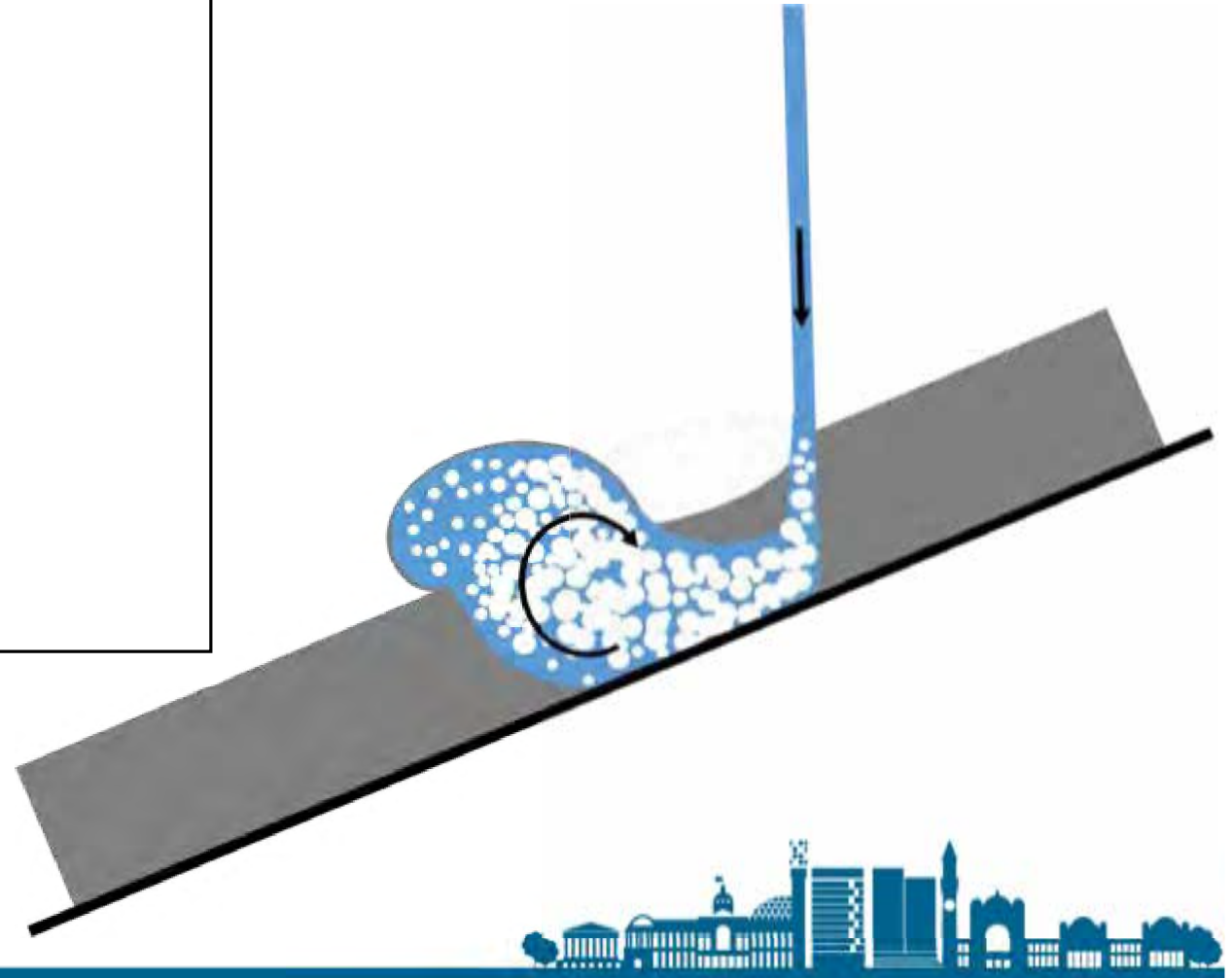
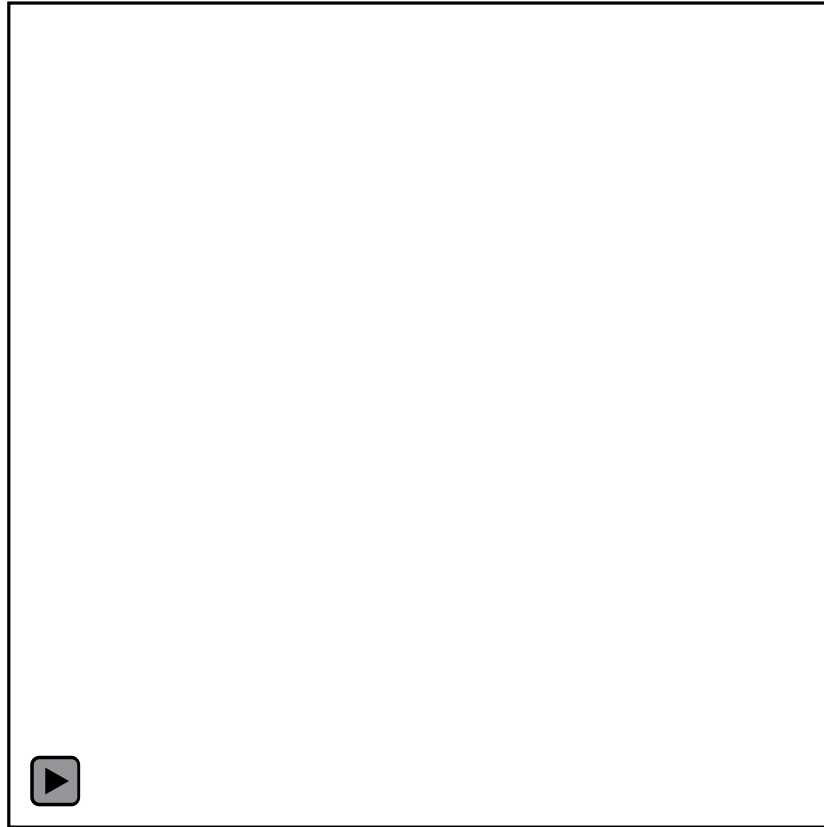
# Entraining Air



# Expansion of water sack

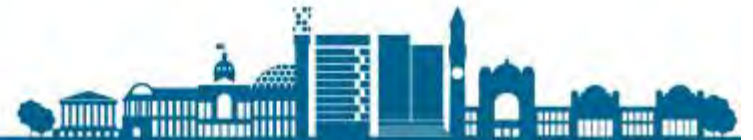


# Crowning of deposit



# Conclusion

- Manufacturability is...
  - Understanding scaleup
  - Working out how the equipment actually works
  - What does the equipment actually do to the product?
- Constraints are complex: microbial safety, product acceptability and cost
- Water and energy are parts of the manufacturing process
- How do you clean 3D printers?







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BIRMINGHAM

Thank you

