Starch-based foaming

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KTH / SCA

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Objective

- Develop biocomposite foams as a ”green” packaging material
  - Sustainable
  - Biodegradable
- Starch-based foams reinforced with cellulose
  - Improved stiffness
  - Improved moisture resistance
- Substitutes for e.g. polystyrene materials

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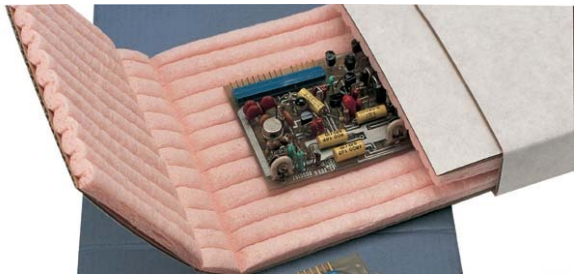
Examples of starch foams

Batch-moulded inserts for for packaging (SCA)

Continuous extrusion of loose-fill for packaging (Novamont)



Continuous extrusion of foamed sheets (Novamont)

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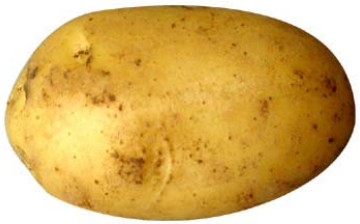
Starch – background

+ Available in large quantities
+ Low-cost material. ~500€/tonne
+ Easy to plasticize / dissolve in water
+ Readily biodegradable

- Brittle material
- Moisture sensitive
- Food-based feedstock



Potato

Corn

Cassava

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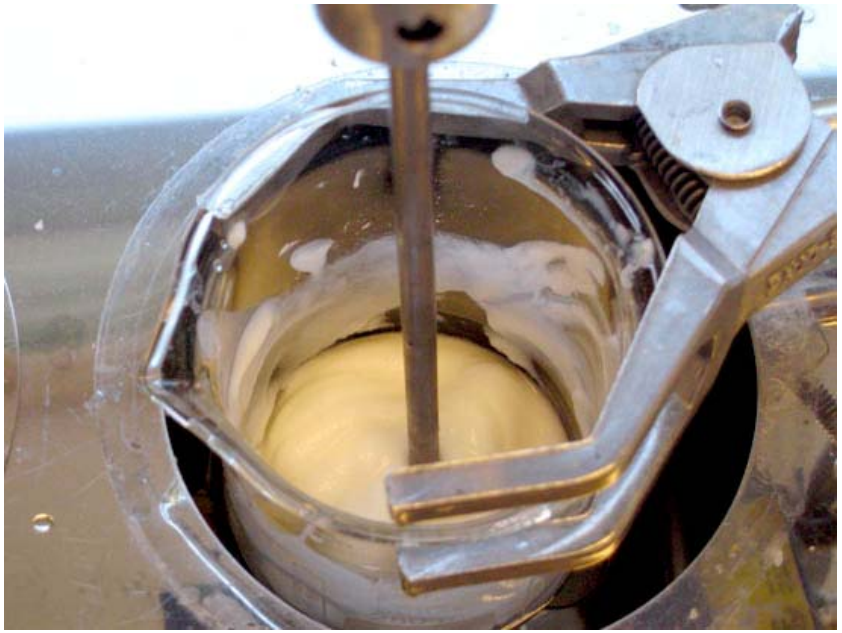
Wet compounding of starch and MFC



- Easy to disperse starch and MFC in water suspensions
- MFC is plasticized by water, prevents aggregation
- Starch granules dissolves upon gelatinization
- Facilitates dispersion down to fibril scale

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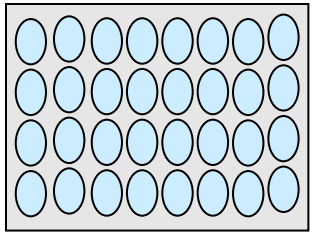
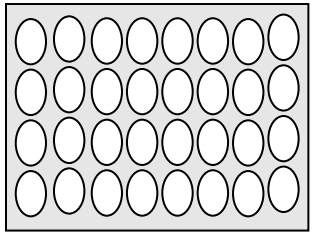
Type 1. Freeze-dried foams (KTH)

Freezing



Drying in vacuum



Aqueous gel of MFC dispersed in a starch solution.

Nucleation of ice crystals when the gel is frozen.

A porous foam is obtained when the ice crystals are removed by sublimation.

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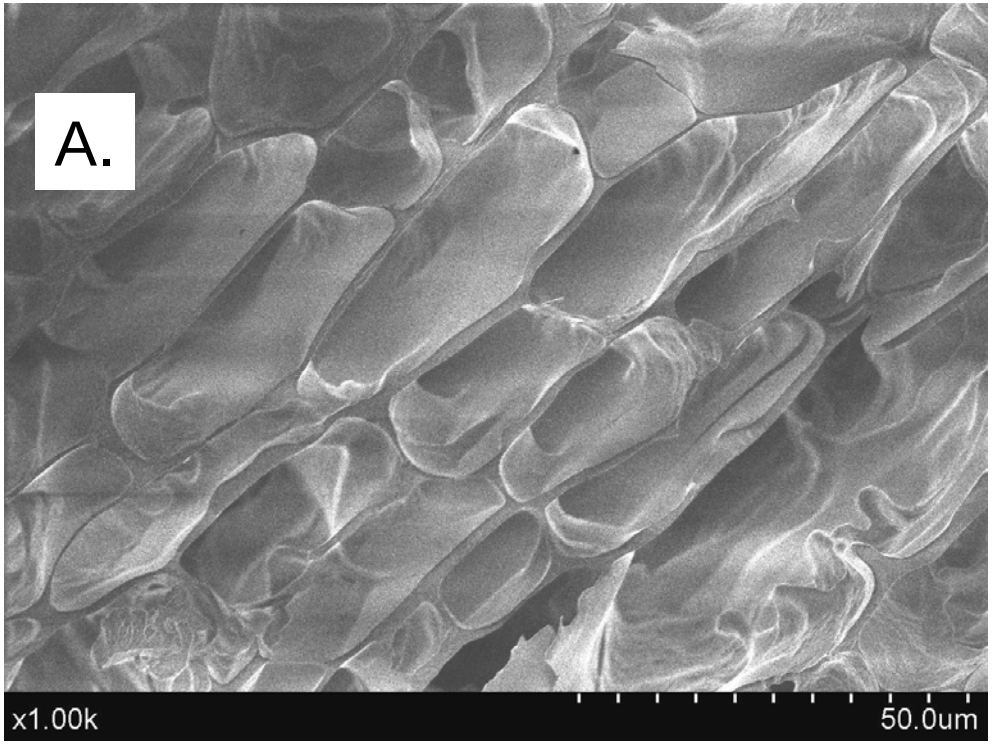
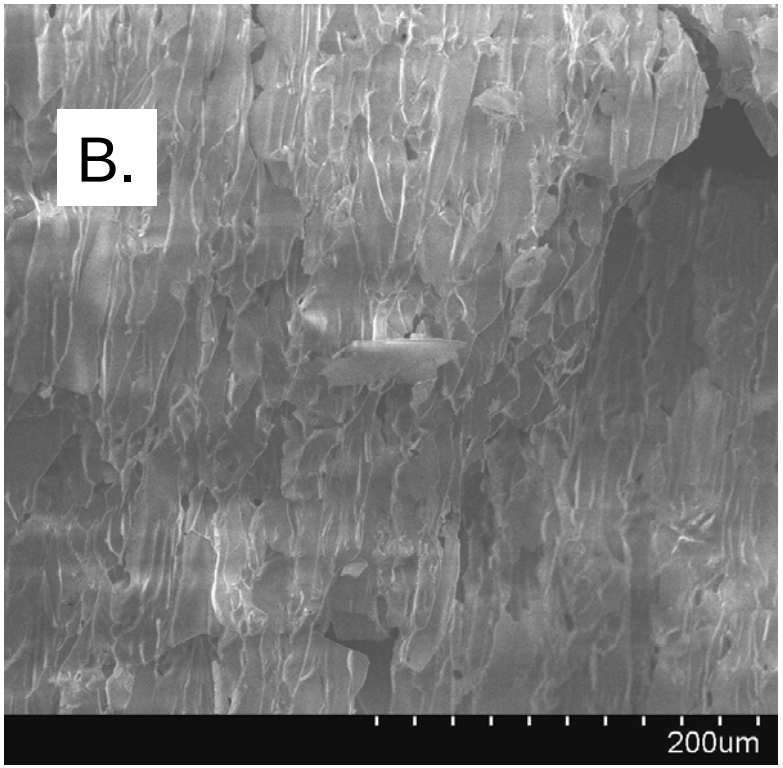
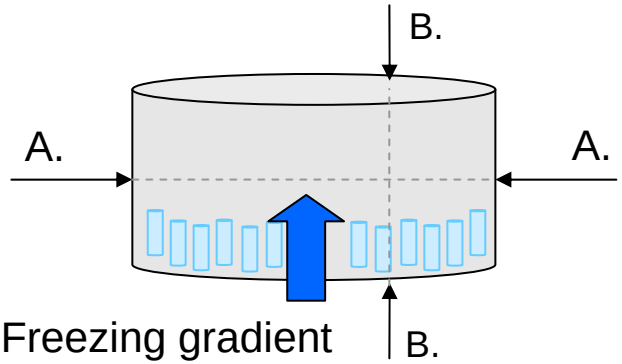
Freeze-dried foams – Morphology

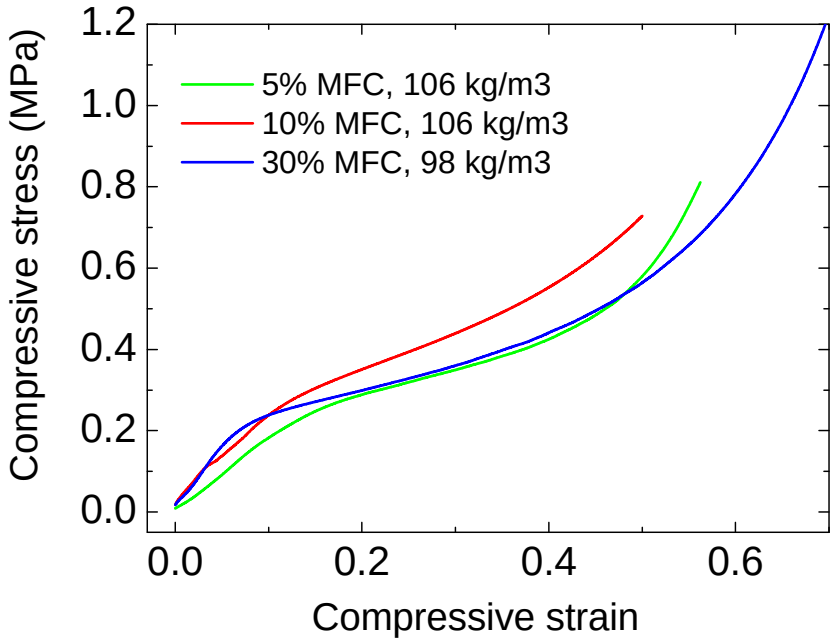




Starch with 3% MFC



Freeze-dried foams – Compression mechanics

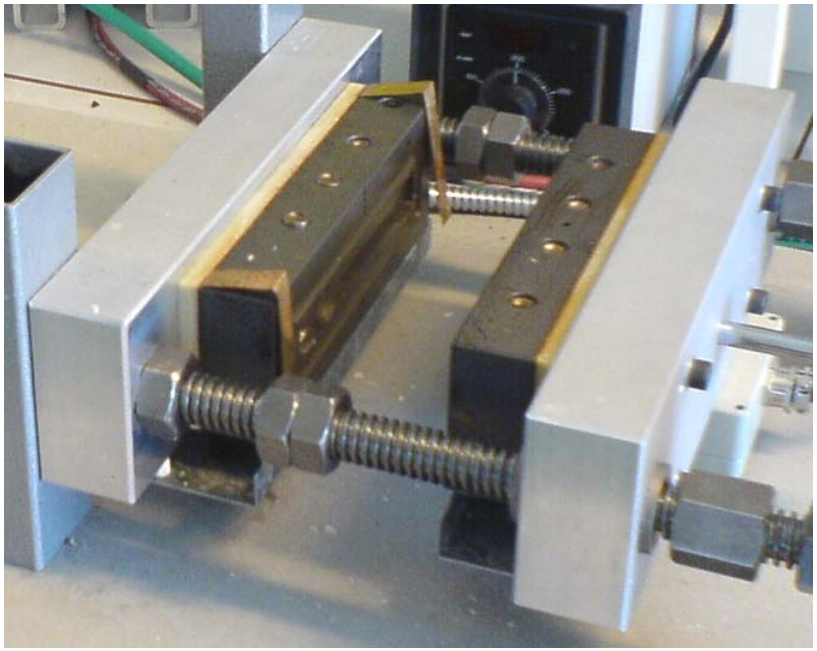


MFC content	Density (kg/m^3)	Yield strength (MPa)	Youngs' Modulus (MPa)
0%	70	0.04 ± 0.01	0.41 ± 0.1
0%	110	0.22 ± 0.03	2.6 ± 0.7
5%	106	0.26 ± 0.05	2.4 ± 0.8
10%	106	0.27 ± 0.02	3.4 ± 0.8
30%	98	0.23 ± 0.03	4.2 ± 0.8

Freeze-dried foams – Conclusions

- Lab-scale technique
- Suitable for processing dilute MFC suspensions
- Elegant way of dewatering the gel and obtain a porous structure.
- Can tailor the density and morphology of the foam
- Useful for determining the potential of MFC reinforcement

Type 2. Injection moulded foams (SCA)



- Cold dispersion of the raw materials in water.
- Injection of the blend into a hot mould.
- Baking for 2-4 minutes at 200°C, all water evaporates.

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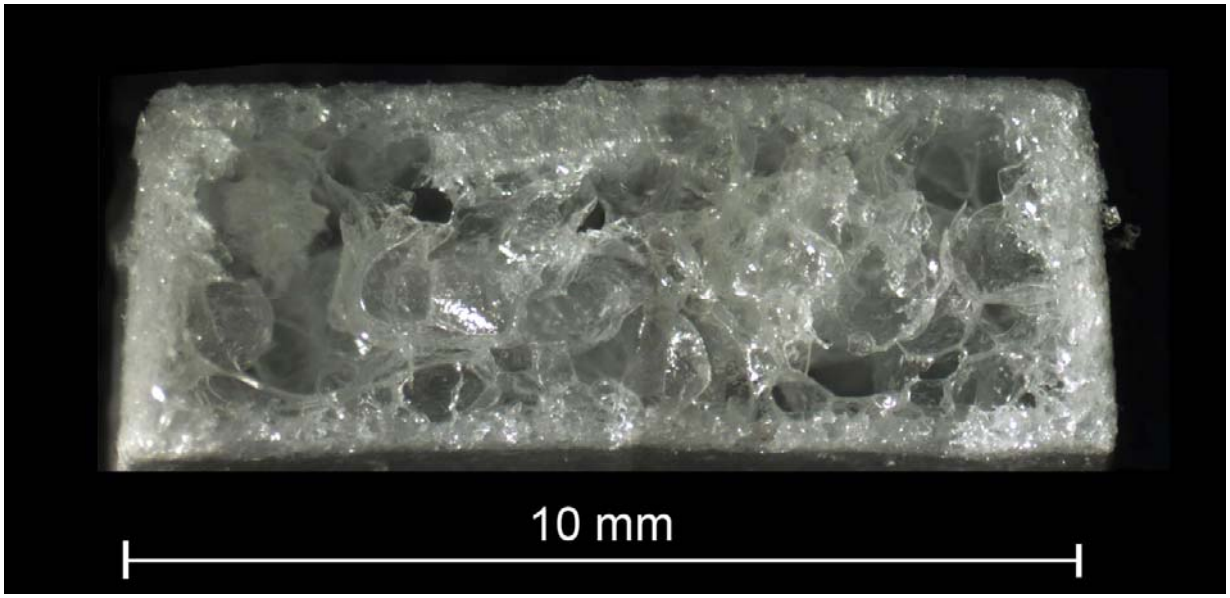
Injection moulded foams - Morphology



- Sandwich structure obtained
  - Solid outer skin
  - Internal foam structure

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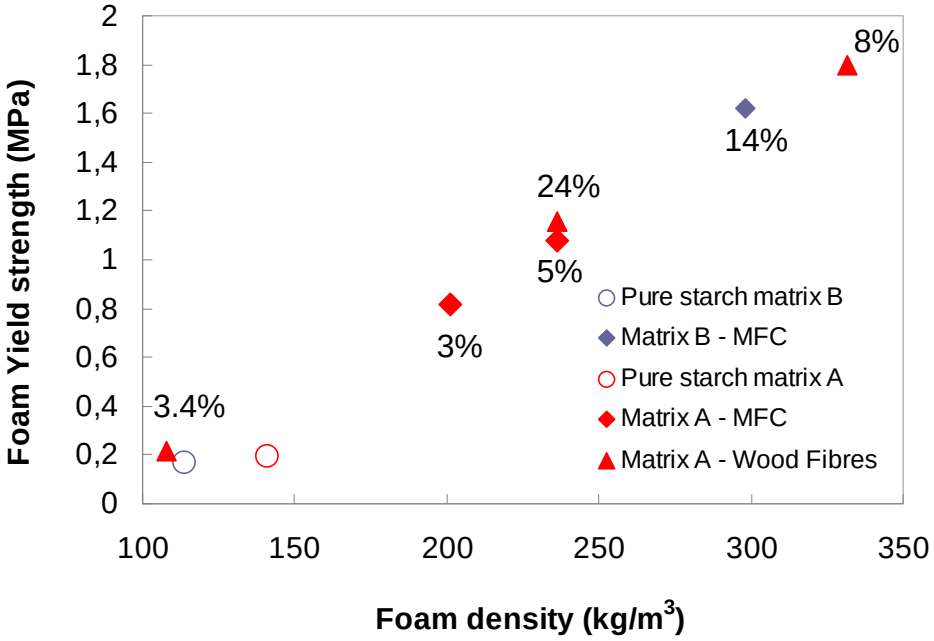
Injection moulded foams – Compression mechanics



Series description	Reinforcement (%)	Foam density (kg/m^3)	σ_{pl}^* (MPa)	E^* (MPa)
Pure Starch matrix A	0	141	0.20	4.0
Matrix A and MFC	2.9%	201	0.82	16
Matrix A and MFC	5.0%	236	1.08	17
Matrix A and WF	3.4%	108	0.21	5.8
Matrix A and WF	8.4%	332	1.80	26
Matrix A and WF	24%	236	1.16	22
Ref. EPS	0	20	0.12	4.7

Injection moulded foams – Conclusions

- Injection moulded starch foams show open macroscopic cells
- These foams can reach similar stiffness and yield strength as compared to EPS, but higher foam densities are required.
- MFC is more efficient than fibres for improving the yield strength at low reinforcement levels.

3. Extruded starch foams

- Foams can be extruded from plasticized starch:
  - Temp. 150 – 200°C
  - Moisture content 15-25%
  - High pressure
- Water acts both as plasticizer and blowing agent.
- Novamont has developed foaming grade starch.

Extrusion of plasticized starch

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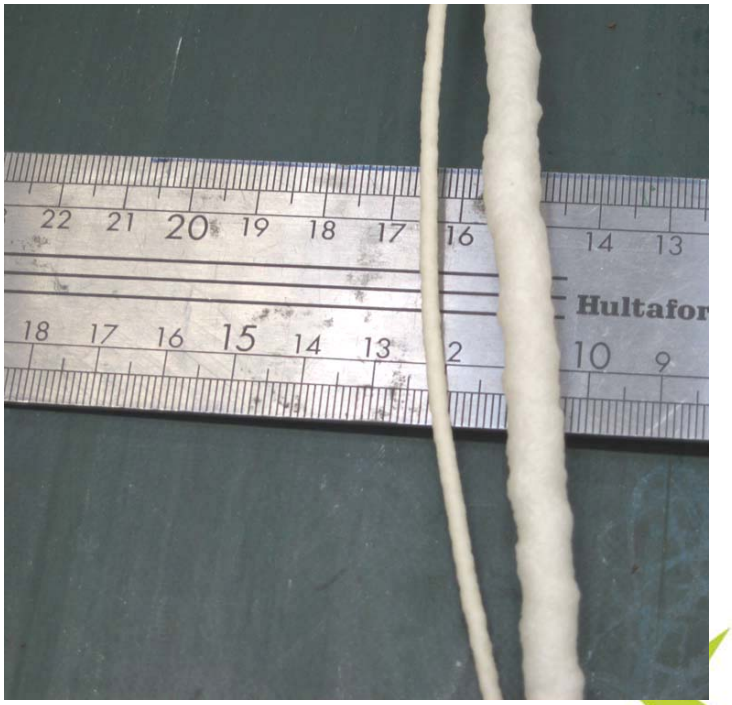
Extruded starch foams

- Instant foaming after the die exit of the extruder
- First attempt KTH – SCA
  - Radial expansion factor: 4x
  - Foam density: ~ 75 kg/m^3
- Remains to develop starch-MFC compounds for extrusion.
  - Redispersible from semidry state
  - Must prevent fibril aggregation at these low moisture contents.



Extruded starch before / after foaming

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4. Moulded foams from expanded particles (SCA)

- Evaluation of moulded block foams of starch as a substitute for EPS.
- Concept tested with loose fillers as pre-expanded particles.

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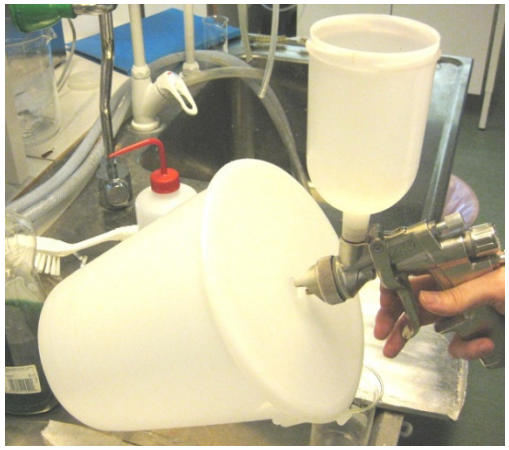
Moulded particular foams - Principle

Extrusion of foamed starch particles → Moisture impregnation of starch particles → Hot air moulding of block foam

Loose-fillers



Moulded particular foams - Compression mechanics

Foam	Foam density (kg/m^3)	E-modulus in compression (MPa)	Yield strength in compression (kPa)
Moulded cellular starch foams	**35 ± 5**	**0.21 ± 0.04** (1)	**16 ± 4** (1)
EPS reference	20	4.7	120
EPS reference	30	9	200

(1): Compression mechanics of moulded samples are weaker in comparison to Mater-Bi Loose-Filler products.

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Moulded particular starch foams - Conclusions

- Low densities achieved
- Narrow optimum for the applied water content:
  - promote adhesion
  - prevent dissolution and shrinkage
- Compression strength not as good as EPS
  - Less contact area between particles as compared to EPS

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Overview: Present foaming techniques

Foaming technique	Foam density (kg/m^3)	Composite foams	Available scale	Possibilities for upscaling
Freeze-drying 	50 - 200	Yes, MFC	Lab-scale	-
Batch Moulding 	100 - 300	Yes, fibres and MFC	Up to industrial scale	+
Extrusion 	8-11	N/A	Up to industrial scale	++
Extrusion + moulding 	30 - 45	N/A	Lab-scale	(+)

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