DAN-ISO A/S

PURrecy

”Sustainable insulation products”

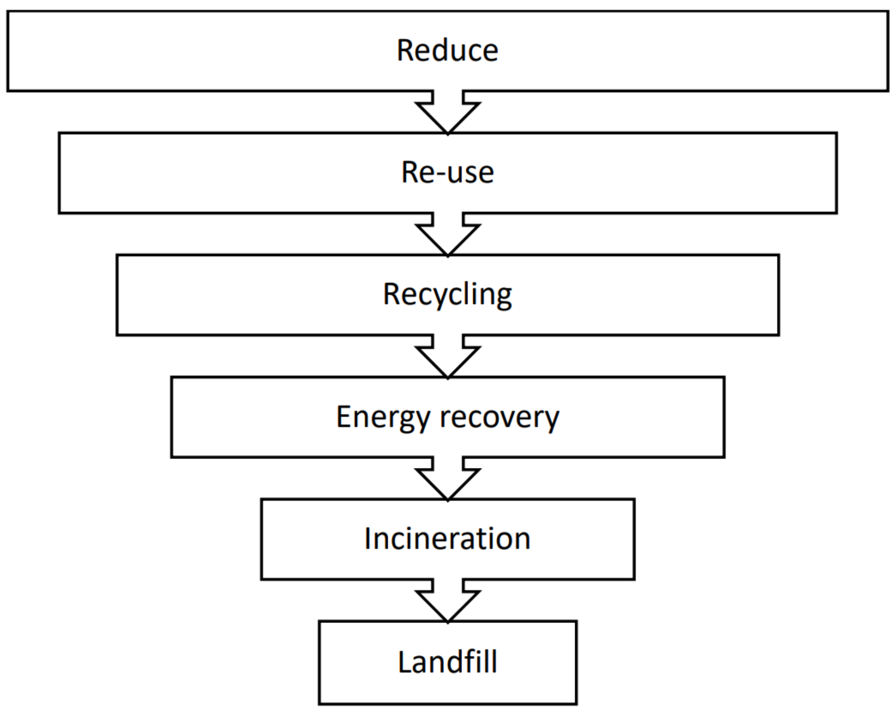
Why?

- Lots of waste
- We can do this better
- A shame to incinerate good material

What have we done until now?

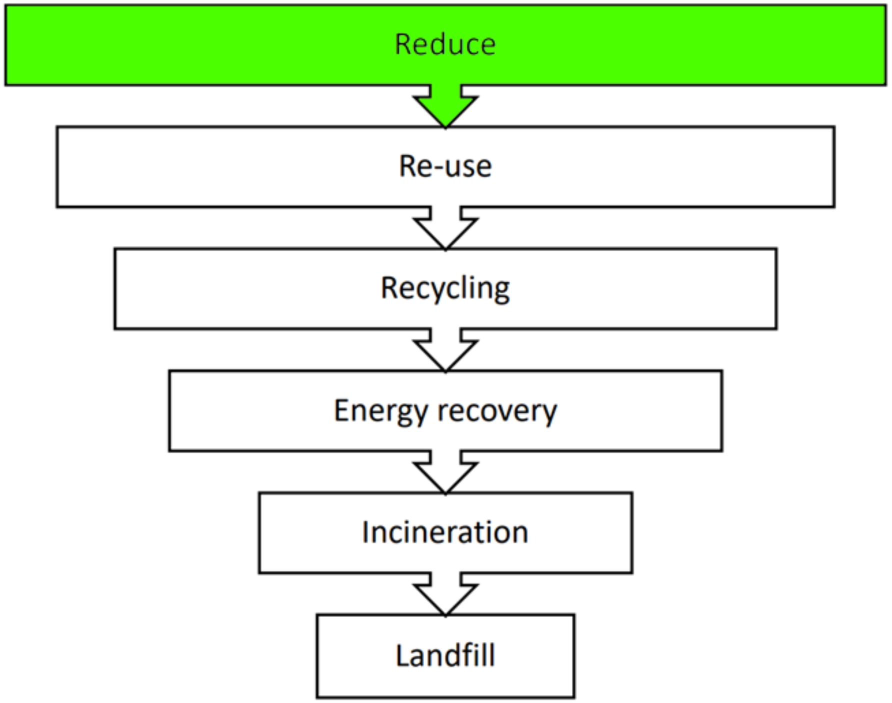
How can we improve?

- What are the official recommendations for waste disposal?
- EU Directive 2008/98/EC: prevention, prepare for reuse, recycling, other recovery and disposal
- Waste hierarchy (Lansink's Ladder)



Current practices

- Highly efficient and optimized production minimizes waste
- High quality products ensure a long service life before requiring replacement

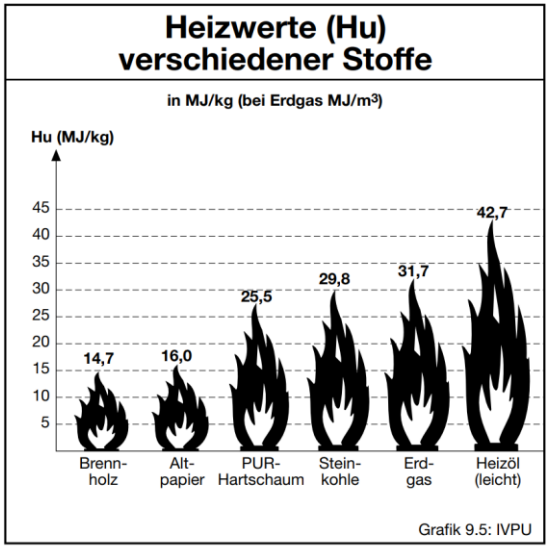


Sustainable PUR

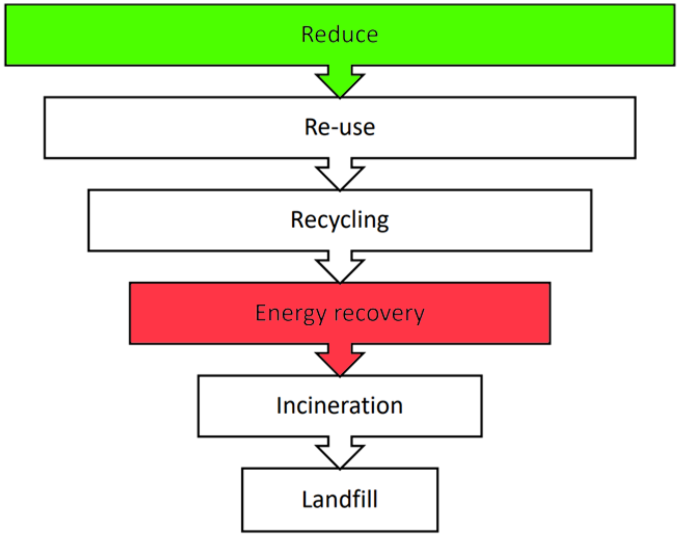
- PUR waste is particularly difficult to recycle
- Until about 20 years ago, the consensus was that incineration and energy recovery were best practice.

The European PU industry, specifically for rigid PU foam, consider the recovery of energy from scrap material PUR foam from construction and demolition waste to be the best disposal option as laid down in various position papers [71,72].

Kilde: Zevenhoven, 2004, Treatment and Disposal of Polyurethane Wastes: Options for Recovery and Recycling

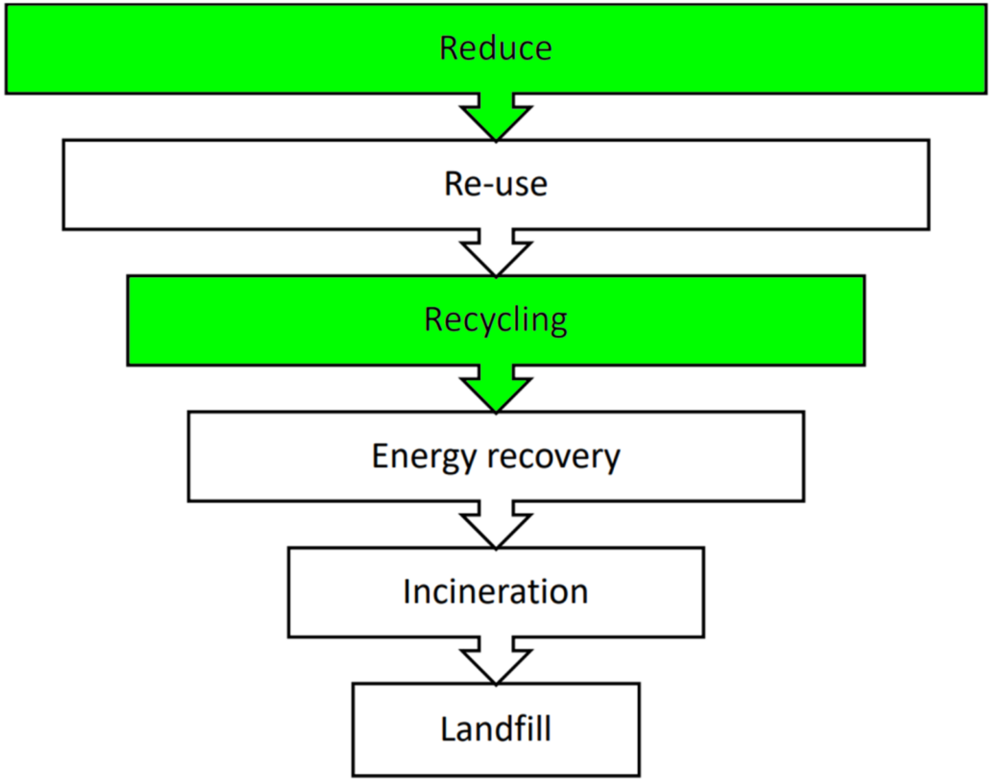


Calorific values of PUR foam compared with other energy sources

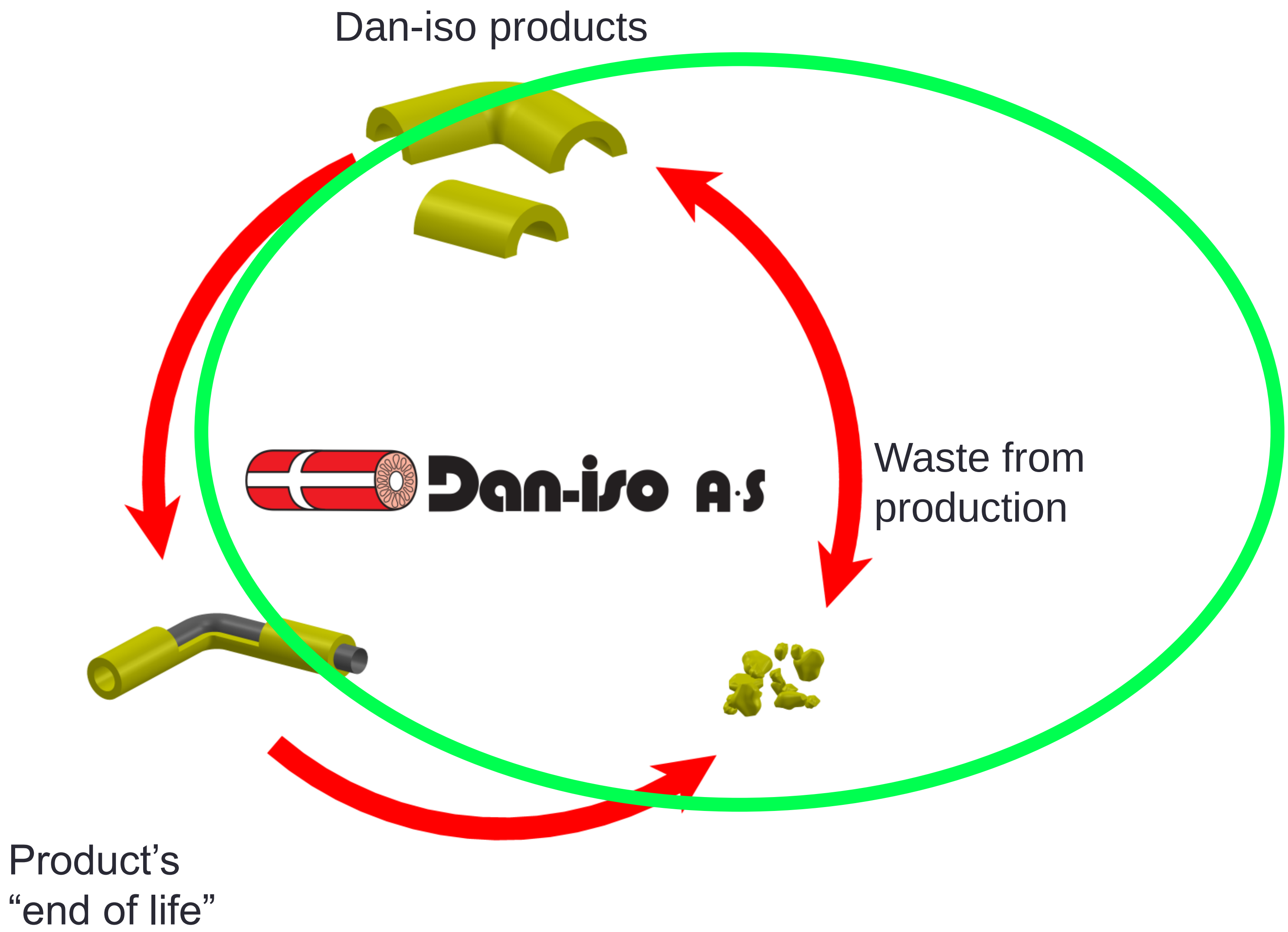


Our Goals for the Project

- We do already a lot to reduce material usage,
- We want to recycle!



Our Vision for the Project

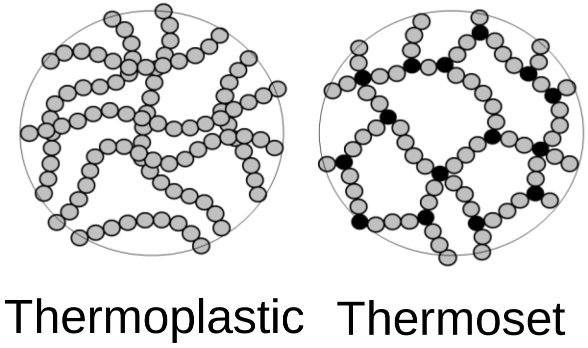


Our Requirements

- We must be able to use our own waste
- It must be profitable
- It must be a real green solution
- Processes must be kept in-house
- Keep it simple!

Which way to go?

- PUR foams can't be recycled using the most common methods.
- Thermosets contain strong crosslinks that prevent recycling
- 4 main strategies for recycling
- What should we choose?
- The low hanging fruit



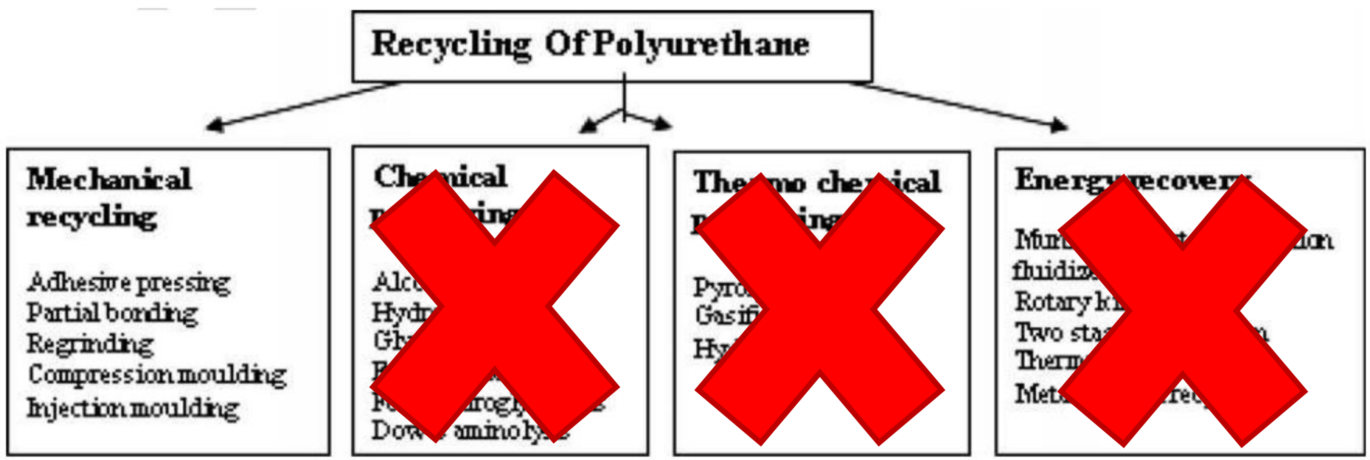


Fig. 1. Overview of options for polyurethane recycling [16].

Mechanical Methods

- It’s easy to find examples of these methods in use
- None of them fit Dan-iso’s products or production line

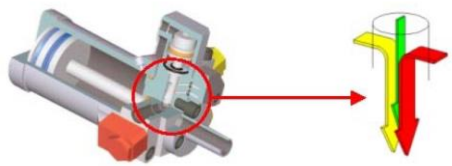
Re-bonded flexible foam

Recycled PUR plate from *Sundby*

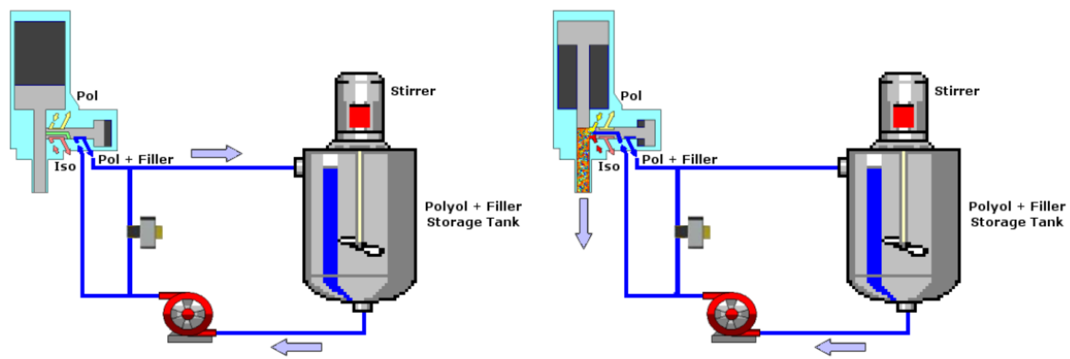
Concrete with PUR aggregates
[Václavík et al., 2012]

Have Others Tried?

- Several examples can be found in the open literature.
- Cannon Afros and Mobius Technologies have developed machine prototypes for this purpose.



Picture 7 - Cannon FPL /3 Mixing Head with High Efficiency Axial Components Mixing



Picture 8 – Cannon prototype filler injection kit layout showing recycling and pouring phases

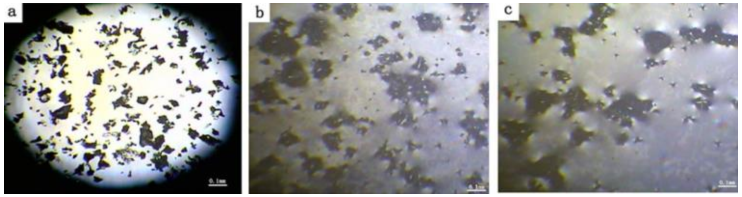
CONCLUSIONS

The results obtained show that recycled PU powder can be used in moulded car seats at levels of up to 7% on the overall foam weight. Mobius selected this level as it was demonstrated in earlier trials that at such a level, the mechanical and physical properties of the moulded foam parts were not significantly affected and seat foams were still meeting the specific OEM specifications for car seats.

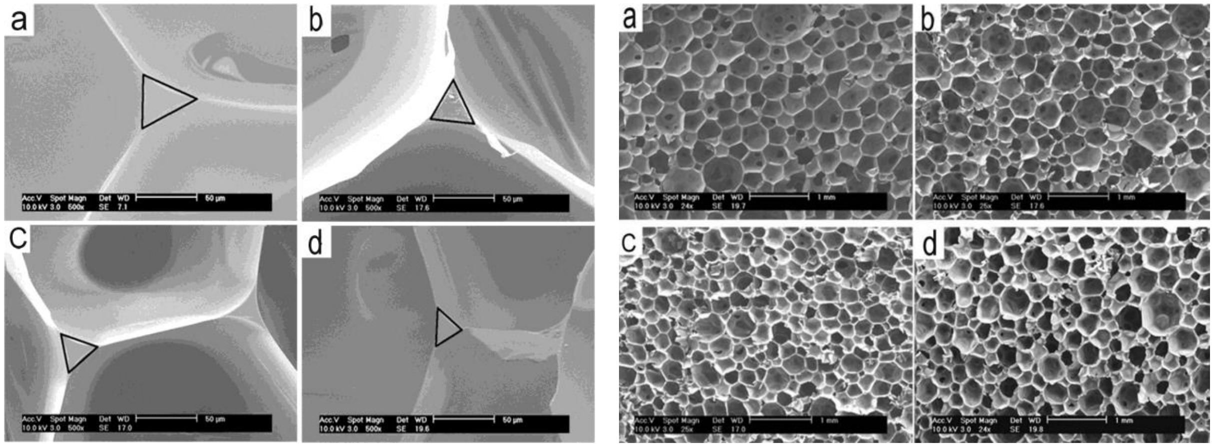
Kilde: ANDREOLLI, STEFANO & CHARIATI, CHRISTIAN & BERTHEVAS, PAUL & VILLWOCK, ROBERT. (2015). Innovative Filler Injection System for Powdered Recycled Urethane.

Have Others Tried?

- Yang et al. (2013) reached up to 15% recycled powder material in a rigid foam
 (Fudan University, Shanghai)
- Good properties at 5% and 10% powder content
- Reaching 15% requires several extra processes and additives



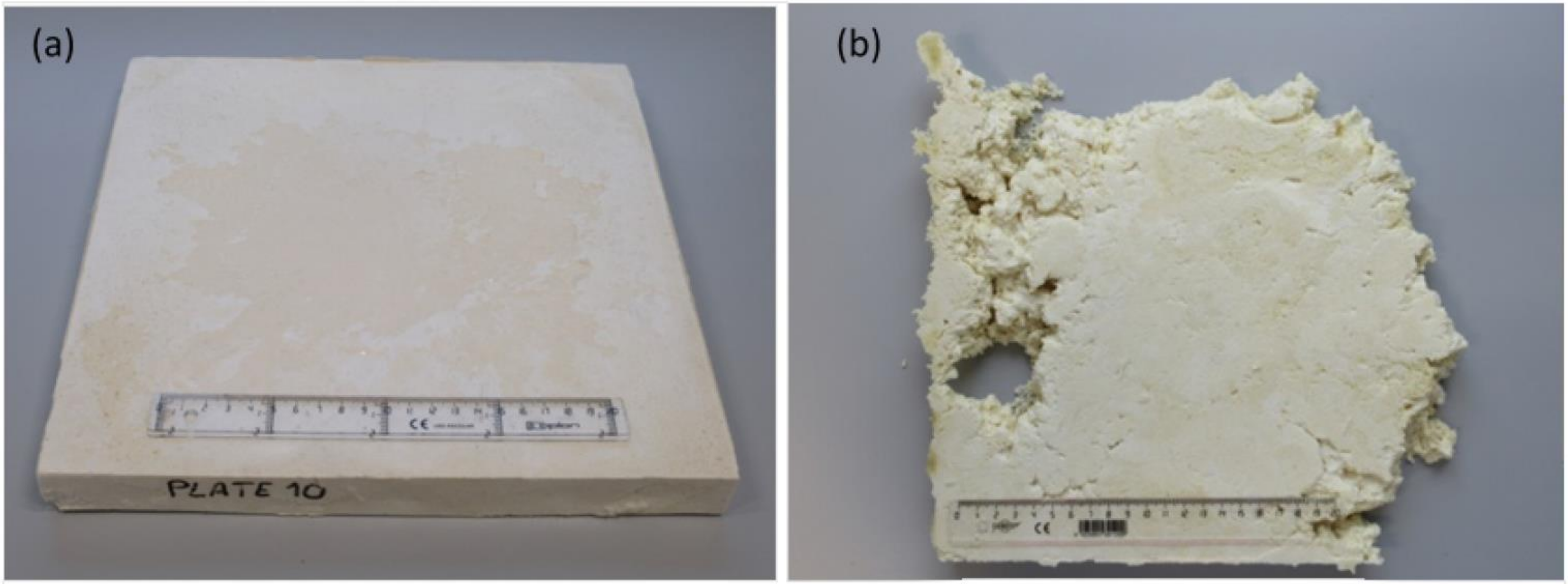
Dispersion of particles in polyol



Foam structure with various contents of recycled material

Have Others Tried?

- Aranberri et al. (2022) reached up to 5% with good results
- They recommend op to 3% for best results
- A maximum of 3 to 10% is mentioned by most sources
- A few sources cite op to 15% recycled material, but this requires expensive and complicated processes
- Dan-iso saw this as a challenge worth taking



(**a**) Plates of rigid polyurethane foams with 3 wt% and (**b**) 10 wt% of recycled polyurethane foam powder.

[Aranberri et al. 2022]

Preliminary Experiments

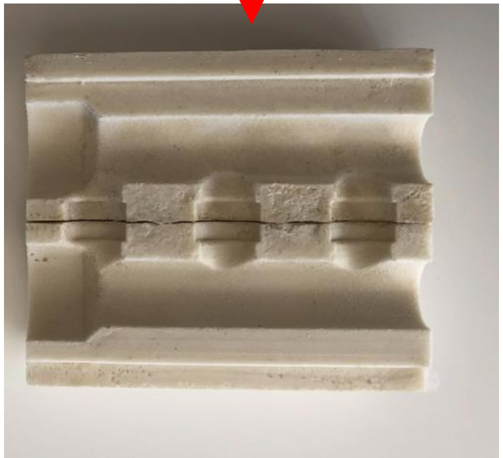
- Even with low quantities of PUR powder the liquid becomes very viscous
- This poses a big challenge to existing machinery
- Not so easy (after all)

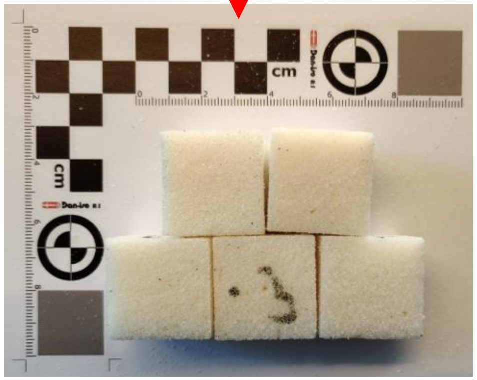
Sample	Polyol	Polyol/ PPU5wt%	Polyol/ PPU10wt%	Polyol/ PPU15wt%
Viscosity (mPa s)	1900	3400	5480	>10,000

Viscosity of polyol with PUR powder [Yang et al. 2013]

Incremental Development

- Small quantities of recyclate to begin with (2-3%)
- Slow but steady progress to 25% and beyond
- Always with a focus on production
- The goal was always a marketable product





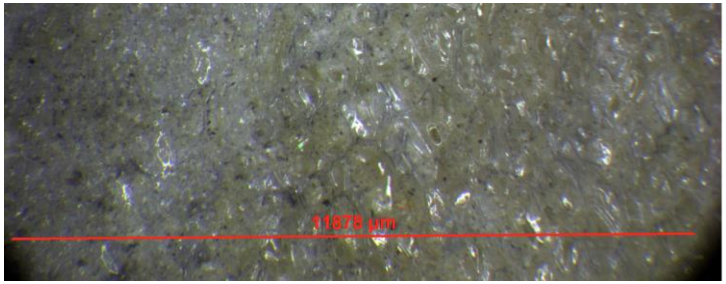
Identification of Key Parameters

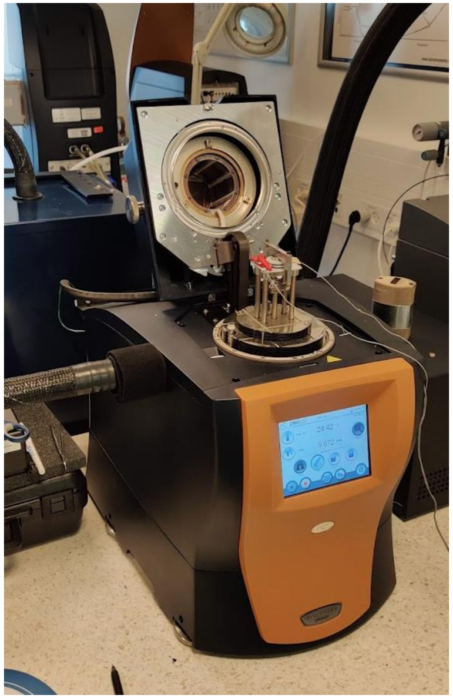
- Input parameters:
  - Blowing agents
  - Mixing methods
  - Particle surface
  - Particle size
  - …
- Material properties:
  - Density
  - Compressive strength
  - Lambda
  - Stiffness
  - …
- Production parameters:
  - Interaction with different mold shapes
  - Interaction of processes with our own machinery
  - Extra processes that require implementation
  - …

Material Tests

- The material properties and production parameters that govern them have been examined by various methods in cooperation with Aalborg University, Institute for Materials and Production.

- An ongoing student project addressed the automatization of key processes for setting up a serial production.



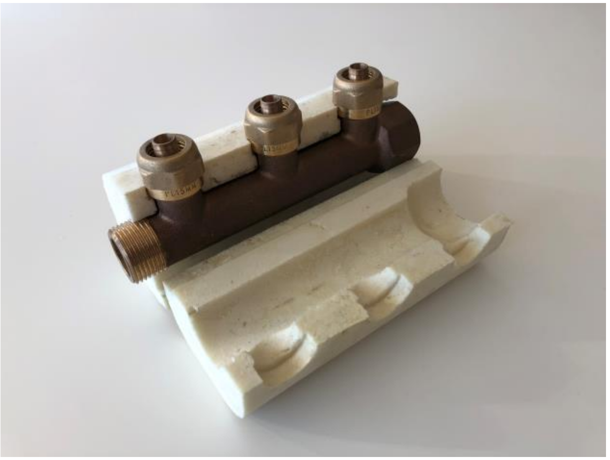


Where is Dan-iso?

To tracks:

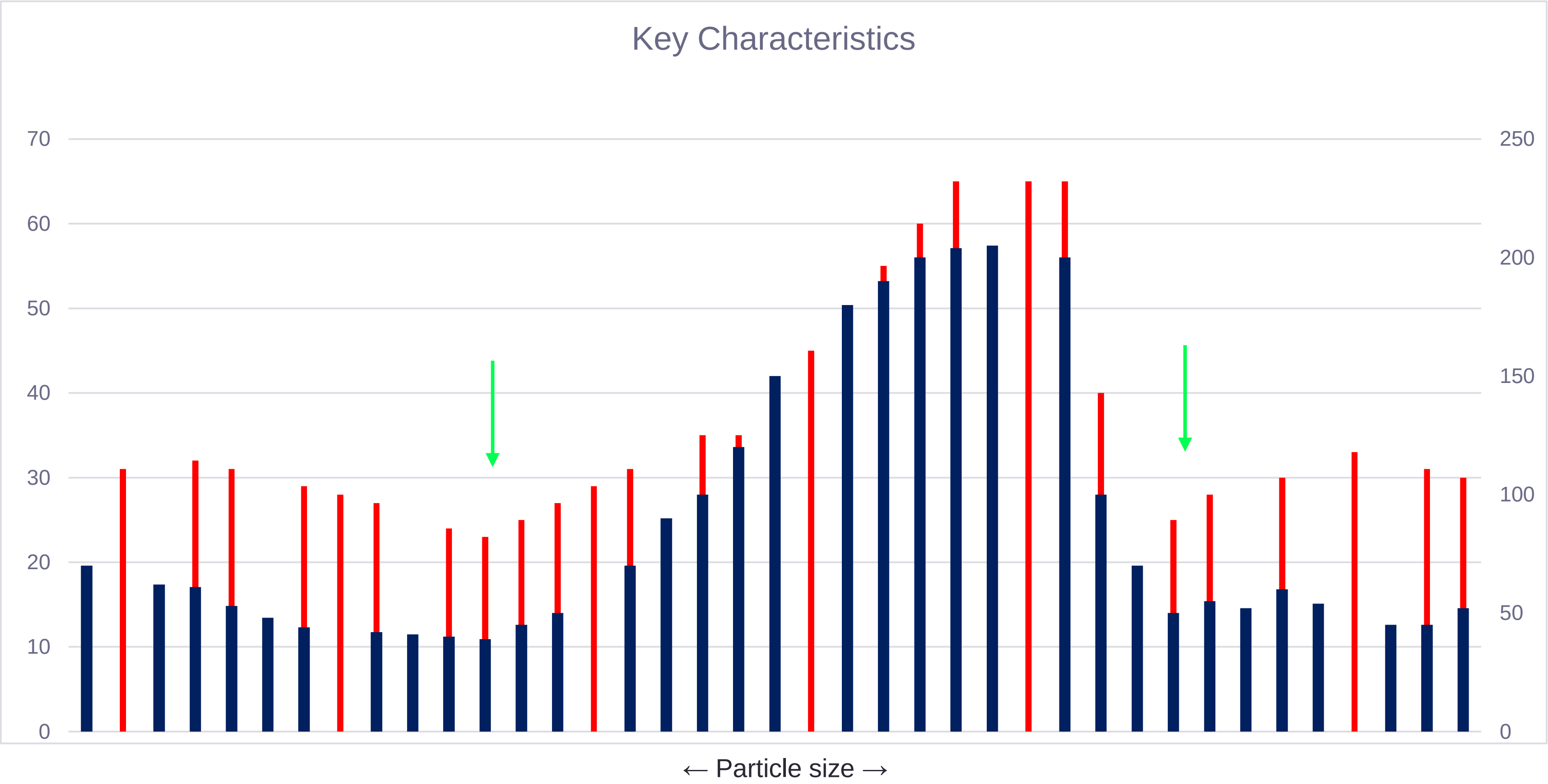
- Track 1: 40% to 45% recycled material
  - **Pros**:
  - High content of recycled material
  - Requires few new processes
  - Can be implemented in our existing production line
  - Good compressive strength
  - Material utilization ~95%
  - **Cons**:
  - Lambda values raise a bit (2-3mW/m·K)
  - Cosmetic differences compared to virgin foam

- Track 2: 23% to 27% recycled material
  - **Pros**:
  - Really good insulation
  - Some measurements show slightly better values than pure foam (1-2mW/m·K)
  - Very flexible with respect to different geometries
  - Material utilization ~97%
  - **Cons**:
  - Reduction of compressive strength compared to virgin foam
  - Requires several new processes
  - Required the development and testing of new machinery and processes



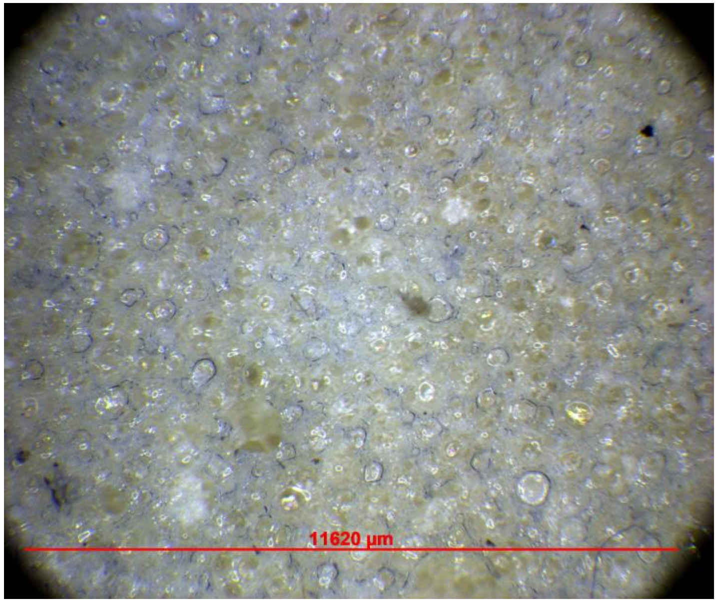
Why Two Tracks?

- The sweet spots of both properties coincide
- Other properties, such as compressive strength, top also at these ”sweet-spots”
- “Something” happens around there

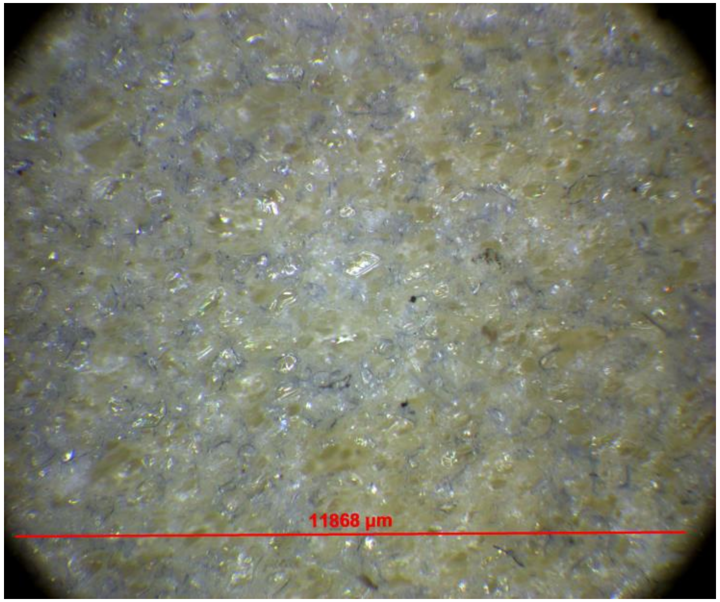


Why Right There?

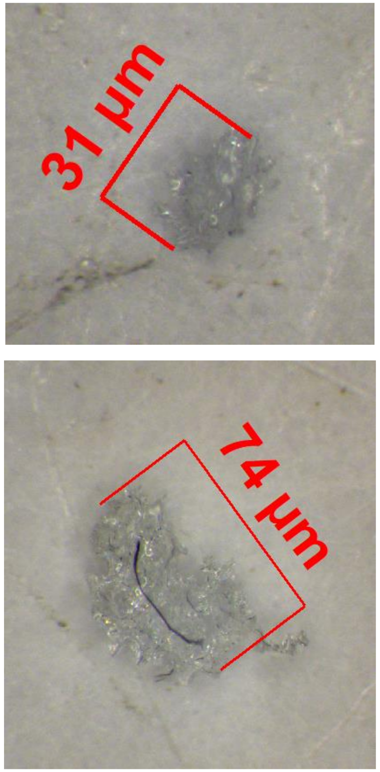
- We don't know for sure (yet)
- We see a very even dispersion of particles in both cases
- The characteristic surface of the particles "fits" cell size
  - Good for foaming
- Good "packing" of particles in the liquid phase
- Last but not least, both ranges fit out production capabilities



Microscopic structure of virgin foam



Microscopic structure of foam with 25% PUR



Particles under the microscope

Why Right There?

For small particles:

- We see a very uniform distribution of the particles
- The characteristic surface of the particles "fits" the cell structure
  - This results in good foaming
- Particles in the liquid phase are well dispersed

Pore structure of 15% sample

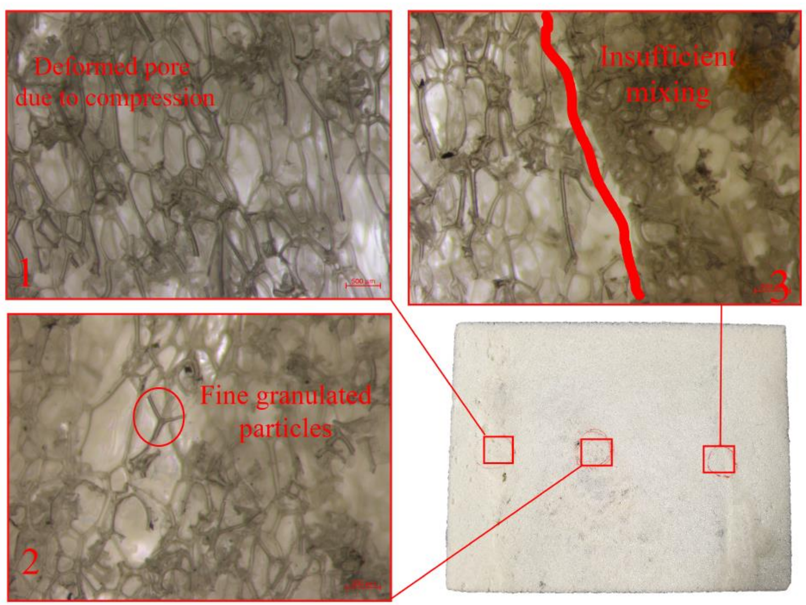


Figure G.2. Fine granulated 15% sample

Microscopic structure of foam with15% recyclate

Why Right There?

For large particles:

- The particle size allows flow of the liquid phase
- The characteristic surface of the particles has limited heat energy absorption
  - Good for foaming
- Last but not least, both techniques are suitable for production

Pore structure of 35% coarse granulated sample

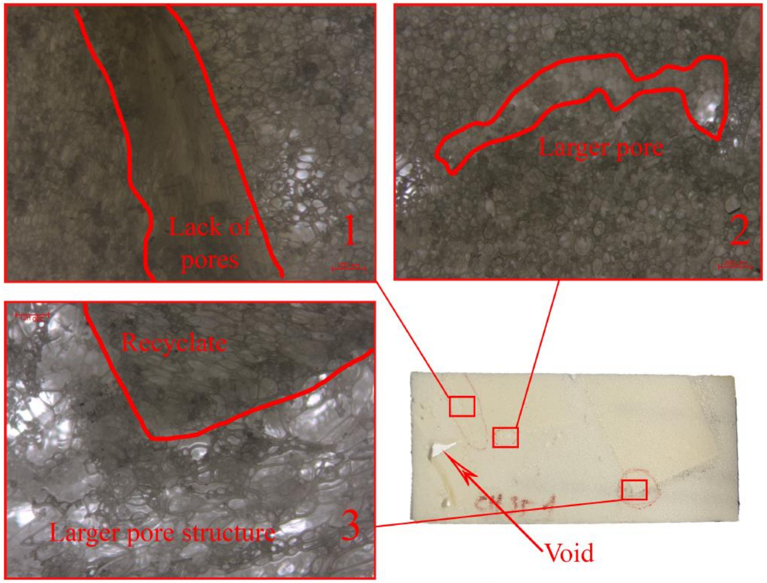
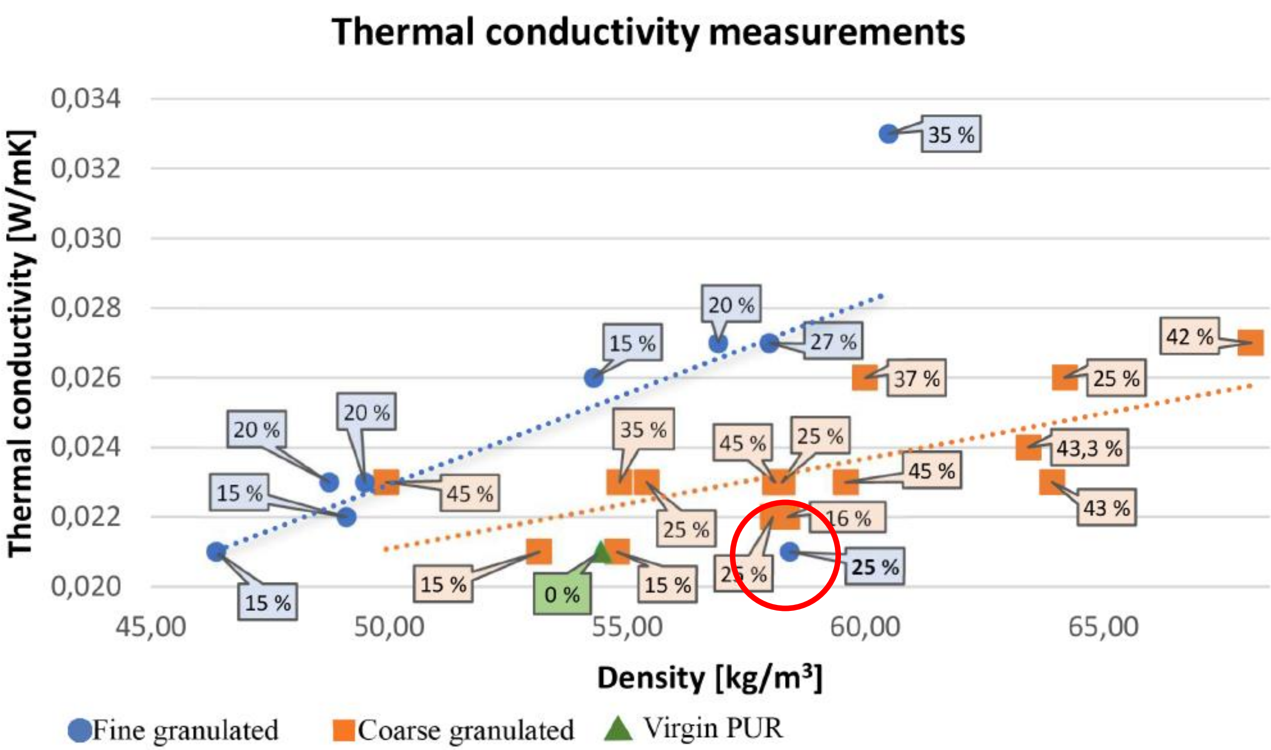


Figure G.7. Coarse granulated 35% sample

Microscopic structure of foam with 35% recyclate

Detailed parametric study

- De mekaniske og termiske egenskaber ved forskellige genanvendelsesprocenter og produktionsteknikker er blevet undersøgt
- Ved de seneste produktionsteknikker opnår vi enestående isoleringsværdier med op til 25% regenerat



Preliminary EPD

- A preliminary EPD has been undertaken un cooperation with Aalborg University.
- The EPC shows considerable improvements compared to standard PUR

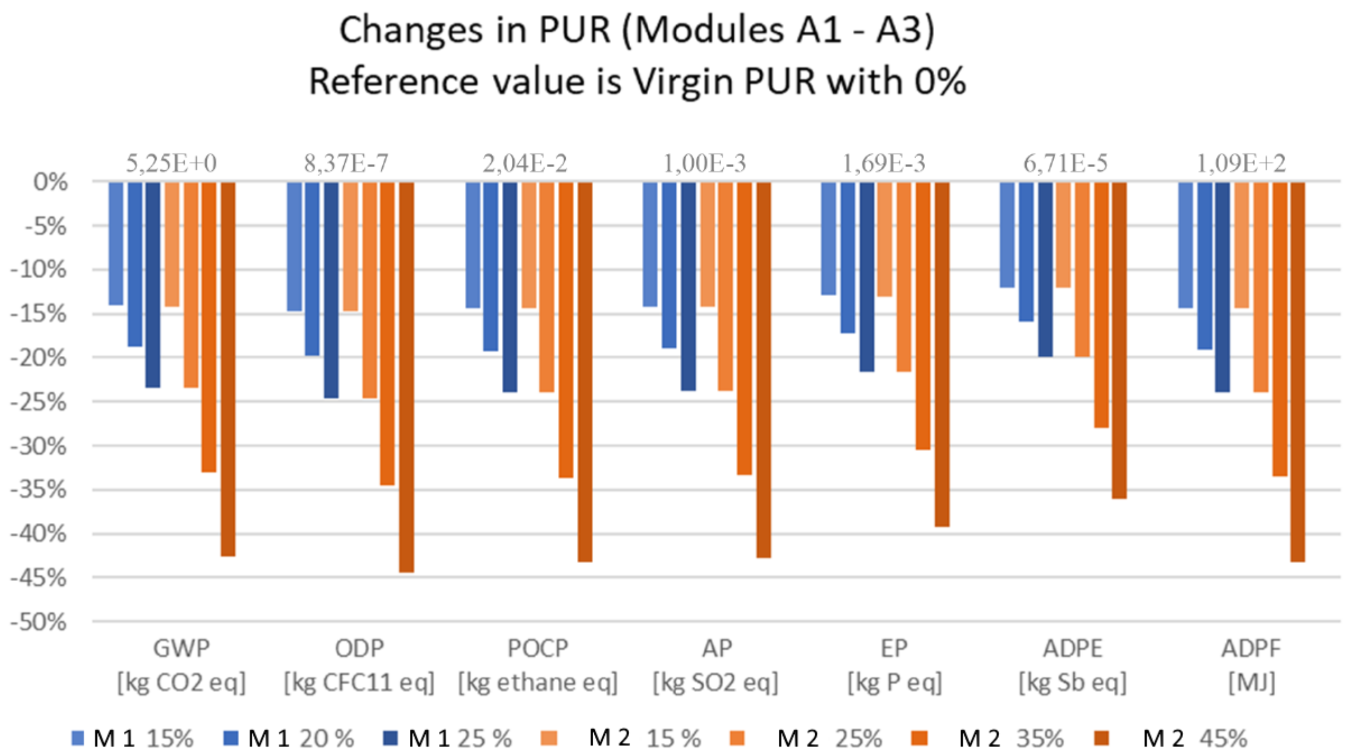
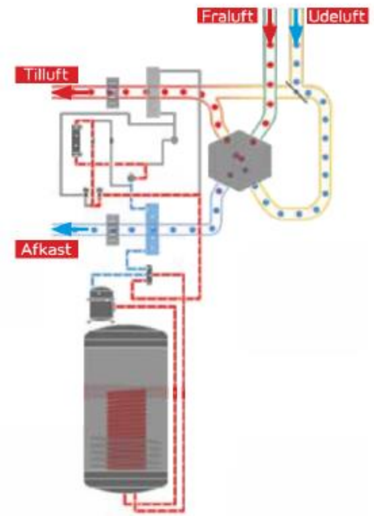


Figure G.3. Changes in PUR (Modules A1 - A3)

What's Next?

- Acquire a deeper understanding in order to increase the percentage of recycled material
  - Continue along both paths
- Explore practical applications
  - Project with AAU Build (DHW and energy expenditures)
- Examine sustainability
  - Project with AAU Build on material LCA
- We have two stable processes, they must be automatized



Circular Products