TNO innovation for life

FEASIBILITY MATTRESS RECYCLING

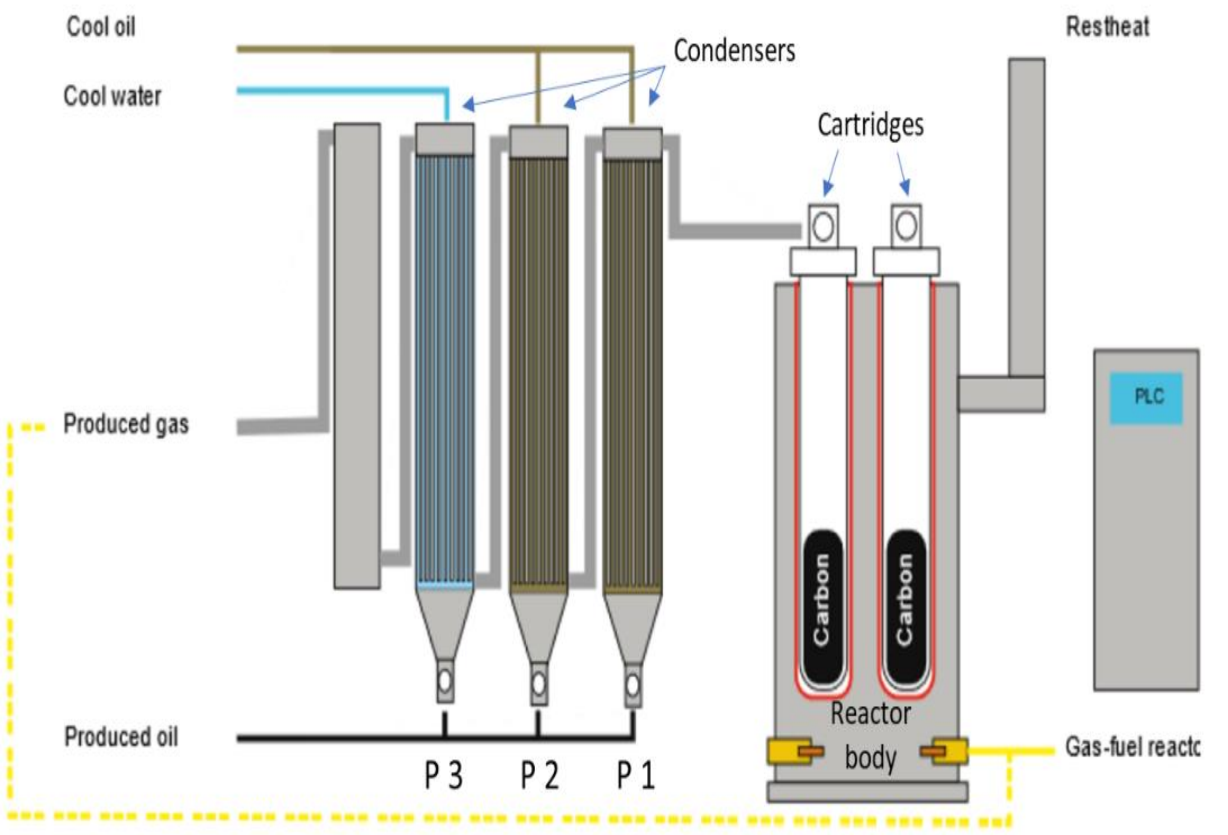
TNO MEASUREMENT CAMPAIGN | PEDRO ABELHA, JAAP KIEL

INTRODUCTION
THERMOCHEMICAL MATTRESS RECYCLING

- Increase recycling percentage for mattresses beyond levels of mechanical recycling to meet circularity targets for the furniture sector
- Several pyrolysis technologies assessed in previous PRIMA project
- ENERPY semi-continuous slow pyrolysis selected as most promising
- Robust technology for difficult / mixed material streams
- Test campaign for detailed technology assessment, initiated by CBM and industry partners, to create sufficient confidence and pave the way for further development, demonstration and market introduction
- Accompanying independent measurement campaign by TNO

EXPERIMENTAL APPROACH (1)
ENERPY PILOT PLANT IN FARMSUM, THE NETHERLANDS

- Semi-continuous or fed-batch slow pyrolysis
- Enerpy pilot reactor: ceramic lining, 4 natural gas heaters for indirect heating, 4 locations to house feedstock cartridges
- Cylindrical cartridges typically containing 10-20 kg feedstock
- Pyrolysis gas condenser section: 2 oil-cooled, 1 water/glycol cooled
- Test campaign (4 days):
  - Empty cartridge run
  - Latex run – 1 cartridge
  - Latex run – 4 cartridges sequential
  - Tick run – 2 cartridges sequential
  - Dry mattress run – 2 cartridges in parallel
  - Wet mattress run – 2 cartridges sequential
- Pyrolysis temperature: 600 °C



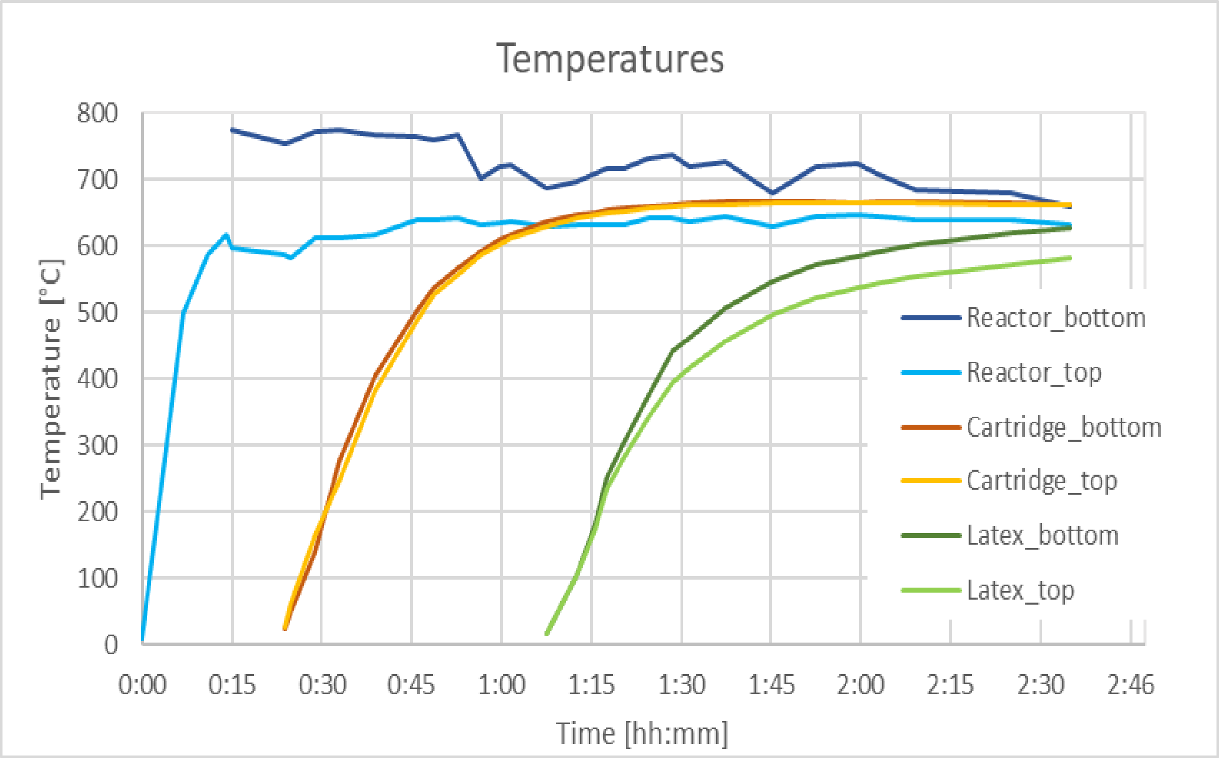
EXPERIMENTAL APPROACH (2)
TNO MEASUREMENT CAMPAIGN

- Aimed at establishing mass and energy balances, (the dynamics of) the temperature distribution in the process and the composition of pyrolysis oil, gas and char produced

- Measurements / analyses:
  - Process temperatures
  - Natural gas consumption
  - Pyrolysis gas flow rate (Ne tracer method) and calculated calorific value
  - Pyrolysis gas composition:
    - Online (Ne, O_2, N_2, CO, CO_2, CH_4, C_2H_4, C_2H_6, C_2H_2, H_2S, COS, benzene, toluene)
    - Gas bag sampling + offline GC-FID analysis (longer chain hydrocarbons)
    - Wet sampling + offline analysis (HCN, NH_3 and HCl)
  - Pyrolysis oil analysis (calorific value, proximate, ultimate, chromatography)
  - Pyrolysis char analysis (calorific value, proximate, ultimate)

RESULTS (1)
TEMPERATURE PROFILES AND PROCESS HEAT REQUIREMENTS

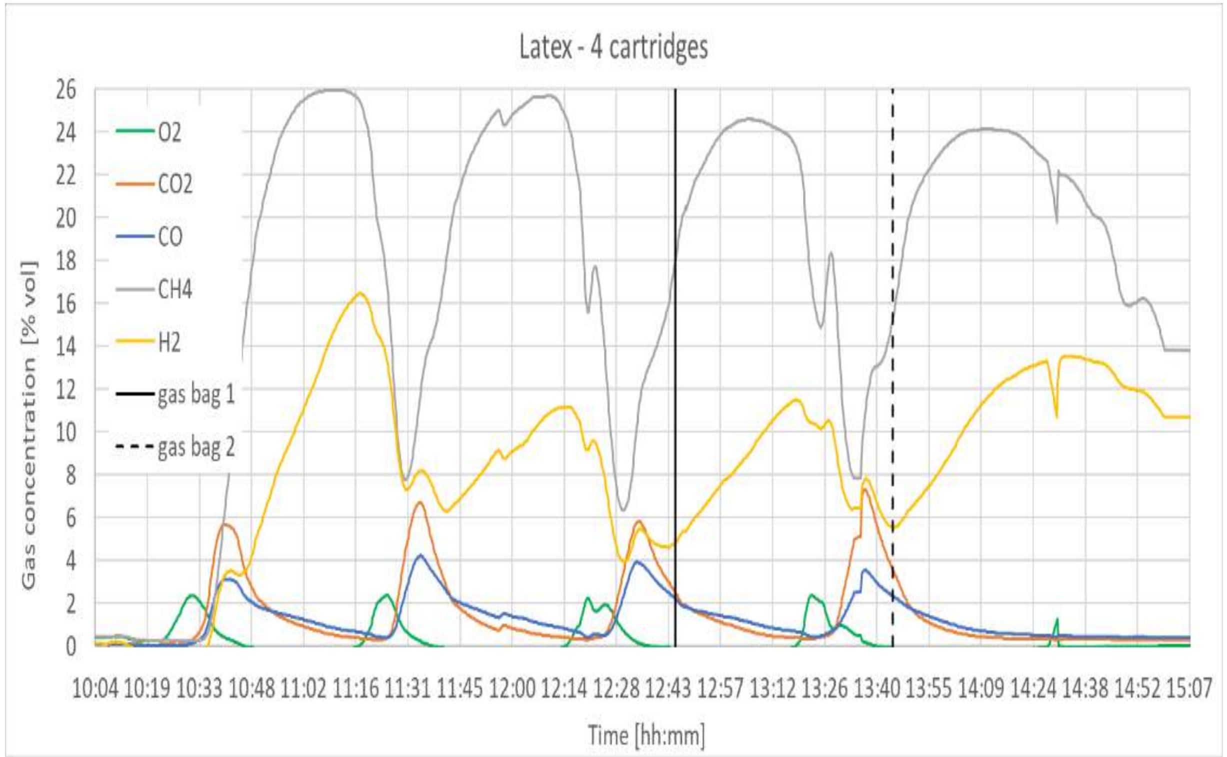
- Natural gas heaters allow fast heating of the reactor
- Heating cartridges and their content to setpoint temperature takes considerably more time
- Slow pyrolysis process
- Substantial energy consumption for process heat due to pilot plant operation not being optimized; room for optimization includes:
  - cartridge filling degree (more mass processed per batch)
  - way of processing (in series/parallel, reduce placement time between cartridges)
  - installation size (only 4 cartridge positions, for tests sometimes only 1 or 2 used)
  - minimizing heat losses
  - utilizing flue gas heat



Temperature profiles in the reactor (blue lines), the empty cartridge (red/yellow lines) and the cartridge filled with latex (green lines)

RESULTS (2)
PYROLYSIS GAS COMPOSITION

- Semi-continuous, fed-batch operation
- Some initial oxygen, because no cartridge flushing before pyrolysis (selected operating condition)
- Latex pyrolysis gas: energy content 57 MJ/kg (HHV), composition* mainly methane (34% vol), hydrogen (14% vol), ethane (13% vol), ethene (10% vol) and propene (6% vol), significant amounts of sulphur compounds
- Tick pyrolysis gas: energy content 24 MJ/kg (HHV), composition* mainly CO_2 (37% vol), CO (23% vol), methane (18% vol), hydrogen (7% vol), ethene (4.7% vol), ethane (3.4% vol) and propene (2.8% vol)
- Dry and wet whole mattress show in-between results

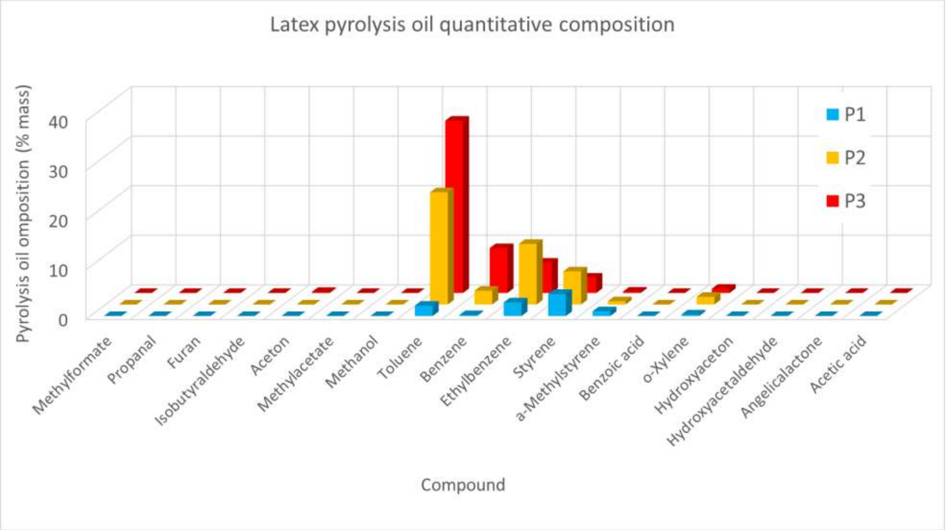


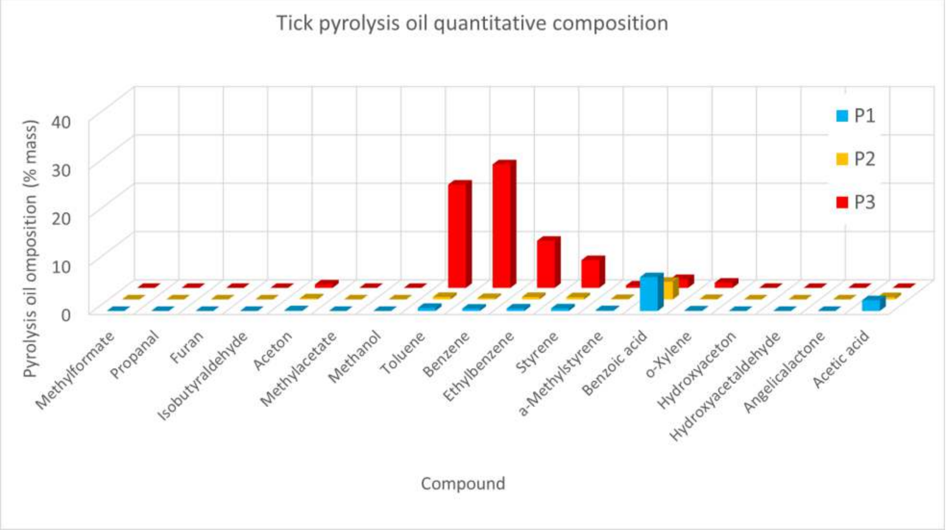
Permanent gas composition (dry basis) analysis during the pyrolysis of 4 consecutive cartridges filled with latex

* Composition on N_2-free, dry basis

RESULTS (3)
PYROLYSIS OIL COMPOSITION

- Latex oil fractions: energy content 41-42 MJ/kg (HHV), rich in styrene, toluene, benzene and ethylbenzene, significant amounts of sulphur compounds
- Tick oil fractions: energy content 6.5-39 MJ/kg (HHV), rich in benzoic acid (and styrene, toluene, benzene, ethylbenzene)
- Oils may be used for process heat, circular chemical feedstock or other fuel oil applications, but for latex sulphur levels (0.48-0.81% mass) point of attention
- Dry and wet whole mattress show in-between results





GC-MS quantitative results of the latex and tick pyrolysis oil (3 fractions discriminated)

RESULTS (4)
MASS & ENERGY BALANCES

- Results for mass and energy balances and pyrolysis oil compositions somewhat obscured by incomplete recovery of pyrolysis oil (stayed behind in the pilot plant piping)
- Latex converted mainly to pyrolysis oil (65- 85% mass), for tick a more even product distribution of 32% mass gas, 23-48% mass oil and 20% mass char
- Chemical energy in the pyrolysis products roughly equal to the chemical energy in the feedstock; latex: chemical energy mainly in pyrolysis oil (70-80%); tick: chemical energy mainly in char (35%) and gas (31%)
- For the latex case (4 cartridges), energy in gas and char not enough to sustain the pyrolysis process, part of the oil needed as well; for all other cases, energy demand for the pyrolysis process higher than energy contained in the pyrolysis products; but again: room for optimization
- Dry and wet whole mattress show in-between results

Feedstock:	Latex	Tick	Dry mattress	Wet mattress
obs:	4 cartridges	2 cartridges	2 cartridges	2 cartridges
Total mass in (kg)	80.80	40.71	27.28	18.50
Oil out P1 (kg)	45.54	4.47	3.52	3.47
Oil out P2 (kg)	5.31	2.54	0.98	0.86
Oil out P3 (kg)	1.41	2.17	1.24	0.41
Metal springs out (kg)	-	-	12.03	4.38
Char out (kg)	2.76	8.14	2.26	2.38
Gas out (kg)	7.96	13.05	4.08	5.04
Total mass out (kg)	62.99	30.37	24.12	16.54
Balance IN/OUT (%)	78.00	74.60	88.40	89.40

Feedstock:	Mass in (kg)*	Oil out (%m/m)	Char out (%m/m)	Gas out (%m/m)	Mass yield (%)	Mass missing (kg) *
Latex	80.80	64.7	3.4	9.9	78.0	14.1
Tick	40.71	22.6	20.0	32.1	74.6	10.3
Dry mattress	15.25	37.7	14.8	26.8	79.2	3.2
Wet mattress	14.12	33.6	16.8	35.7	86.1	2.0

Overall mass balances; * values presented on a fuel-material basis (not counting with the metal springs)

SUMMARY CONCLUSIONS (1)

- Successful measurement campaign for 4 different mattress recycling feedstocks, pyrolyzed in the Enerpy pilot plant at 1 temperature level (600 ºC) providing detailed, accurate insight in plant performance and pyrolysis product quality
- Process conditions not optimized; e.g., cartridge filling degree and way of processing, installation size (only 4 cartridge positions), minimizing heat losses and utilizing flue gas heat present opportunities for improvement
- Slow pyrolysis (e.g., 1h15m for a cartridge with 20 kg latex) required substantial gross specific energy consumption (natural gas in case of this pilot plant), viz. 37-110 MJ per kilogram of feedstock; with full utilization of flue gas heat, remaining specific energy demand of 16-53 MJ/kg (with 19-40 MJ/kg feedstock higher heating values); however, plenty of room for optimization
- Results for mass and energy balances and pyrolysis oil compositions somewhat obscured by incomplete recovery of pyrolysis oil, however this had a limited impact on the quality of the results
- Dry and wet whole mattress generally show results in between latex and tick
- At 600 °C, latex converted mainly to pyrolysis oil, for tick a more even product distribution
- Chemical energy in the pyrolysis products roughly equal to the chemical energy in the feedstock; latex: chemical energy mainly in pyrolysis oil; tick: chemical energy mainly in char and gas
- For the latex case (4 cartridges), energy in gas and char not enough to sustain the pyrolysis process, part of the oil needed as well; for all other cases, energy demand for the pyrolysis process higher than energy contained in the pyrolysis products; but again: room for optimization

SUMMARY CONCLUSIONS (2)

- Pyrolysis gases significantly different:
  - Latex: energy content 57 MJ/kg (HHV), mainly methane, hydrogen, ethane, ethene and propene, significant amounts of sulphur compounds
  - Tick: energy content 24 MJ/kg (HHV), mainly CO_2, CO, methane, hydrogen, ethene, ethane and propene
  - Gases may be used to provide process heat, if proper gas cleaning applied; ethane, ethene and propene might be recovered as circular building blocks for the chemical industry

- Pyrolysis oil composition significantly different:
  - Latex: energy content 41-42 MJ/kg (HHV), rich in styrene, toluene, benzene and ethylbenzene, significant amounts of sulphur compounds
  - Tick: energy content 6.5-39 MJ/kg (HHV), rich in benzoic acid (and styrene, toluene, benzene, ethylbenzene)
  - Oils may be used for process heat or other fuel oil applications, but for latex sulphur levels point of attention; significant amounts of valuable compounds might be recovered as circular building blocks for the chemical industry

- Pyrolysis char:
  - Ash elements end up mainly in the char, except most volatile elements (e.g., S and Cl)
  - Latex: char not suitable for direct use as a fuel for process heat due to large amounts of sulphur, bromine, chlorine and fluorine
  - Tick: significantly lower amounts of these elements, but much richer in N leading to NO_x formation during combustion

RECOMMENDATIONS

- Further **optimize the measurement campaigns**: ensure complete oil recovery (to avoid mixing of oil from different runs) and monitor electricity consumption
- Assess options for **process optimization** (in view of demo/full-scale design): e.g., cartridge filling degree and way of processing, installation size, minimizing heat losses, and recovery and utilization the heat in the flue gases
- Conduct further piloting to determine **optimum process conditions** (in particular pyrolysis temperature) for each feedstock, e.g. in terms of optimizing product composition
- Conduct further studies and experimental work to assess the **potential for higher-added-value application** of the pyrolysis oil to create circularity / loop closure and boost the business case, concerning:
  - Staged condensation approach
  - Possible selective separation/extraction of specific compounds (e.g., styrene, toluene, benzene, ethylbenzene)
  - Development of specific applications with industry partners
- To a certain extent, this may hold for the pyrolysis gas as well (e.g., ethene, propene) albeit in more specialized applications

THANK YOU FOR YOUR TIME

TNO Energy Transition

Jaap Kiel

Email: jaap.kiel@TNO.nl

Tel: +31 (0) 6 26 43 49 26

TNO innovation for life