«Development and demonstration of an ecological, innovative system for in house waste recycling»

An innovative, ecological system for in-house recycling of municipal solid waste (paper, plastic and metal packaging waste)

D. Xevgenos, N. Athanasopoulos, P. Kostazos, D. Manolakos, M. Kasidoni, K. Moustakas, D. Malamis, M. Loizidou

Dimitrios Xevgenos
Mechanical Engineer, NTUA
d.xevgenos@gmail.com

Presentation Outline

- Introduction
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- Conclusions

Presentation Outline

- **Introduction**
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- Conclusions

Links between the use of material sources and waste

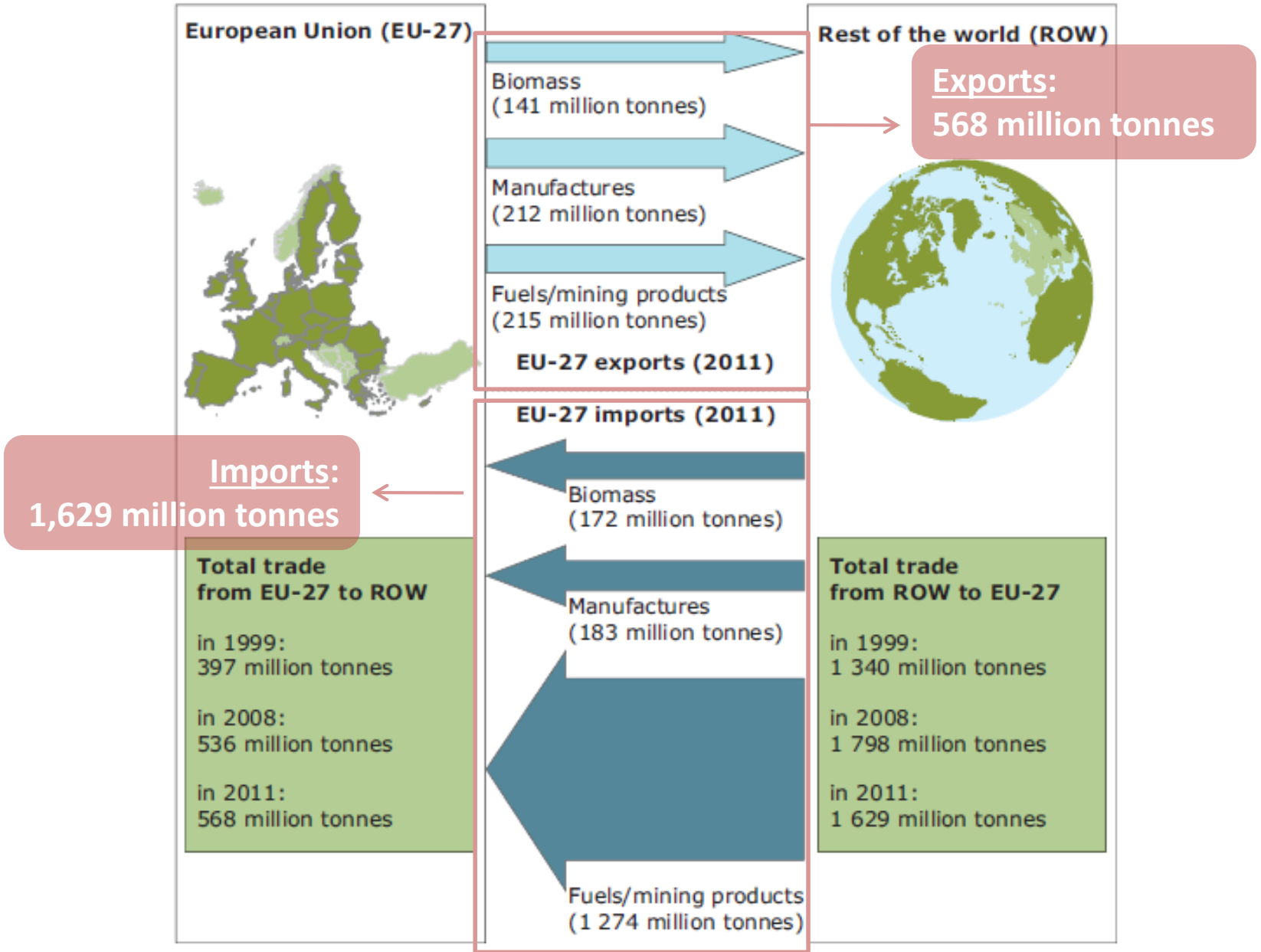
Role of waste in resource supply

- Much of the waste we throw away can be recycled. Recycling reduces the amount of waste that ends up in landfill sites, while cutting down on the amount of material needed from the natural environment.

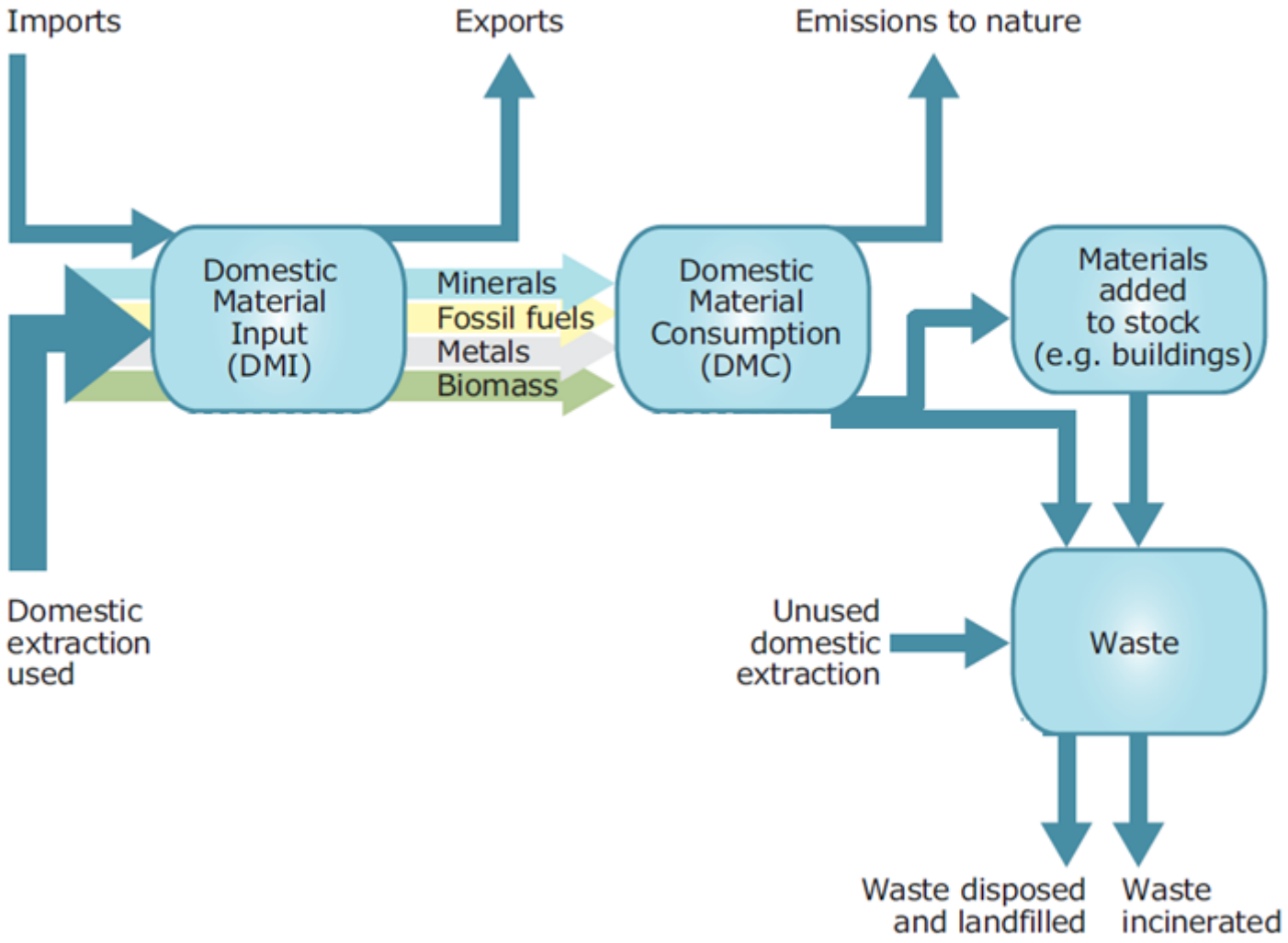
- This is important because Europe is dependent on imports of scarce raw materials, and recycling provides EU industries with essential supplies recovered from waste such as paper, glass, plastic and metals, as well as precious metals from used electronic appliances.

Source: *Material resources and waste — 2012 update (2012)*

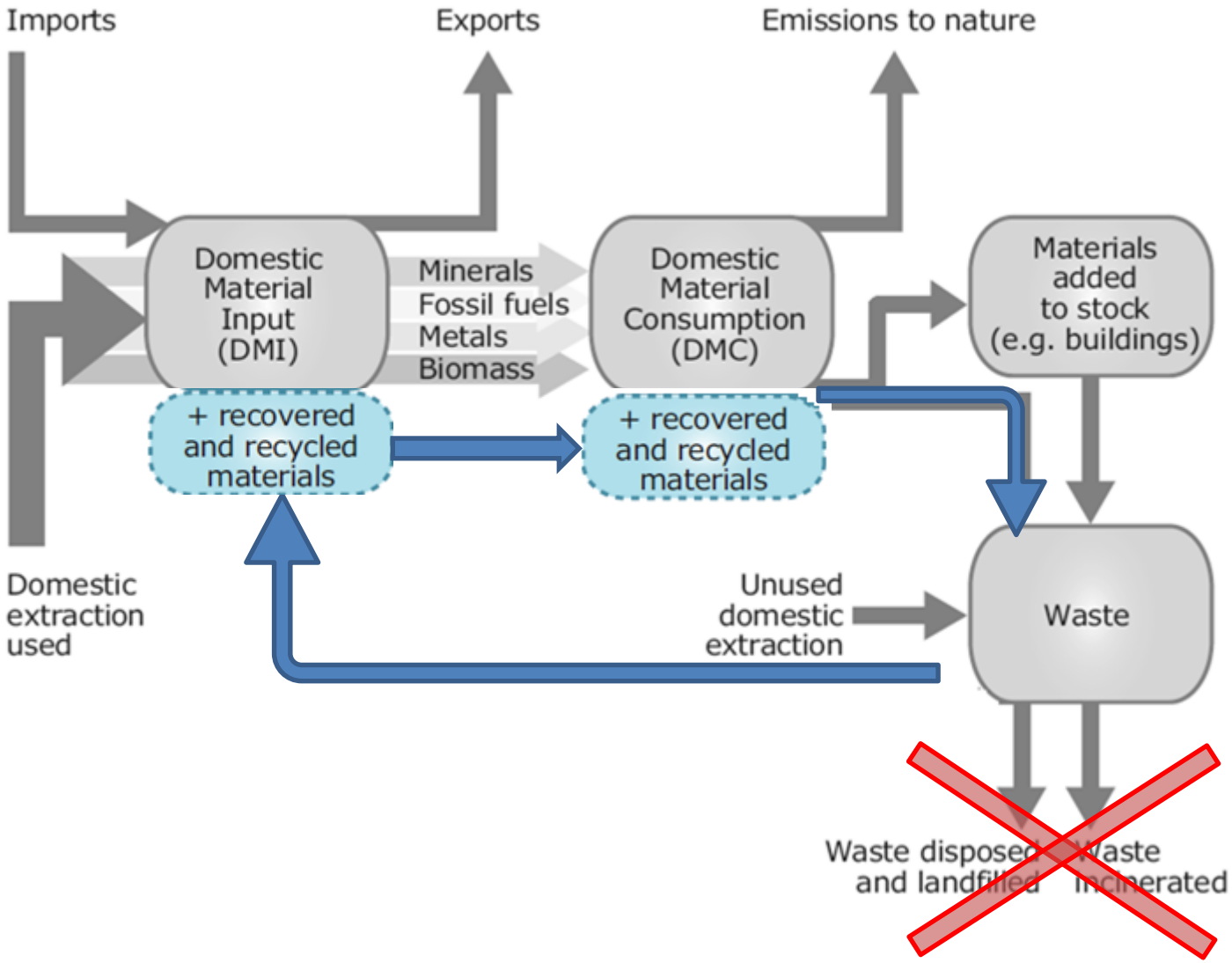
EU-27 physical trade balance with the rest of the world, 2011



Linear lifecycle



Closed-loop lifecycle

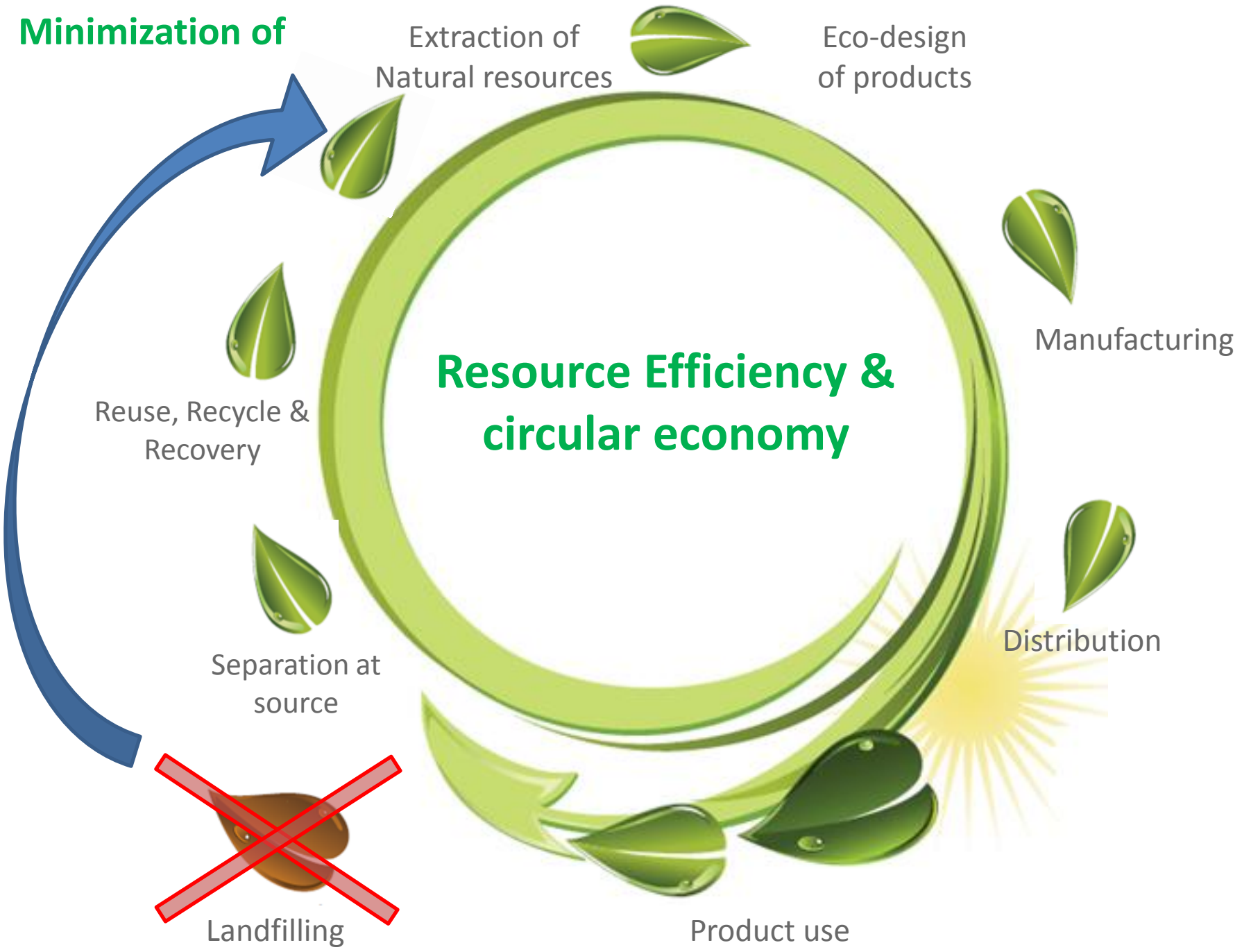


Introduction: Waste & natural resources

- Each year in the European Union:
  - we consume around 7.3 billion tonnes of resources and
  - we throw away around 3 billion tonnes of waste,
  - of which only 40% is being re-used or recycled, the rest going to landfill or incineration.

Introduction: Waste & natural resources

- If this quantity of waste was recycled then:
  - the equivalent of 148 million tonnes of CO_2 emissions could be avoided annually;
  - Around 5.25 billion euro would be saved from the recovery of recyclables such as paper, glass, plastics, aluminium and steel per year.
  - 500,000 new jobs at least would be created.


Minimization of
Extraction of Natural resources
Eco-design of products
Manufacturing
Distribution
Product use
Landfilling
Separation at source
Reuse, Recycle & Recovery
Resource Efficiency & circular economy

Presentation Outline

- Introduction
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- Conclusions

Presentation Outline

- Introduction
- **Preliminary Design Considerations**
- Experimental & Sensitivity Analysis
- Conclusions

Article 11

Re-use and recycling

1. Member States shall take measures, as appropriate, to promote the re-use of products and preparing for re-use activities, notably by encouraging the establishment and support of re-use and repair networks, the use of economic instruments, procurement criteria, quantitative objectives or other measures.

Member States shall take measures to promote high quality recycling and, to this end, shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors.

Subject to Article 10(2), by 2015 separate collection shall be set up for at least the following: paper, metal, plastic and glass.

2. In order to comply with the objectives of this Directive, and move towards a European recycling society with a high level of resource efficiency, Member States shall take the necessary measures designed to achieve the following targets:

(a) by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as

4. By 31 December 2014 at the latest, the Commission shall examine the measures and the targets referred to in paragraph 2 with a view to, if necessary, reinforcing the targets and considering the setting of targets for other waste streams. The report of the Commission, accompanied by a proposal if appropriate, shall be sent to the European Parliament and the Council. In its report, the Commission shall take into account the relevant environmental, economic and social impacts of setting the targets.

5. Every three years, in accordance with Article 37, Member States shall report to the Commission on their record with regard to meeting the targets. If targets are not met, this report shall include the reasons for failure and the actions the Member State intends to take to meet those targets.

Article 12

Disposal

Member States shall ensure that, where recovery in accordance with Article 10(1) is not undertaken, waste undergoes safe disposal operations which meet the provisions of Article 13 on the protection of human health and the environment.

([1]) OJ L 332, 9.12.2002, p. 1.

- Waste Framework Directive (2008/98/EC)

Waste Stream		Price Range (€/tonne)	
Paper	News & PAMs	105	117
	Mixed papers: domestic	70	76
	Mixed papers: export	76	82
	OCC: domestic	82	88
	OCC: export	94	100
	Multigrade	117	123
	Best white no.2	205	217
Plastic	Clear PET	281	340
	Coloured PET	59	70
	Mixed Bottles	100	188
	Natural HDPE	387	445
	Mixed HDPE	176	188
Other plastics	LDPE 98/2	293	305
Ferrous metals	Grade 0A	135	158
	Grade 4C	147	176
	Grade 7B	117	135
	Grade 10	111	135
Non-Ferrous metals	Copper dry bright wire	5157	5274
	Aluminium pure cuttings	1055	1113
	Lead batteries	586	645
	18/8 stainless steel solids	797	961
Cans	Aluminium: baled/densified	762	820
	Steel	141	188
	Mixed	129	176
Glass	Clear	41	53
	Amber	29	47
	Green	18	35
	Mixed	6	29

- Price range per waste stream and quality

Final selection of waste streams

Taking into consideration the above, six (6) different waste streams will be separately sorted:

- Ferrous containers (e.g. tin cans);
- Aluminium;
- Plastic made of high density polyethylene (HDPE);
- Plastic containers (such as water bottles);
- Drink Cardboard boxes (such as milk containers);
- Printed paper (collected, not compressed).

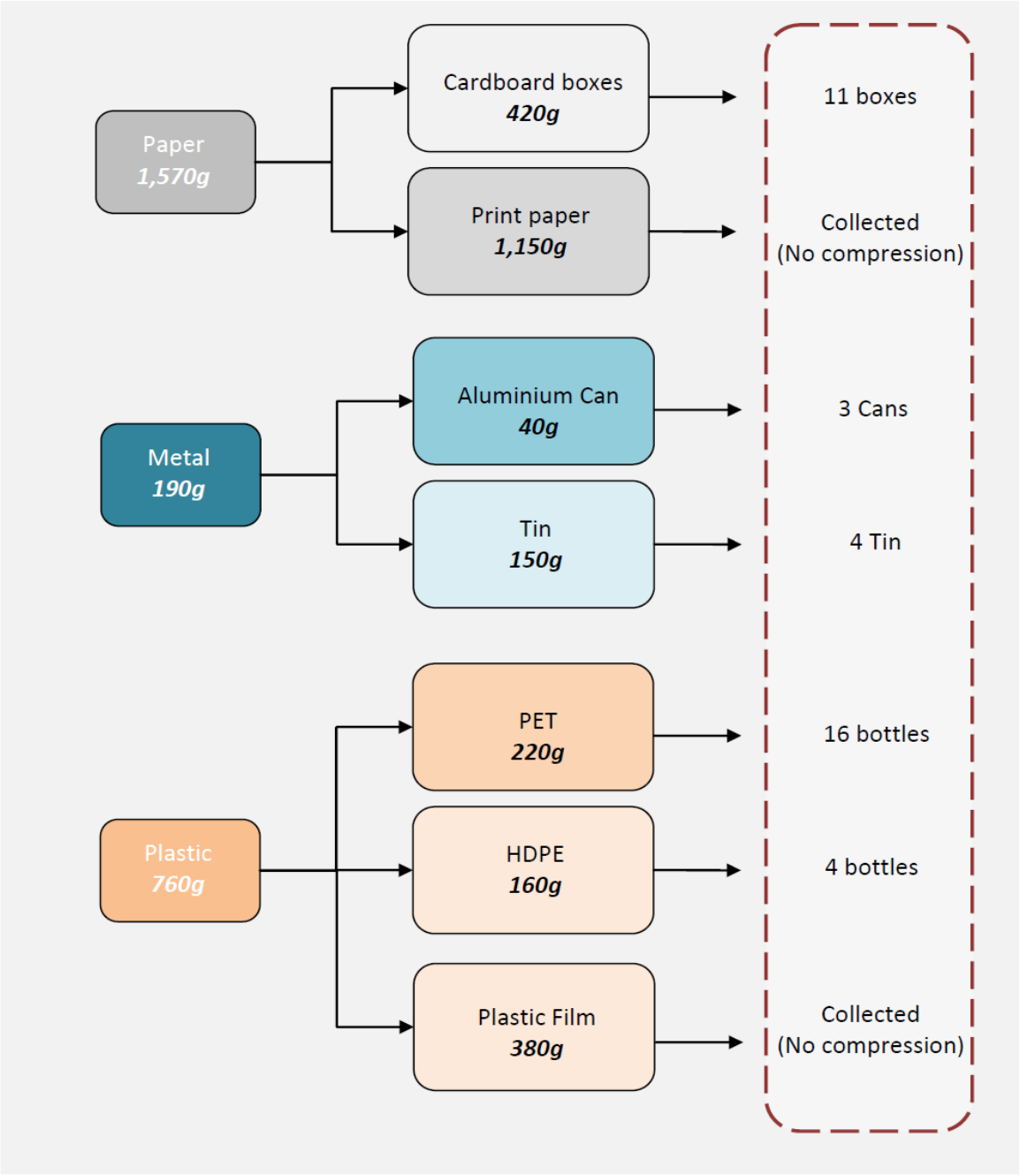
Presentation Outline

- Introduction
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- Conclusions

Presentation Outline

- Introduction
- Preliminary Design Considerations
- **Experimental & Sensitivity Analysis**
- Conclusions

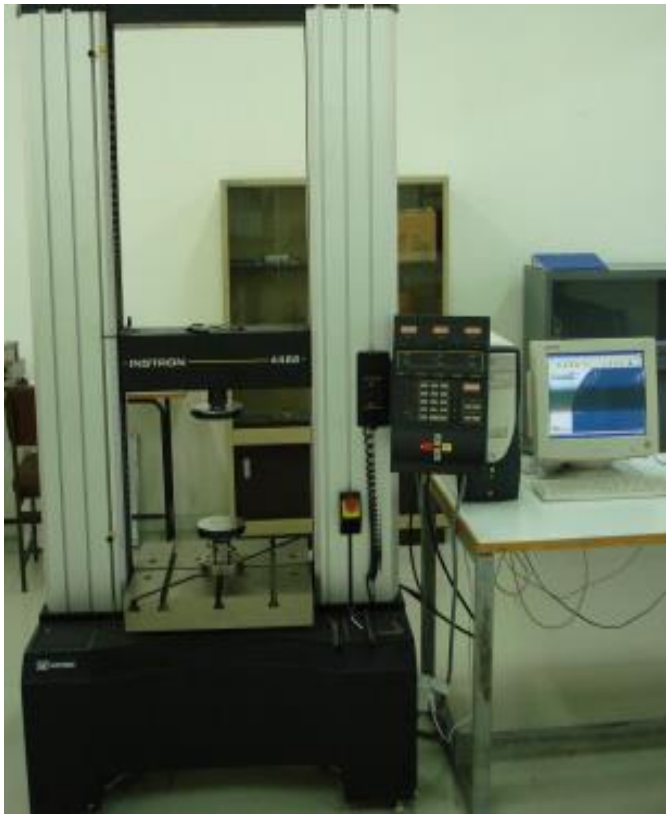
Recyclable household waste simulated and tested

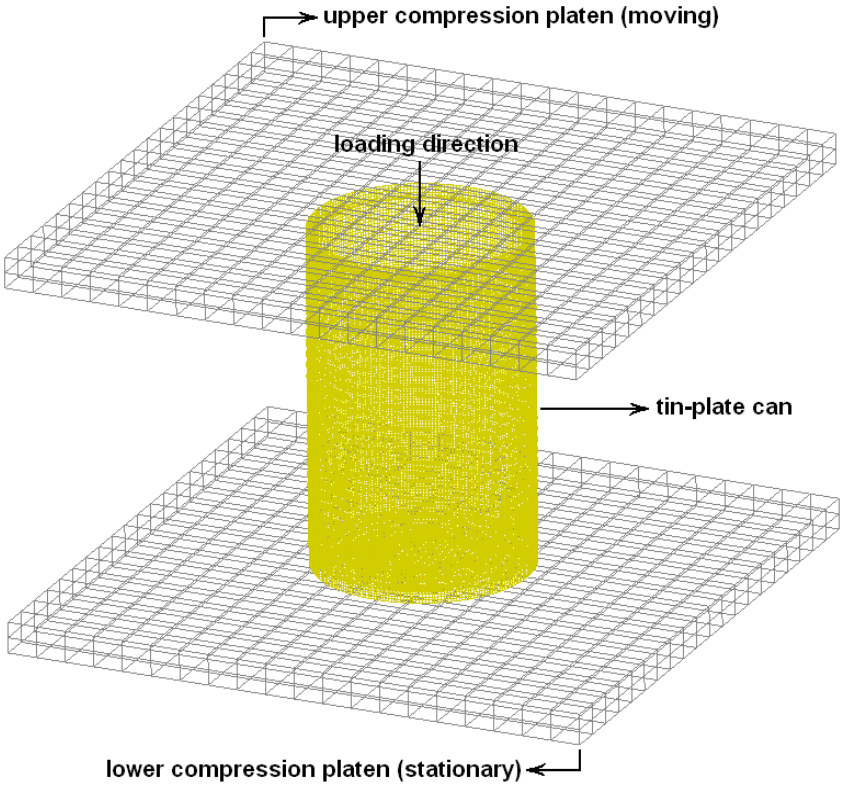


- Typical packaging waste generated by a typical household

(4-member family)

Experimental equipment/set-up





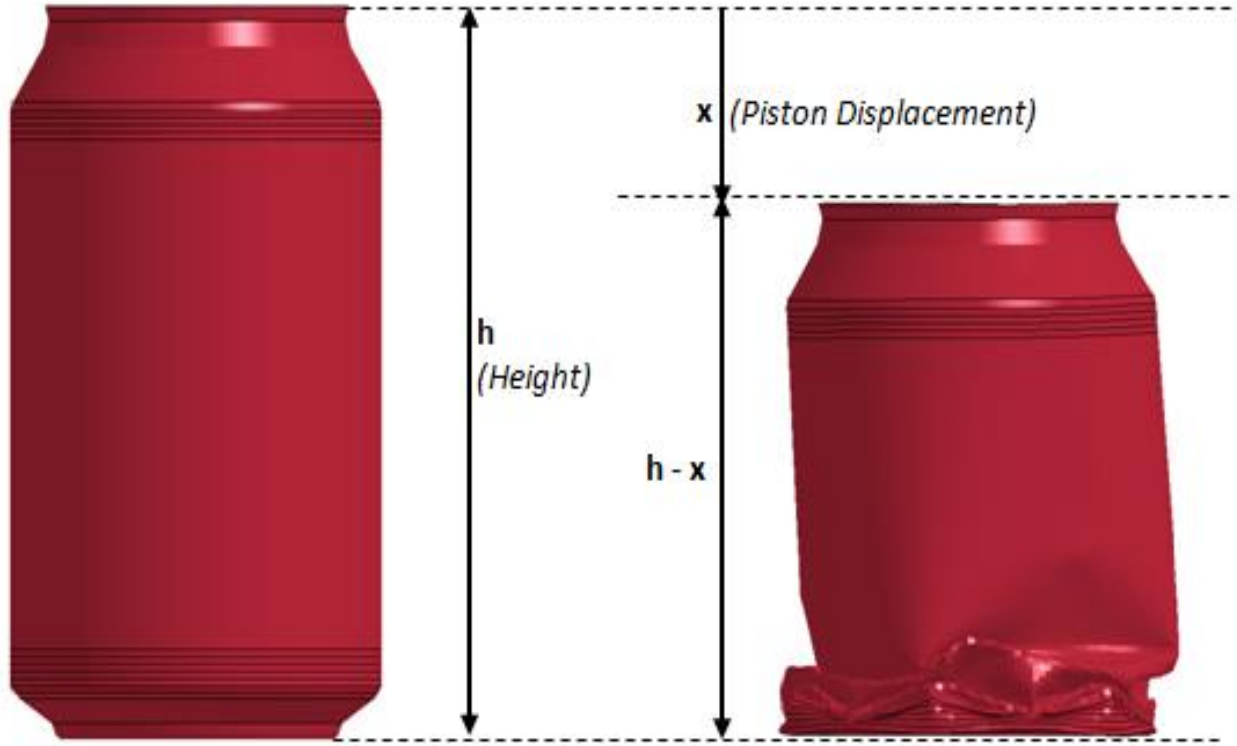
Fully automated INSTRON 4482 Universal Testing Machine of 100 kN loading capacity

The explicit FE Code LS-DYNA was used to simulate the collapse mechanism.

The compression ratio presented in the table is given by the following formula:

$$Compression\ Ratio = \frac{h}{h - x}$$

In the following figure the example of aluminium can is given on how the compression ratio is used within this work.

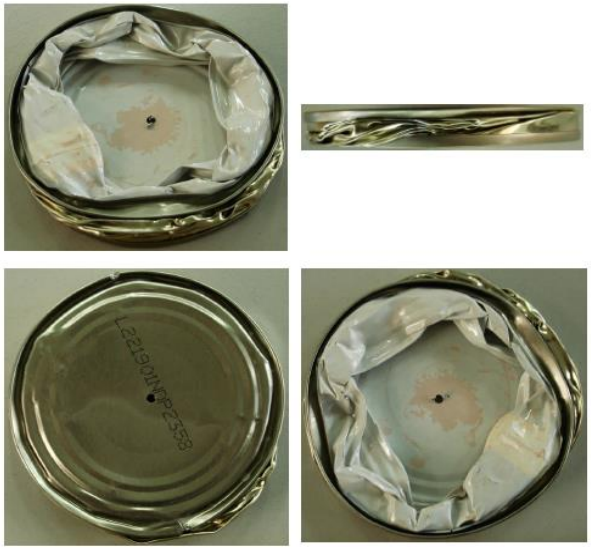


Tins

Height [mm]:	109
Diameter [mm]:	Ø 73.3
Wall thickness [mm]:	0.17 – 1.15
Initial Volume [lt]:	0.4
Weight [g]:	41.9

Design Variables:
- Energy absorbed by the tin [J], *see Diagram 5-1*;
- Compressive Load Requirements [N], *see Diagram 5-2*.

Note: For the purposes of the energy calculations, it has been assumed that four tins are disposed of every day by a 4-member family (see also Section 4.3).



FEM Analysis

1 2 3 4 5

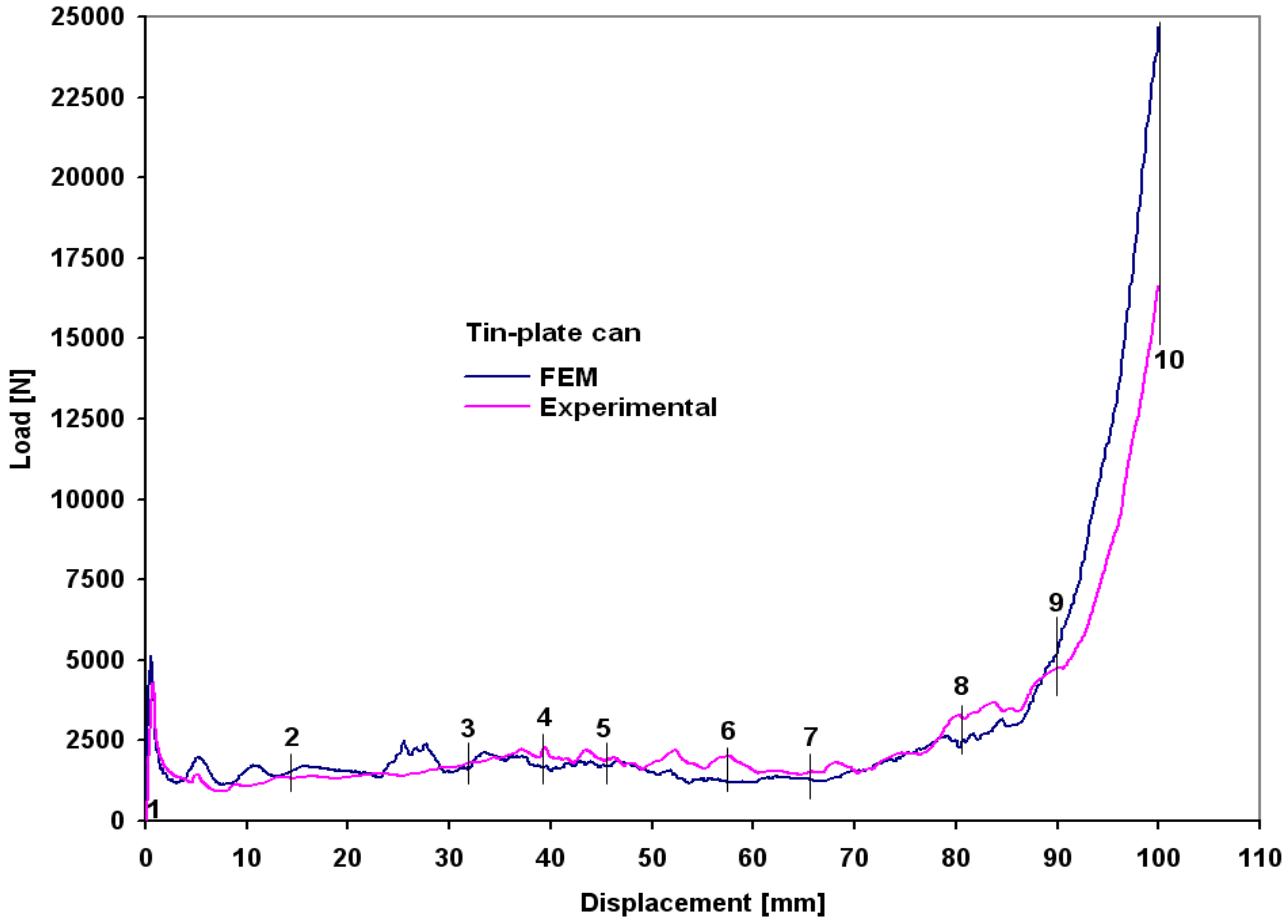
6 7 8 9 10

Experimental

1 2 3 4 5

6 7 8 9 10

Simulation VS Experimental



Results

- **Compression Ratio**: 12 or more;
- **Final Volume**: 0.4 liters / 12 = 0.03liters;

  If we consider a small bag (35 lt) and assume that 4 tins are disposed daily by a 4-member family (0.12liters), it can be achieved a 42 weeks storage (~1 year storage)
- **Compressive Load Requirements**: ~2.4 tonnes;
- **Energy requirements**: 368.5J (~0.1Wh). Assuming 4 tins disposed of daily, the total energy required is around 0.4Wh (or 146 Wh on a yearly basis).

2. Aluminium cans

Height [mm]:	115.4
Diameter [mm]:	Ø 66.1
Wall thickness [mm]:	0.10 – 1.16
Initial Volume [lt]:	0.33
Weight [g]:	12.4

Design Variables:

- Energy absorbed by the aluminium can [J], *see Diagram 5-3*;
- Compressive Load requirements [N], *see Diagram 5-4*.

Note: For the purposes of the energy calculations, it has been assumed that three aluminium cans are disposed of every day by a 4-member family. (see also Section 4.3).

FEM Analysis

1 2 3 4 5

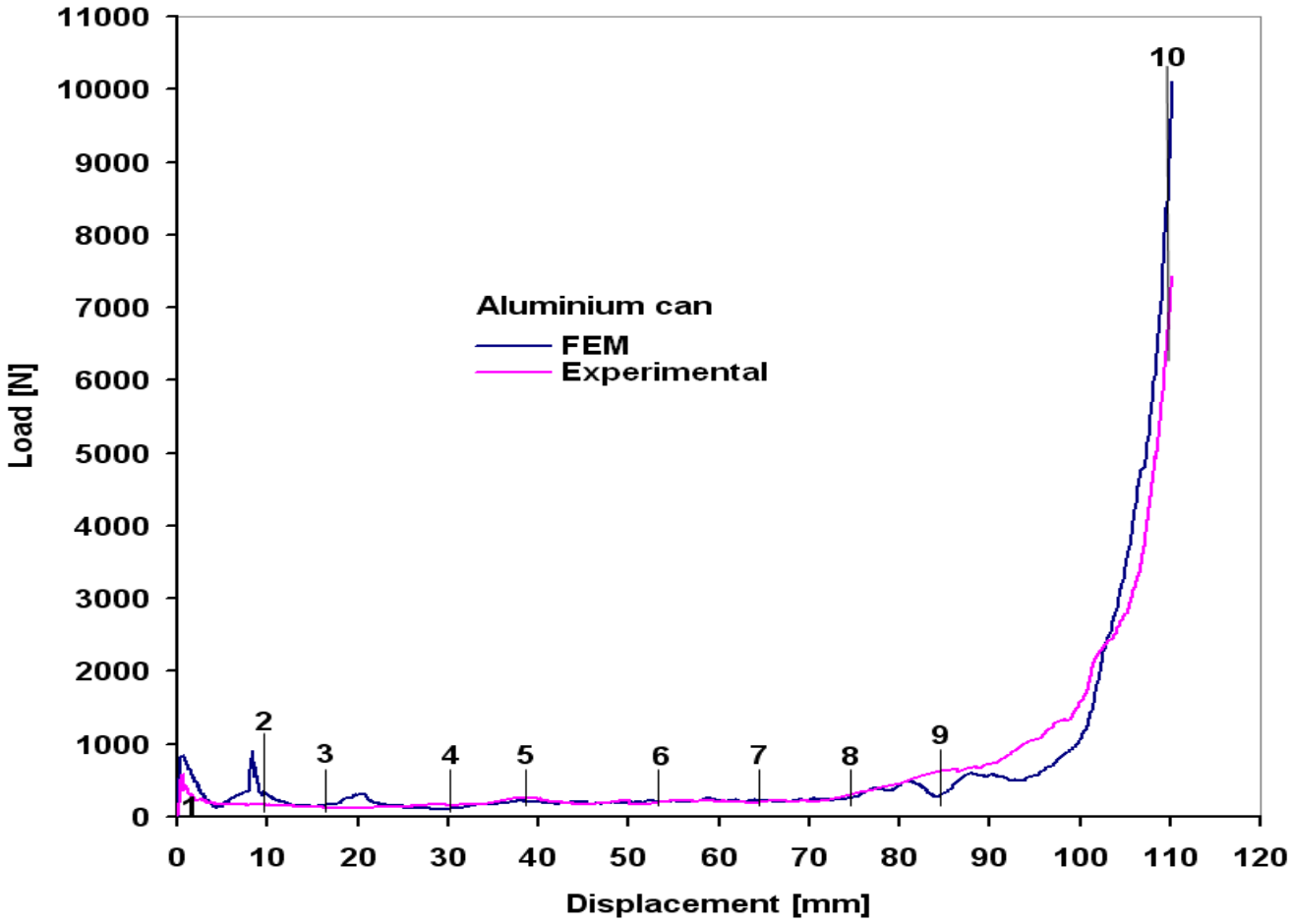
6 7 8 9 10

Experiment

1 2 3 4 5

6 7 8 9 10

Simulation VS Experimental



Results

- **Compression Ratio**: 21 or more;
- **Final Volume**: 0.33 liters / 21 = 0.0157liters;

  If we consider a small bag (35 lt) and assume that 3 aluminium cans disposed of daily by a 4-member family (0.0471liters), it can be achieved a 2 years storage.
- **Compressive Load Requirements**: ~0.9 tonnes;
- **Energy requirements**: 84.37J (~0.023Wh).

  Assuming three cans disposed of daily, the total energy required is around 0.069Wh (or 25 Wh on a yearly basis).

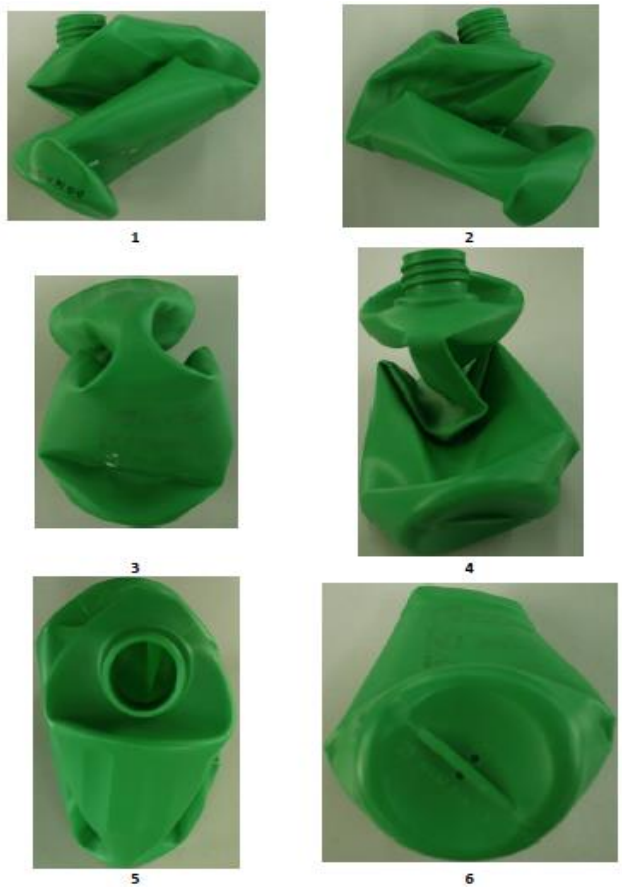
3. HDPE bottles

Height [mm]:	261.2
Diameter [mm]:	Ø 74.5
Wall thickness [mm]:	0.43 – 3.45
Initial Volume [lt]:	0.75
Weight [g]:	43

Design Variables:

- Energy absorbed by the HDPE bottle [J], *see Diagram 5-5*;
- Compressive Load requirements [N], *see Diagram 5-6*.

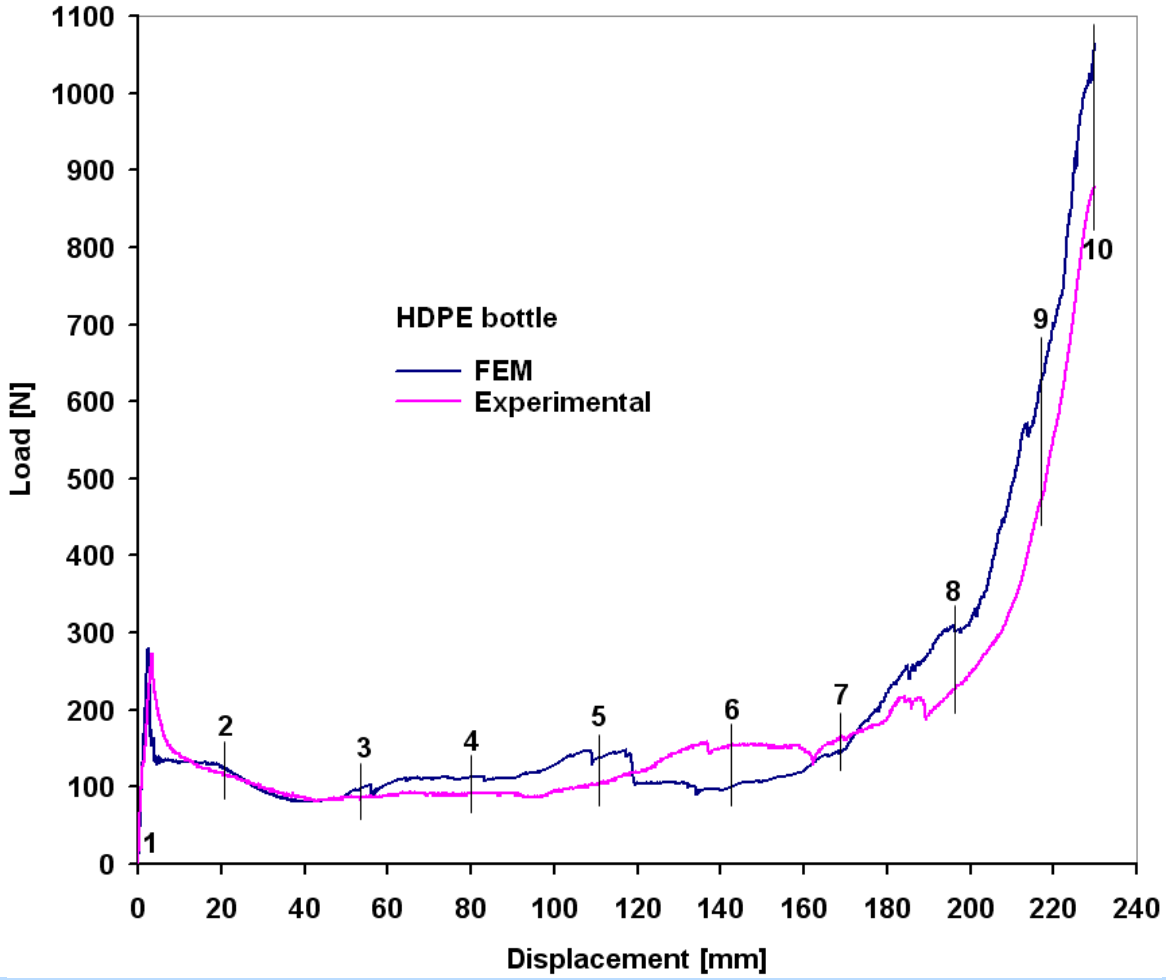
Note: For the purposes of the energy calculations, it has been assumed that four HDPE bottles are disposed of every day by a 4-member family (see also Section 4.3).



FEM Analysis

Experiment

Simulation VS Experimental



Results

- **Compression Ratio**: 8 or more;
- **Final Volume**: 0.75 liters / 8 = 0.09375liters;

  If we consider a small bag (35 lt) and assume that 4 HDPE bottles are disposed daily by a 4-member family (0.375 liters), it can be achieved a thirteen weeks storage.
- **Compressive Load Requirements**: ~0.1 tonnes;
- **Energy requirements**: 54.91J (~0.015Wh).

  Assuming four bottles disposed daily, the total energy required is around 0.06Wh (or 22 Wh on a yearly basis).

4. PET bottles

Height [mm]:	210
Diameter [mm]:	Ø 65.3
Wall thickness [mm]:	0.14 – 1.5
Initial Volume [lt]:	0.5
Weight [g]:	13.5

Design Variables:

- Energy absorbed by the PET bottle [J], *see Diagram 5-7*;
- Compressive Load requirements [N], *see Diagram 5-8*.

Note: For the purposes of the energy calculations, it has been assumed that sixteen PET bottles are disposed of every day by a 4-member family (see also Section 4.3).

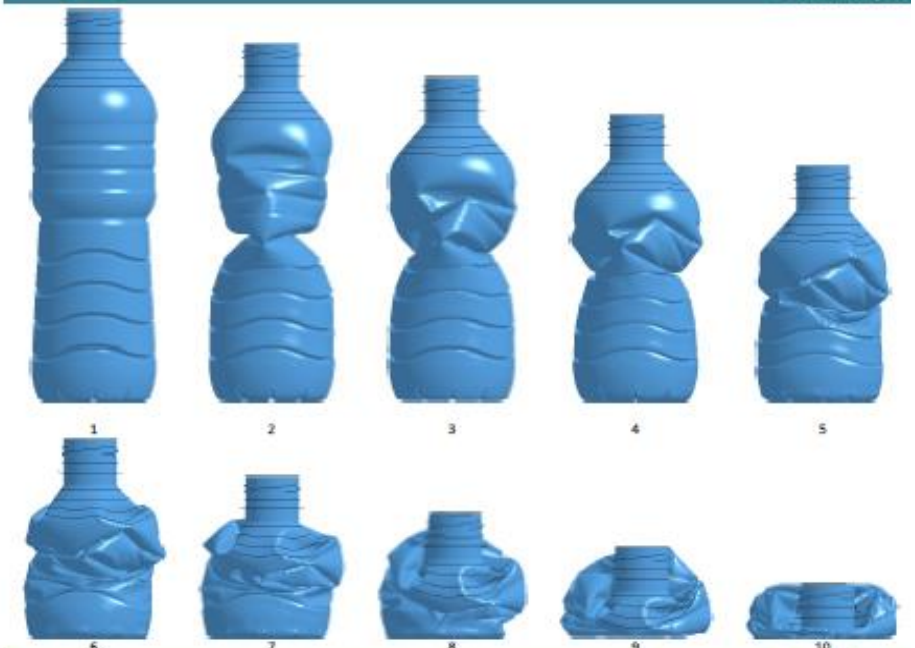
1

2

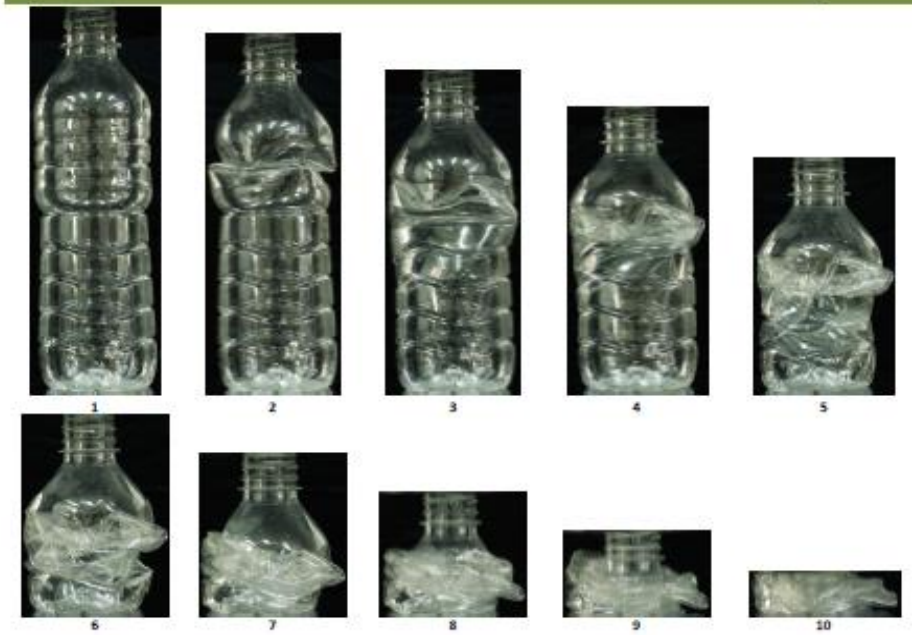
3

4

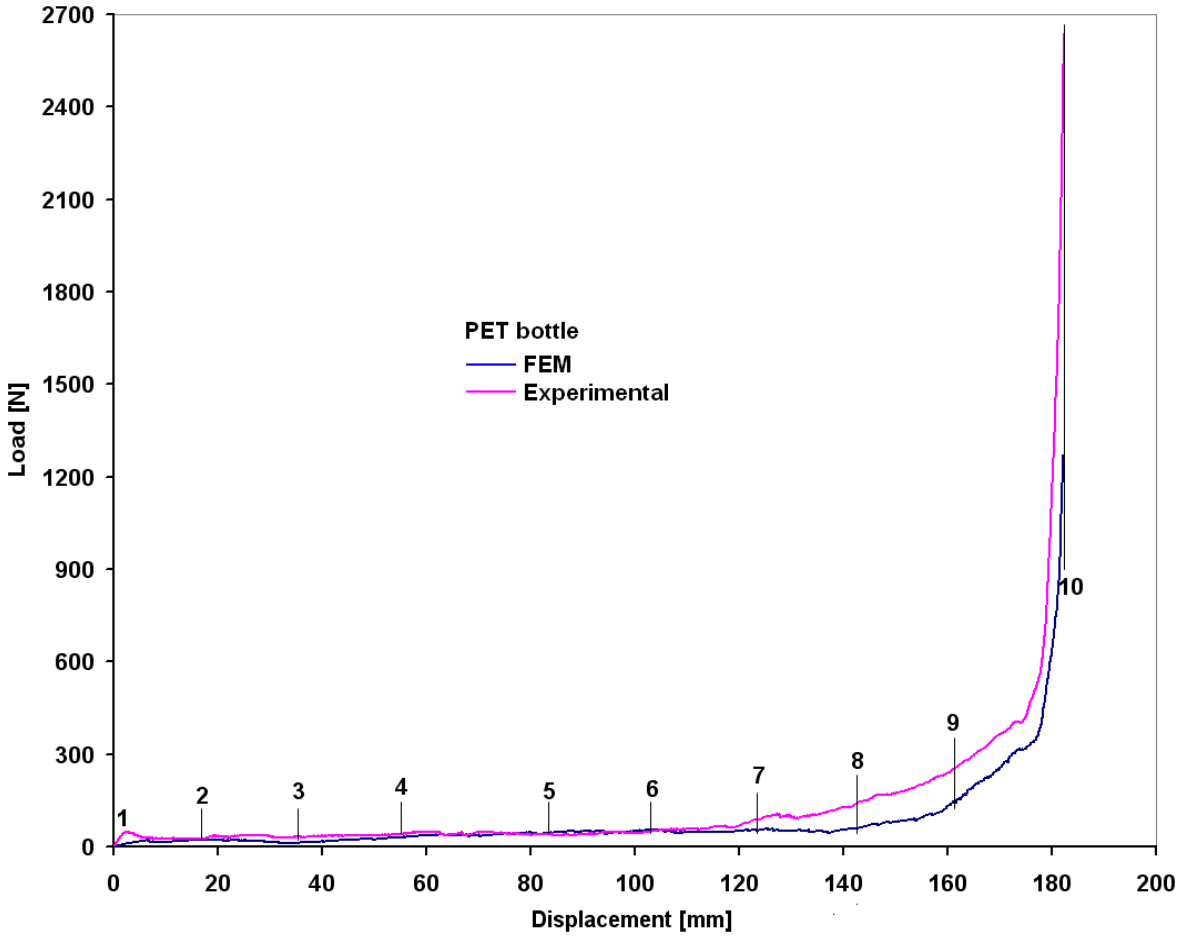
FEM Analysis



Experiment



Simulation VS Experimental



Results

- **Compression Ratio**: 7 or more;
- **Final Volume**: 0.5 liters / 7 = 0.071liters;

  If we consider a small bag (35 lt) and assume that 16 PET bottles are disposed daily by a 4-member family (1.136 liters), it can be achieved a four weeks storage.
- **Compressive Load Requirements**: ~0.13 tonnes;
- **Energy requirements**: 17.52J (~0.005Wh).

  Assuming sixteen PET bottles are disposed daily, the total energy required is around 0.08Wh (or 29.2 Wh on a daily basis).

4. Cardboard boxes & Tetrapak

Height [mm]:	244.1
Length [mm]:	65
Width [mm]	60
Wall thickness [mm]:	0.6 – 4.2
Initial Volume [lt]:	1
Weight [g]:	37.9

Design Variables:

- Energy absorbed by the drink cardboard box [J], *see Diagram 5-9*;
- Compressive Load requirements [N], *see Diagram 5-10*.

Note: For the purposes of the energy calculations, it has been assumed that eleven cardboard boxes are disposed of every day by a 4-member family (see also Section 4.3).

1

2

3

4

5

6

FEM Analysis

1 2 3 4 5

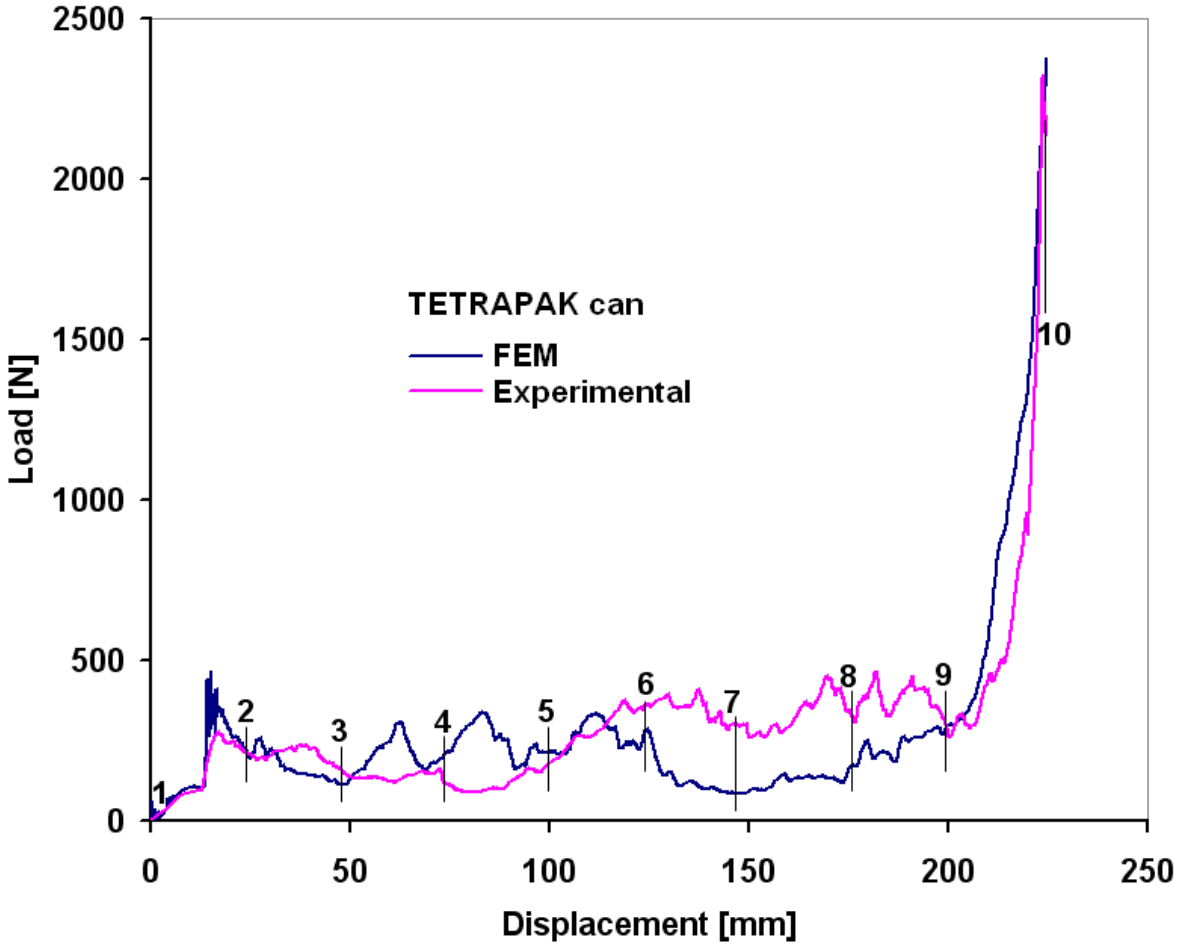
6 7 8 9 10

Experiment

1 2 3 4 5

6 7 8 9 10

Simulation VS Experimental



Results

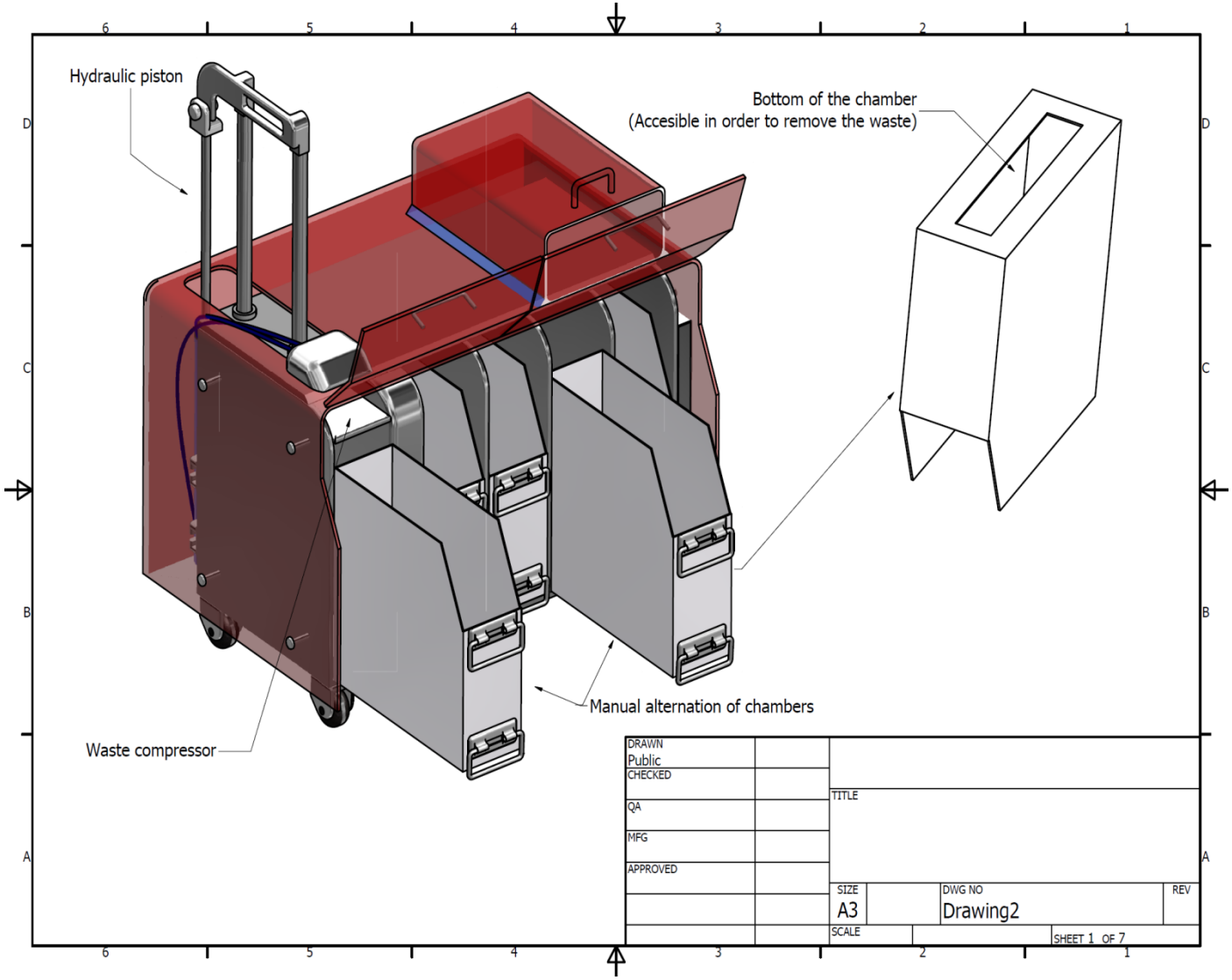
- **Compression Ratio**: 17 or more;
- **Final Volume**: 1 liter / 7 = 0.059 liters;

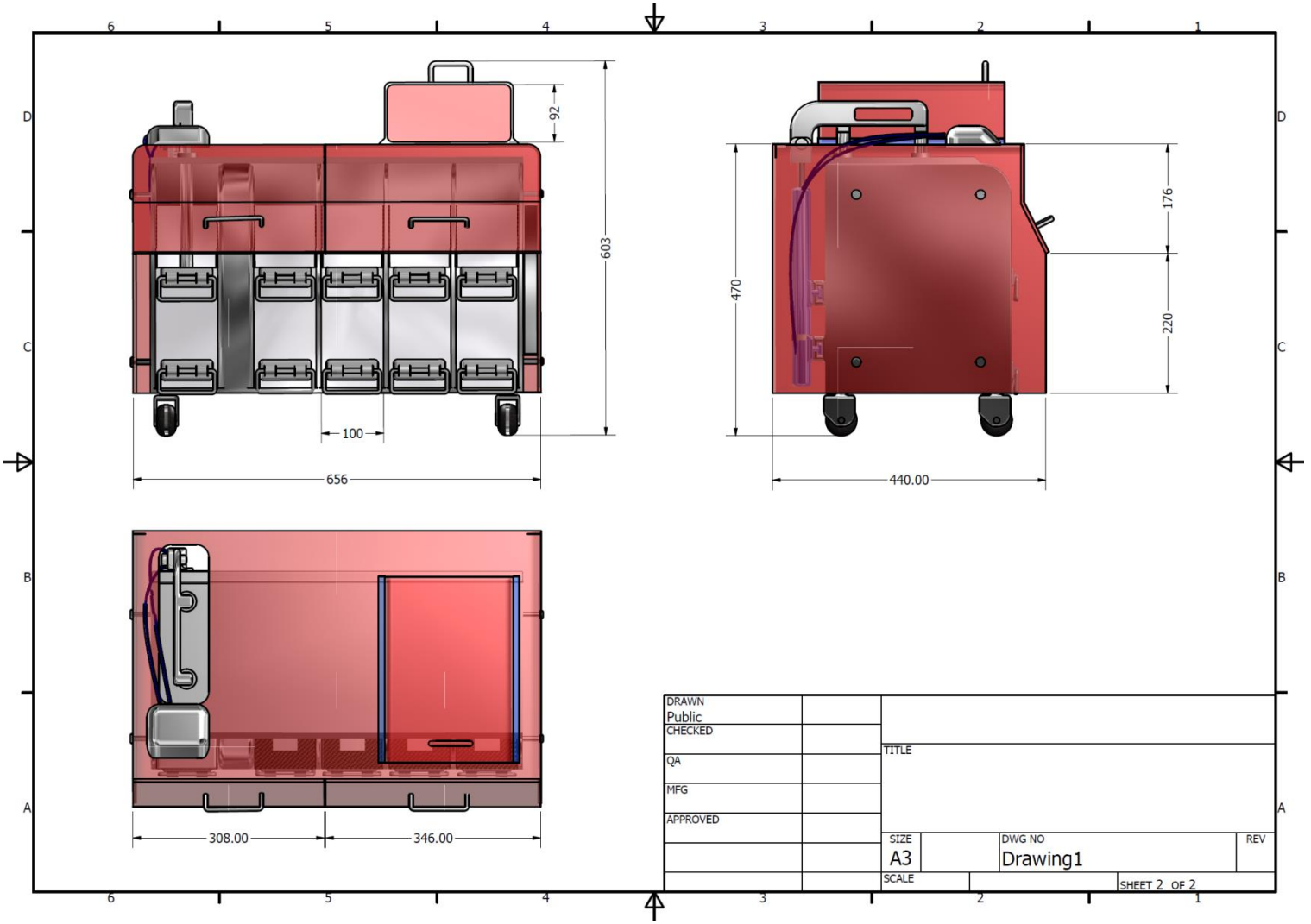
  If we consider a small bag (35 lt) and assume that 11 drink cardboard boxes are disposed daily by a 4-member family (0.065 liters), it can be achieved 1.5 year storage time.
- **Compressive Load Requirements**: ~0.42 tonnes;
- **Energy requirements**: 97.42J (~0.027Wh).

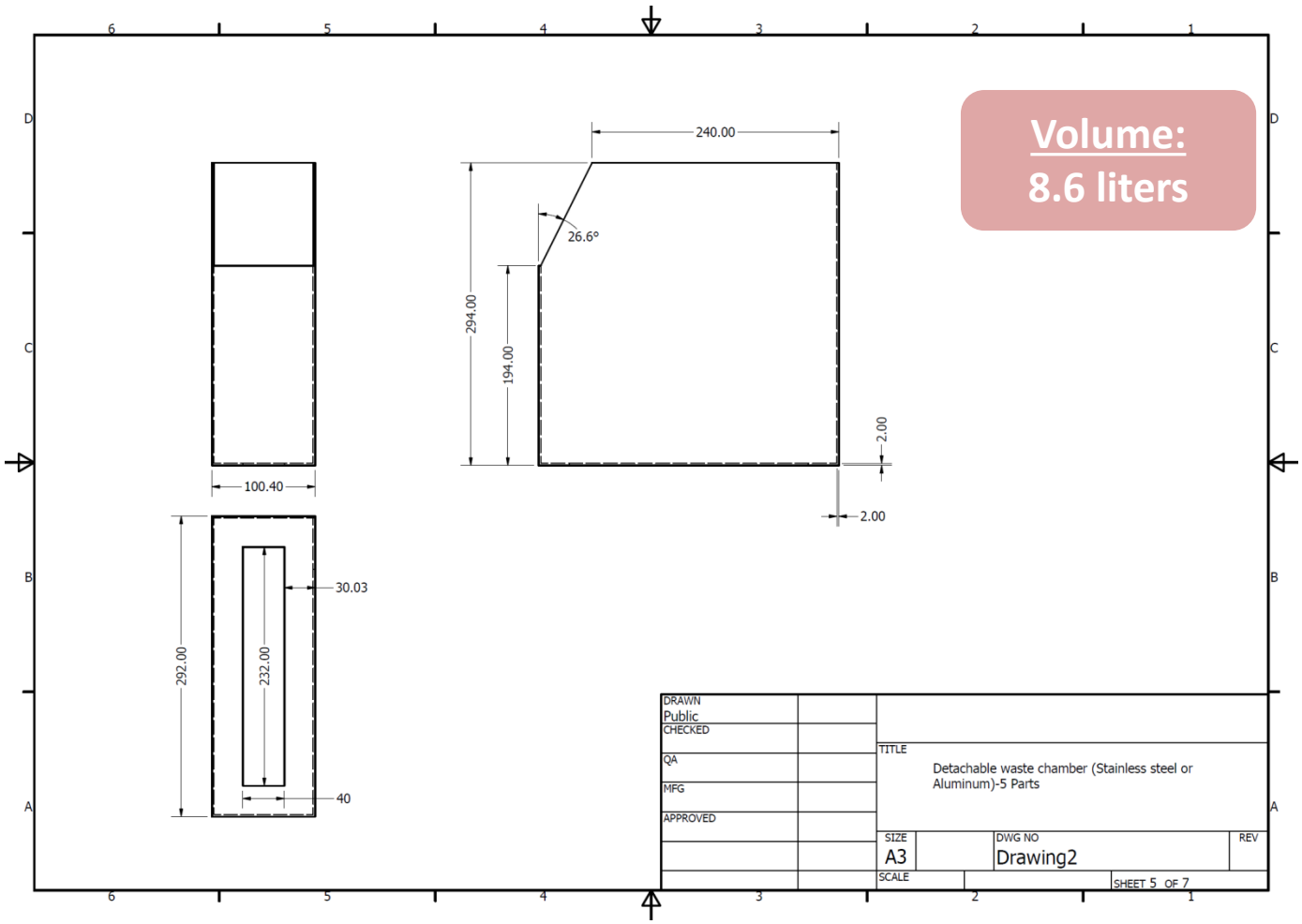
  Assuming eleven cardboard boxes are disposed daily, the total energy required is around 0.3Wh (or 108 Wh on a yearly basis).

Results

Item	Number	Compression ratio	Compressive Load (kg)	Energy per item (J)	Total energy (Wh)	
					Daily	Yearly
Tin can	4	12	2,400	368.5	0.4Wh	146 Wh
Aluminium can	3	22	900	84.37	0.07Wh	25.55 Wh
HDPE bottle	4	8.4	100	54.91	0.06Wh	21.9 Wh
PET bottle	16	7.55	130	17.52	0.08Wh	29.2 Wh
Tetrapak	11	17.4	422	97.42	0.3 Wh	109.5 Wh
				Total	0.91 Wh	~ 330 Wh (or 0.02€)


Hydraulic piston
Bottom of the chamber
(Accesible in order to remove the waste)
Manual alternation of chambers
Waste compressor
DRAWN
Public
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
A3
DWG NO
Drawing2
REV
SCALE
SHEET 1 OF 7


92
603
100
656
470
176
220
440.00
308.00
346.00
DRAWN
Public
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
A3
DWG NO
Drawing1
REV
SCALE
SHEET 2 OF 2



Volume:
8.6 liters

Presentation Outline

- Introduction
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- Conclusions

Presentation Outline

- Introduction
- Preliminary Design Considerations
- Experimental & Sensitivity Analysis
- **Conclusions**

Conclusions

- Turning waste into commodities and setting up resource efficient waste management systems: a need with not only an environmental rationale, but also a factor of competitiveness.
- The global waste market, from collection to recycling, is estimated at EUR 400 billion per annum and holds significant potential for job creation.
- Recycling must be promoted and energy recovery should be seen as a sub-optimal option so as to move towards zero waste and circular economies.

Conclusions

- This requires that new eco-innovative technologies are developed based on source separation techniques
- In some year we may realize that centralized treatment facilities may not be the solution to the waste management problem. This conference points to a new direction: the waste must be treated at source
- The Recycling@Home system provides a decentralized solution, with excellent results (quality) of end-products, since it is based on fine separation of different recyclable waste streams at source.