POLITECNICO
MILANO 1863

(CS)² @ DICA

FROM WASTE TREATMENT TO RESOURCES MANAGEMENT: STRENGTHS AND WEAKNESSES OF THE CIRCULAR ECONOMY CONCEPT

Prof. Mario GROSSO (mario.grosso@polimi.it)

Milano, February 12th, 2019

AWARE
Assessment on WAste and REsources

THE "AWARE" RESEARCH GROUP AT DICA – POLITECNICO DI MILANO

Assessment on **WA**ste and **RE**sources

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1 tenure-track assistant professor: L. Rigamonti

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3 research collaborators: C. Tua, E. Brivio, V. Arosio

AWARE
Assessment on WAste and REsources

www.aware.polimi.it

"AWARE" GROUP RESEARCH ACTIVITIES

- Environmental impact of waste treatment plants: mass flux analysis of macropollutants and toxic micropollutants, especially from incineration plants
- Mass and energy balances of integrated municipal waste management systems and of the different sub-units (e.g. material recycling, biological treatments, waste-to-energy plants)
- Waste management in developing countries
- Environmental evaluation of the integration and synergies between material and energy recovery from waste (e.g. recovery of metals and inert fraction from waste incineration bottom ash)
- Life Cycle Thinking approach (life cycle assessment and life cycle costing) applied to remediation technologies: solid waste treatment, waste water treatment, soil remediation
- Methodological developments of LCA
- Environmental evaluation of carbon capture and storage/utilisation technologies (CCS/CCU)

THE "AWARE" RESEARCH GROUP AT DICA – POLITECNICO DI MILANO

Activities are carried out at the Department of Civil and Environmental Engineering (DICA) and at the LEAP laboratory (Piacenza), within the MatER Research Centre, established in 2011

A strict connection with colleagues from Energy Engineering is established

AWARE
Assessment on WAste and REsources

www.aware.polimi.it

LEAP
Laboratorio Energia e Ambiente Piacenza

mater
materia & energia da rifiuti
materials & energy from refuse

www.mater.polimi.it

Outline

- Setting the scene: waste management and circular economy
- Waste prevention and re-use
- Recycling and its limitations
- The case of incineration bottom ash
- Prevention of food waste and its management
- A new perspective for circular economy

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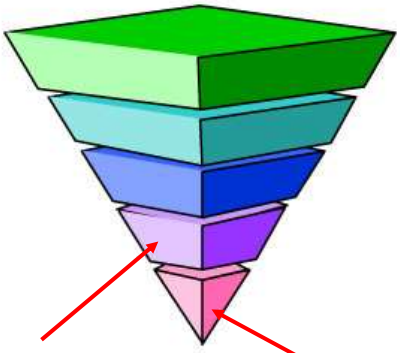
The Waste Framework Directive (2008/98/EC)

The waste hierarchy



Prevention
If you can't prevent, then....
Prepare for reuse
If you can't prepare for reuse, then....
Recycle
If you can't recycle, then....
Recover other value (e.g. energy)
If you can't recover value, then....
Disposal
Landfill if no alternative available.

High efficiency incineration

Landfill + low efficiency incineration

The Waste Framework Directive (2008/98/EC)

The waste hierarchy

"When applying the waste hierarchy, Member States shall take measures to encourage the options that deliver the best overall environmental outcome

This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste"

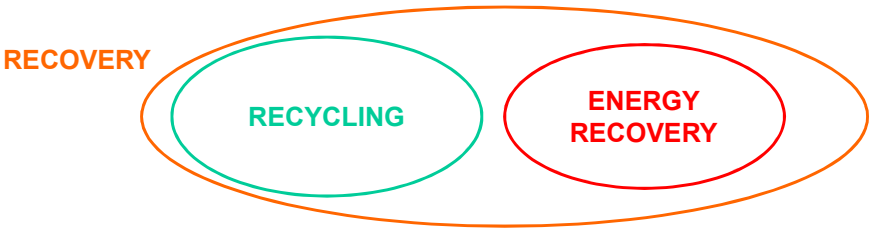
→ LCA plays a key role!

The new Circular Economy Package (EU, 2018)

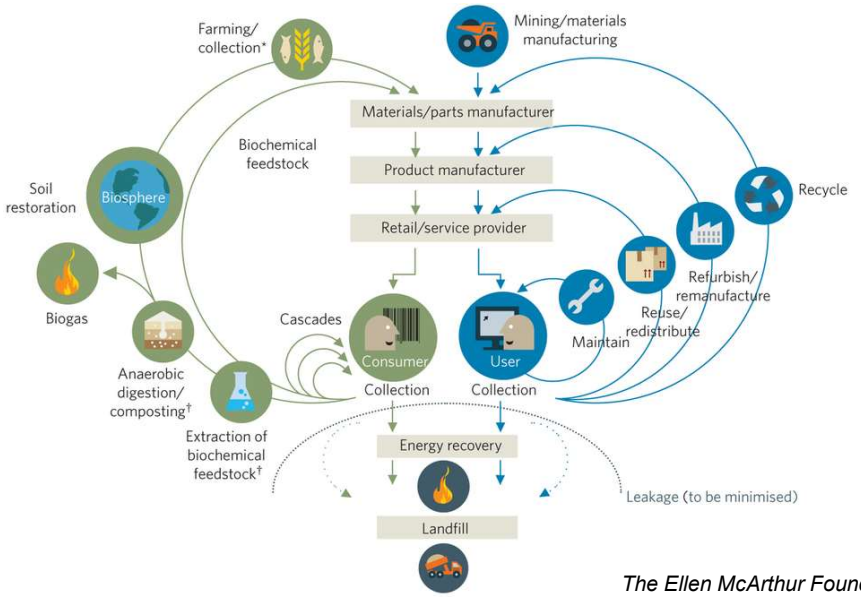
The revised legislative proposals on waste set clear targets for reduction of waste and establish an ambitious and credible long-term path for waste management and recycling. Key elements of the revised waste proposal include:

- ✓ A common EU target for recycling 65% of municipal waste by 2030;
- ✓ A common EU target for recycling 75% of packaging waste by 2030;
- ✓ A binding landfill target to **reduce landfill** to maximum of 10% of municipal waste by 2030;
- ✓ A **ban on landfilling** of separately collected waste;
- ✓ Promotion of economic instruments to **discourage landfilling**;
- ✓ Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- ✓ Concrete measures to promote re-use and stimulate industrial symbiosis - turning one industry's by-product into another industry's raw material;
- ✓ Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (eg for packaging, batteries, electric and electronic equipments, vehicles).

Recycling vs. recovery

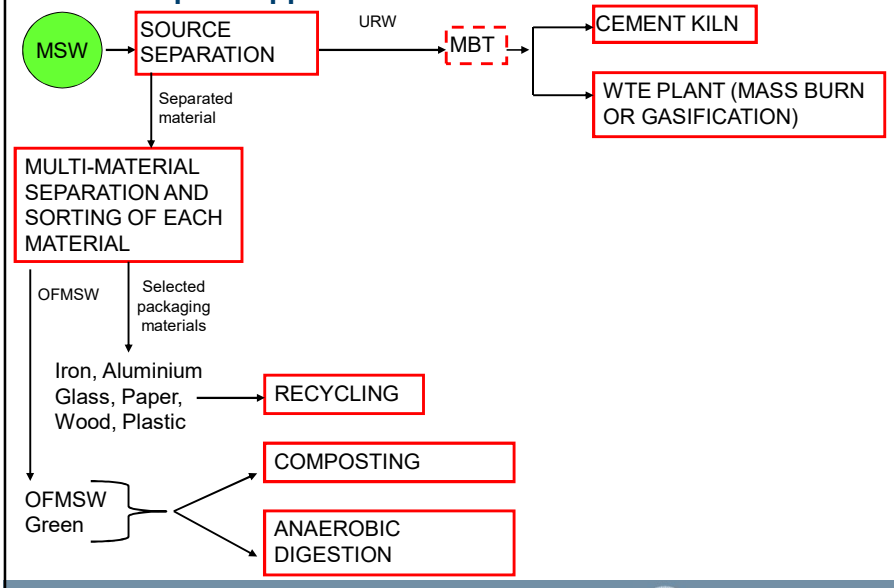


Circular economy…



The Ellen McArthur Foundation

Integrated waste management scenarios: conceptual approach



Integrated waste management scenarios: conceptual approach

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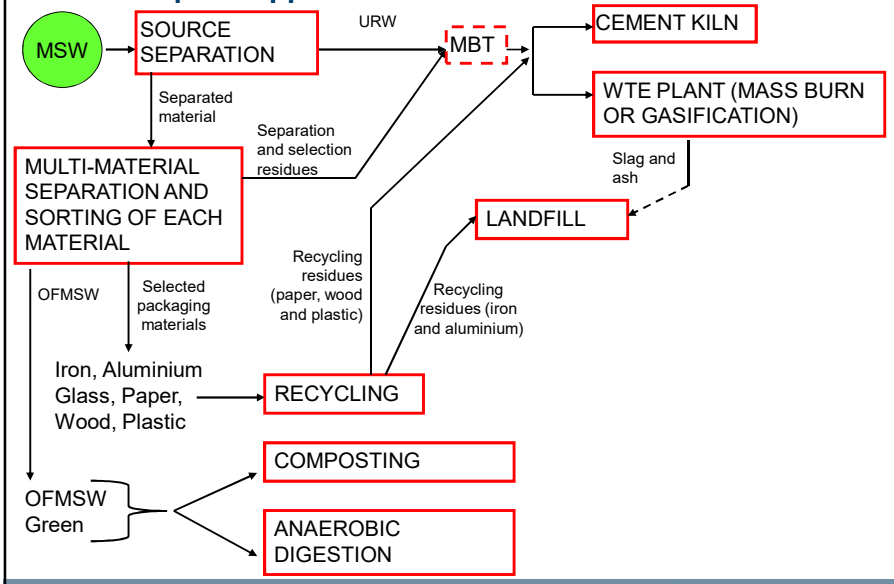

Integrated waste management scenarios: conceptual approach

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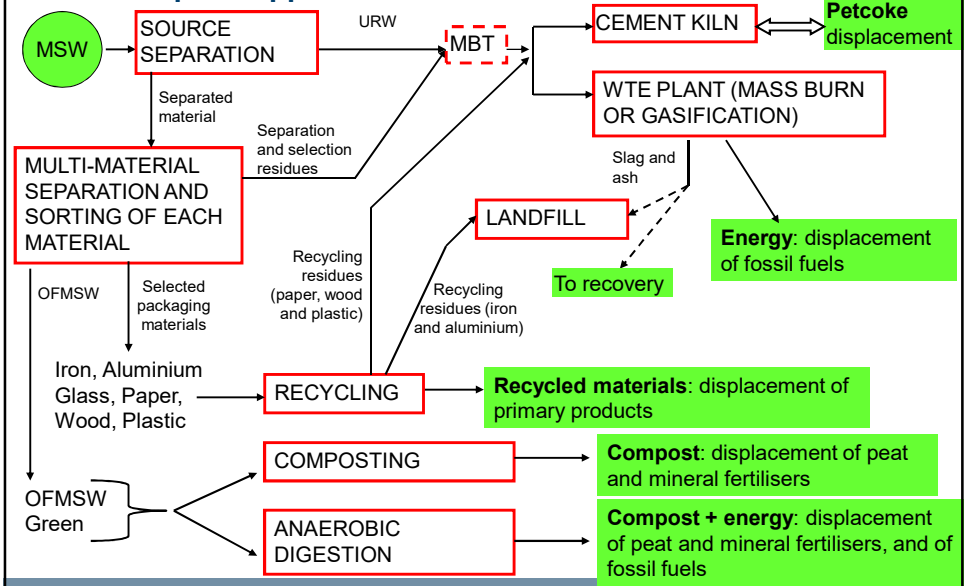

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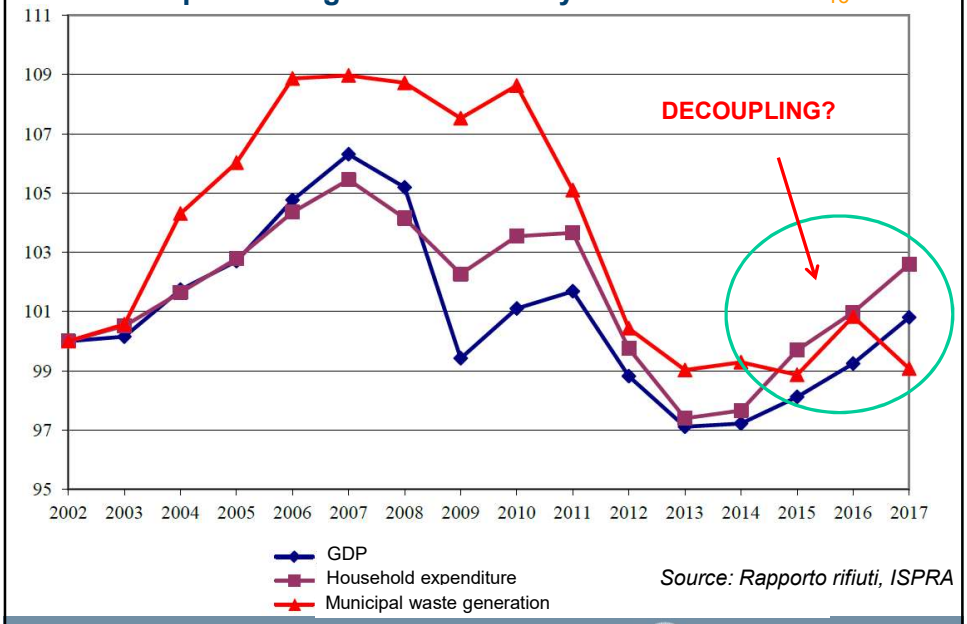
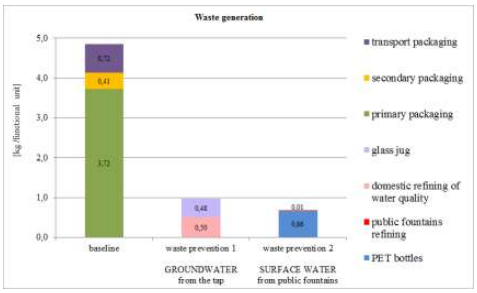
Municipal waste generation in Italy

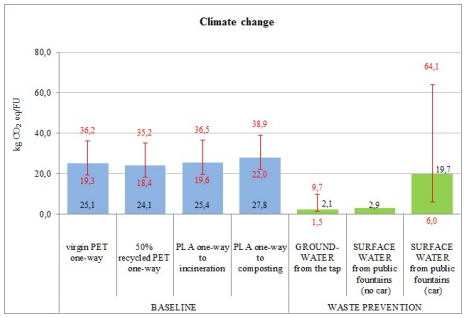


Source: Rapporto rifiuti, ISPRA

WASTE PREVENTION ACTIVITIES

Water from tap or from public fountains instead of single-use bottles





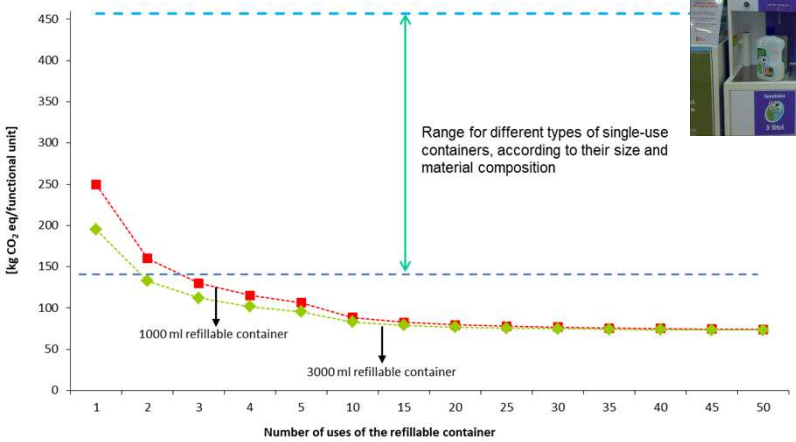
F.U.: the consumption of 152 litres of drinking water by one Italian citizen

In typical conditions, the use of public network water directly from the tap results in the best scenario, while if water is withdrawn from public fountains, its further transportation by private car can involve significant impacts

Nessi S., Rigamonti L., Grosso M. (2012). *"LCA of waste prevention activities: a case study for drinking water in Italy"*. Journal of Environmental Management, 108, 73-83.

WASTE PREVENTION ACTIVITIES

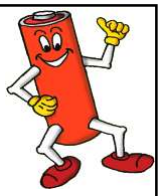
Loose distribution of liquid detergents instead of the traditional distribution (based on single-use packaging)

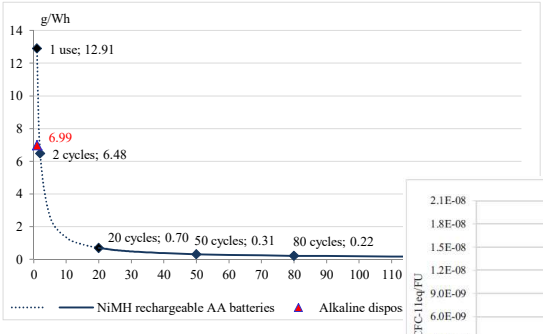


Nessi S., Rigamonti L., Grosso M. (2014). *"Waste prevention in liquid detergent distribution: a comparison based on life cycle assessment"*. Science of the Total Environment, 499, 373-383.

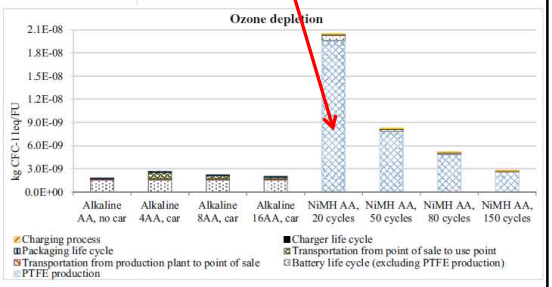
WASTE PREVENTION ACTIVITIES

Disposable vs. rechargeable household batteries





PTFE in the anode



A minimum number of 50 charge cycles allows a robust reduction of the potential impacts for all the analysed impact categories excluding the Ozone Depletion

Dolci G., Tua C., Grosso M., Rigamonti L. (2016) *"Life Cycle Assessment of consumption choices: a comparison between disposable and rechargeable household batteries"*. International Journal of Life Cycle Assessment 21:1691–1705

LCA & WASTE PREVENTION ACTIVITIES

Lessons learned

- ✓ Preventing the production of waste does not automatically imply a better overall performance (e.g. water from public fountains if car is used)
- ✓ Burden shifting may play a role (e.g. impacts of the tank used in the loose distribution of detergents)
- ✓ Compared to traditional waste management and treatment, the effectiveness of waste prevention activities is strongly dependent on the behaviour of citizens/consumers
- ✓ Prevention activities have different potential to reduce waste and environmental impacts of the overall system

An **LCA-based guidance** is needed to support local authorities wishing to implement waste prevention practices, as well as for citizens to make such practices really effective

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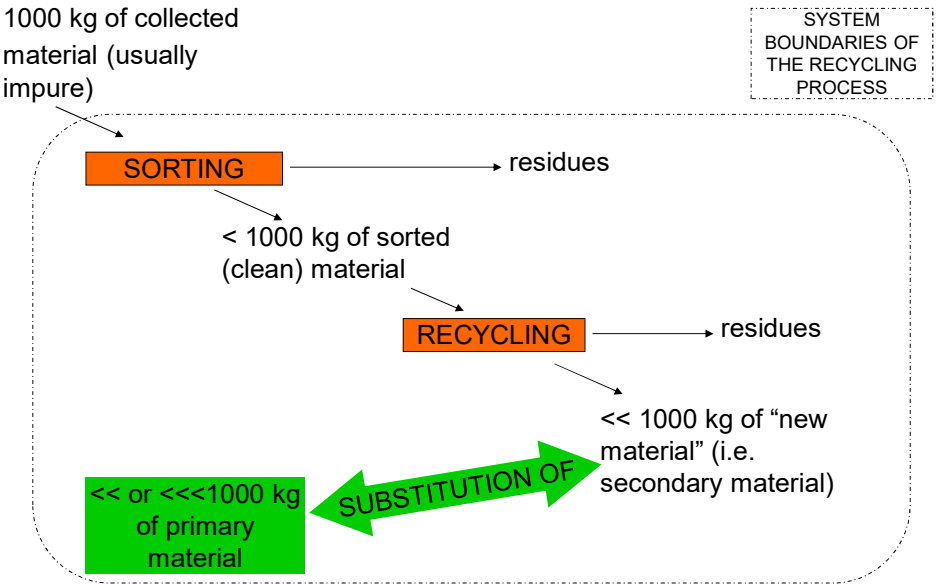
General mass balance of the recycling process



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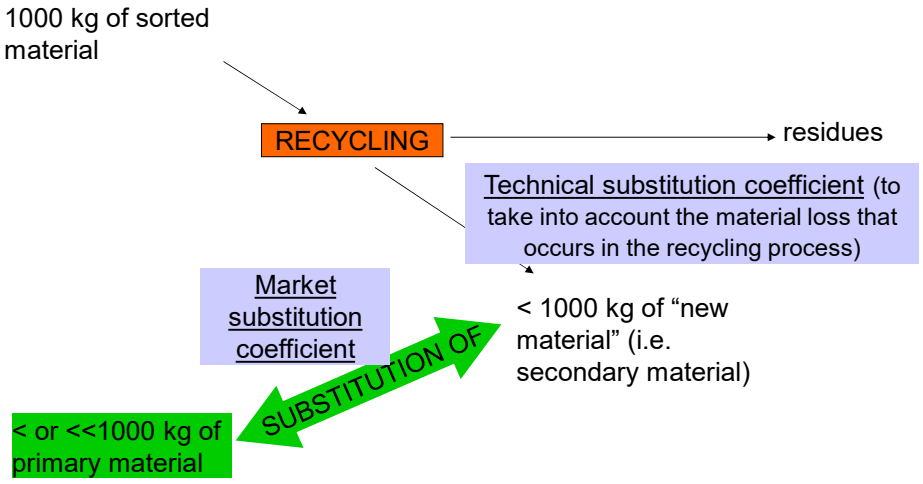


Recycling vs. "downcycling"

General assumptions:

Plastic, **paper** and **wood** are progressively degraded during recycling
→ possible "downcycling"
→ 1 to <1 substitution of primary materials

Steel, **aluminium** and **glass** are not degraded with recycling
→ "permanent" materials
→ 1 to 1 substitution with corresponding primary materials

Is this still the case? Recent research is starting to question such approach

Quality of secondary materials

Steel and iron

- **Copper and tin** impurities will build up and cannot be removed in the remelting processes (*Nakamura et al., 2012*)

Aluminium

- The quality of secondary aluminium is affected by its **oxidation level** and by the content of alloying elements (*Biganzoli and Grosso, 2013; Nakajima et al., 2010)*

Plastic

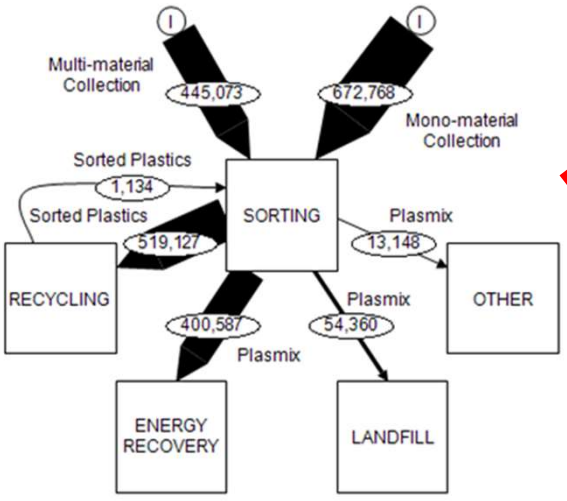
- **Stabilizers** like cadmium, lead and tin, as well as **flame retardants**, might contaminate the recycled products, as well as the presence of **additives** (ex. Cr) (*Kral et al., 2013; Pivnenko et al. 2013*)

Paper

- **Mineral oils** might contaminate paperboards, limiting its use in the food packaging sector (*Kral et al., 2013; Pivnenko et al. 2013*)

Rigamonti L., Niero M., Haupt M., Grosso M., Judl J. (2018) *"Recycling processes and quality of secondary materials: Food for thought for waste-management-oriented life cycle assessment studies"* Waste Management 76, 261-265

THE MANAGEMENT OF PLASTIC PACKAGING WASTE IN ITALY



BEFORE THE CHINA BAN!

Italian Material Flow Analysis (MFA) of source separated plastics in 2016 (t/y)

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Opportunities for materials recovery from incineration bottom ash

1. Bottom ash recovery is a crucial step of the wider concept of circular economy
2. Some materials present in waste can be effectively recovered only after the thermal treatment, thanks to:
   - ✓ Concentration, i.e. of the inert fractions, of precious metals
   - ✓ Removal of organic contamination
   - ✓ Removal of combustible fractions in poly-laminated items
3. **Aluminium** can play its double contribution with respect to **material** and **energy** recovery

PRINCIPLE OF "THERMO-RECYCLING"

Opportunities for materials recovery from incineration bottom ash

"THERMO-RECYCLING"

Courtesy of Daniel Boeni, www.zar.ch

ALUMINIUM AND WASTE-TO-ENERGY

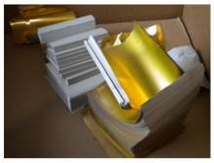
ALUMINIUM IN BOTTOM ASH
A key role

✓ Several items containing aluminium are not separated at the source (foil, poly-laminated foil)
✓ High market value
✓ An undesirable element (in its metallic form) for most of the uses of the inert fraction
✓ Undergoes volatilisation and oxidation during combustion (difficult to establish a mass balance)

✓Energy and/or material recovery?
✓ Is thin foil (< 50 µm) completely oxidised with release of energy?
✓ What can be actually recovered from bottom ash?

ALUMINIUM AND WASTE-TO-ENERGY

Examples of aluminium foils found in municipal waste



Al 10 µm

Paper 30 g m^{-2}

Wax 2 g m^{-2}

Al 10 µm

Paper 20 g m^{-2}

PE 9 g m^{-2}

Wax 11 g m^{-2}

12/60/12 µm

Triplex Alu/PE/Alu

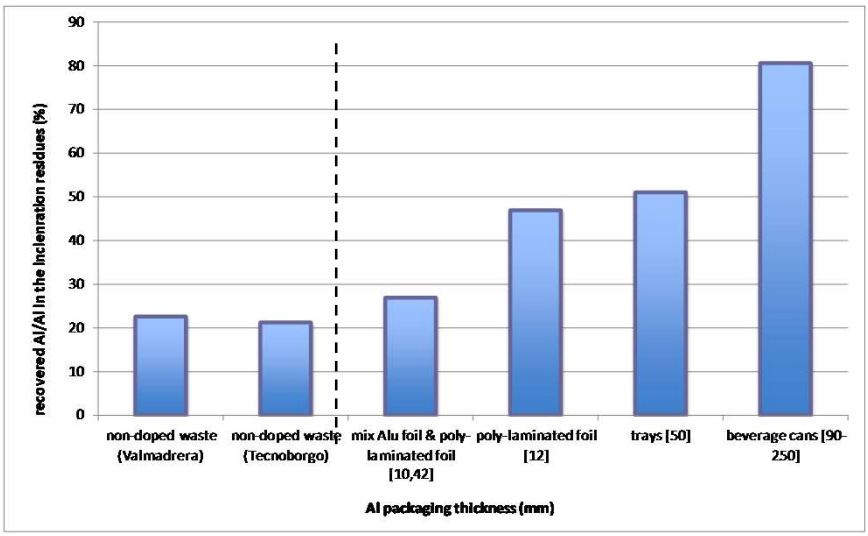
Wax 2.5 g m^{-2} per each side

Al 38 µm

PE 45 µm

ALUMINIUM AND WASTE-TO-ENERGY

Thickness vs recovery

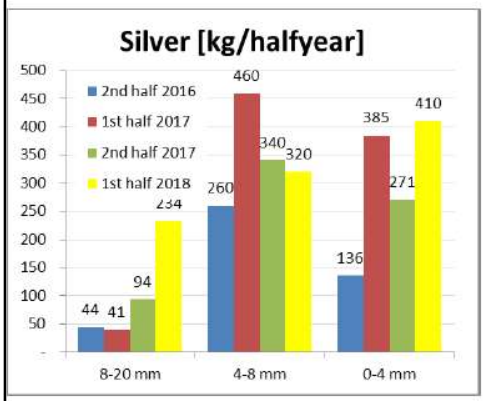


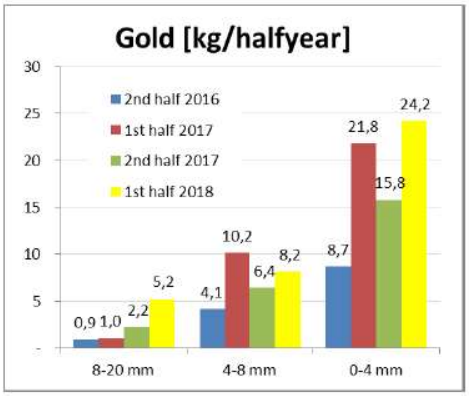
L. Biganzoli, L. Gorla, S. Nessi, M. Grosso (2012) *"Volatilisation and oxidation of aluminium scraps fed into incineration furnaces"* Waste Management 32, 2266–2272

Examples of metals extracted from bottom ash

METALS RECOVERY FROM INCINERATION BOTTOM ASH

Not just steel, aluminium, copper…





HVC plant, The Netherlands (Jan-Peter Born, 2018)

Opportunities for materials recovery from incineration bottom ash

Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2008/98/EC on waste

Point 18

Member States should, for the purposes of calculating whether the preparation for reuse and recycling targets are achieved, be able to take into account […] the recycling of metals that takes place in conjunction with incineration

In order to ensure a uniform calculation of this data, the Commission will adopt detailed rules […] on the quality criteria for recycled metals […]

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CIRCULARITY AND FOOD WASTE

- How can we achieve circularity in the food waste management?
- Anaerobic digestion with biomethane production is a solution
- But again the quality of the produced materials (compost, digestate) is crucial
- Bioplastic vs. paper bags for food waste collection: which is the best solution?
- A comprehensive approach must be adopted, including all the upstream and downstream stages

RESEARCH ON FOOD WASTE

REDUCE

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

A PROJECT OF RESEARCH, EDUCATION AND COMMUNICATION

- Biennial **PROJECT** (December 2015 - December 2017) supported by the **ITALIAN MINISTRY OF THE ENVIRONMENT** with the objective to concur to **REDUCE FOOD WASTE AT THE NATIONAL LEVEL** according to the **NATIONAL WASTE PREVENTION PROGRAMME**

- **RESEARCH TEAM**

COORDINATOR	DISTAL - Università di Bologna
PARTNERS	DEIM - Università della Tuscia
	DICA - Politecnico di Milano
	DIES - Università degli Studi di Udine
	SIAN - Azienda ULSS 20 di Verona

http://www.sprecozero.it/cose-il-progetto-reduce/

RESEARCH ON FOOD WASTE

REDUCE

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

A PROJECT OF RESEARCH, EDUCATION AND COMMUNICATION

Our role in the project:

- ✓ To carry out waste composition analysis on the Residual Waste (RW) and on the organic fraction separated at the source, in order to quantify the avoidable food waste
- ✓ To estimate the environmental impacts of food waste, based on LCA

RESEARCH ON FOOD WASTE

Classification of food waste based on its **edibility**
(EU FUSIONS Project guidelines)

AVOIDABLE
edible food, at some point prior to disposal, discarded regardless of the reason

POSSIBLY AVOIDABLE
edible parts of food which some people eat and others not or that can be eaten when prepared in one way but not in

NOT AVOIDABLE
parts of food which are inedible under normal circumstances

RESEARCH ON FOOD WASTE

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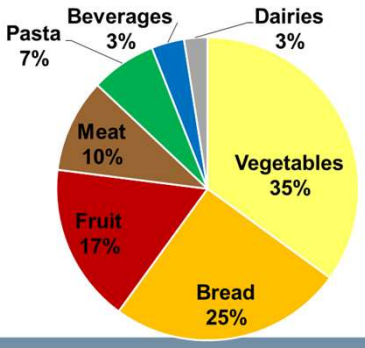
ESTIMATES for NORTHERN ITALY (kg/in./year)

MUNICIPAL WASTE	494
TOTAL FOOD WASTE	89 - 112 AVERAGE: 98
AVOIDABLE FOOD WASTE	**13 - 39** **AVERAGE: 27**



AVERAGE COMPOSITION
(weight %)

RESEARCH ON FOOD WASTE

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SELECTED IMPACT INDICATORS

- **IMPACTS ON CLIMATE**
  (total GHGs emissions)

- **IMPACTS ON WATER RESOURCES**
  (overall consumption of 'blue water')

- **IMPACTS ON THE SOIL**
  (total occupied agricultural land)

RESEARCH ON FOOD WASTE

System boundaries

- Agricultural/animal production
- Industrial processing
- Transport
- Distribution / Sale
- Consumption
- End-of-life

RESEARCH ON FOOD WASTE

27 kg/in./y (Northern Italy)

1.64 Mt/y (Italy)

0.13% food waste worldwide

AVOIDABLE FOOD WASTE

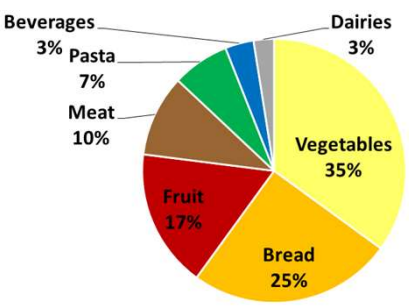
CLIMATE (CO_2-eq - IPPC, 2013)	
64	kg CO_2-eq/in/y
3.9	Mt CO_2/y
0.9%	**GHG national emissions (2015)**

WATER RESOURCES	
3.2	m^3/in/y
197	Mm^3/y
1.8%	**national water volume for irrigation (2009/2010)**

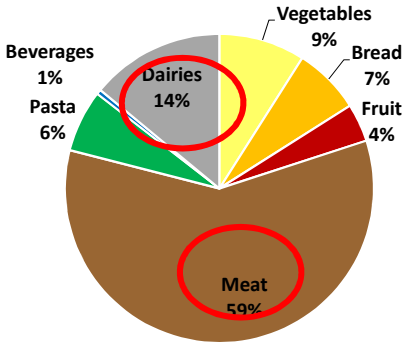
AGRICULTURAL LAND	
78	m^2/in/y
4719	km^2/y
3.8%	**useful agricultural land (2013)**

RESEARCH ON FOOD WASTE

AVOIDABLE WASTE COMPOSITION



GHG IMPACT



FOOD WASTE COLLECTION

The type of collection bags plays a fundamental role in determining the management at the domestic level, in the collection, and in the treatment plants

- **Mater-Bi® biodegradable plastic bags**; these bags exist in two types:
  A. specifically designed for the organic waste collection
  B. conventional shopping bags that can be re-used for the collection of the organic fraction

- **bags made of recycled paper** with reinforced bottom

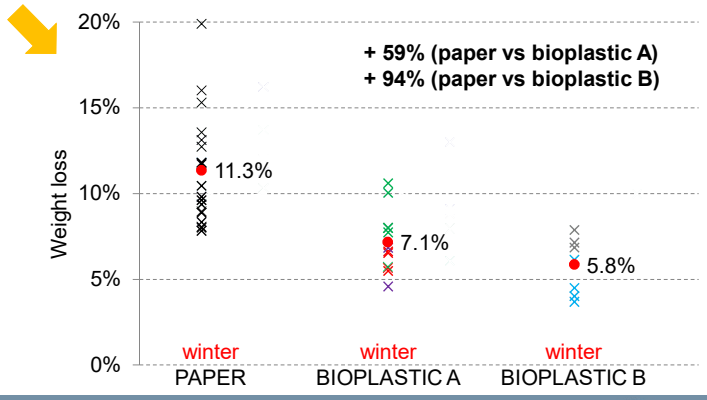
HOUSEHOLD STORAGE ANALYSIS

Evaluation of the waste weight loss in the time between the delivery in the bag by the user and the collection

Transpiration properties of the paper bag that allow to oxygenate organic waste

→ immediate activation of the aerobic degradation process

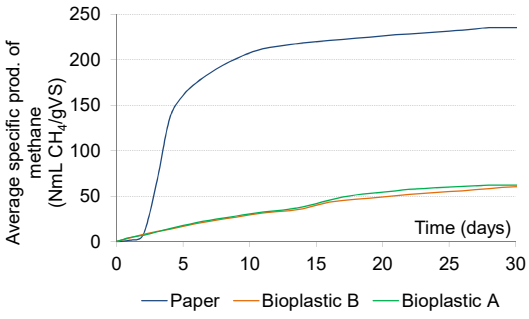
→ increase of the waste temperature that leads to a moisture reduction and to the consequent weight loss



BMP TESTS

Among the organic waste treatments, anaerobic digestion is rapidly increasing, due to a more favourable energy balance with respect to composting and to the presence of economic incentives

Evaluation of the biomethane production under anaerobic conditions at the laboratory level, by means of BMP (Biochemical Methane Potential) tests

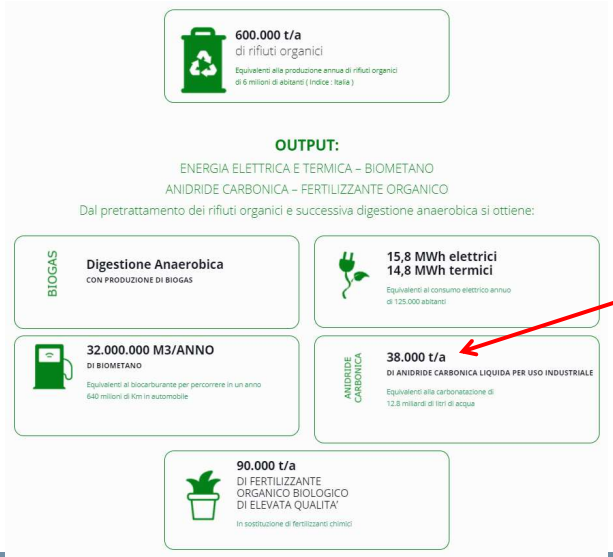


Bag material	Bioplastic A	Paper
BMP_{TQ} (NmL CH_4/g TQ)	59.5	207.9
Bag weight (gTQ/bag)	7.4	22.4
Bags capacity (kg organic/bag)	2.4	2.3
BMP (NmL CH_4/ kg organic)	183	2,025

≈ 10 times higher

CIRCULARITY AND FOOD WASTE

Recent experiences in Italy include the Montello plant



Achieving negative emissions at the site!

http://www.montello-spa.it/

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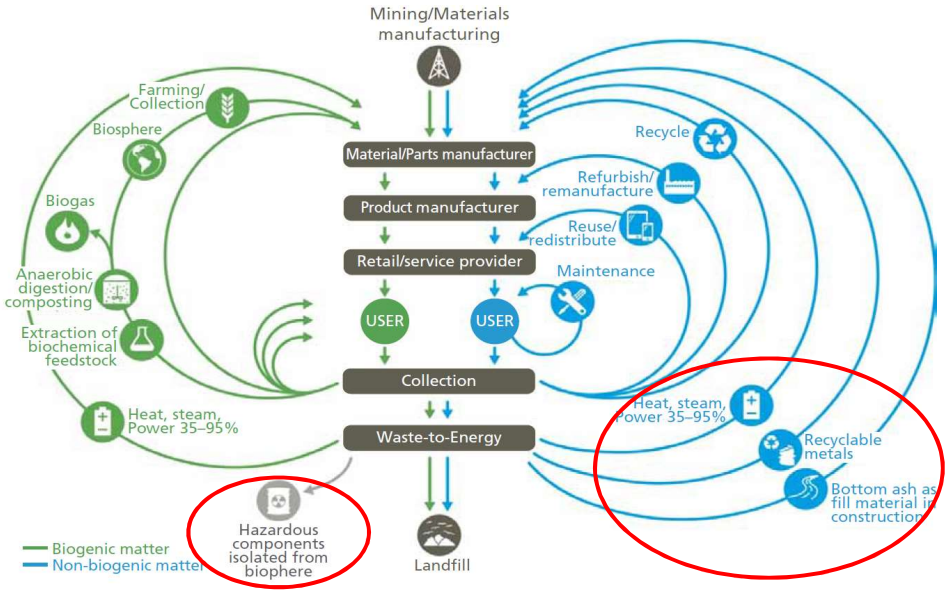
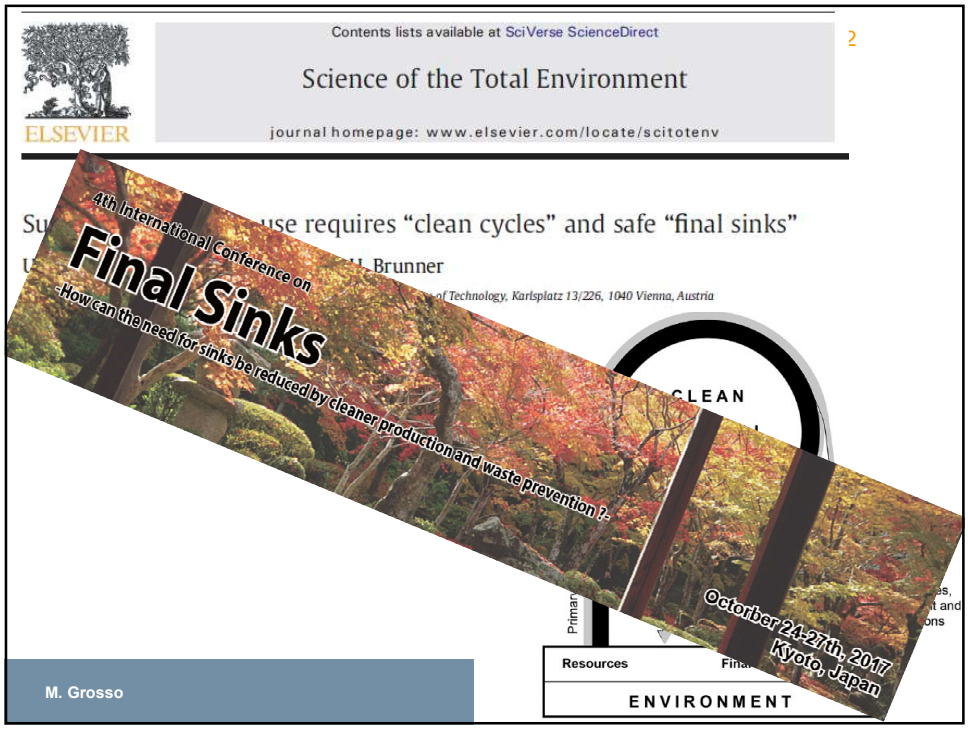
Circular economy… comprehensive…





CONCLUSIONS AND PERSPECTIVES

- There is no doubt that the implementation of a circular economy is the way forward
- Still a wider concept of circularity must be considered, including the synergic role of energy recovery and the presence of safe final sinks
- Quality of the recycled materials is the key
- Complexity of products does not help, but trade-offs must be carefully evaluated
- Ecodesign is the essential part of the story (design for re-use, for disassembly, for recycling,…)

Dissemination

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Mario Grosso
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DOVE VANNO A FINIRE I NOSTRI RIFIUTI?
La scienza di riciclare, gestire, smaltire gli scarti
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GRAZIE!

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