Ηλεκτρονικά Απόβλητα : Περιβαλλοντικές Επιπτώσεις, Πρακτικές Διαχείρισης & Δυνατότητες Αξιοποίησης

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ΕΡΓΑΣΤΗΡΙΟ ΠΕΡΙΒΑΛΛΟΝΤΙΚΗΣ ΔΙΑΧΕΙΡΙΣΗΣ ΚΑΙ ΒΙΟΜΗΧΑΝΙΚΗΣ ΟΙΚΟΛΟΓΙΑΣ

Τμήμα Μηχανικών Παραγωγής & Διοίκησης
Πολυτεχνική Σχολή, Δημοκρίτειο Πανεπιστήμιο Θράκης

Είμαστε ικανοποιημένοι ?

Είμαστε ικανοποιημένοι?

Circuit board heating

Yellow smoke from acid bath

Burning cables in open air

Smelted lead

- Toner sweeping
- Dismantling electronic equipment
- Melting plastic

Stripping wires

Wong *et al.*, 2007

Known and Suspected Routes of e-waste Dumping

There is currently no system for tracking legal or illegal (under international law) shipments of electronic waste, and therefore, there is no quantitative data on volumes or even all of the true destinations. Some electronic waste is shipped as "working equipment" only to end-up as waste upon arrival. This map indicates information collected through investigations by organizations such as the Basel Action Network, Silicon Valley Toxics Coalition, Toxics Link India, SCOPE (in Pakistan), Greenpeace and others.

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- Περιβαλλοντικές επιπτώσεις
- Πρακτικές διαχείρισης
- Αξιοποίηση ηλεκτρονικών αποβλήτων
- Συμπεράσματα - Προτάσεις

Ορισμοί

Overview of selected definitions of WEEE or e-waste

Reference	Definition
EU WEEE Directive (EU, 2002a)	"Electrical or electronic equipment which is waste... including all components, sub-assemblies and consumables, which are part of the product at the time of discarding." Directive 75/442/EEC, Article 1(a) defines "waste" as "any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force."
Basel Action Network (Puckett and Smith, 2002)	"E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users."
OECD (2001)	"Any appliance using an electric power supply that has reached its end-of-life."
SINHA (2004)	"An electrically powered appliance that no longer satisfies the current owner for its original purpose."
StEP (2005)	E-waste refers to "...the reverse supply chain which collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes."

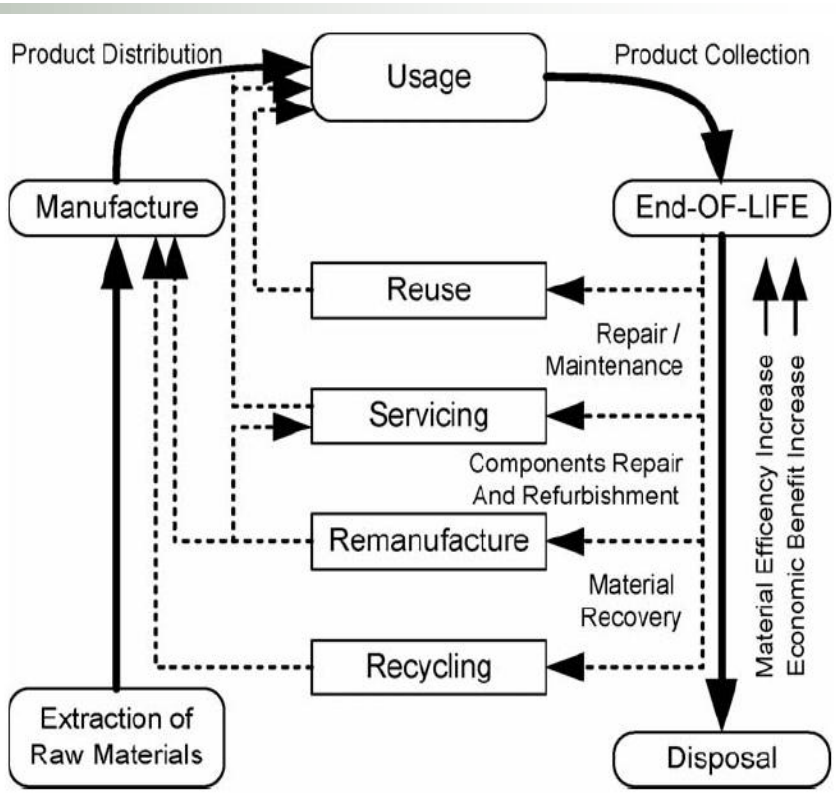
WEEE : Waste Electrical Electronic Equipment
ΑΗΗΕ : Απόβλητα Ηλεκτρικού Ηλεκτρονικού Εξοπλισμού

Κατηγορίες ΑΗΗΕ

WEEE categories according to the EU directive on WEEE (EU, 2002a)

No.	Category	Label
1	Large household appliances	Large HH
2	Small household appliances	Small HH
3	IT and telecommunications equipment	ICT
4	Consumer equipment	CE
5	Lighting equipment	Lighting
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	E & E tools
7	Toys, leisure and sports equipment	Toys
8	Medical devices (with the exception of all implanted and infected products)	Medical equipment
9	Monitoring and control instruments	M & C
10	Automatic dispensers	Dispensers

Γιατί να ασχοληθούμε με τα ΑΗΗΕ ?



- Potentially toxic
- Environmental contamination
- Bio-accumulation of chemicals
- Health effects (humans, ecosystems)

Environmental issues

- Re-use of e-waste
- Recycling of e-waste
- Recovery of metals from e-waste
- Improvement of Management Systems

Management & Economic issues

- Consumption habits
- Population increase
- Developing countries enter the market

Social issues

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- Conclusions-Proposals

Περιγραφή του Προβλήματος

- Γνωρίζετε ότι ο μέσος άνθρωπος κατά τη διάρκεια ζωής του, θα πετάξει περίπου **3,3 τόνους** ηλεκτρικών και ηλεκτρονικών συσκευών;

Γιγαντιαίο ανθρώπινο ομοίωμα ύψους 7 μέτρων, κατασκευασμένο από παλαιές ηλεκτρονικές συσκευές, ισοδύναμες με το συνολικό όγκο ΑΗΗΕ που παράγει ο μέσος Βρετανός πολίτης.

Υφιστάμενη και μελλοντική παραγωγή ΑΗΗΕ

- Annual production : 20–50 Mt (UNEP)
  - EU-15: 5.5 Mt
  - EU-27: 8.3–9.1 Mt
  - USA: 2.6 Mt
  - China: 2.5 Mt
  - India: 0.33 Mt
  - Thailand: 0.10 Mt
  - Greece: 0.18 Mt
- 1–4% of the municipal waste production (1636 Mt/year)
- -9% by volume of municipal waste in rich countries
- PCs, mobiles, TVs : 5.5 Mt (2010), 9.8 Mt (2015)

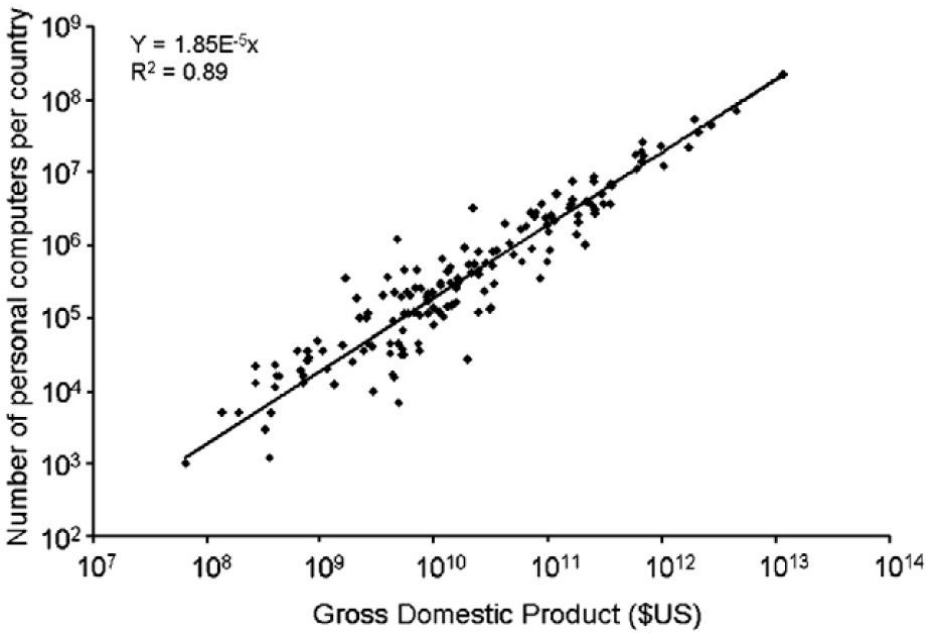
$$E-waste(kg/year)=\frac{Mass(kg)\times Units}{Lifespan(years)}$$

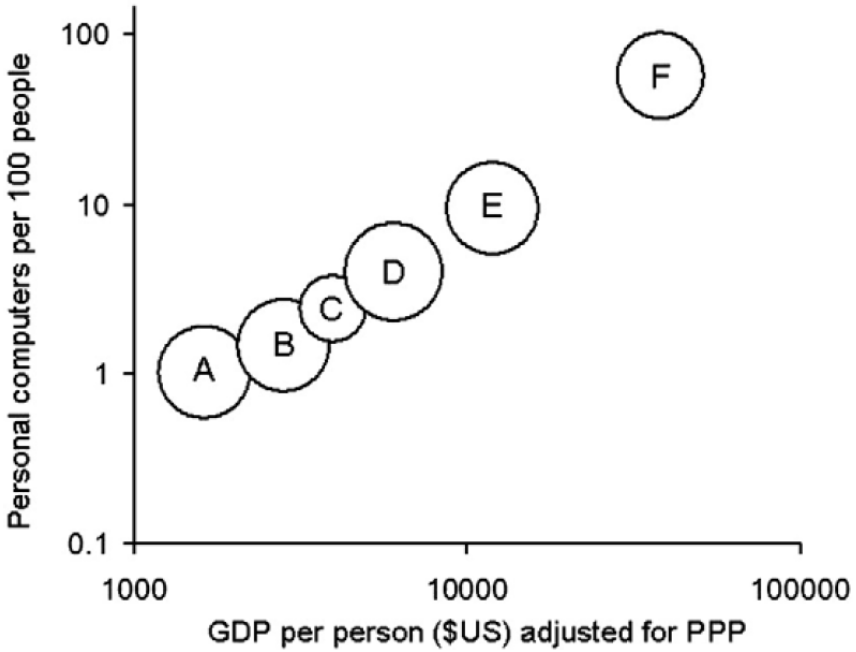
Οι ΗΥ με μέσο χρόνο ζωής 3 έτη, συνιστούν μεγαλύτερο ποσοστό των ΑΗΗΕ από τα ψυγεία και τους φούρνους που έχουν 10-12 έτη χρόνο ζωής.

List of common Waste Electrical and Electronic Equipment (WEEE) items, including those normally considered as E-waste.

Item	Wt of Item (kg)	Typical life (year)
WEEE normally considered E-waste		
Computer[a]	25	3
Facsimile machine	3	5
High-fidelity system[b]	10	10
Mobile telephone[b]	0.1	2
Electronic games[b]	3	5
Photocopier	60	8
Radio[b]	2	10
Television[c]	30	5
Video recorder and DVD player[b]	5	5
WEEE not normally considered E-waste		
Air conditioning unit	55	12
Dish washer[b]	50	10
Electric cooker[b]	60	10
Electric heaters[b]	5	20
Food mixer[b]	1	5
Freezer[b]	35	10
Hair dryer[b]	1	10
Iron[b]	1	10
Kettle[b]	1	3
Microwave[b]	15	7
Refrigerator[b]	35	10
Telephone[b]	1	5
Toaster[b]	1	5
Tumble dryer[b]	35	10
Vacuum cleaner[b]	10	10
Washing machine[b]	65	8

Υφιστάμενη και μελλοντική παραγωγή AHHE





	Population (bn)	Dominant geographic regions
A	1.30	Sub-Saharan Africa, Bangladesh, Pakistan
B	1.17	India
C	0.66	South East Asia
D	1.33	China
E	0.98	Eastern Europe, Latin America
F	1.27	Western Europe, United States, Australasia

Ενδεικτικές τάσεις στην Κίνα

$$E-waste(kg/year)=\frac{Mass(kg)\times Units}{Lifespan(years)}$$

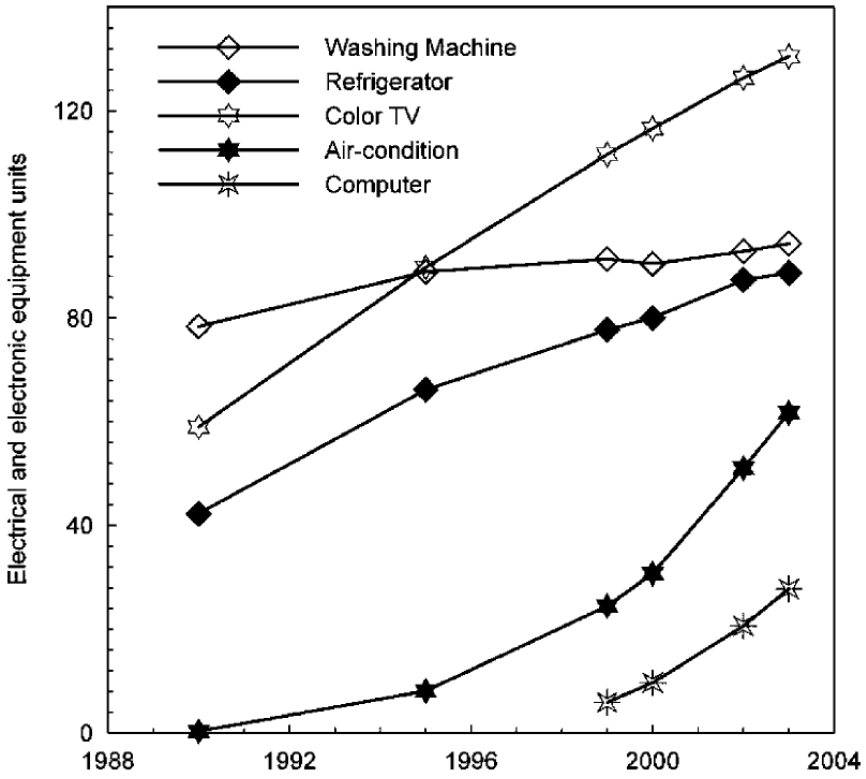


Fig. EEE / 100 families in China.

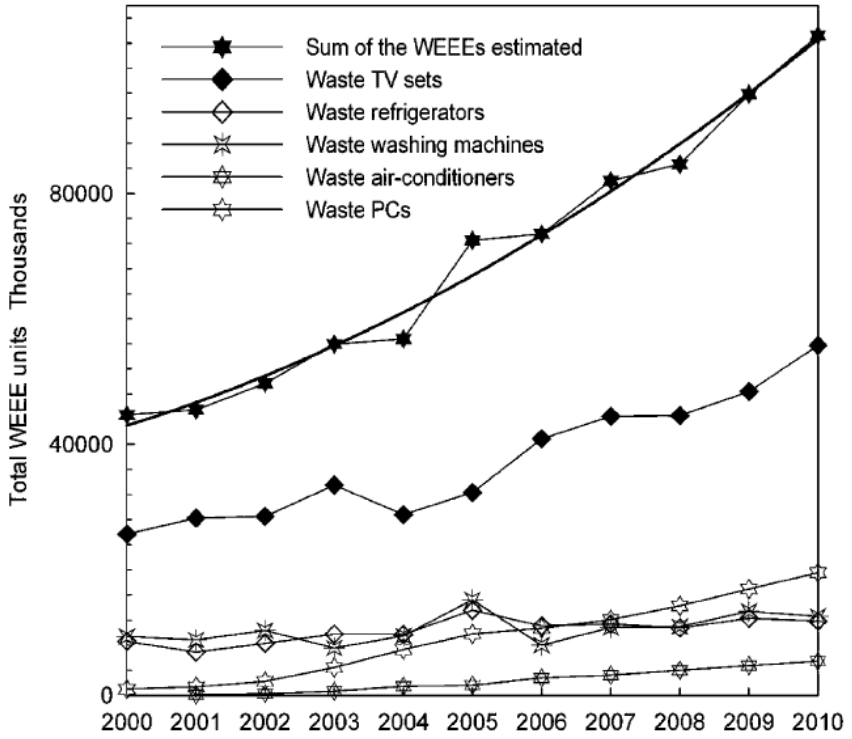


Fig. Generation of e-waste in China.

Μελλοντική παραγωγή ΑΗΗΕ

- Changes in technology (green design, recycled materials, etc.) affect the E-waste produced.
- Short innovation cycles of hardware have led to a high turnover of devices (CPU lifespan 4–6 years in 1997, 2 years in 2005)
- Average PC mass: 25 kg (desktop computer with CRT monitor)
- LCD monitors and the prevalence of laptop and netbook PCs (1-3 Kg) significantly reduce the average mass of a discarded computer.

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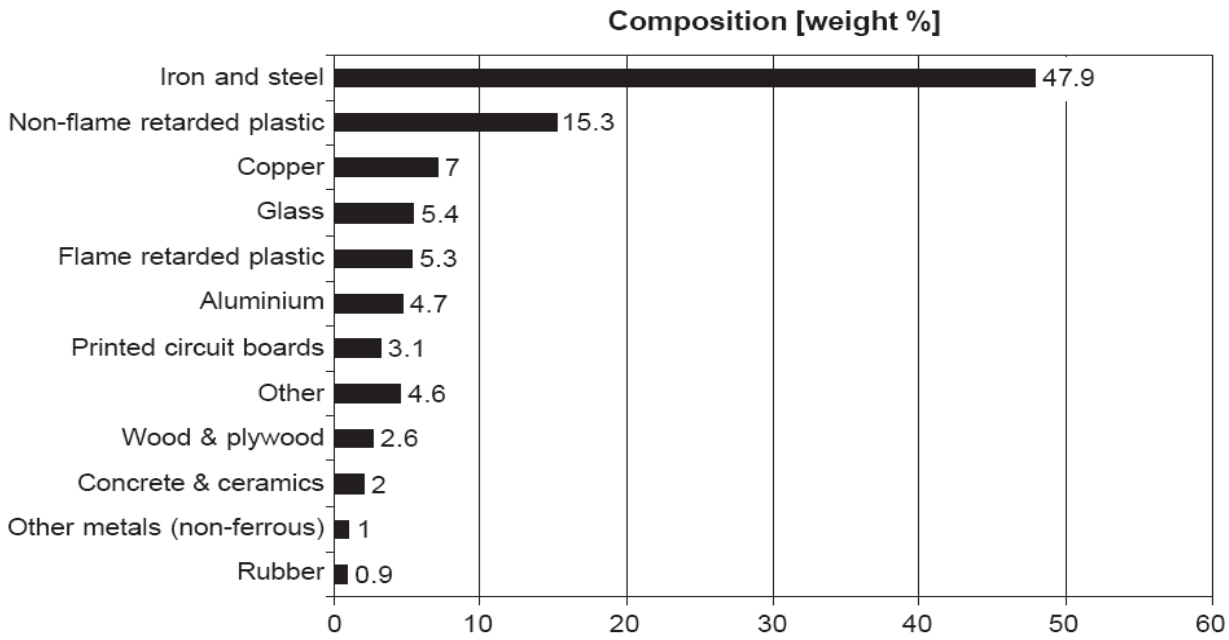
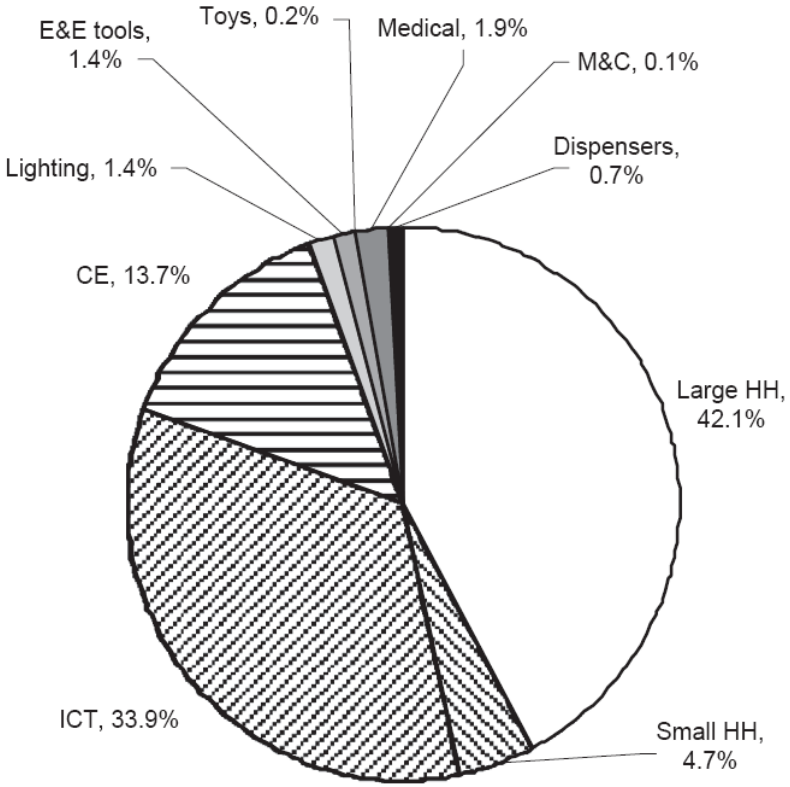
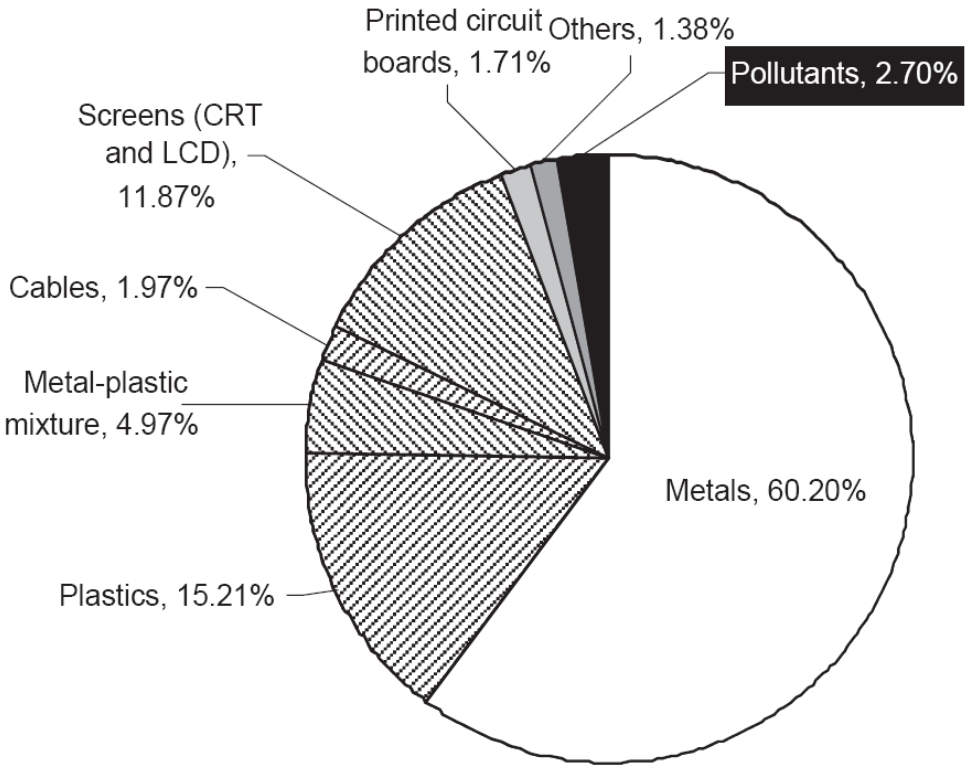
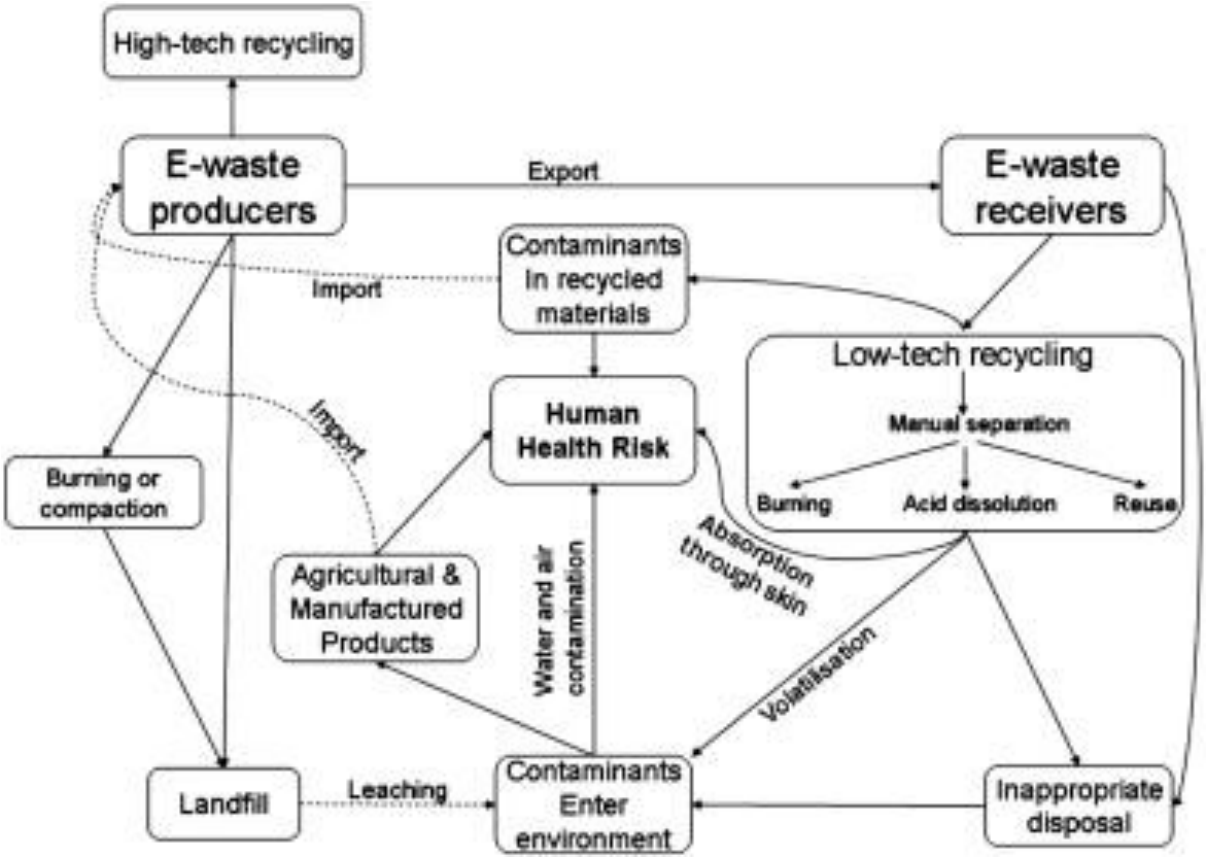
Σύσταση ΑΗΗΕ







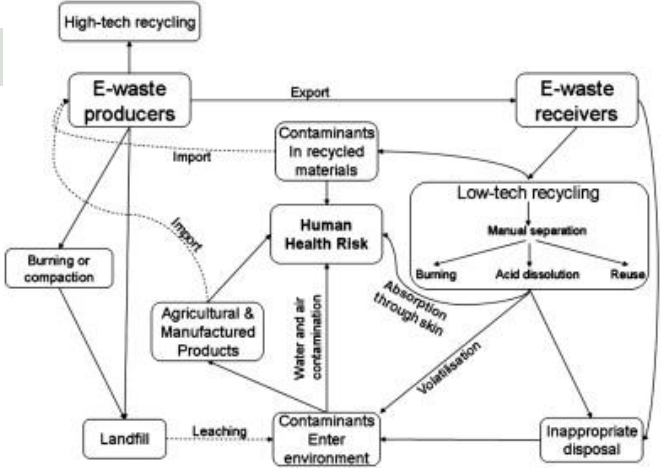
Ροές ρυπαντών συνδεδεμένων με ΑΗΗΕ



Περιβαλλοντικοί ρύποι στα ΑΗΗΕ

Contaminant	Relationship with E-waste	Typical E-waste concentration (mg/kg)[a]	Annual global emission in E-waste (tons)[b]
Polybrominated diphenyl ethers (PBDEs) polybrominated biphenyls (PBBs) tetrabromobisphenol-A (TBBPA)	Flame retardants		
Polychlorinated biphenyls (PCB)	Condensers, transformers	14	280
Chlorofluorocarbon (CFC)	Cooling units, insulation foam		
Polycyclic aromatic hydrocarbons (PAHs)	Product of combustion		
Polyhalogenated aromatic hydrocarbons (PHAHs)	Product of low-temperature combustion		
Polychlronated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs)	Product of low-temperature combustion of PVCs and other plastics		
Americium (Am)	Smoke detectors		
Antimony	Flame retardants, plastics (Ernst et al., (2003))	1700	34,000
Arsenic (As)	Doping material for Si		
Barium (Ba)	Getters in cathode ray tubes (CRTs)		
Beryllium (Be)	Silicon-controlled rectifiers		
Cadmium (Cd)	Batteries, toners, plastics	180	3600
Chromium (Cr)	Data tapes and floppy disks	9900	198,000
Copper (Cu)	Wiring	41,000	820,000
Gallium (Ga)	Semiconductors		
Indium (In)	LCD displays		
Lead (Pb)	Solder (Kang and Schoenung, (2005)), CRTs, batteries	2900	58,000
Lithium (Li)	Batteries		
Mercury (Hg)	Fluorescent lamps, batteries, switches	0.68	13.6
Nickel (Ni)	Batteries	10,300	206,000
Selenium (Se)	Rectifiers		
Silver (Ag)	Wiring, switches		
Tin (Sn)	Solder (Kang and Schoenung, (2005)), LCD screens	2400	48,000
Zinc (Zn)		5100	102,000
Rare earth elements	CRT screens		

Περιβαλλοντικοί ρύποι στα ΑΗΗΕ



- PAHs (emissions from e-waste incineration at low temperatures)
- Dioxins (incineration of cable insulating plastic emits 100 times more dioxins that the incineration of municipal wastes)
- Contaminants end up at recycling centers, at landfills and finally to environmental media, for example:
  - 5 Kt of Cu /year
  - PBDEs (flame retarders) that are lipophile compounds and are bio-accumulated to human tissues
  - CFCs emanating from air conditioners and refrigerators disposed at landfills depleting the ozone layer
  - TCLP tests indicated that the quality of leachates emanating from e-wastes may satisfy the environmental limits however it was toxic to aquatic organisms.

Περιβαλλοντικοί ρύποι στα ΑΗΗΕ

- The above mentioned problem are augmented considering the facts that:
  - The majority of e-wastes are co-disposed with municipal wastes with no further treatment
  - The "hidden flows" of e-waste (80% of the collected for recycling e-waste stream is exported to Asian and African countries, where their management is under less strict environmental conditions)

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Ευρωπαϊκή Ένωση

- E-waste are targeted for reasons related with:
  - Prevention of environmental contamination
  - Exploitation of resources
  - Less pressure on landfills
- 3 pillars in the EU legislation: 1. prevention, 2. recycling, 3. re-use of e-wastes
- 2 relevant EU Directives:
  - The Restriction of Hazardous Substances (RoHS) Directive (2002/95/EC) introduces a requirement for the substitution of those substances posing the main environmental problems during the disposal and recycling of E-waste.
  - The Directive 2002/96/EC developed to help reduce the levels of E-waste disposed to landfill and to encourage resource efficiency through recycling and reuse. This Directive sets out measures for the collection, treatment, recovery and recycling and focuses on the Extended Producer Responsibility (EPR). Its main points are:
    - Electronic equipment design should be oriented to easy dismantling and recovery.
    - E-wastes should be collected separately from other wastes and their collection should not burden households.
    - The target for entering the management system is 4 kg/year/inhabitant.
    - From 2007 manufacturers should be in the position to recover and re-use a certain percent (depending on the e-waste type) ranging between 50-80%.
    - Manufacturers are responsible for the financing of the e-waste management system.

Ελλάδα

- Mean annual e-waste production :
  - Approximately 170 Kt or
  - 3.8% of the municipal waste (www.electrocycle.gr)
  - 90% of e-waste was mixed with other municipal wastes or was recycled with other material (i.e. scrap) with no prior treatment (“grey recycling”)

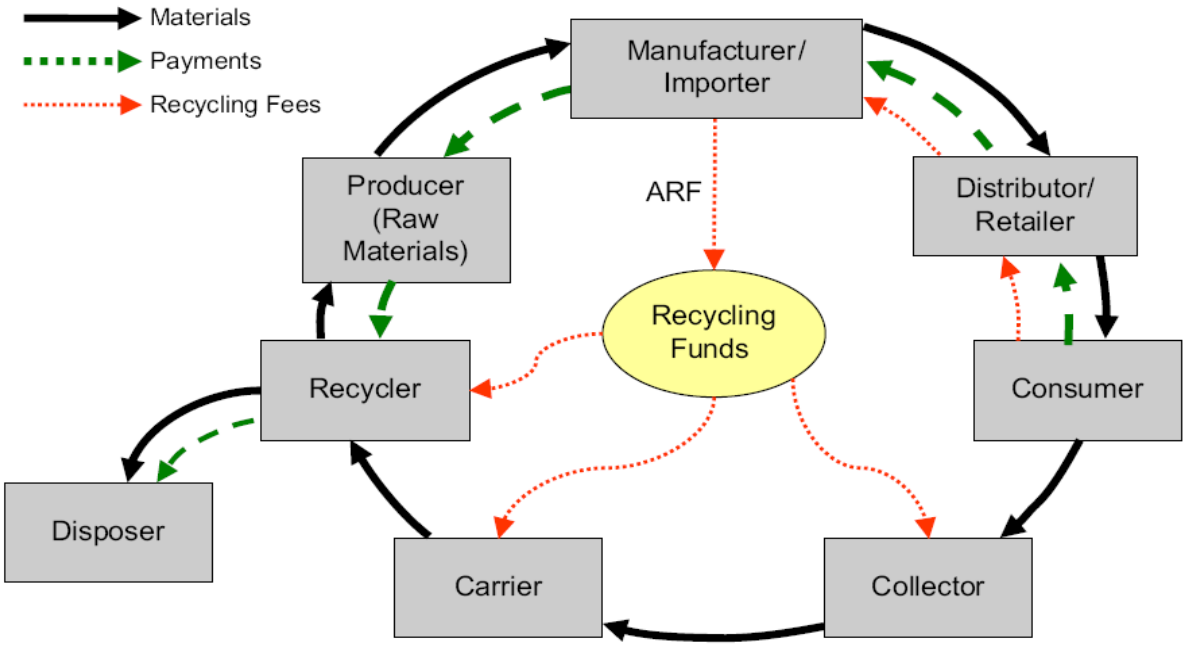
- 2004: operation of an authorized collective alternative e-waste Management system (www.electrocycle.gr) with main responsibilities:
  - the collection, transport and treatment at dedicated installations
  - the satisfaction of a national target set to 44 Kt/year or 4 kg/inhabitant/year (similar to the EU target)

- Record
  - 2005: 0.1 Kt
  - 2007: 31.5 Kt
  - 2008: 47 Kt

However, even today the household appliances are disposed with an uncontrolled management practice involving their collection and transport by peddlers to installations for metal recovery

Ελβετία

- 1st country with an official e-waste management system (law enforced in 1998).
- 2 different e-waste recycling systems
  - "brown" e-waste (i.e. PCs, TV, radios, etc.)
  - "white" e-waste (washing machines, refrigerators, ovens, etc.)
- The manufactures are responsible for the operation of the system
- Financing through a special recycling fee incorporated in the product price
- 75 Kt of e-waste processed in 2004



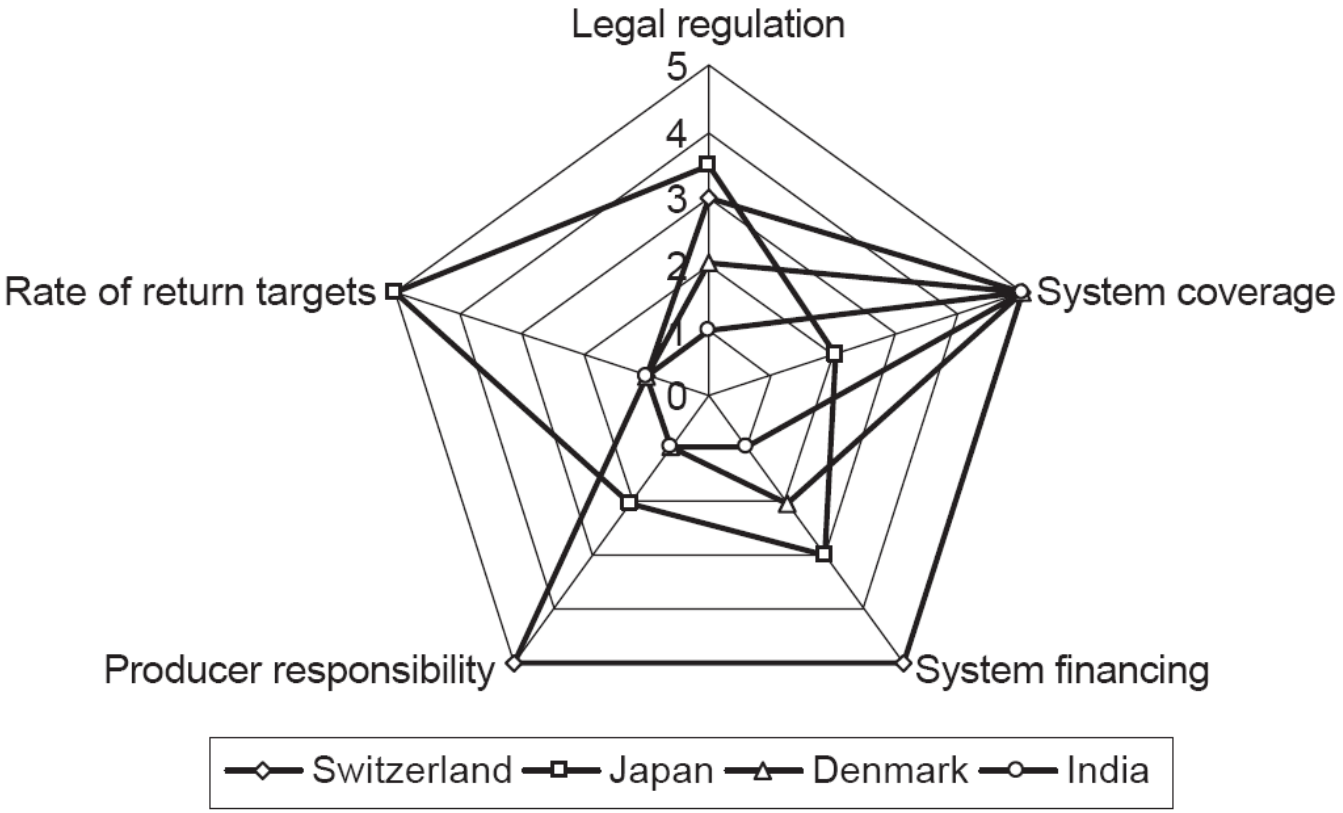
Ιαπωνία (3R society, reduce-reuse-recycle)

- Consumers pay a fee on the return of used **large electronic products** (air-conditioners, TVs, refrigerators, washing machines) to retailers.
- Withdrawal scheme since 1998 for those 4 types of e-waste.
- Until 2004, 41 recycling installations and 380 intermediate collection centers financed by government, municipalities and electronic companies
- A basic characteristic of the Japanese system is the initial dismantling of large pieces for a more efficient management of the dismantled e-waste
  - Welding with no insulation
  - Absence of brominated compounds (in accordance with the RoHS EU Directive)
  - Design of lighter products, Design for dismantling, Design for recycling, Design for re-use, etc.

- Similar management scheme since 2003 for the collection and recycling of **used PCs** (2 categories):
  - Bought before 10/2001 recycling is financed (20-30€)
  - Bought after 10/2001, the recycling costs are incorporated in the price as recycling tax
  - Ideal example of the Manufacturer Responsibility to recycle its products, since they have the physical and the financial responsibility for recycling

However the success story of e-waste recycling in Japan is based on the social responsibility, on the environmental consciousness and on the spirit of discipline of Japanese people (personal judgment)

Comparison of E-waste management systems



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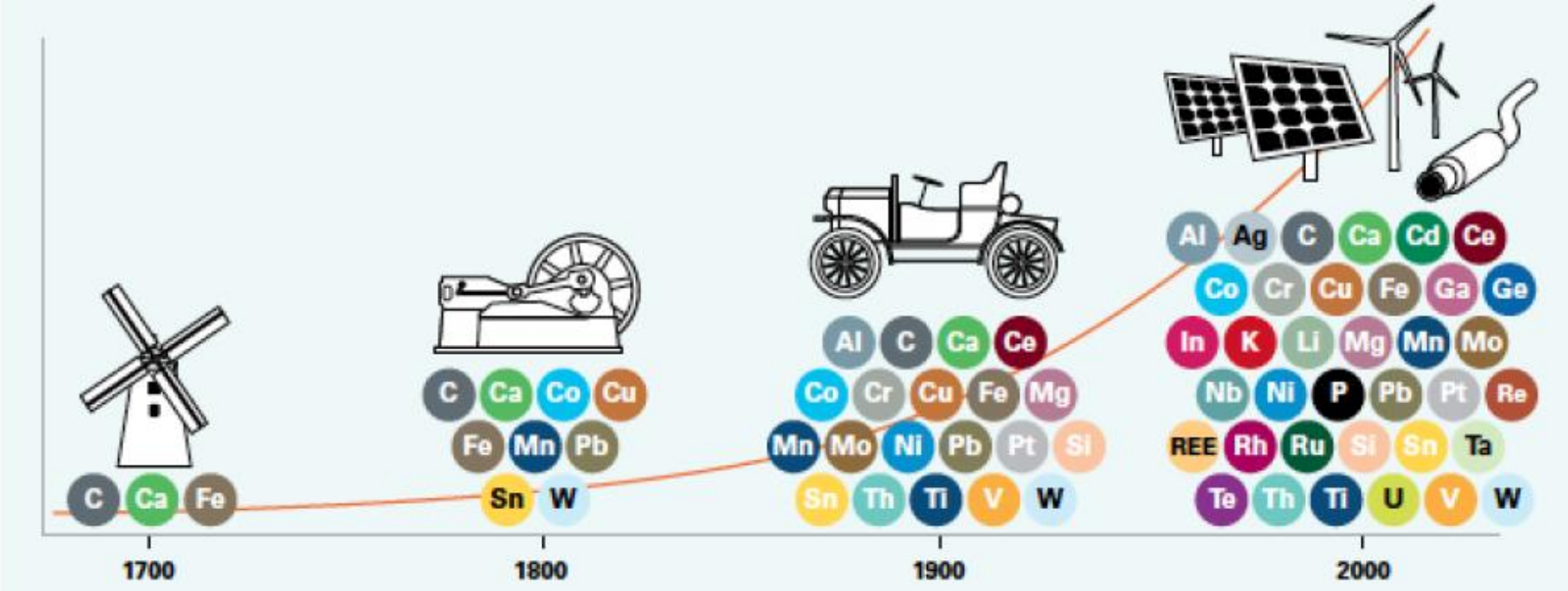
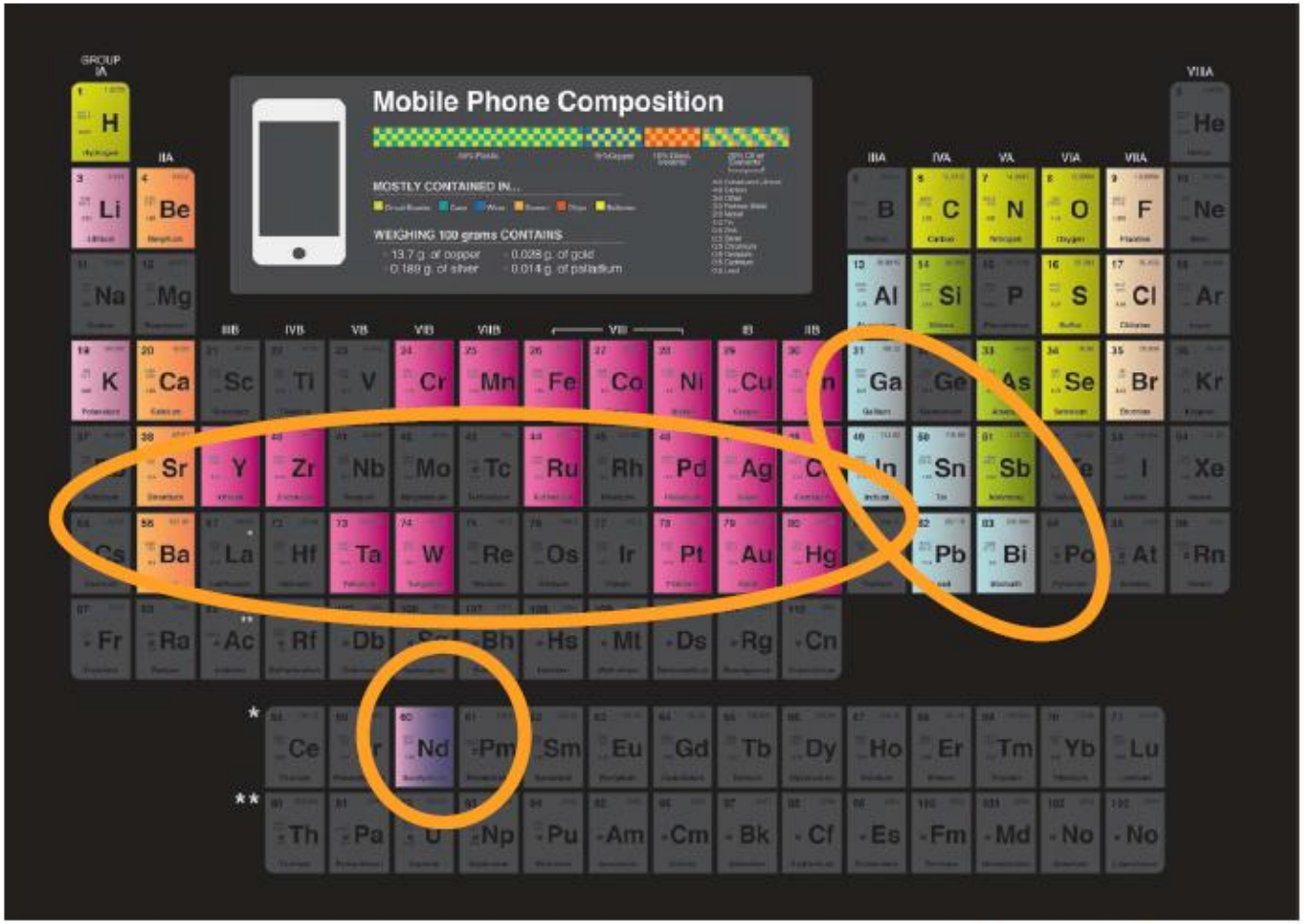
Τεχνολογική εξέλιξη και χρήση χημικών στοιχείων



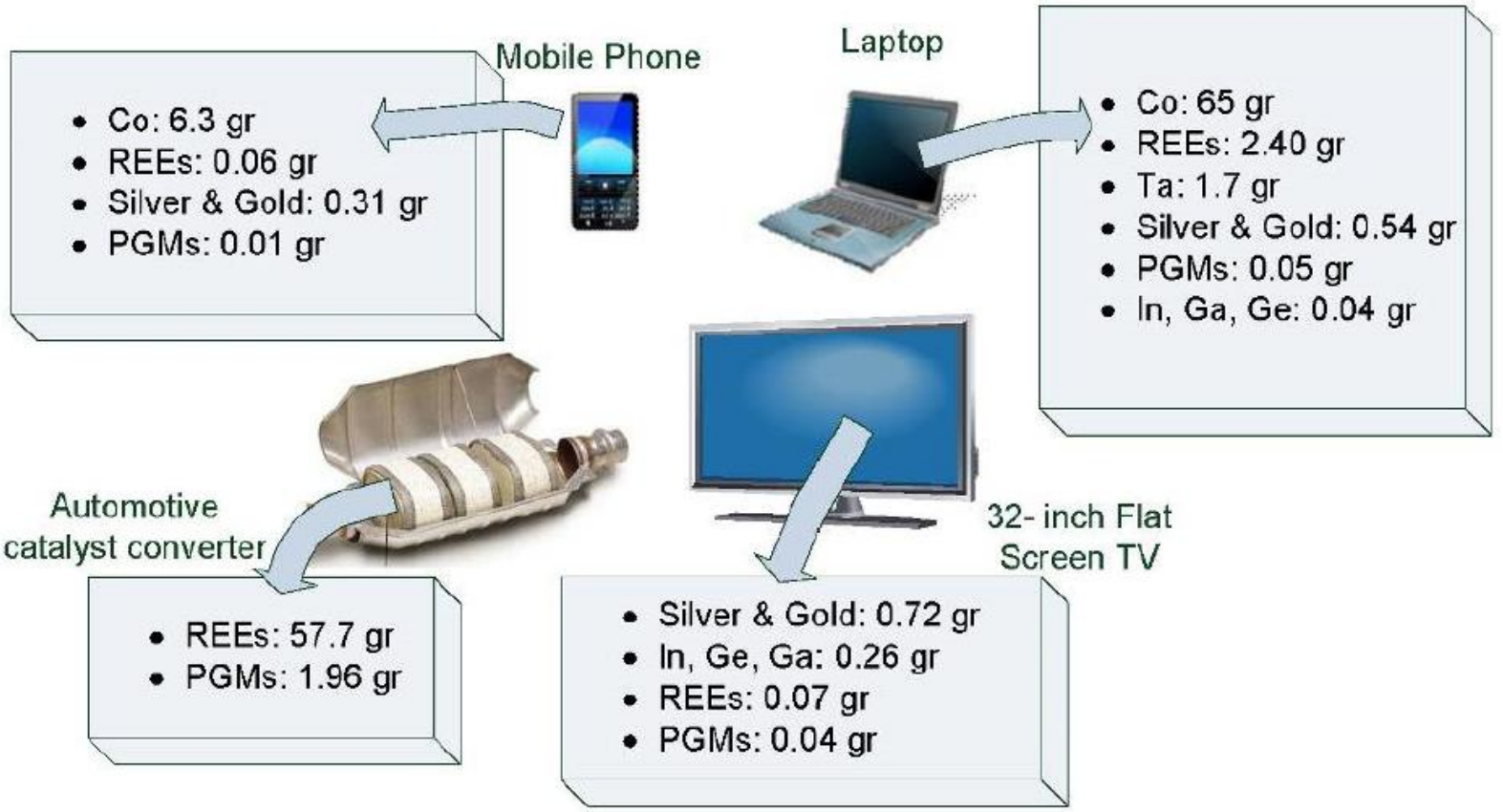
Τεχνολογικά Μέταλλα

Σε αντίθεση με τα βασικά μέταλλα (Fe, Al, Cu, Zn) που χρησιμοποιούνται σε μεγάλες ποσότητες, η πρόοδος στην επιστήμη των υλικών προώθησε μια νέα ομάδα μετάλλων που χρησιμοποιούνται σε πολύ μικρές ποσότητες για να βελτιώσουν δραστικά τις ιδιότητες του επιθυμητού κράματος.

Τα μέταλλα αυτά ονομάζονται «Τεχνολογικά Μέταλλα».

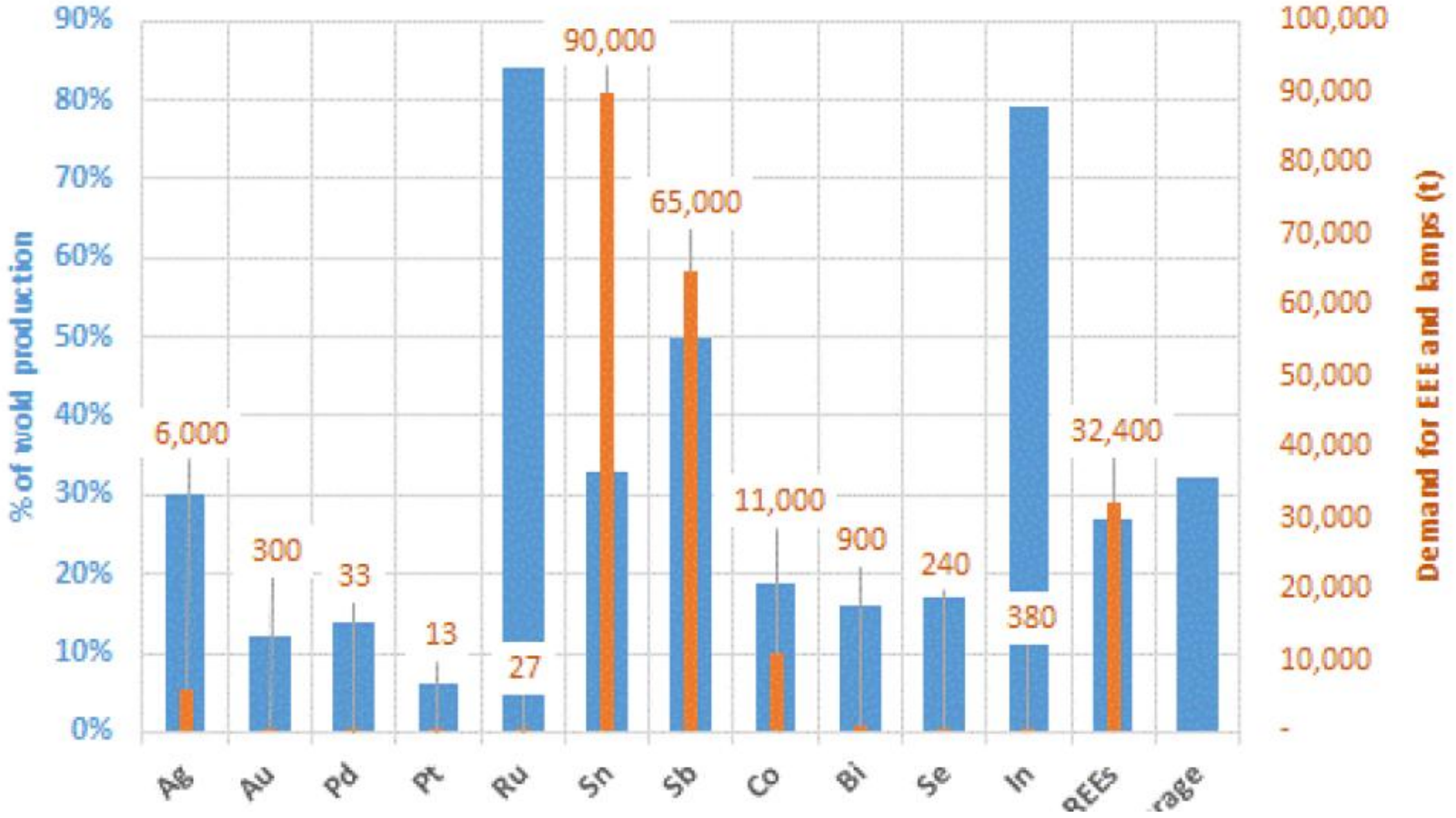


Τεχνολογικά μέταλλα στην καθημερινότητα



- RREs (Rare Earth Elements)
- PGMs (Platinum Group Metals)
- 1t scrap από HY περιέχει περισσότερο Au από 17t μεταλλεύματος
- 1t κινητών (6.000 τεμ.) περιέχει πολύτιμα μέταλλα συνολικής αξίας 15.000€

Ζήτηση Τεχνολογικών Μετάλλων



Σχήμα. Παγκόσμια ζήτηση ΤΜ (σε τόνους) για ηλεκτρονικό εξοπλισμό (πορτοκαλί) και σύγκριση (σαν ποσοστό % κβ) στην πρωτογενή παραγωγή του για το έτος 2006.

Τεχνολογικά Μέταλλα στην Ευρώπη

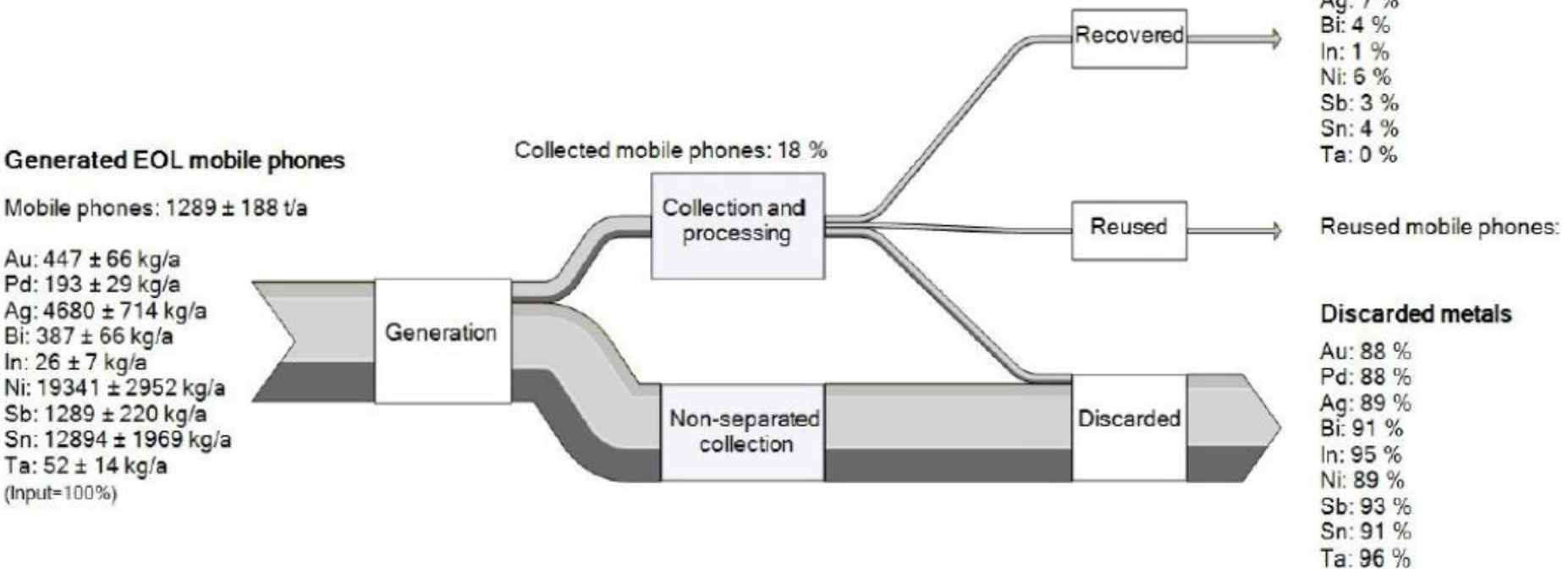
	Current Technological Uses	Emerging Technologies	Most common use as	EU Import dependence	Recycling Rate
Sb	Plastics, Semiconductors, LEDs, Glass, Batteries, Alloys	Photovoltaics	Sb_2O_3	100%	11%
Be	Electric appliances and Electronic equipment, X-Ray scanners, Ceramics	Nuclear fusion	BeO, Metallic	100%	19%
Co	Li-ion batteries, Alloys, Industrial catalysts	Super alloys, Permanent magnets	WC-Co SmCo $LiCoO_2$	100%	16%
Ga	Intergraded circuits, Semi-conductors, LEDs, Laser	Photovoltaics	GaAs GaN Al-Ga-S Ga-In-N	subject to strong fluctuations	0%
Ge	Infrared optics, LEDs, Semi-conductors, Industrial catalysts	Fiber optics	Si-Ge	100%	0%
In	Flat panel displays, LEDs, Alloys	Thin film solar cells	Ga-In-N In_2O_3	100%	0.30%
PGM	Automotive catalysts, Electronics and Electrics, Jewelry, Catalysts	Fuel Cells	Metallic	100%	35%
REE	Electronic and Electrics, HD drives, Motors, Flat panel displays, LEDs, Automotive catalysts, Ceramics, Glass, Alloys, Industrial catalysts	Fuel Cells, Superconductor, Wind turbines, Hybrid Cars,...	Nd (Pr, Dy) $_2Fe_{14}B$, $Y_3Al_5O_{12}$ $Y_2O_3.ZrO_2$, La_2O_3, $CeMgAl_{11}O_{19}$ $(Y,Gd)BO_3.Eu$ Y_2O_3:Eu, $LaPO_4$:Tb	100%	1%
Ta	Capacitors (electronics), Medicine, Alloys, Glass	Super alloys, Micro-Capacitors	Metallic	100%	4%

[11] *Tackling The Challenges In Commodity Markets And On Raw Materials*, European Commission COM 25, (**2011**).

Πόσο πετάμε ?

Recycling of Critical Resources

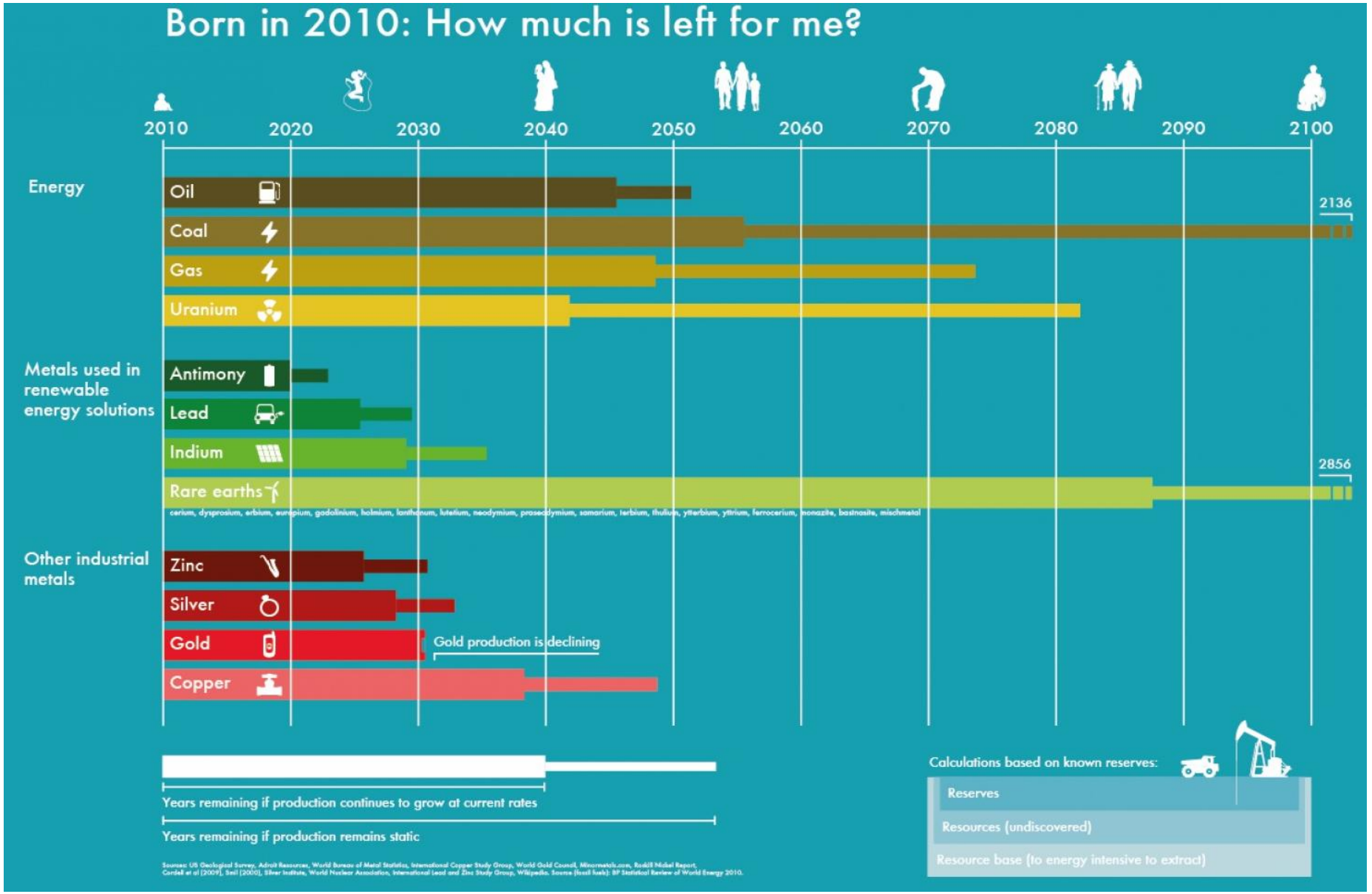
V. S. Rotter, P. Chancerel



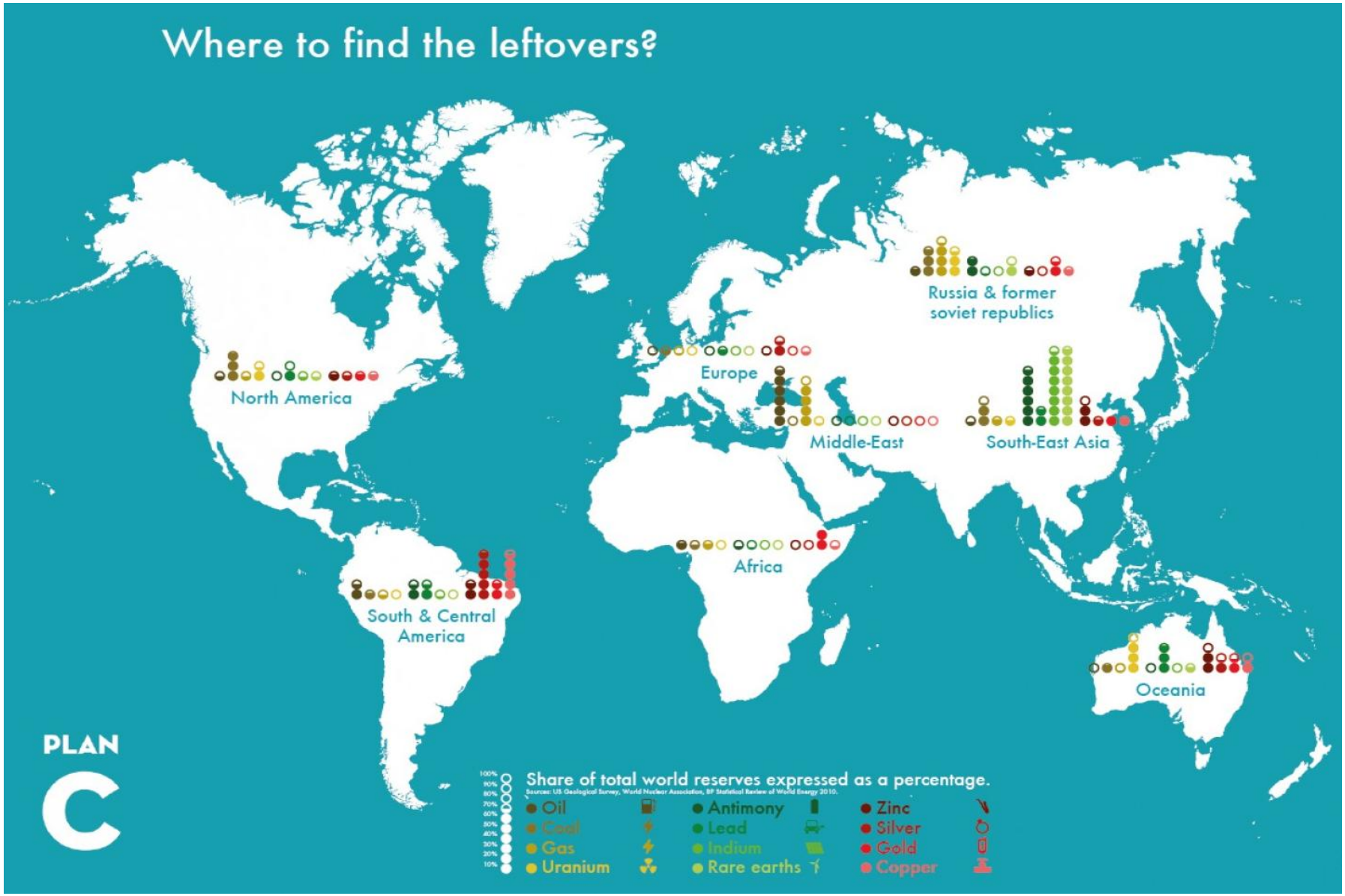
Πόσες εισαγωγές στην ΕΕ θα γλυτώναμε?

Potential TM import supply reduction				
TM	2010 EU Total External Imports (tones)	Approximation of TM in all EEE and lamps sold annually EU (tones)	% of raw material Imports which could be avoided through TM recycling	
			100% recycling efficiency	Current Recycling Scheme
Ag*	9,543	1,500	16%	5%
Au*	2,855	75	3%	1%
PGMs	206	18	9%	3%
Sn	41,500	22,500	54%	9%
Co	9,149	2,750	30%	9%
In	129	95	74%	3%
REEs	12,700	8,100	64%	0%
*(Ag and Au imports are largely related to economic activities)				

Πόσο έμεινε για μένα ?



Που βρίσκεται ?



Βρίσκεται όμως και εδώ !

Ροή μετάλλων από τη Λιθόσφαιρα στην Τεχνόσφαιρα

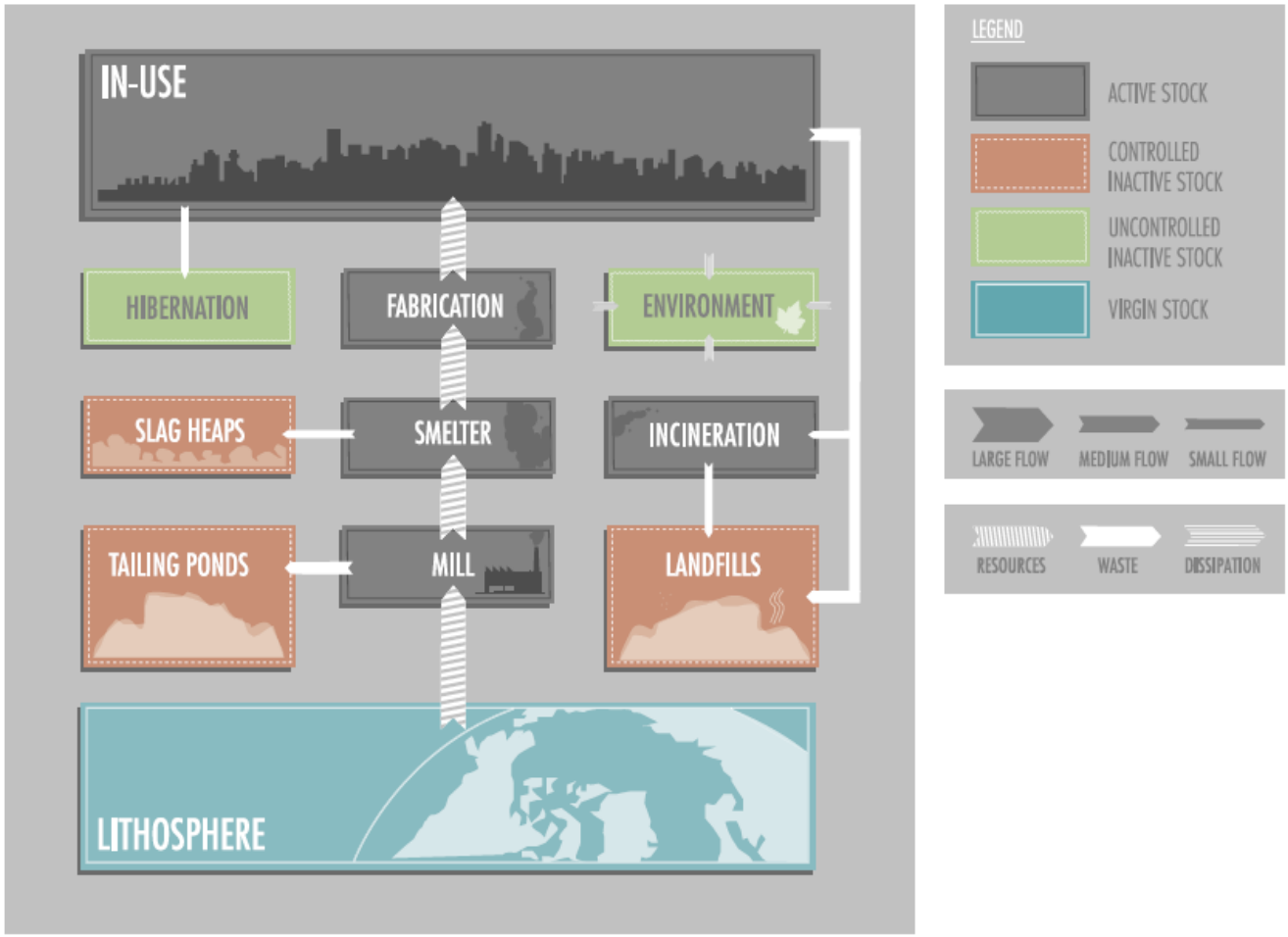


Fig. 1. Diagram showing how metals from the lithosphere linearly accumulate in different stocks situated in the technospere. The magnitude of the flows are based on cycles of anthropogenic iron (Wang et al., 2007; Kuo et al., 2007) and copper (Graedel et al., 2004; Kuo et al., 2007). From all stocks, secondary metals dissipate into the surrounding environment (land, sea, air or even space). Note that the figure is a simplification, for example, slag can originate from a smelter as well as be a residue from further pyrometallurgical processes.

Γιατί είναι σημαντική

- Εξοικονόμηση Φυσικών Πόρων
- Ανάπτυξη Κυκλικής Οικονομίας
- Εξοικονόμηση Οικονομικών Πόρων

Δομή Παρουσίασης

- Εισαγωγή
- Παραγωγή ηλεκτρονικών αποβλήτων (υφιστάμενη, μελλοντική)
- Περιβαλλοντικές επιπτώσεις
- Πρακτικές διαχείρισης
- Αξιοποίηση ηλεκτρονικών αποβλήτων
- Συμπεράσματα – Προτάσεις

Συμπεράσματα

- E-waste are ubiquitous in our society
- E-waste are of complex chemical composition and inevitably end up to environmental media
- The environmental contamination from their inappropriate management has degraded the environment mainly in developing countries where they are directed for recycling and recovery of metals
- The e-waste fluxes are difficult to be quantified in local and international level
- NGOs and environmental groups exert pressure for the extinction of the hazardous substances contained in electronic devices resulting to “greener: electronics. Indicatively:
  - Production of “halogen-free” devices not contributing to PCBs and dioxin production
  - Replacement of flame retardards based on bromine with others based on phosphorus
  - Introduction of legislative restrictions (i.e. Pb, Hg, Cr, PBBs and PBDE <1000 mg/kg, RoHS Directive, etc.)

Συμπεράσματα

- An ideal Management Scheme for E-wastes should comprise:
  - the separation of the e-waste stream from other solid wastes
  - The re-use (when and where possible) of the discarded electronics
  - The recycling of e-wastes for the recovery of raw materials and basic metals

- A Management scheme for E-wastes should also be rationally designed and structured so that:
  - the financial profit from the recovery and
  - the environmental advantages from the
    - collection
    - transport and
    - management of the e-waste

  are greater compared to the required consumption of resources and energy for the operation of the management scheme

Έρευνα

Objective

to quantify – calculate the threshold beyond which

- collection only or
- collection and recycling in different extent, or
- collection, recycling, recovery and re-use in different extent,

is harmful for a specific E-waste stream.

Approach

- the methodological framework of the Life Cycle Assessment (LCA) with
- emphasis in the final phases of the E-products (utilization period, end-of-life scenarios, etc.)

Results

The initial results indicate that depending on

- the distance travelled to incorporate the E-waste to the management scheme
- the extent of recycling, recovery any re-use

recycling is not as environmental friendly as expected.

This work can be a useful tool for manufacturers and policy makers when designing a e-waste management system.

Σχετικό άρθρο

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Review Article

E-waste: Environmental Problems and Current Management

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Ηλεκτρονικά απόβλητα:
περιβαλλοντικές επιπτώσεις, πρακτικές διαχείρισης και δυνατότητες αξιοποίησης

Ευχαριστώ για την προσοχή σας

Δρ. Γεώργιος Γκαϊντατζής
Επίκουρος Καθηγητής

ΕΡΓΑΣΤΗΡΙΟ
ΠΕΡΙΒΑΛΛΟΝΤΙΚΗΣ ΔΙΑΧΕΙΡΙΣΗΣ
ΚΑΙ ΒΙΟΜΗΧΑΝΙΚΗΣ ΟΙΚΟΛΟΓΙΑΣ

Τμήμα Μηχανικών Παραγωγής & Διοίκησης
Πολυτεχνική Σχολή, Δημοκρίτειο Πανεπιστήμιο Θράκης