LEITAT Technological Center
managing your technologies
member of TECNIO

Workshop on life cycle evaluation and energy use for different production processes of nanomaterials

LCA of nano-enabled products. Nanopolytox and Ecotexnano case studies

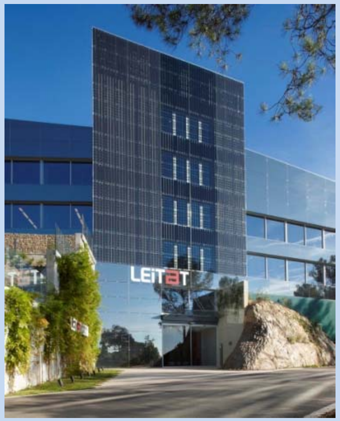
Dr. *Vincent Jamier*
LEITAT Technological Center
16 April 2015 - Turku, Finland

Who are we?

LEITAT is The brand entity **of Acondicionamiento Tarrasense,** a private non-profit organization**.**

Since 1906

Evolving its expanding activities and committed to knowledge generation and technology transfer toward the Industry



MISSION

Creating and transferring economic, social and sustainable value to businesses and organizations, through research and technology processes.

VISION

To become a Technology Partner for businesses and public organizations, by creating a corporate culture that allows sustained growth and efficiency of action.

CORPORATE CULTURE

PRINCIPLES:

- Creativity
- Innovation
- Sustainability
- Environmental responsibility
- Diversity
- Efficiency
- Efficacy

VALUES:

- Dynamism
- Independence
- Commitment
- Confidentiality
- Market orientation
- Global Perspective
- Talent

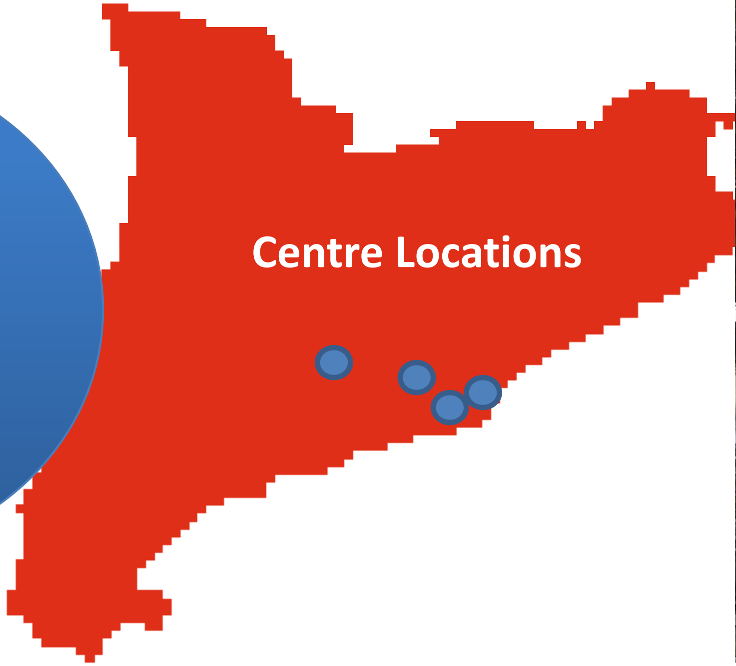
LEITAT

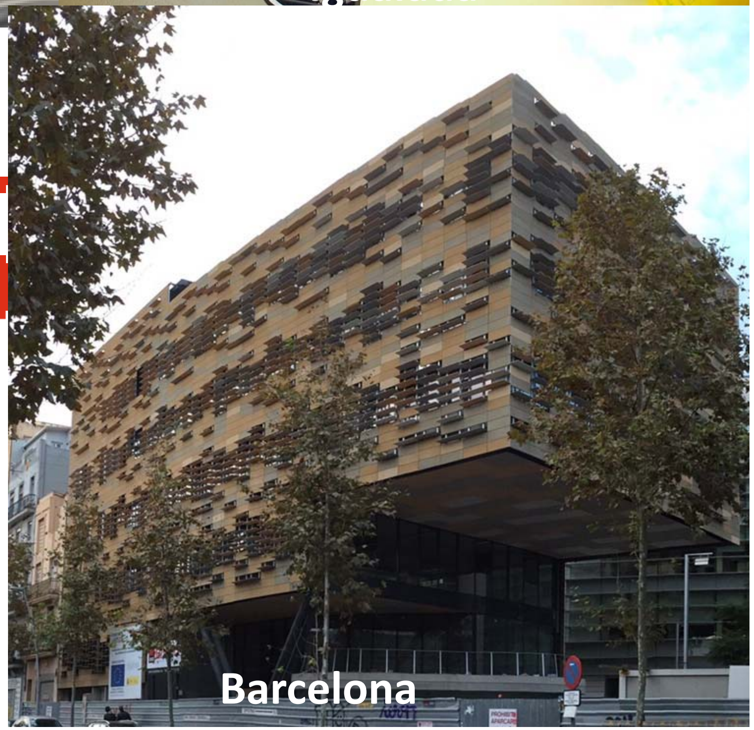
Scientific Park Barcelona

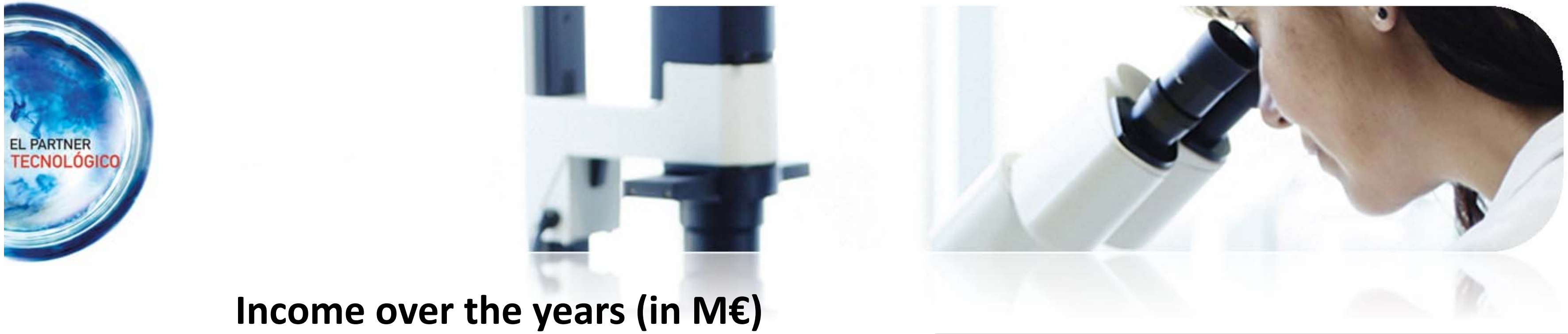
Terrassa


Igualada

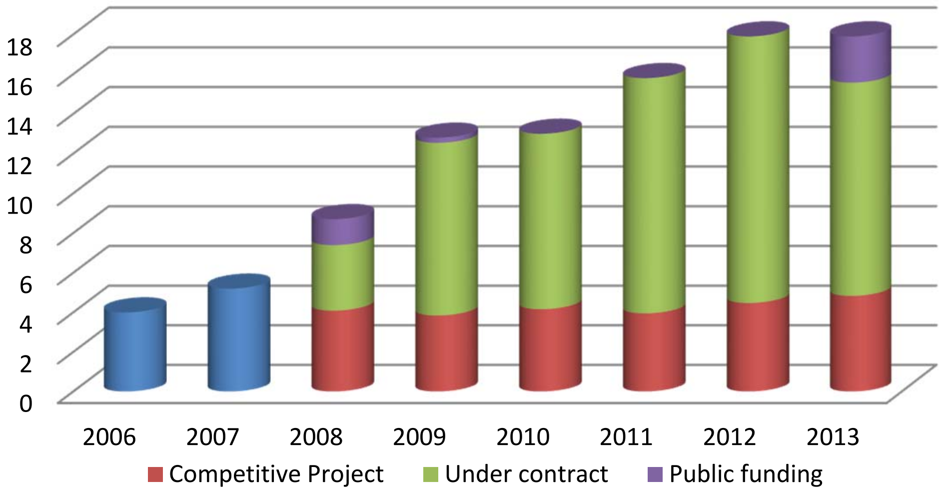
Who are we?

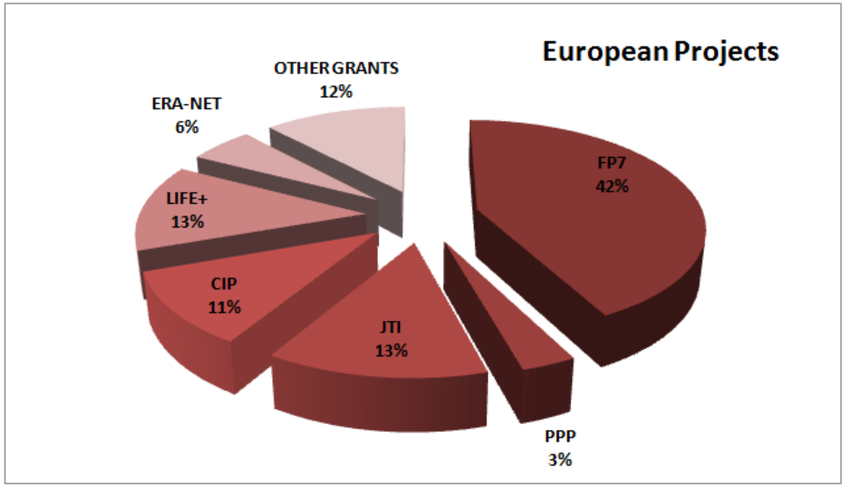



Barcelona

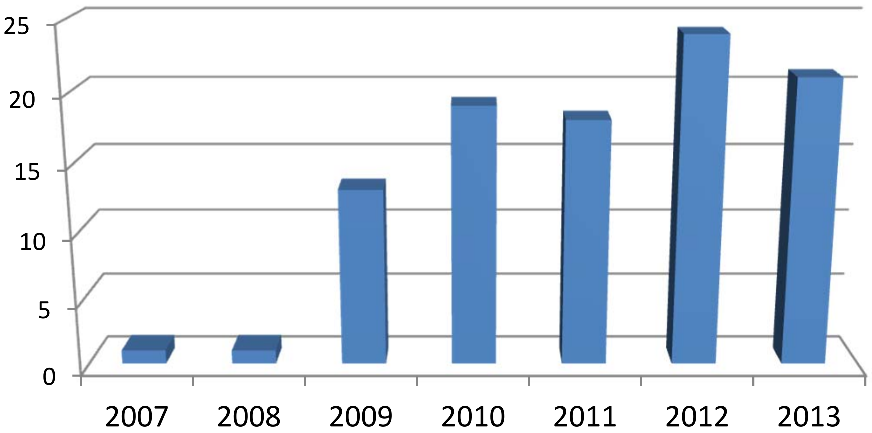


Income over the years (in M€)





Number of EU projects



LEITAT

This presentation:

- ❑ Life Cycle Thinking in nanotechnologies
- ❑ 2 case studies:

1. NANOPOLYTOX project

2. ECOTEXNANO project

WHY???

Scarce studies have generated data for the

Difficulties in nanomaterial release determination

As emerging products

Absence of Fate and intake models for exposure factor determination

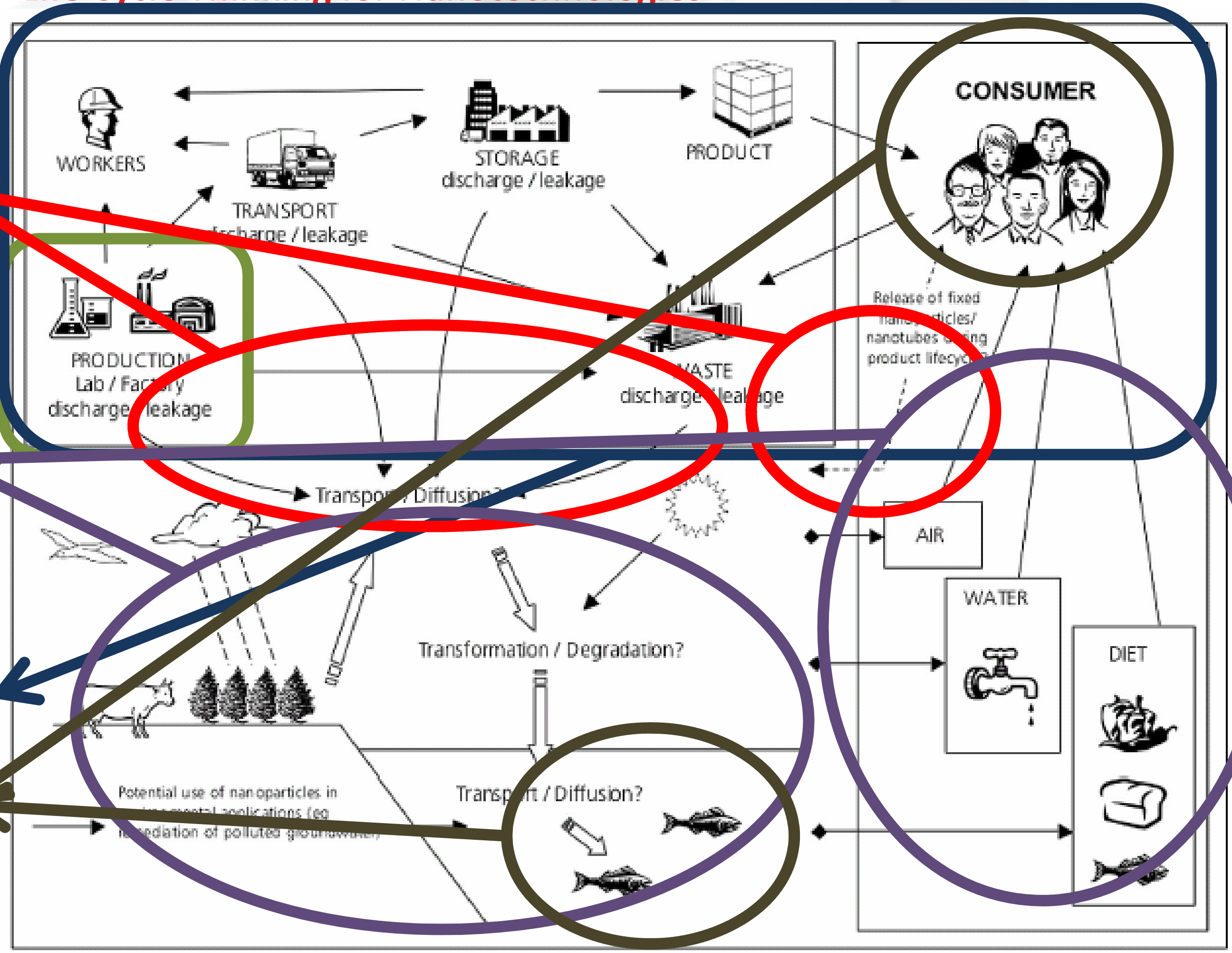
d

inventory data for the **whole life cycle** and include **the**

Lack of hazard data for the characterization factor determination

LCA studies

Life Cycle Thinking for Nanotechnologies



Adopted from The Royal Society & Royal Academy of Engineering 2004

MAIN GAPS AND SHORTCOMINGS OF LCA ON NANOTECHNOLOGY

- Synthesis and production processes:
  - wide variety in the production processes of nanomaterials and evolving fast
  - The information is also often confidential and proprietary
  - Different synthesis methods, different properties: CASE BY CASE
- Limited knowledge on Release of nanomaterials (especially during use phase and end-of-life phase).
- How to evaluate exposure from release data? EXPOSURE MODELLING
- Limited knowledge on the transformations and concentrations of nanomaterials in the environment.
- Environmental fate modelling of released nanomaterials: Need for adaptation of existing models (developed mainly for organic compounds)
- Uncertainty in toxicity: surface properties, functionalization, interaction with environmental media,

NANOPOLYTOX project

FP7-NMP-ENV-2009Project; Number: 247899; 2010-2013

Full Title: "Toxicological impact of nanomaterials derived from processing, weathering and recycling from polymer nanocomposites used in various industrial applications"

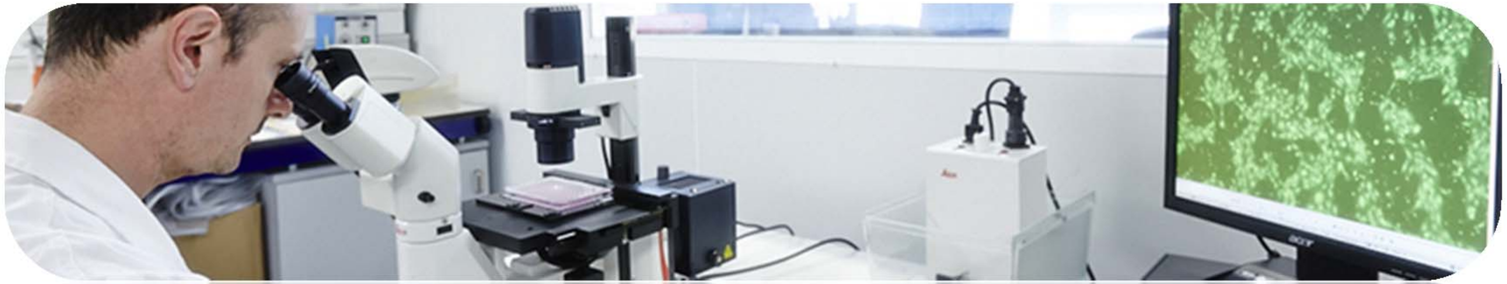
http://www.nanopolytox.eu/

•The **main objective** of NANOPOLYTOX is the **monitoring of the life cycle** of three families of nanomaterials (**carbon nanotubes, nanoclays** and **metal oxide nanoparticles**) when embedded in selected polymeric hosts.

•The project included monitoring of the **chemical and physical properties** of the nanomaterials and their **toxicity** from the synthesis, processing, aging, and recycling to their disposal, covering their migration and/or release during their life cycle.

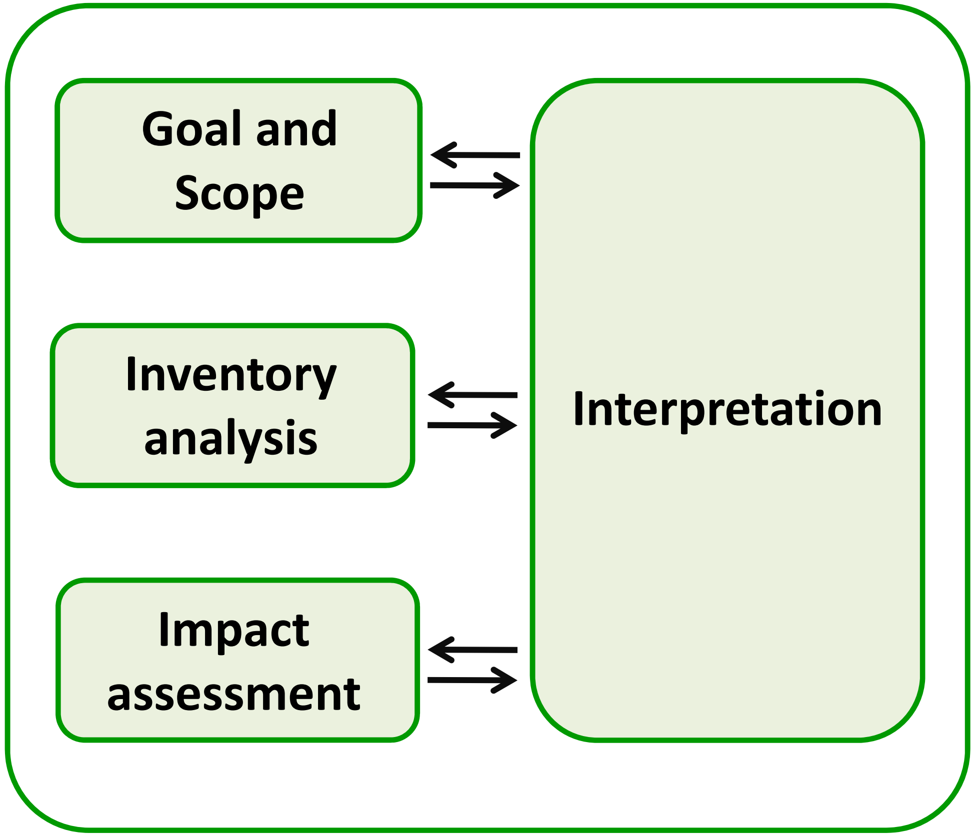
•The theoretical analysis of the data obtained during the project lead to the development of **predictive models to assess the biological and environmental fate of the studied nanomaterials**.

•The overall human health and environmental impact were assessed by **LCIA analysis**, specifically designed for nanomaterials.

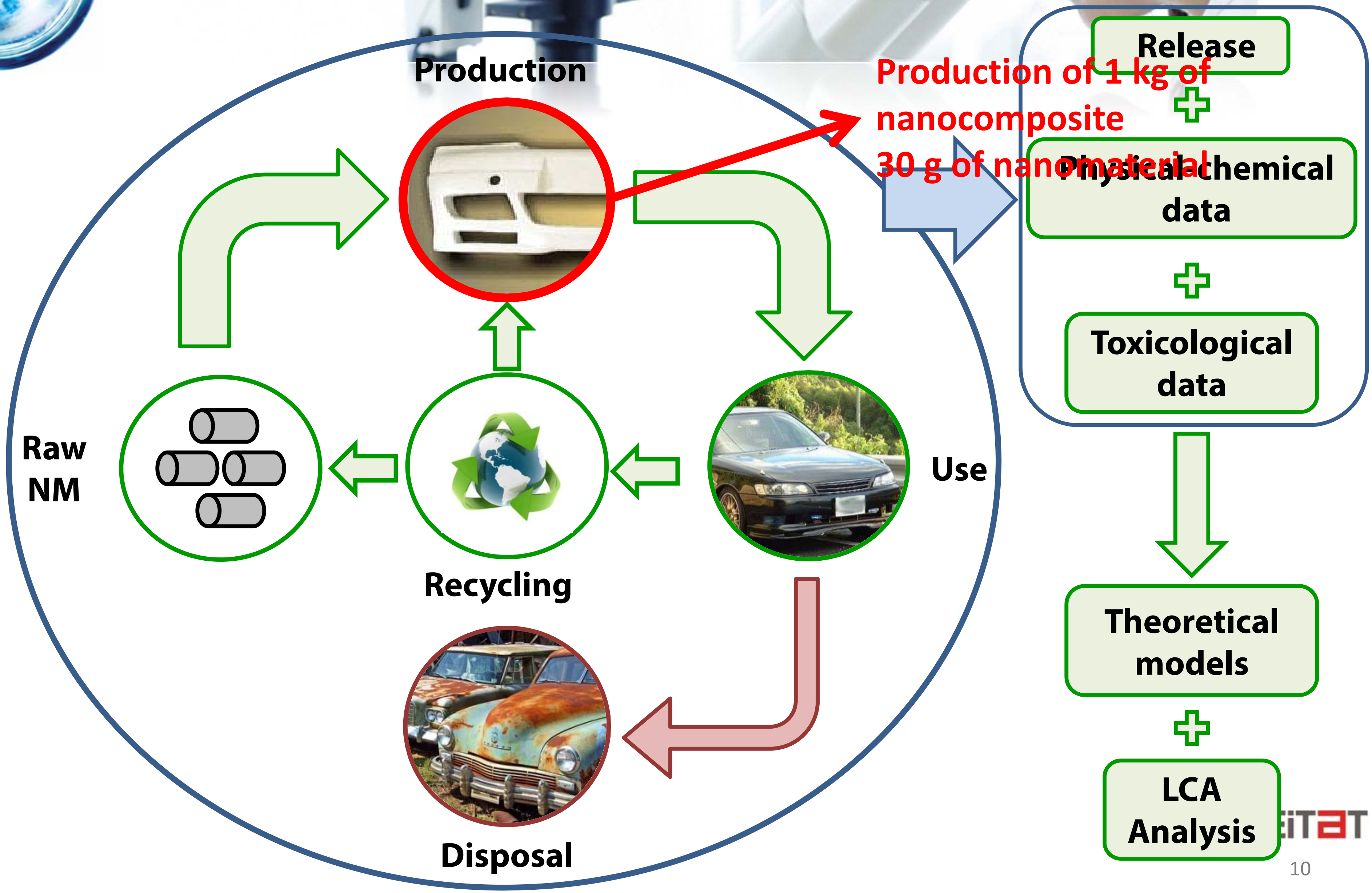


Life Cycle Assessment Framework (ISO 14044)

Standardized methodology: ISOs 14040 and 14044
European Platform on LCA: http://ec.europa.eu/environment/ipp/lca.htm



LCA Approach in Nanopolytox



nanopolytox

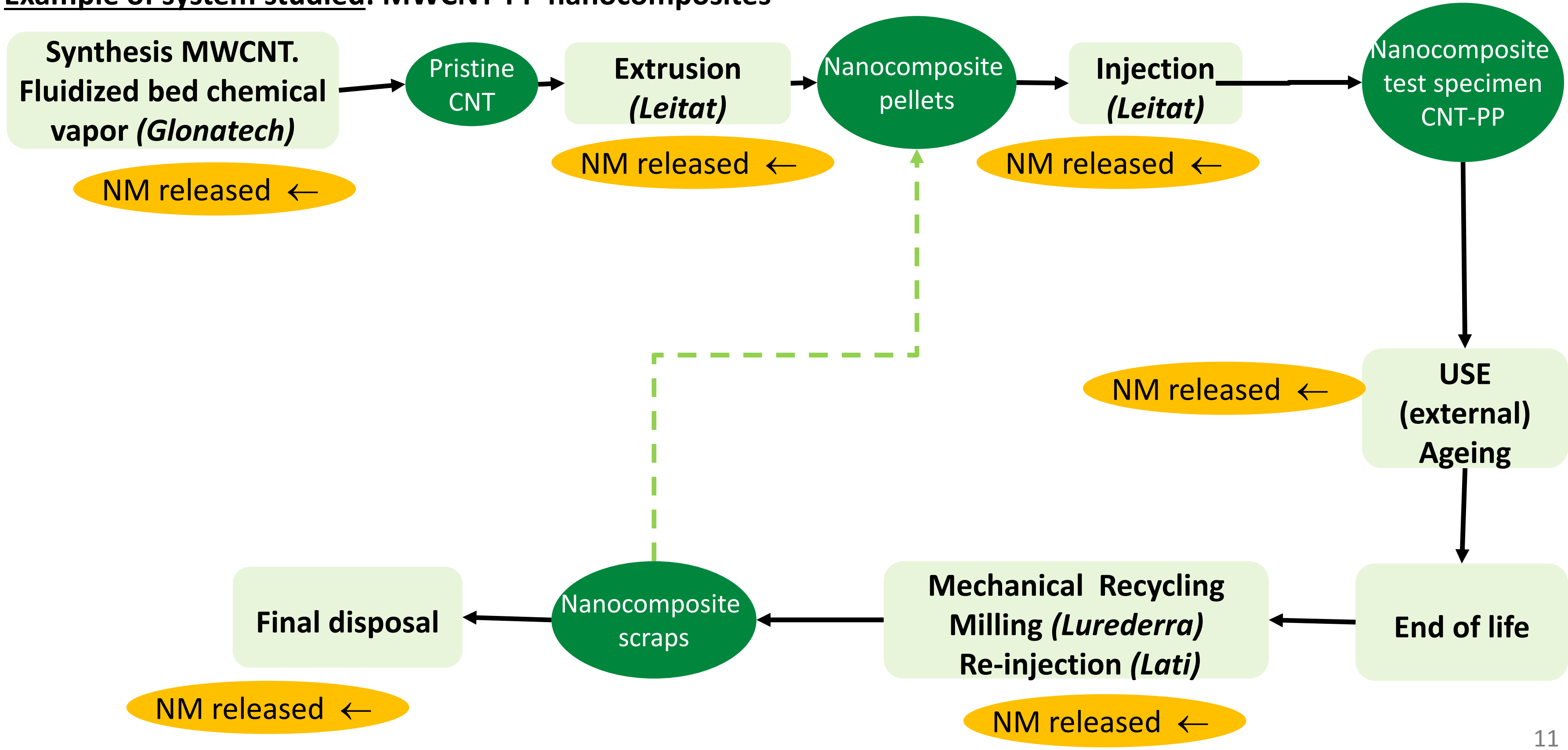
EL PARTNER TECNOLÓGICO

Goal and scope definition

Four Selected nanomaterials to be studied in a comprehensive LCA:

- MWCNT-PP nanocomposite;
- Zinc Oxide – Ethylene vinyl acetate (EVA) nanocomposites;
- Clay – EVA nanocomposites;
- Titanium Dioxide – PA nanocomposite

<u>Example of system studied</u>: MWCNT-PP nanocomposites



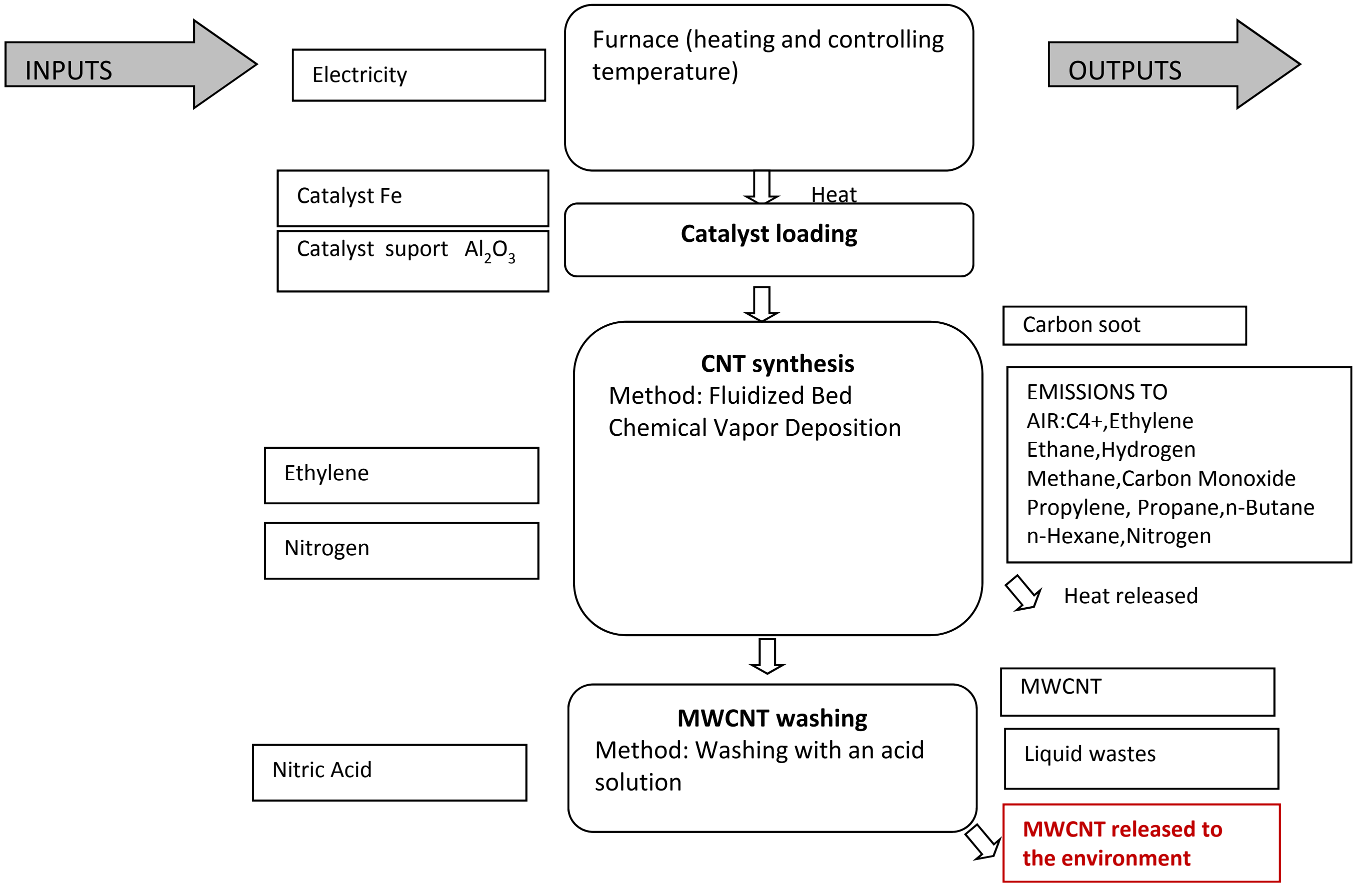
Life Cycle Inventory (LCI)
MWCNT - Synthesis

Synthesis → Functionalisation → Nanocomposite → Use → Waste treatment

Synthesis process: fluidized bed chemical vapour deposition (CDV),

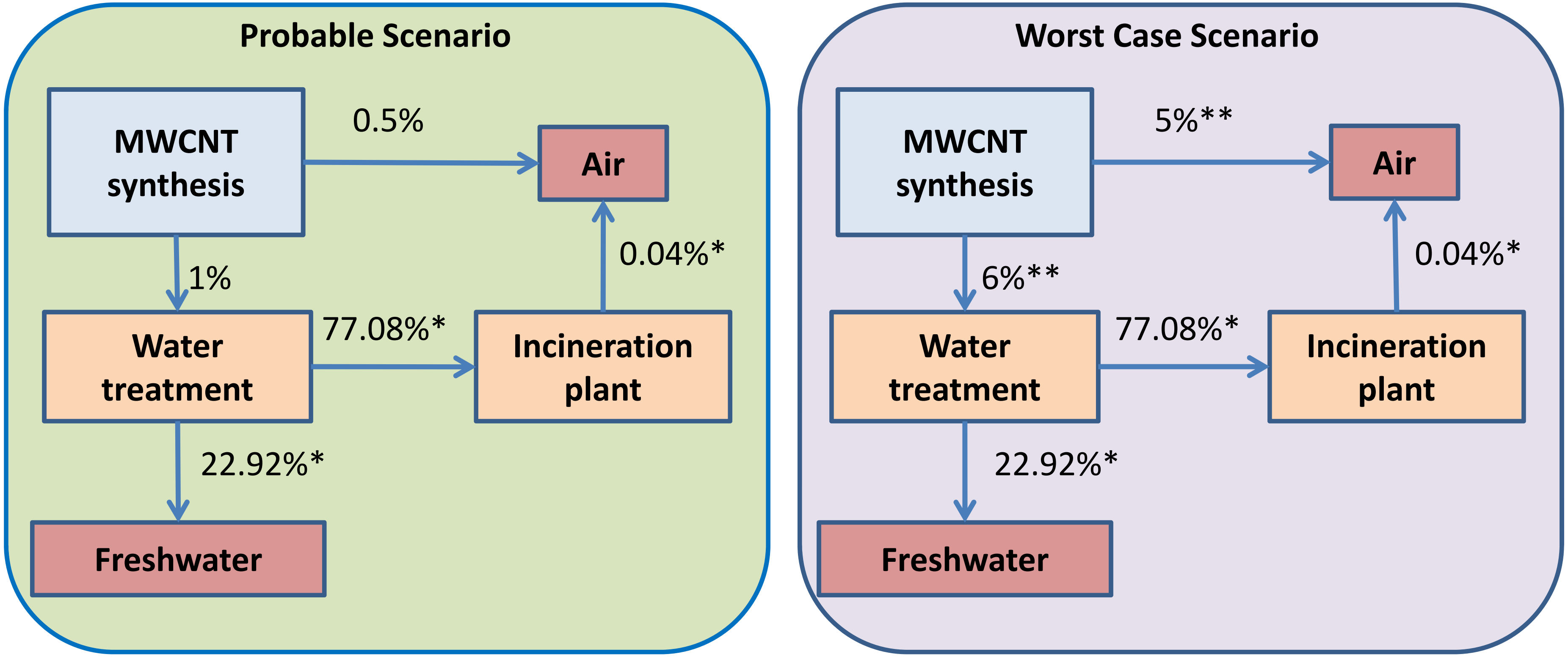
Reference flow: 30 g of multi-wall carbon nanotubes 97-98% (MWCNTs)

Technology: Semi-pilot unit.



Released NM in the Synthetic Process

Synthesis → Nanocomposite → Use → Waste treatment



Environ. Sci. Technol. ***2008***, 42, 4447; *Environ. Sci. Technol.* **2009,** 43, 9216

** 'Guidance on information requirements and chemical safety assessment'.Part D: R16. ECHA

Release of MWCNT during all life cycle of composites

-Production of 1 Kg nanocomposite (3% MWCNT in PP) [MWCNT synthesis + nanocomposite synthesis]

	Probable Scenario	Worst Case Scenario
Air	0.171 + 0.170 g	1.907 + 0.861 g
Freshwater	0.078 + 0 g	0.524 + 0.157 g

-1 year use of 1 kg nanocomposite (3% MWCNT in PP)

	Probable Scenario	Worst Case Scenario
Freshwater	0.017 g	0.068 g

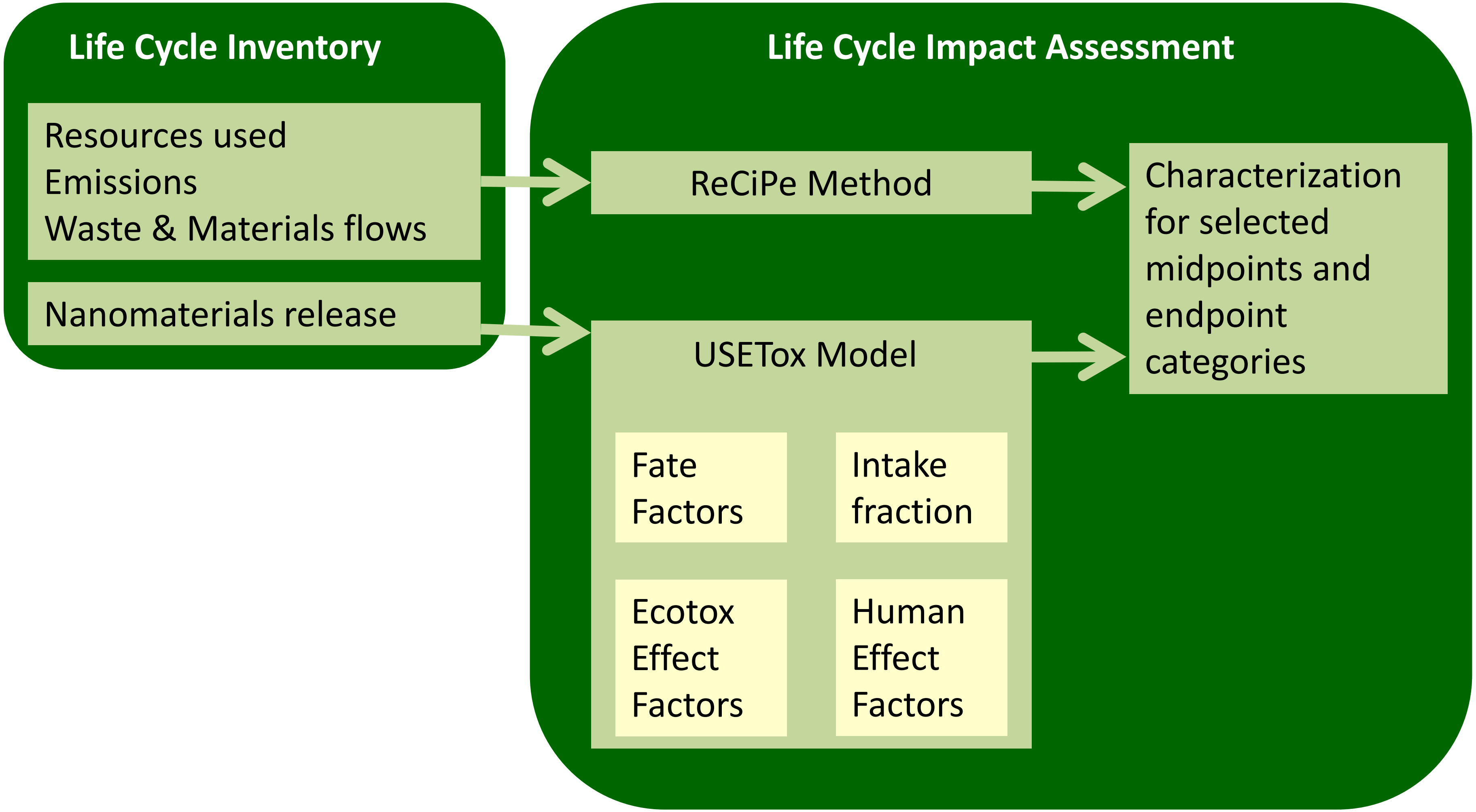
-Waste treatment of 1 kg nanocomposite (3% MWCNT in PP)

	Probable Scenario	Worst Case Scenario
Air	0.005 g	0.012 g

nanopolytox

EL PARTNER TECNOLÓGICO

Life Cycle Impact Assessment (LCIA)



nanopolytox

EL PARTNER TECNOLÓGICO

Life Cycle Impact Assessment (LCIA)

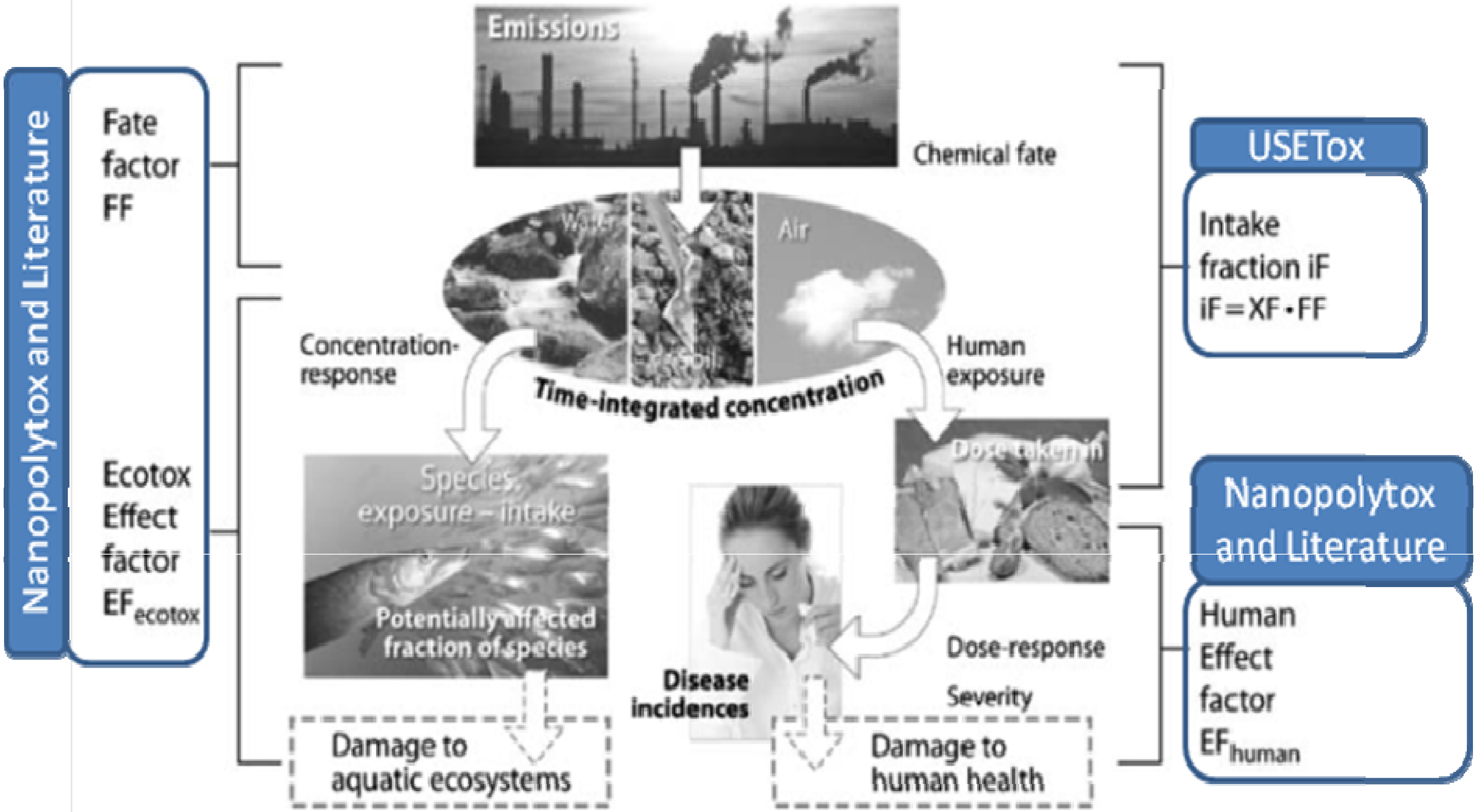
ReCiPe method

	Midpoint impact category name	Abbr.	Endpoint impact category* HH	ED	RA
	climate change	CC	+	+	
	ozone depletion	OD	+	–	
	terrestrial acidification	TA		+	
	freshwater eurotrophication	FE		+	
	marine eurotrophication	ME		–	
NM →	human toxicity	HT	+		
	Photochemical oxidant formation	POF	+	–	
	particulate matter formation	PMF	+		
	terrestrial ecotoxicity	TET		+	
NM →	freshwater ecotoxicity	FET		+	
	marine ecotoxicity	MET		+	
	iosnising radiation	IR	+		
	agricultural land occupation	ALO		+	–
	urban land occupation	ULO		+	–
	natural land transformation	NLT		+	–
	water depletion	WD			–
	mineral resource depletion	MRD			+
	fosil fuel depletion	FD			+

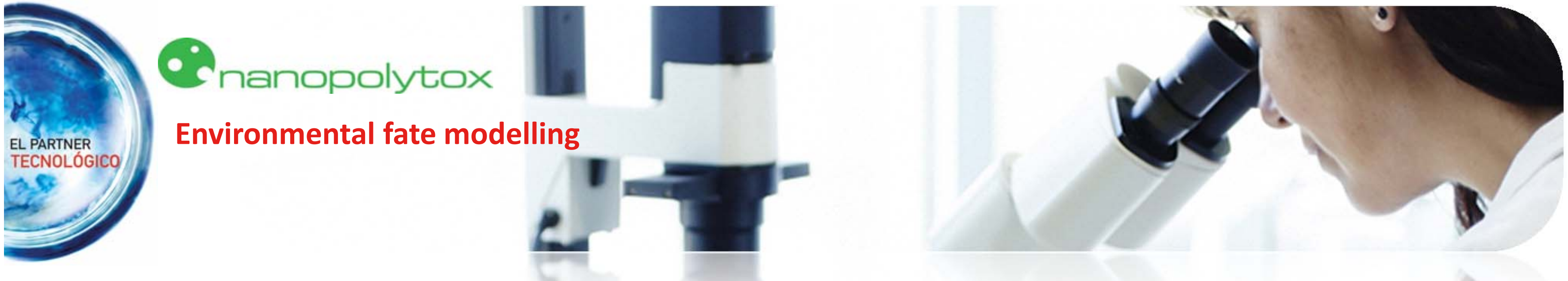
* **HH**: Human Health Damage; **ED**: Ecosystems damage; **RA**: Resource Availability Damage

+: Quantitative connection has been established in ReCiPe 2008 for this link; **–**: No quantitative connection has been established for this link in ReCiPe 2008

Life Cycle Impact Assessment (LCIA)



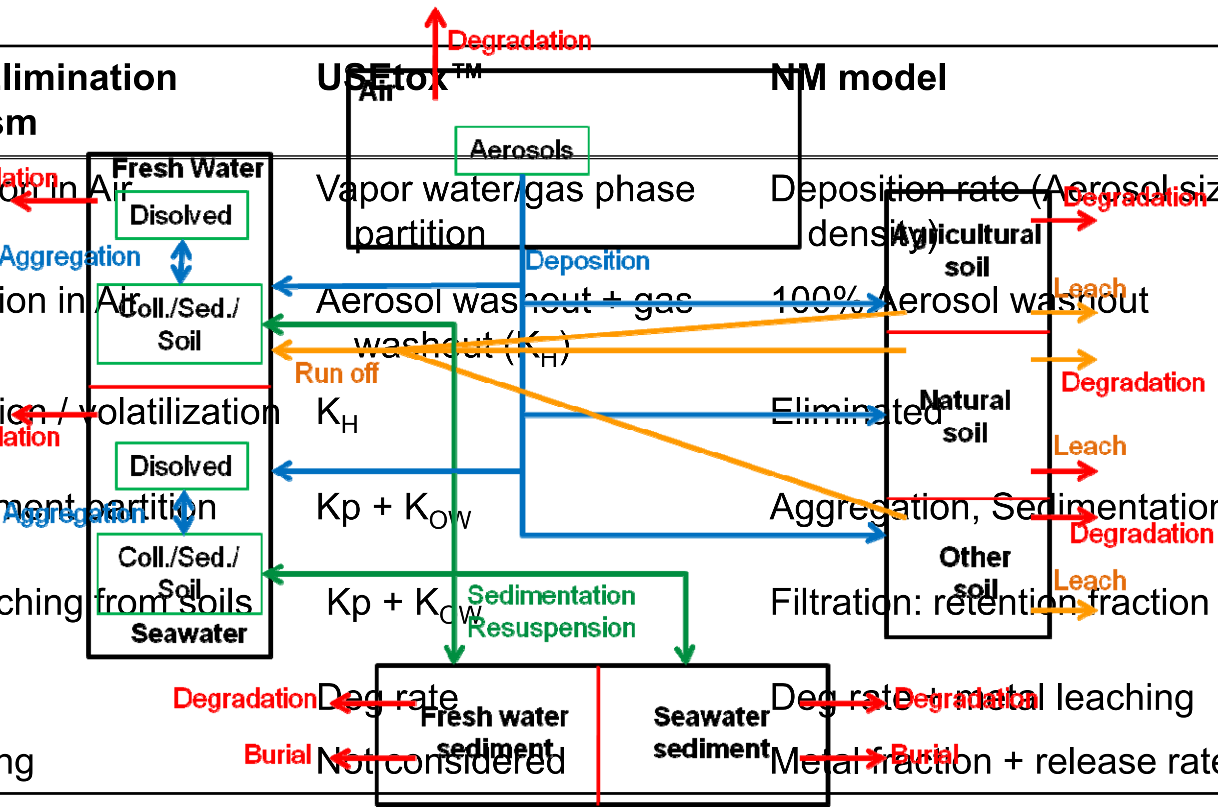
From Rosenbaum *et al.*, **2010**



Environmental fate modelling

USEtox™ Fate model is basically designed for organic compounds and derives most distribution and biodistribution factors from few physico-chemical endpoints. This is not possible with nanomaterials, so we modified the model using different distribution equations. Moreover**, bioaccumulation and intake parameters cannot be derived** from K_{OW} and have to be introduced case by case

Transport/Elimination mechanism	USEtox™	NM model
Dry Deposition in Air	Vapor water/gas phase partition	Deposition rate (Aerosol size, density)
Wet Deposition in Air	Aerosol washout + gas washout (K_H)	100% Aerosol washout
Gas absorption / volatilization	K_H	Eliminated
Water / sediment partition	Kp + K_{OW}	Aggregation, Sedimentation rate
Run off / leaching from soils	Kp + K_{OW}	Filtration: retention fraction
Degradation	Deg rate	Deg rate + metal leaching
Metal leaching	Not considered	Metal fraction + release rate



Derivation following the general USEtox methodology

For example, for ecotoxicity:

1. Collection of available toxicity data for MWCNTs in freshwater organisms and estimation of single species EC_{50}

2. Derivation of HC50 following this formula :

   Log HC50 = 1/n species · SUM (log EC_{50} for each tropic level)

   HC50 values = 12.7 mg/L (best estimate); 4.9 mg/L (worst-case)

3. Derivation of Ecotoxiciy Effect Factor:

   EF = (0.5/HC50)

   EF = 39 m^3/kg (best estimate) and 102 m^3/kg (worst-case)

Main problems:

- (Eco)toxicity studies focused on most common nanomaterials.
- Tests done with the same compound but different material (size, shape, surface chemistry).
- Absence of clear SOP. Comparison between studies is difficult.
- Absence of dosimetry studies. Real exposure vs. supposed exposure.

EL PARTNER TECNOLÓGICO

nanopolytox

MWCNT Characterisation factors

Characterization Factor = Fate Factor x Intake Factor x Effect Factor

Human health characterization factor

[cases/$kg_{emitted}$]:

	Emission to ***urban air***			*Emission to* ***cont. rural air***			*Emission to* ***cont. freshwater***		
	cancer	non-canc.	total	cancer	non-canc.	total	cancer	non-canc.	total
Average	1,5E-05	1,5E-05	2,9E-05	1,7E-06	1,7E-06	3,4E-06	1,4E-07	1,4E-07	2,7E-07
Worth case	1,5E-04	1,5E-04	2,9E-04	1,6E-05	1,6E-05	3,3E-05	1,4E-07	1,4E-07	2,7E-07

[DALY/$kg_{emitted}$]:

	Emission to ***urban air***			*Emission to* ***cont. rural air***			*Emission to* ***cont. freshwater***		
	cancer	non-canc.	total	cancer	non-canc.	total	cancer	non-canc.	total
Average	5.7E-05	5.7E-05	1,1E-04	6,5E-06	6,5E-06	1,3E-05	5,3E-07	5,3E-07	1,0E-06
Worth case	5.7E-04	5.7E-04	1,1E-03	6,1E-05	6,1E-05	1,2E-04	5,3E-07	5,3E-07	1,0E-06

Ecotoxicological characterization factor

[PDF·m^3·day/kg]:

	Emission to ***urban air***	*Emission to* ***cont. rural air***	*Emission to* ***cont. freshwater***
Average	1,8E+02	1,8E+02	4,5E+02
Worth Case	4,6E+02	4,6E+02	1,2E+03

nanopolytox

EL PARTNER TECNOLÓGICO

Effect of released MWCNT (release x charac. factors)

Human health effect

		Probable scenario DALY	Worst case scenario DALY
MWCNT synthesis	cancer	1,15E-09	1,17E-07
	non-cancer	1,15E-09	1,17E-07
	total	2,31E-09	2,33E-07
Nanocomposite synthesis	cancer	1,11E-09	5,26E-08
	non-cancer	1,11E-09	5,26E-08
	total	2,22E-09	1,05E-07
Use	cancer	9,01E-12	3,60E-11
	non-cancer	9,01E-12	3,60E-11
	total	1,80E-11	7,21E-11
Waste treatment	cancer	2,85E-10	6,84E-09
	non-cancer	2,85E-10	6,84E-09
	total	5,70E-10	1,37E-08
Total	cancer	2,55E-09	1,76E-07
	non-cancer	2,55E-09	1,76E-07
	total	5,11E-09	3,53E-07

Ecotoxicological characterization factor

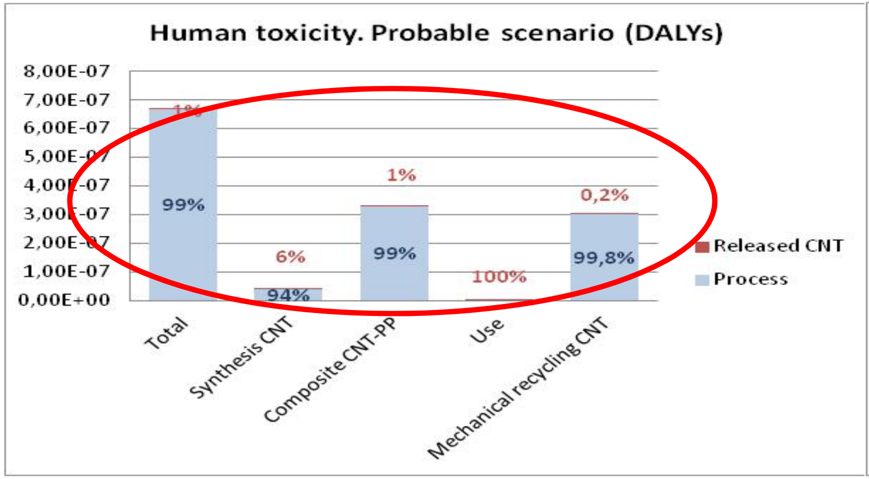
	Probable scenario		Worst case scenario	
	PDF·m³·day	species·year	PDF·m³·day	species*year
MWCNT synthesis	6,58E-02	2,39E-13	1,51E+00	3,25E-12
Nanocomposite synthesis	3,06E-02	6,61E-14	5,84E-01	1,20E-12
Use	7,65E-03	1,65E-14	8,16E-02	1,76E-13
Waste treatment	9,00E-04	1,95E-15	5,52E-03	1,19E-14
Total	1,05E-01	3,24E-13	2,18E+00	4,64E-12

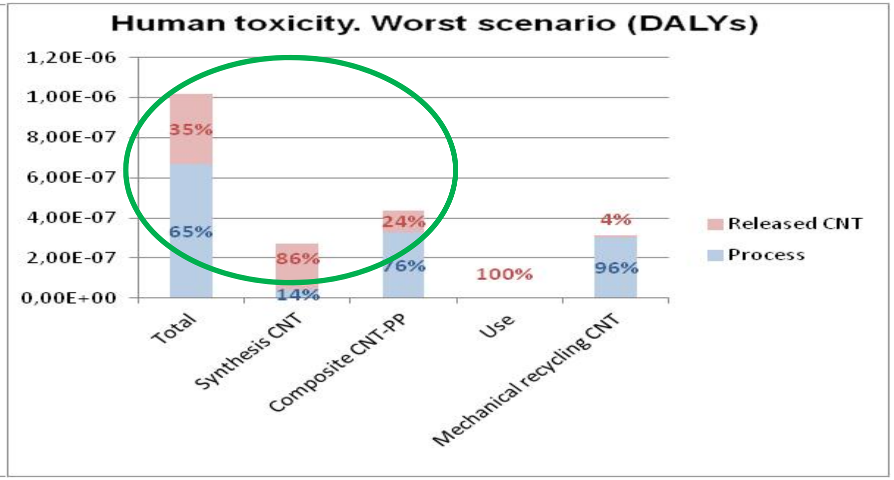
nanopolytox

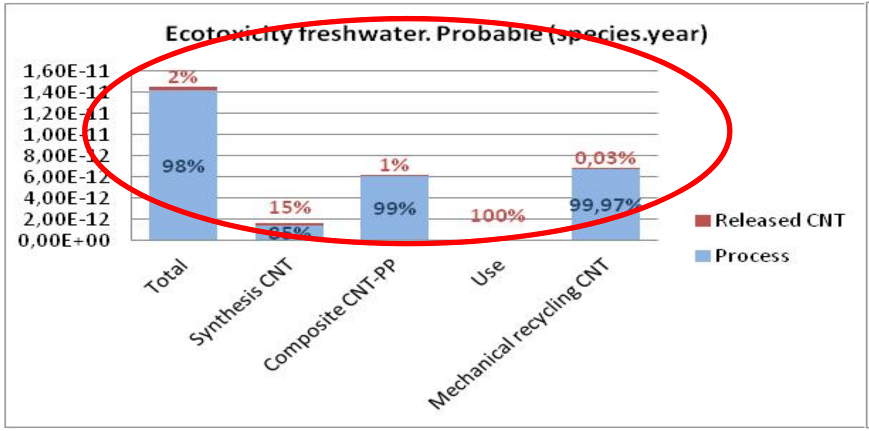
EL PARTNER TECNOLÓGICO

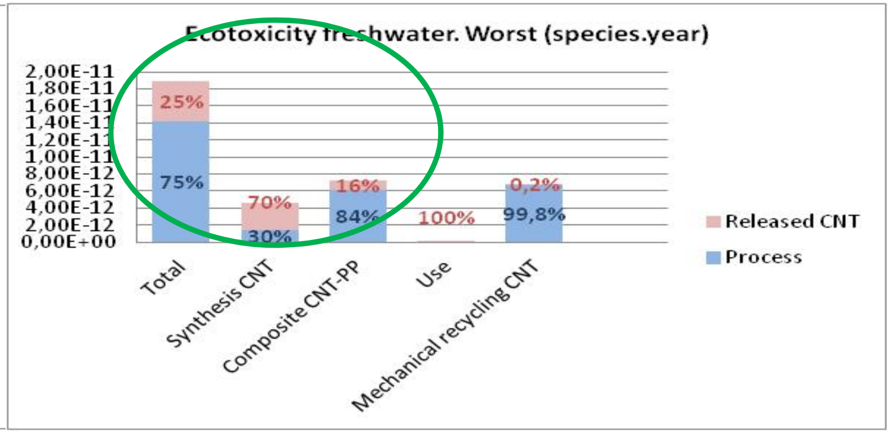
LCIA (ReCiPe)
MWCNT - Nanocomposite

The contribution over Human Toxicity and Ecotoxicity Freshwater is small in the **probable scenario** but quite important in the **Worst Case**









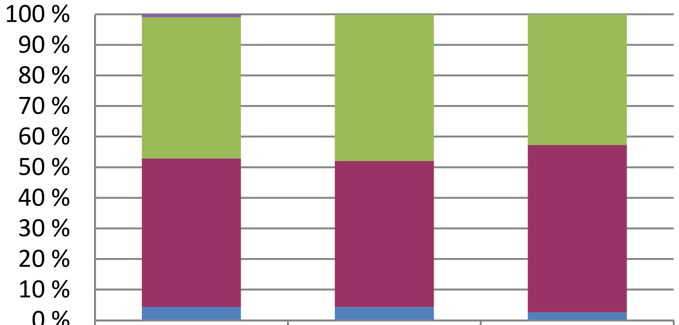
EL PARTNER TECNOLÓGICO

nanopolytox

LCIA (ReCiPe)
MWCNT - Nanocomposite

Damage on Human Health and Distribution of impacts at endpoint level (damage) incorporating the effect of released MWCNT in toxicity categories

(Endpoint indicators. Worst case scenario)



	DALY Human health	species.yr Ecosystems	$ Resources
CNT released	1,0151%	0,0028%	
Mechanical recycling CNT	46%	48%	43%
Composite CNT-PP	49%	48%	55%
Synthesis CNT	4%	4%	3%

But the contribution to the total Damage on Human Health and Damage on the Ecosystems is low even in the Worst Case Scenario

Contribution of the different impact categories to the three damage levels (endpoint, worst case scenario)

	Unit category	**Units**	**Contribution**
DAMAGE ON HUMAN HEALTH	Climate change Human Health	DALY	84%
	Ozone depletion	DALY	0,01%
	Human toxicity	DALY	3%
	Photochemical oxidant formation	DALY	2%
	Particulate matter formation	DALY	0,01%
	Ionising radiation	DALY	0,3%
DAMAGE ON ECOSYSTEMS	Climate change Ecosystems	species.yr	97%
	Terrestrial acidification	species.yr	0,2%
	Freshwater eutrophication	species.yr	0,01%
	Terrestrial ecotoxicity	species.yr	0,1%
	Freshwater ecotoxicity	species.yr	0,01%
	Marine ecotoxicity	species.yr	0,00002%
	Agricultural land occupation	species.yr	1,0%
	Urban land occupation	species.yr	0,4%
	Natural land transformation	species.yr	1,2%
DAMAGE ON RESOURCES	Metal depletion	$	0,004%
	Fossil depletion	$	99,996%

Conclusions

• LCA approach for nanotechnology and nano-products can provide useful information about the main environmental impacts and benefits of this emerging technology.

• At inventory stage, it should be kept in mind that experimental and **lab scale processes can vary from industrial scale processes**.

• When nano-based products are assessed through life cycle assessment, **it is important to include nanoparticles flows and the changes/modifications that these nanoparticles can have during the product life**, since the impact that these nanoparticles can cause if they are released to the environment can be relevant in some stages.

• Potential **impacts of released nanoparticles should be included in the impact assessment step**. Prospective LCA approaches are needed and experimental data on characteristics and toxicity of nanoparticles coming from research projects should be included in LCA methodologies.

• Adapted **exposure and fate modelling are needed** in order to have complete results on the environmental performance of nano-products during all life cycle stages.

• **Adapted Standard Operating Procedure (SOP) for hazard, intake and bioaccumulation are necessary** to have good impact determination,

ECOTEXNANO project

LIFE12ENV/ES/000667; Start date: 01/10/2013 End date: 30/09/2016

Full Title: “Innovative tool to improve risk assessment and promote the safe use of nanomaterials in the textile finishing industry”

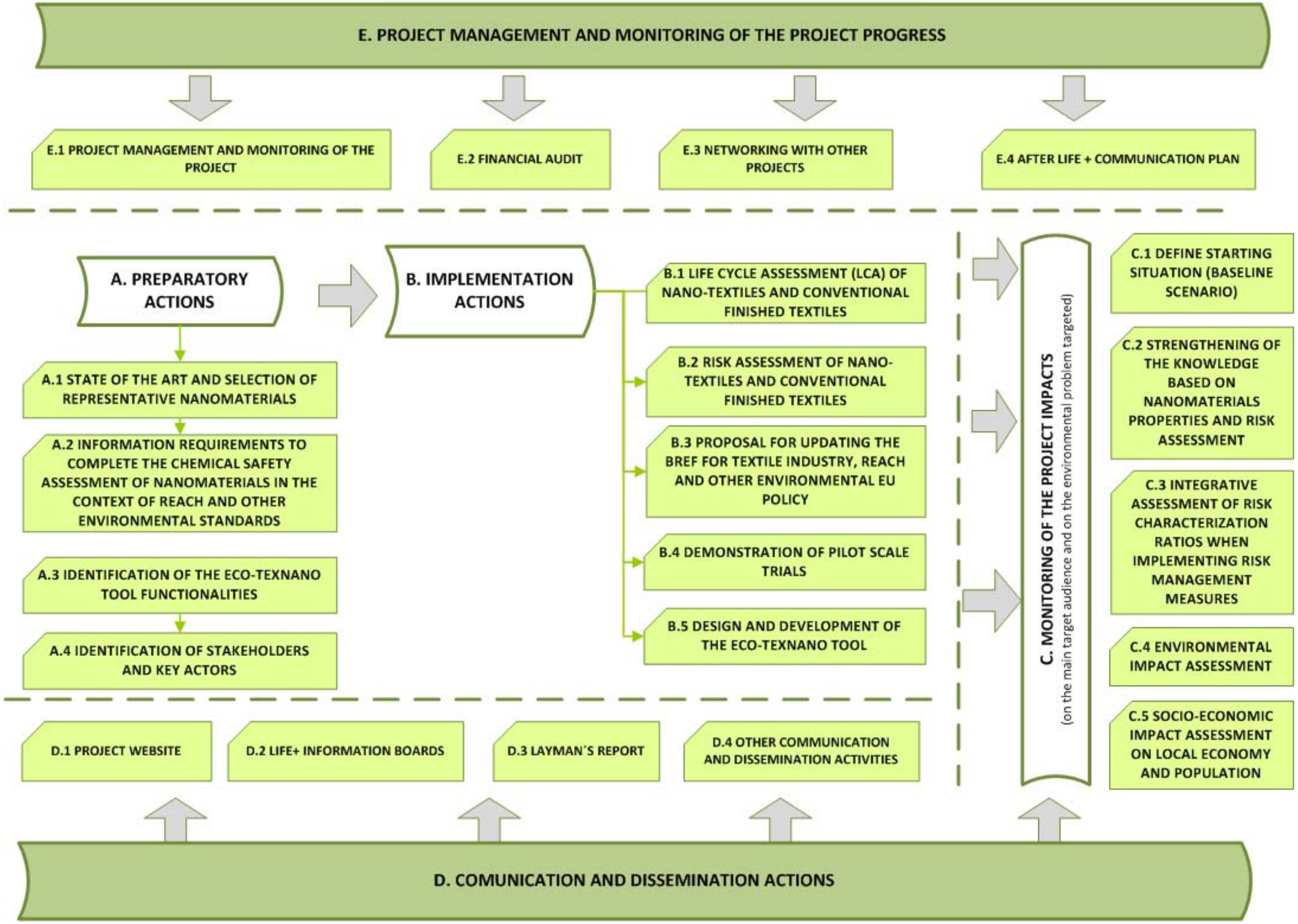
http://www.life-ecotexnano.eu/

Key objectives:

1. Provide the textile finishing industry a user-friendly tool to improve the knowledge on risk assessment of nanomaterials and to promote the safe use along their life cycle.

2. Identify and reduce the environmental, health and safety impacts carrying out a comprehensive Life Cycle.

Work Programme



LCA Scope

✓4 textile technical properties:

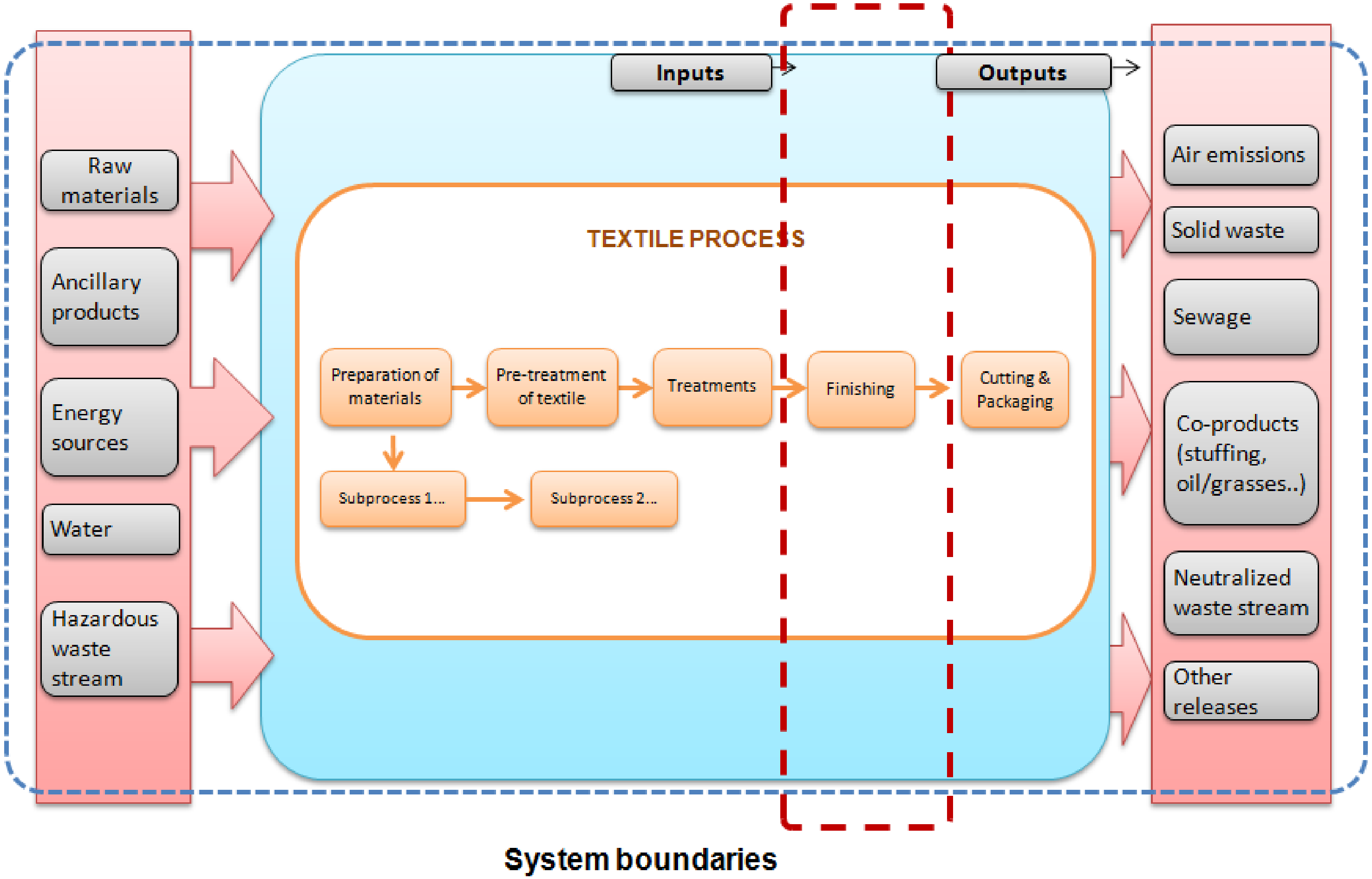
Soil-release
UV protection
Antibacterial
Flame retardant

✓Pilots scale trials:

PIACENZA (Italy)	VINCOLOR (Spain)
Soil-release	Soil-release
UV protection	Flame retardant
Antibacterial	

LCA Scope

✓**Focused on finishing textile process:**



EL PARTNER TECNOLÓGICO

LCA Scope

ecotex nano

LCA is being performed on:

conventional processes ⟷ **LCA** ⟷ **nano-based processes**

Environmental assessment					
PILOT	**PIACENZA**			**VINCOLOR**	
PROPERTY	**Antibacterial**	**UV protection**	**Soil release**	**Soil release**	**Flame retardant**
Conventional	x	x	x	x	x
Nanomaterial*	Silver	TiO2	C6 based fluorochemical	C6 based fluorochemical	Montmorillonite nanoclay / Silica

*Selection criteria based on both “commercially available” and “technically demonstrated on the selected textile applications”

At this stage we have obtained **preliminary results** on the environmental performance of the **conventional processes** used for **soil release** applications in two fabrics from **Vincolor (MIRAGE and DIVINE)**

LEITAT

LCA future results

✓ Identification of the significant impacts related to the process analyzed

✓ Evaluation of impacts in accordance with the objectives and scope of the study to draw conclusions and / or recommendations.

✓ Environmental impact contribution among different stages

✓ Environmental impacts compared to conventional process

✓ Specific results are translated into:

✓ Expected end date: **March 2016**

LEITAT
Acondicionamiento Tarrasense
Tel. (+34) 93 788 23 00
Fax (+34) 93 789 19 06

www. leitat.org
info@leitat.org

Terrassa
C. de la Innovació, 2
08225 Terrassa (Barcelona)

Barcelona
Parc Científic de Barcelona
C. Baldiri Reixach, 15-21
08028 Barcelona

Vilanova del Camí
Centre d'Innovació Anoia
Carrer dels Impressors, 12
08788 Vilanova del Camí

Terrassa
innpulso
Ciudad de la Ciencia
y la Innovación

SOCIAL NET:

THANK YOU!

LEITAT Technological Center
managing your technologies
member of TECNIO

Dr Vincent Jamier– vjamier@leitat.org
International Projects Office
Nanotechnology & Advanced Materials