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January 27th 2010, Congress centre Het Pand Onderbergen, Gent, Belgium

Modelling and comparing the environmental efficiency of new and existing technologies to treat toxic wastewater

M. Almemark[1], K. Westling[1], M. Ek[1], C. Junestedt[1]
M. Ekenberg[2]
G. Mascolo[3], G. Laera[3]
S. Malato[4], A. Zapata[4], C. Sirtori[4]
C. Bayer [5]

[1] IVL Swedish Environmental Research Institute Ltd
[2] AnoxKaldnes
[3] IRSA Istituto di Ricerca sulle Acque Bari
[4] PSA Plataforma Solar de Almería
[5] RWTH Aachen University

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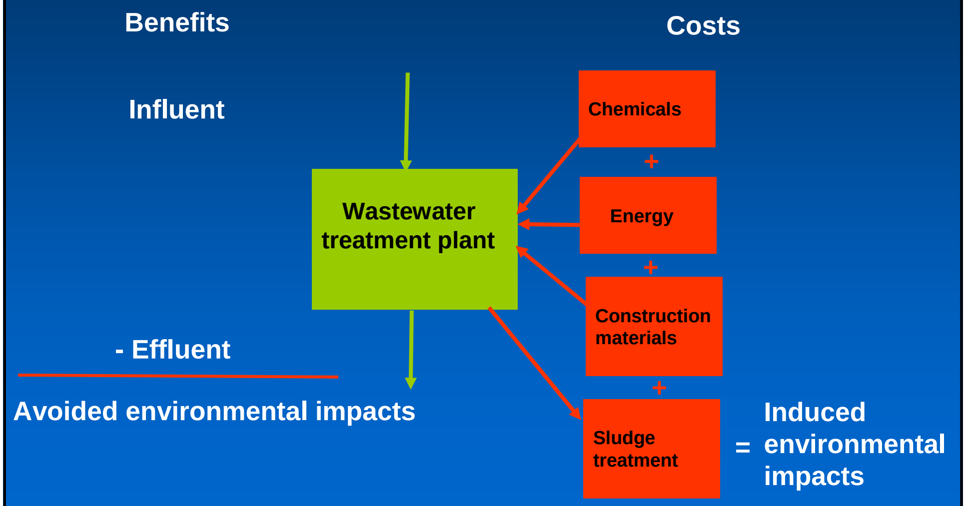
The Technologies

Moving-bed bioreactor + activated carbon from charcoal	MBBR + AC	Reference case Design by AnoxKaldnes
Photo-Fenton + Immob. Biomass Reactor	Ph-F + IBR	Experimental data from PSA Modelling by PSA/IVL
Immobilised Biomass Reactor + Photo-Fenton	IBR + Ph-F	Experimental data from PSA Modelling by PSA/IVL
Membrane Bioreactor with ozonation of recirculating permeate	MBR with ozonation	Experimental data from IRSA Plant design by IVL with the aid of Wedeco and Björks Rostfria (supplier of MBR:s)
Extraction with NaOH in a Membrane contactor + Immob. Biomass Reactor	MC + IBR	Fictitious "tailor-made" design MC model from RWTH IBR model from PSA/IVL

Environmental efficiency – Environmental cost/benefit assessment



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Key Performance Indicators

Benefits

- ✓ Avoided eutrophication (nutrient enrichment)
- ✓ Avoided ecotoxicity

Costs

- ✓ Induced eutrophication
- ✓ Induced ecotoxicity
- ✓ Induced global warming
- ✓ Induced acidification
- ✓ Induced photochemical ozone near the ground
- ✓ Induced resource use

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Indicator descriptions

Impact category	Inventory parameters	Impact assessment potential EDIP[1] characterisation
Nutrient enrichment (eutrophication)	NH_3 to air Nitrogen oxides to air N-tot to water P-tot to air and water	kg NO_3^- equivalents / kg emission. Calculated from the Redfield ratio for biomass: 16 moles N / mole P $C_{106}H_{263}O_{110}N_{16}P$. 1 kg P = 32,03 kg NO_3^- equivalents
COD (eutrophication)	COD	Eutrophication potential from degradation of biomass: 138 moles O_2 / mole biomass => 1 kg COD => 0,225 kg NO_3^- equiv.
Ecotoxicity	Specific compounds, e.g.: Heavy metals Organic chemicals NH_4^+	m³ water / kg substance = f · BIO · 1/PNEC f = distribution factor BIO = biodegradation factor PNEC = predicted no-effect conc.

[1] Environmental Design of Industrial Products, H. Wenzel et al., Techn. Univ. Denmark

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Indicator descriptions (cont.)

Impact category	Inventory parameters	Impact assessment potential
Global warming potential	CO_2, fossil CO CH_4 Halogenated HC Hydrocarbons (NMVOC) N_2O	kg CO_2 equiv./kg substance
Acidifying potential	Mineral acids NH_3 to air Nitrogen oxides (NO_x) Sulphur oxides	kg SO_2 equiv./kg substance
Photochemical oxidant (ozone creation) potential	Organic compounds to air (NMVOC, VOC, HC) CO	kg C_2H_4 equiv./kg substance. NO_x dependent

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SIXTH FRAMEWORK PROGRAMME

Balancing benefits and costs of different types

Method: Normalisation

The quantitative measure of each type of impact is divided by the total emission of that impact per year per person in a specified region.

Result

All impacts are measured as person equivalents (pe) · years

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SIXTH FRAMEWORK PROGRAMME

Normalisation and weighting

EDIP97

Impact category	Unit	Normalization reference	Reference year	Weighting factor	Reference year	Reference region
Environmental impacts						
Global						
Global warming	kg CO_2-eq/pers/year	8,70E+03	1994	1,1	2004	World
Ozone depletion	kg CFC-11-eq/pers/ar	0,103	1994	63	2004	World
Regional and local						
Photochem oz. Form.	kg C_2H_4-eq/pers/year	25	1994	1,3	2004	EU-15
Acidification	kg SO_2-eq/pers/year	74	1994	1,3	2004	EU-15
Nutrient enrichment	kg NO_3^--eq/pers/year	119	1994	1,2	2004	EU-15
-N-equivalents	kg N-eq/pers/year	24	1994	1,4	2004	EU-15
-P-equivalents	kg P-eq/pers/year	0,4	1994	1	2004	EU-15
Ecotoxicity						
- water acute	m^3 water/pers/year	2,91E+04	1994	1,1	2004	EU-15
- water chronic	m^3 water/pers/year	3,52E+05	1994	1,2	2004	EU-15
- soil chronic	m^3 soil/pers/year	9,64E+05	1994	1	2004	EU-15
Human toxicity						
- via air	m^3 air/pers/year	3,06E+09	1994	1,1	2004	EU-15
- via water	m^3 water/pers/year	5,22E+04	1994	1,3	2004	EU-15
- via soil	m^3 soil/pers/year	1,27E+02	1994	1,2	2004	EU-15

The Methodology

Life Cycle Assessment according to ISO 14044:2006 (CEN)

Goal and Scope

- **Assess and compare the environmental performance of the technologies – strength and weaknesses**
- **Assess the environmental efficiency of each technology. Is it overall beneficial?**

Functional unit

1 m^3 of a pharmaceutical wastewater with a standardised composition

The standard pharmaceutical wastewater

Wastewater flow	5	m^3/day
Nalidixic acid	0,045	kg/m^3
DOC	0,775	kg/m^3
COD	2,66	kg/m^3
TSS	0,496	kg/m^3
N-tot (from nalidixic acid)	0,00543	kg/m^3
PO_4^{3-}	0,010	kg/m^3
Na^+	2	kg/m^3
Cl^-	2,8	kg/m^3
SO_4^{2-}	0,16	kg/m^3
Ca^{2+}	0,02	kg/m^3
pH	4	

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System boundaries

- Influent wastewater to the treatment
- Supply of necessary commodities and construction materials from natural resources
- Impacts in the receiving waters
- Treatment of wastes, such as sludge

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Geographical boundaries

Supply of commodities: Europe in general

Electricity: Southern Europe (Spain)

Receiving water for the treated wastewater: Fresh-water course.

Spanish average electricity 2002 [1]

Type of generated power	% of supply mix
Hard coal	28.2
Lignite	4.7
Heavy fuel oil	11.6
Natural gas	13.2
Blast furnace gas	0.5
Nuclear power	25.6
Hydropower	10.7
Wind power	3.5
Biomass, solid and gaseous	1.6
Waste incineration	0.2
Other sources	0.2

[1] GaBi Professional database, PE International, Stuttgart

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Materials and methods

Experimental data from the process developing WP:s

↓

Model the process as far as is possible. Design a treatment plant for the standardised wastewater.

↓

Use the design in the inventory for a LCA of the treatment process, including supply of commodities. Environmental data for electricity and other commodities from databases, mainly Ecoinvent

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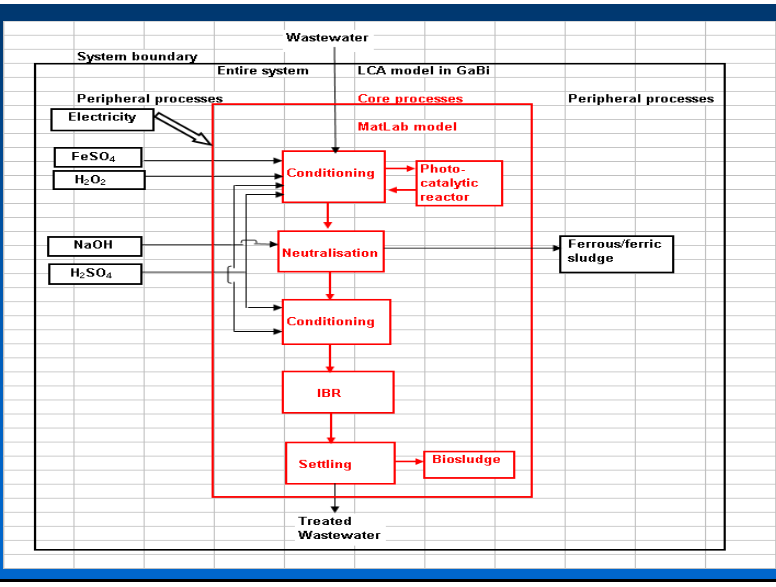
Example Photo-Fenton + IBR. Core/peripherial processes, system boundary



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Treatment performance

	Nalidixic acid removal %	COD/TOC removal %	*Nitrogen removal %*	*Phosphorus removal %*
MBBR +AC	**90**	**88**	*-120*	*70*
Ph-F + IBR	**98**	**98**	*8*	*98*
IBR + Ph-F	**98**	**99**	*8*	*96*
MBR with ozonation	**96**	**98**	*0*	*ca. 30 %*
MC + IBR	**98**	**96**	*8*	*96*

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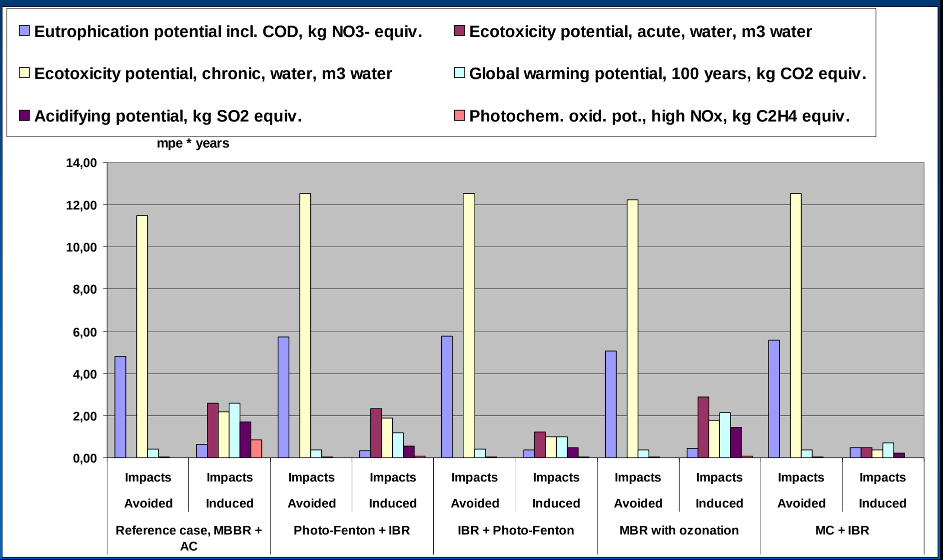
Normalised avoided and induced impacts



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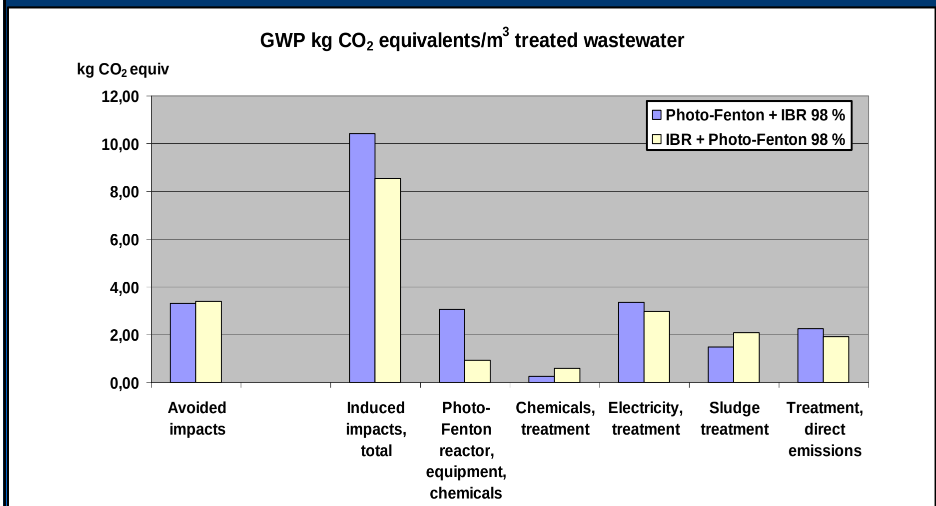
Avoided and induced greenhouse gas effect, Photo-Fenton / IBR



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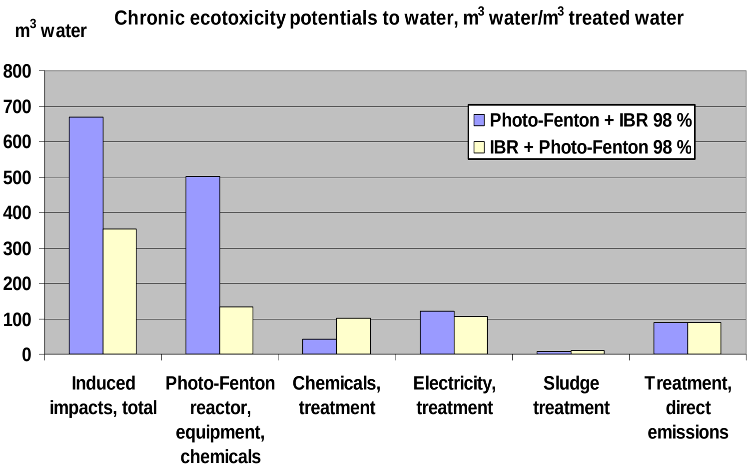
Chronic ecotoxicity, induced and remaining, Photo-Fenton / IBR



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Interpretation at this point

- There is a large uncertainty in the toxicity assessment and some uncertainty in the treatment process data.
- The overall environmental balance-sheet is positive for all technologies, but given the uncertainty the efficiency of the use of chemicals and energy should be improved to ensure a positive balance.
- Obviously the environmental balance-sheet depends heavily on the source of electricity and chemicals used. Search for alternative sources of supply is a further potential for improvement.
- The maximally possible removal rate of nalidixic acid must not necessarily be the best solution for the environment, when the environmental impacts of the upstream processes are considered.

Acknowledgment

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