UNIVERSITAT ROVIRA I VIRGILI

Chemical Engineering Department

Life Cycle Assessment of a Biodiesel plant

Haydée Yrigoyen

Francesc Castells

Department of Chemical Engineering, URV,
Tarragona, Spain

Research Group on
Environmental Management and Analysis

AGA

Introduction

The industry needs methods to identify, quantify and reduce the environmental effects generated by its activity.

A methodology to obtain the environmental and economical profile of a process plant is necessary.

General objective

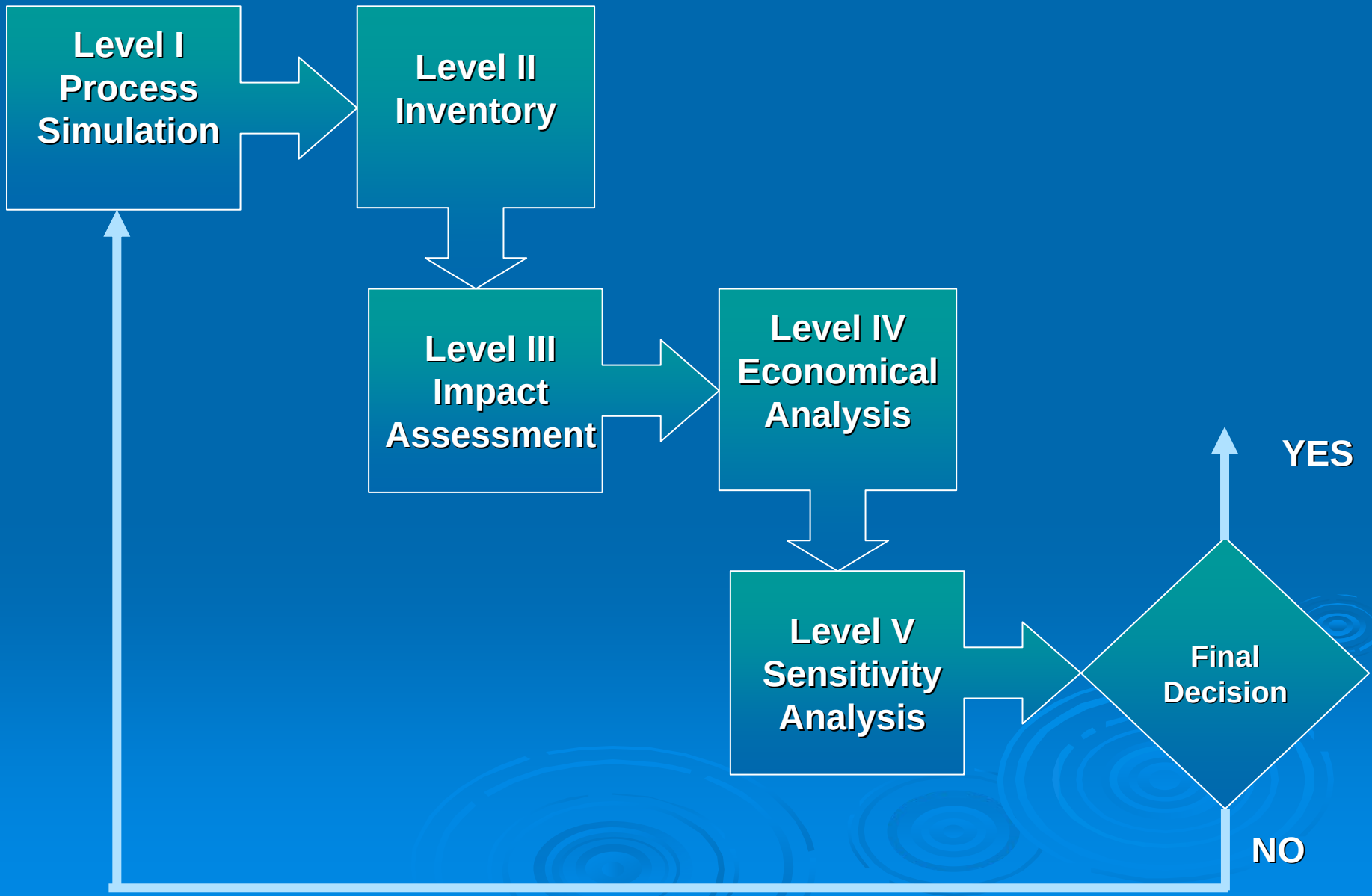
Process analysis methodology

Simulation, environmental and economic criteria in the decision-making step

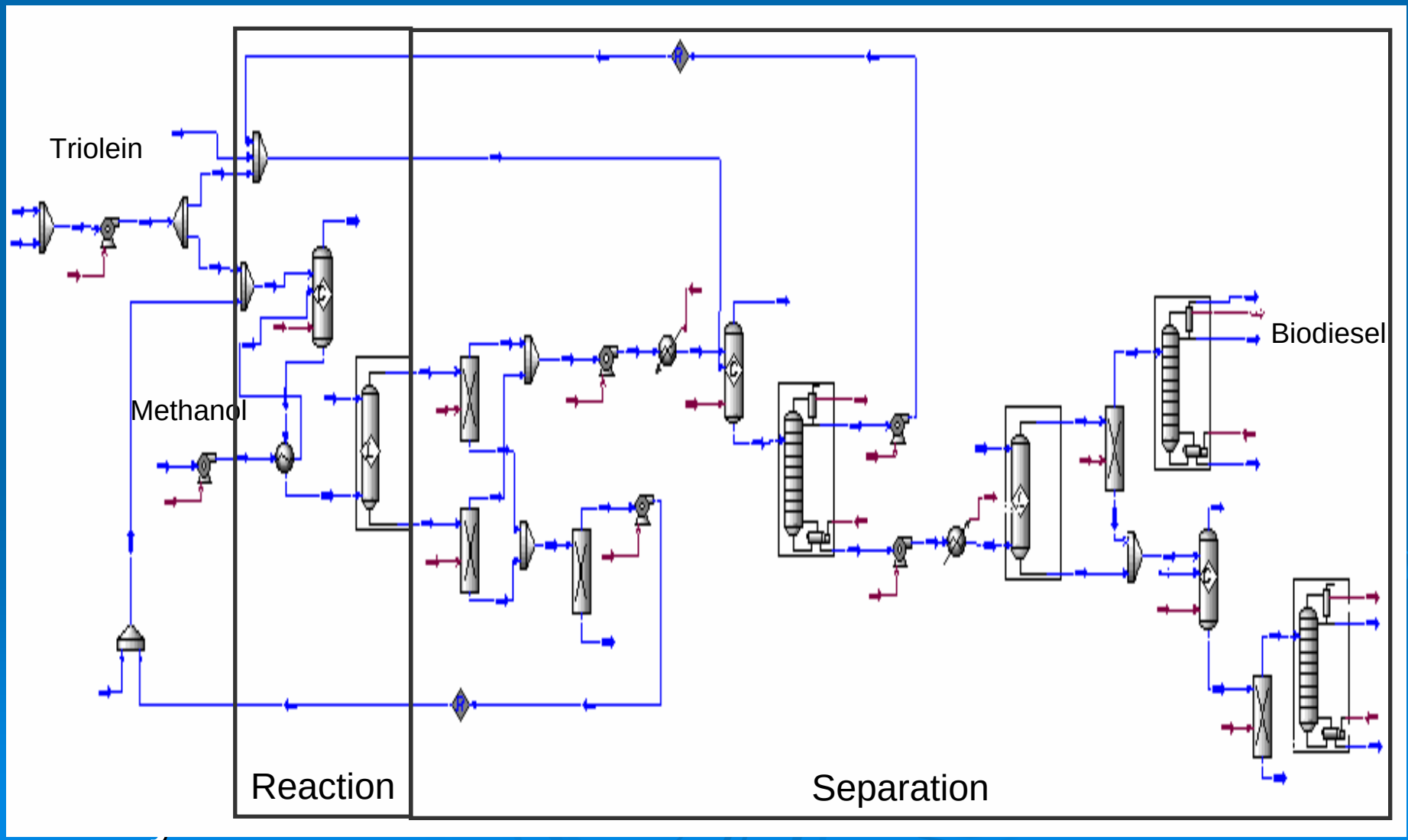
Specific objectives

- Conception and description of the methodology
- Construction of a tool → validate the methodology
- Environmental database { impact categories; sub-processes
- Integration of economic aspects
- Incorporation of sensitivity analysis

Methodology



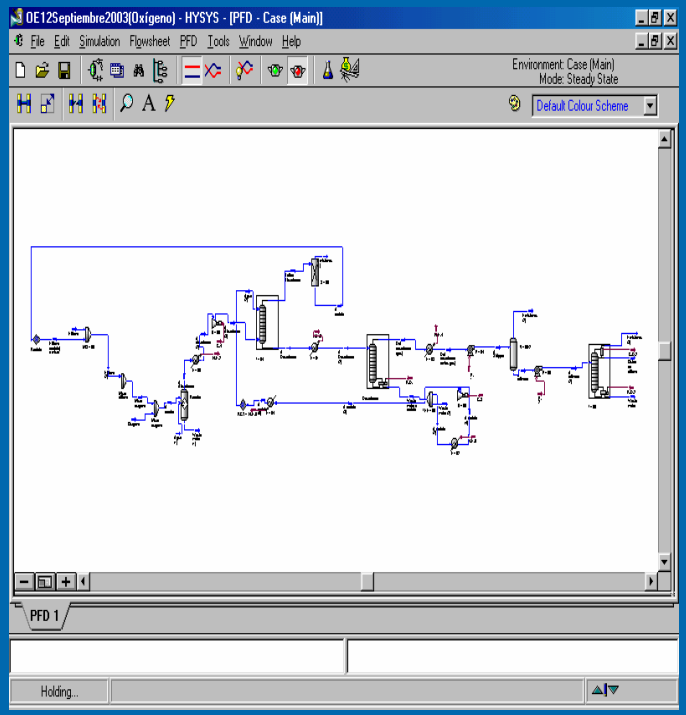
Level I: Process Simulation



Level I: Process Simulation

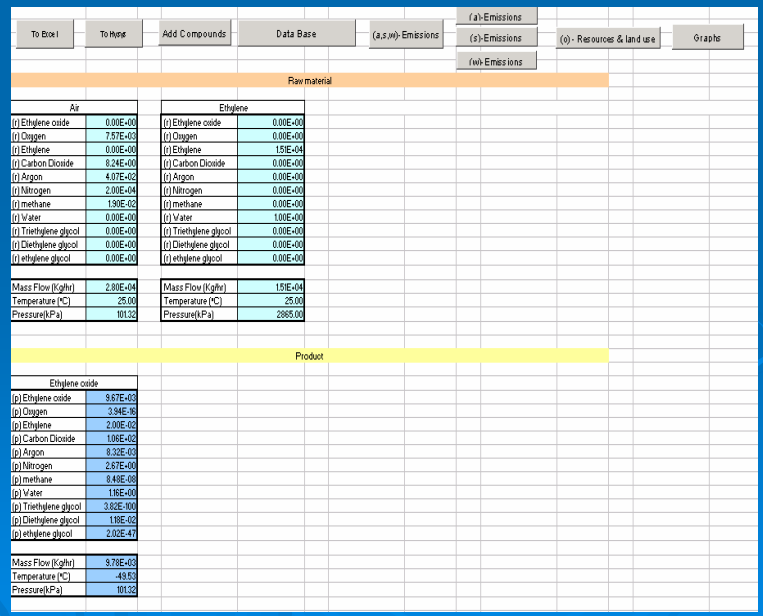
Industry

User intervention



ASPEN Hysys®

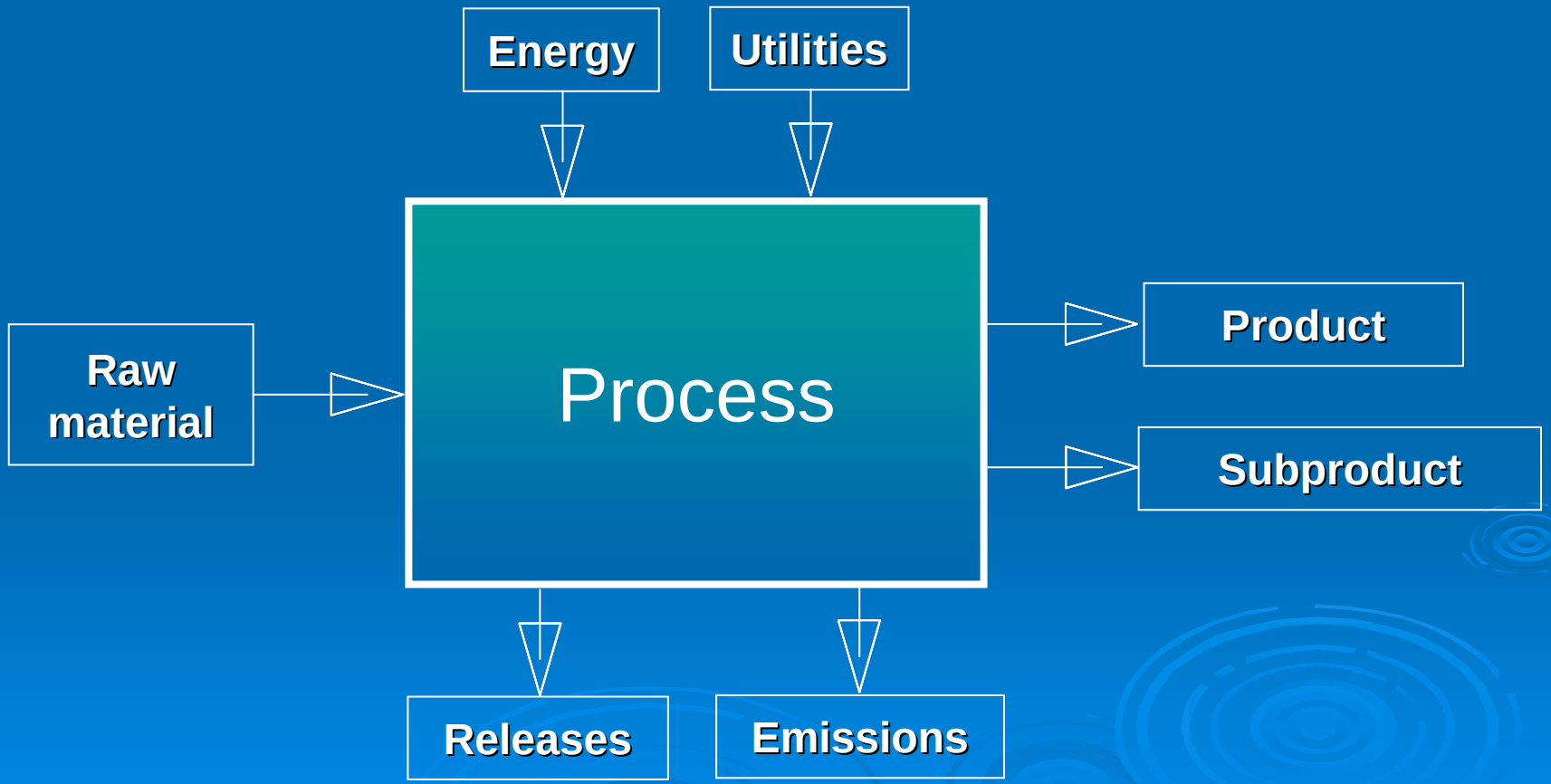
Visual basic



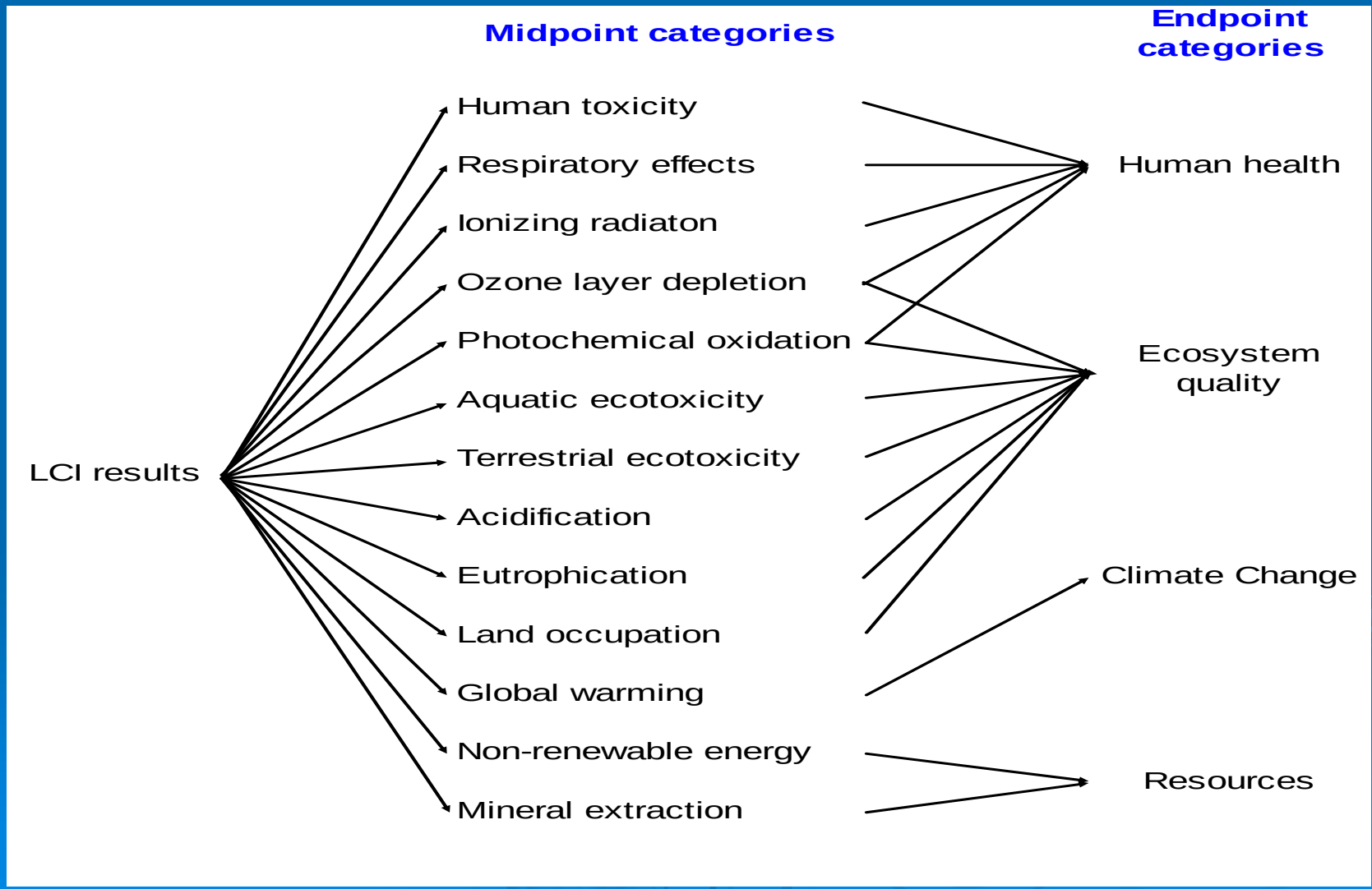
Excel®

Level II: Inventory

- Sectional analysis



Level III: Impact Assessment



Level III: Impact Assessment

- Methods:
  - CML
  - Eco-indicator 99
  - IMPACT 2002+
- Time horizon
- Mid & end-point categories
- Extraction or receiving environment:
  - Air (26 $\rightarrow$ 96)
  - Water (17 $\rightarrow$ 48)
  - Soil (15 $\rightarrow$ 42)
  - Natural resources / landscape (9 $\rightarrow$ 21)

Level III: Impact Assessment

	Midpoint categories	Endpoint categories	Total
Global Warming Potential	CML, IMPACT 2002+ Time horizon: 20, 100, net 100 min, net 100 max, 500		11
Damages to human health caused by climate change		ECOINDICATOR 99, IMPACT 2002+	4
Ozone layer depletion	CML		8
Human health effects caused by ozone layer depletion		ECOINDICATOR 99, IMPACT 2002+	5
Human toxicity	CML, IMPACT 2002+ Time horizon: inf., 20, 100, 500 Carcinogenic, non-carcinogenic		7
Human toxicity		ECOINDICATOR 99, IMPACT 2002+	6
Ecotoxicity	CML, IMPACT 2002+ Time horizon: inf., 20, 100, 500 Aquatic, sedimental: freshwater and marine Terrestrial		22
Ecotoxicity caused by ecotoxic emissions		ECOINDICATOR 99, IMPACT 2002+	5
Photochemical Oxidation	CML, IMPACT 2002+ very high NOx, high NOx, low Nox		6
Respiratory effects on humans caused by organic substances		ECOINDICATOR 99, IMPACT 2002+	4

Level III: Impact Assessment

		Impact Category$_1$	Impact Category$_2$	Impact Category$_3$	..... Category$_n$
Comp$_1$	Subprocess$_1$	A_{111}	A_{211}	A_{311}	A_{n11}
	Subprocess$_2$	B_{121}	B_{221}	B_{321}	B_{n21}
	Subprocess$_3$	C_{131}	C_{231}	C_{331}	C_{n31}
Comp$_2$	Subprocess$_1$	D_{112}	D_{212}	D_{312}	D_{n12}
	Subprocess$_2$	E_{122}	E_{222}	E_{322}	E_{n22}
	Subprocess$_3$	F_{132}	F_{232}	F_{332}	F_{n32}
.	.	.	.	.	.
.	.	.	.	.	.
Comp$_m$	Subprocess$_1$	G_{11m}	G_{21m}	G_{31m}	G_{n1m}
	Subprocess$_2$	H_{12m}	H_{22m}	H_{32m}	H_{n2m}
	Subprocess$_3$	Y_{13m}	Y_{23m}	Y_{33m}	Y_{n3m}

Level IV: Economical Analysis

- Initial information:
  - Operating costs
  - Employees, salary and working days
  - Plant life period (10 years)
  - Annual interest rate (10%)

Level IV: Economical Analysis

- Obtained information:
  - Production cost
  - Selling Program
  - Equilibrium point
  - Cash Flows

Level IV: Economical Analysis

- Economical indicators:
  - Net Present Value (NPV, €)
  - Payback Period (PP, years)
  - Discounted Payback Period (DPP, years)
  - Internal Rate of Return (IRR, %)
  - Modified Internal Rate of Return (MIRR, %)

Level V: Sensitivity Analysis

- Compound and associated process stage with higher contribution to each impact category.
  - Impact category $\rightarrow$ objective function
  - Compound $\rightarrow$ variables

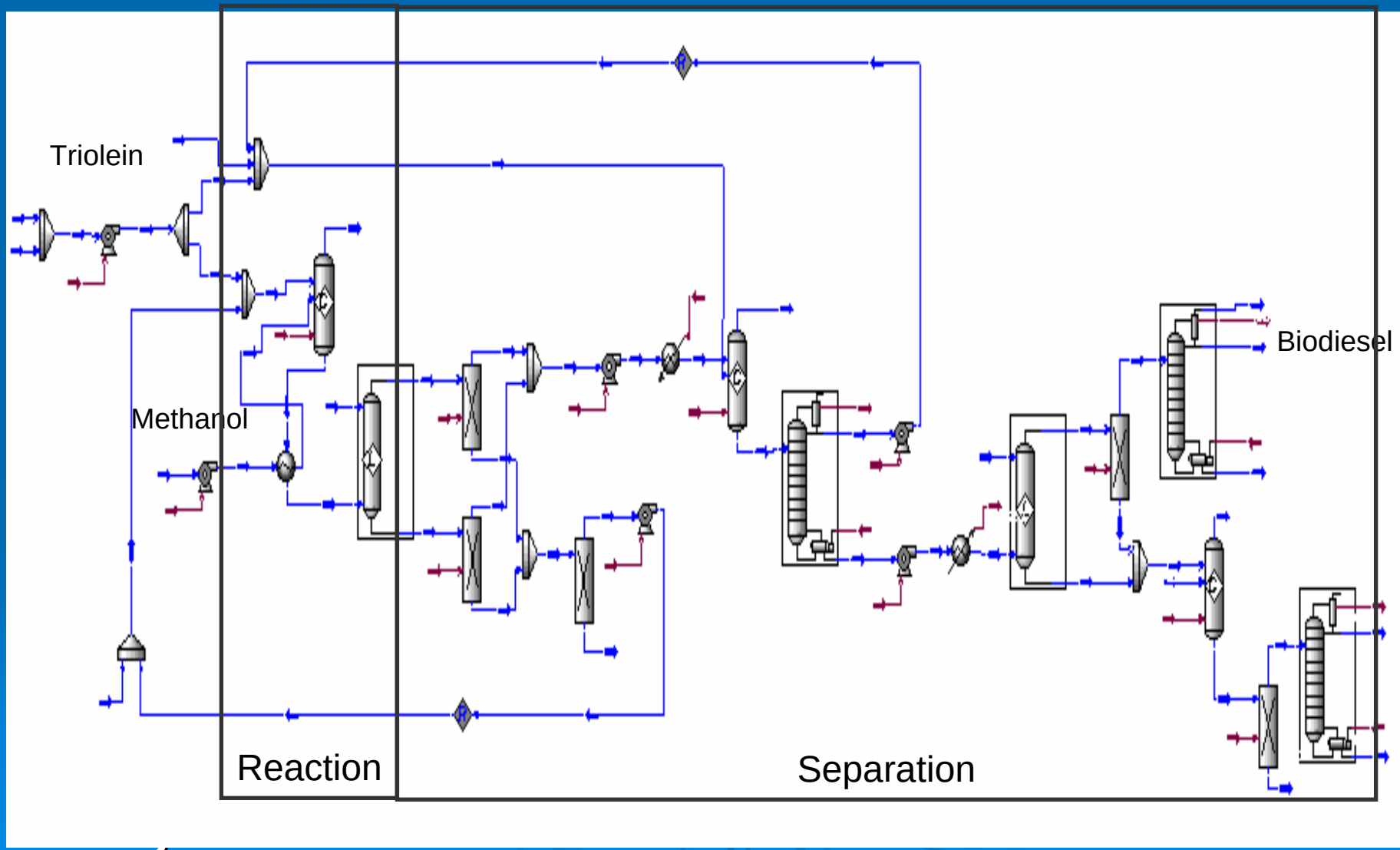
Case Study : Biodiesel

- Functional unit: 1 kg of Biodiesel
- Topologies centered in the catalyst:
  - Alkali
  - Acid

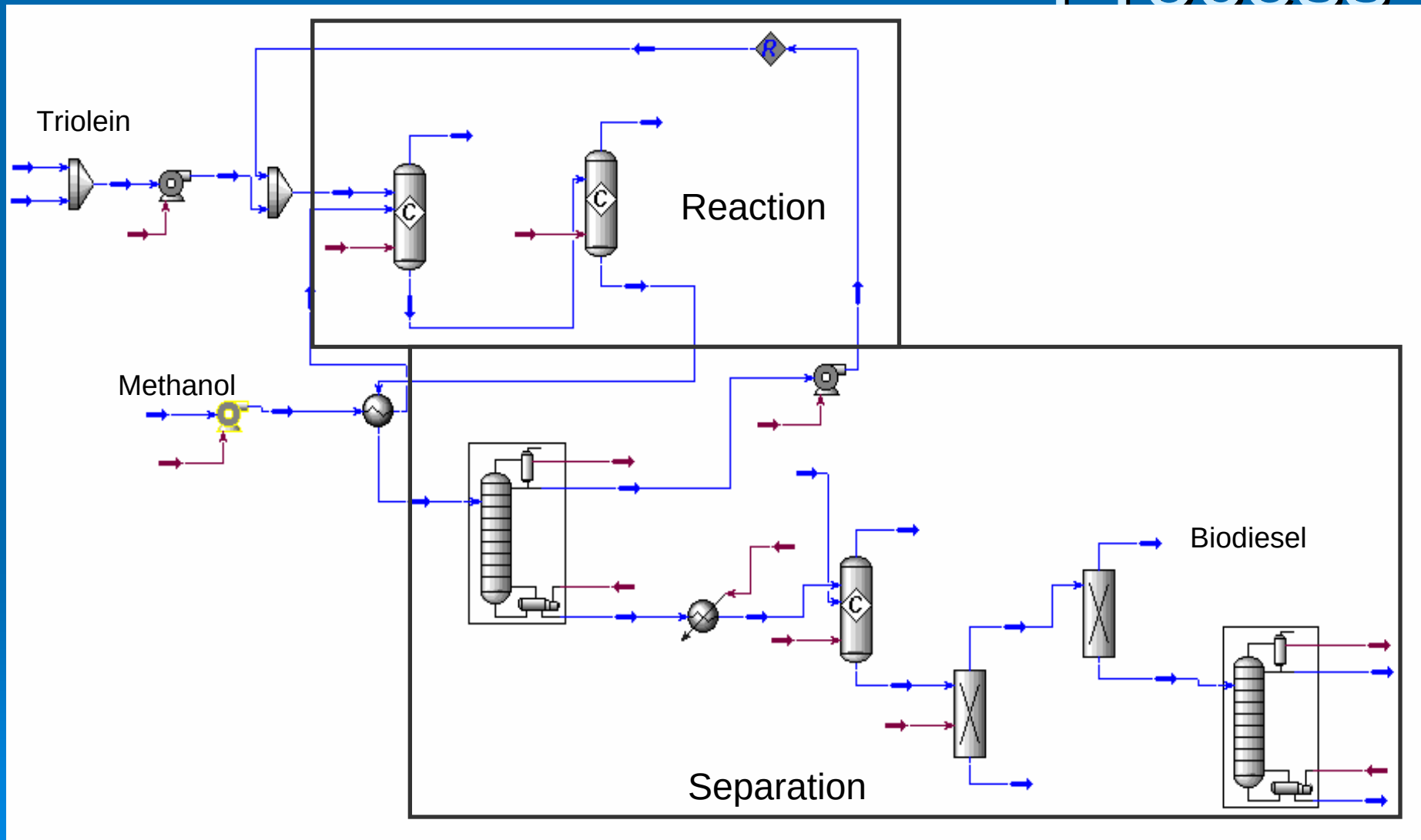
  - Glycerol production as avoided load

Case Study : Biodiesel Process

Alkali-catalyzed configuration



Case Study : Biodiesel Process

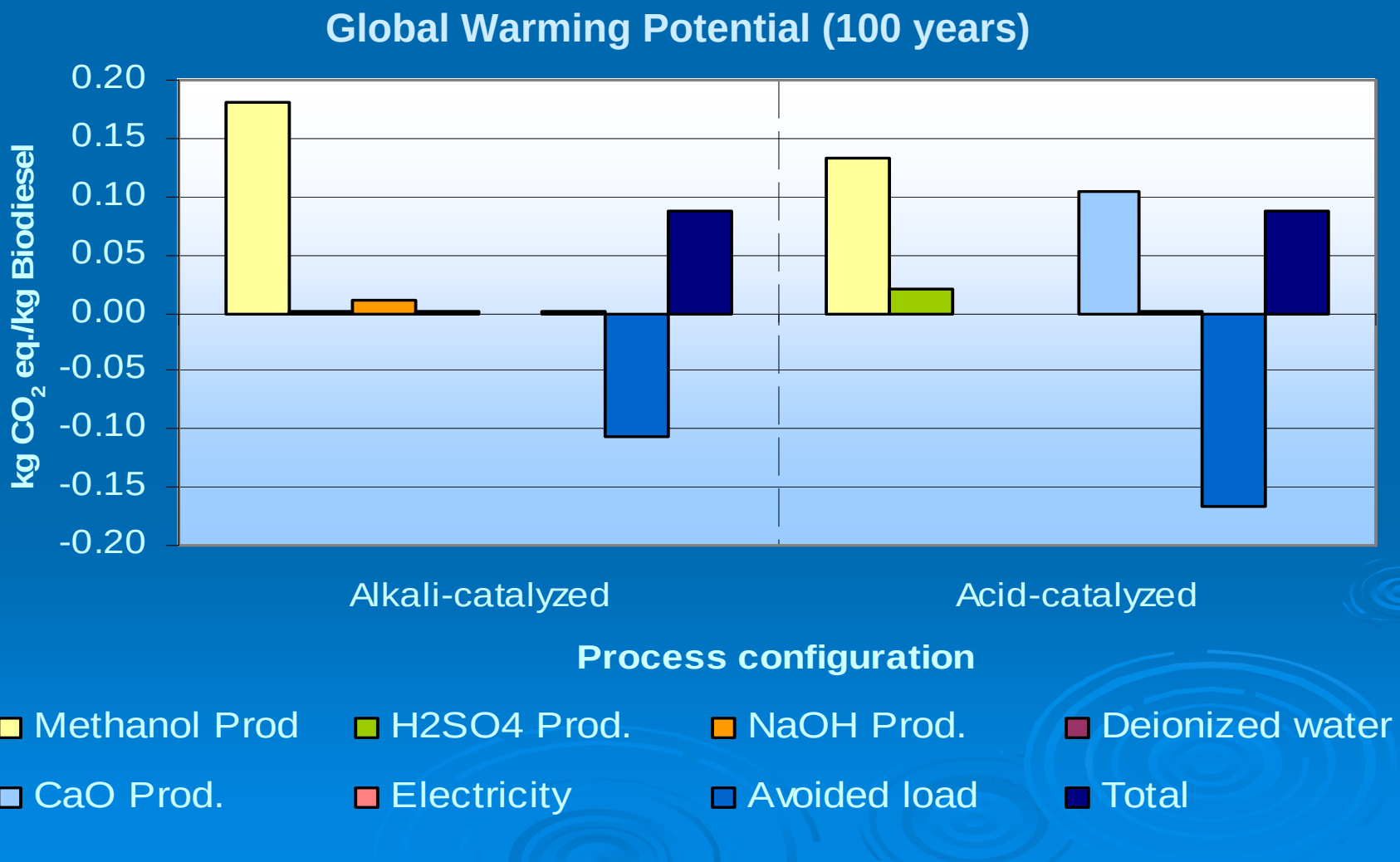


- **Glycerol**

Case Study : Biodiesel Impact Assessment

Method:		CML	CML	CML	CML	CML	CML	CML	CML
impact category:		Human toxicity	Human toxicity	Human toxicity	Human toxicity	Freshwater aquatic	Freshwater aquatic	Freshwater aquatic	Freshwater aquatic
alternatives:		HTP inf.	HTP 20	HTP 100	HTP 500	FAETP inf.	FAETP 20	FAETP 100	FAETP 500
		kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.	kg 1,4-DCB eq.
(w) Phenol	Methanol_Prod	2.23E-08	2.23E-08	2.23E-08	2.23E-08	1.08E-04	1.08E-04	1.08E-04	1.08E-04
	Glycerol_Prod	-8.54E-09	-8.54E-09	-8.54E-09	-8.54E-09	-4.12E-05	-4.12E-05	-4.12E-05	-4.12E-05
	H2SO4_Prod	8.89E-12	8.89E-12	8.89E-12	8.89E-12	4.29E-08	4.29E-08	4.29E-08	4.29E-08
	CaO_Prod	4.03E-10	4.03E-10	4.03E-10	4.03E-10	1.94E-06	1.94E-06	1.94E-06	1.94E-06
(w) Phosphates	Methanol_Prod	-	-	-	-	-	-	-	-
	CaO_Prod	-	-	-	-	-	-	-	-
(w) Phosphorus	Methanol_Prod	-	-	-	-	-	-	-	-
	Glycerol_Prod	-	-	-	-	-	-	-	-
	CaO_Prod	-	-	-	-	-	-	-	-
(w) Polycyclic Aromatic Hydroca	Methanol_Prod	1.32E-02	1.30E-02	1.32E-02	1.32E-02	1.30E-03	1.30E-03	1.30E-03	1.30E-03
	CaO_Prod	1.78E-04	1.74E-04	1.78E-04	1.78E-04	1.75E-05	1.75E-05	1.75E-05	1.75E-05
(w) Selenium	Methanol_Prod	8.09E-05	7.29E-07	7.58E-07	8.93E-07	4.22E-06	4.19E-06	4.19E-06	4.19E-06
	CaO_Prod	1.10E-06	9.88E-09	1.03E-08	1.21E-08	5.71E-08	5.67E-08	5.67E-08	5.67E-08
(w) Sulphates	Methanol_Prod	-	-	-	-	-	-	-	-
	Glycerol_Prod	-	-	-	-	-	-	-	-
	CaO_Prod	-	-	-	-	-	-	-	-
(w) Tetrachloroethylene	Methanol_Prod	1.68E-13	1.68E-13	1.68E-13	1.68E-13	2.05E-14	2.05E-14	2.05E-14	2.05E-14
	CaO_Prod	1.45E-14	1.45E-14	1.45E-14	1.45E-14	1.77E-15	1.77E-15	1.77E-15	1.77E-15
(w) Toluene	Methanol_Prod	1.23E-07	1.23E-07	1.23E-07	1.23E-07	1.20E-07	1.20E-07	1.20E-07	1.20E-07
	CaO_Prod	2.28E-09	2.28E-09	2.28E-09	2.28E-09	2.22E-09	2.22E-09	2.22E-09	2.22E-09
(w) Trichloroethylene	Methanol_Prod	6.10E-11	6.10E-11	6.10E-11	6.10E-11	1.77E-13	1.77E-13	1.77E-13	1.77E-13
	CaO_Prod	5.27E-12	5.27E-12	5.27E-12	5.27E-12	1.53E-14	1.53E-14	1.53E-14	1.53E-14

Case Study : Biodiesel Impact Assessment



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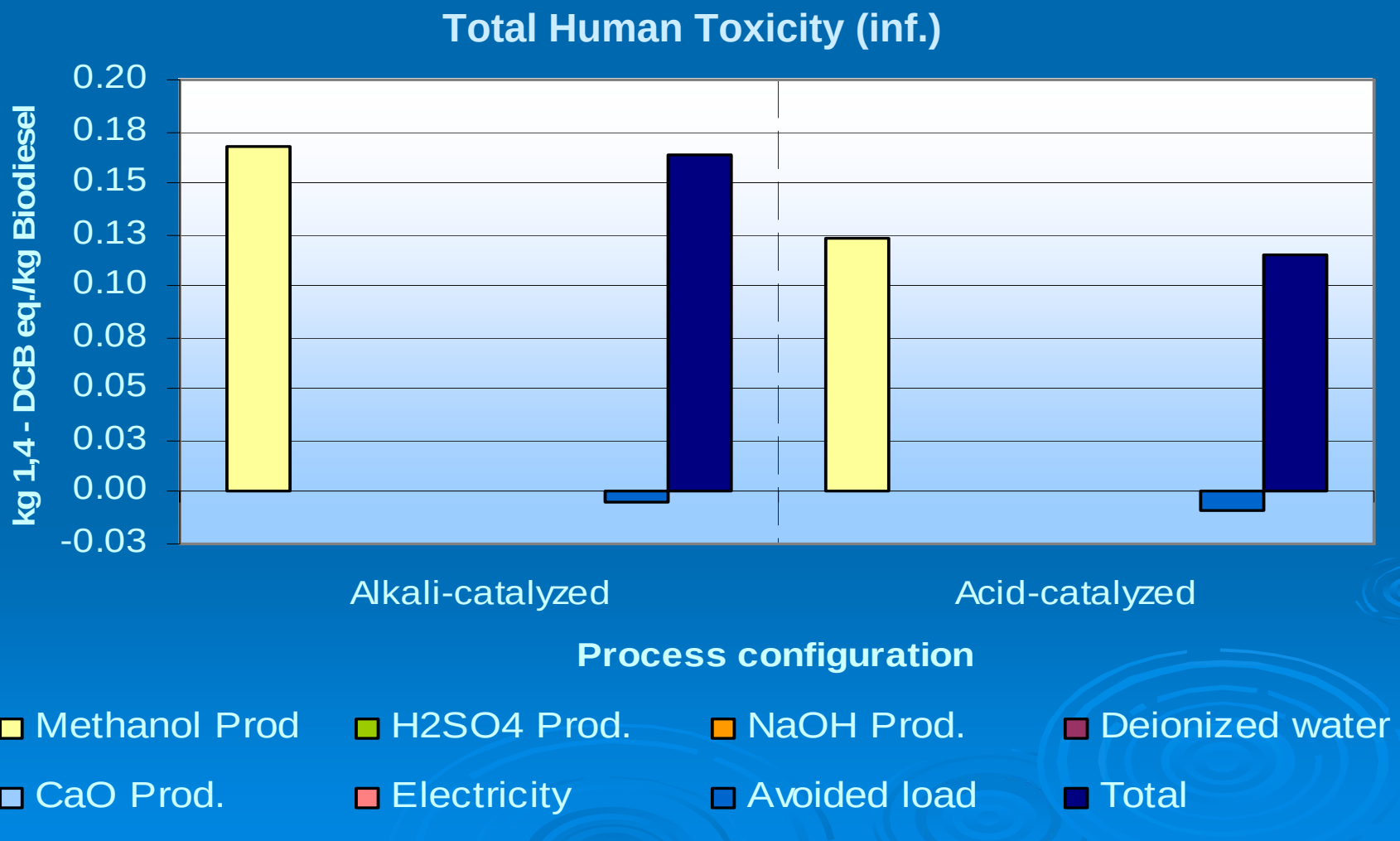
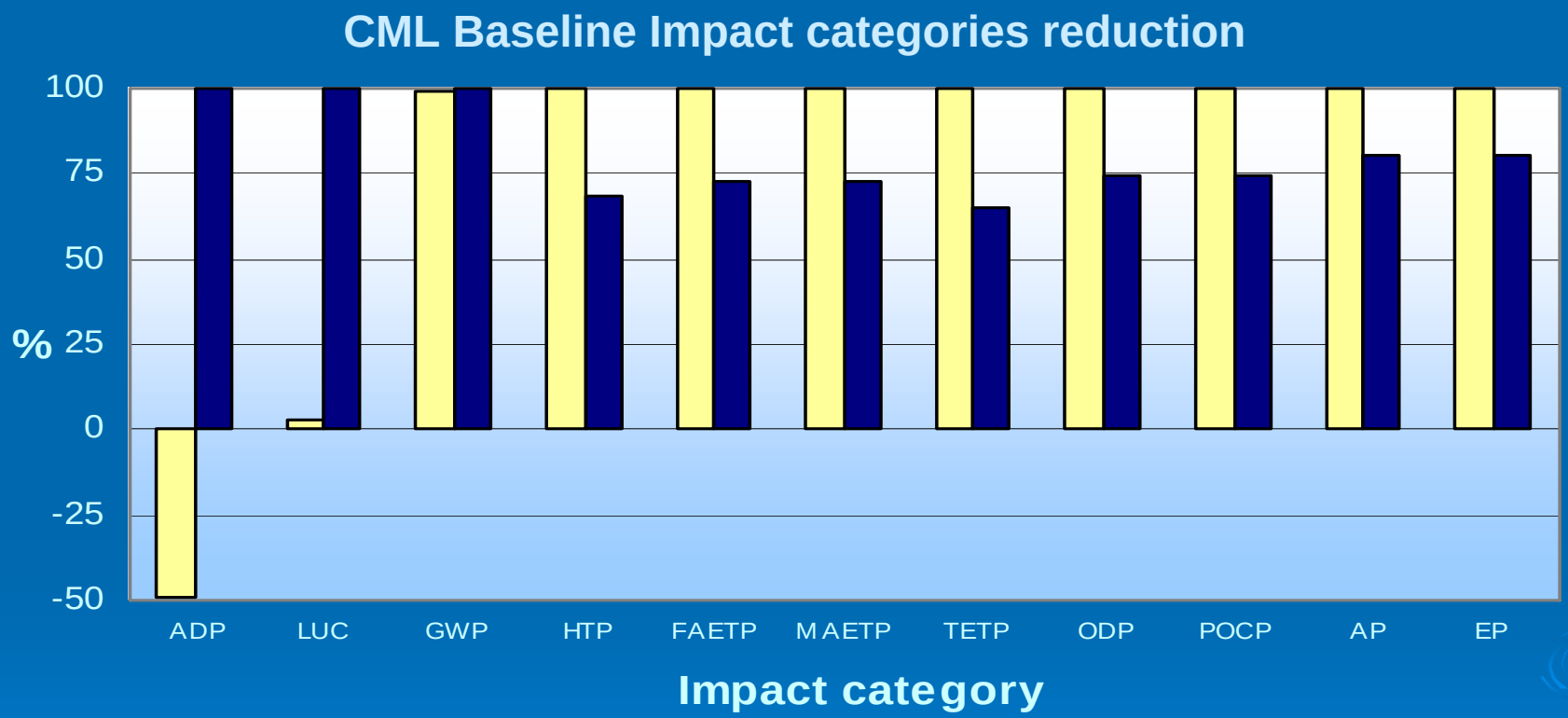


Case Study : Biodiesel Impact Assessment

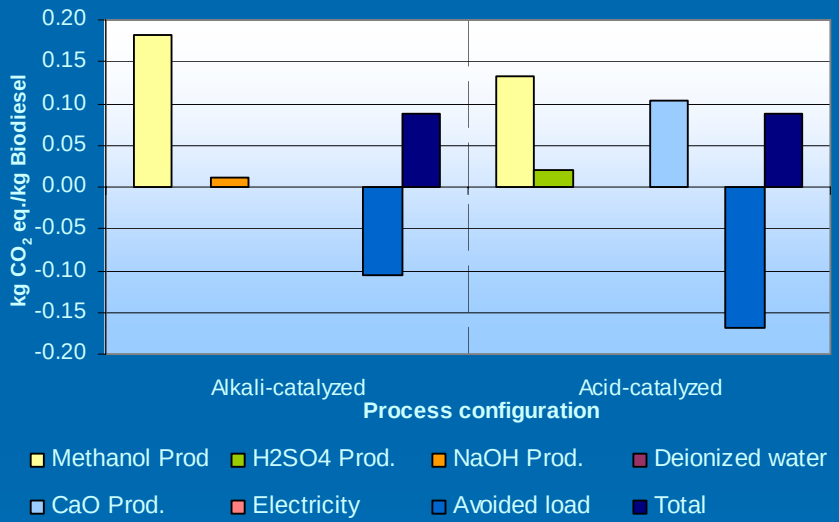


ADP	Abiotic depletion	LUC	Landuse increase	GWP	Global warming
HTP	Human toxicity	FAETP	Freshwater aquatic ecotoxicity	MAETP	Marine aquatic ecotoxicity
TETP	Terrestrial ecotoxicity	ODP	Stratospheric ozone depletion	POCP	Photo-oxidant formation
AP	Acidification	EP	Eutrophication		

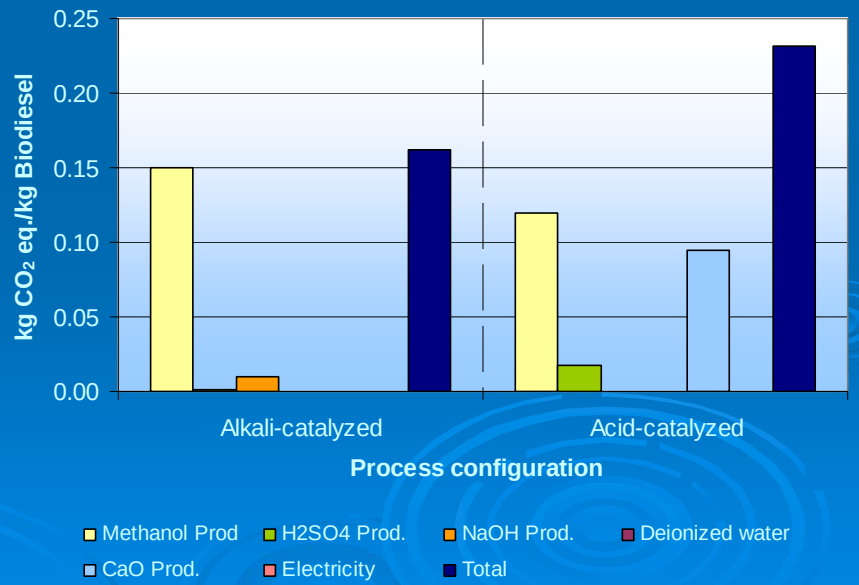
Case Study : Biodiesel Impact Assessment

Effect of allocation: Global Warming

Glycerol Production as avoided load



Glycerol Production as by product



Case Study : Biodiesel Economical Analysis

	Alkali catalyzed	Acid catalyzed
$NPV_{(thousand €)}$	14430.69	18175.74
$IRR_{(\%)}$	11.94	12.62
$MIRR_{(\%)}$	9.51	10.73
$PP_{(years)}$	6.36	5.67
$DPP_{(years)}$	8.33	7.21

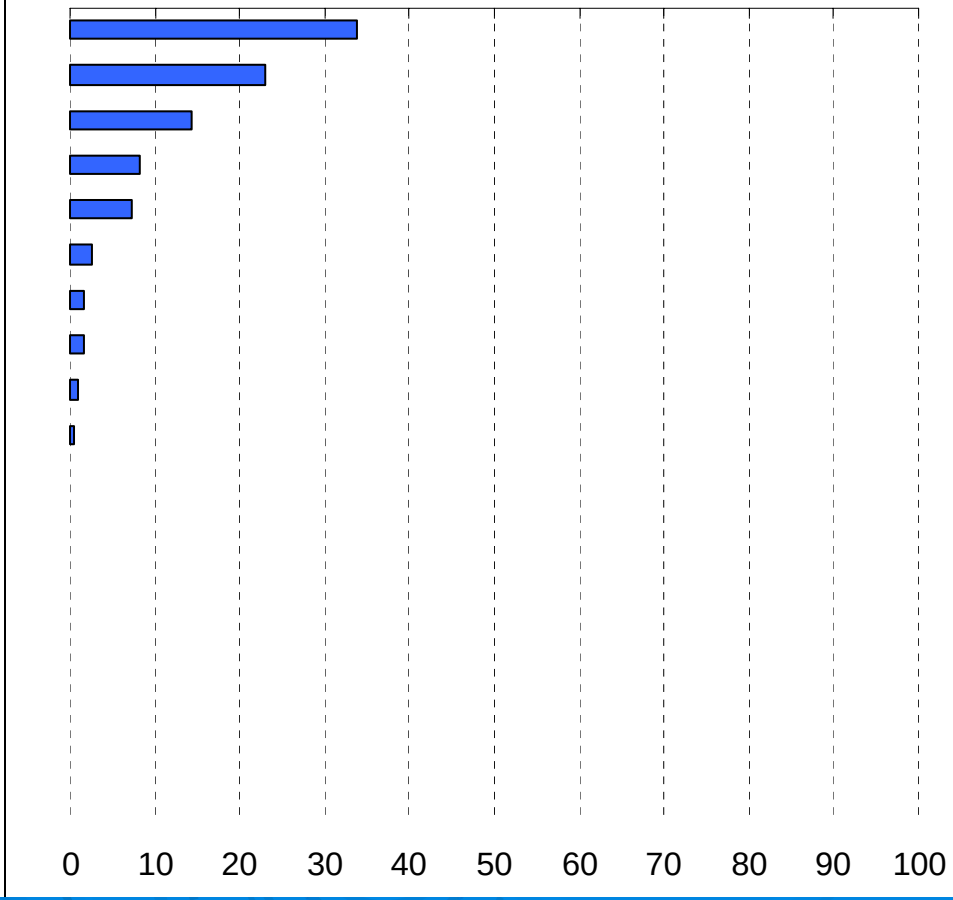
Case Study : Biodiesel Comparison

Impact category	Process configuration Alkaly catalyzed	Acid catalyzed
Depletion of abiotic resources	1.0	2.0
Land use	1.0	2.0
Climate change	1.3	1.7
Stratospheric ozone depletion	1.0	2.0
Human toxicity	1.0	2.0
Ecotoxicity	1.0	2.0
Photo-oxidant formation	1.0	2.0
Acidification	2.0	1.0
Eutrophication	1.0	2.0
Average	1.1	1.9
Economical Indicator		
NPV	1	2
IRR	1	2
MIRR	1	2
PP	1	2
DPP	1	2
Average	1.0	2.0

Case Study : Biodiesel Sensitivity Analysis

Total Human Toxicity (inf.) associated to the acid-catalyzed configuration

Compound	
(a) Nickel (Methanol Prod.)	33.8%
(a) Arsenic (Methanol Prod.)	23.1%
(a) Vanadium (Methanol Prod.)	14.2%
(w) Polycyclic Aromatic Hydrocarbons (Methanol Prod.)	8.2%
(a) Hydrogen Fluoride (Methanol Prod.)	7.3%
(a) Dioxins (unspecified)(Glycerol Prod.)	2.6%
(a) Benzene (Methanol Prod.)	1.7%
(a) Cadmium (Methanol Prod.)	1.5%
(w) Barium(Methanol Prod.)	1.0%
(a) Selenium(Methanol Prod.)	0.4%
(w) Copper (Methanol Prod.)	0.2%
(a) Berylium(Methanol Prod.)	0.2%
(a) antimony(Electricity)	0.2%
(s) Cobalt(Electricity)	0.2%
(w) Toluene (CaO Prod.)	0.2%
(a) Phenol (Methanol Prod.)	0.2%
(a) Lead (Electricity)	0.2%
(a) Cobalt (Electricity)	0.1%



Case Study : Biodiesel

- The tool is generalized to any industrial process
- Personalized graphical presentation
- Database automatic search

Conclusions

- Information obtained using the developed methodology and tool:
  - Process Flow Diagram
  - Configurations evaluation
    - Sectional analysis
  - Environmental profile
  - Economic profile $\rightarrow$ € viability

Any industrial process

Conclusions

- The methodology helps decision-making to select the best option
- The tool is:
  - automatic → minimal intervention
  - easy to use
  - adaptable to the user necessities
  - modifiable → updates

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¡Thank you for your attention!

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