Training course

Deliverable D**6.1** – Report
Work Package **5**: Dissemination, external communication and training courses.

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- ☐ External reviewer
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Training course

In agreement with University of Split, we decided to held the training course in Bologna in the ENEA premises. The Training Course was held 29 September 2011, at ENEA Research Centre E. Clementel.

The goals of the training course were:

1. Introducing the FC-HyGuide project and the final version of the guidance document
2. Provide the audience with a sort of road map of the FC-HyGuide document and annexes, which has to be used for all upcoming LCA activities within the FCH JU
3. Enable a correct and effective use of the developed documents and support tools (templates and examples).
4. get comments, questions and discussions, interaction, constructive feedback.

The workshop was organised with the contributions of many members as reported in the following table:

Nr	Fam. name	Name	Organisation	Email address
1	MASONI	Paolo	ENEA	Paolo.masoni@enea.it
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The attendance was quite satisfactory: 31 participants attended the meeting from different countries and different organisations. Here after the complete list of participants.

Bologna training course - List of participants

Nr	Fam. name	Name	Organisation	Email address
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The 31 participants were divided in working groups as following:

Group 1

Provision 6: Method, assumption and impact limitation
Provision 12: Functional unit
Provision 15: Multifunctionality
Provision 18: Cut-off criteria
Provision 19: Life Cycle Impact Assessment
Provision 34: Evaluation of results

Groups 2 and 4

Provision 3: Product system description
Provision 4: Goal of the LCA study
Provision 19: Life Cycle Impact Assessment
Provision 20: Type and sources of data and information

Provision 30: Classification and characterisation
Groups 3 and 5
Provision 4: Goal of the LCA study
Provision 11: Scope of the LCA study
Provision 16: System boundaries
Provision 25: Identifying processes within the system boundaries
Provision 34 : Evaluation of results

The WG leaders were:

Group 1: Sergio Ulgiati
Group 2: Gabriella Fiorentino, Silvia Bargigli
Group 3: Amalia Zucaro, Andela Vukman
Group 4: Paolo Masoni
Group 5: Alessandra Zamagni, Frano Barbir

Material distributed:

- Guidance document (Deliverable 3.2)
- Examples of application of FC Guide to:SOFC, PEMFC, MCFC (deliverable D 5.1)
- Case study on hydrogen (annex 1)
- ILCD Editor (annex 2)
- ILCD Handbook (annex 3)
- Introduction (annex 4)
- List of training course organizers (Annex 5)
- overview of guidance document (annex 6)
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Here after the agenda of the training course

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Time	Topic	Content
9.00	Registration	Delegate package with: - Tag name - list of participants and instructors - Guidance document - Paper and pen - Attendance certificate
9.30	Welcome, goal and scope of the day	Description of the project FC-HyGuide, its relations with LCA standards and FCH JU calls.
9.45	The ILCD Handbook and Data Network	Brief introduction and general overview
10.00	FC Hy Guide documents and annexes	Brief description of the Guidance Document "Performing Life Cycle Assessment for Hydrogen and Fuel cell technology", its content and annexes
11.00	Coffee break	
11.20	Application of the FC Guide (Guidance Document for Fuel Cells): examples	Examples of how to meet the provisions of the Guidance Document for Fuel Cells. Interactive session with work in groups. Plenary discussion
13.15	Lunch in ENEA's cafeteria	
14.00	Hydrogen case study	Examples of how to meet the provisions of the Guidance Document for Hydrogen production.
15.30	Data collection template	Guided tour
16.00	Coffee break	
16.20	ILCD editor for the preparation of ILCD compliant data sets	Guided tour
16.40	Wrap up and Questions & Answers	
17.00	Closure	

Annex 1

Case study on hydrogen

FC-Hy Guide

Training Course

Case study Hydrogen

29 September 2011, Bologna

Oliver Schuller

PE INTERNATIONAL

FC-Hy Guide

Content

A) Introduction on hydrogen producing systems

B) Goal

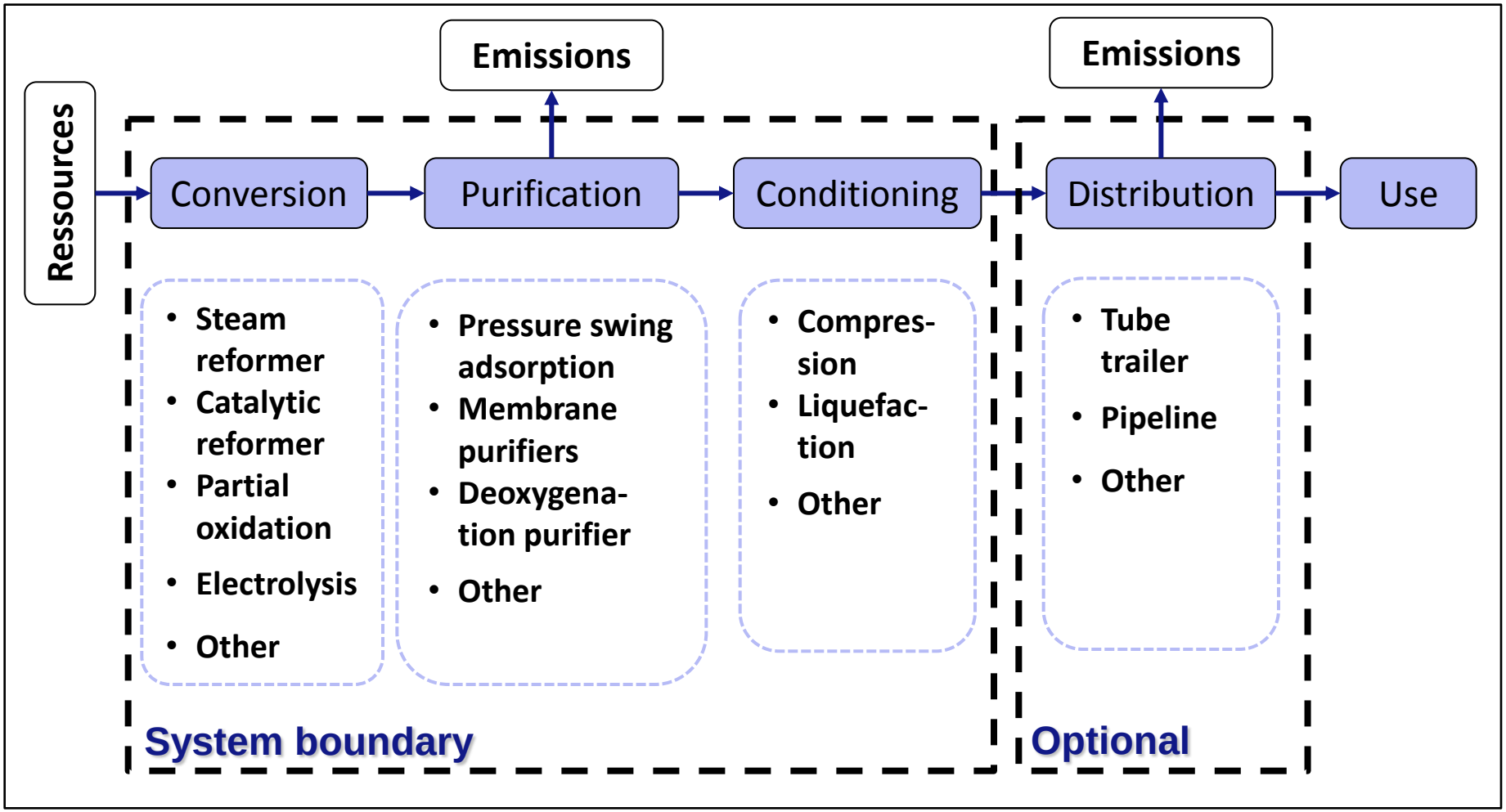
C) Scope

D) Life Cycle Inventory analysis

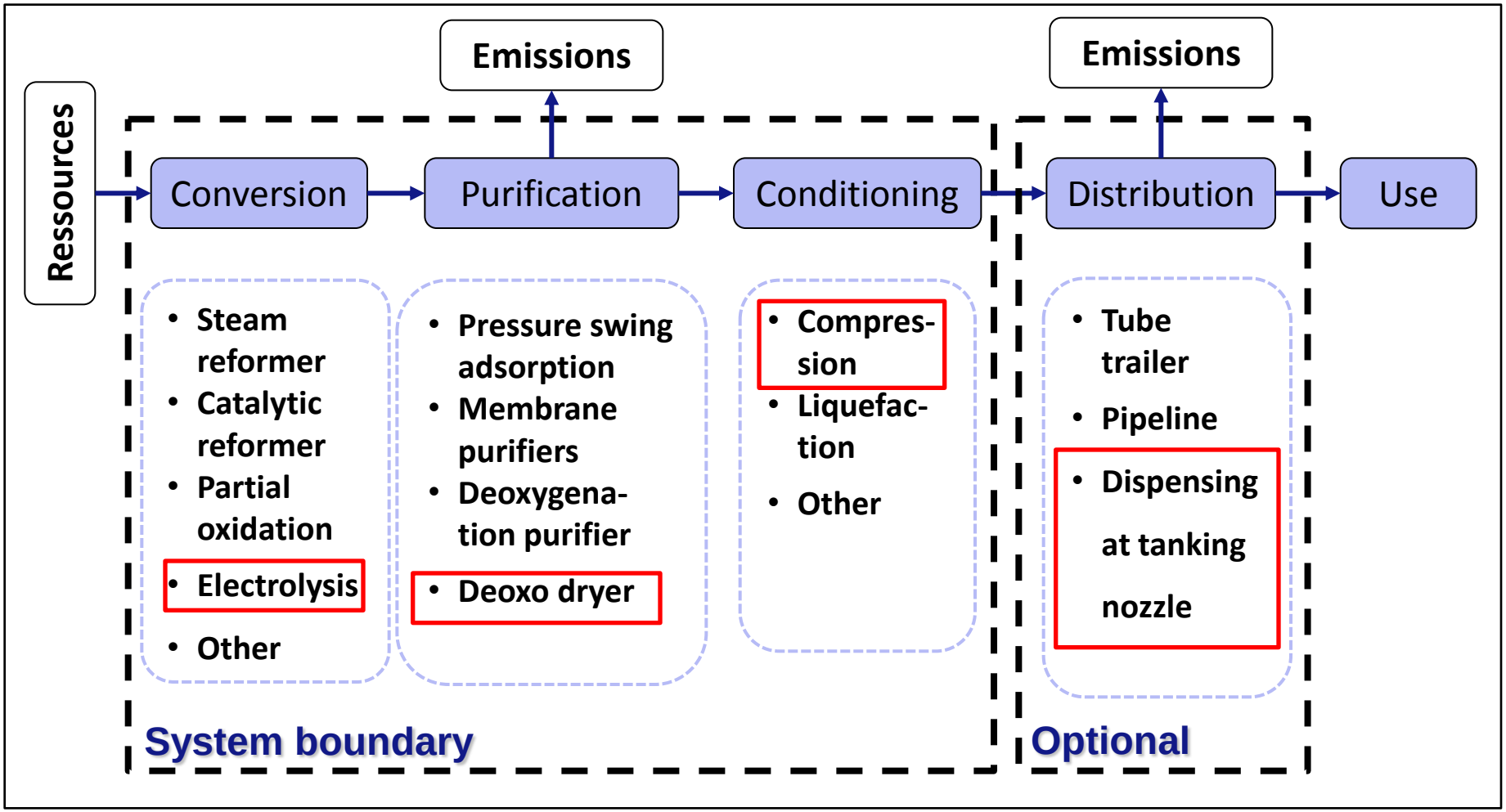
E) Life Cycle Impact Assessment

F) Interpretation and quality control

A) Introduction on hydrogen production systems



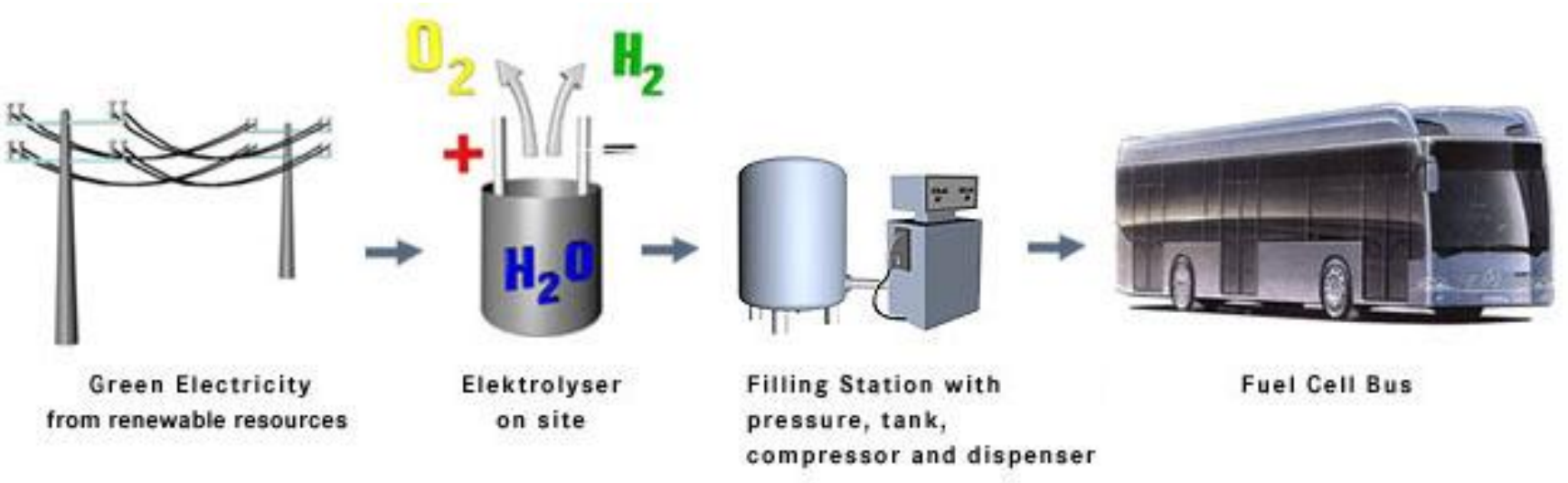
Introduction on hydrogen production systems - Case Study



Example: Electrolyser

Hydrogen service station
Hamburg-Hummelsbüttel
CUTE-Project

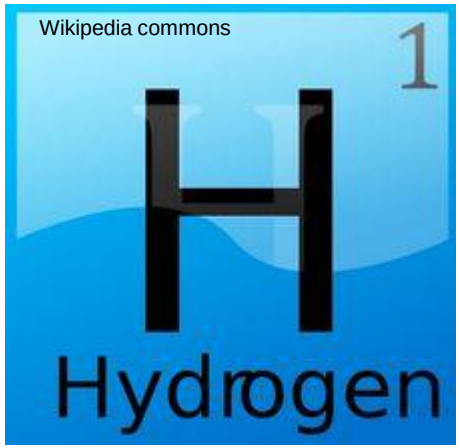
Example: Electrolyser



Source: www.fuel-cell-bus-club.com

Product related information

- State the hydrogen properties



Product related information - Case Study

- 99.995 % purity (SAE J2719)
- Gaseous
- 440 bar @ 85°C (350 bar @ Ambient temperature)

Description of hydrogen producer and the product system

State information regarding the hydrogen producer and production system (capacity, number of sites, technology used, geographical coverage)

Description of hydrogen producer and the product system - Case Study

- Overall H_2 production capacity
- Number of sites
- Production technologies used
- Geographical coverage by region

- Literature study on several electrolyser manufactures
- Several sites with 60-100 Nm^3/h production capacity across Europe and manufactures
- Alkaline -Water electrolysis
- EU-27

Description of hydrogen producer and the product system - Case Study

- Specific production technology
- Production capacity
- Any on-site electricity production
- Location of site
- Construction year
- Technical service life
- Type of production site
- Storage type

- Alkaline -Water electrolysis
- Capacity: 60 Nm^3/h
- No on-site electricity or heat production
- EU-27
- 2003-2006
- 10-30 years depending on component
- On-site, small scale
- High-pressure storage, multi-bench systems

B) Goal of the Life Cycle Assessment study on hydrogen production

Intended application(s)

- Describe the intended application(s)

Intended application(s) - Case Study

- Test of practical applicability of developed guidance document on performing LCA on hydrogen production !

In actual application, e.g.:

- Environmental evaluation of an hydrogen production system using electrolysis production technology.
- Evaluation of primary energy demand (renewable + non-renewable) of the product system.

Method, assumptions and impact limitations

- Detail any assumptions or limitations

Method, assumptions and impact limitations - Case Study

- CML2010 methods for LCIA used
- Investigated midpoint categories:
  - Global Warming Potential (GWP)
  - Acidification Potential (AP)
  - Eutrophication Potential (EP)
  - Photochemical Ozone Creation Potential (POCP)
  - Non-renewable and Renewable Primary Energy Demand (PED non-renewable + PED renewable)
- Endpoints are not investigated

Reasons for carrying out the study explanation

- Describe the reason for carrying out the study

Reasons for carrying out the study
Case Study

- Micro level study based on situation A to evaluate environmental impacts and energy demand of hydrogen production by decentralized water electrolysis
- Generic literature based study which has not to be as accurate as possible, but to check applicability of the hydrogen guidance document with a case study

Target audience explanation

- Describe the target audience

Target audience
Case Study

- LCA-practitioners, technical experts
- Focus is on technical information

Comparisons intended to be disclosed to the public - Case Study

- Non comparative study
- Disclosed to the public
- Third party critical review mandatory, but not performed due to case study character

Commissioner of the study

- Identify the commissioner of the study and name all organisations that have any relevant influence on the study

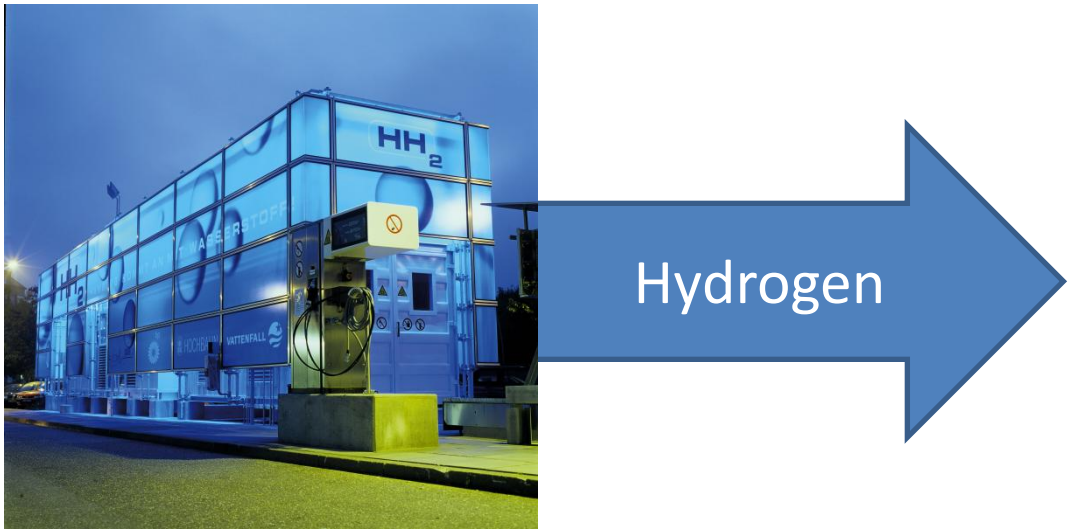
  - Project team HyGuide
  - Guidance document development team

C) Scope of the Life Cycle Assessment study on hydrogen production

Functional unit / Reference flow

- The functional unit is defined as a “quantified performance of a product system for use as a reference unit” (ISO 14040)

  ➢ Define the functional unit or the reference flow



Functional unit / Reference flow Case Study

- Functional unit: 1 MJ of hydrogen (net calorific value (NCV))
- Reference flow: 1 MJ of hydrogen (net calorific value (NCV)) with 99,995 % purity and 350 bar @ ambient temperature

Multi-functionality explanation

- Analyse if there are any co-products created and/or generated heat used by another process in order to identify if multi-functionality exits

Multi-functionality
Case Study

- Water electrolysis (no chlorine-alkali-electrolysis) so no direct co-products except of oxygen
- Co-product oxygen is released to the environment; no technical usage; no impacts allocated to oxygen

→ no multi-functionality within the system boundaries

System boundary, relevant flows and cut-off

- Define the system boundary
  - The system boundary shall be consistent with the goal of the study (ISO 14040)
  - The premises the system boundary is based on shall be identified and explained
  - Show the chosen system boundary in a flow chart

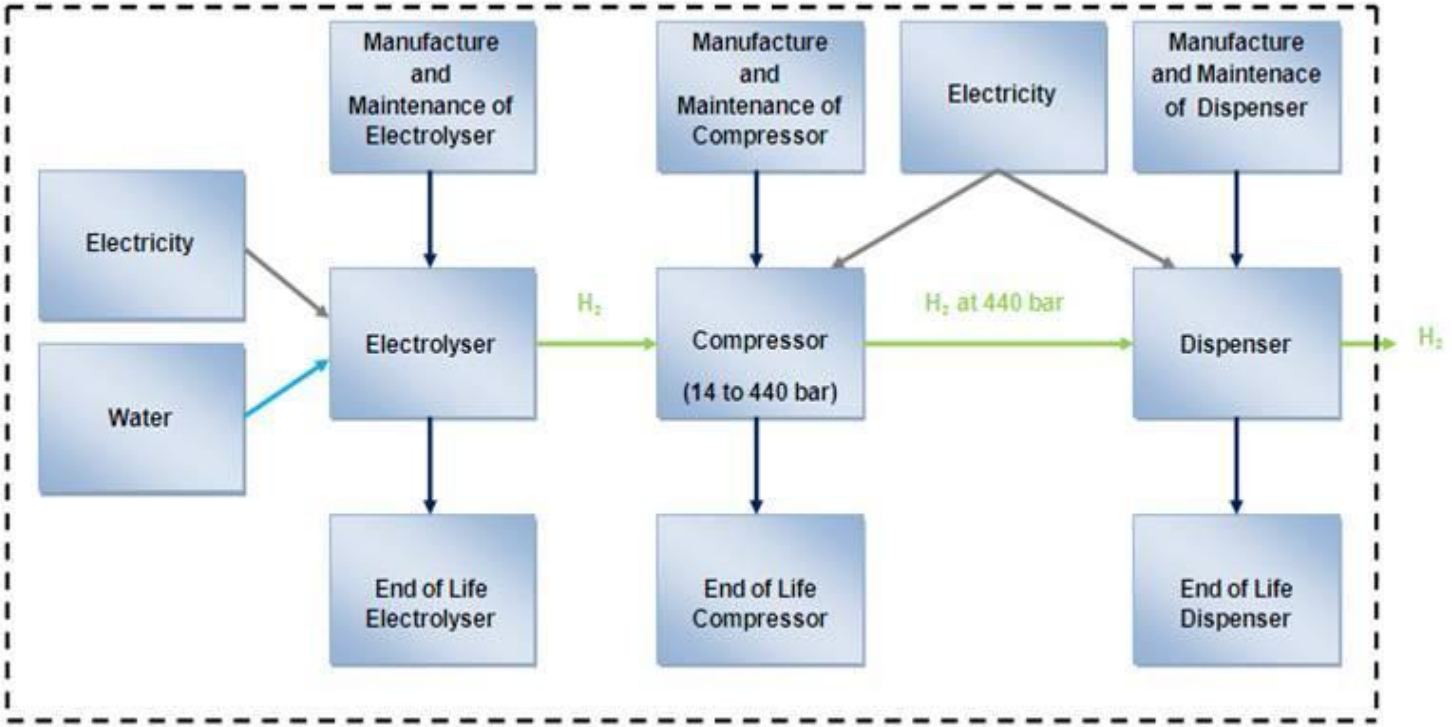
- State relevant flows
- State the flows which are cut-off

System boundary, relevant flows and cut-off explanation

Examples of possible relevant flows

Technology	Input	Output
Electrolysis	Electricity	Hydrogen
	Tap water	Oxygen
	Supply material (e.g. potassium hydroxide for electrolyte)	
	Operating supplies and spare parts	

System boundary, relevant flows and cut-off Case Study



„Well To Tank“ production of hydrogen

Cut-off of 5% in terms of environmental relevance was applied

Type, quality and sources of required data and information – Case Study

Shall: Include all product inputs and outputs to and from the foreground system to other technical systems.

Shall: Take into account all resources from nature and emissions to nature of the foreground and background system. Exceptions are allowed in accordance with the cut-off criteria

Shall: Use data which reflects the technology actually used and represents the region the process takes place

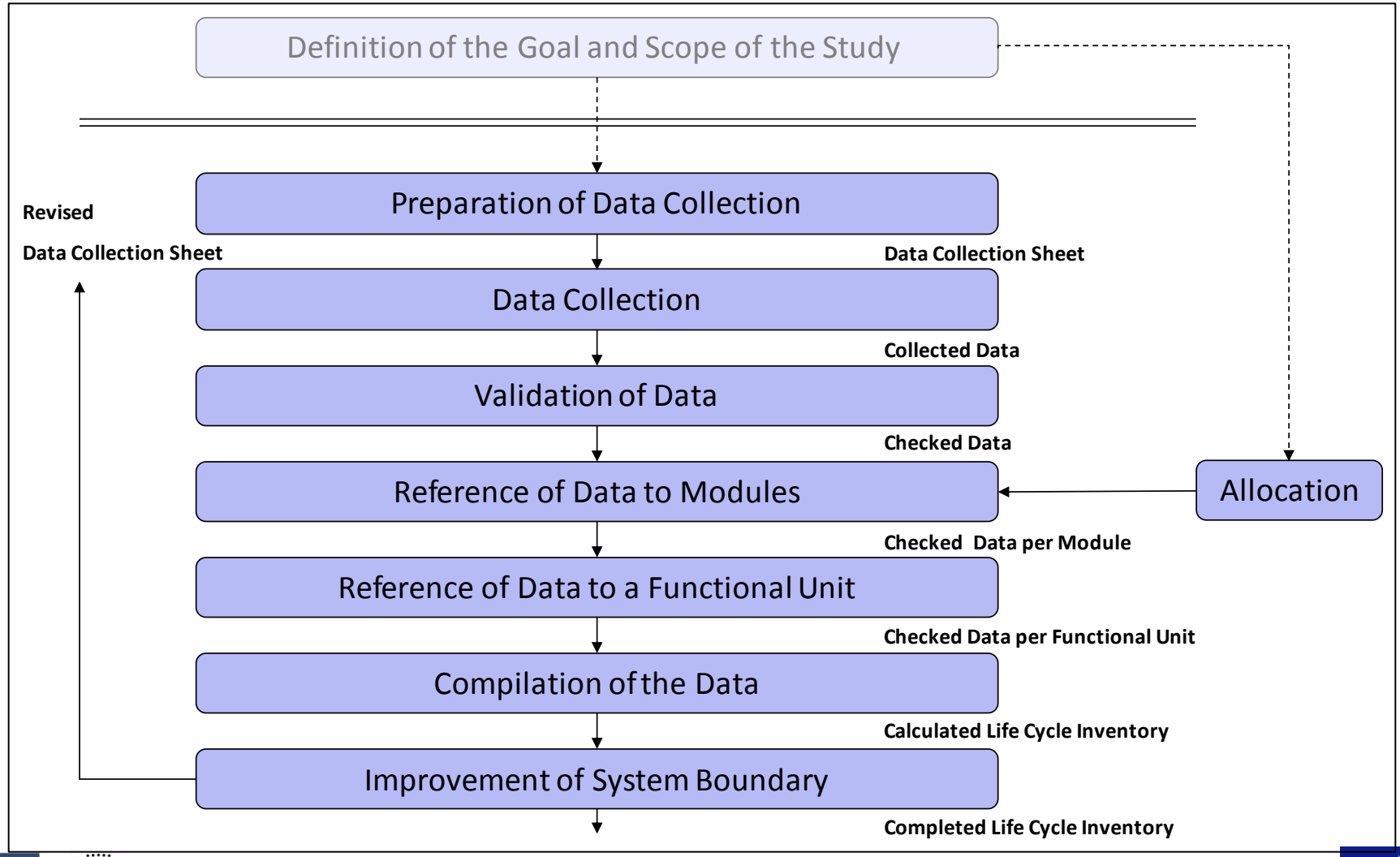
Should: If specific data are not available, comparable data can be used.

Shall: Describe the closing of data gaps using comparable data in the LCA report.

Intended reporting

- Intended Reporting:
  - Decide form of reporting (e.g. detailed report and/or data set, exec summary only)
  - Decide level of reporting (e.g. internal, external, third-party report, publicly accessible)

D) Life Cycle Inventory Analysis of the study on hydrogen production



Data collection

- Describe the data collection, e.g. how long the data were measured, in which way

FC-Hy Guide

Data collection – Case Study

- Electrolysis data are provided by manufacturers and operators of the units within a multi-year European demonstration project
- Several independent electrolyser sites and their associated hydrogen supply units were selected and modelled
- Electrolysers are averaged by a horizontal approach in equal shares.
- Downstream of electrolyser process chain is also averaged horizontally, in equal shares.
- Foreground data from manufacturers and operators are of high quality (measured primary data)
- Background data taken from the ELCD database if available, data gaps closed with data sets taken from the GaBi databases

Selection of of generic Life Cycle Inventory data

1. The European Reference Life Cycle Database (ELCD)

If there are no applicable data in above mentioned data base available use the following priorities:

2. ILCD compliant data sets
3. ILCD entry level data sets
4. Databases using the ILCD format (e.g. GaBi databases)
5. other LCA databases; recipes and formulations; patents; stoichiometric models; legal limits; data of similar processes, etc., but the data has to at least fulfil the ILCD flow nomenclature and conventions.

http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm

Selection of of generic Life Cycle Inventory data – Case Study

- The data shall be representative for the applied technology and for geographical and temporal coverage
- The data supplier and the quality of the background data shall be known
- The data shall be modelled consistent i.e. the processes used shall be modelled using the same methodology and for similar processes the same system boundariessystem boundary.

Consideration of re-use, recycling, and energy recovery

- State re-use, recycling and energy recovery processes within the system boundaries

a blue recycle symbol image by wayne ruston from Fotolia.com

Consideration of re-use, recycling, and energy recovery – Case Study

- The electrolyser, compressor and dispenser consist mainly of metal and a small amount of plastic (high recycling rates). EoL treatment for those parts and their components was considered
- Metals:
  - Closed-loop modelling for recycling material
  - Credit given for remaining recycling material
- Plastics:
  - Waste-to-energy modelling
  - Credit given for generated electricity with EU-27 grid mix

Calculation of Life Cycle Inventory results

- Which software are you using?

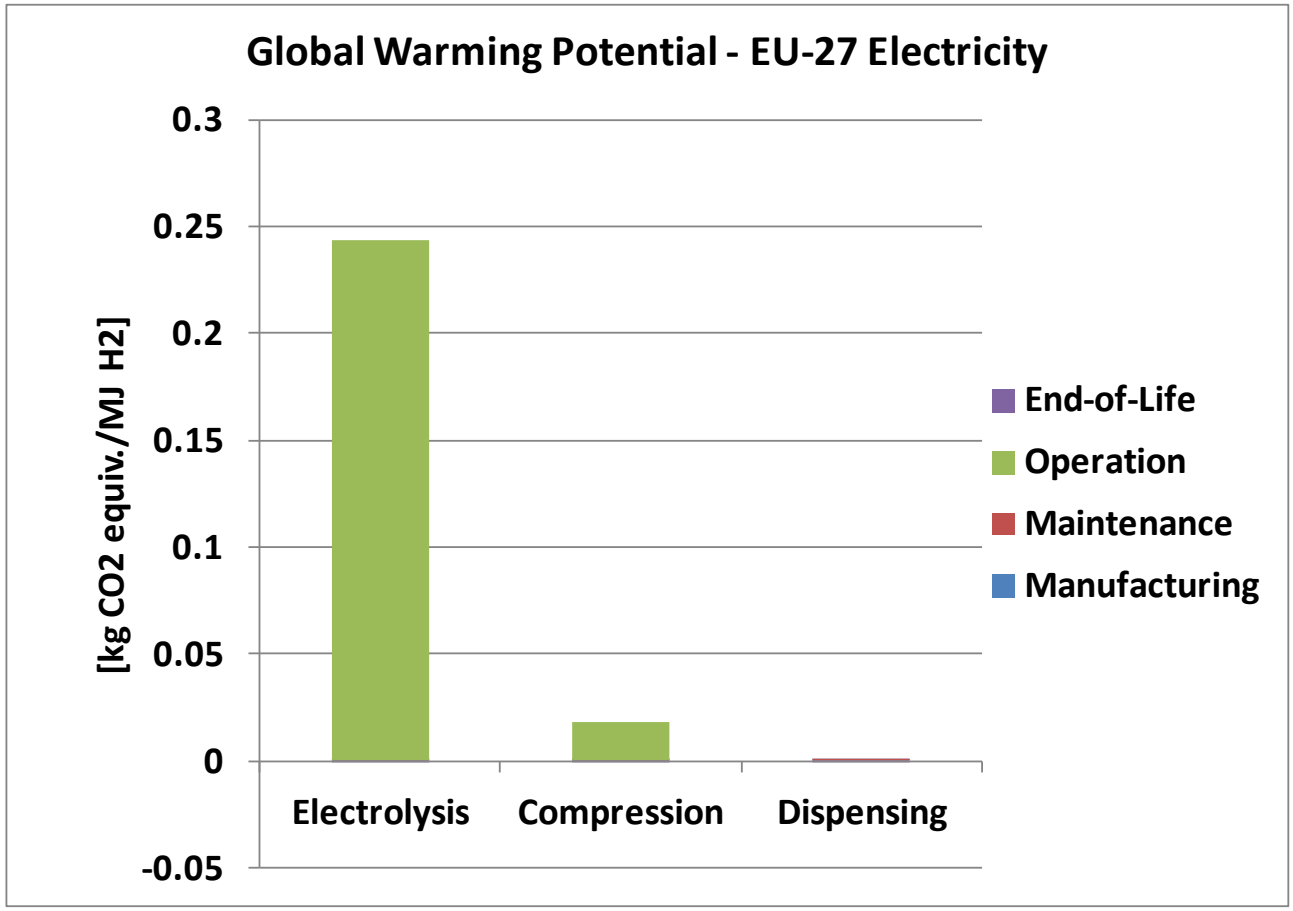
Calculation of Life Cycle Inventory results – Case Study

- All results were calculated with the GaBi-Software

Life Cycle Impact Analysis

- Classification and characterisation
  - Show results
- Normalisation (not recommended)
  - State whether there is normalisation applied
- Weighting (not recommended)
  - State whether weighting is applied

Life Cycle Impact Analysis – Case Study

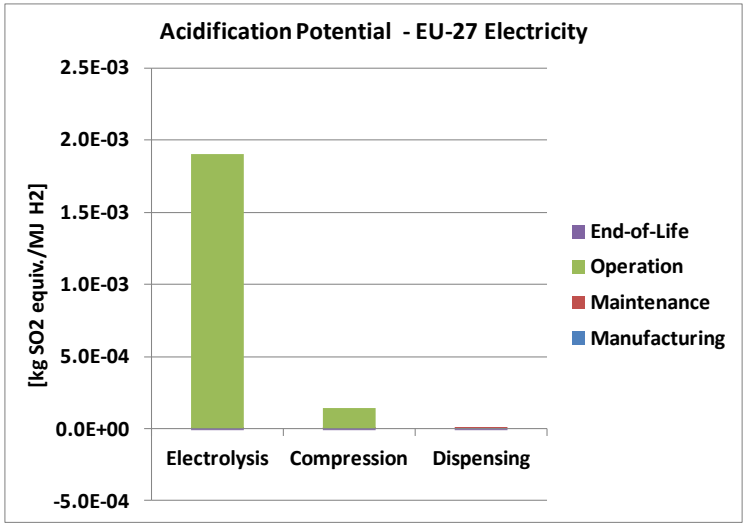


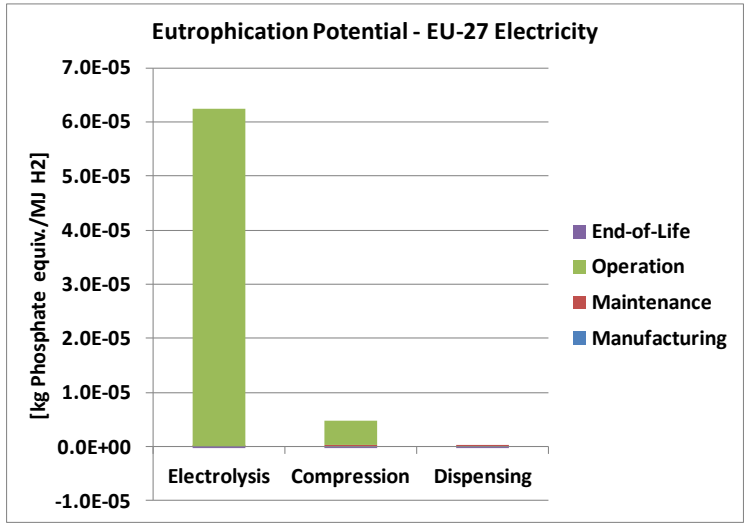
Significant impacts from Operation phase

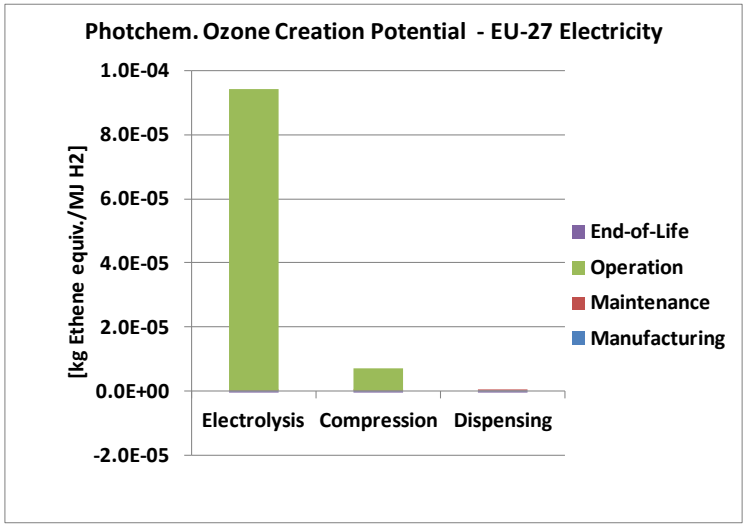
Infrastructure is negligible

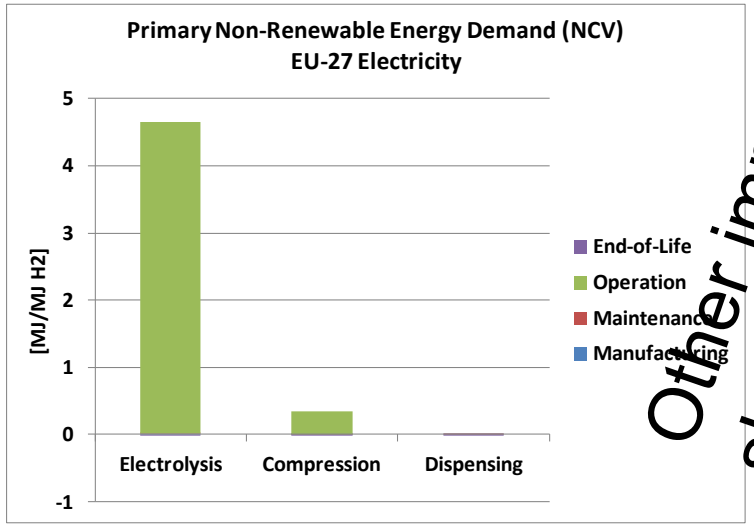
Most impacts occur during the Electrolysis. Minor impacts in the Compression, Dispensing negligible

Life Cycle Impact Analysis – Case Study









Other impact categories show similar results

F) Interpretation and quality control of the study of hydrogen production

Shall: Identify significant issues

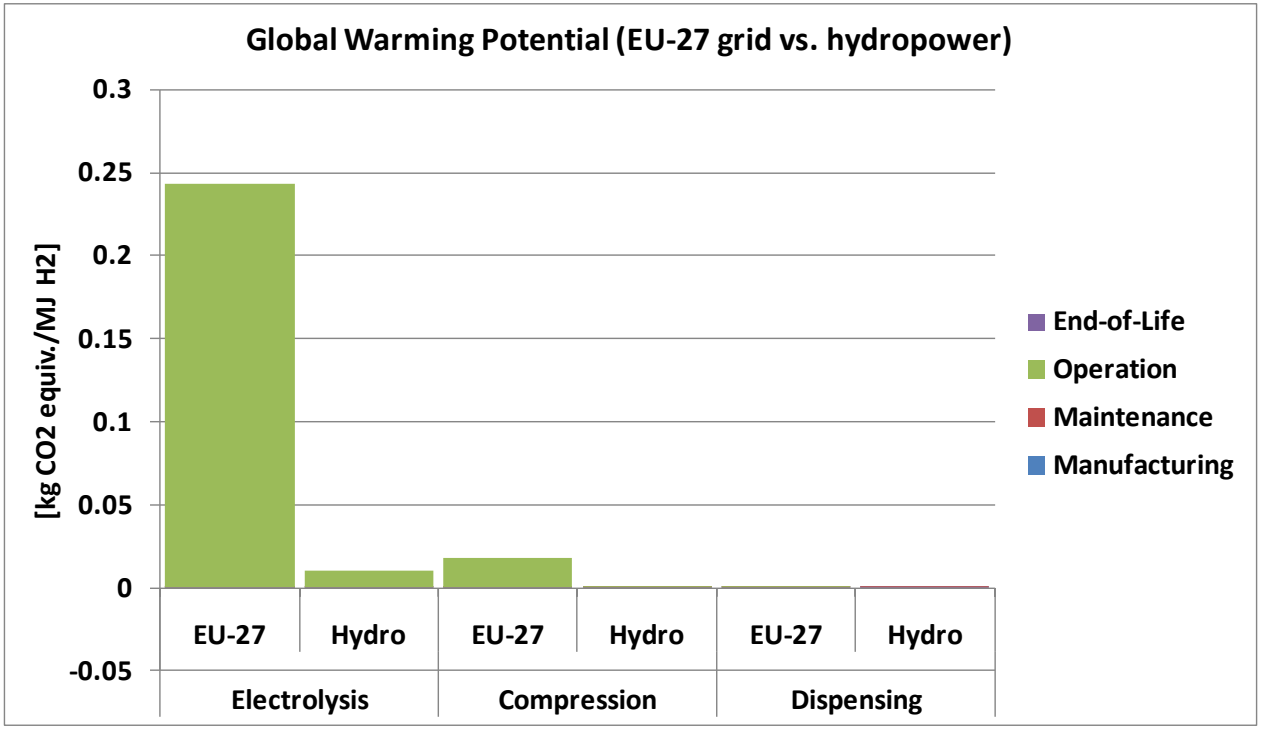
Should: Use graphs (e.g. stacked columns or pie chart) to identify the greatest contributors

Should: Be aware of potential significant issues that e.g. might be cut-off or allocated to another system

F) Interpretation and quality control of the study of hydrogen production

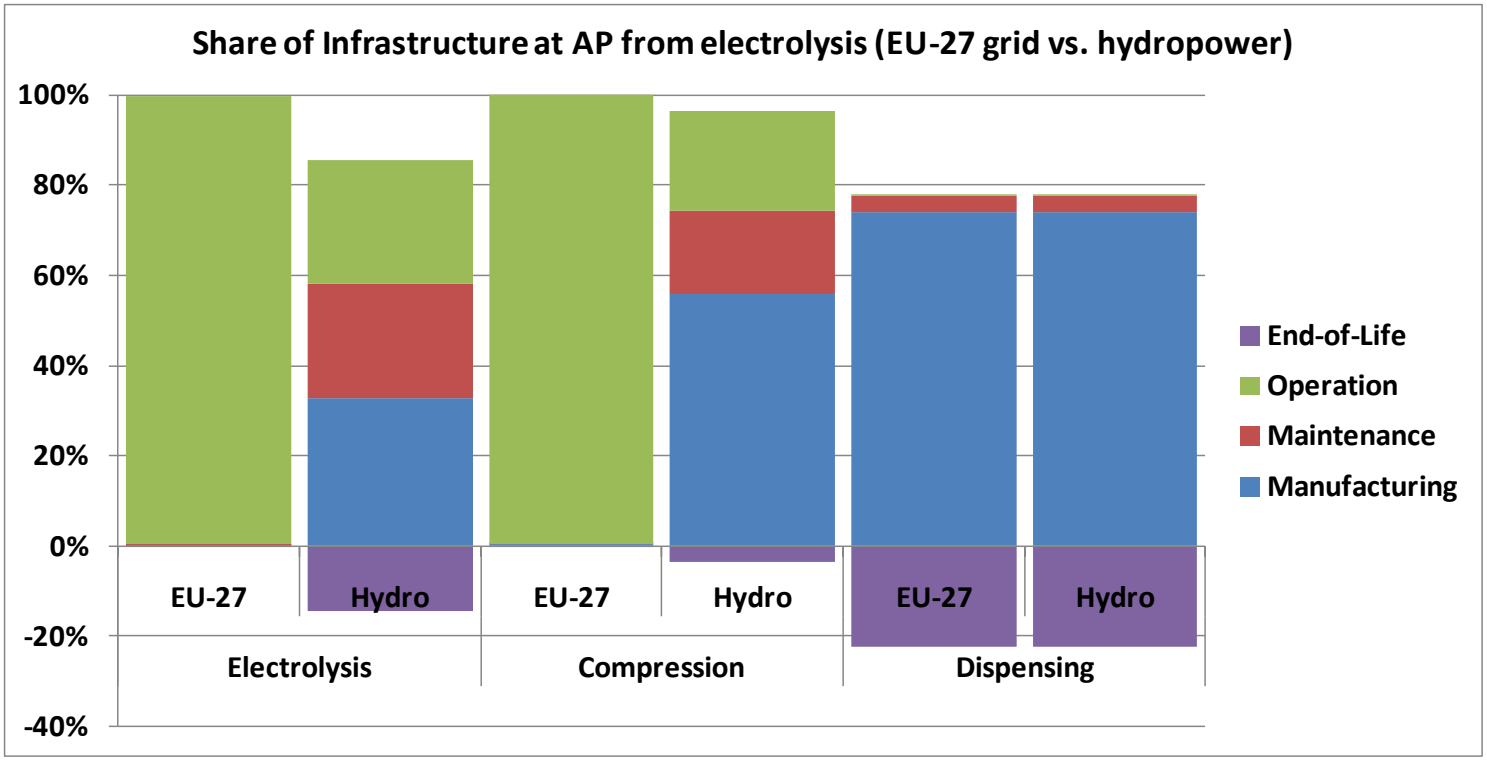
EU-27 grid and hydropower

Impacts drastically decline when renewable energy like hydropower is used



Environmental Impacts of hydrogen production by alkaline water electrolysis are strongly dependent on the electricity used
Other impact categories show similar results

F) Interpretation and quality control of the study of hydrogen production

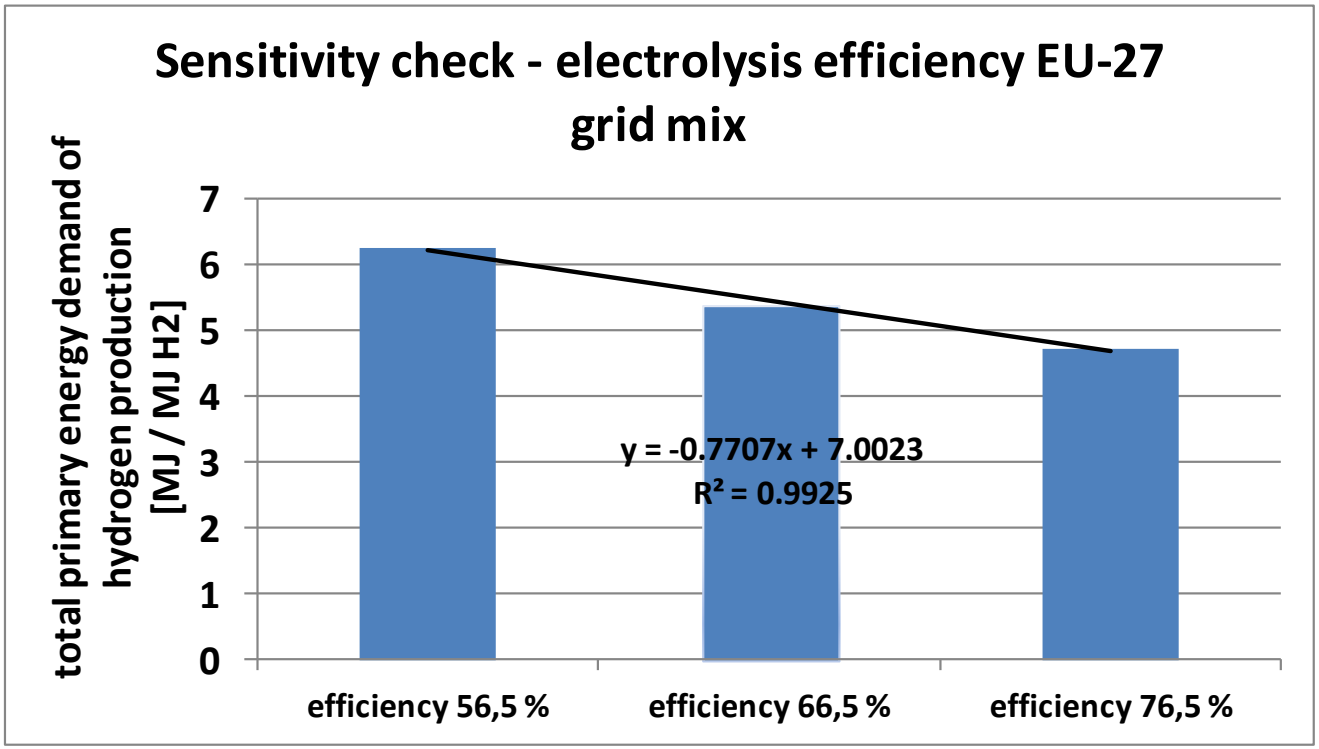


When hydropower is used total impacts decline, but relative share of infrastructure becomes more important (exemplary shown for Acidification Potential)

Evaluation of results

- Perform a completeness check
- Perform a sensitivity check
- Perform a consistency check
- Perform an uncertainty check

Sensitivity Check



The efficiency of the electrolyser is an important parameter. Altering the efficiency by +/- 10% points results in less respectively higher energy consumption with an approximately linear correlation. The diagram shows the expected results. Other impact categories follow the same correlation.

Conclusions, limitations and recommendations

Conclusions:

- The majority of the environmental impacts during the lifespan of the electrolyser occur due to electricity usage in the operation phase, especially when the European electricity grid mix is utilised.
- The share of maintenance, manufacturing and End-of-Life becomes significantly more relevant when hydropower is used instead of grid electricity. Nevertheless, the total impacts decline to very small shares in comparison to the electricity grid mix.

Conclusions, limitations and recommendations

Limitations:

- Only Global Warming Potential, Acidification Potential, Eutrophication Potential, Photochemical Ozone Creation Potential and Primary Energy Demand are considered, and conclusions are drawn from these categories.

Conclusions, limitations and recommendations

Recommendations:

- GWP can be reduced over 95%, and total primary energy demand about 60% when electricity from the grid is substituted by hydropower
- Higher efficiency of the electrolyser can reduce environmental impacts clearly
- For a more holistic approach, the study should be repeated with more impact categories like ADP and HTP. Besides a third party critical review should also be undertaken. For this case study such a review has been omitted.

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FC-Hy Guide

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Annex 2

ILCD Editor

Training Course

ILCD editor for ILCD compliant data sets

29 September 2011, Bologna

FC-Hy Guide

Research Centre E. Clementel

Alessandra Zamagni

LCA and Ecodesign Laboratory

ILCD data sets - overview

- The ELCD database and upcoming ILCD data sets (data network) are in XML format
- Extensible Markup Language (XML) is a set of rules for encoding documents in machine-readable form
- It is an free of charge open standard
- Can be entered also directly by programming without any tools

Example of an existing ELCD data set

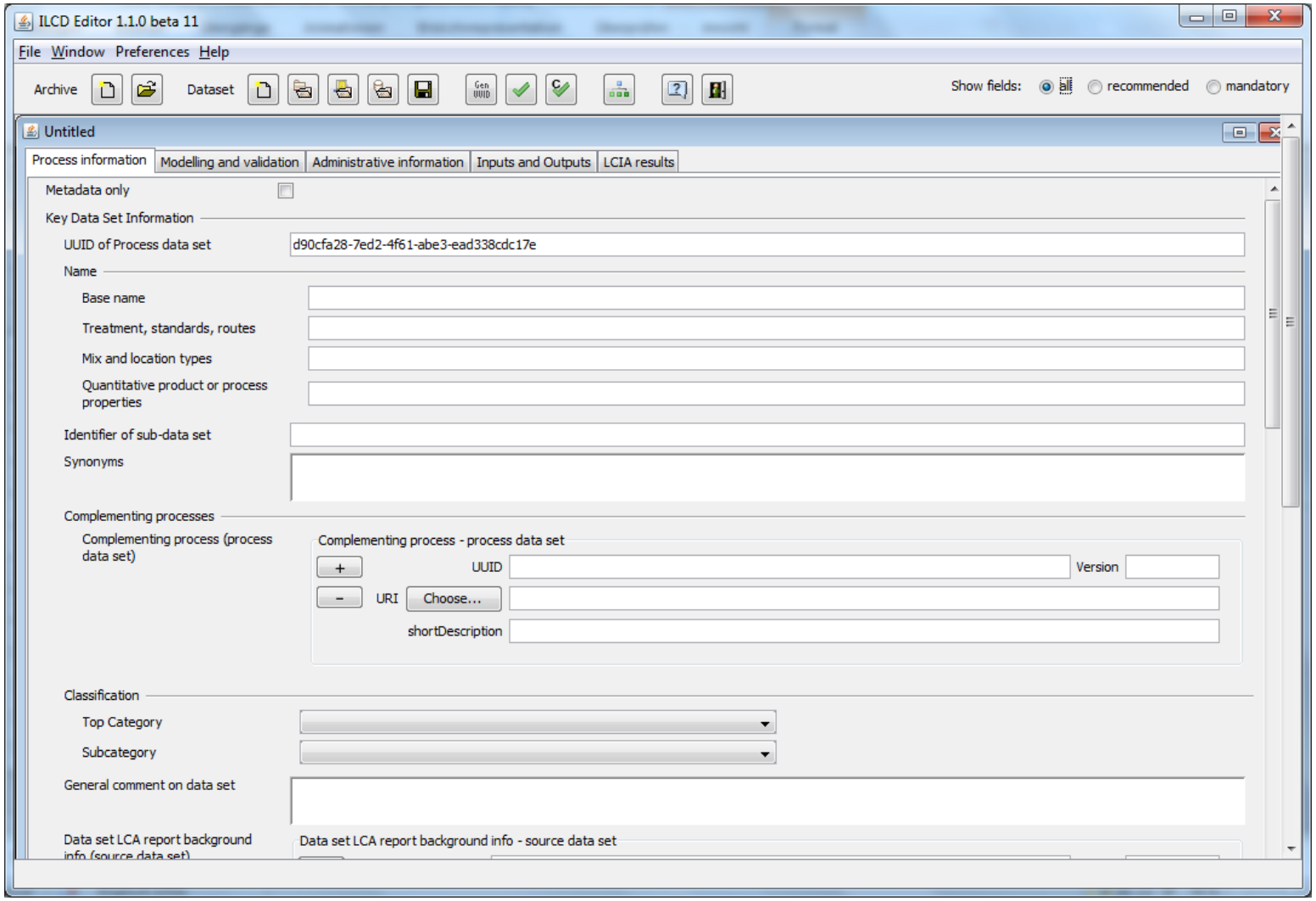
Process data set: Electricity Mix; AC; consumption mix, at consumer; < 1kV (en)	
Table of Contents: Process information - Modelling and validation - Administrative information - Inputs and Outputs	
Process information	
Key Data Set Information	
Location	EU-27
Geographical representativeness description	The data set represents the country / region specific situation, focusing on the main technologies, the region specific characteristics and / or import statistics.
Reference year	2002
Name	Base name; Treatment, standards, routes; Mix and location types; Quantitative product or process properties Electricity Mix; AC; consumption mix, at consumer; < 1kV
Use advice for data set	Use by low voltage electricity customers without own electricity generators or transformers (e.g. at SME and private), which use electricity directly from the grid. The data set can be used for all LCI/LCA studies where electricity is needed.
Technical purpose of product or process	Low voltage (<1kV) electricity for final consumers.
Synonyms	power grid mix
Classification	Class name / Hierarchy level Energy carriers and technologies / Electricity
General comment on data set	Good overall data quality. Energy carrier mix information based on official statistical information including import/export. Detailed power plant models were used, which combine measured emissions plus calculated values for not measured emissions of e.g. organics or heavy metals. Energy carrier extraction and processing data is of sufficient to good (e.g. refinery) data quality. Inventory is partly based on primary industry data, partly on secondary literature data.
	Copyright? Yes Owner of data set (contact data set) PE INTERNATIONAL
Quantitative reference	
Reference flow(s)	electricity mix; AC; consumption mix, at consumer; < 1kV - 3.6 MJ (Net calorific value)
Time representativeness	
Data set valid until:	2010
Time representativeness description	Annual average
Geographical representativeness	
Technological representativeness	

Preparing the data sets: ILCD Editor 1.1.0 beta 11

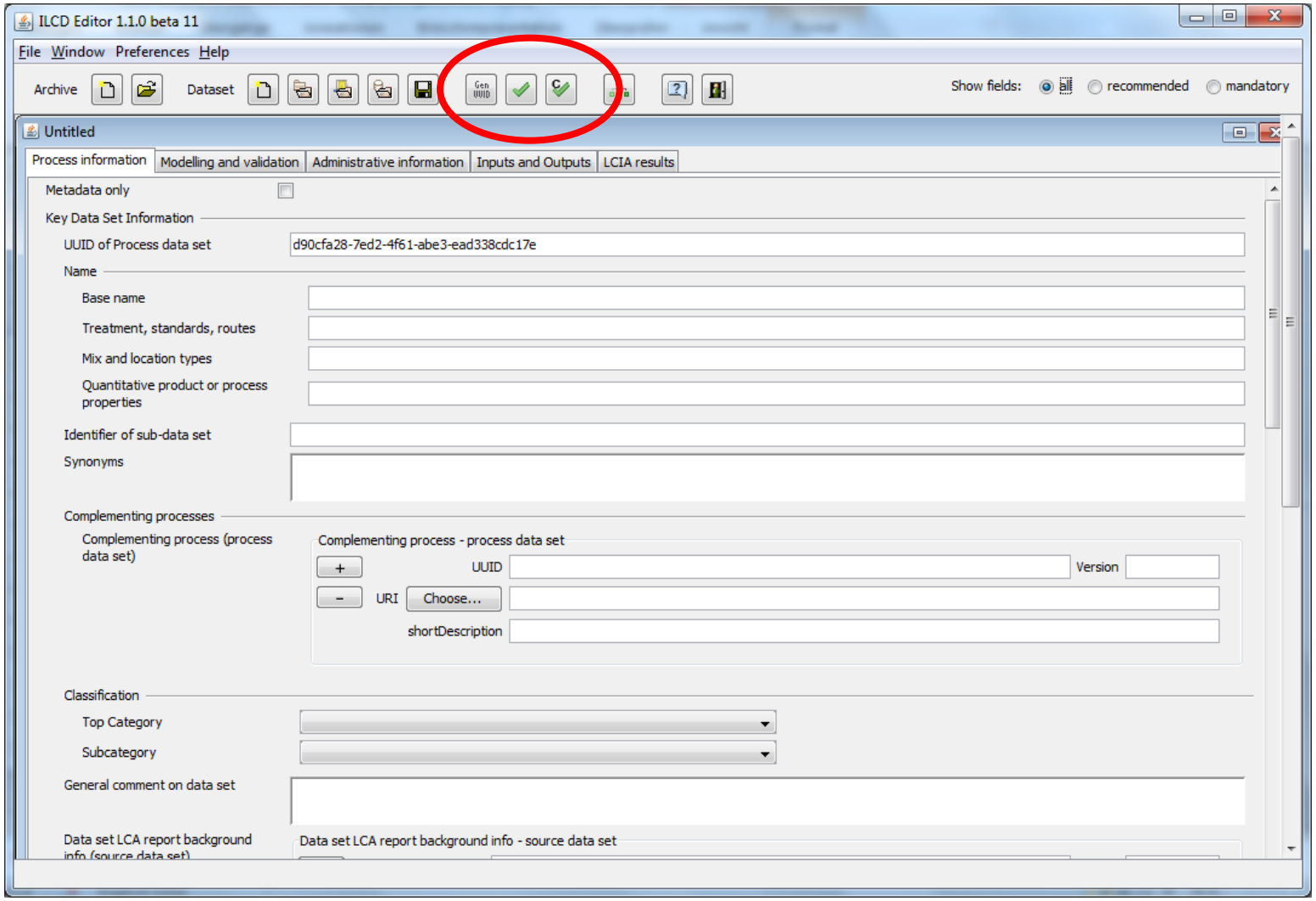
- Java application, provided by JRC, that works within an internet browser
- This software helps you to create and edit ILCD formatted data sets (version 1.1) and to check whether they are formally valid and meet the compliance requirements
- From 02.05.2011, the editor is available also for editing LCIA method data sets (draft)
- Available also an application to convert ILCD formatted process data sets to MS Excel format (ILCD2XLS converter beta)
- The editor supports the following ILCD data set types: Process, Flow, Flow property, Unit group, Contact, Source.

Available at: http://lct.jrc.ec.europa.eu/assessment/tools

ILCD Editor 1.1.0 beta 11

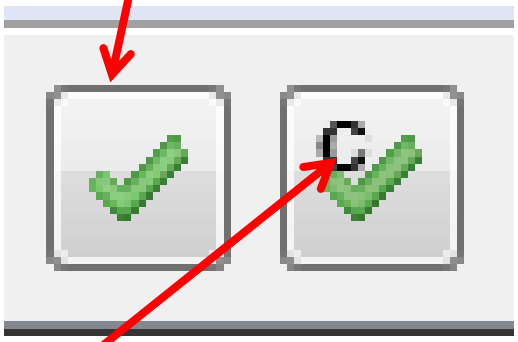


ILCD Editor 1.1.0 beta 11 – validity check and ILCD compliance check



ILCD Editor 1.1.0 beta 11 – validity check and ILCD compliance check

- The green "Validate Dataset" button in the editor's toolbar performs a validity check of the dataset.
- It allows to check automaticaly whether a data set is formally a valid ILCD 1.1 formatted data set



- The "Check ILCD compliance“ button, will perform a check against the ILCD Compliance rules whether the documentation extent meets the documentation requirements

Uploading ILCD data sets

- After the data sets are created they can be displayed in the browser
- They can be uploaded into the ILCD data network
- The network is independently managed network of several servers
- The data sets are open and can be downloaded freely
- Starting point is the ILCD homepage
  http://lct.jrc.ec.europa.eu/

- Some examples

Support from the Fc-Hy project

- Metadata template, for documenting the data set according to ILCD requirements (full and entry level)
- **Process information**
  - Key data set information
  - Quantitative reference
  - Time, geographical, technological representativeness
- **Modelling and validation**
  - LCI method and allocation
  - Data (source, treatment, representativeness)
  - Completeness, validation and compliance
- **Administrative information**
  - Commissioner and goal
  - Data set generator and modeller
  - Data entry by
  - Publication and ownership
- **Inputs and outputs (see data collection template)**

Acknowledgment

The research leading to these results has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement n° [256850].

Annex 3

ILCD Handbook (annex 4)

Training Course

The ILCD Handbook and Data Network

29 September 2011, Bologna

FC-Hy Guide

Research Centre E. Clementel

Alessandra Zamagni

LCA and Ecodesign Laboratory

International Reference Life Cycle Data System (ILCD)

- ILCD Handbook
  - A series of ***technical guidance documents*** in line with the ISO 14040 series.
- ILCD Data Network
  - web-based, decentralised ***network*** of Life Cycle Inventory (LCI) data sets

FC-Hy Guide

Background

- Several initiatives, schemes, instruments, non co-ordinated
- Inconsistencies due to differences in data and methods
- ISO standard exists but there is room for interpretation

There is the need of a common internationally co-ordinated guidance

ILCD Handbook - overview

- A response to the need for consistent and quality-assured LCA data and assessment
- A guidance for LCA in policy and business, in line with and expanding on ISO 14040 and 14044
- Main characteristics:
  - Broad range of questions (micro, meso/macro, monitoring)
  - All kind of LCA-related outputs: LCI data sets, LCIA, LCA studies, review and quality assurance
  - Not a training material for beginners
  - Detailed *Provisions* on how to deal with methodologically related questions

General structure 1

- General Guidance
  - General guide for Life Cycle Assessment - Detailed guidance
  - General guide for Life Cycle Assessment - Provisions and Action Steps
  - Specific guide for Life Cycle Inventory data sets
- LCIA
  - Recommended Life Cycle Impact Assessment models and indicators (under finalisation)
  - Framework and requirements for Life Cycle Impact Assessment models and indicators
  - Background document: Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment

General structure 2

- Review
  - Review schemes for Life Cycle Assessment
  - Reviewer qualification for Life Cycle Inventory data sets
  - Review scope, methods and documentation (in preparation)
- Nomenclature and other conventions (→ ILCD reference elementary flows, flow properties, unit groups)

GENERAL GUIDANCE

Main characteristics

- 3 decision-context situations, which determine the modelling approach to be adopted:
  - **Situation A**: micro level
  - **Situation B**: meso/macro level
  - **Situation C**: accounting (C1: Monitoring, C2: Descriptive)
- Criteria for distinguishing among the different contexts:
  - Whether a decision is to be supported
  - The extent of changes

Decision-context situation A

- Decision support related to inform the purchase of products that are on the market or the product development
  - no structural consequences outside the decision-scope, i.e. are supposed not to change production capacity.
- Example: Ecodesign study on a new computer mouse model comparing conventional and bio-based polymers for the casing (Source: JRC 2011)
- LCI modelling
  - attributional model of the existing life cycle
  - multifunctionality: substitution

Decision context situation B

- Meso/macro-level decisions (e.g. on raw materials strategies, technology scenarios, policy options) assumed to have structural consequences outside the decision-scope, i.e. they are supposed to change production capacity.
- Example: Policy study analysing the mandatory replacement by 2025 of 50% of all polymers in the U.S. by bio-based polymers (Source: JRC 2011)
- LCI modelling:
  - consequential model of all processes that are structurally affected
  - consider consequences & constraints
  - mix of long-term marginal processes
  - all structurally unaffected are modeled under situation A

Decision context situation C

- Documentation of the system's life cycle under analysis, no interest in any potential additional consequences on other parts of the economy.
- **C1**: Considering existing benefits of avoided burdens

  Example: Monitoring the environmental performance of nation-wide Italian waste management

  LCI modelling: identical to Situation A
- **C2**: Purely descriptive, i.e. not considering any benefits of avoided burdens

  LCI modelling: purely attributional model; allocation among co-functions

LCIA

LCIA recommendations

- Under preparation: recommendations on methods that should be used in LCIA.
- Global scope (whenever possible)
- Level of recommendations identified:
  - **I**: recommended and satisfactory (e.g. climate change)
  - **II**: recommended, some improvements needed (e.g. acidification)
  - **III**: recommended, but to be applied with caution (e.g. human toxicity)
  - **Interim**: a method was considered the best among the analysed methods, but is still too immature to be recommended (e.g. ionising radiation).

REVIEW

Review: schemes and qualifications

- Review schemes
  - Identification of 12 applications and 2 review types (indipendent external review and indipendent external panel review)
- Reviewer qualifications for LCI data sets
  - LCA methodology expertise; Knowledge of applicable review rules; Review/verification experience; Technical know-how
  - Reviewer registry under implementation: web application for LCA reviewers to registry in the register db
- Review scope, methods and documentation (in development)

FC-Hy Guide

LCA applications and review types

Application	Review type		Required involvement of interested parties
	Independent external review	Independent external panel review	
Micro level LCI data sets	X		
LCIA model		X	
LCIA factors	X		
Comparative assertions on micro-level (e.g. products) disclosed to the public		X	Yes
Meso/macro level decision support LCA studies / Meso/macro life cycle based accounting indicators		X	Yes
Meso/macro level LCA studies	X		Yes
LCA studies for identifying Type I Ecolabel criteria and Eco-design Key Environmental Performance Indicators (KEPIs)		X	Yes
Indirect aspects in Environmental Management Schemes (EMS)	X		
Micro level LCA studies/ Micro level monitoring indicator	X		
Environmental product declarations[1]	X		Yes
Environmental product declarations for B2B[1]	X		
Product Category Rules (PCR) for type III, product-group and sector-specific guides		X	Yes

Source: JRC 2011

ILCD DATA SETS and ILCD DATA NETWORK

ILCD compliance

- All requirements of ILCD Handbook documents, as applicable for the specific application type and study, shall be fulfilled
- From IT perspective, the data set complies with the ILCD data set format if the data set is ILCD format schema valid
- Nomenclature and reference elementary flow, flow property and unit group data sets apply are to be applied according to the ILCD "Nomenclature and other conventions“
- Entry-level requirements are defined for the first years of building up the ILCD Data Network.

Entry level requirements 1

Compliance area	ILCD Data Network - Entry-level	ILCD-compliance (details see Tab. 6)
Documentation	• Minimum documentation extent specified • ILCD format	• Minimum documentation extent specified • ILCD format to be used
Nomenclature	• Compliance with ILCD nomenclature document (e.g. use of ILCD reference elementary flows for IT compatible inventories), • *Certain aggregated elementary flows (e.g. VOC) are permitted* • *Terminology use not enforced.*	• Compliance with ILCD nomenclature document and use of ILCD reference elementary flow, flow property and unit group data sets • ILCD terminology to be used
Data quality	• *"Not defined", i.e. no data quality levels (Note: this requirement is covered as part of "Documentation")* • *Data quality needs to be stated using ISO quality criteria only* • Technological, geographical and time-related representativeness to be documented	• 3 levels of data quality differentiated ("high quality", "basic quality", "data estimate"), covering among others quantitative criteria for accuracy, completeness and precision. Differentiated quality ratings on Data quality, Methodological consistency, Nomenclature etc. are documented inside data set.
Method	• ISO 14040 and -44 compliance process-based LCA • *Methodological ILCD-compliance not enforced; applied modelling framework(s) and allocation/substitution approaches to be documented*	• ISO 14040 and -44 compliance process-based LCA • Methodological ILCD-compliance, differentiated by the archetype goal situations A, B, C1 and C2

Entry level requirements 2

Review	▪ ***Use of reviewers from registry not required*** ▪ ***"Qualified reviewer" required (based on ISO 14025):*** • ***knowledge of relevant sector*** • ***knowledge of represented process or product*** • ***LCA method expertise and experience***	• **ILCD-registered, qualified "Independent external reviewer" [ILCD reviewer registry, point system: LCA expertise and experience, experience in relevance sector, review experience - in line with ISO 14044 and 14025]**
	• ***Qualified independent external reviewer in line with ISO 14044 (chapter 6.1) requirements BUT separate review report is not required (review documented in data set) OR*** • ***Qualified independent internal reviewer in line with ISO 14044 (chapter 6.1) requirements, BUT*** **separate review report is required (minim review scope defined), in addition to documentation provided within data set**	• **Separate review report required, in addition to documentation provided in data set**
	• ***Review on unit process level may not be required, depending on data quality claims***	• **Type, scope and methods of review in line with ILCD Handbook (e.g. "Independent external review"), typically on level of the unit processes also of any included background system is required**

ELCD database and ILCD Data Network

- ELCD (European Reference Life Cycle Database): about 300 LCI data sets from EU-level business associations and other sources (key materials, energy carriers, transport, waste management)
- Available free of charge at http://lca.jrc.ec.europa.eu/lcainfohub/datasetSearch.vm. No access or use restriction.
- ILCD Data Network: an infrastructure for better availability of consistent and quality-assured LCA data. It is under implementation

Acknowledgment

The research leading to these results has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement n° [256850].

Annex 4

Introduction to Bologna Training course

FC-Hy Guide

Training Course

29 September 2011, Bologna

ENEA

Research Centre

E. Clementel

Ing. Paolo Masoni

Head, LCA and Ecodesign Laboratory

Schedule - Morning

Time	Topic	Content
9.00	Registration	Delegate package with: - Tag name - list of participants and instructors - Guidance document - Paper and pen - Attendance certificate
9.30	Welcome, goal and scope of the day	Description of the project FC-HyGuide, its relations with LCA standards and FCH JU calls.
9.45	The ILCD Handbook and Data Network	Brief introduction and general overview
10.00	FC Hy Guide documents and annexes	Brief description of the Guidance Document "Performing Life Cycle Assessment for Hydrogen and Fuel cell technology", its content and annexes
11.00	Coffee break	
11.20	Application of the FC Guide (Guidance Document for Fuel Cells): examples	Examples of how to meet the provisions of the Guidance Document for Fuel Cells. Interactive session with work in groups. Plenary discussion
13.15	Lunch in ENEA's cafeteria	

Schedule – Afternoon

Time	*Topic*	*Content*
14.00	Hydrogen case study	Examples of how to meet the provisions of the Guidance Document for Hydrogen production.
15.30	Data collection template	Guided tour
16.00	Coffee break	
16.20	ILCD editor for the preparation of ILCD compliant data sets	Guided tour
16.40	Wrap up and Questions & Answers	
17.00	Closure	

Goals and expectations

- **Our goals:**
  - Introducing the FC-HyGuide project and the (almost) final version of the guidance document (not approved yet by the EC)
  - Provide you with a sort of road map of the FC-HyGuide document and annexes, which has to be used for all upcoming LCA activities within the FCH JU
  - Enable a correct and effective use of the developed documents and support tools (templates and examples)
- **Our Expectations:**
  - Comments, questions and discussions→ Strong interaction
  - Constructive feedback.
- **Agenda is indicative** as we will adapt the lessons to your reactions

The problem addressed

- The Fuel Cells and Hydrogen Joint Undertaking (FCH-JU):
  - *"Sustainability is a key driver of the FCH JU activities and it is necessary to assess the new developments towards these goals**. Life Cycle Assessment will therefore be applied throughout the FCH JU on a programme level.**"*
- However, the main critics addressed to LCA are:
  - **Weak comparability** among different studies on the same product
  - **Complexity** of the method, which hampers its applicability in the industrial context.

Weak comparability

- ISO standards leave a high degree of freedom to practioners: **subjectivity** linked to some methodological choices (e.g. allocation, system boundary definition, modelling, etc.)
- ILCD Handbook (HB) addresses this question, providing **guidance** on all the LCA process, from the definition of the Decision Context, to specific requirements for review process
- However, ILCD HB is necessarely still **generic** as it applies to all possible sectors, technologies, decision contexes, LCA applications

Reduction of complexity

- LCA is necessarely a **complex method**, as in a generic life cycle system many parameters can affect the final results
- However, when a sufficient **knowledge** of a specific product/technology/system is available, the practitioner can **focus** her/his efforts on the real **relevant aspects** of the life cycle
- This is the only possible way to reduce the complexity of an LCA study, keeping a sufficient **scientific robustness** to the results (**relevance** of results):

"less and correct"

Third tier of harmonisation

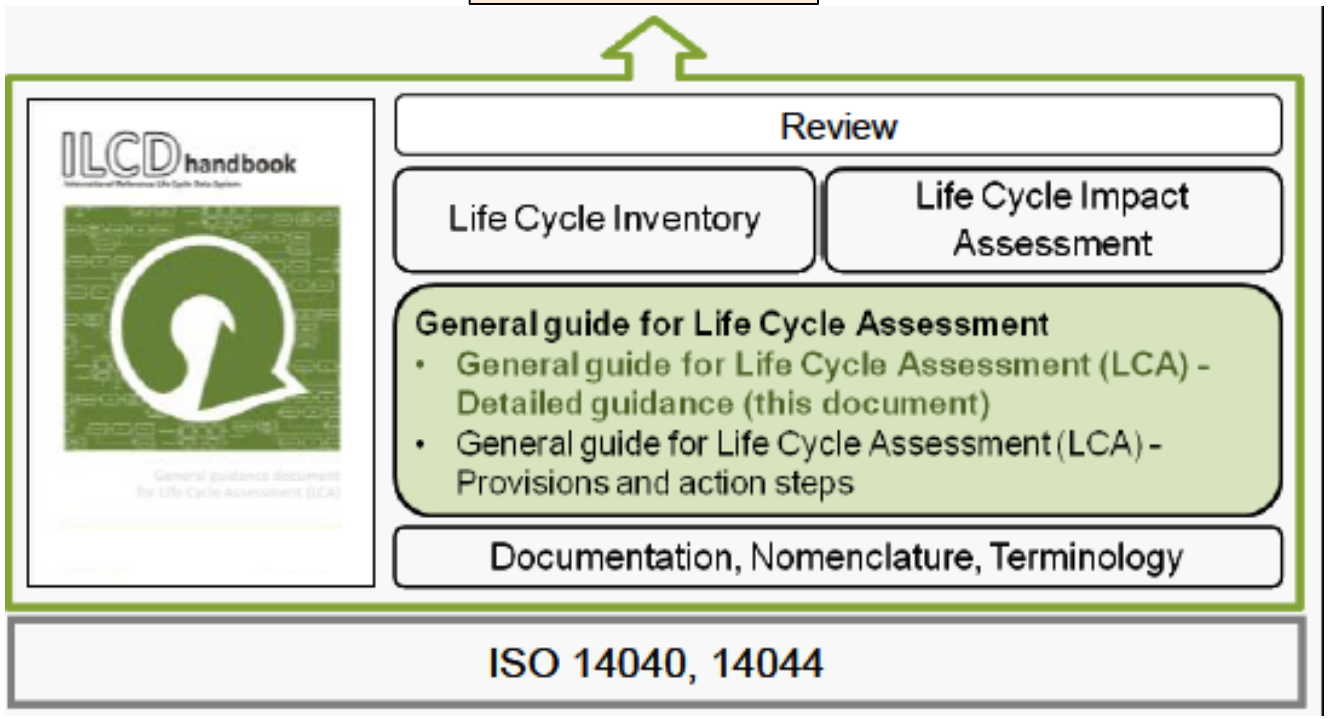
FC-Hy Guide

3rd tier

FC-Hy Guide

Guidance document for performing LCAs on Fuel Cell Technologies FC-Guide

Specific guidance for a product group.



2nd tier

Provisions depending on the decision context and application

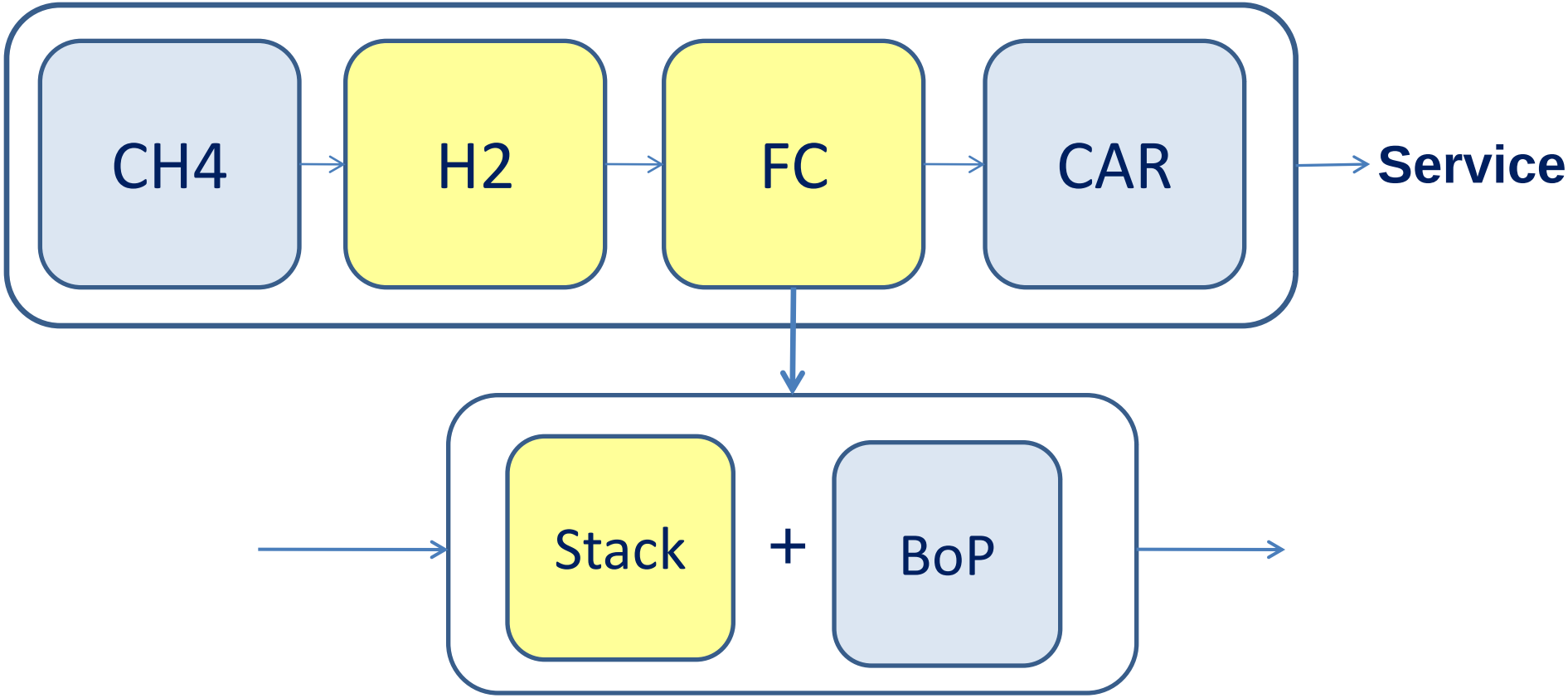
1st tier

General rules

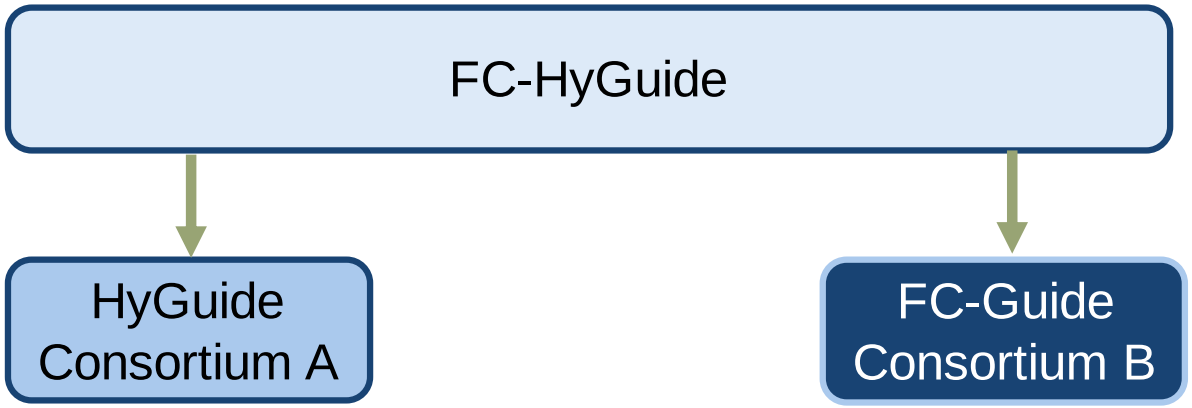
Output of the project

- Prepare and make available to the final user **knowledge and a pre-elaborated set of information**, ready to be used:
  - **FC Guide** (information and provisions)
  - **Templates**: Data collection, Data documentation, Reporting
  - **Examples** from case studies
  - **Training** (today☺)
- Target: technology developers, LCA practitioners

Modular approach



FC-HyGuide



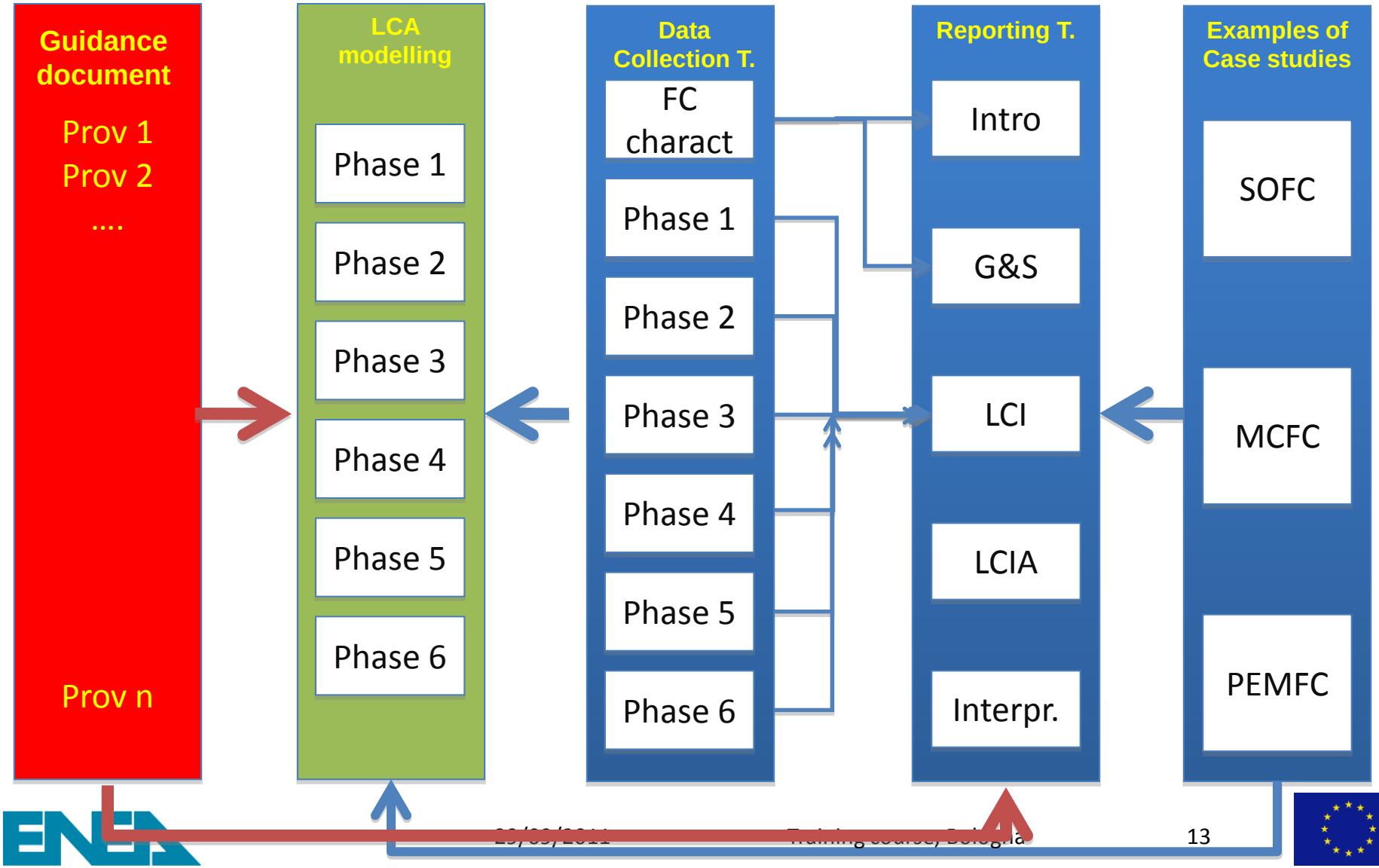
"Hydrogen supply technologies"

"Fuel Cell technologies"

→ FC-HyGuide = HyGuide + FC-Guide

TOC of FC-HyGuide

How to use the documents



Acknowledgment

The research leading to these results has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement n° [256850].

Annex 5

List of training course organizers

Bologna training course organisers

Nr	Fam. name	Name	Organisation	Email address
1	MASONI	Paolo	ENEA	Paolo.masoni@enea.it
2	SHULLER	Oliver	PE International	o.schuller@pe-international.com
3	ZAMAGNI	Alessandra	ENEA	Alessandra.zamagni@enea.it
4	ULGIATI	Sergio	UNIPARTHENOPE	Sergio.ulgiati@uniparthenope.it
5	ZUCARO	Amalia	UNIPARTHENOPE	Amalia.zucaro@uniparthenope.it
6	FIORENTINO	Gabriella	UNIPARTHENOPE	Gabriella.fiorentino@uniparthenope.it

Annex 6

Overview of guidance document

FC-Hy Guide

Training Course

Guidance Document

29 September 2011, Bologna

ENEA

Research Centre

E. Clementel

Content

- Compliance
- Project structure / Development process of the guide
- Covered Technologies
- Structure of the guidance document

FC-Hy Guide

Introduction to the project

The overall goal of the call "SP1-JTI-FCH.2009.5.5 LIFE CYCLE ASSESSMENT (LCA)" is to develop a specific guidance document for application to hydrogen and fuel cell technologies and related training material with courses for practitioners in industry and research.

This is to be based on and in line with the International Reference Life Cycle Data System (ILCD) Handbook, co-developed by the European Commission's JRC-IES.

- A guidance document – based on the ILCD handbook – that is scientifically sound, industry accepted and quality assured (reviewed)
- LCA study reporting template, tailor-made to hydrogen and fuel cell technologies
- Broad dissemination among LCA practitioners and industry,
- A website, as a central information point and as fully integrated component of the ILCD data network, with public and restricted access areas.

Project timeline

	Apr		May		Jun		Jul		Aug		Sept	
Preparation and consultation of guidance document												
Public consultation												
Revision of the advanced document												
Review and finalization of the document												
Dissemination, external communication and training courses												
2 Training courses												
Case studies												
Case studies												
Review of the case studies												

Public
ENEA/ PE
PE/ENEA together with advisory board/review panel

FC-HyGuide
Project partners

HyGuide:

PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

University of Stuttgart
Chair of Building Physics (LBP)
Life Cycle Engineering (GaBi)

KIT
Karlsruher Institut für Technologie

JRC ie
EUROPEAN COMMISSION Institute for Energy

FAST
Federazione delle associazioni scientifiche e tecniche
fondata nel 1897

EHA
EUROPEAN HYDROGEN ASSOCIATION

FC-Guide:

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

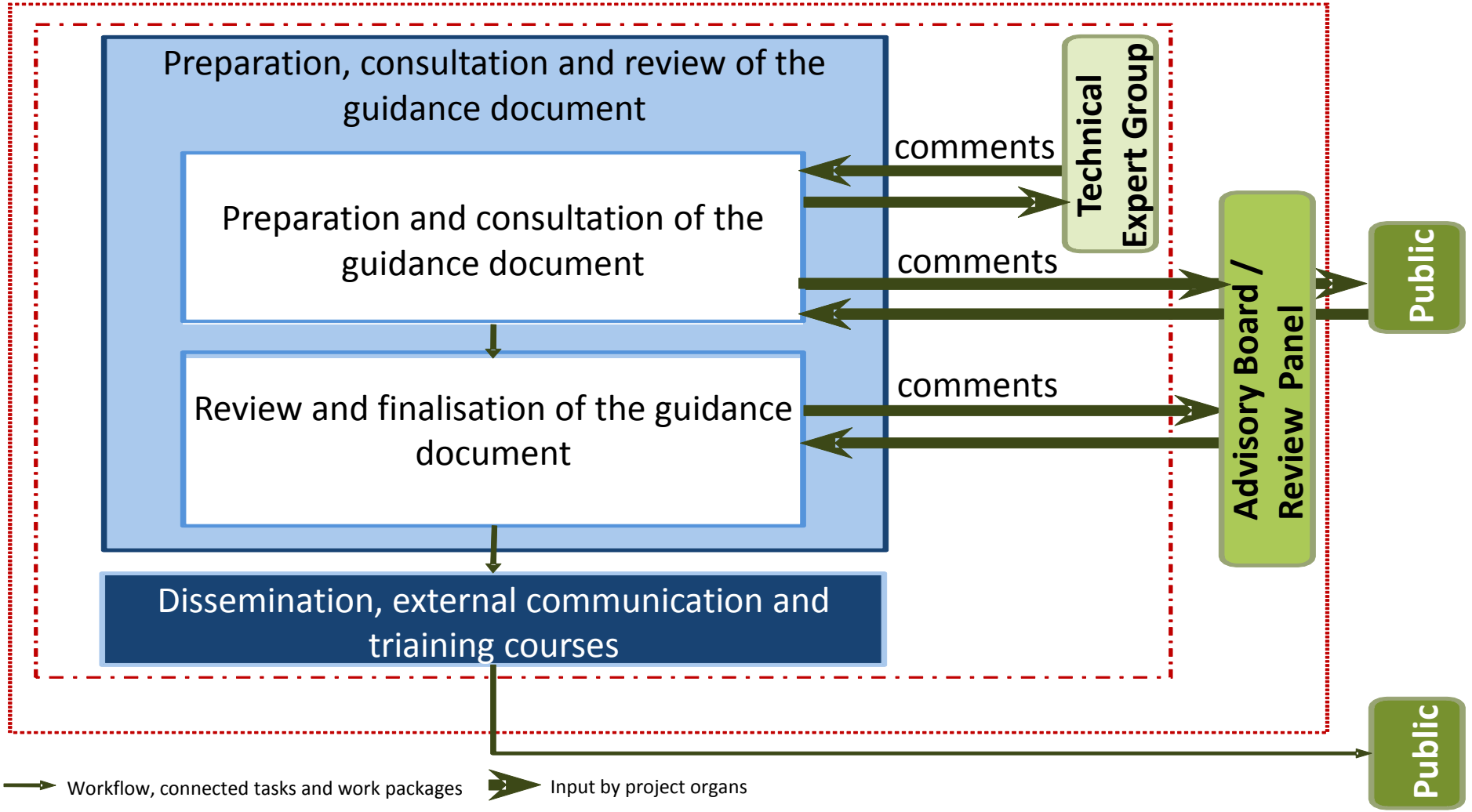
FCB

Università degli Studi di Napoli Parthenope

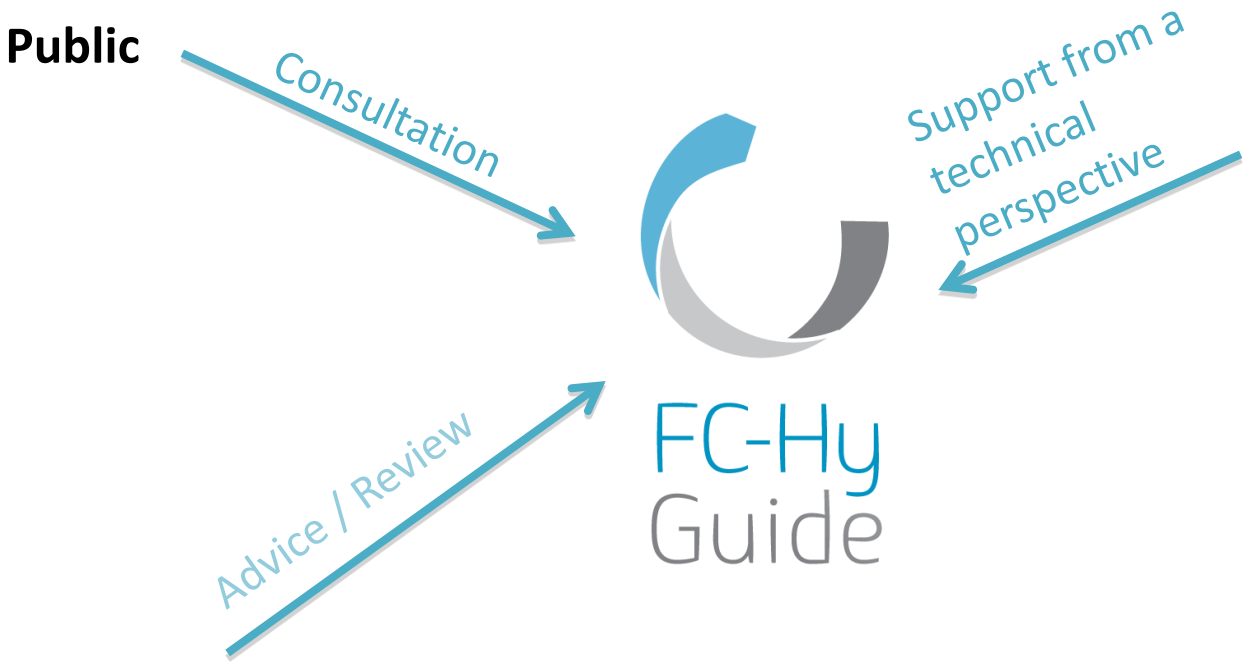
TU Graz
Graz University of Technology

PLANET
GbR

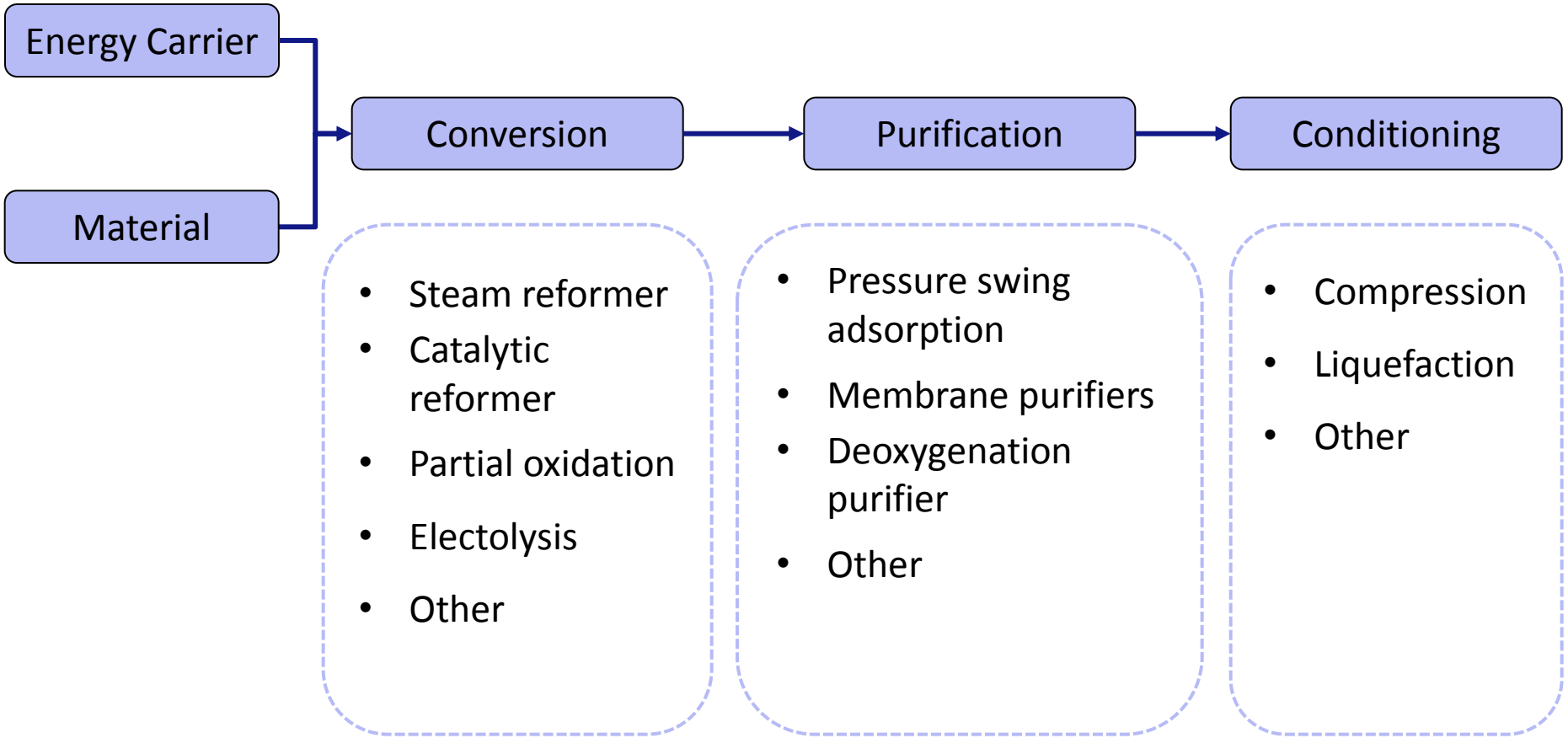
FC-HyGuide
Project Structure



FC-HyGuide Management structure



Covered technologies: Hydrogen



Covered technologies: FC

FC stack
FC system

- polymer electrolyte membrane fuel cell (PEMFC)
- molten carbonate fuel cell (MCFC)
- solid oxide fuel cell (SOFC)

Structure of the guidance document

Part I: General information

Part II: Guidance on performing a Life Cycle Assessment study on hydrogen production and Fuel Cell Systems

Annex I: Reporting template

Annex II: Documentation according to ILCD

Annex III: Data collection template

Annex IV: Review reporting template

Annex V: Example from case study

FC-Hy Guide

Part I - General Information

1. About this document

2. How to use this document

3. Introduction to Life Cycle Assessment

FC-Hy Guide

Part II

Guidance on performing a Life Cycle Assessment study on hydrogen production and Fuel Cell Systems

FC-Hy Guide

Part II – General

General information

- Product group
- Product related information
- Description of producer

LCA specific

- Goal and Scope
- Functional unit and reference flow
- System boundaries
- Cut-Off criteria
- Inventory Analysis
- Multifunctional processes
- Data collection
- Impact assessment categories and methods

Reporting

- Pre-determined parameters for reporting LCA data
- Additional environmental information
- Report format
- Period of validity of the study

FC-Hy Guide

Part II – Production Specific Data: Hydrogen

Product related information

- Purity
- Aggregate state
- Pressure
- Temperature
- Impurities
- Produced quantities

Description of hydrogen producer

- Overall H_2 production capacity
- Number of sites
- Productions technologies used
- Geographical coverage by region

Product system description

- Specific production technology
- Production capacity
- Any on site electricity
- Location of site
- Construction year
- Technical service life
- Type of production site
- Storage type

Part II – Functional Unit: Hydrogen

Functional unit : "1 MJ of hydrogen (net calorific value (NCV))"

Reference Flow : "1 MJ of hydrogen (net calorific value (NCV)) with XX % purity and YY bar @ ZZ ° C"

Part II – Production Specific Data: FC

Description of FC producer

- overall FC production capacity
- number of sites
- geographical coverage by region
- information on products- or management system-related certifications

Product system description

- technology used
- year of construction
- type of production site

Part II – Production Specific Data: FC

Product related information

- trade name
- type of electrolyte used
- primary functions
- electrical power
- thermal power
- efficiency
- rated voltage
- rated current
- range of temperatures and operating temperature
- weight
- dimensions
- fuel used and its technical specifications
- expected service life
- description of the intended use

Part II – Functional Unit: FC

Functional unit

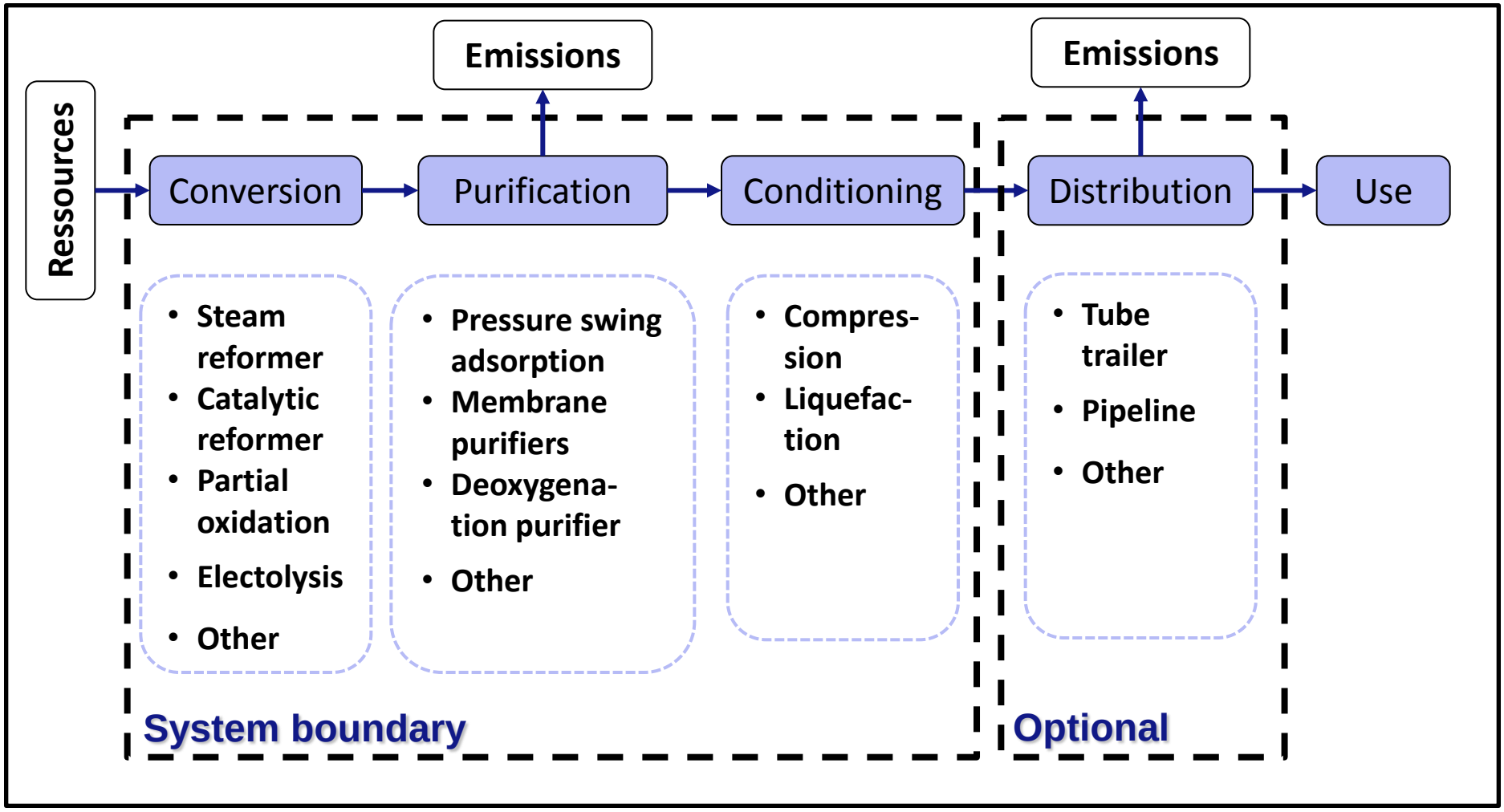
- Stack : power capacity of the manufactured stack expressed in kW_{ex}
- FC System: production of a certain amount of electricity and useful thermal energy in a given number of years expressed in MJ_{ex}

Reference Flow

number of FC modules, stacks or whole systems, required to produce the amount of energy or exergy defined in the functional unit

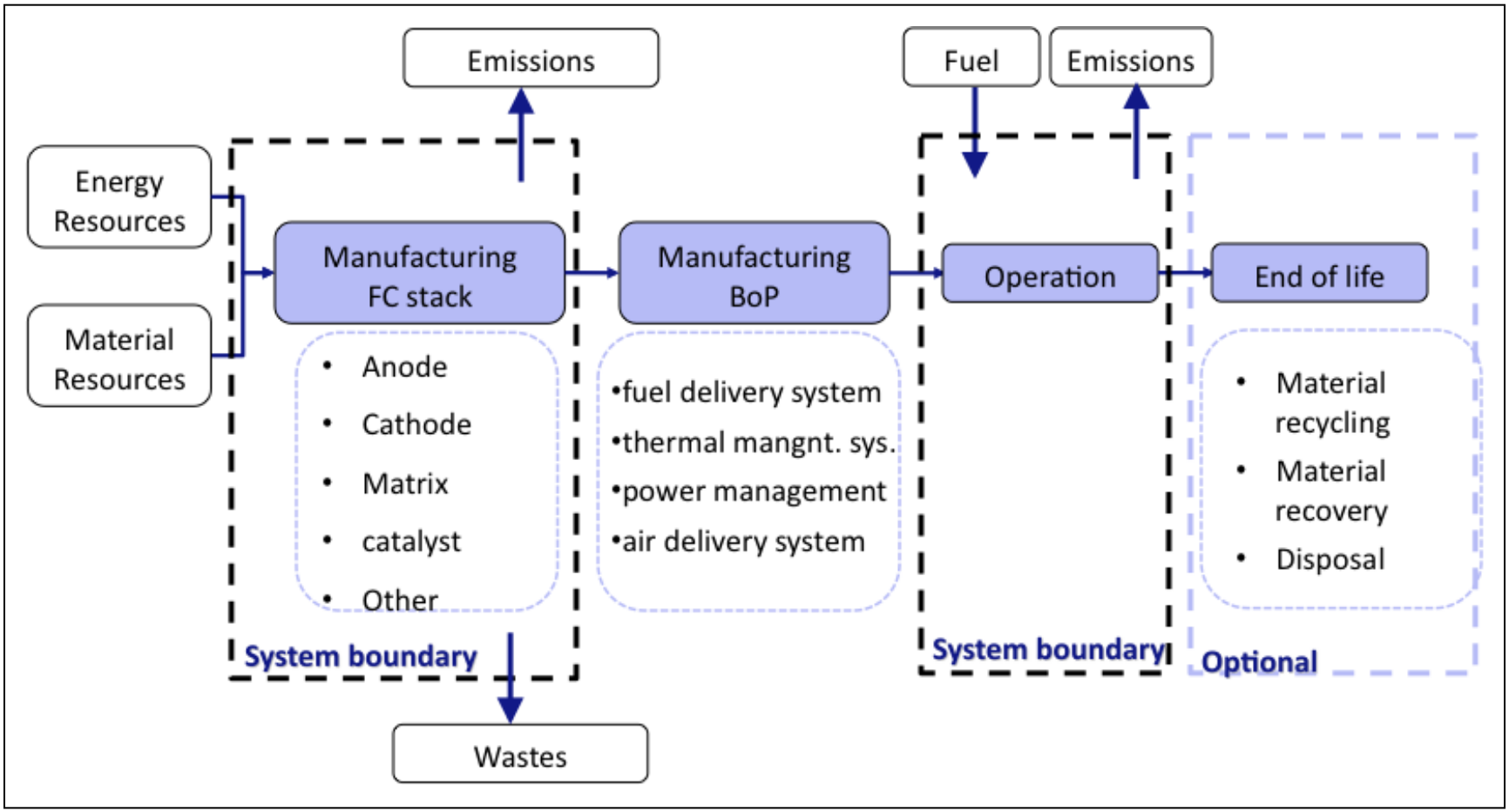
Part II – System Boundaries

Hydrogen



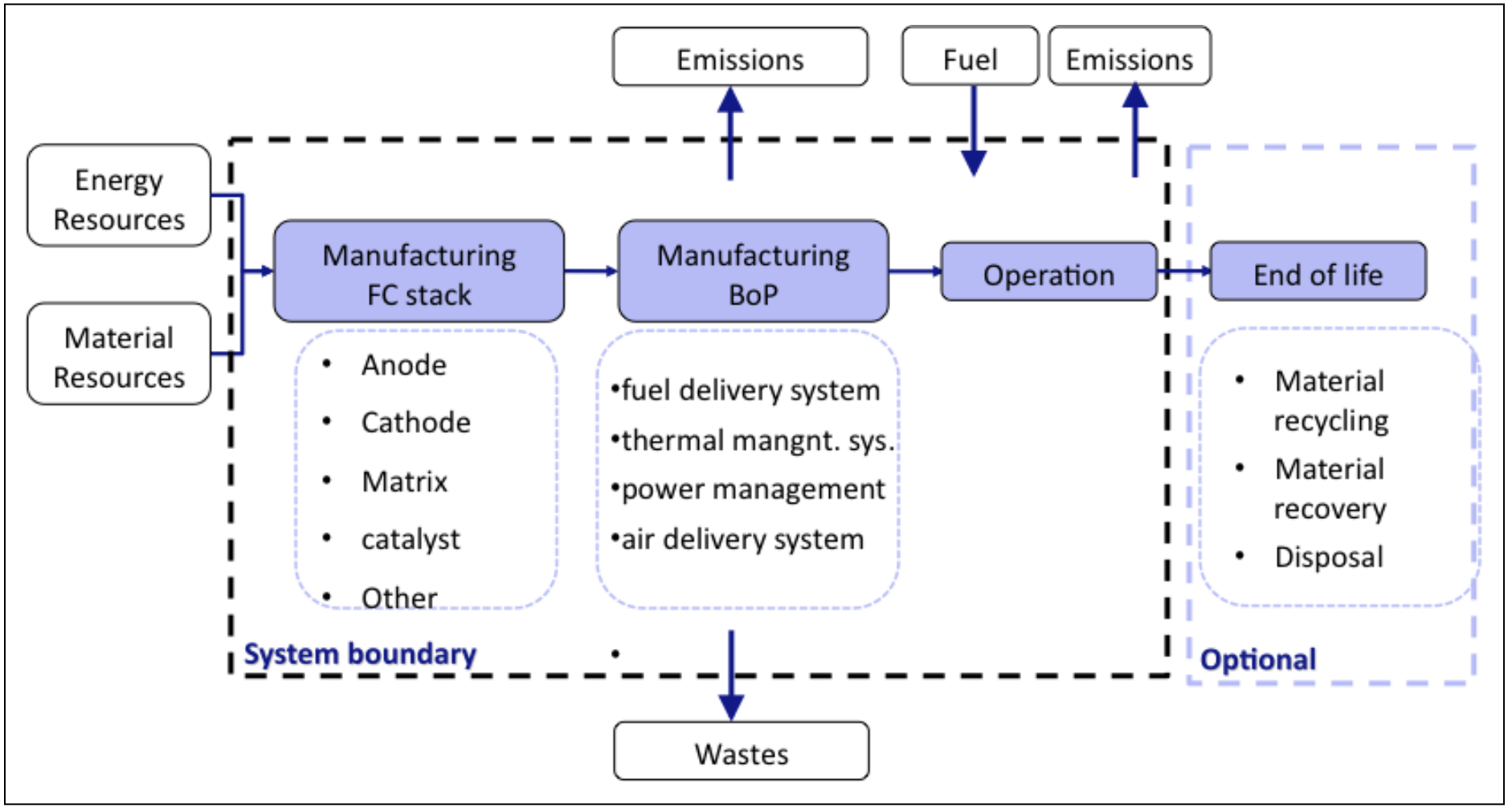
Part II – System Boundaries

FC: Stack

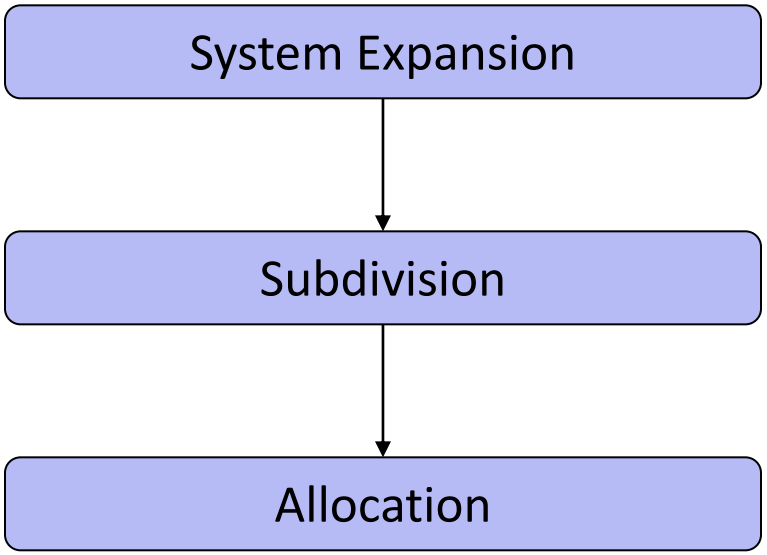


Part II – System Boundaries

FC: System



Part II – Multifunctional processes



If possible

Point out if the subdivided process is suitable

a) Physical properties

b) Economic properties

FC-Hy Guide

Part II – Data Collection and Cut-Off

Guidelines for data collection

- At least one start-up and shut-down sequence shall be included
- Regular maintenance shall be included
- Auxiliaries like pressurised air and so on shall be included
- If seasonal influences exist they shall be included (either measured or estimated)
- The period measured shall be long enough to cover business as usual without irregularities

→ Max. 5 % Cut-Off regarding environmental impact of the entire system

Part II - Impact assessment categories and impact assessments methods

JRC impact categories If available, else

Impact categories of Centre of environmental science (CML) recommended

Part II - Impact assessment categories and impact assessments methods

Shall: Use the following impact categories:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Photochemical Ozone Creation Potential (POCP)

Shall: In addition to these environmental impact categories use the following environmental indicators:

- Non-renewable Primary Energy Demand (PED non-renewable)
- Renewable Primary Energy Demand (PED renewable)

Part II - Impact assessment categories and impact assessments methods

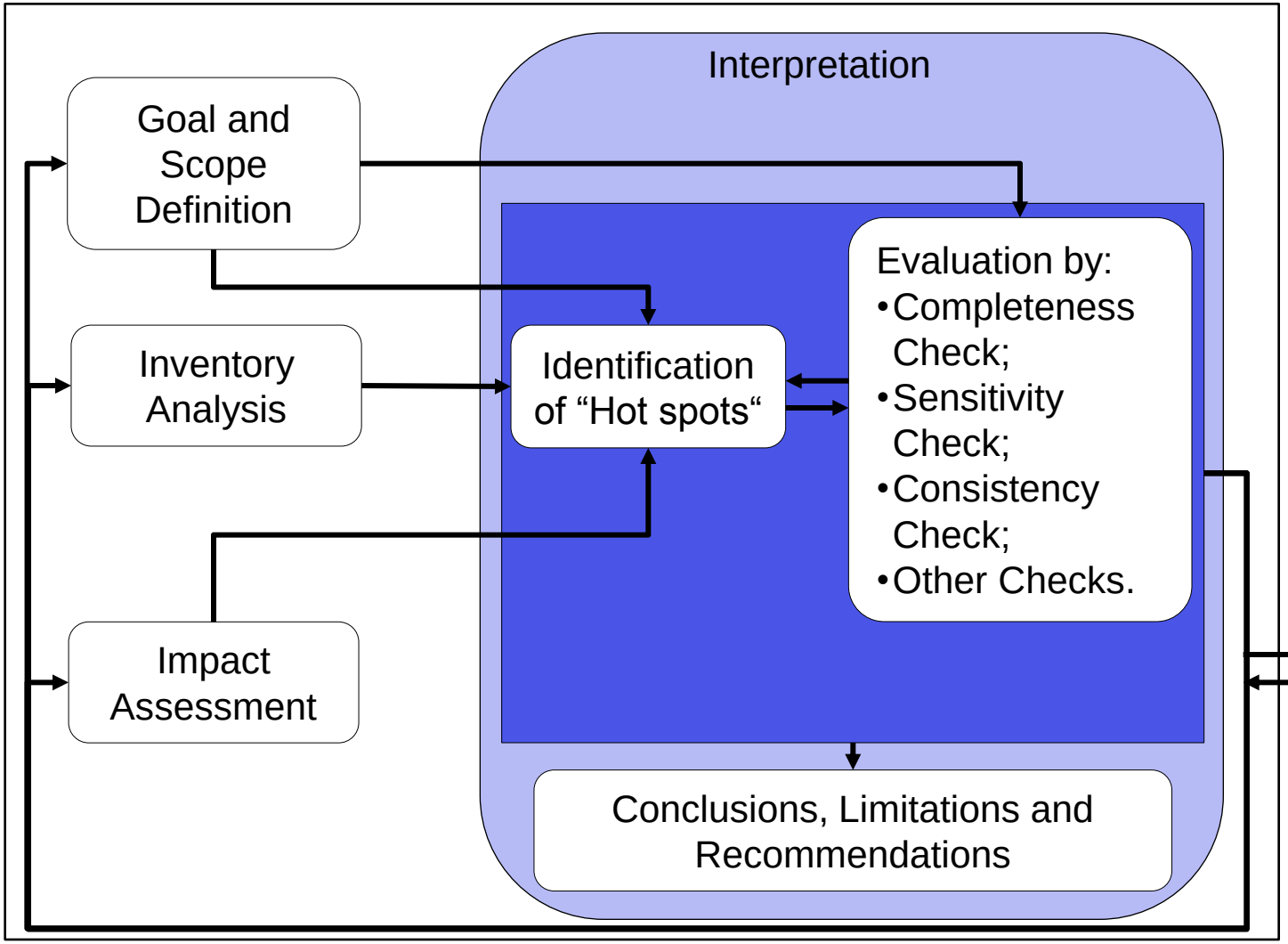
Should: The following impact categories could be used additionally

- Ozone depletion potential
- Human toxicity
- Respiratory inorganics
- Ionising radiation
- Ecotoxicity (freshwater, marine, terrestrial)
- Land use
- Resource depletion

Part II – Additional information and reporting

- Any hazardous or toxic substances, wastes or other used or released should be mentioned in the final report either as usual or accidental release
- Any other environmental impacts that may occur and could be important, shall be reported even if they can't be quantified yet
- Results and conclusions of the LCA study shall be completely and accurately reported without bias to the intended audience
- The validity of the study shall be chosen according to the expected lifetime of the facility (e.g. laboratory scale: 2 to 5 years validity, refinery 10 to 15 years)

Interpretation and quality control



Direct Applications:

- Product Development and Improvement
- Strategic Planning
- Public Policy Making
- Marketing
- Other

Reporting

- Executive Summary
- Technical Summary
- Main content
- Annex

Critical review

- **Should:** For internal studies an independent internal review is recommended if an external review is not planned.
- **Shall:** A critical review is necessary if the study is intended to be disclosed to the public
- **Shall:** A critical review panel (at least 3 reviewers) is necessary if the study is comparative and intended to be disclosed to the public

Acknowledgment

The research leading to these results has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement n° [256850].

Annex 7

Working groups

FC-Hy Guide

Training Course

Working Groups

29 September 2011, Bologna

ENEA Research Centre

E. Clementel

Working Groups

Group 1

Provision 6: Method, assumption and impact limitation

Provision 12: Functional unit

Provision 15: Multifunctionality

Provision 18: Cut-off criteria

Provision 19: Life Cycle Impact Assessment

Provision 34: Evaluation of results

Groups 2 and 4

Provision 3: Product system description

Provision 4: Goal of the LCA study

Provision 19: Life Cycle Impact Assessment

Provision 20: Type and sources of data and information

Provision 30: Classification and characterisation

Working Groups

Groups 3 and 5

Provision 4: Goal of the LCA study
Provision 11: Scope of the LCA study
Provision 16: System boundaries
Provision 25: Identifying processes within the system boundaries
Provision 34 : Evaluation of results

Working Groups

Group 1: Sergio Ulgiati

Group 2: Gabriella Fiorentino, Silvia Bargigli

Group 3: Amalia Zucaro, Andela Vukman

Group 4: Paolo Masoni

Group 5: Alessandra Zamagni, Frano Barbir

FC-Hy Guide

Working Groups

Provisions Worked Out in Groups

- Provision 3: Product system description
- Provision 4: Goal of the LCA study
- Provision 6: Method, assumption and impact limitation
- Provision 11: Scope of the LCA study
- Provision 12: Functional unit
- Provision 15: Multifunctionality
- Provision 16: System boundaries
- Provision 18: Cut-off criteria
- Provision 19: Life Cycle Impact Assessment
- Provision 20: Type and sources of data and information
- Provision 25: Identifying processes within the system boundaries
- Provision 30: Classification and characterisation
- Provision 34: Evaluation of results

Provision 3: Product system description

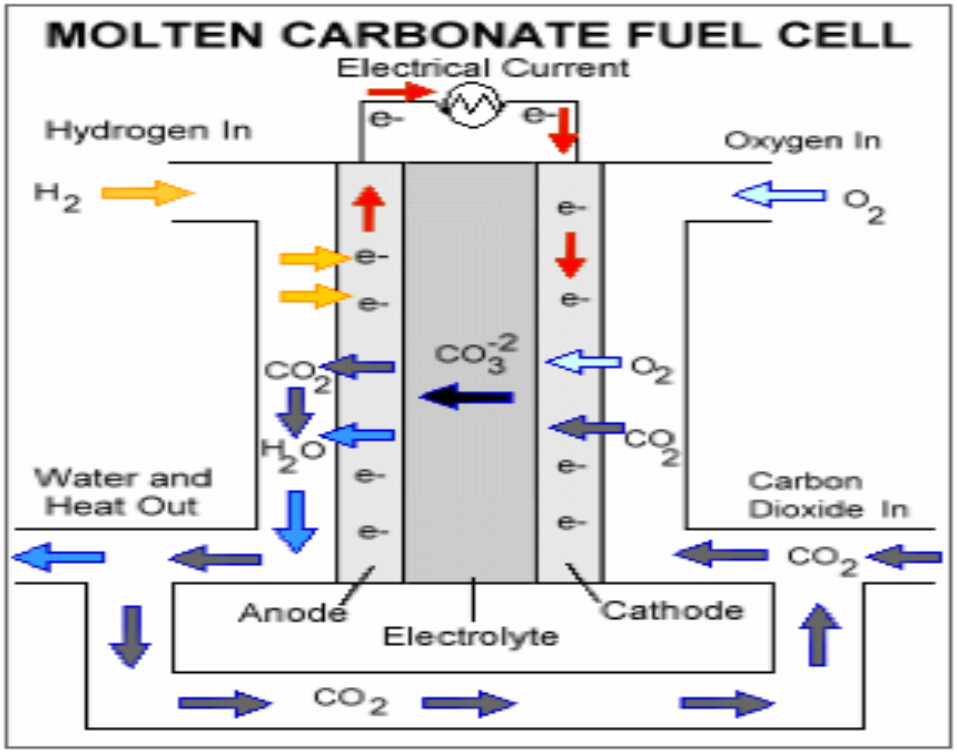
The author of the LCA study shall provide a general description of the FC life cycle, including the main components, the production processes and the use phase. To show the evaluated system, a process flow diagram shall be included. Generally the description of the FC (stack or system) has to include information on:

- *Technology used*
- *Year of construction*
- *Type of production site (laboratory, pre-commercial, commercial scale)*

If the study evaluates only components or a part of the production chain, only these components/parts have to be described but the product system which they are part of shall be named.

Provision 3: Product system description

Molten Carbonate Fuel Cells (MCFCs) are high-temperature fuel cells, that operate at temperatures of 650° C



anode: $H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$

cathode: $CO_2 + ½\ O_2 + 2e^- \rightarrow CO_3^{2-}$

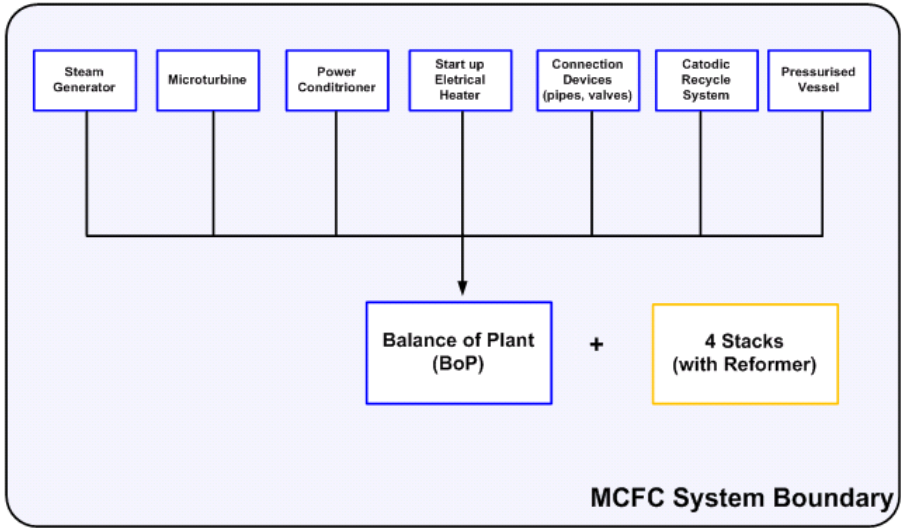
global reaction: $H_2 + ½\ O_2 \rightarrow H_2O$ + electricity + heat

Provision 3: Product system description

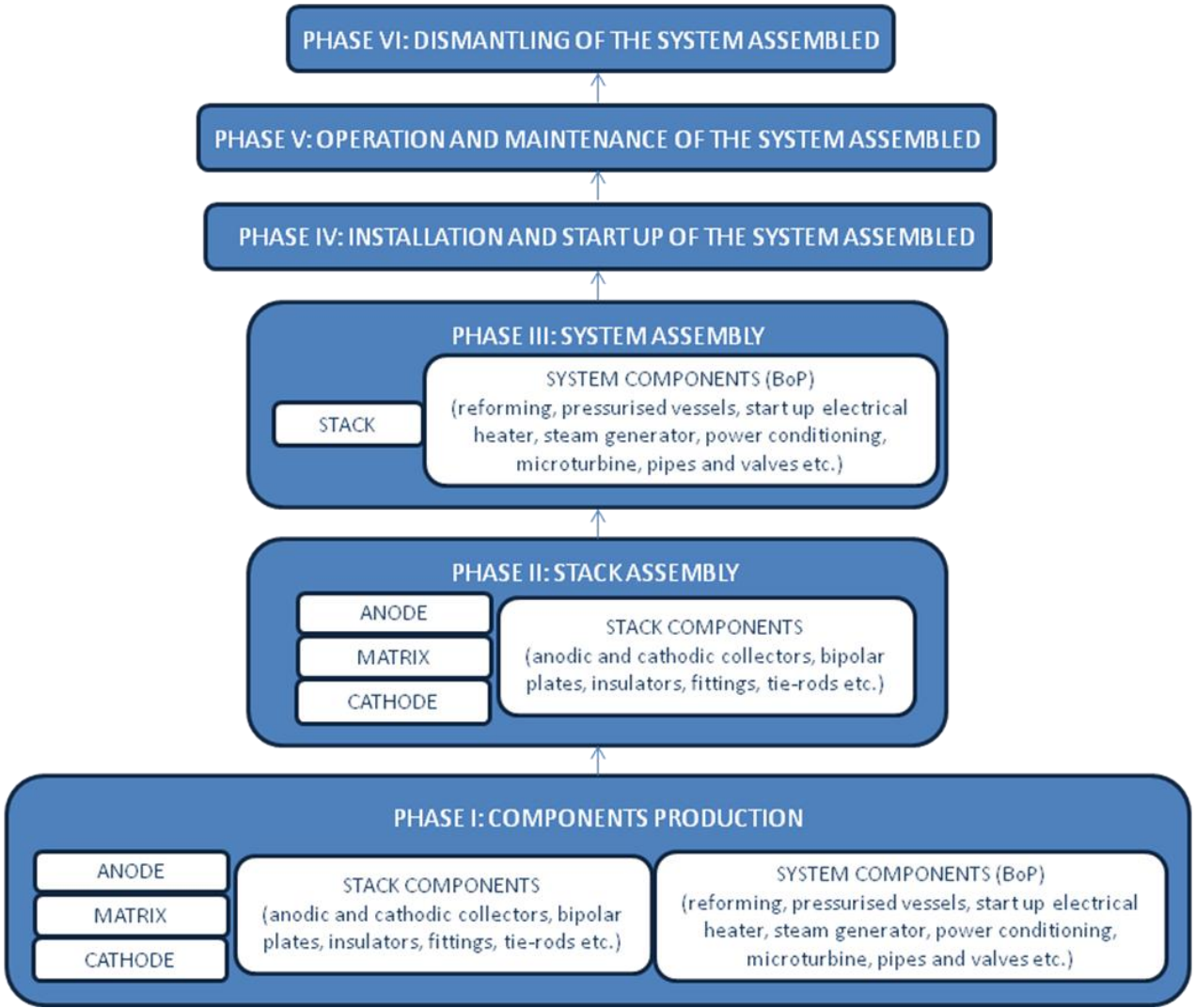
Each active cell comprises one ***anode***, one ***cathode*** and three ***layers of matrix.***

Each stack consists of ***230 active cells***, assembled together by means of specific steel components, such as ***anodic and cathodic collectors***, ***bipolar plates***, ***tie-rods***, ***fittings*** etc.

The BoP includes ***reformer***, ***pressurized vessels***, start up ***electrical heater***, ***steam generator***, ***power conditioner, pipes***, ***valves***, ***cathodic recycle system*** and ***microturbine***).



Provision 3: Product system description



Provision 4: Goal of the LCA study

The goal of the study shall be clearly defined in the report according to the goal and scope definition of the ISO 14044 standard.

GOAL:

- evaluation of the generated impacts
- identification of the most significant and sensitive steps that can be improved in their environmental performance by means of careful monitoring and strict environmental rules
- identify the technological challenges and weaknesses of production and use chains:
  - the breakdown of production and use processes into steps
  - the detection of unsolved problems, risks, environmental aspects related to specific production and use patterns
  - bottlenecks affecting the whole performance

SPECIFIC ASPECTS:

Intended applications; Method, assumption and impact limitation; Reasons for carrying out the study; Target audience; Comparison intended to be disclosed to the public; Commissioner of the study

Provision 6: Method, assumption and impact limitation

Sufficient consistency of methods, assumptions as well as data throughout the LCI/LCA study shall be assured. Any inconsistencies shall be documented and consequences on the conclusion of the study documented.

MAIN ASSUMPTIONS MADE:

- LHV (lower heating value) is used for energy calculations.
- The CML 2001 is used for Life Cycle Impact Assessment
- The study meets the data quality requirements of ILCD Handbook (and ISO 14040:2006 and 14044:2006). Only very recent data have been entered (last 5 years).
- the selection of impact categories derives from the specific characteristics of FCs: Global Warming (GWP), Acidification (AP), Eutrophication (EP), Photochemical Oxidation (POP), Ozone Layer Depletion (ODP), Human Toxicity (HTP) and Abiotic (ADP), Water Depletion (WDP). Other impact categories related to, e.g., radioactivity and noise are considered irrelevant and therefore excluded.
- According to previous studies in literature, industrial machinery and plant buildings are considered negligible compared to FC components and operational inputs, although the technology is not yet in its mature phase.

Provision 6: Method, assumption and impact limitation

•The three case studies refer to the the same functional unit, same system boundaries, same data degree of accuracy, same LCIA methods

HOWEVER

In the comparison among MCFCs, SOFCs and PEMFCs, some limitations due to scale factors and to differences in the operational conditions (temperature, used fuel, power output and use pattern) have to be considered.

For instance:

- PEMFCs are for mobile application (vehicles) while SOFCs and MCFCs are stationary
- PEMFCs are low temperature, while SOFCs and MCFCs are high temperature
- MCFCs use methane internally reformed to hydrogen, while SOFCs and PEMFCs are directly fed by H2 from previous reforming

thus adding to the difficulty of a direct comparison of the LCA studies.

Provision 11: Scope of the LCA study

The scope firstly defines the object of the LCA study. The object may be either an FC stack or a whole FC system. They cover all the single components and process steps, such as the active components (anode, cathode, matrix) and the steel parts.

Our study include:

- Function and Multifunctionality
- Functional unit and reference flow
- Units
- System boundaries
- Definition of relevant flows
- Cut-off criteria
- Life Cycle Impact Assessment methods and categories
- Type and sources of required data and information
- Data quality requirements (primary, secundary, geographic)
- Comparisons criteria
- Review aspects
- Reporting

Provision 11: Scope of the LCA study

The objects of MCFC LCA study are:

- MCFC stack (125 kWel);
- Complete system (4 stacks + BoP-Balance of Plant, 500 kWel) over its complete turnover time (20 years);
- Complete system operation for electricity production fueled by natural gas.

Each active cell comprises one ***anode***, one ***cathode*** and three ***layers of matrix.***

Each stack consists of ***230 active cells***, assembled together by means of specific steel components, such as ***anodic and cathodic collectors***, ***bipolar plates***, ***tie-rods***, ***fittings*** etc.

The BoP includes ***reformer***, ***pressurized vessels***, start up ***electrical heater***, ***steam generator***, ***power conditioner, pipes***, ***valves***, ***cathodic recycle system*** and ***microturbine***).

Provision 12: Functional unit

- ***FC stack:*** *The functional unit shall be the power capacity of the manufactured stack expressed in kW (energy if electricity is the only valuable product, exergy if both electricity and heat are valuable products; in this case the share of electricity and heat shall be declared).*
- ***FC System:*** *The functional unit shall be "production of a certain amount of electricity and useful thermal energy in a given number of years", expressed in* MJ_{ex}*. The share of electricity and heat shall be declared. If the thermal output of the FC is not used, the FU is only the production of electricity, expressed in* MJ_{el}*.*

The service life span shall be chosen with respect to the expected lifetime and in context to the time the facility is already running, and adequately supported with experimental results and/or other technical analysis. It is suggested to define the service life using a 10% of degradation of the FC performance.

Provision 12: Functional unit

***MCFC stack and System (4 stacks + BoP*)**

In the analyzed system, electricity and heat are the main outputs: both an electric power output and a thermal power output can be provided. Considering both the production of the MCFC stack module, the stack+BoP system, and finally its operating phase, different functional units should be chosen, calculated on the basis of the delivered electricity and heat. The following equation applies to the output power, in order to convert energy to exergy:

Total Power output (kW_{ex}) = Electric Power (kW_{el}) + ε* Thermal Power (kW_{th}).

where ε =1-(Ta/Tm) is the Carnot factor. T_a is the ambient temperature and Tm the thermodynamic mean temperature between T_o (temperature of delivered heat) and T_r (return flow temperature).

A similar equation applies to delivered electricity and heat:

Exergy delivered (kWh_{ex}) = Electricity delivered (kWh_{el}) + ε* Heat delivered (kWh_{th})

HOWEVER:

in the present case study the system's usable heat output is not converted into an actually used service by means of cogeneration devices. Therefore, the only valuable product taken into account is electricity. The functional units chosen are therefore only referred to the electric power capacity of the manufactured stack (125 kW_{el}) and system (4 stacks + BoP, 500 kW_{el}).

Provision 12: Functional unit

MCFC System's operation

Since the thermal output is not used, the functional unit for the operating MCFC system refers the electricity generated by a TWINSTACK module in its lifetime.

Considering

* an electrical power output of 500 kW,
* an expected number of operative hours per year of 8000 hours
* an estimated lifetime of 20 years,

the system functional unit was calculated as:

power output (500 kW) x service time (20 years per 8000 hours/yr= 160000 hours) =

= 80 GWh_{el} (2.89E+08 MJ_{el}).

This value was chosen as the operating system's functional unit.

Provision 15: Multifunctionality

FCs are a typical example of multifunctional process as their main products are electricity and heat. The use of the produced heat shall be analysed in order to identify if an allocation problem exist.

Allocation alternatives:

- Allocating to mass, energy, exergy, economic value of products
- System expansion and no allocation
- Only one product considered

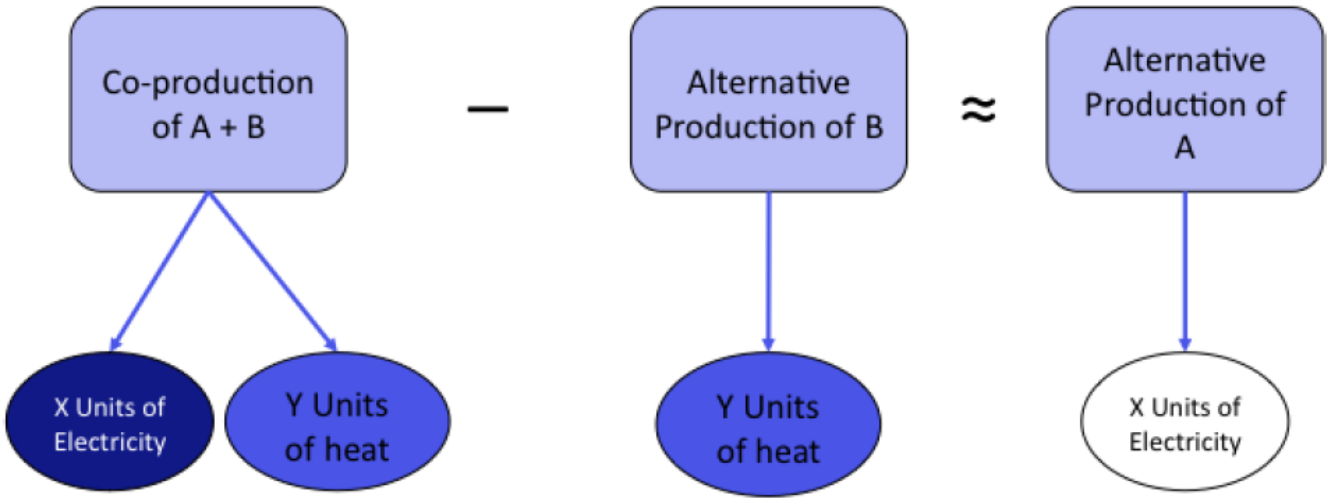
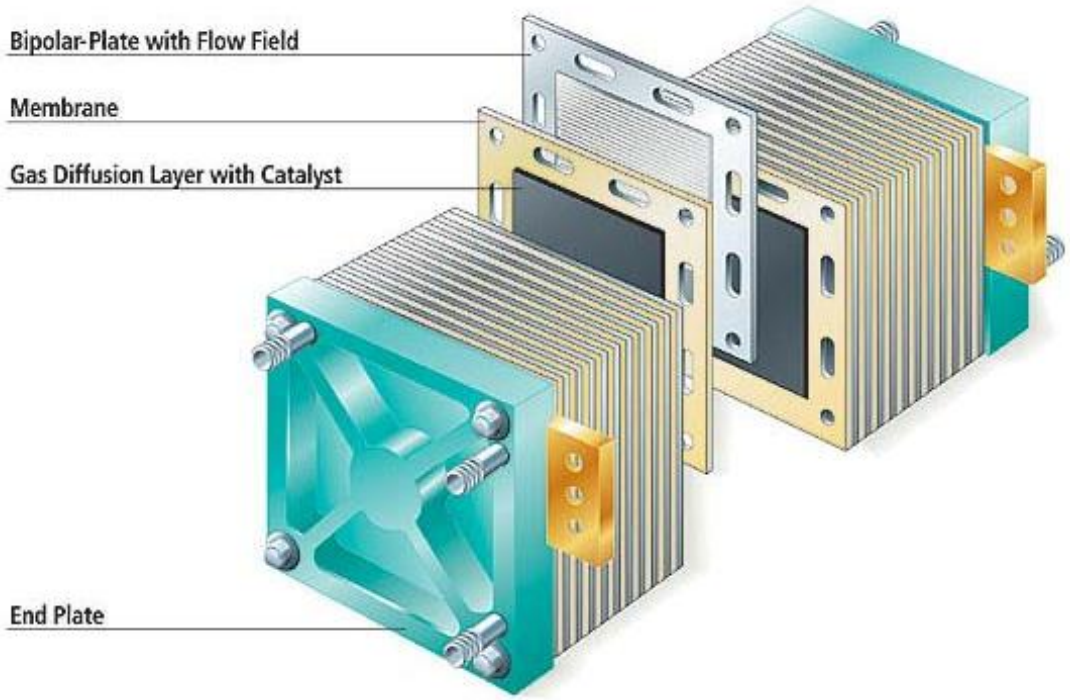


Figure 6: System expansion for solving multifunctionality (Source: JRC 2010) (modified)

Provision 16: System boundaries

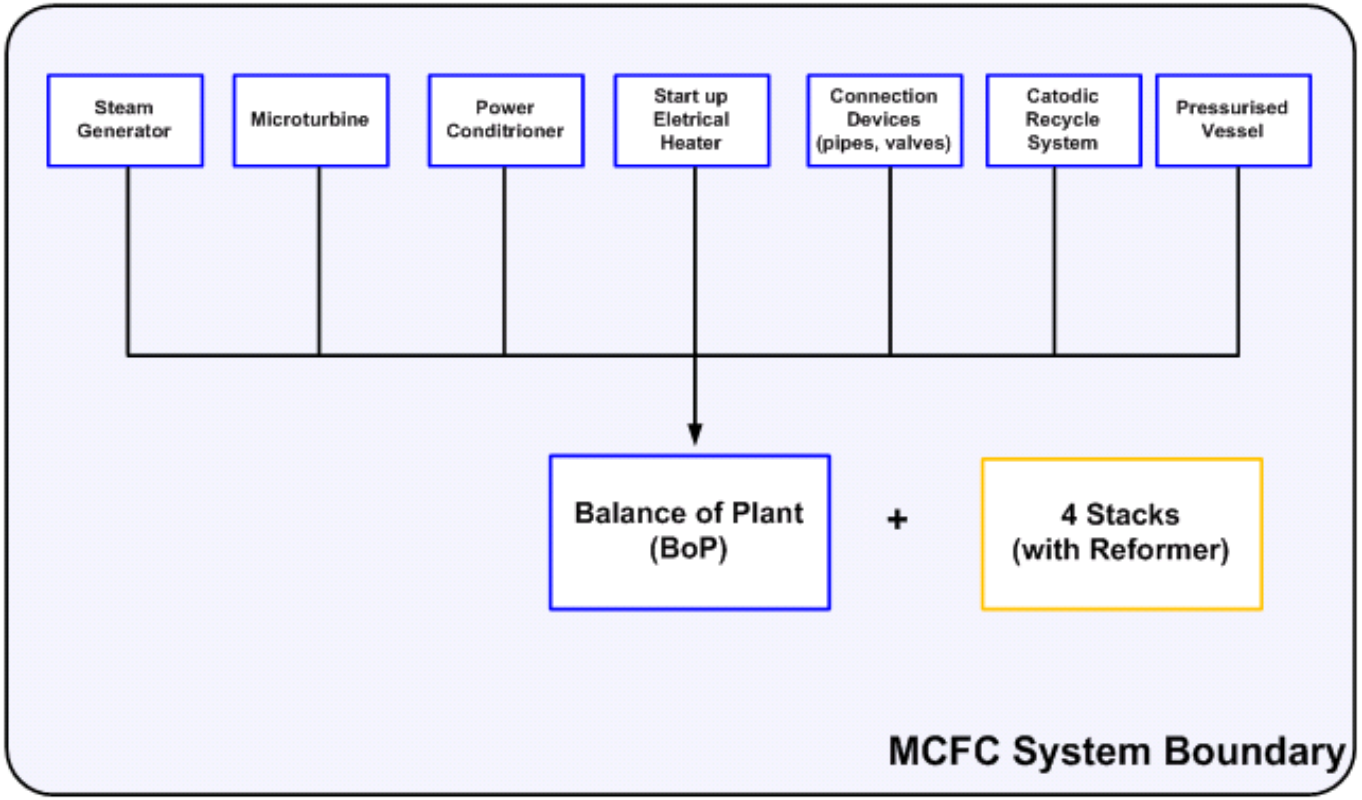
The system boundaries of an LCA on FC are defined according to the assessed product system. In the case of FC system mostly a "cradle to grave" view is applied. Cradle to gate is instead used in the case of FC stack, where the absence of the BoP makes it impossible to assess the use phase. In both cases, the production of the fuel is not included.



System 1

MCFC stack (125 kWel), includes the production phase, analysed starting from the extraction of resources and the supply of energy and chemicals in the preparation phase, also properly accounting of the related emissions.

Provision 16: System boundaries

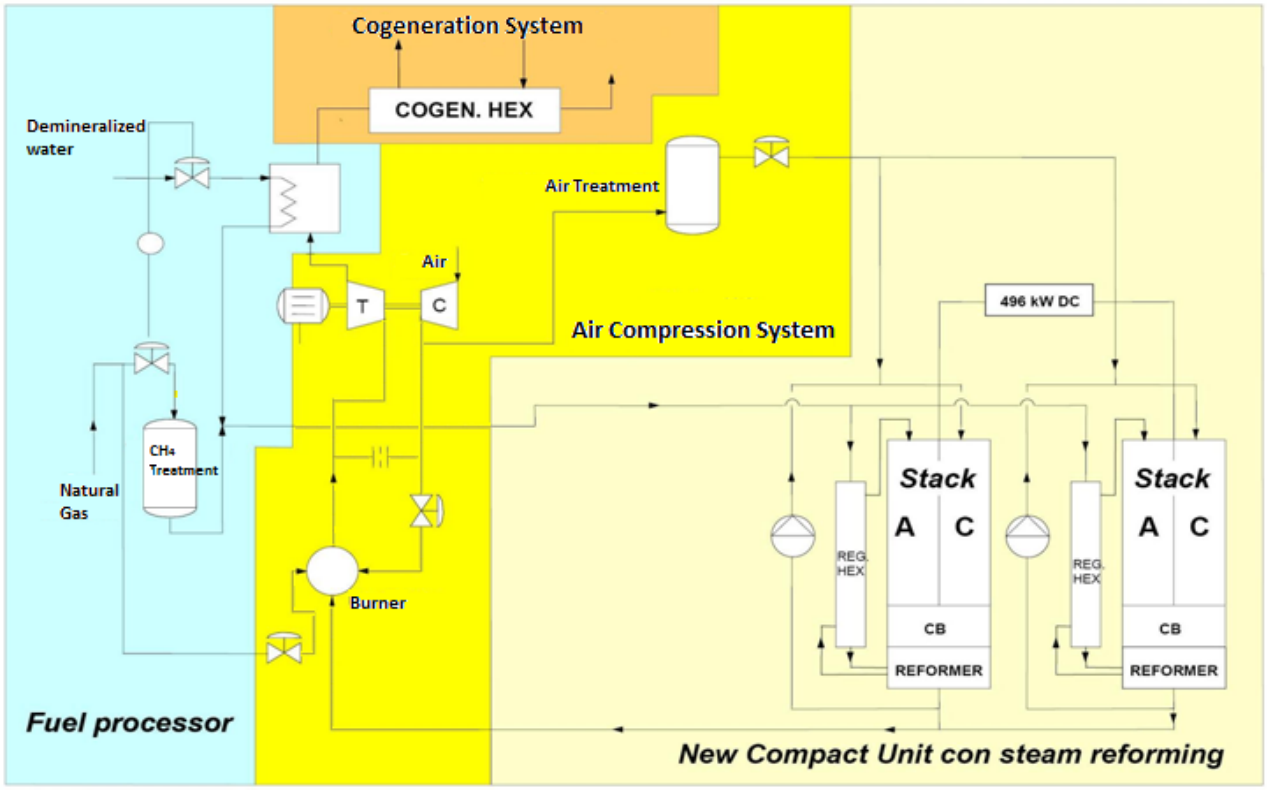


System2:

500 kWel MCFC Boundary as for the system 1, also for BoP components (mining, manufacturing, etc.)

Provision 16: System boundaries

System3: TWINSTACK+ Fuel. Boundary includes fuel extraction and processing



- ✓Pink area: stacks and reformers,
- ✓Yellow area:air compressor, an exhaust gases burner and a small turbine supporting the air compressor and the natural gas pre-heating step;
- ✓Light blue area: natural gas input and pretreatment;
- ✓Orange area: the cogeneration heat exchanger, for potential use of waste heat.

Provision 18: Cut-off criteria

All cut-offs shall not go beyond 2 % of mass or energy balance of the entire system (foreground and background). If the Cut-off is too coarse the system boundaries might be reconsidered.

In this LCA study all the cut-offs are set at 2%.

Inputs that contribute less than 2% to the mass or energy of the total product system's inputs as well as less than 2% to the environmental impacts are not accounted for.

Environmental impacts calculated with and without 2% cut-off do not differ significantly in most impact categories. In some cases the difference is larger. For this reason the choice of the cut-off percentage remains up to the experience of the LCA analyst, who may decide to adopt a smaller cut-off in order to highlight and discuss the importance of selected inputs to specific categories.

Provision 18: Cut-off criteria

Impact category	Unit	MCFC stack (without cut-off)	MCFC stack (with 2% cut-off)
Abiotic depletion	kg Sb eq	3.56E+02	3.53E+02
Acidification	kg SO_2 eq	1.46E+03	1.45E+03
Eutrophication	kg PO_4^{---} eq	1.76E+02	1.70E+02
Global warming (GWP100)	kg CO_2 eq	5.05E+04	4.96E+04
Ozone layer depletion (ODP)	kg CFC-11 eq	1.78E-02	1.76E-02
Human toxicity	kg 1,4-DB eq	3.96E+05	3.70E+05
Photochemical oxidation	kg C_2H_4	6.01E+01	5.79E+01

MCFC stack (125 kWel)

MCFC system (500 kWel), supposed to be operating for 20 years (including 16 stacks and 4 reformers)

Impact category	Unit	MCFC system (without cut-off)	MCFC system (with 2% cut-off)
Abiotic depletion	kg Sb eq	2.71E+04	1.03E+04
Acidification	kg SO_2 eq	1.37E+06	1.37E+06
Eutrophication	kg PO_4^{---} eq	2.18E+04	2.09E+04
Global warming (GWP100)	kg CO_2 eq	3.78E+06	3.50E+06
Ozone layer depletion (ODP)	kg CFC-11 eq	5.27E-01	5.24E-01
Human toxicity	kg 1,4-DB eq	2.08E+07	1.87E+07
Photochemical oxidation	kg C_2H_4	5.50E+04	5.48E+04

Provision 19: Life Cycle Impact Assessment

Scoping the LCA study, the LCIA methods to be applied shall be defined. When available, the methods, models and characterisation factors identified in the Guidance document under preparation by the JRC-IES, through the European Platform on LCA, shall be used. Until then, the CML impact assessment methods shall be used (CML 2001). Within the CML-method the Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Ozone Creation Potential (POCP) and Abiotic Depletion (ADP) (van Oers et al., 2001) shall be used.

Provision 19: Life Cycle Impact Assessment

The midpoint CML impact assessment methods are recommended by JRC-IES to convert all the inputs and outputs flows, collected and reported in the inventory, into impact indicator related to human health, natural environment and resource depletion.

The ***CML 2 baseline 2000*** applied to the MCFC study is a mid-point method developed by the Centre of Environmental Science at Leiden University. This method provides characterisation and normalisation factors updated on a regular basis, which can be profitably used to quantify environmental impacts for different impact categories.

This study considers the impact categories of:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Photochemical Oxidation Potential (POCP)
- Abiotic Depletion (ADP)
- Ozone Layer Depletion (ODP)
- Human Toxicity (HTP)

Provision 20: Type and sources of data and information

Inputs and outputs to and from the foreground system to other technical systems shall be included. All resources from nature and emissions to nature of the foreground and background system should be taken into account. Exceptions are allowed in accordance with the cut- off criteria (section 6.3.3). Data used shall reflect the technology actually used, depending also on the region where the process occurs. If specific data is not available, comparable data can be used. The closing of data gaps with comparable data shall be described in the LCA report.

Provision 20: Type and sources of data and information

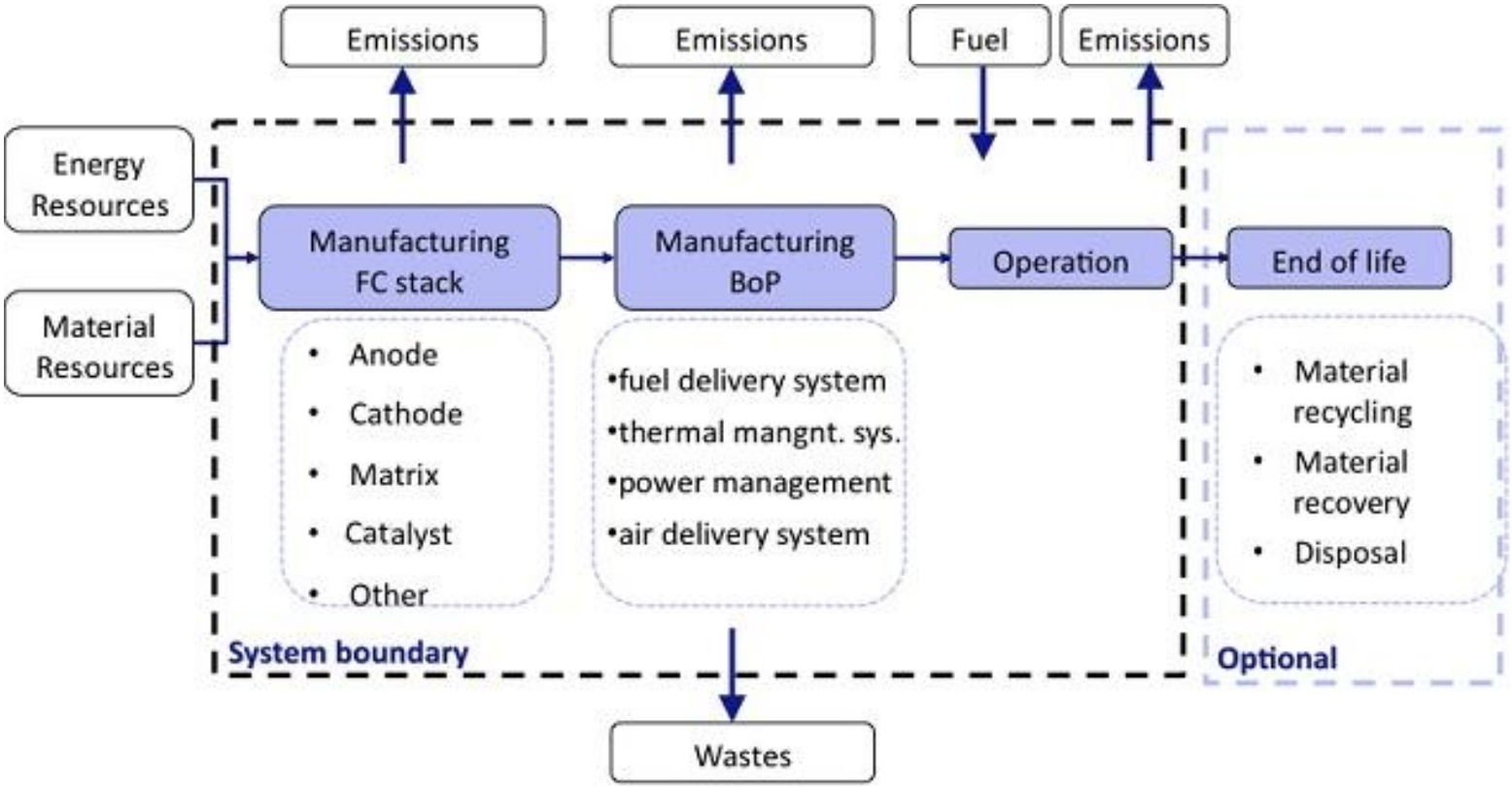
Data used in this LCA study reflect the most recent technology used by Ansaldo Fuel Cells in the production of MCFCs and were provided by Ansaldo itself within a collaborative agreement (primary data). Therefore, most of the input and output flows to and from the foreground system as well as resources from nature and emissions to nature of the foreground and background system are qualitatively and quantitatively assessed based on the information provided by the producer. In the case of the background systems, data from existing databases, mainly Ecoinvent Unit Processes library, are used. Some of the data not accessible from the company were obtained from recently published scientific literature. Other sources of data were ENEA and FN-Fabbricazioni Nucleari, operating in Italy for the design, manufacture and commercial development of MCFCs.

FOREGROUND PROCESSES	BACKGROUND PROCESSES
• anode production	• mineral extraction
• cathode production	• mineral manufacturing
• matrix production	• raw materials supply
• other stack components production	• energy supply
• BoP components production	• electricity mix
• stack assembly	• natural gas supply
• system assembly	
• energy requirements	

Provision 25: Identifying processes within the system boundaries

It has to be defined which foreground and background processes are taken into account in the LCA. Foreground processes are identified following a supply-chain logic. For the fuel cell stack they include e.g. the manufacturing of the anode, cathode and the matrix, their assembly in a FC module, start-up and maintenance. For the fuel cell system, the foreground includes also the manufacturing of the BoP. Details are provided in figures 11 14, 15 and 16. The background system comprises related upstream processes (supply chain of energy and materials) and downstream processes as well. The important upstream processes like raw material extraction shall be included; the related infrastructure may be included. It is recommended to use already existing aggregated data e.g. from ELCD, which comprises complete upstream processes (e.g. energy supply), including the infrastructure. The infrastructure (e.g. means of transportation or pipelines) may be included in line with the cut-off criteria (section 6.3.3).

Provision 25: Identifying processes within the system boundaries



Provision 25: Identifying processes within the system boundaries

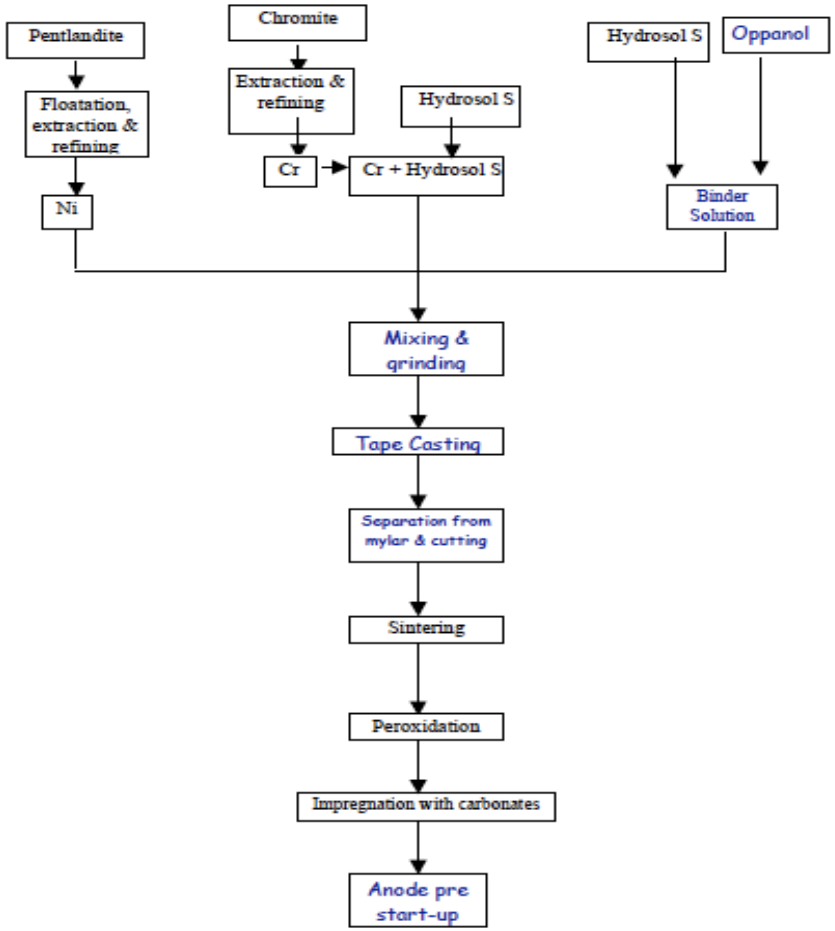
In all cases (**MCFC stack, MCFC system , TWINSTACK)** the system boundaries include foreground and background flows.

- Foreground flows include all processes related to the production and use of the MCFC itself, consisting of all the main production processes like the manufacturing of anode, cathode and matrix and their assembly for the MCFC stack, the manufacturing of the Balance of Plant and the start-up of the MCFC system.
- Background flows deal with almost all material and energy flows to and from the foreground system, such as infrastructure processes for the supply of the energy, power plants, power lines, mining, etc. Raw materials, used resources, primary products, additives, auxiliary materials and energy entering the system and electricity, heat, emissions to air, emissions to water, residues, waste and energy leaving the system have to be all taken into account as background data.

Provision 25: Identifying processes within the system boundaries

FOREGROUND PROCESSES	BACKGROUND PROCESSES
• anode production	• mineral extraction
• cathode production	• mineral manufacturing
• matrix production	• raw materials supply
• other stack components production	• energy supply
• BoP components production	• electricity mix
• stack assembly	• natural gas supply
• system assembly	
• energy requirements	

Provision 25: Identifying processes within the system boundaries



Provision 30: Classification and characterization

The following impact categories already identify in the scope phase shall be evaluated: global warming potential, acidification potential, eutrophication potential, photochemical ozone creation potential, abiotic depletion. When available, the methods, models and characterisation factors identified in the Guidance document under preparation by the JRC-IES, through the European Platform on LCA, shall be used. Until then, the CML impact assessment method shall be used, with the most updated version:

- *Global warming potential (GWP) (IPPC, 2007); kg CO2 eq.*
- *Acidification potential (AP) (Huijbregts, 1999); kg SO2 eq.*
- *Eutrophication potential (EP) (Huijbregts, 1992); kg PO4- eq.*
- *Abiotic depletion (AD) (van Oers et al., 2001); kg antimony eq.*

The method is implemented in all the major software tools available in the market. If the assessment is performed with spreadsheets in excel, the list of characterisation factors is available at the following address http://cml.leiden.edu/software/data-cmlia.html. A comparison across the impact categories shall not be done. Summing up shall not be done across impact categories.

Provision 30: Classification and characterization

The software tool used for the classification and characterization of the MCFC technology was SimaPro 7.3 and, among the methods available within this software, the method CML 2000 was selected.

The classification is the step in which the elementary flows are assigned to one or more of the selected impact categories, whereas the following step is characterization, i.e. the definition of how much impact an emission contributes with regard to a specific impact category.

The CML 2000 method automatically calculates the results multiplying the inventory values by appropriate characterization factors. Each factor has a different unit, depending on the specific impact category considered, and thus the results from different categories cannot be neither directly compared nor summed up. The units used for the characterization factors make reference to a specific chemical species or item, the environmental burden of which is known based on previous studies and is taken as reference impact.

Species that contribute to the same category as the reference species are evaluated in proportion to the impact generated (e.g. a species that contributes to global warming 10 times more than CO2 is credited a Global Warming Potential Factors of 10 g CO2-equivalent, so that its mass is converted into an equivalent mass of CO2 by multiplying by the G.W.P.F.).

Provision 30: Classification and characterization

Impact category	Unit	MCFC stack (without cut-off)	MCFC stack (with 2% cut-off)
Abiotic depletion	kg Sb eq	3.56E+02	3.53E+02
Acidification	kg SO_2 eq	1.46E+03	1.45E+03
Eutrophication	kg PO_4^{---} eq	1.76E+02	1.70E+02
Global warming (GWP100)	kg CO_2 eq	5.05E+04	4.96E+04
Ozone layer depletion (ODP)	kg CFC-11 eq	1.78E-02	1.76E-02
Human toxicity	kg 1,4-DB eq	3.96E+05	3.70E+05
Photochemical oxidation	kg C_2H_4	6.01E+01	5.79E+01

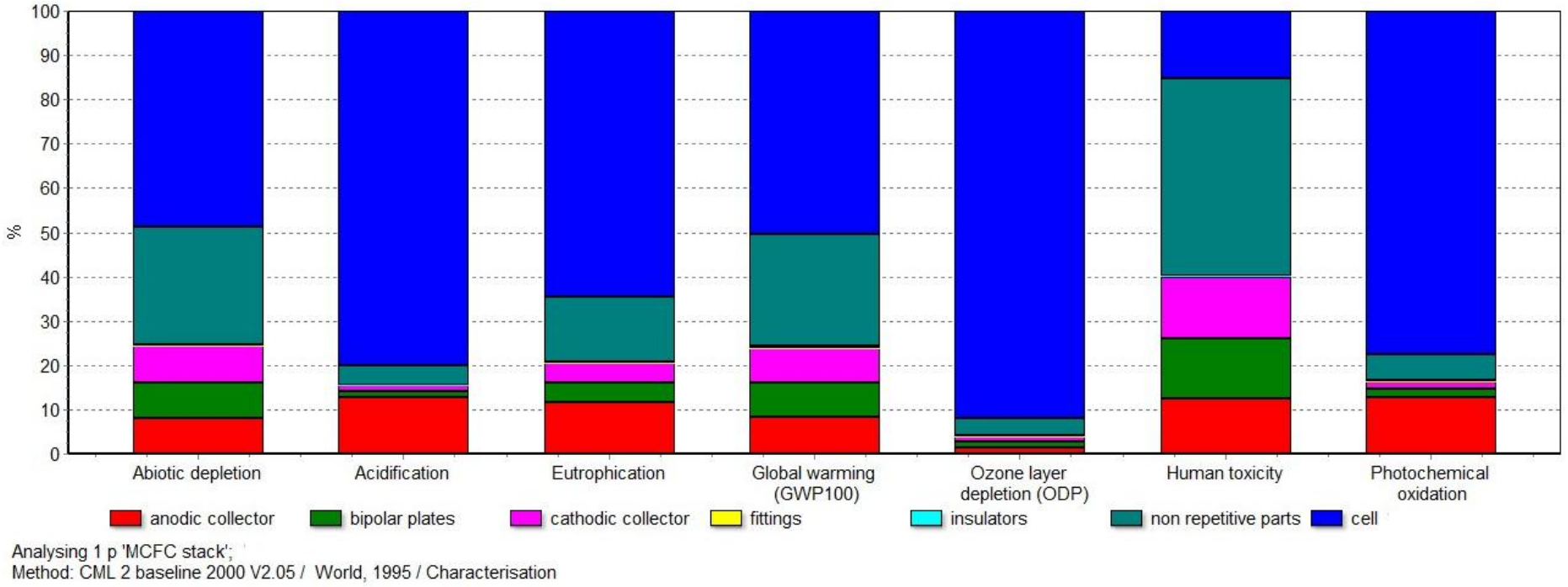
MCFC stack (125 kW_{el})

MCFC system (500 kW_{el}), supposed to be operating for 20 years (including 16 stacks and 4 reformers)

Impact category	Unit	MCFC system (without cut-off)	MCFC system (with 2% cut-off)
Abiotic depletion	kg Sb eq	2.71E+04	1.03E+04
Acidification	kg SO_2 eq	1.37E+06	1.37E+06
Eutrophication	kg PO_4^{---} eq	2.18E+04	2.09E+04
Global warming (GWP100)	kg CO_2 eq	3.78E+06	3.50E+06
Ozone layer depletion (ODP)	kg CFC-11 eq	5.27E-01	5.24E-01
Human toxicity	kg 1,4-DB eq	2.08E+07	1.87E+07
Photochemical oxidation	kg C_2H_4	5.50E+04	5.48E+04

Provision 30: Classification and characterization

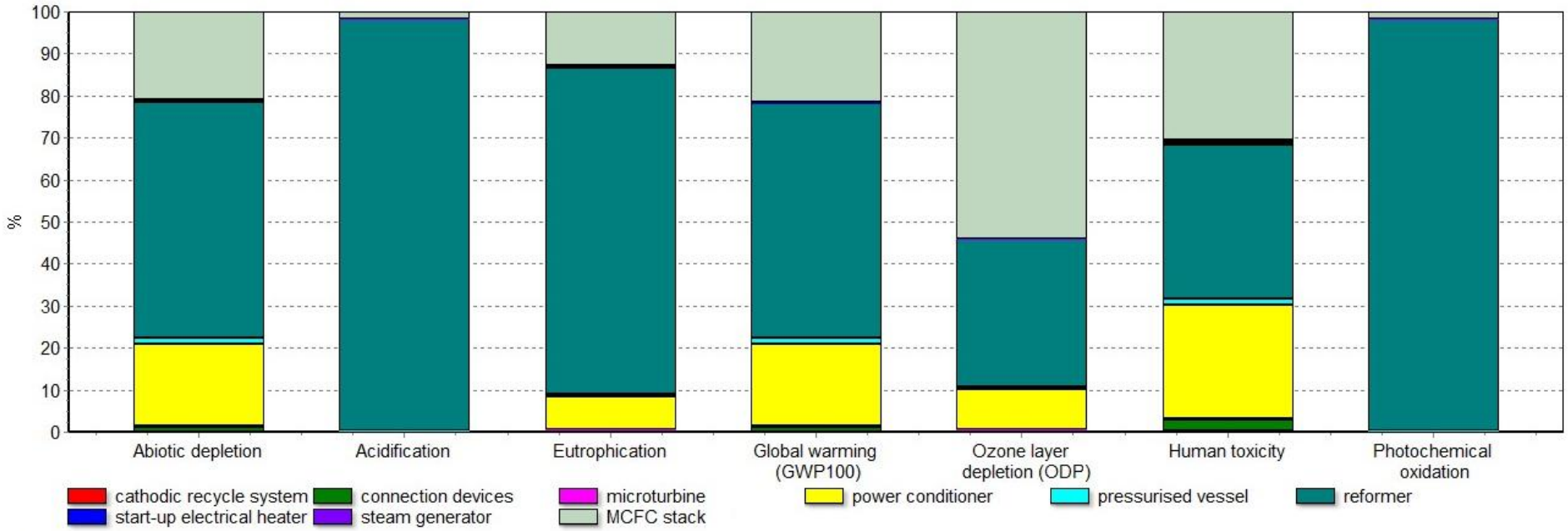
MCFC stack



Analysing 1 p 'MCFC stack';
Method: CML 2 baseline 2000 V2.05 / World, 1995 / Characterisation

Provision 30: Classification and characterization

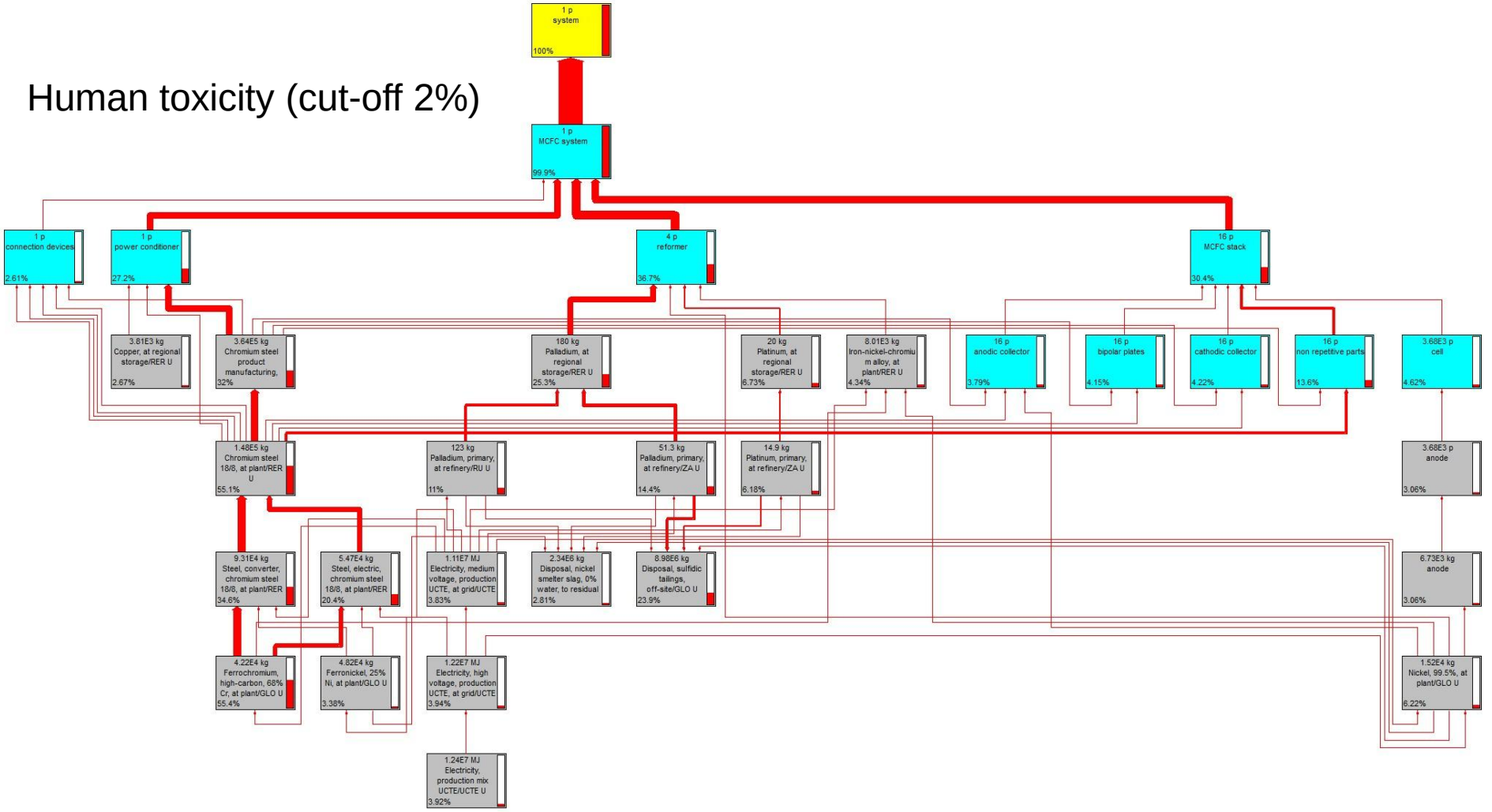
MCFC system



Analysing 1 p 'MCFC system';
Method: CML 2 baseline 2000 V2.05 / World, 1995 / Characterisation

Provision 30: Classification and characterization

Human toxicity (cut-off 2%)



Provision 34 : Evaluation of results

- ***Completeness check:*** *Evaluate LCI model completeness (process coverage):*
  - *for comparative assertion, the cut-off shall always be met also by mass and energy, in addition to environmental impact*
  - *the final achieved degree of completeness shall be reported. If the aimed at or necessary completeness cannot be achieved, it shall be decided whether the scope or even the goal needs to be revised or redefined.*
- ***Sensitivity check:*** *identify the sensitive among the significant issues and analyse the sensitivity of these for the overall results:*
  - *evaluate the sensitivity of the LCIA results to key flows, process parameter settings, etc.*
  - *improve robustness of sensitive data, parameter, assumptions*
  - *report final achievements.*
- ***Consistency check:*** *Especially for comparative studies, check whether differences in data quality are consistent with the goal and scope of the studies, check whether the impact assessment steps have been consistently applied and in line with goal and scope, evaluate the relevance of any inconsistencies identified for the results and document them.*
- ***Uncertainty check:*** *perform uncertainty calculation of data/parameters according to the available techniques- report final achievements.*

Provision 34 : Evaluation of results

Completeness check

The validity of results achieved depends, first of all, on the degree of completeness of the study. In the MCFC LCA study, all elementary flows of quantitative relevance to the overall environmental impact of the system as well as the relevant steps of the production and functioning of a MCFC system are included.

- The cut-off criteria adopted (2%) can be considered met and therefore the goal and scope of the present study are accomplished.
- Foreground data about the active components manufacturing processes, their assembly into a stack, the production of Balance of Plant and the assembly of the system itself, and finally its operation phase are based on data provided by producer companies.
- Background data are gathered from updated datasets recommended by the Joint Research Centre of the European Commission and commercially available.

Provision 34 : Evaluation of results

Completeness check

Data missing:

- Some data regarding the energy consumption in the assembly phase were not accounted for, due to a lack of primary data, and should be included in future studies in order to achieve a better level of completeness.
- The disposal phase was not evaluated, due to lack of enough and reliable research on FC decommissioning.

Provision 34 : Evaluation of results

Sensitivity check

Sensitivity check aims at determining the robustness of the results of a LCA study and allows to determine what level of accuracy is necessary for a flow to make the analysed system sufficiently useful and valid. Sensitivity analysis can also indicate which input/output values are reasonable to use in the analysis. Sensitivity analysis is helpful in making decisions or recommendations, since it provides information such as:

- how robust is the scenario proposed in the face of different values of process parameters;
- under what circumstances the scenario proposed would change;
- how the optimal scenario changes in different circumstances.

Provision 34 : Evaluation of results

Sensitivity check

	IMPACT CATEGORY	SENSITIVITY PARAMETER	CONTRIBUTION TO THE IMPACT
Cell	Acidification	Nickel	91.30%
		Secondary nickel	2.25%
Stack (125 KW_{el})	Global warming	Electricity, medium voltage, production IT*	29.50%
		Electricity, medium voltage, average production EU°	24.40%
System (500 KW_{el})	Ozone layer depletion	Palladium	30.10%
		Secondary palladium	2.01%
System + Naural Gas	Abiotic depletion	Natural gas (Industry Data, SimaPro)	94.10%
		Natural gas (Ecoinvent, average EU°)	99.70%

Provision 34 : Evaluation of results

Consistency check

Assumptions, methods and data were double-checked for consistency throughout both the LCI and LCIA study.

- ❑ Inventory data result to be consistent in terms of time-related, geographical and technological representativeness.
- ❑ Mass and energy flows have been double-checked in relation to the size and power of the system, with special attention to the consistency at the different scales (single cell, 125 kW stack, 500 kW module and operation over time).
- ❑ The data used in the different steps and scales are internally consistent.
- ❑ The impact assessment results are consistent and in line with the goal and scope initially defined.

Provision 34 : Evaluation of results

Uncertainty check

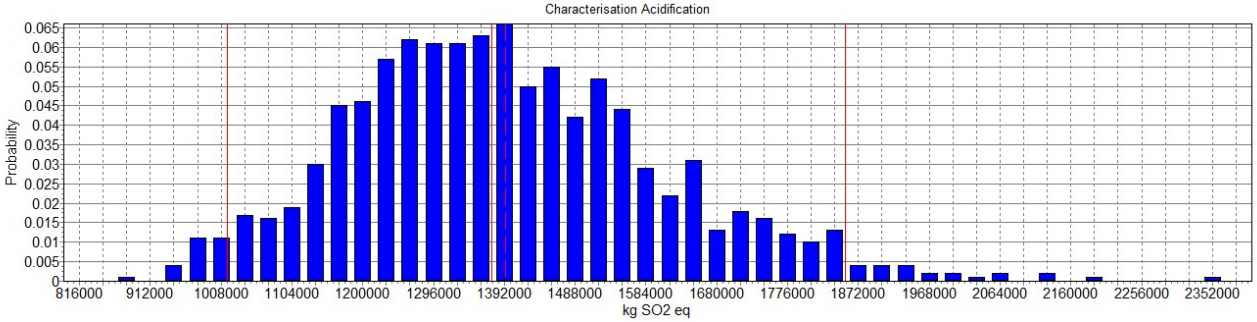
LCA data are always characterized by a given level of uncertainty that depends on source of data and processing steps. Uncertainty can refer to:

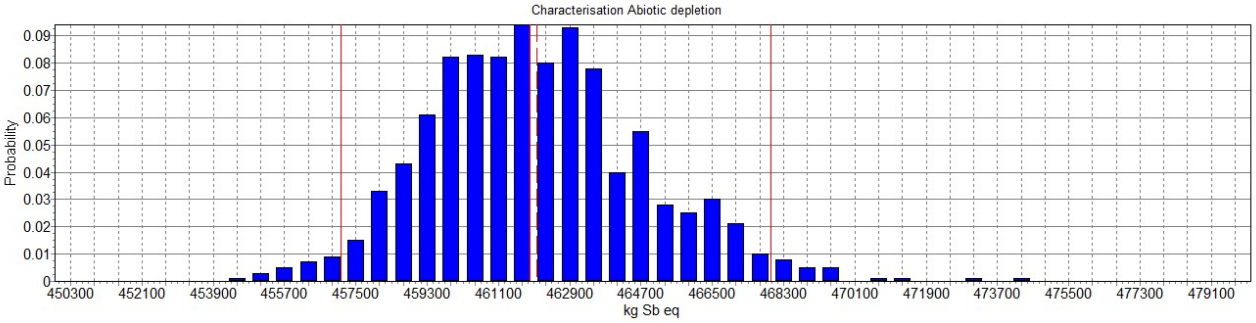
- ***Foreground data:*** primary data is related to the confidentiality of data provided by the producer, to the accuracy in data collection and processing or to the level of process optimization applied in the producer company.
- ***Background data:*** accuracy and updating of the database used and it cannot be easily checked by the analyst.

Provision 34 : Evaluation of results

Uncertainty check

In the MCFC study the main uncertainty and its consequences on results were addressed in our study through Monte Carlo analysis, within the SimaPro 7.3 software.
The Monte Carlo analysis was carried out with a confidence interval of 95% and a fixed number of runs (1000).





Results appear robust against uncertainty and possible errors. Finally, the assessment is multi-level and detailed enough to be able to provide an overview of the improvement potentialities based on technical and use recommendations.

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