

Eco-Space Project – Environmental Impact of new technologies

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ABSTRACT

In the current industry, environment begins to be a major criterion for development of new products. Success of a technology is due to its innovative and low cost assets but also due to its sustainability. Competitiveness involves industries to see beyond environmental regulations by integrating eco-efficiency of products and technologies as choice criteria for future development.

By dealing with high performances technologies, space sector do not escape of the need to develop products with a minimized environmental impact.

Started in 2013 the Eco-Space project, R&T Airbus DS project, has been initiated in order to face this challenge.

Main objectives of the project are to develop and enhance eco-design approach within new development and promote and give consistency to the "green" initiatives.

As sustainable technologies should be compliant with regulations, induce less environmental impacts and cost reductions, one key objective of Eco-Space project is to integrate Life Cycle Assessment methodology and contribute to reach the cost target.

Assessing the "green" aspect of a new technology entails the following question:
"Which criteria must be validated for a technology in order to be stated as a 'green technology'?"
"What should be set-up in order to ensure a consistent communication?"

By focusing on only few specific criteria (ex: avoiding REACH impacted substances or decreasing CO₂ emissions), too many technologies are claimed to be "green technologies" without matching with essential criteria.

For space sector, environmental criteria have to be settled in order to enhance sustainable technology developments.

In order to be exhaustive and avoid shifting of environmental impacts, Life Cycle Assessment has been chosen as a base for the methodology developed by Airbus DS.

The oral presentation purpose is to present the approach followed by Airbus DS Space Systems for the integration of environmental assessment in new technologies development

This methodology is being applied on some pilot cases covering various applications within space sector. Assessment results of one of these pilot cases will also be presented as an illustration during the presentation.

1 GENERAL INTRODUCTION

The protection of the human health and environment is demanded by citizens increasingly, driving public authorities and regulators to continuously endorse new regulations in that domain and amend existing ones periodically. The global environmental laws and regulations are subject to an almost exponential growth for the past and the upcoming years.

This puts the space sector under pressure due to risks of supply chain disruption linked to this new legislation, in addition to the increasingly environmental awareness of customers, client operators, employees and stakeholders.

Space sector rely on basic technologies which are sometimes not primarily driven by the needs of space but mostly by the evolution of terrestrial sectors. Today, more and more researches are ongoing on "green-technologies".

By focusing on only few specific criteria (ex: avoiding REACH impacted substance or decreasing CO₂ emissions) too many technologies are claimed to be "green technologies" without matching with essential criteria.

For space sector, environmental criteria have to be settled in order to enhance sustainable technology developments.

Within Airbus DS Space Systems, these drivers conduct to identify dedicated methodology in order to ensure that new "green" technologies reach environmental and costs targets for the company.

Therefore it is necessary to master and assess cost and environmental impacts of new technologies compared to conventional technologies devoted to the same applications. Similar existing approach such as European Union Initiative called ETV (Environmental Technology Verification), EPD (Environmental Product Declaration) have been implemented within different industry sector.

This paper will describe the Eco-Space project and the methodology proposed in order to assess the Space System R&T "green" technologies portfolio.

2 ECO-SPACE PROJECT

Eco-Space is an Airbus DS R&T project which contributes to the reduction of the Environmental impact of space programs, taking into consideration the overall life-cycle and the management of residual waste and pollution resulting from space activities, both in the Earth ecosphere and in space.

This project supports the development of "Green Technologies", increases the efficient use of resources, quantifies the environmental impacts and establishes the consistency between Design-to-Environment and Design-to-Cost approach.

Eco-Space R&T project seeks to expand Airbus DS Space Systems knowledge of its environmental impacts through the entire life cycle of space activities. This involves assessing the impacts of Airbus DS Space Systems products & technologies with a view to adopting an eco-friendly approach, as a way of

minimizing costs and environmental impacts in the future. Its promote life-cycle thinking and Life Cycle Assessment.

Life Cycle Assessment (LCA) methodology is a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental, health and resources depletion issues that are associated with Airbus DS goods and services.

LCA takes into account a product's full life cycle: from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste. LCA studies thereby help to avoid resolving one environmental problem while creating others.

Hence, LCA helps to prevent, for example causing waste-related issues while reducing resources consumption, increasing land use or acid rain while reducing resources consumption or increasing emissions in one country while reducing in another.

LCA is therefore a powerful decision support tool, contributing also to improve efficiency.

International Standard Organization 14040 & 14044 states the framework, the principles and the general requirements for LCA.

This multi-criteria approach is widely used in several sector, it is often time used for mass produced activities. Airbus DS consider that this methodology needs to be adapted to the space sector specificities. Space specificities are mainly low production rates with specialized materials, long and complex life cycle and unique impacts on the environment beyond the earth and the atmosphere.

The objective of Eco-Space project is also to implement and promote the eco-design approach in Airbus DS Space Systems projects in order to anticipate environmental regulations and mitigate supply-chain disruptions risks.

3 GREEN TECHNOLOGIES

3.1 Rise up of Green Technologies

A "Green Technologies" is an answer to the growing environmental awareness. These technologies are usually developed in order to mitigate supply-chain disruption due to the legislation.

Airbus DS is affected by a set of environmental laws and regulations in particular because of its complex product portfolio resulting from legal requirements and increased of customer requirements.

REACH is a European Commission Regulation concerning the Registration, Evaluation, Authorization and Restriction of Chemicals.

REACH regulates the use of Substances of Very High Concern (SVHC) within Europe targeting for a long term ban and forcing industry towards substitution with less hazardous substances.

Suppliers, subcontractors and Airbus DS are expected to be faced with a numerous obsolescence cases.

Most SVHCs will undergo the authorization process with the aim to assure that the risks from SVHCs are properly controlled and that they are progressively replaced by suitable alternative substances or technologies.

Following this approach, Airbus DS Space Systems Materials & Processes laboratories are working on new technologies such as new resin with less hazardous compounds, alternative surface treatments avoiding Chrome VI usage, alternative propellants avoiding hydrazine...

Reach is often seen as a constraint for industry but it occurs that threat could be turned into opportunity. Recent studies demonstrate that REACH is a factor of fostering innovation in Europe and obliges industry to find and qualify alternative solutions without hazardous substances.

More and more technologies are developed and claimed "Green Technologies" by focusing on only few specific criteria without matching with essential ones.

Within Eco-Space project, the objective is to consider a set of environmental aspects and to integrate different life cycle phases in the evaluation of such technologies.

In this way it appears to be very interesting to integrate a systematic Life Cycle approach within technology development in order to avoid burden shifting and communication only focused on hazardous substances replacement.

A new technology can have a limited impact on one category and a significant impact in another making it difficult to clearly state that a product is in absolute terms "better" than another one.

Therefore there is a clear need to evaluate globally these new technologies with a life cycle approach and a multi-criteria methodology.

Life Cycle Assessment (LCA) represents the most appropriate tool to compare environmental impact of different technologies if same perimeter and same environmental impacts are studied.

3.2 Evaluation of Green Technologies

In order to quantify and guarantee the level of technological maturity and readiness of technologies and support decision making on development priorities, US procurement agencies has defined the Technology Readiness Level methodology (TRL).

In 2005, NASA, ESA, CNES, DLR and JAXA decided to coordinate the definition and use of TRL.

In 2006, Airbus Group designed 9 levels of TRL scale for internal usage:

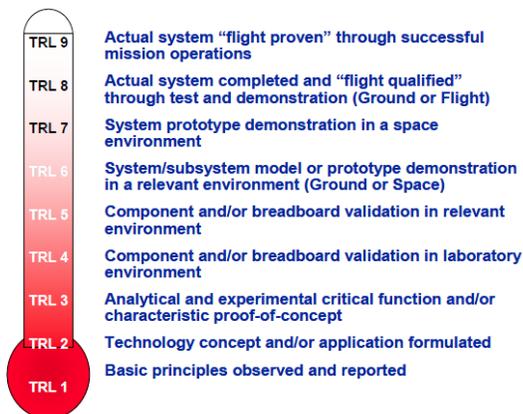


Figure 1: TRL scale within Airbus DS Space Systems

The proposition of Eco-Space project is to integrate environmental assessment at each TRL phases.

Usually a Life Cycle Assessment is performed at TRL6, 7, 8 or 9 when enough data are determined by the R&T Project team and a first demonstrator has been built. In this way data collection is easier to perform for raw materials phase, manufacturing phase and transports phase. For uses and maintenance phases, hypotheses are usually taken.

The approach proposed in this paper is a shared approach within "Design for Environment" working group at Airbus Group level; already implemented within Airbus Aircraft it shows a good feedback and arise interest of the different R&T project teams. Today Airbus Helicopters and Airbus DS Space Systems, through the Eco-Space project, are working on the implementation of such methodology.

The objective of this approach is first to integrate Life Cycle Assessment systematically in the technology development at high TRL. At low TRL the aim is to integrate a simplified environmental assessment based on environmental check and environmental regulations diagnosis.

By intervening at the earliest stage of the technology development it allows to have a better understanding and visibility of potential environmental impacts, whether positive or negative, and steer further developmental steps towards the most eco-efficient solution with a life cycle approach.

Five life cycle phases are usually considered:

- **Raw Materials:** extraction and production of primary materials involved
- **Transport:** distance from the processing of the raw material to the final product's distribution ; transport from manufacturing to launch site,
- **Manufacturing:** industrial processes and assemblies implemented during the manufacturing
- **Use (launch campaign, launch event, MQO):** use and maintenance steps
- **End of life:** dismantling, different scenario for the end of life of parts/assemblies, space debris

Environmental aspects for a life cycle approach are mainly:

- **Energy Consumption**
- **Material Consumption**
- **Material Hazardous Aspect**
- **Primary Material Risk**
- **Air Emissions : CO₂, SO_x, NO_x, VOC**
- **Waste Production Rate**
- **Waste Treatment / Recyclability**

The systematic integration of environmental aspects in the TRL Reviews permits to:

- Identify potential risks posed to the environment by the technologies or to the technologies development by environmental constraints,
- Promote ecological benefits of a technology by making them more visible and by providing a complete and objective view of technology's environmental aspects through its life cycle.

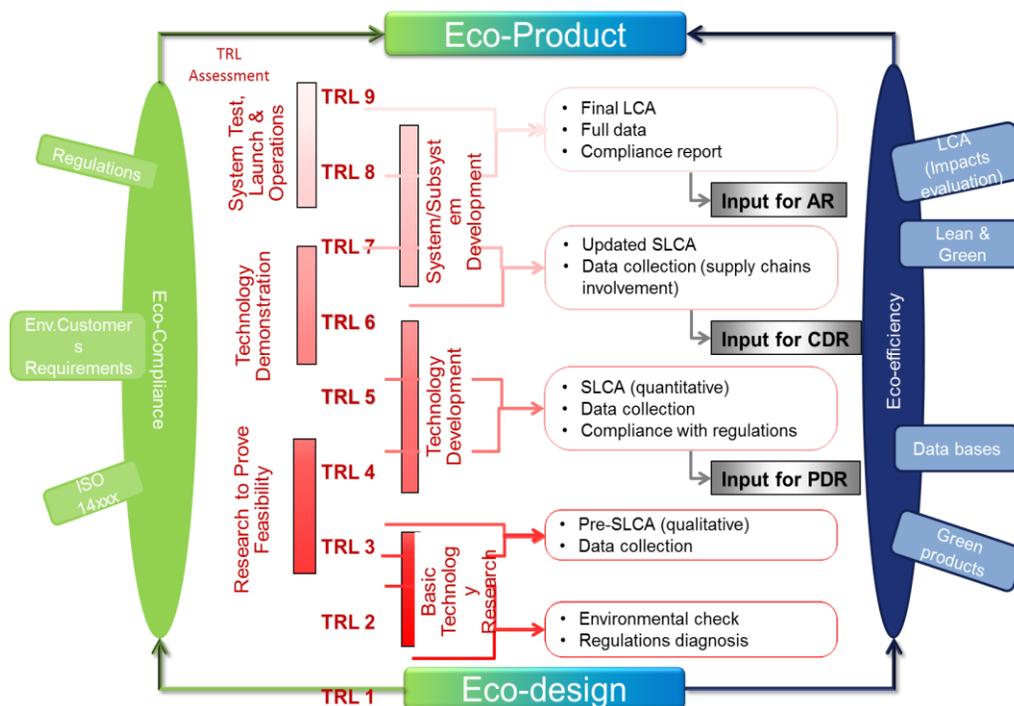


Figure 2: Environmental criteria integrated within TRL Scale - Eco-Space Project

❖ **TRL 1 / 2 : Environmental check , Regulations diagnosis**

At very low TRL very few information are available, general principles of the technology is known by the R&T Project team. Therefore the objective is only to identify potential significant environmental impacts.

Considering the whole life cycle and environmental aspects, this step enables to identify if technologies have positive or negative impacts on environment. For this step, a qualitative assessment is performed based on engineering view.

An analysis of the environmental regulations which could impact the technology is also performed at this step.

❖ **TRL 3/4 : Pre-SLCA (Simplified Life Cycle Assessment)**

This step pushes the assessment further into the details and awareness. The aim is to provide a preliminary qualitative assessment of environmental impacts for each selected option and a recommendation regarding the need to launch or not a Life Cycle Assessment for more detailed study.

The main factors leading to recommend a LCA study include:

- ⇒ High level of impacts (++) or (--)
- ⇒ Major conflict between parameters (for e.g. low VOC vs high energy consumption)
- ⇒ Big Data gaps / uncertainty
- ⇒ Major interest from the customers to establish detailed environmental footprint of their technology.

In this step, Airbus DS Space Systems proposes to use a dedicated matrix which enables to identify:

- Potential regulation compliance risks,
- Hot spots and improvements based on eco-design aspects.

For each phase-impact, a qualitative quotation is established (- - ; - ; 0 ; + ; ++). This allows a relatively quick assessment with the technical specialist.

Depending of the quotation, experts should define the LCA scope and reach a common agreement before launching the study.

❖ **TRL5/6 : Integration of Simplified LCA**

Based on the TRL4 agreement a Simplified LCA is launched with a very first loop of data collection.

Results aim to show more in details the potential environmental improvements that can be integrated in the technology development and the environmental benefits/opportunities. The Simplified LCA is a semi-quantitative study focusing on a minimum of two life cycle phases.

❖ **TRL 7/8/9 : Quantitative Simplified Life Cycle Assessment**

In this step there is a better knowledge of materials, industrial processes and logistics scenarios. An update of data collection could be performed in order to produce a first quantitative assessment of environmental impacts including more life cycle phases and more environmental aspects.

With this approach, Airbus DS Space Systems reaches its objectives:

- Contribute to continuous improvements of R&T developments,
- Provide objective view of environmental footprint of R&T technologies through environmental assessment,
- Bring knowledge and awareness of environmental aspects to the R&T community (anticipation of regulatory constraints; new requirements during the development, knowledge on high impact areas...)
- Contribute to steer R&T towards "green technologies"

It is important to notice that since the assessments are meant to compare technologies (either new technology with baseline or several options for a new technology), it is important to precisely define the baseline and/or the perimeter of the various options.

4 APPLICATIONS CASE: ALTERNATIVE PROPELLANTS

Major concerns of public authorities and customers came up from the propulsion environmental impact of launchers.

Areas where green technologies have been developed in the first place are the green propulsion with a key target today on the reduction of propellants toxicities.

A recent driver for green propulsion development is the inclusion of Hydrazine on REACH's list of substances of very high concern (SVHC).

Hence, the ESA CleanSpace program promotes the development of alternative “green” propellants.

Alternative propellants are used as pilot cases in the Eco-Space project. These propellants are well known for their low toxic properties compared to Hydrazine, but are there really “green” considering their environmental impact on a full life cycle?

The methodology explained above has been applied to compare new propellants intended to replace hydrazine liquid propellant for specific applications. Hydrogen Peroxide (H₂O₂) is one of these propellants.

The specific application covered in this study is the replacement of hydrazine for the Ariane 5 SCA (System Control Attitude) module.



Figure 3: Vehicle Equipment Bay containing System Control Attitude (SCA)

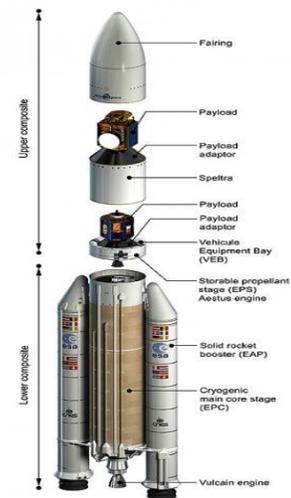


Figure 4: Ariane 5 with VEB (with SCA) emplacement

The LCA on H₂O₂ and Hydrazine is taking into account the overall life cycle of propellants, from the propellant synthesis until propellant released during use phase of SCA.

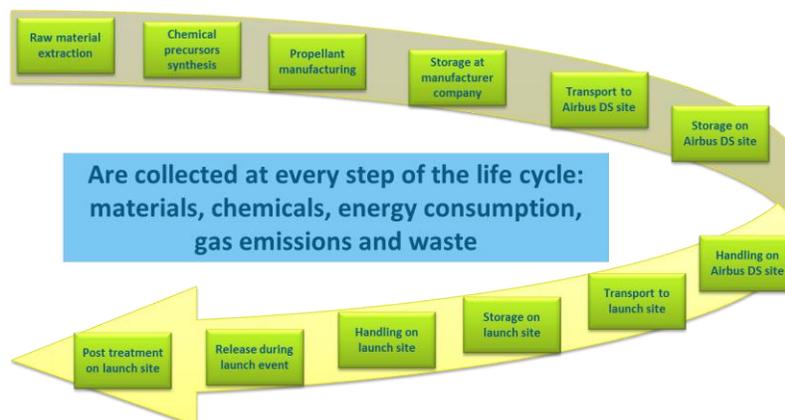


Figure 5: Life Cycle perimeter of the study H₂O₂ and Hydrazine for SCA application

A first assessment has been done without a detailed data collection. This assessment has been performed with R&T experts and is based on engineering vision (corresponding to TRL 3/4 methodology).

Matrix results are presented below:

| | Innovative Case | Reference Case |
|---------------------------------|--|--|
| | H ₂ O ₂ propellant for SCA application | Hydrazine propellant for SCA application |
| Synthesis Energy Consumption | + | - |
| Material Consumption | = | = |
| Material Hazardous Aspect | ++ | -- |
| Primary Material Risk | + | - |
| Air Emission | + | - |
| Waste Production Rate | ++ | -- |
| Waste Treatment / Recyclability | ++ | -- |

Table 1: Environmental Check of H₂O₂ and Hydrazine – SCA Application

At this step, it seems that Materials Hazardous aspects, Waste Production Rate, Waste Treatment and Recyclability appears as environmental benefice for H₂O₂ propellant. It comes from the fact that H₂O₂ is less toxic than hydrazine (benefice on hazardous aspect & waste treatment). Furthermore hydrazine wastes requires flushing with water and iso-propyl alcohol instead of only water for H₂O₂.

Considering studies at higher maturity level, a data collection of inputs and outputs interacting with the propellants has been performed at every steps of the life cycle.

Main attention is devoted to the materials and chemicals which are taking part of the propellant synthesis, to the energy consumption of every process or transport and to the global rate of waste.

All these inputs and outputs flows are then linked to environmental impacts using common LCA calculation methods and tools. To cover a large range of environmental concerns, the following environmental impacts indicators are taken into account:

- Climate Change
- Ozone Layer Depletion
- Terrestrial Acidification
- Human Toxicity
- Photochemical Oxidant Formation
- Terrestrial Ecotoxicity
- Freshwater Ecotoxicity
- Metal Depletion
- Fossil Resource Depletion

A very first environmental impact assessment of propellants has been done with some hypothesis.

Main hypothesis are presented below:

- Energy consumption of purification processes for Hydrazine & H₂O₂ (estimation)
- Complete decomposition reaction of propellant in the thruster reactor following these reactions have been considered for use phase :
 - o $2 \text{N}_2\text{H}_4 \rightarrow 2\text{NH}_3 + \text{N}_2 + \text{H}_2$
 - o $2 \text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2 \text{H}_2\text{O}$
- An estimation has been done for the energy consumption of air conditioning at Kourou site (based on the global consumption of the fueling hall building),
- Use phase has been evaluated through conventional LCA software. As these softwares are clearly based on a terrestrial impact modelization, research and deeper studies have to be performed in order to take into account the accurate environmental impacts of use phase within and beyond atmosphere.

Therefore precautions have to be taken with the results presented below.

The graphs and results should be considered as first trend of environmental impact assessment of hydrazine and H₂O₂ for SCA applications.

4.1 Comparison of Hydrazine and H₂O₂ over the entire life cycle for SCA application

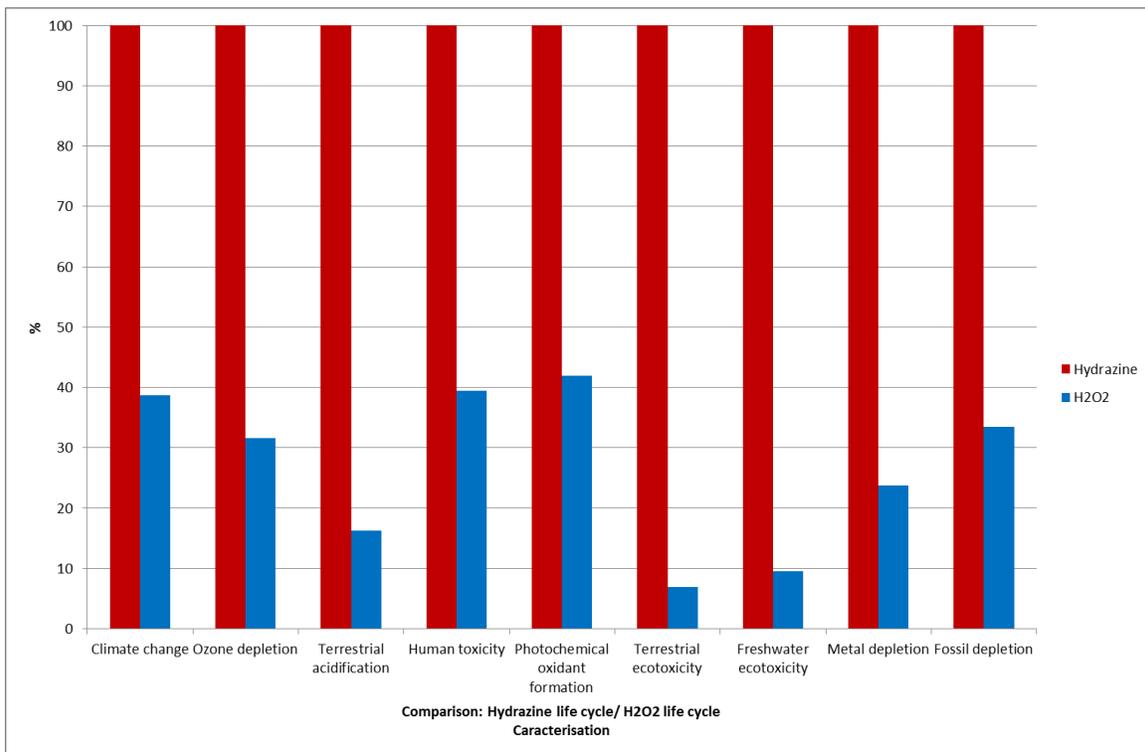


Figure 6: Comparison of Hydrazine life cycle phase & H₂O₂ – SCA Application

This diagram compare the full life cycle of Hydrazine and H₂O₂ for a SCA application. This life cycle start from the chemical precursor's synthesis until use phase of propellants within SCA, including post-treatment operations on launch site.

Considering that the functional unit is **the propellant needed for one SCA application during an A5 launch**, the quantity of Hydrazine and H₂O₂ needed are a little bit different.

Due to different density and Isp (Specific Impulse) for Hydrazine and H₂O₂, different quantities have been considered for each propellants.

H₂O₂ propellants are less impacting than Hydrazine propellants on every environmental impact criteria.

| Catégorie d'impact | Unité | Hydrazine | H2O2 |
|---------------------------------|--------------|-----------|---------|
| Climate change | kg CO2 eq | 11363 | 4401 |
| Ozone depletion | kg CFC-11 eq | 0,00138 | 0,00043 |
| Terrestrial acidification | kg SO2 eq | 188 | 31 |
| Human toxicity | kg 1,4-DB eq | 151505 | 59790 |
| Photochemical oxidant formation | kg NMVOC | 45 | 19 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 76 | 5 |
| Freshwater ecotoxicity | kg 1,4-DB eq | 425 | 40 |
| Metal depletion | kg Fe eq | 382 | 91 |
| Fossil depletion | kg oil eq | 4104 | 1372 |

Table 2: Quantitative results of propellants environmental impact

Climate change, human toxicity and photochemical oxidant formation seem to be the main environmental impact of H₂O₂ relatively to Hydrazine; this is mainly due to high energy consumption during synthesis phase.

4.2 Focus on Hydrazine propellant for SCA application

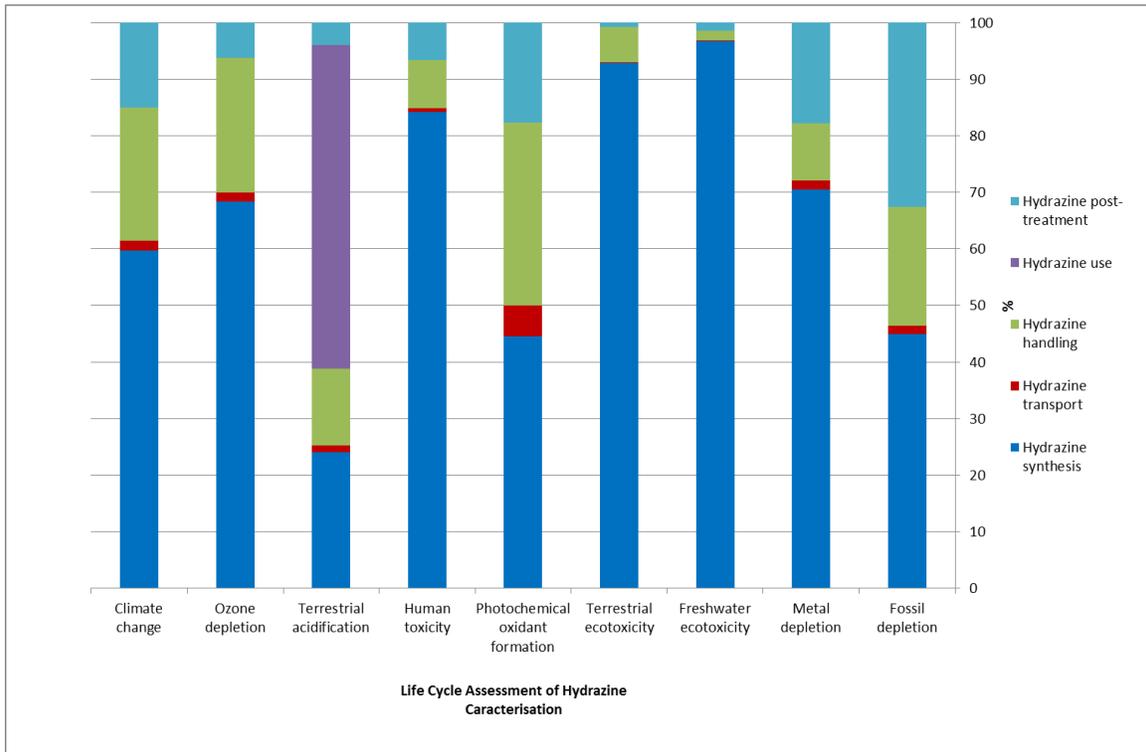


Figure 7: Hydrazine Life cycle phases – SCA Application

Synthesis phase based on Rashig process and handling phase are the most impacting phase on the environmental impact; this is mainly due to electricity consumption during these two phases.

Rq: Use phase has been calculated with LCA software considering that the emissions of SCA are taking place at low altitude. As we know, emissions release of SCA take place within the upstream phase of atmosphere and further; this can definitely alter interactions with the environment.

The main impacts of use phase are essentially on acidification indicators due to ammonia release during decomposition of Hydrazine within the thruster.

This figure depicts also that transport phase has a low environmental impact when considering the overall life cycle.

4.3 Focus on H₂O₂ propellant for SCA application

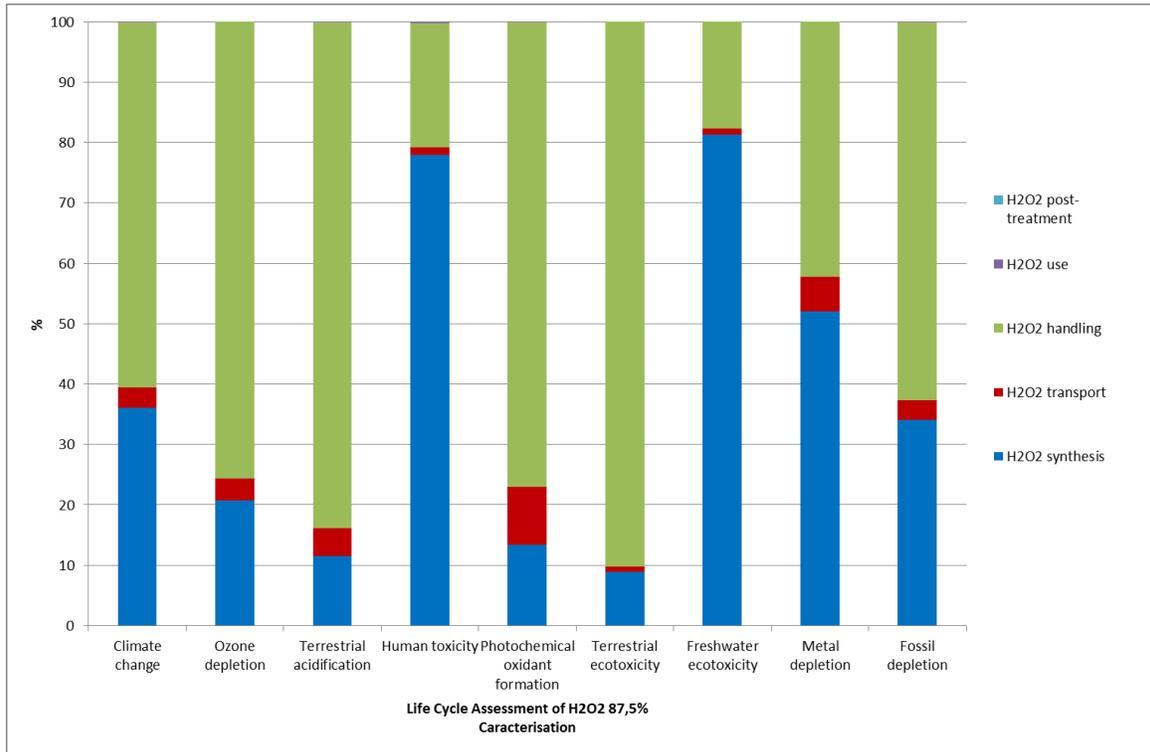


Figure 8: H₂O₂ Life cycle phases – SCA Application

Handling phase is the most impacting phase because of the significant amount of energy needed for the air conditioning of fueling hall on Kourou site.

Synthesis phase (based on Anthraquinone process) has a significant impact on metal and fossil depletion. For metal depletion it is mainly due to the construction of a dedicated chemical plant for the Anthraquinone process.

Fossil depletion environmental impact comes from the consumption of liquid hydrogen and steam during the synthesis process.

The use phase is negligible due to innocuous substances released during decomposition of H₂O₂.

This pilot study is on-going and further data collection should be performed in order to assess in a more accurate way the environmental impact of Hydrazine and alternative propellants.

5 CONCLUSIONS

Alternative propellants communication is oriented on non-toxicities properties. The first result of the study demonstrates that it is effectively the very first environmental benefice overall the life cycle for Hydrogen Peroxide propellant.

Behind this statement, it appears that human toxicity and freshwater eco-toxicity are the most environmental impact of H₂O₂ mainly due to high energy consumption during synthesis phase (Anthraquinone process).

For this pilot case, the results of the simplified LCA study confirm what was expected at the preliminary environmental diagnosis made at low TRL: hydrogen peroxide has a significant environmental benefice compared to Hydrazine on all environmental indicators.

Simplified LCA is being applied on other intended "green propellant" (ADN based propellant, HAN based propellant, etc.) in order to confirm their environmental benefice considering an entire life cycle.

In summary, different methodologies can be settled in order to assess the environmental impact of a new technology all along its maturity development.

At low TRL, first qualitative environmental consideration can give some trend of the potential impact. Then this environmental impact can be quantitatively estimate using simplified LCA when TRL is higher.

Within Airbus DS Space Systems, the Eco-Space project has been settled in order to

There is a will to have a harmonized vision on potential green technology for Airbus DS. These development are leading by environmental regulations but must be measured considering a wide range of environmental concerns, as preconized by LCA.

In this way, Airbus DS Space Systems is committed to the ESA Clean Space Initiative and contributes to the big challenge for space industry: keeping the competitive advantage for Europe and decreasing the environmental footprint on Earth and Space.

6 REFERENCES

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