Environmental Life Cycle Criteria for Propellant Selection Decision-Making

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ABSTRACT

A system of previously undefined environmental life cycle cost elements were developed for use in the propellant selection processes for spacecraft launch propulsion systems, with input from the National Aeronautics and Space Administration (NASA), the Swedish Space Corporation, and stakeholders in industry and academia. These environmental life cycle cost elements were incorporated into a life cycle cost analysis of toxic propellant (hydrazine) versus green (High Performance Green Propellant) through a modified cost benefit analysis. Environmental cost element line items within the life cycle were identified as costs or benefits (cost reductions or avoided costs). A case study was also implemented to further illustrate these findings, resulting in a real-world 66% reduction in Phase E (operational) mission cost for High Performance Green Propellant (HPGP) compared with hydrazine. Based on the analysis, the largest environmental cost drivers were facility operations and maintenance, end of life disposal, and transportation, with the major costs being associated with health and human safety protection.

Keywords: Decision Making, Environment, High Performance Propellant, Life Cycle, Propellant Selection

INTRODUCTION

In response to increasing global awareness and concern about environmental stewardship, researchers are exploring ways to minimize the use of hazardous materials in space and earth-based applications. Over the past 50 years, the U.S. and foreign launch systems in the public domain have used ammonium perchlorate (AP) and hydrazine as the preferred propellants for their solid and liquid propulsion systems.

These propellants have been known to provide outstanding performance and reliability. Unfortunately, this remarkable performance comes with a significant trade-off in risk and “hidden” costs as it relates to hazards to humans and the environment in the manufacturing, storage, transportation, operations, and disposal of these toxic materials. Many of these “hidden” costs stem from the strict regulations that govern safe handling of hazardous and carcinogenic materials. As the space community develops new technologies to meet the needs of the next generation of launch vehicles and spacecraft,
the international community and government entities are demanding that the environmental impact of industrial processes, including launch vehicle and spacecraft processes be included in the overall cost analyses.

This research defines a set of criteria for environmental components to be used to perform trade analysis for propellant selection decisions. Previous studies typically focused on economic, performance, and risk characteristics, and did not account for many of the “hidden” costs incurred. In order to make informed decisions about alternative options, costs incurred over the full life-cycle of the propellant must be addressed - from its manufacture, including the raw material acquisition, to its eventual disposal. This research discusses methodological issues related to how environmental costs should be considered in life cycle cost comparisons. Criteria were established by walking through on-site operations and procedures in facilities responsible for each phase of the life cycle. Based on the information gathered, a detailed compilation of the external environmental life cycle processes and related costs was established, including: manufacturing and storage; general safety considerations; site control and access; air monitoring; personal protective equipment (PPE); decontamination procedures; transportation by rail, sea, air, and public highway; operations and maintenance; and end of life disposal. The research conducted focuses on liquid propellants, assuming the use of Anhydrous Hydrazine monopropellant as a baseline, and provides no comparison consideration for Monomethyl Hydrazine (MMH) for bipropellant use.

Lending credence to the significance of the hidden costs, a case study approach was implemented as a way to examine these external environmental cost factors using real data. The case study for this effort was the PRISMA MISSION, which served as a test-bed for formation flying and rendezvous technology in space. This mission consists of two spacecraft, the larger of which contains both a hydrazine monopropellant system as a baseline, and an HPGP monopropellant system to demonstrate new technologies. Of the many results, most notable are that all operations associated with the HPGP system were declared non-hazardous and required a third of the amount of manpower needed for Hydrazine; and that the environmental cost factors analyzed revealed a reduction in cost by over \( \frac{2}{3} \) from the baseline. The resulting data indicate that the biggest environmental cost drivers over the life cycle of the propellant are facility operations and maintenance, end of life disposal, and transportation. The costs associated with health and human safety protection while operating with hazardous materials is a major cost driver for propellant selection and present significant direct, indirect, and capital costs over the life of the propellant. These costs must be included in future alternative propellant trade analyses.

This analysis resulted in environmental cost elements that should be included in future total life cycle cost analyses. These environmental cost elements should be identified for both the baseline option and the alternative option over the expected life of the propellant. When environmental costs are included in the analysis, one can potentially bridge the gap between traditional investment and return on investment models in a timeframe that can be acceptable to investment decision-makers. Once environmental costs are coupled with the economic and risk costs, one can more easily identify and address environmental constraints that prohibit growth and development, and spur innovation, allowing for the development of sustainable propulsion systems for the future.

**Industry Approaches**

While NASA’s internal trade analyses did not include environmental costs over the life cycle, an extensive search of the literature was conducted to survey other efforts to assess their treatment of environmental impacts over the life cycle. Several trade studies regarding propellant options for future architectures have been performed across NASA in recent history, including the Explorations System Architecture Study (ESAS), the Crew Exploration Vehicle...