# Gridded Ion Engine Standardised Electric Propulsion Platforms

**IEPC-2017-552**

*Presented at the 35th International Electric Propulsion Conference*
*Georgia Institute of Technology • Atlanta, Georgia • USA*
*October 8 – 12, 2017*

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**Abstract: Within the frame of the H2020 Research program - COMPET-3-2016-a SRC - In-Space Electrical Propulsion and Station Keeping, Incremental Line - Gridded Ion Engines of the European Union, a Research and Innovation contract No 730002 has been awarded to a consortium with ArianeGroup as Coordinator, and consisting of QinetiQ, Airbus Defence and Space, Crisa, OHB, AST Advanced Space Technologies, Mars Space and University of Southampton. The consortium will develop, build and test up to TRL5 the first European Plug and Play Gridded Ion Engine Standardised Electric Propulsion Platform (GIESEPP) to operate ArianeGroup and QinetiQ Space ion engines. These are the only European ion engines that are space-proven, and the consortium's intention is to improve European competitiveness and to maintain and secure the European non-dependence in this field. The project will design and develop a standardised electric propulsion platform for 200-700W and 5kW applications, which has the capability to run either ArianeGroup or QinetiQ thrusters. In addition, the 5kW electric propulsion system will be designed to allow clustering for 20kW electric propulsion systems for space transportation, exploration and interplanetary missions and commercial telecom. In order to cope with challenging mission scenarios, Dual Mode functionality (High Thrust / Lower Specific Impuls and Lower Thrust / High specific Impuls) of the thrusters will be realized.**

**This ensures that the beneficial high Isp characteristics of Gridded Ion Engines are maintained, whilst also offering a competitive higher thrust mode. The GIESEPP systems will not be limited to xenon as an operating medium; assessments will be performed to ensure functionality with alternative propellants. The approach to system standardization and the resulting solutions will provide highly cost competitive and innovative EPS for current and future satellite markets, whilst meeting the cost efficiency requirements. The project will result in a roadmap to higher TRL by 2023-2024, providing a cost competitive electric propulsion system that will meet the highest standards for an industrialized, rapid production process. The anticipated business case is targeted for long term exploitation up to 2030 strengthening Europe's technological and economical competiveness in a very fast changing market environment.**

## Nomenclature

| | |
|---|---|
| **AG** | ArianeGroup GmbH |
| **Airbus DS** | Airbus Defence and Space GmbH |
| **ARTEMIS** | Advanced Relay and TEchnology MISsion |
| **AST** | Advanced Space Technologies GmbH |
| **CDR** | Critical Design Review |
| **CR** | Concept Review |
| **DC** | Direct Current |
| **EC** | European Commission |
| **EM** | Engineering Model |
| **EOR** | Electric Orbit Raising |
| **EP** | Electric Propulsion |
| **EPIC** | Electric Propulsion Innovation and Competitiveness |
| **EPR** | Electronic Pressure Regulator |
| **EPS** | Electric Propulsion System |
| **ESA** | European Space Agency |
| **ESTEC** | European Space Technology Centre |
| **EU-FP7** | European Research Program |
| **EU-H2020** | European Research Program |
| **EURECA** | European Scientific Mission |
| **EVO** | Evolution |
| **EWSK** | East-West or Longitude Station Keeping |
| **FAKEL** | Russian electric propulsion system development company |
| **FCU** | Flow Control Unit |
| **FM** | Flight Model |
| **FPGA** | Field Programmable Gate Array |
| **GEO** | Geostationary Orbit |
| **GIE** | Gridded Ion Engines |
| **GIESEPP** | Gridded Ion Engines Standardised Electric Propulsion Platform |
| **GOCE** | Gravity and steady state Ocean Circculation Explorer |
| **GPS** | Global Positioning System |
| **GTO** | Geotransfer Orbit |
| **HEMP Thruster** | Hoch Effizienter Mehrstufen Plasma Thruster |
| **HET** | Hall Effect Thruster |
| **HV** | High Voltage |

| | |
|---|---|
| **HW/SW** | Hardware / Software |
| **I/F** | Interface |
| **ISP / Isp** | Specific Impulse |
| **KP** | Key Points |
| **LEO** | Low Earth Orbit |
| **LEOP** | Launch early Operation |
| **LISA** | European Scientific Mission |
| **MAIT** | Manufacturing, Assembly Integration and Test |
| **MEO** | Medium Earth Orbit |
| **MIL-STD** | US Military Standard |
| **MSC/MSL** | Mars Space Limited |
| **N/S** | North-South |
| **NASA** | US Space Agency |
| **NRC** | Non Recurring Costs |
| **NSSK** | North-South Station Keeping |
| **NTR** | Neutralizer |
| **OHB** | Orbitale Hochtechnologie Bremen SE |
| **P/T** | Power to Thrust ratio |
| **PDR** | Preliminary Design Review |
| **PHVC** | Positive High Voltage Converter |
| **PPU** | Power Processing Unit |
| **PRR** | Preliminary Requirements Review |
| **PSA** | Programme Support Activitiy |
| **PSCU** | Power Switching and Control Unit |
| **QiQ** | QinetiQ |
| **RF(G)** | Radio Frequency (Generator) |
| **RING CUSP** | Thruster from QinetiQ |
| **RIT** | Radiofrequency Ion Thruster |
| **RITA** | Radio Frequency Ion Thruster Assembly |
| **S/C** | Spacecraft |
| **SK** | Station Keeping |
| **SRC** | Strategic Research Cluster |
| **SRR** | System Requirements Review |
| **TBC** | To be confirmed |
| **TRB** | Test Review Board |
| **T-RC** | Ring Cusp Thruster from QinetiQ |
| **TRL** | Technical Readiness Level (1-9) |
| **TRR** | Test Readiness Review |
| **WBS** | Work Breakdown Structure |
| **XFC(U)** | Xenon Flow Control (Unit) |
| **XPMS** | Xenon Propellant Management System |

## I. Introduction

Electric Propulsion (EP) provides an order of magnitude improvement in fuel efficiency over chemical propulsion systems, enabling less launcher cost, longer operational life, or increased revenue for operators because of the increase in payload that EP facilitates. The US adopted EP for its commercial telecommunication satellites ("comsats") far earlier than in Europe: Boeing was the first commercial satellite manufacturer to use EP, and started flying Gridded Ion Engines in the late 1990s. Today, gridded ion engines from the USA, and Hall Effect Thrusters (HET) from both the USA and the EU, are being selected for geostationary telecommunication missions. The difference in engine type arises through performance requirements: typically HETs are used for higher thrust and therefore faster orbit repositioning, whereas gridded ion engines have twice the fuel efficiency as HETs and therefore yield far more significant savings in satellite mass and cost.

Gridded Ion Engines give satellite manufacturers a choice: the ability to lower their costs through lowering the mass of their satellites, rather than the HET's ability to earn revenue earlier through a faster time to reach station. Operators such as Eutelsat have stated their need for both types of system. A competitive European Gridded Ion Engine will give Europe the ability to compete in this growing worldwide market.

Europe has two manufacturers of Gridded Ion Engines, ArianeGroup in Germany who builds the Radiofrequency Ion Thrusters (RIT-series) and QinetiQ in the UK who builds the T-series Ion Thrusters. This European EP heritage is based in the domain of scientific endeavors such as GOCE and BepiColombo, and the demonstrator telecoms platform, ARTEMIS.

- The European telecoms demonstrator platform, ARTEMIS, was successfully rescued from a partial launcher failure through the use of ArianeGroup RIT10 Gridded Engine.
- ESA's GOCE mission could not have been performed without QinetiQ's T5 Gridded Engine.
- ESA's BepiColombo mission would have been severely constrained without a T6 Gridded Engine.

Market volume will grow from one-off sales to over one hundred systems per year across telecommunications, navigation and science satellites. Constellations such as One Web could lead to hundreds of additional EP sales worldwide. Emerging markets are also foreseen for growing areas such as debris removal, refueling and end-of-life disposal from small to large satellites. Europe's ability to compete in this market will depend in part in having a wide portfolio of EP solutions, of which Gridded Ion Engines are a key part.

Our consortium has developed the concept of a "standardized EP system" which will operate either an RIT-series or a T-series thruster. ArianeGroup and QinetiQ are collaborating by developing two EP system concepts, and designing and developing them through to TRL5. The first concept, GIESEPP1L will target the LEO market and new mega constellations, whilst the second concept, GIESEPP1G, will target the growing telecoms market. The EP system and thruster experience of both organizations are complementary and the collaborative program of work will share the mutual goal of an innovative, high performance and price-competitive EP system that extends EP systems beyond the state-of-the-art. This significantly reduces costs because it avoids duplication of system development costs for both gridded ion engines. It also means that there would be a larger number of common components produce for the worldwide market, leading to very competitive prices.

The project has started in January 2017, project duration is 48 months.

## II. H2020 Research Program

Horizon 2020[1] is the biggest European Union Research and Innovation program ever with nearly €80 billion of funding available over 7 years (2014 to 2020) – in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market.

Within the Space Program of H2020, many calls have been issued to support the development of ready to market solutions as well as basic research leading to innovative products.

The participation and the award of a Grant Agreement is taking place in highly competitive environment as the awards are linked to the best ideas with the most commercial and business impact potential.

The following statics underlines the excellence character of the research program:

| Year | Evaluated Proposals | Grants Awarded | Award Rate |
|---|---|---|---|
| 2014 | 209 | 39 | 19% |
| 2015 | 231 | 32 | 14% |
| 2016 | 160 | 30 | 19% |
| 2017 | 190 | Evaluation ongoing | Evaluations ongoing |

**Table 1: H2020 Space Statistics**

The challenge of the dedicated Electric Propulsion strategic research cluster (SRC) within the H2020 Space Program is to enable major advances in Electric Propulsion for in-space operations and transportation, in order to contribute to guarantee the leadership through competitiveness and non-dependence of European capabilities in electric propulsion at world level within the 2020-2030 timeframe, always in coherence with the existing and planned developments at national, commercial and ESA level.

The forwarded and expected impacts form the GIESEPP[2] project are:

- To develop, in the mid-term, the European capacity to compete in the worldwide arena of electric propulsion satellites.
- To substantially increase medium and long term competitiveness of existing EP system technologies with a technology/application-driven approach.
- To pursue developments which shall be mainly market-oriented, beneficial at system level and with a strategic view to long term needs.
- To enable medium and longer term applications: Telecom, Space Transportation, LEO, MEO, Exploration and Science.
- To anticipate ambitious long-term market evolution and strategic opportunities, so that the developed systems create new markets and shape existing ones.

## III. GIESEPP Objectives

The main objective of GIESEPP is to offer a standardized EP system in which the choice of the thrusters (RIT or T-series thruster) can be made by the customer. The system will consist of a propellant management unit, a power processing unit and a thruster. The overall system architecture is schematically shown in Figure 1 for both the T-series and RIT options.

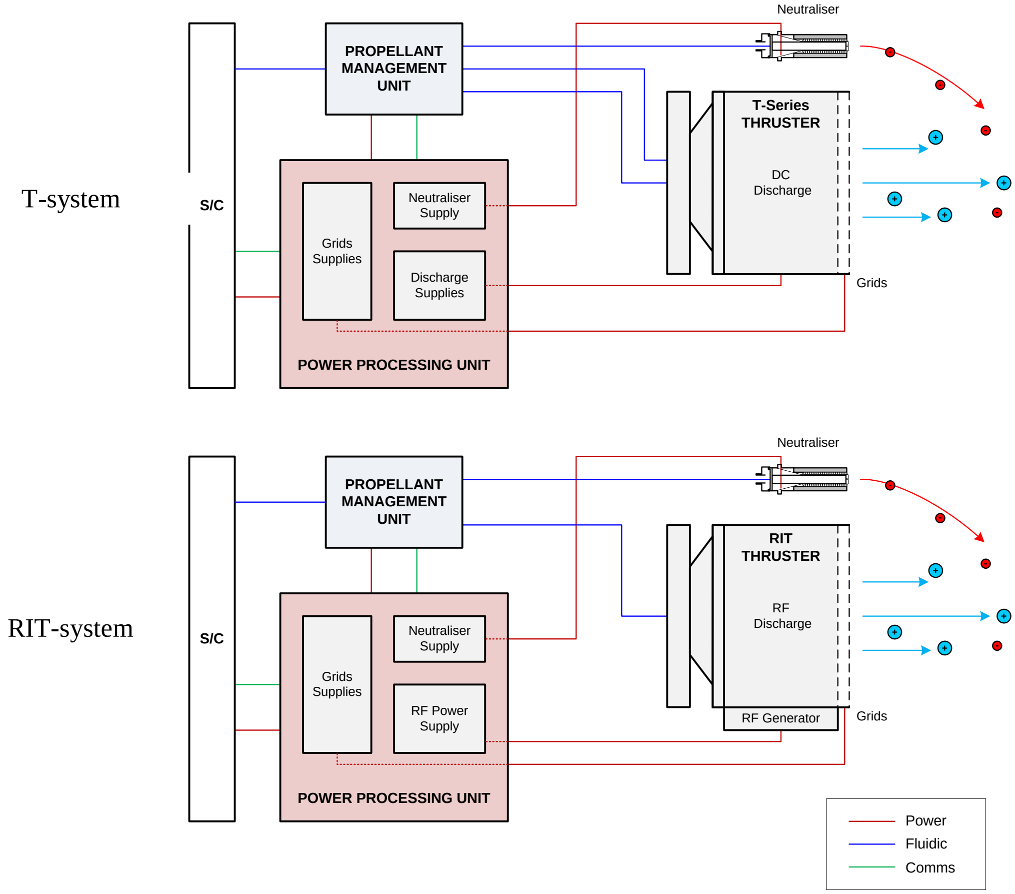



**Figure 1: GIESEPP Functional Schematic**

In particular the aims are to:

**On system Level**

- gain worldwide technology leadership in the fields of high Isp electric propulsion and Xenon fluid control systems and maintaining and securing European non-dependence

- Determine the performance requirements of LEO constellation and GEO telecom satellites.
- Define system operating points for LEO constellation and future telecoms satellites, including dual-mode performance for telecoms satellites.
- Define the Electric Propulsion System (EPS) architecture and specify the system components.
- Achieve a significant reduction of the EPS cost, targeting at least a 30% reduction of the current European products.
- Standardisation of testing sequences and methods for significant cost reduction for the recurring phase.

**On Subsystem Level**

- Incrementally develop the European RIT-series and T-series GIE thrusters to improve performance, share common interfaces wherever possible, and drive down thruster costs.
- Develop a PPU design that has the capability to drive either the T-series or the RIT-series thrusters, whilst driving down costs.
- Develop an XPMS (Propellant Control) design that reduces complexity, mass and cost.
- Define a stand-alone neutraliser capable of supporting either the T-series or RIT-series GIE.

**Towards Flight Opportunity**

- Perform system testing of the standardised systems to demonstrate performance to TRL5.
- Assess and select an alternative propellant, and perform confidence tests using this propellant with breadboard model RIT-series and T-series GIE.
- Demonstrate the readiness for next EPIC phase and develop a roadmap towards the main target to qualify the system for an In-Orbit Demonstrator or other flight opportunity.

**Address the Public**

- Dissemination and exploitation of the results.
- Promote convincing results of GIESEPP to decision makers at agencies and international customers

The following table summarizes the directing requirements of the project

| **GIESEPP General Guidelines** |
|---|
| to enable major advances in Electric Propulsion for in-space operations and transportation, in order to contribute to guarantee the leadership through competitiveness and non-dependence of European capabilities in electric propulsion at world level within the 2020-2030 timeframe |
| The developments shall include modelling/ simulation and standardised testing with reliable diagnostic tools of each equipment in the subsystem as well as of the EPS. |
| The activity shall go beyond the present state of the art and, preferably, the expected state of the art at the time of completion if alternative technologies are being developed outside Europe. |
| The project shall demonstrate the readiness and interest to carry the developments further on through future calls of this SRC, by including a long-term plan for the developments to reach the TRL targeted in the EPIC |
| **GIESEPP 1G (5kW), Telecommunication and Navigation** |
| Target TRL5 at the end of the project |
| Target TRL8 at the end of the SRC (2023/2024) |
| Dual mode. The EPS should be optimized to work in two different points for two different types of functions: EOR with high thrust to minimise the time to final orbit; and SK with high efficiency to minimize the propellant used in the in-orbit operations. In the case of GIE, it is expected that the effort for dual mode will mainly aim to improve the thrust level for EOR at an adequate *P/T* ratio. |
| EPS Power > 5 kW for EOR mode, > 3 kW for SK mode. The EPS should demonstrate power performances beyond the state of the art, justifying the specific power performance selected with an analysis of the medium to long term market needs. |
| P/T ~ 21.5 W/mN for EOR mode,~ 30 W/mN for SK mode. The time to orbit is a critical requirement from satellite operators and is fully dependent on the *P/T* ratio. |
| Isp, > 3000 s for EOR mode, > 4500 s for SK mode. The EPS efficiency in orbit operations is a critical requirement from satellite operators to optimize the mass of the propellant. The higher *Isp* the better, but this requirement is a trade-off of several performances |
| Innovative and cheaper PPU. The EPS should propose Innovative and cheaper PPUs (addressing complexity vs. cost), covering: industrialisation, simplification of the design, modularity and in-orbit reconfiguration. An asset |

| |
|---|
| would be a complementary study of alternative simplified PPU concepts for general orbit transfer application using direct input from spacecraft solar power systems. |
| **GIESEPP 1L 2L (200-700W), LEO** |
| Target TRL5 at the end of the COMPET-3-2016 project |
| Target TRL8 at the end of the SRC (2023/2024) if the project were to continue |
| Cycles, Due to the eclipses, a large number of cycles are needed for operation in LEO. Thus, the design shall take into account the impact that it has on performances and lifetime of the EPS. This number of cycles shall be compliant with the lifetime requirement of the platforms (currently around 5 years). |
| Power, 200-700W |
| P/T, ~ 25 (W/mN), Low *P/T* ratios are needed in order to obtain useful Thrust when little power is available. |
| Isp, 3500 (s). The EPS efficiency may be less important for the often mass-limited LEO missions than a high *Isp*. The higher the *Isp* the better, but this requirement is a trade-off of several performance parameters. |
| Innovative and cheaper PPU |
| EPS Cost, < 200 k€ (indicative) |
| **GIESEPP 1S (20kW), Space Transportation / Exploration / Interplanetary applications** |
| Target TRL5 at the end of the COMPET-3-2016 project |
| Target TRL5 at the end of the SRC (2023/2024) if the project were to continue |
| Lifetime (Total Impulse), The required large total impulse implies a very long period of thrust operation. Thus, the lifetime of the system must be analysed and improved where necessary, in order to ensure that the system can meet the mission needs. |
| Power, > 20 kW, The EPS should demonstrate power performances beyond the state of the art, justifying the specific power performance |
| P/T, < 35 W/mN |
| Isp >6000s |
| Innovative and cheaper PPU |

**Table 2: High Level GIESEPP Requirements**

Following these requirements and the anticipated concepts, the following benefits and impacts on the electric propulsion technology will be realized:

| State of the Art (Pre GIESEPP) | Beyond State of the Art (Post GIESEPP) |
|---|---|
| • 5k W EP systems for single GIE thruster types (T and RIT series)<br>• High PPU cost<br>• Isp either below 2000 or above 4000 s<br>• low TRL or Part obsolescence for low power GIE EP Systems<br>• single unit production capacity for low and high power EP system<br>• No high power commercial solution for 20kW segment<br>• Xe as standard propellant | • EP system for transfer missions at 30% reduced cost and complexity for European competitiveness operating with no changes as plug and play for both QinetiQ and ArianeGroup thrusters<br>• High performance thrusters operating in dual mode at a large range of specific impulses (2500 – 6000 s) to close the gap in performance range<br>• Low cost EP system for small satellite mega constellation<br>• Commercial high power systems<br>• high production capability for low cost EP<br>• Xe as standard propellant and additional alternative propellants |

**Table 3: State of the Art vs. Future**

| State of the Art (Pre GIESEPP) | Beyond State of the Art (Post GIESEPP) |
|---|---|
| • 5k W EP systems for single GIE thruster types (T and RIT series)<br>• High PPU cost<br>• Isp either below 2000 or above 4000 s<br>• low TRL or Part obsolescence for low power GIE EP Systems<br>• single unit production capacity for low and high power EP system<br>• No high power commercial solution for 20kW segment<br>• Xe as standard propellant | • EP system for transfer missions at 30% reduced cost and complexity for European competitiveness operating with no changes as plug and play for both QinetiQ and ArianeGroup thrusters<br>• High performance thrusters operating in dual mode at a large range of specific impulses (2500 – 6000 s) to close the gap in performance range<br>• Low cost EP system for small satellite mega constellation<br>• Commercial high power systems<br>• high production capability for low cost EP<br>• Xe as standard propellant and additional alternative propellants |

**Table 4: State of the Art vs. Future**

## IV. GIESEPP Concepts

The concept allows providing the first European Plug and Play Gridded Ion Engine Standardised Electric Propulsion Platform (GIESEPP) to operate with ArianeGroup and QinetiQ Space ion engines. The 500W application range will be covered by GIESEPP 1L and GIESEPP 2L satisfying current and expected demands for LEO satellites. GIESEPP 1G will cover 5kW application range for GEO telecom market.

In addition, the 5kW electric propulsion system will be designed to allow clustering towards GIESEPP 1S as a 20kW EPS for space transportation, exploration and interplanetary missions. GIESEPP 1S is also a smart modular and clustered solution for potential high power telecommunication platforms. In order to cope with challenging mission scenarios, Dual Mode functionality of the thrusters will be realized. This ensures that the beneficial high Isp characteristics of Gridded Ion Engines are maintained, whilst also offering a competitive higher thrust mode. In the following the anticipated GIESEPP concept and the involvement of the partners will be shown and discussed.

### A. GIESEPP 1L (500 W)

The GIESEPP1L system is targeted at LEO Constellations. The high Isp of GIE provides good mass savings, and builds on European heritage from the successful ESA GOCE and ARTEMIS missions. GIESEPP 1L will consist of:

- 1 x Thruster
- 1 x Power Processing Unit PPU 1L from CRISA
- 1 x Electronic Pressure Regulator EPR from AST
- 1 x Flow Control Unit FCU from AST
- 1 x set of Harness, Filters and Sensors

The system can be run with either the ArianeGroup RIT10EVO or QinetiQ's T5 thruster. For both thrusters, all internal and external, mechanical, fluidic and electrical interfaces, GIESEPP internal and to the satellite will be identical wherever possible. Both engines can take advantage of the same neutraliser cathode. The differences between the two engines are the need for a local Radiofrequency Generator (RFG) for the RIT10EVO, and additional power supplies for the T5 anode, solenoid and cathode functions.

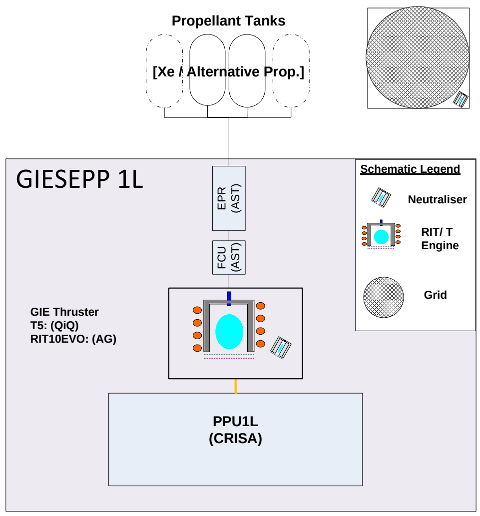



**Figure 2: High Level Depiction GIESEPP 1L**

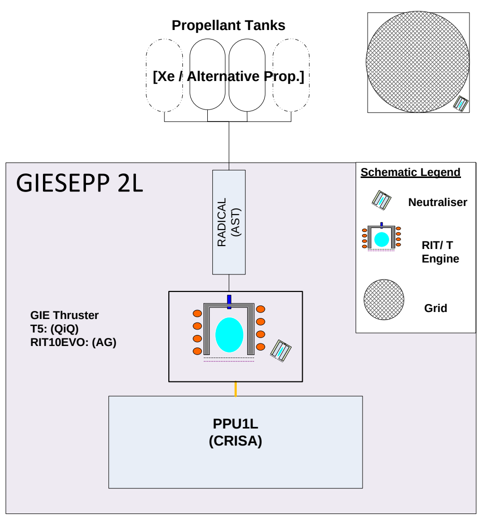



**Figure 3: High Level Depiction GIESEPP 2L**

The exchangeability of the thrusters through a common system definition offers good value for money, because the European Commission's investment supports both types of European GIE. The key goals of the GIESEPP1L development are to substantially drive down recurring costs (a target of €200k is assumed), whilst aiming for performance improvements to meet the demands identified by the mission requirements analysis performed earlier phase of the project. The target TRL at the end of 2020 is TRL5, achieved through testing of a complete system.

### B. GIESEPP 2L (500W)

GIESEPP2L is also targeted at LEO Constellations and is an incremental development of the XPMS (consisting of the FCU and EPR) used in GIESEPP1L. Other than the fluidic elements, GIESEPP 2L is identical to GIESEPP 1L. The EPR and FCU are replaced by RADICAL in order to further improve the system recurring costs.

GIESEPP 2L will be assessed and analyzed with respect to cost vs. performance aspects. This approach is taken to de-risk the development of the EP system and provide an incremental improvement which can be tested and compared with the results from the GIESEPP1L tests. The target TRL at the end of the phase 1 of this program is TRL5, achieved through testing of a complete system.

### C. GIESEPP 1G (5kW)

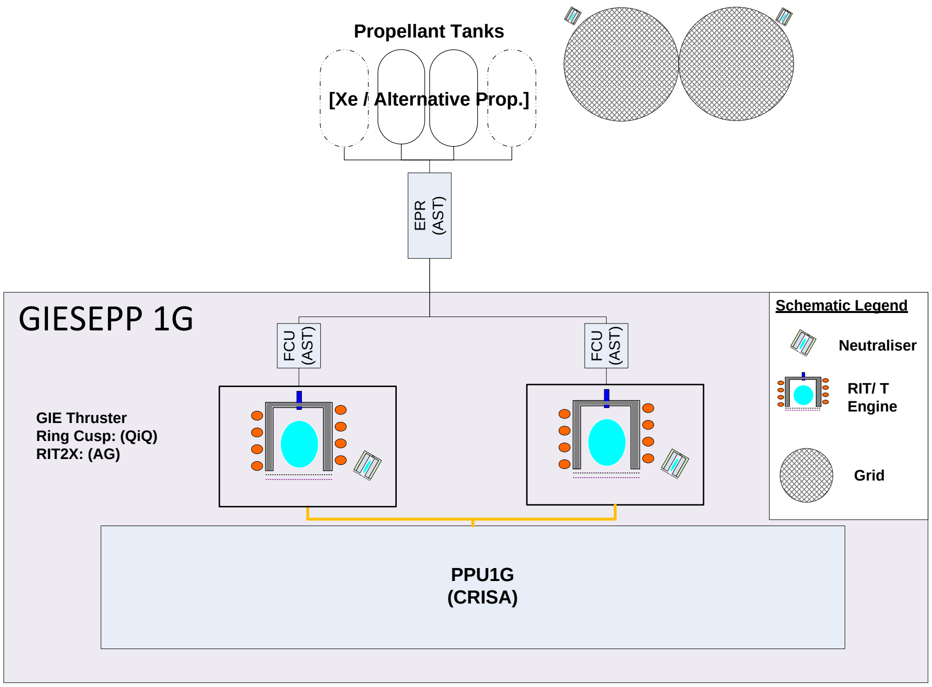



**Figure 4: High Level Depiction GIESEPP 1G**

The GIESEPP1G system is targeted at GEO Telecoms. The high Isp of GIE provides good mass savings, so it has the potential to lower launch costs, increase mission lifetime or improve payload mass. The GIESEPP1G builds on European heritage from previous European and national funding programs. It includes:

- 2 x Thrusters
- 1 x Power Processing Unit PPU 1G from CRISA
- 1 x Electronic Pressure Regulator EPR from AST
- 2 x Flow Control Units FCU from AST
- 1 x set of Harness, Filters and Sensors

The concept with two thrusters is necessary to satisfy potential lifetime and operational failure requirements achieving an operational safe and optimal 5kW system. The system can be run with either the ASL RIT2X of ArianeGroup or QinetiQ's Ring Cusp thruster, T-RC. Taking the same approach as for GIESEPP1L, both thrusters will share mechanical, fluidic and electrical interfaces wherever possible, meaning that interfaces to the satellite will be standardized. Both engines can take advantage of the same neutraliser cathode, and the differences between the two engines are the same as for the 1L system, i.e. that the RIT2X needs a local Radiofrequency Generator (RFG), and the T-RC an additional power supply for the anode and cathode functions, although in this case the T-RC does not require a variable magnetic circuit and therefore can eliminate a power supply.

The key goals of the GIESEPP1G development are to substantially drive down recurring costs (a target of 30% reduction over the current costs is assumed), whilst aiming for performance improvements to meet the demands identified by the mission requirements analysis performed early on the work program. The target TRL at the end of the phase 1 of this program is TRL5, achieved through testing of a complete system.

### D. GIESEPP 1S (20kW)

GIESEPP1S is targeted at larger platforms where more power is available, typically expected to be for exploration, space transportation and interplanetary applications. GIESEPP1S is a clustering of the 5kW system GIESEPP1G to achieve a 20kW system design. The intention is to use the GIESEPP1G design with no further modifications of the hardware. All EP system aspects covering GIESEPP1S will be implemented in GIESEPP1G and it consists of 4 x GIESEPP 1G, i.e.:

- 8 x Thrusters
- 4 x Power Processing Unit PPU 1G from CRISA
- 4 x Electronic Pressure Regulator EPR from AST
- 8 x Flow Control Units FCU from AST

- 1 x set of Harness, Filters and Sensors

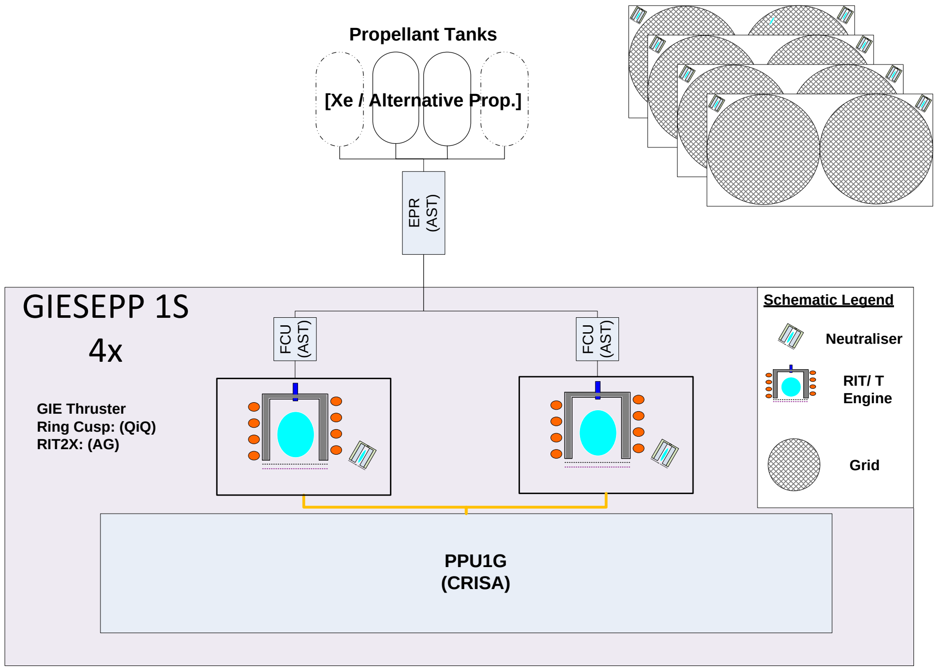



**Figure 5: High Level Depiction GIESEPP 1S**

## V. GIESEPP Application and Mission Scenarios

The following Figure 6 summarises all targeted missions scenarios. However, detailed requirement definition is ongoing. The segmentation has been performed with regard to the major mission requirements:

- Power
- Wet mass
- Life
- Transfer time (for orbit raising manoeuvres)

GIESEPP can be applied on all listed mission scenarios. At this stage, assessments considering EPS costs are ongoing. The results of such assessments will help to re-iterate the constraints and requirements to such missions.
The consortium had identified had identified typical design and accommodation concepts for each type of mission.

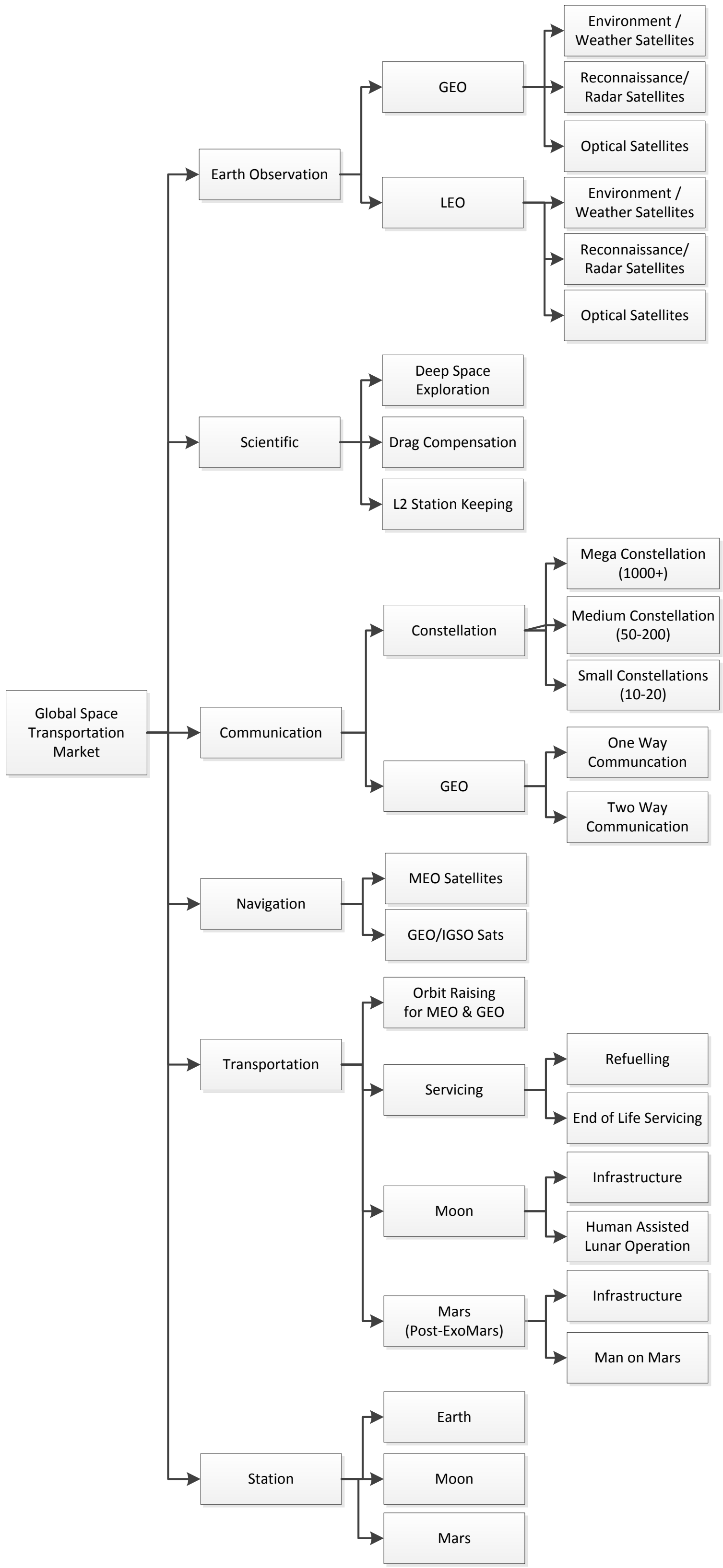



**Figure 6: Mission Scenarios for GIESEPP Systems**

## VI. GIESEPP Partner Involvement, Components and Inter-Disciplinary Considerations

The consortium is capable to contribute with all necessary development, manufacturing and testing capabilities for all necessary hardware and knowledge for developing, designing and qualifying the targeted electric propulsion systems.

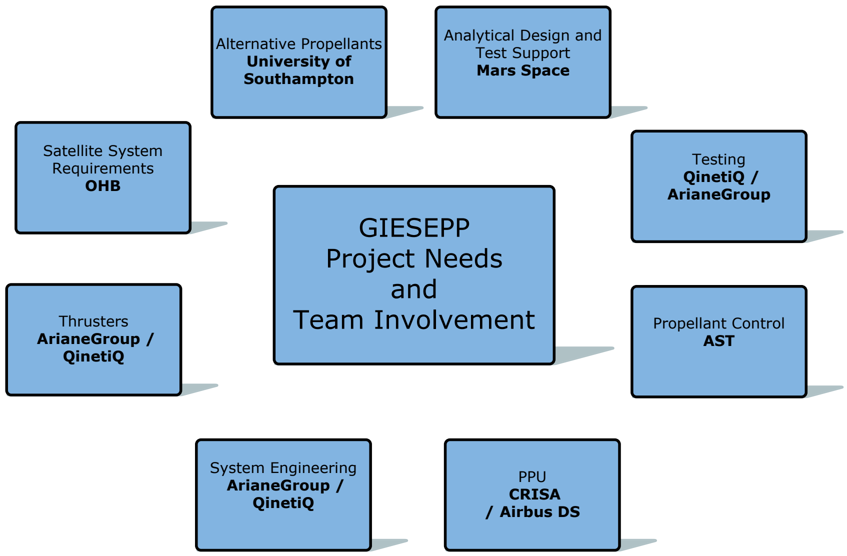



**Figure 7: Partner Involvement in GIESEPP**

### E. Satellite System Requirements

OHB is a well-recognized satellite prime with large experience covering the objectives of GIESEPP. OHB is providing requirements for electric propulsion system for candidate satellite platforms. They are used by the EP system to derive different system concepts with sizing and operational scenarios. OHB is also involved in Incremental Calls for HET and HEMPT - this ensures that the set of requirements will be consolidated with other technology lines according to the market needs and to avoid double efforts as requested.

### F. Thrusters

Thruster requirements for LEO and GEO missions are evaluated through a requirements review, followed by the introduction of relevant design changes. Since the thruster requirements are to be determined during the implementation of the program, the activities identified here are only an indication of what might be completed: the detail will be determined following this review.

The QiQ and AG engines could be made suitable for commercial applications. Reductions in thruster volume and mass may be required which may at least partly be achieved by reducing the performance requirements, compared to the new commercial driven requirements. Further gains could be made by adopting newer technology within the subsystems. Costs could be improved by introducing design changes to simplify manufacture, such as improving the electric power harness design.

Requirements may require an assessment of the grids, in particular to determine their life limit at the required thrust. This will be performed if possible by comparison with past information, but otherwise will be assessed mathematically using specialized software.

Design changes will be assessed through a Design Review, following which thrusters will be provided to Engineering Model (EM) level. A key aim of the standardized system is the use of a common neutralizer.

### G. Thruster - RIT2X

In order to suffice with call requirements and the expected future different customer demands, an electric propulsion design is required that allows for modification / customization for different application without invalidating earlier qualification heritage. The scalability of the Gridded Ion technology allows to slightly modify thrusters e.g. in dimensions in order to allow optimum operation in different set points.

For thrusters in the 5kW-power regime, the RIT 2X has been selected as the design that shall be made later on available for multiple missions and customers. Compared to the RIT22, the RIT 2X (diameter 20 to 29 cm) is improved in design mainly to ease manufacturing and test but also to further increase robustness.
The RIT 2X will have a bigger active grid-diameter and is up-scaled compared to the RIT22. The thruster interfaces which require adaptation to the GIESEPP specific needs will be redesigned.
The RIT2X Thruster is divided in the following subassemblies:

- Grid system
- Ionizer-RF-Coil subassembly
- Housing
- Interface flange
- Neutralizer
- Radiofrequency Generator
- Gas inlet
- Particle Filters

The grid system consists of a screen grid, which is made of Molybdenum and an acceleration grid which is made of graphite. The Ionizer is made of ceramic material and the RF-Coil is made of copper. The housing and interface flange are manufactured of titanium.

The targeted performance of the thruster can be summarized in the following table

| RIT 2X | | | | | RIT10EVO |
|---|---|---|---|---|---|
| Performance Parameter | | Operating Mode | | | Operating Mode |
| | | High Thrust | High Isp | SK | ~25 |
| Thrust | [mN] | >190 | tbc | >80 | 25 |
| Isp | [s] | >2500 | >6000 | >3400 | >3500 |
| Thruster Power | [W] | <4200 | tbc | <2200 | 200-700 |
| P/T | [W/mN] | ~21.5 | tbc | ~30 | ~25 |

**Table 5: Targeted performance parameters of RIT Thrusters**

### H. Thruster - RIT10EVO

The RIT 10EVO thruster is based on the long heritage of the RIT 10 thruster, which was successfully flown on EURECA and is still flying on ARTEMIS. Subsequently, during the RIT 22 development phase, design improvements were introduced and verified in test campaigns. These improvements are mainly to simplify manufacturing and assembly processes with regard to cost saving and reproducibility. These changes were also introduced in the RIT 10 design, therefore the name RIT10EVO. More precisely, these were the grids mounting and alignment, the tolerances for the ionization vessel manufacturing and the jigs for the RF coil mounting.

### I. Thrusters - RIT10EVO/RIT2X Radio Frequency Generator

The RF−Generator (RFG) produces RF energy that is induced by inductive coupling to the discharge vessel for ionization of the xenon propellant of the RIT-Thruster. The principle is, to couple the RF energy in an optimum way to the variable impedance of the plasma in the thruster's discharge vessel. Only for the condition that phase angle between RF-voltage and RF-current is forced to be equal to zero, the load impedance of the RFG is real and, as a result, the power transfer condition into the applied series resonance coupling circuit is optimum. The RFG is supplied by two DC voltage sources that are both generated by the RFG-PPU, an auxiliary supply and a variable primary supply for RF power control, from which the RF−Generator produces a phase controlled RF power, directly connected via an R/C/L series resonant network to the discharge vessel at the RIT−thruster. The RF energy is inductively coupled into the plasma via the RF-coil, which is attached to the outer diameter of the case of the discharge vessel. The RF generates xenon plasma inside the discharge vessel of the RIT. The RFG is supplied by two DC voltage sources that are both generated by the RFG-PPU, an auxiliary supply and a variable primary supply for RF power control. The efficiency of the RF-Generator is better than 92% for a load range of 80 to 100%, and better than 85% for a load range of 50 to 80% depending on the input voltage. On the basis of the well tested RFG-900, the RFG-1000 will undergo a design optimization activity that contains miniaturization, design simplifications and performance improvements (higher power throughput). The RFG-1000 will have a box size of 160 x 100 x 50 mm (L x W x H), and a mass in the order of 900g.

### J. Thrusters – Neutralizer

The GIESEPP designs will take into account a common neutralizer design for each application. This decision is made so that the common PPU is designed around one neutralizer design only, whichever engine is selected for future applications. This approach simplifies the system design, and lowers its cost.

QinetiQ has extensive experience in hollow cathodes. This expertise stems from four decades of development and testing of hollow cathodes for the T1, T2, T4, T5, UK-10, UK-25 and most recently the T6 gridded ion thrusters and a number of Hall Effect Thrusters. The 3mm cathodes were successfully flown on ESA's ARTEMIS and GOCE programs. The 7mm cathodes were scaled from the 3mm devices and configured for both gridded ion engines and HETs. The two applications of QinetiQ cathode share the same internal functional components but are packaged appropriately for the different mounting requirements.

For this Project, neutralizer requirements for LEO, Telecoms, Navigation and Scientific missions will be evaluated through a requirements review followed by the introduction of relevant design changes. Since the neutralizer requirements are to be determined during the implementation of the program, the activities identified here are only an indication of what might be completed: the detail will be determined following the requirements review.

### K. Thruster - T5

Two of QinetiQ's T5 gridded ion engines were flown on ESA's Gravity and steady state Ocean Circulation Explorer (GOCE), for which they provided the continuous, precision thrust capability needed to maintain a highly accurate orbit at extremely low altitudes. Intended for a nominal one year mission, the system operated flawlessly for four years. The GOCE system, and consequently the thrusters, was characterised by very demanding, complex performance parameters to deliver state-of the-art satellite orbit maintenance at a very low orbit of 240km. This leads to a more complex and un-optimised thruster cost. There are, however, several means to reduce the repeat build cost which is a key requirement for the LEO market. A key aim of the standardised system is the use of a common neutraliser. The 3mm neutraliser cathode is used to maintain spacecraft charge, and for T5 it is physically integrated into the engine. Removal of this neutraliser will lead to a simpler, cheaper product.

### L. Thruster - Ring Cusp

QinetiQ's existing T6 system is a Kaufman-thruster based system that is currently being qualified for BepiColombo, and which operates at a specific power of 33 W/mN. This is driven by the high Specific Impulse at which the system operates (4300s) and was originally designed for this performance because of the specific impulse requirements of BepiColombo. At that time, commercial Geostationary Earth Orbit (GEO) Telecoms applications were limited solely to NSSK operations, which do not require high thrust levels and hence are less influenced by the specific power. A ring-cusp discharge chamber configuration is more efficient than a Kaufman engine, operating at approximately 150W/A compared to 260W/A. This improved discharge chamber efficiency directly reduces the specific power achieved by the ring cusp ion engine compared to the Kaufman engine. Furthermore, the power dissipated within the discharge chamber is significantly reduced. This yields the significant benefit of being able to increase the discharge chamber plasma density, and hence extracted beam current and thrust, whilst respecting temperature limitations imposed by the cable harness. Another advantage of the ring-cusp design is that the entire discharge chamber, with the exception of the cathode tip and screen grid, are biased at anode potential. The energies of bombarding ions from the discharge plasma are therefore below the sputter threshold of conventional metallic materials, effectively eliminating erosion of the discharge chamber as a potential life-limiting factor. These advantages have prompted QinetiQ to evolve the T6 thruster with the adoption of a ring-cusp discharge chamber for future commercial applications. For this Project, thruster requirements for Telecoms/ Navigation and Exploration missions will be evaluated through a requirements review at QinetiQ, followed by the introduction of relevant design changes. Since the thruster requirements are to be determined during the implementation of the program, the activities identified here are only an indication of what might be completed: the detail will be determined following this review.

Design activities will be focussed around the implementation of a ring cusp discharge chamber and associated discharge cathode into a design similar to the T6 engine as used on BepiColombo. This will take into account modelling and predictions from the Mars Space Ltd activities within the program. Requirements are likely to require an assessment of the grids, in particular to determine their life limit at the required thrust. This will be performed if possible by comparison with past information, but otherwise will be assessed mathematically using specialised software. The 7mm neutraliser cathode is, like on T5, physically integrated into the engine. This item will therefore be removed from the design, leading to product simplification. Design changes will be assessed through a Design Review at QinetiQ, following which a T-RC will be manufactured to Engineering Model (EM) level.

**M. Dual Mode Functionality**

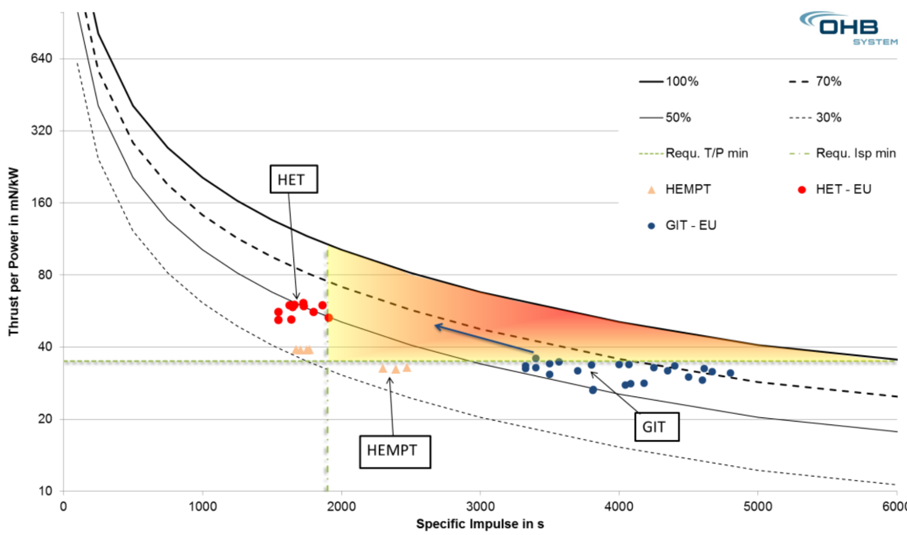



**Figure 8: Performance needs improvements by Dual Mode**

Gridded ion thrusters are known and accepted for their high specific impulse capabilities. Thrusters in the 200-700W class provide more than 3,000s of specific impulse and engines of the 5kW class have demonstrated more than 4,500s in dedicated endurance test. This ensures maximum propellant saving and makes them favourite for north south station keeping and space exploration missions with high delta-v demand. The higher the available power the higher the specific impulse (e.g. RIT-22 has demonstrated higher than 6,000 s) and the more advantageous on wet mass saving. The concept of operating geostationary satellites "all electric" introduces a new operational mode. For the orbit raising maneuver the maximum thrust in a given power limit becomes decisive. Thus, a dual mode is implemented on gridded ion engines allowing to operate either in high thrust domain (typically 150mN) to minimize time to final orbit or to operate in max. Isp generation domain as described before. A power to thrust ratio about 21.5W/mN is considered as optimum fulfilling both propellant saving and acceptable orbit transfer time. The physical nature of "specific impulse" is the exhaust *velocity* of the ions expelled from the thruster. Considering the kinetic energy of the ions is linking the specific impulse to the power to thrust ratio and shows that a PTTR of 21,5W/mN is related with a reduced specific impulse. Lower specific impulse means also that more ions have to be produced and expelled per time (unit) and this has consequences for the thruster design. The grid system has to be capable of accelerating high currents at lower voltage (typ. 4-5A@ 900V instead of ~ 2A @ 1800V for typ. high specific impulse thrusters) and the ionizer has to provide at least two times higher ion currents in the orbit raising mode. This is preferably related with a further improvement of the ionization efficiency. The optimization of the grid system for dual mode operation is similar for ArianeGroup and the QinetiQ thruster technology. It is basically focused on ion optics design, thermos-elastic analysis and adequate production technology. Precision of manufacturing and the full understanding of the thermal behaviour of the grids in all operational states are mandatory because lowering the specific impulse is related with reducing the grid to grid distance. The principle feasibility of dual mode grids has already been demonstrated by ArianeGroup and QinetiQ: In 2015 a RIT 2X Engineering model was operated at 900V/4A (21.5 W/mN; Isp 2400s). Also the first steps towards efficiency improved ionizers have been made by QinetiQ and ArianeGroup. QinetiQ have presented the concept of a cusp field ionizer and ArianeGroup have introduced a new ionizer vessel shape which was under test in the above mentioned demonstration test. Tasks for GIESEPP are the optimization of the new ionizer design in terms of length and finalization of the new shape. The design of the RF-coil provides leverage to a further improvement of the ionization efficiency.

### N. Power Processing Unit -GIESEPP 1G, GIESEPP 1L

PPU (Power Processing Unit) is in charge of conditioning the input power delivered by the platform towards the different parts of the thrusters, as well as, the control, management and reporting of the health status of the thruster to the platform. In order to cope with challenging requirements of the project, cost oriented design and Plug & Play philosophy the PPU is proposed to be modular. Modular approach can benefit from the heritage of past projects developed by Airbus DS, for example GOCE mission for ESA and from the on-going designs, for example T6 and RIT2X. This project is proposed to go further on this modular philosophy. Ongoing programs have a reduced modularity that shows that the concept could be extended for GIESEPP, for example, T6 PPU being delivered by Airbus DS Electronics has a modularity that provided the possibility of satisfying two programs with the same design just by re-arrangement on the number of modules. Two modules were proposed called DANS (Discharge-Anode-Neutraliser supplies) and BS (Beam Supply) modules, which depending on the architecture of the PPS could embark different configurations. For example, BEPI-COLOMBO mission embarks 2xDANS and 4BS, to achieve a complete failure free architecture. The modularity concept could be defined on different levels, from sub-system point of view, as it is shown on previous paragraphs of this document, with the definition of GIESEPP 1L, 1S and 1G, up to electronic functions levels. Concerning the PPU the first level of modularity concerns the following:

- Common Modules
- Specific Modules

ll the effort will be put on trying to define an architecture which will include as much common modules as possible in order to reduce the effort of customization for each customer. Specific modules would come from two different requirements, customization needed because of specific operation of the thruster or specific needs of the final customer. On the frame of GIESEPP all modules will be considered (common and specific) and if in the future a customer asks for a de-scope of the PPU to make it more specific it will be studied case by case considering that the modular approach will make this effort easier. The PPU parts that need to be assessed as part of the Common Modules are:

- Control Module: including auxiliary supply, FPGA*, input bus protections, communication data bus towards the platform, direct telemetries and statuses
- High Voltage Module
- Neutraliser electronics
- Power supplies towards XFCs
- Switching unit: including relays to select the operating thruster
- Acceleration Grid Power Supply

The PPU parts that need to be assessed as part of the Specific Modules are:

- RFG-PPU: power supplies towards the RF generator
- Anode power supply
- Ignitor / Strike power supply
- Magnet power supply

### O. Propellant Control - XPMS

Two propellant control baselines are proposed. One follows a classical design made of a dedicated pressure regulator. The pressure regulator reduces the tank pressure to a low pressure level. The low pressure node is the input of flow control units that supply the individual thruster modules. The subsystem of this classic design is referred to as Xenon Propellant Management System (XPMS). An alternative design named "RADICAL" combines pressure reduction and flow control in one unit. This design allows significant cost reduction but is limited by special system constraints. The proposed xenon propellant management system (XPMS) for a typical gridded ion thruster system is characterized as follow: the primary functions like pressure regulation, propellant filtering and flow control are divided in different devices to separate the high pressure node from the low pressure side. It is considered to be the best layout with respect to system mass and safety issues during integration but other solutions will be assessed. It also allows the configuration of the functional blocks with respect to mission driven requirements (e.g. redundancy). In the XPMS the Xenon from a single or multiple tanks enters the electronic pressure regulator assembly (EPR) on the high pressure node side. The tanks are not part of the proposal. All AST units have filters in inlet and outlet to ease handling and integration. These protective filters have only a small filter capacity and are not intended for cleaning of contaminated gas flows. It is planned to install a large capacity filter in each line. Depending on the subsystem level analysis of system requirements, the redundancy scheme will be defined. Each redundant branch uses its own electronic pressure regulator (EPR). For very demanding missions an interlink valve may be installed to switch between the EPRs. This crosslink can be done due to the triple serial redundancy for close inside the EPR. Even in the case of a "fail open" of the interlink valve, two further "fail open" inside any EPR can be tolerated by the system.

The operation of the EPR selects the related branch for thruster operation. A system of two thrusters (with one neutralizer each) per branch is assumed as baseline but also other configurations can be implemented. In this example each thruster/cathode combination is controlled by one µFCU device. The EPR and the FCU are controlled and driven by the thruster's PPU. The valve control is done by a pull-in/hold logic that reduces the power consumption. Only 24V pulse width modulated signals with pull-in levels of less than 100 mA (FCU) and 500 mA (EPR) are required. For different thruster classes the EPR part of the XPMS can remain unchanged. Only the FCU requires a modification. For an adaptation to different gas flows, the internal channels structure has to be modified to adjust the flow resistance according the required maximum flow. The number of outlet flow lines to the thrusters differs for the RIT and the QiQ thruster. This can either be covered by individual FCUs or by a fix flow split behind the FCU for the QiQ. The decision will be part of the detailed system analysis. A second method to adjust the flow range of a FCU is the modification of the inlet pressure. By using an electronic pressure regulator a system is capable to adjust this value in flight. For the proposed work this can be used for an optimization of different working points in dual mode operation strategies. For the GIESEPP 1L configuration two sub-configurations will be analysed. One is similar to the GIESEPP 1G configuration but the two FCU are located on two different redundancy branches. As alternative one EPR and one FCU form one branch, while the second EPR and the second FCU stay cold redundant.

### P. Electronic Pressure Regulator

The design baseline of the EPR has been developed under a FP7 funded project ("mPRS"). The ongoing three years project will end Dec. 2016 with the prequalification of the EPR. Currently the components have been developed and a first EPR EM has been manufactured. The EPR accepts a Xenon inlet pressure of up to 180 bar. The two stage device reduces the pressure internally to an intermediate pressure and then to the finally controlled outlet pressure. The outlet pressure can be chosen between 0.8 bar and 8 bar. The EPR is also able to drive small Xenon cold gas thrusters (not part of the project) as required for all-electric satellites.

### Q. Flow Control Unit

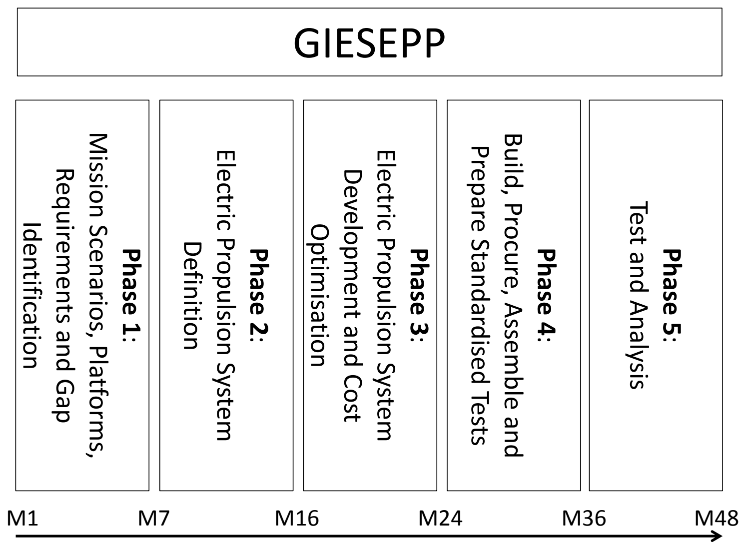
The design baseline of the µFCU has been developed and pre-qualified under a EU-FP7 funded project ("µFCU"). The flow control unit comprises an isolation valve in the inlet stream and one valve for each outlet. The outlet valves are chopped to generate a pulsed gas stream. An internal fluidic filter circuit damps out the pulses so that a constant gas stream leaves the unit. For easy handling the µFCU has 5µm particle filters integrated into inlet and outlet ports. The full scale flow range of the µFCU can be adjusted by design of the internal flow resistors. The operation between 0.1 mg/s full scale range and 5 mg/s has already been demonstrated. A 20 mg/s full scale FCU would be within design limits for nominal inlet pressure of 2 bars. Higher flows of e.g. 40 mg/s seem to be feasible at increased inlet pressure.

The µFCU has been developed and pre-qualified to a wide range of environmental conditions. "Pre-qualification" means that the unit went through the test campaigns typical for a formal qualification (functional, performance, leakage, vibration, pressure, thermal vacuum).
Coupling tests have already been performed with different sized gridded ion thrusters (RIT-22, RIT-µX) at University of Giessen and ESTEC to verify the operation on system level.

### R. Propellant Control - High Pressure Flow Control Unit (RADICAL)

The RADICAL concept uses the same base technologies and components like the EPR. Also the operational scheme shows some similarities but instead of three serial valves like in the EPR, the RADICAL uses only two valves that are pulse width modulated. The first valve expands the gas from inlet pressure to an intermediate pressure level. This level is below the critical pressure of Xenon. Due to the single stage and the transition from supercritical to subcritical phase, the intermediate pressure is only roughly controlled. The second valve is controlled within the closed loop control for the required anode flow. The neutralizer flow is proportional to the anode flow with a fixed flow ratio. A limitation of the RADICAL concept is the reduced throttle range as the pulse width controlled pressure reduction requires a flow restrictor that limits the dynamics of the system. The major advantage is the small number of components and a simplified production process. This allows significant cost advantages in series production. To our knowledge, RADICAL is the only system concept that has the potential to bring the unit price for large production batches in the ranges required for mega constellations.

## VII. GIESEPP Implementation




The GIESEPP project and its execution are divided in five phases.
Within phase 1 candidate platforms for

- LEO
- GEO and
- space transportation, exploration and interplanetary

missions have been defined and assessed toward implementation of the GIESEPP platform as driving design element for the candidate satellite platform. Preliminary requirements have been provided and assessed from EP subsystem and component point of view. The requirement breakdown on component level and the existing technical evaluation heritage will allow the identification of technical and performance gaps of all key EP elements (PPU, thrusters, and fluid management). In addition, first assessments regarding the functionality with alternative propellants have started on single component level and on GIESEPP systems level. System trade-offs have been performed ending by a preliminary GIESEPP definition for the complete EPS and the single components. This has phase has been successfully concluded in July 2017.
Phase 2 will be dedicated to the definition of the GIESEPP system coping with the requirements of the platforms prime. After the concept review of the EPS, design assessments on platform level will be performed in order to define design sensitivity parameters influencing both GIESEPP design on one hand and candidate platforms design on the other hand. The design sensitivity (technical and economical) parameters will lead to further refinement of the candidate platforms requirements toward the GIESEPP systems and in consequence to its components. Specifications of the components of GIESEPP will be defined and design and development plans will be set up.

After the SRR, final mission parameters will be defined taking into account the iterated GIESEPP systems. The phase will allow the identification of key cost driving requirements. Their re-assessment toward cost optimization will be analyzed in terms of performance and overall economic impact. Beside a maximum reduction of sat requirements, the second major cost optimization aspect will be dedicated a well-defined components and system design enabling a serial production of GIESEPP 1L, 2L and 1G. Therefore a result of this phase is to examine the

GIESEPP system and component designs with respect to high numbered units production involving to manufacturing technologies such as Additive Layer Manufacturing.
The cost optimized development plan will include a set of components bread boards and representative tests in preparation for a successful EM TRR scheduled after the hardware building phase.
In phase 4 engineering models for the targeted TRL qualification will be built and assembled.
After successful TRR, the testing and qualification phase will be performed.
The next main phase of the project can be summarized in the next figure and will be subject of next call in European Research Program.

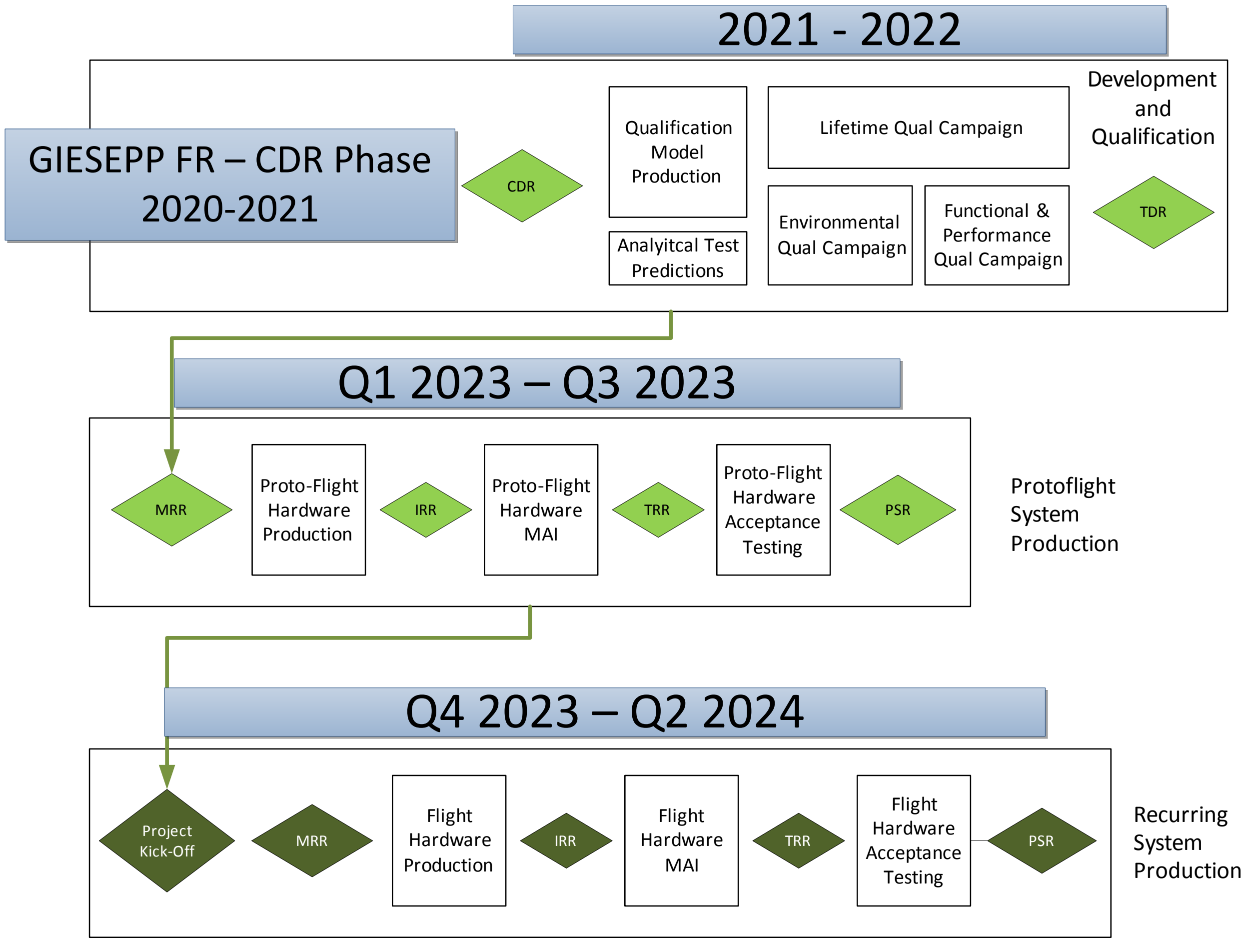



**Figure 9: Work Logic for 2020-2023/24 (Forecast Planning)**

## VIII. Conclusion

The GIESEPP Project has been presented highlighting the objectives and the commercial outcomes. The GIESEPP consortium consists of leading organizations in the satellite industry and research in Europe. Each partner has the requisite profile or expertise and lab or facilities to successfully achieve the project objectives. All partners have previous experience in co-operation, and have demonstrated their ability to carry out research and development of new technologies and overcome conflicts. This emphasizes the link of the state-of-the-art, development and the system approach to development of electric propulsion systems. This will be of strategic importance and enforce the expected impact.

The industrial participants are well-established and respected multi-national companies with large market shares in Europe, as well as other parts of the world. They have a world leading engineering knowledge and capability in the area of technology and product development as well as manufacturing. From a commercial perspective, the participating companies are key partners and suppliers in the European Space Program. The participation of scientists, from universities will also ensure that GIESEPP obtains access to innovative analytical knowledge in this field.

## Acknowledgments

Funded by the Horizon 2020 Framework Programme of the European Union

Special thanks to Florence Béroud from the Research Executive Agency (REA) of the European Commission and all members of the Programme Support Activity (PSA) EPIC[3] for the technical discussions and project guidance support.

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