Activities of the Strategic Research Cluster on Space Electric Propulsion (2015-2021)

ESTORIL, PORTUGAL | 09 – 13 MAY 2022

Natalia Franco Rodríguez (1)**, José González del Amo** (2)

(1) *Centre for the Development of Industrial Technology, Madrid, Spain, natalia.franco@cdti.es*
(2) *European Space Agency, Noordwijk, The Netherlands, jose.gonzalez@esa.int*

KEYWORDS: Strategic Research Cluster, Programme Support Activity, electric propulsion, incremental, disruptive, Horizon 2020, Horizon Europe, European Commission.

ABSTRACT:

The Strategic Research Cluster (SRC) on Space Electric Propulsion (EP) is the European Commission (EC) instrument into the European Union's Horizon 2020 (H2020) and the beginning Horizon Europe (HE) research and innovation programme. The SRC objective is to target mid- and long-term challenges in the space electric propulsion field, considered strategic for Europe. The SRC is implemented through a Programme Support Activity (PSA) coordinating individual and specific research and development Operational Grants (OGs). The OGs activities aim at producing a significant demonstration and achievements of a specific technology in line with a defined roadmap.

The Electric Propulsion SRC implementation and its roadmap are presented, and the PSA and Operational Grants activities are described. Finally, SRC next steps are detailed, and future challenges are outlined.

1. INTRODUCTION

With the SRC the EC introduced a new instrument into the European Union's Horizon 2020 research and innovation programme [1]. The idea of the SRCs is to enable the EC to target mid-term to long-term objectives in their research programmes. This will not be done by creating large projects with great funding and long runtimes but by combining the results of different smaller projects, called "operational grants", to achieve a common goal. The coordination and interaction of these OGs will be ensured by means of a PSA and a dedicated Collaboration Agreement. The SRC is a coordinated effort of individual research and development grants that aim at producing a significant demonstration of a specific technology.

This way of working has been continued during the beginning of Horizon Europe research and innovation programme [2].

2. ELECTRICAL PROPULSION STRATEGIC RESEARCH CLUSTER (SRC)

The SRC on "In-space Electrical Propulsion and station keeping" was part of the Horizon 2020 Space theme.

As a first step to build up the Electric Propulsion SRC, a call for proposals for the Programme Support Activity was issued in December 2013 as part of the first Space Work Programme in Horizon 2020 [3]. In summer 2014 the proposal was selected and since 1st October of the same year the PSA "EPIC" is operating. EPIC stands for Electric Propulsion Innovation & Competitiveness.

The next step for the SRC was the publishing of the call for proposals for the first Operational Grants on the Space Work Programme 2016-2017 [4] under topic COMPET-3-2016 and the selection of its proposals.

The following step for the SRC was the preparation and publishing of the call for proposals for the second phase of Operational Grants on the Space Work Programme 2018-2020 [5] under topics SPACE-13-TEC-2019 and SPACE-28-TEC-2020 and the subsequent future selection and implementation of its proposals.

In parallel, in November 2019 EPIC PSA was extended (EPIC2) until March 2023 to continue its work.

Finally, and within the Space Work Programme 2021-2022, the first one of HE, a new call for proposals, under topic HORIZON-CL4-2022-SPACE-01-12 [6], was published at the end of 2021. This call has been closed at mid-February 2022.

This article takes a closer look into the logic of the SRC on "In-space Electric Propulsion" calls, the EPIC PSA activities and the objectives and technical details of the on-going Operational Grants.

2.1. Electric propulsion, a strategic interest for Europe

Electric propulsion makes use of electrical power to accelerate a propellant by different possible electrical and/or magnetic means. Compared to chemical thrusters, electric propulsion requires considerably less mass to accelerate a spacecraft. The propellant is ejected up to twenty times faster than from a conventional chemical thruster and thus delivers an up to twenty times higher impulse per unit of propellant mass. Therefore, the overall system can be much more mass efficient, and satellites equipped with EP Systems may either carry more payload or be launched with a less powerful and less expensive launcher. The use of EP Systems for station keeping of geostationary communication satellites is well established and the use of EP Systems may enable new space applications and missions.

The different applications which currently make use of electric propulsion or may make use of it in the future are: LEO (for example, earth observation, earth science, constellations), MEO (navigation), GEO (telecommunications and earth observation), space transportation (launcher kick stages, space tugs), space science, interplanetary missions and space exploration. For these different types of missions and requirements, the technology is faced with operational challenges to be able to cope with different type of maneuvers, such as: continuous LEO operations (air-drag compensation), electric transfer from GTO to GEO, Station Keeping (SK), Electric Orbit Raising (EOR), interplanetary cruise, extreme fine and agile attitude control, long-endurance missions, etc.

Major mass savings can be achieved if EP Systems are used for orbit raising. Due to their lower thrust, the transfer time is longer compared to chemical propulsion (several months instead of some weeks). These applications span a very wide range of requirements. No single EP System may be optimum for all these applications. The "All-electric" satellites, which use electric propulsion for both orbit raising and station keeping, are not a new vision anymore and in the coming decades they may take an increasing share of the commercial communication satellite market. All-electric European satellites are Electra (by OHB Systems) and Neosat (by Airbus DS and THAS), and there are other hybrid satellites under development preparing Europe satellite manufacturers and satellite operators to play in the new Satellite electric propulsion arena.

High-thrust power units that could accomplish the orbit transfer electrically are in great demand. At the same time, also simple, reliable, and cost-efficient EP Systems for application in satellite constellations could suit the market.

At least four Low Earth Orbit (LEO) satellite constellations are today in development to provide faster communications to remote locations on land and at sea: Starlink, OneWeb, Kuiper and Lightspeed.

Space-X (US) has already launched over 1000 satellites, named Starlink, into LEO and aims to have more than 1500 satellites in orbit by mid-2022. Their goal is to have an operational constellation of around 12000 satellites at 350-550 km by 2026. These satellites, of about 300kg each, are built in house and use in-house built, low-power, krypton-fed, single Hall Thruster systems to adjust position on orbit, maintain altitude and deorbit.

OneWeb (UK) has already launched 110 satellites and aims to have the first 648 satellites operational by end of 2022. Their goal is to have a constellation of around 7000 satellites at 1200 km. Their satellites are built by external manufactures (Airbus) and use low-power, single Hall Thruster systems to raise the orbit, maintain the satellite on station and for de-orbit. Some of the components used in the Hall Thruster system are from European suppliers but the thrusters are non-European.

Amazon (US) is also planning its own LEO constellation under Project Kuiper. The initial constellation foreseen 3236 satellites orbiting at 350-650 km. These satellites also plan to use Hall Thruster systems to raise the orbit, maintain the satellite on station and for de-orbit.

In February 2021, Thales Alenia Space announced to have been selected by Canadian operator Telesat to build the broadband 298-satellites constellation named Lightspeed. These satellites, of about 700 kg each, operate in a combination of polar orbits (78 satellites, 6 planes, 1012 km of altitude) and inclined orbits (220 satellites, 20 planes, 1325 km of altitude) for complete global internet coverage and will use krypton-fed Electric Propulsion technologies for orbit raising, orbit maintenance and de-orbit. This constellation plans to be in service starting from 2023.

The British satellite operator Inmarsat is also planning to deploy 150-175 satellites in LEO to join the satellites in its GEO and HEO fleet from 2026 in a constellation called Orchestra.

European players are working on promising technologies, which could be transformed into marketable EP Systems to achieve commercial success.

In Europe, developments have been carried out in all the different areas of electric propulsion over the last four decades. Now the most promising technologies for Europe, from the mature type of thrusters, are based on the Hall Effect Thruster (HET), the Gridded Ion Engine (GIE) and the Highly Efficient Multistage Plasma Thruster (HEMPT). The European Commission acknowledged the relevance of EP technology and has an objective: “To contribute to guarantee the leadership of European capabilities in electric propulsion at world level within the 2020-2030 timeframe”. The SRC offers a unique opportunity to carry out coordinated research and development activities of high impact and consistency paving the way for this objective.

The SRC will be implemented through a system of grants that consists of a Programme Support Activity (PSA), and of the Operational Grants (OGs). The objective of this system of grants is that the expected results of each individual grant can be combined to achieve the overall objective of the SRC.

2.2. EPIC Programme Support Activity

Electric Propulsion Innovation and Competitiveness (EPIC) is the PSA of the EP Strategic Research Cluster H2020 [7]. The project is a grant (nº 640199) funded by the H2020 2014 Space Work Programme and extended by the HE 2019 Space Work Programme (nº 872002). The European Space Agency (ESA) is the project coordinator of the EPIC PSA, and the other partners in the consortium are several European National Agencies: ASI (Agenzia Spaziale Italiana), BELSPO (Belgian Science Policy Office), CDTI (Centro para el Desarrollo Tecnológico Industrial), CNES (Centre National D’Etudes Spatiales), DLR (Deutsches Zentrum für Luft- und Raumfahrt), UKSA (United Kingdom Space Agency); and two space industrial associations (EUROSPACE and SME4SPACE).

The main role of the PSA is to elaborate a roadmap and an implementation plan for the whole SRC, to provide advice to the EC for the description of the operational grants, as well as to assess the results of the OGs with respect to the SRC EPIC roadmap, in order to check if they are compatible and expected to achieve the SRC objectives. The roadmap describes a plan to increase European competitiveness in electric propulsion. The Operational Grants shall address different technological challenges identified in the roadmap.

The EPIC PSA main tasks are the following: evaluation on the state of the art and needs, definition of SRC roadmap and master plan, definition of the SRC Call topics and related documents, SRC risk management, definition of the collaboration aspects (CoA), assessment of the progress and results of the Operational Grants, dissemination, and education activities.

The EPIC PSA webpage is: http://epic-src.eu/.

Figure 1: EPIC logo

3. SRC EPIC ROADMAP

The SRC EPIC roadmap work logic is explained in the following paragraphs.

First, the state of the art in electric propulsion and related EP technologies were analyzed by the EPIC PSA. At the same time, requirements and needs from all stakeholders were identified. This was performed in the first EPIC Workshop in Brussels in November 2014.

The second step was the prioritization of the EP technologies. This exercise was again performed in contact with the interested stakeholders, in the frame of the second EPIC Workshop in Stockholm in February 2015. This work logic produced the integrated roadmap that describes the technology to be developed through the H2020 SRC.

Many EP technologies are available in Europe, and some are in advanced development stages or have already flight heritage, but others very promising ones are in early stages of its development. On the thruster side, three technologies targeting the commercial market are available with Technology Readiness Level (TRL) ranging from 7 to 9. Thruster technologies with lower and medium TRL or others targeting less developed applications or less market-oriented, such as space science, constellations, exploration and others, are being developed in Europe as well, many of them by universities or research institutes.

The EPIC PSA has taken a technology versus application-based approach in order to arrive at a prioritization of the thruster technologies to be further developed through the SRC. The most mature technologies targeting the commercial market, Hall Effect Thruster (HET), Gridded Ion Engine (GIE), and High Efficiency Multistage Plasma Thruster (HEMPT), are found to have individual profiles and offer slightly different responses to the different application requirements. For station keeping, the HET currently seem to be a bit at the low end of required specific impulse, nevertheless they are currently the most used EP Systems for this purpose. In the orbit raising case, GIE thrusters are now slightly below the range of desired thrust-to-power ratio, but the full EP satellites now operational are using GIE for orbit transfer. HEMP thrusters are deemed to perform between HET and GIE but have no flight heritage yet. So, all three mature technologies have the potential to serve the commercial market but need to develop individually in one or other direction for future success. For the SRC and the PSA, these three technologies are called the “Incremental Technologies”.

The SRC EPIC roadmap developed by the EPIC PSA during H2020 was built on the prioritization results and was structured along two lines, Incremental Technologies and Disruptive Technologies, comprising two successive phases: a first one starting with the 2016 Call, and a second one with 2019 Call for Disruptive Technologies, and with 2020 Call for Incremental Technologies.

The second roadmap, created for HE, includes a new line, the Generic line, focus on technologies and building blocks towards products. This roadmap comprises three phases, starting with the 2022 Call for Generic Line (closed the past February 16th).

The principal target of the SRC EPIC roadmaps is to increase the competitiveness of the EP Systems developed in Europe. The expected competitive position in the European and non-European markets takes into consideration: future missions, valorization of competencies/technologies already developed at European level in other national, European and/or international projects, performances gain achieved through disruptive technology advancement, potential spin-off initiatives for cross-related fields, integration capability within launch systems worldwide, etc.

3.1. Incremental Technologies line

The Incremental Technologies are the most mature technologies, i.e. the ones with high TRL and possibly with flight heritage, with the physical principal well understood, and with established performances in all of the relevant parameters: thrust (T), specific impulse (Isp), power/thrust ratio (P/T), total impulse, and lifetime: HET, GIE, and HEMPT.

In the SRC, the Incremental Technologies EP Systems aiming at enabling capabilities like operating at dual mode, higher/lower power, Electric Orbit Raising/Station Keeping, required by several applications and markets; and improve the current performances and reduce the cost of the EP Systems, in order to increase the competitiveness of the European systems. Their application domains targeted are telecom/MEO (including navigation), space transportation, LEO (including constellations) and exploration / Interplanetary / science.

3.2. Disruptive Technologies line

The Disruptive Technologies are very promising EP thruster concepts or transversal EP technologies which could disrupt the propulsion sector by providing a radical improvement in performance and/or cost reduction, leading to become the preferred technology for certain applications/markets; or enable new markets or applications not possible with the existing (Incremental) technologies. Their application domains are also telecom, space transportation, LEO (including constellations), MEO, exploration, interplanetary and science, but not limited to new applications and markets.

Promising EP thrusters are for example: Helicon Plasma Thrusters (HPT), Electron Cyclotron Resonance Thrusters (ECRT), Magneto Plasma Dynamic Thrusters (MPDT), Pulsed Plasma Thrusters (PPT), Field Emission Electric Propulsion thrusters (FEEP), micro-propulsion EP thrusters, electrospray thrusters and any other innovative electric thruster concepts; but not the ones derived from HET, GIE or HEMPT.

Transversal EP technologies are for example radical innovations in Power Processing Units (PPU), magnetic nozzles, alternative propellants, testing techniques, new materials, modelling and simulations codes, new PPU and electrical system architecture for EP, hybrid solution to drive different types of EP thrusters, or any other promising and potentially transversal disruptive concept. In the field of disruptive technologies new ideas are encouraged, as long as the proposals can demonstrate a disruptive potential of the technology in question or/and enable new applications or current applications with better performance parameters. Deep space missions or new satellite applications or constellations are some examples of niches for disruptive technologies. Some number of thruster technologies of presently low and medium TRL may strive to develop into this regime, or likewise towards other niche applications or new markets.

3.3. Generic Building Block Technologies line

At the beginning of HE and with the creation of the second SRC EPIC roadmap, a new technology line was opened to increase the effort for maturating Generic Building Block Technologies for:

- thruster components (anode configuration, magnetic optimization, cathode, materials, alternative propellants, new manufacturing processes, etc.)
- electric power architecture and products (PPU, direct drive, etc.)
- Fluidic management system and components.

The objective is to achieve higher TRLs in the development of this building Blocks and possibly with flight heritage.

This line allows to prepare the evolution of the 4 incremental power classes EP systems and most promising disruptive developments to anticipate and to adapt to future market and application needs.

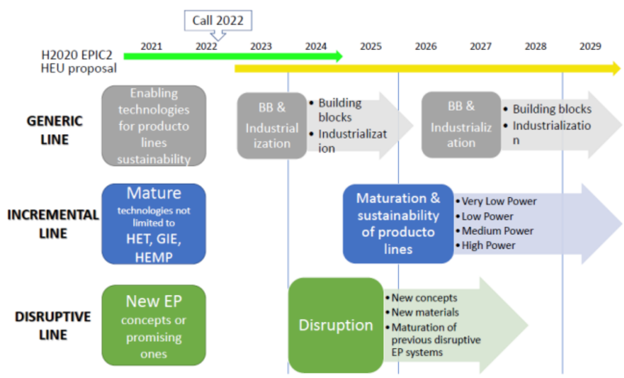

Figure 2: Roadmap diagram

4. GUIDELINES & REQUIREMENTS

The general SRC EPIC roadmaps are characterized by a technology/application approach whose layout presents two domains: the thruster domain and the application domain.

Some common aspects to all thruster-based systems are the following: alternative/non-conventional propellants, high power testing facilities and diagnostics, EP Systems testing methods and standardization of EP testing. Requirement's definition, mission and system impacts should be considered to better address the EP System developments for the targeted applications.

Each EP System, for the purpose of the roadmaps, shall include the development of the thruster with the following sub-elements: the thruster components, which includes the thruster itself (discharge chamber, anode, grids) and it(s) cathode(s) or neutraliser(s); the fluidic management system, including the valves, filters, pipes, pressure regulators, mass flow controllers; and last but not least the power components, which includes the PPU, thruster switching unit and other components such as electrical filters.

Specific guidelines and requirements are drafted by the EPIC PSA and published by the EC for the Call for Proposals as detail reference information in line with the SRC EPIC roadmaps.

4.1. Incremental Technologies guidelines and requirements

For all Incremental Technologies (HET/GIE/HEMPT) activities, the main action needed is to improve the current state of the art of the complete EP system (higher TRLs), improve the performances specified and reduce the cost of the EP System, in order to satisfy the medium and future needs of different markets.

The projects shall cover the development, validation (including testing) of the EP System following the relevant ECSS Standards, and testing shall be performed in a relevant environment.

The projects are meant to cover the following aspects of the EP Systems: thruster, cathode, PPU and fluidic management system.

Incremental Technologies requirements identify specific challenges for each application because each of the three EP System Incremental Technologies (HET/GIE/HEMPT) is based on different physics phenomena and different concept architecture. The performance requirements have been selected to request equivalent efforts beyond the actual state of the art for each technology. Therefore, all performance parameters targeted are technology specific and specifies for each application domain, including target TRL, dual mode voltage, EP System power for EOR and SK mode, P/T power to thrust ratio for EOR and SK mode, specific impulse (Isp) for EOR and SK mode, thrust resolution, lifetime (total impulse), live time cycles, innovative and cheaper PPU specifications, recurring EP System cost reduction targets. Specific details can be found in the EPIC webpage.

Proposals were presenting an adequate approach addressing the relevant applications to be covered in a balanced way including all aspects and equipment of the EP System (thruster, cathode, PPU and fluidic management system). Proposed developments also included modelling/simulation and testing of each equipment in the subsystem as well as of the EP System. Regarding the system impacts, thermal dissipation, plasma effects, electromagnetic interaction or any other effects were taken into account including considerations on integration of the EP System into the spacecraft. To reduce the cost of the full EP System for increasing competitiveness in the markets, proposals had to clarify the expected cost (indicative) reduction for the whole EP System and the specific subsystems together with a clear methodology.

4.2. Disruptive Technologies guidelines and requirements

The difference between Incremental and Disruptive Technologies is that the second ones has not define a specify market/application.

For all Disruptive Technologies activities, the main action need is to focus on promoting the Research, Technology and Development (RTD) of very promising and potentially disruptive concepts in the field of electric propulsion, in order to increase the currently low or medium TRL of potentially breakthrough concepts which in the long term could change the electric propulsion landscape.

Disruptive Technologies, foresees funding of a certain maximum number of proposals for disruptive EP thrusters and some of them will be devoted to transversal technology (to the EP System), like a radically innovative PPU which would enable a much more cost-efficient EP Systems, or any other idea or technology which could change the whole picture. The thruster technologies mentioned in the roadmap, which are under development in Europe, are meant to be known examples of what could be considered Disruptive Technologies.

Electric propulsion thrusters currently at low and medium TRL and not part of the Incremental Technologies, are the focus of this line. The expected concepts are such as: Helicon Plasma Thrusters (HPT), Electron Cyclotron Resonance Thrusters (ECRT), Magneto Plasma Dynamic Thrusters (MPDT), Pulsed Plasma Thrusters (PPT), Field Emission Electric Propulsion thrusters (FEEP), micro-propulsion and electrospray EP thrusters, and any other innovative electric thruster concepts; but not the ones derived from HET, GIE or HEMPT.

The activities proposed should include modelling, development and testing beyond the current state of the art in order to: understand fundamental physical processes and their impact on performance; improve current thruster performances (thrust, specific impulse, power/thrust ratio, magnetic thrust vectoring, throttability, efficiency, lifetime, noise, etc.); progress the development of associated cathodes/neutralizers, if applicable to a thruster; investigate alternative propellants to Xenon and/or non-conventional propellants; understood as gases constituting the atmosphere of a planet, such as oxygen, nitrogen and combinations in the case of the Earth, with consideration to potential applications; further analyses the impact of the thruster on the whole EP System.

It is important to acknowledge that there might be other elements in the EP System, aside from the thruster, with the ability to provoke a radical disruption. For example, new Power Processing Unit (PPU) concepts or architectures could substantially decrease the overall cost of the system. It is therefore also important and expected that proposals explore the potential for breakthrough innovation of Transversal Disruptive EP Technologies, such as: radical innovations in PPU; magnetic nozzles; alternative propellants; testing techniques; new materials; modelling and simulations codes; new PPU and electrical system architecture for EP; hybrid solution to drive different types of EP thrusters; or any other promising and potentially Transversal Disruptive Technology enable new performances, cost reduction and/or access to new applications or current applications with better performance parameters.

Other important areas as standardization and diagnostics, characterization of EP systems on orbit and next generation industrial manufacturing processes could be also part of this technological line.

Proposals shall go beyond the present state of the art, preferably the expected state of the art at the time of completion if alternative technologies are being developed outside Europe. Persistent monitoring of the state of art within the electric propulsion sector throughout the project will be important. Proposals shall also explain and be ready to demonstrate how the proposed concept meets the Disruptive definition proposed in the call topic and what is it the expected impact of the development in the electric propulsion landscape, including the timeframe. In addition, proposals shall include a validation and verification plan, including milestones and one or more validation and verification methods to apply through the course of the project, which would allow verifying how the development targets are being met and how the landscape disruption shall take place in the future.

4.3. Generic Building Block Technologies guidelines and requirements

This third technology line has been added to support and feed incremental product lines developments with innovation and disruption. Also, to cover other important areas which have not been considered in the first SRC EPIC roadmap as standardization and diagnostics, characterization of EP systems on orbit and next generation industrial manufacturing processes.

The proposals shall mature, for both incremental and disruptive technologies at mid TRLs: Generic Building Blocks technologies for thruster component (anode configuration, magnetic nozzle, cathode, materials); EP electric power architecture and products (PPU, direct drive); fluidic management systems and components. Furthermore, they shall address industrialization aspects for high TRL solutions (standardization, diagnostics, characterization in orbit, manufacturing process) and support adaptation/specific qualification to enable IOD/IOV opportunities.

5. ELECTRIC PROPULSION SRC 2016 CALL EVALUATION RESULTS

The proposals selected under COMPET-3-2016-a (Incremental Technologies) were the 3 proposals presented: CHEOPS, on HET; GIESEPP on GIE; and HEMPT-NG on HEMPT technologies.

The proposals selected under COMPET-3-2016-b (Disruptive Technologies) were 3 proposals from 18 presented: GaNOMIC on PPU innovative Disruptive Transversal Technologies; HiperLoc-EP, on Electrospray Colloid Electric Propulsion System (ECEP Systems) thrusters; and MINOTOR on Electron Cyclotron Resonance Accelerator (ECRA) thrusters; all three promising Disruptive Technologies.

A brief explanation and presentation of these SRC Operational Grants and their performed activities and results are presented in line with the provisions of the SRC Collaboration Agreement and its confidentiality provisions.

5.1. CHEOPS

CHEOPS stands for Consortium for Hall Effect in Orbit Propulsion System.

CHEOPS proposed to develop three different Hall Effect Thruster electric propulsion systems: a dual mode EP Systems for GEO applications; a low power for LEO application; and a >20 kW high thrust EP Systems for exploration applications.

The dual mode and low power targeted a System PDR review, covering the development of the following elements: thruster, cathode, PPU and FMS.

Through a detailed development plan the project has demonstrated its ability to achieve by the end of CHEOPS Phase II (2023) the following: a) TRL7-8 for dual mode and low power; b) high power HET EP Systems TRL6. Common transverse activities have included advanced numerical design tools for electric propulsion which will further understand the observable behavior and interactions with the satellite platform and predict performances of a given design. This includes alternative propellants and the ability to estimate the system lifetime. Finally significant progresses have been made in establishing a HET performances measurement standard and developing advanced non-intrusive tests for measuring thruster erosion.

The CHEOPS consortium was led by Safran Aircraft Engines and is comprised of representatives of the biggest European Prime satellite makers (Airbus Defense and Space, OHB System, Thales Alenia Space), the full EP Systems supply chain (Advanced Space Technologies, Bradford Engineering, Deutsches Zentrum fuer Luft – und Raumfahrt (DLR), SITAEL) and supported by academia and research centres (Centre National de la Recherche Scientifique, Chalmers Technology University, SME4SPACE, Universidad Carlos III de Madrid).

CHEOPS project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 730135. For further information visit the CHEOPS website (www.cheops-h2020.eu/).

CHEOPS project ended the 30th April 2021.

5.2. GIESEPP

GIESEPP stands for Gridded Ion Engine Standardised Electric Propulsion Platforms.

GIESEPP proposed an innovative activity to develop, build and test to TRL5 the first European Plug and Play Gridded Ion Engine Standardised Electric Propulsion Platform (GIESEPP) to operate Airbus Safran Launchers and QinetiQ Space ion engines. These are the only European ion engines in the 200-700W (LEO) and 5kW (GEO) domains that are space-proven, and the consortium's intention was to improve European competitiveness and to maintain and secure the European non-dependence in this field.

The project has designed and developed a standardised electric propulsion platform for 200-700W and 5kW applications, which has the capability to run either Airbus Safran Launchers or QinetiQ thrusters. In addition, the 5kW electric propulsion system was designed to allow clustering for 20kW EP Systems for space transportation, exploration and interplanetary missions. In order to cope with challenging mission scenarios, Dual Mode functionality of the thrusters will be realised. This ensured that the beneficial high Isp characteristics of Gridded Ion Engines were maintained, whilst was also offering a competitive higher thrust mode. The GIESEPP systems was not limited to xenon as an operating medium; assessments were performed to ensure functionality with alternative propellants.

The approach to system standardisation and the resulting solutions have provided highly cost competitive and innovative EP Systems for current and future satellite markets, whilst meeting the cost efficiency requirements.

The activity also provided the roadmap to higher TRL by 2023-2024, providing a cost competitive EP Systems. For further information visit the GIESEPP web (www.giesepp.com/).

GIESEPP project ended the 31st October 2021.

5.3. HEMPT-NG

HEMPT-NG stands for High Efficiency Multistage Plasma Thruster – Next Generation.

HEMPT-NG addressed "to increase the competitiveness of EP Systems developed in Europe" by developing an integrated solution based on HEMPT (Highly Efficient Multistage Plasma Thruster), the fluidic management system, and the power processing unit.

The objective of the project was to raise the performance of all components beyond current state-of-the-art. The final products were planned to consist of two EPS:

- One EPS for LEO applications with a power between 200 to 700 W and an Isp of 1600s (target TRL 5).
- One EPS optimised for Telecom/ Navigation (GEO) applications with a power from 3 to 5 kW and an ISP of up to 3000s (target TRL 5/6).
- Both thrusters were planned to be capable of dual-mode operations allowing orbit raising and station keeping with the same EPS.

The HEMPT technology offers unique innovative features compared to other EP technologies and makes HEMP a good candidate to being used for constellations.

The HEMPT-NG consortium was led by TES (Thales Electronic Systems GmbH), subsidiary of the Thales Group, responsible for thruster equipment and integrated EP Systems. European industrial partners were: Thales Alenia Space (FR, BE, DE), OHB System, Airbus Defence and Space and Aerospazio Tecnologie, who brought their expertise in spacecraft mission studies, equipment development and testing capacities. The University of Greifswald provided the plasma simulation to support the thrusters developed. These partners in five European member-states (Germany, France, UK, Belgium, Italy) developed an economical and well-performing HEMPT LEO and GEO EP Systems to guarantee European leadership and competitiveness, as well as the non-dependence of European capabilities in electric propulsion.

HEMPT-NG project ended the 31st July 2021.

5.4. GaNOMIC

GaNOMIC stands for GaN in One Module Integrated Converter for EP Systems.

The consortium planned to develop a highly integrated PPU to globally reduce the cost of EP systems.

The project proposed to focus on a disruptive 5.5 kW power converter beyond the state of the art combining innovative technologies such as GaN switches, digital control, adaptive filtering, and embedded packaging.

Significant improvements were expected in terms of cost, mass and volume targeting part list reduction (by 2), converter efficiency (97.5%) and optimized thermal characteristics (200°C), translating into system optimization and increased power requirements.

GaNOMIC potentially constitutes a solid technical basis for future Direct Drive configurations, and further down the line, to "distributed" configurations where the PPU can be eliminated altogether.

In addition to promoting and accelerating the development of breakthrough EP-related concepts, the consortium members have identified other markets, e.g. aeronautics and automotive, which could benefit from these innovating high performance power converter.

For further information visit the GaNOMIC project web: (www.ganomic.eu/).

GaNOMIC project ended the 30th September 2021.

5.5. HiperLoc-EP

HiperLoc-EP stands for High-Performance Low-Cost Electric Propulsion for small satellites.

The HiperLoc-EP project aimed to use a novel approach to develop an Electrospray Colloid Electric Propulsion System (ECEP System). The project has developed a disruptive electric propulsion technology that provides a high-performance EP System at a cost that is at least one order of magnitude lower than its competitors at the beginning of the project, with the capability of enhance the functionality, performance and the value of many micro/nanosatellite missions.

The objectives included identifying the performance requirements, enhancing the TRL for an ECEP System, and understanding key processes in order to determine the optimal way to operate an ECEP System. Also included in this project were the design, manufacture and test of an ECEP System breadboard.

The 4 consortium participants all have specific expertise in miniaturized and/or electric propulsion technologies for spacecraft:

- QMUL (United Kingdom) provides the leading understanding and expertise in Europe of electrospray processes and systems, having pioneered this research for the past 16 years.
- SystematIC (Netherlands) is an IC design house with focus on analog and mixed signal integrated circuit. Has delivered power supply and control circuitry to the Delphi C3 nanosatellite.
- The team also includes Airbus DS (United Kingdom) – one of Europe's leading satellite prime contractors and a recognized expert within the field of electric propulsion and as a user of such systems.
- NanoSpace AB (Sweden), has expertise in miniaturized propulsion systems and was among the first to fly a propulsion system onboard a CubeSat in 2015.

HiperLoc-EP project ended the 30th June 2019.

5.6. MINOTOR

MINOTOR stands for MagnetIc NOzzle thruster with elecTron cyclOtron Resonance.

MINOTOR's strategic objective was to demonstrate the feasibility of the ECRA technology as a disruptive game-changer in electric propulsion.

Based on electron cyclotron resonance as the sole ionization and acceleration process, ECRA is a cathodeless thruster with magnetic nozzle, allowing thrust vectoring. It has a significant advantage in terms of global system cost and reliability compared to mature technologies. It is also scalable and can potentially be considered for all electric propulsion applications, from microsatellites to space tugs.

Although the first results obtained with ECRA were encouraging, the complexity of the physics at play were an obstacle for the understanding and development of the technology. Thus, in-depth numerical and experimental investigations took place in MINOTOR.

The main objective of the project was to bring the ECRA technology from TRL3 to TRL4/5, in order to demonstrate its potential in a large range of thrust levels.

The consortium was composed of academic experts to perform the research activities on ECRA, along with experienced industrial partners to quantify its disruptive advantages on the propulsion subsystem and its market positioning.

- ONERA (France, Coordinator) oversaw most experimental investigations of the thruster configuration.
- University Carlos III de Madrid (Spain) developed the codes and implement the numerical modeling of the thruster.
- Thales Microelectronics (France) demonstrated a high efficiency microwave generator technology.

- Universitaet Giessen (Germany) conducted the higher power tests (1 kW) and the erosion test on the 200 W prototype.
- Thales Alenia Space Belgium SA (Belgium) investigated the impact of the ECRA technology on the PPU architecture and cost.
- Safran Aircraft Engines (France) provided expertise in electric propulsion thruster production and performance.
- L-up (France) helped on the project management.

MINOTOR project ended the 31st July 2019.

For further information visit the MINOTOR website (www.minotor-project.eu/).

6. ELECTRIC PROPULSION SRC 2019 – DISRUPTIVE LINE.

The evaluation process of the H2020 EP Strategic Research Cluster (SRC) 2019 Call finalized by July 2019. The selected proposals kicked off their Operational Grants and started their developments and activities by the end of 2019-beginning of 2020.

A brief explanation and presentation of these ongoing SRC Operational Grants and their projects, objectives, ongoing activities and expected results are presented in line with the provisions of the SRC Collaboration Agreement and its confidentiality provisions.

6.1. AETHER

AETHER stands for Air-breathing Electric Thruster.

The main objective of AETHER project is to develop a new concept of electric propulsion system, namely an airbreathing engine, based on some preliminary activities carried out by the prime Sitael under and ESA project.

The AETHER project will advance the thruster design towards a flight representative stage, experimentally demonstrating sufficient and reliable net thrust production for the target applications. This will be achieved through the design optimization of the various thruster components, careful selection of materials and proper diagnostics tools, based on system-level design considerations.

Successful completion of the AETHER project will advance the electric propulsion portfolio of Europe with the world-first EP air-breathing engine, potentially shifting the paradigm of VLEO, LEO and planetary missions.

The consortium of AETHER project is coordinated by Sitael (IT) together with Von Karman Institute (BE), University of Surrey (UK), Dedalos (GR), TransMIT (DE), RHO (AT) and ASTOS (DE).

AETHER project received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N. 870436. For further information visit the AETHER website (www.aether-h2020.eu/).

6.2. EDDA

EDDA stands for European Direct Drive Architecture.

The EU-funded EDDA project envisages the perfection of the power chain efficiency of a spacecraft with the use of electric propulsion (EP). This innovation directly supplies electric thrusters with solar EP without power conversion. EP uses electrical power to enhance the propulsive performances of the EP thrusters, obtaining better results than those of conventional chemical thrusters. The benefits of the innovation are considerable savings in volume and costs, removal of power converters, improvement of efficiency and decrease of thermal dissipation. The project will test the solution in real operational conditions to prove its adaptability to spacecraft.

The objective is to develop, build and test a demonstrator of a high voltage and high power direct-drive concept.

This innovative architecture supplies directly electric thrusters by a 300V-400V Solar Array without power conversion vs 28-100V in the current state of the art. The advantages are to remove power converters, to save mass, dissipation and cost, and to improve significantly the overall efficiency and reduce the thermal dissipation. In addition, at satellite level, it corresponds to a reduction of thrust duration, saving mission time.

The ability of the concept to be applied to various thrusters’ technologies is key to maximize the impact of the architecture. Therefore, this study is based on a transversal aspect of Electric Propulsion to be demonstrated on two different Electric Thruster technologies: Hall Effect Thruster (HET) from Sitael (Italy) and High Efficiency Multistage Plasma Thruster (HEMPT) from Thales-D (Germany).

EDDA demonstration is based on a thruster plasma analysis (UC3M, Spain). Cathod Reference Point electronics, HET, vacuum chamber for complete testing are provided by Sitael. The bus voltage control loop and associated hardware are designed and manufactured by TAS-B. Coordination at satellite level is performed by TAS-F. Efficient Innovation provides effective management and associated tools.

Tests will follow real operational conditions: no Sun, variation of illumination, thruster start-up and switch off, quick variation of consumption, and will demonstrate the robustness of this architecture easily adaptable to spacecraft (telecommunication satellites for Electric Orbit Raising reduction, In Orbit Servicing and Space-tugs, interplanetary carriers).

EDDA project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.870470. For further information visit the EDDA website (www.edda-h2020.eu/).

6.3. HIPATIA

HIPATIA stands for HelIcon PlasmA Thruster for In-space Applications.

The helicon plasma thruster (HPT) is a radio frequency-powered plasma propulsion technology that can perform well while eliminating many issues that have affected electric propulsion systems (EPSs) to date. The EU-funded HIPATIA project seeks to provide a cost-effective solution for large constellations of small satellites. It aims to verify the function and performance of an EPS based on the HPT technology for its application in non-geostationary satellite constellations and other small spacecraft. To improve HPT performance, the project plans to integrate the system and verify it against market needs.

The goal of HIPATIA (HelIcon PlasmA Thruster for In-Space Applications) is to verify the function and performances of an Electric Propulsion System based on the Helicon Plasma Thruster (HPT) technology, for its application in non-geostationary satellites constellations and other small spacecrafts.

The Helicon Plasma Thruster (HPT), a technology under development by SENER and UC3M, is a radiofrequency powered plasma propulsion technology that can offer a good level of performance while eliminating many of the design and manufacturability issues - electrodes, high voltage electronics, and complex fabrication - which have afflicted EP systems to date. Given the relatively simple and robust design of the HPT technology (no grids neither cathode), the HIPATIA project has the potential for providing a cost-effective solution for large constellation of small satellites (<500 kg, <750W of power for EP).

The impacts associated to have a disruptive thruster in high TRLs would not be achieved unless the complete EP System has proven its integration and operation consistency. HIPATIA will advance the development status of the HPT up to TRL6-7, but it will also face the integration challenges of a complete EP System, constituted by the HPT Thruster Unit, the Radiofrequency and power Unit that feeds it with power and the Propellant Flow Control Unit that controls the pressure and mass flow. The System will be integrated and verified against the requirements derived from the market needs. Development activities will be complemented with research and experimental task, in order to propose design actions to improve the HPT performances.

The Consortium, constituted by SENER, UC3M, ADS, CNRS and AST, brings to HIPATIA a solid background in the development, integration and test of Electric Propulsion Systems to successfully achieve the defined Project goal.

HIPATIA project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.870542. For further information visit the HIPATIA website (www.hipatia..eu/).

6.4. NEMESIS

NEMESIS stands for Novel Electride Material for Enhanced electrical propulSIon Solutions.

It is a transversal project strategically aiming at developing electride-based cathode technology which is compatible with all kinds of electric propulsion (EP) systems requiring neutralization or electron emission addressing the full span of required electron currents from 50 mA to 5 A.

The ceramic electride C12A7:e- has excellent materials properties for thermionic devices for EP applications. Its properties are superior to those of conventional ceramics currently employed in EP neutralizer technology. It is anticipated that C12A7:e- neutralizer technology is a potential game changer widening the applicability of EP immensely by enabling new mission scenarios due to higher reliability, compatibility with alternative propellants, lower power consumption on satellite and less thermal load at low costs.

The challenge is to fully transfer the theoretically ideal materials properties of C12A7:e- to neutralizer and any other kind or necessary electron emitting devices in order to fully make use of its potential for application in order to achieve the best performance and reliability and become a disruptive force in the cost-driven satellite market. The interdisciplinary NEMESIS consortium addresses with task by establishing the full chain from materials synthesis via processing to device design, fabrication and testing. All links of the chain are interlocked and will be permanently validated. Four types of ceramic-based neutralizer and electron emitters device concepts will be addressed and matured to TRL4 aiming specifically at exploring the anticipated strengths of C12A7:e-.

The 36 months NEMESIS project is executed by an experienced interdisciplinary consortium of 5 partners from 4 countries: 2 SMEs ATD (Spain, Coordinator), Exotrail (France), 2 universities Justus Liebig University Giessen (Germany), Universidad Politécnica de Madrid (Spain), and 1 research institute FOTEC (Austria).

NEMESIS project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 870506. For further information visit the NEMESIS website (www.nemesis-space.eu/).

6.5. PJP

PJP stands for Plasma Jet Pack.

The ©Plasma Jet Pack is a pulsed electrical thruster that uses solid metallic propellant. The main function of this product is to ensure the orbit manoeuvres of nanosatellites by generating a thrust. The PJP provides the flexibility to make the following missions:

- Orbit rising
- Station keeping
- Orbital transfer
- De-orbiting & re-entry
- In-flight formation
- Docking
- In-flight inspection.

On demand, PJP ejects high speed neutral metallic plasma in space, and consequently, transfers momentum to the satellite. Depending on the thrust level needed, the pulse frequency can vary from 0 to f_max.

The vacuum arc thruster (VAT) physics allows eroding solid metal propellant thanks to an electrical discharge in vacuum between two electrodes: the cathode (solid propellant) and the anode (passive electrode). The PJP is classified in the pulsed electromagnetic thruster's category. The PJP uses capacitive storage: capacitors banks are connected to the terminals of the electrodes and are waiting for the High Voltage Trigger System (HVTS) to begin the main discharge. Because the vacuum is an electrical insulator, the role of the HVTS is to provide matter in the inter-electrodes region in order to ignite the arc in vacuum at lower voltage between electrodes. Therefore, the frequency of the plasma pulses is the frequency of the HVTS.

Finally, by triggering a discharge between two electrodes, the vacuum arc physics enables sublimation, ionization and acceleration of neutral plasma from solid metallic propellant. The PJP does not have the disadvantages of other gas-fed technologies (storage tank, valves, flow control valves, piping, grid erosion, neutralizer, etc.) but has the main advantage to get solid propellant with high specific impulse. This technology offers high total impulse in a very small volume without any pre-heating process or safety integration constraints.

The PJP is at TRL 4 and the goal of the H2020 project is to upgrade it to TRL 7.

The consortium of PJP project is coordinated by Comat (FR) together with OHB (SW), CNRS (FR), Munich Uni (GE), Thales Alenia SF (FR) and Plasma Solve (CZ).

PJP project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 870444. For further information visit the PJP website (www.plasmajetpack.com/).

6.6. iFACT

iFACT stands for iodine Fed Advanced Cusp field Thruster.

The project aims to further develop the Advanced Cusp Field Thruster (ACFT) technology, using iodine as propellant and a neutraliser based on calcium aluminates.

iFACT consists of an Advanced Cusp Field Thruster (ACFT), a simple PPU, a thermionic Emitter, a novel propellant feeding architecture, which is optimized for iodine. The ACFT has been invented by Airbus in 2017. Due to its simplicity, paired with efficiency, the fact that it is easy to ignite and its excellent performance data with iodine, it is tailored as key element for an extremely simple, efficient and low-cost Electric Propulsion Subsystem (EPS). The baseline thruster (300 W input power) can be used with a simple thermionic cathode. The simple operation of the ACFT enables a reduced (wrt. number of parts and control circuits) but efficient PPU. These components are paired with a unique iodine feeding architecture which is capable to disrupt the electric propulsion market.

Based on this, the proposal will focus on:

- Iodine as disruptive propellant for electric thruster
- maturation of the Advanced Cusp Field Thruster (ACFT) as disruptive thruster principle, in three different power classes,
- development of a novel, disruptive, extremely simplified low-cost Power Processing Unit (PPU)
- use of calcium aluminate (C12A7) as disruptive, low-work function emitter material for cathodes
- development of a European Iodine compatible long firing test facility.

The consortium of iFACT project is coordinated by Airbus Defence & Space GmbH (GE) together with Airbus Defence & Space SAS (FR), EASN Technology Innovation Services BVBA (BE), UNIVERSITY OF SOUTHAMPTON (UK), Fraunhofer-Institut (GE), Aerospazio (IT), JUSTUS-LIEBIG-UNIVERSITAET GIESSEN (GE) and ENDUROSAT AD (BU).

iFACT project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 870336. For further information visit the iFACT website (www.epic-ifact.eu/).

7. ELECTRIC PROPULSION SRC 2020 – INCREMENTAL LINE.

The evaluation process of the H2020 EP Strategic Research Cluster (SRC) 2020 Call finalized by July 2020. The selected proposals kicked off their Operational Grants and started their developments and activities by the first quarter of 2021.

A brief explanation and presentation of these ongoing SRC Operational Grants and their projects, objectives, ongoing activities and expected results are presented in line with the provisions of the SRC Collaboration Agreement and its confidentiality provisions.

7.1. HEMPT-NG2

The objective of the HEMPT-NG2 consortium is to continue to develop, simulate, build and qualify the High Efficiency Multistage Plasma Thruster – Next Generation (HEMPT-NG2) system, with the application to operate a LEO-Thruster for use of station keeping, orbit raising and orbit maneuvering of satellites in constellations.

The HEMPT-NG2 project will contribute to increase the competitiveness of space electrical propulsion systems developed in Europe by developing an integrated solution based on the HEMPT (Highly Efficient Multistage Plasma Thruster) technology for the different LEO satellites.

This project will increase the capacity to compete within a worldwide market in term of cost, performances and production capacity. So, the interest of the whole consortium (Aerospazio Tecnologie SARL, ASP & Space GmbH, University Greiswald, Thales Alenia Space Belgium, Thales Alenia Space UK and Thales Germany) is to increase the competitiveness of space electrical propulsion systems developed in Europe by developing an integrated solution based on the HEMPT technology for the LEO satellites.

HEMPT-NG2 project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.101004140. For further information visit the HEMPT-NG2 website (www.hempt-ng.eu/).

7.2. ASPIRE

ASPIRE stands for Advance Space Propulsion for Innovative Realization of space Exploration.

The recent developments in high-power Hall thruster systems, thanks to the optimal combination of performance and reliability, are enabling a wide set of mission scenarios. These technological advantages, coupled with the increasing availability of power onboard satellite platforms, are encouraging several spacecraft manufacturers to focus on the implementation of high-power Hall thruster systems.

Despite these potential advantages, several factors have limited the possibility of reaching qualified status for these systems, such as huge costs and availability of test facility.

ASPIRE aims to increase the TRL of 20kW Hall Thruster system up to 6 by exploiting results obtained within CHEOPS. The project will cover many aspects, from mission scenarios analysis and satellite architecture consolidation to thruster unit TRL raise to 7 and enabling reduced-cost qualification. To keep operational and development costs as low as possible, krypton is maintained as baseline propellant.

The ASPIRE project also aims at augmenting the numerical modelling capability necessary for qualification of high-power EP systems, which lacks in Europe. The numerical models, developed and refined by three academic partners in the frame of this project, will be validated with the data gathered in more than 1000 hours of firing with Kr. Artificial intelligence is used to develop a novel simulation-aided qualification strategy, representing an exclusive European asset for the foreseen qualification and flight in the 2020-2030 decade.

ASPIRE project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.101004366. For further information visit the ASPIRE website (www.aspire-h2020.eu/).

7.3. CHEOPS Medium Power

Based on CHEOPS Phase I results, CHEOPS MEDIUM POWER will perform incremental developments on system and sub-system levels in order to achieve TRL6/7 by 2023.

CHEOPS MP will further mature the different system elements (Thruster Unit, PPU, FMS) by addressing the following key challenges: non-recurring and recurring cost reduction in terms of design, manufacturing, test qualification and time to deliver, as well as propellent efficiency in order to increase valuable payload and generate revenues. These advancements will fit into a less than 10kg thruster working at both 250 and 400V.

The project will deliver for the thruster unit an optimised design for a very high thrust and improved lifecycle durations. On an industrial level the project aims at reduced fabrication cycles, improved quality, leaner manufacture, faster assembly lead times, and improved tolerance management. The Power processing unit will be optimised by removing unnecessary functions and re-selecting cheaper key components with at least constant reliability levels. The project's scope extends to FMS level where space qualifiable COTS will be used to provide maximum mission suitability for variable number of thrusters per satellite.

The consortium of CHEOPS MP project is coordinated by SAFRAN Aircraft Engines (FR) together with Aerospazio Technologie (IT), Bradford Engineering (NE), Chalmers Tekniska Hogskola (SW), CNRS (FR), Thales (BE), SME4SPACE (BE) and Carlos III University (SP).

CHEOPS MP project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.101004226. For further information visit the CHEOPS MP website (www.mp.cheops-h2020.eu/).

7.4. CHEOPS Low Power

The LEO satellite market evolution sets a quick innovation pace for the satellite industry. High performances, compatibility with high production rates, adaptability and competitive prices are key in order to gain and maintain a strategic position. Based on a market analysis an EPS with a cost lower than 200K and a power range from 200W-1000W meets future satellite market needs, increasing European competitiveness on the worldwide satellite arena.

CHEOPS Phase 2 LP will deliver incremental developments for the first fully European Low Power EPS bringing the Thruster Unit and the FMS to TRL7 and the PPU to TRL6. The system will be optimized with Xenon and compatible with Krypton.

CHEOPS LP will permit the detailed design of the different system elements (TU, PPU, FMS) by addressing the following key challenges: compactness, modularity, optimized in-service life, low cost and high production rates, as well as flexible propellant management. Also, a multi-point qualification approach for the thruster unit enabling reduction of recurring costs through a more standard and common approach for all customers is considered. For this, CHEOPS LP will use a design to cost approach, COTS components and lean production approaches. CHEOPS LP will fully take advantage of new technologies and develop supporting advanced numerical design tools for electric propulsion, allowing to understand the observable behavior of a given thruster in its environment and predicting future performance.

The project will achieve significant progress in setting a HET diagnostics standard thus preparing its implementation in the future In Orbit Demonstrator.

The consortium of CHEOPS LP project is the same of the CHEOPS MP.

CHEOPS LP project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.101004331. For further information visit the CHEOPS LP website (www.lp.cheops-h2020.eu/).

7.5. GIESEPP Medium Power

The GIESEPP consortium proposes to continue the activity started under COMPET-3-2016-a to develop, build and test to TRL6/7 the first European Plug and Play Gridded Ion Engine Standardised Electric Propul-sion Platform (GIESEPP) to operate ArianeGroup ion engines with option of alternative thrusters, for a medium power application.

The consortium's intention will be:

- to reach a TRL6/7 of the medium power system with at least partial qualification to allow flight readiness
- to improve European competiveness in this field by
  - ✓ optimising industrialisation both on thruster unit and EPS level
  - ✓ increasing the GIE systems production capacities
  - ✓ significantly reducing the recurring costs
- and to maintain and secure the European non-dependence on this crucial technological field.

The project will significantly advance design and development of this standardised electric propulsion platform for GEO (and MEO) applications:

- In order to cope with challenging mission scenarios, dual mode functionality of the thrusters will be realised. This ensures that the beneficial high Isp characteristics of Gridded Ion Engines are maintained, whilst also offering a competitive higher thrust mode
- Activities will be covered not only by the competence of experts in their respective fields but also by the use of advanced Engineering Models (EM), respectively Qualification Models (EQM)
- The GIESEPP systems will not be limited to xenon as an operating medium; assessment will be performed to ensure functionality with alternative propellants
- The proposal will describe the roadmap to higher TRL beyond 2023/2024, providing a cost competitive EPS that will meet the highest standards for an industrialised, rapid production process
- The anticipated business case is targeted for long term exploitation up to 2030 strengthening Europe technological and economic competitiveness in a very fast changing market environment.

GIESEPP MP project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N.101004349. For further information visit the GIESEPP MP website (www.gieseppmp.eu/).

8. ELECTRIC PROPULSION SRC ACTIVITY

The European Health and Digital Executive Agency (HaDEA) is responsible for the proposal evaluation using independent experts, and the management, monitoring and payment of the ongoing SRC Operational Grants, including the EPIC PSA. All ongoing SRC Operational Grants are developing its technology activities in line with their Grant Agreements monitored by HaDEA and the results and achievements will be disseminated by them in due time by the selected channels, including the EPIC PSA.

The EPIC PSA current activities are focusing on the assessment of the progress and results of the ongoing Operational Grants steaming from the SRC 2019 and 2020 Calls, in the context of the SRC objectives, always in coordination with HaDEA. The PSA is participating in most of the progress meetings and technical reviews with designated PSA teams.

The evaluation on the state of the art and the market needs is a continuous activity for the PSA in other to update, if necessary, the SRC EPIC roadmap and master plan.

In preparation of the next phase of the SRC EPIC roadmap, the EPIC PSA is already giving support to EC on the definition of the SRC Call texts, related documents and technical annexes for the next SRC 2023 Call topic.

Regarding the next steps on the dissemination and educational activities, the EPIC PSA will contribute as required in all EC HE Info Days at national and international level to inform, promote and disseminate all the information regarding the EP SRC, the PSA activities, the SRC EPIC roadmap and the SRC Operational Grants activities.

The EPIC PSA has organized six dedicated EPIC Workshops, the first one was in Brussels (Belgium) from 25 to 28 November 2014, organized by CNES and BELSPO; the second one was in Stockholm (Sweden)11-12 February 2015 organised by DLR with the help of the THAG Swedish Delegation; the third in Madrid (Spain) took place on 24-25 October 2017, organized by CDTI; the next one took place on 15-17 October 2018 in London (United Kingdom); the fifth one took place on 21-23 October 2019 in Noordwijk (Netherlands); and the last one took place the last 4-6 April in Cologne (Germany), organized by DLR. The EPIC Workshop scope is to present the Horizon Europe Electric Propulsion SRC activities to the electric propulsion community and stakeholders and to collect and assess the latest EP technology developments in Europe.

Figure 3: 2022 Workshop header

In concurrence with the EPIC Workshops, the EPIC PSA has organized in collaboration with local universities and research organizations active in EP, four dedicated educational activities called: EPIC Lecture Series. The first one in Madrid (Spain) on 26 October 2017; the next one on 18-19 October 2018 in London (United Kingdom), third one on 24-25 October 2019 in Noordwijk (Netherlands) and last one on 7-8 April 2022 in Cologne (Germany).

The EPIC Lecture Series objective is to provide to science and engineering university students (bachelor, master, PhD) with a selection of lectures on space electric propulsion, from the basic technology and concepts to the latest developments. The EPIC Lecture Series cover different subjects such as: basic electric propulsion physics and technology, electric propulsion subsystem elements, relevant physical models, current developments and technological challenges, experimental and measurement techniques, and examples of past, ongoing, and future missions using electric propulsion. Lectures are imparted by invited prominent professors and researchers in the field of space electric propulsion from Europe.

Further information can be found in (http://epic-src.eu/lectureseries2017/).

9. ACKNOWLEDGMENTS

This paper has been drafted by the EPIC PSA in collaboration with the Electric Propulsion SRC Operational Grants in line with the provisions of the SRC Collaboration Agreement. The EPIC PSA has received funding from the European Union's Horizon 2020 and Horizon Europe research and innovation programme under Grant Agreement N. 872002. This paper reflects only the EPIC PSA Consortium's view. The EC and the HaDEA are not responsible for any use that may be made of the information it contains.

10. ABBREVIATIONS AND ACRONYMS

CoA *Collaboration Aspects*
COTS *Commercial off-the-shelf*
EC *European Commission*
ECEP *Electrospray Colloid Electric Propulsion*
ECRA *Electron Cyclotron Resonance Accelerator*
ECRT *Electron Cyclotron Resonance Thruster*
ECSS *European Cooperation for Space Standardization*
EP *Electric Propulsion*
EPIC *Electric Propulsion Innovation & Competitiveness*
EOR *Electric Orbit Raising*
ESA *European Space Agency*
FEEP *Field Emission Electric Propulsion*
FMS *Fuel Management System*
GEO *Greostationary Earth Orbit*
GIE *Gridded Ion Engine*
GTO *Greostationary Transfer Orbit*
H2020 *Horizon 2020*
HaDEA *Health and Digital Executive Agency*
HE *Horizon Europe*
HEMPT *High Efficiency Multistage Plasma Thruster*
HEO *Highly Elliptical Orbit*
HET *Hall Effect Thruster*
HPT *Helicon Plasma Thruster*
Isp *Specific Impulse [s]*
LEO *Low Earth Orbit*
MEO *Medium Earth Orbit*
MPDT *Magneto Plasma Dynamic Thruster*
P *Power [W]*
PDR *Preliminary Design Review*
PPT *Pulsed Plasma Thruster*
PPU *Power Processing Unit*
PSA *Programme Support Activity*
P/T *Power/Thrust ratio [W/mN]*
OG *Operational Grant*
RTD *Research, Technology and Development*
SK *Station Keeping*
SRC *Strategic Research Cluster*
T *Thrust [N]*
TRL *Technology Readiness Level*
TU *Thruster Unit*

11. REFERENCES

1. European Commission, “HORIZON 2020, The EU Framework Programme for Research and Innovation, Space” Horizon 2020 web for Space area [online database], URL: http://ec.europa.eu/programmes/horizon2020/en/area/space-0

2. European Commision, “HORIZON EUROPE” Horizon Europe web, URL: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

3. European Commission, “Horizon 2020 Work Programme 2014 – 2015 - 5. Leadership in enabling and industrial technologies iii. Space Revised” Horizon 2020 web for Space Work Programmes [online database], URL: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-leit-space_en.pdf

4. European Commission, “Horizon 2020 Work Programme 2016 – 2017 - 5 iii. Leadership in Enabling and Industrial Technologies – Space” Horizon 2020 web for Space Work Programmes [online database], URL: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-leit-space_en.pdf

5. European Commission, “Horizon 2020 Work Programme 2018 – 2020 - 5 iii. Leadership in Enabling and Industrial Technologies – Space” Horizon 2020 web for Space Work Programmes [online database], URL: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-leit-space_en.pdf

6. European Commission, “Horizon Europe Work Programme 2021-2022 - 7. Digital, Industry and Space”. Horizon Europe web for Space Work Programmes [online database], URL: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-7-digital-industry-and-space_horizon-2021-2022_en.pdf

7. EPIC, “Electric Propulsion Innovation & Competitiveness (EPIC), the PSA for the Electric Propulsion SRC” EPIC web for EPIC public documents [online database], URL: http://epic-src.eu/epic-public-documents/