Disruptive technologies for space Power and Propulsion

DiPoP

A presentation of the Final Report

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SUMMARY
Presentation of the FINAL REPORT

- Non-Fission Space Power and Propulsion
  - DiPoP Roadmap for European micro-particle propulsion
- Nuclear Electric Propulsion and PPU (Power processing units)
  - DiPoP Primary Electric Propulsion Roadmap
- Nuclear Thermal Propulsion / Power conversion systems
  - DiPoP Nuclear Thermal Propulsion Roadmap
- Fission Nuclear Power Source in Space Applications
  - DiPoP FISSION NUCLEAR POWER GENERATION ROADMAP
- Nuclear Public Acceptance, Public Dissemination, Safety and Sustainability
- Space Power and Propulsion Applications

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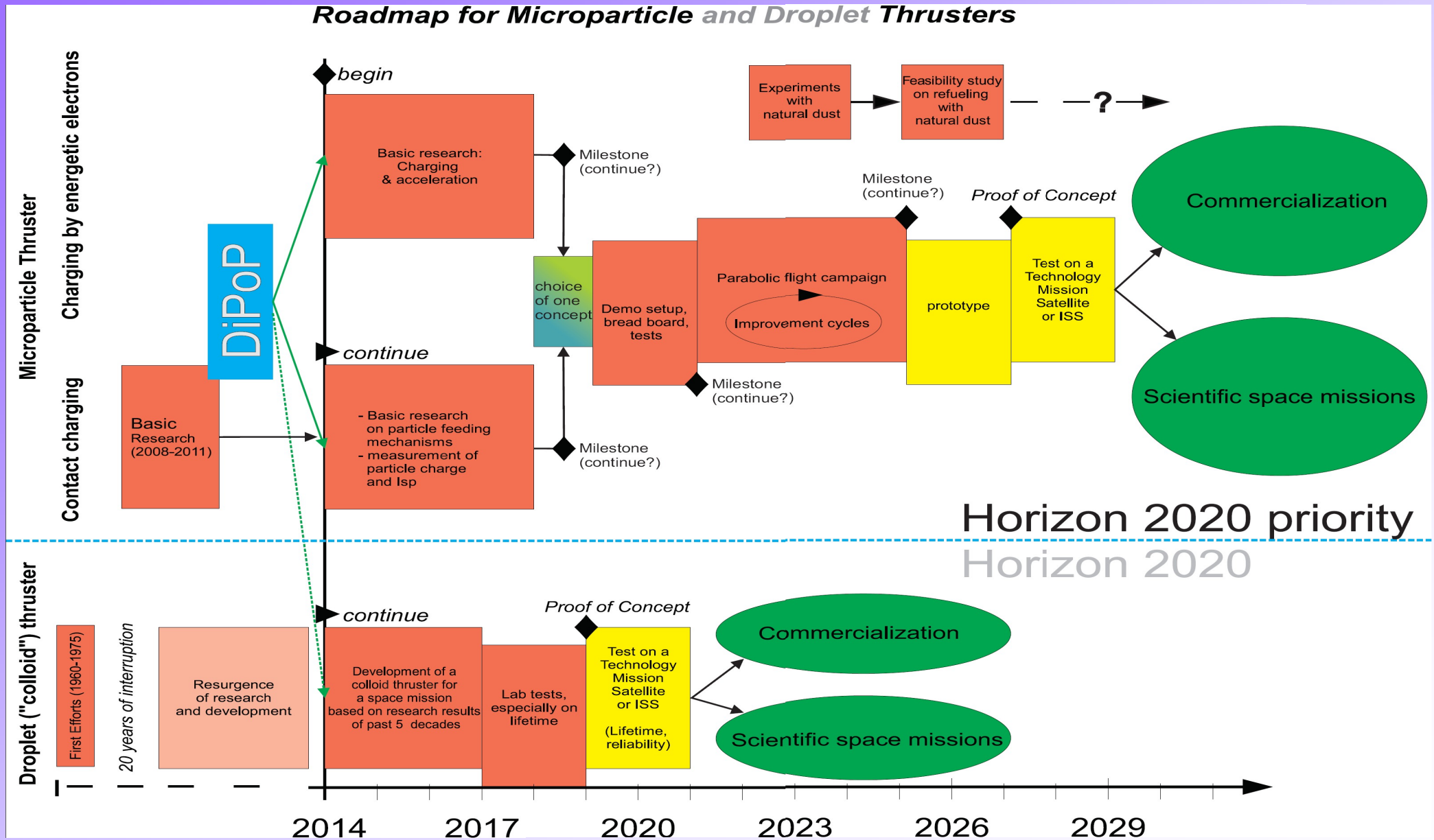
- Non-Fission Space Power and Propulsion
  - **DLR and CAU have setup a large list of disruptive space power and propulsion technologies.**
  - Non-Fission Space Power
    - High temperature superconductors
      Lower mass of wires but current materials must be cooled to very low temperatures
    - Thinned multi junction cells and panel
      Strongly absorbs sunlight, thinner film than other semiconductor materials.However co-evaporation gives uniformity issues over large areas.
    - Stirling cycle thermoelectric radioisotope generator
      Increase specific power of RTGs but Isotopes are scarce resources, Ethical and social issues of using (too much) plutonium
    - Quantum-Dot Solar cell
      High potential efficiency, Mechanical flexibility and low cost, clean power generation but until now, low levels of efficiency
  - Propulsion
    - SABRE Engine (may be subject to intellectual property rights)
      Saves on propellant weight, increasing payload fraction, but high complexity.
    - Alternative Solid Propellants: CL-20
      High performance, High energy content, Very high energy density but Relatively sensitive to both impact and friction
    - Micro Electric Space Propulsion (MEP)/ Micro-particle Propulsion
      Flexible, Lightweight, High- efficiency, Scalable propulsion but no real spaceflight experience exists.
    - Pulsed inductive thruster (may be subject to intellectual property rights)
      Requires no electrodes but energy efficiency is low.

DiPoP Roadmap for European micro-particle propulsion



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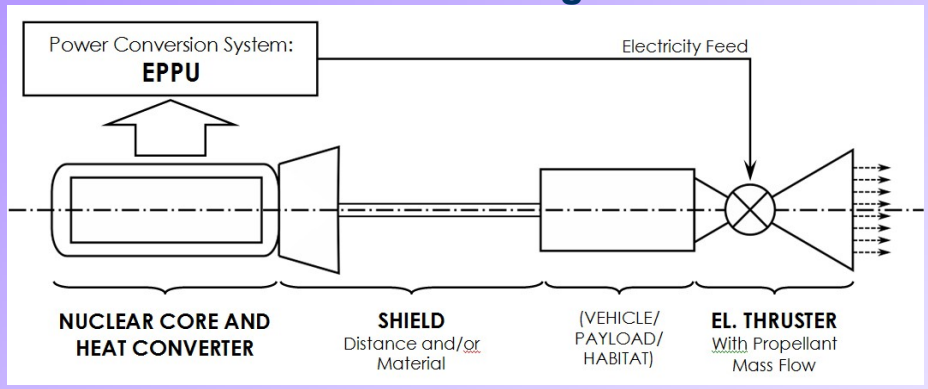
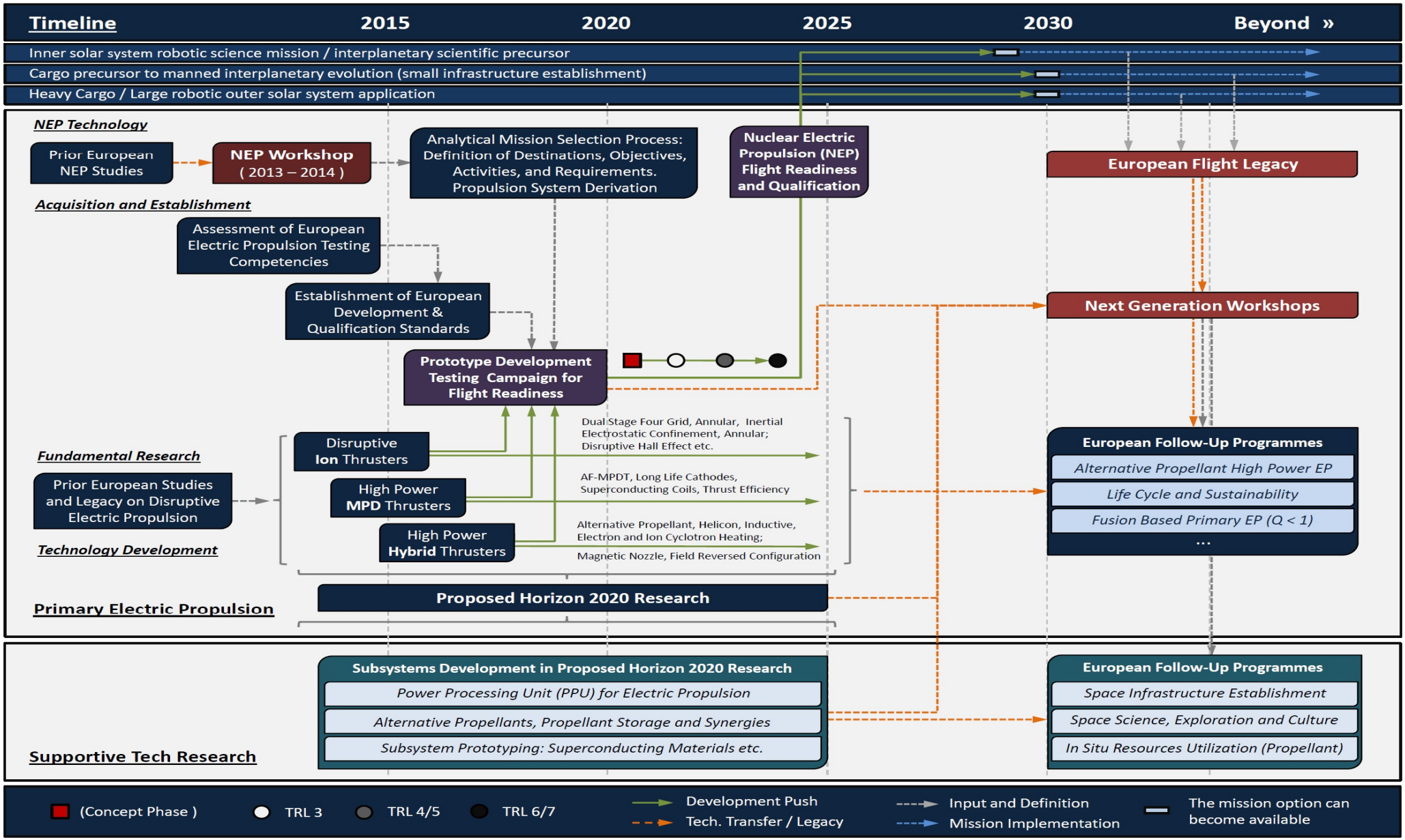
Nuclear Electric Propulsion and PPU (Power processing units) :

- An assessment of mission and nuclear electric propulsion system options and power management and distribution and electric propulsion power processing issues has been undertaken by SEP. The analysis identifies also the constraints on design options from external factors such as mission requirements and launch capability.
- **The preferred way at this stage is for a nuclear electric propulsion generator (NEP) to be compatible with all the available EP technologies**



- **Overviews of the technologies available and of the specific needs induced by Nuclear power generator have been reviewed. Among them:**
  - Mission and Nuclear Electric Propulsion System Options
  - Electric Propulsion Technology Options
  - Thermal to Electrical Energy Conversion.
  - Power Management and Distribution (PMAD)
- **The main conclusion (summarized in a Basic Evaluation Matrix) is that there are many factors to take into consideration, many of which are mission dependent.**
  - Consequently, an awareness of the principal advantages and disadvantages of the various technical options is the best that can be achieved in any early stage.
  - Also many features of the technology options are to some extent overlapping and have significant variations in potential performance.

DiPoP Primary Electric Propulsion Roadmap



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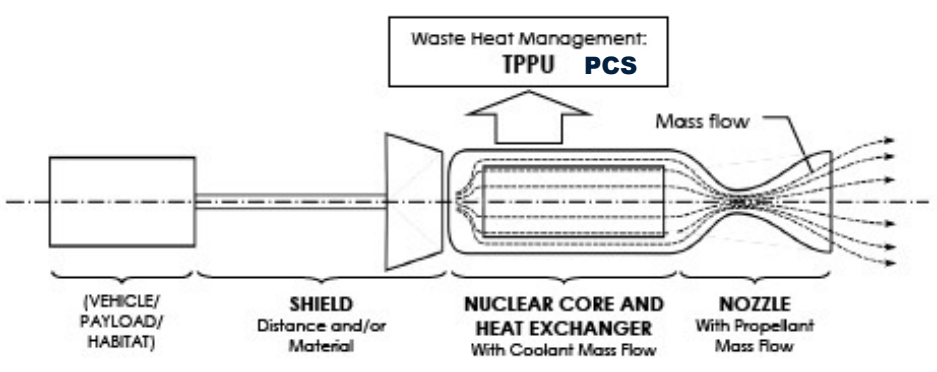
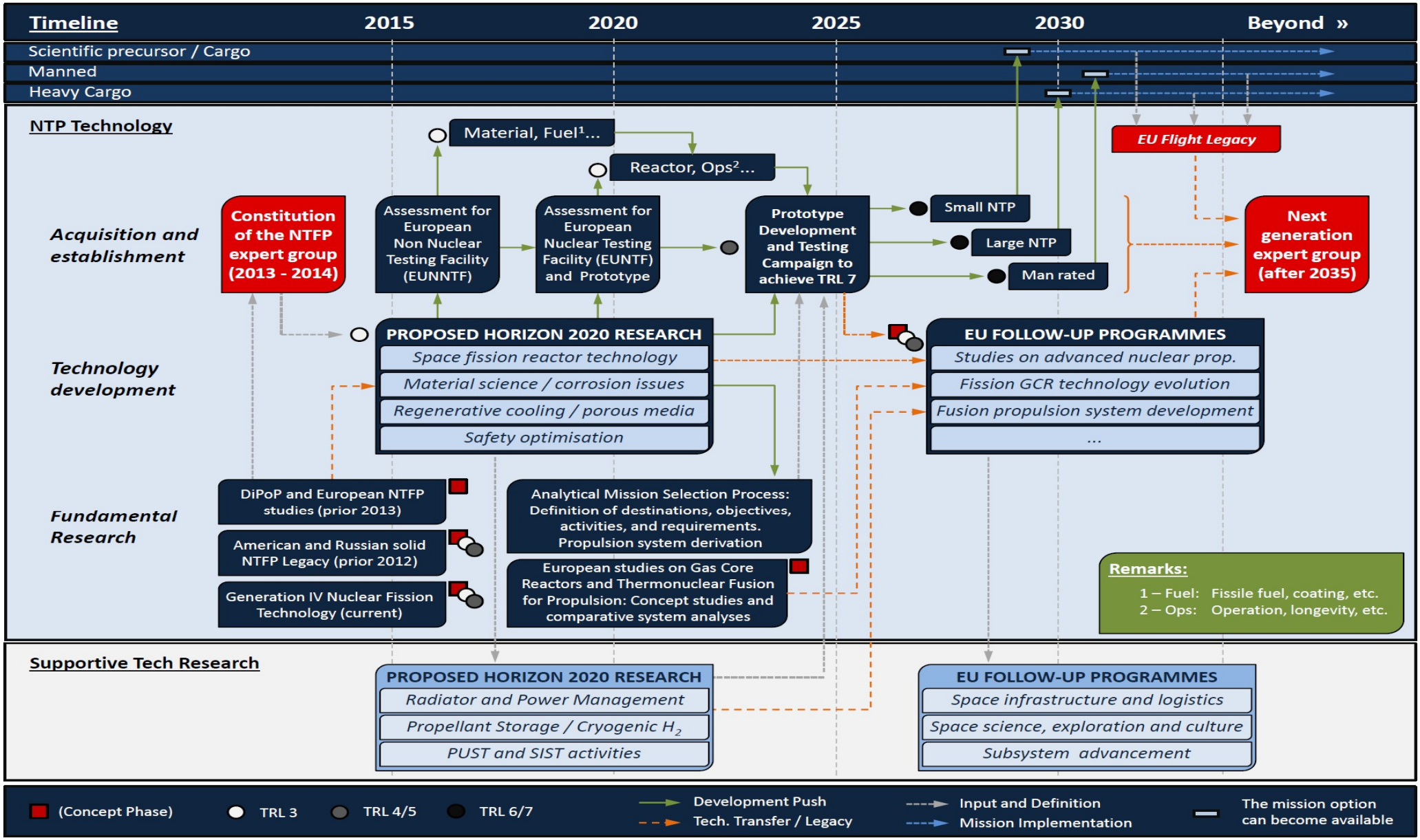
- Nuclear Thermal Propulsion / Power conversion systems : The analysis lead by IRS Stuttgart focuses on Thermal Propulsion (TP)
  - Better overall efficiencies and system mass for a same energy source (less stages of conversion)
  - Both disruptive and advanced systems analyzed: wrt technology readiness levels (TRL).
  - Disruptive: Systems like NERVA (extensive investigation/ground testing) but lack in-flight experimentation
  - Advanced concept: Fusion Propulsion not yet fully technically available (breakthrough can be expected in the next two decades…)



- **Power conversion systems (PCS) : a vital subsystem of nuclear propulsion.**
  - Nuclear systems always involve enormous fluxes of heat (after shutdown). The PCS manages these heat fluxes and can even recover waste heat for other purposes.
- **Main conclusion (summarized in with an Evaluation Matrix of concepts of NTP) provides a preliminary assessment of the NTP concepts**.
  - Even with technology available in the short or medium term significant breakthrough ventures are possible.
  - An exemplary voyage to Mars could consist in a space craft of 100 metric tons departing from an infrastructure in low Earth's orbit.

DiPoP Nuclear Thermal Propulsion Roadmap



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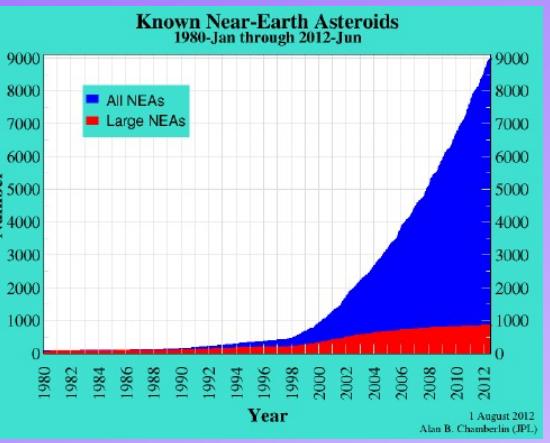
Fission Nuclear Power Source in Space Applications (1/2)

- The analyses lead by SEP and ISIS have been focused on the selection of space applications (power 30 or a 200 kWe)
  - Missions to the Outer Planets
  - Removing 'dead spacecraft'/debris: if safety issues can be satisfactorily addressed
  - Near Earth Objects (NEO) management (as part of SSA), NEO mining and ground-penetrating radar, NEO asteroids or comets Earth collision avoidance
    - Defense of the planet is seen as a compelling argument for public acceptance of fission reactors if there is no other way of deflecting a large earth-bound NEO asteroid.
    - Trend is for the number of NEO < 100 m double in 10 years, which can lead to disastrous consequences
    - NEP larger deflection but much longer trip time.
    - NTP faster trip time but lower angular deflection (by impact)



- **Nuclear Power Source** : technical, capability, expertise and infrastructure considerations
  - Discussed in detail with European, Russian and US partners through an Advisory Board.
  - Direct invitation for Europe to participate in Russia's MEGAWAT Class Nuclear Power and Propulsion System (NPPS)
- **The findings of the analysis performed on the applications are the following:**
  - 30kWe: NEP small robotic missions outer solar system, NEO surveys and high power instrument.
  - 200 kWe: NEO deflection, mining, exploration missions, infrastructure (support manned mission) for interplanetary transportation.

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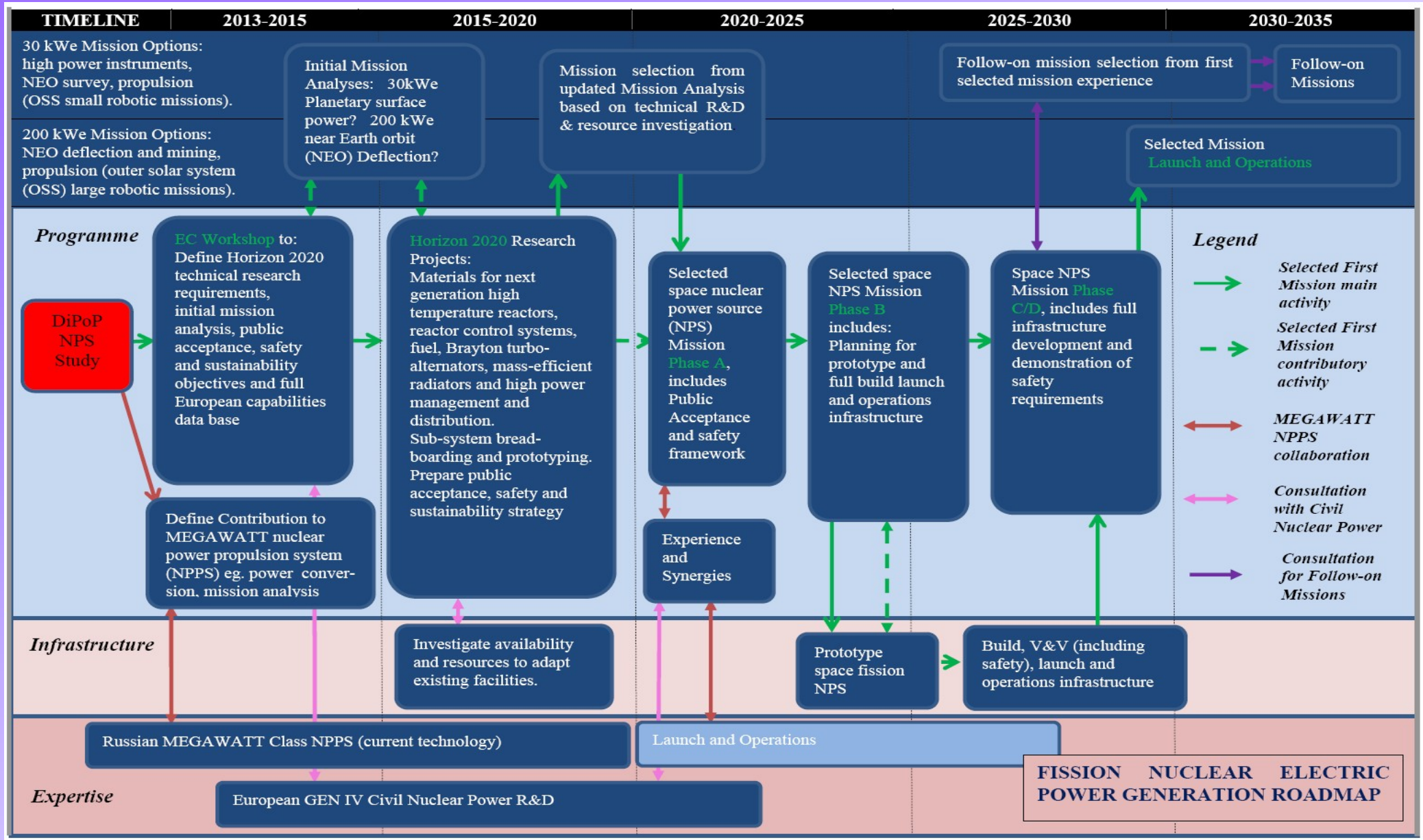
- Fission Nuclear Power Source in Space Applications (2/2)
  - **Main Recommendations**
    - The EC is invited to initiate a program line (within the Horizon 2020 programme) to:
      - Identify and prioritise objectives and applications requiring fission nuclear power,
      - Exploring or initiating a short term collaboration in the Russian Heavy Spaceship and NPPS (Turbo-alternator technology)
      - Assessing the technical development (for higher performance) of high temperature Brayton power conversion cycle including both reactor and turbo-alternator technology.
      - Build a full database of the relevant European expertise and infrastructure,
      - Establish a timetable to achieve a European regulatory safety framework for nuclear power sources
      - The EC is invited to hold a workshop with all relevant European (and potential collaborating nations) nuclear and space organisations to mainly define specific research and development projects based on High Temperature reactors, HT turbo-alternators, HT radiator materials
    - The ESA is invited to make provisions for
      - Analysis of candidate missions identified in the workshop within the General Studies programme,
      - The feasibility study of a candidate mission with a view to defining the resources required to deliver it either by Europe alone or in collaboration.

DiPoP FISSION NUCLEAR POWER GENERATION ROADMAP



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- Nuclear Public Acceptance, Public Dissemination, Safety and Sustainability
  - The analysis was lead by IRS Stuttgart : Preliminary recommendations and directives for the project responsible concerning their behavior, communication and activities
  - **For a new disruptive technologies, there will always be concerns about safety or ecological effect of a technology. Communication should be :**
    - Transparent and intelligible, to enable people to assess the sincerity of the participants,
    - Also, the content of the communication needs to make people understand
      - The relative and absolute numbers connected with funding, the funding source(s),
      - Merit and benefits of the technological project to the society.
    - Hence, strategies and preliminary recommendations regarding experts
      - Consider their social setup, behaviour and attitude towards project and the public,
      - Consider their language skills and levels,
      - Follow the development of communication and its instruments,
      - Consider values and ethics, Commit to technology assessment,
      - Apply measures according to their finding.
  - **Lessons learned :Support a 'safety culture' by creating incentives to continually assess and consider implementation of safety enhancements**
    - Include 'nuclear safety' elements in all major reviews
    - Establish, integrate a nuclear safety risk analysis team into entire design and development process and Independent evaluation of safety analyses
  - **Finally dissemination of the information has been found an essential part for enabling the public acceptance.**
    - An according dissemination strategy has been developed with two main branches, one for the scientific and one for the general public. The first will rely on the hard facts and the results of the project, the other on social permeation

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- Space Power and Propulsion Applications
  - In addition to the recommendations to develop in parallel high power electric propulsion technologies in line with 30 kWe and 200 kWe and energy sources, the analysis lead by DLR concludes with two major ideas:
  - **The public acceptance**
    - Achieving public acceptance for realizing and using disruptive space power and propulsion technologies studied in DiPoP can be achieved - with full success - through a rational/emotional balance treatment.
    - For this reason, such disruptive space power and propulsion technologies and applications studied in DiPoP are an interdisciplinary project, which demands long term effort.
  - **The international achievements of the independent European leadership in space power and propulsion technologies applications in future space missions.**
    - Achieving international enforcement, especially under an European leadership or in minimum with a true, equal balanced partnership of Europe with other space nations is a goal.
    - For reaching that status, EC could push a manned space flight to an asteroid because that is a public as well as a political attractive goal :
      - For preparing a protection of population in case of hazard or for Space Situational Awareness (SSA).
      - Manned asteroid flight demands future technology level achievements, which could bring European space industry in much higher levels while restructuring activities and business (raw material mining in asteroids) of European space organisations and industry.