

SOLAR POWER FROM SPACE – EUROPEAN STRATEGY IN THE LIGHT OF GLOBAL SUSTAINABLE DEVELOPMENT

Programme plan

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1 INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

This document describes the goal, the strategy and the different phases of the programme “Solar Power From Space - European Strategy in the light of Global Sustainable Development”, specifying the high level requirements, the activities and the general deliverables of each of the phases. The programme “Solar Power From Space – European Strategy in the light of Global Sustainable Development” is also called “SPS – Programme” or only the “Programme”.

This Programme plan (PP) describes the overall working plan on the Programme in the timeframe 2003-2005 and serves as guideline for all activities and studies to be conducted in the frame of the Programme. It is considered as a “living” document that follows the progress of the work and adapts to its development. It will be attached as an annexe to all individual Statements of Work for studies performed under the Programme.

1.2 BACKGROUND

This chapter presents first a short overview over the global energy situation today, including an outlook over the timeframe of this Programme. The general motivation for the two main applications of SPS to be discussed in this Programme, power generation for Europe and for space exploration are outlined in paragraphs 1.2.2 and 1.2.3.

1.2.1 Global Energy Situation

Until the 18th century, the energy need for human activities was taken from renewable biomass burning. The industrial revolution, starting in the mid 19th century was based on coal burning, peaking in the early 20th century, when almost 80% of humanities energy need was taken from coal. During the same period, the total need for energy steadily increased, more or less in parallel with world population. The energy needs for the even faster evolution of the 20th century was based on oil and gas burning, successively lowering the shares of coal, which continued to increase in absolute terms. Since the oil crisis in the 70s, while still increasing in absolute terms,, the share of oil and gas levelled at about 60% for the benefit of nuclear energy, representing now about 15% of the of the total global energy supply.¹ While human population has quadrupled in the 20th century, primary power consumption has increased 16-fold.²

All forecasts for the 21st century agree on a continuous and substantial increase in the worldwide energy demand. History tells us, that the availability of affordable energy and the level of development are closely linked. The current increase in energy consumptions is

¹ International Energy Agency, World Energy Outlook 2002; *OECD/IEA*, 2002

² J.R. McNeill, *Something New Under the Sun: An Environmental History of the Twentieth Century*, Norton, New York, 2000

already mainly driven by developments in developing countries. This trend will be reinforced within the next 50 years. By the end of this century, the total primary energy requirements will double in the most optimistic case, assuming radical changes, massive, global scale investments into renewable energy sources and/or high global inequity, and increase 5-fold under normal realistic growth assumptions, supposing “only” improvements in energy density. The 2002 worldwide energy requirement is about $1.061e14$ kWh.³

In the last years, the fossil fuel greenhouse theory has become more and more credible as we continue – based on an increasing number of scientific observations – to better understand the links between fossil fuel burning, climate change and environmental impacts. All factors indicate that the additional power requirements of the 21st century, in any case several times the entire present level, should come from CO₂ emission free energy sources. In a recent review article in *Science* 18 US scientists compared the different technical solutions to the energy problem of the 21st century. Solar power satellites as well as terrestrial renewable options were identified as one promising option for the 21st century.⁴

Based on the technical state of the art of the year 1995, NASA proposed a CO₂ emission free space based solution after a 2 year trade-off study.⁵ During the last 10 years, some concepts for large scale terrestrial renewable energy plants have been forwarded. A preliminary assessment of the possibility to fulfil the global energy need with a worldwide network of solar thermal collector plants and high voltage transmission lines was presented in 1999.⁶

1.2.2 Solar Energy for Europe – European Specificities

While the energy generation for the development of the 21st century is a global problem, each region presents its own characteristics, determined by the availability of natural resources, climatic and geographic conditions. Today, Europe is depending to 50% on energy import. The dependence is expected to grow up to 70% until 2020, implying strategic vulnerability especially since there is only a limited number of supply regions⁷. Europe has furthermore taken the lead in international programmes to reduce the global CO₂ emission level and bears at least some moral burden to show the example. While the target is a 7% reduction of its emissions until 2008/12 compared to 1990, the actual trend shows a 5% increase, calling for substantial changes.

This Programme shall limit its considerations in the field of renewable, CO₂-emission free terrestrial energies to solar power plants. Other sources might be taken into consideration as a supplement, e.g. to reduce storage needs.

³ Energy units should be given in [kWh]. Power units should be given in [W]. Numbers in [Btu], [toe], [J], [erg] and [calories] shall all be converted into [kWh].

⁴ Hoffert et al.; Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet; *Science*, Vol 298, p. 981ff, November 2002

⁵ NASA; Space Solar Power – A fresh look at the feasibility of generating solar power in space for the use on Earth, *NASA Report* Nr. SAIC-97/1005, 1997

⁶ M. Klimke; *Systemanalytischer Vergleich von erd- und weltraumgestützten Solarkraftwerken zur Deckung des globalen Energiebedarfs*, Doctoral Thesis Universität Stuttgart, DLR Forschungsbericht 2001-12, 2001

⁷ Green Paper “Energy – Towards a European strategy for the security of energy supply”; *European Commission*, ISBN 92-894-0319-5; 2001

For a strategic comparison between terrestrial and space based renewable, CO₂ emission free energy systems, geographic characteristics play an important role in addition to other parameters like development, availability of resources and infrastructure. In this respect, the conclusions for Japan for example are most likely completely different than the ones for Europe, or Africa. For the use of direct solar irradiation for large scale energy generation, Europe itself has in fact two major disadvantages in this respect: a relatively high population density and thus limited amount of unused, cheap land surfaces, and its geographical location quite far from the equator. On the other hand, the worldwide best suited region for generating power via direct solar irradiation, the North African Sahara is very close. Since the timescales of SPS Programme is in the order of 20 to 30 years, it is legitimate to suppose a closer economic and political involvement of the North African region into Europe, including the use of Sahara for power generation.

1.2.3 Energy for Space Exploration and Space Applications

Power is one of the enabling crucial elements of space missions. Since the very beginning the importance of efficiently using the only abundant power source in space: solar power was recognized and most of the spacecraft are solar powered. Until now, physics limits the efficient use of solar power to a sphere around the sun extending approximately until the Martian orbit since the available power level per m² decreases with the power of 2 as the distance increases. This physical limitations lead to the use of nuclear power sources for planetary missions further than Mars. Nuclear power sources (NPS) are also considered as one of the options for energy intensive robotic and human Mars missions.

Recent progress in space solar power satellites and wireless power transmission (WPT) suggest that applications of space solar power systems may provide an alternative to nuclear power sources in certain cases. This seems to be valid as well for an eventual Earth Mars transportation system as well as to power planetary surface stations. Within the considered timeframe, the possibility to supply Earth bound orbital platforms could also be an option.

One of the current arguments in favour of NPS for Mars missions is that solar powered Mars exploration is only possible in the near equator regions, while water is expected rather at polar regions. SPS and WPT would overcome this limitation of on surface photovoltaic devices. Europe does not possess NPS, extensively used as RTGs by the US and in form of fission reactors by the Soviet Union and Russia. The development of NPS capabilities in Europe would require significant resources.

This study will thus also investigate roughly three different options for supplying solar power from space to space: The power supply of exploration missions beyond low Earth orbits and whether solar power satellites could provide a viable alternative in the timeframe under consideration for robotic and human Mars exploration (~2030), the supply of power to large power-demanding spacecraft in Earth orbits and the supply of power to Earth orbiting space stations.

1.3 OVERALL GOALS OF THE PROGRAMME

Based on the above considerations, the entire Programme works towards the following goals, that are specified in detail in the description of the work plan of the Programme under section 2:

- Perform a scientifically sound and objective comparison of space based and comparable ground based power generation solutions,
- Identification of possible synergies between ground and space based power generation solutions,
- Assessment of the potential role of SPS for space exploration,
- Establishment of one to three innovative, realistic and promising SPS concepts,
- Identification of major technical SPS areas, demanding research and development,
- Perform two to three feasibility studies for near-term demonstrator missions that provide enough information to support a decision on further activities
- Assessment of the most promising ways to integrate SPS into a hydrogen-based economy,
- Provision of focus, stimulus and coordination to European research on SPS,
- Identification of promising opportunities for international cooperation.

The overall Programme shall be divided into three logical phases.

1.4 OBJECTIVES OF THE WORK

The overall objective of the work is to produce support material for the Agency and its Member States to evaluate the possibilities of Solar Power Satellites and formulate a European strategy for space solar power in the light of sustainable global development.

1.5 DEFINITION OF TERMS

The following terms should be used during the entire Programme in all documentation and correspondence, at the Programme as well as at the study and contractor and subcontractor level in order to achieve consistency of terms.

Programme	also called “SPS Programme” or “entire Programme” makes reference to the overall entire effort as described in this document, lasting about 18 to 24 month and being subdivided into several individual studies.
Study	shall be the name used for the individual studies performed within the SPS Programme.
System architecture	shall mean a complete end-to-end solution for delivering space solar power to a designated user; it comprises several system concepts and includes all space and ground elements
System	shall mean a key system-level design approach; it is typically defined in

concept terms of technology used

For the purpose of this document, 'shall', 'should' and 'desirable' or 'optional' are used to define the priority of the requirements, activities or deliverables, with the meaning described by:

- 'shall' are mandatory;
- 'should' are strongly recommended, but may be replaced by a different technical solution with equivalent or better functionality or deleted for well justified reasons;
- 'desirable' or 'optional' are not mandatory but improve the quality and value of the Technical proposal if converted into 'shall'.

'Should' and 'desirable' / 'optional' requirements or activities remaining in the Technical proposal shall be, in agreement with the ESA Technical Representative, converted to 'shall' requirements or activities, or deleted during the negotiation phase or after the necessary investigations have been performed.

1.6 ACRONYMS AND ABBREVIATIONS

ACT	Advanced Concepts Team
CDF	Concurrent Design Facility
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
ISS	International Space Station
NPS	Nuclear Power Sources
PP	Programme plan
PRR	Preliminary Requirements Preview
SMP	Study Management Plan
SoW	Statement of Work
SPS	Solar Power Satellites
TBC	to be confirmed (by the Agency)
TBD	to be determined (by the contractor)
TBS	to be specified (by the Agency)
TT	Topical Team
WPs	Work Packages
WPT	Wireless Power Transmission

1.7 REFERENCE DOCUMENTS

The following documents and studies shall constitute the basis of the work and be known by all participants:

- ESA/DLR; System Concepts, Architectures and Technologies for Space Exploration and Utilisation (SE&U Study), *European Space Agency Contract Report*; 1999
- Space Solar Power – A Fresh Look At the Feasibility of Generating Solar Power in Space for Use on Earth; Science Applications International Cooperation, Futron Corporation, NASA; NASA Report Number SAIC-97/1005, 1997
- P.Glaser, F. Davidson, K. Csigi; Solar Power Satellites; ed: John Mason, *John Wiley & Sons*, 1998

The following, non-exhaustive list of documents on the subject provide valuable information and should be known by all participants:

- International Energy Agency, World Energy Outlook 2002; *OECD/IEA*, 2002
- W. Seboldt, M. Klimke; European Sail Tower SPS Concept, *Acta Astronautica* Vol. 48, No.5-12, pp. 785-792, 2001
- M. Klimke; *Systemanalytischer Vergleich von erd- und weltraumgestützten Solarkraftwerken zur Deckung des globalen Energiebedarfs*, Doctoral Thesis Universität Stuttgart, DLR Forschungsbericht 2001-12, 2001
- National Research Council; *Laying the Foundation for Space Solar Power – An Assessment of NASA’s Space Solar Power Investment Strategy*, National Academy Press, Washington, 2001
- Green Paper “Energy – Towards a European strategy for the security of energy supply”; *European Commission*, ISBN 92-894-0319-5; 2001
- G. Pignolet, The case study for microwave power transportation in Réunion island; *Space Energy and Transportation*, Vol. 4, No 3,4; 1999
- G. Pignolet et al.; Demonstrating SPS Technologies on Earth: SPS-IdR Studies in Réunion Island towards point-to-point operational WPT ; *Space Energy and Transportation*, Vol. 1, No3, 168ff, 1996
- National Research Council; *Electric Power From Orbit: A Critique of a Satellite Power System*, National Academy Press, Washington, 1981
- Office of Technology Assessment; *Solar Power Satellites*, NTIS No. PB82-108846, Washington, US Government Printing Office, 1981
- P. Glaser; Power from the Sun: Its Future, *Science*, Vol. 162, No 3856, pp 857-866, 1968

2 DETAILED PHASE DESCRIPTION

2.1 PHASE 1: GENERAL VIABILITY PHASE

2.1.1 General Description

The worldwide primary power requirement in 2002 is about 12 TW. By mid of this century, humanity most probably will need several times this amount. The fossil fuel greenhouse theory has become more and more credible as we continue – based on an increasing number of scientific observations – to better understand the links between fossil fuel burning, climate change and environmental impacts. All factors indicate that the additional power requirements of the 21st century, several times the entire present level, should come from CO₂ emission free energy sources. Based on the technical state of the art of the year 1995, NASA proposed a CO₂ emission free space based solution after a 2-year trade-off study.⁸ During the last 10 years, some concepts based on large-scale terrestrial renewable energy sources have been forwarded. A preliminary assessment of the possibility to fulfil the entire worldwide energy need with a worldwide network of solar thermal collector plants and high voltage transmission lines was presented in 1999.⁹ In a recent review article published by 18 outstanding US scientists in *Science*, solar power satellites as well as terrestrial renewable options were identified as one of the promising solutions for the 21st century.¹⁰

Power from space for terrestrial use

In the case of power for terrestrial uses, this phase shall assess the viability of terrestrial solutions comparable to the most recent space based solutions as proposed by NASA, the ESA/DLR SE&U study and in Japan (ISAS, NASDA). No new space based systems shall be developed during phase I, but the fully calculated ones shall serve as reference. Special attention shall be given to specificities of the European situation. The power levels proposed in the NASA Fresh Look Study and the ESA/DLR SE&U study range from several hundreds of MW to several hundred of GW, depending on the targeted consumer market. In the SE&U study, the supply of about 500 GW, the European need in 2020 was discussed.

In particular, this phase will address the following questions:

1. Provision of base load power:
 - Geostationary solutions as designed by the Reference Study and the Fresh Look Study would provide 24 hours baseload power. In order to deliver baseload power with terrestrial renewable energy plants, located at the same geographical longitude as the consumer, combinations of solar power plants with either other

⁸ NASA; Space Solar Power – A fresh look at the feasibility of generating solar power in space for the use on Earth, *NASA Report* Nr. SAIC-97/1005, 1997

⁹ M. Klimke; *Systemanalytischer Vergleich von erd- und weltraumgestützten Solarkraftwerken zur Deckung des globalen Energiebedarfs*, Doctoral Thesis Universität Stuttgart, DLR Forschungsbericht 2001-12, 2001

¹⁰ Hoffert et al.; Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet; *Science*, Vol 298, p. 981ff, November 2002

renewable power sources available during evening hours and at night (e.g. wind power), or storage capacities seem to be necessary. What would be the most favourable solution with nowadays technology as well as with realistic technology advances in 20 to 30 years, in terms of production and material costs, reliability and risk? How these solutions would compare to the internationally proposed space based solutions for the different power levels studied?

2. Provision of peak load power:

In a first step towards a substantial increase of the power share from renewable energy sources, the provision of only peak load power could be an option. Space based options would then probably be global and in LEO or MEO.

- How these space-based options would compare to terrestrial options in terms of production and material costs, reliability and risk? The comparison shall be on power levels assessed for the peak load power models of the space based solutions.

3. Combination of terrestrial and space based systems:

Until now, no thorough assessment has been published, focussing on potential synergies between terrestrial and space based architecture concepts.

- Could an appropriately chosen space based system supplement terrestrial options?
- How would a space based system compare with terrestrial CO₂-free solutions (e.g. wind, storage)?

Consumer electricity load peaks in Europe are occurring in the morning and evening hours, with some variations between the different months of a year. Solar power electricity generation capacity usually peaks in the early afternoon hours (all local time).

- Can the choice of an appropriate orbit significantly reduce the required storage capacities of terrestrial power plants?

4. Viability of the concepts in terms of energy return times

All in all, the energy balance of a terrestrial and space based system has to be largely positive, assuring a clear net energy return over a reasonable lifetime. Preliminary ESA internal assessments taking into account only orders of magnitude show a positive net energy balance over the projected lifetimes of currently proposed systems.

- A more in depth assessment shall provide reliable values including realistic maintenance and operations energy costs, material processing and production energy costs as well as servicing energy demands for some of the NASA Fresh Look Study and the ESA SE&U study designs. These values shall be compared to values for terrestrial power plants.

It is important in this phase, that – for the first time – research groups focussed on terrestrial renewable energy plant solutions work closely together with researcher working on space based solutions, linking the research communities and providing the assessment additional credibility.

5. Legal aspects of solar power satellites

- Solar power satellites constitute in any proposed design a project of worldwide attention and global dimension. The novelty of such an endeavour implies a lack of understanding of the legal implications, calling for an early stage assessment of

the legal aspects under some of the important branches of law most probably concerned: international law including space law, environmental law, treaties on disarmament and frequency allocations in the frame of ITU. The possibilities and possible restrictions caused by the existing legal framework shall be assessed during the first phase of the Programme.

Power from space for space exploration

Power availability is one of the crucial enabling elements of space exploration. Until now, nuclear power sources are required for longer planetary surface missions as well as missions further than Mars. As outlined in section 1.2.3, recent progress in space solar power satellites and wireless power transmission however suggest that applications of space solar power systems may provide an alternative to nuclear power sources in certain cases.

6. Solar Power Satellites as viable power sources for space exploration and applications
 - Based on existing data, it shall be assessed whether solar power satellites could provide a viable alternative in the timeframe under consideration for robotic and human exploration, with special emphasis on Mars (~2030).
 - In space solar power generation capabilities at power levels suitable for in space applications shall be assessed.
 - A technical feasibility and resulting system architecture level trade-off for three specific space mission scenarios shall be done:
 - large, high power needs for earth orbiting spacecraft,
 - interplanetary missions beyond the Martian orbit,
 - Martian and lunar surface missions

The Agency is considering organising workshops and seminars to accompany the work undertaken in this phase. Each of the workshops would aim to elaborate on specific aspects of the different options for energy-generation, -transportation and storage. Experts in the respective fields will provide insight into the state of research and foreseeable developments. The workshops are intended to be open to interested participants, especially from the European Network on SPS.

The entire Programme has also to be seen in the frame of the ongoing efforts in the field of energy research in the frame of the 6th European Framework Programme (6th FP) on Research. In this respect, the participation in the Expression of Interest (EoI) ESSPERANS (Annex B) to create a European Network of Excellence has to be taken into account throughout the entire Programme. More specifically, the work addressing tasks 1 to 6 shall include paragraphs especially targeting the aims of ESSPERANS.

2.1.2 Study Structure

Tasks 1 to 4 as listed above will be addressed within a single study. In order to ensure the objectivity and widely accepted credibility of the comparisons and tradeoffs included, the study will probably be managed neither by advocates for terrestrial solar power solutions nor space solar power solutions but by an “independent” entity, that should ideally lead a consortium regrouping space and terrestrial competence, thus including research groups

having demonstrated research, development and implementation experience with terrestrial solar plants and research groups with demonstrated experience in the study of space solar power satellite solutions.

A mid-term review is foreseen to show approximately three month after kick-off the first results of a preliminary comparison of space and terrestrial power generation solutions.

For the assessment of the legal aspects of solar power satellites (task 5), academic expertise in pure space law as well as telecommunications law deems required. The study of legal aspects of solar power satellites will be performed by a research centre focussed on these branched of international law. This study would last approximately 3 to 4 month and is quite small scale.

The study addressing task 6 of the first phase will be done separately. It will be approximately the same length than the study dealing with tasks 1-4. This study requires thorough knowledge of space power needs, especially for exploration mission and competence in laser generation as well as laser power transmission.

Based on the results of the studies addressing tasks 1 to 6, a more general assessment will be made by the ESA Technical Officer assisted by the Topical Team. This assessment will take into account among others the following important parameters:

- technical risks,
- strategic and political risk,
- innovation generation capabilities,
- potential ecologic impacts,
- spin-off capabilities,
- potential health effects.

Several studies should be undertaken in close cooperation with the Advanced Concepts Team (ACT) at ESA. The ACT is supposed to be integrated in the work and data exchange should be kept between the ACT and the contractors.

2.2 PHASE 2: SYSTEM ARCHITECTURE LEVEL TRADE-OFF

2.2.1 General Description

In phase II, a limited system architecture level trade off study shall be performed. The study shall build upon the outcome of the NASA Fresh Look Study and the ESA SE&U study. It shall take into account the legal framework, determined during phase I. The main focus of the trade-off study shall be on

- new and innovative concepts, offering substantial improvements to existing models,
- the identification of technology areas,
 - that demand further research and development for SPS to be realized,
 - in which European industry and research institutes already have demonstrated international leadership,

- that show near- to mid-term potential in other areas than SPS;
- the establishment of roadmaps specific to the identified priority research areas,
- the possible integration of SPS concepts into future energy systems (e.g. hydrogen based energy systems),
- *the assessment of the potential role of SPS concepts for space exploration,*
- the identification of one to three most promising concepts.

The exact content of the work to be performed under phase II depends heavily on the findings during phase I. ESA internal assessments however come to the conclusion, that space based and Earth based systems with comparable power delivery capabilities range in the same order of magnitude in terms of overall cost. The further description of phase II is based on these findings, which still have to be either confirmed or confuted during the detailed assessment of phase I.

Despite the inherent global nature of most of the SPS concepts for power for Earth use, the trade-off study shall focus on the specific European situation. In case of potential promising synergies between ground and space based power plants as outcome of the phase I of the Programme, these aspects shall receive special attention. The overall energy pay-back times shall be assessed for all forwarded concepts and compared to other CO₂ emission free solutions.

In case of potential promising possibilities of solar power satellites to substitute nuclear power sources for exploration missions, a system-architecture level trade off shall identify two to three concepts fulfilling the requirements.

Phase II will start at earliest after the mid-term review of the study on terrestrial alternatives scheduled during phase I of the Programme and it shall last about 6 months.

2.2.2 Study Structure

Without anticipating the outcome of Phase I, the work performed under Phase II will most probably have to be performed in a single study, lasting about 6 month.

2.3 PHASE 3: TECHNOLOGY FOCUS AND DEMONSTRATOR MISSION SELECTION

2.3.1 General Description

Phase III of the Programme will focus on the few technology areas, identified during phase II. Promising, feasible near term, Earth or space based demonstrator missions will be identified and two to three feasibility studies for such missions will be elaborated in coherence with the roadmap elaborated during Phase II.

These feasibility studies will also include the assessment of possibilities of international participation. Priority will be given to overall cost and expected technological benefit. Taking into account the European participation in the ISS programme, the possibilities the ISS is offering and the international nature of both the ISS and future SPS activities, special attention will be given to potential demonstrator missions making use of the ISS.

The feasibility studies are planned to be done up to a level of details that will allow at the end of Phase III, based on the elaborated documents, to initiate if appropriate such a demonstrator mission. For this purpose, these feasibility studies will provide in addition to the technical details enough managerial and economic information to allow for such a decision to be made under regular conditions. The feasibility studies should be furthermore performed in a way that is suitable to smoothly follow-on with a phase-A study at the ESA CDF facility.

Phase III should last about 7 to 8 month.

At the end of phase III, the different studies will be assembled into a consolidated document representing the European strategy in the field of solar power satellites, including the feasibility studies, which will serve as decision basis for further activities.

2.3.2 Study Structure

The Structure under Phase III is most likely to be performed in a single study, addressing all the aspects listed above.

3 PROGRAMME ORGANISATION

The entire Programme is subdivided into several individual studies that will be in themselves consistent and individually handled. They will furthermore integrate into the entire plan as outlined in this document and be part of the final Programme report at the end of the Programme period.

3.1 PROGRAMME SCHEDULE

The Programme is divided into three phases:

- PHASE I: GENERAL VIABILITY PHASE

Duration: 5 to 6 months

Studies: Assessment of comparable terrestrial solutions (for Europe) with possible synergies from space systems
Legal aspects of SPS
Assessment of space solar power options for space-to-space power transmission applications

- PHASE II: SYSTEM ARCHITECTURE LEVEL TRADE-OFF

Duration: 6 months

Studies: System Architecture Trade-off Study
Integration of space systems with terrestrial solar plants (optional)

- PHASE III: TECHNOLOGY FOCUS AND DEMONSTRATOR MISSION SELECTION

Duration: 7-8 months

Studies: 2-3 feasibility studies for near-term demonstrator missions for selected identified technology priorities for Europe

3.2 STUDY STRUCTURES

Each individual study shall have the following study milestones:

#	Milestones
SM1	Kick-off
SM2	Mid-term Review
SM3	Study Final Presentation

3.3 PROGRAMME MANAGEMENT

3.3.1 Programme Plan (PP)

This Programme Plan (PP) is intended to define and organise all the activities within the Programme.

The PP will provide the overall guideline for the entire programme and serve as reference frame for the individual studies. The PP is prepared by the ESA Technical Officer and made available to all members of the European Network for Solar Power Satellites as well as any other interested party or contractor. It is kept updated by the ESA Technical Officer as necessary throughout the programme. Major changes will be discussed with the Topical Team.

3.3.2 Topical Team (TT)

In order to assist the ESA Technical Officer in the management, organisation and project controlling of the Programme, a Topical Team has been established. It comprises individuals with demonstrated expertise and experience in the field of Solar Power Satellites.

3.3.3 Studies

Each study will have an individual Statement of Work, a Study Organisation Plan and clearly defined milestones and deliverables. The organisation of the activities to be performed within this contract will be detailed by the Contractor into Work Packages. Studies have to fulfil the overall Programme requirements as outlined in this document. A close cooperation between the contractors and the ESA Advanced Concepts Team is planned.

3.3.4 Deliverables

At the end of each phase, it is planned to issue intermediate reports by the ACT, assembling the different studies performed during the phase.

The detailed list of deliverables of each individual study will be laid out in the studies SoW. The final reports of the studies will be available in MS Word format, following some basic formatting rules determined by ESA in order to facilitate their integration.

3.3.4.1 Technical Documents

The language to be used for all study deliverables will be English. All documents should be delivered in MS Word format.

3.4 PROGRAMME DURATION

The tasks identified in this programme should be accomplished in not more than 2 years.

ANNEXE A.1

OVERVIEW OF MAJOR STUDIES ON SOLAR POWER SATELLITE

The general idea to make use of solar irradiation in space as energy source was present already in the very first publications about space exploration by the Russian visionary and father of modern space travel Konstantin Tsiolkovski. The idea was proposed in a concrete way in 1968 by the Czech-US engineer Peter Glaser. Some smaller studies and experiments validating parts of the concepts were undertaken, leading to the exhaustive NASA/DoE “Reference Study” of 1977-1981.

One of the major experiments was the wireless transmission of about 30 kW over a distance of 1.54km at 2.388 GHz made by JPL at the Goldstone facility in the Mojave Desert. The measured μ -wave transmission efficiency was as high as 82%, leading to an overall system efficiency of about 52%. Motivated by the oil crisis, the reference study addressed several different aspects of SPS and came up with the “reference design”: a constellation of 60 geostationary satellites each beaming 5 GW via μ -wave to designated ground stations around the globe. Most importantly, it concluded that there were no principal technical “show-stoppers” to the concept.

In 1981 two studies, “Electric Power From Orbit: A Critique of a Satellite Power System”¹¹ and “Solar Power Satellites”¹², restated the principal feasibility but came also to the conclusion that the urgent energy need from SPS does not exist, that there were several major technical challenges still to overcome and that the economic basis was too thin for the time being. Following this assessment, the DoE/NASA working group was dissolved.

Activities continued on a system level basis and smaller scale. Some important experiments were undertaken especially in the field of wireless power transmission via μ -wave (Canada, Japan). In the early 1990s, interest in SPS rose on an international level. Following the first SPS symposium 1986 in Paris, the SPS91 in Paris, the SPS92 in Rio in the frame of the UN Environment and Development summit, as well as the inclusion of the power sessions in the annual IAF congresses demonstrate the international dimensions. Following the 1979 study

¹¹ National Academy of Sciences, Electric power from orbit: a critique of a satellite power system; National Academy Press, 1981

¹² Office of Technology Assessment, Solar Power Satellites; Report OTA-E-144, 1981

by the Japanese electronics research society, and recognizing the strategic importance for the archipelago, the Japanese industry and trade ministry MITI integrates the ISAS working group on SPS at the end of 1980s.

Between 1995 and 1997, NASA conducted a new “complete” SPS study, the “Fresh Look Study”, followed in 1998 by the Space Solar Power Concept Definition Study and in 1999 by the “Space Solar Power Exploratory Research and Technology Programme (SERT). In parallel, Canada initiated the “Canadian Space Power Initiative”, Japan studied the Fresh Look options for Japan in 97 and 98 before initiating a dedicated own SPS programme managed by NASDA in 1999 and to be finished with the end of the Japanese fiscal year in 2003. In Europe CNES restudied the concept issuing in 1999 the report “*Nouvelles perspectives des centrales solaires spatiales et de la TESF*”. Solar power from space was also studied within the ESA “Space Exploration and Utilisation (SE&U)” study by DLR, developing the European Sail Tower SPS concept.

Table 1: Important SPS dates, studies and conferences (preliminary).

1925	idea the Konstantin Tsiolkovski	Russia
1968	SPS proposal by Peter Glaser	USA
1968-72	NASA (+DoE, ETA, NRC, NAS) SPS evaluation	USA
1975	JPL WPT Goldstone experiment, Mojave desert	USA
1978-80	“Concept Development and Evaluation Programme” (CDEP) by the Energy Research and Development Administration (ERDA)	USA
1979	DoE/NASA Reference Study	USA
1979	ESA Study “European Aspects of Solar Power Satellites” ¹³	ESA
1986	SPS86 Symposium in Paris/Gif sur Yvette	F/international
1987	Project “Stationary High Altitude Relay Platform (SHARP)” for WPT by Canadian Ministry for Communication	Canada
end 80s	Lunar soil utilisation studies include SPS	USA
1990	inclusion of Space Power sessions into IAF conferences	international
1991	SPS91 Symposium in Paris	F/international
1992	SPS92 Symposium in Rio de Janeiro	Brasil/international
1992	ISU SSP’92 Design Project on Solar Power Satellites	Japan/International
1993	Project ISY-METS, WPT and space plasma interactions	Japan
1993	WPT93 Conference, San Antonio	USA
1993	UNESCO World Solar Summit, Paris	F/international
1994	KEPCO and Kobe Univ. Study on terrestrial WPT appl.	Japan
1995	WPT95 Conference, Kobe	Japan/international
1995-97	NASA “Fresh Look Study”	USA
1997	SPS97/WPT97 Symposium, Montréal	Canada
1997-98	The Canadian Space Power Initiative	Canada
1998	NASA “Space Solar Power Concept Definition Study”	USA
1998	WPT demonstration at La Réunion	France
1999	ESA Study “Space Exploration and Utilisation”	ESA
1999-01	NASA “Space Solar Power Exploration Research and Technology Programme” (SERT)	
2001	WPT01 Conference, La Réunion	France
2001	Laying the Foundations for Space Solar Power: An Assessment of NASA’s Space Solar Power Investment Strategy, National Research Council	NASA

¹³ Ruth, J., Westphal, W., Study on European Aspects of Solar Power Satellites; ESA-CR 3705/78/F/DK(SC), 1979

ANNEXE A.2

ESSPERANS – EXPRESSION OF INTEREST FOR A NETWORK OF EXCELLENCE IN THE 6TH FP

**Expression of Interest for
An Integrated Project for
Advancing Knowledge on Enabling Technologies for Sustainable Energy
Systems:**

“Energy, Space, Solar Power, Environment: Research Actions for a New Society” :

ESSPERANS

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Rationale

This integrated project aims to address the research priority 1.1.6.1.ii “*Research activities having an impact in the medium and longer term for sustainable development, global change and ecosystems*”. It focuses on new and advanced concepts in renewable energy technologies with a very significant future energy potential for the world and EU energy supply and requiring long term research to make these technologies competitive with conventional fuels.

Its departure point is the following: clean and abundant energy supply for the future is one of the most critical problems facing humanity in the coming decades: first, fossil fuels are “finite” in the mathematical sense, and, new, abundant, clean and renewable future energy sources should be introduced without delay ; second, by ejecting into the Earth atmosphere in about one century a significant fraction of the carbon accumulated during billion years, the equilibrium of the ecosystem is strongly perturbed, and a global and durable solution should be anticipated now in order to stop this trend.

As such, these problems can only be handled by holistic and world scale approaches that require long term research, development and demonstration, as well as mobilising considerable resources, both in expertise and funding. On the other hand, every means to immediately reduce the CO₂ emissions and the energetic dependency on fossil fuels should be introduced. This is particularly crucial for the EU energy supply independence.

Therefore, the integrated project ESSPERANS is conceived as a cluster of research actions which should be developed following a roadmap leading to the introduction at the Earth scale of clean, abundant, and renewable energy sources.

Objectives

They are listed below in a kind of chronological order, from medium term to long term objectives; this means that the integrated project ESSPERANS should organise research activities in a progressive way following a technology roadmap to be established in order to develop the enabling technologies at the right time and if possible before (or in collaboration with) USA and Japan. The predicted time frame goes from today to 2040. The cluster of planned research actions aims to:

- A] Develop means to immediately reduce the use of fossil fuels
- B] Develop the use of Decentralised Energy Resources
- C] Develop direct hydrogen combustion technologies
- D] Develop CO₂ capture and recycling technologies for very large power systems

- E] Develop clean and cost effective production methods of hydrogen
F] Develop clean and cost effective production methods of electricity

[Objectives A, B, C] To contribute to achieve these objectives, which are relatively medium term objectives, ESSPERANS will develop research actions on high efficiency Gas Turbines, focusing on

- Gas turbine fuel flexibility, hydrogen / natural gas mixtures-hytane, catalytic combustion, high efficiency hydrogen driven gas turbines
- Liquid biofuels, gasification of biomass to produce H₂-rich clean syngas
- Hydrogen combustion technology for gas turbines

These research actions could be developed by consortia such as AFTUR (Alternative Fuels for Industrial Gas Turbines, a 5th FP project starting in Fall 2002) composed of 21 partners from 8 member states, and supported by EuMIGT. The AFTUR consortium could be enlarged to other partners, from industry (including energy utilities) and academia.

Research actions on hydrogen combustion technologies will rely on the expertise of European combustion science and technology community, organised in EU member states as sections of the International Combustion Institute (head quarters in Pittsburgh, PA, USA) and also co-ordinated by the Federation of the European Sections of the Combustion Institute, which also include the sections of Russia, Poland, Hungary and Turkey.

It is important to mention here the potential synergy between priority 1.1.6 on Sustainable development, global change and ecosystems, which is addressed in this integrated project and the priority 1.1.4. on Aeronautics and Space, through the development of safe H₂ combustion technologies for the implementation of ultra-clean aircraft using liquid hydrogen as fuel (project Cryoplane).

Another research action should focus on

- Fuel Cell /Gas Turbine hybrid systems for decentralised energy production.

To conduct this kind of research activity, the integrated project ESSPERANS should co-operate with Integrated Projects on Fuel Cells especially those active on high temperature fuel cells (SOFC).

[Objective D] To achieve this objective, the integrated project ESSPERANS aims to develop research actions on

- CO₂ recycling to produce CO and Oxygen or to produce CH₄

In order to avoid the difficult problem of CO₂ storage after its capture from large scale fossil fuel plants, research actions on recycling CO₂ should be developed in collaboration with integrated projects on CO₂ capture. Several options should be investigated and demonstrated, such as :

- Catalytic transformation of CO₂ into CO and Oxygen.

The technology for such transformations exists; they should be evaluated in co-operation with appropriate NoEs and Integrated Projects. Again, the potential synergy with priority 1.1.4 on Aeronautics and Space should be mentioned as the capture and transformation of Martian CO₂ into oxygen and CO are today important R&D topics both for ESA and NASA, for Mars mission using in situ resources.

- The captured CO₂ could be transformed into CH₄ by processing it with H₂.

This process obviously needs cost effective hydrogen production (see below).

[Objective E] Clean and cost effective production of H₂.

Hydrogen is expected to become a major energy vector, opening important industrial markets on hydrogen production, storage, transportation, its direct combustion or use in fuel cells. Cost effective and clean production technologies will play a crucial role in this process. Electrolysis (or dissociation) of seawater with photovoltaic electricity appears to be the best option. This needs low cost solar cells such as hybrid solar cells and the use of Earth or Space Solar Energy for electricity production (see below). This research action should be conducted together with NoEs and Integrated Projects active in PV technologies.

[Objective F] Clean and cost effective production of Electricity

For the clean and abundant production of electricity in the long term, the only sustainable approach is the transformation of solar energy into electricity. There are two sub options: Earth based or Space based, including their combination. Space Solar Energy necessitates low cost space access technology and therefore should be conducted together with Integrated Projects in space propulsion and transportation.

One of these options is to install very large PV farms on orbit or, for example, on the Moon, to convert the electricity into microwaves or laser beams and to beam it down to Earth, to orbital platforms or to spacecraft, for example, to provide power to satellites, or to spacecraft using electric propulsion for orbit change or planetary missions. Giga-watt scale space solar electricity production units are envisaged and their global feasibility has been assessed in the US by NASA and DoE and in Japan by METI. The European Space Agency has also recently acknowledged this development. Europe should not be absent in the development of this long term technological challenge, which may well be the ultimate solution for sustainable energy supply to the Earth for the next century.

As above, this objective can induce a strong synergy with the priority 1.1.4 on Aeronautics and Space, especially to promote a large market for low cost and/or reusable launcher technologies, therefore to support the European space transportation industry and to support the European satellite industry by providing abundant power in orbit. Furthermore, research on the Space Solar Energy objective is expected to induce several innovation spin offs, e.g. in wireless power transmission and laser technologies, where European SMEs can be major players. In this area strong co-operation with Russian institutes should be sought of.

Need and Relevance

Priority 1.1.6 clearly indicates that new and advanced concepts in renewable energy technologies are needed and that focus should be put on technologies with a significant future energy potential and requiring long-term research integrated at the European level.

The Integrated Project ESSPERANS aims to start innovative research to advance knowledge for enabling technologies to set the path for future clean and abundant electricity and hydrogen production. As explained above, ESSPERANS is conceived as a cluster of projects to be implemented progressively, in order, first, to reduce the use of fossil fuels for energy production and, later, to introduce the intensive use of solar energy for poly-generation of electricity and hydrogen.

This ambitious objective necessitates the integration of several expertise domains, activities, and resources. The time scale of such a project is several decades. Therefore, the European mobilisation is mandatory to continuously pursue the efforts and also to make the necessary links with similarly ambitious projects in preparation in the USA and Japan.

Scale of ambition and critical mass

As stated above, the ambition of ESSPERANS is to contribute to solve the energy problem of Europe, to sustainable world scale development and to the control of global change. It consists of several steps that should contribute cumulatively to this objective.

The progressive introduction of hydrogen (or more and more hydrogenated fuels) as fuel into gas turbines is one such objective. This will increase the potential of distributed production of clean energy, together with innovative technologies such as CO₂ capture and recycling and fuel cells. The mastering of the combustion technologies for advanced industrial gas turbines will also open the way to the use of hydrogen in car engines and aeronautics.

Clean and abundant production of hydrogen from seawater is another objective. Poly-generation of hydrogen and electricity from solar energy is the ultimate objective. Intermediary objectives are the development of low cost and/or reusable space launchers, the mastering of the development of large orbital structures by robotics, the development of wireless power transmission and high power laser technologies.

Europe has the capability to assemble the critical mass to advance simultaneously on these cumulative objectives and ultimately attain the global objective of clean and abundant energy production for sustainable development. Since mid-nineties, USA (NASA and DOE) and Japan (METI) are considerably increasing their efforts towards the same direction, in particular in hydrogen combustion technologies and space solar energy. The European Union should not be absent in this long term challenge and should be able to demonstrate its ability to develop and implement such large scale and ambitious projects.

To achieve this objective, a strong and long term effort should be devoted to support Industries and Research Centers, on extended multidisciplinary system studies together with basic and applied R&D programs, especially in the fields of hydrogen combustion technologies, low cost space propulsion and transportation systems, high efficiency solar energy conversion and transmission systems. The Consortium ESSPERANS is aiming at contributing to this objective.

Integration

The integration aimed at by ESSPERANS is multi-faceted. Multidisciplinary integration is mandatory regarding the diversity of expertise needed to achieve the cumulative objectives. Integration of various activities is needed to progressively develop the necessary knowledge basis to implement the aimed technologies and to demonstrate them. Advanced hydrogen fuelled gas turbines are one example of activity integration; development and demonstration of solar space power technologies are another example. ESSPERANS will also very strongly contribute to the strengthening of the European Research Area by promoting connections and co-operation between various research and technology communities active in areas such as combustion and propulsion, gas turbines, hydrogen production, storage and transport, fuel cells, space transportation, solar cells, wireless power transmission, lasers, etc. In order to sustain such a multi-faceted project in the long term, it is also mandatory to train students in innovative, multidisciplinary and multi-cultural curricula (including social, financial, risk and international law aspects of large scale projects), to the establishment of which ESSPERANS will contribute.

The names and the expertise areas of the partners supporting this EoI, at this stage, are listed below.

PARTNER	COUNTRY	TYPE	AREAS of EXPERTISE	CONTACT
CNRS-EPEE-LCSR	FR	REC	Energy, Combustion, propulsion	I. Gökalp
CNRS-Aérothermique	FR	REC	Space Propulsion	J-C. Lengrand
CNRS-CORIA	FR	REC	Energy, Combustion, propulsion	M. Ledoux
EADS-LV	FR	IND	Space transportation	H. Hollanders
CEA-RIPAULT	FR	INS	Fuel cells, solar cells, Energy	A. Varoquaux
IFP	FR	INS	Gas Turbines, Energy	E. Lebas
AUXITROL	FR	IND	Sensors, Aeronautics	O. Legras
Prospective2100, EDF	FR	ORG	Energy	L. Deschamps
Univ. Cath. Louvain	BE	UNIV	Combustion, Emissions	J. Vandooren
Univ. Beira Interior	PT	UNIV	Combustion, Propulsion	J. Barata
Tech. Univ.Lisbon	PT	UNIV	Energy, Combustion, Hydrogen	M. Carvalho, M. Heitor
CRES	GR	INS	Biomass, Energy	C. Panoutsou
Agri. Univ. Athens	GR	UNIV	Biomass, Energy	G. Papadakis
Cardiff Univ.	UK	UNIV	Combustion, Energy, Biomass	N. Syred, T. Griffiths
Queen Mary &WC	UK	UNIV	Combustion, Gas Turbines	C. Lawn
UMIST	UK	UNIV	Combustion, Energy	Y. Zhang
Cranfield Univ.	UK	UNIV	Combustion, Energy	J.B. Moss
ENEA	IT	INS	Energy, Combustion, Gas Turbines	G. Giuseppe
Univ. Naples	IT	UNIV	Energy, Combustion	A. Cavaliere
CNR-IRC	IT	REC	Energy, Combustion	F. Beretta
Univ. Roma Tre	IT	UNIV	Energy, Biomass	G. Cerri
Univ. Firenze	IT	UNIV	Energy, Gas Turbines	F. Martelli
Nuove Pignone	IT	IND	Gas Turbines	H. Bornemann
ESA	NL	ORG	European Space Agency	M. Lang
Univ. Twente	NL	UNIV	Energy, Combustion, Biomass	J.B. Kok, E.A. Bramer
KEMA	NL	ORG	Energy, DER, Combustion, CO2	P. Welberg
KTH	SE	UNIV	Energy, Combustion, Gas Turbines	T. Fransson
TPS Termiska Processer	SE	IND	Energy, Biomass, Hydrogen	L. Waldheim
Univ. Lund	SE	UNIV	Energy, Combustion, Gas Turbines	M. Alden, T. Torisson
Univ. Zaragoza	ES	UNIV	Energy, Combustion	J. Ballester
CIEMAT	ES	UNIV	Energy, Solar	P.L. Garcia-Ybarra
Hungarian Acad. Sci.	Hongrie	REC	Energy, Combustion	S. Dobe
RIAME	RU	INST	Space Propulsion	V. Kim