11 Target Manufacturing Capability and Delivery

11.1 Scope

Target manufacturing and delivery for HiPER is discussed in two main themes: 1) technical issues relating to production and 2) associated issues, such as infrastructure and target design specification. Aspects of commercialisation are also considered.

This work has been compiled through coordination of European academic groups, the CEA groups in France associated with Laser Megajoule, and the private sector (General Atomic Inc.) in the US.

It should be noted that the baseline target design is only at the conceptual stage whose details have not yet been fully established. This is because the design will be informed by the upcoming experimental programmes on European, US and Japanese facilities.

The above themes can be addressed by establishing a sufficiently broad target fabrication capability including particularly close and efficient integration with the physics, modelling and experimental work streams during the period of this project. Furthermore work on new materials to produce high efficiency targets will be similarly embedded and integrated within the target fabrication activity.

11.2 Work package objectives

The task ahead has been broken down into the following areas:

1) Generate design specifications for HiPER targets (IFE and complex experimental targets). Specifically for IFE targets to examine high gain solutions, including the use of new materials.

2) Assess technical feasibility of producing all target types, prioritised through analysis of the risks to timely delivery.

3) Identify risks for target production and propose methods of risk reduction.

4) Assess European capability to fabricate the majority of targets for all HiPER programmes, specifically identifying infrastructure which needs to be put in place, including timescales.

5) Propose structure for target fabrication activity that is maximally integrated with all relevant work packages to ensure rapid response to evolutions in design (modelling) and experimental programmes.

11.3 Technical background

The HiPER programmes will require a wide range of solid targets for “high energy density” physics studies. Such targets can be classified into three (overlapping) types: a) high gain for IFE science, b) high gain for IFE scale-up to a commercial reactor programme, and c) science programmes.

In general type a) targets will almost certainly have a thin-walled microballoon component with an internal layer of solid deuterium or deuterium/tritium ice. For some targets the layer may be carried on a foam. It is anticipated that significant improvements in yield can be achieved by advances in foam materials and technology. Also many of the type a) targets will have a cone inserted through the side of the microballoon. Initial experiments, for example in electron or proton transport, will not require the ice layer, however, cryogenic targets will need to be fielded as the experimental campaigns progress.

Targets of type b) will have the same general features as type a) but the emphasis will be towards demonstrating high number scale-up capabilities, simplifying the physics design and relaxing the specifications whilst maintaining robust performance.

Targets of type c) will encompass a wide range of morphologies and materials including multi-component targets and multi-element target clusters. Also a range of type c) targets will be used to experimentally establish parameters required for (iteratively) designing target types a) and b). In addition, theoretical and experimental analysis of target debris, shrapnel and radiation production will be integrated into the target design and fabrication activities.

Because IFE targets are central to the HiPER project and since they are the most technically challenging to make they will be discussed in more detail here.

11.4 Specifically identified challenges – risk identification

Extensive discussions have been held to identify specific issues (across all target types) where there is uncertainty or risk at a level which needs to be specifically addressed. The results are summarised in the following table:

1	Cryogenic capability
1.1	Cryogenic layering of non-spherical target (solid ice and foam)
1.2	Tritium Handling
1.3	Capsule/cone joint at cryogenic temperatures
1.4	Cryogenic target (transport and) insertion
2	New/novel materials
3	Capsule and cone production
4	Metrology
5	High number scale-up
6	Modelling of materials and processes to inform fabrication
7	Target design/positioning to reduce debris
8	Range of targets for science programmes

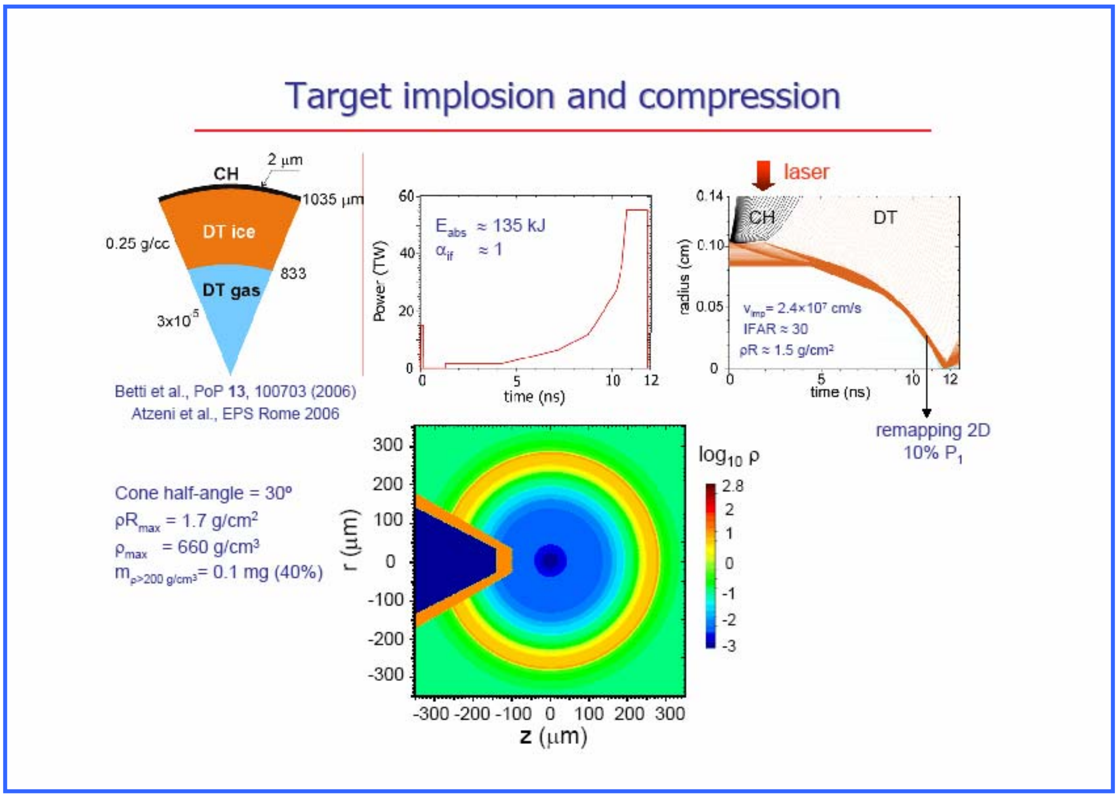
Shading key

Established (but challenging) technology
Technology requiring significant innovation for HiPER

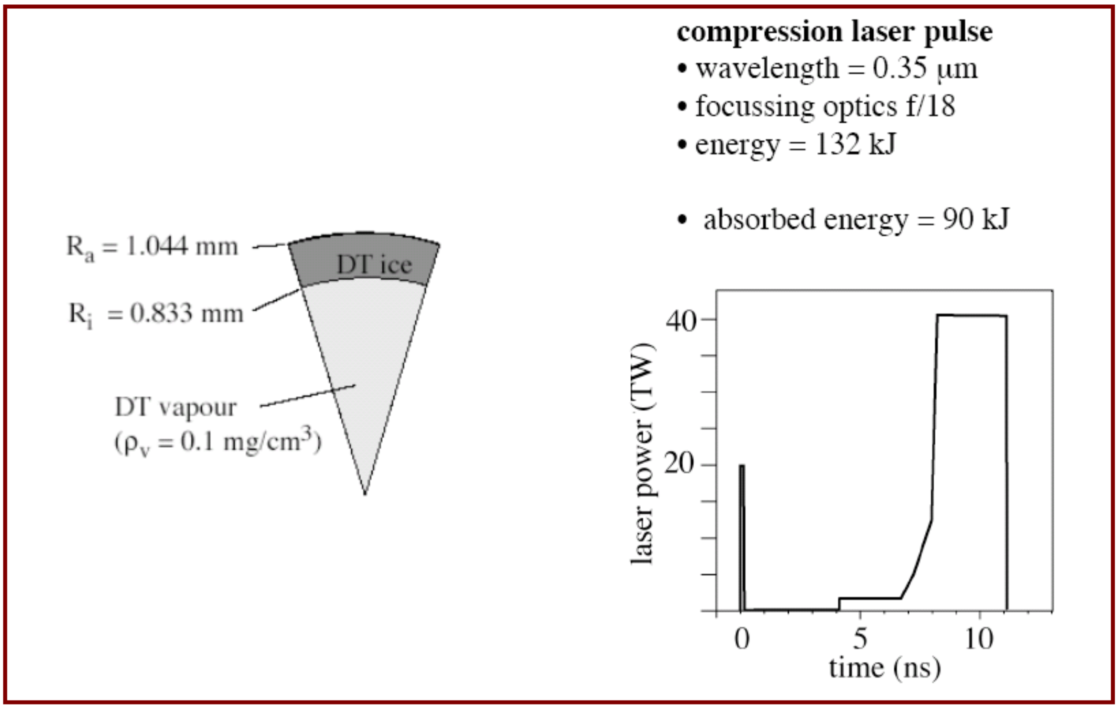
11.5 IFE target baseline design specification

At this stage in the HiPER project a detailed design specification for fusion target(s) has not been finalised and indeed the design will be iteratively refined as the experimental programmes progress. However, two proposals for conceptual baseline designs are explored here to illuminate discussion of target fabrication issues. These are shown schematically below:

Baseline IFE Target #1



Baseline IFE Target #2



11.6 Existing target fabrication capabilities relevant to HiPER

The current capabilities for target fabrication that have been considered for HiPER fall into three communities:

- Academic European laboratories and universities.
  Currently within the EU there are a number of centres of expertise in microtarget fabrication. The centres are distributed throughout the EU and are currently not well co-ordinated since historically there has been no need. In 2006 RAL co-ordinated two target fabrication workshops:
    - An EU Target Fabrication workshop with Laserlab (Framework 6) funding. The meeting was attended by 15 delegates from 12 institutions across 8 countries. The workshop assessed current EU target fabrication facilities and capabilities and proposed collaboration mechanisms which are currently being introduced.
    - A HiPER Target Fabrication workshop which was attended by 16 delegates from 12 institutions and 9 countries. Discussion mainly focussed on identifying specific technical challenges for HiPER targetry (reported above) and how to address those challenges, both technically and in terms of developing sufficient infrastructure within the EU.

- CEA France.
  As part of the Laser Megajoule (LMJ) programme there are two main centres of expertise:
    - Specifically for cryogenic capability the Low Temperature Laboratory of CEA/Grenoble (SBT) has, since 1994, been in charge of the conceptual design and prototype production of cryogenics for LMJ.
    - The Valduc laboratory which has a comprehensive capability for fusion target manufacture

- US infrastructure: General Atomics Inc. and Lawrence Livermore National Laboratory
    - The Chemistry and Materials Science Directorate of Lawrence Livermore National Laboratory, through the NanoScience Laboratory, has an established (experimental and multi-scale modelling) programme in the development of new materials that should significantly increase the efficiency of high energy density targets and lead to increased yield in IFE targets.
    - GA (General Atomics Inc.) is a US-based commercial company which produces a large variety of microtargets and components for high power laser experiments. The company has access to a wide range of techniques and expertise including close integration in cryogenic target delivery programmes. GA also has experience in examining feasibility and commercial issues associated with the scale-up of fusion target production for a power production programme.

Although European researchers have significant strength in the physics research related to fast ignition, the capability in Europe for the *production* of complex targets is scarce and/or limited to defence laboratories. A key task for the preparatory phase must therefore be to establish a credible route to securing an effective capability in a timely fashion.

Some technologies developed at LMJ and NIF could clearly be directly extended to HiPER and the future IFE power production programmes. Collaboration with experienced groups will significantly decrease the risks for HiPER as well as reduce the length of many R&D programmes.

To enable the required level of target fabrication for HiPER it is essential to increase collaboration across EU within civilian programmes to develop core capabilities and to collaborate with facilities and companies that have relevant experience during this preparatory phase.

HiPER target fabrication will deal with a range of significant technical challenges. Target fabrication also occupies a place within HiPER from which, when optimised, significant utility can be achieved by providing target delivery in a highly time responsive mode to design modifications and on-going experimental feedback.

11.7 The role of European civilian institutions

The academic institutions will bring a fresh perspective that should offer an excellent opportunity to look for novel targetry solutions both in terms of operational organisation and technical challenges. All targetry issues for HiPER can be analysed from a fresh perspective and look to propose innovative and cost-saving solutions. A principal goal for HiPER is to establish a route for commercial IFE and so such an approach could yield considerable IP and financial gain.

Lead tasks for the academic European institutions:

Task Description	Deliverables
Lead, specify and co-ordinate HiPER target fabrication activities.	Progress according to delivery plan.
Analysis of European infrastructure requirements to enable all necessary aspects of HiPER IFE target fabrication.	Report specifying actions required to install all necessary infrastructure including timescales.
Analysis of fabrication capabilities which will be required for HiPER science programmes targets.	Report describing current capabilities and identifying required additional capabilities.
Examine new materials, especially for improving yield of IFE targets.	Report on production, characterisation and suitability of new materials.
Study foam layering of shells.	Report on production, characterisation and suitability of layered foams.
Detail tritium handling procedures.	Document summarizing tritium handling procedures.
Computational modelling of cone-shell target layering including target and thermal (shroud) environment. Modelling of structural integrity.	Summary of results of thermal and structural modelling.

11.8 The role of the CEA laboratories

CEA has extensive experience in producing cryogenic targets which are similar in design to HiPER cryogenic targets. The experience includes the full range of devices required for placing a cryogenic target in an interaction chamber, such as target positioner, layering shroud, shroud remover, cryostats and ancillary equipment.

The main responsibility for CEA will be to propose designs for fielding HiPER cryogenic targets by modifying and extending established technologies.

Task Description	Deliverable
Design a system to field HiPER cryogenic targets based on modifying existing technology for both fill tube and permeation. Cryogenic infrastructure: design of cryostats, DT fill apparatus, target positioner, thermal shroud and shroud remover; mK control of target fill and layering. Specify permeation facility and technologies for transport of cryogenic targets.	Produce report covering all aspects of cryogenic target production for HiPER including infrastructure.
Produce cost estimates for HiPER single shot cryogenic capability.	Breakdown of costings for delivering single shot cryogenic capability.

Cross-cutting themes:

- Link to chamber design workpackage (vacuum must be less than 10^{-6} mb to avoid condensation on outside of shroud).
- Link to tritium handling subtask
- Integrate all packages with modelling, materials science and physics groups.

11.9 The role of GA and LLNL

The collaboration which already exists between UPM (Spain) and LLNL in the development of new materials for increasing the efficiency of high energy density targets will be extended for application to HiPER IFE targets.

Task Description	Deliverables
Propose plausible methods for mass-production of cone-shell targets including mass-production of; capsules and foam shells, capsule hole cutting, assembly and layering. Perform laboratory-scale demonstration of key techniques.	Report covering suggested methods for mass-production. Report on scaled demonstration of mass-production techniques including confidence analysis for full scale up.
Analyse high repetition rate injection and tracking techniques including target placement accuracy.	Report on injection and tracking techniques including assessment of accuracy acceptability and repercussions for HiPER design.
Cost analysis for continuous high repetition rate (cryogenic) IFE target production and insertion including; optimised solution(s) and infrastructure (such as a target manufacturing plant).	Report detailing cost analysis for high repetition rates.
Examine new materials, especially for improving yield of IFE targets.	Couple to European institution work