Executive Summary:

The FP7 E-ELT Preparation Programme (hereinafter referred to as E-ELT Prep) complemented the Detailed Design (Phase B) of the 42-m diameter European Extremely Large Telescope (E-ELT) project, conducted by the European Southern Observatory (ESO) on behalf of its 14 Member States. The E-ELT Prep had a total budget of about EUR 6.8 M, including a EUR 5 M contribution from the European Commission (EC) under its 7th Framework Programme and ran for two and a half years, from 1 January 2008 to 30 June 2010. The E-ELT Prep activities were conducted by ESO as a mono-partner, in collaboration with 26 third party institutes in 8 ESO Member States.

The aim of the E-ELT Prep Work Packages (WP) was to help preparations for a 2010 decision by the ESO Council to give a go-ahead for building the Facility, concentrating on a number of not directly design-related, yet crucial items. Important aspects were to establish efficient coordination with other similar projects world-wide (WP2), strengthening of the system engineering process within the E-ELT Project Office (WP8), evaluating financial mechanisms (WP7) that may support the funding of the EUR 1000 M plus Facility and developing close links with critical industries (WP3). Optimizing the science output of the E-ELT is paramount, and the E-ELT Prep aimed to fully develop the Design Reference Mission (WP4), and provide a blueprint for scientific access to the telescope data output (WP5). Large multi-national teams of astronomers and engineers in the ESO community were organized in networks (WP6) to develop the powerful and innovative instruments that will be at the heart of the E-ELT scientific capability. Eight instrument concepts were studied by the community in the frame of the E-ELT Detailed Design. Upgrade paths (WP9) were considered to establish new enabling technologies that will permit upgrading of the first light observing capabilities, e.g. for Earth-like exo-planet detection, study of the first lights in the early universe, etc. The E-ELT Prep activities started in early 2008 and by the end of the contract in June 2010, with minor deviations, all of the 23 project milestones were completed and all of the 72 deliverables accomplished.

Project Context and Objectives:

The aim of the E-ELT Prep Work Packages (WP) was to help ESO to be fully prepared for the 2010 decision by the ESO Council to give a go-ahead to build the Facility. Important aspects were the setting up of a proper internal structure of the E-ELT Project Office (WP8), the full financial package (WP7) to build the EUR 1000 M plus Facility, close links with critical industries (WP3), and to establish efficient coordination with other similar projects world-wide (WP2). Optimizing the science output of the E-ELT was paramount, and the design reference mission (WP4) and a detailed blueprint for science access to the facility (WP5) were developed. Finally, the basic R&D knowledge for crucial upgrades to the E-ELT initial observing capabilities, e.g. for exo-planet detection, study of the 1st light in the universe, etc., was developed (WP9) and the ESO community organized itself in networks (WP6) to be fully prepared for its future crucial role in building powerful and innovative focal instruments for the Facility.

Key to the E-ELT endeavour was the high level of involvement and commitment of the ESO member states throughout the life cycle of the E-ELT, making it a facility "for the community and by the community". This was invaluable for the establishment of a comprehensive Science Case and the development of crucial enabling technologies. It was also the vehicle by which the complex post-focal instruments will start their respective development phases.

The FP7 E-ELT Preparation Programme comprised a number of transnational activities for which EC support was integral in establishing the appropriate framework to conduct them. Apart from the "E-ELT Prep Management" (WP1), these were the following:

WP2 - ELT International Cooperation - had the aim to explore the possibilities of involving external partners for the E-ELT development and link it with the other planned ELT projects to optimize their combined scientific output. Under this WP, efficient coordination at the project managers' and engineering level was established between the E-ELT and the - technologically close - North American TMT project and discussions were ongoing with a number of possible international partners for the E-ELT project. One example is the adoption by the TMT project of a baseline primary mirror segment size for their telescope that is the same as for the E-ELT, thereby opening a big potential market for the European industry.

WP3 - E-ELT Industrial Links - had the aim to maximize the links with the industrial partners and establish policies on connected issues, e.g. public relation and knowledge transfer. Under this WP, a number of industrial relations activities were undertaken. Visits were organized to industrial partners in Austria, Czech Republic, Denmark, Finland, France, Italy, Netherlands, Portugal, Spain, Sweden and UK. The report of the publicity associated with ELT astronomy and the final draft report of the E-ELT standards documentation were produced and delivered.

WP4 - Developmemt of the E-ELT Design Reference Mission (DRM) - had the aim to develop a comprehensive set of observing proposals and simulated science data, in particular to maintain the alignment of the E-ELT Project with its community's scientific aspirations. Under this WP, the set of simulated data for the DRM was developed and analysed to determine whether the science goals were met. The second workshop on the E-ELT Design Reference Mission and the Design Reference Science Plan (DRSP) was held at ESO on 26 - 28 May 2009. The final report on the DRM, which presents the majority of the work of this WP, was delivered on 30 June 2010.

WP5 - E-ELT Science Access - had the aim to define scientific requirements on key areas of the interaction between science users and the E-ELT facility. Under this WP, the final reports on the four key areas where the science users will interact with the E-ELT facility, namely a) the user access to the facility, b) the data processing, c) the data mining, and d) the observing conditions prediction tools were prepared and delivered.

WP6 - Networks of Nodes of Expertise - had the aim to help the European institutes with prime expertise in the technologies crucial to the Upgrade Paths WP 09000, to coordinate their work and co-opt newly formed groups inside and outside ESO member states. Under this WP, the four important networks on:

a) advanced cryogenic techniques for ELT observatory,
b) techniques for high contrast high angular resolution imaging,
c) ultra-accurate wavelength calibration techniques, and
d) wide-field adaptive optics assisted imaging were established with a total of twelve research institutes (including ESO).

All of the four networks have basically reached their two main goals, namely to review the status of the topics and to propose/plan a path for the future developments with the inclusion of scientists and engineers from institutes beyond the original nodes. All of the four final reports were delivered.

WP7 - Financial Mechanisms - had the aim to explore external public and private funding possibilities. Under this WP, funding scenarios for the E-ELT construction were developed. The main result being the loan offered by the European Investment Bank (EIB) of up to 300 M EUR towards the construction of the E-ELT. This is outlined in more detail in the final report on possible external financing partnerships.

WP8 - Project Structure and Planning - had the aim focused on the preparation of the organization of the E-ELT Project structure.Under this WP, software tools were developed and data bases populated to handle the E-ELT Project Office needs in the areas of requirements management, interfaces and process flow for the next construction phase. All of the six reports were delivered.

WP9 - Upgrade Paths - had the aim to pursue by design and prototyping the development of the advanced Instrumentation and Adaptive Optics subsystems required to further enhance the E-ELT Facility scientific capabilities 5 to 10 years after start of operation. Under this WP, enabling technologies were developed by fifteen research institutes (including ESO). Four important R&D areas for bringing advanced observing capabilities to E-ELT instruments were explored:

a) Ultra-accurate wavelength calibration techniques,
b) Multi-object Adaptive Optics (MOAO) concept validation
c) Development of a high-contrast imaging toolbox and

d) Multi-conjugate Adaptive Optics (MCAO) performance evaluation.

The following significant technical results were achieved:

Regarding topic a), the Fabry Perot calibration system was integrated and successfully tested. The radial velocity stability is fully compliant with the initial specifications. The cryostat was built in the laboratory and tested.

Regarding topic b), the full end-to-end analysis and error budget of the MOAO-based integral field spectrograph were performed. The Variable Curvature Mirror was developed and validated. The EAGLE MOAO demonstrator CANARY using natural guide stars was designed and manufactured. The metrology concept for EAGLE was validated.

Regarding topic c), the Fresnel Free Experiment (FFREE) was designed and developed. The Self Coherent Camera was designed and developed. The development and experimental validation of the Four-quadrant Phase Mask (4QPM) and the Apodized Pupil Lyot Coronographs (APLC) and of the Speckle Nulling concept on the High Order Test-bench (HOT) were carried out. The development and breadboard experiment of the Slicer Spectrograph for high contrast imaging and of the Lenslet Pupil Apodization experiment for high contrast imaging was performed.

Regarding topic d), the full end-to-end analysis and error budget of the MCAO module were performed. The conceptual design of the MCAO module was prepared. The LGS WFS breadboard was designed and developed.

This is outlined in great detail in the activity report for WP9. All documents and reports (deliverables WP9-D1 through WP9-D35) were prepared and delivered.

Project Results:

WP2 International Cooperation

The ASTRONET infrastructure roadmap released in November 2008 rated the E-ELT as the ground-based 1st scientific priority for European astronomy together with SKA, the E-ELT being first in scheduling terms. This resulted from an independent assessment by representatives of the community under guidance of the funding Agencies, and is thus not an E-ELT Prep result per se. It nevertheless deserves to be mentioned here as obtaining this highest level priority was an absolute prerequisite for seeking a decision in 2010, by largely the same funding Agencies, to build the Facility. Collaboration with TMT has been most effective. This resulted in the finalisation of a formal agreement with TMT to exchange information on site testing, mirror segment and AO. For example the production of mirror segments is going to require huge industrial involvement with significant impacts on costs and timelines and this commonality is expected to have a very positive effect on both projects.

WP3 Industrial Links

Standards:
Activities on the safety conformity and industrial involvement in the review of the standards and procedures were proposed. The project worked together with a product assurance company in the member states (ISQ/Portugal) to review the standards and processes of the project and the detailed report was used to update a variety of standards.

Mechanical:
The mechanical standards for the E-ELT project are established and documented. They are now adopted as a baseline for ESO as a whole. The first issue reported in the mid-term review has been updated and is available on the project web site (WP3-D5c).

Electrical / Electronics:
The electrical standards described in the mid-term report have been adopted by the project.

Software and control system standards:
The telescope control system standards have been adopted as per the mid-term report. A control engineering handbook was produced and is available on the project web site (WP3, D5b). These are critical components of the design and prototyping phase. The standards and manuals provide the basis for many of the contracts (not all as, for example, design and manufacturing of mirrors is unaffected). The standards are also used in the upgrade of Paranal subsystems to the E-ELT standards, a critical component of the ESO strategy of field tests of the E-ELT control system.

WP4 Design Reference Mission (DRM)

The major effort of this WP was to develop and analyse simulated data for the DRM. This involved using scientific input, in the form of observing proposals, from the Science Working Group (SWG) and technical information about the telescope, atmosphere and instruments in order to produce simulated data for each of the DRM science cases. The data were then analysed to determine whether the science goals are met.

The set of science cases that were studied are:

S3: From giant to terrestrial exoplanets: detection, characterization and evolution
- Direct imaging of terrestrial and giant exoplanets
- Detection of New Earths

S9: Circumstellar disks
- Imaging the planet-forming regions of circumstellar disks

S5: Young stellar clusters (incl. Galactic Centre)
- Characterizing the lowest mass freely floating objects in star forming regions
- The Centers of Massive Dense Young Clusters: deep ELT infrared imaging and 3D spectroscopy
- Giant-planet-mass objects in the Large Magellanic Cloud

G4: Imaging and spectroscopy of resolved stellar populations in galaxies
- The Resolved Stellar Populations of Elliptical Galaxies
- The Chemo-Dynamical Structure of Galaxies
- First Stars relics in the Milky-Way and satellites

G9: Black holes / AGN
- A Survey of Black Holes in Different Environments

C10: The physics of high redshift galaxies
- The Physics and Mass Assembly of Galaxies out to z ~ 6
- High resolution imaging of high redshift galaxies

C4: First light - the highest redshift galaxies
- The highest redshift galaxies at z > 6

C2: A dynamical measurement of the expansion history of the Universe
- Monitoring the redshift-drift of the Lyman forest - a direct measurement of the dynamical evolution of the Universe.

The individual case reports are being made public on the web site at http://www.eso.org/sci/facilities/eelt/science/drm/cases.html. The full set of reports make up the final DRM report (WP4, D3).

Deliverable documents:

(a) An initial assessment was carried out of the impact of site choice on science (deliverable WP4-D1), delivered in January 2009. The assessment consisted of a table showing which DRM cases are sensitive (or not) to which site parameters (such as

suitability of the site for adaptive optics, background emission at various wavelengths, and the hemisphere in which the site is located). Such a table can be used to assess, for example, which science cases would become difficult, or even impossible, to carry out if the site were particularly weak in a one or more parameter.
(b) An assessment on the impact of instrumentation choices on the DRM (deliverable WP4-D2) was delivered in September 2009. The report included a summary of the specifications of the instrumentation studies at the time (shortly after the end of the instrument Phase-1 reviews), and a table comparing these specifications with the requirements of the science cases in the DRM. The conclusion of the report was that most of the DRM science cases could be carried out with the instruments under study. Possible exceptions were the high-redshift galaxy cases (C10-2, C10-3 and C4-1), that require larger fields of view than envisaged, both in terms of imaging FOV and patrol field in multi-object spectroscopy modes. However it was noted that this capability can be recovered to some extent by multiple pointings, although this will of course impact the time required to complete these programs.
(c) The final DRM report (WP4-D3) contains the methods, results and conclusions of the DRM simulations described above. The work was carried out under scientific guidance of the SWG. The report is a comprehensive document that demonstrates the feasibility of the key science cases for the telescope. It will be used as a supplement to the ELT construction proposal and key results from the simulations are being used to quantify the science case.

WP5 Science Access

Task 1: Analysis of the user interfaces required for proposal and observation preparation, and proposal submission
E-ELT users will face challenges which differ significantly from those presented by existing large telescopes. The report reviews how user interaction with the E-ELT can be optimized in three areas: preparation of the proposal; preparation of the observations; and assessment of the data quality. A number of specific requirements have been identified and reviewed, including the need for: a fully integrated proposal-handling system; an end-to-end observations simulator; and a record, for each exposure, of enough information to allow Point Spread Function (PSF) reconstruction. We list the requirements we've identified for optimizing interaction between the E-ELT and its users in these three areas specified in our remit (CR = critical requirement, HR = high-priority requirement):

Integrated Proposal-Handling System

CR 2.1 - Sharing of data between different stages of the process (proposal-writing, appraisal, scheduling etc.)
CR 2.2 - Expert system within each component of the process (e.g. proposal submission, end-to-end simulator), to streamline interactions with the user
HR 2.3 - Tutorials, e.g. multi-media walk-through
HR 2.4 - High level of human interaction (helpdesks).

Proposal-Preparation Tool

CR 3.1 - End-to-end observations simulator

CR 3.1.1 - Analytical estimate of the AO-delivered PSF, together with full simulations of the PSF for a few standard setups / conditions
HR 3.1.2 - Full simulation of the AO-delivered PSF for arbitrary configuration and conditions
HR 3.1.3 - Simulated configuration information and calibration data to accompany simulated data, to allow the latter to be processed using the standard pipelines
HR 3.1.4 - Library of typical astronomical targets (spectra, spatial information etc), with options for user to define own targets
HR 3.1.5 - Prediction of observing overheads
HR 3.1.6 - User-configurability of the modelling parameters used by the end-to-end simulator, e.g. to calculate the PSF
HR 3.2 - Tool to view technical information from previous proposals.

CR 3.3 - Tool to search for guide stars
HR 3.3.1 - Tool should also be able to search for calibration targets
HR 3.4 - Tool (or interface) to search archive for previous observations of the target/s with the E-ELT
HR 3.5 - Integrated tool for checking observing constraints
HR 3.5.1 - Tool to prepare finding charts and/or present pre-existing information about a target
HR 3.5.2 - Tool to define observing constraints imposed by the moon and 37 other objects
HR 3.5.3 - Tool to plot airmass vs. date
HR 3.5.4 - Tool to show lunar phase as a function of UT and date
HR 3.5.5 - Tool to estimate the probability that the required observing conditions will be met, on any given night.

Technical-Appraisal / Scientific Assessment

CR 4.1 - Recording of results from technical appraisal and scientific assessment.
CR 4.2 - Access control, to define who can see the results from technical appraisal and scientific assessment.
CR 4.3 - Automation of the technical-appraisal process, as far as is possible, e.g. via the end-to-end simulator.

Observing Preparation

CR 5.1 - Focal-plane setup tool
HR 5.2 - System of access control for observing-setup parameters, to allow some users to specify values of parameters which are usually set only by observatory systems / staff.

Assessment of Data-Quality

CR 6.1 - Empirical measurements of data quality, to accompany the observed data
CR 6.2 - Detailed record of system configuration, from atmosphere through to detector, for each observation
HR 6.2.1 - The configuration information should include a record of the WFS data, as a function of time during the observation, which is detailed enough to allow reconstruction of the AO-delivered PSF.

CR 6.3 - It should be possible for users to download from the observatory whatever calibration and quality-control information are relevant to the observations, but not provided with them
HR 6.4 - Tool for plotting observatory quality-control data measurements against time.
HR 6.5 - The data shown in the quality-control plots should be downloadable in common formats (e.g. text table, csv file) so that users can plot the parameters against each other.

User Interface

CR 7.1 - The various user interfaces must minimise the amount of effort expended by users to reach their goals, and minimise the opportunities for mistakes to be made, by meeting the criteria identified in the report.

Task 2: Definition of the capabilities that the ELT-specific processing pipelines should provide.

For several months, several experts belonging to the main organizations all around the world were contacted and provided a first-hand knowledge of the state-of-the-art in the field. In order to better illustrate specific requirements that could arise in the future, the eight planned first generation candidate instruments for the E-ELT were addressed in detail, considering all the observing modes and their corresponding requirements. For all the instruments we have considered calibration requirements, data reduction, intermediate products, science ready products, data volume and conclusions.

The main conclusions of the work are the following:

- Reliable data pipelines increase scientific return. This includes planning software and sequencing, optimized data reduction pipelines, data distribution and archives. The project will seriously benefit if the software is available from the beginning.
- Pipelines should be scientific-validated data pipelines.
- A modular and extensible approach using open standards, object-oriented technologies and the use of agile methodologies will promote rapid development.
- Full development of error propagation techniques is identified as a new contribution very promising.
- The involvement of the astronomical community in the process of software development would be highly desirable.
- The current set of instruments considered for E-ELT do not imply revolutionary observing modes or techniques so some reusing of existing algorithms will be possible.
- The data processing will benefit of being considered as a software development process. Previous experience provides several lessons already learned from previous projects (code repository, minimization of branches, auto-organization, reuse, ...).
- There are several lessons learned from previous pipeline developments (scripting support, simulators, ...).
- The pipelines have to be open to the emerging Virtual Observatory initiative.

The document lists and reviews a minimum set of requirements for any E-ELT data reduction pipelines. There are high-level requirements (public, extensible, parallelizable, documentation, scripting, operating system flavours, ...), execution and deployment requirements, time requirements, memory requirements, logging and alarm requirements, provenance requirements, data representation and storage requirements and quality control requirements among others. From these requirements some guidelines can be extracted (for example, python was identified as the scripting language with more potential).

The report presents also a review of the available astronomical domain resources, including formats and alternative software methodologies. In this sense the decoupling of data reduction and data persistency has several advantages identified. Strong support is again for the reuse of algorithms and functionality among the different pipelines.

Task 3: Analysis of Virtual Observatory requirements on ELT data, and of further requirements on Virtual Observatory tools

As a huge data producer, the E-ELT will need to use VO technologies from the very beginning in order to honour the principle of "maximise scientific return": The quantum leap forward this project represents in terms of discovery potential, demands also a step forward in the way the data is shared once the proprietary period is over.
The questions addressed have been studied in detail and the conclusions we have arrived at can be summarised as follows:

VO standards to be developed:

- The most important VO data access protocols (SIAP, SSAP, TAP and VOTable) have reached a mature stage and can be used for E-ELT data.
- However, there are several observing elements that need further standardization efforts, namely:
- Integral Field Spectroscopy: In the Virtual Observatory, there is not yet a standard way of both querying and modelling data cubes. Preliminary modelling work and tools have already been developed.
- Adaptive Optics, Coronography and Polarimetry: No standard data models have been defined yet in the VO for these types of observations.

VO tools to be developed or upgraded:

The current set of VO tools should be enough for a basic manipulation of nearly all the data formats the E-ELT will provide. Nevertheless, we can foresee the evolution of the existing tools and the emergence of new ones for similar purposes. This competition will likely converge into better tools by the time the E-ELT is in operation.

By using middleware software (e.g. SAMP), existing VO applications could be combined, hence reusing their functionality. This could open the possibility of developing on a reasonable schedule specialized applications if needed.

Requirements the VO should put on the E-ELT output products:

Although E-ELT VO services will be implemented as a translation layer on top of internal data representation and processing infrastructure, VO standards impose a set of good practices (e.g. restricted set of Unified Content Descriptors) that could be fruitfully translated in the internal representation of the project data, also easing the mapping between this internal representation and the VO products.

Task 4: Definition of the capabilities of the required weather prediction tool

Different aspects related to the weather conditions have been analysed:

Satellite and synoptic data analysis

We analysed the most relevant meteorological parameters available from local instrumentation and satellite data in the most relevant sites suitable for large modern telescopes. We have investigated a wide variety of topographic and climatic conditions: a steep oceanic island (La Palma), a rather flat plateau covered by trees (Mt. Graham), and a number of desertic peaks located in middle-northern Chile (La Silla, Paranal, Toloncha r).

We have correlated the classical meteorological parameters (temperature, humidity, pressure, wind speed and direction) with the observing conditions, in particular with the seeing. The most relevant result is the high sensitivity of the seeing to the thermal conditions quantified in terms of vertical gradient, combined with the wind speed. We concluded that the prediction of the outside temperature and temperature variations is crucial for the quality of the observations within the limits indicated in our study.

A detailed study of dust data available at TNG at La Palma was carried out. It revealed that:

a) The average content of dust at La Palma during the year is comparable to other sites;
b) There are episodes of dust storms with a two order of magnitudes, or more, increase of the dust concentration, in winter and in summer, almost equally distributed, but with a higher dust concentration increase in summer;
c) The average extinction during the dust storms is 0.2 mag. in V;
d) The typical dusty layer altitude is about 5 km above the site;
e) The particles affecting the visual absorptions are mainly the big ones (above one micron) in spite of their lower density compared to the submicron ones.

We studied also the correlation of the dust extinction with the aerosol index measured by TOMS satellites, in particular by Earth Probe. There is a rather low correlation, with dusty episodes missing in the satellite data and vice versa. We concluded that the 12 hours average difference between the satellite measurements and the night time observations, and the specific topography of the island could be among the most important reasons for the lack of correlation. The wavelength used by the satellite is a very crucial point because it determines the altitude weighting function of the measurements.

Analysis of the impact of dust on IR observations is in progress. There is apparently no long-term trend in the dust storms above La Palma.

We determined the statistical fraction of clear nights from GOES12 satellite at La Palma and Mt. Graham using direct brightness measurements. We have compared the near IR data at 6.7 and 10.7 micron (B3 and b4 bands) using the two channels independently. At La Palma we found a concordance of 80.7% of clear night for ground and satellite data. At Mt. Graham we found a better agreement (97%) between the heliograph and satellite data. This analysis has been extended to other sites using a more sophisticated procedure based on the correlation of the same B3 and B4 bands of the previous analysis and including also the CO2 band (B6). The flux in these bands is the average over 1 deg. areas that strongly reduce the uncertainty to about 2-3 %. The main result is that it was possible to derive an atmospheric correlation function based on the correlation among the three used bands. We found that the atmospheric correlation function is correlated with the quality of the nights in terms of seeing as shown in Figure 9 above: the worse seeing occurs when the atmospheric function shows variations. In the analysis we introduced the concept of stable nights as the best prediction of photometric nights. We found that Tolonchar appears to be the best site with 77% of stable nights, while Paranal is the best site for clear nights (88%).

Sodium Layer:

Extremely Large Telescopes require the generation of a certain number of Laser Guide Stars (LGSs), which provide the references feeding the various Adaptive Optics Systems (AO). The production of LGSs based on resonant optical backscattering emission from the sodium layer in the mesopause (at an altitude around 90 km) is assumed to be the most feasible technique for this class of telescopes. Besides the constraints imposed by the finite altitude of the sodium layer and the inability to provide global tilt information, other aspects of the dynamics of the sodium layer require its characterization in order to be taken into account in the design and operation of the AO systems.

We have reviewed the current knowledge of the sodium layer focusing on the three main aspects whose proper characterization is crucial for the performance of the AO systems: the abundance of atoms, the layer altitude and thickness (that is directly related to the LGS image elongation due to perspective and the finite thickness of the layer) and the stability of the layer.

The Na abundance:

The quality of the AO correction is mainly determined by the number of photons received at each subaperture in the wave-front sensor (as measured by the signal to noise ratio, SNR). SNR is a critical parameter (and one the led to the choice of LGS to overcome sky coverage limitations of natural guide star based AO). In the case of Na LGS, the number of photons received is directly related to the amount of Na atoms present each moment above the observatory. Other technological aspects also affect the received photon flux, but abundance is going to play a limit role and will determine the laser power requirements. However, the obvious solution to increase the laser emission power is not only a technological challenge: the quantum structure of the Na atoms limits the resonant emission flux and, therefore, an efficient excitation of the atoms is required.

The Na altitude and elongation:

An accurate knowledge of the altitude profile and elongation significantly contributes to improve both the LGS spot profile and the SNR. Recently, Tallon et al (2008; SPIE, 7015) have analysed the wavefront errors obtained with different reconstruction methods as a function of the Na LGS elongation for different reconstruction algorithms in an ideal case, demonstrating the importance of such knowledge. The best reconstruction is with a MAP (maximum a priori) algorithm, which requires that some previous information must be provided (specifically the centroid altitude and the FWHM). That is, an efficient reconstruction is only possible by providing the most accurate Na layer parameters.

The Na layer stability:

Commonly, standard values of parameters are assumed for simulations, such as a perfect Gaussian profile for Na LGSs centred at 90km, with a FWHM of 10 km and a total abundance of ~$2*10^9$ atoms/cm2. However, the Na layer is strongly affected by global and local effects, either seasonal or very short time-scaled, up to milliseconds, which must be taken into account for a correct focus stabilization necessary for a correct AO reconstruction. Many of these effects are latitude dependent or even may be locally governed by other upper-atmosphere phenomena such as auroras or meteor showers. Another frequent phenomenon observed at all latitudes is appearance of sporadic layers (i.e. the sodium layer may spontaneously divide into multiple sporadic layers, usually no more than two, with lifetimes from a few minutes to many hours). The altitude of the layer centroid may change by 5-10 km in a few minutes in such cases. Other non favourable effects include enhanced thin layers, more frequent at low and high latitudes. These very narrow layers have density up to 10 times the normal level, lifetimes ranging from minutes to hours and thickness from a few hundred meters to about 2 km.

Weather and Seeing prevision:

ELTs are very expensive and it is crucial to optimize the observing time in order to produce the best scientific output. Flexible scheduling (i.e. executing each observing program when the conditions are best suited for it) requires the knowledge one hour to one day in advance of what the weather and the seeing will be, both for infrastructure management and to schedule e.g. high angular resolution observations. In this study we used the surface temperature, the surface wind speed, the surface humidity, the surface pressure, the optical turbulence profile and the wind speed profile to generate predictions. Cloud cover and precipitation have not been analysed yet with this model.

The ultimate model would take into account temperature and velocities from mesoscale (100km) down to viscosity scales (1cm), which is today impossible even for the biggest computers. Weather prevision can be reliable on 1km grid scales, using "grid nesting" from global large-scale models (about 50km) down to 1km with a mesoscale type model. Seeing forecast can be inferred from turbulence parameterization, which means that turbulent microstructure should be deduced from atmosphere macrostructure. Turbulence parameterization can rely on different assumptions, like local kinetic energy and vertical scale or local gradient of potential temperature and gradient of the wind speed.

In this study, we used the Weather Research Forecast (WRF) model coupled with global analysis prevision, and we assumed a turbulence parameterization based on temperature and wind speed gradient. In order to compare our model results to real cases, we selected data from the Observatorio Roque de los Muchachos at La Palma where a weather station gave ground meteorology and MASS+ DIMM gave seeing and optical turbulence profiles. Seeing comparison is less convincing than meteorological parameters since better parameterization should be obtained with a much finer grid scale of say 200x200 m2.

In order to implement the software used in this study, a four-processor server was necessary. WRF has been installed, which communicates with a global forecast archive, in real time, and makes a one-day prevision, with a one hour sampling time. We used three sub nesting to reach the highest horizontal resolution of 1km. The full one-day forecast needs about one hour CPU computing time.

WP6 Networks of Nodes of Expertise

The network WP within the Program had the scope to provide a discussion and planning forum of four topics relevant to the upgrade parts. They were complementary and interlaced with the technical studies conducted within WP 9000, with the exception of network on advanced cryogenic techniques which however was related to the overall mechanical and infrastructure design work of the E-ELT. The outcome of the discussions and of the work which has followed is included in the extensive reports which were the main deliverables of the WP.

All of the four networks have basically reached their two main goals: to review the status of the topics and to propose/plan a path for the future developments with the inclusion of scientists and engineers from institutes beyond the original nodes.

WP8 Project Structure and Planning

Requirements management:

The Dynamic Object Oriented Requirements System (DOORS) database being used by the project is now properly populated with the requirements arising from the contracts and the project. The requirements manager has been working actively with all Work Package managers to ingest into the database the individual requirements and to ensure that linking is performed where appropriate. Extensive effort has been put into validating the requirements as established within the database with the actual needs of the project (see project web site, WP8-D6b, Doc. Nr. E-TRE-ESO-313-0673). Furthermore, the DOORS manual was updated and is available on the project web site (see WP8-D6a, Doc. Nr. E-TRE-ESO-313-0072).

The Work Breakdown Structure of the project has evolved during the design process to better reflect the product breakdown as the contractors provide their inputs. The mapping of the work breakdown structure into the database and the use of a requirements management process allows this work to be absorbed into the project structures seamlessly and with confidence that requirements are not lost or links between critical subsystems not cut.

The work breakdown structure is now generated for the construction phase of the project thereby meeting a critical requirement for the FP7 supported activities. The document was updated and is available on the project web site (see WP8-D4, Doc. Nr. E-TRE-ESO-313-0061).

System modelling:

Following on from the early work on system modelling reported in the mid-term report the modelling effort has been focused on following up the control system simulations and the preparation of meaningful requirements for the telescope control system.

System modelling has been developing control scenarios including the various offloads between mirrors in the telescope train and the detailed simulation of the control system. The Technical Interfaces SYSML Report is available on the project web site (WP8-D5). SYSML has been used as modelling language to validate the control system architecture. It has been applied to the higher levels of the control system.

Interfaces:

The work on interfaces has been largely incremental during the second phase of the project. In the first phase the tools necessary for creation of the necessary interfaces were generated and the bulk of the critical interfaces defined. In the second phase the interfaces diagram was populated more extensively and the number of drawings and interfaces largely expanded.

Additionally the management of the Configuration Item Data List (CIDL) was placed on a firm footing with additional tools generated that interface the CIDL with the ESO archiving system.

WP9 Upgrade Paths

Highlight in task 9200:

The Fabry Perot calibration system was integrated and successfully tested. RV stability is fully compliant with the initial specifications by Observatoire de Genève.
The cryostat was built in the laboratory and tested by ESO.

Highlights in task 9300:

- Full end to end analysis and error budget of MOAO based integral field spectrograph by ONERA
- Development and validation of the Variable Curvature Mirrors by Laboratoire de Marseille
- Design and Manufacturing of the EAGLE MOAO demonstrator CANARY phase A
- NGS by University Durham and Observatoire de Paris
- Validation of the metrology concept for EAGLE by UKATC.

Highlights in task 9400:

- Design and development of the Fresnel Free Experiment (FFREE) by LAOG
- Design and development of the Self coherent camera at Observatoire de Paris
- Development and experimental validation of the 4QPM and APLC coronagraphs by Observatoire de Paris and ESO
- Development and experimental validation of the Speckle Nulling concept on HOT by ESO
- Development and breadboard experiment of the Slicer spectrograph for high contrast imaging by University of Oxford
- Development and breadboard experiment of the Lenslet pupil Apodization experiment for high contrast imaging by University of Padova.

Highlight in task 9500:

- Full end to end analysis and error budget of MCAO module by ONERA and ESO
- Conceptual design of the MCAO module by INAF/Bologna
- LGS WFS breadboard design and development at INAF/Bologna.

Potential Impact:

The need for Research & Development programmes:

Historically, progress in the performance of astronomical telescopes and their associated instrumentation has been strongly linked with technological advances. A short list of technologies developed in the 1990s for the ESO Very Large Telescope (or VLT in short), both novel and traditional technologies utilised beyond customary limits and novel combinations of existing technologies, includes: large zero-expansion glass blanks, large metal blanks, the whole concept and arsenal of active optics, a number of cryogenic components, and the whole concept (for ground-based observatories) of an integrated data flow operation, from telescope time request to observing data extraction from a large archive. While some of these developments were initially tailored to their direct use for the VLT project - whose feasibility relied heavily on their successful development and deployment - all are now used well beyond their initial conception.

The EUR 1 billiono E-ELT project similarly features an even larger suite of enabling technologies, first to make it feasible at an affordable cost, but also to ensure that its full scientific potential is realised. This R&D effort started almost a decade ago, with the intention of demonstrating proof of concept and developing the required new technologies in collaboration with industry. The consolidated global expenditure through the design phase will be nearly 100 Million Euros (or 10% of the project's estimated total cost) by the end of 2010. About 25% of the activities were co-ordinated under the aegis of the EC FP6 programme, funded mostly by ESO, industry and academic institutes and supported by the European Commission through developmental programmes the outcomes of which have the potential for wider application in other projects and in other fields.

Pursuing more speculative long-term development programmes is also essential to develop the capabilities that will enable maximum exploitation of the investment in the E-ELT over its lifetime and prepare the ground for future generations of telescopes and instrumentation. ESO's E-ELT is one of several Extremely Large Telescope (ELT) projects under development world-wide, with two competing projects in the United States. The work done in pursuit of the E-ELT will contribute to positioning Europe at the forefront world-wide of future advances, and bring to Europe significant returns in science, technology and industrial contracts - both for construction and from development of spin-out products.

Current status of E-ELT Research and Development:

In the present Phase B (detailed design) of the project, the R&D effort covers in particular the primary mirror optical segments, position sensors and actuators, the huge convex secondary mirror, the telescope dome and structure, and the large first stage adaptive optics system that is an integral part of the telescope. Success of these developments is a prerequisite for the E-ELT to move to the construction phase.

The current programme also aims to demonstrate, by end 2010, the potential for future technological breakthroughs through a long-term approach to development. For example, novel advanced concepts working towards the suppression of atmospheric turbulence through Adaptive Optics (AO) are a must for the E-ELT, whether for exo-planet direct detection with high-contrast extreme AO, establishing the stellar formation history in galaxies with wide-field multi-conjugate AO, or hunting for the first light in the Universe with high-multiplex multi-object AO . Much progress has been made in establishing and understanding these novel concepts, and in building the foundations for an AO toolbox complete with actuators, sensors and real-time computing firmware, according to the exacting E-ELT requirements. Efforts are now ramping up for the development of the multi-lasers and their associated opto-mechanical and detector systems that are essential to access (nearly) the whole sky with the E-ELT facility while maintaining excellent AO corrections. These developments will keep ESO and the many participating European laboratories and industries at the forefront in this high-tech area where they have played a pioneering role since the early 1990s. Furthermore, the close interactions between ESO and European industry built up over the design and development phase contribute to the development of new industrial and commercial capabilities in Europe and the generation of new products that can be marketed under licensing agreements. An example is the work on laser technology carried out as part of the E-ELT Design Phase for which there are now two licences.

Other crucial domains encompass very high performance, yet affordable, large photon detectors covering the whole E-ELT operating wavelength range from the near-ultraviolet to the mid-infrared (a total of 6 octaves) and cryogenic opto-electronic components and robotic systems. As fully experienced for the VLT facility, the planning for the ELT incorporates a rolling R&D programme as an integral part not only of its design and construction phases, but also over the entire operational lifetime of the facility. This is an essential element to allow the facility to keep pace with and adapt to advances in the field and more generally maintain the E-ELT competitiveness on the world stage.

The current VLT 2nd generation instrument programme, which includes a number of research institutes through sizable consortia, is playing an additional major role in developing a number of pathfinders to future E-ELT instrumentation while at the same time bringing state of the art novel observing capabilities to the VLT.

More generally, the E-ELT project benefits considerably from many relevant R&D efforts being undertaken by Research Institutes, in particular astrophysical laboratories, mostly in its Member States, even if not all were initiated to respond to E-ELT needs.

Wider technological impact:

As the long list of newly developed or "planned to be developed" technology shows, ELTs will have (and already have had) a considerable technological impact. What is noteworthy is that these novel techniques and technologies are already being taken up and applied in other fields in ways that were not thought of in the initial planning of the project. Thus, for example, the techniques of adaptive optics are finding application in biological microscopy to improve image quality, and have the potential for greater impact as these new applications are developed further (see http://www.optoiq.com/index/photonics-technologies-applications/lfw-display/lfw-article-display/0470058636/articles/optoiq2/photonics-technologies/technology-products/optical-components/optical-mems/2010/5/microscopy-imaging.html for example).

A further key technology area for the E-ELT is the development and incorporation into the ESO system of sophisticated data reduction pipelines to transform instrument digital outputs into science-ready data expressed in physical units. A large fraction of the E-ELT output is expected to be in the form of Adaptive Optics enhanced images and spectra which are notoriously more difficult to process than standard seeing-limited (i.e. blurred by atmospheric turbulence) data and thus present a significant challenge to the various instrument construction teams that will develop them. The development of specific massive data reduction tools for fundamental research has a history of opening up new parameter space in other fields, such as medical and social science research, enabling analysis of massive data sets in ways that were not previously achievable; and similar lateral benefits can be expected from the developments for the E-ELT.

In order to maximise the societal benefit of the new technologies being developed, an effective and structured technology transfer activity that can make the bridge to fields and applications outside the world of astronomy is necessary. ESO has recently started to establish a formal Intellectual Property (IP) management system in order to respond in a timely manner when potentially patentable technology or transferable know-how appears in the pipeline. In addition to the two licenses for laser technology mentioned above, another patent application has recently been filed for an image slicer; and it is anticipated that more such developments will follow, although the scale and timing is, by the very nature of the work, difficult to predict. The formalisation of the IP management system was prompted by the recognition of the responsibility of ESO to protect the interests of its Member States, the wider European community and the European Research Area (ERA), and to retain the potential for the ESO Member States and Europe to reap the economic and societal benefits of their financial investments and intellectual developments. To the limited extent that elements of IP have been created under the funding from the Framework Programme, this pro-active IP policy also fulfils the obligation to actively seek IP protection for knowledge developed under an EC contract.

Industry/Research Laboratories Networking:

Developing and ultimately deploying the many enabling technologies critically needed for the E-ELT and briefly summarized above is a huge and highly complex endeavour, requiring a number of carefully orchestrated programmes conducted between many Research Laboratories and Industries in ESO Member States and relying on a high level of interaction and communication between them. The majority of these developments have emerged from cooperative programmes between ESO and various ad-hoc consortia, while others were/are done under various EC-sponsored agreements (OPTICON, ELT Design Study & E-ELT Preparatory).

OPTICON , the optical-infrared coordination network involving European Funding Agencies, Research Institutes including ESO, and industrial firms, has provided an umbrella under the FP6 I3 programme for the exploration of a number of seed technologies, especially for post-focal instruments and AO system. The OPTICON FP7 programme will continue this long-term commitment, with engagement but without financial commitment from ESO, exploring e.g. the potential of novel photonic devices to break the present post-focal instruments' tendency to gigantism. This is work that is also of wider interest to astronomy and again demonstrates the interplay between the push to develop technologies for the E-ELT and the drawing of wider benefit to the astronomical community.

OPTICON was also instrumental in kick-starting, in 2003, the development of the Science Case for a European Extremely Large Telescope, with a large participation by the astronomical community. This effort was redirected and expanded 2½ years ago to the formulation of a Design Reference Mission (DRM), a set of nine comprehensive science drivers for the E-ELT backed by extensive simulations to explore the potential power and limits of the facility. The DRM development is conducted jointly by FP6/7 OPTICON and under Work Package #4 of the FP7 E-ELT Preparation Programme led by ESO, with extensive feedback from the Community including several well attended workshops.

In another programme enabled by the EC Framework Programme and engaging a wide community of astronomers in Europe, some enabling technologies for the Telescope major subsystems (dome, structure, main opto-mechanical components, internal adaptive optics...) were developed under the now completed FP6 ELT Design Study. This was coordinated by ESO, and involved many industries and research institutes. Fundamental advances were made that have the potential for application to other telescopes, mainly through prototyping, test-bed experiments and demonstrators in critical domains. As an example, the MAD demonstrator established for the first time (for non-solar astrophysics) both in the Lab and on-sky the validity of multi-conjugate adaptive optics, a key technique to correct atmospheric turbulence in a large field of view.

It should be noted that while all E-ELT telescope sub-systems design contracts have been signed with industrial firms, a number of research institutes are engaged by the firms as sub-contractors or consultants.

The networking of research laboratories extends beyond the E-ELT, in both geographical coverage and time, to the mutual benefit of all involved. The E-ELT technological programme maintains close links with the other competing ELT projects worldwide, and especially with the Thirty Meter Telescope (TMT) project Team, whose technological needs have much commonality with the E-ELT. One key result has been a common choice for the primary mirror segment size; a decision that should greatly help both projects to get this critical component, which has a very small number of possible suppliers worldwide, fabricated in a timely manner and at minimal cost. ESO has also started a technical cooperation and collaboration with TMT, Keck, the Giant Magellan Telescope (GMT) and AURA for the development of sodium laser sources (see below).

The enabling technologies being developed now will be incorporated in successive generations of sophisticated post-focal instruments and advanced telescope systems, complete with sophisticated data reduction pipelines. This will be an ongoing endeavour, with the prospect of bringing together institutes and industry in long-term relationships to support and develop not only the technology programmes themselves but also increase mutual awareness and understanding. In the preparatory phase, four

Networks of Research Institutes on topical technological expertise (Advanced Cryogenics, High Contrast Diffraction-limited Imaging, Ultra-accurate Wavelength Calibration, 'Wide-Field' Imaging) related to E-ELT instrument requirements, were organized under Work Package # 6 of the FP7 E-ELT Prep Programme. They included a total of 20 different Institutes from 10 European Nations , plus ESO.

European Industrial Benefits:

The design of the E-ELT as presently being undertaken by ESO involves a large proportion of competitive tendering to high-tech Industries, mostly in its Member States, with a mid-2010 deadline for delivery of the completed designs. ESO has an independent programme of developing industrial contacts across all programmes, and has actively sought out the best that European industry has to offer. Hundreds of firms have been contacted and further follow-up has taken place with the many interested parties. For the E-ELT activity, some support has been provided under Work Package #3 (Industrial Links) in the FP7 E-ELT Preparation Programme.

This deliberate effort to involve as much of high-tech European Industry as possible is pursued not only for the E-ELT's sake, but crucially also to help raise the competitiveness of European Industry in general, and particularly for present and future calls for tenders from other Extremely Large Telescope project Teams, like the North-American TMT and GMT.

Even so, there remain relevant technological domains in which non-European and in particular US Industry has a definite lead. Examples include:

- Infrared scientific detectors, a fundamental staple for post-focal instruments and AO systems;
- Micro deformable mirrors for Extreme AO.

Where the present US lead is such that trying to duplicate these capabilities on the timescale needed to maintain the European lead on the E-ELT would be unrealistic, the E-ELT project team are closely following the US developments, collaborating directly with US industrial firms where appropriate, e.g. in the vital IR detector area and taking their product line in the E-ELT baseline design.

However, as demonstrated above, the active pursuit with European Industries, either through ESO or directly by individual European countries, of promising alternative technological approaches to key challenges has the potential to deliver significant benefits to Europe. These R&D efforts are relatively modest in financial terms - typically a few million Euros per item - and carry quite large failure risks. However, if successful, they could not only deliver advantages for the project in terms of performance, risk mitigation and possibly cost but also have large impacts outside the narrow field of astronomy by enabling new capability in European industry.

In these and other relevant technological domains, the improvements arising from the investments in developmental work made by ESO in the VLT and E-ELT in particular are yielding results, such that Europe is edging ahead of the competition in these fields to take over leads traditionally held by the US. Examples include:

- wavefront sensors that will be the best in the world, being developed by ESO working with Selex UK (infrared) and e2V UK (optical);
- second generation sodium lasers, now licensed to TOPTICA (Germany) and generating wide international interest;
- major contracts for deformable mirrors that are stimulating designs, working with Microgate & ADS (Italy) and CILAS (France).

European-wide Education and Public Outreach Impact of the E-ELT

The Need for Education and Public Outreach:

We live in an era of unprecedented scientific progress, and in a world increasingly dominated by the resulting technological developments that directly influence the quality of people's daily lives and the future economic prosperity of countries. At the same time, major scientific (and philosophical) questions about ourselves and the world we live in remain open, intriguing and challenging scientists at the cutting edge and the general populace alike.

Information and awareness about science; understanding of its capabilities, limitations and impact; and appreciation of the link between fundamental scientific research and the technological advances that power modern society is therefore essential to facilitate educated decisions on a whole range of key issues. The role of science communication is to provide such information, with the aim of raising the baseline appreciation of science; allowing people to learn about exciting developments; and bringing achievements in science into the public eye and to the attention of important stakeholders such as politicians and industry.

Although ESO's primary focus is naturally the requirements of its Member States, its activities in this area extend to the wider community across Europe (and beyond), in recognition of the wider responsibility and the importance of science understanding in the modern world.

Astronomical discoveries in general, including the ones that will come out of the E-ELT, can easily excite the general public's innate curiosity about the Universe we live in. For an organization like ESO which is operating and building major observational facilities (the VLT and ALMA) and planning the future E-ELT, the often quite dramatic pictures and videos that such facilities generate provide rich opportunities to reach a wide audience. ESO's planning for the E-ELT includes particular attention to how best to capitalise on this opportunity.

As flagship projects financed by society at large, and competing for funding in national economies, large infrastructures, such as ESO's telescopes or the particle physics facilities of CERN also have a responsibility to provide to the public an appreciation and understanding of the uses to which their funding is put, particularly in a financially difficult climate.

The "social contract" between ESO and its funders is not complete until its scientific results and achievements are communicated. To address such matters ESO has set up a strong Education and Public Outreach department (ePOD) to cover the twin communication-education aspects across ESO's entire portfolio, including in particular the E-ELT, as well as to provide services for ESA's part of the Hubble Space Telescope.

Societal Impact

Impact on the Host Country for the E-ELT:

The E-ELT baseline site, Cerro Armazones in Chile, was chosen on the basis of stringent performance-related requirements including extreme dryness, absence of clouds and low night-time temperature. The site will be an extension of ESO's Paranal site, home of the VLT.

The construction of such a major new Research Infrastructure, even on a site adjacent to a well-established facility, will have a major impact on Chile although the co-location with the existing facility means that the effect, though substantial, will nevertheless be incremental rather than revolutionary. During construction phase it is likely that local industry will play a significant role at either the contractor or sub-contractor levels, especially in the civil engineering area.

In the following operational phase, there will be a requirement for both long-term employment of skilled manpower for observation preparation and execution and for maintenance and upgrading of the facility, together with involvement of local industries and services (e.g. for catering). A detailed estimate, based on past experience, and detailed operations plans that analyse the activities of running the observatory hour-by-hour, gives a total on-site annual operation expenditure for the observatory of 30 M per year, about half of which spent in the host country. The existing facilities have already led to the forging of cultural links at many levels between ESO and Chile. As host to ESO and a number of other observatories, Chile has guaranteed access to a range of astronomical facilities. This has been a significant factor in the development of astronomy in Chile (for which some funding has been provided annually by ESO), and more specifically in astronomical, technical and cultural developments in the regions where the observatories are located. This direct independent relationship between ESO and Chile complements the current broad cooperation agreement on Science and Technology between the European Union and Chile.

Impact on Member States:

A major part of the socio-economic E-ELT impact will be felt within Europe, as has been the case for the VLT and continues to be the case for ALMA. The majority of the expenditure in the construction phase will be in Europe, in the high-tech industries of the ESO Member States. In partnership with the dense network of Astrophysical Research Institutes partly managed by the ESO Member States through their respective funding Agencies, these will develop the E-ELT and continuously upgrade its capabilities during its expected lifetime of at least 40 years. The long-term impact on Member States' industry can be seen very clearly from the massive benefits to Europe's mirror manufacturing capability at REOSC and Schott as a result of ESO's investment in the VLT. The ERA is also the location of ESO's core user constituency, which besides being the ultimate end-users of the facilities through their observations and analysis of data and publication of results are also key players in the design and development of new telescopes and instruments, providing essential scientific input and feedback at all stages from the initial concepts to the mature operating facility. These are crucial ingredients in bringing new astrophysical concepts to fruition, ensuring immense economic, scientific and technological dividends from the E-ELT for Europe.

Wider Global Impact:

The E-ELT will be the first of the new generation of super-telescopes, and will be a flagship project not just for Europe but also for the whole of astronomy. While ESO's approach for the development of the E-ELT aims at maximizing its spin-offs in the Member States, and to a significant extent in Chile as well, the E-ELT's overall impact will, as already outlined, reverberate worldwide. One area of particular impact globally is that of astronomical data use by astronomers of every location and nationality. After a short proprietary period, all E-ELT data will be accessible on-line, complete with associated calibration data and in a form (e.g. with associated physical units) that is essentially ready for scientific exploitation. As is already the case for the other ESO telescopes' data, any user on his/her computer will be able to access E-ELT data seamlessly through the same interface as other archives from most major observatories, whether ground or space-based. Since a large fraction of astronomical investigations require collection of data on a set of astrophysical objects from a number of different infrastructures, e.g. in order to get multi-wavelength information from the full gamma rays to low radio frequencies range, this is an essential ingredient to boost scientific efficiency. This is also expected to be a big help - if surely not self-sufficient - to enable scientists in developing countries to perform cutting-edge astrophysical research.

In the Design Phase, the ESO community and its counterparts around the world have increased collaboration as they work to develop new technologies and optimum solutions to common problems (e.g. the cooperation with TMT on mirror segment design).

Similarly, existing contacts were strengthened and new ones opened up through the co-operation between ESO and other supertelescope design teams in the initial selection and testing in parallel, and measuring the same variables to the same standards, of a wide variety of sites as potential locations of these super telescopes. In the case of Europe, the testing was funded at least in part by the EC. For ESO and its Member States, a further new dimension is opened up by the interest of non-European countries in joining ESO, and the Council has expressed its willingness to consider seriously such interests. ESO is already regarded as world-leading in the current facilities. There is now an increasingly strong prospect that this will lead to Europe, in the form of ESO, leading an intercontinental organisation that will lead the world in scientific and technological achievements for the next several decades.

In addition, the opening up of new avenues of collaboration in the scientific field can be expected to increase interaction with individuals and organisations from non-

European countries in a variety of fields not directly connected with ESO's activities, at a time when such connections are becoming increasingly important for diplomatic and political reasons.

Summary and Conclusions:

Development of the European Extremely Large Telescope Facility is currently nearing the end of the detailed Design Phase, with the actual decision to build expected during 2011. The development of enabling technologies and of the comprehensive science case has already had a significant structuring effect in bringing together individual researchers, laboratories and industrial firms all over Europe within various R&D programmes, including within agreements with the European Commission. The global investment of effort over the last decade, and particularly in the last four years, can be roughly estimated at 1200 person-years: this is quite modest, but has been spread over a relatively small number (< 100) of high-tech laboratories and industries. Similarly, the outreach programme of the E-ELT towards the layman is only just starting, but the project is already becoming quite visible in the media.

Once the construction decision has been taken, the capital investment of close to 1B in the E-ELT project will increase by a full order of magnitude the impact of the project in the three domains covered in this document: technological, educational and economic. In particular, the continuing investment for operating and upgrading the telescope and its suite of instruments is expected to continue at an annual level of 5% of initial capital cost for at least 30 years. The bulk of this expenditure will happen in the Member States; with a significant fraction of the on-site costs directed towards Chile. Besides this purely financial aspect, the E-ELT project is already generating at least pan-European collaborations between scientists and engineers and contributing to a number of technological advances of interest for society.

Finally, as a powerful way to observe the unknown and reveal the wonders of our Universe, the E-ELT will play a crucial role in raising science and technology awareness and appreciation among the non-specialist and the public in general. Even in the target field of astronomy, experience has shown that up to 80% of the discoveries made with a new telescope were not predicted in the original science case - even when all the objectives of that case have been addressed. Nevertheless, the potential cultural as well as scientific impact of even the predicted areas of scientific advances is immense. To take just one example, the direct detection of exo-planets in the habitable zone referred to in section 2.2 above, leading to the possibility of detection of extra-terrestrial life, would unquestionably revolutionise the way in which we see ourselves and our place in the Universe.

The main dissemination activities such as meetings with/presentations of the E-ELT to industrial partners are described hereafter:

- Meeting with industry at SPIE meeting in Marseille (June 23-28, 2008). ESO was strongly represented at the SPIE meeting in Marseille. The stand promoting ESO and the E-ELT was used as starting point to introduce the project to potential industrial partners and to show how the VLT and ALMA were used by industrial partners to promote their high-technology developments.
- Detectors Workshop in Oxford (July 1-2, 2008). At a dedicated workshop in Oxford, the E-ELT was presented to European industrial partners developing detectors. The emphasis was put on the anticipated needs of the E-ELT project for detectors in the optical to mid-infrared.

- Ireland visit (July 31, 2008). A delegation from the Irish government visited the ESO headquarters and was introduced to the industrial return and promotion that project such as the VLT, ALMA and the E-ELT can represent for national industries.
- Meeting with industrial partners at JENAM Vienna (September 8-12, 2008). The ESO stand at the Joint European and National Astronomical Meeting in Vienna was used as anchor point to present the VLT, ALMA and E-ELT projects and the related potential for publicity to industrial partners.
- ASPERA Meeting Brussels (September 29, 2008). The E-ELT project was presented to potential industrial partners attending the Astro-Particles ERA-NET in Brussels.
- Visit to IUCAA, Pune India (October 11-15, 2008). During a promotional visit at the Inter-University Centre for Astronomy and Astrophysics several potential IT partners to European industry were visited and familiarise with the E-ELT project and its potential for publicity.
- Meeting with industrial partners at SOCHIAS, Santiago, Chile (January 14-16, 2009). The E-ELT project was presented to potential industrial partners to European companies in Chile during the annual meeting of the SOciedad CHIlena de AStronomia in Santiago.
- Meeting with industry in Berlin (January 20, 2009). A dedicated full day meeting with potential German industrial partners was organised by the Bundesministerium für Bildung und Forschung in Berlin at which the publicity potential of the VLT, ALMA and E-ELT projects was presented and individual discussion with industrial partners were conducted.
- Meeting with industrial partners at JENAM in Hatfield (April 19-25, 2009). The ESO stand at the Joint European and National Astronomical Meeting in Hatfield was used as anchor point to present the VLT, ALMA and E-ELT projects and the related potential for publicity to industrial partners.
- Meeting with industrial partners during the "AO for ELTs" conference in Paris (June 22-26, 2009). The E-ELT project was presented to industrial partners specialised in optics / adaptive optics and related electronics during the "Adaptive Optics for Extremely Large Telescopes" meeting held in Paris.
- Meeting with industrial partners during IAU in Rio de Janeiro, Brazil (August 3-15, 2009). The large ESO stand erected for the two weeks meeting of the International Astronomical Union was used for numerous discussions with and presentations to industrial partners.
- Meeting with industrial partners during AG in Potsdam (October 21-25, 2009). The E-ELT and related potential for publicity was presented to German industrial partners present at the Tagung der Astronomischen Gesellschaft in Potsdam.
- Projection of the IMAX 3D documentary "The Eye 3D", followed by a reception sponsored by Shott in Munich (October 30, 2009). The 'premiere' of the 3D IMAX documentary about the Paranal observatory and the VLT was used by industrial partners with the help of ESO for a promotional reception in the planetarium.
- Presentation of the E-ELT in Jena (January 20, 2010). The ESO VLT and E-ELT projects were introduce at a dedicated presentation in Jena.
- Presentation of the E-ELT at the DLR in Köln-Porz (April 27, 2010). The ESO VLT and E-ELT projects were introduce at a dedicated presentation at the Centre for Deutsche Luft- und Raumfahrt in Köln-Porz.

The above activities have been supported by the production of material (in particular printed brochures and flyers) directly made available to industrial partners for their own promotion. These included: a glossy 60 pages science brochure presenting the science case of the E-ELT, handouts and brochures, pictures, videos, 3D models.

List of Websites:
http://www.eso.org/public/teles-instr/e-elt.html