CERN/SPC/1183/Rev.2
CERN/3654/Rev.2
Original: English
29 September 2022

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For recommendation	**SCIENTIFIC POLICY COMMITTEE** 330th Meeting **25-26 September 2022**	-
For decision	**RESTRICTED COUNCIL** 209th Session **29 September 2022**	Simple majority of Member States represented and voting

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

PLANS AND DELIVERABLES FOR THE 2023 MID-TERM REVIEW

This document describes the plans and deliverables for the mid-term review of the Future Circular Collider Feasibility Study, which is proposed to take place in autumn 2023. The Scientific Policy Committee is invited to recommend and the Council is invited to approve these plans and deliverables.

FUTURE CIRCULAR COLLIDER FEASIBILITY STUDY:

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I. INTRODUCTION

Following one of the recommendations of the 2020 update of the European Strategy for Particle Physics, which states that *"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. … Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update …"* (CERN/3493/C/Rev.), in 2021 the CERN Management launched the Future Circular Collider (FCC) Feasibility Study (FS). The main deliverables and milestones of the Study itself were presented to the Council at its Session in June 2021 (CERN/3588), and at that same Session the Council approved the FCC FS organisational structure (CERN/3566/ Rev.2 and Annex I below).

The results of the Study will be presented in a Feasibility Study Report, to be submitted to the Council by the end of 2025. An intermediate step, in the form of a mid-term review to be carried out in 2023, was proposed by the Management in CERN/3588 and supported by the Council; such a review will allow the Council to assess the progress in the various areas of the Study.

The CERN Management proposes that:

- the review takes place in autumn 2023, and that the results be presented to the Scientific Policy Committee, the Finance Committee and the Council at the Session in December 2023[1];
- the scientific and technical results be reviewed by the FCC FS Scientific Advisory Committee (see Annex I), augmented by additional experts as needed;
- the cost and financial feasibility, which will focus on the first-stage project (tunnel, technical infrastructure, FCC-ee machine and injectors), be reviewed by a committee including external experts, as proposed in CERN/3588;

[1] Dedicated presentations to the Council's subordinate bodies in November 2023 may be envisaged to allow these bodies to provide input to the Council.

- regular reports are given to the Council and its subordinate bodies on the work progress towards the review.

This document describes the main objectives of the Feasibility Study (Section II) and the deliverables of the mid-term review (Section III).

II. MAIN OBJECTIVES OF THE FCC FEASIBILITY STUDY

The high-level objectives of the Feasibility Study are:

- Optimisation of the placement and layout of the ring and related infrastructure, and demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and the surface areas*;*
- Preparation, together with the Host States, of the administrative processes required for a potential project approval, with focus on identifying and overcoming potential showstoppers;
- Optimisation of the design of the electron-positron (FCC-ee) and hadron (FCC-hh) colliders and their injector chains, supported by targeted R&D programmes to develop the key technologies required;
- Development and documentation of the main components of the technical infrastructure;
- Elaboration of a sustainable operational model for the colliders and the experiments in terms of human and financial resource needs, environmental aspects and energy efficiency;
- Development of a consolidated cost estimate, as well as the funding and organisational models needed for the project's technical design completion, implementation and operation;
- Identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project;
- Consolidation of the physics case and detector concepts for both FCC-ee and FCC-hh.

III. DELIVERABLES FOR THE 2023 MID-TERM REVIEW

The deliverables proposed for the 2023 mid-term review are summarised below, broken down into eight categories. More details are given in Appendix II. A mid-term review report,

supported by additional documentation on each of the deliverables, will be submitted to the review committees and to the Council and its subordinate bodies, as input for the review.
It should be noted that CERN is ready to work closely with the relevant authorities and experts in the Host States with regard to territorial, administrative, environmental and communication aspects.

Deliverables 1: Definition of the baseline scenario

- Choice of the preferred placement for the FCC ring, as the working hypothesis for the Feasibility Study;
- Adaptation of the project and its main parameters (civil engineering design, technical infrastructure, energy consumption, collider layouts, optics, straight sections, machine parameters, etc.) to the chosen placement, updating the design presented in the Conceptual Design Report (CDR) completed in 2018[2]. This will constitute the baseline scenario for the Feasibility Study;
- Update of the construction schedule for the tunnel, the technical infrastructure, and the colliders according to the baseline scenario.

Deliverables 2: Civil engineering

- Preliminary layout and design of the underground structures (tunnel, shafts, caverns, etc.) including assessment of the construction concepts and updated estimates of the excavation materials;
- Preliminary layout and design of the buildings for two typical surface sites, one for an experimental area and one for a technical area;
- Identification of the high-risk areas in preparation for the related investigations. Once the size and the placement of the ring have been defined, the areas presenting particular risks (e.g. the crossing under the lake) can be identified. This will be done by an external consultant (the contract is scheduled to be signed in July 2022) which will assess the existing sub-surface geological data and determine locations where additional site investigations should be carried out in order to improve the understanding of the geological conditions and to reduce cost and schedule risk. The selected areas will be subject to specific site investigations to be undertaken by another specialised contractor

[2] https://fcc-cdr.web.cern.ch

in 2024 and 2025. The investigations are expected to involve around 40 drillings and the laying of around 100 km of seismic lines.

Deliverables 3: Processes and implementation studies with the Host States

- Documentation of the methodology used to develop the placement of the ring, and comprehensive documentation of the preferred placement;
- Updated territorial constraints and environmental challenges in an environmental information system;
- Preliminary results of road access studies;
- Launch of railroad access study and agricultural impact study;
- Subject to the authorisation of the Host State authorities, and with their active support, launch of the environmental initial-state analysis;
- Development of a sustainable energy supply concept;
- Finalisation of the first batch of communication products (brochures accompanying local and regional activities; general website; website targeting local and regional activities);
- Documentation of the results of the "*molasse* re-use potentials" study, based on the outcome of the "Mining the Future" international, challenge-based competition;
- Documentation of the first batch of socio-economic benefit potentials (the values of tourism, training and industrial spillovers; initial estimates of indirect and induced job creation).

Deliverables 4: Technical infrastructure

- Updated requirements for the main technical infrastructure systems (electrical network, cooling and ventilation, cryogenics) for the baseline scenario, and elaboration of the preliminary conceptual design and layout;
- Documentation of the overall integration and resource requirements (grid connections, power lines and overall ratings, water flow requirements and water resources in/out, etc.).

Deliverables 5: FCC-ee accelerator

- Updated FCC-ee layout for the baseline scenario, including the injectors and the injection line(s);

- Updated superconducting radiofrequency system layout, configurations and parameters for all modes of operation;
- R&D plans for the key accelerator technologies up until the potential start of construction in the early 2030s;
- Comparative study of the SPS against a 10-20 GeV linac as the FCC-ee pre-booster (operation impact, cost, performance, etc.);
- Completion of the design of the collider optics, arc integration concept and preparation for arc-cell mock-up;
- Comparative study for the operation sequence between a) a staged increase in energy from Z to W, ZH, $t\bar{t}$ production and b) a start at the ZH production energy followed by operation at lower/higher energy points, based on physics and other requirements, and analysis of the impact on the accelerator, cost, resources and schedule.

Deliverables 6: FCC-hh accelerator

- Development of R&D plans, schedule and deliverables for Nb_3Sn, high-temperature superconducting (HTS) and hybrid magnets for FCC-hh. The list of the strategic R&D topics to cover includes: 16-T superconducting, high-field, dual-aperture accelerator magnets; and demonstration of the feasibility of industrial-scale and cost-effective manufacture of high-performance Nb_3Sn superconducting wire and high-temperature superconductors. Importantly, the FCC integrated project timeline also allows for the exploration and development of HTS magnet technology, and if possible hybrid magnets, enabling improved performance, i.e. higher fields, or higher operation temperature. The key deliverable here will be a summary of the state of the art and R&D plans for Nb_3Sn magnets, for high-temperature superconducting magnets and for hybrid magnets;
- Updated FCC-hh layout under the baseline scenario, including the injection lines from the LHC and/or a possible superconducting SPS. The overall layout of the FCC-hh has been deeply revised following the outcome of the placement studies. This comprises a new ring circumference, an exact four-fold ring symmetry, and two types of straight section: short ones to house each of the four experiments and longer ones to house the various technical systems (collimation, dump, RF, and injection). The layout is compatible with an injection scheme that delivers the beams to the FCC-hh ring from the LHC or a superconducting SPS;

- Integration study of the FCC-hh injection lines with the FCC tunnel. A new approach to the design of the injection lines for the FCC-hh is being implemented with a view to shortening the overall tunnel length for the transfer lines; their last section has been assumed to be in the main ring tunnel, installed on top of the superconducting collider magnets. In this section of the injection line the layout is based on normal conducting magnets, which greatly simplifies the overall design and integration. As an option, the normal conducting magnets can be replaced by permanent magnets, which brings further advantages to the overall layout;
- Completion of the design of the collider optics with new designs for collimation and extraction/dump insertions. The new layout imposes several in-depth changes in the overall configuration of the FCC-hh ring. The design of the straight sections for the experiments has been reviewed compared to the design presented in the CDR, in terms of their geometry and the detail of the optical solutions. The design of the straight sections for the technical systems has been deeply reviewed due to the change in length and the different functionalities attributed to them. This entails new optical designs and detailed studies to validate their performance. The deliverables will also include the new designs of the regular arcs and dispersion suppressors, the experiment straight sections, the beam dump and injection straight section, the collimation straight sections and the RF and injection straight section.

Deliverables 7: Project cost and financial feasibility

- Updated project cost estimate for the chosen ring placement and the baseline scenario, following the review by an expert committee;
- Updated spending profile as a function of time for the first-stage project (tunnel, technical infrastructure, FCC-ee machine and injectors);
- Expected sharing scenario for the contributions from outside the CERN budget, based on preliminary discussions with the Council and other stakeholders.

Deliverables 8: Physics, experiments and detectors

- Documentation of the specificities of the FCC-ee and FCC-hh physics cases and their complementarity for the characterisation of the Standard Model (SM) Higgs boson and other processes;

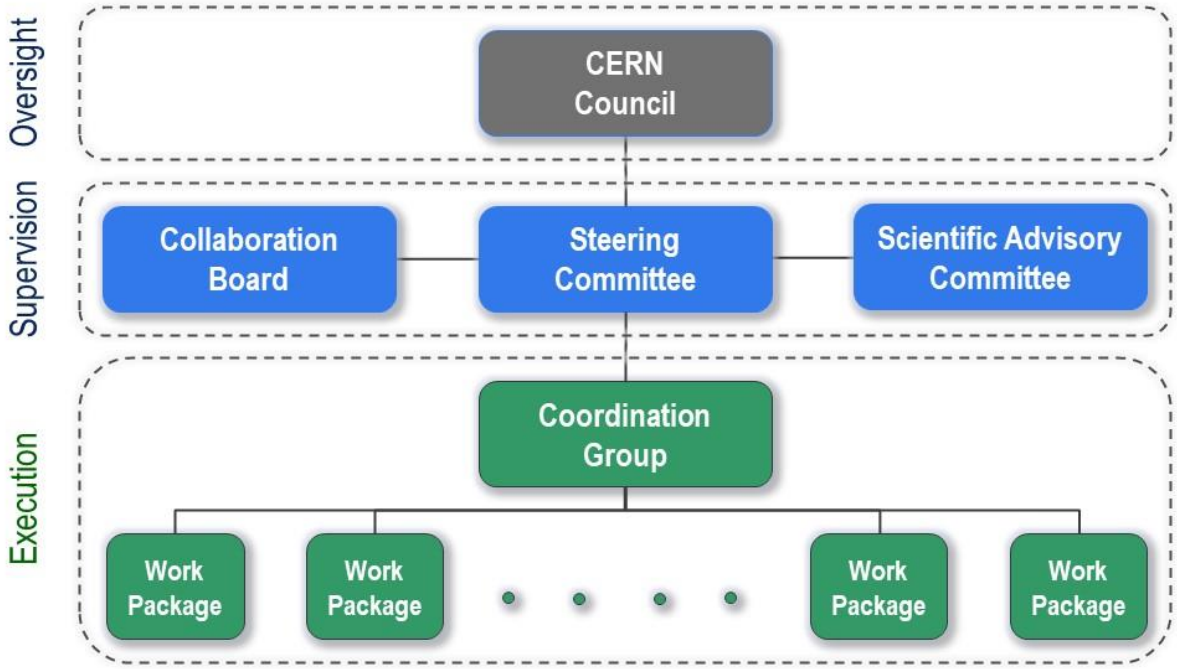
- Strategic plans for the improved theoretical calculations needed to reduce the theoretical uncertainties towards matching the FCC-ee expected statistical precision for the most important measurements.
- First documentation of the main detector requirements to fully exploit the FCC-ee physics opportunities, in particular to reduce the experimental systematic uncertainties towards matching the expected statistical precision for the most important measurements.

IV. CONCLUSIONS

This document describes the plans and deliverables for the mid-term review of the Future Circular Collider Feasibility Study, which is scheduled to take place in autumn 2023. The Council is invited to approve these plans and deliverables.

ANNEX I: Organisational structure of the FCC Feasibility Study

The figure below shows the organisational structure of the FCC Feasibility Study (from CERN/3566/ Rev.2). It should be noted that the chair of the Scientific Advisory Committee is an *ex-officio* member of the Scientific Policy Committee.



ANNEX II: Detailed description of the deliverables for the 2023 mid-term review

Deliverables 1: Definition of the baseline scenario

- Choice of the preferred placement for the FCC ring, as the working hypothesis for the Feasibility Study;
    - The preferred scenario, a 91-km long circular infrastructure with eight surface sites connected to the underground structure will be described in detail, including a) landscaping and urban planning aspects, b) environmental aspects, c) access (road and rail), d) opportunities in the vicinity (electricity and water resources, waste heat re-use, synergies with district services such as healthcare providers, emergency services and industries, etc.).
- Adaptation of the project and its main parameters (civil engineering design, technical infrastructure, collider layouts, optics, straight sections, machine parameters, etc.) to the chosen placement, updating the design presented in the Conceptual Design Report completed in 2018. This will constitute the baseline scenario for the Feasibility Study;
    - The baseline scenario for the Feasibility Study and the main parameters of the FCC colliders will be described. The technical infrastructure system requirements and parameters will be summarised for each of the eight surface sites according to the new layout and machine optimisation. The civil engineering layout will also be described.
- Update of the construction schedule for the tunnel, the technical infrastructure, and the colliders according to the baseline scenario.

Deliverables 2: Civil engineering

- Preliminary layout and design of the underground structures (tunnel, shafts, caverns, etc.) including assessment of the construction concepts and updated estimates of the excavation materials;
    - The layout and design of the underground structures will be summarised and a high-level explanation of the geological environment provided. An assessment of the soil/rock types that will need to be excavated will be given, together with the

construction methods envisaged and an estimate of the volume of materials to be excavated. The areas requiring site investigations due to the uncertain geology of the subsurface will be identified with a view to reducing construction risks. The potential and motivations for staging certain civil engineering (CE) activities between FCC-ee and FCC-hh will be summarised and the resulting impact on the construction techniques and schedules will be discussed.

- For the tunnel, the report will:
  - describe the typical cross-section highlighting key features such as the ventilation spaces, drainage, tolerance envelope, etc.;
  - provide typical construction methodologies for passing through the expected ground conditions;
  - describe the geometrical layout of the underground RF infrastructure;
  - describe the construction methodologies focussing on the vertical cores and the vertical access points, referencing HL-LHC as a recent experience of this type of construction technique;
  - report the functional requirements for the injector tunnel and the envisaged CE solution;
  - describe possible staged construction techniques for the beam dumps and comment on schedule impact if significant;
  - describe options for staging CE activities between FCC-ee and FCC-hh, the resulting functional requirements and possible construction techniques, and comment on schedule impact if significant.
- For the shafts, the report will:
  - explain the one-shaft concept for the experiments;
  - provide dimensions for typical shafts and an explanation of the ovoid shaft concept for the equipment shafts;
  - provide typical construction methodologies for passing through moraine, molasse and limestone and for passing through water-bearing strata.
- For the caverns, the report will:
  - describe a typical experiment cavern with dimensions, shape, etc.;
  - describe a typical service cavern with dimensions, shape, etc.;
  - mention the other caverns likely to be needed and their number;
  - detail typical methodologies for the construction of caverns in molasse and limestone;
  - outline the technical risks associated with the construction of large caverns;
  - discuss staging options from FCC-ee to FCC-hh.

- Preliminary layout and design of the buildings for two typical surface sites, one for an experiment area and one for a technical area;

    - The report will:

        - describe the overall concept for the surface sites for the four experiments and for the four (smaller) technical areas;
        - describe the typical environments within which the surface sites will be placed;
        - describe the typical environmental risks to be addressed in the context of CE works and potential mitigation measures;
        - describe typical CE works required outside the site (access roads, drainage systems, etc.);
        - describe the CE structures required for a typical experiment area surface site using Point A as an example;
        - describe the CE structures required for a typical technical surface site using Point B as an example.

- Identification of the high-risk areas in preparation for the related investigations. Once the size and the placement of the ring have been defined, the areas presenting particular risks (e.g. the crossing under the lake) can be identified. This will be done by an external consultant (the contract has been signed) which will assess the existing sub-surface geological data and determine locations where additional site investigations should be carried out in order to improve the understanding of the geological conditions and to reduce cost and schedule risk. The selected areas will be subject to specific site investigations to be undertaken by another specialised contractor in 2024 and 2025. The investigations are expected to involve around 40 drillings and the laying of around 100 km of seismic lines.

Deliverables 3: Processes and implementation studies with the Host States

- Documentation of the methodology used to develop the placement of the ring, and comprehensive documentation of the preferred placement;

    - A comprehensive report will describe in detail the methodology and process that led to the choice of preferred layout and placement scenario. The process was based on the "avoid-reduce-compensate" methodology that is anchored in French law and widely implemented in Switzerland.

- Three factors drive the process of developing a suitable layout and placement scenario, and the boundary conditions that should be respected will be explained in the report: 1) achieving scientific excellence to attract a large user community over long time periods, 2) achieving societal acceptability and territorial compatibility and 3) controlling project risks and costs.

- The report will compile the various constraints and opportunities that have been identified throughout the initial FCC exploratory studies and their evolution since then. They include, but are not limited to geological features, subsurface and surface water, topography, protected and urbanised zones, planned projects and projects under construction, transport infrastructures (road, rail), wastelands, industrial infrastructures, resources (electricity, water, services), sensitive zones and the constraints and opportunities recorded in regional development plans on the 2035 time horizon. The report will include a high-level assessment of very diverse placement hypotheses such as trans-Jura and lake variants and will summarise the early ideas discussed between 2013 and 2016, which led to the development of a structured, iterative and formal scenario development process in cooperation with competent bodies in both Host States and domain experts urban planning, natural environment, transport, technical and natural resources.

- Updated territorial constraints and environmental challenges in an environmental information system;
    - The study has mandated a consortium of companies to design and set up an "Environmental Information System" ("EIS") based on CERN's existing geographical information system. The system is initially intended to be used to capture and document initial environmental states in the land affected by the preferred layout and placement scenario. The information managed by this system will be the foundation of the report with respect to the environmental initial state. For the mid-term review, the EIS foundation (databases, IT systems, fundamental maps and data sets capturing the evolution of the environmental and territorial constraints) is intended to be in place for use by FCC Feasibility Study contributors, by the territorial stakeholders in France and Switzerland and by contractors working on environmental studies and site investigations, by civil engineering consultants and technical infrastructure consultants.
- Preliminary results of road access studies;

- Launch of railroad access study and agricultural impact study;
    - The status and intermediate results of the railroad access study and of the agricultural impact study will be summarised.

- Subject to the authorisation of the Host State authorities, and with their active support, launch of the environmental initial-state analysis;
    - A report will describe the approach and intermediate status of the environmental initial state studies as the legally required pre-condition for the environmental evaluation process in both France and Switzerland. The initial state studies rely on the selection of a preferred scenario in order to be able to control the time, efforts and costs of the initial study. These studies, scheduled to be carried out over a period of three years until the completion of the Feasibility Study, record the environmental aspects in the locations that will be concerned by FCC-related construction and operation activities. They also include a high-level forecast of the evolution of the affected places with and without an FCC project. Aspects are recorded and analysed using a combination of map, database and field investigations. They include:
        - the physical environment, including climatic and meteorological conditions, topography of sites and access points, geology, surface water, hydrology, soil profile, land cover and land use and existing soil pollution;
        - the natural environment, including flora, fauna, biodiversity, presence and relevance of habitats, presence and conditions of forests, existence and evolution of protection zones;
        - heritage and landscape, including viewpoints and sites of cultural, natural importance and historical importance;
        - the human environment, including an agricultural economic study comprising an assessment of the loss of the affected spaces, transport infrastructures, constructed areas and their evolution, technical and strategic infrastructures of national interest, demography and development, analysis of risks relating to technical infrastructures;
        - public health and emergency services, security, education, housing, industry and commerce and cultural and religious activities;
        - air, including air quality and types of pollutants;
        - noise, including level, frequency and places of occurrence;
        - light, in particular artificial light pollution, including source, type, intensity, direction, places of occurrence and duration;
        - vibration, including source, type, level, frequency, places of occurrence and duration;
        - non-ionising radiation, including source, type, level, frequency, places of occurrence and duration;

        - ionising radiation, including source, type and level.
    - Analysis of this data will indicate the level of sensitivities in the affected zones and allow a statement to be made, at an early stage, about the in-principle feasibility of constructing and operating a new research infrastructure in the local region; it will also allow avoidance, reduction and compensation measures to be developed thereby allowing the feasibility conditions to be determined.

- Development of a sustainable energy supply concept;
    - The deliverable will outline a preliminary concept for the supply of FCC-ee with electrical energy as well as possible ways of adapting the FCC-ee operation mode and energy consumption to the availability of electrical energy on the regional grid. The report will also document the potential for waste heat reuse and give examples of opportunities in the region. Areas of technology R&D aimed at increasing energy efficiency and their corresponding potential impact on FCC-ee energy consumption will be summarised.
- Finalisation of the first batch of communication products (brochures accompanying local and regional activities; general website; website targeting local and regional activities);
    - Work has progressed with the Host States and the first batch of communication products, including brochures, posters, webpages and videos, will be ready for delivery. This deliverable includes:
        - a communication plan relating to the environmental initial state analysis and the subsurface investigations;
        - a website, a brochure and short video clips providing information about the environmental initial state analysis and the subsurface investigations;
        - a brochure providing information about the socio-economic benefits including local benefit creation (jobs, infrastructure developments, resource supplies, etc.).
- Documentation of the results of the "*molasse* re-use potentials" study, based on the outcome of the "Mining the Future" international, challenge-based competition;
    - This deliverable is based on the outcome of the "Mining the Future" competition, the winner of which will be announced on 27 September 2022 - following evaluation by an international jury of experts.
    - The report will summarise the 12 proposals submitted by consortia from academia, industry and spin-off companies, and will provide detailed information on the 4 proposals selected for the final competition round.

- An evaluation of the level of readiness of the four solutions proposed by the competition finalists will be presented and the potential uses discussed in the framework of the FCC MATEX (excavated material management concept), depending on the status of applicability, type and quantity of material referenced in the proposal and possible opportunities for the region to benefit from the application of this solution in other projects/areas.

- Documentation of the first batch of socio-economic benefit potentials (the values of tourism, training and industrial spillovers; initial estimates of indirect and induced job creation).

  - This deliverable will be developed in the framework of the EC co-funded H2020 Future Circular Collider Innovation Study (FCCIS). It includes quantitative, conservative monetary estimates limited to justifiable causal relationships with the FCC programme for a number of socio-economic impact pathways, which have been defined in a plan for the analysis of the FCC socio-economic impacts:

    - Value of training: An updated report concerning the value of training at the FCC-ee for undergraduate and graduate students, post-doctoral researchers and early-stage researchers and engineers, measured using an expected lifetime salary premium earned in comparison to people with comparable profiles but who do not have the opportunity to take part in an international, high-tech project such as the FCC. This estimate is based on anonymous surveys of persons who have been active in CERN projects and who report on their career and salary evolution.
    - Industrial spillovers: Forecast the value of industrial spillovers for the construction and operation of the various FCC-ee scenarios. Industrial spillovers are a measurement of the added earnings that companies are able to obtain as a consequence of high technological intensity contracts relating to the design, construction and operation of the FCC research infrastructure. This estimate is based on long-term observations of the evolution of companies that have worked and are currently working with CERN, in particular on the LHC programme.
    - Value generated by on-site visitors: This refers to visitors who will explore the FCC construction site, the LHC experiments becoming accessible to the public throughout more extended periods and the FCC experiments. The quantitative estimates are, on the one hand, based on internationally established leisure time values used in the "Travel Cost Method" and on the result of a survey on the actual expenditure of visitors coming to CERN. As more data becomes available, the estimates may be extended to off-site visitors of museums and exhibitions that feature CERN FCC research programme-related shows, as is the case today with the LHC programme.

- Estimated "Public Good Value": this quantity represents a monetary estimate that the general public or selected population groups associate with the scientific research carried out by a new particle collider. The value is estimated by specialised companies using the so called "contingent valuation", a survey-based economic technique for the valuation of non-market resources, such as environmental preservation. These companies ensure that an adequate sample of the population is compiled, that the surveys are administered in a quality-assured process and that the descriptive statistics are carried out according to established international norms as a basis of the data to serve for further analysis. Based on the data obtained, economists develop a parameterised model that allows an overall estimate to be made of the Public Good Value for a set of countries who are considered to contribute to and profit from the FCC research infrastructure.
- Job market creation: The estimation for the job market considers non-science and non-research jobs that are directly related to the construction and operation of the research infrastructure, indirect jobs upstream required to produce the equipment for the construction and to supply the resources and services needed for operation and the induced jobs that are a result of the construction and operation activities. As far as possible, job creation effects are reported regionally in a global context, i.e. jobs activated in different countries, based on past involvement of countries in CERN projects and based on their financial contributions in the past. These estimates are developed based on a standard Input-Output model that has been developed specifically to capture such effects for the EU and the OECD by a group of economics researchers and which is regularly used by EU member states to estimate the effects of infrastructure development projects.
- Local spending by FCC users: The economic value of expenditure of residents in the region who are actively involved in the FCC programme is estimated based on data from national statistics. This information may also indicate the economic loss that the region would experience if the FCC research infrastructure was not built.
- Economic value and environmental carbon footprint reduction potentials: Present preliminary results from the estimation of the economic value and environmental carbon footprint reduction potentials relating to the recovery of waste heat from particle accelerators and experiments, based on average market prices for conventional and waste-heat-based district heating installations elsewhere in Europe. The estimates follow a conservative approach, considering that only a fraction of the heat can be effectively captured and supplied.
- The value of the excavated material: Estimation of the market value of products and services that potentially can be created from re-using some of the excavated materials. These estimates are based on the business plans that companies have been requested to supply in the framework of the "Mining the Future" challenge-based innovation competition for the identification of re-use pathways for the "molasse" materials that are not re-usable at present. Considering that the Host States have not yet validated a placement scenario, no detailed information is currently

available about the geological conditions in the vicinity of the preferred scenario, and the uncertainty about the possibility of re-using the excavated materials is therefore high. The estimates will thus be based on assumptions for being able to re-use only a small fraction of the materials, merely in order to highlight the potential. Detailed estimates will only be possible once pilot plants for the selected re-use cases have been built and demonstrated, once more detailed information about the composition of the materials becomes available and once the excavation methods have at least been defined for the purpose of such a study (note: the chosen excavation methods have a significant impact on the re-usability of the excavated materials and may also be driven by some of the re-use pathways).

- Estimating the residual asset values: This estimate, based on standard depreciation rates, is crucial for the demonstration of the sustainability of the FCC, since the sustainability comes from the concept of presenting a long-term integrated FCC-ee/FCC-hh programme in which a subsequent high-energy hadron collider leverages the infrastructures that have been built up in a first phase. These assets include but may not be limited to subsurface and surface site structures, road and railway accesses, electricity and water connection supply and treatment infrastructures, radiofrequency systems, cryogenics systems, cooling and ventilation, transport and installation facilities.

Deliverables 4: Technical infrastructure

- Updated requirements for the main technical infrastructure systems (electrical network, cooling and ventilation, cryogenics) for the baseline scenario, and elaboration of the preliminary conceptual design and layout;

    - The report will summarise the requirements for and parameters of the main technical infrastructure systems (electrical network, cooling and ventilation, cryogenics) in tabular form for each of the eight FCC-ee surface sites. The parameters will correspond to the new baseline scenario, namely the updated collider design and layout; it will also outline, per surface site of FCC-ee, the requirements in terms of surface area (footprint) and rating for the main technical infrastructure systems.

- Documentation of the overall integration and resource requirements (grid connections, power lines and overall ratings, water flow requirements and water resources in/out, etc.).

- The report will summarise the external resource requirements (e.g. electricity, water) for each of the eight surface sites for FCC-ee and outline the initial state as well as the concepts for obtaining the required resources (supply, storage, treatment if necessary, etc.).

Deliverables 5: FCC-ee accelerator

- Updated FCC-ee layout for the baseline scenario, including the injectors and the injection line(s);
    - The machine optics have been adapted to the new layout with eight surface sites instead of twelve, a circumference of about 91.1 km and a perfect four-fold superperiodicity, which allows either two or four collision points and experiments.
    - A new baseline layout has been developed for the pre-injector, where positrons are now generated at a primary electron beam energy of 6 GeV (previously 4.46 GeV) and each linac is operated only with a single unique energy profile; both these changes will boost the performance. A novel type of positron source is being developed for FCC-ee, a prototype of which will be constructed and later tested with beam, at the PSI SwissFEL at primary energies of between 0.5 and 6 GeV.
- Updated superconducting radiofrequency system layout, configurations and parameters for all modes of operation;
    - The overall optimisation of the RF configuration and integration for the FCC-ee collider and the full-energy booster is given major attention since the RF system is a key technology for FCC-ee in terms of performance, cost and sustainability. In addition, specific constraints for the RF configuration arise from the precise energy calibration required for Z and W running.
- R&D plans for the key accelerator technologies until the potential start of construction in the early 2030s;
- A study comparing the SPS against a 10-20 GeV linac as the FCC-ee pre-booster (operation impact, cost, performance, etc.);

- The comparative analysis of using either the SPS or a dedicated high-energy linac as a pre-booster for the FCC-ee is being pursued by the injector working group, together with PSI, in the framework of CHART2. The deliverable report will summarise the overall design, performance and other key aspects such as power consumption, siting and impact on a concurrent hadron fixed-target programme.
- Completion of the design of the collider optics, arc integration concept and preparation for arc-cell mock-up;

- Comparative study for the operation sequence between a) a staged increase in energy from Z to W, ZH, $t\bar{t}$ production and b) a start at the ZH production energy followed by operation at lower/higher energy points, based on physics and other requirements, and analysis of the impact on the accelerator, cost, resources and schedule.

    - The RF implications for working point sequences that are non-monotonic in energy appear significant; a comparative analysis against the baseline scenario (staged energy increase) will be summarised in this deliverable report.

Deliverables 6: FCC-hh accelerator

- Development of R&D plans, schedule and deliverables for Nb_3Sn, high-temperature superconducting (HTS) and hybrid magnets for FCC-hh. The list of the strategic R&D topics to cover includes: 16 Tesla superconducting high-field dual aperture accelerator magnet; cost-effective and high-performance Nb_3Sn superconducting wire at industrial scale; high-temperature superconductors. Importantly, the FCC integrated project timeline also allows for the exploration and development of HTS magnet technology, and if possible hybrid magnets, enabling improved performance, i.e. higher fields, or higher operation temperature. The deliverable will summarize the state of the art and R&D plans for Nb_3Sn magnets, for high-temperature superconducting magnets and for hybrid magnets;
- Updated FCC-hh layout under the baseline scenario, including the injection lines from the LHC and/or a possible superconducting SPS. The overall layout of the FCC-hh has been deeply revised following the outcome of the placement studies. This comprises a new ring circumference, an exact four-fold ring symmetry, and two types of straight sections: a shorter one housing the four experiments and a longer one housing the technical systems (collimation, dump, RF, and injection). The layout is compatible with

an injection scheme that delivers the beams to the FCC-hh ring from the LHC or a superconducting SPS;

- Integration study of the FCC-hh injection lines with the FCC tunnel. A new approach to the design of the injection lines for the FCC-hh is being implemented in view of shortening the overall tunnel length for the transfer lines, their last section has been assumed to be in the main ring tunnel, installed on top of the superconducting collider magnets. In this section of the injection line the layout is based on normal conducting magnets, which greatly simplifies the overall design and integration. As an option, the normal conducting magnets can be replaced by permanent magnets, which brings further advantages to the overall layout;
- Completion of the design of the collider optics with new designs for collimation and extraction/dump insertions. The new layout imposes some in-depth changes in the overall configuration of the FCC-hh ring. The experimental straight sections have been reviewed since the version presented in the CDR, in terms of their geometry and the detail of the optical solutions. The technical straight sections have been deeply reviewed due to the change in length and the different functionalities associated with them. This entails new optical designs and detailed studies to validate their performance. The deliverables will include the new designs of the regular arcs and dispersion suppressors, the experimental straight sections, the beam dump and injection straight section, collimation straight sections and the RF and injection straight section.

Deliverables 7: Project cost and financial feasibility

- Updated project cost estimate for the chosen ring placement and the baseline scenario, following the review by an expert committee;
    - The deliverable will provide an updated estimate of the cost for the stage 1 project, i.e. the construction of the entire civil engineering infrastructure, the technical infrastructure, the collider and the detectors for FCC-ee.
- Updated spending profile over time for the first-stage project (tunnel, technical infrastructure, FCC-ee machine and injectors);
    - Based on the updated cost estimate and expert review mentioned above.

- Expected sharing scenario for the contributions from outside the CERN budget, based on preliminary discussions with the Council and other stakeholders.

Deliverables 8: Physics, experiments and detectors

- Documentation of the specificities of the FCC-ee and FCC-hh physics cases and their complementarity for the characterisation of the Standard Model Higgs boson and other processes;

    - Consolidation of the physics case and detector concepts for both colliders. In the area of physics, experiments and detectors that are covered by the Physics, Experiments and Detectors work package, activities will continue on consolidating the physics case for the integrated FCC programme and the corresponding requirements for theoretical calculations and Monte Carlo generators. The FCC-hh detector concepts will be revisited in light of the evolution of the physics landscape and the experience gained with the High-Luminosity LHC detector upgrades, whilst for FCC-ee several detector concepts are being considered and benchmarked to meet the requirements of ultra-precise Higgs boson and electroweak measurements. The cost drivers for construction and operation will be evaluated and requirements for accelerator performance, technical infrastructure, integration and civil engineering will be formulated. Detector design and R&D will proceed in collaboration with the R&D for future detectors initiative at CERN, and with the activities that will emerge from the Detector Roadmap being developed under the auspices of ECFA.

- Strategic plans for the improved theoretical calculations needed to reduce the theoretical uncertainties towards matching the FCC-ee expected statistical precision for the most important measurements.

    - FCC-ee: The full exploitation of the significantly increased experimental precision in Z-pole observables, W boson and top quark masses, b and τ decays, and a broad array of Higgs observables necessitates SM predictions that are accurate at a level commensurate with this precision. In addition, detailed precision-analysis of Beyond the Standard Model effects within concrete models and effective theories will open up new options on the road to discoveries.

  - FCC-hh will have unique capabilities for testing SM phenomena at ultra-high energies, in particular the mechanism of electroweak symmetry breaking, for measuring some Higgs boson couplings with unprecedented precision and for providing broad coverage for direct particle discovery. Theory calculations are needed for the evaluation of (often large) backgrounds, expected signal rates and optimisation of experimental search strategies.

  - This deliverable will be in the form of tables of (pseudo-)observables, with an estimate of experimental (statistical) target precision for each entry, and an accompanying text containing brief explanations of the theory inputs that are needed for the ``measurement'' of these quantities.

- First documentation of the main detector requirements to be able to fully exploit the FCC-ee physics opportunities, in particular to reduce the experimental systematic uncertainties with a view to matching the expected statistical precision for the most important measurements.

  - Improve the evaluation of the requirements for FCC-ee experiments using key physics processes that drive the physics case as benchmarks. This will be done using fast or fully simulated data, to extract the necessary performances that satisfy the ultimate desired measurement uncertainty.

  - Particular emphasis on identification of the main systematic uncertainties and on strategies to reduce them to meet the expected statistical precision. Development and evaluation of experiment concepts, for both general-purpose detectors and detectors primarily targeting specific physics cases, such as flavour.