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Technology Readiness Level: Guidance Principles for Renewable Energy technologies

Annexes

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Contents

I. COMMON TRENDS TO ALL TECHNOLOGIES

Throughout the execution of the project, the GoG has evolved into a living document, as it was amended with the integration of up-to-date information coming from the interaction with stakeholders in the 10 RE fields.

The homogenisation of common trends faced challenges when addressing readiness levels which diverge from one technology to another. As matter stands, technology development processes do not follow the same path depending on their particularities (interface with environment, manufacturing readiness, testing and validation steps, etc.). This means that the definition of the common trends should be robust enough in order to comply with all technology readiness levels. It is assumed that examples are valuable information in terms of acceptability towards future users of the GoG. In this context, the provision of examples should be encouraged in the guidance documents.

The following table provides an overview of the common trends identified.

TRL 1: Basic principles observed
• Identification of the new concept • Identification of the integration of the concept • Identification of expected barriers • Identification of applications • Identification of materials and technologies based on theoretical fundamentals/literature data • Preliminary evaluation of potential benefits of the concept over the existing ones

TRL 2: Technology concept formulated
• Enhanced knowledge of technologies, materials and interfaces is acquired • New concept is investigated and refined • First evaluation about the feasibility is performed • Initial numerical knowledge • Qualitative description of interactions between technologies • Definition of the prototyping approach and preliminary technical specifications for laboratory test

TRL 3: Experimental proof of concept
• First laboratory scale prototype (proof-of-concept) or numerical model realized • Testing at laboratory level of the innovative technological element (being material, sub-component, software tool, …), but not the whole integrated system • Key parameters characterizing the technology (or the fuel) are identified • Verification of experimental application through simulation tools and cross-validation with literature data (if applicable).

TRL 4: Technology validated in lab
• (Reduced scale) prototype developed and integrated with complementing sub-systems at laboratory level • Validation of the new technology through enhanced numerical analysis (if applicable). • Key Performance Indicators are measurable • The prototype shows repeatable/stable performance (either TRL4 or TRL5, depending on the technology)

TRL 5: Technology validated in relevant environment
• Integration of components with supporting elements and auxiliaries in the (large scale) prototype • Robustness is proven in the (simulated) relevant working environment • The prototype shows repeatable/stable performance (either TRL4 or TRL5, depending on the technology) • The process is reliable and the performances match the expectations (either TRL5 or TRL6, depending on the technology) • Other relevant parameters concerning scale-up, environmental, regulatory and socio-economic issues are defined and qualitatively assessed

TRL 6: Technology pilot demonstrated in relevant environment
• Demonstration in relevant environment of the technology fine-tuned to a variety of operating conditions • The process is reliable and the performances match the expectations (either TRL5 or TRL6, depending on the technology) • Interoperability with other connected technologies is demonstrated • Manufacturing approach is defined (either TRL6 or TRL7, depending on the technology) • Environmental, regulatory and socio-economic issues are addressed

TRL 7: System prototype demonstration in operational environment
• (Full scale) pre-commercial system is demonstrated in operational environment. • Compliancy with relevant environment conditions, authorization issues, local / national standards is guaranteed, at least for the demo site • The integration of upstream and downstream technologies has been verified and validated. • Manufacturing approach is defined (either TRL6 or TRL7, depending on the technology)

TRL 8: System complete and qualified
• Technology experimented in deployment conditions (i.e. real world) and has proven its functioning in its final form. • Manufacturing process is stable enough for entering a low-rate production. • Training and maintenance documentation are completed. • Integration at system level is completed and mature. • Full compliance with obligations, certifications and standards of the addressed markets

TRL 9: Actual system proven in operational environment
• Technology proven fully operational and ready for commercialization • Full production chain is in place and all materials are available • System optimized for full rate production

Table 1 Common trends observed in all guidance documents

II. FINAL GUIDANCE DOCUMENTS

1. PHOTOVOLTAICS - FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY: PHOTOVOLTAICS	
TRL #1	**Basic principles observed**
	Description Basic research. Principles postulated and observed but no experimental proof available
	Identification of scientific concept and interfaces Starting from published research and data from literature, a promising new concept related to photovoltaic technology is identified. The system is summarily described, identifying the basic technology and the materials needed. The fundamental of the concept is investigated, and the expected barriers identified. TRL 1 is defined according the following elements and features: - identification of the new materials and technology related to the PV cells, modules and other components (i.e. wafer based-technology, thin-film PV technology or other technologies based on promising concepts, nanotechnologies and nanomaterials, substrates, glasses, encapsulant, interconnection technologies) and preliminary design.
	Checkpoints
	Once readiness level 1 is achieved, the scientific concept is observed and documented. This means: - definition of the scientific concept; - identification of adequate materials and technologies on the basis of data found in the literature; - achievement of fundamental knowledge of materials and interfaces; - Identification of expected barriers; - First guess of how much time it will take to become a technology possible applicable on the market; - evaluation of the potential benefits of the new concept over the existing ones.

TRL #2	**Technology concept formulated**
	Description Technology formulation. Concept and application have been formulated
	Proof of concept or sample prototyping approach definition and first experimental results An enhanced knowledge of the materials and the interfaces is acquired, based on scientific principles and including published papers and patents. A proof of concept or sample prototyping approach is identified and described for the individual cells or other specific PV technologies at laboratory scale. A suitable design is proposed. Functionality measuring solar energy conversion is starting to be evaluated, also based on comparison with similar devices in the literature/modelling. If other technologies are required, the integration issues are identified. TRL 2 is defined according the following elements and features: - identification of design procedures of the new PV cell or other specific PV technologies with demonstration of the photovoltaic effect and definition of the cell sample prototyping approach; - first evaluation of the feasibility of the technology is performed.
	Checkpoints
	Once readiness level 2 is achieved, the applied technological concept has been defined. This means:

	- initial empirical / numerical knowledge, understanding and identification of materials (including pros and cons), interfaces, procedures and physical characteristics; - Proof of concept or sample prototyping approach determination for test laboratory; - preliminary feasibility is performed.

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	Development of a proof-of-concept prototype, experimental evaluation and compatibility evaluation Experimental set-up is completed: this includes separate studies of independent elements of the technology at laboratory level and their integration. To better evaluate components integration at module level, characterization tests are undertaken (e.g. optoelectronic for cells) and/or simulation activities are required and the first efficiency measurements of the first prototype are made. KPIs relevant for the technology are identified. The results from laboratory studies permit the quantification of the present performance. TRL 3 is defined according the following elements and features: - Development of a proof-of-concept prototype of the new PV cell or PV technology including, at minimum, performance measurements (e.g. conversion efficiency, stability); - Confirmation that the proposed PV cell or PV technology could interface with existing surrounding components of the wider PV system (i.e. relationships with all the components of the photovoltaic system other than the photovoltaic panel: inverters, transformers, wiring, etc.) and identification of most suitable components. If the proposed PV PV cell or PV technology is unlikely to be able to interface with existing surrounding components of the wider PV system then changes to components need to be identified and the process of designing these components must start.
	Checkpoints
	Once readiness level 3 has been achieved, the applied technological concept has been defined. This means: - Prototype has been built through integration of technologies at laboratory level; - verification of compatibility between PV cell or PV technology and supporting technologies; - validation through numerical analysis (if applicable); - identification of prototype strength and weakness; - check the performances against a set of well-defined and repeatable experimental conditions; - KPIs are identified.

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Validation of experimental application, manufacturability and interoperability The photovoltaic system components are integrated and their compatibility validated at laboratory level in a small scale prototype. Also the compatibility with other technologies is verified. Validation can be also made through an enhanced numerical model.

	In respect to TRL3, TRL 4 is defined according the following elements and features of the new PV cell or PV technology: - better reliability; - the device dimensions are closer to final scale (e.g. module, energy production unit, ...); - improved efficiency.
	Checkpoints
	Once readiness level 4 has been achieved, the applied technological concept is experimented and validated. This means: - the new PV cell or PV technology is reproducible and it is reliable/stable for its intended application; - device dimensions are closer to final scale; - validation with enhanced numerical model; - performances are repeatable and stable

TRL #5	Technology validated in relevant environment
	Description Large scale prototype tested in intended environment
	Validation of experimental application and production in simulated environment The photovoltaic components are integrated in a first complete system, with additional supporting elements (i.e. hardware and software) and auxiliaries, to be tested and validated in a (simulated) relevant working environment. It includes testing in different environmental conditions (e.g. varying irradiance levels, shading, mechanical loading, humidity levels...). TRL 5 is defined according the following elements and features: - photovoltaic module or technology large scale lab prototype is built and tested in (simulated) relevant environment, with natural or artificially simulated environmental conditions. Efficiency is calculated on testing results and matches with expected performances; - BoS components are integrated in the large scale lab prototype; - The robustness of the system is proven in the simulated environment.
	Checkpoints
	Once readiness level 5 has been achieved, the technology is ready for full-scale. This means: - Non technological parameters (environmental, social acceptance, regulatory) are defined and qualitatively assessed; - PV module or technology lab prototype completed; - testing and validation in simulated relevant environment finished matching the expected performances; - quantification of an early average performance ratio (i.e. solar yield [kWh/(kW$_p$*yr)] in function of solar irradiation level [kWh/(m^2*yr)]).

TRL #6	Technology demonstrated in relevant environment
	Description Prototype system tested in intended environment close to expected performance
	Technology application functioning, manufacturing and pilot system verified The integrated photovoltaic system (first pilot scale product) is verified in a relevant realistic environment. The manufacturing approach is investigated: production demonstration includes prototype materials, tools, test equipment and personnel skills. Potential investors express interest in the application of technology: qualitative risk analysis and risk mitigation strategy are carried out and preliminary market analysis is performed. The system is integrated following standardization and norms compliance; installation procedures are defined and installation authorizations and H&S issues

	are taken into account. TRL 6 is defined according the following elements and features: - photovoltaic pilot system (including all relevant mechanical, electrical components) is built and demonstrated in relevant environment, analyzing the behavior with different natural solar irradiation. - Performances are calculated based on demonstration results
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to full-scale. This means: - technology demonstrated in relevant environment; - conceptual design of the manufacturing line is drafted.

	System prototype demonstration in operational environment
TRL #7	**Description** **Demonstration system operating in operational environment at pre-commercial stage**
	Full scale pre-comercial demonstrator integrated and demonstrated in field (operational environment) The full scale pre-commercial photovoltaic system is demonstrated in an operational environment. Manufacturing processes and procedures are demonstrated in an industrially relevant environment: production planning is complete. Currently the production process can be run for a limited period. The integration of upstream and downstream technologies has been verified and validated also in an operational environment. Control and communication systems guarantee also an independent test mode to allow long term demonstration. The system is installed and runs following local standards and norms; installation procedures are qualified. TRL 7 is defined according to the following elements and features: - photovoltaic full scale pilot system (including all relevant mechanical, electrical components) is built and demonstrated in operational environment, analyzing the behavior with different natural solar irradiation and conditions. Performances are calculated based on demonstration results.
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at full-scale. This means: - pre commercial installation demonstrated in field (operational environment); - verification of the expected efficiency, in an operational environment; - reliability of the integrated full scale prototype; - manufacturing approach demonstrated; - system stability under long-term real-time outdoor conditions is confirmed.

	System complete and qualified
TRL #8	**Description** **First of a kind commercial system. Manufacturing issues solved**
	System completed and qualified through test and demonstration The full scale photovoltaic system is tested in real world and has proven its functioning in its final form. Manufacturing process is stable enough for entering in a high-rate production and all materials are available: manufacturing processes and procedures are established, controlled and measurable to meet design key characteristics tolerances. Training and maintenance documentation are completed and available to the end users. All the standards and certifications requested are respected.

	TRL 8 is defined according the following elements and features: - **the complete photovoltaic system and manufacturing process are working in a reliable and continuous way. Unexpected faults and failures may happen. Feedbacks are given to improve the system.**
	Checkpoints
	Once readiness 8 is achieved, the system is incorporated in commercial design. This means: - **technology in its final form and under expected conditions;** - **limited and stable production of the technology is demonstrated;** - **mandatory certifications completed;**

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Actual system operational **The PV power system is proven operational. Actual application of the technology is ready for deployment at large production rate. The integration with other supporting technologies is mature.** **The system is ready for full rate production: materials, manufacturing processes and procedures, test equipment are in production and controlled. Lean practices are established.**
	Checkpoints
	Once readiness level 9 is achieved, the system is ready for full-scale deployment. This means: - **PV power system fully operational, at optimized energy yield under field conditions;** - **scale-up production optimized for high volumes;** - **operability and maintainability of the system proven in the field.**

2. CONCENTRATED SOLAR POWER – FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : CONCENTRATED SOLAR POWER	
TRL #1	**Basic principles observed**
	Description **Basic research. Principles postulated and observed but no experimental proof available**
	Identification of scientific concept and interfaces. **Scientific research towards application: it deals with the definition of the technical concept and is supported by information that includes published research or other references that identify the principles that underlie the technology.** **Identification of the concept and its integration in the whole conversion process, required technologies and final application(s).** **Examples of results and knowledge qualifying this TRL:** **i) Preliminary optical draft design of the collectors (in terms of shape, size, targeted concentration ratio, acceptance angle etc.), identification of possible materials (absorbance, transmittance, reflectance) and evaluation of thermal losses towards an analytical definition of a global efficiency of solar collection.** **ii) Preliminary draft design of the receiver in terms of size and shape and identification of the material, evaluation of the capture fraction of the receiver and analysis of its thermal balance.** **iii) Identification of innovative heat transfer thermal fluid (HTF) in terms of environmental and performance issues related to both required solar collection and power production process temperatures.** **Preliminary analysis of the temperature, pressure, mass flow rate values of the HTF throughout the system (preliminary Balance of Plant analysis) and identification of critical process phases (i.e. 2-phase presence, thermos-physical properties changes in the process).** **Preliminary chemical and physical compatibility analysis of the HTF with traditional CSP plant materials.** **Preliminary compatibility analysis of the HTF with traditional process equipment such as valves, pumps, metering, sensoring, expansion vessel towards the future development of specific measures and technologies for HTF exploitation.** **iv) Preliminary definition of the material and design of the thermal energy storage (TES) in terms of: thermal capacity, heat exchange, TES material compatibility, hazard and properties stability. Evaluation of the role of the TES in terms of storage temperature, promptness, interaction with the HTF.** **v) Preliminary innovative concept design and layout of the plant according to HTF properties (T, p, chemical composition), interaction with the collected thermal solar input, off-design and control strategies for operating with unstable thermal inputs.**
	Checkpoints
	- **Identification of possible materials and technologies;** - **Preliminary concept design and layout (e.g. preliminary heat and mass balance);** - **Preliminary evaluation of the potential benefits, risks, hazards and technological barriers of the new concept over the existing ones.**

TRL #2	Technology concept formulated
	Description **Technology formulation. Concept and application have been formulated**
	Preliminary numerical modeling or testing of the intended concept or system. Identification of preliminary prototyping approach for the realization of subcomponents/technology/materials to be implemented. Quantitative knowledge of potential benefits of the concept or system. Quantitative assessment of the process governing parameters. Examples of results and knowledge qualifying this TRL: i) Identification of design procedures of collectors/receivers and preliminary evaluation of how to realize and install them, identification of most suitable materials. Evaluation of thermal losses towards an analytical definition of a global efficiency of solar collection and a preliminary cost evaluation; ii) Definition of the most suitable innovative thermal fluid in terms of environmental and performance issues, preliminary cost analysis considering yearly leakage and compatibility with process equipment (modification costs analysis); iii) Identification of the material and design procedures of the TES in terms of manufacturing and installation. Evaluation of specific capacity/cost function and capacity/time duration of the TES towards an analytical definition of the cycle storage efficiency and a preliminary cost evaluation; iv) Identification of power block technology (e.g. turbomachinery), preliminary design according to HTF properties, numerical analysis. Outline of possible off-design and control strategies.
	Checkpoints
	- Technical performance analysis of the concept is achieved; - Benefits of the new concept or system are quantitatively assessed; - Statement of interactions between components; - Preliminary risks and hazards analysis with related mitigation strategies is done; - Preliminary specification of the materials required for developing the prototype; - First simulation numerical model of the concept

TRL #3	Experimental proof of concept
	Description **Applied research. First laboratory tests complete; proof of concept**
	Development of experimental application is initiated at materials, subcomponent or power plant level (proof of concept prototype). At this TRL, simulation activities are very important for the evaluation of the whole plant and subcomponents analysis and performance (e.g. structural FEM, CFD, control, detailed thermodynamic cycle simulations, etc.). Identification of integration potential. KPIs characterizing the technology are identified. Examples of results and knowledge qualifying this TRL: i) First proof-of-concept prototype, FEM structural and numerical analysis to validate the design of collector/receiver. Simulation analysis with literature solar irradiation data input towards the evaluation of the performance of the collector/receiver;

	ii) First numerical analysis (CFD) of the behaviour of the HTF in piping and process equipment; iii) First proof-of-concept prototype, FEM structural and numerical analysis to validate the design and the performance of the TES (thermal energy degradation, etc.). Simulation of the TES management strategy according to the different purpose of the TES; iv) First proof-of-concept prototype, FEM structural and numerical analysis to validate the design of the whole system. Identification and verification, at simulation level, of off-design and control strategies.
	Checkpoints
	- First proof-of-concept prototype ready and preliminary tested; - Key parameters characterizing the technology are identified; - Verification of the technologies through consolidated simulation tools and cross-validation of the numerical models thanks to literature data (if applicable).

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Small scale prototype is developed and integrated with auxiliary systems (e.g. fluid conditioning, metering, data acquisition and control) at lab level. Repeatable performances are provided by the prototype measured through the KPIs previously identified. Examples of results and knowledge qualifying this TRL: i) Realization of a small scale prototype of the solar collector/receiver tested with real case functionalities and conditions that can be artificially emulated for a preliminary validation at lab scale; ii) Chemical and physical Lab analysis of the compliancy of the HTF with material and process conditions (temperature and pressure); iii) Realization of a small scale prototype where thermal flows from the solar field can be physically emulated by electric heaters or controlled thermal flows. Validation of the TES management; iv) Realization of a small scale prototype where mass flows can be physically emulated by electric heaters or controlled mass flows from dedicated compressors/HTF intake etc. Validation of off-design and control strategies as well as structural design; v) If the subcomponents of a CSP plant are tested separately, the compatibility between the tested technologies is validated through other experimental tests data or by a Hardware-in-the-Loop approach.
	Checkpoints
	- Realization and testing of prototype at laboratory scale; - Validation of simulation activities (if applicable).

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	A significant scale prototype is developed and integrated together with auxiliaries (e.g. fluid conditioning, metering, data acquisition and control) and its compliancy with relevant environment conditions (i.e. rain, humidity, dust, wind ...). Reliable performances are provided by the prototype in line with the expectations. Non-technological parameters (environmental, social acceptance, regulatory) are

	defined and qualitatively assessed. **Examples of results and knowledge qualifying this TRL:** **i) Realization of a significant scale prototype of the collector/receiver tested with an open-field irradiation at local scale or with real case functionalities and conditions that can be artificially emulated;** **ii) Use of the HTF in sub-component prototype;** **iii) Realization of a significant scale prototype where thermal flows from the solar field can be physically emulated by electric heaters or controlled thermal flows. Demonstration of the TES management;** **iv) Realization of a significant scale prototype where mass flows can be physically emulated by electric heaters or controlled mass flows from dedicated compressors/HTF intake etc.. Demonstration of off-design and control strategies and of structural analysis.**
	Checkpoints
	- **Realization of a significant scale prototype fully integrated with auxiliaries and control and tested in relevant controlled environment;** - **Non-technological parameters (environmental, social acceptance, regulatory) are defined and qualitatively assessed;** - **Performances match the expectations.**

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	A pilot scale product or system is developed and integrated together with all auxiliaries (fluid conditioning, metering, data acquisition and control) and in compliance with relevant environment conditions (i.e. rain, humidity, dust…) and it is installed and tested in relevant environment (on field), analyzing its different behaviour with different solar irradiation conditions. **Subsystems are able to interact each other, modifying their behaviour according to the others in first complete control system.** **The product manufacturing chain and installation procedures are defined, including personal skills and tools needed. Other non-technical parameters are addressed as well.** **Technical and economic parameters of the technology are sufficient to define a business plan.** **Examples of results and knowledge qualifying this TRL:** i) **Realization of a pilot of the collector/receiver tested with an open-field irradiation at local scale and able to modify its behavior according to the whole plant management.** ii) **HTF tested in all the subcomponents and considering the interconnection of them** iii) **Realization of a pilot with thermal flows provided by local solar field in order to demonstrate TES performance and management with a real solar input** iv) **Realization of a pilot where mass flows are provided by local solar fields with the support of auxiliary boilers or TES.**
	Checkpoints
	- **Realization of a pilot fully integrated with auxiliaries and control and installed on the field;** - **Measurement of prototype performance in different seasons and with different irradiation profile completed;**

	- Manufacturing chain and installation procedures are drafted and ready for integration into a project breakdown structure (with time, personnel effort and skills, resources needed, etc.).

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	A full scale pre-commercial demonstrator is installed and connected to be tested to its final process purpose (e.g. connected to the grid, to a district, to an industrial load, to thermal storage, to power block, …). **Compliancy with relevant environment conditions, authorization issues, grid operability, local National standards is analyzed and guaranteed, at least for the demonstration site. The demonstrator is able to guarantee its functionalities due to a proper control and management strategy and an adequate maintenance approach, but it's able to operate also in test mode not affecting the final purpose in case of faults that can occur during this demonstration.** **The product manufacturing chain and installation process are fully developed.** **Similar concept layouts and plants can be replicated, at least at design level, in different geographic and irradiation conditions.** **Examples of results and knowledge qualifying this TRL:** i) **Installation of the full scale collector/receiver in an open-field full scale irradiation area: performance is verified with different solar irradiations, thermal power collection is validated according to the specifications of the whole plant.** ii) **HTF tested in all the subcomponents and considering their interconnection** iii) **Installation of the full scale TES operating in a connected-to-grid/connected-to-load power plant: performance verified with different solar irradiations; thermal input to the power block guaranteed according to the specifications and to the production strategy of the whole plant.** iv) **Installation and operation of a full scale power block prototype in connected to-grid or connected-to-load scenarios.**
	Checkpoints
	- **Realization of a full scale complete pre-commercial demonstrator** - **Tests of demonstrator in several real irradiation conditions** - **Manufacturing chain and installation process has been specified**

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	The technology is experimented in deployment conditions (as subcomponents or whole plants) and has proven its functioning in its final purposes in all environmental conditions and able to act both in grid connected/load connected modes. **Manufacturing chain and installation process are stable enough for entering in a low-rate production and all materials are available: manufacturing processes and procedures are established and controlled and measurable to meet design key characteristic tolerances.** **Full compliance with obligations, certifications and standards of the addressed markets.** **Manuals for training and maintenance documentation are available.** **Reliable functioning of all the subcomponents: only unpredicted faults and failure are not yet completely addressed, because only after a full scale test campaign it will be possible to analyse all the operating aspects of the technology**
	Checkpoints
	- **Full compliance with obligations, certifications and standards of the**

	addressed markets; - For components: production ready to move from development to commercialization; - For CSP plants: they are able to produce power in grid connected mode or according to its final application.

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	System and subcomponents ready for full operation production: materials, manufacturing processes and procedures, test equipment are in production and controlled. Lean practices are established. Several plants are installed all over the world. Different companies propose the technologies and maintenance services in their portfolio, providing specific and customized modifications.
	Checkpoints
	Once readiness 9 is achieved, the single subsystems, the engineering services for the realization of the CSP plant and the operating plant itself are ready for full-scale deployment and commercialisation all over the world. This means: - system fully operational - integration of technology proven in operational environment - full rate power production

3. HYDROPOWER – FINAL GUIDANCE DOCUMENT

<table>
<tr><th colspan="2">RE TECHNOLOGY : HYDROPOWER</th></tr>
<tr><td rowspan="5">TRL #1</td><td>Basic principles observed</td></tr>
<tr><td>Description
Basic research. Principles postulated and observed but no experimental proof available</td></tr>
<tr><td>Identification of scientific concept and interfaces
Starting from relevant research and data from literature, a promising new concept related to hydro technology is identified. The fields of application may vary from power production (turbine, generator,…) electrical components (inverter, transformer, grid interfaces,…),automation, water ways and hydraulic steel structures, civil works and construction methods, communication and sensor technologies, auxiliary and security components, to software tools aiding the individuation and design or analysis of the hydropower energy conversion scheme.
The theoretical fundamentals of the concept are investigated; the concept is summarily described, identifying the basic technologies beyond the concept and the materials needed.
The expected barriers and applications are identified.
TRL 1 is defined according the following elements and features:
- identification of the concept related to new materials and/or technologies (e.g.: very low head pump/turbine, new electrical devices for grid stabilization, reduced inertia turbines, high efficiency pumps, software tools, etc.);
- identification of new design criteria (if relevant).</td></tr>
<tr><td>Checkpoints</td></tr>
<tr><td>Once readiness level 1 is achieved, the scientific concept is observed and documented. This means:
- definition of the scientific or technical concept;
- identification of adequate materials and/or technologies on the basis of theoretical fundamentals and data found in the literature;
- achievement of fundamental knowledge of materials and interfaces;
- identification of expected barriers and potential applications;
- evaluation of the potential benefits of the new concept over the existing ones.</td></tr>
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<table>
<tr><td rowspan="3">TRL #2</td><td>Technology concept formulated</td></tr>
<tr><td>Description
Technology formulation. Concept and application have been formulated</td></tr>
<tr><td>First numerical results and sample prototyping approach definition
An enhanced knowledge of the technologies, materials and the interfaces is acquired, based on scientific principles and including published papers and patents. Preliminary feasibility investigation is performed.
Since devices and experimental evaluation of them in the hydro power field is capital intensive due to physical dimensions, it is important to set up the correct numerical approach and identify the correct approach for the development of small scale but relevant prototypes.
A sample prototyping approach is identified and described for the new concept at laboratory scale. A suitable design is proposed.
If other technologies are required, the integration issues are identified.</td></tr>
</table>

	TRL 2 is defined according the following elements and features: - **the new concept is investigated and refined with a numerical/analytical approach, mathematical model creations and simulations;** - **the model design is individuated;** - **first evaluation of the feasibility of the technology is performed;** **identification of (potentially) key parameters on the basis of which evaluate the performance of the proof-of-concepts (within the TRL 3) performances.**
	Checkpoints
	Once readiness level 2 is achieved, the new concept has been numerically refined and model design is identified. This means: - **initial knowledge gained by analytical/numerical simulations, understanding and identification (including pros and cons) of design concepts, materials, interfaces, procedures and physical characteristics;** - **early stage analytical results validating the new concept for test laboratory; preliminary feasibility is performed and benefits quantitatively assessed (e.g. on sustainability issues, social impact, etc.).**

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	Realization of a proof-of-concept prototype/model and set up of the test rig **Following a specific design, a first lab scale prototype or appropriate numerical model is realized.** **The experimental or virtual test rig is completed and coupled with the prototype/model (proof of concept); it is possible to operate the test rig among a proper range of experimental conditions, with well defined KPIs.** **The prototype/model could be, among others, a new type of turbine (very low head turbine, low inertia turbine, etc.), electrical components or water intake, an innovative software tool for turbine tailor made design or unconventional site identification, etc.**
	Checkpoints
	Once readiness level 3 has been achieved, the applied technological concept has been defined. This means: - **a proof-of-concept by the developed prototype/model following a specific and numerically validated (if applicable) design;** - **realization of a test rig or virtual model capable of hosting the prototype and reproducing the necessary conditions needed for a complete prototype characterization;** - **identification and choice of the most suitable test condition to be assumed when designing the test-rig or the experimental characterization of the new concept;** - **identification of prototype strength and weakness for testing purposes.**

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment (“ugly” prototype)**
	Small scale prototype/model validation **The boundary conditions, experimental conditions or a series of numerical setups have been developed in order to perform relevant measurements and/or calculations.** **The new concept is experimentally validated at laboratory level in a small scale prototype. Components integration has been achieved. The relevant parameters (key performance indicators, KPIs) can be measured.**

	A first set of experimental data has been obtained and could be used to improve the numerical model in order to reiterate the numerical analysis to better investigate and validate the new component/device. **Repeatable performances are provided by the first small scale prototype/simplified model. A series of different prototypes/models has been developed until performances in line with expectations are proved.** **Prototype dimensions are not yet at the real scale, as concerns physical devices. The model complexity is not yet ready for complete description, in case of virtual tools.**
	Checkpoints
	Once readiness level 4 has been achieved, the small scale prototype is experimented and validated, or the model is in an improved version. This means: - **small scale prototype or simplified model performances checked against a set of well-defined and repeatable conditions;** - **new device/component validation through an advanced, experimentally refined numerical analysis of the integrated system (if applicable);** - **the prototype/model performances are reproducible and the prototype/model is reliable for its intended application;** - **analysis of measurement data and comparison with simulation results.**

TRL #5	**Technology validated in lab**
	Description **Large scale prototype tested in intended environment**
	Realization of large scale prototype for relevant environment **Once the experimental characterization of small scale prototypes and an advanced numerical investigation of the new device have delivered significant results and information (as for TRL 4), the large scale prototype design has been developed.** **Following this design phase, a large scale prototype is completed; all the necessary devices and interfaces are developed, also taking into account the need for monitoring equipment.** **Non-technological parameters are identified and assessed.** **The prototype is suitable to be installed and operated in a relevant environment.** **Verification of realistic sites and potential customers can be performed.**
	Checkpoints
	Once readiness level 5 has been achieved, the technology prototype is at large scale and resembles the full scale application. This means: - **the large scale prototype has been realized , suitable to be installed and operated in a relevant environment, and it can successfully withstand disturbances of other origin without damaging the additional equipment and existing devices on site;** - **performances (KPIs) are confirmed and in line with expectations.**

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	Technology validated in relevant environment **A real scale pilot is developed and integrated together with auxiliaries and interfaces (e.g. hydraulic actuation system, power controller, metering, data acquisition, civil works, etc.) and it is able to act both in grid connected/load connected mode. Compliance with relevant environment conditions is fully achieved (i.e. pressure, site morphology, etc).** **Reliable performances are provided by the pilot in line with the requirements, that include operational, licensing, regulatory, environmental and safety aspects of the**

	pilot site.
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to full-scale and it is operative. This means: - full scale pilot integrated with the knowledge of the surrounding systems and operated in field (operational environment); - reliable performances are provided by the full scale pilot in line with the above specified requirements; - performance of the prototype on laboratory and real site level are compared; - compliance with operational, regulatory, environmental and safety requirements for the Pilot site is achieved.

TRL #7	**System prototype demonstration in operational environment**
	Description Demonstration system operating in operational environment at pre-commercial stage
	Full scale system demonstrated in operational environments This level deals with demonstration of actual (full scale) pre-commercial system in operational environment and also integrates verified and validated technologies in different operational environments. Hydropower is closely related to site-specific characteristics, so within TRL 7 it is necessary to have the capability to decline the new design approach into different relevant applications. The need of identifying and/or developing manufacturing lines, processes or procedures is analyzed with reference to an industrially relevant environment. Control and communication systems allow long term demonstration/operation. The system is installed and operates following specific local standards and norms; installation procedures are qualified.
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at full-scale and adaptable to different application cases. This means: - demonstrator operated in field and adaptable to different operational environments; - verification of the expected efficiency, in an operational environment; - manufacturing approach drafted (if applicable); - system stability under long-term real-time operational conditions is confirmed. - technical, social and environmental impacts are determined.

TRL #8	**System complete and qualified**
	Description First of a kind commercial system. Manufacturing issues solved
	System completed and qualified, manufacturing line available The system completion is achieved and, based on real site application feedback, it is qualified. Unexpected faults and failures may occur. Manufacturing process is stable enough for entering in a low-rate production and all sub-systems are available: manufacturing processes and procedures are established, controlled and measurable to meet design key characteristics tolerances. Operation and maintenance documentation is completed and available to the end users. All the standards requested are respected.
	Checkpoints

	Once readiness 8 is achieved, the system is incorporated in commercial design. This means: - **technology is mature and operates under expected conditions;** - **limited but stable production of the technology is demonstrated (if applicable);** - **O&M procedures and spare parts are defined;** **mandatory standards fulfilled.**

	Actual system proven in operational environment
TRL #9	**Description** **Full commercial application, technology available for consumers**
	Actual system operational **The technology developed within the innovative design approach is operational. Actual application of the technology is ready for deployment at market-induced production rate. The integration with other supporting technologies is fully operational.** **Sub-components, manufacturing processes and procedures, test equipment are in production and controlled with established efficient methods.**
	Checkpoints
	Once readiness level 9 is achieved, the system is ready for full-scale deployment. This means: - **new technology fully operational at optimized efficiency/reliability under field conditions;** - **scale-up production optimized for market-induced volumes;** **operability and maintainability of the system proven in the field.**

4. WIND – FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : WIND	
TRL #1	**Basic principles observed**
	Description **Basic research. Principles postulated and observed but no experimental proof available**
	Identification of scientific concept and interfaces **Starting from relevant research and data from literature, a promising new concept related to wind technology is identified. The specific/particular new concept of a wind technology is summarily described, identifying the basic technology and the components and materials needed.** **The particular new concept is developed (i.e. foundation, tower, nacelle, blades, generator, bear and drive systems, electromechanical components, technical solutions, control, monitoring and communication tools, etc.), taking into account its preliminary/possible use (e.g. onshore, offshore, urban environment, etc.).**
	Checkpoints
	Once readiness level 1 is achieved, the scientific concept is observed and documented. This means: - **definition of the scientific concept;** - **definition of its possible use;** - **identification of adequate materials and technologies on the basis of data found in the literature;** - **identification of expected barriers and evaluation of the potential benefits of the new concept over the existing ones;** - **a rough estimation of time-to-market exists.**

TRL #2	**Technology concept formulated**
	Description **Technology formulation. Concept and application have been formulated**
	Sample prototyping approach definition and first experimental/simulation results **An enhanced knowledge of the materials, the interfaces and the operation is acquired, based on scientific principles and including published papers and patents.** **A sample prototyping approach is identified and described for the individual and specific component of the wind technology at laboratory scale. A suitable design is proposed. Functionality measuring wind energy conversion is starting to be evaluated, also based on comparison with similar solutions in the literature/modelling.** **If other technologies are required, the integration issues are identified.** **TRL 2 is defined according the following elements and features:** - **identification of design procedures of the new technology with demonstration of the improvements and definition of the new component prototyping approach;** - **first evaluation of the feasibility of the technology is performed (i.e. availability of new building materials, new production techniques of airfoils, availability of most advanced electronic components, etc.).**
	Checkpoints
	Once readiness level 2 is achieved, the applied technological concept has been defined. This means: - **initial knowledge from experimental/simulation results, understanding and identification of materials (including pros and cons), interfaces, operation, procedures and physical characteristics;** - **sample prototyping approach determination for test laboratory/numerical simulations;** - **preliminary feasibility is performed.**

TRL #3	Experimental proof of concept
	Description **Applied research. First laboratory tests complete; proof of concept**
	Development of a proof-of-concept prototype, experimental evaluation and compatibility evaluation Experimental set-up is completed: this includes separate studies of independent elements of the technology at laboratory level, or equivalent numerical analysis in case of new software development. KPIs characterizing the technology are defined. The new concept integration at wind power unit/plant level (i.e. relationships with all the components: blades, towers, generators, gearboxes, transformers, wiring, etc.) is evaluated. If the proposed wind technology is unlikely to be able to interface with existing surrounding components/concepts of the wider system then changes to components/concepts need to be identified and the process of designing these components must start. Characterization tests are undertaken (e.g. wind tunnel, floating, electrical load testing) and/or simulation activities are required and the first measurements on the specific characteristics and parameters of the first prototype are made. The results from laboratory studies permit the quantification of the performance (e.g. conversion efficiency, robustness, static and dynamic behavior, etc.).
	Checkpoints
	Once readiness level 3 has been achieved, the applied technological concept has been defined. This means: - proof-of-concept prototype has been built in controlled environment(i.e. laboratory if tests are feasible or equivalent simulations); - identification of compatibility between new wind technology and surrounding technologies; - validation through numerical analysis (if applicable); - identification of prototype strength and weakness; - KPIs characterizing the technology are defined; - check of the performances against a set of well-defined and repeatable experimental conditions.

TRL #4	Technology validated in lab
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Validation of experimental application, and interoperability The system components are integrated and their compatibility validated at laboratory level in a low-level prototype. In addition, the compatibility with other technologies is verified through tests (e.g. wind tunnel, test rigs on ground or water). Possible issues related to the technology and its applications (e.g. vibration and stability in water environment) have been identified. KPIs are now measurable. In respect to TRL3, TRL 4 is defined according the following elements and features of the new wind technology: - the prototype of the new technology is realized through integration of relevant components; - validation of the new technology through enhanced numerical analysis (if applicable).
	Checkpoints
	Once readiness level 4 has been achieved, the applied technological concept is experimented and validated. This means: - the new wind technology concept/component is reliable/stable for its intended application; - performances are confirmed and in line with previous prototype; -

	- KPIs can be measured for technology evaluation; - first assessment of the liaison and/or interferences with relevant best practices and international standards (if applicable).

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	Validation of experimental application and production in simulated environment The concepts/components are integrated in a first complete system, with additional supporting elements (i.e. hardware and software) and auxiliaries, to be tested and validated in a simulated relevant environment. It includes testing in different environmental conditions (e.g. varying wind speed and turbulence levels, pressure, temperature, mechanical loading, sea waves, electrical parameters, etc.). TRL 5 is defined according the following elements and features: - the system with the new wind technology, at a large-scale lab prototype, is built and tested in simulated relevant environment, with natural or artificially simulated environmental conditions (e.g. wind/waves); - key performance indicators (KPIs) are calculated on testing results and fulfill the expected performances; - the robustness of the system is proven in the simulated environment.
	Checkpoints
	Once readiness level 5 has been achieved, the technology is ready for full-scale. This means: - new wind technology lab prototype completed; - testing and validation in simulated relevant environment finished fulfilling the expected performances; - quantification of KPIs (e.g. energy production, loads, component's lifetime, etc...); - Other relevant non-technological parameters (regulatory aspects, environmental impact, social acceptance, etc.) are evaluated.

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	Technology application functioning, manufacturing and pilot system demonstrated The integrated system (first pilot scale product) is demonstrated in a relevant realistic environment, also provintg the interoperability of the connected technologies. The manufacturing approach is defined: production demonstration includes prototype materials, tools, test equipment and personnel skills. The system is integrated following standardization and norms compliance; installation procedures are defined and installation authorizations, environmental and Health & Safety issues are taken into account along with a first study on the logistics of the transportation of the components to the final operational site. TRL 6 is defined according the following elements and features: - pilot system (including all relevant mechanical, electrical components) is built and demonstrated in relevant environment and operative conditions; - performances are calculated based on demonstration results; - reliable and safe operations are demonstrated.
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to pilot scale. This means: - technology demonstrated in relevant environment; - conceptual design of the manufacturing is drafted;

	- first logistics concept completed for the installation/implementation in field; - major reliability and HSE issues solved.

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	Full scale pre-commercial system integrated and demonstrated in field (operational environment) **Once readiness level 7 is achieved, the technology concept is validated at full-scale. This means:** - installation and implementation demonstrated in field (operational environment), compliant with local regulations; - verification of the expected KPIs, in an operational environment; - reliability and robustness of the integrated full scale system under long-term operational environment conditions is confirmed; - manufacturing approach demonstrated; - logistics studies at full scale level have been completed; - standardization framework has been analyzed.
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at full-scale. This means: - installation and implementation demonstrated in field (operational environment); - verification of the expected KPIs, in an operational environment; - reliability and robustness of the integrated full scale system under long-term operational environment conditions is confirmed; - manufacturing approach demonstrated; - logistics studies at full scale level have been completed; - standardization framework has been analyzed.

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	System completed and qualified through test and demonstration **The full scale system is tested in real world and has proven its functioning in its final form.** **Manufacturing process is ready for entering in a high-rate production and all materials are available: manufacturing processes and delivery and installation procedures are established.** **Training and maintenance documentation are completed and available to the end users.** **All the standards and certifications requested are respected.** **TRL 8 is defined according to the following elements and features:** - the complete system and manufacturing process are working in a reliable and continuous way. Unexpected faults and failures may happen. Feedbacks are given to improve the system; - logistics of transportation and installation procedures have been applied and are ready for next final step of large production and commercial use (TRL#9).
	Checkpoints
	Once readiness 8 is achieved, the system is incorporated in commercial design. This means: - technology is in its final form and under expected conditions; - limited and stable production of the technology is demonstrated; - training and maintenance documentation is available; - compliance with the relevant international standards and regulations is accomplished;

	- all possible logistics and installation issues have been analyzed and fixed.

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Actual system operational **The system is proven operational. Actual application of the technology is fully deployed at large production rate. The integration with other surrounding technologies is mature.** **Sub-components, manufacturing processes and procedures, test equipment are in production and controlled with established efficient methods.** **All main issues on transportation, installation and operation of the system have been overtaken.**
	Checkpoints
	Once readiness level 9 is achieved, the system is at full-scale deployment. This means: - **operation and maintenance of the system proven in the field;** - **scale-up production optimized for high volumes.**

5. RE H&C – FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : RE H&C

TRL	**Basic principles observed**
TRL #1	**Description** **Basic research. Principles postulated and observed but no experimental proof available**
	Identification of the innovative scientific concepts ranging from materials up to systems, the scale of which is dependent on the scope considered, to increase and optimize the use of thermal energy coming from renewable sources for heating and cooling. **This identification should be based on published research data or other sound references.** **Examples of results and knowledge qualifying this TRL:** - **Identification of innovative heat transfer thermal fluid (HTF) in terms of environmental and performance issues;** - **Identification of innovative and high performance insulation materials to decrease heat losses in DHC network pipes;** - **Innovative layout of an heat exchanger to improve heat recovery from geothermal system and to optimize the surface used by the heat exchanger;** - **Preliminary definition of the material and design of the thermal energy storage (TES) in terms of: thermal capacity, heat exchange, TES material compatibility, hazard and properties stability. Evaluation of the role of the TES in terms of storage temperature, promptness;** - **A new layout to optimize demand – supply matching for a heating system based on geothermal sources and constituted by heat pumps, heat storage tanks and boreholes;** - **Preliminary innovative conceptual design and layout of a heating and cooling system;** - **Development of an innovative polygeneration process in hybrid solar-biomass system for combined power, cooling and desalination;** - **Identification of operation control strategies optimizing the demand – supply matching;** - **Identification of strategies to optimize H&C distribution for DHC networks (e.g. by means of variable speed pumps).**
	Checkpoints
	- **Identification of possible material, components and systems;** - **Preliminary concept design;** - **Preliminary evaluation of the potential benefits, risks, hazards and technological gaps of the new concept over the existing ones.**

TRL	**Technology concept formulated**
TRL #2	**Description** **Technology formulation. Concept and application have been formulated**
	The technology concept, its application and interfaces to other systems are defined. **Preliminary modeling of the intended concept or system is available.** **Identification of preliminary prototyping approach for the realization of systems or sub-systems.** **Examples:** - **Definition of properties of the innovative HTF in terms of environmental and**

	performance issues; - Identification of the material and design procedures of heat exchanger in terms of manufacturing and installation. Preliminary numerical analysis to gain quantitative knowledge of potential benefits; - Identification of the material and design procedures of the TES in terms of manufacturing and installation; - Definition of the functional block diagram of the proposed system layout; - Preliminary modeling of the proposed system layout to gain initial knowledge of potential benefits (e.g. energy savings); - Definition of the prototyping approach in terms of technologies, materials, dimensions, etc.; - Preliminary screening of costs and benefits for materials, systems or sub-systems.
	Checkpoints
	- Technical performance analysis of the concept is achieved; - Qualitative assessment of benefits of the new concept or system is done; - Statement of interactions between components – qualitative assessment; - Definition of the prototyping approach and preliminary technical specifications (e.g. technologies, dimensions).

	Experimental proof of concept
TRL #3	**Description** **Applied research. First laboratory tests complete; proof of concept**
	First model completed and preliminarily tested. Development of experimental application is initiated at component, system or sub-system level. The first proof of concept prototype could be developed either by creating laboratory prototypes or numerical models to run numerical simulations (e.g. structural FEM, CFD, control, detailed thermodynamic cycle simulations, etc.). Examples: - First numerical analysis (CFD) of the behavior of the innovative HTF in piping and process equipment; - First proof of concept prototype of the innovative HTF and test in a simplified system; - First proof-of-concept prototype, computational structural and energy analysis to validate the design and the performance of the heat exchanger; - Evaluation of specific capacity/cost function and capacity/time duration of the TES towards an analytical definition of the cycle storage efficiency and a preliminary cost evaluation; - Numerical analysis of the system, including all the characteristics and properties of the main components (Heat pump, heat storage tank, geothermal boreholes) as defined in the prototyping approach, in order to obtain a proof of concept; - Assumptions can be taken into account for simulating external boundaries conditions (Ground temperature, heating or cooling demand) and secondary components (e.g. auxiliary systems).
	Checkpoints
	- First proof-of-concept prototype (or numerical model) ready and preliminarily tested; - Parameters characterizing the technology are measured/calculated;

	- Verification of the proof of concept through consolidated simulation tools and cross-validation of the numerical models thanks to literature data (if applicable); - Quantitative assessment of benefits of the new concept or system is done; - Preliminary cost analysis is done.

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Small scale prototype of the system or sub-systems is developed in laboratory. The prototype is stable, thus repeatable performances are provided. Interoperability between the tested technology and the other connected technologies is evaluated. When a small scale prototype is not feasible a validated simulation model is provided considering the real operating conditions. Examples: - Chemical and physical Lab analysis of the compliancy of the innovative HTF with material and process conditions (temperature and pressure); - Realization of a small scale prototype of the heat exchanger where thermal flows can be physically emulated by electric heaters or controlled thermal flows. The compatibility with other components (storage tank or heat pump) is validated; - Detailed numerical modeling of the system, including all the characteristic and properties of the components and the external boundaries condition (e.g ground temperature, heating and cooling demand). Operational condition has to be simulated with dynamic analysis; - A small scale prototype of the system is realized, proving the integration of the different components and validating the numerical model. The operational conditions (ground heat exchange) of the system are physically emulated by electric heaters or controlled thermal flows.
	Checkpoints
	- Realization and testing of the integrated prototype at laboratory scale; - The prototype is stable/reliable; - Evaluation of interoperability with other subsystems is done; - Validation of simulation model is done (if applicable).

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	A significant scale prototype is developed and integrated together with other technologies at system level in intended environment (simulated or actual). It includes testing in different environmental conditions. Examples: - Use of the innovative HTF in sub-component prototype. - Realization of a full scale prototype of the heat exchanger is realized and performance and compatibility with other components are validated in an intended environment. - A significant scale prototype of the system is realized, proving the integration of the different components and testing the system at full scale.
	Checkpoints
	- Realization of a significant scale prototype fully integrated with auxiliaries

	and control and tested in intended environment; - **Social impact preliminary evaluation.**

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	A significant scale prototype is fine-tuned to a variety of operating conditions together with other technologies at system level and in compliance with relevant environment conditions. The prototype is installed and tested in intended environment (on field). Reliable performances are provided by the prototype in line with the expectations. **Interoperability between the tested technology and the other connected technologies is optimized.** Examples: - **HTF tested in all the subcomponents and considering the interconnection of them in a prototype where performances are demonstrated in real and significant environmental conditions;** - **The heat exchanger is tested on field in a dedicated prototype, connected to a heating/cooling system. Performance and compatibility with other components are demonstrated in the intended environmental conditions;** - **The complete system is tested on field in a dedicated prototype. Performances of the new layout are demonstrated in the intended environmental conditions.**
	Checkpoints
	- **Realization of a prototype fully integrated with other technologies at system level and fine-tuned on field;** - **Measurement of prototype performances in different and extreme environmental conditions;** - **Performances match the expectations.**

TRL #7	**Technology validated in relevant environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	A full scale demonstrator is installed and connected to be tested to its final process purpose (e.g. at apartment, building or district level). **Compliance with relevant environment conditions, authorization issues, local / national standards are analyzed and guaranteed, at least for the demonstration site.** **The demonstrator is able to guarantee its functionalities due to a proper control and management strategy and an adequate maintenance approach.** **When it comes to the systems level, similar concept layouts and plants can be replicated in different operational conditions.** **Detailed cost analysis is performed.** **Manufacturing processes requiring investments are identified. The manufacturing risks towards prototyping are identified as well as manufacturing cost drivers and Key performance parameters.** **Needs for tooling, facilities, material and skills are identified.** **Technical and economic parameters of the technology are sufficient to define a business plan.** **Examples:** - **HTF tested in a full scale demonstrator;** - **The heat exchanger and related heating/cooling system is tested on field in different real operational environments (e.g. real apartment or building in different climatic zones);**

	- The complete system is tested on field in different real operational environments (e.g. real apartment or building in different climatic zones).
	Checkpoints
	- Realization of a full scale complete demonstrator at apartment, building or district level; - Demonstrator operational under different environment conditions; - Manufacturing chain and installation process have been specified; - LCA/LCC studies are completed.

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	The material or system is experimented in deployment conditions and has proven its functioning in its final purposes in relevant environmental conditions. Manufacturing chain and installation process are stable enough for entering in a low-rate production and all materials are available. Manuals for training and maintenance documentation are available. Examples: - HTF has proven performance under market conditions; - The heat exchanger has proven performance under market conditions; - The complete system is certified for market application.
	Checkpoints
	- Technology fully operational under market conditions; - Integration of technology proven in operational environment; - Standardization process implemented; - Compliance with certifications of the addressed markets; - Societal impact assessment completed.

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Material, or system and sub-systems ready for full operation production: materials, manufacturing processes and procedures, test equipment are in production and controlled. Lean practices are established. Different companies offer the technologies and maintenance services in their portfolio, providing specific and customized modifications.
	Checkpoints
	- Technology available on the market; - Full rate production.

6. GEOTHERMAL – FINAL GUIDANCE DOCUMENT

<table>
<tr><th colspan="2">RE TECHNOLOGY : GEOTHERMAL</th></tr>
<tr><td colspan="2">The geothermal RE sector includes many different matters, activities and scientific/technologic aspects. In brief the whole life of every geothermal program/project comprehends and requires the fulfillment of different basic phases: site identification; surface exploration; deep exploration; well tests/field models/field evaluation; plant/field engineering; plant construction/installation/operation and management (including operation monitoring). Consequently a very large number of different kinds of arguments/ideas/solutions can be proposed. Accordingly, the expression concept indicates the whole of conceptual/laboratory, design/realization aspects of the proposal which can be related to one or more of the phases as above.</td></tr>
<tr><td rowspan="5">TRL #1</td><td>Basic principles observed</td></tr>
<tr><td>Description
Basic research. Principles postulated and observed but no experimental proof available</td></tr>
<tr><td>Identification of scientific concept and interfaces
On the basis of published theoretical studies, field and lab experimental researches, data from various sides, promising new ideas/solutions are assumed/identified/proposed with regard to:
- innovative theoretical concept regarding the possibility to access the earth's interior heat;
- innovative theoretical approach to the economical exploration and exploitation of geothermal resources;
- innovative theoretical way to improve the effectiveness of the traditional and "ripe" technologic components and systems relevant to, e.g.: site identification; surface exploration; deep exploration; well tests/field models/field evaluation; plant/field engineering; plant construction/installation/operation and management (including operation monitoring).
The presentation of the proposal should include: the theoretical fundamentals on which is based; the guiding concept; the core preliminary description; the hypothesized expected results/applications/benefits; the broad indication of possible/expected barriers.
Examples of system, technologic and manufacturing arguments for this TRL:
- Systems/methodologies for the identification of geothermal promising large areas and specific sites to be explored (e.g. new or improved geophysical, geochemical, volcanologic, etc. surveys; improvement of data elaboration methodologies, new or better interpretation and modeling methods).
- Improvement of methodologies, equipment, instruments, data elaboration/interpretation/ modeling devoted to the testing activity after the drillings and to the estimation of reserves.
- Improved conceptual/realization design of the electric production plant (dry and wet steam, ORC plants, hybrid systems, hot-dry rocks utilization, cascade uses, etc.).
- New criteria and/or improvements of technical performances relevant to design, to equipment and materials of the FCDS's (Fluid collection and disposal systems).
- Optimization of the criteria for best management of the geothermal field in terms of extraction and reinjection rates and quantitative parameters, total efficiency, environment protection, safeguard of the reservoir equilibrium.
- Improvements in the design, technology, materials and manufacturing of other component and systems in the geo-thermoelectric production (e.g. separators, cooling towers, etc.).</td></tr>
<tr><td>Checkpoints</td></tr>
<tr><td>Level 1 readiness means that the basic initial knowledge and very preliminary</td></tr>
</table>

analysis elements, to be further thoroughly analyzed, are present. This means:

- Definition of the concept and its target based on a credible theoretic scientific approach;
- Identification of reliable technologies, criteria and methodologies based on literature data;
- Preliminary broad qualitative evaluation of expected benefits of the concept;
- Preliminary broad identification of expected barriers;
- A rough estimation of time-to-market exists.

TRL #2

Technology concept formulated

Description

Technology formulation. Concept and application have been formulated

Strengthening of the knowledge of the fundamental elements of the proposal. Preliminary program and modeling.

The preliminary data/ideas entry of TRL 1 are better and more deeply analyzed and in particular:

- Better identification of the final target and of the expected results of the proposed concept.
- Enhanced knowledge of the theoretical approaches and of the current worldwide state-of-art of the arguments of the proposed concept.
- Preliminary program of actions in order to reach the final target of the initiative.
- Elaboration of preliminary design of the prototyping process for the objective of the concept.
- Qualitative (ev. semi-quantitative) definition of the assumed benefits.

Examples of results and knowledge qualifying this TRL:

- Elaboration of systems/methodologies for a better detection of the underground geologic and tectonic structures and of the thermal gradient/heat-flux.
  Methodological and/or instrumental improvements of geophysical, geochemical, volcanologic, etc., surveys, developed at preliminary design level including program of actions and procedures.
- Concepts relevant to methodological and/or instrumental/software progress relevant to the data elaboration, interpretation, modeling.
- Preliminary design and schematic step program of actions devoted to increase the efficiency and significance of the wells testing activity for exploration, exploitation and/or reinjection (improvement of methodologies, equipment, instruments, data elaboration/interpretation/modeling).
- Preliminary design and schematic action program relevant to advancements of the methodologies presently applied in the engineering of the reservoir, of the production, of the plant. The same in relation to arguments as the estimation of reserves, and the good management of the field (total efficiency, environment protection, safeguard of the reservoir equilibrium, subsidence/micro-seismicity monitoring, etc.).
- First preliminary engineering of innovative concepts, materials, manufacturing and operative methods for the various kinds of geothermal energy production and for the FCDS (Fluid collection and disposal system).
- Technology or system to contrast or mitigate the barriers affecting the development and diffusion of the geothermal sector.
- Preliminary concept (including design, running methodologies, technologic solutions, materials and manufacturing), aimed to improve the performances of the auxiliary systems of the plant.

Checkpoints

Level 2 readiness means that the basic elements of the proposal have been better analyzed in respect to Level 1 and the following steps of the whole proposed concept have been clarified, which means:

- The scientific and technical preliminary reliability analysis of the concept is

	quite achieved; - The expected benefits and feasibility of the proposal are preliminarily assessed; - The possible relations and influences between components are initially analyzed; - An initial specification of the activities required for developing the prototype is done; - A preliminary simulation model of the concept is presented.

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	Starting of experimental application regarding engineering activities and focus on materials, technologies, and context. - The set-up of most activities pertinent to the proposal is almost completed. - The operative program of almost all the phases is quite finished. - Some preliminary activities of the program started and some preliminary results are available. - The numerical and/or physical simulation model of the concept (methodologies/software/"intellectual" products) is under operation. The prototype relevant to hardware components is constructed and installed. - The other context and complementary conditions correlated with the project are sufficiently identified and evaluated (generation units, auxiliary systems, subcomponents...). Examples of results and knowledge qualifying this TRL: - First demonstrative model (ev. prototype), with numerical analysis to validate the design of the instrumentation/methodology. Simulation analysis with evaluation of the performance of the component/system interested by the innovative aspects of the concept. - Elaboration of suitable methodology and related software for treatment and interpretation of the experimental data collected during the field surveys as well as during the production/interference tests of the wells. - Outline plan of new alternative proposed for the main components of the generation plant (turbine, evaporators, ORC cycle, etc.) and for the secondary/auxiliary ones (FCDS, civil works, cooling towers, etc.). - First proof-of-concept prototype, of the original instruments, equipment, main and secondary/auxiliary components indicated in the concept with first results of the evaluation tests. - Advanced evaluation, subject to successive moderate adjustments, of the possible "mining risk" for the investor.
	Checkpoints
	Level 3 readiness means that all the basic elements of the concept are identified, most of them have been analyzed, many of them have been measured and the successive steps of the whole project are clearly defined which means: - First proof-of-concept laboratory level prototype is ready and have been preliminary tested; - Parameters characterizing the concept are fully identified, and many of them are verified and cross-validated with simulation tools/numerical models against benchmark; - The scientific and technical preliminary reliability analysis of the concept is performed; - Selection of the suitable materials and components is achieved.

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**

	The experimental application, through models and prototype, is in an advanced stage, as well as other key context aspects of the concept. - **The prototype (hardware components of the concept) is developed and reliable quantitative indications in terms of performances of the concept can be achieved.** - **Many activities of the program regarding design activities, technologies identifications, materials selection, context matters, etc. are under execution, and preliminary results are achieved.** - **The simulation numerical and/or physical model ("works of intellect"/methodologic/software products) of the concept is in an advanced stage.** - **The collateral non-technical complementary parameters of the concept (risks, barriers, etc.) are evaluated.** **Examples of results and knowledge qualifying this TRL:** - **Realization of the small scale prototype and achievement of first results in terms of efficiency and performances of the hardware components (e.g. turbine, separation/evaporation units, plant auxiliary components, parts of FCDS, special devices/instrumentation for deep drillings, etc.).** - **Elaboration of numerical and/or physical model and achievement of credible results in terms of efficiency/performances for the "works of intellect"/methodologies/software related to the concept.**
	Checkpoints
	Level 4 readiness marks the end of the preparatory activities and the passage to the realization ones which means: - **The applied technological concept is experimented through the realization of a prototype and its actual initial performances are measurable;** - **The successive steps for the development of the prototype are defined in coherence with the preliminary results and the expected targets;** - **The risks and of possible barriers for the application have been acknowledged related preliminary mitigation strategies have been highlighted.**

	Technology validated in relevant environment
TRL #5	**Description** **Large scale prototype tested in intended environment**
	Completion and validation of the experimental application at demonstrative level. - **The simulation numerical/physical model of the concept and/or the prototype - completely developed and integrated with auxiliary systems - is put in exercise.** - **The interpretation of the test results of model/prototype is complete as well as the conclusions in terms of effectiveness and adequacy of the concept.** - **The quantitative performances of the concept achieved from the tests on the model/prototype allow the decision to proceed with pre-industrial scale or not;** - **A preliminary investigation of environmental impact is performed.** **Examples of results and knowledge qualifying this TRL:** - **Startup of the significant scale prototype of the concept and running in operative conditions equal or very close to those expected for the following pre-industrial and industrial realizations.** - **Achievement from the tests of repeatable results to evaluate the effectiveness of the concept and reliability of the qualitative and quantitative results.** - **Adequacy of the pointed out performances as well as of the other feasibility conditions to fit the technical specifications/conditions required by a wider scale (pre-industrial, industrial) application.**
	Checkpoints
	Level 5 readiness marks the end of the preliminary experimental and analytical activities and the availability of all experimental fully significant tests which are preliminary to the realization of the concept at a wider scale (pre-industrial), which means:

	- Realization of all the technical and non-technical tests on the model/prototype; - Repeatable results in terms of performances allow the validation of the concept; - Integration of needed components and auxiliaries is demonstrated; - The comprehensive analysis of the achieved technical and non-technical results and the overall feasibility evaluation allow (or not) to proceed ahead with the program and to assume the relevant decisions.

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	Start of production at wider (pre-industrial) scale **The concept is developed at pre-industrial scale on the basis of the results of the previous validated and demonstrated experimental application.** - If the concept consists of hardware realization this means: to establish the specific engineering for the wider scale; to establish the manufacturing processes and related procedures; to carry out the construction and the installation of the system/component according to local standards and regulations; to carry out the start-up, the test, and entering into operation; to control the exercise and evaluate the performances of the concept. - If the concept consists of software this TRL could require an eventual adaptation to the wider scale (if necessary) and the exercise in different operative situations in order to appreciate the effectiveness and performances of the new tool in the wider scale situation. - The environmental compatibility at pre-industrial scale of the concept has been ascertained. **Examples of results and knowledge qualifying this TRL:** - Development of the concept already developed in the previous TRLs, at experimental and demonstrative level, in completely operative, even if pre-industrial, real conditions of application as size, location, services and auxiliary systems etc. - Application in real conditions of the software developed for the same purposes as above briefly and partly summarized. - The manufacturing, installation and running procedures of the concept are decided and applied in real operative conditions. - The procedures for the control and monitoring of the operation and for the evaluation of the effectiveness and performances of the concept originalities are established and applied in real operative conditions.
	Checkpoints
	Level 6 readiness marks the beginning of the actual operations aimed to introduce the concept in the market thanks to the realization of the concept at a wider scale (pre-industrial), which means: - Demonstration of the reliability and correct working conditions as well as of the expected performances of the concept in operational and almost full scale conditions; - Verification and preliminary validation (or adjustment) of the engineering produced for the wider scale/s.

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	Completion of production at wider (pre-industrial) scale **The full scale pre-industrial realization of the concept is completed. The demonstration has been conducted through exhaustive tests up to its final process reaching the formulation purposes. The manufacturing process, procedures and the**

	production program are established and validated. The compliancy with relevant environment conditions, authorization issues, grid operability, local-national standards is analyzed and guaranteed, at least for the demonstration site. The only remaining steps pertaining to this TRL 7 which are necessary to fulfill all the requirements for the complete passage to the full industrial production are: - Design of different methodological and/or technologic versions of specific parts of the already proven and validated concept in order to provide different solutions for possible/probable specific market personalized requirements. - Development of eventual necessary engineering adjustments of the proven and validated concept (e.g. investigation depth and definition levels for surveys and tests, power plant different sizes, particular environmental protection requirements, etc.) in order to assure the same can be replicated in other very different context conditions. - Market analysis to evaluate as clearly as possible the actual strength and weakness points, the competitiveness positioning, the market penetration chances, the entrepreneurial interest (profitability, prospects, etc.) of the full industrial production of the concept. Examples of results and knowledge qualifying this TRL: - The efficiency, the feasibility and the performance of the pre-industrial concept (including the "intellectual" products and the instrumental, mechanic, civil, electric, electronic components and systems) have been verified and validated in normal operational conditions. - The same feasibility and the performance parameters have been integrated/completed/ adjusted with variations related to different normative or market requirements. - As an example of proper adjustments can be mentioned very particular context conditions (e.g. releases of liquid/gaseous pollutants in the environment, specific prohibitive prescriptions terms relevant to landscape protection) which can deeply change radically the "normal" technical and economic parameters of the concept.
	Checkpoints
	Level 7 readiness marks the completion of the operational wide scale (pre-industrial) concept, the ripening of results and the beginning of industrial phase aimed to the introduction in the market which means: - Final demonstration and validation of the reliability and working performances of the full-scale concept. - Verification and validation of the technical aspects related to the full-scale concept, (engineering, manufacturing industrial processes, related procedures, etc.). - Confirmation or adjustment of the economic aspects of the industrial level concept (investment, O&M budget, production times). - Proper adjustments of technical, economical parameters of the concept in function of particular market and environmental/landscape requirements and regulations. - Final identification and deep analysis of the various obstacles and barriers which could hamper the application and the diffusion of the geothermal concept and final identification of the ways to contrast or mitigate these barriers.

TRL #8	**System complete and qualified**
	Description First of a kind commercial system. Manufacturing issues solved
	System Complete And Qualified - Establishment of industrial production of the concept - All the technical and non-technical matters, aspects and activities involved in the finalization of the concept have been completed. All the technical and non-technical problems, barriers, uncertainties, expected results and performances

	have been solved/reached/confirmed. The full industrial feasibility is demonstrated. The only remaining steps pertaining to this TRL 8, which are necessary to reach the full industrial production are: - Extension or adaptation of the engineering relevant to the testing, manufacturing and management procedures (training and maintenance ones included) to the different national regulations at worldwide level or to the expected penetration market. - Eventual design and constructive final adjustments/improvements of the pre-industrial product before the large-scale industrial production. - Final economic analysis and final data relevant to production costs, production times, competitiveness together with establishment of market policies and business plans. - Start of industrial wide scale production (hardware products) or application (intellectual, methodological, software products). Examples of results and knowledge qualifying this TRL: - The state-of-art of the concept has reached such as a sufficient knowledge level in all the aspects to permit the conscious and reliable investment and funds allocation. - The variations of the technical and economical parameters of the concept in case of particular market, environmental and landscape requirements and conditions, have been considered and defined. - The equipment and the installation/auxiliary structures and services are ready to start the industrial production. - The commercial activity started and proceeds on-going. The commercialization activities are extended to all the aspects and the complements of the concept.
	Checkpoints
	Level 8 readiness marks the beginning of industrial phase for the introduction in the market and the progressive diffusion which means: - Definitive finalization and establishment of all the technical and non-technical matters; - Elaboration of proper variants of the technical aspects and/or the economical parameters in order to fit specific market, environmental and landscape conditioning conditions; - Definitive economic and financial budget, business plan, with establishment of market policies; - Marketing operations in advanced stage.

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Complete maturity of the concept at industrial scale The innovative concept (being hardware products as electro-mechanical systems, components, devices, instrumentation, etc., or “intellectual” products as techno-scientific methodological applications, software, etc.) is completely defined and mature for deployment at large industrial production rate. The maturity of the concept and the already reached introduction in the market do not exclude successive complementary actions to maintain and expand the trade positions as: - Design of improvement of the concept deriving from the exercise of the same. - Readiness of technologic variants and adjustments of design and economic parameters in function of specific market and environmental and landscape conditions. - There is the possibility to provide on demand specific and customized variants of the concept. - Development of complementary sectors (spare parts warehouses, assistance for failures and accidents, ordinary maintenance services, etc.)

	- **Formulation and design of different other products directly derived from the know-how achieved through the developed concept.** - **Marketing of the main concept, and variants.** - **Promotion, advertising, information campaign.** - **Agreements with economic operators for further expansion and development.** **Examples of results and knowledge qualifying this TRL:** - **Many applications of the concept are installed and operative.** - **The commercial activity is running at full capacity.** - **The trade and assistance networks have been established and are operative as well as the agreements with eventual partners, concessionaries, licensee.** - **Different companies propose the concept technologies and maintenance services in their portfolio.**
	Checkpoints
	Level 9 readiness marks the completion of industrial phase and the organized presence of the concept in the geothermal market which means: - **Concept fully operational from the productive, commercial, market point of view;** - **Support commercial and technical assistance network established and operational;** - **Presence of in-force sale contracts and long term agreements;** - **Advanced acquisition of knowledge and reputation in the geothermal world.**

7. RENEWABLE ALTERNATIVE FUELS – FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : RENEWABLE ALTERNATIVE FUELS

TRL #1	**Basic principles observed**
	Description **Basic research. Principles postulated and observed but no experimental proof available**
	A new concept related to renewable alternative fuels is proposed. It could consist of a fuel, different from the existing ones, or of an innovative way to produce or to convert a fuel. Technical options for the concept are identified and relevant literature data reviewed. Examples of results and knowledge qualifying this TRL: - Identification of an innovative fuel, in terms of environmental and performance issues; - Identification of a new production process, to increase and optimize the use of renewable sources; - Concept on new materials (e.g. feedstocks, catalysts, intermediates, etc.), processes and their characteristics. Evaluation of the potential benefits of the new concept over the existing ones and indication of safety issues should be reported to support a better understanding of the technology.
	Checkpoints
	Once readiness level 1 is achieved, the scientific concept is observed and documented. This means: - Identification of possible materials, components and systems and relevant risks and hazards; - Preliminary concept design - Preliminary evaluation of the potential benefits and technological gaps of the new concept over the existing ones.

TRL #2	**Technology concept formulated**
	Description **Technology formulation. Concept and application have been formulated**
	The technology concept, its application and interfaces to other systems are defined. Preliminary modeling of the intended concept or system is available. Identification of preliminary proof of concept approach for the realization of systems or sub-systems is performed. Identification of preliminary fuel lab production or conversion steps is performed. Examples of results and knowledge qualifying this TRL: - Estimation of innovative way to fuel production or conversion; - First indication of fuel composition and properties (e.g. lower and higher heating values…); - Definition of the proof of concept approach in terms of technologies, materials, etc.
	Checkpoints
	Once readiness level 2 is achieved, the applied technological concept has been defined. This means: - Technical analysis of the concept is investigated; - Interactions between components are qualitatively assessed; - Qualitative assessment of advantages (e.g. environmental, technological, economical) of the new concept, fuel or system is done; - Proof of concept approach and preliminary technical specifications (e.g.

	technologies, compositions, limitations) is defined.

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	First model completed and preliminarily tested. Development of experimental application is initiated at component, system or sub-system level. The first proof of concept prototype is developed by laboratory set-up. Innovative ways to fuel production or conversion and its manufacturing approach are tested through bench-scale experiments. Characterization of fundamental properties is made. Numerical models and simulations (e.g. structural FEM, CFD, control, detailed thermodynamic cycle simulations, etc.) if available should support laboratory testing. Examples: - First proof of concept prototype of the innovative fuel and test in a simplified system; - First proof of concept prototype of the innovative manufacturing approach, at laboratory scale; - Preliminary validation of the assumption performed so far, with reference to fuel characteristics and performances; - Evaluation of conversion performances.
	Checkpoints
	Once readiness level 3 has been achieved, the applied technological concept has been defined. This means: - The concept is tested through laboratory scale; - Parameters characterizing the fuel or the technology are measured/calculated; - First proof-of-concept prototype is ready and preliminarily tested; - Verification of the proof of concept through consolidated simulation tools and cross-validation of the numerical models thanks to literature data (if applicable) is done. - Qualitative assessment of advantages (e.g. environmental, technological, economical) of the new concept, fuel or system is demonstrated.

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Small scale prototype of the system or sub-systems is developed in laboratory. The prototype can achieve repeatable/stable performance. Integration between the tested technology and the other sub-systems is proven at laboratory level. When a small scale prototype is not feasible a validated simulation model is provided considering the real operating conditions. Examples of results and knowledge qualifying this TRL: - Fuel production or conversion process parameters and features are established; - Validation of the assumption performed so far, with reference to fuel characteristics and performances; - Quantification of range of admissible impurities.
	Checkpoints
	Once readiness level 4 has been achieved, the applied technological concept is experimented and validated. This means: - The fuel or the process is tested and validated at laboratory scale; - The prototype characteristics are defined;

	- The prototype can achieve repeatable/stable performance; - Integration with complementing subsystems is done; - Quantitative assessment of advantages (e.g. environmental, technological, economical) of the new concept, fuel or system is demonstrated; - The hazards associated to the technology should be identified.

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	A large scale laboratory prototype is developed and integrated together with other subsystems in intended working environment. It includes testing in different operating conditions. Examples: - Realization of a large scale laboratory prototype; - Storage and utility connections are included in the prototype;
	Checkpoints
	Once readiness level 5 has been achieved, the technology is ready to move forward to pilot scale. This means: - A large scale laboratory prototype is realized and tested in intended working environment; - The manufacturing process parameters are defined; - Information to perform environmental and socio-economic sustainability assessment is available; - Life cycle analysis could be done;

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	A pilot scale prototype is fine-tuned to a variety of operating conditions together with other subsystem and in compliance with intended working conditions (on field). Reliable performances are provided by the pilot scale prototype in line with the expectations. Interoperability between the tested technology and the other connected technologies is optimized. Examples: - Fuel production process demonstrated in real working conditions.
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to pilot scale. This means: - The technology is demonstrated in working environment conditions; - Fuel characteristics are stable; - The process is safe and reliable; - Realization of a pilot scale prototype that could be integrated with other subsystems and fine-tuned on field; - Measurement of pilot scale prototype performance in different and relevant extreme conditions; - Performance matches the KPIs; - Social acceptance is evaluated.

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	A demonstrator is installed to be tested to its final process purpose.

	All fuel qualification steps are completed. Compliance with relevant environment conditions, authorization issues, local / national standards are analyzed and guaranteed, at least for the demonstration site. The demonstrator is able to guarantee its functionalities due to a proper control and management strategy and an adequate maintenance approach. When it comes to the systems level, similar concept layouts and plants can be replicated in different operational conditions. Manufacturing processes requiring investments are identified. The manufacturing risks towards prototyping are identified as well as manufacturing cost drivers and KPIs. Needs for tooling, facilities, material and skills are identified.
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at demonstration scale. This means: - System/technology demonstrated in field under different working conditions; - Manufacturing approach is demonstrated; - Life cycle assessment and life cycle costing are re-evaluated; - Regulatory aspects are analysed and followed.

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	The technology is experimented in deployment conditions (i.e. real world) and has proven its functioning in its final purposes in working conditions. Manufacturing chain and installation process are stable enough for entering in a low-rate production and all materials are available. Limiting factors are still present to move to commercial scale production. Examples: - The new fuel has proven performance under potential market conditions; - The production plant has proven performance under potential market conditions; - The complete system is certified for market application
	Checkpoints
	Readiness level 8 is achieved, once: - Technology is proven in its final form and under expected conditions; - Production is potentially commercially viable; - Compliance with legal obligations of the technology is in place.

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Limiting factors are solved. The technology is ready for full operation production.
	Checkpoints
	Readiness level 9 is achieved, once: - Technology available for the market; - Full rate production readiness; - Business plan is available.

8. OCEAN – FINAL GUIDANCE DOCUMENT

<table>
<tr><th colspan="2">RE TECHNOLOGY : OCEAN ENERGY</th></tr>
<tr><td rowspan="5">TRL #1</td><td>Basic principles observed</td></tr>
<tr><td>Description
Basic research. Principles postulated and observed but no experimental proof available</td></tr>
<tr><td>Identification of basic principles, performers and interfaces.
The principles that underlie the technology are defined, and this analysis is supported by information that includes published research and/or other references investigating the identified principle.
The concept exists only on paper / software form, no hardware still exists.
A prime-principle based analytical model of the principles exploited (i.e. not representing the whole device), implemented into a first approximation model, should be developed based on the available published research. A set of relevant operating conditions should be considered.
Usually no mechanical/electrical efficiencies are included at this stage.
Interfaces (i.e. characterization of the relationships) with other technologies (e.g. overall device or other subsystems) in the frame of system integration have been identified.</td></tr>
<tr><td>Checkpoints</td></tr>
<tr><td>Once readiness level 1 is achieved, the scientific concept is observed and documented. This means:
- definition of principles underlying the technology;
- evaluation of the benefit of the technology in comparison with other existing technologies;
- first identification of interfaces with the other systems.</td></tr>
</table>

<table>
<tr><td rowspan="5">TRL #2</td><td>Technology concept formulated</td></tr>
<tr><td>Description
Technology formulation. Concept and application have been defined</td></tr>
<tr><td>Definition of the technological concept and considerations about manufacturing aspects.
The practical application is defined. The analyses conducted in TRL1 are expanded toward considering the other necessary systems to convert the absorbed energy into electrical energy, at a level able to identify the main technological barriers.
At this stage, usually, it is not necessary to investigate the other sub-systems' performance.
In addition to the influence of monochromatic waves, irregular waves based on relevant sea states can be considered for WECs. For tidal devices, typical current velocity variation with water depth and typical turbulence levels may be considered.
The analyses are usually analytical/numerical, even if some basic experimental work to support the basic principles exploited could be carried out.
Published papers and patents may support the development of the concept.
Functional requirements are investigated and documented, and potential market has been identified.
Manufacturing approaches or capabilities needed to develop the concept are identified: it includes study of materials and processes approaches as well as modelling and simulation.
Preliminary installation consideration are performed.
A proof-of-concept integration of the systems should be carried out.</td></tr>
<tr><td>Checkpoints</td></tr>
<tr><td>Once readiness level 2 is achieved, the applied technological concept has been defined. This means:
- definition of application
- identification of materials and suppliers</td></tr>
</table>

	- statement of interactions between technologies - identification of main technological and non-technological challenges - early consideration of commercial value of the technology. - Operational environment: the environment is not simulated / is simulated to a limited extent

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	Analytical and first experimental proof-of-concept of the critical function/main characteristics, identification of manufacturability and compatibility **Ad-hoc and on purpose R&D is now initiated.** **The main principles, characteristics, and performance of the concept are validated, using analytical studies and experimental campaigns at an appropriate scale level, in controlled conditions (laboratories). These laboratories should be able to reproduce the main wave (WEC) and tidal (tidal device) characteristics: small/medium ocean/wave basins, wave/flume tanks, and towing tanks are good examples. These studies focus on the main elements of the WEC/tidal system, and usually not on the integrated system.** **Numerical modelling and simulations can be used to complement the physical experiments.** **At this stage, it is advisable to explore as many relevant parameter ranges as possible in the design space, since it is still possible to change the main characteristic of the device at a relatively low cost.** **An analysis to identify the manufacturability of the main elements using state-of-the-art commercial techniques is performed.** **A preliminary value analysis is carried out.** **A risk mitigation strategy is documented.** **A compatibility analysis among the main energy-conversion elements is carried out.**
	Checkpoints
	Once readiness 3 has been achieved, the applied technological concept has been defined. This means: - analytical and experimental (lab scale, controlled environment) investigations of the main component/s of the device (i.e. absorber element, energy conversion elements if not available off the shelf, sub-components) - main energy-conversion elements manufacturability, installation, and operability analysis - compatibility analysis between main energy-conversion technologies - preliminary risk mitigation analysis - scale of testing: tests are conducted in a controlled environment (lab), and only on the main component/s of the technology (not the whole integrated system) - operational environment: the most relevant aspects of the environment (monochromatic wave height/frequency ranges, sea states' significant wave height and zero-crossing period for WEC, current speed and/or tidal ranges for tidal devices) are simulated in a controlled environment (lab). - fidelity: the main component/s of the system are reproduced and tested at a scaled level, to represent the main characteristics influencing the energy absorbed/transformed - Confirmation of expected results estimated in the previous TRLs

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Component and system validation in a laboratory environment, manufacturability and interoperability **This is a fundamental step of the development of WEC and tidal devices, focusing on**

	the analysis and validation of the performance of the device in (lab simulated) real conditions, and assessing the performance sensitivities with respect to the main environmental condition parameters. **The separate components are now analysed from a whole-system point of view, therefore a system engineering approach should be adopted. This validation occurs at laboratory level, i.e. not in the field, measuring the relevant parameters linked to these main aspects: device performance, environmental loads (wind, waves, currents), control strategy, support structure system (fixed or floating).** **The experimental analyses, complemented by a range of analytical and numerical analyses, are conducted on a larger scale (~1:10-1:25), higher fidelity models, matching the overall configuration in the most important aspects, and using a more comprehensive set of environmental conditions. For WEC, a more comprehensive number of sea states and tidal condition ranges are considered. For tidal devices, typical current speed time histories, variation of current speed with depth, and typical turbulence ranges should be considered. For both, survival conditions needs to be considered.** **Medium/large ocean/wave basins and/or large flumes and towing tanks are typically used at this stage.** **The aim of these analyses is wider than TRL3, since their scope includes the definition of the power take off (PTO) control strategies, and the verification of the support structure design (fixed/floating support structure and mooring system).** **A reference site/set of sites is chosen, or a representative generic site can be adopted.** **Based on the analytical and experimental data: A) a first estimation of the operational and survival loads is derived, allowing a preliminary design and elementary costing, B) the measured power absorbed in a range of metocean conditions will allow and estimation of the annual energy yield.** **Manufacturing processes requiring investments are identified. The manufacturing risks towards prototyping are identified as well as manufacturing cost drivers and Key performance parameters.** **Needs for tooling, facilities, material and skills are identified.** **Project risk management is integrated within project management.**
	Checkpoints
	Once readiness 4 has been achieved, the applied technological concept is experimented and validated. This means: - **testing and validation at laboratory level of technology gathering separate elements** - **validation of interoperability** - **manufacturing, installation, and operation investments/costs identified** - **risk management integrated in the project** - **scale of testing: tests are conducted in a controlled environment (lab), and integrating the main elements** - **operational environment: the relevant aspects of the environment are simulated in a controlled environment (lab).** - **survival load cases should also be considered** - **fidelity: some of the component/s of the system are reproduced and tested at a scaled level** - **a detailed assessment of the commercial value is produced**

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	Laboratory scale, almost-prototype experimental validation and in simulated environment **The major improvement from TRL 4 to TRL 5 consists in the enhanced model fidelity and environmental conditions fidelity of the experiments. The model tested is almost a prototype, allowing the quantitative measurement of the performance, but still**

tested in controlled (lab) or benign (sheltered sites) conditions.
The technological components are integrated with additional supporting elements (e.g. hardware and software) to be tested in a simulated environment.
The technology is able to establish, manage and terminate the integration with other technologies; this means there is a sufficient control between technologies.
Manufacturing component prototypes are created and a manufacturing strategy is defined.

Checkpoints

Once readiness 5 has been achieved, the technology is ready for full-scale. This means:

- testing and validation in simulated environment finished
- control capacity towards integration at system level
- manufacturing prototype completed
- manufacturing strategy defined (including cost model)
- scale of testing: tested in a relevant, but still controlled, environment.
- operational environment: all the main aspects are represented in the lab, including not only the conditions influencing the power production level, but also those relevant for all the other sub-systems of the whole device.
- fidelity: the scaled model configuration is similar to the full scale configuration in most relevant aspects (including balance of plant systems)
- PTO conversion efficiency (electrical) - Storm survival - identification of suppliers for TRL6 (relevant benign environment)
- Upscaling study based on test results is performed
- A refined detailed assessment of the commercial value is produced

TRL #6

Technology demonstrated in relevant environment

Description

Prototype system tested in intended environment close to expected performance

Technology application functioning, manufacturing and integration prototyped.
The major difference between TRL5 and 6 is the move from testing in laboratory conditions to a natural site, where the conditions cannot be controlled.
This is a fundamental intermediate step between the lab scale model and the intended final scale, to troubleshoot the technical issues and to reduce the financial risks, since a “benign” natural site is chosen. This site is closer to shore than an operational site (easier installation/maintenance), not exposed to the full open seas conditions (typically in bays), but still representing a relevant environment compatible with the scale of the prototype.
The device is fully operational, i.e. is able to produce energy, but since still at scale level and being only one device rather than an array of devices, the total power produced is limited, i.e. there is no need to connect the device to the grid (even if the main effects of the grid should be simulated).
The analytical and numerical models can be validated by the experimental data gathered, which could be considered at full scale level, i.e. not suffering from substantial scaling errors.
In order to test the device in a relevant environment, not only the maturity of the device but also the maturity of the company developing the device is proven.
It will be necessary to define in details the manufacturing, deployment, servicing, maintenance, certification, licensing and site permitting techniques and approaches, therefore substantially enhancing the personnel skills.
The technology is not only able to control information, but to specify what relevant data to exchange and also to translate information coming from a foreign/external data structure.

Checkpoints

Once readiness 6 is achieved, the technology is enlarged to near full-scale, engineering/prototype scale, and deployed in a natural but “benign” site. This means:

- technology demonstrated in relevant environment

	- project management approaches are practised - servicing and maintenance techniques, even if at a smaller scale and for a limited amount of time, are practised - certification and insurance requirements, licensing and permitting challenges are satisfied - process and tooling mature - capacity of structuring information at system level - operational environment: the device is tested in a "benign" test natural site, i.e. the metocean conditions cannot be controlled, but these are suitable for a scaled prototype, avoiding extreme conditions - fidelity: the scaled model configuration is similar to the full scale configuration in all but minor aspects - details for intended final scale installation defined - design and manufacturing for intended final scale defined - simulation for energy production achieved - An updated and refined detailed assessment of the commercial value is produced

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	Application prototype integrated and demonstrated in field (operational environment), initial consideration and analysis at array level. Prototype at operational level: the technology is demonstrated in an industrially relevant environment, at final scale, but still stand alone (no array). The location should represent the correct metocean conditions for the device scale used, and ideally should be placed near the proposed wave park site, but could still be a test centre. The device is tested over a comprehensive range of relevant conditions One of the main focus at this stage is to gain operational experience for the WEC/tidal device, since in the previous TRL levels the testing time length could have been limited to few months, while at TRL7 continuous/discontinuous test for a period long enough to create confidence with respect to reliability and services can be envisaged. The power production level and power quality is validated, and all the engineering aspects are proven. Final scale decommissioning strategies need now to be defined and proven. The economics aspects are proven at a near final scale/final scale level, even if for a one-off, bespoke design. By applying mass production estimates, a first estimation of the cost of energy produced by a park of tidal devices/WEC can be derived. Manufacturing processes and procedures are demonstrated: production planning is complete. The integration of technologies has been verified and validated.
	Checkpoints
	Once readiness 7 is achieved, the technology concept validated at full-scale. This means: - pilot demonstrated in field (operational environment) - relevant operational experience in gained - reliability of integrated pilot - manufacturing and deployment techniques are proven - scale of testing: a pilot system at final scale - operational environment: the device is tested in a natural site with representative real sea conditions - fidelity: the prototype configuration is virtually the same as the full scale system

	- all information for a commercial proposition are available - environmental aspects are considered and implemented in the final scale - a certification roadmap is defined

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	System completed and qualified through test and demonstration **The technology is experimented in deployment conditions (i.e. real world) and has proven its functioning in its final form.** **At this stage all the systems are verified from life-cycle point of view, i.e. the higher energy metocean conditions (more rare) experienced verify the fitness of the system in survival conditions, when maximum design load conditions can occur.** **The environmental impact assessment performed in the previous phases is here refined and validated, and even if no long-term effects can be measured, the environmental impact of the manufacturing, transporting, installing, commissioning and decommissioning phases can be measured.** **Array interactions should be analysed and estimated analytically and numerically, and ad-hoc tests in controlled conditions (lab), at scale level, may be conducted.** **If it has not been done before, existing stakeholders and local communities should be contacted at this stage, in order to avoid potential future show-stoppers.** **Manufacturing process is stable enough for entering in a low-rate production and all materials are available: manufacturing processes and procedures are established and controlled to meet design key characteristics tolerances.** **Training and maintenance documentation are completed.** **Integration at system level is completed.** **Technology is deployed and operating in operational condition.**
	Checkpoints
	Once readiness 8 is achieved, the system is incorporated in commercial design. This means: - technology in its final form and under expected conditions - readiness for low-rate production - integration in operational environment - scale of testing: a pilot system - operational environment: the device is tested in a natural site with representative real sea conditions - fidelity: the prototype configuration is virtually the same as the final scale system - Power matrix/function can be fully extracted according to IEC standards - Number of hours/availability are maximized - Health and condition are monitored - Energy production is validated to confirm the economic plan - Environmental impacts are contained - Commercialization plan is fully formulated

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Actual array system operational – Economics validation **The tidal energy or WEC system is demonstrated at array level, even if it may consist of only few systems (3-5 devices). This will prove the economic feasibility (when extrapolated to the commercial farm level) of the system, making it a commercial product.** **All the previous analyses, in all the disciplines (technological, economic, social, and environmental) are now expanded, verified, and validated at array level.** **The hydrodynamics interactions between the devices are verified, as well as the**

	array connection grid between the devices, the power conditioning equipment (substation), and the connection to the shore and the energy grid. This includes the aspects of their assembly, installation and decommissioning. **The quantity and quality of the power supplied to the grid is assessed over a long period of time, during which the array of devices is exposed to a full range of operational and survival conditions.** **The economic feasibility is proven at a (mini) array level, and meaningful extrapolation can be derived for a large tidal/wave farm.** **The consenting, licensing, permits, certification, insurance, health & safety procedures are further defined and expanded at array level, reaching full maturity.** **The system is ready for full rate production: materials, manufacturing processes and procedures, test equipment are in production and controlled.** **rformance and reliability of farm are demonstrated.**
	Checkpoints
	Once readiness 9 is achieved, the system is ready for full-scale deployment and commercialisation. This means: - **system fully operational, including the inter-device energy grid, the substation, and the connection to the shore energy grid** - **integration of technology proven in operational environment** - **full-rate production** - **system ready for commercialisation** - **scale of testing: 1:1 (final scale), an array of 3-5 (or more) devices** - **operational environment: the devices are deployed in a real commercial site, exposed to the full range of operational conditions** - **fidelity: the device is identical to the commercial product (apart from the necessary adjustments for the different location conditions)** - **failure report/log** - **farm power matrix/curve** - **Business case for commercial technology sales**

9. BIOENERGY – BIOLOGICAL PATHWAY – FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : BIOENERGY – BIOLOGICAL PATHWAY	
TRL #1	**Basic principles observed**
	Description **Basic research. Principles postulated and observed but no experimental proof available**
	A new concept related to development of feedstock and/or biological processing of organic input materials (biomass and/or organic waste) for energy purposes is proposed. It could consist of, for example: - a new concept to improve quality and/or quantity of feedstocks; - the exploitation of a new feedstock, different from the currently used ones; - an innovative way to convert organic input into an energy carrier; - new concept for provision of energy from biomass or bio-based energy carrier (e.g.: microbial fuel cells, innovative turbines, engines, etc.); - new concept for upstream/downstream technologies (e.g. separation).Technical options for the concept are identified and relevant literature data and research results reviewed. The theoretical fundamentals of the concept are investigated; the concept is summarily described, with preliminary identification of the potential benefits and barriers.
	Checkpoints
	Once readiness level 1 is achieved, the scientific concept is observed and documented. This means: - Identification of a gap in the literature and definition of the new scientific or technical concepts; - Identification of fundamentals of the concept such as feedstock, bio-based materials, components and systems; - Preliminary evaluation of the potential benefits and barriers of the new concept over the existing ones.

TRL #2	**Technology concept formulated**
	Description **Technology formulation. Concept and application have been defined**
	The technology concept, its potential applications and interfaces to other systems are defined and analysed. Preliminary modeling of the intended process and/or testing of the intended material is carried out in order to obtain the first numerical results. Identification of preliminary proof of concept approach for the realization of systems or sub-systems is performed. For example, in this TRL, a first characterization of feedstock physico-chemical properties (e.g. composition structure, functionalities, etc.) is provided, or a basic mathematical model of the biomass processing or conversion system is elaborated.
	Checkpoints
	Once readiness level 2 is achieved, the new concept has been numerically refined. This means: - Initial numerical knowledge, understanding and identification of design concepts, materials, processes and physical characteristics is achieved; - Relationships between components and/or systems are qualitatively described; - Definition of the proof of concept for laboratory tests and/or simulations.

TRL #3	**Experimental proof of concept**
	Description **Applied research. First laboratory tests complete; proof of concept**
	First proof of concept is developed by laboratory set-up and/or first mathematical

	model is completed and preliminarily applied. Innovative paths to feedstock provision/generation, biomass processing or energy conversion are tested through bench-scale experiments or numerical simulations (e.g. kinetics) in order to achieve first numerical experimental results on the specific technology.
	Checkpoints
	Once readiness level 3 is achieved, the applied technological concept has been defined. This means: - First proof of concept test is carried out experimentally or numerically; - Verification of the proof of concept through simulation tools and cross-validation of the mathematical models thanks to literature data is done (if applicable); - The system characteristics are defined for the design of a prototype; - Key parameters characterizing the feedstock, the process or the technology are identified.

TRL #4	**Technology validated in lab**
	Description **Small scale prototype built in a laboratory environment ("ugly" prototype)**
	Small scale prototype of the system or sub-system is developed in laboratory and tested. The performance of the prototype is calculated through suitable key performance indicators. The integration between the tested technology and the other sub-systems is investigated at laboratory level (e.g.: feedstocks under development, output of conversion system, concentration of product, downstreaming technologies). When a physical small scale prototype is not feasible, a simulation model is provided, validated on the basis of experimental data.
	Checkpoints
	Once readiness level 4 is achieved, the applied technological concept is experimented and validated. This means: - The prototype is designed according to the specifications previously defined; - The feedstock/process is tested and validated at laboratory scale (or simulated through a suitable model if physical tests are not feasible); - The key performance indicators are measurable; - A first analysis of the integration with complementing sub-systems is performed.

TRL #5	**Technology validated in relevant environment**
	Description **Large scale prototype tested in intended environment**
	A large scale laboratory prototype *(for feedstocks: experimental lines)*[1] with repeatable and stable outputs under different operating conditions is developed and integrated together with other sub-systems in relevant working environment.. The technical performance of the prototype is quantified through suitable indicators, and other relevant parameters are defined (concerning scale-up, environmental, regulatory and socio-economic issues) and used to validate the previously developed

[1] In contrast to other types of renewable energy, where research is mostly directed to the development of new technologies for the conversion/processing of wind/light/waves (etc.) into energy, the production of bioenergy from biomass requires innovation on both the establishment of better conversion/processing technologies and on the development (and cultivation) of dedicated feedstocks. Given the great relevance of both aspects in the definition of TRLs for Biological pathways. Hence, from TRL 5 to TRL 9 the distinctions needed to refer to feedstock object are highlighted in italics.

	concept or to define the changes required to achieve satisfactory results. **Among others, feedstocks availability issues are preliminarily considered in the evaluation.**
	Checkpoints
	Once readiness level 5 is achieved, the technology is ready to move forward to pilot scale. This means: - **A large scale laboratory prototype is realized, controlled and tested in intended working environment;** - **The prototype shows repeatable/stable performance;** **Information to perform environmental and socio-economic sustainability assessment is available and a first qualitative analysis is carried out.**

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	The lab scale prototype is scaled up to pilot scale *(or to elite lines in the feedstock case)* once scaling up criteria are defined and main related issues are solved. **The prototype is fine-tuned to a variety of operating conditions together with other sub-systems and in compliance with intended working conditions (on field).** **The pilot scale prototype provides performances in line with the expectations concerning for example: conversion efficiency, carbon yield, concentration, product quality (e.g.: heating value, chemical composition), emissions, process safety, etc.** **Interoperability among the tested technology and the other connected technologies is proved.** **An advanced evaluation of environmental, regulatory and socio-economic issues is performed.**
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to pilot scale. This means: - **A pilot scale prototype that could be integrated with other subsystems and fine-tuned on field is realized;** - **The technology is demonstrated in working environment conditions (including relevant extreme conditions);** - **The process is safe, reliable and provides a performance in line with the expectations, guaranteeing advantages with reference to the existing technologies.**

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	A pre-commercial demonstrator is installed and tested in different operating conditions and to its final process purpose, i.e. integrated with relevant feedstock provision, upstream and/or downstream processes. **Compliance with relevant environment conditions, authorization issues, local/national standards is analyzed and guaranteed, at least for the demonstration site.** **The demonstrator is able to guarantee its functionalities due to an adequate feedstocks availability and to a proper management strategy.** **Interoperability among the tested technology and the other connected technologies is optimized.** **Manufacturing approach is investigated and a preliminary design of production planning is carried out. Life Cycle Assessment should be performed.**
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at demonstration scale. This means: - **System/technology/*feedstock* is demonstrated at pre-commercial scale, in field, under different working conditions and integrated with upstream and**

	downstream processes; - **Control and management of the technology are demonstrated as adequate in a relevant operational environment and optimized parameters are determined;** - **Regulatory aspects are analysed under authorization, environmental and safety perspectives;** - **Social acceptance is evaluated.**

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	System completed and qualified through test and demonstration **The technology/*feedstock* is experimented in deployment conditions (i.e. real world) and has proven its functioning in its final purposes in working conditions.** **Manufacturing and other stages requiring investments are identified; the risks across the entire chain, including contingency plan, towards commercialization are identified and low-rate production is demonstrated.** **Limiting factors are still present to move to commercial scale production.** **Compliance with regulatory requirements concerning authorizations, environmental and safety aspects, local/national standards is analyzed and guaranteed at the final scale of the technology implementation.**
	Checkpoints
	Once readiness level 8 is achieved, the system is incorporated in commercial design. This means: - **Technology is proven in its final form and under expected conditions;** - **Feedstock provision and competition with other markets is fully considered;** - **Manufacturing approach is demonstrated at low-rate production;** - **Full compliance of the technology with legal obligations, certifications and standards of the addressed markets is guaranteed;** - **Limiting factors for full commercialization are identified.**

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Limiting factors are solved and the technology *or commercial varieties (for feedstocks)* is *(are)* ready for full-rate production. The actual commercialization depends on the availability of the required feedstock on the markets where the economical/social/environmental sustainability is ensured, and the competition issues Full production chain is in place.
	Checkpoints
	Once readiness 9 is achieved, the system is ready for full-scale deployment and commercialisation. This means: - **Technology is available for the market guaranteeing economical/social/environmental sustainability;** - **Full-rate production readiness is achieved;** - **Business plan is available.**

10. BIOENERGY – THERMOCHEMICAL PATHWAY - FINAL GUIDANCE DOCUMENT

RE TECHNOLOGY : BIOENERGY THERMOCHEMICAL PATHWAY	
TRL #1	**Basic principles observed**
	Description **Basic research. Principles postulated and observed but no experimental proof available**
	A new concept related to thermochemical processing/conversion of biomass and other bio-based feedstocks is proposed. It could consist of the exploitation of a new raw material, different from the currently used ones, or of an innovative way to convert feedstock into a bioenergy carrier (e.g.: torrefaction, pyrolysis, gasification, etc.) or of an innovative way to convert feedstock or the carrier produced as above into final energy in different forms (e.g.: innovative boilers, turbines, ICEs, ORCs, fuel cells, etc.). Technical options for the concept are identified and relevant literature data and research results reviewed. Examples of innovative concepts qualifying this TRL: - innovative feedstock material, in terms of environmental and performance issues; - new pre-treatment, post-treatment and/or conversion process; - new concept for production of final energy from biomass materials (including organic waste) or fuels from those materials. The theoretical fundamentals of the concept are investigated; the concept is summarily described, with preliminary identification of the potential benefits and barriers.
	Checkpoints
	Once readiness level 1 is achieved, the scientific concept is observed and documented. This means: - Identification of a gap in the literature for the definition of the new scientific or technical concepts; - Identification of fundamentals of the concept such as feedstocks, biomass materials, components and systems; - Preliminary evaluation of the potential benefits and barriers of the new concept.

TRL #2	**Technology concept formulated**
	Description **Technology formulation. Concept and application have been defined**
	The technology concept, its potential applications and interfaces to other systems are defined and analysed. Preliminary modeling of the intended process and/or testing of the intended material is carried out in order to obtain the first quantitative results. Identification of preliminary proof of concept approach for the realization of systems or sub-systems is performed. For example, in this TRL, a first quantification of biomass physico-chemical properties (composition, heating values, etc.) is provided, or a basic mathematical model of the biomass pre-treatment or conversion or upgrading systems is elaborated.
	Checkpoints
	Once readiness level 2 is achieved, the new concept has been numerically refined. This means: - Initial quantitative knowledge, understanding and identification of design concepts, materials, processes and physical characteristics is achieved; - Relationships between components and/or systems are qualitatively assessed; - Definition of the proof of concept approach for laboratory tests and/or simulations.

TRL #3

Experimental proof of concept

Description

Applied research. First laboratory tests complete; proof of concept

First proof of concept prototype is developed by laboratory set-up and/or first quantitative model is completed and preliminarily applied.

Innovative paths to biomass provision, pre-treatment or energy conversion are tested through bench-scale experiments or numerical tools (e.g. thermodynamic and process simulations) in order to achieve first numerical experimental results on the specific technology.

Checkpoints

Once readiness level 3 is achieved, the applied technological concept has been defined. This means:

- First proof of concept test is carried out experimentally and/or numerically;
- Verification of the proof of concept through consolidated simulation tools and cross-validation of the numerical models based on literature data (if applicable) is done;
- The prototype characteristics are sufficiently defined for its design;
- Parameters characterizing the biomass or the technology or the final product are identified.

TRL #4

Technology validated in lab

Description

Small scale prototype built in a laboratory environment ("ugly" prototype)

Small scale prototype of the system or sub-system is developed in laboratory and tested using a biomass or other bio-based feedstocks or simulated equivalents.

Suitable key performance indicators are identified and the performance of the prototype is assessed.

The integration between the tested technology and the other sub-systems is analyzed at laboratory level (e.g.: output of pre-treatment or conversion system is suitable for following processing).

When a physical prototype and/or the physical integration is not feasible, a validated simulation model is provided considering the real operating conditions.

Checkpoints

Once readiness level 4 is achieved, the applied technological concept is experimented and validated. This means:

- The prototype is designed;
- The material or process is tested and validated at laboratory scale (or simulated through a suitable model if physical tests are not feasible);
- A first analysis of the integration with complementing sub-systems is performed.

TRL #5

Technology validated in relevant environment

Description

Large scale prototype tested in intended environment

Repeatable and stable outputs are obtained under different operating conditions using an advanced prototype, operated, controlled and monitored in the relevant working environment.

The performance is quantified through key performance indicators.

Other relevant parameters concerning scale-up, environmental, regulatory and socio-economic issues are defined and qualitatively assessed. For example, biomass availability and land use conflicts arising from food and bioenergy production issues should be preliminarily considered in the evaluation.

Such findings are used to validate the previously developed concept or to define the changes required to achieve satisfactory results..

Checkpoints

	Once readiness level 5 is achieved, the technology is ready to move forward to pilot scale. This means: - A large scale prototype has been realized, controlled and tested in intended working environment; - The prototype can achieve repeatable/stable performance; - Information to perform environmental and socio-economic sustainability assessments is available and the first qualitative assessments have been carried out.

TRL #6	**Technology demonstrated in relevant environment**
	Description **Prototype system tested in intended environment close to expected performance**
	The technology is scaled up to pilot size to confirm performance close to expectations, and fine-tuned to a variety of operating conditions under intended working environment. The integration with other sub-systems is demonstrated. The pilot scale prototype provides performance in line with the expectations concerning for example: product quality and physico-chemical characteristics (in the case of biomass pre-treatment technologies), conversion efficiency (in the case of processing technologies), emissions, process safety, etc. An advanced evaluation of environmental, regulatory and socio-economic issues is performed.
	Checkpoints
	Once readiness level 6 is achieved, the technology is enlarged to pilot scale. This means: - A pilot scale prototype that could be integrated with other subsystems and fine-tuned on field has been realized; - The efficacy of the technology in working environment conditions is tested (including relevant extreme conditions); - The process is reliable, can be operated safely and provides a performance in line with the expectations, guaranteeing advantages with reference to the existing technologies.

TRL #7	**System prototype demonstration in operational environment**
	Description **Demonstration system operating in operational environment at pre-commercial stage**
	A pre-commercial demonstrator is installed and tested in different operating conditions and to its final process purpose, i.e. integrated with relevant upstream and/or downstream processes. For example, in case of a biomass pre-treatment technology, the subsequent use of the output is included in the test/analysis, or in case of an energy conversion technology, the target use of the output (electricity, steam, hot water, etc.) is demonstrated. Compliance with relevant environment conditions, authorization issues, local/national standards is analyzed and guaranteed, at least for the demonstration site. The demonstrator is able to guarantee its performance. The availability of an adequate feedstock is demonstrated (where relevant). Economic parameters are assessed and a proper control and management strategy is in place. Interfaces between the tested technology and connected technologies are demonstrated at pre-commercial scale. Manufacturing approach is investigated and a preliminary design of production planning is carried out.
	Checkpoints
	Once readiness level 7 is achieved, the technology concept is validated at pre-commercial scale. This means: - System/technology is demonstrated at pre-commercial scale, on field, under

	different working conditions and integrated with upstream and downstream processes; - Control and management of the technology is demonstrated in a relevant operational environment; - Compliance with regulatory requirements for technology commercialization is analysed in terms of authorization, environmental and safety perspectives; - Social acceptance is evaluated.

TRL #8	**System complete and qualified**
	Description **First of a kind commercial system. Manufacturing issues solved**
	The technology is proven in deployment conditions (i.e. real world) and can guarantee its performance in working conditions. **Manufacturing stages requiring investments are identified; the manufacturing risks towards commercialization are identified and low-rate production is demonstrated.** **Improvements for full rate production are identified from operation of first of a kind system, including technical and economic aspects.** **Compliance with regulatory requirements concerning authorization, environmental and safety aspects, local/national standards is proven at the final scale of the technology implementation. Social acceptance issues are addressed.**
	Checkpoints
	Once readiness level 8 is achieved, the system is incorporated in commercial design. This means: - **Technology is proven in its final form and under expected conditions;** - **Feedstock provision and competition with other markets is fully considered, when relevant;** - **Manufacturing approach is demonstrated at low-rate production;** - **Quality of outputs is steady over long testing and compliant with the market expectations;** - **Environmental, social and economic performances are in line with the expectations and gained social acceptance;** - **Full compliance of the technology with legal obligations, certifications and standards of the addressed markets is guaranteed;** - **Improvements for full rate production are identified.**

TRL #9	**Actual system proven in operational environment**
	Description **Full commercial application, technology available for consumers**
	Production has been streamlined in line with the needs of commercial production requirements. The technology is in its commercial operation phase and is therefore ready for full-rate production and commercialization. Performance guarantees are available. **The actual commercialization depends on the local availability of the required biomass on the markets where the economical/social/environmental sustainability is ensured, and on competition issues.** **Full production chain is in place and all materials are available.**
	Checkpoints
	Once readiness 9 is achieved, the system is ready for full-scale deployment and commercialisation. This means: - **Technology is available for the market;** - **Full-rate production readiness is achieved;** - **The economic/social/environmental sustainability have been addressed and proven at commercial scale;** - **The information needed for business planning is available and guaranteed.**

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