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Project acronym: RESISTANT

Project title: Large riblet surface with super hardness, mechanical and temperature resistance by nano functionalization

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Thematic Priority: PILOTS-03-2017 Pilot lines for manufacturing of nanotextured surfaces with mechanically enhanced properties

Starting date of project: 1st of January, 2018

Duration: 48 months

D9.2 – ReSiSTant Commercialization Technology Roadmap

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Organisation name of lead contractor for this deliverable: RINA

Dissemination Level		
PU	Public	**X**
CO	Confidential, only for members of the consortium (including the Commission Services)	

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List of abbreviations / Nomenclature

Abbreviation	Definition
BP	Business Plan
BM	Business Model
CAPEX	Capital Expenditure
CEN	European Committee for Standardization
CRL	Commercialization Readiness Level
DOD	Department of Defense
EHS	Environment, Health And Safety
EU	Europe
HSE	Health Safety Environment
IPR	Intellectual Property Mangement
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
MRL	Manufacturing Readiness Level
MRO	Maintenance, Repair and Overhaul
OECD	Organization for Economic Co-operation and Development
OPEX	Operating Expenses
R&D	Research & Development
TRL	Technology Readiness Level
SLCA	Social Life Cycle Assessment

1 Introduction

The present document represents deliverable "D9.2 - ReSiSTant Commercialization Technology Roadmap", developed under the responsibility of Rina Consulting (RINA C) in the framework of Task 9.3 "Market Analysis and provisional business models" led by RINA-C.

Being the ReSiSTant project a "Demonstration-to-Market" cross-sectoral project (turbomachinery, nanotechnologies, manufacturing process), this document aims to provide a commercialization technology roadmap towards the marketability of the project outcomes within 2025.

Parallel and preliminary activities have been included in D9.1 ""Business models to support the partners aiming at the commercial exploitation of the project results" where business strategies to successfully put on the market the innovative products developed have been proposed and described.

The proposed roadmap has the following purposes:

- to define a technological roadmap to bring from TRL 7 to TRL9 the project outcomes within 2025;
- to analyze the technological and non-technological barriers to be overcome towards solutions marketability within 2025 also considering IPR management;
- to take into account the standardization aspects and safety issues;
- to maximize the exploitation, market uptake and impact of the ReSiSTant innovations.

As most of the above mentioned aspects will be investigated during the project from M24 (December 2019) on, it was agreed to provide within the present document the methodological framework for developing the ReSiSTant Commercialization Technology Roadmap as well as the approach for data gathering from the other WPs focusing on the mentioned activities. Definition of input/output would be critical to correctly estimate actions needed for the roadmap development and the contribution of all the partners would be also required.

In this framework, the document has been structured in the following chapters:

- **Chapter 2** provides the project overview, main results and roles of partners in the main project achievement;
- **Chapter 3** provides the methodology followed for the activities to be carried out;
- **Chapter 4** provides the framework for the ReSiSTant Commercialization Technology Roadmap;
- **Chapter 5** provides main conclusions and next steps.

It is important to underline that this document, and in particular Chapter 4 is providing the methodological approach to be followed and the main aspects that will be taken into account within the final roadmap. The final version of the ReSiSTant Commercialization Technology Roadmap will be included in Deliverable "D9.3 - Plan for the upscale and optimization of ReSiSTant demonstrator pilot lines". As already explained, this decision was taken based on the fact that most of the aspects related to road mapping activities both on a technical and economical point of view, will be discussed and faced later on in the project (standardization, safety and reliability, technological up scaling of manufacturing line) or in parallel to this task (e.g. business modelling activities). This is the reason why this document is providing the methodological framework as well as the aspect to be taken into account while main contributions and inputs to fill in those aspects (in terms of gap identification and actions foreseen) will be done according to the time scaling of the other tasks.

As a conclusion, this document may be considered as an Implementation Roadmap for the valorization of nano enabled technologies, services and products developed within the project. This Implementation Roadmap will be then filled in with an inclusive approach, involving project partners by mean of surveys/workshops and face to face meetings.

2 RESISTANT Project and main results

The main objective of ReSiSTant project is **to develop, upscale and industrially demonstrate up to TRL 7 reliable manufacturing processes to obtain nanostructured riblet surfaces** to be applied in Aircraft Turbofan Engines and industrial compressors to reduce drag and the related fuel consumption and emissions or power input respectively. Indeed, ReSiSTant consortium aims at the realization of simple, safe, low cost in terms of CAPEX and OPEX, replicable deposition and manufacturing process able to realize large scaled areas with highly ReSiSTant nano- and microstructured surfaces to be applied on newly built and existing turbomachinery blades in order to increase their performances and reduce their wear. ReSiSTant innovation (nanocoatings and their manufacturing process) will be demonstrated in two different industrial lines, embedded into the product portfolio of three globally acting enterprises from the consortium (GEDE, MES and LHT).
Indeed, MAN Energy Solutions (MES) is a world market leader in the field of industrial compressors. GE Aviation (GEDE) is one of the leading companies worldwide developing and researching high efficient jet turbines. Last one is Lufthansa Technik AG (LHT), a world leading aircraft MRO (Maintenance, Repair and Overhaul) company which covers the aftermarket and retrofit market.
These partners are being supported in the innovation deployment by two top level innovation and market oriented research centres (PROD, IFAM) and two European leading polytechnic universities (RWTH, TUG), with a strong focus on applied research in turbomachinery. The whole value chain of the cycle is covered by global manufacture leaders (RINA-C, NCT, BST).
Hereafter a short description of the two demonstrators is provided according to their current status[1]. In particular demonstrator 1 has been splitted into two type of demonstrators (1a and 1b) to take into account the new and the existing aircraft engine applications.

- **Demonstrator 1a: Test rig at Graz University of Technology**

Demonstrator 1 consists in the application of nanoriblet in an aircraft turbofan engine with the aim of determine the benefit of riblets applied to turbine frame and/or airfoil surfaces in terms of performance efficiency, fuel consumption reduction, noise level reduction.
In **Error! Reference source not found.** the current state of the test rig (lower half) and the modified version (upper half) of the test rig used in ReSiSTant are shown. Coloured parts are being designed, manufactured and assembled in the project.

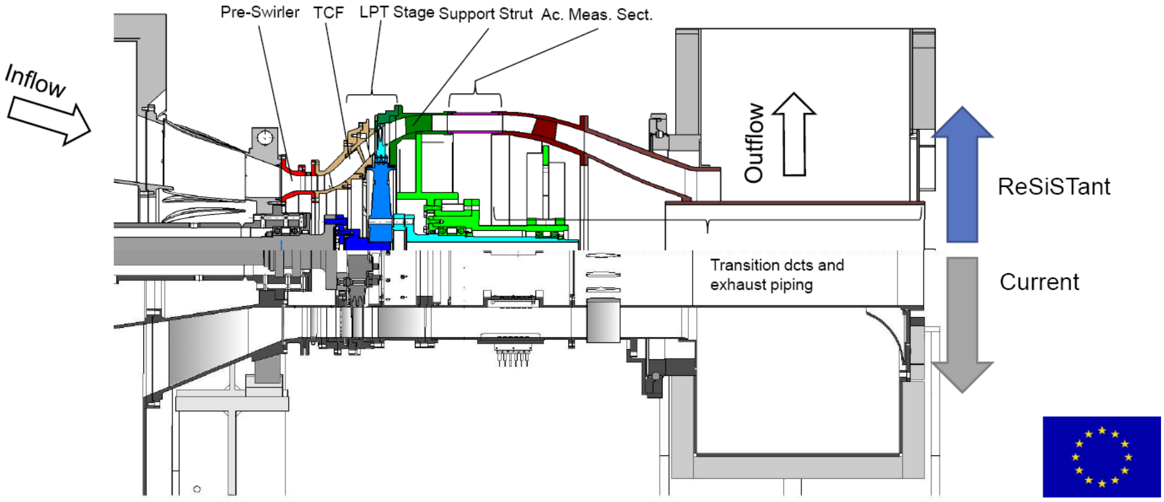

Figure 2.1: DEM1 test rig design (currently and modified)

[1] Source: D6.1: "Demonstration KPI Panel"

This modified design of the test rig, with particular attention to the turbine centre frame and the low pressure turbine rotor, is representative of a state of the art for what concerns the low pressure turbine engine module.

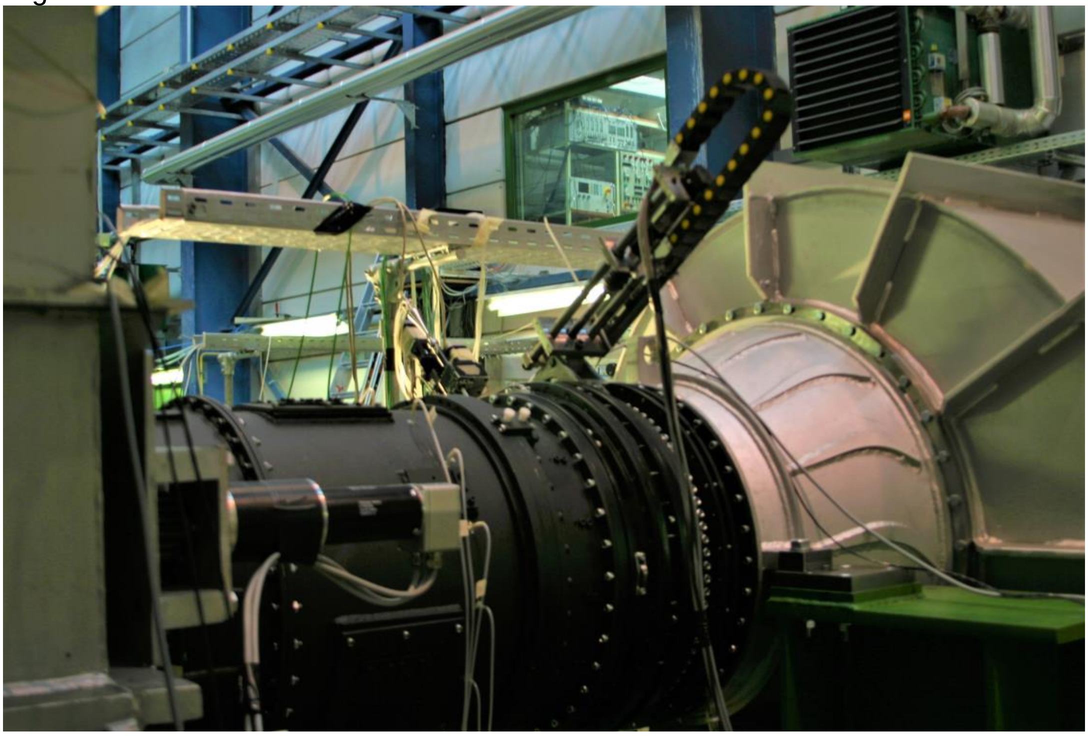

Figure 2.2: DEM1 installed on this tests bench

- **Demonstrator 1b: Test rig at Lufthansa Technik**

Demonstrator 1b consists of a used CFM 56 engine from an Airbus A340. As it is a retired engine, there are not airworthiness limitations. It is employed to test nanoriblet coated turbine blades in validation experiments and CFM simulations.

Figure 2.3: Test rig at LHT

In the following images, the instrumentation used on the test rig is described:

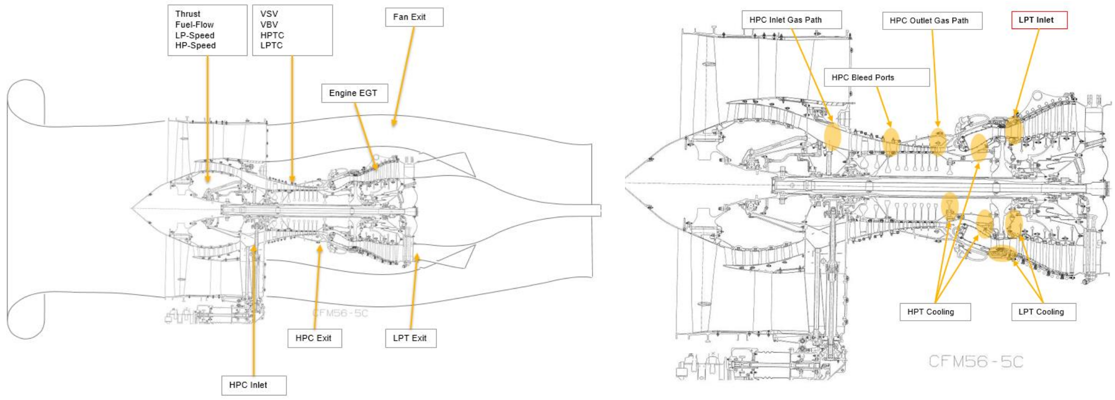

Figure 2.4 Instrumentation for validation experiments

- **Demonstrator 2: Test rig at RWTH Aachen University**

Demonstrator 2 consists in the application of nanoriblet in an industrial compressor with the aim of reducing the aerodynamics shear stress losses increasing the efficiency, the corrosion protection and the potential lifetime.

Figure 2.5 shows the modified test rig design of Demonstrator 2, upgraded for a wider range of operating conditions. This allows a higher flexibility in terms of the investigation of radial compressor stages. The main characteristic of the test rig is the closed loop setup enabling testing conditions at increased inlet pressure.

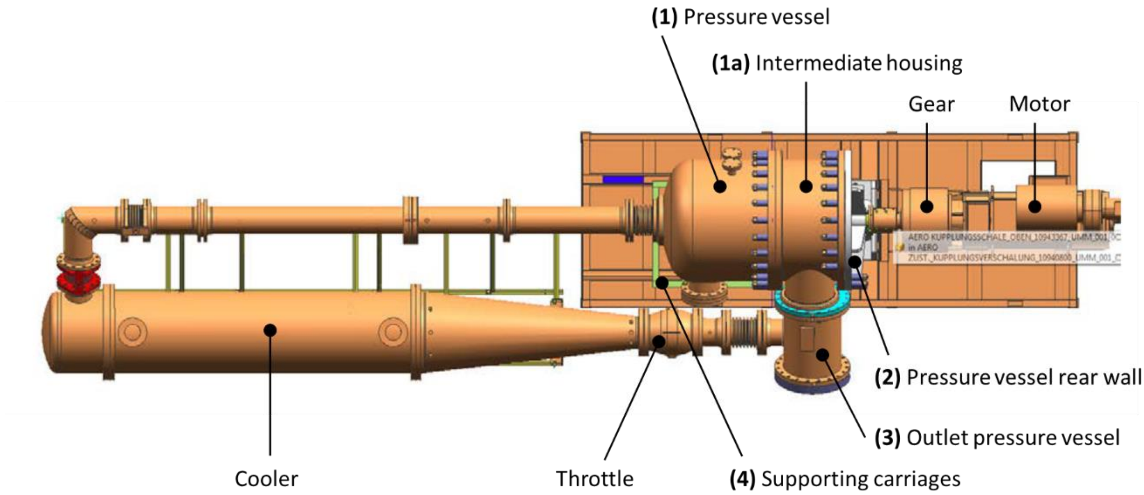

Figure 2.5: DEM2 test rig with modified design

Indeed, the main goal of the riblet application in centrifugal compressor stages is the reduction of losses leading to an increased performance. Hence, less energy is needed for the same pressurization of the working fluid. In a different way of evaluation, a higher outlet pressure can be achieved at the same rate of drive power.

Figure 2.6: Test rig of Demonstrator 2 at IKDG, RWTH Aachen

The consortium is dedicating strong efforts to achieve, after project completion and a time-to-market of 1-5 years, commercial exploitation of these results strongly driven by internal industrial stakeholders such as GEDE, MES and LHT. The purpose of the road mapping activities is therefore to guide this process, highlighting main technical and non-technical actions that shall be foreseen towards solutions successful marketability within 2025.

3 Methodology for road mapping activities development

3.1 Background

Innovations in nanotechnology are making a revolution in manufacturing and production, creating new materials and products through novel processes for commercial applications. New products based on nanotechnology with novel characteristics are continuing to grow and benefit the society. Nevertheless, in some fields of application the nano- related technologies and materials' commercialization are still facing several challenges. Indeed, commercialization of nanotechnology based products from research to economically viable products is particularly vulnerable to the so called "Valley of Death" point of commercialisation graph (Figure 3.1) compared to any other technologies due to the reasons related to a product focus, market engagement, scale up and product development.

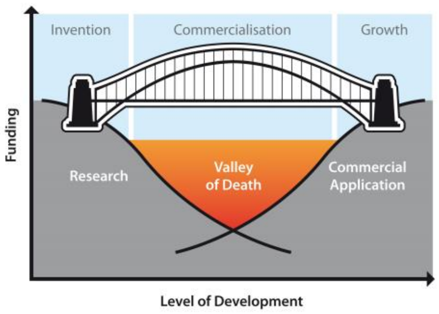

Figure 3.1: Valley of death gap

Valley of Death is indeed the gap between a positive scientific result of a researcher and obtaining supporting funds for commercialization and prototyping of the products[2]. Since the cost of commercialization is very high compared to the invention cost of the product, usually, the scientist who invented the product may not have the interest in commercialization, but the firms invested for such research have to spend to encash its business opportunity. Thus, nano related products commercialization is lagging behind due to many reasons and hence failed to follow the expected generations in its growth stages.

Common challenges to be faced may be also related to:

- the average time delay between research, completion and commercialization that can lie between three to five years;
- the lack of infrastructure due to high cost instruments need;
- the lack of standard evaluation affecting also the potential patenting process,
- the speculation about effects in environmental, health and safety issues of nanotechnology-based products bringing to negative perception of the related products,
- etc.

In this framework, one of the approach to clearly evaluate the main challenges to be faced for the commercialization of a specific product is the "road mapping" approach. A drafting process of designing roadmap may bring opportunity for defining the main gaps towards commercialization and translating them into detailed actions to be foreseen in the related period.

3.2 Methodological approach

The ReSiSTant Commercialization Technology Roadmap aims at including the main short-medium-term actions proposed for the main project results commercialization for the period immediately after the project end, including also cross cutting non-technical actions as well as description of the impact, together with other details (specific challenges, scope of the action, starting and expected TRL, needed resources, etc.). Long-term actions (beyond 2025) will be also drafted. Most of the activities needed for determining in a precise way these actions (providing also quantitative impacts and targets, business modelling and plans link, guidelines for business plans and risk analysis also

[2] McNeil RD, Lowe J, Mastroianni T, Cronin J, Ferk D. Barriers to nanotechnology commercialization. U.S. Department of Commerce Technology Administration, 2007.

with respect to demonstrators, etc.) will be carried on later in the project. Thus, the present document provides the draft version of the ReSiSTant Commercialization Technology Roadmap, namely an Implementation Roadmap for the valorization of nanotechnology- based products relevant for the two demonstrators (application of nanoriblet coatings on aircraft turbofan engine and industrial compressor).

In other words, the Implementation Roadmap provides, with a broader level of details, the methodological approach to develop the final version of the ReSiSTant Commercialization Technology Roadmap. This approach will bring to the identification of the main technical and non-technical actions to be performed at short, medium and long term in order to contribute at bridging the current gap (the so-called Valley of Death) between nanotechnology knowledge and successful commercialisation of nano-enabled riblets in the two application sectors and, hopefully, in other sectors as well (e.g. wind turbine, automotive, power, etc).

As a starting point, an overview of the status of the main project results (namely the nanoriblets) envisaged at the end of the project is needed. Indeed, according also to Figure 3.2 representing the draft roadmap prepared at the proposal stage, the nano riblets are expected to achieve TRL 7 in 2022 with the demonstration of the nano riblets in two dedicated pilot lines.

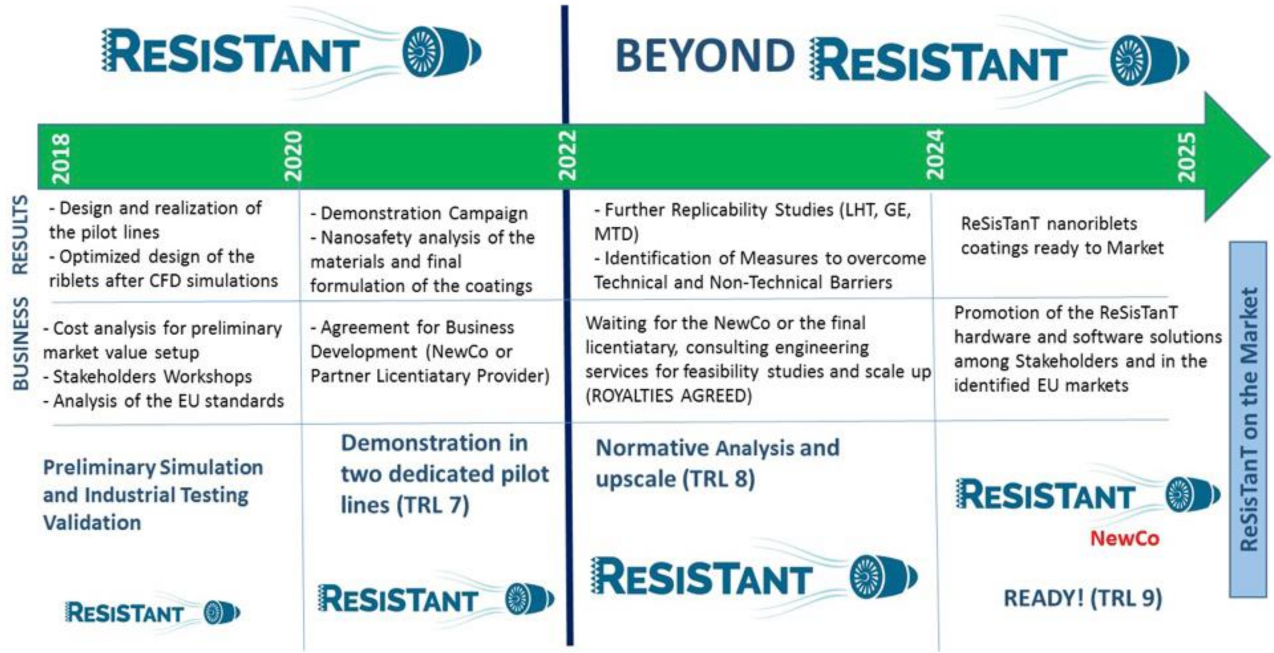

Figure 3.2: ReSiStant draft Commercialization Technology Roadmap (*MTD->MES)

Given this starting point, RINA is going to develop the ReSiStant Commercialization Technology Roadmap with the support of all the partners and according to specific methodological approach. Taking into account the two pilots demonstrations, the ReSiStant Commercialization Technology Roadmap development will leverage on the following four main steps:

- The identification of the main barriers hindering the nanoriblets commercialization,
- The analysis of the above identified barriers, taking into account the related application sectors and their value chain,
- The barriers validation and actions identification,
- The finalization of the ReSiStant Commercialization Technology Roadmap, in terms of visual representation.

These activities will be performed with the support of the project partners (more details in next paragraphs), via questionnaire and phone interviews and remote collaboration (surveys, emails and conference calls).
Thus, the final version of the ReSiStant Commercialization Technology Roadmap will include the main (technical and non-technical) actions able to overcome the identified barriers and thus cover the gaps to achieve the market penetration of the innovative nano riblets in the two identified sectors (new and existing aircrafts' engines and industrial compressors for gas transport) towards TRL 9.

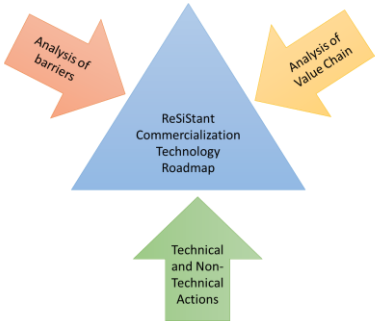

Figure 3.3: Approach towards ReSiStant Commercialization Technology Roadmap

The specific roadmap will be detailed according to the experience acquired in each sector of application of the nano-riblets, including the proposed actions' timeline, some representative images of resulting products and the expected resources needed to carry them out.
Hereafter, more details on the four main steps of the roadmap development.

3.2.1 Barriers identification

In order to identify the gaps between knowledge and market, first step towards the development of the Commercialization Technology Roadmap is the identification of the main barriers towards the marketability of the project. In this framework three main barriers categories have been identified according to the topic they may be referred to:

- TECHNOLOGY, including the barriers related to the nano riblets' production (in terms of both TRL and MRL);
- MARKETING & STRATEGY, including the barriers related to the strategies towards penetrating the market (e.g. business models and plans, market expansion, etc.);
- SOCIETY, including the barriers related to aspects such as safety, education, standardisation, communication, environment and regulation, etc.

The clear identification of the barriers would allow the consortium to evaluate the related (technical and non-technical) actions needed to overcome those barriers, covering the gaps towards the nano-riblets commercialization and market penetration.

3.2.2 Barriers analysis according to the application sectors

Each of the above-mentioned barriers' categories may include different barriers' typologies. This step would mainly consist in the evaluation and description of main subcategories of barriers. In this step, the involvement of project partners would be essential in gathering a comprehensive overview of the potential barriers' typologies as well as in their description.
The barriers typologies would represent the potential obstacles in covering the gap to cover the TRL 9 achievement (for the technological category), to penetrate the market (for the marketing & strategy category) and to achieve the final goal being compliant with the societal challenges (for the societal category).
For some of the barriers' typologies there will be also to take into account the different sectors of application of the nano-riblets (new and existing aircrafts' engines and industrial compressors for gas transport).

3.2.3 Barriers validation and actions identification

Revision of the identified barriers typologies will be then done towards the identification of actions at short, medium and long term to overcome them and solve current gaps.
Actions may be classified into technical and non-technical. Indeed, market related gaps may be solved with a set of technical actions or non-technical actions, depending on the type of problem.

3.2.4 Roadmap finalization

Roadmap finalization will consist in the graphical representation of the road mapping activity. Figure below provides the scheme of the graphical representation that will be used.

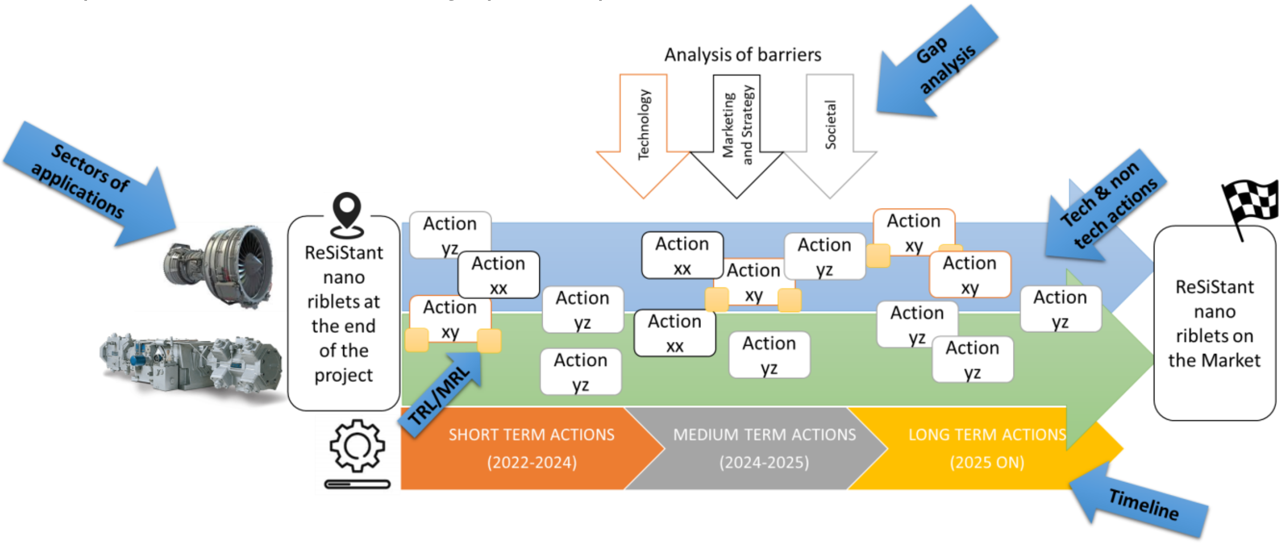

Figure 3.4: Graphical representation of the ReSiStant Commercialization Technology Roadmap

As can be seen, based on the barriers analysis, technical and non-technical actions to cover the existing gap between the foreseen status of the nano riblets at the end of the project and their market penetration are organized in short, medium and long term. Each action is described, in the same representation, in the related value chain step related to the sector of application which can be found according to the type of barriers' category (technology, marketing and strategy, societal). In particular, the technology actions (orange boxes) will be accompanied by two series of numbers, referring to TRL/MRL at the beginning and at the end of the timeframe of the related action, evaluated by the consortium during project meetings and workshops.

The roadmap will be provided also with a table including more details on the type of barriers identified, partners identifying it, relation with tasks and WPs activity as well as the short, medium and long term (technical and non-technical) actions pointed out. This table will be used in the next months to gather inputs from partners as long as the different activities are being carried out.

Table 3.1 provides an example of the table used for the data gathering process to be implemented in the next months to collect data required as long as the related activities go on. As already mentioned, most of these activities are foreseen to end later on in the project (M40, M42, M48) and this is the main reason for which the present document is providing the methodological approach and a preliminary analysis of the road mapping activities. Thus, data gathering to fill in the roadmap graphical representation will be performed in the next months and the final version of the roadmap will be included in D9.3 "Plan for the upscale and optimization of ReSiSTant demonstrator pilot lines".

Table 3.1: Template for Roadmap specifications gathering

Barrier category	Barrier typology	Action Title	Type of action (T/NT)	Responsible WP/partner
Technology	Material	Scouting of enabling manufacturing techniques to scale up innovative productions through the Identification of breakthrough market models	T	WP9 (RINA-C)

Finally, another way to graphically represent the results of the road mapping activity will be by mean of a Gantt chart (see figure below). The proposed technological and non-technological actions are grouped depending on the different categories to which they belong. Each action will be described with its code, title and timeline term chosen and validated by the project consortium.

			Short term		Medium term		Long term		
	Action Code	Action Title	2022	2023	2024	2025	2026	2027	2028
Nano riblet for (new and existing) Aircraft Engine	NR-AE-T001								
	NR-AE-M&S001								
	NR-AE-S001								
Nano riblet for industrial gas transport compressors									

TECHNOLOGY
MARKETING & STRATEGY
SOCIETY

Figure 3.5: ReSiStant Commercialization Technology Roadmap Gantt

4 Commercialization Technology Roadmap development

Commercialization is the process of turning new technologies into successful commercial products. In other words, commercialization covers a wide variety of arrays in technical, commercial, and financial areas, which transform a new technology to useful products or services[3]. In this framework, the reference behind the ReSiStant Commercialization Technology Roadmap may be found in the Commercialisation Readiness Scale (see Appendix A). The Commercial Readiness Level (CRL) scale shall be used as a framework for defining the spectrum of commercial maturity, from basic market research to full deployment. Indeed, an analysis of CRL for the nano riblets developed in the two sectors of reference at the end of the project would allow the consortium to have a clear idea of the starting point for their commercialization strategy. Based on the starting CRL identified, the steps to climb up the CRL ladder will be then evaluated and the main barriers depicted as well. As described within the previous paragraphs, the main barriers' categories have been already identified, namely TECHNOLOGY, MARKETING and STRATEGY and SOCIETAL. These three categories shall include all the potential barriers that may arise at the end of the project towards the nano riblets commercialization. Table below provides a first draft of the potential barriers' typologies that may be investigated along the project development as well as the related specific gaps/needs. The gaps identified will be then translated into dedicated actions to be carried out towards market penetration.

Table 4.1: Barriers' categories, typologies, and related potential gaps/needs identification

Barrier category	Specific barrier related to	Related gap/need
TECHNOLOGY	TRL	Reproducibility
		Reliability & durability
		Other
	MRL	Costs
		Efficiency (LCA/LCCA/SLCA)
		Scalability/Supply chain
		Other
MARKETING & STRATEGY	Market and Industry Knowledge	Competition
		Acceptability
		Other
	Strategy	Business Modelling (BM)
		Investments
		Feasibility (BP)
		Intellectual Property Management
		Other
SOCIETY	Regulatory framework	Regulation
		Standardization
		Other
	Acceptability	Environmental, Health & Safety risk assessment
		Education and communication
		Other

[3] Commercialization of Nanotechnology in Developing Countries - Roya Naseri, Reza Davoodi, 2011 3rd International Conference on Information and Financial Engineering IPEDR vol.12 (2011) © (2011) IACSIT Press, Singapore

At low TRL (<6) technology and manufacturing are the main barriers, at high TRL (8) the marketing is the main barrier[4]. This could be summarized by the two following comments:

- The barrier of technology decreases when the project matures,
- The marketing & strategy and societal aspects grow in importance at high levels.

Paragraphs below provide more details on each category, evaluating the main typologies of barriers.

4.1 Technology

Technology maturity of the nanoriblets is mainly driven by two factors: the Technology Readiness Level (see definition and related scale in Appendix B) and the Manufacturing Readiness Level (see definition and related scale in Appendix C). Thus, barriers will be investigated with respect both to the optimization of the nanomaterial for the nano riblets as well as to the developing, upscaling and industrially demonstrating their manufacturing process up to TRL 9.

Indeed, at the end of the project it is expected to achieve a TRL 7 for the two nanoriblets demonstrators' rigs in a real operational environment and thus, further actions towards higher TRL and MRL shall be detailed.

Table below provides the preliminary identification of potential gaps/needs according to technological barriers as well as the main WPs from which inputs and collaborations will be needed.

Table 4.2: Technological barriers category, typologies and related gaps/needs

Barrier category	Specific barrier related to	Related gap/need	Collaboration from WPs and inputs from related tasks
TECHNOLOGY	TRL	Reproducibility	- WP2 (output of design options and expected impact) - WP4 (feasibility studies, LCA, LCC, SLCA)) - WP5 (optimization of nanostructured materials)
		Reliability & durability	
		Other	
	MRL	Costs	- WP3 (DEM assembly and commissioning) - WP4 (preliminary life cycle sustainability of the pilot lines) - WP5 (upscaling of the nanostructured coating material production at industrial level) - WP6/WP7 (manufacturing and testing) - WP9 (optimization of up-scaled manufacturing line)
		Efficiency (LCA/LCC)	
		Scalability/Supply chain	
		Other	

4.1.1 Technology Readiness Level

Concerning the TRL, main barriers that can be found out may be related to the reproducibility, reliability and durability of the nanoriblets, with respect to the requirements of their field of applications. Thus, once achieved and proved the TRL 7 at the two DEMs, it shall be investigated

[4] NanoCom - Barriers and Success Factors; Commercialisation Readiness Scale (2009)

the further investment needed in further testing, model formulations for coatings, technical process control and development to upgrade and upscale the technology till TRL 8 and then till TRL 9.

4.1.2 Manufacturing Readiness Level

Instead, concerning the manufacturing process, potential barriers related to the cost-efficiency of the process may arise, as for example the lack of access to adapted equipment necessary for pre-production development as well as lack of resources for increasing production capability. Thus, actions towards the manufacturing process scalability shall be performed towards full commercial scale for the nano-riblets. These actions may include cost/performance model, manufacturing cost model, or other quantitative analysis geared toward validating the value proposition for the proposed technology. Main issues are related to the identification of key costs, manufacturing, and scalability risks associated with the proposed process and how these will be addressed after the end of the project

4.2 Marketing and Strategy

As long as the technological barriers will be solved while increasing the related TRL and MRL, the most critical barriers will come out to be those related to the marketing and strategies towards the products (nano-riblets) wider distribution and commercialization. Those barriers may be evaluated from two different perspective:

- An external perspective aimed at investigating the potential barriers to market entry coming from the market itself (e.g. competition and acceptability from the customers).
- An internal perspective aimed at investigating potential barriers related to the viability of the business models identified, the feasibility of the investments needed after the project end by mean of dedicated business plan as well as of proper management of intellectual property.

Table below provides the preliminary identification of potential gaps/needs according to Marketing and Strategy barriers as well as the main WPs from which inputs and collaborations will be needed.

Table 4.3: Marketing & Strategy barriers category, typologies and related gaps/needs

Barrier category	Specific barrier related to	Related GAP/need	Collaboration from WPs and inputs from related tasks
MARKETING & STRATEGY	Market and Industry Knowledge	Competition	- WP7/WP8 (outputs from DEM) - WP9 (Market analysis and provisional business models, business plan for both pilot lines, stakeholders engagement)
		Acceptability	
		Other	
	Strategy	Business Modelling (BM)	
		Investments	
		Feasibility (BP)	
		Intellectual Property Management	
		Other	

4.2.1 Market and Industry Knowledge

Among the different barriers towards market penetration, attention shall focus on the potential competitors as well as on the perception of the new products by potential customers. In this framework, specific synergies with industrial players within the consortium is foresee to better evaluate how to make the products competitive and the potential customers confident and loyal.

4.2.2 Strategy

The successful commercial exploitation of the nano-based products developed within the project requires relevant levels of collaboration (both vertical and horizontal) across many different actors, in order to adequately address the inherent complexities associated with the lifecycles of such products. From an adequate barriers analysis, several gaps to be still covered may arise in the framework of the proper strategy to be implemented for market penetration, such as for example gaps in the capability, knowledge and availability of current team resources/expertise necessary to advance the various steps after the project end. It would be also important to evaluate how and when the team plans to address each gap (new partnerships, advisors, consultants, conferences, etc.).
Moreover, the necessary and substantial investment capital cash may often be lacking early in the business, and high processing costs for nano-products, perception of long lead time for nano-products, and difficulties in process scalability may also be relevant barriers.
Thus, actions should be foreseen to identify who is expected to serve as the next source(s) of private or public funding needed for the next phases of development that follows the end of the project and what is the plan to engage them after the project end.
Last but not least, Intellectual Property Management is an aspect of vital importance for new ventures needing core technology licenses and help from investors. There is the need to implement Intellectual Property Strategy, having clear the status of the IP landscape related to the product formulation and manufacturing process before the end of the project as well as potential issues (e.g. related to the management of potential conflicts of interests) that may arise if new plans for disposition/ownership of the intellectual property, including intellectual property agreements or memorandums of understanding, are foreseen between members of the project team after the project end.

4.3 Society

The societal barriers may be related to the following aspects:

- Regulatory Framework, including all the aspects related to Regulation and Standardization;
- Acceptability, including all the aspects related to the Environmental, Health & Safety issues as well as the education and communication issues.

Table below provides the preliminary identification of potential gaps/needs according to societal barriers as well as the main WPs from which inputs and collaborations will be needed.

Table 4.4: Societal barriers category, typologies and related gaps/needs

<table>
<tr><th>Barrier category</th><th>Specific barrier related to</th><th>Related GAP/need</th><th>Collaboration from WPs and inputs from related tasks</th></tr>
<tr><td rowspan="6">SOCIETY</td><td rowspan="3">Regulatory framework</td><td>Regulation</td><td rowspan="6">WP5 (Nano safety test results)
WP9 (stakeholders engagement, standardization strategy)
WP10 (report on “evidence ReSiStant product safety, dissemination strategy)</td></tr>
<tr><td>Standardization</td></tr>
<tr><td>Other</td></tr>
<tr><td rowspan="3">Acceptability</td><td>Environmental, Health & Safety risk assessment</td></tr>
<tr><td>Education and communication</td></tr>
<tr><td>Other</td></tr>
</table>

4.3.1 Regulatory framework

Concerning the regulatory framework, regulatory aspects are usually seen to have a positive impact on the further product commercialisation, particular if a more streamlined global approach can be expected. Nevertheless, legislation and regulation barriers may also prevent consumers and market parties to use nano-riblets as a powerful solution to increase efficiency, reduce blades wear and

OPEX. For example, aviation sector has a very strong regulatory and standardization framework and also nanocoating laying manufacturing process and nanocoating formulation has to respect specific Health and Safety concerns (fire hazard, workers' health etc.).
The current EU legal framework has several horizontal and vertical measures for regulating nanomaterials. In October 2012, the European Commission published the Second Regulatory Review on Nanomaterials stating that substances in nanoform are no different than other substances, in that "some may be toxic and some may not." Addressing nanomaterials and nanotechnologies, the Commission encapsulates the regulatory challenge: "ensuring that society can benefit from the innovation and competitiveness of nanotechnology and a high level of health, safety and environmental protection."
Existing horizontal (not nano specific) and sector-specific legislation ensures that the risks which may be associated with some nanomaterials are effectively controlled. Indeed, under the current regulatory network industry is already obliged to put safe products on the market.
Most important horizontal legislation is the REACH Regulation (EC) No 1907/2006 which covers all chemical substances, also in their nano forms and it remains the best possible framework for the risk management on nanomaterial.
According to the type of vertical regulation addressing nanomaterials applied to specific sectors such as foods, cosmetics, etc. the definition of nanomaterial got confused, markedly different. These definitions – such as all the other present definitions are however "moving" definitions; which means that they are earmarked to be replaced or amended in case scientific progress so dictates. These projected changes, however, create serious difficulties in the interpretation and enforcement of nanomaterials used in different end-use applications.
Besides the EU efforts to solve these issues, Member States themselves are also creating their mandatory or voluntary regulatory requirements.
Considering the available extensive body of horizontal and vertical regulatory requirements, the introduction of additional measures is only warranted if on-going research reveals risks which are not covered by the existing legislation.
In this framework, it is clear that a regulatory harmonized approach is imperative to minimize market barriers and fosters the development of nanotechnology across the single market.
In 2016, the third release of the Regulatory Review on Nanomaterials have been done. The review of the environmental legislation, which was carried out for the second regulatory review, was updated, in order to investigate whether the gaps and challenges identified in the 2012 review have been addressed and whether new gaps have emerged. Information were thus aimed at investigating:

- Whether existing legislation has effectively dealt with nanomaterials;
- Whether a regulatory change has happened and if it was effective;
- Whether scientific progress has removed obstacles in implementation and enforcement;
- Whether a specific development can be consistently applied across all legislation on nanomaterials;
- Whether the information is only relevant and applicable to one specific piece of legislation or one specific substance/material/product.

In this context, inputs from detailed analysis of the regulatory framework would help in identifying specific challenges for the ReSiStant project. In order to gather more insights and recommendations on how to overcome any potential regulatory barriers, two aspects will be exploited:

- The organization of the stakeholders workshop at M30/42 involving also stakeholders from regulatory framework;
- The liaison / collaboration with other similar EU-funded projects (especially those funded under this same call) will be sought in particular for policy relevant issues such as regulatory framework, business models, obstacles to innovation.

Instead, concerning standardization aspects, there is the need to evaluate the reference standards for each aspect of the new nano-based coatings: research, production, products, and waste disposal.

The key issues in nanotechnology standardization in ISO and CEN are definitions and coordination of measurement methods standard development between the Technical Committees.
From the HSE point of view especially the risk management is asked, i.e. exposure and hazard quantification. This leads to the central question of the definition of a nanomaterial and the related tox and exposure studies, to be requested additionally to the regular REACH process.
Further analysis in the project will be done also considering the application sectors (aviation sector has a very strong regulatory and standardization framework and also nanocoating laying manufacturing process and nanocoating formulation has to respect specific Health and Safety concerns (fire hazard, workers' health etc.)). This analysis would constitute precious inputs for the final Commercialization Technology Roadmap in case actions should be needed.
Also in this framework, collaboration with projects working on similar topics and active involvement of stakeholders involved in the standardization process will be fostered to evaluate next steps after the end of the project towards market penetration. Engagement with main standardization bodies, such as CEN, ISO and OECD, by actively participating in Technical Commissions and Working Groups, and by proposing specific ISO/CEN work items, to integrate the developed and validated methodology into the current standardization work, would be key.

4.3.2 Acceptability

Concerning the potential acceptability of the nano-riblets by the market, this may be fostered by a detailed assessment of potential Environmental as well as Health and Safety Risks, together with a proper training and communication campaigns.
Indeed, an integrated risk research framework is needed to manage nanotechnology environmental and health and safety issues and shall be included within the ReSiStant Commercialization Technology Roadmap.
Indeed, nano technology applications development is closely related to safety concerns. Within this project, a so-called safe-by-design approach is chosen by addressing nanorelated environment, health and safety (EHS) issues connected to the design of the projects´ products. This will cover materials, processes and the products respectively their nano-related safety issues. Existing data on potential toxicity of materials/structures (e.g. biocompatibility tests according to ISO 10993 provided by TRI, etc.) are being screened. Indeed, human exposure to nanomaterials in the workplace and indoor and outdoor environments shows a need for early monitoring of workers subject to high nanotech exposures and toxicity concerns.
Evaluation of processes (with special focus on workers' safety) including exposure measurements at the lab facilities are being conducted, and screening of potential safety concerns along the life-cycle (consumer and environmental issues) will lead to evidence of safety for the products of this project.
In the next months' activities, the whole manufacturing pilot line of the riblet nanostructured coating will be also analyzed taking into account nano safety issues (potential environmental and health risks associated with the manufacture, use, distribution and disposal of nanomaterials such as their toxicity and chemical behavior with metallic turbomachinery blades). Also non-technological aspects (such as a complete Risk Assessment of the new process) will be investigated in order to favor the upscale and the replication of the process and its standardization, thanks to a complete techo-economic feasibility study of the innovative manufacturing process.
Also in this case, continuous collaboration will be encouraged with the EU nanosafety cluster via contributing project outputs, as well as taking into account safe-by-design aspects published within the cluster.

5 Conclusions

This document represents deliverable “D9.2 - ReSiSTant Commercialization Technology Roadmap”, developed under the responsibility of Rina Consulting (RINA C) in the framework of Task 9.3 “Market Analysis and provisional business models” led by RINA-C.

In particular, this document provides the methodological framework for developing the ReSiSTant Commercialization Technology Roadmap as well as the approach for data gathering from the other WPs towards the implementation of the described approach. The final version of the ReSiSTant Commercialization Technology Roadmap will be included in Deliverable “D9.3 - Plan for the upscale and optimization of ReSiSTant demonstrator pilot lines”. This decision has been agreed based on the fact that most of the aspects related to road mapping activities both on a technical and economical point of view, would have been discussed and faced later on in the project (standardization, safety and reliability, technological up scaling of manufacturing line) or in parallel to this task (e.g. business modelling activities). This document can be thus considered as an Implementation Roadmap for the valorization of nano enabled technologies, services and products developed within the project.

The methodological approach for its development leverages on four main steps:

- The barriers identification,
- The barriers analysis in the context of the two application sectors,
- The barriers validation and actions identification,
- Finalization of the ReSiStant Commercialization Technology Roadmap, in terms of visual representation of the roadmap.

As a final result, the consortium will be provided with a graphical representation (by mean both of a dedicated scheme - Figure 3.4 and a Gantt chart - Figure 3.5) of the project Commercialization Technology Roadmap. This roadmap will include the main (technical and non-technical) actions able to overcome the identified barriers and thus cover the gaps to achieve the market penetration of the nano riblet in the two identified sectors (new and existing aircrafts’ engines and industrial compressors for gas transport) towards TRL 9.

6 Appendixes

Appendix A: Commercial Readiness Level Scale

Please note that proposed technologies are not expected to be commercially mature at the start of the project period, nor must any specific CRL be reached by the project's end.

Table 6.1: CRL scale

CRL	Description
1	Knowledge of applications, use-cases & market constraints is limited and incidental, or has yet to be obtained at all.
2	A cursory familiarity with potential applications, markets, and existing competitive technologies/products exists. Market research is derived primarily from secondary sources. Product ideas based on the new technology may exist, but are speculative and not validated.
3	A more developed understanding of potential applications, technology use-cases, market requirements/constraints, and a familiarity with competitive technologies and products allows for initial consideration of the technology as product. One or more "strawman" product hypotheses are created, and may be iteratively refined based on data from further technology and market analysis. Commercialization analysis incorporates a stronger dependence on primary research and considers not only current market realities but also expected future requirements.
4	A primary product hypothesis is identified and refined through additional technology-product-market analysis and discussions with potential customers and/or users. Mapping technology/product attributes against market needs highlights a clear value proposition. A basic cost-performance model is created to support the value proposition and provide initial insight into design trade-offs. Basic competitive analysis is carried out to illustrate unique features and advantages of technology. Potential suppliers, partners, and customers are identified and mapped in an initial value-chain analysis. Any certification or regulatory requirements for product or process are identified.
5	A deep understanding of the target application and market is achieved, and the product is defined. A comprehensive cost-performance model is created to further validate the value proposition and provide a detailed understanding of product design trade-offs. Relationships are established with potential suppliers, partners, and customers, all of whom are now engaged in providing input on market requirements and product definition. A comprehensive competitive analysis is carried out. A basic financial model is built with initial projections for near- and long-term sales, costs, revenue, margins, etc.
6	Market/customer needs and how those translate to product needs are defined and documented (e.g. in market and product requirements documents). Product design optimization is carried out considering detailed market and product requirements, cost/performance trade-offs, manufacturing trade-offs, etc. Partnerships are formed with key stakeholders across the value chain (e.g. suppliers, partners, customers). All certification and regulatory requirements for the product are well understood and appropriate steps for compliance are underway. Financial models continue to be refined.
7	Product design is complete. Supply and customer agreements are in place, and all stakeholders are engaged in product/process qualifications. All necessary certifications and/or regulatory compliance for product and production operations are accommodated. Comprehensive financial models and projections have been built and validated for early stage and late stage production.

8	Customer qualifications are complete, and initial products are manufactured and sold. Commercialization readiness continues to mature to support larger scale production and sales. Assumptions are continually and iteratively validated to accommodate market dynamics.
9	Widespread deployment is achieved.

Appendix B: Technology Readiness Level

Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program, developed at NASA during the 1970s. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology. The European Commission advised EU-funded research and innovation projects to adopt the scale in 2010. TRLs were consequently used in 2014 in the EU Horizon 2020 program. Below the TRL scale is provided.

Table 6.2: Technology Readiness Level scale

TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Appendix C: Manufacturing Readiness Level

The manufacturing readiness level (MRL) is a measure developed by the United States Department of Defense (DOD) to assess the maturity of manufacturing readiness, similar to how technology readiness levels (TRL) are used for technology readiness. They can be used in general industry assessments, or for more specific application in assessing capabilities of possible suppliers.

Table 6.3: Manufacturing Readiness Level scale adapted from DOD

MRL 1	Basic manufacturing implications identified
MRL 2	Manufacturing concepts identified
MRL 3	Manufacturing proof of concept developed
MRL 4	Capability to produce the technology in a laboratory environment
MRL 5	Capability to produce prototype components in a production relevant environment
MRL 6	Capability to produce prototype system or sub system in a production relevant environment
MRL 7	Capability to produce systems, sub systems or components in a production representative environment
MRL 8	Pilot line capability demonstrated. Ready to begin low rate production
MRL 9	Low rate Production demonstrated. Capability in place to begin full rate production
MRL 10	Full rate production demonstrated and lean production practices in place