# The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations

**30 April 2014**

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# INTRODUCTION

EARTO members are very active in National and European research, technology & innovation programmes. In this capacity they have identified an increased use of the Technology Readiness Levels (TRL) scale as a planning tool for innovation management. Having significant experience in innovation creation and management, EARTO members wish to express their views on certain observed limitations and challenges related to the use of TRL as a funding selection and review tool. As every tool, the TRL scale has its strengths as well as its clear limitations. The assessment presented here will show that the TRL scale clearly needs adaptations to fit the funding management purposes given today at EU level. Adaptation is also needed to ensure proper decision-making processes when using the TRL scale based on the reality of today's European research & innovation ecosystem.

Accordingly, EARTO members feel that the TRL scale should be better understood to allow its efficient use in further planning of national and European research, technology & innovation policies and associated funding programmes. In this context, the aim of this paper is to offer the EARTO members' and the broader RDI community's understanding of this scale. RTOs are active throughout the scale and lead projects in all TRL areas in collaboration with the industry at higher TRLs and academia at lower TRLs.

The European Commission is placing emphasis on interactions and convergence across and between the different technologies, non-technological disciplines and their relations to societal challenges. Also user needs will be taken into account in all the fields. **Interaction between disciplines, trans-disciplinary and user-centric approaches are all part of the everyday operation of RTOs.** Hence, RTOs provide the knowledge and expertise needed to solve societal challenges by binding various technologies together, connecting one technology to various applications useful to different industrial contexts, connecting technologies to non-technological disciplines allowing to take users perspective into account as well as look at solutions bridging commercial interests and society needs.

Chapter 1 of this paper describes briefly the background of TRL development and its origins, including some examples of its adaptation to different RDI environments. It is also noted, that TRLs actually in principle exist also outside the Research & Development & Innovation (RDI) context. Most importantly, Chapter 1 presents EARTO members' view on the challenges related to the introduction of TRLs as a funding and review or evaluation tool for research and innovation programmes.

Chapter 2 presents EARTO members' understanding of the TRLs in their operational context. Further, it demonstrates the role of RTOs in supporting Europe's competitiveness and growth. Chapter 3 consists of case examples further supporting the statements of Chapter 2.

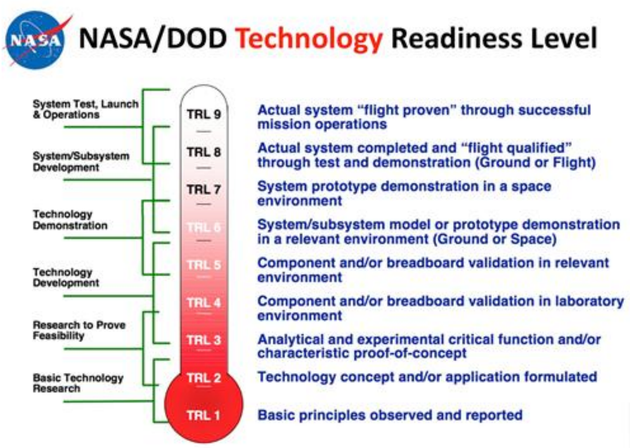
Finally, this paper suggests possible ways to look at further adaptation of the TRL scale to best fit European RDI funding programmes (summary table in annex 1).

## 1. UNDERSTANDING TECHNOLOGY READINESS LEVELS

Today, the TRLs scale is used as a tool for decision making on RDI investments at EU level. Proper implementation of this scheme requires different ways of making this tool operational by adjusting the definitions (or understanding) of the TRLs levels. The scale needs to be adapted to the specific purpose of EU funding for RDI programmes as it does not address the well-known feedback mechanisms intrinsic to innovation processes. This chapter provides an overview of the historical, conceptual and contextual background to the TRL scale to allow further adaptation of the scale to fit the purpose of European policymakers.

**TRL originally developed by NASA to support planning of Space technologies**

The Technology Readiness Level (TRL) scale was developed during the 1970-80's. The National Aeronautics and Space Administration (NASA) introduced the scale as "a discipline-independent, program figure of merit (FOM) to allow more effective assessment of, and communication regarding the maturity of new technologies"[1]. In 1974, Stan Sadin developed the first 7 level scale, which was further refined during the 1990s to the 9 level scale that has gained widespread acceptance across industry and government. In the middle of the first decade after 2000, the scale was widely adopted as a system to define the readiness of technologies throughout the international space development community.




The TRL scale was developed to enable assessment of the maturity of a particular technology and the consistent comparison of maturity between different types of technologies. Although various other management tools were already available for the more business orientated readiness, no tool was available to assess which stage of development a technology was in. This proved to be a problem for planning the development and construction of, for example, the Space Shuttle. When, in 1981, the Space Exploration Initiative was announced, there was an even greater need for a systematic approach to communicate the readiness of technology and forecast implementation between the technological research and mission planning community. Hundreds of people were participating in research, development, manufacturing and use of space technologies, and a clear mode of communication was needed to manage these technology oriented activities.

**The TRL scale has spread to other communities, but with significant adaptation**

Today there is a clear focus on the commercialisation of research results. Therefore a tool to help evaluate this process was clearly needed. This fostered the use and further adaptation of the TRLs scale by communities other than space technology communities. For example, the TRL scale is used by various organisations, from governmental departments like the US-DOD, US-DOE, ESA to large companies like Boeing and Lockheed Martin. Indeed, it is the key element of many Technology Readiness Assessment (TRA) methods. These organisations normally use the US-DOD definitions as a basis, but adapt the precise definitions to suit their needs.

### 1.1. DIFFERENT APPROACHES IN DIFFERENT ORGANISATIONS

As described, the TRL scale originated from the observation that the R&D, operational, and planning communities were faced with problems in communication and synchronisation of scales during technology development for space systems. Development of high-tech technological systems typically depends on the successful synchronised development of the individual technologies needed. If this synchronisation is suboptimal, this will have performance, scheduling and budgetary consequences[1]. The successful development of an innovative system depends highly on the successful management of the alignment of these individual technology pathways.

Assessment of the readiness of the individual technologies will allow risk reduction in budget and planning. This observation was the starting point for the development of the TRL scale and is one of the drivers for its continued use in technology commercialisation and R&D planning. Today it includes the 9 levels (NASA version)[2] shown in the table above.

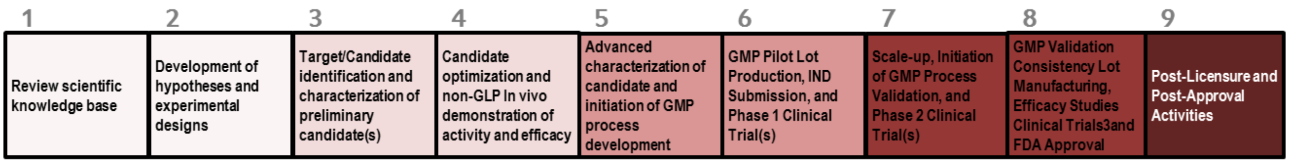
[1] Mankins JC (2009), Technology readiness assessments: A retrospective, Acta Astronautica 65 1216–1223, Pergamon.
[2] United States Department of Defence (2011), Technology Readiness Assessment (TRA)-guidance Washington.

**Original TRL scale is based on assumption that innovation process is linear**

The TRL scale uses a linear approach to research, development and implementation that is common to the prevailing view of innovation in early 1970s. The core object of development is a singular technology (component) that is developed and integrated with other technologies in a broader high-tech, complex product ("Mission operation"). Both aspects are a natural consequence of the fact that the TRL scale originates within the environment of space systems development.

Although having its flaws, the TRL scale is widely used; but it is often adapted to the specific needs of an organisation. An example of this adaption of the TRL approach to the specific needs of the organisation can be found in the US-Department of Health and Human services[3], see Figure 2. The TRL scale is used as an evaluation and planning mechanism to assess the maturity of a drug and allow communication on the status of a specific drug. Although the TRL *scale* is adopted to assess the readiness of Medical Countermeasure Products, an *adaptation* is made to fill the needs of the organisation. It is clear that the wording and definition of the individual levels are different, but the basic 9 level TRL scale is used. Several other examples of this more biomedical adaption can be found, e.g. by NATO and the US-DOD.

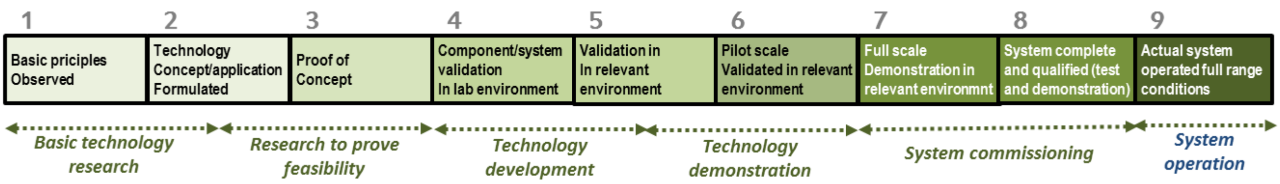
**Figure 2: Adapted definition of the TRL scale used by the US Department of Health and Human services.**




A second type of adaptation can be found in the "Guide to TRA" published by the US Department of Energy[4]. In this guide, more biotechnology and energy based aspects are incorporated. Although the 9 levels are still visible, the description again for each level is slightly different, as shown in Figure 3. An example is TRL6: "Engineering/pilot-scale, similar (prototypical) system validation in relevant environment". The US-DoE uses TRL6 as "relative levels of technological development", using the different types of R&D taking place during the TRLs, i.e.:

- The first stage includes basic technology research and covers both the observation of basic principles as well as the first formulation of the technology concept.
- The second stage focuses on research to prove feasibility and takes the technology concept through first experiments.
- During the third stage technology is developed in a laboratory environment, but still focusing on the basic technological components.
- The following stage is about technology demonstration; taking the technology out of the laboratory and into the operational environment.
- In the stage of System commissioning, the prototype is tested, validated and demonstrated, finalizing the development of the technology and making it fully operational.
- The last stage is the stage of system operation, where the technology is operating on full operational conditions.

**Figure 3: Adaptation of the TRL scale by US-DoE introducing 6 levels of technological development**




**Technology readiness levels are often grouped to produce a more concise scale/classification**

This approach to integrate several TRL levels is also used by several other organisations. The OECD distinguishes 4 research levels: Basic research (TRL1-3), Development (TRL3-5), Demonstration (TRL 6-7), and Early deployment (TRL8-9)[5]. Also the European Investment Bank (EIB), distinguishes only between Research (TRL1-3), Development (TRL 3-6), Innovation (TRL6-8) and Production support (TRL9). The conclusion can be drawn that the distinction between 9 scales is often considered too granular and consolidation to broader classifications is found to be a more practical application of the tool.

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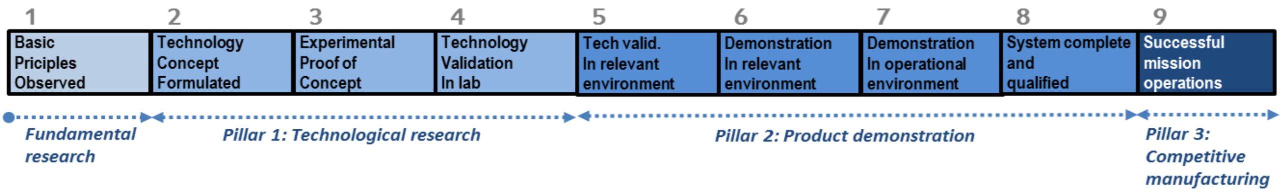
[3] https://www.medicalcountermeasures.gov/federal-initiatives/guidance/integrated-trls.aspx
[4] United States Department of Energy (2011), Technology Readiness Assessment Guide, Washington.
[5] P Ekins (2010), Environmental and Eco-Innovation: Concepts, Evidence and Policies, OECD, Paris.

## 1.2. DIFFERENT WAYS TO DEFINE READINESS AT EU LEVEL

Initiated by findings of the High Level Expert Group on Key Enabling Technologies (HLG-KET), the European Commission has recently adopted the TRL scale, see Figure 4. In 2011, an early study on KETs[6] recommended that the TRL scale be used as "tool for assessing the results and expectation of the projects". This was taken up by the first HLG-KET and posed as a recommendation for the use of the TRL scale to align its RDI activities and balance technological research, product development and demonstration activities within their RDI portfolio[7]. This was adopted by the European Commission and included in their 2012 'Communication on KETs'[8].

***Figure 4: The TRL scale adapted to the KETs HLG three pillar-bridge model***




However, in the 'Communication on KETs' it also becomes apparent that different definitions and criteria are applied to RDI funding, showing that different policy instruments use different approaches. The previously mentioned consolidated classification from the EIB is an example, but also the European Regional Development Fund (ERDF) uses a different scale, distinguishing between basic research, technical & applied research, pilot lines/early product validation actions/advanced manufacturing capabilities, and first production. Many RDI instruments use different approaches to distinguish between the different phases in technology development.

**Assessment of the maturity of technology is used in different EU instruments in various ways**

Horizon 2020 work programs (e.g., Draft work programme 2014 – 2015 NMP) now make use of the TRL scale to make decision on which type of projects to be funded with the proposed TRL level given in call descriptions and (potentially) for use in evaluation. The scale used is included in the table 1. At this stage, despite its inclusion, no sound definition of the individual levels has yet been fully explained and exemplified. It is clear that the adaptation gives little attention to the manufacturing challenges, although in TRL9 the element of "competitive manufacturing" has been included. The EC adaptation still implicitly focuses on a single technology. The aspect of research solutions that will need various technologies is not addressed and such activities are not described. In lieu of adequate definition and exemplification, the scheme is open to interpretation and can hinder communication rather than facilitate it.

**Table 1:**

***TRL scale used in Horizon 2020***

| TRL Scale | Description |
|---|---|
| TRL 1 | Basic principles observed |
| TRL 2 | Technology concept formulated |
| TRL 3 | Experimental proof of concept |
| TRL 4 | Technological validity in a lab |
| TRL 5 | Technology validated in relevant environment |
| TRL 6 | Technology demonstrated in relevant environment |
| TRL 7 | System prototype demonstration in an operational environment. |
| TRL 8 | System completed and qualified |
| TRL 9 | Actual system proven in operational environment |

## 1.3. LIMITATIONS OF THE USE OF TRLS AND THE NEED FOR ADAPTATION

In the previous section, a few different approaches were shown concerning how different organisations use the TRL scale. But there are limitations to this approach which are described below.

### Lack of attention to setbacks in technology maturity

The risk for setbacks in maturity as a crucial characteristic of RDI processes was first integrated in a model in 1986 through the Chain Linked Model[9] and described in several OECD manuals[10]. In contrast to the implicit linear character of the TRL scale, these feedback models show that research is needed even at the higher TRL levels, i.e. that an increase in maturity also requires additional research. Thus, a

[6] PB Larsen, E Van de Velde; E Durinck, HN Piester, L Jakobsen & H Shapiro (2011), Cross-sectoral Analysis of the Impact of International Industrial Policy on Key Enabling Technologies, DTI & Idea Consult, Copenhagen.
[7] HLG-KET (2011), Final report, Brussels.
[8] European Commission (2012), A European strategy for Key Enabling Technologies – A bridge to growth and jobs, Brussels.
[9] Kline (1985). Research, Invention, Innovation and Production: Models and Reality, Report INN-1, March 1985, Mechanical Engineering Department, Stanford University.
[10] TEP report (1986), OECD, Paris.

technology in the stage of pilot production can be thrown back momentarily to the stage of technological feasibility (and require research), as flaws in the product design emerged because of problems in manufacturability.

**Single technology maturity approach**

This limitation is related to another core characteristic of the TRL scale, i.e. its focus on a single technology. As the primary use of the TRL scale is to align different technology developments through communication, the lower levels concern one single technology by definition. However, the higher TRL levels (e.g. TRL8: System completed and qualified), are about integrating different individual technologies, with different maturities into complex products. This means that the original TRL scale is not used to assess maturity of a system (e.g. the Space Shuttle), but is focused on one of its components (e.g. a mirror in the Space Shuttle). This complicates the application of the higher TRL to projects which are typically about complex solutions rather than component development.

**Focus on product development, rather than manufacturability, commercialisation and organisational changes**

The original TRL scale was about product oriented technologies. However, in some TRL adaptations, e.g. manufacturing is also incorporated, such as the ARPA-E guide[11]. Further, attention to non-technological aspects, like the readiness of an innovation to go to market and the readiness of an organisation to implement the innovation, are not incorporated. If the purpose shifts from planning and communication to a broader objective such as assessing eligibility to access specific funding, these aspects should also be part of the activities that can be funded (e.g., assessment of economic feasibility). Indeed, this has been recognised in the recent Horizon 2020 program in that mid to high TRL programs are also asked to provide a business plan for future development.

**Context specificity of TRL scales**

Although the TRL scale has proven to be useful for different organisations, the conclusion can be drawn that actual purpose and use differ. The scale can be used for planning and communication purposes, but also as a supporting tool for decision making on investments. Thus, different purposes lead to different operational needs. Usually this is done by adjusting the definitions of the levels, i.e. the scale needs to be adapted to the specific purpose of the organisation.

## 1.4. The View of EARTO on the Use of TRLs

EARTO believes that the TRL scale can be of added value to assess the eligibility of innovation projects based on their maturity. However, the analysis above shows that the TRL scale requires adaptation before it can be used within a specific context. The Horizon 2020 context is no exception, especially when the original purpose of the TRL scale as a communication and planning tool does not apply.

First the use of the TRLs scale as evaluation tool must be explored. This must be related to the different funding mechanisms for research and innovation existing today. The overall basic distinction in such R&I funding mechanisms is provided by our European State Aid Rules. Within the State Aid Rules, a distinction is made between different activities and different funding intensities, i.e.: Fundamental research (100% funding), Industrial research (50% funding), and Experimental development (25% funding). In addition to these basic distinctions in R&I activities, the receiver of the support can also have an impact on the level of funding, i.e.: large organisations, SMEs, joint activities. With regard to the TRL scale, the TRL levels should also reflect the limitations set by the State Aid Rules.

Secondly, a discussion of the "Valley of Death" is relevant, as this is ostensibly the reason why the TRL scale has been adopted by the European Commission (i.e. the shift of funding towards commercialisation). This asks for explicit attention to pilot production in which scale up of a prototype towards low-rate mass manufacturing is funded. It underpins the need to make a distinction between three different research activities, i.e.: fundamental, industrial, and experimental, but also requires specific attention to manufacturability and readiness of manufacturing technologies.

The third step is to look at the observations described in the previous section and assess their implications:

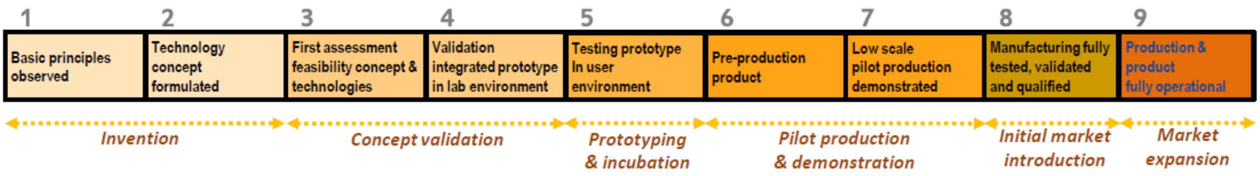
- The setback mechanisms need to be incorporated, as their exclusion would mean that when (not if!) they occur, funding of specific activities would be (temporarily) stopped, leading to unnecessary destruction of capital. The implication is that in every stage certain kinds of R&D should be incorporated.

[11] http://arpa-e.energy.gov

- As a new innovation usually is built up from different technologies, the scaling should make a distinction between R&D on individual technologies, integration of those technologies and pilot production. The manufacturing technologies needed, can be seen as just another technology.
- Innovation is not about technology (product and process) alone. Financial and organisational activities can be crucial to commercial success. These should be incorporated into the definitions, broadening the TRL scale. The development of accompanying services is just one example.

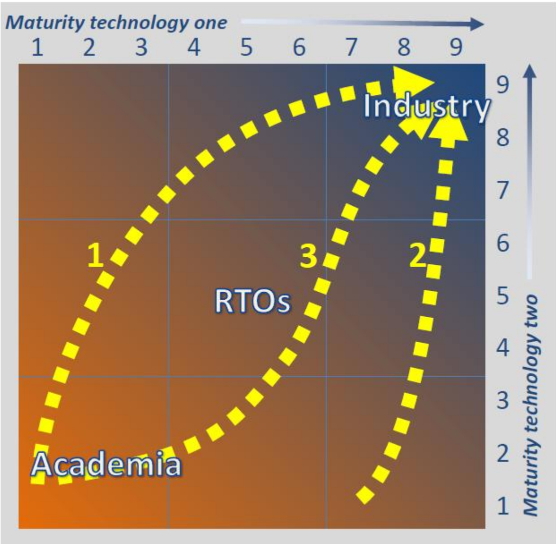
Thus, regarding the definitions of the 9 levels, an integrative approach (combining different technologies and addressing market and organisational issues) should be adopted. The different stages in maturity should be aligned to the various ways governments can support RDI activities. In the scale, manufacturability should also incorporated. A full description of the EARTO TRL scale is included in Annex 1 with a summary in Figure 5.

***Figure 5: EARTO reading on the TRL scales, incorporating manufacturability and including non-technological aspects in a multi-technology adaptation.***




Using this approach, it becomes clear that "Invention" is part of fundamental research, with "Concept validation" being its natural extension allowing early participation from industrial partners. "Prototyping & incubation" can be seen as an integral step towards industrial research and "Pilot production & demonstration" aspects of experimental development. Finally "Full market introduction" and "Market expansion" are fully commercial activities and normally part of the commercial risks companies take.

***Figure 6: 2D approach to the TRL scale, showing three basic routes in the development of an innovation.***




The only further issue to discuss is the multi-technological aspect that is not addressed by the TRL scale. The TRL model is excellent for planning the evolution of the technology steps for a product from idea to commercialization. However, in particular many KET products depend on the availability of a (key) enabling technology with its own evolution from idea to maturity. Sometimes such products are called multi-KET or cross-KET products. A multi-technology approach is needed to address this issue. This can be seen in Figure 6 where two technologies are positioned in a matrix. In this 2D TRL model we encounter the main TRL for the product itself as well as a support TRL for a supportive technology, like a manufacturing technology. Different routes can be followed. If a technology development focuses on a product oriented technology, the maturity of the manufacturing technology (or other product technology) is already high (2). An example is a new industrial biotech product, based on state-of-the-art production technology. In another case, the product already makes use of well researched technologies that must be applied, but manufacturing is still requires significant development (1). Alternatively, both the product and manufacturing technologies must be developed (3).

**A multi-technology process, cannot be modelled with a simple linear approach**

Previously EU innovation programs focused on TRL level 1-3/4. Today focus has shifted to the higher TRL levels. However, individual funding of innovation projects close to TRL 9 cannot be considered appropriate, partly due to the application of the State-Aid rules, which is critical to be able to support commercialization. However, this limitation is also partly due to the fact that a linear application of the TRL scale does not recognize that a product in a high TRL can be accompanied by manufacturing technologies that are still "stuck" in lower TRL levels. The required help to support further R&I developments needed to manufacture this product (low TRL levels) will then not be taken into account. This can potentially lead to problems in the commercialization of products as even if those products are fully developed there will not be market up-take.

One might argue that in practice there will be many support technologies that must evolve simultaneously to higher maturities and that the model must be multi-dimensional. For practical reasons we assume that only one supporting technology is on a critical path to influence a main TRL. The purpose of the 2D model is to illustrate the complexity of innovation projects.

## 2. RTOs ARE ACTIVE THROUGHOUT THE TRLs SCALE

RTOs have a clear role in translating research across the entire TRL scale, in co-operation with existing and emerging industries and academia, from idea to application. Taking an idea from the drawing board through demonstrations, pilots, and practical development hurdles to commercial success requires expertise and infrastructures that RTOs possess and that are heavily used by European industries and national governments already today.

### 2.1. RTOs BRIDGING THE VALLEY OF DEATH

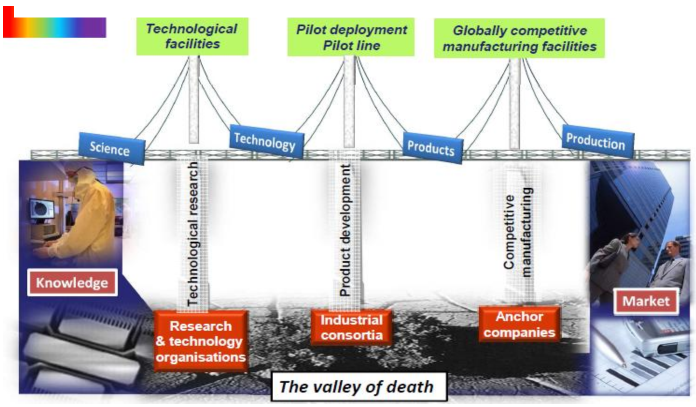
During the last few years, the European Commission has paid much attention to developing a strategy to make Europe more attractive for investments in research, technology, innovation and manufacturing. Currently Europe appears to suffer from a slow process for transferring excellent research and development results into innovative solutions for the markets. That is, Europe needs to improve in bridging this so called "Valley of Death" (Figure 7). As seen above, the TRL scale has been adopted to facilitate this endeavour.

**Bridging the valley of death is a joint effort between Industry and RTOs**

As a consequence of on-going discussions, a lot of emphasis has been given to the role of industry in fostering sustainable growth in Europe. Funding schemes that would allow industry to obtain funding for closer to market activities for the higher TRL levels have been put in place. It should, however, be made clear that bridging "the valley of death" requires a joint effort from research and industry. The input of RTOs, in terms of knowledge, highly skilled resources and research activities, is necessary to ensure the successful translation of research results into commercial products and services.

RTOs play a key role in supporting the development of dedicated research and development infrastructures for large industry as well as SMEs. Existing industries may have a number of production facilities but those are rarely suitable for research and development of new technologies. Industry research infrastructures are typically designed to analyse and develop existing solutions incrementally and may not be adaptable to piloting new technologies. When developing the readiness of a manufacturing process for a new technology together with the development of the product itself, it is necessary to enable scaling of production amounts from single demonstrators to small series. This is often possible only in dedicated research and development infrastructures rather than existing production and/or research lines.

***Figure 7: KETs Valley of Death***
***from the EU HLG KETs Final Report 2011***




**Bridging the valley of death also means solving societal challenges**

The European Commission is placing emphasis on interactions and convergence across and between the different technologies, non-technological disciplines and their relations to societal challenges. User needs will also be taken into account in all fields. RTOs' core activities are based on interactions between disciplines, trans-disciplinary and user-centric approaches. Hence, RTOs provide the knowledge and expertise needed to solve societal challenges by binding various technologies together, connecting one technology to various applications useful to different industrial contexts,

**H2020 Societal challenges:**

- Health, demographic change and wellbeing;
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Climate action, environment, resource efficiency and raw materials;
- Europe in a changing world - inclusive, innovative and reflective societies;
- Secure societies - protecting freedom and security of Europe and its citizens.

connecting technologies to non-technological disciplines incorporating the user perspective into development while looking at solutions that could bridge commercial interests and societal needs. RTOs also provide a resource of specialized and highly skilled personnel and know how, without which the bridging between so many different disciplines & knowledge necessary to solve societal challenges would not be possible.

## 2.2. RTOs Add Value at Every Level of the TRLs Scale

Realising EU competitiveness and growth objectives requires covering technology development from near-basic research to commercially viable solutions available on the market. This means covering technology readiness from level 1 to 9. RTOs are active at all of these levels and there is ample evidence concerning their contribution (see selected examples in Chapter 3) in helping industry take the crucial step from one level to another.

Let us first outline the **5 main contributions from RTOs to EU Industry's competitiveness** which can be summarised as follows:

1. **RTOs are active in translating basic research into applicable solutions**. For example, basic research produces information on how allergic reaction proceeds in humans and RTOs can take this information and use it to develop vaccine technology.
2. **RTOs house various research infrastructures benefitting many stakeholders** (universities, new enterprises, SMEs, large enterprises). For example, a single research infrastructure can be used for completely new technology piloting and spin-off incubation, for testing changes in an existing product, and for validating an emerging concept as a collaborative action of several industrial players. Multi- and inter-disciplinary approaches are key strengths of RTOs when developing solutions for societal challenges.
3. **RTOs perform foresight and support policymaking** (e.g. identification of emerging technologies worth investing in, from an economic and societal point of view). Based on this, RTOs build consortiums needed to further develop these opportunities in concrete products, processes, solutions and services. RTOs also perform further research on possible societal implications. RTO collaboration brings together different industrial players across the value chains and value networks, to collaborate and interact. In this context, technology assessment is an important part of RTO activities to support policymakers with policy development.
4. **RTOs help develop existing products and processes to better suit industry and consumer needs**. RTOs house competence which is needed to take the user point of view into account when developing products, processes, and services. For example, the importance of a life cycle approach in product design is increasing and thus it is important to understand the user's perspective when launching new products.
5. **RTOs train and educate experts** to provide expertise and human resources for other research organisations, industry and government. This is crucial to fulfil the needs of these organisations for high-skilled personnel.

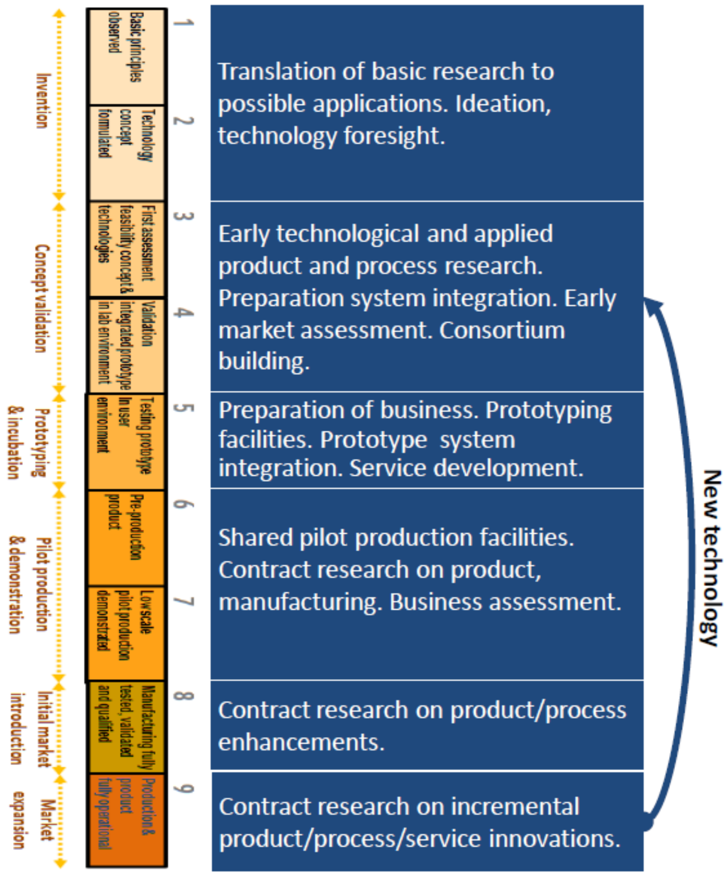
With this in mind, the following paragraphs further explain how RTOs engage in the different TRL levels as illustrated in Figure 9.

**From TRL 1 to TRL 3**, the close connection of RTOs to industry gives them first-hand information on the needs of industry and thus the ability to create innovative concepts of industrial relevance. Further, the close connection of RTOs to academia gives them access to state-of-the-art scientific development and the expertise to make the translation from academic results towards applications. RTOs' research and development infrastructure plays a key role in the formulation of the technology scale as well as in the experimental proof of concept for RDI in existing industries, start-ups, spin-offs, SMEs, and large enterprises seeking growth and/or renewal.

**From TRL 4 to TRL 7**, this is believed to be the most prominent RTOs area. Also here, RTOs typically do not work alone but in collaboration with industrial partners including SMEs, academia and other RTOs. RTOs support the crossing of the valley of death in R&D by providing different physical research infrastructures, expertise, and their unique multidisciplinary approach. Further, RTOs support this crossing by their knowledge of industrial environments, practicalities, and limitations allowing them to be the ideal project lead in certain situations. In this area RTOs typically support existing companies in developing their ideas towards real-world applications. RTOs also develop ideas perhaps originating from basic research or their preceding research towards spin-offs and solutions for industry needs. The creation of whole new industries cannot happen without experience of the entire TRL chain. Technology assessment supports the further shaping of innovations that are more accepted by society.

**From TRL 8 to 9**, RTOs often perform foresight activities that are needed, for example, when introducing new technologies to market. These studies are part of analysing the operational environment and the introduction of emerging technology to it. Activities here are mainly performed by industrial partners with a support of RTOs (see Chapter 3); but for a non-commercial application (space for instance), RTOs have the research facilities to allow the development of specific products or systems proven in an operational environment. Also various user experience studies and analyses are performed by RTOs to support the deployment of technology in its actual operational environment. Demonstration in operational environments may, especially in the case of new technologies and new manufacturing, require fine-tuning on-site. Here RTOs have a supporting role and research is used to find the final settings.

***Figure 9: RTOs add value at every TRL level***




EARTO understands that various discussions are running currently at EU level related to the following question: up to which TRL level should EU Research & Innovation funding programmes support industrial activities. We believe this is an issue the European Commission should carefully evaluate, also in relation to State-aid restrictions. EARTO members will be happy to support the European commission services' discussions on this issue.

## 2.3. RTOs Supporting EU Industry's Competitiveness

RTOs are significant contributors in R&D related to the key enabling technologies (KETs) that at the EU level are seen as being strongly connected to regaining Europe's industrial leadership, e.g. individual KETs: nanotechnology, micro & nano-electronics, photonics, advanced materials, industrial biotechnology, and advanced manufacturing systems – and cross-cutting KETs

**RTOs supporting (existing & large) industry by enabling commercial success**

Existing industries and large enterprises looking for renewal or product/process improvements rely on RTOs' broad understanding of technology, view to the market, and intellectual property rights. The financial situation has forced many enterprises to downscale their in-house research. Competences are therefore not only limited but also typically very focused on the existing business, and inadequate for developing new technologies or exploiting new opportunities (e.g. understanding user needs related to a new technology or product, or the manufacturing process and implications of such).
Here RTOs have solid knowledge on related non-technological issues - human behaviour, service innovations, technology transfer, market developments, innovation policy and industry-related sectorial policies, and even epidemiology - necessary for staying competitive in the markets and supporting existing industries and large enterprises in Europe.

**RTOs supporting SMEs supplying into the value chain of large industry by offering them industry relevant or operational environment in the form of a shared facility**

Today we have value chains with multiple partners where an SME partner can be a material, a component/subassembly or an equipment supplier to another enterprise that is or will deliver a final end product to the market. There exists today a market mismatch where the SME as a smaller entity does not have all the facilities needed to demonstrate the maturity/readiness of their product. Without such facilities they cannot readily become further involved in the value chain associated with their product. Here RTOs play a specific role in supporting SMEs to close the gap (valley of death) in their specific value chain by using research and development facilities, set up and managed by RTOs up to the higher TRLs.

SMEs rarely have the funds to invest in extensive research and development infrastructure in terms of equipment, time, and/or personnel. They typically struggle with access to knowledge and connecting with existing innovation ecosystems. Further, the construction and operation of research infrastructure also often requires a different competence from those essential for running an SME. For SMEs, RTOs can offer access to an industry relevant or operational environment in the form of a shared facility. This allows the SME to test and validate products and processes on a neutral site that can also provide customized research support in an independent manner.

With the trend by enterprises to outsource not only the repetitive supply of components or materials but also the development (design & engineering) of it, SME companies have to evolve to another business model. Being used for short-term orders and direct payments after delivery, SMEs now have to invest upfront and earn return on the investment later on during the subsequent repetitive supply period. An SME today will not have the financial means for such an investment, let alone all the skills, capabilities and facilities needed in the different TRL phases. RTOs have technological infrastructures and facilities as well as trained personnel, and can operate shared or open relevant pilot environments. SMEs can then timeshare or use the RTO facilities under various conditions adapted to their need when and where it becomes apparent.

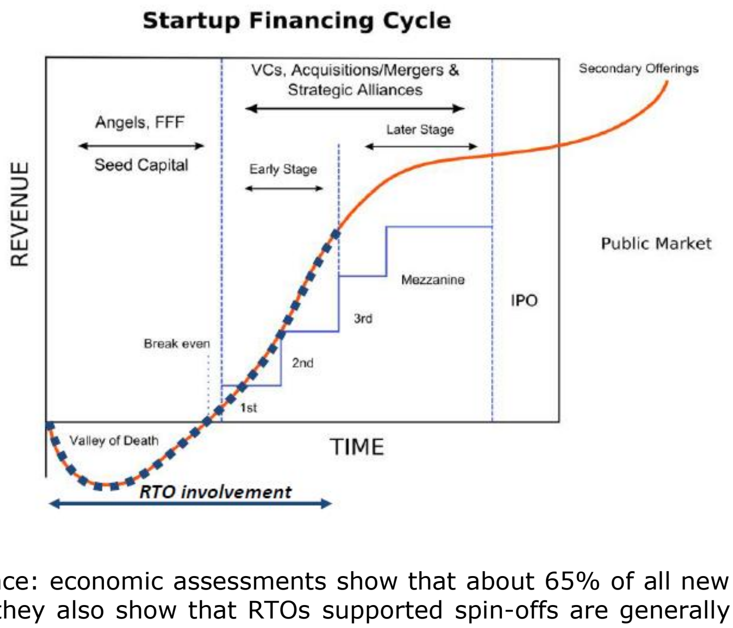
There exists a second use of RTOs in TRL phases from 4-8. If you are an equipment supplier to multiple large end product manufacturers or a materials supplier with a new material you have to prove the benefits of your product to your customers; but, you do not easily have access to full-scale production, or only restricted access this may sometimes even block your ability to sell the same solution to multiple clients. Having access to open or shared environments at RTO is a solution. Further, such suppliers cannot operate a complete relevant pilot production environment or might need an independent organization that can validate the results. Thus, being able to demonstrate the solution of an SME within a relevant, open or shared pilot environment is of commercial value for them.

**RTOs supporting new entrepreneurs, start-ups and creators of spin-offs**

RTOs also play an important role in the initiation of new tech-based companies in which new entrepreneurs take a technological invention to market. The developed technological inventions, based on applied research, can be interesting for existing enterprises, but also lead to spin-off activities. New enterprises are then established and new entrepreneurs supported by broader incubation programs to find seed money, create business models, produce prototypes, assess IP issues, connect to industry and finally create a company that produces new and innovative products. Many European RTOs have created such programs, owned by RTOs but often placed outside their organization to support the skills and networks needed to spin-off companies.

Starting under the umbrella of the RTO, often still partially owned by the RTO, the first steps in the new enterprise are made to transform the invention into a commercial innovative product. In this way, the research and development created by an RTO is valorised in economic activities. The core activity of those start-ups/spin-offs can be both manufacturing of products and/or provision of services.

***Figure 8: Different stages of entrepreneurship, different funding mechanisms***




The RTOs spin-off activity is of high importance: economic assessments show that about 65% of all new jobs emerge from new start-up companies, they also show that RTOs supported spin-offs are generally much more successful in the market than start-ups not being backed by a RTO. In these activities, RTOs cooperate with other stakeholders like Venture Capitalists, other incubator organizations, academic organizations, industry and governments to both support the creation of new businesses and jobs as well as valorise the outcomes of their own research and development.

**RTOs supporting regional, national governments to define their strategic orientations**

RTOs support the industry to move forward in commercialization of new innovative products on the market, but they also support the development of new innovative solutions that address today's societal challenges when the market fails to do so.

Accordingly, in addition to supporting industrial competitiveness, RTOs provide independent advice to their local, regional and/or national governments. By combining the knowledge built partly while supporting the industry and partly developed in collaboration with academia, RTOs are capable of providing expert vision on today's societal challenges combining at the same time technical knowledge on possible (new) solutions not yet developed or picked up by the industry who must manage their specific economic interests.

As such, RTOs are often independent advisers for their governments. This makes RTOs key players in economic development. RTOs are capable of identifying the potential of new technology developments (technology foresight) as solutions to societal challenges that may not have been yet identified by the industry as their key priority and that will not be picked up directly by the market then (i.e. market failure). Such capacity allows the RTOs to be key advisers to their governments in making choices related to key governmental investments related for examples to ageing of population, climate change, mobility, etc. Also advising governments on effective measures to speed up innovation based on their experience of industrial innovation is of added value.

In this role, we see RTOs as great supporters for the crossing of the "valley of death" also in areas not covered by industrial interests, facilitating the development of technical solutions and later on the production of products by bringing different types of public and private stakeholders together to solve societal challenges. Transformation management applying a systemic approach can only be implemented in collaboration. As such RTOs are supporting local, regional or national development of public-public or public-private partnerships targeting societal challenges. In this context, it is not surprising to see that RTOs are very often the independent party in such partnerships, elaborating new innovative technical solutions and transforming them into new products commercialized by already existing industry or by new spin-offs.

**Conclusion**

In summary, RTOs develop innovations in close collaboration with (large & small) industry. Today, RTOs also operate as new business incubators and produce spin-offs. RTOs work not only by creating new business (solutions) based on inventions from within but also by supporting new entrepreneurs. For SME innovation processes, RTOs' research and development infrastructure may be the only way forward offering both technological expertise and the infrastructure to prototype, test and validate inventions. Large enterprises looking for renewal or product/process improvements rely on RTOs' broad understanding of technology, view to the markets, and intellectual property rights. RTOs also provide expert independent advice to their local, regional and national governments, supporting them in deciding necessary next steps towards solving today's societal challenges. As a consequence, RTOs are quite versatile and adaptive, aiming at finding the best innovative techno-economic solutions throughout the whole TRL scale with a variety of partners aiming at keeping industry competitive while solving rather than exacerbating societal challenges.

## 2.4. RTOs Specific Contribution to Higher TRLs

**Low volume mass manufacturing is a necessary step before entering the big markets**

Besides access to a specific infrastructure or pilot line, some RTOs' pilot environments provide companies the possibility for low volume manufacturing preceding high volume mass manufacturing – this is especially valuable for SMEs!. This is, for example, essential in the electronics sector where large volume manufacturing is outsourced to a specialized company giving preference to high volume sales. This leaves SMEs in the waiting mode to see when their product can be processed. Suitable pilot environments enabling SMEs to enter the market more rapidly, gives them a competitive advantage they would otherwise miss. Also, in highly specialized components or systems with limited market volumes, a low volume manufacturing facility can help an innovation needed by larger companies to enter the market.

**At higher TRLs, the need for specialized & highly skilled personnel is high**

At higher TRLs the need for specialized and highly skilled personnel and know how is high. RTOs can not only provide support in the form of contract research but also valuable training for company employees or even be a source from which companies can attract the human capital they need to make their innovation successful.

**RTO knowhow supports user-driven product and service development**

RTO knowhow on user-driven development serves industry entering the markets at the higher TRL levels. Service research performed by RTOs is also necessary when companies are looking for new ways of serving their clients as RTOs typically are familiar with the existing procedures and their limitations. RTOs foresight activities are relevant both at higher TRLs (how will markets and users respond to a product or change in service model?) as well as at lower levels (what are the trends among users, policies?).

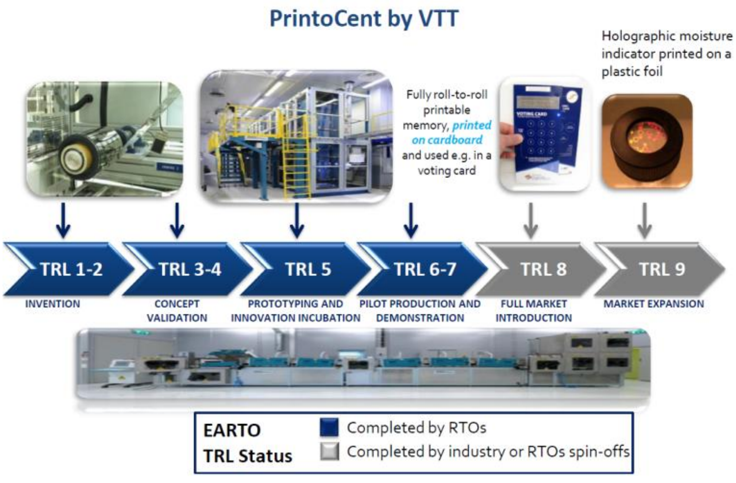
**Technology infrastructure supporting simultaneous development of multiple product generations at varying TRL levels**

An environment capable of producing (in the near future) real products is a pilot line that addresses the so-called pre-production phase. It seems logical to state that technological infrastructures in general might be mapped onto TRL 5-6 and pre-production environments on TRL 7-8, while TRL 1-4 are generally related to laboratory environments, whether owned by RTOs, academia, or industry. Clearly TRL 5-6 are not exclusive for RTOs. Industry also has environments with technological developments in TRL 5-6. It must also be noted, that a pilot environment may be used to support product/technology development on scales 1 to 9, and thus placing the environment itself on the TRL scale does not always make sense. If one would define the current commercial technology to be named generation N, then at the same time the development of generation N+1 is in progress and in the lab environment the initial work on generation N+2 has already been started. All three generations might claim access to the same technological infrastructure. In practice this would lead to time-sharing the infrastructure. In other words, you can encounter technologies at different TRL in any given technological infrastructure.

## 3. Examples of RTOs Working Along The Whole Value Chain

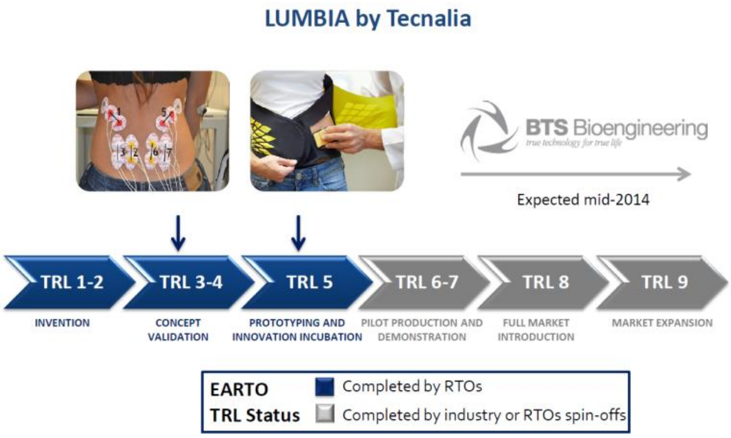
RTOs are organisations involved in research, technology and development working in close cooperation with the industry outside the sphere of higher education managed by their partner universities with whom they can share facilities on a high-tech campus as well as personnel (part-time Professors and hosted PhD students). RTOs are hybrid organisations between two worlds: the industry & higher education. RTOs' challenge is to combine knowledge of those two worlds in order to develop innovative solutions supporting both private industry competitiveness and answering public societal challenges. RTOs balance every day between various spheres of interests: between public-private interests on the one hand and science-applied research on the other. Thanks to this hybrid position between those sometimes conflicting spheres, RTOs have developed a strong position at the intersection of those worlds being able to understand multiple viewpoints and they actively bridge gaps while retaining an independent position. As such they are key partner for both industry and policy makers, able to provide independent advice and solutions along the value chain, and consequently along the TRL scale. The following examples have been chosen to show RTO activities bridging "public" and "private" interests, "basic" and "applied" science, creating "public" or "private" innovative solutions.

**New printed intelligence into PrintoCent pilot factory**



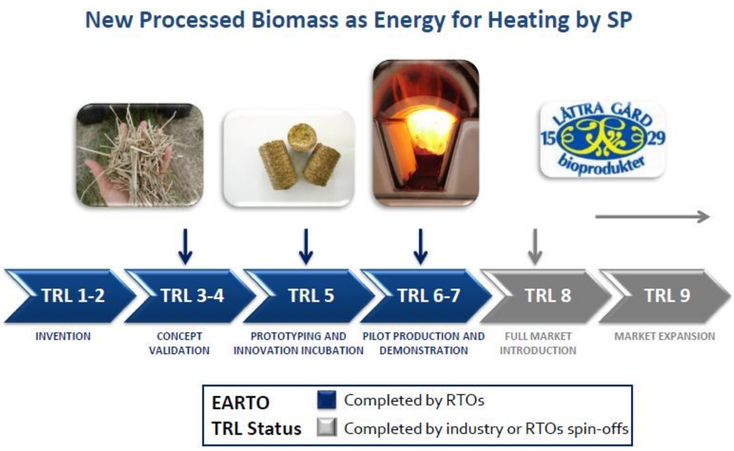

The idea of printed intelligence originated from RTOs and companies rather than from basic research. Idea development required formulation of the scale (What kind of material can be used as ink? What kind of components would be needed? On what kind of material can the inks be printed?). All of those were crucial questions that needed to be answered before massive pilot lines could be thought of. Nowadays this research has led to a whole new industrial branch. After basic scales of printing process and materials were assessed, the actual components were designed and constructed at VTT in Oulu in order to validate the technology. First product ideas were formulated and a manufacturing line for their pilot production prepared. The research and development work has led to a unique collection of several pilot production that enable even piloting mass production. Several product families have been tested (photovoltaics, bio-based printable power sources, printable diagnostics). A total of 14 spin-off companies have been or are currently supported by the pilot facility, and new ideas and refinements are constantly developed.

**LUMBIA, Re-education system against low back pain**



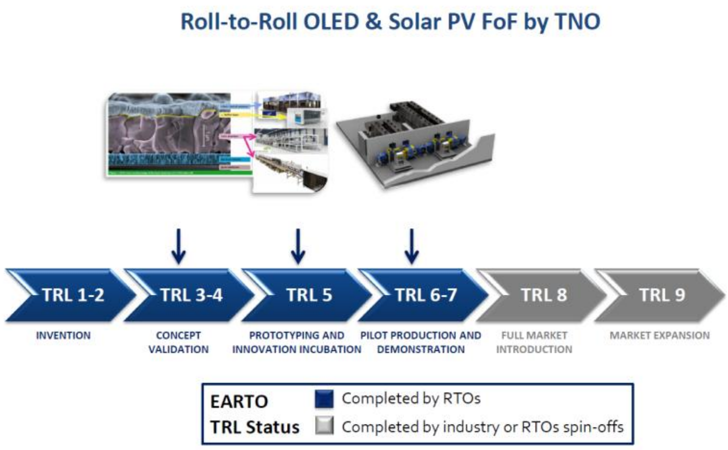

Low Back Pain (LBP) is the leading cause of activity limitation and work absence throughout much of the world. Tecnalia, by means of the FIK initiative (private fund for R&D) and with the crucial contribution of the company BTS Bioengineering, has created LUMBIA, a wearable postural re-education device based on electromyography (EMG), for the assessment, prevention and treatment of low back pain. It acts by alerting the user via on-spot vibro-tactile feedback, when the unaided muscular activation pattern is not adequate. As an assessment tool, LUMBIA is a non-invasive tool that can be used during educational interventions, back training programs, cognitive behavioral treatment plans and multidisciplinary bio- psychosocial rehabilitation plans. In order to be able to bring a device to the market in the EU, the device must meet the essential requirements of the Medical Devices Directive as well as the standards related to its device class. For the US market, any new product needs to meet the Food and Drug Administration's requirements. This step is currently being done by BTS Bioengineering to reach a TRL level 8 stage before full deployment in the market by BTS Bioengineering.

**Innovative Production Process: Processed Biomass, from seed to heat**




Låttra Farm Bioproducts is an agricultural business which has been operating a small-scale commercial briquetting plant in Sweden since 1994. In light of increasing woodchip prices and growing competition for raw material, the plans to start local production of reed canary grass (RCG) briquettes began in 2003. Today, the company has equipment to incorporate RCG as raw material in briquette production; but, more work was needed to achieve an optimal production chain for commercial operations. SP Technical Research Institute of Sweden has worked together with Låttra Farm and local energy providers to develop and optimize the production and briquetting of RCG to achieve high-grade solid fuel which can be used in new and existing heating plants. Work is continuing to further improve the efficiency production and briquetting as a sustainable use of processed biomass from the field to commercial application in building heating.

**Roll-to-Roll OLED & Solar PV Factory of the Future - technological infrastructure for shared material supplier, equipment builders and manufacturer pilot use**



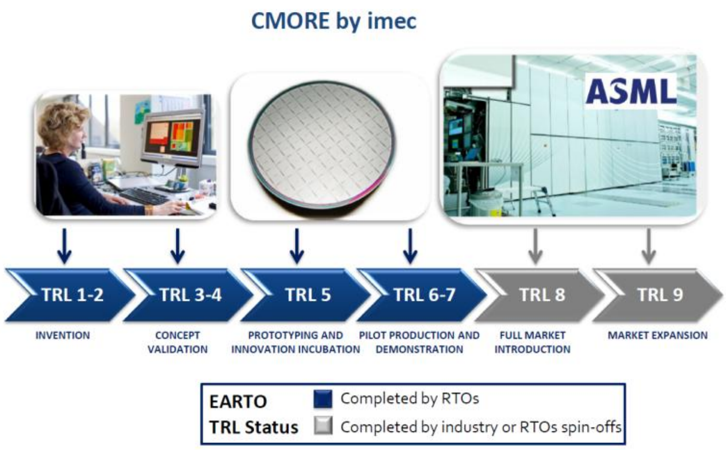

At the Eindhoven Hightech Campus the Solliance building is a factory of the future type of pilot line where materials suppliers, equipment builders and producers of OLED (organic LED)/SolarPV devices operate in a shared environment set-up by a collection of RTOs supported by universities. The roll-2-roll environment is meant for OLED and Solar PV production with a focus on low-cost products for energy applications (sustainable electricity generation and lighting). To be successful it needed to be shown that ultimately the products can be manufactured at very low cost levels meaning minimal usage of material and a continuous flow production. Remarkable is that RTOs worked together to realize this Future of Factory (FoF) pilot environment as a technological infrastructure example. Together the RTOs realized a world-class environment that is attractive for SME partners in combination with often large manufacturing companies. This environment is currently being used to execute different research programs with several industrial partners.

**Improved Railways Traffic Safety thanks to New Laser Scan**

Laser systems can be used to implement highly precise and ultra-fast measuring processes. Railway measuring technology has a huge worldwide need here. One prerequisite for its use is that nobody is damaged or suffers irritations by the laser. Fraunhofer Institute for Physical Measurement Techniques IPM has worked to develop a 3D laser scanner. It can be used outdoors without hesitation. Extremely fast and precise, it is able to spatially measure and monitor the position of the contact wire or the track from a train travelling up to 100 kilometers (62mph) per hour. If the scanner is stationary, it can capture passing trains and check for loads that might have slipped. The laser system has already been marketed and used successful all over the world for rail traffic safety. Not only fast and precise, this system is also highly robust.

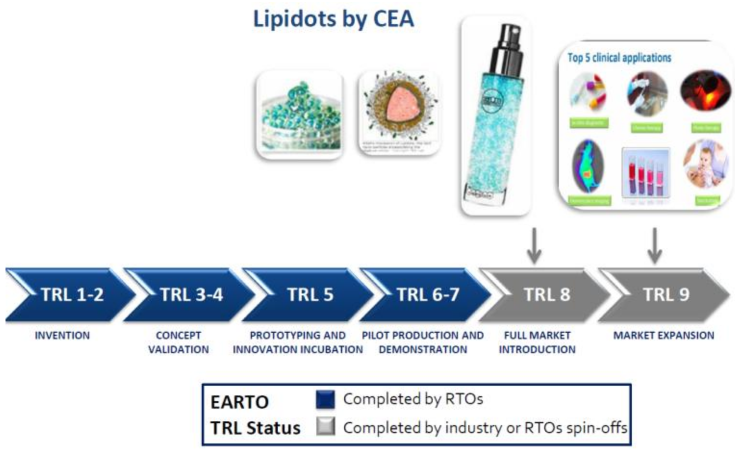

**CMORE, a New Smart Packaged Micro-system**

Via its CMORE initiative, imec offers companies all the services needed to turn innovative ideas into smart packaged microsystem products. The CMORE toolbox contains a wide variety of device technologies on 200mm (e.g. CMOS, Si-photonics, MEMS, image sensors, packaging, etc.) as well as design, testing and reliability. One of the first projects was the production of high-quality EUV sensors for ASML's next-generation lithography tools. The sensors were processed according to ASML's custom designs and specifications, with focus on superior lifetime and sensitivity to direct and high EUV irradiation doses. On this line imec also works together with small companies in other areas like GaN. In this case, the RTO offers to SME's and large companies the ability to access a low volume manufacturing facility.




**Lipidots®, a new Nano-delivery Platform changing today's Cosmetics**

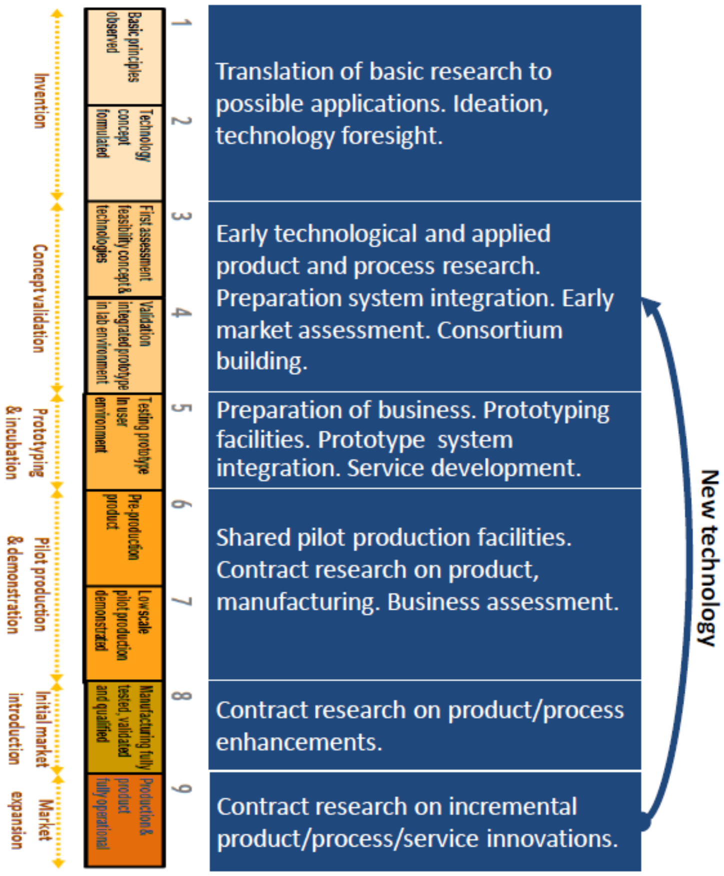
On October 2013, CEA-Leti and Capsum announced that the successful transfer of Leti's patented Lipidots® nanovector technology to Capsum for cosmetic applications has produced the first commercial use of the new technology. Lipidots® is a versatile nano-delivery platform based on tiny droplets of oil for encapsulating and carrying drugs or fluorescent imaging agents to targeted cells in the body for treatment or diagnosis. Leti's partnership with Capsum shows that the technology is easily adapted for applications in the cosmetics industry. This successful technology transfer follows more than seven years of collaboration between Leti and Capsum that included development work on Lipidots®.



The variety of examples clearly indicates that the definition of the TRL levels has to be interpreted depending on the development it is applied to. Further, it should be noted that the role of RTOs at higher TRL levels is more than just supporting a company towards commercialization. In some instances the RTO can be seen as pivotal. In that sense all funding programs should be open to RTOs not only as active participant but also as coordinators for projects with a broad industrial interest.

## Conclusion

Today, the TRLs scale is used as a tool for decision making on R&D investments at EU level. This requires different ways of making this tool operational by adjusting the definitions (or understanding) of the TRLs. EARTO hopes that this paper provides interesting insights on how this could be achieved.




The summary table of EARTO interpretation of the TRL scale can be found again to the right. It is hoped that this will be helpful for policy makers to understand how they could adapt the scale to their specific needs in the various sub-programmes as well as see how they could be supported by RTOs in setting-up and implementing their programmes.

In addition, we hope that this paper demonstrates clearly that RTOs have a clear role in translating research across the entire TRL scale in co-operation with existing and emerging industries and academia, from idea to application. Taking an idea from drawing board through demonstrations, pilots, and practical development hurdles to commercial success requires expertise and infrastructures that RTOs possess and which is heavily used by European industries and national governments today. Special attention should be made to RTOs specific inputs within the higher TRLs levels where RTOs can, e.g. bring specific support to SMEs.

Europe's challenge today is to ensure that the new R&I programme, Horizon2020, will effectively allow Europe to bridge the valley of death so easily visible on the TRL scale, to effectively support European Industrial competitiveness. RTOs main contributions to support Europe's industry to bridge this gap include:

1. RTOs support translating basic research into applicable scales and solutions.
2. RTOs house various research infrastructures, including multi-use research (prototype) and low-rate manufacturing (test & Validation) facilities supporting piloting and pilot-production, benefitting many: large enterprises, SMEs, universities and governments.
3. RTOs perform foresight and ideation actions that feed industrial strategies and and stimulate political decision making.
4. RTOs help developing existing products and processes to better suit industry and consumer needs.
5. RTOs train and educate experts to provide expertise and human resources for other research organisations, industry and government.

Finally, bridging the valley of death comprises not only supporting our industry but also finding solutions to Europe's Societal Challenges. Answers to societal challenges will be found by placing emphasis on interactions and convergence across and between the different technologies, non-technological disciplines and their relations to various societal challenges taking users into account. Interaction between disciplines, trans-disciplinary and user-centric approach are all part of the everyday operation of RTOs. Hence, RTOs provide the knowledge and expertise needed to solve societal challenges by binding various technologies together, connecting one technology to various applications useful to different industrial contexts, connecting technologies to non-technological disciplines allowing to take users perspective into account as well as look at solutions bridging commercial interests and society needs.

## ANNEX 1: TRLS OVERVIEW TABLE

| Cluster | TRL | H2020 terminology | EARTO reading | EARTO definition and description |
|---|---|---|---|---|
| ***Invention*** | TRL1 | Basic principles observed | Basic principles observed | Basic scientific research is translated into potential new basic principles that can be used in new technologies |
| | TRL2 | Technology concept formulated | Technology concept formulated | Potential application of the basic (technological) principles are identified, including their technological concept. Also the first manufacturing principles are explored, as well as possible markets identified. A small research team is established to facilitate assessment of technological feasibility. |
| ***Concept validation*** | TRL3 | Experimental proof of concept. | First assessment of feasibility of the concept and technologies | Based on preliminary study, now actual research is conducted to assess technical and market feasibility of the concept. This includes active R&D on a laboratory scale and first discussions with potential clients. The research team is further expanded and early market feasibility assessed. |
| | TRL4 | Technological validity in a lab | Validation of integrated prototype in a laboratory | Basic technological components are integrated to assess early feasibility by testing in a laboratory environment. Manufacturing is actively researched, identifying the main production principles. Lead markets are engaged to ensure connection with demand. Organisation is prepared to enter into scale up, possible services prepared and a full market analysis conducted. |
| ***Prototyping and incubation*** | TRL5 | Technology validated in relevant environment (industrially relevant environment in the case of KETs) | Testing of the prototype in a user environment | The system is tested in a user environment, connected to the broader technological infrastructure. Actual use is tested and validated. Manufacturing is prepared and tested in a laboratory environment and lead markets can test pre-production products. Fist activities within the organisation are established to further scale up to pilot production and marketing |
| ***Pilot production and demonstration*** | TRL6 | Technology demonstrated in relevant environment (industrially relevant environment in the case of KETs) | Pre-production of the product, including testing in a user environment | Product and manufacturing technologies are now fully integrated in a pilot line or pilot plant (low rate manufacturing). The interaction between the product and manufacturing technologies are assessed and fine-tuned, including additional R&D. Lead markets test the early products and manufacturing process and the organisation of production is made operational (including marketing, logistics, production and others). |
| | TRL7 | System prototype demonstration in an operational environment. | Low scale pilot production demonstrated | Manufacturing of the product is now fully operational at low rate, producing actual commercial products. Lead markets test these final products and organisational implementation is finalized (full marketing established, as well as all other production activities fully organized). The product is formally launched into first early adopter markets. |
| ***Initial market introduction*** | TRL8 | System completed and qualified | Manufacturing fully tested, validated and qualified | Manufacturing of the product, as well as the product final version is now fully established, as well as the organisation of production and marketing. Full launch of the product is now established in national and general early majority markets. |
| ***Market expansion*** | TRL9 | Actual system proven in operational environment (competitive manufacturing in the case of KETs; or in space) | Production and product fully operational and competitive | Full production is sustained, product expanded to larger markets and incremental changes in the product create new versions. Manufacturing and overall production is optimized by continuous incremental innovations to the process. Early majority markets are fully addressed. |