Technology Readiness Level (TRL)

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Kestävää kasvua ja työtä -ohjelma

TAMPEREEN TEKNILLINEN YLIOPISTO

Vipuvoimaa EU:lta 2014–2020

Euroopan unioni
Euroopan aluekehitysrahasto

Technology Readiness Levels (TRLs)

- Support
  - Assessment of the maturity of a particular technology
  - Comparison of maturity between different kinds of technology
- Origin
  - NASA space technology planning
  - Later adapted in multiple case studies by different organisations such as EU

Mankins, J.C. (1995), *Technology Readiness Levels*.

The most common uses of TRL include:

- Communication
- Set a target / Success criteria
- Project planning development
- Proposal development
- Technology selection
- Indicator for readiness of infusion
- Communicate/establish integration agreements
- Portfolio management
- Cost estimation
- Risk indicator

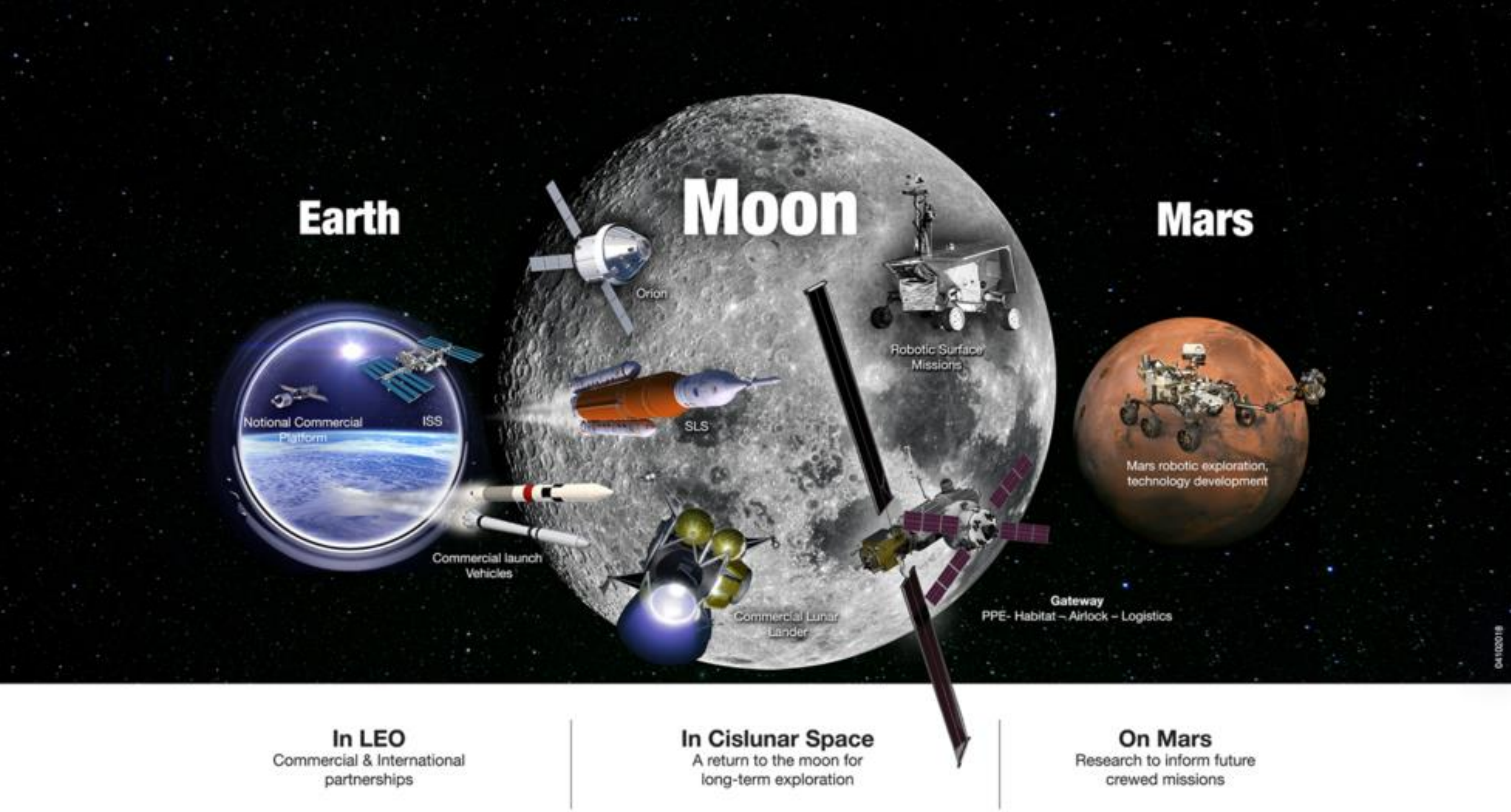
- Guide/measure for engineering development prior to a preliminary design review
- Development tracking
- Determining if the technology is ready for infusion into projects
- Evaluating proposals against the target/success criteria
- Assessing project risk based on technology maturity
- Project formulation
- Technology portfolio management

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005794.pdf

Technology Readiness Levels: EU / European Commission

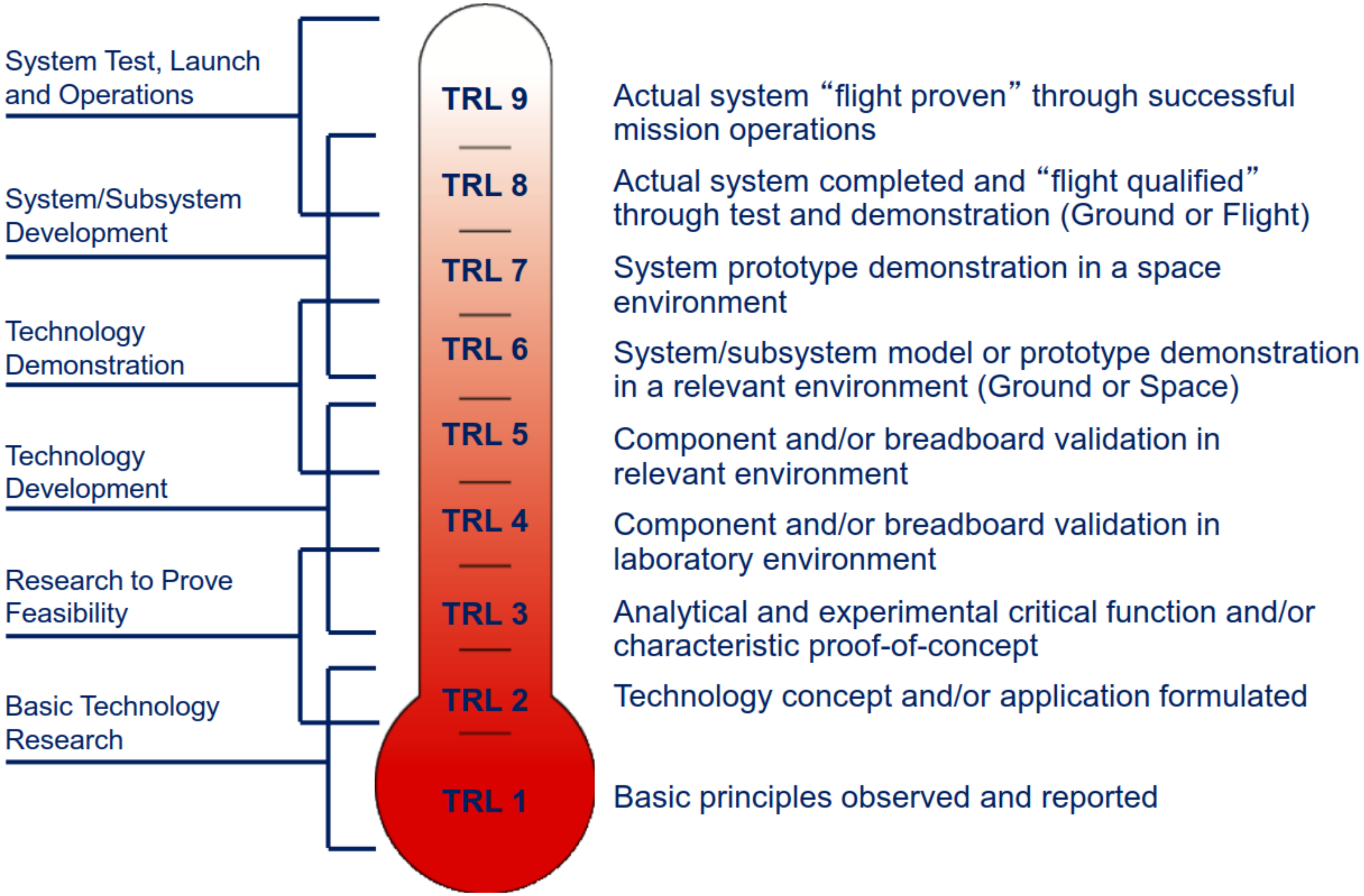
- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology 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)

http://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf



https://www.nasa.gov/feature/nasa-unveils-sustainable-campaign-to-return-to-moon-on-to-mars

Technology Readiness Levels: NASA



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Technology Readiness Assesment: NASA

1. Clarify all **terminology** used in the TRL descriptions
2. Formal gap analysis of **technology needs**
3. Formal assessment of the **TRL for each new technology**
4. Determine overall technology maturity using the ”**weakest link**” concept
5. Prepare a **list of critical technology elements**
6. What is **required to advance the technology** to the desired TRL including work breakdown structure (WBS)
7. Prepare a **roadmap for each technology development project** (cost, schedule, tactics and risk associated)
8. Assess projects

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Technology Readiness Assesment: ESA

1. Formal definition of the **terms** of reference for the assessment (including timing, how technology data will be provided to the process, and the detailed criteria for the TRA).
2. Identification of **key supporting data** (e.g., operating environment and expected system applications).
3. Identification of TRA **Participants** (including appropriate involvement of technologists and/or systems program participants).
4. **Development and delivery of technology data** to the TRA (often including preparatory meetings and/or studies by members of the technology community involved).
5. **Implementation of the TRA** itself (often involving meetings of a formal review committee).
6. Development of a **TRA report**.

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005794.pdf

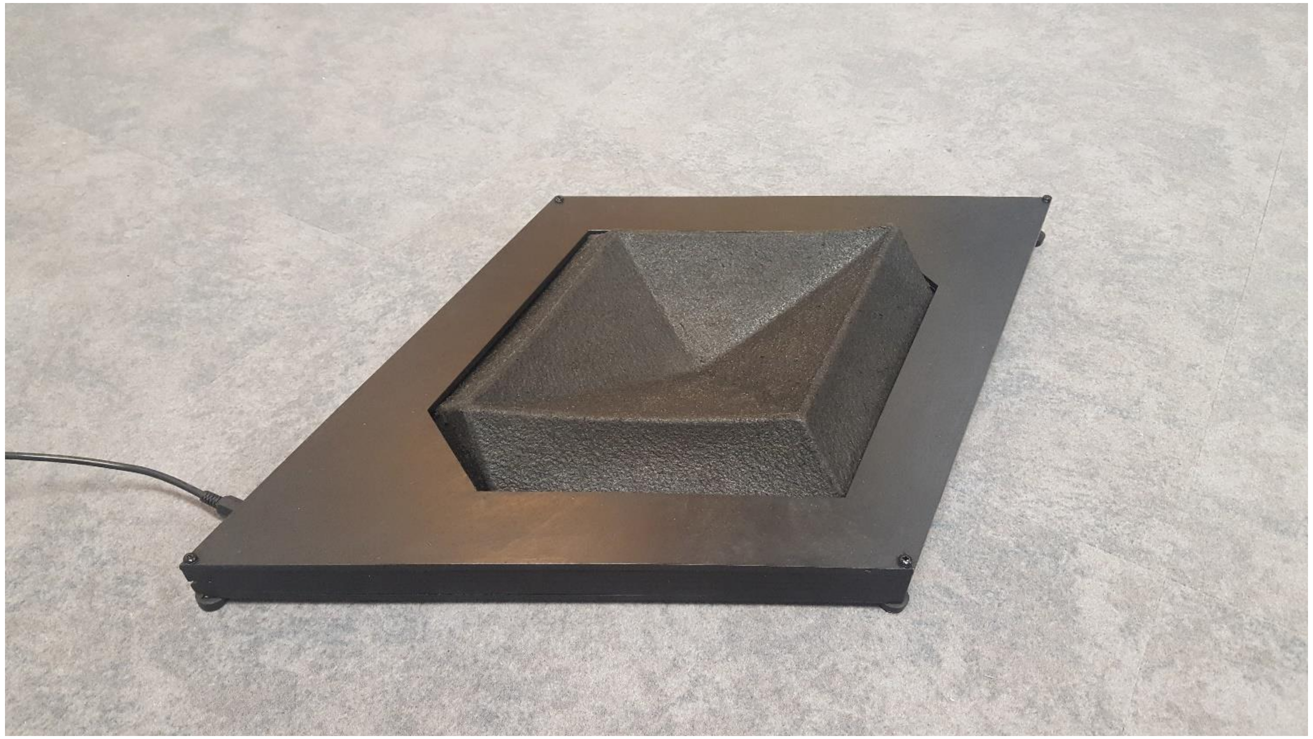
Technology Readiness Assesment: DoD

1. Establish **TRA plan** and **schedule**
2. Form subject matter expert (SME) **team**
3. Identify **technologies to be assessed**
4. Collect **evidence of maturity**
5. **Assess** technology maturity:
    a. SME team assessments
    b. Prepare, coordinate, and submit TRA report
    c. Assistant Secretary of Defense (Research & Evaluation) to review and evaluate

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005794.pdf

Case study: Salmiakki

- Possibilities to combine esthetics and functionality
- Main technologies
  - Nanocellulose (NCF)
  - Carbon nanotubes (CNT)



(Siljander et al. 2018)

Salmiakki - TRL level 6-7

	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
	Basic principles observed and reported.	**Technology concept and/or application formulated.**	**Analytical and experimental critical function and/or characteristic proof of concept.**	**Component and/or breadboard validation in laboratory environment.**	**Component and/or breadboard validation in relevant environment.**	**System/sub-system model or prototype demonstration in an operational environment.**	**System prototype demonstration in an operational environment.**	**Actual system completed and qualified through test and demonstration.**	**Actual system proven in operational environment**
Definition	Basic scientific research that can be turned into an application or a concept under a research and development program is considered.	An idea is proposed for the practical application of current research, but there are no experimental proofs or studies to support the idea.	Active research and development begins, including analytical laboratory-based studies to validate the initial idea, providing an initial "proof of concept."	Basic examples of the proposed technology are built and put together for testing to offer an initial vote of confidence for continued development.	More realistic versions of the proposed technology are tested in real-world or near real-world conditions, which includes initial integration at some level with other operational systems.	A near final version of the technology in which additional design changes are likely is tested in real-life conditions.	The final prototype of the technology that is as close to the operational version as possible at this stage is tested in real-life conditions.	The technology is thoroughly tested and no further major development of the technology is required. Its operation as intended is demonstrated without significant design problems.	The final operational version of the technology is thoroughly demonstrated through normal operations, with only minor problems needing to be fixed. Any further improvements to the technology at this point, whether planned or not, will be treated as a TRL 1.
Hardware Description	Scientific knowledge generated underpinning hardware technology concepts/applications.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform.	The final product is successfully operated in an actual mission.
Software Description	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.
Exit Criteria	Peer reviewed publication of research underlying the proposed concept/application.	Documented description of the application/concept that addresses feasibility and benefit.	Documented analytical/experi-mental results validating predictions of key parameters.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.	Documented test performance demonstrating agreement with analytical predictions.	Documented test performance demonstrating agreement with analytical predictions.	Documented test performance verifying analytical predictions.	Documented mission operational results.

Salmiakki TRL level 6-7

TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Analytical and experimental critical function and/or characteristic proof of concept.	**Component and/or breadboard validation in laboratory environment.**	**Component and/or breadboard validation in relevant environment.**	**System/sub-system model or prototype demonstration in an operational environment.**	**System prototype demonstration in an operational environment.**	**Actual system completed and qualified through test and demonstration.**	**Actual system proven in operational environment**
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Salmiakki TRL level 6-7

TRL 6	TRL 7
System/sub-system model or prototype demonstration in an operational environment.	**System prototype demonstration in an operational environment.**
A near final version of the technology in which additional design changes are likely is tested in real-life conditions.	The final prototype of the technology that is as close to the operational version as possible at this stage is tested in real-life conditions.
A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform.

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Salmiakki TRL level 6-7

- Salmiakki has been demonstrated as a system in an operating environment.
- Next technology level requires more detail design.
  - E.g. enclosure, power supply, final design / design options
- TRL 8 requires that no further engineering is required and the technology does not include any major design issues. Therefore, Salmiakki cannot be considered as TRL 8 technology at the moment.

Case study: automotive interior panel

- Similar to Salmiakki, possibilities to combine esthetics and functionality
- Main technologies
  - – Nanocellulose (NCF)
  - – Carbon nanotubes (CNT)
- NCF-CNT panels would not require Non-Woven Mat process stage

Figure: Traditional door panel

NFC-CNT automotive interior panel - TRL level 3-4

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NFC-CNT automotive interior panel - TRL level 3-4

	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7
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NFC-CNT automotive interior panel - TRL level 4

TRL 3	TRL 4
Analytical and experimental critical function and/or characteristic proof of concept.	**Component and/or breadboard validation in laboratory environment.**
Active research and development begins, including analytical laboratory-based studies to validate the initial idea, providing an initial "proof of concept."	Basic examples of the proposed technology are built and put together for testing to offer an initial vote of confidence for continued development.
Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.

NFC-CNT automotive interior panel - TRL level 3-4

- Analytical and experimental proof of concept (Salmiakki) exists.
- Validation and basic functionality of technology has been tested in laboratory and other environments, but not in the actual operating environment (car)
- Requirements and plans for test environment are required.
- TRL 5 requires that a set of panels, or a single panel, would be designed, produced and tested in a car or car-like environment in varying conditions.
- Also, this concept has more advanced requirements related to how the functionality (heating) should be controlled in order to adapt to climate.

Thank you! Kiitos!

Project's Principal investigators:

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Tomas Björkqvist, Matti Mäntysalo

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Jari Keskinen, Jarkko Pakkanen, Sanna Siljander,
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