TRANSITIONS LAB

TRANSITIONS LAB · READINESS FRAMEWORKS

Technology Readiness Levels

What TRL measures, where it came from, and why it is only one axis of a technology's real readiness.

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START HERE

How to use this resource

This resource explains Technology Readiness Levels (TRL), the nine-point scale used across research, funding, and procurement to describe how mature a technology is. It also explains TRL's single biggest limitation: it measures whether a technology works, not whether society is ready to adopt it.

What this is

A working reference, not a marketing brochure. Read it in order, or jump to the section you need using the contents opposite.

Who it is for

Innovators writing grant applications, funders assessing technical risk, and researchers who need a shared vocabulary for maturity. Also anyone who has seen TRL used and wants to understand what it does and does not capture.

How to get value from it

01 Learn the scale
Sections 1 and 2 give you TRL's origin and the nine levels, level by level. This is the shared language.

02 Understand its limits
Section 3 is the important part: what TRL leaves out, and why a high TRL can still mean a failed technology.

03 See the second axis
Section 4 introduces societal readiness, the axis TRL cannot see, and how the two read together.

04 Apply it honestly
Use TRL to locate technical maturity, then look to the societal axis for the questions that actually decide adoption.

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What is inside

READINESS FRAMEWORKS

A common language for technical maturity

Technology Readiness Levels give a nine-point scale for how mature a technology is, from a first observed principle to a system proven in operation. It is one of the most widely used tools in innovation, and one of the most widely misunderstood.

Before TRL, there was no shared vocabulary for describing how far a technology had actually progressed. A researcher's "nearly ready" and a programme manager's "nearly ready" could mean completely different things. TRL solved that by defining nine discrete, evidence-gated stages, each describing a specific combination of how faithful the prototype is and how realistic the environment it has been tested in.

1974
Sadin's first scale, at NASA

1995
Mankins codifies nine levels

9
levels, basic principle to proven

ORIGINS

From Apollo-era NASA to a global standard

The TRL concept originated at NASA in the 1970s, when engineers needed a common way to describe the maturity of candidate technologies for future missions. Stan Sadin at NASA Headquarters is credited with the first formulation in 1974, a seven-level scale (Sadin, Povinelli & Rosen, 1989). As systems grew more complex, the scale proved too coarse, and John Mankins expanded and codified the nine-level version in a 1995 NASA white paper (Mankins, 1995; 2009). It was later adopted across the US government, the Department of Defense and Energy, the European Space Agency, and the European Commission, becoming a near-universal shorthand for technical maturity.

KEY POINT

Why it spread so far

TRL gave funders, engineers, and procurement officers a single evidence-gated language for technical risk. A grant rubric, a defence procurement gate, and a deep-tech due-diligence check could all point to the same number and mean the same thing. That shared reference is TRL's real achievement.

The spread was not automatic. It happened because TRL solved a coordination problem that many institutions shared at once. A funder needed to compare proposals at different stages; a systems integrator needed to know which components were safe to build on; an investor needed to price technical risk. A single, evidence-gated scale let all of them speak the same language about maturity, even across very different sectors.

That same portability is why TRL eventually travelled far beyond its origins, from spacecraft to energy, health, defence, and software. And it is also why its one blind spot matters so much: a scale used this widely, to gate this much funding, carries its limitation everywhere it goes. The next pages set out the levels in full, and then turn to what the scale cannot see.

THE NINE LEVELS

The scale, level by level

The nine levels trace a technology from first principle to proven operation. Levels 1 to 3 are research; 4 to 6 are development and demonstration; 7 to 9 are deployment. The wording follows the NASA and ESA definitions.

TRL	Stage	What it means
1	Basic principles	Basic principles observed and reported; research begins to translate into applied R&D.;
2	Technology concept	Concept and application formulated; speculative, no experimental proof yet.
3	Proof of concept	Active R&D; begins; analytical and laboratory studies validate key predictions.
4	Validated in lab	Component or breadboard validated in a laboratory environment.
5	Validated in relevant env.	Component validated in a relevant, more realistic environment.
6	Demonstrated in relevant env.	System or prototype demonstrated in a relevant environment.
7	Demonstrated in operation	Prototype demonstrated in an operational environment.
8	System complete & qualified	Actual system completed and qualified through test and demonstration.
9	Proven in operation	Actual system proven in its operational environment through successful operations.

The intervening levels each describe a specific pairing of prototype fidelity and environment realism, which is what makes the scale precise rather than merely ordinal.

STRENGTHS AND LIMITS

A precise instrument, within its boundary

What TRL does well

Shared language. Very different people can agree where a technology stands.

Evidence-gated. Each level must be demonstrated, not asserted, disciplining optimism.

Risk management. It helps funders sequence investment and avoid deploying too early.

What TRL leaves out

Trust and acceptance. Whether people will actually use and believe in the technology.

Equity. Who is reached, and who is left out.

Institutions. Whether regulation, markets, and habits are ready to receive it.

TRL was designed to measure one thing: the maturity of a physical technology within defined engineering boundaries. A tension arises when it is used, as it often is, to judge whether a technology is ready for the real world. Those are not the same question. A technology can reach TRL 9, proven in its operational environment, and still fail on contact with society: rejected by users, blocked by regulation, mistrusted, or unaffordable. Scholars note that attempts to stretch TRL to cover these factors tend to treat readiness as a property of the system rather than a relational feature of the technology-society interaction (Webster & Gardner, 2019; Bruno et al., 2020).

KEY POINT

The core limitation, stated plainly

TRL measures whether a technology works in its intended environment. It does not measure whether society is ready to adopt, trust, govern, and benefit from it. A high TRL and a low societal readiness is one of the most common, and most expensive, blind spots in innovation.

SEEING BOTH AXES

Technical readiness is only half the picture

The clearest way to see TRL's boundary is to plot it against its social counterpart. A technology's true readiness is a position on two axes, not a single number. The vertical axis, societal readiness, is the one TRL cannot see.

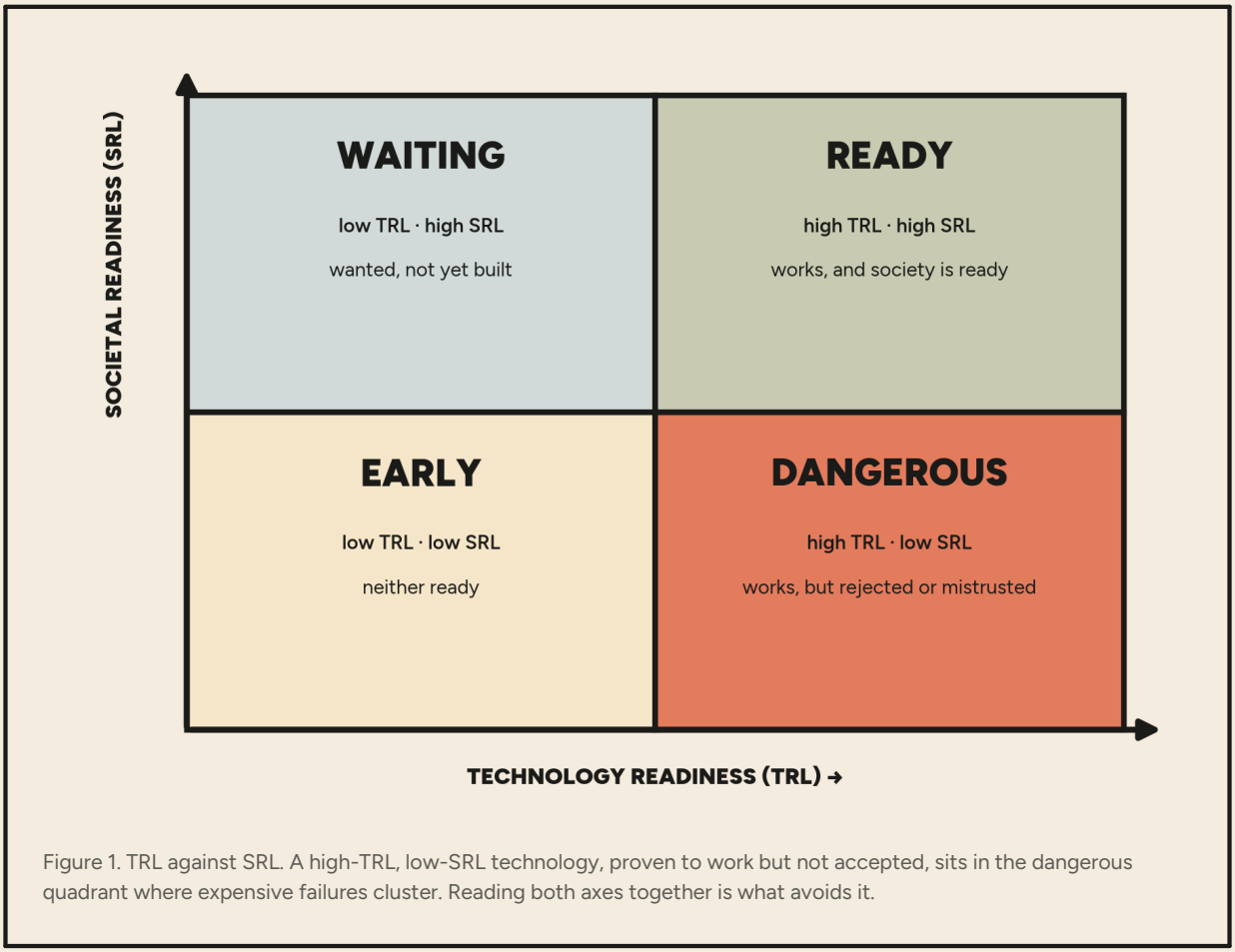

Figure 1. TRL against SRL. A high-TRL, low-SRL technology, proven to work but not accepted, sits in the dangerous quadrant where expensive failures cluster. Reading both axes together is what avoids it.

THE READINESS GAP

Why technical readiness runs ahead

Plotted over time, technical readiness typically races ahead of adoption. The gap between the two is not a delay to be waited out, it is a distinct problem to be measured and managed. That gap is exactly the territory societal readiness describes.

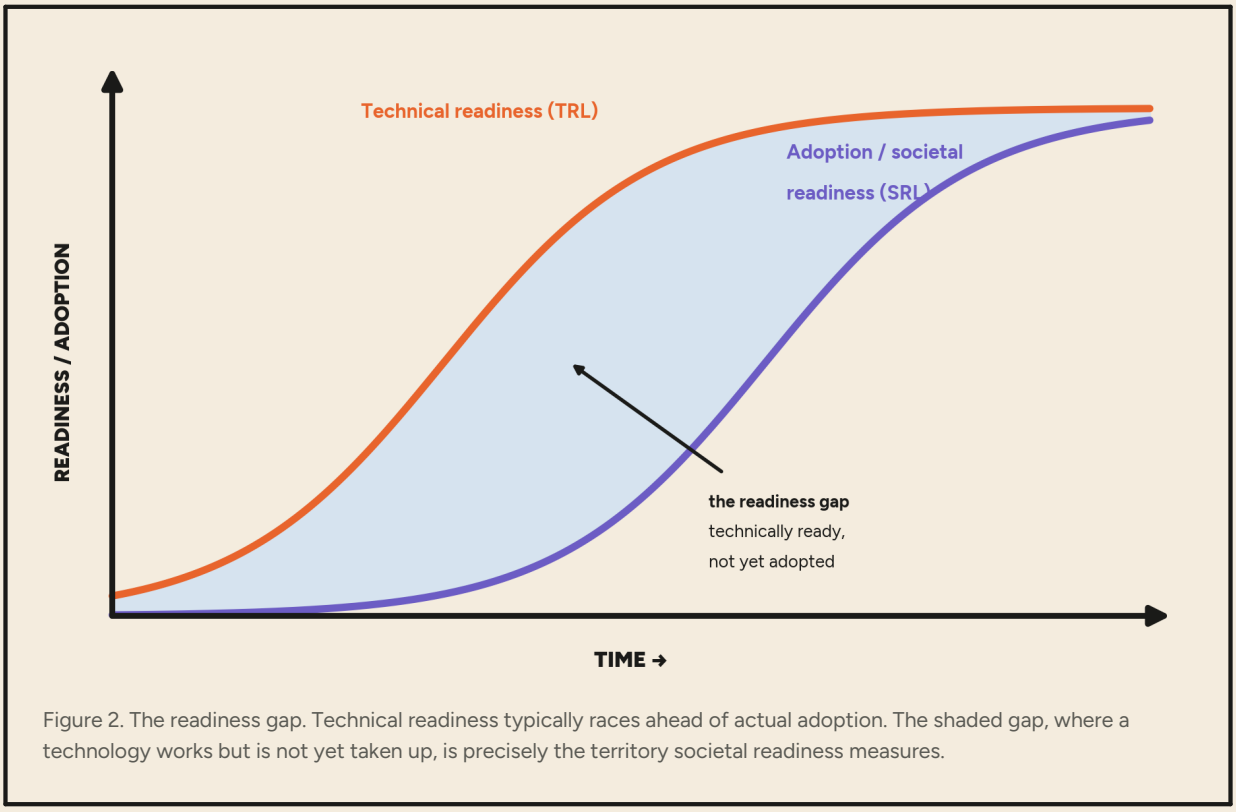

Figure 2. The readiness gap. Technical readiness typically races ahead of actual adoption. The shaded gap, where a technology works but is not yet taken up, is precisely the territory societal readiness measures.

THE MISSING AXIS

Why TRL needs a social counterpart

The recognition that technical maturity is necessary but not sufficient led directly to the development of Societal Readiness Levels (SRL), a parallel nine-point scale that measures how ready society is to adopt and benefit from an innovation. Where TRL asks "does the technology work?", SRL asks "is the technology wanted, trusted, and beneficial in its real social context?"

The two are complementary, not competing. A serious readiness assessment reads both axes together: a technology that is TRL 8 but SRL 3 is not, in any meaningful sense, ready. The Lab's companion guide, Societal Readiness Levels, sets out that second axis in full.

	TRL	SRL
Question	Does the technology work?	Is society ready to adopt it?
Starts from	The technology, from within	A societal need, from outside
Measures	Technical maturity	Social, ethical, legal readiness
Evidence	Lab and field testing	Stakeholder engagement
Blind spot	Trust, equity, acceptance	Technical feasibility

KEY POINT

How the Lab uses TRL

In the Lab's work, TRL is the technical axis and SRL the social one. We use TRL to locate where a technology sits in its engineering maturity, then focus our fieldwork on the societal axis TRL cannot see: who adopts, who is left out, and whether the technology is trusted and beneficial in context. Reading both axes together is the Lab's method.

WORKING WITH TRANSITIONS LAB

From explainer to assessment

This guide explains what TRL measures and where its boundary lies. Locating a real technology on both the technical and the societal axis is what an engagement adds.

IN THIS FREE RESOURCE	IN AN ENGAGEMENT, WE GO FURTHER
The nine levels and their origins, explained.	› A defensible TRL placement for your technology, evidenced rather than asserted.
The boundary of TRL, and why SRL is needed.	› A paired societal-readiness assessment, so both axes are read together.
The strengths and limits, in general.	› Fieldwork on who adopts, who is left out, and what would move the technology across the readiness gap.
The reference list, for further reading.	› A study designed to your decision, benchmarked against the Lab's cross-sector evidence.

The scale here is the vocabulary; an engagement is where a real technology is placed on it and read against society.

If a decision in your work turns on evidence of what a technology or programme actually does to real people, we are glad to talk it through, with no obligation. transitionslab.org

REFERENCES

Sources

TRL is exceptionally well documented, because it was built by public institutions that published their definitions openly. The core sources trace the scale from its NASA origin to its adoption across government, space, and defence, and the critical work that examines its limits.

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KEY POINT

Read alongside

TRL answers only half the readiness question. Its social counterpart, Societal Readiness Levels, is set out in the Lab's companion SRL guide, and the two are best read together: a technology's real readiness is a position on both axes, not a single number.