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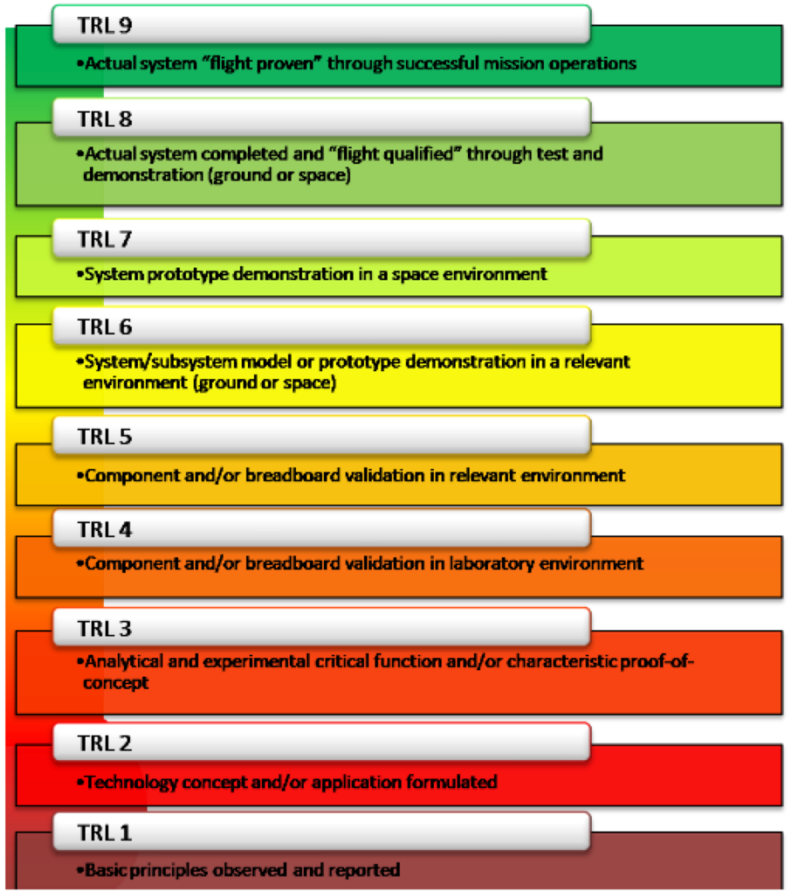
TECHNOLOGY READINESS LEVEL

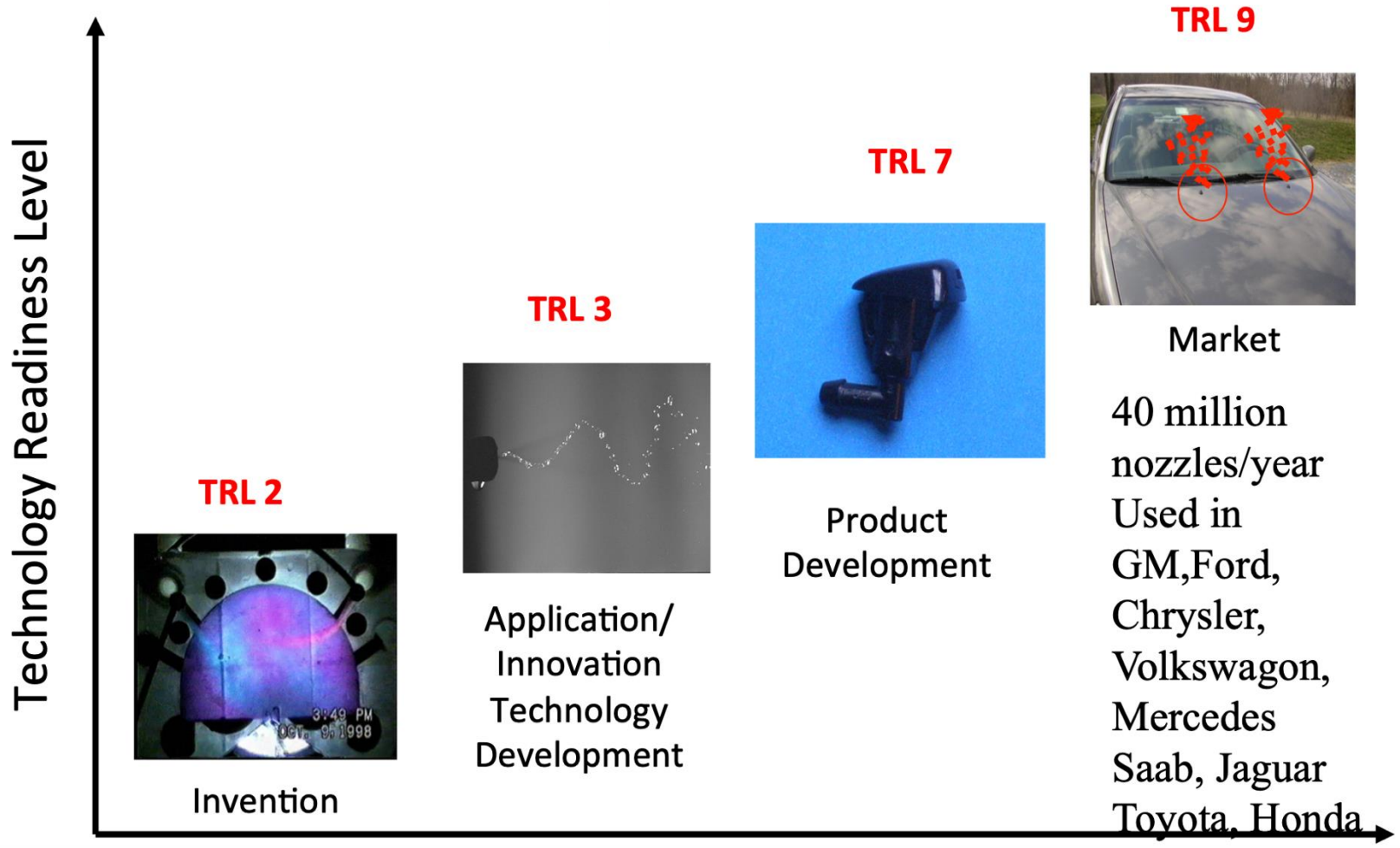
Hiran Vedam

ORIGINS

- **Developed by Stan Stadin from NASA in 1970s and formalized in 1989 and had 7 levels**
  - **.While useful, levels 6 & 7 were confusing and had a lot of scope for interpretation**
- 9 level TRL framework introduced in 1995



EXAMPLE: AUTOMOTIVE WINDSHIELD WASHER NOZZLE



Ref: WIPO EIE Project National Workshop, 2017

TRL IS SUBJECTIVE

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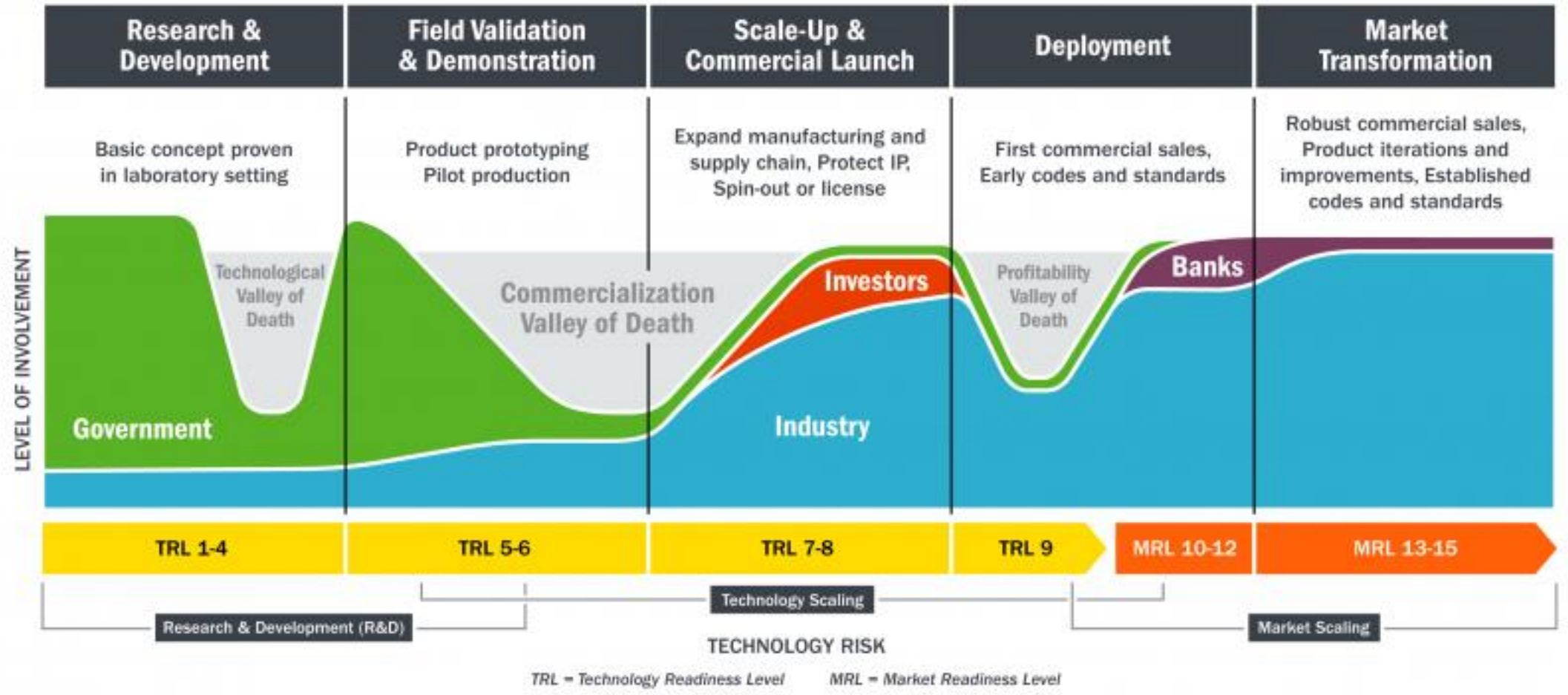
DEPARTMENT OF ENERGY TRL DEFINITION



BIRAC-TRL (EXAMPl

6. ***Artificial intelligence, Big Data Analysis, IoT's, software development & Bioinformatics***

Stage	Technology Readiness Level	Definition
Ideation	TRL-1	• Need identified, • Development of basic use, basic properties of software architecture, Mathematical formulations, and general algorithms.
Proof of Principle	TRL-2	• Research ideas developed • Technology concept or application formulated. • To carry out analytics studies and coding starts & comparing competing technologies
Proof of concept demonstrated	TRL-3	• Concept/Pre-alpha script is ready and working draft is created.
Proof of concept established	TRL-4	• Development of limited functionality environments to validate critical properties and analytical predictions using nonintegrated software components and partially representative data • Laboratory results showing validation of critical properties.
Early stage validation	TRL-5	• Developed Software technologies to integrate with different aspects of existing system • Developed Software technologies implementations conform to target environment/interfaces. Experiments with realistic problems • Rigorous alpha testing
	TRL-6	• Feasibility of the software technology is demonstrated on full-scale realistic problems • Technology validation in a relevant end to-End environment. • Rigorous Beta testing
Late stage Validation	TRL-7	• Rigorous testing & validation by third parties
Pre-commercialization	TRL-8	• ISO/IEC 9126 software quality as per the international standards • Data Privacy & Protection as per international standards (may be complied as per HIPAA Norms) • Launch of the software
Commercialization and post market studies	TRL-9	• Continuous improvement (New versions) as per user demand and feedbacks. • Continuous incorporation of new features as per user demand and feedbacks.

https://www.birac.nic.in/desc_new.php?id=443

TRL HAS LIMITED PREDICTIVE POWER

MANUFACTURING READINESS LEVELS

MRL	Definition
1	Manufacturing Feasibility Assessed
2	Manufacturing Concepts Defined
3	Manufacturing Concepts Developed
4	Capability to produce the technology in a laboratory environment.
5	Capability to produce prototype components in a production relevant environment.
6	Capability to produce a prototype system or subsystem in a production relevant environment.
7	Capability to produce systems, subsystems or components in a production representative environment.
8	Pilot line capability demonstrated. Ready to begin low rate production.
9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.
10	Full Rate Production demonstrated and lean production practices in place.

Source: https://www.dodmrl.com/DCMA_training_SEP_26_16.pdf

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MRL DEFINITIONS

- **Laboratory Environment (MRL 1-4)** – An environment where scientists, design engineers, manufacturing engineers, quality engineers, and production personnel develop and test processes, procedures, and equipment for making a product
- **Production Relevant (MRL 5 & 6)** – An environment with some shop floor production realism present (such as facilities, personnel, tooling, processes, materials etc)
- **Production Representative (MRL 7)** – An environment that has as much production realism as possible, considering the maturity of the design.
- **Pilot Line (MRL 8)** – An environment that incorporates all of the key production realism elements (equipment, personnel skill levels, facilities, materials, components, work instructions, processes, tooling, cleanliness, lighting etc
- **Production Line (MRL 9 & 10)**– An environment that incorporates all capabilities required to manufacture production configuration items, subsystems, or systems

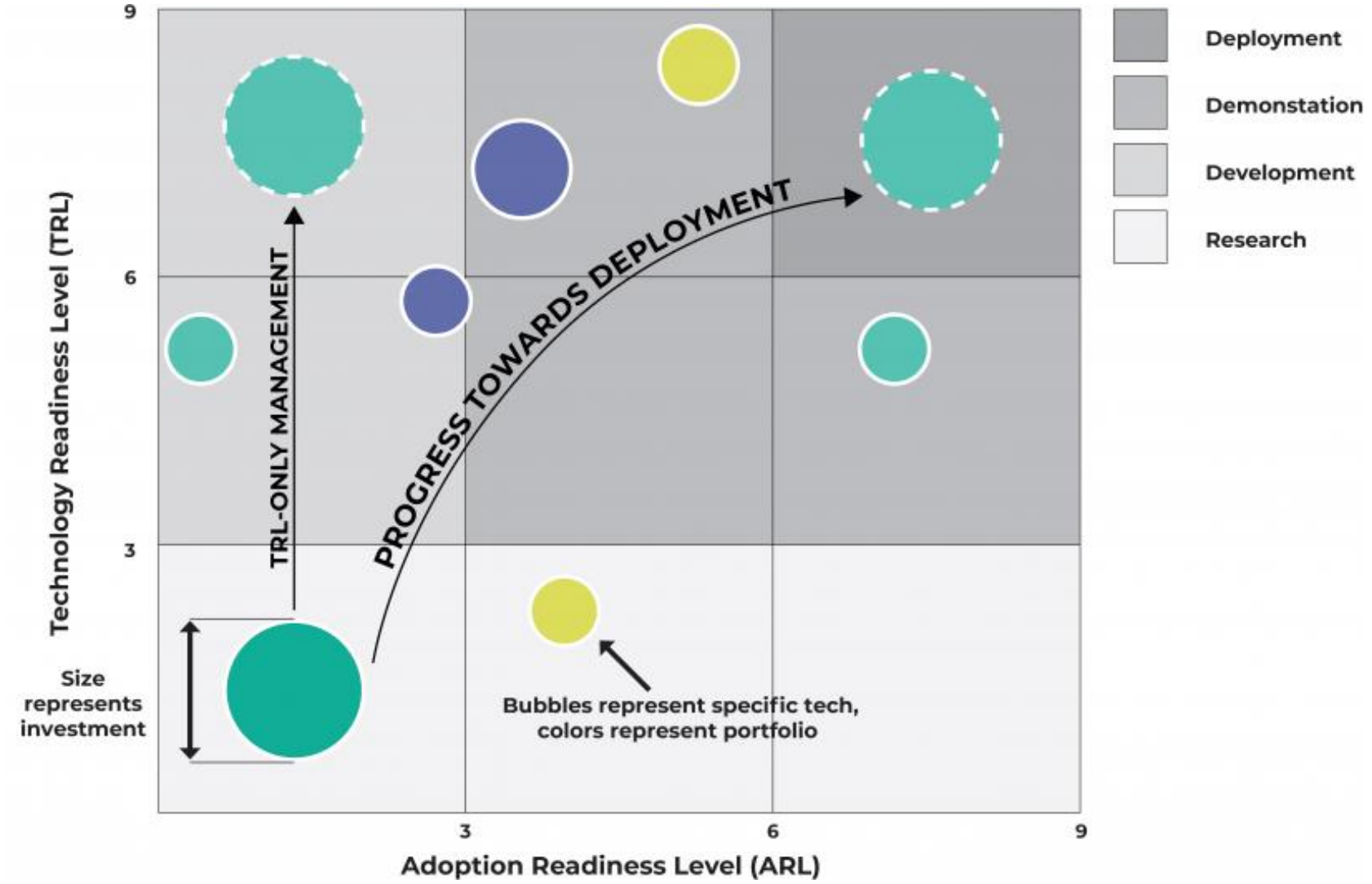
COMMERCIALI--SATION READINESS LEVELS (ARPA-E)

Commercialisation Readiness Level (CRL[33])	Requisite Conditions
CRL 1	Basic value proposition of technology identified and reported
CRL 2	Business concept formulated with potential applications
CRL 3	Business Plans validated with Proof-of-Business-Case
CRL 4	Minimum Viable Product Completed and Pilots initiated
CRL 5	Minimum Marketable Product and Operational Processes Validated
CRL 6	Minimum Marketable Product Deployed in the Market with Operating Revenue Targets
CRL 7	Matured Product Design and Marketing Strategy Validated
CRL 8	Matured Product Deployed in the Market with Targets Achieved
CRL 9	A Trusted Solution and a successful business model established

ADOPTION READINESS LEVEL (DOE)

- Value Proposition
  - Delivered Cost
  - Functional Performance
  - Ease of use/complexity
- Resource Maturity
  - Capital Flow
  - Project development, integration and management
  - Infrastructure
  - Manufacturing and supply chain
  - Material Sourcing
  - Workforce
- Market Acceptance
  - Demand maturity/Market Openness
  - Market size
  - Downstream value chain
- License to Operate
  - Regulatory Environment
  - Policy Environment
  - Permitting and siting
  - Environmental and safety
  - Community Perception

TRL AND ARL


9
6
3
Technology Readiness Level (TRL)
TRL-ONLY MANAGEMENT
PROGRESS TOWARDS DEPLOYMENT
Size represents investment
Bubbles represent specific tech, colors represent portfolio
3
6
9
Adoption Readiness Level (ARL)
Deployment
Demonstation
Development
Research

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WHY DO WE NEED SO MANY DIFFERENT SCALES?

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LAB TO MARKET JOURNEY

RISKS IDENTIFIED BY PARTICIPANTS

- Market volatility
- Feedstock security
- Customer priority changing
- Carbon financing volatility
- Robustness of technology give consistent results)
- Raw materials availability
- Customer acceptance (Adoption of product)
- Consumer awareness
- Lack of technical expertise (Zn, Mn extraction)
- Financial viability
- Cost of technology acquisition
- Market risk
- Inconsistent Supply
- Technology sourcing
- Talent
- Unintended consequences of the product
- Value (preventive vs. curative)
- Ability to work in real-life conditions
- Unit economics
- Import dependencies
- Raw material shortages
- Competition
- Adoption time of customers
- Cash flow and burn rate
- Customer acceptance
- Perception of value
- Ecosystem (precision manufacturing)
- Regulatory
- IP protection
- Support from suppliers
- Market maturity
- Policy framework
- Technology to solution transition

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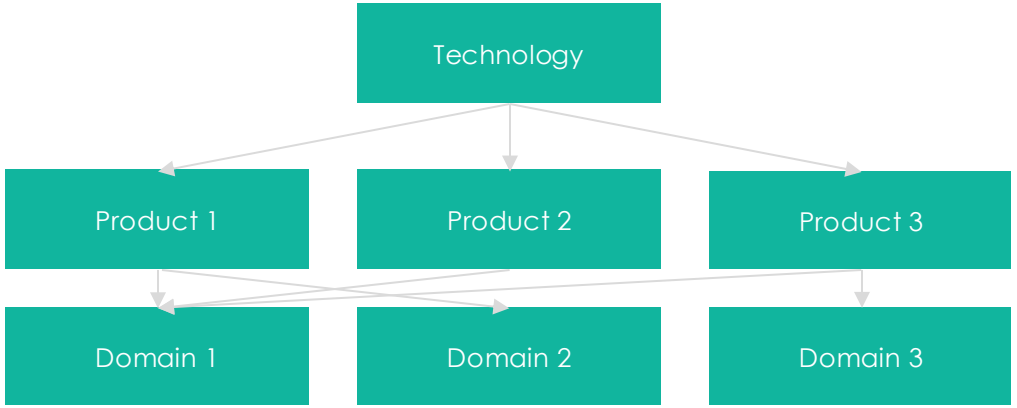
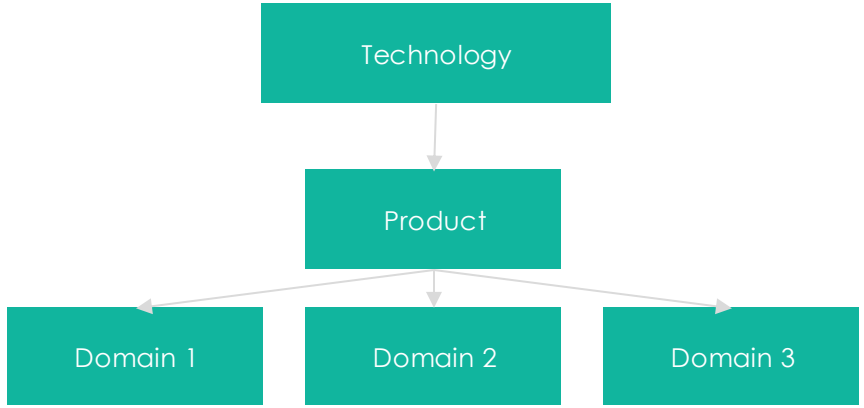
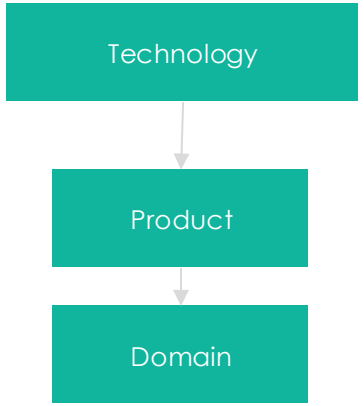
NOT ALL TECHNOLOGIES ARE THE SAME



Ex: Graphene , QD



Ex: Drones



Ex: Waste to Concrete

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NOT ALL TECHNOLOGIES ARE THE SAME

Technology Layer	Characteristics
Base Technologies	Fundamental 'Building Blocks' with applicability across multiple market spaces
Application Technologies	Aggregation of different base technologies
Platforms	Integration of different application technologies to enable new functionality
Applications & Tools	Functionality aimed at end users based on application technologies and platforms
Products	Integrated functionality for users based on base and application technologies, data, meta-data and applications & tools
Services	Integration of products and associated services, including on-boarding, usage and support

Source: Camels, Tigers & Unicorns: Re-Thinking Science And Technology-Enabled Innovation by Uday Phadke, Shailendra Vyakarnam

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NOT ALL TECHNOLOGIES ARE THE SAME

Product

Process

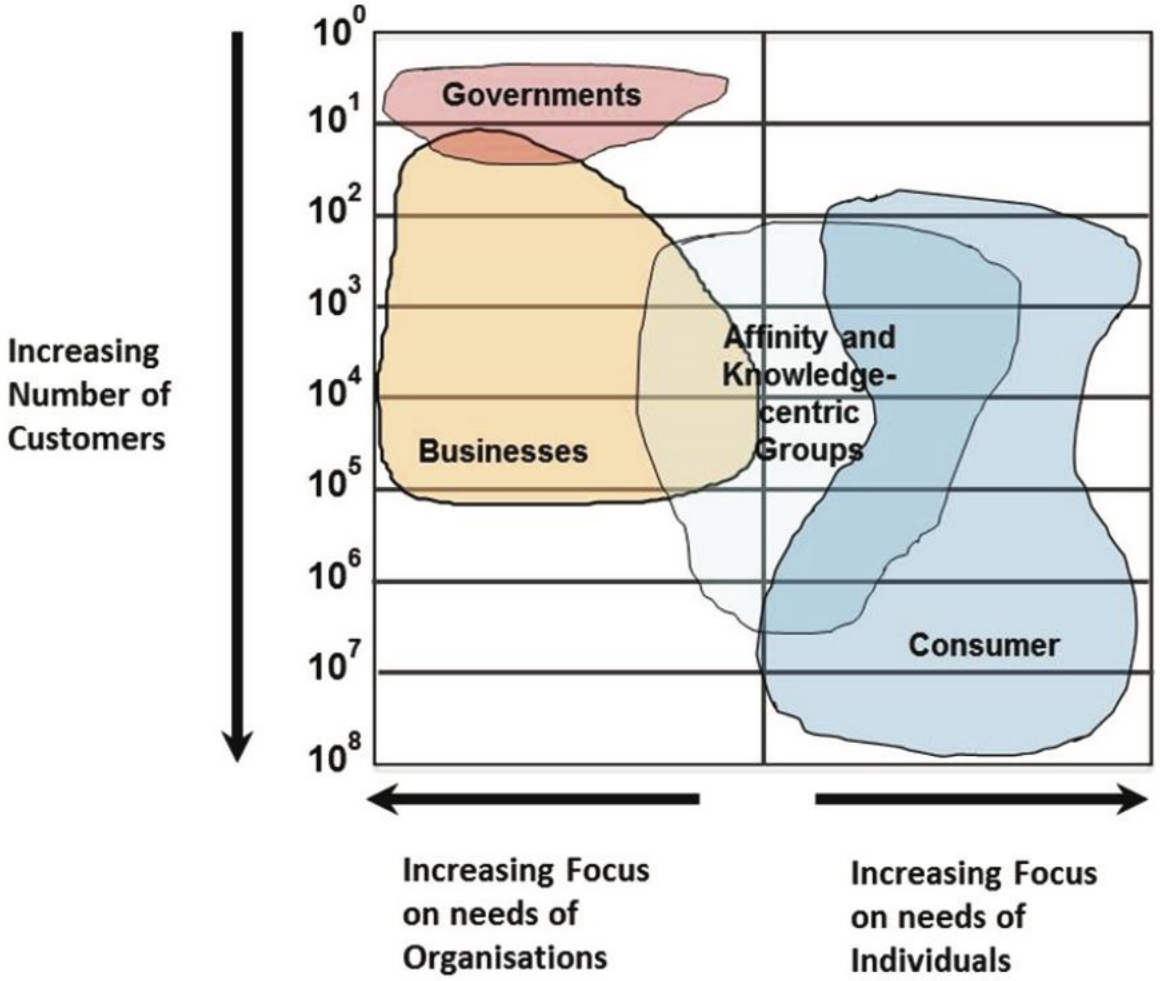
Hardware

System

Sub-System

Software

NOT ALL MARKETS ARE THE SAME



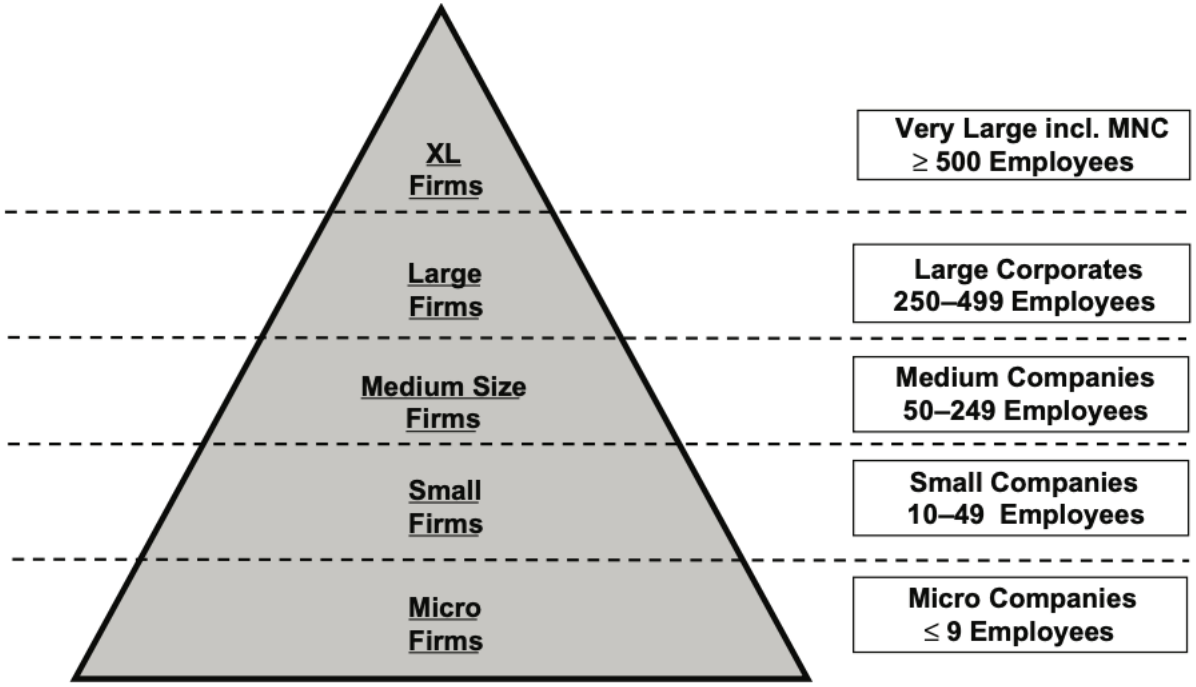
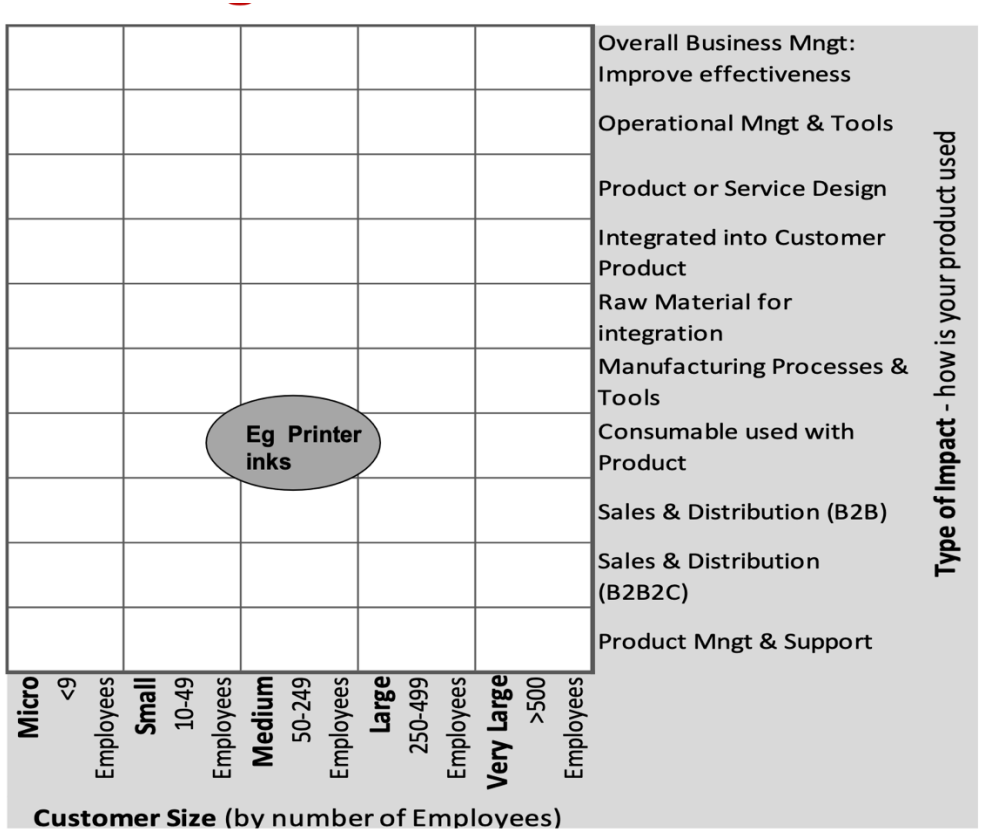


Figure 16: Business Segmentation by Size.

Source: Camels, Tigers & Unicorns: Re-Thinking Science And Technology-Enabled Innovation by Uday Phadke, Shailendra Vyakarnam

NOT ALL MARKETS ARE THE SAME



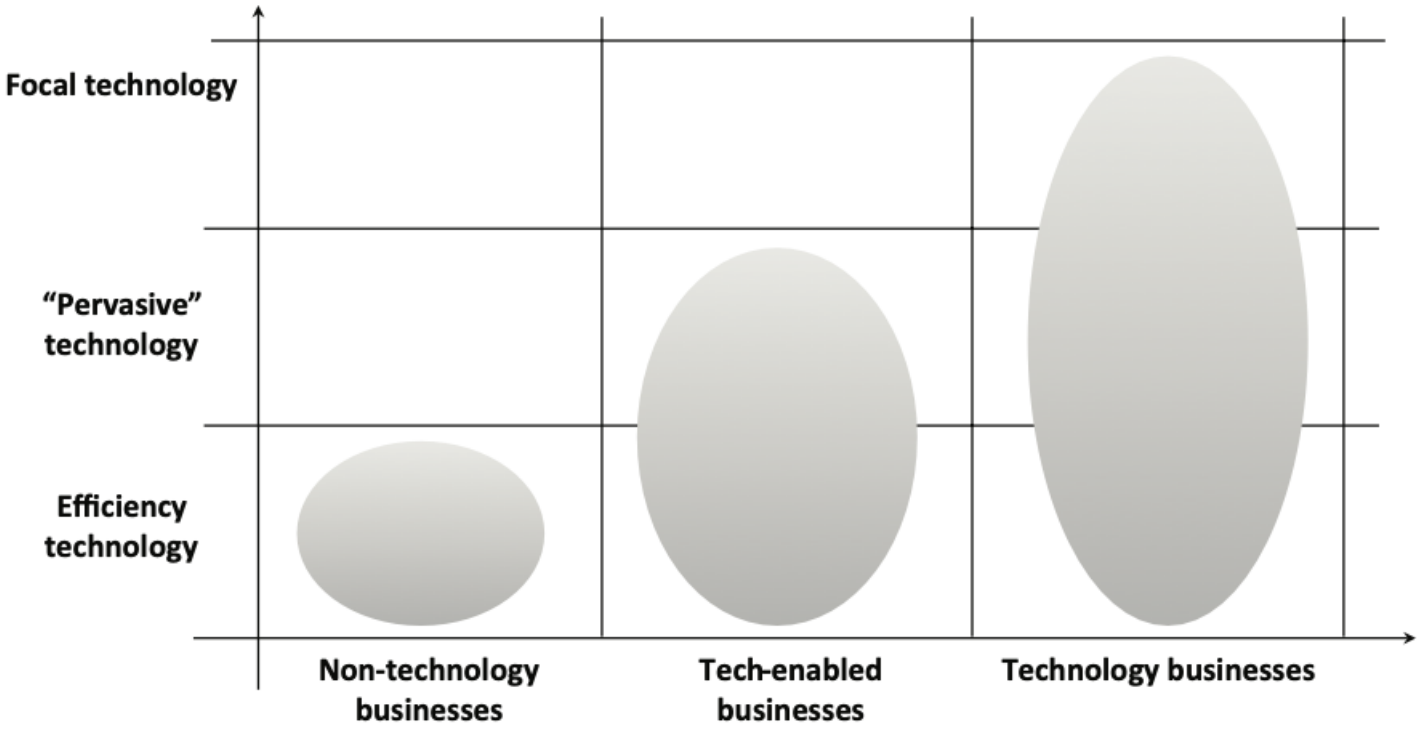


Figure 17: Usage of Technology by Businesses.

Source: Camels, Tigers & Unicorns: Re-Thinking Science And Technology-Enabled Innovation by Uday Phadke, Shailendra Vyakarnam

- **Understand the funding agency's assessment framework**
- **If you are using these scales internally:**
  - **Build specific, robust proof-points for each new technology being developed**
  - **Understand the environment where it should work**
  - **Be prepared for the resource intensity of estimating the TRL**
  - **Consult experts in your field to fully understand the risks and mitigation strategies**