Lecture-1:26.05.22

Systems Engineering & Project Management

(Course Code: OAN0710)

Prof. Amitava Mitra
(amitra@iitj.ac.in)
&
Dr. Mithu Rani Kuiti
mithu@iitj.ac.in)

Systems Engineering & Project Management

1. Technology Management
2. Systems Engineering
3. Project Management

Technology Management:

- *Process of Technology Development and Its Classifications as Technology Readiness Level (TRL) with Examples*
- *Technology Auditing for Identification of TRL.*
- *Guidelines for Basic Engineering Package (BEP) and Detailed Project Report (DPR) Preparation for Developed Technology*
- *Technology Road Mapping*

System Engineering:

- *Introduction to systems Engineering (SE)*
- *Challenges and Motivation*
- *Systems Engineering Landscape*
- *SE Approaches, Law of Diminishing Return,*
- *Various Models for Systems Engineering Life Cycle*
- *Cost-Schedule- performance-risk across the systems Engineering lifecycle*
- *Systems Engineering Standards*

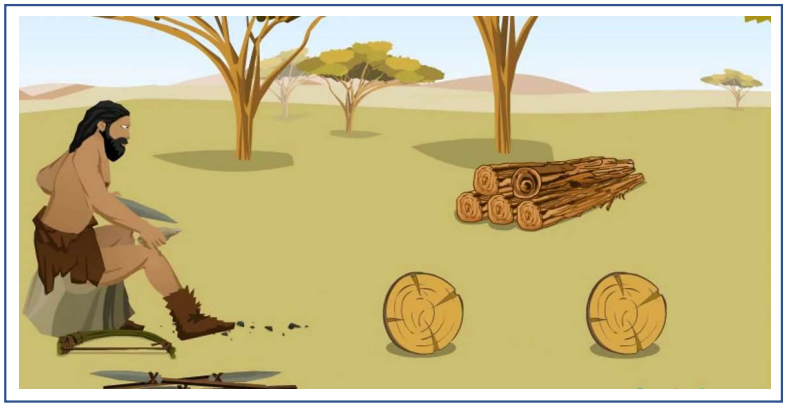
Technology Management

- ❑ Invention
- ❑ Innovation
- ❑ Process of Technology Development
- ❑ Technology Readiness Level
- ❑ Detailed Project Report (DPR)

Technological Invention:

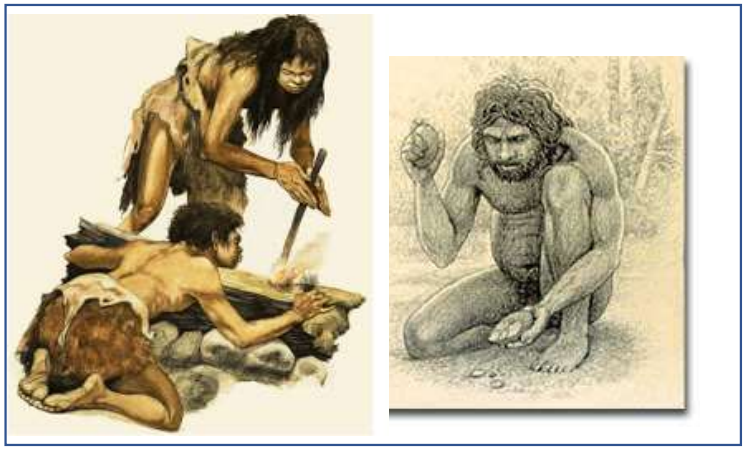
Pointy pieces of stone or bone fixed to the end of a long stick to be used by humans to hunt or fight

Invention:



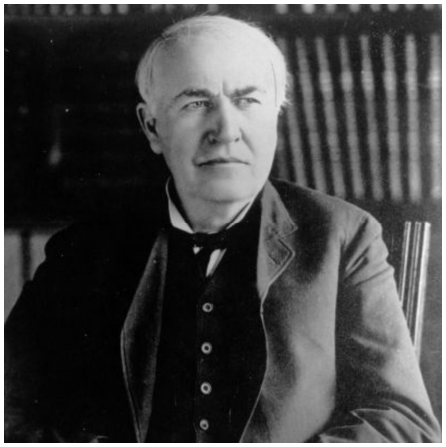
The wheel is possibly the greatest mechanical invention in humanity's history.

Invention:

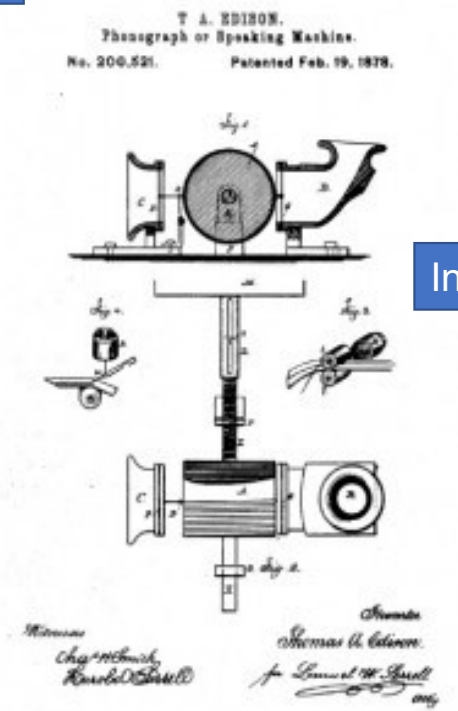


The control of fire by early humans was a turning point in the technological evaluation of human beings

- **Invention** is the creation of a product or introduction of a process for the first time.
- **Invention** is something "new, novel and without precedent"



Thomas Edison is the greatest Inventor for all time



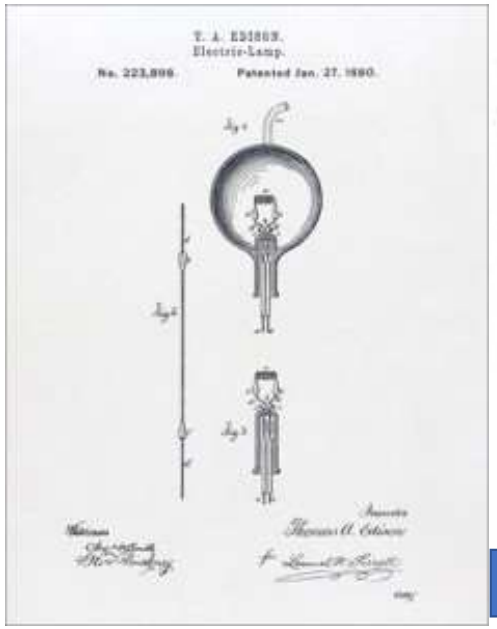
Phonograph: First voice recorder and play it back

Innovation

Gramophone

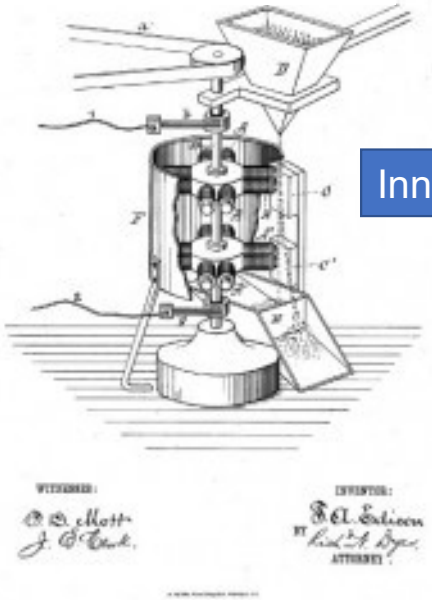
Innovation

Record Player



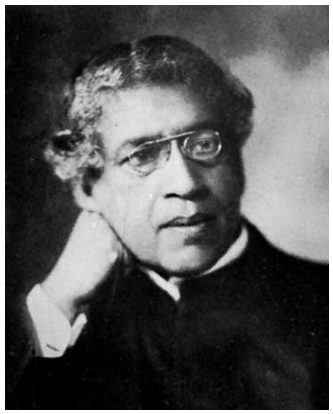
Innovation

Incandescent light bulb: Right filament placed in vacuum bulb

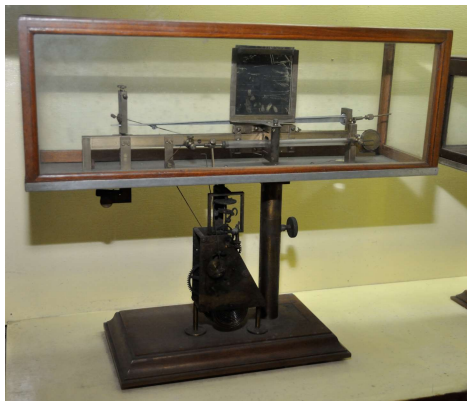


Innovation

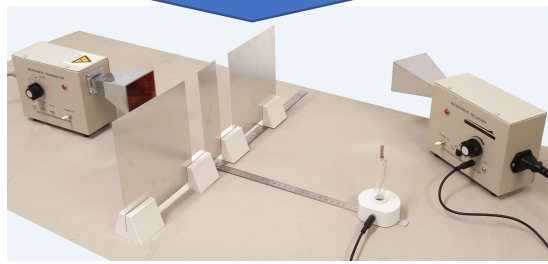
Magnetic Iron ore separator: Enrich Iron Ore from low grade ores



Sir JC Bose (1858-1937)



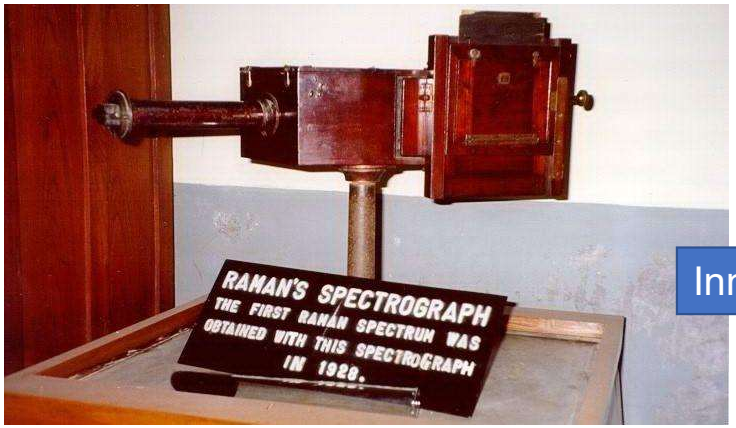
Crescograph for detection of plant growth rate



Innovation

60 GHz microwave apparatus receiver *(left)* used a galena crystal detector inside a horn antenna and galvanometer to detect microwaves.

Sir CV Raman(1930-70)



Raman Spectrometer

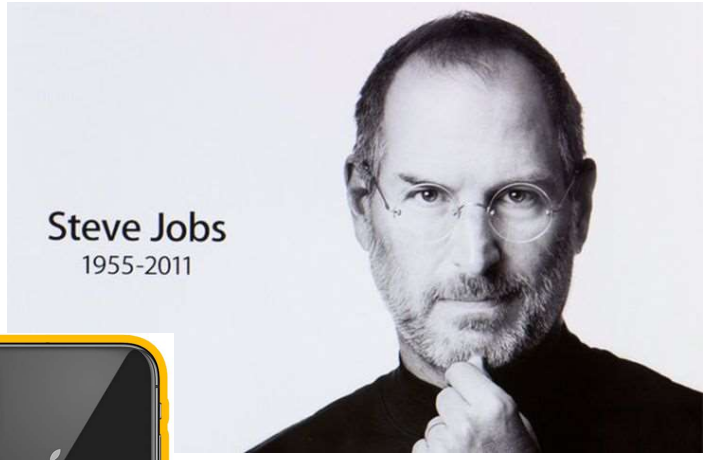
Innovation

Laser Raman

- Innovation happen when someone improves on or makes significant contribution to something that has already been invented
- Innovation is defined as “change that adds value”

- **Invention** is the creation of a product or introduction of a process for the first time.
- **Invention** is something “new, novel and without precedent”

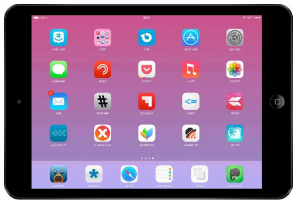
Greatest innovator in modern era : Steven Paul **Jobs**



iPod in 2001

MacBook in 2006

iPhone in 2007

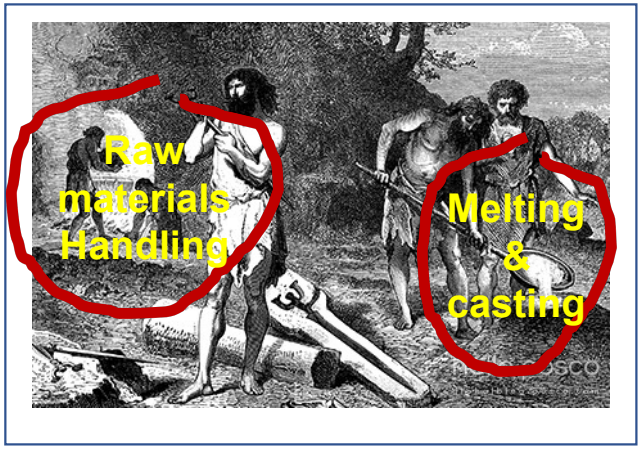


iPad in 2010

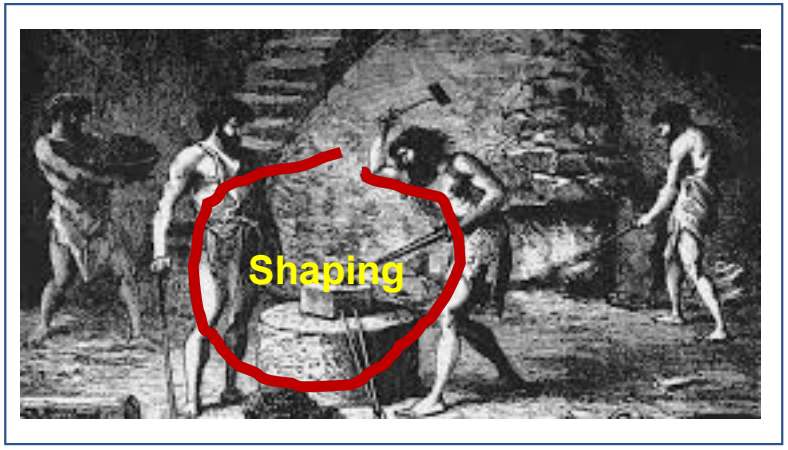
Technology Management

- ❑ Invention
- ❑ Innovation
- ❑ Process of Technology Development
- ❑ Technology Readiness Level (TRL)
- ❑ Basic Engineering Package (BEP) & Detailed Project Report (DPR)

Invention:
Smelting, Preparation of Liquid Metal & Casting



Invention:
Forging & Shaping of Cast Metal



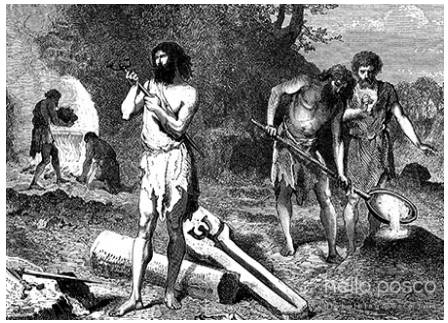
Alloy Addition

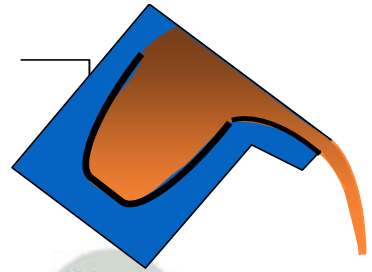
Smelting & Ingot casting

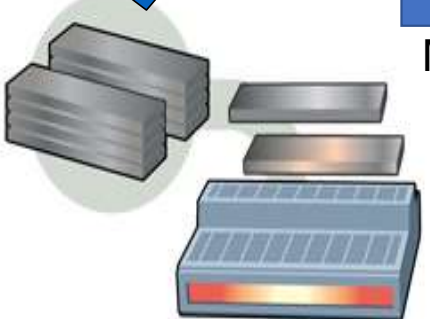
Raw Materials Handling

Invention:

Smelting, Preparation of Liquid Metal & Casting



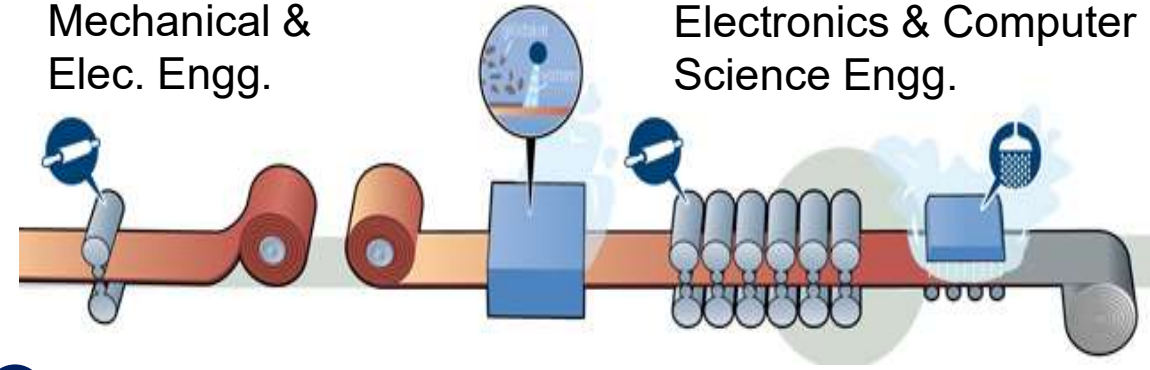




Melting & Casting	Alloy Addition	Smelting & Ingot casting	Raw Materials Handling
Metallurgist	Metallurgist	Metallurgist	Mining Engineer

Mechanical & Elec. Engg.

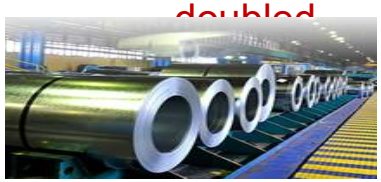
Electronics & Computer Science Engg.



Invention:

Forging & Shaping of Cast Metal

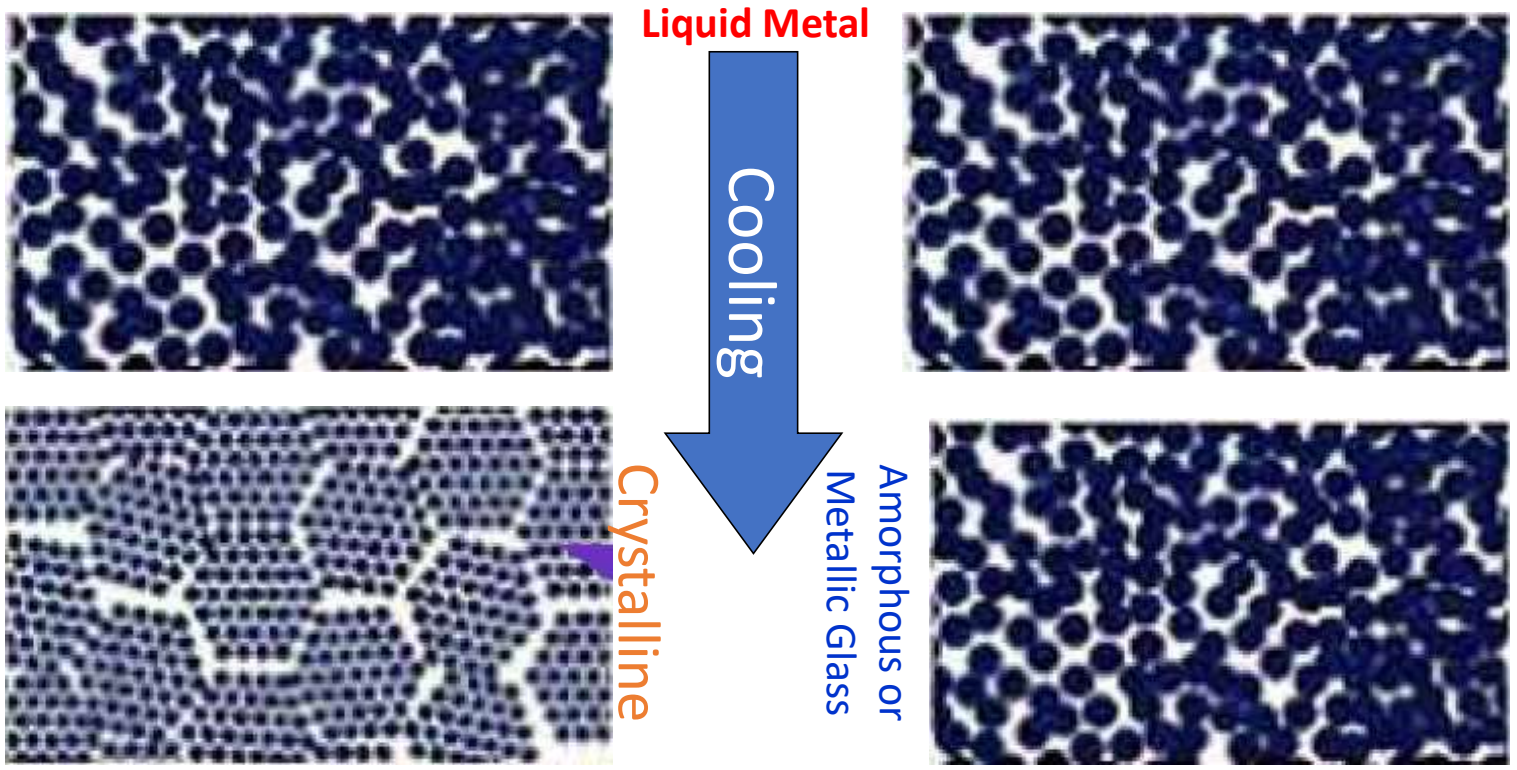
1. The slab are heated in furnaces to the correct rolling temperature of about 1200-1250°C
2. Slab thickness 220mm reduced to 30-12mm (Special care should be taken to reduce the thickness as some steels susceptible to breaking & cracking)
3. The plate is cleaned to remove millscales
4. Two/three/four sections of hot strip materials are matched together, hot rolled, doubled
5. Heated in a continuous pack furnace 800-1000°C
6. Rolled to final thickness (6-3mm) in 3-5 passes & finished at about 750°C/850°C



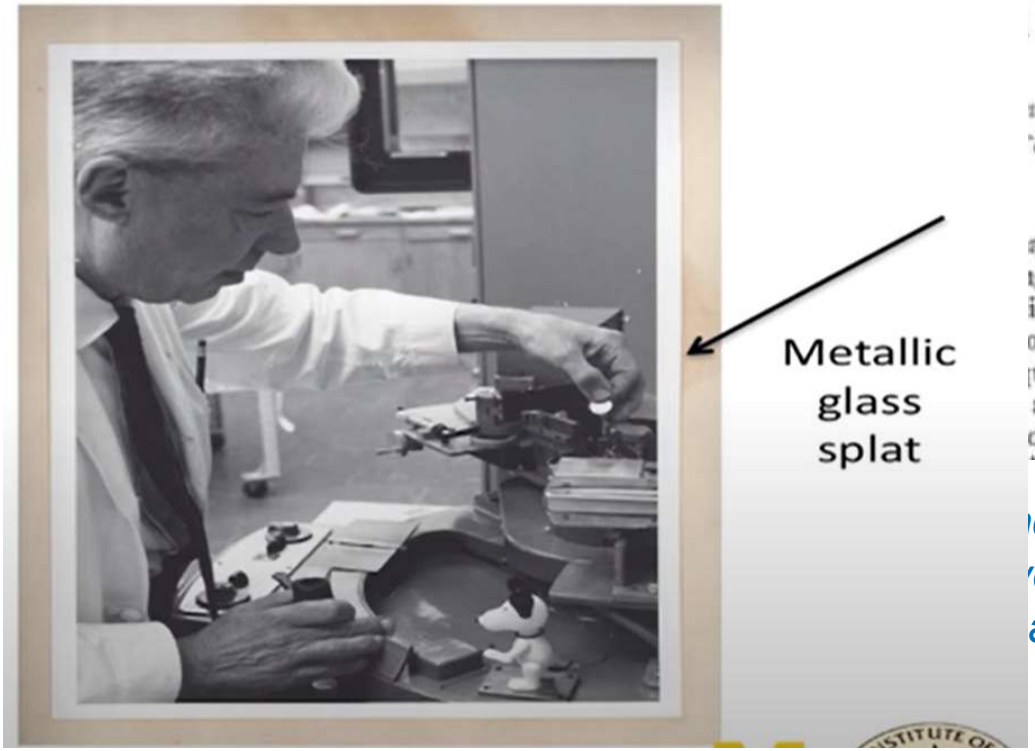
Technology Readiness Level (TRL)

	TRL Scale	Description
Invention	TRL 1	Basic Principles Observed
	TRL 2	Technology Concept Formulated
Concept Validation	TRL 3	Experimental Proof of Concept
	TRL 4	Technology Validity in a Lab
Prototyping & incubation	TRL 5	Technology validate in relevant environment
Pilot Production & Demonstration	TRL 6	Technology demonstrated in relevant environment
	TRL 7	System prototype demonstration in an operational environment
Initial Market Introduction	TRL 8	System completed and qualified
Market Expansion	TRL 9	Actual system proven in operational environment

Ideation


Liquid Metal
Cooling
Crystalline
Amorphous or
Metallic Glass
Cooling
rate 10^6k/s

Pol Duwez – 1960's



g 1136 (1960)

Solutions

all amounts of
igh to prevent
ibrium phases.
ooling consists
uid quenching
a study of the
olid solutions.[1]

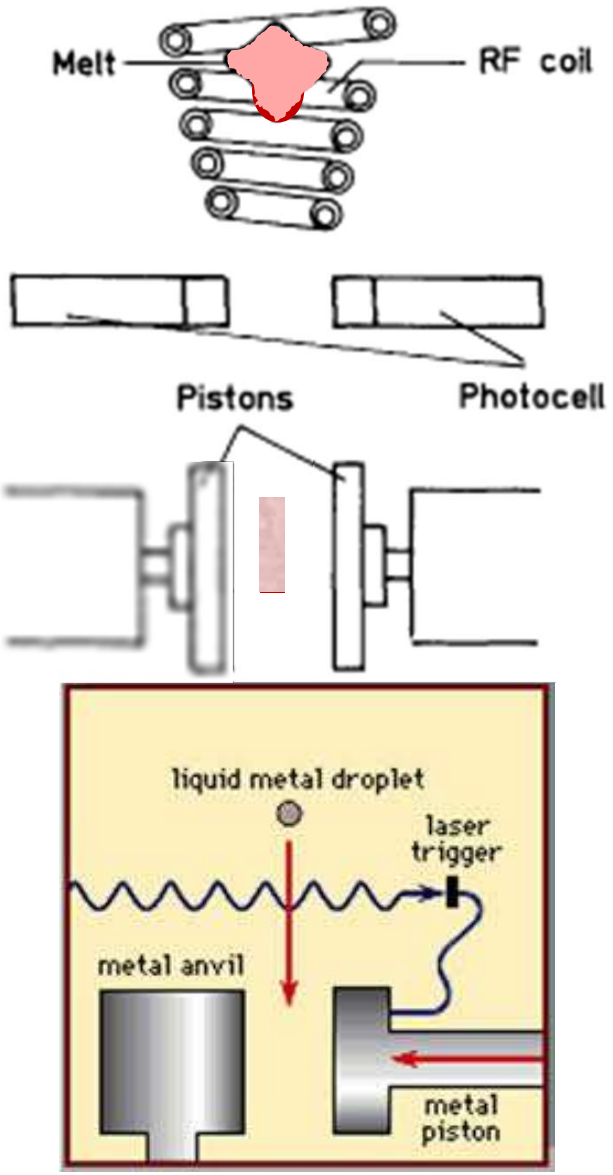
ount of liquid
ent the normal
ases".

- **The first metallic glass phase in $Au_{75}Si_{25}$**

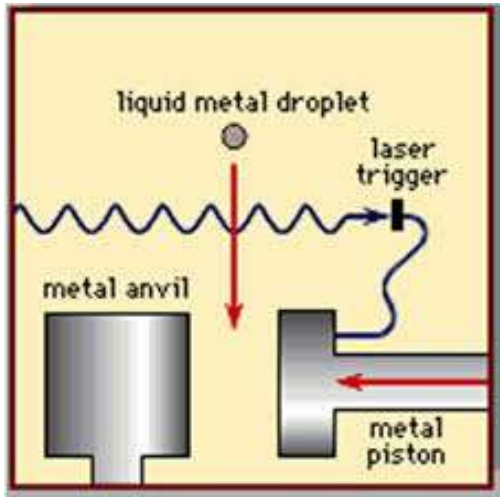
(Basic Research for understanding the material properties)

- Early '70s : It has been established that Fe (Ni, Co) based rapidly solidified materials show Functional (Magnetic) properties and Commercial importance (Technology Readiness Level-1)

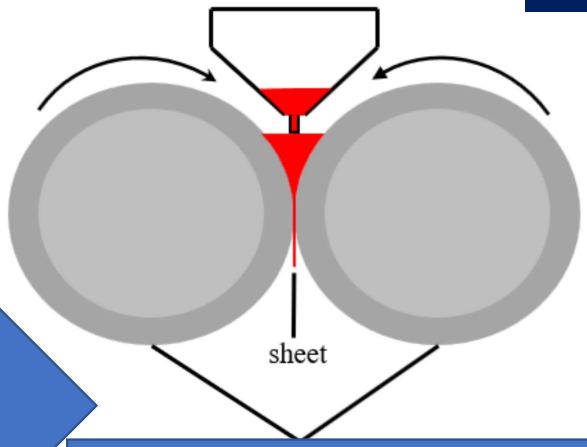
Invention of Rapid Solidification Technique



TRL-2: Technology Concept Formulated



Innovation in cooling system



Internally water cooled roll shells

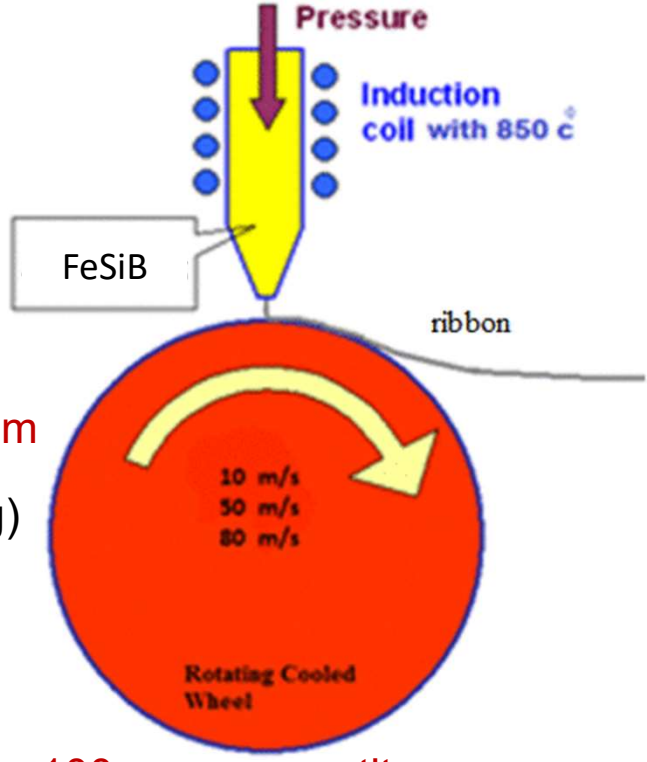
Double roller System

(Splat Quenching)

Invention in cooling system

Single roller System

(Melt Spinning)

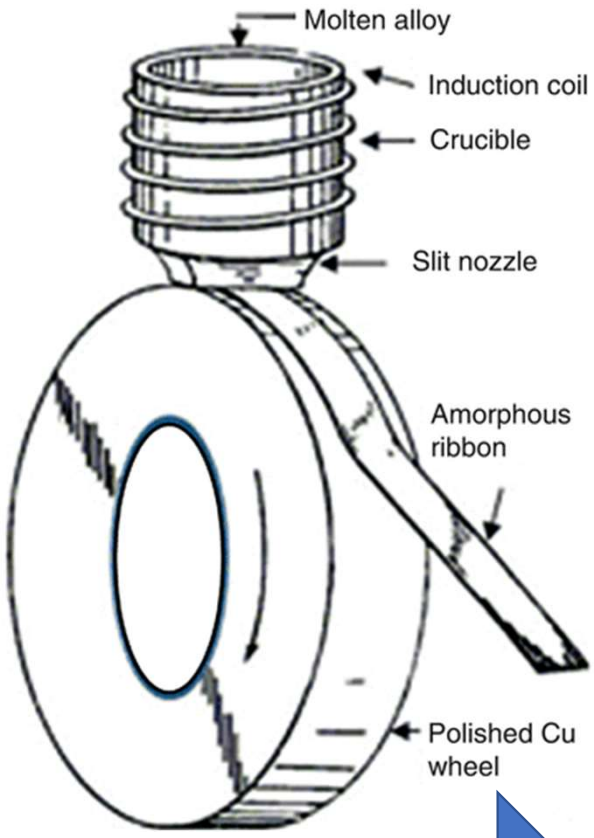


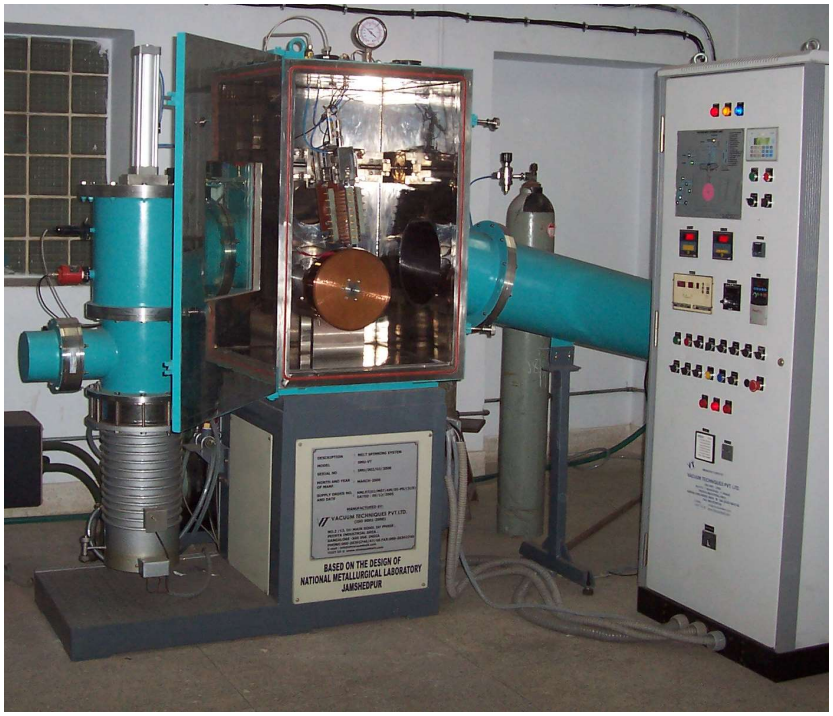
Early'80s: Advantage- Better stability & property, From grams amount to few 100s gram quantity (Technology Readiness Level (TRL)- 2)

TRL-1&2: Transition of basic research to possible applications, ideation, technology foresight

TRL-3: Experimental Proof of Concept

TRL-4: Technology Validity in a Lab





Melt Spinning → Innovation in nozzle → Planar Flow Casting (gram scale to kilogram scale production)

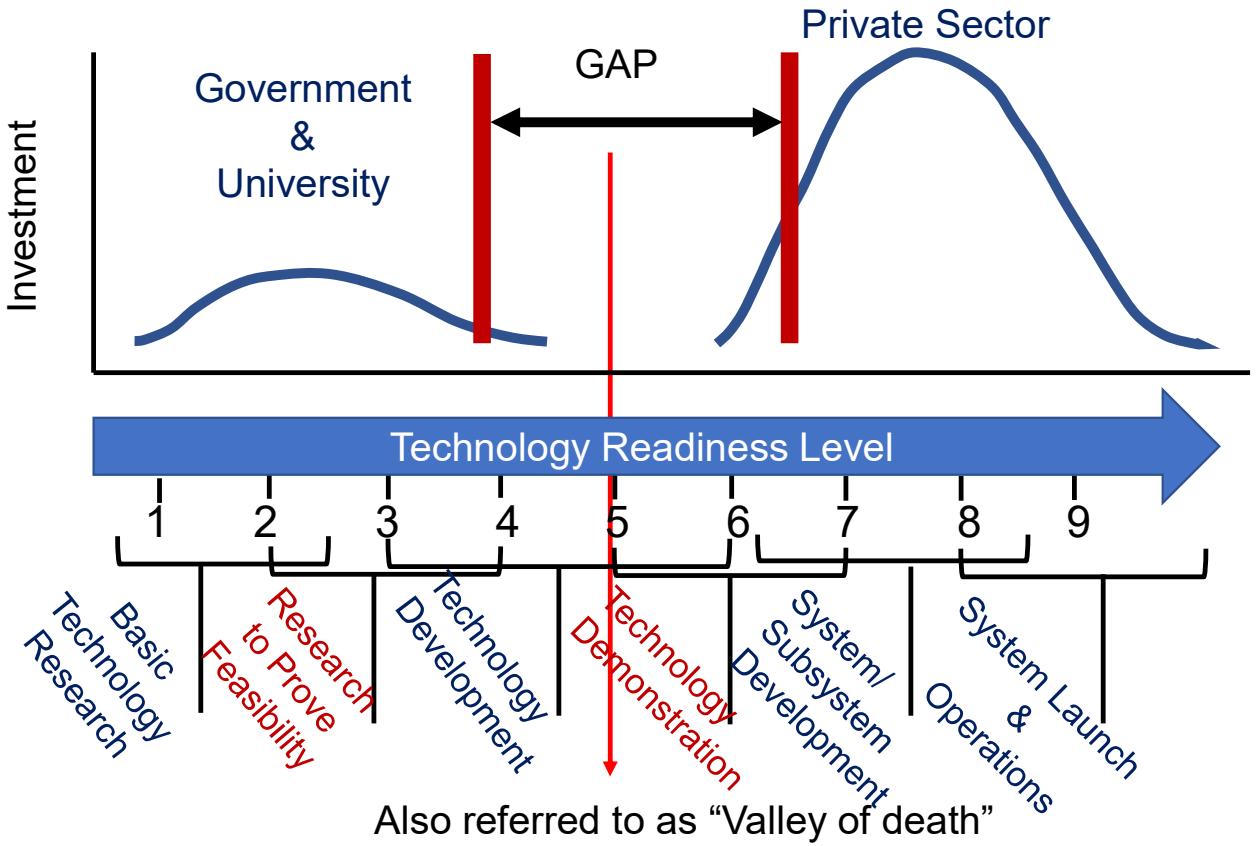
(Technology Readiness Level (TRL)- 3&4)

TRL-3&4: Early technological and applied product and process research. Preparation system integration. Early market assessment.

Technology Readiness Level (TRL)

	TRL Scale	Description
Invention	TRL 1	Transition of basic research to possible applications, ideation, technology foresight
	TRL 2	
Concept Validation	TRL 3	Early technological and applied product and process research. Preparation system integration. Early market assessment. Consortium building
	TRL 4	
Prototyping & incubation	TRL 5	Preparation of business plan. Prototyping facilities. Prototype system integration. Service development
Pilot Production & Demonstration	TRL 6	Shared pilot production facilities. Contract research on product, manufacturing. Business assessment
	TRL 7	
Initial Market Introduction	TRL 8	Contract research on product/process enhancements
Market Expansion	TRL 9	Contract research on incremental product/process /service innovations

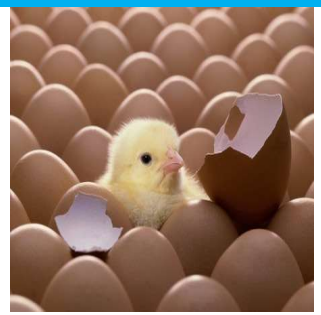
Gap in Manufacturing Innovation



Source: AMP Steering Committee

- ❑ Technology Push-Pull
- ❑ Innovation Centre

Technology Incubation/ Innovation Centre



- **H**elp in technology transfer
- Promotes awareness about technology incubation and new business through commercialization of R & D products and processes.
- **Assist** scientists, faculties, students and engineers (technopreneurs) in pursuing technology, innovation and entrepreneurship objectives
- **A**ssistance to incubates by way of specialized services, viz, patenting, facilitating funding (angel/venture) , helping towards marketing of products & processes, etc.
- **H**elp to create value added newer jobs and services
- Assist in contributing to the local economy (Small & Medium Entrepreneurs")

Services

Advisory Services

- Business Planning, Technology Sourcing & Fund-raising
- Market Research services
- Intellectual Property & Licensing
- Technology Business Analytics services

Scientific Support

- Dedicated lab space
- Scientific and Technical services
- Support from R&D expertise

Business Support

- Address Service
- Techinolgy / business mentoring
- Dedicated, full service office space

Website development and maintenance

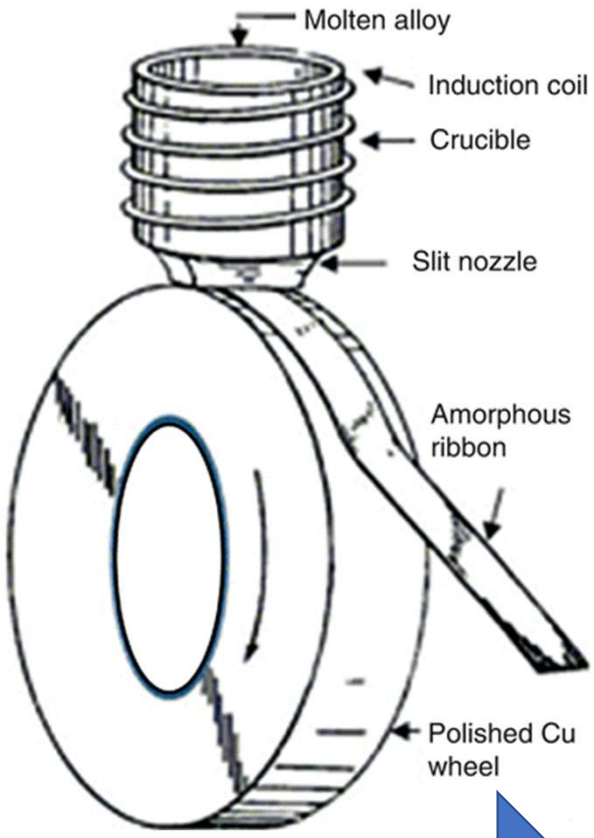
Networking & Events

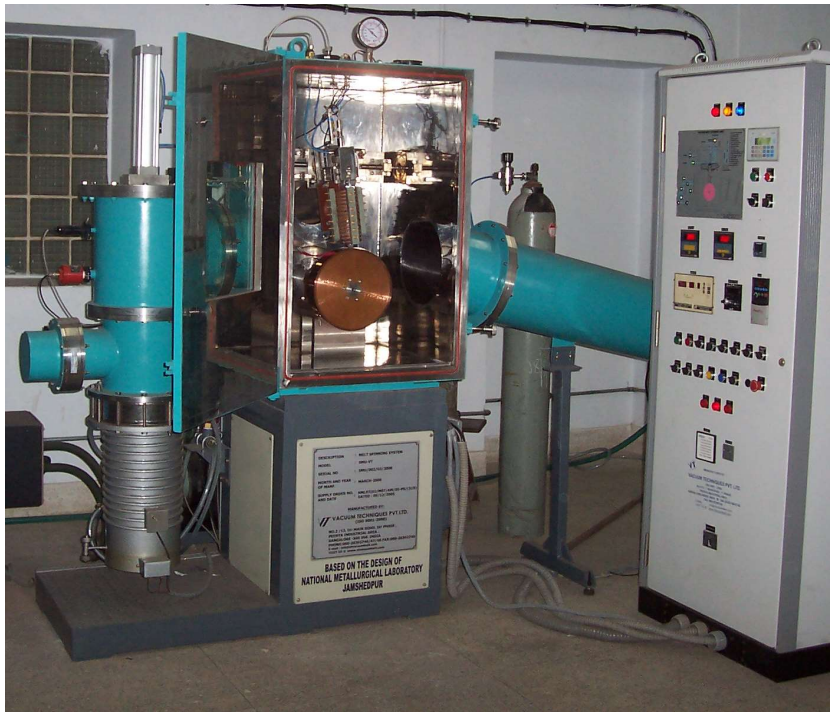
- Meeting Room Service
- Conference/ Lecture/ event management Service
- Cafeteria

IITJ- Technology Innovation & Start-up Centre (TISC)

TRL-3: Experimental Proof of Concept

TRL-4: Technology Validity in a Lab





Melt Spinning → Innovation in nozzle → Planar Flow Casting (gram scale to kilogram scale production)

(Technology Readiness Level (TRL)- 3&4)

TRL-3&4: Early technological and applied product and process research. Preparation system integration. Early market assessment.

Pad-mount amorphous metal transformer

Amorphous metal core

Pole-mount amorphous metal transformer

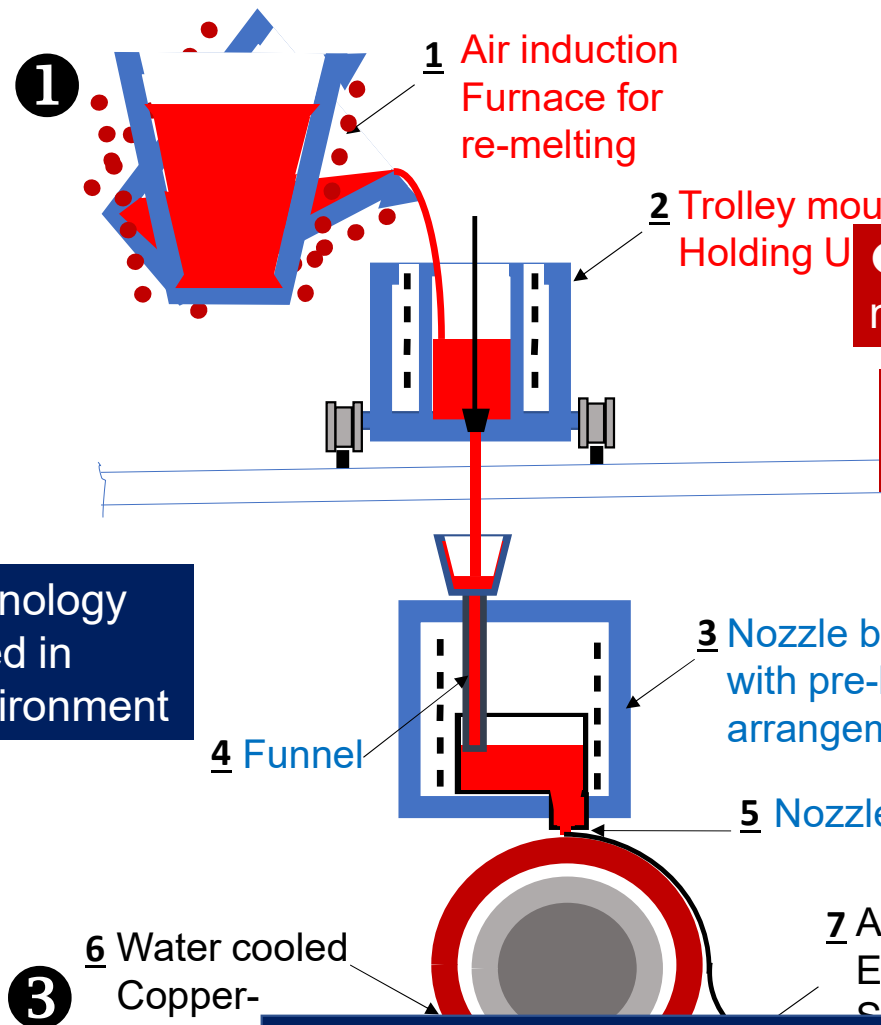
Typical Single phase Core-type

Typical Three phase -5 leg type

Contract research on product/process enhancements. Market introduction & Expansion

Technology Readiness level: 8 & 9

Re-melting and Spinning Scheme



Challenges:

❶Careful choice of raw materials and liquid metal chemistry control

❷Molten metal feed through small nozzle slot onto rapidly moving Cu-drum

❸Water cooling arrangement of Cu drum to achieve ~10^6 K cooling rate

❹On-line sensing and control of thickness

❺Collecting at ~100km/h line speed

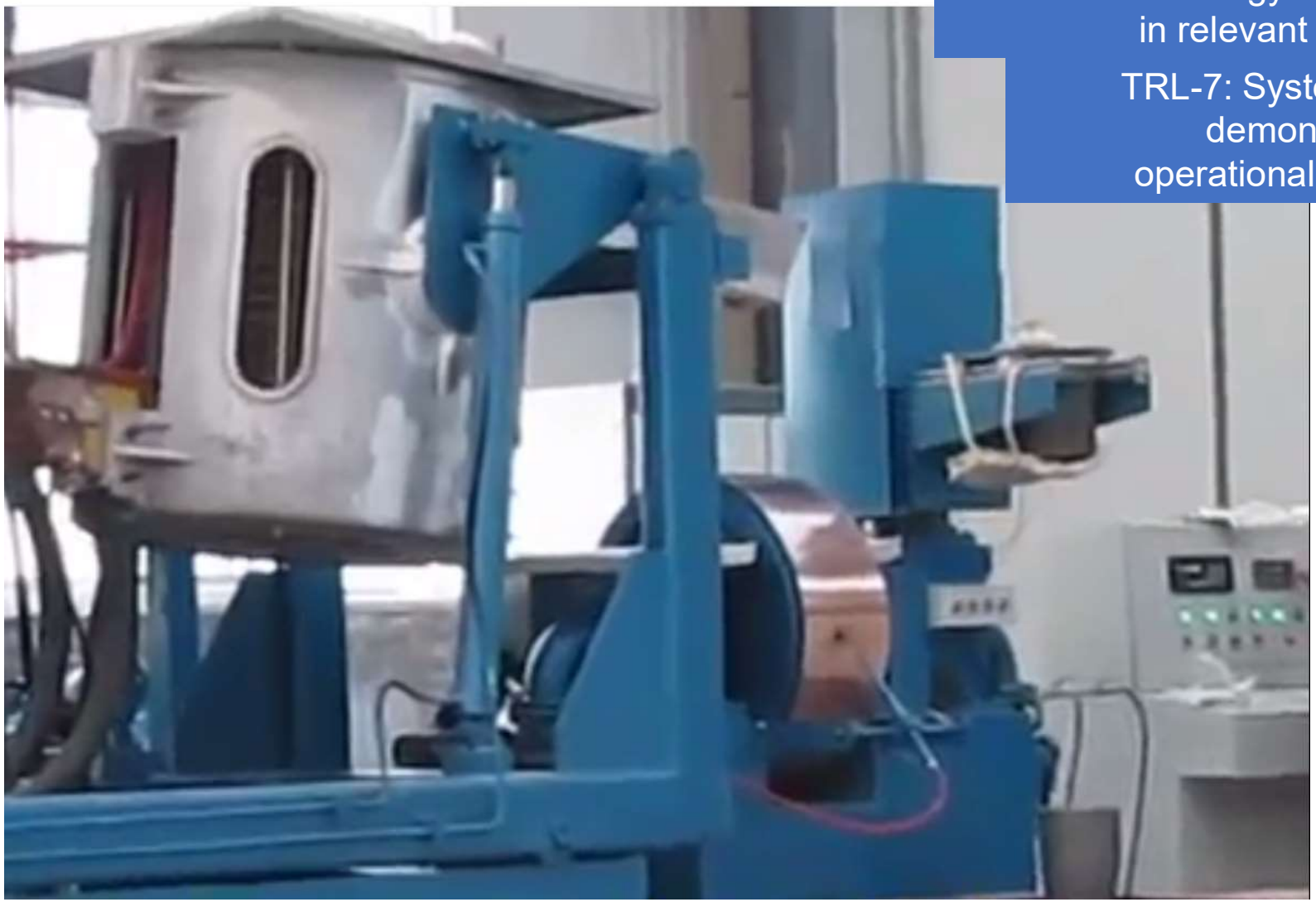
TRL-5: Technology demonstrated in relevant environment

Technology Readiness level: 5

Preparation of business Plan. Preparation of DPR. Prototyping facilities. Prototype system integration. Service development

TRL-6: Technology demonstrated in relevant environment

TRL-7: System prototype demonstration in an operational environment



https://www.youtube.com/watch?v=pkHw-a4eoyc

Per Bach: 250kg/100 wide ribbon of amorphous electrical steel
Per day: More than 5Tonn production

Shared pilot production facilities. Contract research on product, manufacturing. Business assessment

Technology Readiness level: 6-7

Technology Readiness Level (TRL)

	TRL Scale	Description
Invention	TRL 1	Transition of basic research to possible applications, ideation, technology foresight
	TRL 2	
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Technology Readiness Level Assessment
(TRA)
(Auditing document)

Technology Readiness Assessment (TRA)

1. Purpose: This document provides an independent Technology Readiness Assessment (TRA) of < name of the technology>

2. Programme overview

2.1 Programme Objective : < Objective related to the development of identified technology>

2.2 Programme Description < Short description of developed technology>

2.3 System Description

< Describe the overall system, major sub-systems, components and targeted specifications >

2.4 Identification of Critical Technology Elements (CTEs)

< This includes availability of components and relevant skilled personnel>


A Step to Better Health
KSHEER SCANNER
MILK FAT ANALYZER
KSHEER
ANALYZER

Purpose: This document provides an independent Technology Readiness Assessment (TRA) of Acoustic Milk Analyser”

Critical Technology Elements: (i) Sample intake Unit i.e. peristaltic pump (flow rate and fluctuations),

(ii) Measuring unit i.e. ultrasonic transducer

(iii) Control, Computation and human-machine interface unit

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
TRL-1	○ What is the basic scientific concept?	Ultrasonic propagation velocity and signal amplitude is function of density of liquid under investigation. These ultrasonic parameters have been exploited for measurement of milk composition like fat, solid non-fat and water content.	
	○ Has the basic scientific concept(s) been established/reported / published? If yes, references should be provided.	Yes, ultrasonic measurement is well known and commercial systems are also available in Indian as well as in International market.	
Conclusion/Recommendation:			
TRL-2	○ Is there any analytical formulation to establish the applicability of the scientific principle for the target application? Provide references.	Yes, Lab has already developed system for detection of adulteration in milk and there was demand from the industry partners. This is a added feature to the existing Technology developed by the lab.	
	○ Are there some sample experimental results to justify the use of scientific principle for intended applications?	Yes, will be provided on demand	
Conclusion/Recommendation:	Technology passed TRL-2		

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
TRL-3	○ Do you have experimental result of lab level test with the proposed system architecture to show that it meets target specification(s)?	After initial scientific studies basic system was developed. The system was tested with different milk samples in the Lab.	
	○ How many such experiments have been conducted?		
	○ What are the deviations of experimental results from analytical predictions as per specification?		
	○ Supporting information about the experimental set up, graphs, table(s) etc.		
	○ Who, when and where these experiments were conducted?		
Conclusion/Recommendation:			

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
TRL-4	○ Is the experimental evaluation carried out by integrating actual components of the target system. ○ Do you have experimental result in the lab environment with the integrated system. ○ How many such experiments have been conducted. ○ What are the deviation of experimental results from reference system developed for TRL3 evaluation. ○ What are the deviation of experimental results from reference to the target specification(s). ○ Have you conducted experiments with multiple instances of integrated systems. ○ What are the deviation of experimental results over multiple systems. ○ Supporting information about the experimental set up, graphs, table(s) etc. ○ Who, when and where these experiments were conducted.	Initial prototype was developed in 2016. Since then the. System was under testing for almost 2 years in laboratory conditions and also demonstrated at various forums.	
Conclusion/Recommendation :			

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
TRL-5	○ Has the system been tested at lab level by simulating target operational environment (may include temp/humidity/radiation/vibration/EMI/dust/flame proof IS/ water/ impact/ etc.) ○ What are the deviation of experimental results from reference system developed for TRL 4 evaluation. ○ What are the deviations of experimental results from reference to the target specification(s). ○ Supporting information about the experimental set up, graphs, table(s) etc. ○ Who, when and where these experiments were conducted.	System specifications was finalized as comparable with other commercially available in market. No such customer has approached for any specific requirement.	
Conclusion/Recommendation :			

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
TRL-6	○ Is prototype fabricated meeting desired configuration and physical parameters (volume, weight, footprint etc.) ○ Was experiments conducted to evaluate the performance of prototype system in test environment (simulated or operational) may include temp/humidity/radiation/vibration/EMI/dust/flame proof IS/ water/ impact/ etc.) ○ How was the test environment different from operational environment. ○ What are the deviations of experimental results from the target specification(s). ○ Was the test conducted with multiple prototype. What is the deviation of the test result over multiple prototypes (mean error and standard deviation) ○ Supporting information about the experimental set up, graphs, table(s) etc. ○ Who, when and where these experiments were conducted.		
Conclusion/Recommendation :			

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
Conclusion/Recommendation :			
TRL-7	○ Were experiments conducted to evaluate the performance of prototype system in actual operational environment . Was the test done at multiple operational environment. ○ What are the deviations of experimental results from the target specification(s). ○ Supporting information about the experimental set up, graphs, table(s) etc. ○ Who, when and where these experiments were conducted. ○ What problems, if any, detected in the performance of the system in the operational environment. ○ What are plans to resolve the problems.		
Conclusion/Recommendation :			

TRL Level	Description	Remark by the Technology Developer	Evaluation of committee
Conclusion/Recommendation :			
TRL-8	○ What are the test results of the final version of the system under the expected range of environmental condition in which it is expected to operate. ○ What problems, if any, detected in the performance of the system in the operational environment. ○ What are plans to resolve the problems. ○ What are the plans/option/action to resolve the problems before finalizing the deployment.		
Conclusion/Recommendation :			
TRL-9	○ Systems are deployed in field and operational report.		
Conclusion/Recommendation :			

Industry Readiness Level (IRL)

	Industry Readiness Level (IRL)	Description
Research & Development	**IRL1- Conception:**	Early awareness of a need and potential outcomes thought worthy of developing
	IRL 2- Opportunity Development:	Thinking, supported by research, to develop understanding of need and possible approaches to obtain qualitative benefits
	IRL 3- Proof of Concept:	Conceptual design supported by experimentation proves viability and feasibility of the concept.
Demonstration	**IRL 4- Industry Specification:**	Qualitative plans to deliver the concept are supported by positive market and business analyses.
	IRL 5- Prototype:	Prototype assets and/or services, developed under quality controlled methodology are available
	IRL 6- Operational Transition:	Supply of goods and/or services of appropriate and repeatable quality meets market needs
Delivery	**IRL 7- Initial Deployment:**	Operational credibility builds as goods and services are employed, feedback used to confirm user expectations.
	IRL 8- Roll Out:	Supply meets demand in a timely manner, product / service deemed mature and deployable with ease.
Maintenance	**IRL 9- Whole Life Management:**	Continued product / service improvement; business as usual; actual whole life cost measured.

Industry **R**eadiness **L**evel (IRL)

RESEARCH AND DEVELOPMENT

RIRL 1: Conception

Early awareness of a need and potential outcomes thought worthy of developing

The Industry is aware of the opportunity and may have some ideas about implementation and high level benefits, but does not have a clear route to market, a defined customer or a good understanding of the manufacturing process.

RIRL 2: Opportunity Development

Thinking, supported by research, to develop understanding of need and possible approaches to obtain qualitative benefits.

Opportunity is defined to the state that the Industry is able to conceive plans to develop the necessary facilities required for delivery. Co-operation and co-financing amongst several independent entities may be required, but no business case exists as yet and barriers to implementation are not understood.

RIRL 3: Proof of Concept

Conceptual design supported by experimentation proves viability and feasibility of the concept.

Initial business and production plans, with associated test, qualification and certification are available. Draft business case is developed and end customer is identified along with analysis of their needs.

DEMONSTRATION

RIRL 4: Industry Specification

Qualitative plans to deliver the concept are supported by positive market and business analyses.

Technologies required to manufacture/produce or deliver are understood and associated facility capability planning is underway in accordance with the Market potential and supported by the Business Plan. Customers and suppliers have agreement on how realistic demonstration of the research project might be undertaken.

RIRL 5: Prototype

Prototype assets and/or services, developed under quality controlled methodology are available.

The Industry is capable of pre-production using bespoke processes and able to deliver ‘pre-production standard’ goods and services in support of whole system and market development. The conditions for implementation are understood. Agreement between project partners stipulates how the successful project should be exploited.

RIRL 6: Operational Transition

Supply of goods and/or services of appropriate and repeatable quality meets market needs..

The Industry is capable of repeated standards of production to the required levels, and realistic operational demonstrators are in place. The competitive landscape is understood.

DELIVERY

RIRL 7: Initial Deployment

Operational credibility builds as goods and services are employed, feedback used to confirm user expectations.

Low level production begins to ramp up to full production rates in a controlled and planned manner that matches demand and marketing strategies. No barriers from legislative or standardisation point of view exist. The technology is incorporated in to the wider system. Manufacturers are established and ready to deliver.

RIRL 8: Roll Out

Supply meets demand in a timely manner, product / service deemed mature and deployable with ease.

Steady state production output is sustained with supply able to meet demand, with products and services at a mature and qualified state. The product / service is exportable. Customers start to implement the technology because of strong business case, customer or legislative compulsion.

MAINTENANCE

RIRL 9: Whole Life Management

Continued product / service improvement; business as usual; actual whole life cost measured.

Products and / or services are mature with the ability of being supplied off the shelf' to meet expanding demand; with the opportunity to undertake a reasonable level of tailoring to meet new markets. The product / service is in world-wide usage.

Lecture-2 :02.06.22

Systems Engineering & Project Management

(Course Code: OAN0710)

Reference:

Roadmapping for strategy and innovation

Robert Phaal
Centre for Technology Management
Institute for Manufacturing, University of Cambridge

Prof. Amitava Mitra
(amitra@iitj.ac.in)
&
Dr. Mithu Rani Kuiti
mithu@iitj.ac.in)

Technology Roadmapping

"A 'roadmap' is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field".

by Bob Galvin , CEO of Motorola in 1970s

- Technology roadmapping was originally developed by Motorola in the 1970s :

  Purpose: To support improved alignment between technology and product development for providing a structured visual depiction of strategy.

- Roadmapping approaches are now very popular and widely used at various

  - companies
  - sectors and
  - national levels

  to align research and other investments with goals and strategy.

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- Roadmapping approaches are now very popular and widely used at various
  - companies
  - sectors and
  - national levels

to align research and other investments with goals and strategy.

  - It focuses on the need of innovation and business strategy and building consensus on priorities and actions required to move forward

  - The 'Roadmapping' concept is very flexible, and the methods have been adapted to suit many different goals, supporting innovation, strategy and policy development and deployment

- Definition: A **technology roadmap** is a flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific **technology** solutions.

Motorola technology roadmap, for car radios, linking technology investment to product strategy, looking forward 10 years

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Tuning	Push Button		Push Button- Synthesiser			Touch Pad- Synthesiser			Voice Activated	
Selectivity	Ceramic resonator			SAWs			Digital signal Processing			
Subcarrier Function	Stereo				Paging		Data		Maps	
IC-Technology	Linear		5μ CMOS		3μ CMOS		1μ CMOS			
Display	LED		Liquid Crystal				Florescence			
Vehicular Lan						Single wire		Glass Fiber		
Digital Modulation								500 kHz Bandwidth		
Product	RECEIVER 1 Stereo		RECEIVER 2 Plus: Scan Seek		RECEIVER 1 Plus: Personal paging	NEXT GENERATION Plus: Stock market Road information Remote amplifiers			FUTURE GENERATION A NEW SERVICE Super Hi Fi Local maps	

- Definition: A **technology Roadmapping** is a depiction of flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific technology solutions.

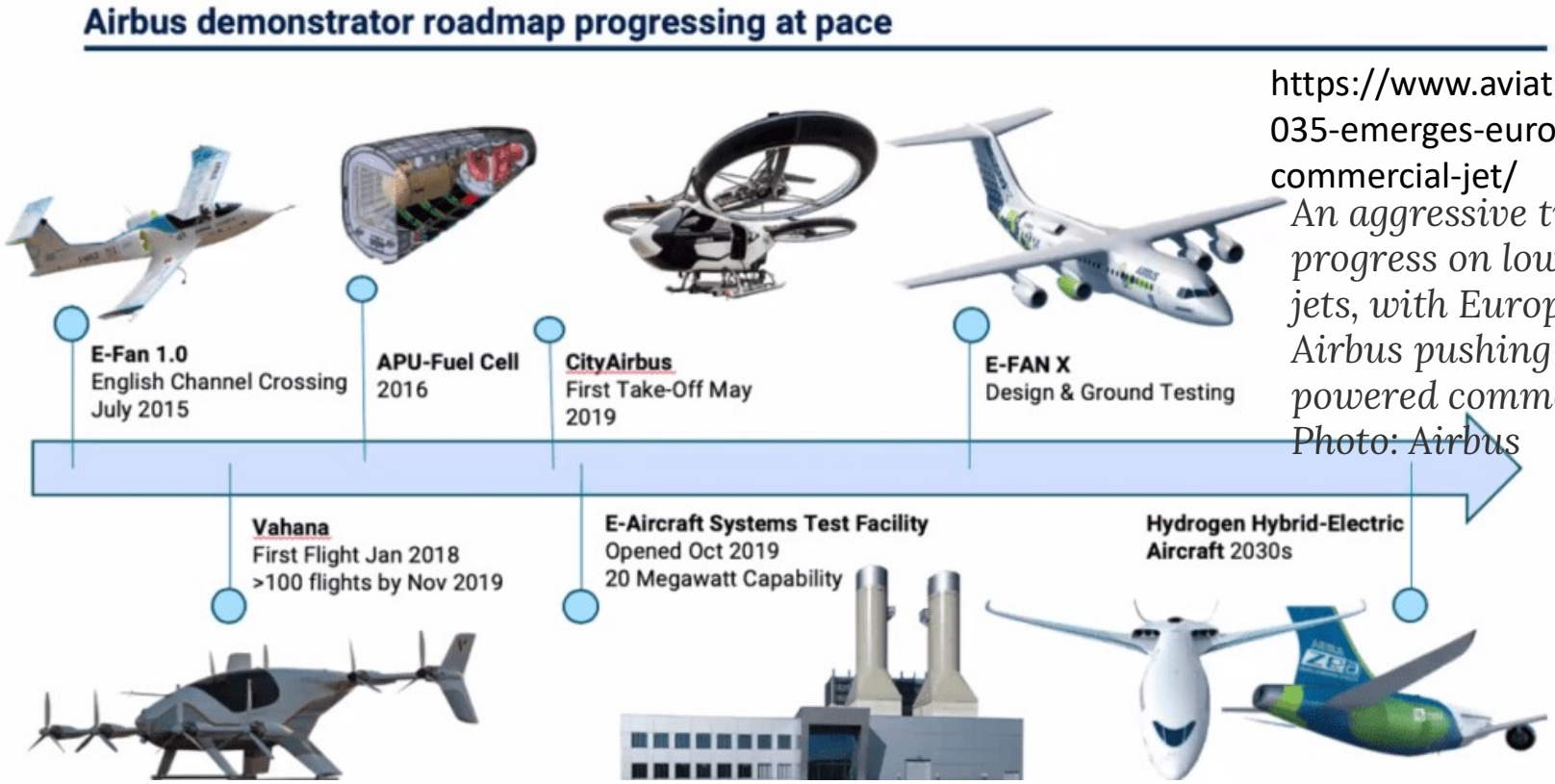
  - It focuses on the need of innovation and business strategies of the organization and building consensus on priorities and actions required to move forward

  - The ‘Roadmapping’ concept is very flexible, and the methods have been adapted to suit many different goals, supporting innovation, strategy and policy development and deployment

- Many different approaches exist for development Roadmapping. It can also be expressed in different forms like

  - Multiple or single layers graphical forms
  - Tables
  - Bars
  - Graphs
  - Flow charts
  - Text

However, the graphical representation of ‘Roadmapping’ provides a high strategic view of the topic of interest



https://www.aviationtoday.com/2020/06/29/2035-emerges-european-target-hydrogen-commercial-jet/

An aggressive timeline has emerged for progress on lower-emission commercial jets, with European governments and Airbus pushing to field a hydrogen-powered commercial product by 2035. Photo: Airbus

- Roadmapping documents are important not just because they are aesthetically pleasing, but because Roadmaps clearly show what one wants to achieve and how one will get there.
- One can create excitement for a big idea and package it in a way that others can understand it easily.
- But Roadmapping is still just a visualization.
  We need to have a **vision** and **strategy** behind the plan.

- A successful product and project teams have clear understanding about the purpose of Vision, Strategy and Roadmapping to build something long lasting

Example: Building of skyscraper

- Vision is the initial thought about what kind of place it will be and why it will matter.
- Strategy is the blueprint for the foundation and framing
- The roadmap builds upon the blueprint with a detailed plan for erecting a fully-functioning structure

- Thus

Vision is the view of the future.

Strategy explains the approach one will take to realize that future state

Roadmapping is the more tactical plan for what one will do to get there (and when you will arrive), guided by the vision and strategy.

- Benefits:
  - In the process of Roadmap Development
    - Makes communication across functional and organizational boundaries
    - Brings together the various key stakeholders and perspectives for building consensus.
    - Identifies technologies that are critical for future customer & product needs
    - Assists leadership in deciding needed technologies, funding levels (prioritization and urgency)
    - Allows leadership to better position their development activities with limited resources
  - Once Roadmap is developed
    - It can be more widely disseminated, acting as reference point for ongoing dialogue and action in a focused way
    - Used by industry to remain competitive and responsive

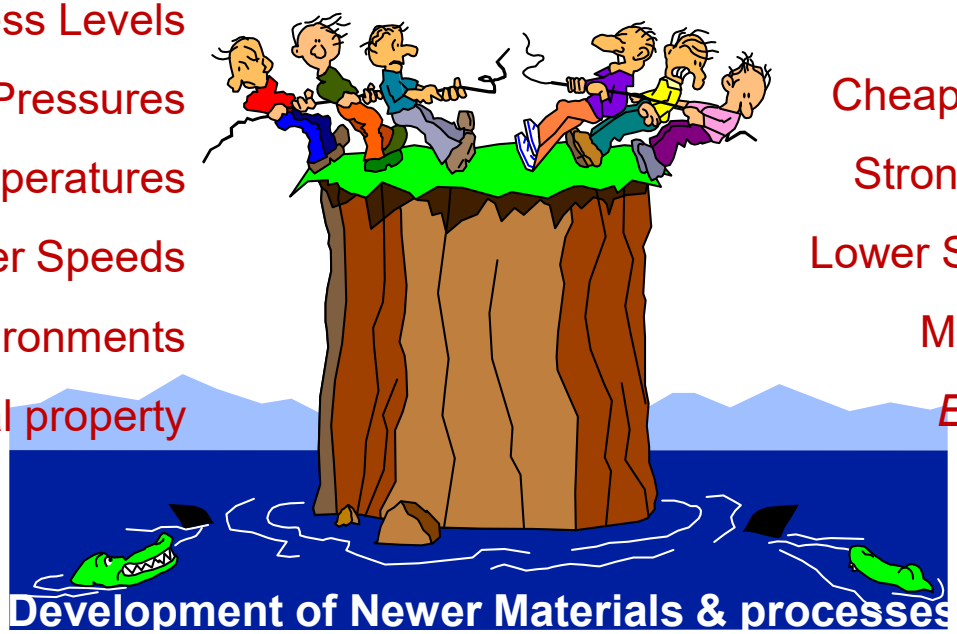
- The most flexible and powerful framework for the creation of roadmaps is through graphical representation comprising of multilayered time based chart to bring together various perspectives into a single visual diagram.

- This type of roadmap enables the stakeholders to view both ‘demand’ and ‘supply’ side and also help in balancing ‘market pull’ and ‘technology push’.

DEMAND ON MATERIALS

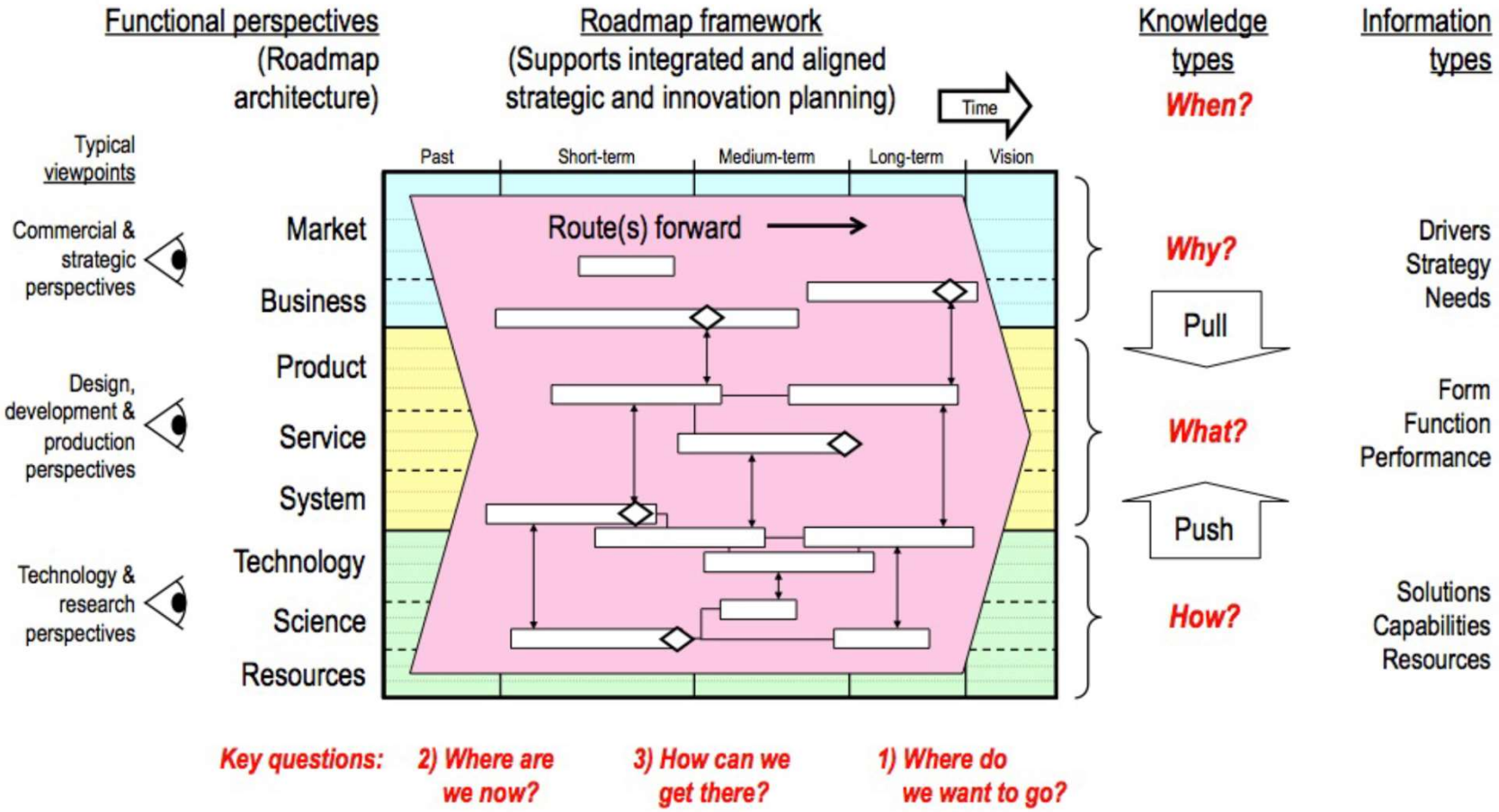
Higher Efficiency vs Increasing Material Cost

- Higher Stress Levels
- Higher Pressures
- Higher Temperatures
- Higher Speeds
- More Severe Environments
- Higher Functional property



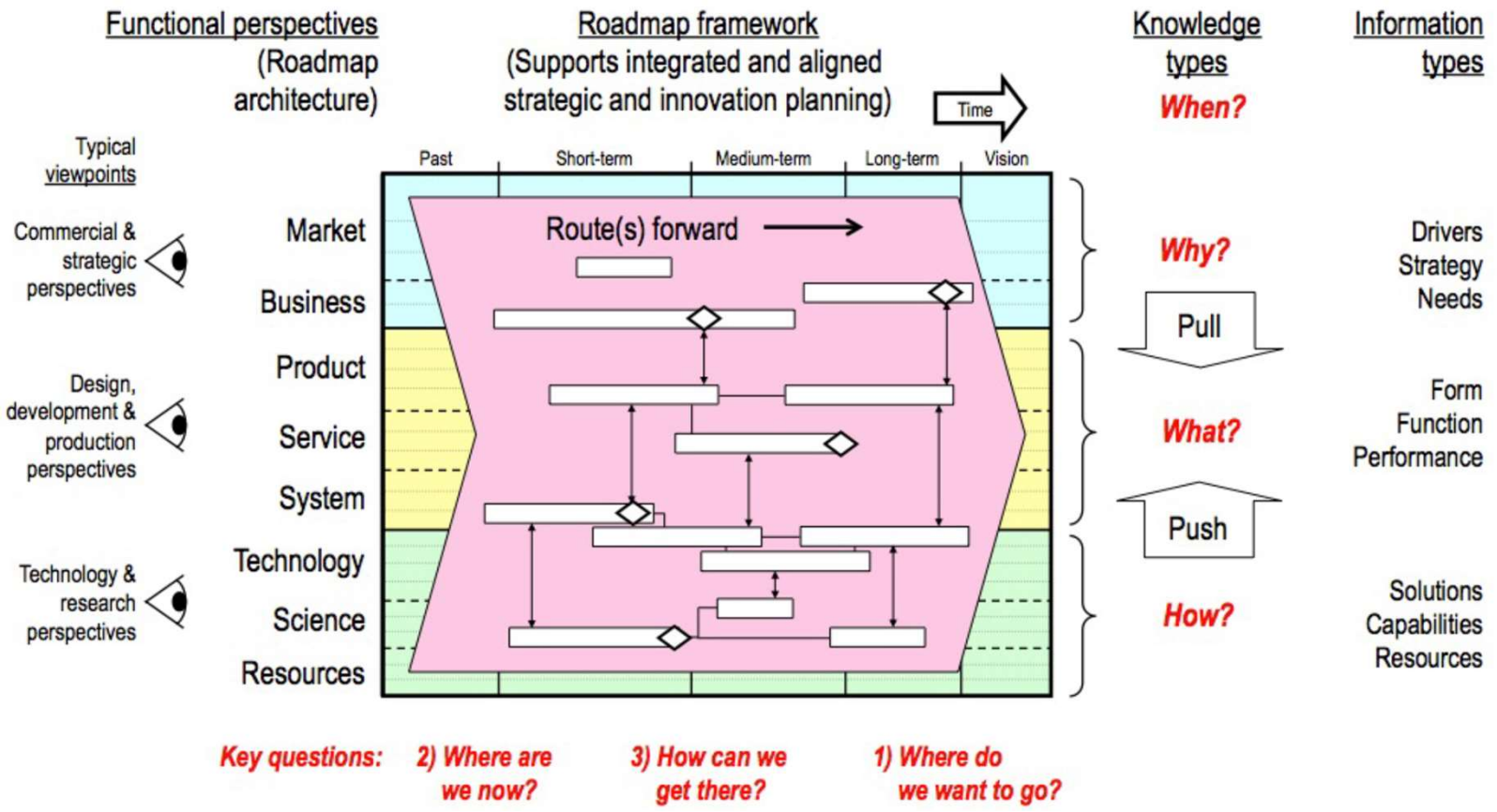
- Cheaper Materials
- Stronger Material
- Lower Section Area
- Miniature size
- *Extended life*

Schematic Representation of multi-layered roadmap: Aligning multiple perspectives



Fundamental generic strategic questions are highlighted in red

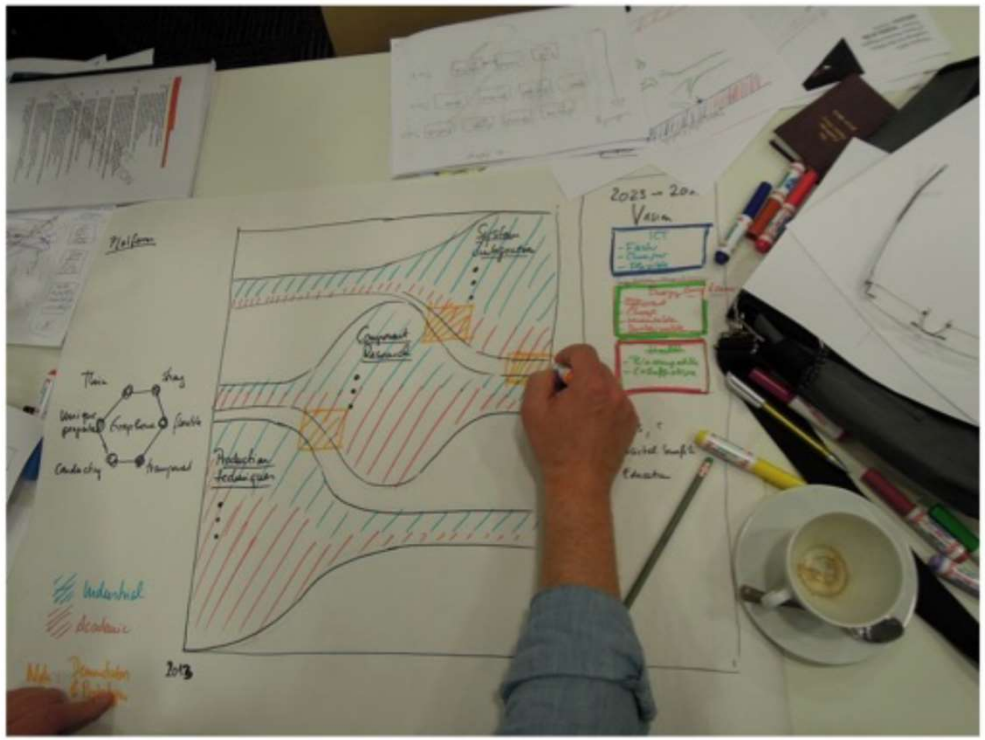
- This holistic roadmap framework shown in Fig. links directly to fundamental questions that apply in any strategic context:
    1. Why do we need to act? What should we do? How should we do it? By when?
    2. Where do we want to go? Where are we now? How can we get there

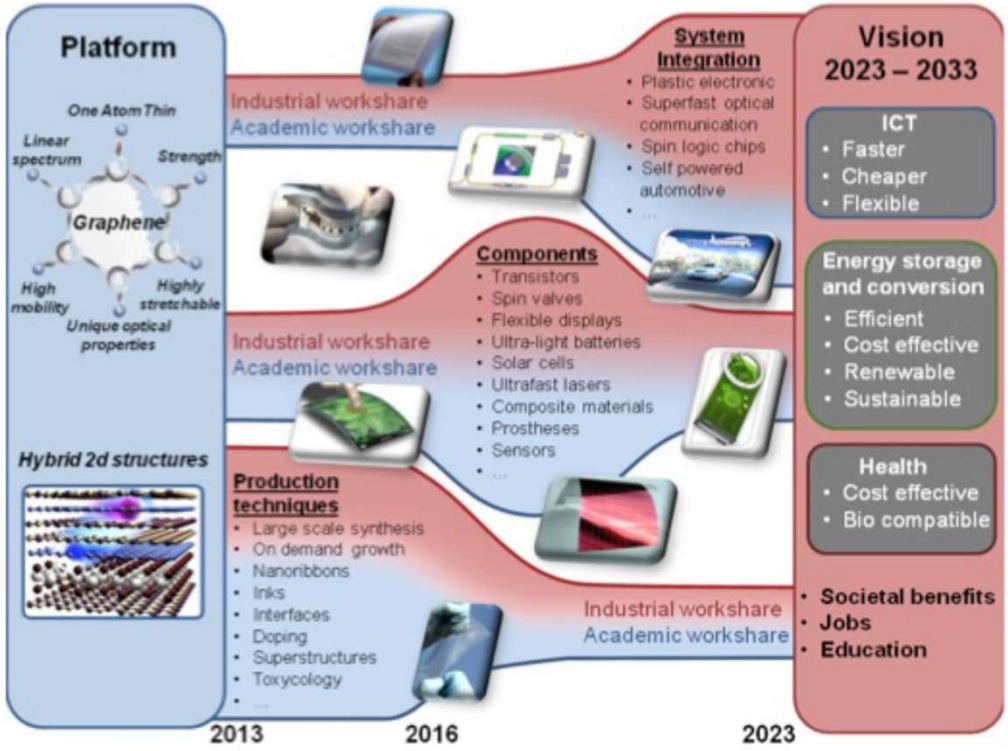


- The generic form of roadmap illustrated above highlights the flexibility of the approach, which can be readily adapted to suit a wide range of goals and contexts.
- In essence, roadmaps are simple, adaptable ‘strategic lenses’ through which the evolution of complex systems can be viewed, supporting dialogue, alignment and consensus.

- The systematic multilayered format is helpful for developing strategy, but may not always be the best way to communicate strategy, depending on context, purpose and audience

- Alternative formats may be helpful for communicating key strategic messages to particular stakeholder groups – for example senior management or investors





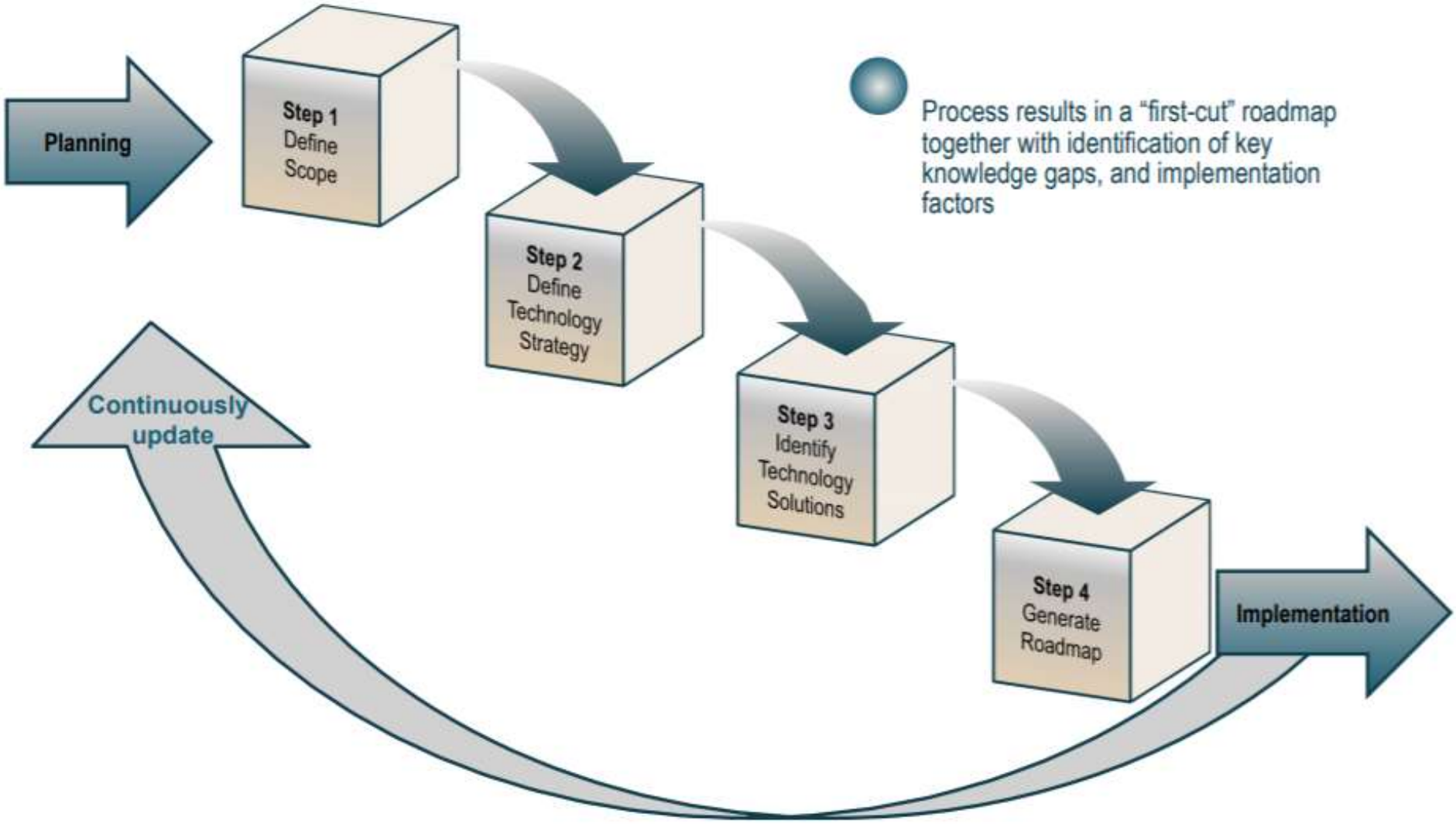
- An example is shown in Fig. where a business roadmap was developed for collaborative research program on the development and application of graphene.

- Define Roadmap Scope
    - Assess technology performance expectations
    - Identify, group, and prioritize internal/external drivers
    - Define Technology Gaps (TG)
    - Identify known risks
    - Conduct SWOT analysis
    - Consider strategic context
  - WHAT IS THE SCOPE?
- Roadmap Planning
    - Define inputs, outputs, units of analysis
    - Select from inputs, technologies to roadmap
    - Identify participants and senior leaders
    - Identify existing acquisition programs/ customers
    - Identify new programs of record required to field technologies
  - WHY ARE WE DOING THIS?

- Technology Roadmapping Is the process, not the end-product

  - Identifies technologies that are critical for future customer & product line needs
  - Assists management in deciding needed technologies, funding levels (prioritization and urgency)
  - Allows management to better position their development activities with ever-limiting resources
  - Necessary to remain competitive & responsive due to ever-shortening product development causing greater need for coordination across the product cycle

❑ Roadmapping Process Steps



End of Technology Management