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Tech Mining to Validate and Refine a Technology Roadmap

Presented by
Geet Lahoti

Authored by
Geet Lahoti, Alan L. Porter, Chuck Zhang, Jan Youtie, Ben Wang, Diana M. Hicks



Outline

1. Motivation
2. Objective
3. Approach
4. Results
5. Conclusion

Motivation

The Future Brought to You by



America is beginning an exciting new chapter in space exploration. To enable the future, NASA has developed a set of roadmaps to define the key new technologies required for our human and robotic explorers to safely venture into deep space, to better understand how our own solar system evolved, and to unravel the mysteries of our universe.

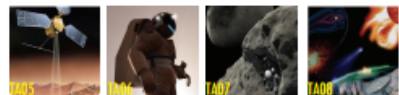
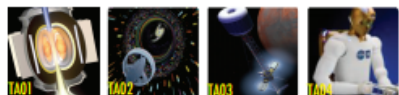
The map you see here is a graphical representation of the NASA Space Technology Roadmaps, serving as a portal to the various technologies that NASA is developing. Let this technology portal serve as a starting point for your adventures beyond the bounds of Earth...

To learn more visit
www.nasa.gov/oct

- TA01 Launch Propulsion Systems
- TA02 In-Space Propulsion Technologies
- TA03 Space Power & Energy Storage
- TA04 Robotics, Tele-Robotics & Autonomous Systems
- TA05 Communication & Navigation
- TA06 Human Health, Life Support & Habitation Systems
- TA07 Human Exploration Destination Systems
- TA08 Science Instruments, Observatories & Sensor Systems
- TA09 Entry, Descent & Landing Systems
- TA10 Nanotechnology
- TA11 Modeling, Simulation, Information Technology & Processing
- TA12 Materials, Structures, Mechanical Systems & Manufacturing
- TA13 Ground & Launch Systems Processing
- TA14 Thermal Management Systems



Motivation



TA01 • LAUNCH PROPULSION SYSTEMS

SOLID ROCKET PROPULSION SYSTEMS

- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

LIQUID ROCKET PROPULSION SYSTEMS

- LH₂/LOX Based
- RP/LOX Based
- CH₄/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

AIR BREATHING PROPULSION SYSTEMS

- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Hybrid Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment Systems
- Fundamental Air Breathing Propulsion Technologies

ANCILLARY PROPULSION SYSTEMS

- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

UNCONVENTIONAL / OTHER PROPULSION SYSTEMS

- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

CHEMICAL PROPULSION

- Liquid Storable
- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro-propulsion

NON-CHEMICAL PROPULSION

- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion
- Advanced (TRL <3) Propulsion Technologies
- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fusion
- Breakthrough Propulsion

SUPPORTING TECHNOLOGIES

- Propellant Storage & Transfer

TA03 • SPACE POWER & ENERGY STORAGE

POWER GENERATION

- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fusion
- Fission

ENERGY STORAGE

- Batteries
- Flywheels
- Regenerative Fuel Cells

POWER MANAGEMENT & DISTRIBUTION

- FDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

CROSS CUTTING TECHNOLOGY

- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

SENSING & PERCEPTION

- 3-D Perception
- Relative Position & Velocity Estimation
- Terrain Mapping, Classification & Characterization
- Natural & Man-made Object Recognition
- Sensor Fusion for Sampling & Manipulation
- Onboard Science Data Analysis

MOBILITY

- Extreme Terrain Mobility
- Below-Surface Mobility
- Above-Surface Mobility
- Small Body/Microgravity Mobility

MANIPULATION

- Robot Arms
- Dexterous Manipulators
- Modeling of Contact Dynamics
- Mobile Manipulation
- Collaborative Manipulation
- Robotic Drilling & Sample Processing

HUMAN-SYSTEMS INTEGRATION

- Multi-Modal Human-Systems Interaction
- Supervisory Control
- Robot-to-Suit Interfaces
- Intent Recognition & Reaction
- Distributed Collaboration
- Common Human-Systems Interfaces
- Safety, Trust, & Interfacing of Robotic/Human Proximity Operations

AUTONOMY

- Vehicle Systems Management & FDIR
- Dynamic Planning & Sequencing Tools
- Autonomous Guidance & Control
- Multi-Agent Coordination
- Adjustable Autonomy
- Terrain Relative Navigation
- Path & Motion Planning with Uncertainty

AUTON. RENDEZVOUS & DOCKING

- Relative Navigation Sensors (long-, mid-, near-range)
- Guidance Algorithms
- Docking & Capture Mechanisms/Interfaces
- Mission/System Managers for Autonomy/Automation

RTA SYSTEMS ENGINEERING

- Modularity/Commonality
- Verification & Validation of Complex Adaptive Systems
- Onboard Computing



TA05 • COMMUNICATION & NAVIGATION

OPTICAL COMM. & NAVIGATION

- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

RADIO FREQUENCY COMMUNICATIONS

- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- Flight & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

INTERNETWORKING

- Disruptive Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

POSITION, NAVIGATION, AND TIMING

- Timekeeping & Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

INTEGRATED TECHNOLOGIES

- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

REVOLUTIONARY CONCEPTS

- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQIF Microwave Amplifier
- Reconfigurable Large-Aperture Using Nanosat Constellations

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEMS & HABITATION SYS.

- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation

EXTRAVEHICULAR ACTIVITY SYSTEMS

- Pressure Garment
- Portable Life Support System
- Power, Avionics & Software

HUMAN HEALTH & PERFORMANCE

- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health
- Human Factors

ENVIRONMENTAL MONITORING, SAFETY & EMERGENCY RESPONSE

- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression, Recovery
- Protective Clothing / Breathing Remediation

RADIATION

- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Radiation prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

IN-SITU RESOURCE UTILIZATION

- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing Products
- Infrastructure Employment

SUSTAINABILITY & SUPPORTABILITY

- Autonomous Logistics
- Management
- Maintenance Systems
- Repair Systems
- Food Production, Processing, & Preservation

"ADVANCED" HUMAN MOBILITY SYSTEMS

- EVA Mobility
- Surface Mobility
- Off-Surface Mobility
- "Advanced" Habitat Systems
- Habitat Evolution
- "Smart" Habitats
- Artificial Gravity

MISSION OPERATIONS & SAFETY

- Crew Training
- Planetary Safety
- Integrated Flight Operations Systems
- Integrated Risk Assessment Tools

CROSS-CUTTING SYSTEMS

- Construction & Assembly
- Particulate Contamination Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

REMOTE SENSING INSTRUMENTS / SENSORS

- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

OBSERVATORIES

- Mirror Systems
- Structures & Antennas
- Distributed Aperture

IN-SITU INSTRUMENTS / SENSOR

- Particles: Charged & Neutral
- Fields & Waves
- In-Situ

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

AEROSIST & ATMOSPHERIC ENTRY

- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Ground Computing
- Deployable Hypersonic Decelerators

DESCENT

- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion

LANDING

- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Small Body Systems

VEHICLE SYSTEMS TECHNOLOGY

- Separation Systems
- System Integration and Analyses
- Atmosphere & surface characterization
- Modeling and Simulation
- Instrumentation and Health Monitoring
- GN&C Sensors and Systems

TA10 • NANOTECHNOLOGY

ENGINEERED MATERIALS & STRUCTURES

- Lightweight Structures
- Damage-Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

ENERGY GENERATION & STORAGE

- Energy Storage
- Energy Generation

PROPULSION

- Propellants
- Propulsion Components
- In-Space Propulsion

SENSORS, ELECTRONICS & DEVICES

- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments



TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

COMPUTING

- Flight Computing
- Ground Computing

MODELING

- Software Modeling & Model-Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science Modeling
- Frameworks, Languages, Tools & Standards

SIMULATION

- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training & Decision Support Systems

INFORMATION PROCESSING

- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

MATERIALS

- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

STRUCTURES

- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

MECHANICAL SYSTEMS

- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

MANUFACTURING

- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

CROSS-CUTTING

- Nondestructive Evaluation
- Model-Based Certification & Sustainment Methods
- Loads and Environments

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

TECHNOLOGIES TO OPTIMIZE THE OPERATIONAL LIFE-CYCLE

- Storage, Distribution & Conservation of Fluids
- Automated Alignment, Coupling, & Assembly Systems
- Autonomous Command & Control for Ground and Integrated Vehicle / Ground Systems

ENVIRONMENTAL AND GREEN TECHNOLOGIES

- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

TECHNOLOGIES TO INCREASE RELIABILITY AND MISSION AVAILABILITY

- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing & Telemetry

TECHNOLOGIES TO IMPROVE MISSION SAFETY/MISSION RISK

- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA14 • THERMAL MANAGEMENT SYSTEMS

CRYOGENIC SYSTEMS

- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

THERMAL CONTROL SYSTEMS

- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage

THERMAL PROTECTION SYSTEMS

- Entry / Ascent TPS
- Plasma Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Space Technology Roadmaps STR • TABS TECHNOLOGY AREA BREAKDOWN STRUCTURE

Motivation

- Since NASA involved experts to develop those roadmaps, we can say the roadmapping process seems to be highly based on experts' opinion.
- Qualitative Technology Roadmapping Process
 - Experts' opinion
 - Subjective elements
 - Limited cognitive horizons
- Also, NASA plans on updating these technology roadmaps on a regular basis.

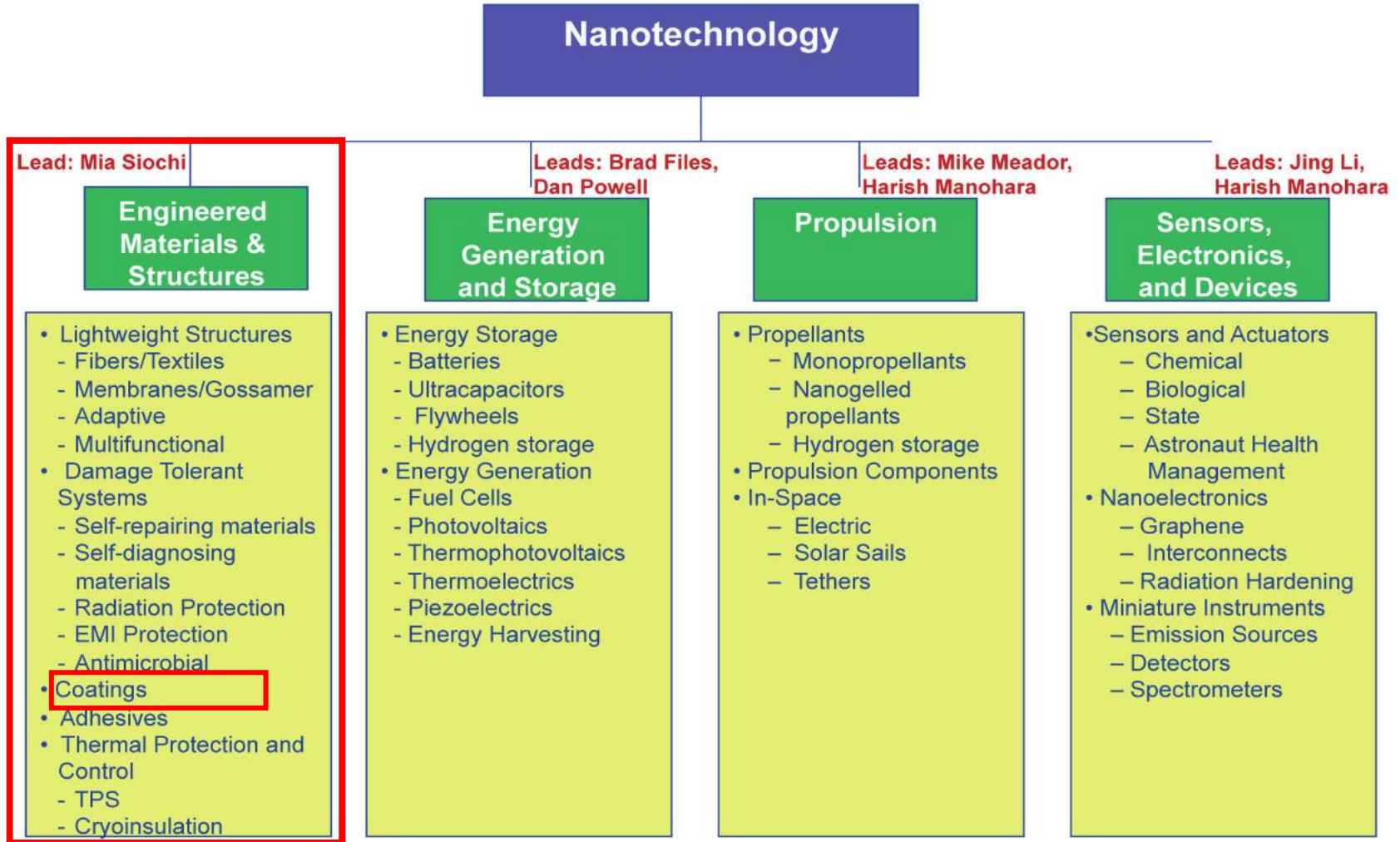
This poses a question:
Are all those predictions as presented in the roadmaps accurate/nearly accurate?

This poses another question: Can there be a way to update these roadmaps with minimal dependence on experts?

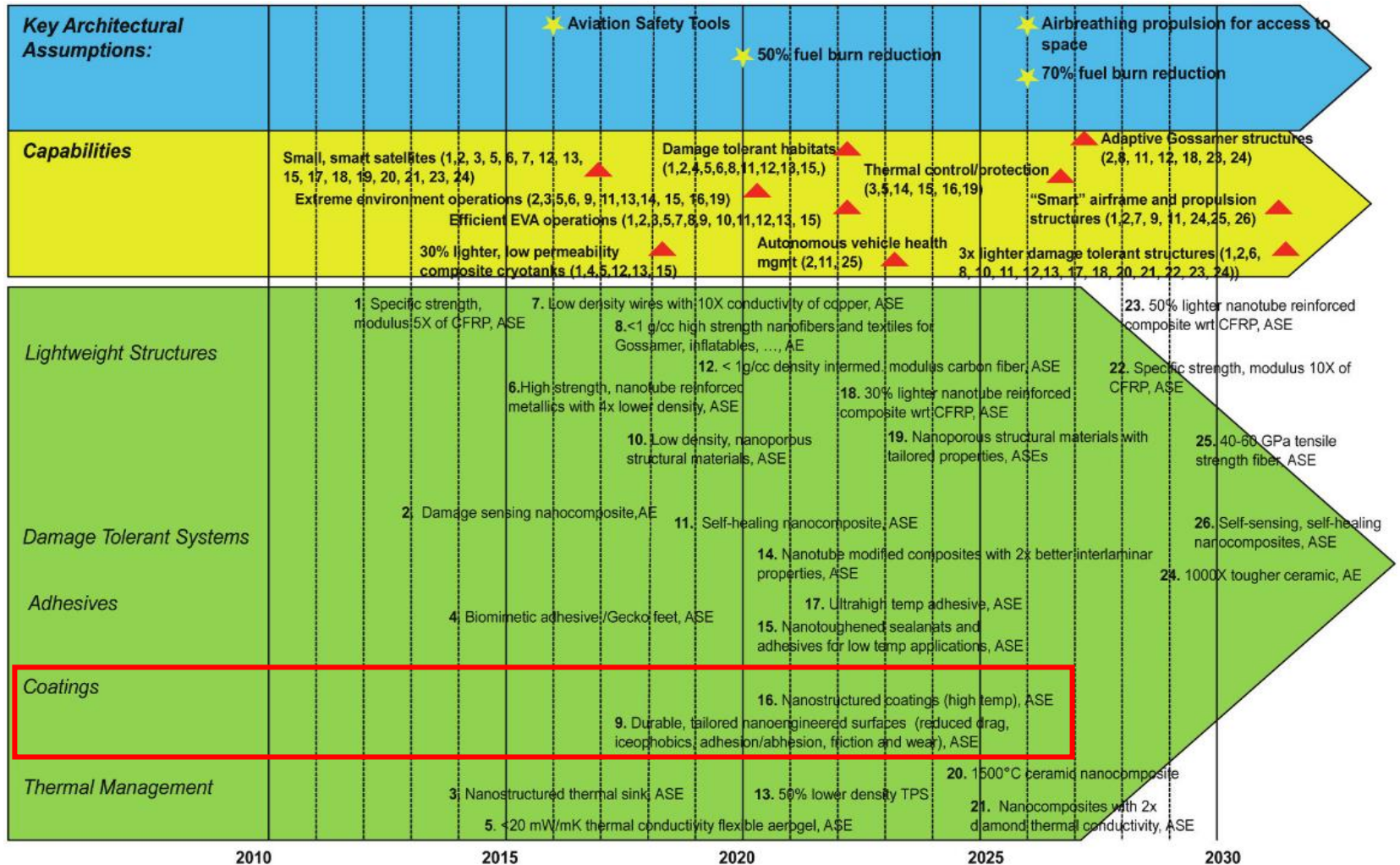
Objective

- 14 Technology Areas!
- 64 sub-roadmaps!!
- We try to answer those questions for a very special case:
 - Technology Area 10: Nanotechnology
 - Engineered Materials and Structures
 - Nanocomposite Coatings

Objective



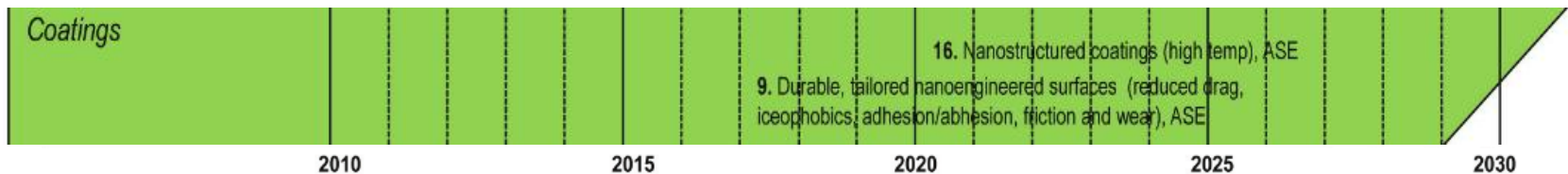
Objective



Engineered Materials and Structures Roadmap (excerpted from NASA Nanotechnology Roadmap, April 2012)

Objective

- Capabilities of Nanocomposite Coatings
 - extreme environment operations
 - efficient extravehicular activity (EVA) operations
 - thermal control/protection
 - smart airframe and propulsion
- Two predictions:



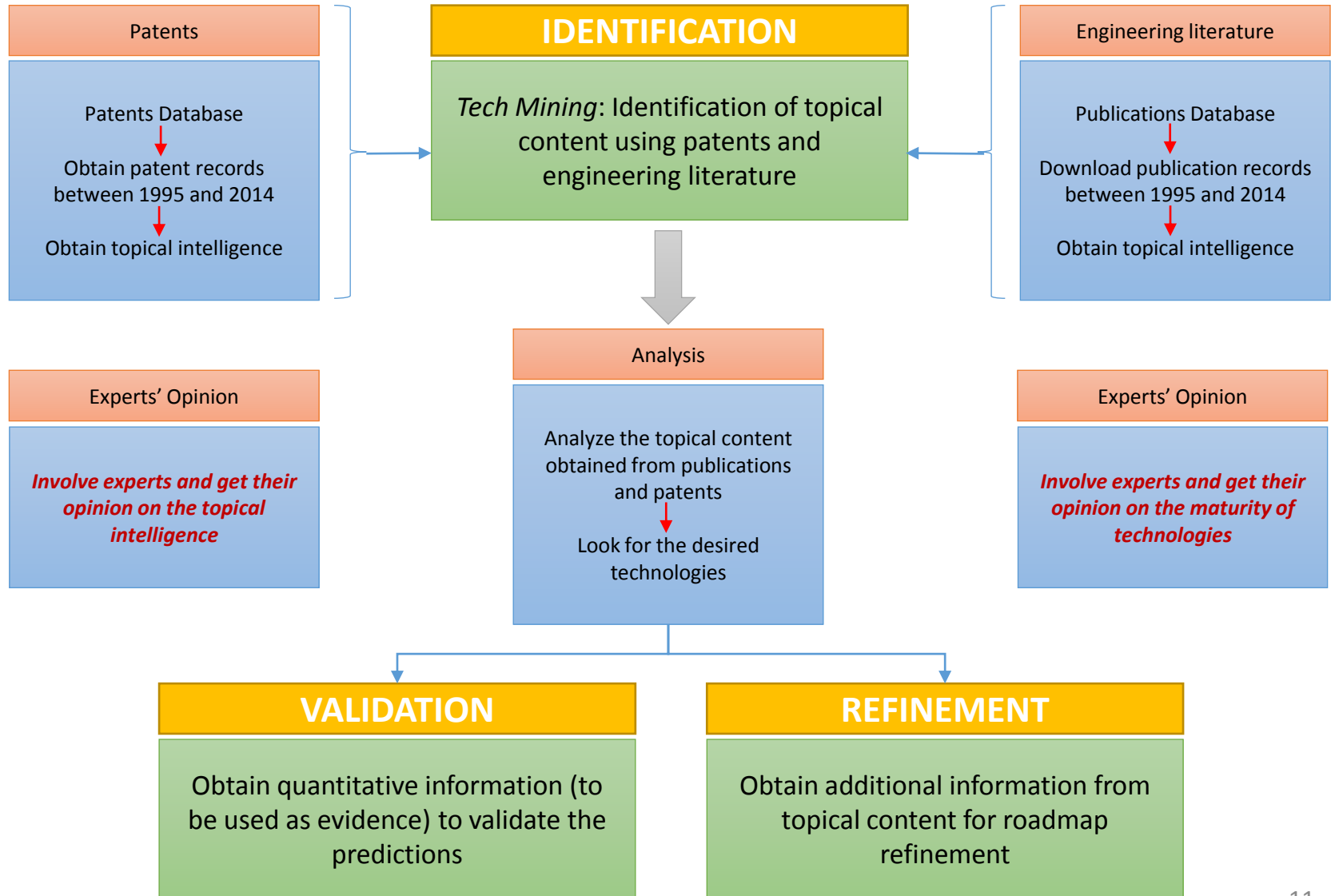
- **Objective of this study:** Validate and refine this technology roadmap section

Approach

- **Tech Mining:** 'Tech mining' is the process of deriving technology intelligence from science, technology and innovation (ST&I) information record sets through text mining (Porter 2005)
- It helps in answering questions such as
 - Who
 - Where
 - What/Which
 - When



Approach



Results

Step 0 Search Strategy

Topic	Coating
Keywords obtained from text of roadmap document and figure representing the roadmap	<ul style="list-style-type: none">- <u>From Text (Roadmap Document)</u> nanocomposite coatings, barrier to oxidation, wear resistance of materials, nanotexturing of surfaces, super-hydrophobic, reduce drag, minimize accretion of ice, dust, and insect contamination, large scale texturing, evaluation of long-term durability of nanoscale features- <u>From Figure (Roadmap)</u> nanostructured coatings (high temperature), durable, tailored nanoengineered surfaces (reduced drag, icephobics, adhesion/abhesion, friction and wear)
Keywords to be used for downloading publication records	nanocomposite coating, nanostructured coating, nanotextured coating, nanostructured surface + coating, nanotextured surface + coating, nanoengineered surface + coating
Search query for obtaining publication and patent records	((TS=("nanocomposit* coatin*" OR "nanostructur* coatin*" OR "nanotextur* coating*" OR "nano composi* coatin*" OR "nano structur* coatin*" OR "nano textur* coatin*")) OR TS=("nanotextur* surfac*" AND coatin*) OR TS=("nanostructur* surfac*" AND coatin*) OR TS=("nanoenginee* surfac*" AND coatin*) OR TS=("nano textur* surfac*" AND coatin*) OR TS=("nano structur* surfac*" AND coatin*) OR TS=("nano enginee* surfac*" AND coatin*)) NOT TS=(bio* OR medic*))

Results

Step 1.1 Identification Phase: Publications Analysis

- 1) Consider a time range: **1995 to 2014**
- 2) Search for **nanocomposite coatings related research papers** in Web of Science
- 3) **2465 publications!**
- 4) Download detailed records (Title, Abstract, Class Codes etc.)

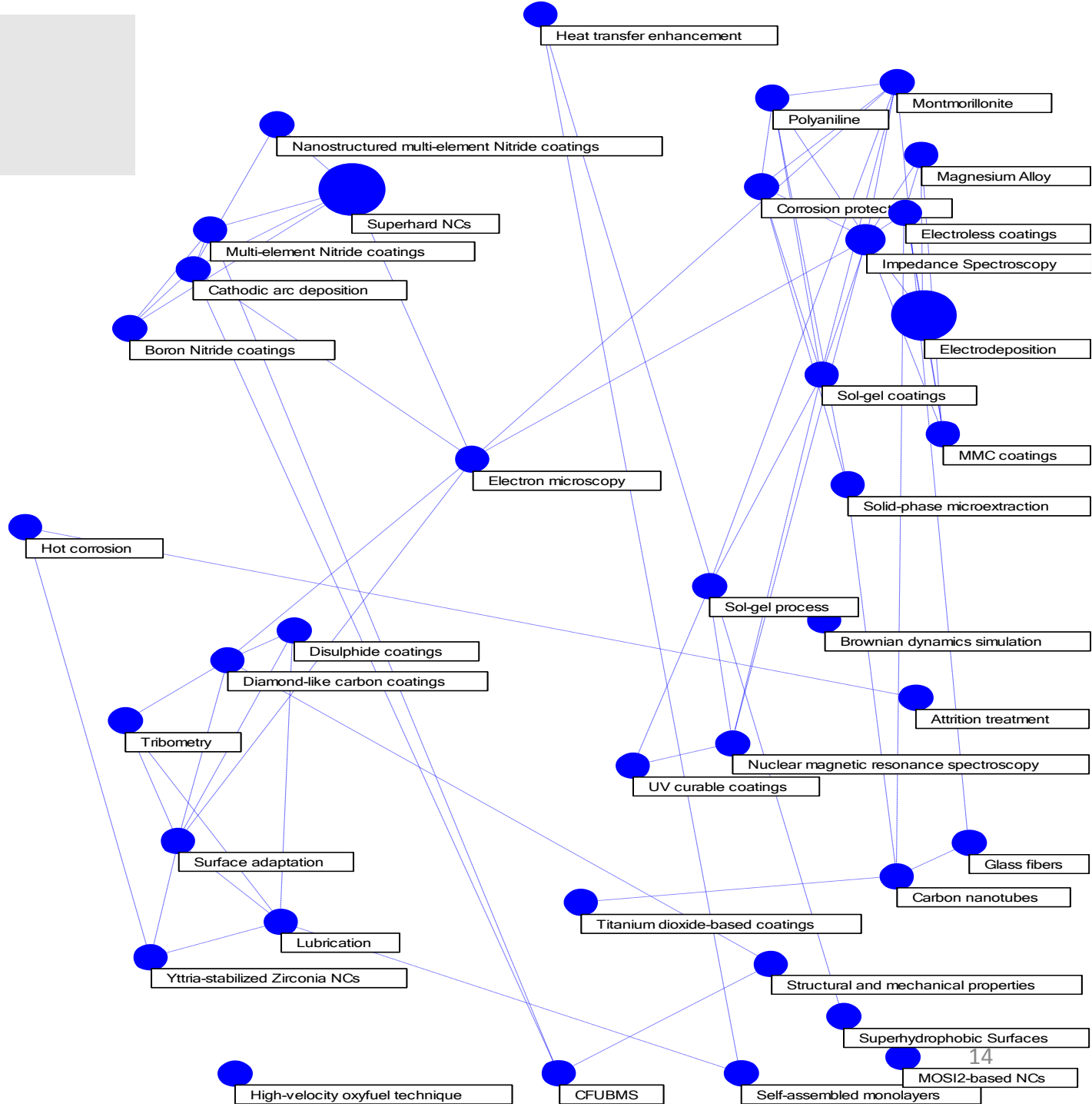
**VantagePoint
(Text Mining
Tool; NLP)**

- 1) Title and its phrases
- 2) Keywords (Plus, Author's)
- 3) WoS Categories
- 4) Publication Year
- 5) Phrases from Abstract
- 6) Author, Affiliation, Journal etc.

- 1) Perform clustering to get **topical content**
- 2) Study the **development trend** for each topic

- 1) Consider a combination of fields: **Keywords (Plus) + Keywords (Author's) + Title Phrases**
- 2) Clean this list using **ClusterSuite in Vantage Point**

Factor Map



37 Clusters covering 86% of the records

Topical Content (Publications)

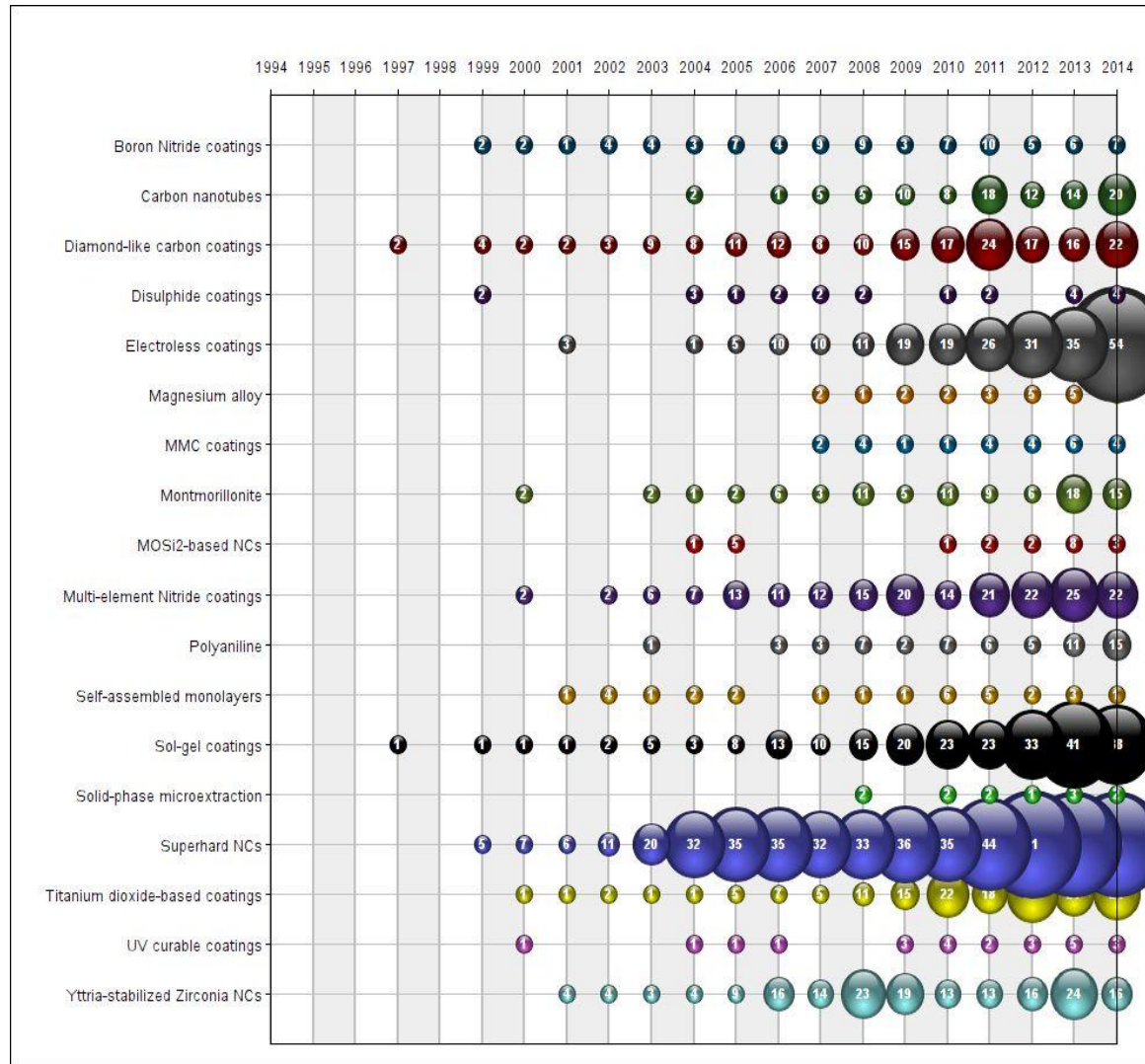
- We classify Clusters in four categories: Nanocomposite Coating type, fabrication method, characterization technique, property
- This gives us a clear picture about the focus areas of theoretical/applied research during 1995-2014

Coating	Related Clusters
Type	Superhard Nanocomposite Coatings, Sol-gel Coatings, Electroless Coatings, Diamond-like Carbon Coatings, Ytria-stabilized Zirconia Nanocomposite Coatings, Titanium Dioxide-based Coatings, Multi-element Nitride Coatings, CNT-based Coatings, Montmorillonite-based Coatings, Boron Nitride Coatings, Nanostructured Multi-element Nitride Coatings, Polyaniline-based Coatings, Self-assembled Monolayer, Magnesium Alloy, MMC Coatings, UV Curable Coatings, Disulphide Coatings, MoSi ₂ -based Nanocomposite Coatings, Solid-phase Microextraction Coatings
Fabrication Method	Electrodeposition, Sol-gel Process, High Velocity Oxy Fuel Technique, Cathodic Arc Deposition, Attrition Treatment, Magnetron Sputtering
Characterization Technique	Electrochemical Impedance Spectroscopy, Electron Microscopy, Tribometry, Brownian Dynamics Simulation, Nuclear Magnetic Resonance Spectroscopy
Property	Lubrication, Corrosion Protection, Superhydrophobic Surfaces, Surface Adaptation, Structural & Mechanical Properties, Heat Transfer Enhancement, Glass Fibres, Hot Corrosion

Topical Content (Publications)

Developmental Trend Analysis

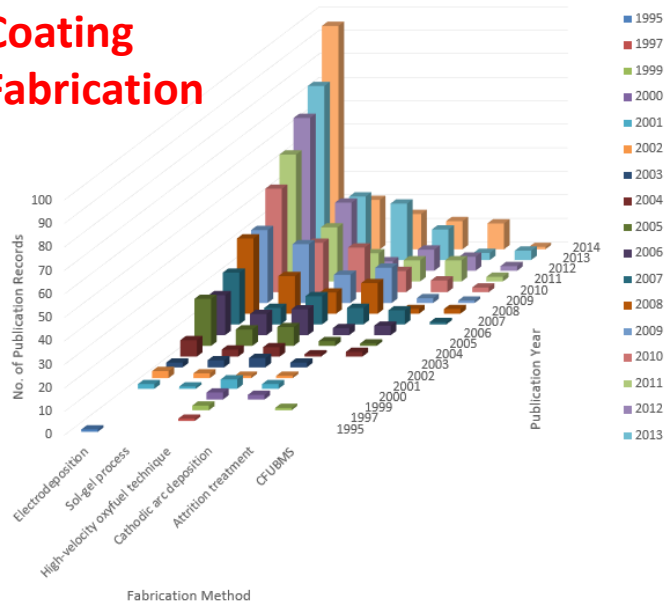
Coating
Type



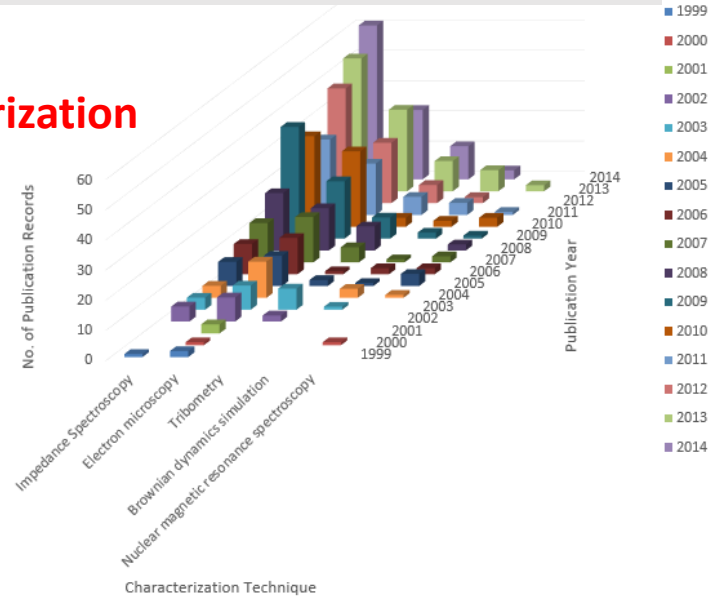
Topical Content (Publications)

Developmental Trend Analysis

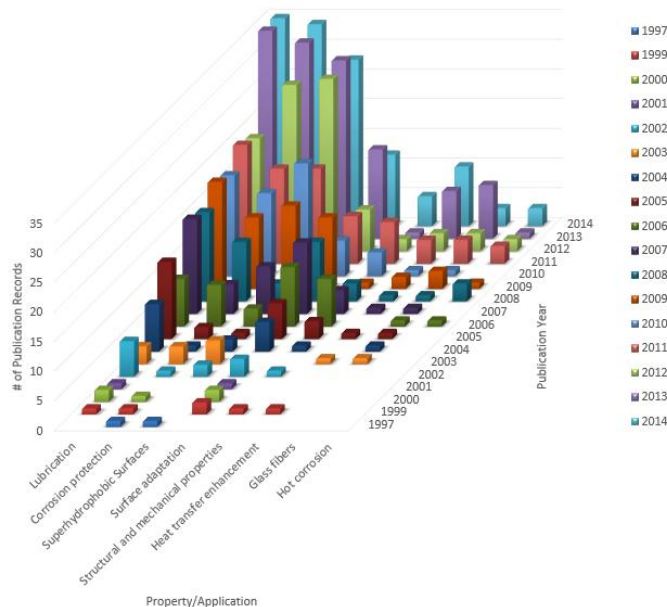
Coating Fabrication



Coating Characterization

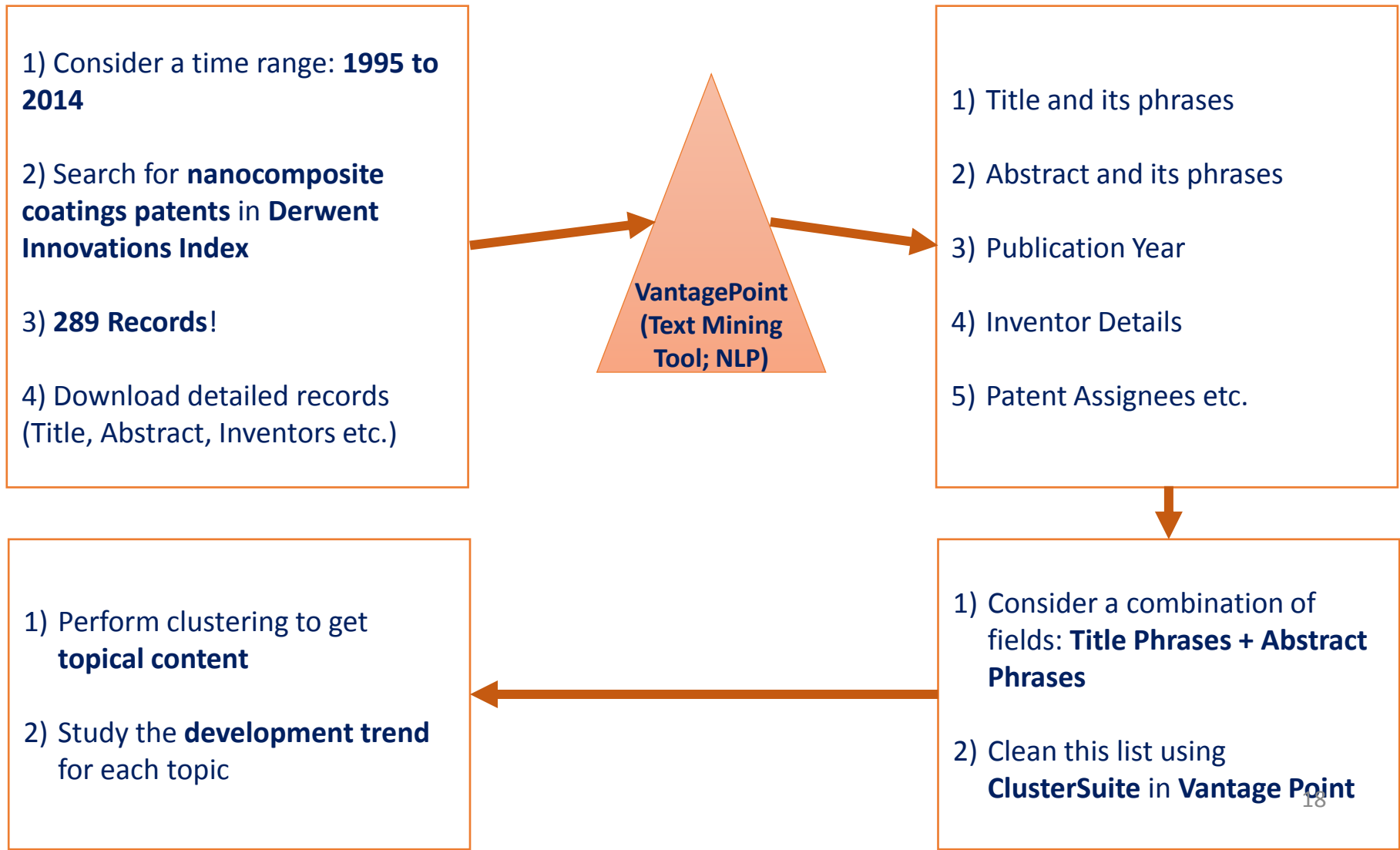


Coating Property

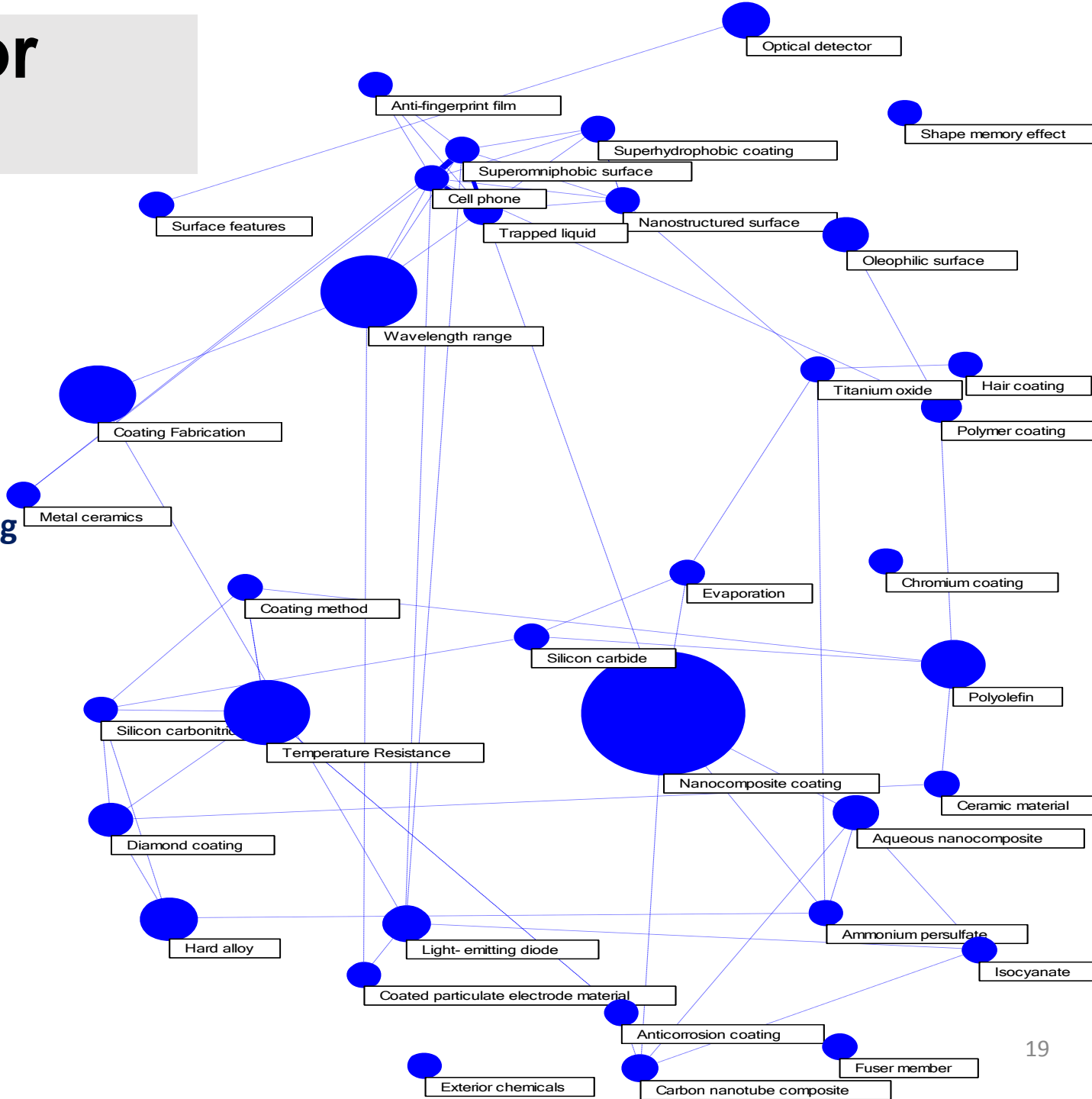


Results

Step 1.2 Identification Phase: Patents Analysis



Factor Map



36 Clusters covering 95% of the records

Topical Content (Patents)

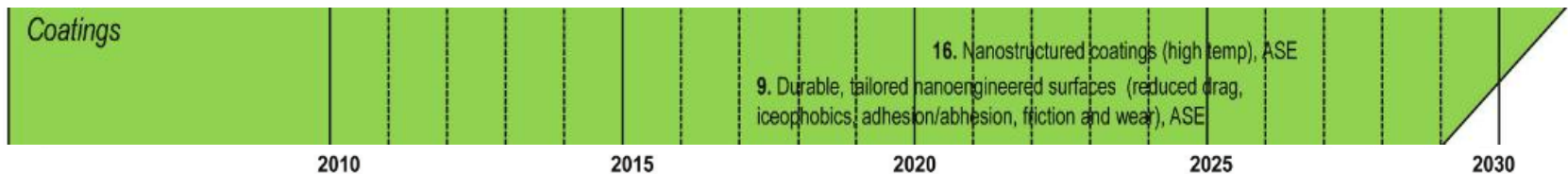
- Here, we could classify cluster in only three categories: Nanocomposite Coating type, fabrication, property
- We can clearly see the innovation areas wherein Nanocomposite Coatings have been finding their tremendous application during 1995-2014

Coating	Related Clusters
Type	Nanocomposite coating, Polyolefin, Hard alloy, Aqueous nanocomposite, Diamond coating, Polymer coating, Carbon nanotube composite, Ceramic material, Silicon carbide, Titanium oxide, Chromium coating, Silicon carbonitride, Isocyanate, Metal ceramics, Ammonium persulfate
Fabrication Method	Coating fabrication, Coating method, Evaporation
Application	Wavelength range, Temperature Resistance, Light- emitting diode, Optical detector, Oleophilic surface, Trapped liquid, Exterior chemicals, Nanostructured surface, Shape memory effect, Superomniphobic surface, Coated particulate electrode material, Superhydrophobic coating, Anti-fingerprint film, Fuser member, Surface features, Hair coating, Anticorrosion coating, Cell phone

Results

Step 2 & 3 Validation and Refinement

- Two components in the “coatings” section

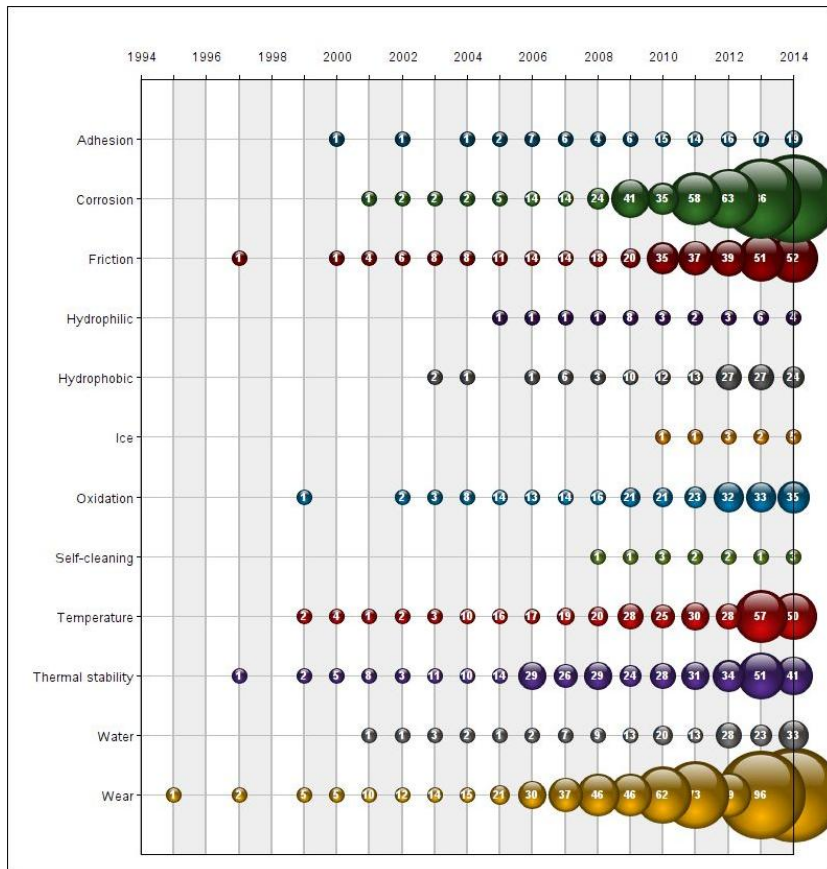


- Now to check for these predictions, we use a set of keywords -- **friction, wear, adhesion, ice, thermal stability, temperature, and oxidation**, and search for these keywords in our topical content and analyze their trend.
- Also, we consider some other keywords such as **corrosion, water, hydrophobic, hydrophilic, and self-cleaning** because information related to these will be helpful for refining the roadmap.

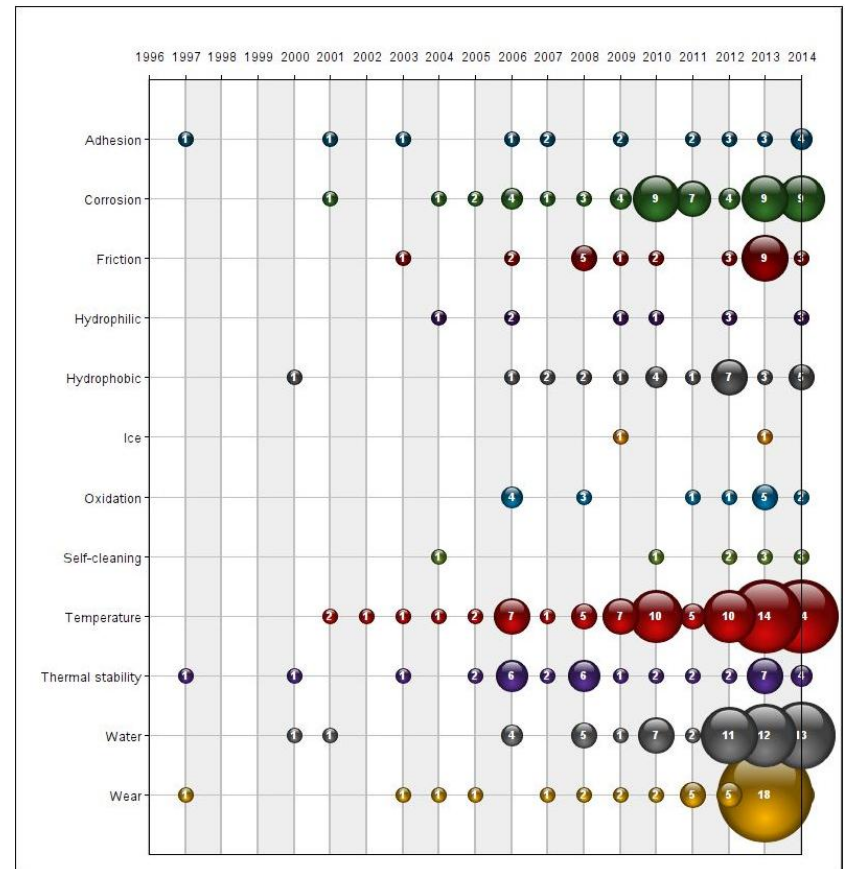
Results

Step 2 & 3 Validation and Refinement

Publication Activity



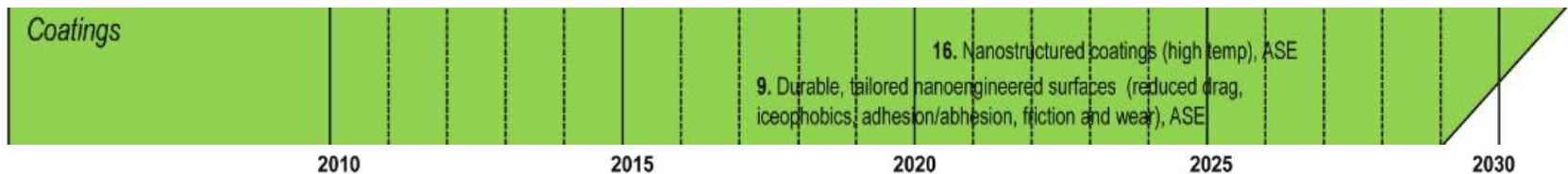
Patenting Activity



Results

Step 2 & 3 Validation and Refinement

- Two components in the “coatings” section

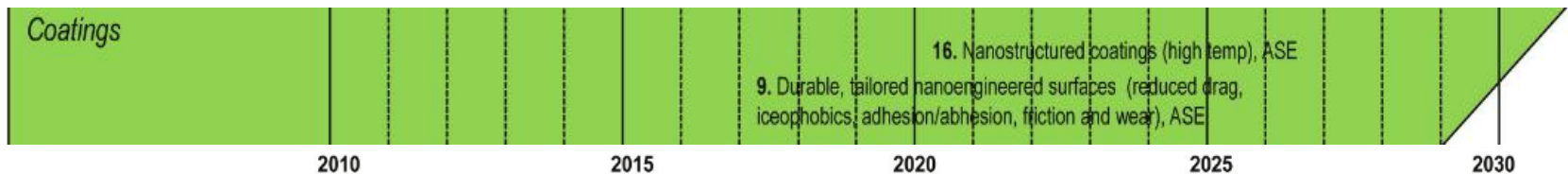


- Substantially **increasing publication activity** in the area of nanocomposite coatings with **high temperature applications**, but a **minimal amount of patenting activity**, it is expected that it would take 10-12 years from 2015 for the maturation of these coatings.
- These coatings would be more thermally stable, resistant to oxidation, and have high-temperature tribological applications.
- Hence, the prediction as made in the roadmap seems likely to prove right.
- Also, the generated topical intelligence suggests that *yttria-stabilized zirconia*, *silicon carbide*, and *ceramic based*, and *diamond-like nanocomposite coatings*, and *high-velocity oxyfuel coating fabrication technique* will be of interest.

Results

Step 2 & 3 Validation and Refinement

- Two components in the “coatings” section

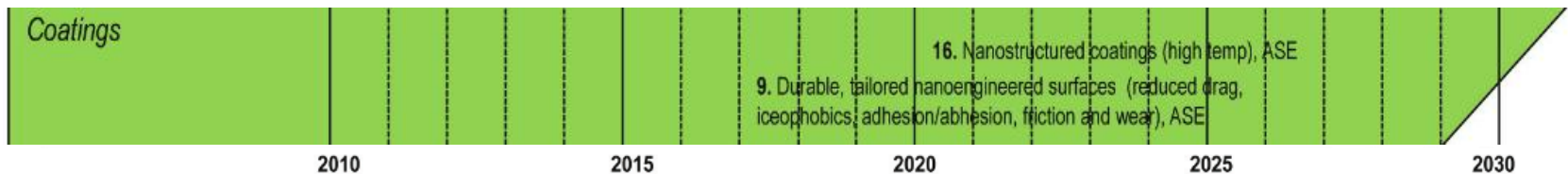


- Growing research interest in the area of nanocomposite coatings with **reduced drag/friction and increased wear resistance**, but not enough patents
- Insignificant publication and patenting activity in the area of nanocomposite coatings having **good adhesion property and ice-phobicity**
- Ice-phobic nature of the NCCs still needs attention of researchers
- Disagree with the prediction shown in the roadmap section. The maturation of these coatings should start from 2020 approximately.
- Topical intelligence points towards *electroless, diamond-like carbon, multi-element nitride and yttria-stabilized zirconia nanocomposite coatings, and high-velocity oxyfuel coating fabrication technique.*

Results

Step 2 & 3 Validation and Refinement

- Two components in the “coatings” section



- Corrosion protection behavior of nanocomposite coatings is being researched but doesn't show a significant patenting activity. It is expected that it would take 10-12 years from 2015 for their maturation.
- Nanocomposite coatings showing hydrophobic nature have been of interest to the researchers but haven't gained a momentum. Also, there are only a few patents for this category. According to experts, it will take at least 15 years from 2015 for the maturation of this technology.

Summary

- Tech Mining → Topical + Keyword Intelligence → Trend Analysis → Validation and Refinement of a Technology Roadmap Section
- Amalgamation of patents, publications and experts' opinion – (*Quantitative + Qualitative*)
- Helping hand for policy makers, strategists, technologists

Thank You!

Questions??

Nanocomposite Coatings Publications vs. Patents

