HFM

High Field Magnets Programme

HFM Scientific and Societal Impact

-

Preliminary findings and discussion about priorities

HFM Forum

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CERN Knowledge Transfer Group

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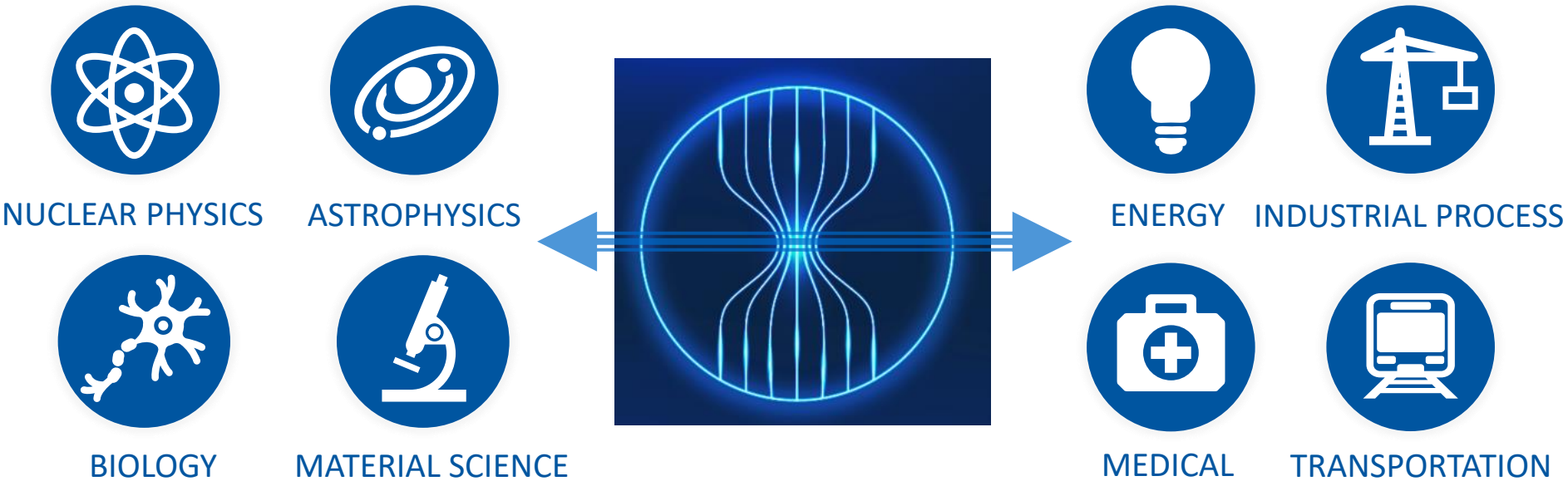
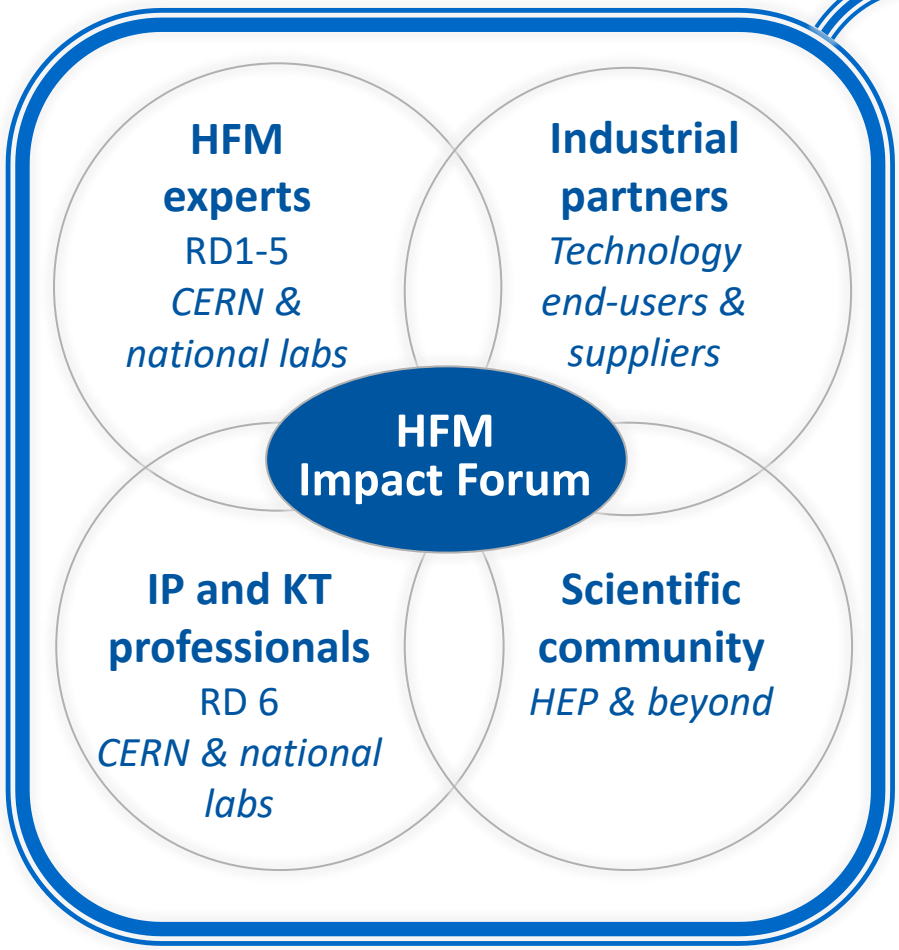
Recall: Scope of the RD Line / Work Package

Goal

Maximize the impact of HFM programme on society and science and facilitate collaboration among stakeholders and dissemination of the results.



General Approach



Collect/analyse perspectives

Integrate requirements

Define value proposition

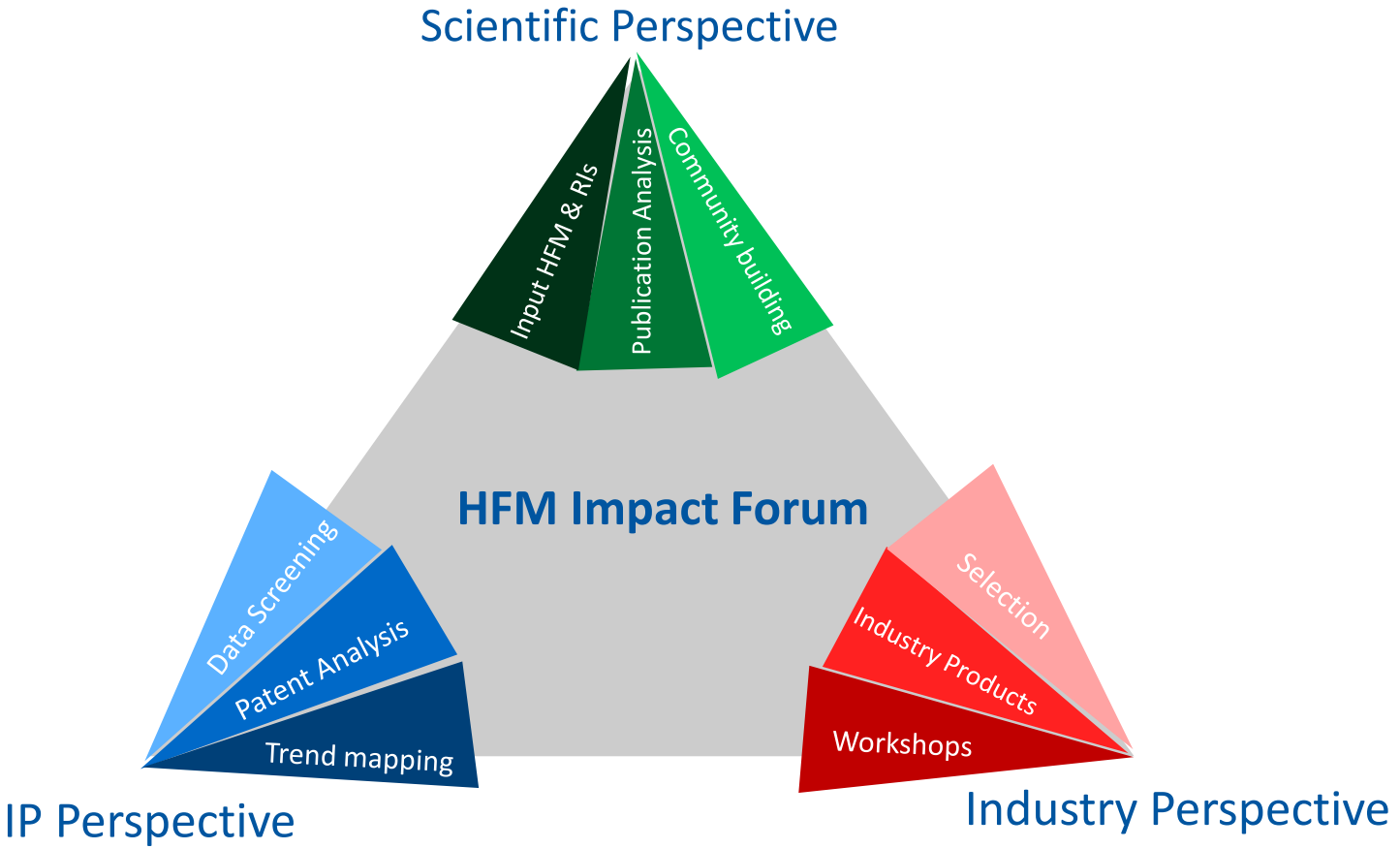
Facilitate exchanges

Establish partnerships

Generate impact together.

Implementation

Triangulation of knowledge sources enables a holistic overview.



Patent Landscape – Results Analysis

Results from Linn Kretzschmar (former WP6.1 Leader)

General Approach

1. Screen **patents** from WIPO's PatentScope using experts-selected **keywords**:
   - Niobium Tin (HFM), Nb3Sn (HFM), Quench Detection (HFM), HTS (REBCO), Nb3Sn Cable, Nb3Sn Wire Production, High Field Magnets, Cryogenics (HFM).

254 patents from 156 unique applicants across 16 countries spread over several decades with a peak in the last 10 years.

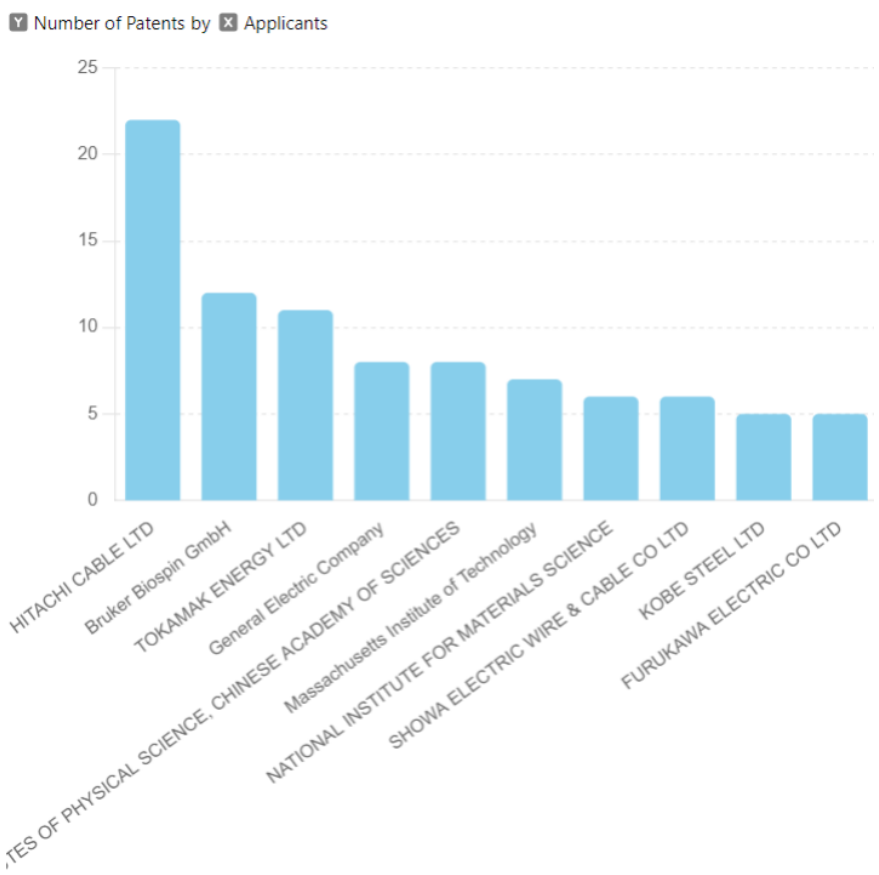
2. Use text-analysis to understand **industry trends**.

Dataset available at: https://cernbox.cern.ch/s/TVTcVKUy3RzOj4f

Results – Patents Analysis

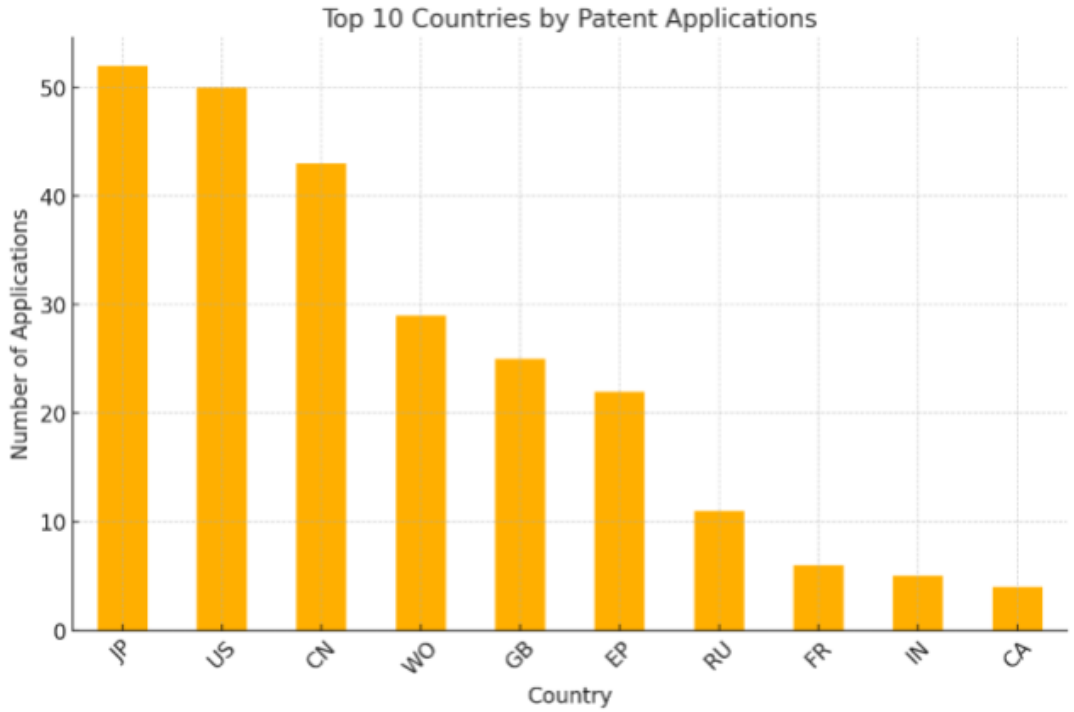
- 254 patents, 70% from industry => High business interest in HFM from the industry.

- Major applicants: Hitachi Cable, Bruker, Tokamak Energy, GE, Chinese Academy of Science, MIT => potential partners/competitors.



Results – Patents Analysis

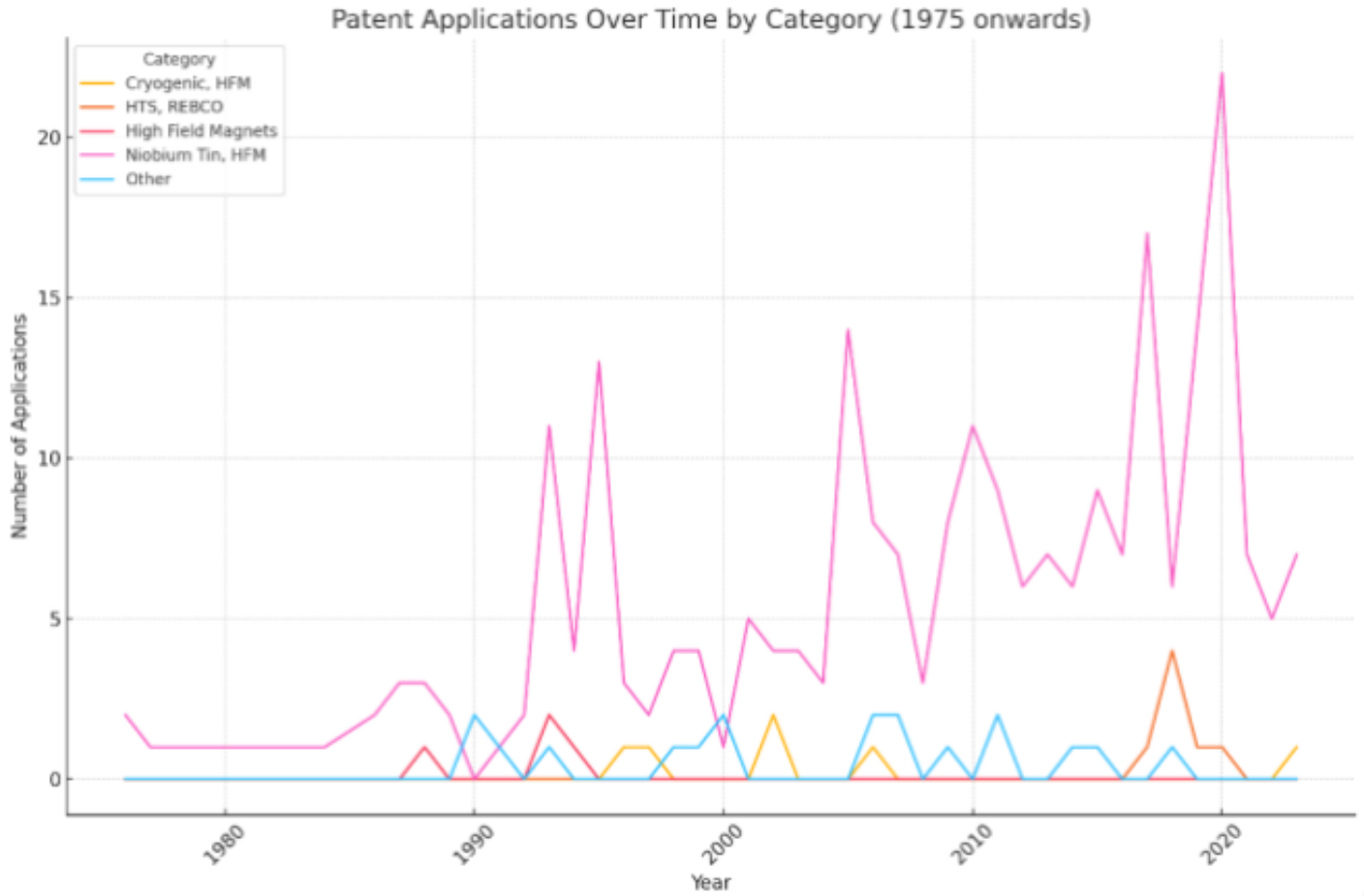
- Patents applied mostly in Japan, US and China, not so much in CERN Member States (about 25% in Europe) => strategic importance of HFM programme for European competitiveness.



WO refers to patents filed internationally, and *EP* refers to patents filed across multiple European countries through a single application

Results – Patents Analysis

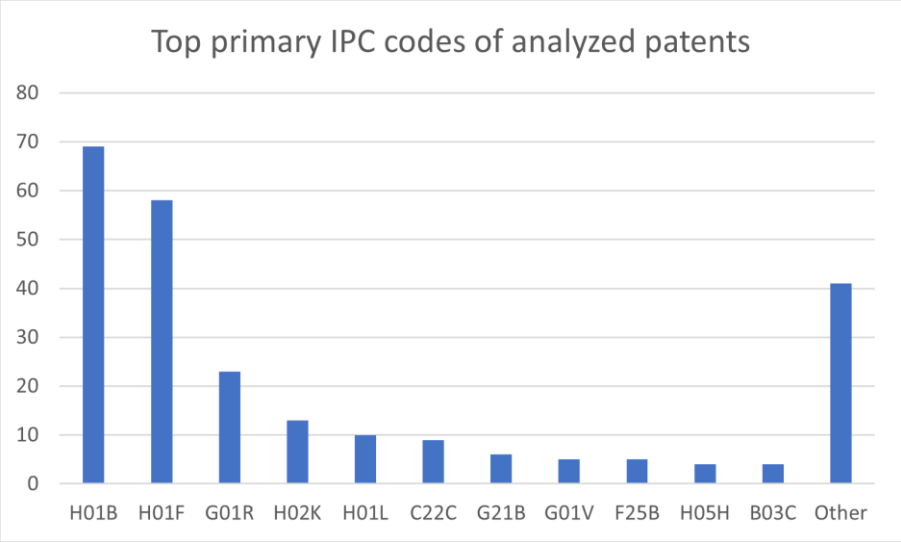
- Growth of patent numbers in specific categories => promising trends.



Results – Patent Family Analysis

International Patent Classification (IPC): worldwide system to classify and categorize patents based on different technology sectors.

- IPC codes come with different amounts of occurrences:
  - Many patents => more interest, higher TRL.
  - Few patents => more opportunities for new research.



H01B (69 patents): cables; conductors; insulators; selection of materials for their conductive, insulating or dielectric properties.

H01F (58 patents): magnets; inductances; transformers; selection of materials for their magnetic properties.

G01R (23 patents): measuring electric variables; measuring magnetic variables.

H02K (13 patents): dynamo-electric machines.

H01L (10 patents): semiconductor devices .

C22C (9 patents): alloys.

G21B (6 patents): nuclear reactor design.

G01V (5 patents): geophysics; gravitational measurements; detecting masses or objects.

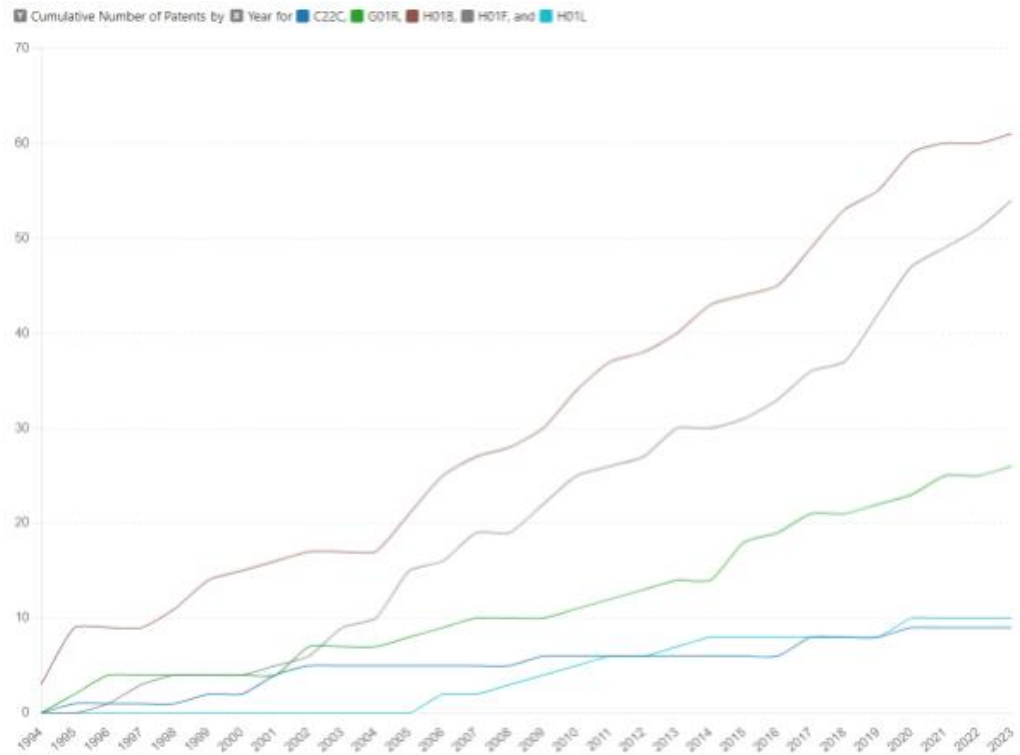
F25B (5 patents): refrigeration machines, plants or systems; combined heating and refrigeration systems; heat pump systems.

H05H (4 patents): plasma technique, production of accelerated electrically- charged particles or of neutrons, production or acceleration of neutral molecular or atomic beams.

B03C (4 patents): magnetic or electrostatic separation of solid materials from solid materials or fluids; separation by high-voltage electric fields.

Results – Patent Family Analysis

- Different growth rates for each IPC family but comparable between components and systems => integrating working components in a new system seems to be the priority.



H01B (Cables, Conductors, Insulators, Materials for Electric Properties)

H01F (Magnets, Inductances, Transformers, Materials for Magnetic Properties)

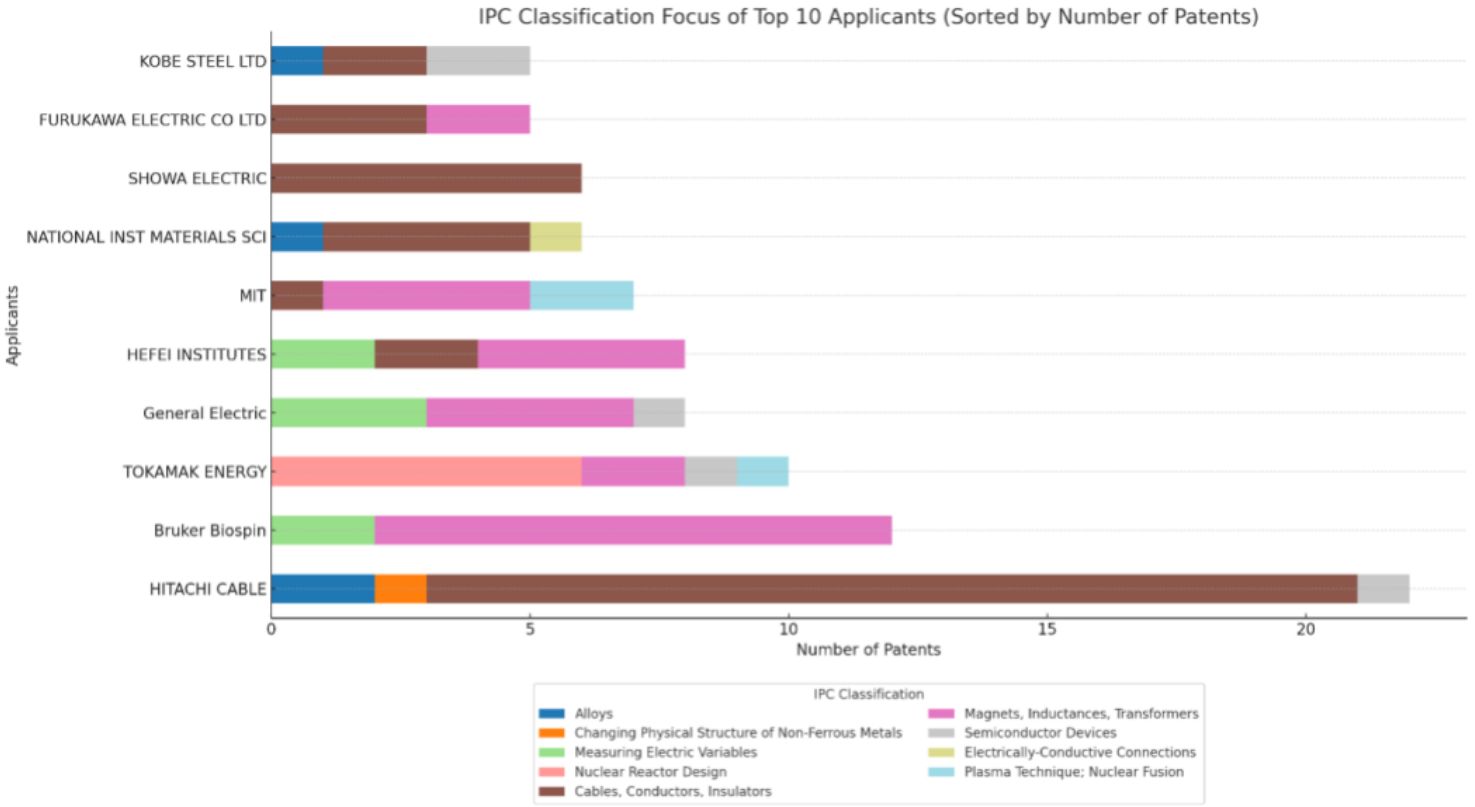
G01R (Measuring Electric & Magnetic Variables)

H01L (Semiconductor Devices)

C22C (Alloys)

Results – Patent Family Analysis

- IPC gives information on dominant focus areas for key applicants => major actors identified for specific technologies.



Results – Keywords Analysis

Idea: Analysing **occurrences of recurring groups of words** informs on key focus areas and evolution **trends**.

Top Trigrams 2000-2007	Top Trigrams 2008-2015	Top Trigram 2016-2023
sn based alloy (9)	main coil section (17)	hts current leads (18)
nb3sn wire rod (9)	diffusion barrier layer (10)	sn based wire (8)
nb3sn based wire (7)	single core wires (10)	based wire rod (8)
hts band conductor (7)	nb3sn wire rod (8)	metal interface layer (8)
inner coil section (6)	cu sn alloy (7)	nb3sn stranded wire (8)
ag sn alloy (6)	hts layer 11 (6)	Nb3sn wire (8)
outer coil section (5)	cu cu based (6)	layer bonded metal (7)
niobium nb niobium (4)	cu based alloy (6)	cu base material (7)
nb niobium alloy (4)	nb nb based (6)	nb3sn wire cable (7)
radially inner coil (4)	nb based alloy (6)	hts protection switch (6)

- Transition from material discovery and coil design to focused HTS applications and material improvements => field maturation.

Highlighted Industry Developments

Idea: Understand **industry priorities** related to the HFM Work Packages.

Procedure: Extract keywords from RD Lines description and match them to patent data to assess the major technological developments done in industry.

RD Line	Extracted keywords from RD Line description	Highlighted developments in the patents
RD1 (64 patents)	• Nb3Sn conductors, high-field magnets, CERN • Procurement, industrialization, specification, acceptance testing • Critical current, magnetothermal stability, heat treatment, characterization • Modeling, diffusion, phase tranformations, experimental techniques • Mechanical and thermomechanical behaviour, cabling degradation, strain testing	• Nb3Sn wires composite materials • Alloy optimization and stranded wire technologies for high-performance cabling • Coil construction • Precursor tubes and layered structures for superconductors
RD2 (59 patents)	• Procurement, testing, qualification, long-length REBCO tapes and cables • REBCO racetrack coils, pancake coils, mechanical properties, performance in high-field • HTS-CC architecture, stability, performance, long-length fabrication	• Multi-layered REBCO tape structures • Mechanical bonding techniques to improve stability under thermal cycling • Soldering methods for tape-stack racetrack coils • Mechanical properties of HTS materials for high-current applications
RD5 (17 patents)	• Magnetic field measurement, field mapping, flux measurement, • Data acquisition, DAQ, measurement software, sensor interface • Croygenic measurement system, superconducting instrumentation, current measurement • Test bench, magnet testing, cryostat, measurement infrastructure • Calibration tools, validation techniques, sensor calibration	• Cryostats • Magnet systems • Measurement apparatus • Mass spectrometers

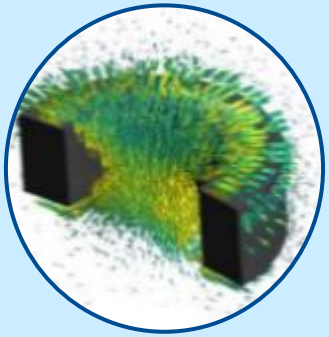
Conclusion – HFM Patent Landscape

- 254 patents from 156 unique applicants selected on the basis of HFM keywords across 16 countries were analyzed. The main results are:
  - Identification of a few **major actors** in **specific technologies** and **high interest from the industry** (70% presence in the patents against academia's 30%).
  - Comparatively **low presence in Europe** with respect to other geographical zones (only 25% fraction), showing **strategic importance** of the HFM programme.
  - Identification of different trends with the patent families:
    - Fields with **lots of developments and interest**, hence **high TRL** and possibly **less opportunities** for breakthroughs (e.g cables, conductors, magnets).
    - Fields with **less developments**, hence **low TRL** and **more opportunities** for breakthroughs, but possibly **lower interest** (dynamo-electric machines, plasma confinement).
  - Field maturation with parallel development on both **components and systems** levels.



HFM Developments with Impact Potential

HFM Developments Applicability (TBD)

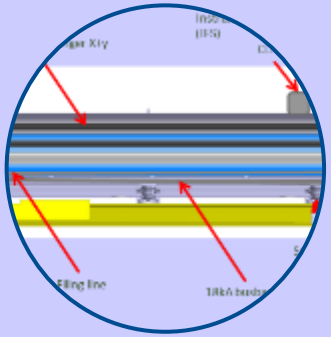


Software:

- Physics models
- Design software
- DAQ
- Processing

Components:

- Conductors
- Wires
- Cables

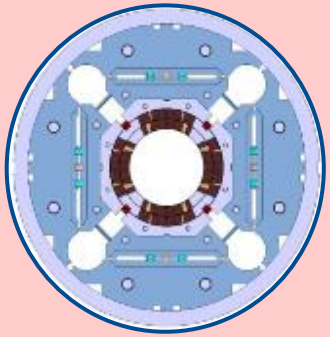


Subsystems:

- Coils
- Measurement and protection systems
- Cryostats

Infrastructures:

- Power supply
- Test benches



Systems:

- LTS Magnets
- HTS Magnets

Technology adaptation <u>complexity</u> for use in different applications, and expected <u>impact</u> level

HFM Developments Examples (TBD)

Level	Technology / Expertise	Possible Collaboration Form
1 - Software	Software tools for magnet design and optimization	Licensing
	Software tools for Electromagnetic field and quench behavior simulation	
2 - Components	Manufacturing and reinforcement techniques for high-field conductors	R&D collaboration
	HTS REBCO tapes and cables	
	Superconducting wires based on innovative materials	
3 - Subsystems	Quench detection and protection systems	R&D collaboration
	Measurement equipment, instrumentation	
4 - Infrastructures	Cryogenic testing facilities	Service
	Magnetic measurement test benches	
5 - Systems	HTS magnet for a specific application	R&D collaboration

Identified Promising Application Areas

Definition of Impact

- **Applied superconductivity experts** in the world are working on very complex problems in specific fields, **outside HFM's scope of activities**.

- Nevertheless, they sometimes face **technological challenges** which are **difficult to overcome** and do have a link to **HFM developments**.

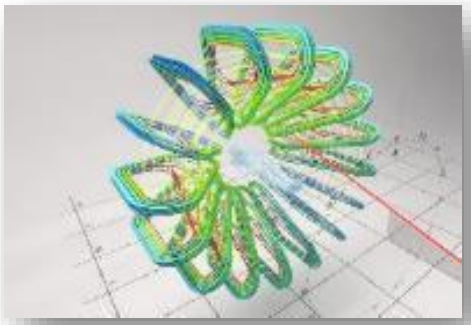
- This can lead to small and incremental, but **valuable** and **critical**, **improvement** through industry partnership, leading to **significant scientific, societal, and economical impact**.

Energy

Level	Technology / Expertise	Application area
1 - Software	Advanced magnet design and simulation software	Optimized design of specialized magnets in **fusion**
2 - Components	Advanced superconductor materials	Increased energy storage and reduced cooling requirements in **Superconducting flywheels**
3 - Subsystems	Solenoid coils	Advanced generation and containment capabilities in **fusion**
	Monitoring fault-detection systems	Safety in **energy generation**
4 - Infrastructures	Radiation tests facilities	Superconducting materials for **fusion**

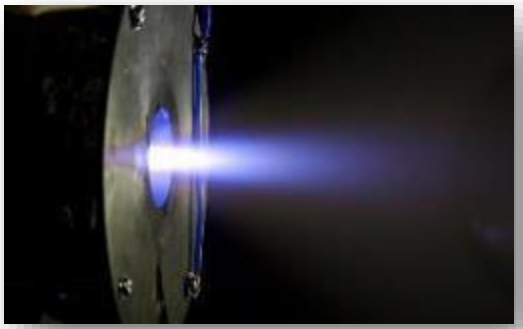
Medicine

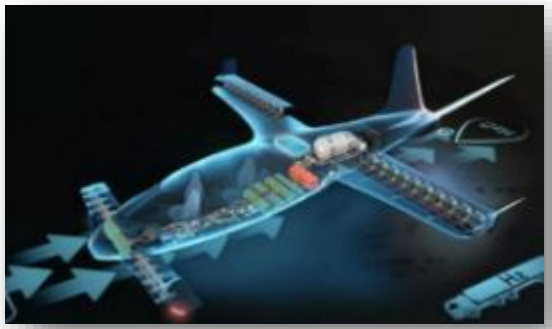
Level	Technology / Expertise	Application area
1 - Software	Advanced magnet design and simulation software	Precise **gantry** magnet geometry for accurate targeting
3 - Subsystems	HTS coils	Lower cryogenics requirements in **medical environments**
4 - Infrastructures	Test benches	Characterization of **MRI** magnets
5 - Systems	High field magnets	Increased SNR and precision in **NMR spectroscopy**



Transport

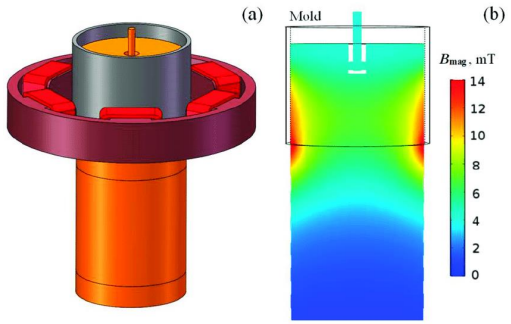
Level	Technology / Expertise	Application area
2 - Components	Advanced superconductor materials	Racetrack for **Magnetic Levitation trains**
3 - Subsystems	HTS coils	High specific impulse propulsion system in **aerospace**
	Compact efficient cooling system	HTS **propulsion motors** for maritime ships and airplanes
4 - Infrastructures	Cable testing facilities	**Onboard superconducting systems**





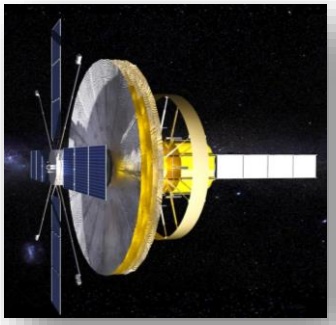
Industrial processes

Level	Technology / Expertise	Application area
1 - Software	Advanced magnet design and simulation software	Optimization of **HTS separators** design
3 - Subsystems	HTS coils	HTS-based high-gradient **magnetic separation systems**
	Monitoring fault-detection systems	Safety in **metallurgy**
4 - Infrastructures	Magnetic measurement test benches	Characterization of magnets for **Electromagnetic stirring**



Astrophysics

Level	Technology / Expertise	Application area
1 – Software	Advanced simulation software	Predicting the **instrument's magnet** operational and quench behaviour
2 – Components	Advanced materials and assembly procedures	Space-grade **mechanical structure** for launch constraints
3 - Subsystems	HTS coils	Improved performances with respect to **NC magnets**
5 – Systems	High field magnets	Increased sensitivity of **cosmic rays detectors**



KT’s Support

As responsible for the scientific and societal impact of the HFM Programme, the Knowledge Transfer group is committed to **support the HFM members**, **including external partners**, in the transfer of technologies and know-how to society, **on the basis of the IP clauses** set out in the HFM collaboration agreements.

Next Steps

Some Questions

- Patent Landscape Analysis:
  - How do the highlighted technological developments from industry **compare to your RD lines** ?
  - Do you have particular **feedback** on the results?
  - Is there any **other specific analysis** that could be interesting to perform on the patents?

- HFM Developments Impact Potential:
  - Do you have any recommendation on the **HFM developments activity** we should focus on?
  - In your Work Packages, do you already see **particularly interesting development** with promising impact potential ?

Some Questions

- Identified promising application areas:
  - Do you agree with the **proposed fields**? Do you have **additional ideas**?
  - Do you have recommendations on which **application fields** should be given **priority**?
  - Are there **technological developments in your Work Packages** which particularly fit some of these fields ?

Next Steps

1. Define HFM Value Proposition:
    1. Identify highest potential technologies & expertise developed within HFM.
    2. Industry-specific needs identification.

2. Define dissemination strategy:
    1. Identify synergies with current CERN knowledge transfer projects.
    2. Develop new applied collaborations in partnerships with selected entities.

3. Stakeholders relations:
    1. Organize thematic industrial workshops (TBD).
    2. Coordinate HFM Impact Forum.

Thank you!

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HFM

High Field Magnets Programme