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Advances in Superconductivity as a road to meet Energy and Health SDGs: joint Japanese and European research teams may take the lead

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Abstract --

Based on a statistical analysis of R&D activities in the field of superconductivity (SC) in a broad sense, the paper reports that Japan’s leadership is strong over the past 20 years, in terms of researchers publications and patents. It also essentially shows that among the main world players, the Japanese normalized contribution is significantly dominating, although some trend towards a diminished leadership is observed in the data over the period 2005 - present time. Finally, the paper highlights that by taking advantage of their internationally recognized expertise in the field, joint Japanese and European research teams may advance superconductivity as a reliable road to meet Energy and Health SDGs (Sustainable Development Goals - UNESCO 2015).

Keywords:

Statistical review of superconductivity-related achievements, energy, health, Okayama University and SDGs, joint Japanese and European leadership in superconductivity.

I – Brief worldwide panorama of major SC outcomes

I. 1 On the lab research side

Superconductivity is necessarily a microscopic phenomenon, appearing at temperatures lower than a material-specific critical temperature Tc and depending on the most detailed and intricate quantum interactions. It also has astonishing macroscopic manifestations, such as the spectacular magnetic levitation, defying the ubiquitous force of gravity. This is perhaps why so many physicists, much like Fermat’s last theorem for mathematicians, were drawn to the fundamental questions raised. Indeed, understanding the microscopic interactions between electrons which lead to superconductivity, has attracted the most brilliant minds, such as R. Feynman, P.W. Anderson, L.

Landau, P. G. de Gennes and many more. One needs only consult the long list of awarded Nobel laureates, whose breakthroughs in the field of superconductivity are widely acclaimed, to recognize this fact.

The challenges in materials science have of course attracted a great number of experimental physicists, contributing thousands of articles in high-ranking journals with experimental results which use all the techniques readily available for physical and chemical characterization. Moreover, a good fraction of the condensed matter science budget has contributed to the field, both in national laboratories and universities, but also in many laboratories linked to the private sector, mainly in the United States, Europe and Japan. However, the history of superconductivity has been characterized by major breakthroughs separated by seemingly long plateaus of intensive work, with frustratingly little new insight. Perhaps this is also the case in other fields of endeavor, particularly in theoretical physics or pure mathematics, wherein the key questions are continually at the limit of human intellectual and technical abilities.

On the other hand, plateaus have been interrupted by fabulous oases with ground-breaking, discoveries, such as in the 1930s of the Meissner-Ochsenfeld effect, the fact that superconductors are perfect diamagnets, followed by the discovery of type II materials where the magnetic field penetrates the superconductor in microscopic vortices, each vortex of rotating currents containing a flux quantum. The theory of Ginzburg and Landau, elaborated in the 1940s and published for the time in 1950, laid the foundation for understanding the macroscopic manifestations of superconductivity from a microscopic wave function, in tandem with the quantum theory of condensed matter. A. Abrikosov, also a member of the ‘Russian school’, had a deep understanding of the Ginzburg-Landau approach, and was able to establish that vortices are arranged in an ordered lattice, now called the Abrikosov vortex lattice. The thermodynamics of the vortex state, the vortex interactions and their motion, turn out to be fundamental in the possible applications of type II superconductors.

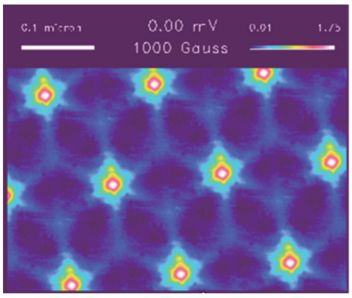


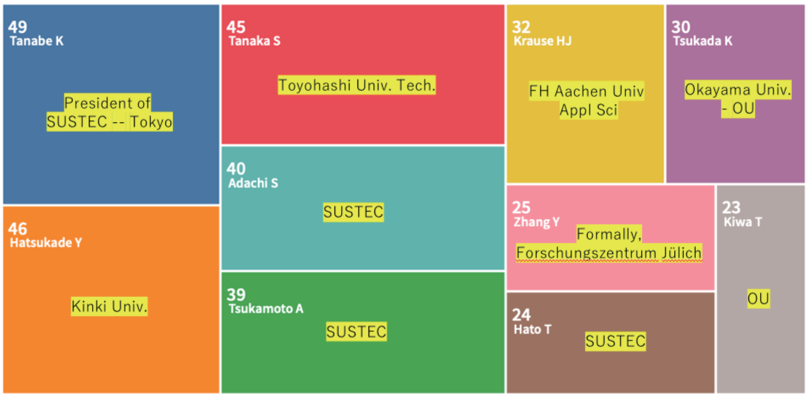
Figure 1: Scanning tunneling spectroscopy (STS) image of $NbSe_2$ in the revealing the vortex lattice, from Harald Hess et al., Bell labs, (1991) [1], and references therein.
Applied field : 1000 Gauss, Image size .35 micron x .3 micron.

A true microscopic theory of superconductivity was elaborated in the late 1950’s by J. Bardeen, L. Cooper and J. R. Schrieffer (BCS). This was a spectacular advancement for a number of reasons: It introduced a new quantum object, the ‘Cooper pair’ of electrons, that in a large number condense into the superfluid. It recognized the basic interaction of the pairing ‘glue’, the lattice vibrations of the solid, or phonons, and provided the key parameters of the transition, such as the critical temperature, the Cooper pairing energy, and more.

This was a major breakthrough in condensed matter physics, whose impact on the understanding of collective phenomena was outstanding. It was even possible to derive the significant macroscopic manifestations of the superfluid, such as the Meissner effect, infinite conductivity, vortices in type II superconductors, and much more.

The ‘golden era’ of conventional superconductivity was crowned by the seminal discovery by B. Josephson of Cooper-pair tunneling between two superconductors across a normal thin barrier, leading to the so-called ‘Josephson effect’. The corresponding applications are highly acclaimed, in particular the SQUID (Superconducting QUantum Interference Device) magnetometer whose sensitivity to the smallest magnetic field is unparalleled (for a review about SQUID see [2], [3], [4]). It is worth noting that Japanese research is in the spotlight in the field of SQUID technology and in particular HTS-SQUID (see Figure 2).

Figure 2: HTS-SQUID best authors (from WoS) - SUSTEC resulted upon refurbishing from the International Superconductivity Technology Center ISTEC (see section III- Patents for more details)



In the meantime, beyond the simple metal elements, material science focused first on different metal alloys, such as niobium-tin, but then on semimetal binary materials, such as transition metals combined with non-metals. Many different properties were discovered and investigated that go beyond this text, but note that, armed with basic ideas of the fundamental parameters of the superconducting state, higher and higher critical temperatures were reached, leveling off at about 24 Kelvin by the mid-1970s. The niobium-germanium compound Nb_3Ge has a critical temperature at this value. Indeed, based on the idea of electron-phonon coupling as the energy required for Cooper pairing, this was considered the highest temperature attainable. Then came the discovery of high-temperature superconductivity (HTS) in the cuprates by G. Bednorz and A. Muller in 1986.

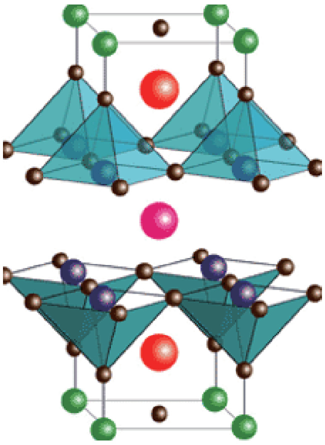


Figure 3: Atomic structure of $YBa_2Cu_3O_{7-\delta}$. This widely studied cuprate has a critical temperature of 93 Kelvin at optimal oxygen doping ($\delta = 0.03$).

Their first paper, reporting the critical temperature of 35 Kelvin in a rare-earth chemically-doped Perovskite LaBaCuO, came as a bombshell. In an unprecedented worldwide rush to the laboratory, soon after very high-Tc materials were discovered such as LaSrCuO (40 Kelvin), BiSrCaCO and YBaCuO (Tc max around 95K), and many more. The class of materials is based on cuprates where the superconductivity is known to be linked to the CuO_2 atomic planes, thus linked to a quasi-two-dimensional electron structure.

Nowadays, this field has regained a great momentum thanks to some very exciting findings regarding hydrides. Indeed, following some previous results pointing towards the same direction, in 2020 it has been shown that an H–C–S compound is able to keep its superconducting state up to about 288 K = 15°C [5], which represents a milestone and makes the dream of superconducting applications working at room temperature (i.e. without any need for cooling systems) much closer. Unfortunately, this material requires a very high pressure of about 2 million atmospheres to show superconductivity at so high temperatures. This makes applications still impractical at the moment, but the fascination of the quest for the “holy grail” of room-temperature, ambient-pressure superconductivity is very high, and the scientific community is taking on the challenge.

It is also important to note the unprecedent breakthroughs that researches for these new superconductors have experienced by using advanced experimental techniques, like synchrotron radiation for instance.

I. 2 Applications

In parallel, and in total symbiosis with lab research, huge SC oriented efforts in industrial communities as well have been performed: amid a range of other fascinating technological breakthroughs permitted by HTc SC, the goal of carrying out electrical supply without any loss at room temperature actually boosted research and greatly stimulated the hunt for this holy grail (see [6] for a substantial recent review).

I. 2. a - Medical and biopharma applications

Currently, the major commercial applications of superconductivity involve low-temperature superconducting materials and high-field magnets in Nuclear Magnetic Resonance (NMR) and medical Magnetic Resonance Imaging (MRI). NMR spectrometers are widely used by different disciplines such as biology, chemistry, pharmacy, and environmental sciences to study the structure, interaction, and kinetics of complex molecules. The expressed need for research spectrometers with the highest possible resolution represents today one of the motivations for the development of the high-temperature superconductor technology. In fact, in addition to their superior properties at relatively higher temperatures, HTS materials also come along with significantly expanded magnetic field capabilities. The first-ever high-resolution NMR spectra at 1.1 GHz – corresponding at 25.9 T – have been recently recorded by using a novel HTS/LTS hybrid superconducting magnet [7].

In the MRI devices, the field homogeneity and stability provided by superconducting magnets are essential to achieve the resolution, precision, and speed required for clinical imaging. Commercial MRI systems operate at a magnetic field between 0.5 and 7 T, but ultra-high field devices, up to 11.7 T, are being developed to increase the spatial and temporal resolution of the images with the ambitious goal of decoding the functioning of the human brain. The latter would lead to unprecedented advances such as Alzeimer's disease, cerebral thromboses, etc.

Another need for such high-performing imaging systems is the detection of early responses on therapeutic modalities for predicting outcomes and adjusting therapies. In addition, innovative methods in radiation therapy such as irradiation with ions that are heavier than protons or Boron Neutron Capture Therapy (BNCT) are currently being introduced in the clinic [8, 9, 10, 11]. This requires extremely powerful accelerators, which must also be very compact to be integrated into a hospital. LTS materials are a prerequisite for this.

I. 2. b - Superconductivity and 'Big Science'

Superconductivity is a core technology that has fueled the progress in high-energy physics accelerators and thermonuclear fusion reactors. The Large Hadron Collider (LHC) at CERN uses more than a thousand superconducting magnetic dipoles and quadrupoles, corresponding to about 1200 tons of Nb-Ti wires cooled at 1.9 K.

Today the prime candidate for the development of the Future Circular Collider (FCC) magnets is the alloy Nb3Sn, but the critical current performance of industrial wires is still not sufficient. Many laboratories around the world took up the challenge to lift the wire performance out of stagnation in view of FCC industrialization of the process. This is a key parameter as FCC will require superconducting materials in massive quantities – an estimate of 9'000 tons of Nb3Sn.

CERN has also plans for upgrading LHC on the medium-short term to the so-called High Luminosity LHC (HL-LHC), expected to come into operation in 2026.To reach the expected HL-LHC luminosity, i.e. the number of useful interactions, it will be necessary to increase the nominal value by a factor of 5. This will be achieved by replacing the actual quadrupoles in the interacting region with high-field Nb_3Sn magnets. High-current MgB_2 cables operating at 25 K in helium gas will be also used.

I. 2. c - Power generation and distribution: the role of superconductors

Powerful new superconducting generators, high-capacity cables and fault current limiters are among the solutions that will enhance the efficiency and reliability of electricity generation, transport and distribution.

In the generator application, superconductors provide technical solutions to upscale the power generation and reduce the weight of wind turbines, which will also lower the production price of electricity from renewable sources. For instance, the European project ECOSWING recently allowed testing the first superconducting wind turbine connected to the electricity grid in Thyborøn, Denmark [12].

Among all HTS power applications, cables are probably the most experienced. One of the main advantages resulting from the use of HTS cables is their high power density. In congested urban areas, expanding the capacity of an underground power line can involve digging up streets and can be expensive and disruptive. Because superconductors can carry orders of magnitude more current than conventional conductors of the same cross-section, a convenient use for HTS cables is their installation as retrofit cables in some existing paths where the conventional copper cables are operating at their limits. The AMPACITY project represents a remarkable example [13]: in the city of Essen, Germany, a 10 kV-2.3kA superconducting cable has been integrated in the electric grid of the downtown since 2014. The cable has made it possible to simplify the architecture of the distribution network without giving up redundancy, while adding resilience thanks to a fault current limiter.

Despite all these achievements, SC research, however, started to gradually fade away in Europe from the beginning of the 2000s, and support momentum for research was progressively reoriented to research delivering concrete achievements in the shorter term. The recent Covid epidemic even strengthened this trend.

In contrast in Japan, over the same period, SC research remained lively: this is what non-Japanese SC researchers can observe, feel, and live when collaborating with Japanese SC research teams and companies. To give more substance to these impressions and observations, a statistical comparative analysis of SC R&D activities in Japan, Europe, USA, and other countries active in the field, has been performed. These are the topics of the following sections.

II - Soundness of Superconductivity research as a performing tool for SDGs

The 17 Sustainable Development Goals (UNESCO-2015) serve as a universal call to action to protect the planet and improve the lives and prospects of all global citizens. Since 2015, these global goals for sustainable development have been translated and embedded into the strategic direction of institutions at national and local levels.

Okayama University is significantly committed to realizing SDGs tackling world’s most pressing challenges such as poverty, hunger, and inequality, while ensuring social inclusion, environmental sustainability and economic prosperity (see [14]).

Universities are hubs for knowledge, discovery, and innovation that can provide the expertise, resources, and know-how to contribute and move the UN 2030 Agenda forward. A wealth of new knowledge is steadily generated by Okayama University high-level professors and researchers, thus passing a rich legacy to the next generations.

Beyond the classroom, the SDGs embody core themes of sustainability and well-being.

II - 1 - Superconductivity for SDGoal # 7 "Affordable and Clean Energy" and Goal # 13 "Climate Action"

Superconductivity, in general, allows perfect current transmission without losses. This makes it a valuable resource for sustainability in several aspects. High-temperature superconducting (HTSC) materials will be crucial for sustainable everyday eco-friendly applications and more attractive for the United Nations’ SDGs. Superconducting magnets can be used as high-field magnets in magnetic resonance imaging, nuclear magnetic resonance, water purification, magnetic drug delivery, etc. In the future, DC electric energy from solar plants in Africa could be transported worldwide, especially to cold countries, using superconducting cables. Superconducting technology is an efficient way to create sustainability as well as reduce greenhouse gases.

Mitigating climate change, clean environment, global peace, financial growth, and future development of the world require new materials that improve the quality of life: SC materials can be huge hope carriers.

II - 2 - Superconductivity for SDGoal # 3 "Good Health and Well-being"

Numerous reports mention the need of leveraging cutting-edge quantum detectors to design light and portable MRI machines working at ultra-low magnetic fields for 1/5th of the cost. MRI’s are non-invasive and provide high-quality images, yet remain incredibly scarce.

Even a large portion of the OECD countries, which are the best supplied, fail to pass the threshold of 15 machines per million inhabitants recommended by the WHO. Consequences are appalling: the waiting time to get an exam is extremely long (34 days on average in France) and the use of MRI is restricted to the most urgent cases.

Magnetic field homogeneity and stability provided by superconducting magnets are essential to achieve the resolution, precision, and speed required for high precision clinical imaging. Commercial MRI systems operate at a magnetic field between 0.5 and 7 T, but ultra-high field devices, up to 11.7 T, are being developed to increase the spatial and temporal resolution of the images with the ambitious goal of decoding the functioning of our the human brain. The latter would lead to unprecedented advances in a number of brain diseases such as Alzeimer's disease, cerebral thromboses, etc.

III - Statistical analysis of SC leaderships around the world

20 to 30 years after the 1980-1990 'golden age' of Superconductivity, when American, European and Japanese research groups were greatly contributing the advances in the field, the landscape of still active major players has significantly faded.

Concerning the Japanese activities, although there is no Japanese fellow among the Nobel Prizes in SC, many Japanese researchers have brought up outstanding contributions to the field.
Following is a brief chronology issued from "Kakenhi bear fruit with fundamental research" by Pr. H. Fukuyama [15]: 1986 - Confirmation of superconductivity (Meissner effect) in copper oxides, and identification of their chemical composition and crystal structure (S. Tanaka, K. Kitazawa, S. Uchida, and H. Takagi), 1987 - "LaSrCuO" (K. Kohji et al.) -- 1988 - "Bismuth copper oxides" (H. Maeda) --1989 - "Electron-doped copper oxides" (Y. Tokura, H. Takagi, S. Uchida) -- 1994 - "Sr_2RuO_4" (Y. Maeno) -- 1996 - "Copper oxide ladder compounds" (J. Akimitsu, N. Mori) -- 2001 - "MgB_2" (J. Akimitsu) -- 2003 - "Cobalt oxides" (E. Muromachi) -- 2004 - "Bismuth-based copper oxide and related superconductors - LaSrCuO" (H. Eisaki [16]) -- 2005 - "Origin of the metallic properties of heavily boron-doped superconducting diamond" -- (T. Yokoya et al. [17]) -- 2008 - Iron pnictides (H. Hosono [18]).

More recently:

2012 - BiS_2 based superconductor (Y. Mizuguchi, Y. Takano [19])

2015 - Review and Japanese MEXT support to SC research - Iron pnictides (H. Hosono [20])

2018 - Unconventional superconductors from magic-angle graphene superlattices - (MIT, Harvard and the National Institute for Materials Science, Tsukuba, Japan [21])

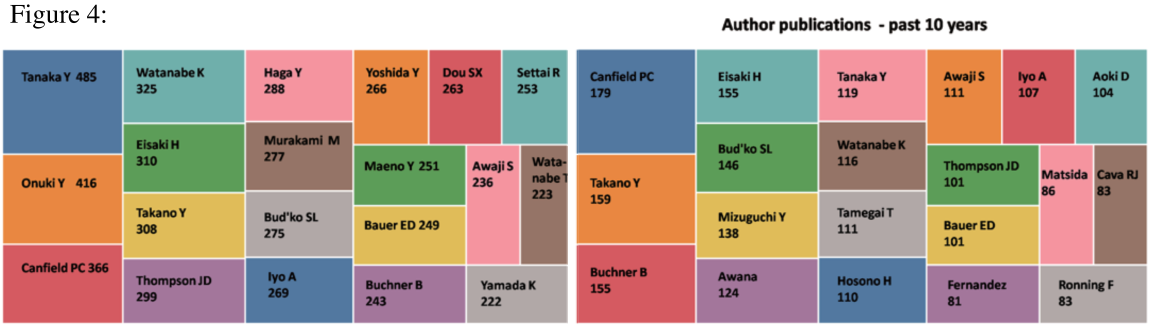
2019 - High interest in Iridates such as SrIr$_2$, SC under pressure. See for instance a contribution from Okayama University [22].

To substantiate the strength of a Europe - Japan axis, a statistical approach of R&D productivity in SC has been performed. It aims at providing some insight of the respective powers in the field.

III - 1 Scientific Papers -- Top Researchers

The 2 graphs (from Web of Science - WoS) of figure 4 depict the SC productivity per researcher. Integration over 10 and 20 years show a clear predominance of Japanese researchers. The trend is however at the reduction of the predominance over time.
Looking into details (table of figure 5): a decline is observed in the total figures. Indeed, over the past 10 years the number of papers is significantly lower than the half of 20 years' period: 2369 (10 years) vs 2912 (half of 20 years).

Figure 4:



(a) Author publications in SC over the past 20 years (Web of Science - WoS)
14 Japanese among the 20 best

(b) Over 10 years

11 Japanese over the 20 best

Maybe the 20-year period includes researchers much older from the ‘golden age’ who retired around 2010. Also, the last 10 years have shown a remarkable increase in other technologies, such as AI and robotics, photonics, spintronics, that naturally attracted new young researchers.
Nevertheless, over the 20 year period, the fantastic discoveries by Akimitsu (MgB$_2$) and Hosono (Iron-based SC) accounts for nearly 12% of all high-critical temperature publications ! See plot of figure 5.

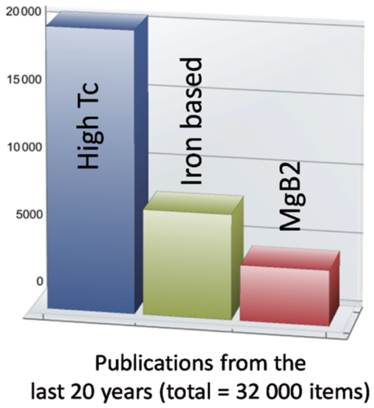
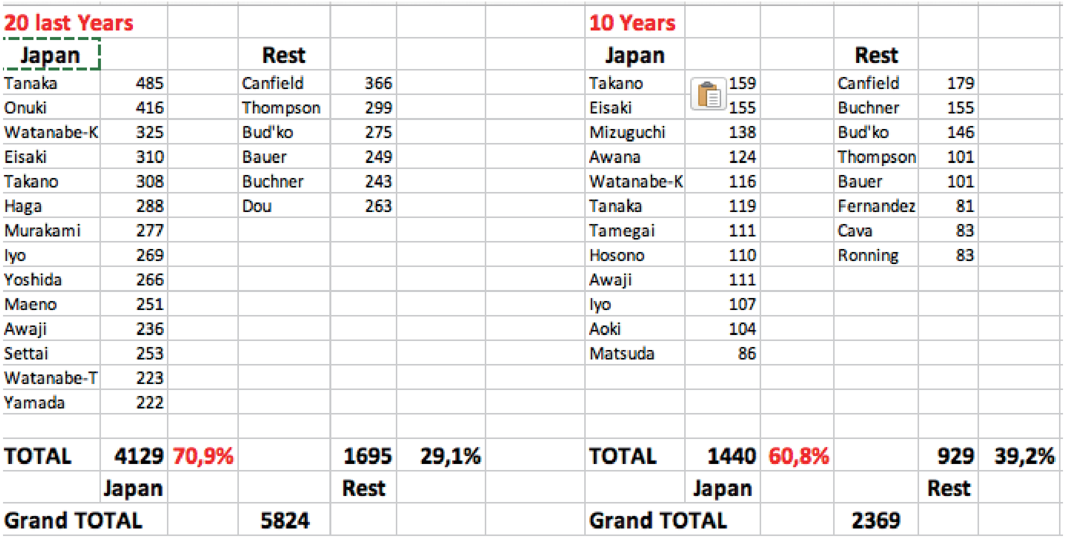


Figure 5: total number of papers in HTS and the MgB$_2$ and Iron- based SC Japanese ones.

Table1: Number of papers authored by the 20 most prolific authors in the world in the field of SC. Authors citizenship is expressed as Japan/rest of the world - NB: the table does not include Chinese authors although their contributions have become predominant in the 10 past years (==> 2020)



20 last Years							10 Years					
Japan			**Rest**				**Japan**			**Rest**		
Tanaka	485		Canfield	366			Takano	159		Canfield	179	
Onuki	416		Thompson	299			Eisaki	155		Buchner	155	
Watanabe-K	325		Bud'ko	275			Mizuguchi	138		Bud'ko	146	
Eisaki	310		Bauer	249			Awana	124		Thompson	101	
Takano	308		Buchner	243			Watanabe-K	116		Bauer	101	
Haga	288		Dou	263			Tanaka	119		Fernandez	81	
Murakami	277						Tamegai	111		Cava	83	
Iyo	269						Hosono	110		Ronning	83	
Yoshida	266						Awaji	111				
Maeno	251						Iyo	107				
Awaji	236						Aoki	104				
Settai	253						Matsuda	86				
Watanabe-T	223											
Yamada	222											
TOTAL	**4129**	**70,9%**		**1695**	**29,1%**		**TOTAL**	**1440**	**60,8%**		**929**	**39,2%**
	Japan			**Rest**				**Japan**			**Rest**	
Grand TOTAL			**5824**				**Grand TOTAL**			**2369**		

III - 2 Papers vs Countries / Regions

Looking at the past 10 years, browsing web of science (WoS) with the keyword "superconductivity" provided the following outcomes:

a - More than 7000 publications out of 26275 entries were found for USA. China comes next, followed by Japan and Germany (see figure 6). A more accurate picture is given by weighing data as a function of the respective populations (Europe: 450 millions, Japan: 126 millions). The productivity of Japanese scientists in this field is higher than that of their European colleagues.

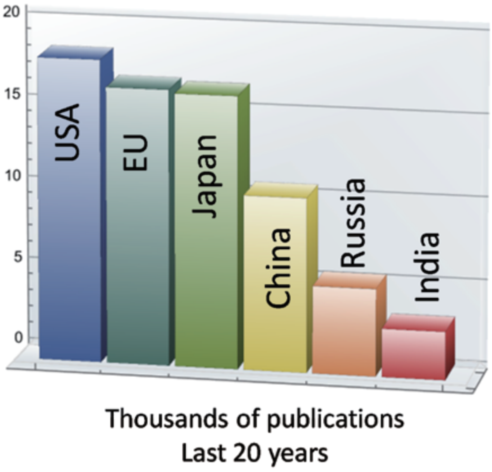
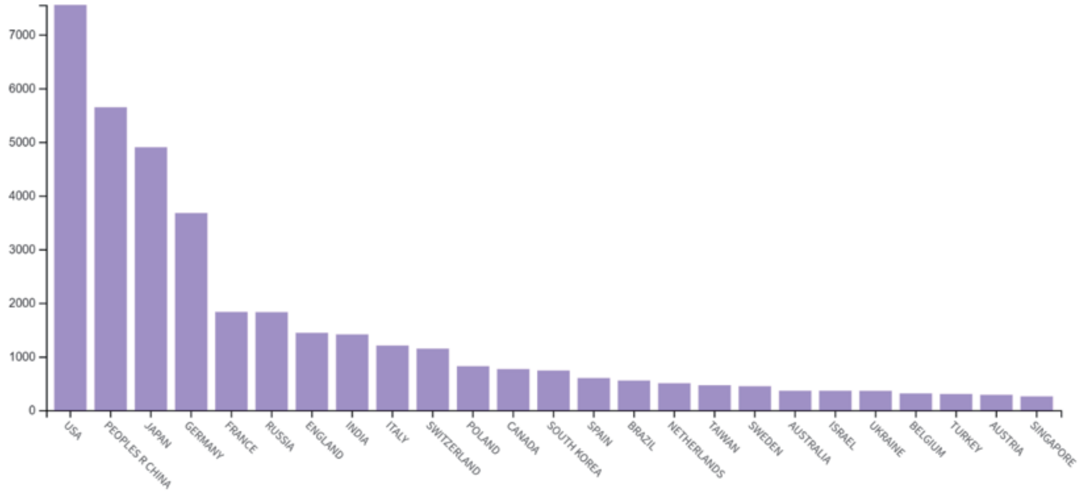


Figure 6

b - A slightly different weighing scheme has also been used to investigate the absolute numbers of publications on superconductivity released in EU and the Japanese level: figures of physical societies in both zones have been considered.

Figure 7: Distribution by country of the SC related papers published over the past 10 years.



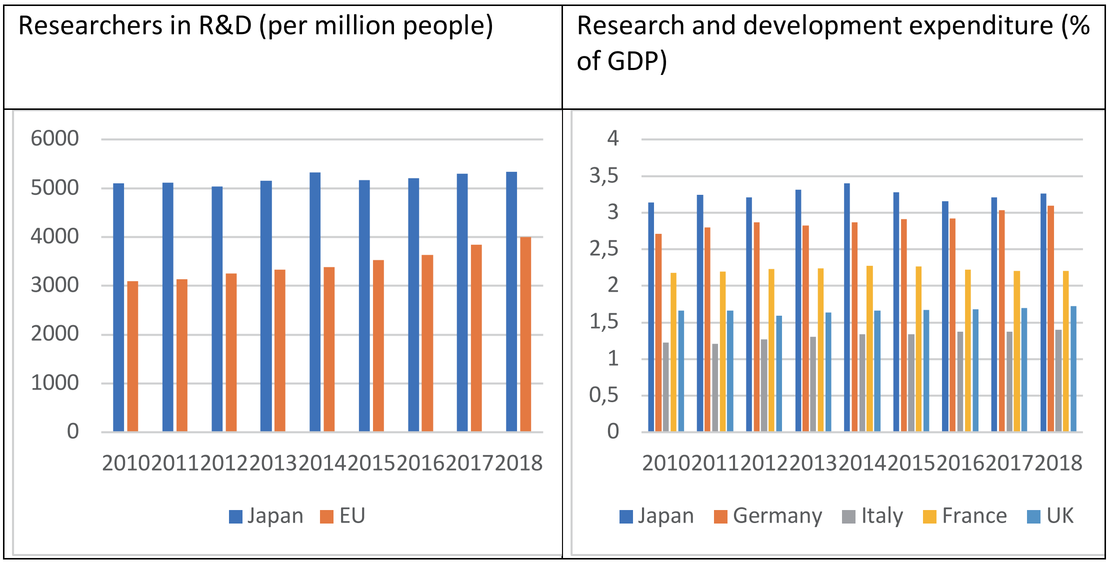
Those indicators have been selected to go beyond academic research. Indeed this approach can also include researchers in companies that may as well be members of local physical societies. Finally, we assume that the number of members of physical societies in both EU and Japan was constant during the past 10 years. Following those premises (see figure 7), we found that 17 000 Japanese researchers published 4 900 papers on superconductivity during the past10 years, which gives a ratio of 0.288 papers per researcher. In Europe, 120 000 researchers (including UK and Switzerland) published 12 271 papers on that topic, with a ratio of 0.102. From those data Japanese researchers are thus twice more productive than their Europeans colleagues. Interestingly, Japanese researchers are also more productive than their US colleagues whose ratio is 0.151. As no data were available from Chinese researchers, we couldn't replicate our analysis for this country.

We have checked that results are not significantly altered if we restrict our analysis to the top 5 physics journals (Physical Review B, Physical Review Letters and similar top-ranking journals). Japanese remain twice as productive as their European colleagues (with a ratio of 0.123 of high-quality publications in superconductivity against 0.055 of European researchers), highlighting that Japan is leading also in terms of publications impact.

It should be noted that Japan has been for many years strongly committed in developing strategies on superconductors. Public budgets allocate to this area more financing programs than Europe(see for example the 2015 review paper [20] on a 4-year-long research project supported by the Japanese Government to explore new superconducting materials and relevant functional materials).

Data from the World Bank [23] (see figure 8) show that in the 2010 to 2018 period the number of Japanese researchers in R&D (per million people) is higher than in the European Union. And comparison of R&D expenditure in terms of GDP %, of Japan, Germany, France Italy and the UK, ends up to similar comment.

Figure 8: Time dependence of researchers populations and research budget in a range of European countries and in Japan (from World Bank data [23])


Researchers in R&D (per million people)

Research and development expenditure (% of GDP)

Moreover, restricting the analysis to solid-state physics, this quote by Prof. Fukuyama (University of Tokyo) highlights the role of funding in contributing to the excellence of Japanese research in this field : « *Japan's current global lead in solid-state physics and the broader field of material science is entirely a product of the extensive financial support its government has extended to undertakings in basic research over many years. I cannot adequately underscore in words the importance of Kakenhi (Japan Society for the Promotion of Science (JSPS) -- Kakenhi: Grants-in-Aid for Scientific Research) by supporting research in a bottom up approach*».

The strong interest and productivity of some European countries in this field (Germany, France and Italy in particular) show that researchers are quite active in this field also among Europeans. As a result, a partnership that involves these EU countries together with Japan should be highly beneficial for both European and Japanese researchers.

III - 3 Patents

Japanese government has been supporting for years the development of a range of applications in SC, contributing in keeping quite prominent the patents production in the field. Materials and architectures for the high-Tc wires of the second generation (2G HTS) and their applications in a variety of practical devices are spearheads for sustainable development of human society and for the growing need for safer, cleaner, and more reliable energy supply.

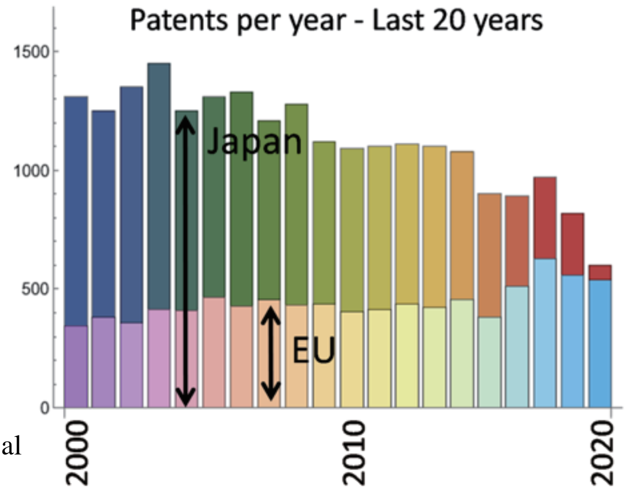


Figure 9: Japanese SC patents

For example, the development of the electrical propulsion airplane supported by the New Energy and Industrial Technology Development Organization (NEDO). This aims at the effective flight with a superconducting electric motor as a substitute for one of a jet engine. In 2012, NEDO has also provided support in the development of a superconducting pump for liquid hydrogen.

Companies like SuperOx in Tokyo area, produce and sell the second generation high temperature superconducting wires (2GHTS). They aim ~~at~~ to supply the cable market with 1 000km - 10 000km a year.

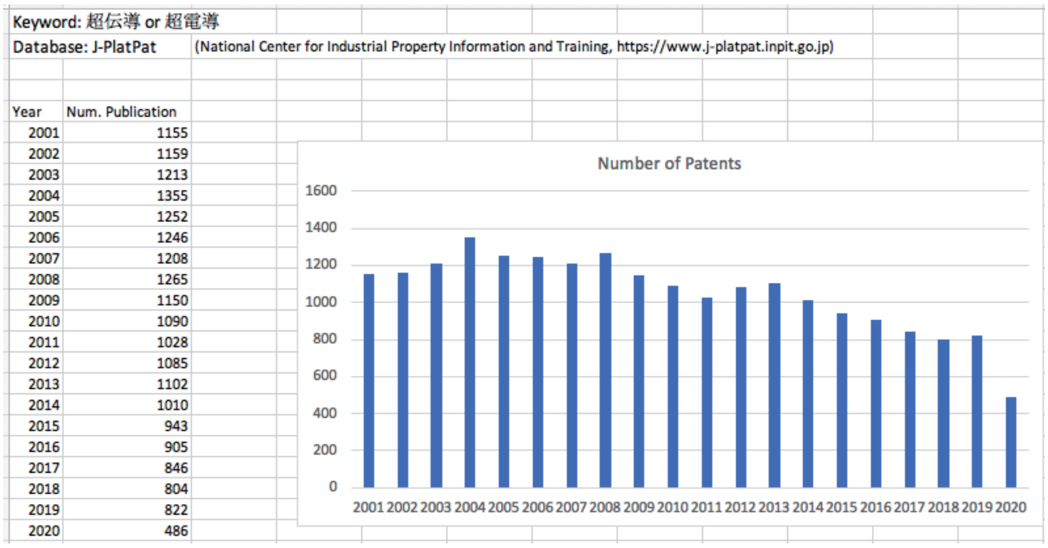
The plots of Figures 9 (Data from WoS) and 10 show that from early 2000s Japanese have been very active in SC intellectual property. Data sets are issued from WoS and a specific Japanese database. They are in good agreement. From 2015 however, Japanese figures indicate a mitigating trend. In Europe, slightly but steadily figures are positively oriented and the situation in both world areas are close to each in 2020 (2020 is a very specific Covid period). Those trends have to be confirmed on a future period of 5-10 years. In Japan Basic Policies 2018 and Economic Growth Strategy 2018, are committed to promote SDGs through collaborating with the private sector and promoting international cooperation will likely bring new strength in the development of SC applications and as a result new momentum to patent industry.

For extended details on Japanese patents production see for instance the International Superconductivity Technology Center (ISTEC) report on national projects available at:
http://www.istec.or.jp/index-E.html

and

http://www.istec.or.jp/web21/pdf/14_03/all.pdf

ISTEC was restructured in June 2016 - And gave rise in particular to SUSTEC
https://sustec.jp/index-e.html



Keyword: 超伝導 or 超電導
Database: J-PlatPat (National Center for Industrial Property Information and Training, https://www.j-platpat.inpit.go.jp)

Year	Num. Publication
2001	1155
2002	1159
2003	1213
2004	1355
2005	1252
2006	1246
2007	1208
2008	1265
2009	1150
2010	1090
2011	1028
2012	1085
2013	1102
2014	1010
2015	943
2016	905
2017	846
2018	804
2019	822
2020	486

Figure 10: SC patents number in Japan (from the Japanese database : J-PlatPat)

For more details:
 - 2017 - report on SC - From Innovation Research Corporation (in Japanese)

技術動向分析イノベーションレポート
No.R180821101

超電導

分析対象特許情報： 日本（ＪＰ）

2018年8月21日発行

Figure 11: Reference of a SC report outcomes issued from the Innovation Research Corporation

IV- Concluding remarks - Relevance of Europe-Japan joint efforts in superconductivity as a tool for meeting SDGs

Mitigating climate change, clean environment, global peace, financial growth, and future development of the world require new technologies that improve the quality of life.

Sustainable development is a core principle of the Treaty on European Union and a priority objective for the Union's internal and external policies. The Commission has developed the EU SDG indicator set, used to monitor progress towards the Sustainable Development Goals in an EU context. This set has been developed in a very broad consultative process, which involved many stakeholders including the Member States, Council Committees, NGOs, academia, and international organizations.

Japan wishes to be a substantial world leader for the promotion of the SDGs in the international community. Especially, Japan is willing to take initiative to demonstrate how to realize a rich and vibrant future amid of globalization and population aging as Japan's SDGs Model. Currently, Basic Policies 2018 and Economic Growth Strategy 2018, are clearly committed to promote SDGs through collaborating with the private sector and promoting international cooperation. Japan is also interested in accelerating innovative financing.

To meet global expectations from International institutions and mitigating climate change, clean environment, global peace, financial growth, and future development of the world require new materials that improve the quality of life: SC materials can be huge hope carriers. HTS are potentially keys in the suite of technologies that can help facilitate grid modernization and increase energy security. Powerful new superconducting generators, high-capacity cables, and fault current limiters are among the solutions that will enhance the efficiency and reliability of electricity generation, transport, and distribution.

This paper shows that Japan leadership is strong over the past 20 years, in terms of researchers publications and patents. It also essentially shows that among the main world players, the Japanese normalized contribution is significantly dominating, although some trend towards a diminished leadership is observed in the data over the period 2005 - present time. Finally, based on their internationally recognized expertises in the field, joint Japanese and European research teams may take the lead for advancing superconductivity on a reliable road to meet Energy and Health SDGs (Sustainable Development Goals - UNESCO 2015).

* On leave from CNRS since 2014

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