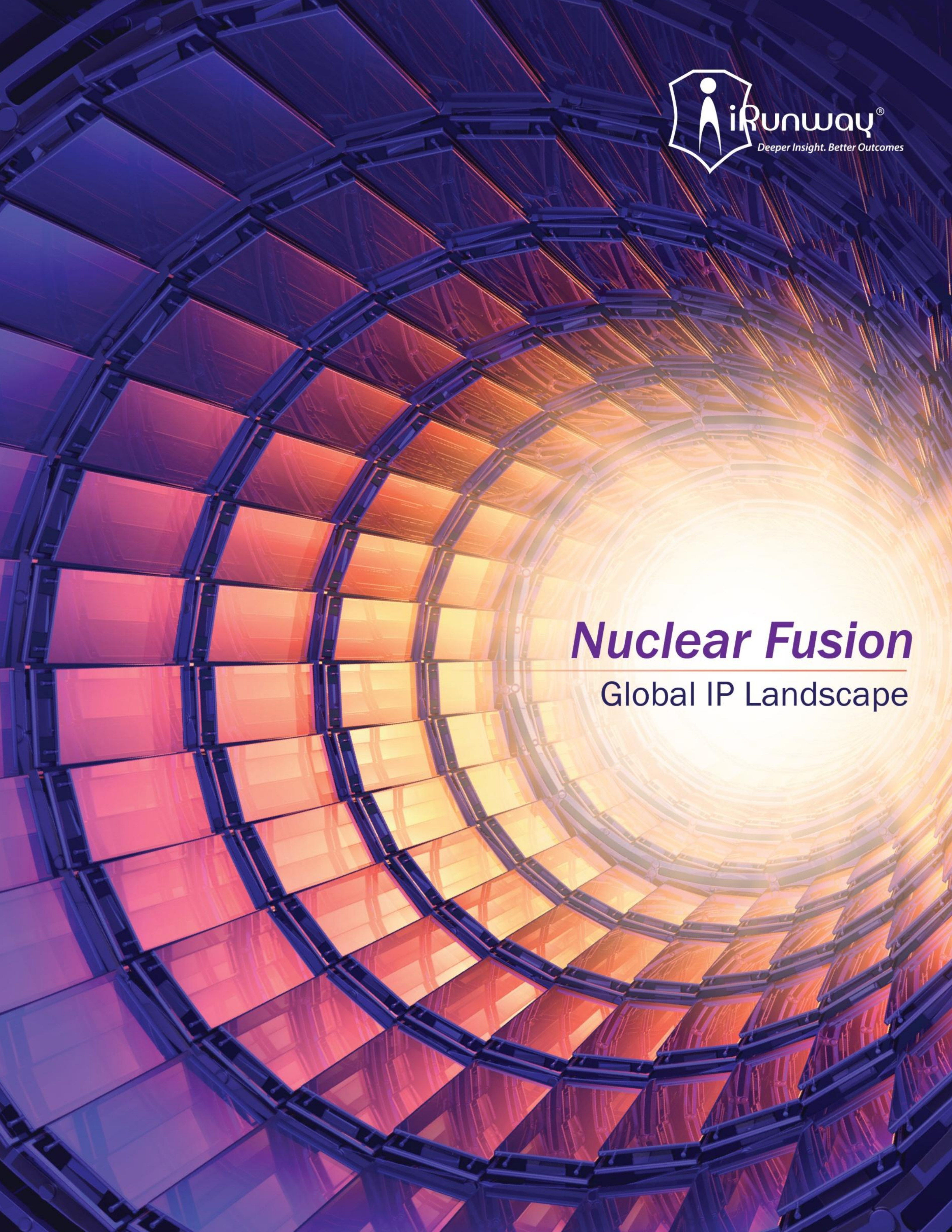

iRunway®

Deeper Insight. Better Outcomes

Nuclear Fusion

Global IP Landscape

Contents

1 Executive Summary

There is rising inhibition across the world towards nuclear fission technology owing to safety concerns of fission reactors and nuclear waste disposal. This has led to the closure of many fission power plants in recent times. Germany has already phased out nine of its 17 fission reactors, and it intends to close the rest by 2022.[1] Switzerland is following suit. At a time when countries are desperately looking for clean energy alternatives that are capable of providing higher energy output, nuclear fusion comes as a preferred alternative. Unlike in fission reactors, the chain of reaction comes to a halt in fusion reactors during a failure. This property also makes fusion reactors a safer alternative where disasters like the ones in Chernobyl and Fukushima can be prevented.[2]

Scientists have been battling several challenges to make nuclear fusion commercially viable. For one, nuclear fusion as a commercial source of energy is viable only if the amount of energy required to heat and confine raw materials for the reaction is less than the actual energy produced, i.e. fuel gain is greater than 1. Another challenge is confining plasma for long time periods to sustain a reaction. While in early 2014, US scientists succeeded in producing fuel gain of more than unity by boot-strapping[3], the tokamak and Wendelstein 7-X reactors have overcome several barriers, aiding deeper research.

Hence, while commercial power generation using nuclear fusion was once considered a wild goose chase, pressing concerns of an energy hungry world has spurred governments and private players alike to make tremendous investments in recent years. In 2015, government agencies such as ARPA-E awarded approximately $30 million to nine fusion ventures. Further, high profile investors such as Microsoft cofounder Paul Allen and Amazon founder Jeff Bezos have invested millions of dollars in nuclear fusion ventures such as Tri-alpha and General Fusion.[4] In February 2016, Germany initiated a test run of its Wendelstein 7-X fusion reactor and successfully contained the plasma for a substantial 0.25 seconds.[5] Soon after, China made headlines for sustaining a fusion reaction for 102 seconds at its Experimental Advanced Superconducting Tokamak (EAST).[6]

Nuclear fusion is no longer appearing to be a fool's errand. While the number of patents filed is few, it is beginning to grow. iRunway's research found 5,347 global IP assets[7] in fusion technology, of which 3,052 have been granted a patent status. Figure 1 maps geographies owning the most IP assets:

1 "The future of nuclear energy Half-death", *The Economist,* October 31, 2015
2 Safety of Nuclear Power Reactors, *World Nuclear Association*, August 2015
3 "Experiments show initial gain in fusion fuel",*ScienceDaily,* February 12, 2014
4 https://www.sciencenews.org/article/nuclear-fusion-gets-boost-private-sector-startups
5 "Nuclear fusion comes two steps closer", *The World Weekly*, February 11, 2016
6 "Chinese scientists achieve a huge milestone in nuclear fusion reaction", *Dispatch Tribunal*, February 15, 2016
7 IP assets include patent applications and granted patents.

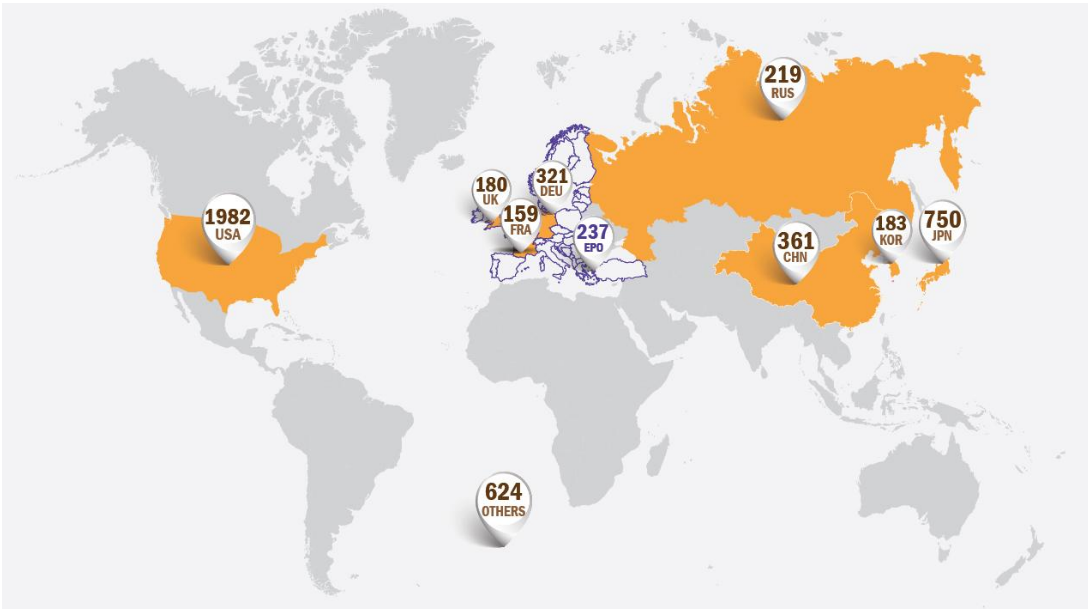

Figure 1: Geographies owning the most number of IP assets in Nuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

Inertial confinement and magnetic confinement are traditional areas of research witnessing active patenting. The top 10 IP asset assignees collectively own 17% of the global IP assets, shows Figure 2. Of this, 502 IP assets are related to magneto-inertial confinement, of which over 60% has expired, suggesting the technology as a fertile ground for invention and innovation, without fear of litigation.

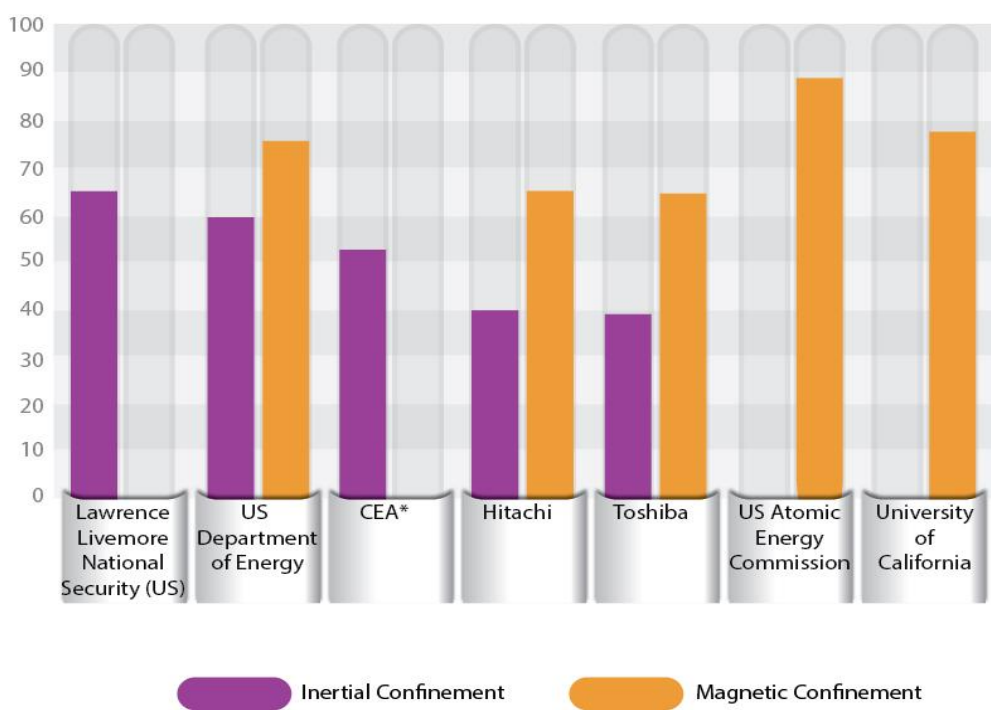

Figure 2: Leading IP asset owners in Inertial Confinement and Magneto-Inertial Confinement (Source: iRunway analysis based on patent data from Questel Orbit)

iRunway's research found that no IP asset related to nuclear fusion technology was involved in litigation. This can be attributed to the complexity of the technology and the fact that its commercialization will occur only after realizing profitable returns. This points to a possibility in the near future. Researchers in UK have affirmed that the country will be the first to roll out fusion power plants and that electricity from the reaction can be expected by 2025.[8]

[8] "UK to be First country to roll out nuclear fusion power plants, say experts", *Martin, Sean, Express*, February 15, 2016

2 Nuclear Fusion Technology Landscape

Growing concern behind the massive demand for coal to produce electricity and the tremendous volume of carbon-dioxide it ejects into the atmosphere is finally reaching a crescendo. Energy producers are actively looking to nuclear technology as a saviour for mankind's electricity demands in the very near future. While nuclear fission was put to practice for commercial generation of electricity, harmful pollution caused by faulty reactors that led to damaging radiation and hazards caused by improper waste disposal has propelled researchers to look for safer alternatives. Several countries, including Germany and France, have begun closing down their nuclear fission reactors on grounds of environmental safety.

Renewable sources of energy such as solar, wind and water cannot be harnessed with much reliability considering the vagaries of weather. In such circumstances, nuclear fusion appears to be a viable clean fuel for electricity generation. Research has proven that nuclear fusion can produce as much energy as burning 100 tonnes of coal with just the small quantity of lithium that is used in a laptop battery, and with a small bath of water, in an environmentally safe manner. Hydrogen gas (or other fusion fuel) is heated to a temperature of around 100-150 million degrees Celsius to turn it into plasma – the fourth state of matter – where negatively charged electrons in atoms are separated from positively charged nuclei. Deuterium and tritium (isotopes of hydrogen) fuse together to form helium and neutron, and, in turn, release massive amounts of energy.

In 1939, German-American scientist Hans Albrecht Bethe published two papers on stellar nucleosynthesis that won him a Nobel Prize in physics. However, Bethe's theory did not address the creation of heavier nuclei. Since material cannot confine the plasma at such temperatures, four techniques have been researched as useful for the task of plasma confinement: magnetic confinement, electrostatic confinement, inertial confinement and magneto-inertial confinement. There is another theoretical concept of non-thermal fusion wherein fusion reactions occur at normal temperatures.

In 1950, two soviet scientists proposed the tokamak structure that revolutionized the technology. Back then, scientists were challenged to maintain the high temperature to allow a reaction to occur. The need to contain the high temperature plasma resulted in extensive research in magnetic pinching. Magnetic pinching, also referred to as Bennet pinch, is a method of compressing electrically conducting filaments by magnetic forces, similar to what occurs in lightning bolts and solar flares. It was one of the first mechanisms used for controlled nuclear fusion reaction. The electrically conducting filament is usually plasma, but it can also be a solid, liquid or metal. The design of the tokamak was modified to incorporate this effect, while the need for high temperature saw the advent of lasers in the 1960s. This approach led to another technique of containing and heating fusion fuel.[9] Figure 1 shows a cross-section of the Tokomak being constructed by the ITER. The doughnut shaped nuclear reactor is the key to confining plasma and generating fusion power which is commercially viable.

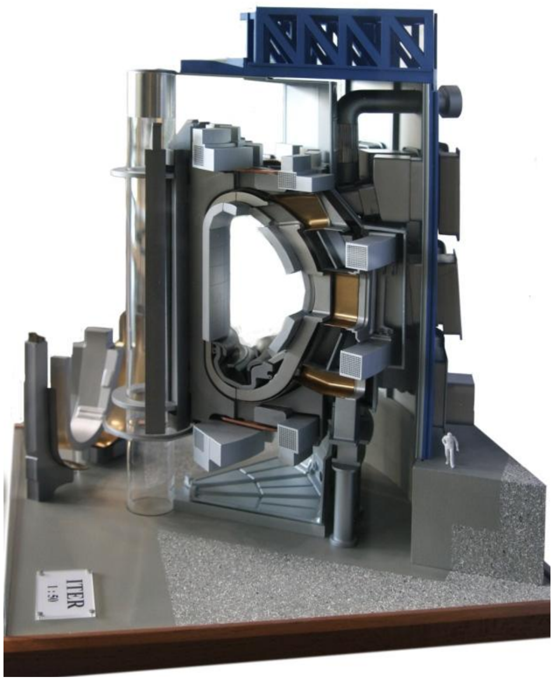

Figure 3: Cross-section of the ITER Tokamak being built in France. (Source: Wikipedia)

The tokamak encouraged scientists to indulge in intrinsic research to improve fusion reactor structures and process efficiency. However, it faced a critical challenge of maintaining uniformity of the magnetic field to confine plasma uniformly and improve the number density of the fuel to enable a reaction with higher probability.

In a tokamak, magnetic coils are arranged in a doughnut structure that creates an extremely strong magnetic field in the centre, with a weak periphery. To overcome this, scientists created stellarator houses where heavy magnetic coils are arranged in a twisted structure to confine plasma for a longer period, thus increasing the overall energy output.

Germany has begun intense research in laser technology by entities like the National Ignition Facility is yielding positive results with a considerable increase in the capability of firing laser shots. Laser shots are used to ignite the fuel and cause an implosion to create high density for a fusion reaction to occur. A goal target of 300 shots for 2015 has already been met.[10]

9 "Brief history of fusion power", *LPP Fusion*, retrieved on November 6, 2015
10 "Efficiency Improvements", *Lawrence Livermore National Laboratory*, retrieved on November 6, 2015

3 Nuclear Fusion Patent Landscape

Nuclear fusion is charting the future of power resource management, encouraging several countries to engage in researching this technology. The recent developments in global warming and its link to increasing emissions is coercing scientists towards a global collaboration to speed up research on this technology and plug scientific gaps.

There is fast-paced research happening at the National Ignition Facility (NIF), International Thermonuclear Experimental Reactor (ITER) and the Wendelstein 7-X. USA is the IP leader in this technology space, followed by Japan and China. The breakthrough at the Soviet tokamak gave a much-needed fillip to nuclear fusion technology that moved from being linked to atomic weapons to becoming a "big science" for research in the 1970s.

Figure 4 shows the nuclear fusion technology taxonomy across categories:

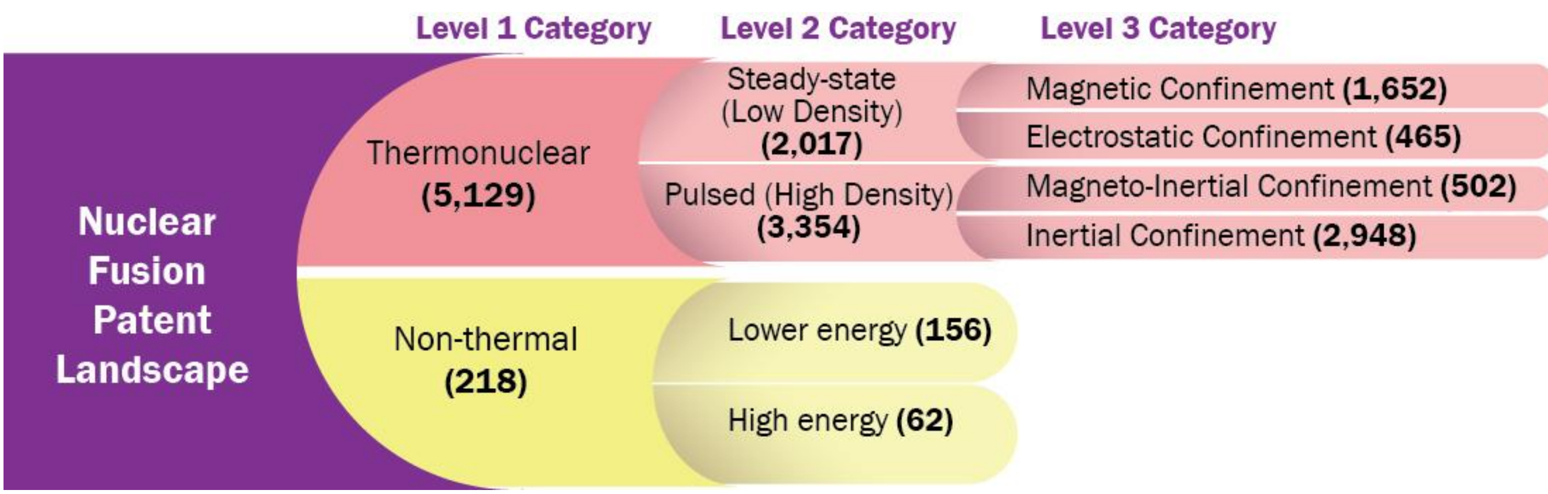

Figure 4: Distribution of Nuclear Fusion IP assets across the Technology Taxonomy (Source: S.C. Hsu, Los Alamos National Laboratory)

There are several tokamaks being built across the world to aid research in the technology. UK is spearheading the development of the Joint European Torus (JET) and Mega Amp Spherical Tokamak (MAST), and the USA is working on the Tokamak Fusion Test Reactor (TFTR) besides researching at the ITER. China is experimenting on the Experimental Advanced Superconducting Tokamak (EAST) and is also developing the Chinese Fusion Engineering Test Reactor (CFETR) which is slated to be larger than the ITER and is expected to begin operations in 2030.[11]

[11] World Nuclear Association, retrieved on February 24, 2016

Please refer to Table 3 in the Appendix to for a detailed description of different techniques that are used to trigger a nuclear fusion.

3.1 Patent Categories & Classification

Nuclear fusion is in the evolution phase, with limited patenting activity. There are 5,378 IP assets globally, of which 5,129 assets are related to thermonuclear fusion and 218 are related to sub-domains of non-thermal fusion technology. Of these, 3,052 applications have been granted a patent status; 2,984 patents are related to thermonuclear fusion and 68 to non-thermal fusion technology.

Inertial confinement and magnetic confinement are traditional areas of research in nuclear fusion technology, catering to significant patenting activity. There are very limited patents in non-thermal fusion technologies, including cold fusion and muon-catalyzed fusion, as there is no accepted theoretical model for this process yet.

Cold fusion conducted by scientists across the world under varying conditions has provided negative results and is being researched at a theoretical level. This non-reliability and lack of assurance in the production of fusion by-products and energy makes it an unpopular area of research. Similarly, muon-catalyzed fusion is also not popular among researchers as the process requires a large amount of energy to create muons, which is not optimal for commercial power generation. However, there is a growing level of laboratory curiosity at a theoretical level.

3.2 Geographical distribution of patents

A global view of the nuclear fusion technology patent landscape, as charted in Figure 5 below, shows that the US has the highest number of IP assets, followed by Japan and China. Russia was one of the earliest players in the nuclear fusion space. It owns 219 IP assets (including 85 IP assets that were owned by the erstwhile USSR). There are 331 WIPO applications[12] filed in nuclear fusion technology.

As discussed earlier, while the number of patents filed in nuclear fusion technology are far and few, a global increase in research owing to a rise in demand for cleaner forms of energy is witnessing a steady increase in inventions that are being secured with the patent shield. There has been a consistent rise in the number of patents filed in the last three decades. The invention of the doughnut-shaped tokamak and the successful experiment of earning a fuel gain of greater than unity has encouraged scientists and researchers to deep dive into this new technology. Figure 6 charts the global patent filing and grant trend in nuclear fusion technology.

[12] WIPO applications have not been included in the chart as they cover a multitude of geographies.

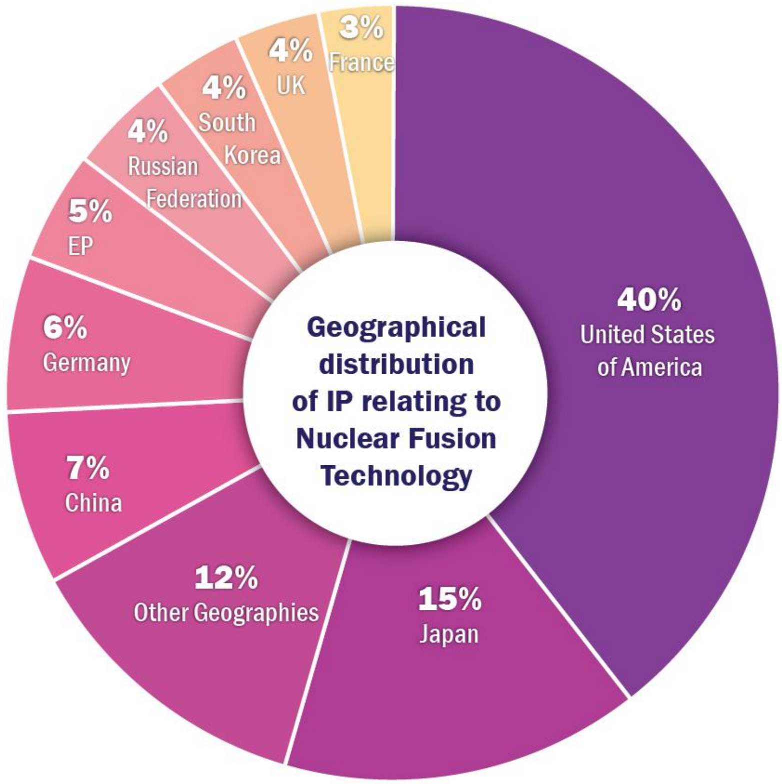

Figure 5: Geographical Distribution of IP in Nuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

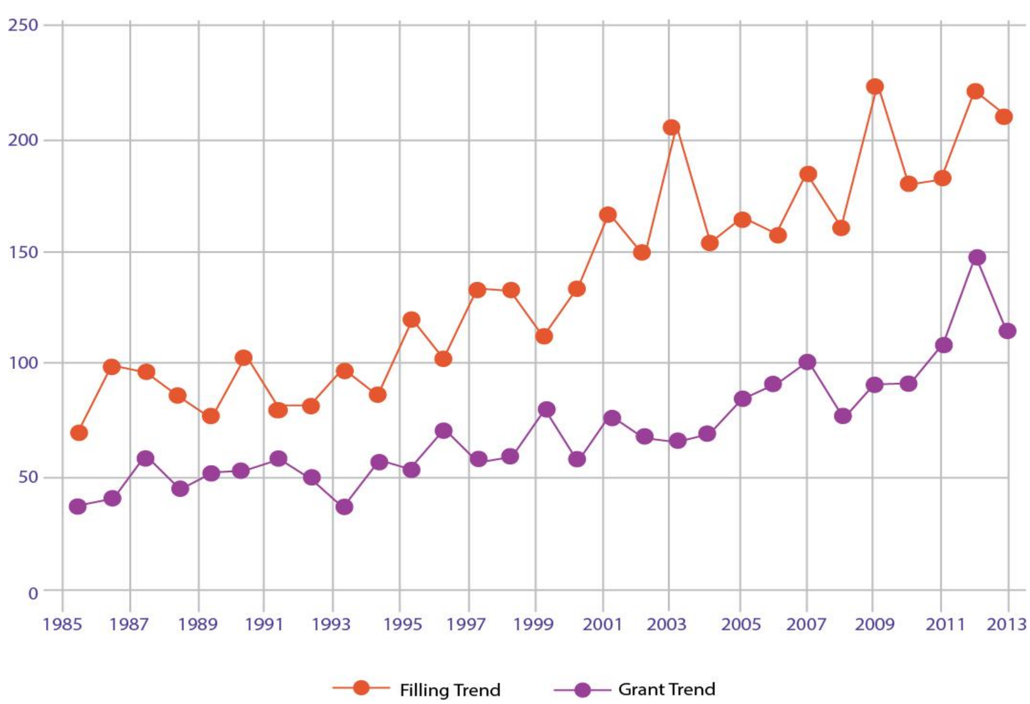

Figure 6: Global Filing and Grant Trend of IP assets in Nuclear Fusion technology (Source: iRunway analysis based on patent data from Questel Orbit)

Figure 7 shows the filing trends for the top geographies by IP asset count, with each circle mentioning the number of patents for the assignee.

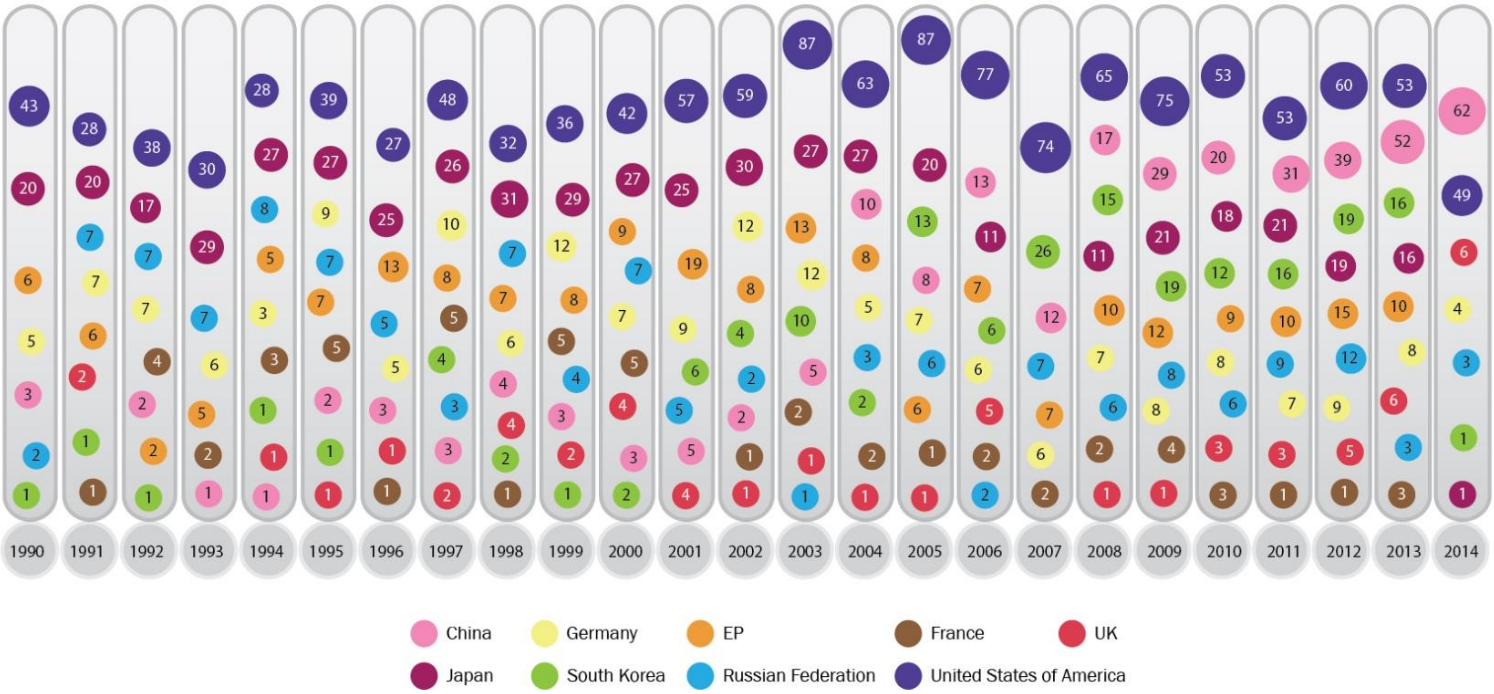

Figure 7: Global Filing and Grant Trend of IP assets in Nuclear Fusion technology (Source: iRunway analysis based on patent data from Questel Orbit)

China has been an active patentee of nuclear fusion technology. This can be attributed to the recent dramatic increase in smog and other pollution related ill-effects caused by the country's high dependence on fossil fuels. The Chinese government is taking great efforts to turn to alternate forms of energy that will suffice the country's huge energy demand for electricity. China is spearheading its nuclear fusion tech with two projects:

- **The Experimental Advanced Superconducting Tokamak (EAST) -** This is a magnetic fusion reactor experiment which is being handled by the Institute of Plasma Physics under the Chinese Academy of Sciences.[13]
- **The Keda Torus eXperiment (KTX) -** This is a reverse field pinch device being developed by the University of Science and Technology of China. The experiment is an extension of China's Magnetic Confinement Fusion program.[14]

United Kingdom is spending 14% of its total energy research budget on fusion technology.[15] Besides contributing to the ITER and JET experiments, UK is working on its own fusion device - the Mega Amp

[13] "EAST- Experimental Advanced Superconducting Tokamak", *Institute of Plasma Physics CAS*, December 14, 2015
[14] "New nuclear fusion device put into operation (2)", Can, Yuan, *People's Daily Online*, November 4, 2015

Spherical Tokamak (MAST). The MAST facility is handled by the Culham Centre for Fusion Energy in Oxfordshire. The tokamak is getting an upgrade with an input beam power of 12.5 Megawatts, up from 7.5 Megawatts.[16]

South Korea is also in the race for revolutionary fusion energy research. It is conducting intrinsic research in magnetic confinement fusion with the Korea Superconducting Tokamak Advanced Research (KSTAR). The country's National Fusion Research Institute is leading another fusion program that is expected to be completed by 2030. The project, called the K-Demo, will be a prototype for commercial level fusion reactors.[17]

3.3 Leading Patent Assignees in Nuclear Fusion Technology

The US Department of Energy holds the largest patent portfolio in nuclear fusion technology with 139 IP assets, of which 127 are granted. The top assignees include universities, research institutes and companies.

Figure 8 charts the leading assignees in the global nuclear fusion landscape with respect to their portfolio size:

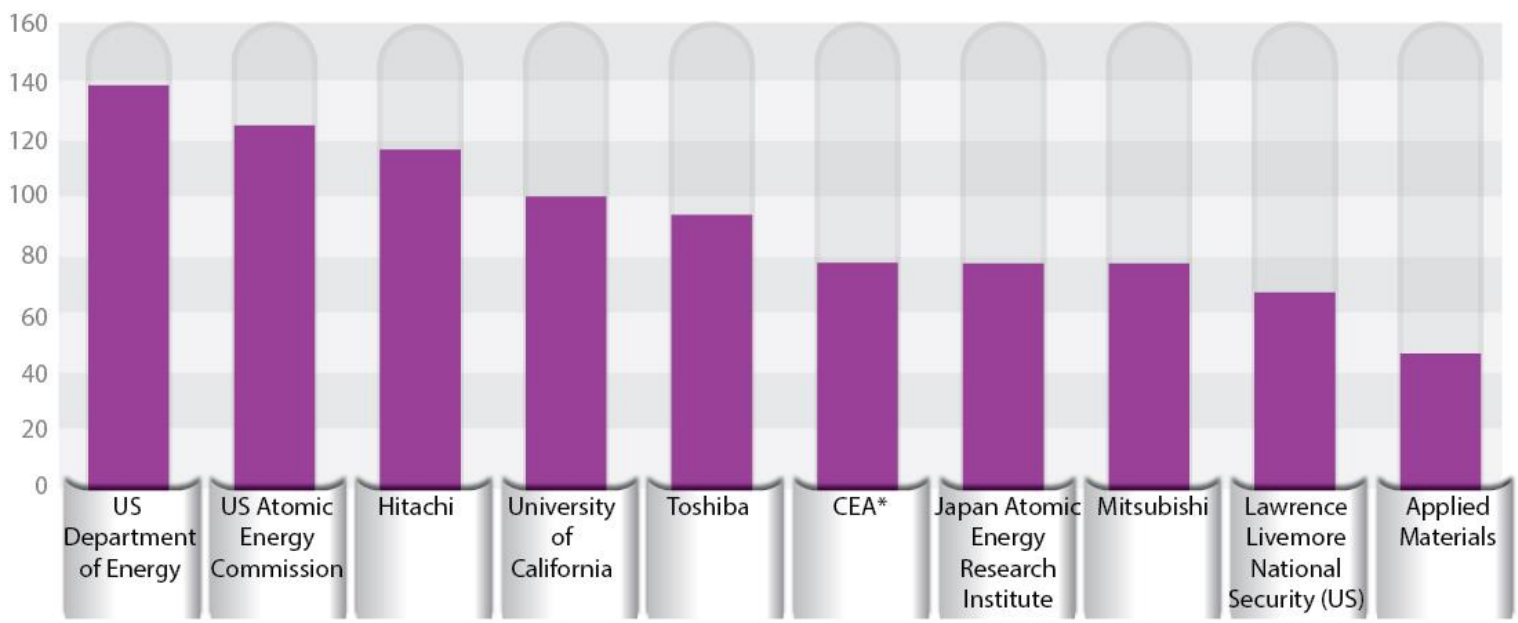

Figure 8: Leading Owners of Nuclear Fusion Patent Portfolios in the World (Source: iRunway analysis based on patent data from Questel Orbit)

[15] "China spends big on nuclear fusion as French plan falls behind", Pearce, Fred, *New Scientist*, July 23, 2015
[16] "MAST Upgrade", *Culham Centre for Fusion Energy*, December 14, 2015
[17] "South Korea makes billion-dollar bet on fusion power", Park, Soo Bin, *Nature*, January 21, 2013

4 Thermonuclear Fusion

Thermonuclear fusion is being hailed as the future of energy resource on Earth. If the ITER gains successful momentum, it will usher in an era of an almost limitless source of energy which is clean, safe and commercially viable. This is because deuterium and tritium – the two isotopes of hydrogen that are used for fusion reactions – are abundant and effective in use. For instance, one kilogram of either one of the isotopes is said to produce the same amount of energy as that produced by 10 million kilograms of fossil fuels. This has renewed interest in the subject in recent times, resulting in growing globally patenting activity in this space.

The US Department of Energy leads in research on thermonuclear fusion, owning approximately 3% of the global IP assets. The leading nine assignees collectively own approximately 17% of the world's IP assets in nuclear fusion technology. The remaining 83% IP assets are distributed across a gamut of assignees across the world. Figure 9 shows the global distribution of thermonuclear fusion patents:

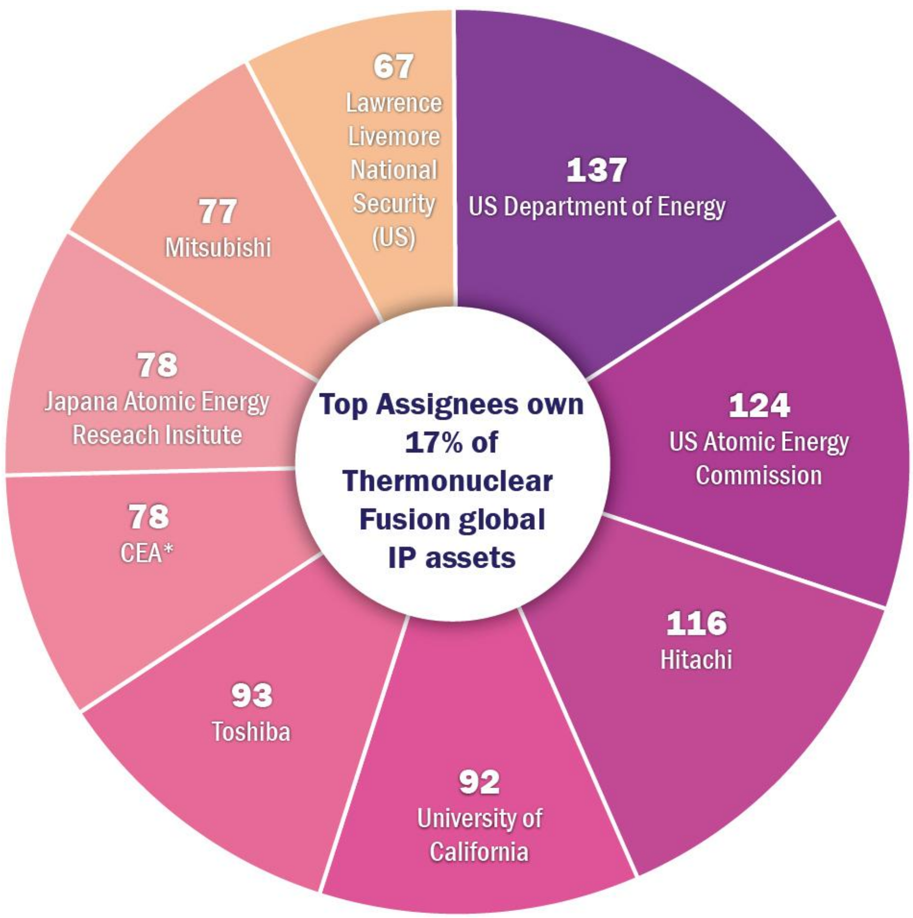

Figure 9: Distribution of Thermonuclear Fusion IP assets among Top Assignees (Source: iRunway analysis based on patent data from Questel Orbit)

While these top nine assignees own about 17 per cent of the global IP assets, 3 per cent of the global IP assets in thermonuclear fusion have been assigned to individual patentees. The remaining 83 per cent is distributed among various inventors across geographies.

Table 1 charts the distribution of the remaining 83 percent of thermonuclear fusion IP assets geography/ patent office-wise.

Geography	Number of Thermonuclear Fusion IP Assets
United States of America	1,719
Japan	476
China	320
Germany	287
WIPO	275
European Patent Office (EP)	194
South Korea	158
United Kingdom	152
Russia	128
France	124

Table 1: Distribution of the remaining 83% of Thermonuclear Fusion IP Assets among Global Assignees (Source: iRunway analysis based on patent data from Questel Orbit)

While the United States stands out as the undisputed leader in this space, there is a considerable level of consistent research being conducted in the other major patent office jurisdictions and geographies. South Korea, United Kingdom, Russia and France own over a 100 IP assets each in thermonuclear fusion technology. This coupled with their experiments on fusion reactors the ITER, tokamak, Wendelstein 7-X and EAST is setting the stage for the world to witness an increase in the number of their IP assets in this space in the coming years.

4.1 Thermonuclear Fusion vs. Thermonuclear Pulsed - An Analysis

A thermonuclear fusion reaction can provide harvestable power output when the reaction takes place in a dynamic equilibrium or is pulsed very quickly. Thermonuclear fusion can hence be either steady-state or pulsed based on the power generated in the fusion reaction.

Thermonuclear steady-state fusion involves heating fusion fuel to ultra-high temperatures until a fusion reaction occurs, generating continuous output. Pulsed thermonuclear fusion, on the contrary, involves igniting several fuel pellets at a high repetition rate to produce reliable energy output. Table 2 compares the two techniques:

Feature	Thermonuclear Steady-State	Thermonuclear Pulsed
Nature of output power	Continuous	Pulsated
Input energy source	Large heating currents	Lasers/Ion beams/Z-pinch
Confinement method	Magnetic fields Electric fields	Inertial confinement Magneto-Inertial Confinement
Plasma density required for fusion	Lower	Higher
Confinement time of plasma required for fusion	Higher	Lower

Table 2: Feature Comparison of Level 2 categories of Thermonuclear Fusion

Figure 10 below shows the distribution of global IP assets in Level 2 categories of thermonuclear fusion among the top assignees. The US Atomic Energy Commission started researching thermonuclear fusion technology in the 1950s. AEC has a high number of patents in the thermonuclear steady state category and most of its incremental research was conducted on the tokamak. Hitachi and Toshiba have also been actively developing thermal steady-state fusion technology over pulsed fusion technology.

France-based CEA (Commissariat à l'énergie atomique et aux énergies alternatives) operates a facility called the Cadarache, specializing in nuclear energy research. The CEA has a key project called *Le Laser Mégajoule* (The Megajoule Laser) where researchers are experimenting on delivering millions of joules of light energy to millimeter size targets in time durations of billionths of a second. The facility is carrying out direct illumination inertial confinement fusion experiments using hotspot ignition.[18]

[18] "The Megajoule Laser", *Le Laser Mègajoule*, Retrieved on December 15, 2015

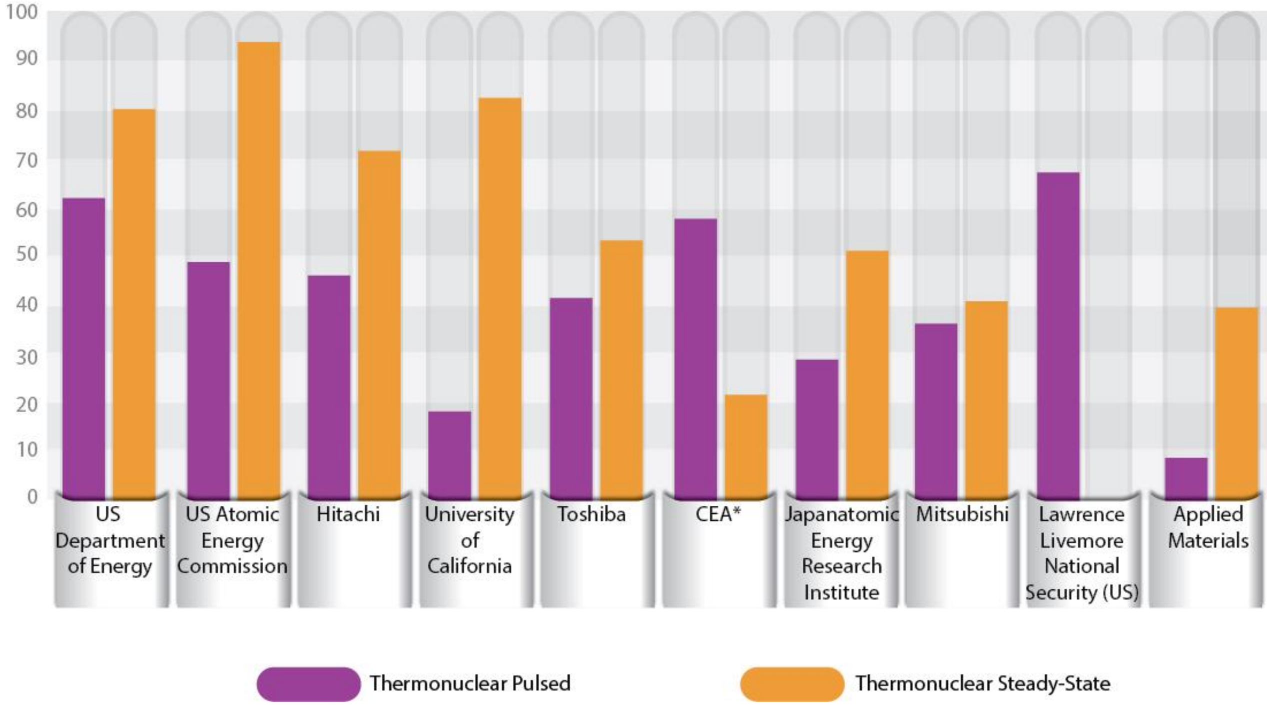

Figure 10: Distribution of Thermonuclear Fusion IP assets in portfolios of Top Assignees across Level 2 Categories (Source: iRunway analysis based on patent data from Questel Orbit)

Figure 11 charts the global filing trend in Level 3 Categories of thermonuclear fusion.

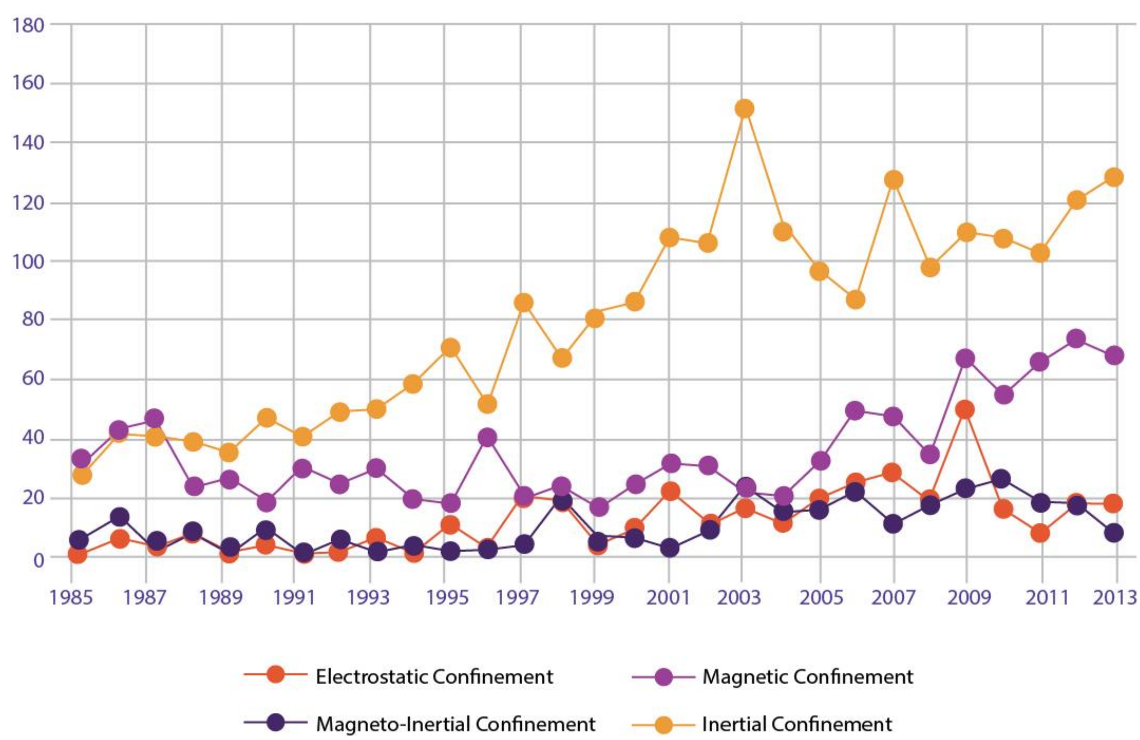

Figure 11: Global Patent Filing Trend across Level 3 Categories of Thermonuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

4.1.1 Magnetic Confinement – The premier technique

Research in nuclear fusion technology commenced with the advent of this plasma confinement technique, making it the oldest in the book. The tokamak incorporated magnets to confine the plasma for fusion reactions. Figure 12 maps the top geographies and globally leading patent assignees of magnetic confinement technology.

The tokamak was invented and successfully created by Russia/USSR. The word tokamak itself is derived from the Russian translation of "toroidal chamber with magnetic coils". It is one of the key IP asset owners in magnetic confinement technology. Russia is currently working on upgrading its superconducting tokamak T-15. It is also creating a hybrid nuclear reactor that will combine the aspects of a tokamak and a nuclear plant reactor to enable both nuclear fusion and fission.[19]

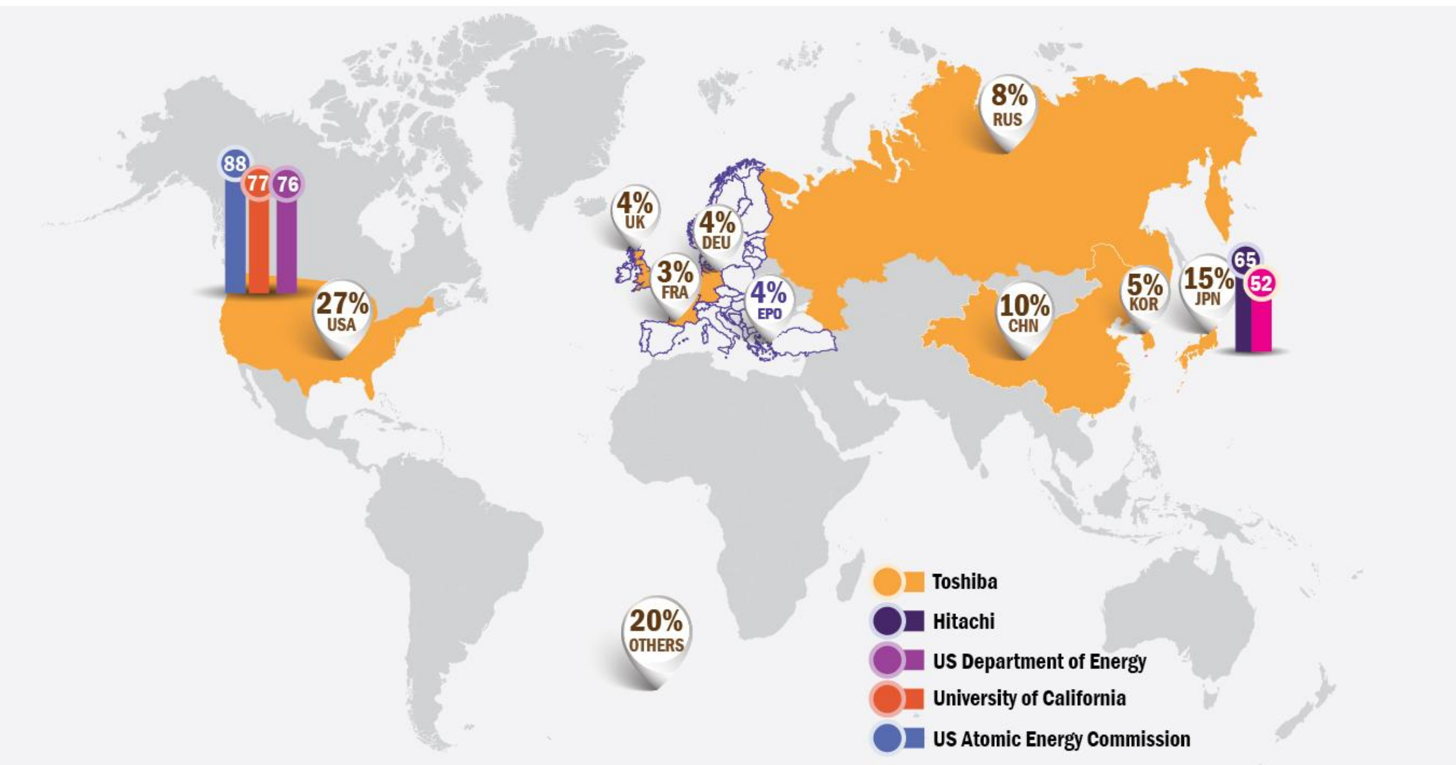

Figure 12: Leading Geographies and Top Assignees of Magnetic Confinement Technology Patents (Source: iRunway analysis based on patent data from Questel Orbit)

Japanese tech giants Toshiba, Hitachi and Mitsubishi are actively involved in magnetic confinement research, making Japan one of the top geographies owning IP assets in magnetic confinement technology. The three companies have been awarded contracts to advance superconducting magnet

19 "Russia develops hybrid fusion-fission reactor, offers China role", *RT*, October 17,2014

technology for Japan's fusion research.[20] Toshiba is manufacturing magnetic field systems required to confine plasma for the ITER and Hitachi for the Large Helical Device (LHD). China is also an IP asset leader in this fusion technique. It is presently researching on two tokamaks - the China Fusion Engineering Test Reactor (CFETR) and the Experimental Advanced Superconducting Tokamak (EAST).

4.1.2 Electrostatic Confinement – An un-Maxwellian Approach

Electrostatic confinement is a nuclear fusion approach where the reaction takes place outside of the thermal equilibrium. While it was considered as a possible viable approach for electricity production, it was soon realized that ions were not necessarily colliding with each other at all times, thus resulting in energy loss. The technology is generating research interest, but is still in a nascent stage of exploration. Figure 13 maps the top geographies and globally leading patent assignees of electrostatic confinement technology.

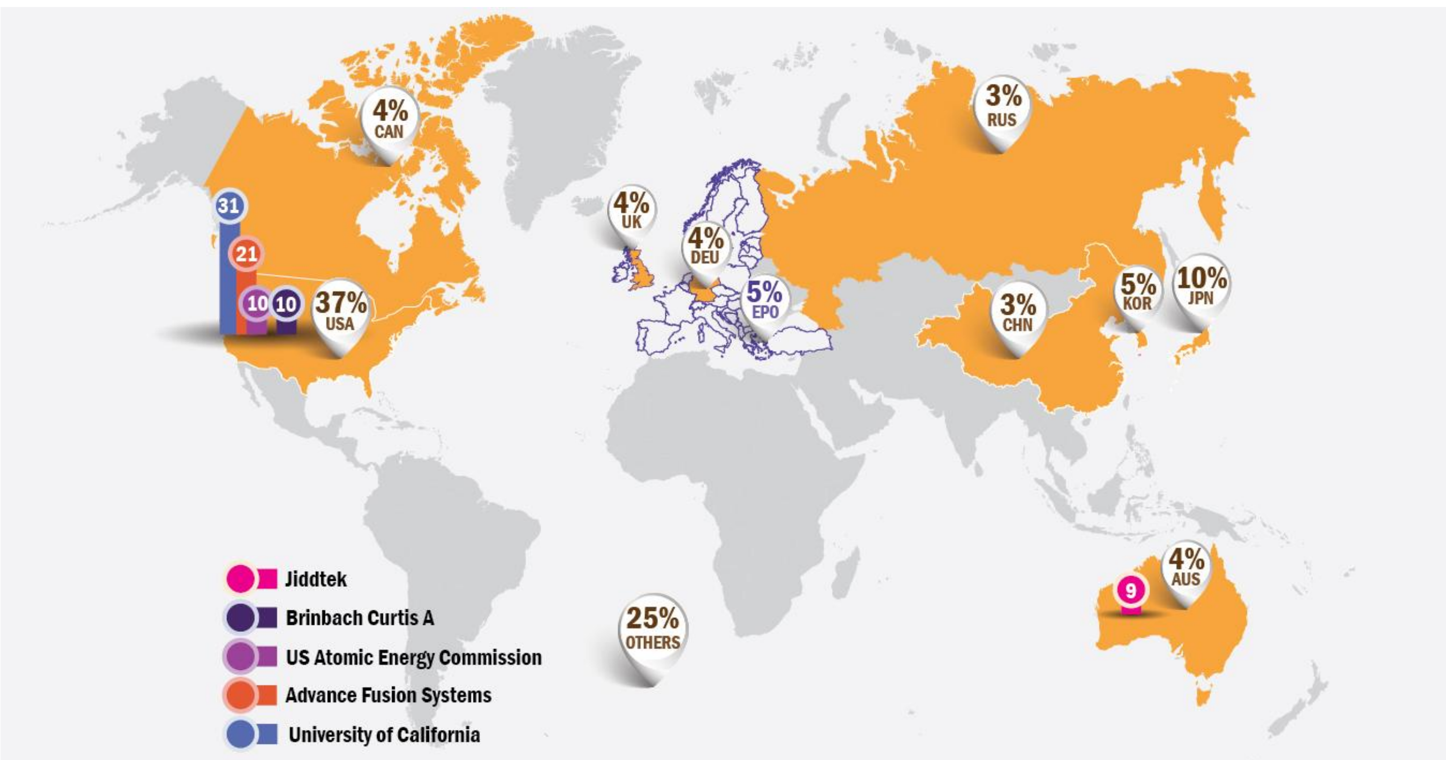

Figure 13: Leading Geographies and Top Assignees of Electrostatic Confinement Technology Patents (Source: iRunway analysis based on patent data from Questel Orbit)

USA is the IP leader in electrostatic confinement techniques. Among the top five global patent assignees in this technology domain, four belong to the USA. This list includes an individual patentee, Curtis Birnbach, who is the president and CTO of Advanced Fusion Systems.

[20] *International Partnerships in Large Science Projects*, page 47, Sedor, Joanne

Australia is also a leading IP asset owner for this confinement technique with 16 IP assets. Jiddtek Pty Ltd., an Australian company specializing in plasma physics and fusion technology, is working on generating dense beams of high energy neutral atoms and ions that are capable of reaching ultra-high energies within a few centimeters distance. It is creating neutron generators for deuterium-deuterium and deuterium-tritium interactions for nuclear fusion reactions using this technology.[21]

4.1.3 Inertial Confinement – Physical basis of Current Research

Inertial confinement has the most active ongoing research in nuclear fusion. The category has the highest number of IP assets, with USA as a front runner in terms of research and IP. The Lawrence Livermore National Security Laboratory (LLNL), a science and technology research facility founded by the University of California, is involved in extensive research in inertial confinement technology. Figure 14 maps the top geographies and globally leading patent assignees of inertial confinement technology.

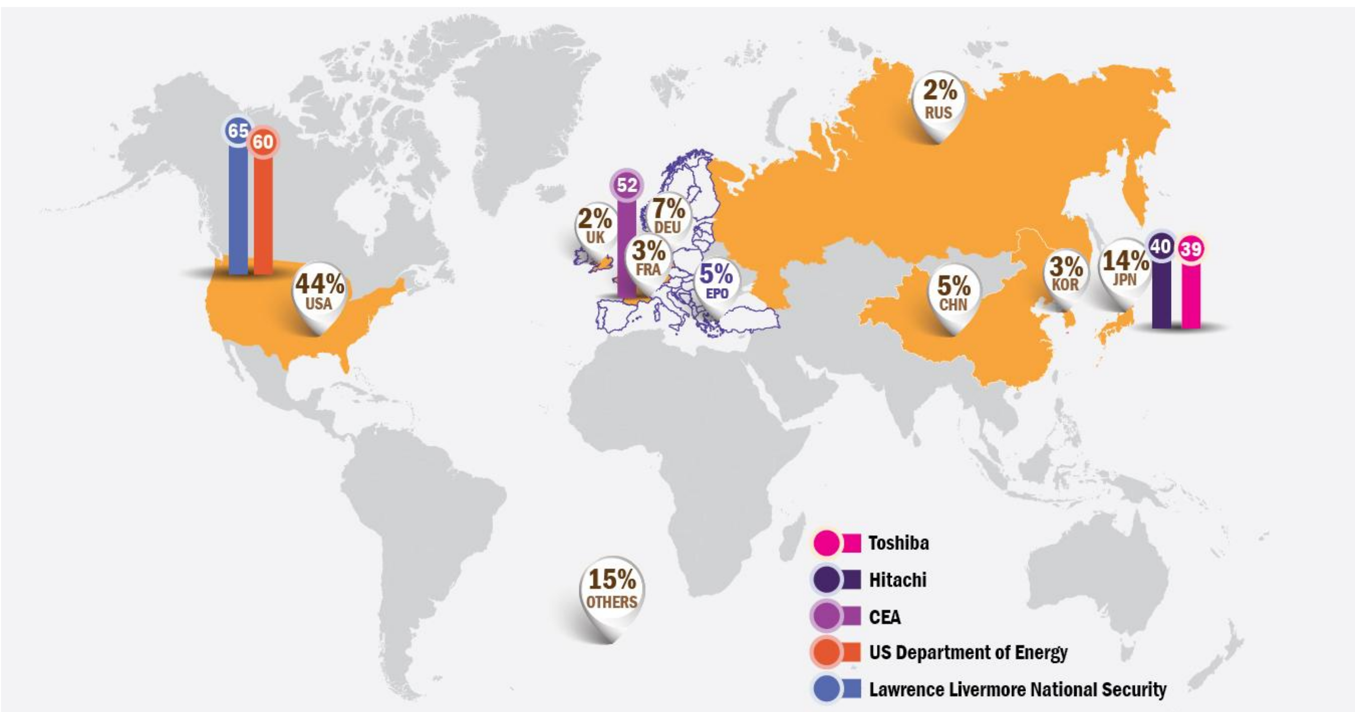

Figure 14: Leading Geographies and Top Assignees of Inertial Confinement Technology Patents (Source: iRunway analysis based on patent data from Questel Orbit)

The US DOE contributes a large fund pool for conducting experiments here. This facility is home to the National Ignition Facility (NIF), the largest inertial confinement fusion device and the largest laser in the world.[22] LLNL is also working on the Titan Laser - a petawatt laser for fast ignition of inertial

[21] Jiddtek Homepage, Retrieved on December 14, 2015
[22] "World's Most Powerful Laser Fires Most Powerful Blast", *Discovery News*, March 22, 2012

confinement fusion target.[23] With Hitachi and Toshiba foraying into plasma confinement technology, Japan figures as one of the leaders in this space. France is also among the top geographies for inertial confinement owing to the CEA investing heavily in *Le Laser Mégajoule* (The Megajoule Laser).

4.1.4 Magneto-Inertial Confinement – A Hybrid Approach

Magnetic confinement and inertial confinement are the traditional areas of research in thermonuclear fusion technology; hence, there is significant patenting activity in these sub-domains. However, there is limited patenting activity in magneto-inertial confinement technology. This is because it is a hybrid of magnetic and inertial confinement, which may result in increased plasma instability that arises due to both magnetic fields and lasers/ion beams. Despite the theoretical advantages magneto-inertial confinement is expected to offer, it makes the confinement more difficult in comparison to magnetic or inertial confinement alone. Figure 15 maps the top geographies and globally leading patent assignees of magneto-inertial confinement technology.

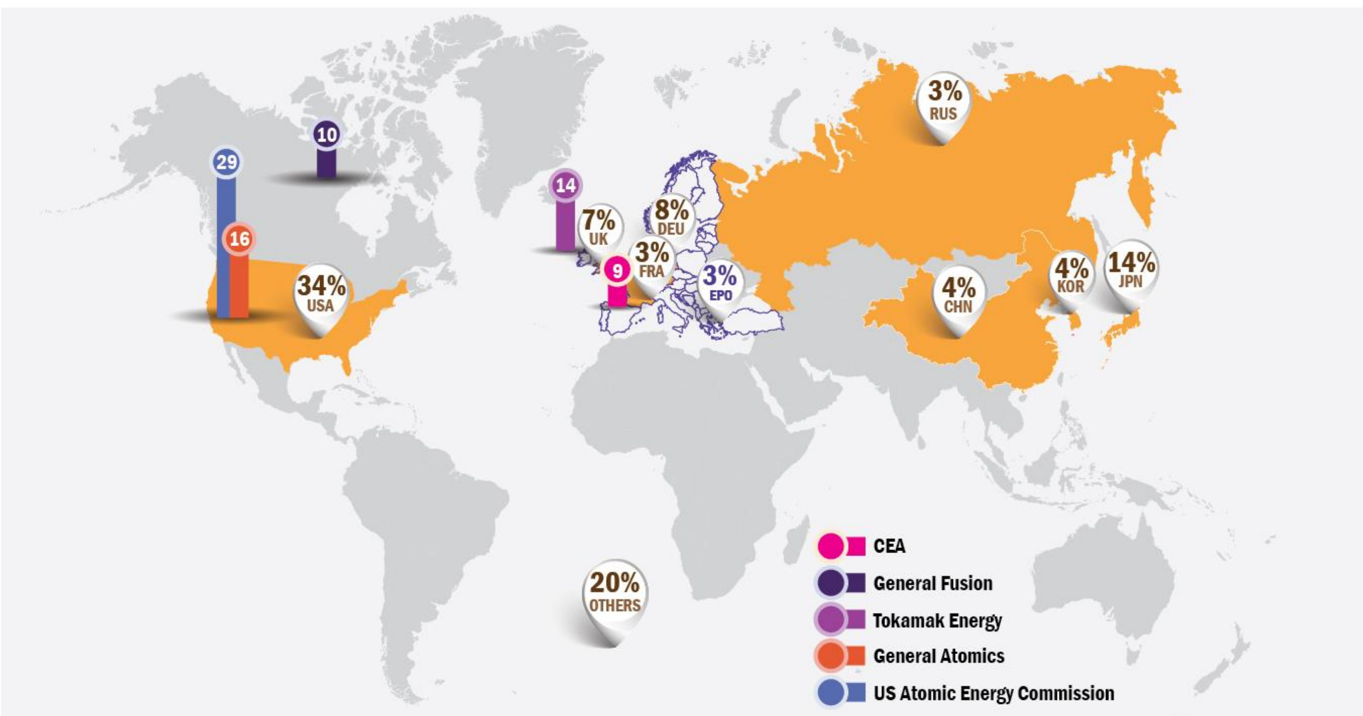

Figure 15: Leading Geographies and Top Assignees of Inertial Confinement Technology IP Assets (Source: iRunway analysis based on patent data from Questel Orbit)

USA, Japan and Germany are the leading IP asset owners in magneto-inertial confinement. USA-based General Atomics has created the DIII-D tokamak in collaboration with over 90 international institutions. The company is also helping build the central solenoid power system for the ITER, which

[23] "Titan Leads the Way in Laser-Matter Science", Rennie, Gabriele, *Science & Technology Review*, December 15, 2015

will be the largest semiconducting pulsed magnet.[24] It is supplying its technology to the Lawrence Livermore National Laboratory for developing their laser technology for the NIF project.

UK is another prominent leader in this space. Tokamak Energy (formerly Tokamak Solutions) is a UK-based company that designs spherical tokamaks and compact fusion reactors. It is heavily involved in researching magneto-inertial confinement technology. The company has raised private investments of over $15 million and has built a tokamak capable of producing plasma pulses up to 20 seconds. Its combined tokamak technology, with superconductor technology, is poised to be the premier creator of a tokamak employing high temperature superconducting magnets[25].

4.2 Portfolio Health of Thermonuclear Fusion – Active/Expired Status

Of the 5,347 global IP assets related to nuclear fusion, approximately 62% (3,328) of the assets have expired. Of these 3,328 patents and applications, 61% expired due to non-payment of patent fees, while 33% expired due to end of patent life, and the remaining due to revocation.

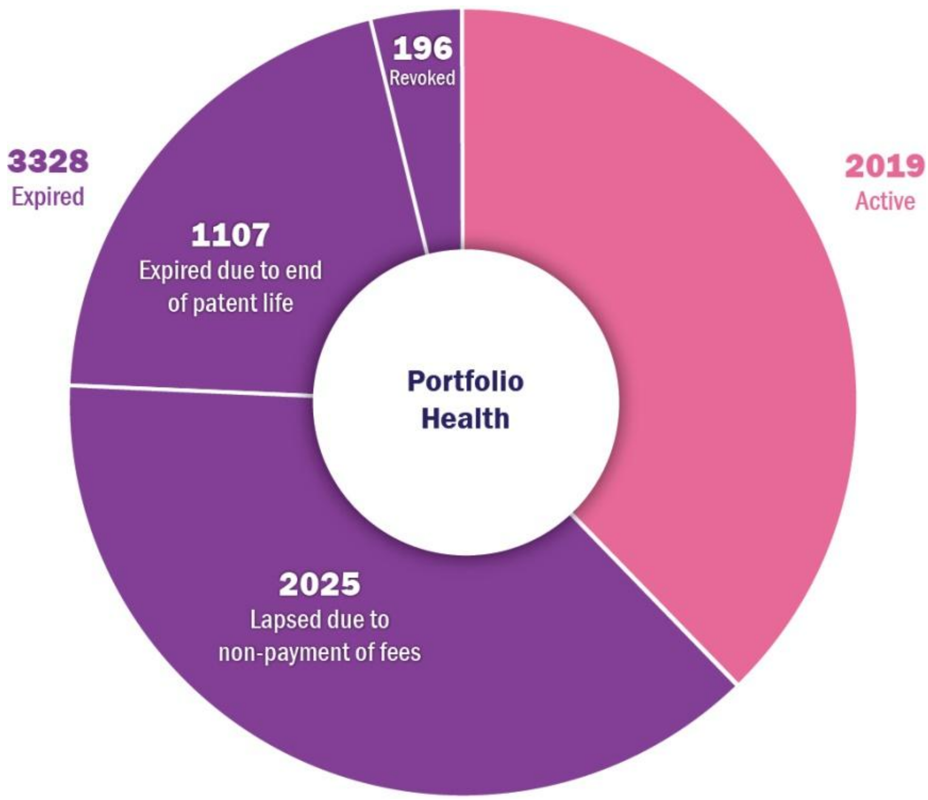

Figure 16: Health of global IP Portfolio of Thermonuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

24 Magnetic Fusion Energy, *General Atomics and Affiliated Companies*, December 14, 2015
25 About Tokamak Energy, *Tokamak Energy* website, December 14, 2015

Figure 16 above shows the ratio of lapsed patents in a category to the total patents in the category is the highest in the case of non-thermal low energy fusion, followed by non-thermal high energy fusion. These two categories are still very hypothetical and hence could have been a driving force behind halting payments of maintenance fee. Figure 17 highlights the category-wise details of the patents that have expired, in comparison with alive patents.

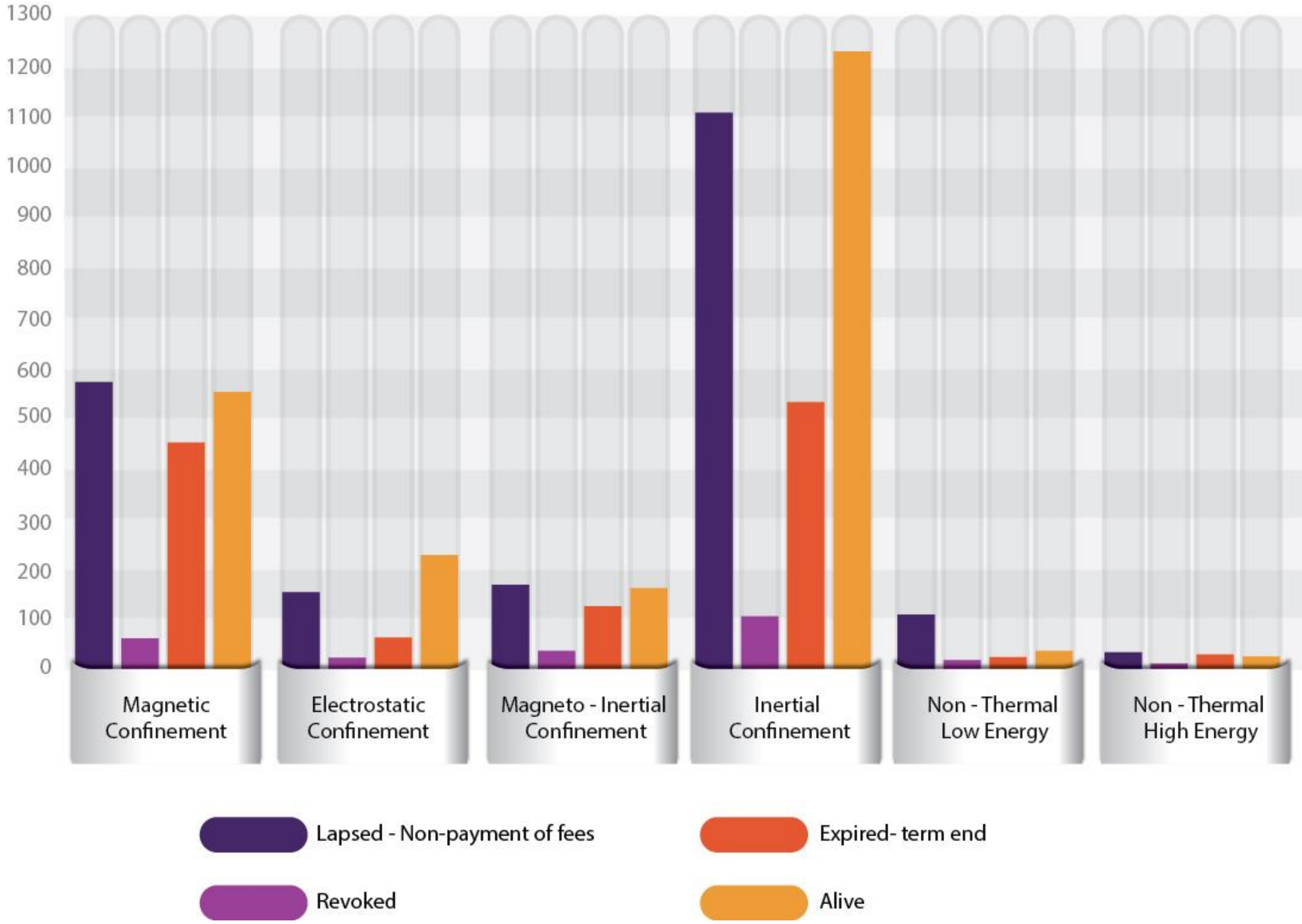

Figure 17: Category-wise portfolio health comparison (Source: iRunway analysis based on patent data from Questel Orbit)

Inertial confinement has the most number of alive patents, pointing to a promising development of this technology. However, the more interesting technology categories for development are inertial confinement and magnetic confinement, which include the maximum number of expired patents.

A comparison of the ratio of number of patents expired in these research domains due to end of term to the total number of patents in thermonuclear fusion shows that the ratio is higher for magnetic confinement as it is older than inertial technology. With a majority of patents ending up in the basket of expiry, these technology segments may witness increased business activity considering there is no patent minefield that can deter their market entry with patent shields. Businesses can build on innovations and accelerate the development of thermonuclear fusion technology, especially with regard to manufacturing techniques.

In addition, the high number of expired patents also increases the perceived and actual value of the remaining active patents and future patents, thus incentivizing businesses to increase R&D investments in this space. This is likely to shift the focus towards developing technology silos and patenting incremental techniques.

5 Key Assignees

5.1 US Department of Energy

The United States Department of Energy (DOE) is a cabinet-level department of the United States government. It is concerned with policies related to energy and safety of handling nuclear material, and is responsible for the U.S. nuclear program, nuclear reactor production for the naval force, and other energy related activities. This agency is headquartered in Southwest Washington DC, and is the leading patent owner in nuclear fusion technology with 139 IP assets.

DOE's annual R&D spends in fusion energy space has been about $500 million over the past few years. This is approximately 8-10% of the department's overall R&D spending.[26] Figure 18 highlights the DOE's spending figures for the different energy research areas it has invested in:

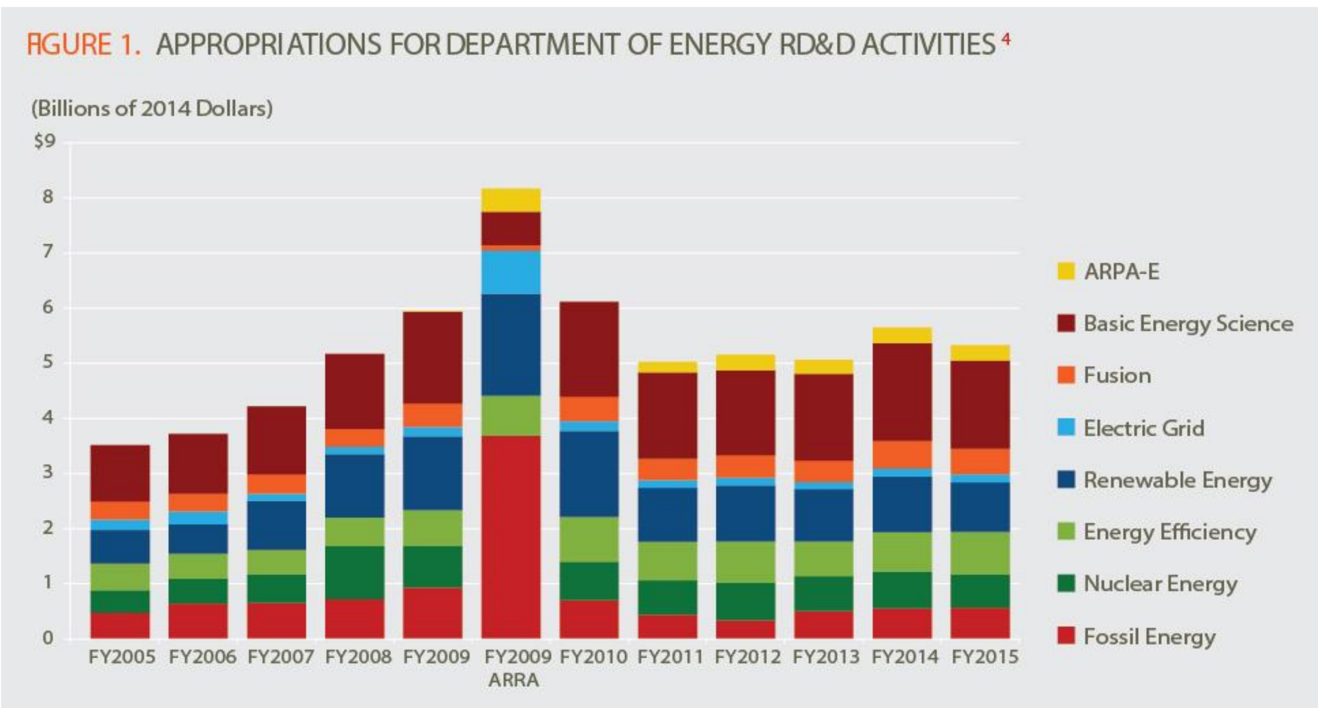

Figure 18: Appropriations for US DOE RD&D activities
(Source: *AEIC*)

In the financial year of 2015, DOE made a 26% higher appropriation of funds towards nuclear fusion energy, which is higher than that recommended by the American Energy Innovation Council (AEIC). This shows the high potential of fusion energy has been identified by the DOE. Figure 19 charts a comparison of the DOE's appropriations against AEIC's recommendations:

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[26] "The U.S. Will Spend $5 Billion On Energy Research In 2015 – Where Is It Going?", *OilPrice.com*, March 4, 2015

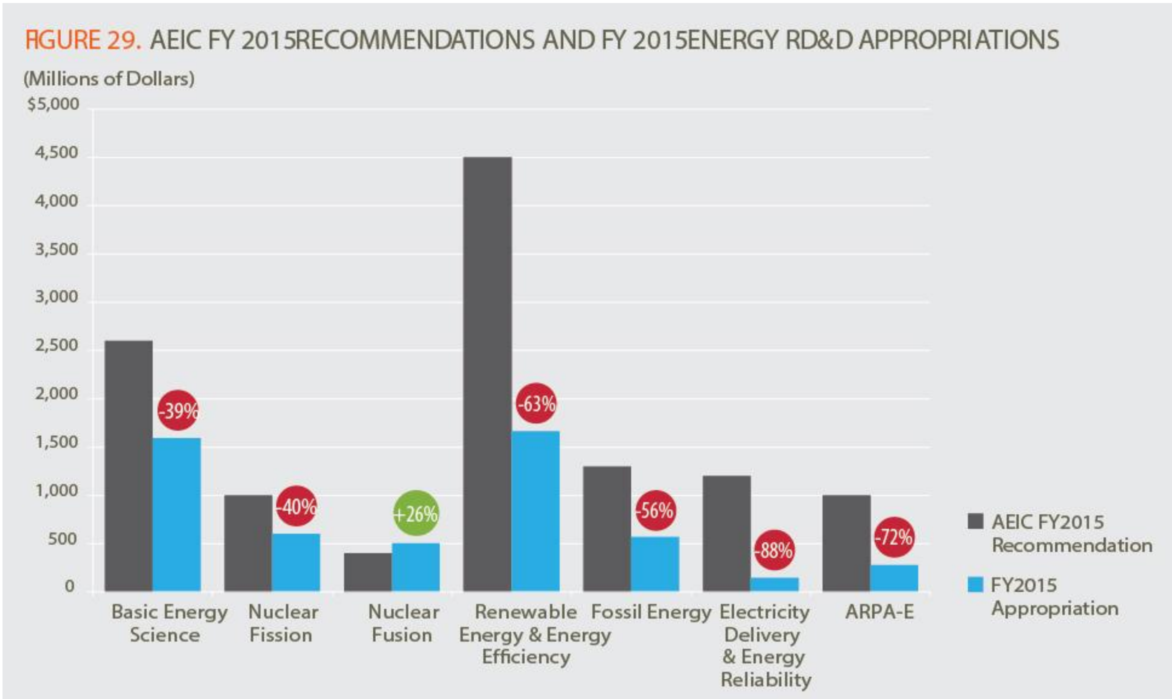


Figure 19: Appropriations for US DOE RD&D activities compared to AEIC recommendations (Source*: AEIC*)

Figure 20 maps the filing and grant trend of IP assets owned by the US Department of Energy.

Figure 20: Nuclear Fusion Filing and Grant Trend of US Department Of Energy (Source: iRunway analysis based on patent data from Questel Orbit)

The US DOE has only one active patent in its portfolio. Figure 21 charts its count of global IP assets across Level 3 categories of nuclear fusion technology.

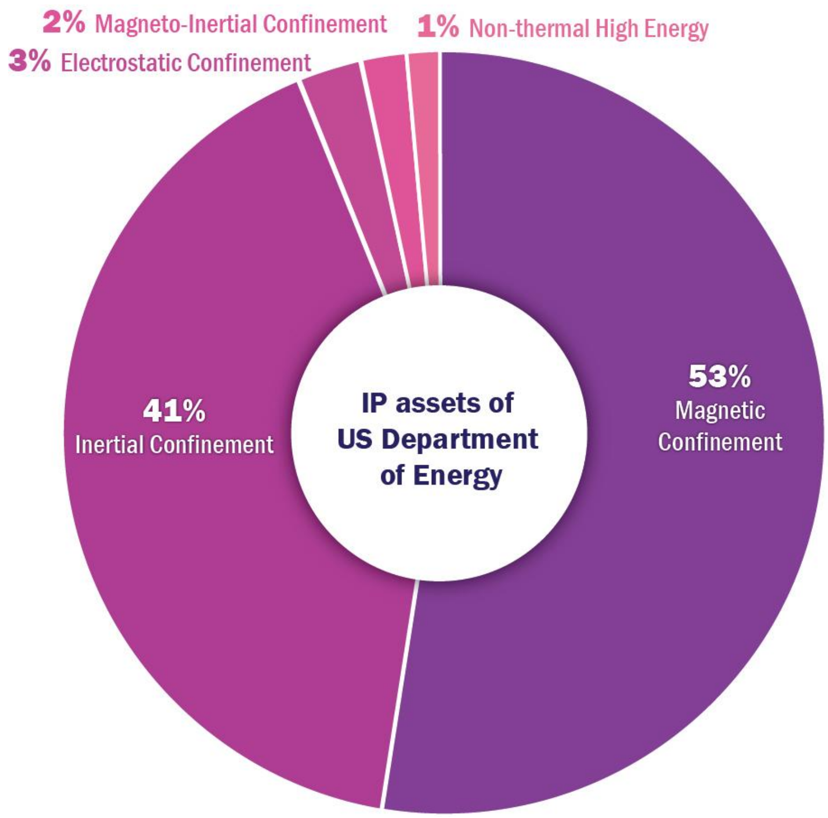
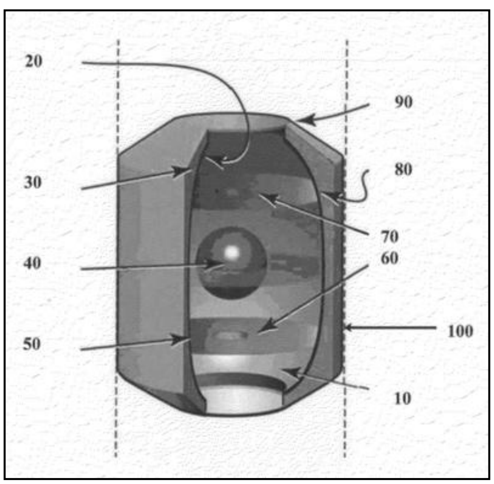


Figure 21: Distribution of Nuclear Fusion Patents across Level 3 Categories in US DOE's portfolio (Source: iRunway analysis based on patent data from Questel Orbit)

The department has primarily invested in researching magnetic confinement technology. It also has a high number of IP assets in the inertial confinement domain. The National Ignition Facility, that it operates, is revolutionizing laser technologies used in inertial confinement fusion. Very little research has been done in the area of non-thermal nuclear fusion.



Source: Patent US 20120114088

DOE owns a notable inertial fusion technology patent application US 20120114088 titled "Indirect Drive Targets for Fusion Power". The invention describes a "hohlraum" which contains fusion fuel within a capsule. This invention has the advantage of precision reconfiguration of target assembly and force and torque feedback, to provide greater system flexibility for accommodating any changes in target design.

5.2 Atomic Energy Commission

The United States Atomic Energy Commission (AEC) is an agency of the United States government for the improvement of atomic science and technology. In 1975, the AEC was disintegrated with its regulatory functions being transferred to the Nuclear Regulatory Commission (NRC) and the other to the US Department of Energy. It owns 124 IP assets in the field of Nuclear Fusion.

Figure 22 maps the filing trend and the grant trend of nuclear fusion patents in the US AEC's portfolio.

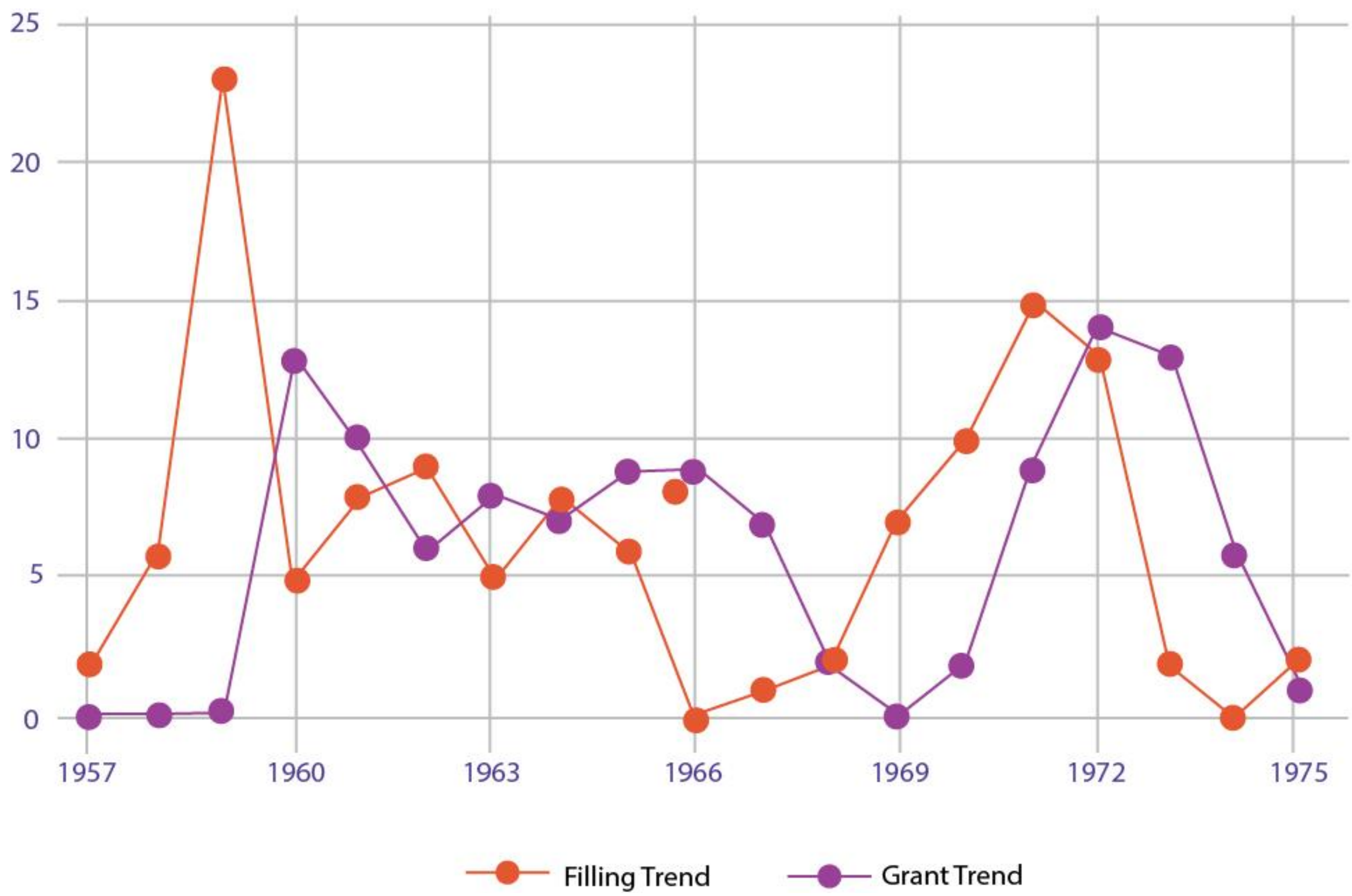


Figure 22: US Atomic Energy Commission's Patent Filing and Grant Trend in Nuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

A majority of AEC's research and development activities in nuclear fusion has been focused in the area of magnetic confinement fusion. The pie chart below shows the count of IP assets of the US ACE across technology categories. With 88 IP assets, magnetic confinement fusion is the category with the greatest focus. The organization has also invested considerably in developing inertial confinement and magneto-inertia confinement technologies. Electrostatic confinement has attracted the least focus, while AEC has not indulged in any research activity in the area of non-thermal nuclear fusion.

Figure 23 charts the US Atomic Energy Commission's count of global IP assets across Level 3 categories of nuclear fusion technology.

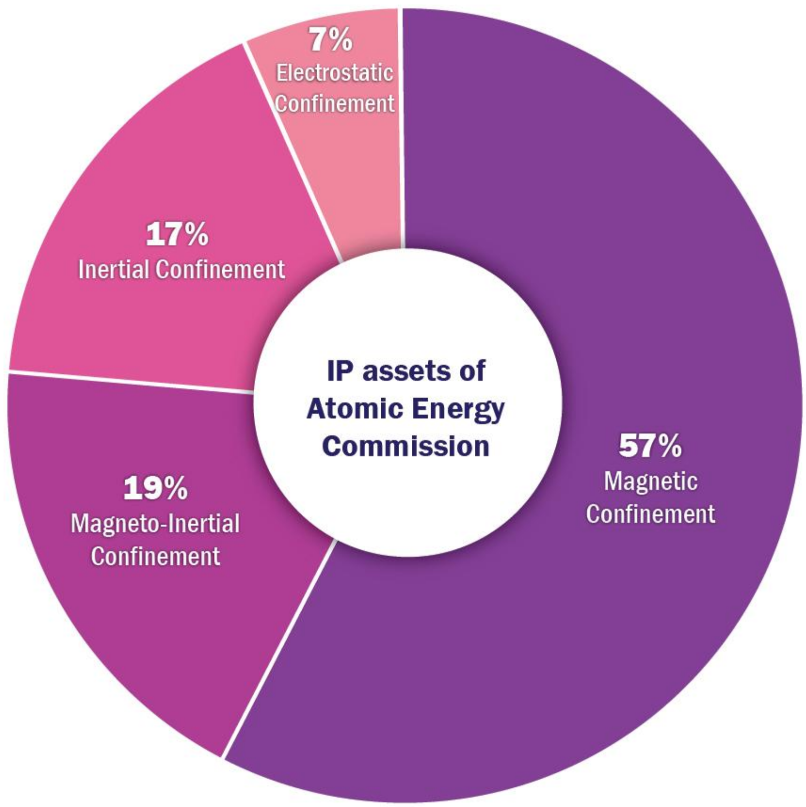


Figure 23: Distribution of Nuclear Fusion Patents across Level 3 Categories in US AEC's portfolio (Source: iRunway analysis based on patent data from Questel Orbit)

5.3 Hitachi

Established in 1910, Hitachi is a Japan-based multinational corporation that is working in a number of different sectors, including the energy sector. It has been heavily involved in a nuclear energy project in conjunction with GE for the creation of PRISM (Power Reactor Innovative Small Module) reactors. With many R&D laboratories around the world, Hitachi's research in nuclear fusion technologies has been immense. It currently owns a total of 117 IP assets in this technology domain.

Hitachi has been researching superconducting technology since the late 1950s. Japan's Large Helical Device (LHD) for nuclear fusion research employs Hitachi's superconductors. Figure 24 shows the filing trend and the grant trend of IP assets owned by Hitachi.

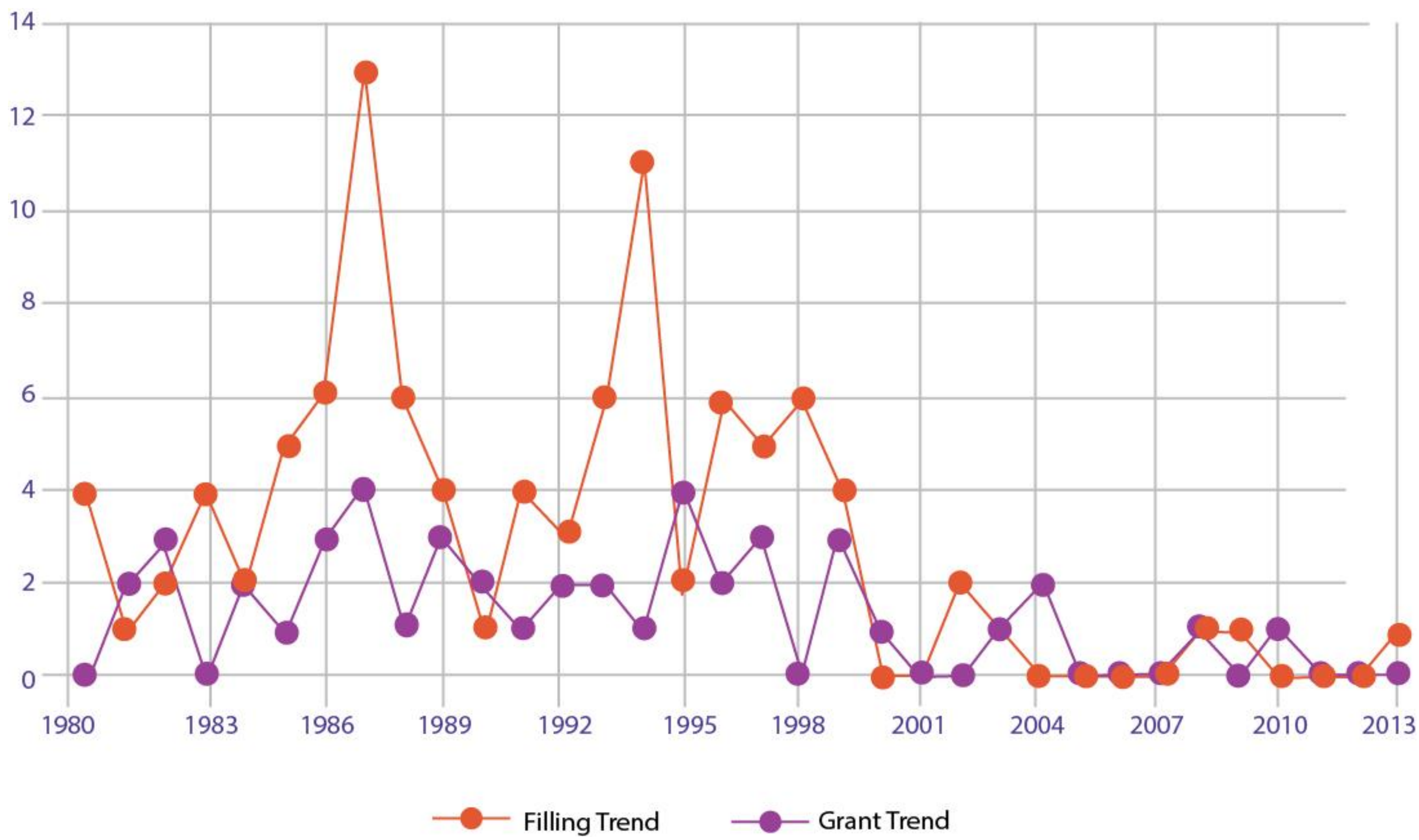


Figure 24: Hitachi's Patent Filing and Grant Trend in Nuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

Of its 117 IP assets in this space, Hitachi has seven active patents, of which six are granted patents and one is a pending application. The rest have expired. Figure 25 charts the company's count of global IP assets across Level 3 categories of nuclear fusion technology.

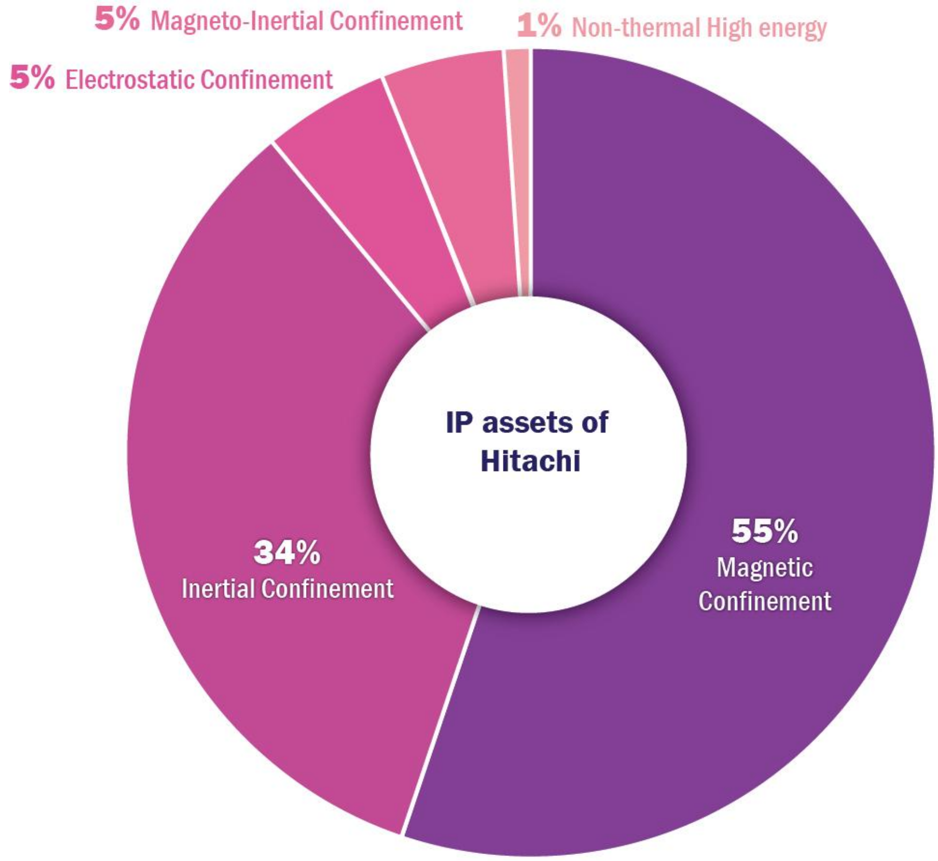


Figure 25: Distribution of Nuclear Fusion Patents across Level 3 Categories in Hitachi's portfolio (Source: iRunway analysis based on patent data from Questel Orbit)

5.4 University of California

Established in 1868 under the public university system in Berkeley, University of California introduced the nuclear engineering program in 1958. Since then, the university has been active in its research of nuclear fusion technologies and owns 100 IP assets in this technology domain.

Figure 26 charts the nuclear fusion technology patent filing and grant trends owned by the University of California. Between 2003 and 2006, the university published several research papers relating to magnetic confinement. This indicates a peak in research activity during this period that translates into the peak in patent filing activity in that three-year period.

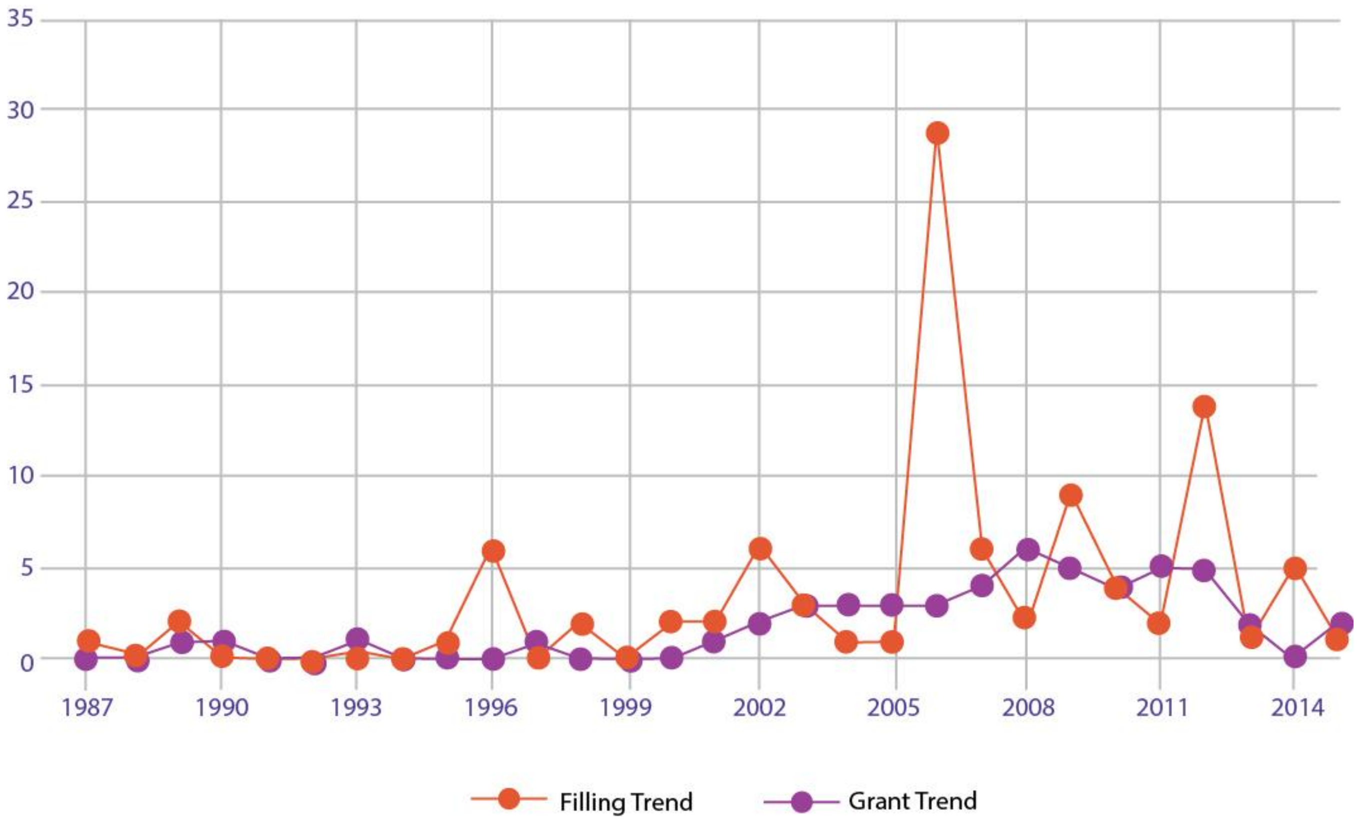


Figure 26: University of California's Patent Filing and Grant Trend in Nuclear Fusion Technology (Source: iRunway analysis based on patent data from Questel Orbit)

There are a total of 81 active patents, of which 48 are granted IP assets and the remaining 33 are pending applications. The university owns a majority of its IP assets in the Magnetic Confinement category. It has very few IP assets in the magneto-inertial confinement category. Also, there has been no research in the area of non-thermal low energy nuclear fusion. Figure 27 charts University of California's count of global IP assets across Level 3 categories of nuclear fusion technology:

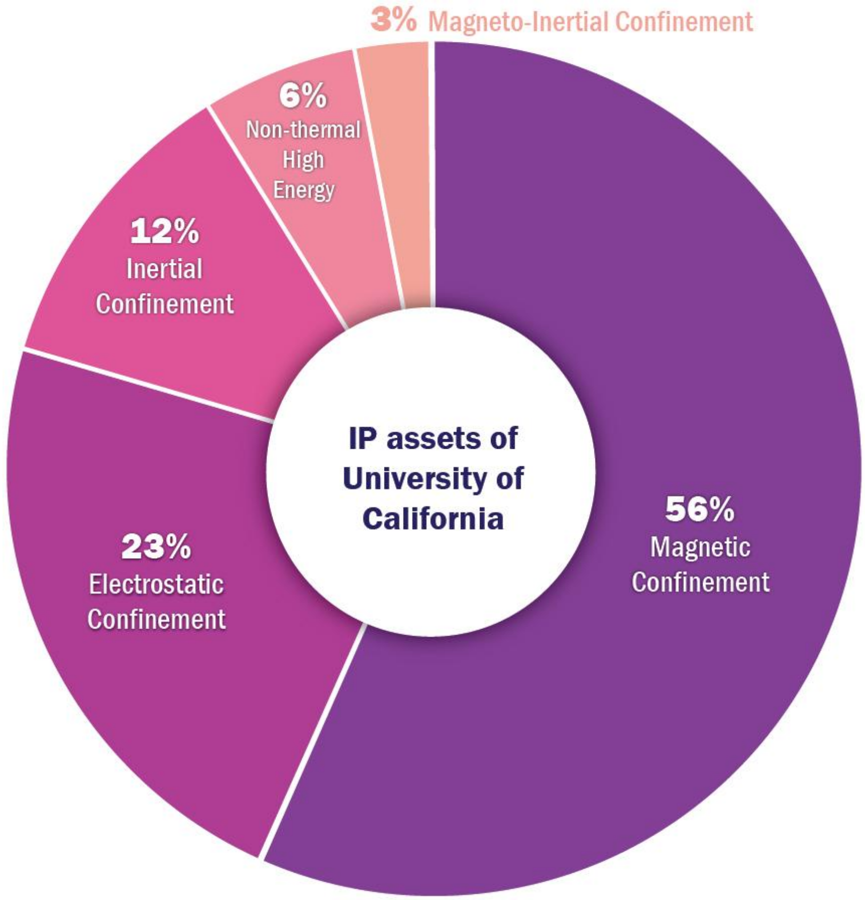
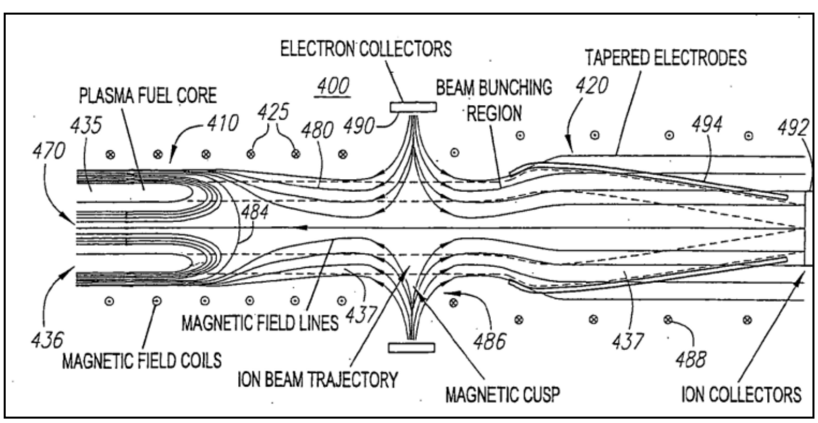


Figure 27: Distribution of Nuclear Fusion Patents across Level 3 Categories in University of California's portfolio (Source: iRunway analysis based on patent data from Questel Orbit)

The University owns a patent application [US 20120027151](US 20120027151) titled "Inductive plasma source and plasma containment". The invention describes controlled fusion in a field reversed configuration (FRC) magnetic topology wherein transport of ions and electrons happens in a guided manner.



Source: Patent US 20120027151

A neutral gas is distributed over a coil of wound wires, which are then energized to ionize the gas into plasma. The plasma is rotated in a way such that the magnetic field created by the plasma interacts with guide magnetic field of external field coils of the reactor chamber. The resulting field forms an FRC topology.

5.5 Toshiba

Toshiba, a Japan based company, has been involved with nuclear energy since the early 2000s. It is a leading researcher in nuclear fusion technology and owns 94 IP assets. Toshiba has signed a contract with Japan Atomic Energy Agency for manufacturing superconducting toroidal coils for the ITER reactor. The coils will be used to generate magnetic fields for confining plasma for the fusion process[27]. Figure 28 charts Toshiba's patent filing and grant trends in this technology.

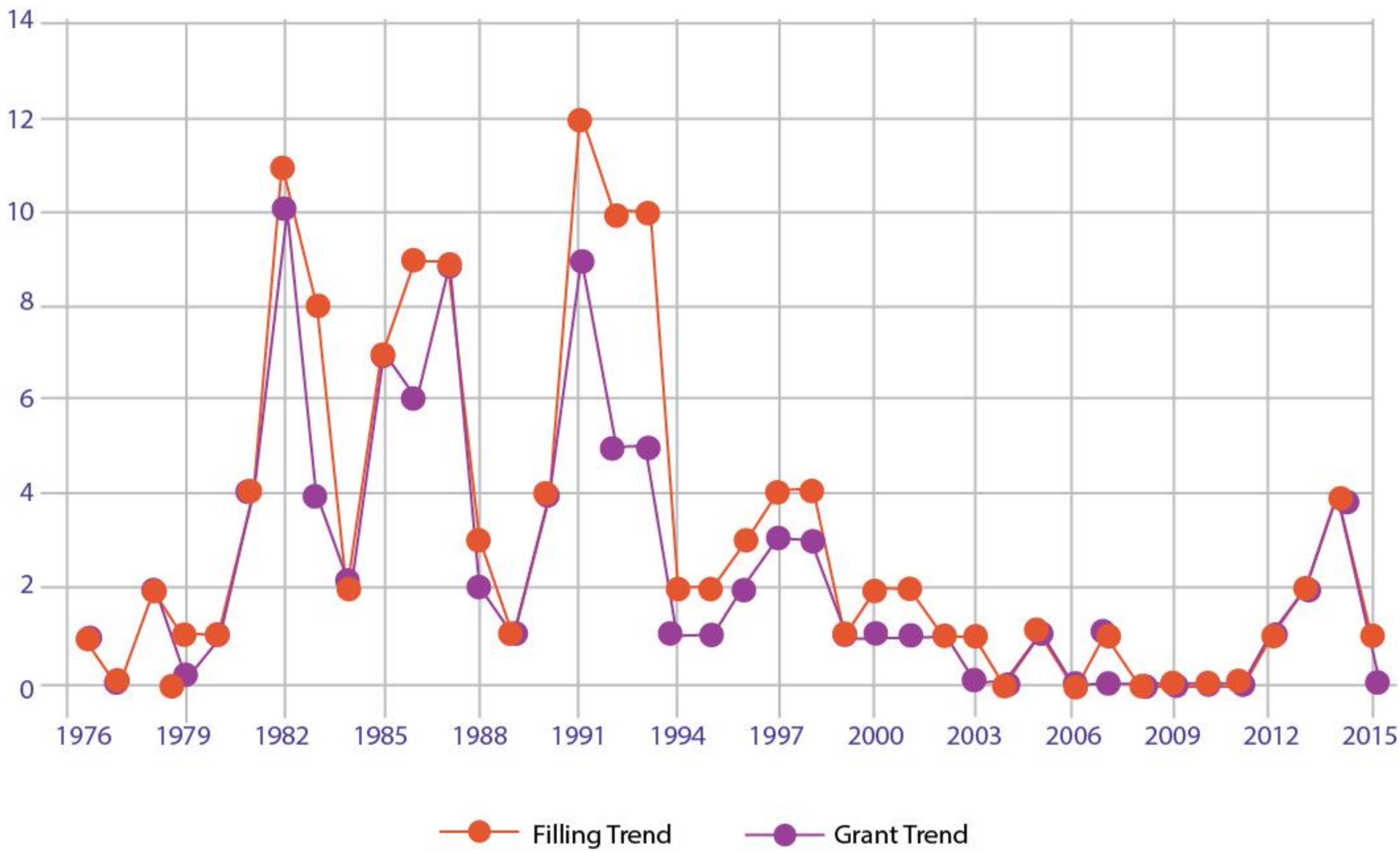


Figure 28: Toshiba's Patent Filing and Grant Trend in Nuclear Fusion Technology
(Source: iRunway analysis based on patent data from Questel Orbit)

The company has 11 active patents in its overall portfolio of 94 IP assets. Figure 29 charts the percentage of Toshiba's IP assets across Level 3 categories. Toshiba does not own any IP asset in electrostatic confinement and non-thermal low energy nuclear fusion. Most of its research is focused on magnetic and inertial confinement fusion techniques.

27 "Toshiba Wins a Contract for ITER's Superconducting Coils", *Toshiba Press Release*, retrieved November 25, 2015

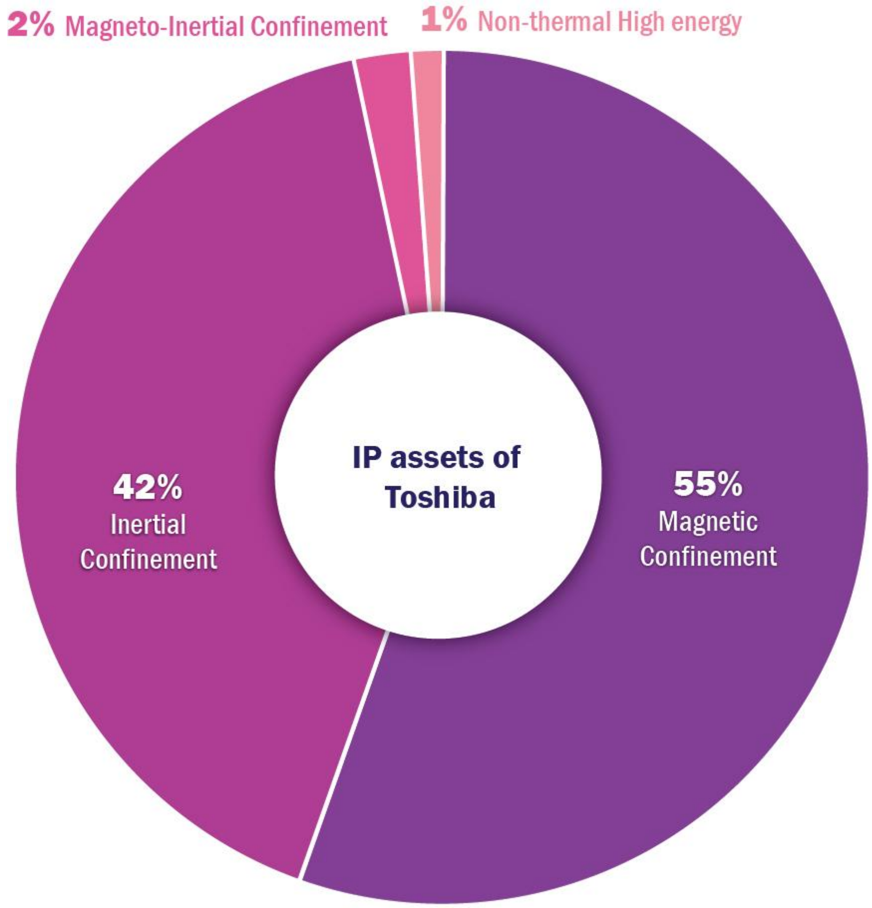


Figure 29: Distribution of Nuclear Fusion Patents across Level 3 Categories in Toshiba's portfolio (Source: iRunway analysis based on patent data from Questel Orbit)

6 Nuclear Fusion Roadmap

In recent years, scientists have been able to overcome many hurdles associated with energy production using nuclear fusion technology. The Joint European Torus (JET) is the largest tokamak in the world. The JET has proved a technical feasibility of producing fusion energy from deuterium and tritium fuels. It has produced 16MW of fusion power already and is currently working on making fusion work on a power plant scale.[28]

The following projects are also being implemented to achieve a target of nuclear fusion power generation within 30 years:

- **ITER (International Thermonuclear Experimental Reactor):** The ITER is currently under construction in France and is being designed to produce ten times more fusion power than the power consumed by the reactor system.[29] The project is supported by the EU, India, Japan, China, Russia, South Korea and the USA. Its aim is to produce 500 megawatts of output power from the 50 megawatts required for the reactor operation.
- **IFMIF (International Fusion Materials Irradiation Facility):** This is a material testing facility that has undertaken the task of determining potential materials for use as fuels in the nuclear fusion reactions.[30]
- **The National Ignition Facility (NIF):** The NIF is an Inertial Confinement Fusion research facility located at the Lawrence Livermore National Laboratory in Livermore, California. The facility, constructed by the US Department of Energy, has met a target of 300 laser shots for FY 2015 to rapidly compress a tiny fuel pellet so that it undergoes fusion at its core. It is currently aiming for a 400 shots target for FY 2016.[31]
- **Max Planck Institute for Plasma Physics (IPP):** This German based institute has developed the Wendelstein 7-X stellarator (W7-X) that is scheduled to go live in the near future. The W7-X is the largest stellarator in the world. The toroidal shaped device has 50 non-planar and 20 planar superconducting magnetic coils to generate the magnetic fields required to contain the plasma. The institute also has an experimental tokamak – the ASDEX Upgrade and is also working in cooperation with ITER and JET projects.
- **DEMOnstration Power Plant (DEMO):** This is a proposed collection of nuclear fusion reactors that will supply fusion generated electricity to the power grid. It is a test on the viability of fusion

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28 "Introduction to fusion", *Culham Centre for Fusion Energy*, retrieved November 6, 2015
29 "The international ITER Project for fusion: Why?", *ITER website*, retrieved November 6, 2015
30 "The IFMIF – International Fusion Materials Irradiation Facility", *IFMIF website*, retrieved November 6, 2015
31 "Efficiency Improvements", *Lawrence Livermore National Laboratory*, retrieved November 6, 2015

reactors to produce electricity for commercial purposes. The success of ITER will determine the future of this project.[32]

Nuclear fusion has gone beyond government interest. Private companies and investors alike see the potential of this clean energy generating technology. Private players are also conducting research in nuclear fusion, independent from the government. Much of their money is coming from futuristic investors, who know if the idea is a success, this will be a billion dollar market. The following private entities are working on this technology:

- **General Fusion:** This is a Canadian company involved in the development of fusion power based on magnetized target fusion (MTF). The company plans to mechanically compress plasma, using physical rams that transmit shock waves, to cause fusion in a central pellet. The company owns two granted US patents. These are US 8537958 titled "Systems and methods for compressing plasma" and US 8891719 titled "Systems and methods for plasma compression with recycling of projectiles". The patents describe techniques to compress plasma toroids, by injecting the plasma into a funnel made of liquid metal or impacting the plasma to a cavity in a liquid metal. The plasma can be compressed to a density and/or temperature sufficient to initiate fusion reactions. The company has garnered a total of $62.04 million in five rounds of investing.
  Bezos Expeditions (Jeff Bezos' personal venture capital investments), Business Development Bank of Canada, Cenovus Energy and Sustainable Development Technology Canada are some of the investors involved. The most recent funding (of around $27 million) came from a group of investors, with a major chunk of the amount coming from the Government of Malaysia's investment fund – Khazanah Nasional Berhad.
- **Tri Alpha Energy:** This private funded California-based company is working on revolutionizing the technique of confinement of plasma. The company has built a reactor where a Field-Reversed Configuration (FRC) of the reactor's magnetic field is used to hold the plasma together. The company has filed for an application US 20150245461 titled "Negative ion-based neutral beam injector". The application describes a neutral beam injection method, to accelerate and heat the plasma, using an ion source to produce a negative ion beam. Conventional neutral beam injectors were based on positive ions.
  The company also plans to use a fuel mixture of Hydrogen and Boron for the fusion reactions instead of the commonly used Deuterium-Tritium fuel. This reaction produces no neutrons and hence minimizes radioactive waste. However, this requires much higher temperatures for fusion.
  Tri Alpha Energy has received a cumulative amount of $40 million in 2 rounds of funding. Some of

32 "Introduction to fusion", *Culham Centre for Fusion Energy*, retrieved November 6, 2015

the investors include Goldman Sachs, Microsoft co-founder Paul Allen and New Enterprise Associates.[33] The company has also received an undisclosed amount of funding from a Russian state owned firm – Rusnano Group.[34]

- **Helion Energy:** This Washington-based company is working on a fusion reactor - "The Fusion Engine". The reactor will use magneto-inertial confinement fusion, where, stability of steady magnetic fusion and heating of pulsed inertial fusion are combined. The Fusion Engine is being designed to use helium from engine exhaust and deuterium from sea water for fuel. The fuel will be heated to form plasma and be compressed by magnetic fields to reach the fusion temperatures. Pulsed magnetic fields will be used for the acceleration of the plasma.[35]

  Helion energy is a spin-off of the MSNW LLC. MSNW LLC owns one US patent (US 9082516) and a US application (US 20110293056) in nuclear fusion technology. It has licensed this technology to Helion Energy[36]. The granted patent describes a method of establishing a magnetically insulated fusion process where FRC plasma is created first. A metal shell residing in proximity of the FRC plasma is collapsed and this causes compression of the plasma to fusion conditions.

  Helion Energy has received a cumulative funding of $12.11 million investment in 2 rounds of funding. Of this total, Mithril Capital Management and Y Combinator have provided the seed amount of $1.5 million. The U.S. Department of Energy has also expressed its interest in their technology and have invested $5 million in it[37].
- **MSNW LLC:** Based out of Redmond, USA, MSNW LLC is developing revolutionary space propulsion technologies. The company is exploring the use of nuclear fusion to power rockets for space travel. The project has been funded partly by the NASA's Innovative Advanced Concepts Program and has already received two rounds of funding.[38]
- **Industrial Heat:** This North Carolina-based start-up is working on Low Energy Nuclear Reactions (LENR), also called cold fusion. The start-up is backed by investments from private equity firm Cherokee Industrial Partners. The company acquired rights to E-Cat technology in 2014. This technology uses nickel and hydrogen in a LENR system to generate industrial levels of heat energy. The company has raised over $11 million.[39] In August 2015, the company filed a WIPO application WO 2015127263 titled "Energy-producing reaction devices, systems and related methods".

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33 "Tri Alpha Energy", *Crunchbase.com*, retrieved November 6, 2015
34 "The secret U.S.-Russian nuclear fusion project", Halper, Mark, *ZDNet*, May 6, 2013
35 Helion Energy Homepage, retrieved November 6, 2015
36 "Fusion Energy Generation", *MSNW*, retrieved November 6, 2015
37 "Helion Energy raised $10.9 million and has filed to raise $21 million which would be enough to build a breakeven scale fusion machine in 2016-2017", Wang, Brian, *nextBIGfuture,* August 18,2015
38 http://www.space.com/20609-nuclear-fusion-rocket-mars.html
39 "Darden: Cold fusion-focused Industrial Heat showing 'some success'", Ohnesorge, Lauren, Triangle Business Journal, April 16, 2015

7 Conclusion

Non-thermal fusion technologies, including cold fusion and muon-catalyzed fusion, are not so popular and have very limited patenting activity. Magnetic confinement and inertial confinement are the traditional areas of research and have significant patenting activity. Magneto-inertial confinement is a hybrid of magnetic and inertial confinement and one of the primary drawbacks of this process is the increased plasma instabilities due to both magnetic fields and lasers/ion beams. This has reduced the patenting activity in this sub-domain despite its theoretical advantages.

Nuclear fusion research requires cooperation on a global scale. Many massive fusion reactor projects have some of the largest global economies contributing in both cash and skilled labour. The United States of America is currently the leader in the technology's IP space with about 2,000 IP assets. Japan, China and Germany respectively follow and the IP assets of all three countries combined add up to about 1400 IP assets.

The US Department of Energy is the leading IP asset owner in the nuclear fusion domain with 139 global IP assets. It has also been observed that more than half of the IP assets in nuclear fusion technology have expired, majority of which have expired due to non-payment of fees. This could be attributed to the fact that patentees realized the non-commercial viability of these technologies, and decided to allow it to lapse on economic grounds.

Nuclear fusion technology is still in a research phase and there are no nuclear power plants currently that are commercially viable sources of energy (generates more power than the power consumed to execute the reaction). Since there aren't any commercial nuclear power generators, IP litigation in this domain is also non-existent.

8 Appendix

Plasma: This fourth state of matter is attained by heating and pressurizing a gas at extremely high temperatures to a point that atoms within the gas lose electrons and exist in the form of ions. Plasma can also be created by subjecting a gas to strong electromagnetic fields created by lasers.

Deuterium: This is an isotope of Hydrogen containing 1 proton, 1 neutron and one electron. Deuterium can be extracted from water.

Tritium: This is the second isotope of Hydrogen. Its nucleus contains one proton and two neutrons.

Tokamak: This is a device that uses a magnetic field to confine plasma. The tokamak is a doughnut/toroid shaped vacuum vessel. Fusion fuel is placed in the vessel and heated to form plasma. Superconducting coils surrounding the vessel generate magnetic fields that confine the plasma for the fusion reaction.

Stellarator: This is also device that can be used to magnetically confine plasma for a Nuclear Fusion reaction to occur. While tokamaks are toroidal shaped with uniform circular magnetic coils surrounding the structure, the stellarators are not azimuthally symmetric. They rather have a discrete rotational symmetry. This makes the magnetic fields generated within the chamber to be twisted. Even though this makes construction of a stellarator much more complex and expensive than the tokamak, it provides an advantage that the plasma can be confined for a longer time and thereby fusion can occur more easily.

Field-Reversed Configuration: This is a magnetic field topology for confinement of plasma, whereby the resultant magnetic field lines formed are closed. There is no central penetration and the toroidal field is also negligible. The electric current induced in the plasma produces a poloidal magnetic field which interacts with the external applied electric field to form a resultant self-confined field. This magnetic field geometry is different from conventional reactors, such as the ones in tokamak. The need to make the reactor structure in a toroidal shape is eliminated, and the reactor can instead be made cylindrical. This leads to cheaper and simpler construction of the reactor and easier maintenance.

Cold Fusion: A type of nuclear fusion reaction that occurs at near room temperature. The reaction is currently only in a hypothetical stage; no experimental proof has been documented as of yet.

Active Patent: This is a granted patent that is currently alive and enforceable. This means that all the necessary patent maintenance fees have been paid and the patent has also not crossed its life term.

Fusion Technique	Description	Ongoing projects
Magnetic Confinement	Magnetic fields are used to heat and confine plasma.	General Atomic's DIII-D is the largest operating tokamak in the US. ITER will be the world's largest nuclear fusion reactor once it begins operations.
Electrostatic Confinement *Polywell*	Static electric fields are used to heat and confine plasma. High voltage electricity is used to create an electrostatic potential well. Positively charged ions fall into the negatively charged well and fuse.	EMC2 San Diego is currently working on a polywell project for the US Navy – the Wiffleball Polyhedral Device WB8.
Inertial Confinement	Lasers or ion beams are used to heat and confine plasma. The time for this fusion reaction is limited by the inertia of the fuel. ***Direct Illumination***: Lasers or ion beams are directly aimed at a hydrogen pellet to heat it and aid fusion. ***Indirect Illumination:*** A hydrogen pellet is placed inside a black box. Lasers or ion beams are deposited on the inner surface of the black box, producing black body radiation, which is then absorbed by the pellet.	National Ignition Facility (NIF) is the world's largest laser system combining 192 individual beams to compress hydrogen fuel.
Magneto-Inertial Confinement *Magnetized Target Fusion (MTF)*	A hybrid of magnetic confinement and inertial confinement, this method creates a magnetic field to confine plasma at a density lower than inertial confinement, and uses impulsive drivers (such as laser liners) to heat it with a confinement time lesser than magnetic confinement.	This technique is being researched by private groups, including General Fusion.
Low Energy Non-Thermal *Cold Fusion*	The fusion reaction occurs at room or lower temperatures, and involves electrolysis of water on Pd electrodes.	North Carolina-based start-up Industrial Heat is actively researching this technology.
High Energy Non-Thermal *Muon-catalyzed Fusion*	Muon particles are similar to electrons but are 207 times more massive. The muons replace electrons in atoms. The nuclei are hence drawn 207 times more closely, thereby increasing the probability of fusion.	The method is being researched at a theoretical stage.

Table 3: Description of Nuclear Fusion techniques

9 Methodology

The objective of this technology landscape analysis was to analyze and identify trends in the nuclear fusion patent landscape. The identified trends were analyzed to extract inferences. Further, the landscape was analyzed to determine the patent density in this domain.

The technology taxonomy was obtained with the help of an expert from the US Department of Energy. The researchers created search strings for various categories of the technology, accounting an exhaustive set of keywords in each category.

The data for this report was obtained using Questel Orbit patent database. The date of data extraction was November 17th, 2015. Various fields important to the technology landscape analysis were also obtained from this database.

The total number of unique global IP assets were analyzed from the data set and categorized into the taxonomy categories. The IP assets were then carefully curated by our experts to remove any irrelevant results (such as fusion of nuclei of biological cells) and to ensure that the IP assets were categorized into the appropriate sub-categories based on the technology described in the invention.

Analysis and inferences were drawn based on the collated & curated data set and information available from trusted sources.

10 Author Profile

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Sankar is the Vice President of Solutioning at iRunway. He provides thought leadership in IP and drives solution development. Sankar is an expert in designing IP monetization programs for patent owners and he provides key technical insights that help IP attorneys profoundly improve licensing and litigation outcomes.

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