Intellectual Property Office

KTN the Knowledge Transfer Network

A patent landscape analysis of thermoelectric generators

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This report was prepared for the Knowledge Transfer Network by the
UK Intellectual Property Office Informatics Team
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Knowledge Transfer Network
Bailey House
4-10 Barttelot Road
Horsham
West Sussex
RH12 1DQ
@KTNUK

www.ktn-uk.org

Intellectual Property Office
Concept House
Cardiff Road
Newport
NP10 8QQ
United Kingdom

e-mail: *informatics@ipo.gov.uk*

www.ipo.gov.uk/informatics

Contents

1 Introduction

Thermoelectric energy generators exploit the Seebeck effect, according to which electricity is generated from a temperature difference between opposite segments of a conducting material typically having a columnar grid structure. A detailed investigation of materials for transduction and storage was conducted by the Energy Harvesting Special Interest Group (EH SIG) and published on *www.ktn-uk.org*. Temperature differentials result in heat flow and, consequently, charge flow or in other words electric current. Performance of a thermoelectric generator is primarily defined by conducting material properties, its geometry and the temperature differential between the cold and the hot ends. As a result there is a broad range of thermoelectric generators producing from microwatts to kilowatts of energy. Devices that produce under 1Wt of power would be of interest to Energy Harvesting applications and used in autonomous electronics including wearable devices and various sensor systems. More powerful devices could be used in energy recovery and generation and applications range from steel works to interplanetary space missions.

Patent data can give a valuable insight into innovative activity, to the extent that it has been codified in patent applications. The Knowledge Transfer Network (KTN) is investigating the field of thermoelectric generators (TEGs) and is interested in a patent landscape analysis of thermoelectric generators in general as well as a detailed analysis of a specific subset of this data, namely patents relating to radioisotope thermoelectric generators (RTGs). The main beneficiaries of this report are expected to be Energy Harvesting and Space communities but it would also be applicable to a number of other industry sectors and areas of research.

The dataset used for analysis was extracted from worldwide patent databases following detailed discussion and consultation with patent examiners from the Intellectual Property Office who are experts in the field and who, on a day-to-day basis, search, examine and grant patent applications relating to thermoelectric generators. The KTN is interested in assessing recent innovation in the field of thermoelectric generators, so the dataset was limited to reflect the last 10 years (2005-2014).

This report is based on the analysis of published patent application data rather than granted patent data. Published patent application data gives more information about technological activity than granted patent data because a number of factors determine whether an application ever proceeds to grant; these include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

2 Thermoelectric generators – worldwide patent analysis

2.1 Overview

Table 1 gives a summary of the worldwide dataset used for the analysis of the thermoelectric generator (TEG) patent landscape. All of the analysis undertaken in this report was performed on this dataset or a subset of this dataset. The worldwide dataset for TEG patents published between 2005 and 2014 contains almost 32,000 published patents equating to almost 9000 patent families.

Published patents may be at the application or grant stage, so are not necessarily granted patents. A patent family is one or more published patents originating from a single original (priority) application. Analysis by patent family more accurately reflects the number of inventions present because generally there is one invention per patent family, whereas analysis by raw number of patent publications inevitably involves multiple counting because one patent family may contain dozens of patent publications if the applicant files for the same invention in more than one country. Hence analysis by patent family gives more accurate results regarding the inventive effort that patenting activity represents.

Table 1: Summary of worldwide patent dataset for thermoelectric generators

Number of patent families	8863
Number of patent publications	31,818
Publication year range	2005-2014
Peak publication year	2013
Top applicant	Toyota (Japan)
Number of patent assignees	6528
Number of inventors	14,428
Priority countries	43
IPC sub-groups	5710

2.2 Filing profiles

Figure 1 shows the total number of published patents by publication year and Figure 2 shows the total number of patent families by priority year (considered to be the best indication of when the original invention took place). Figure 1 suggests a gradual increase in TEG patenting in recent years with over a 50% increase in the number of TEG patents published in 2014 compared to 2005. Figure 2 does not show any patents filed after 2012 because a patent application is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2013 and 2014 data is incomplete and has been ignored.

In real-world terms only limited information can be gleaned from the upwards trends shown in Figure 1 and Figure 2 because overall patenting levels globally continue to grow at an ever-increasing rate. Figure 3 addresses this issue by normalising the data shown in Figure 1 and Figure 2 and presenting the annual change in the size of the worldwide patent databases across all technologies against the year-on-year change in the size of the TEG dataset. For example, between 2009 and 2010 worldwide patenting across all areas of technology increased by 2% and this can be compared to a 12.5% increase in TEG patenting over the same time period.

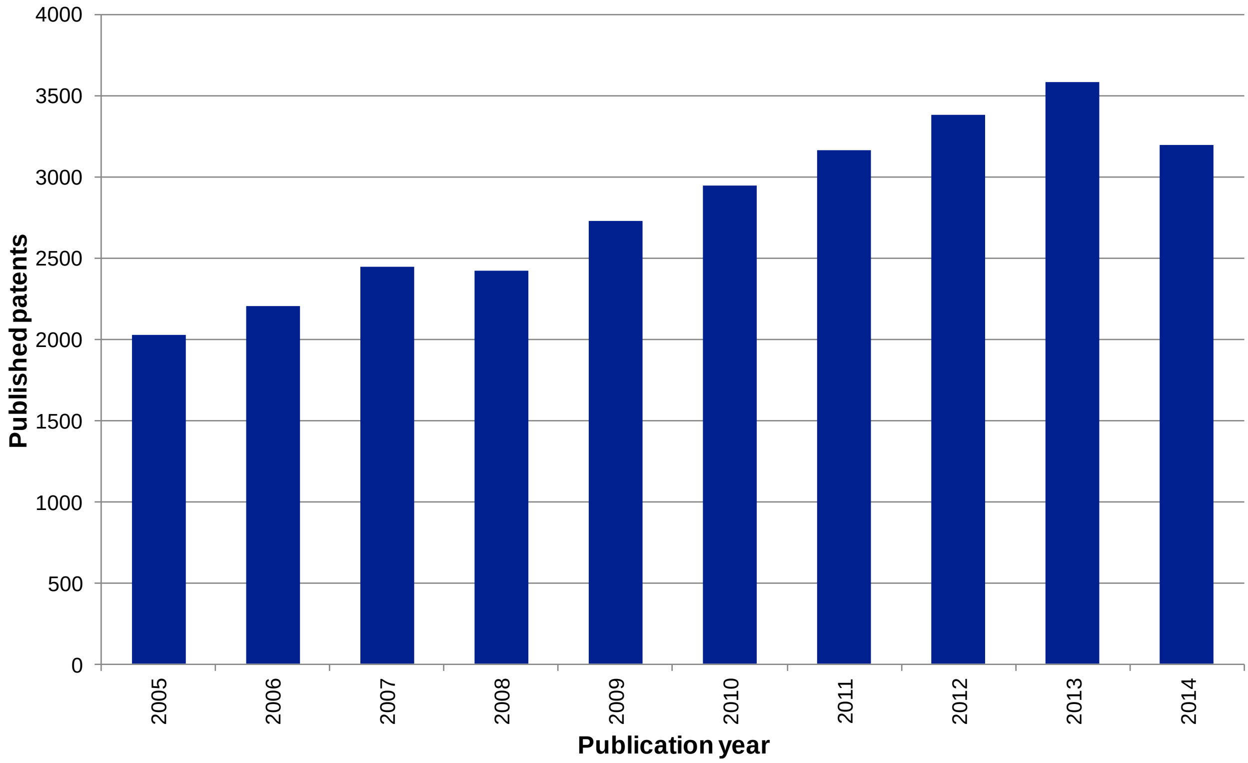

Figure 1: Patent publications by publication year

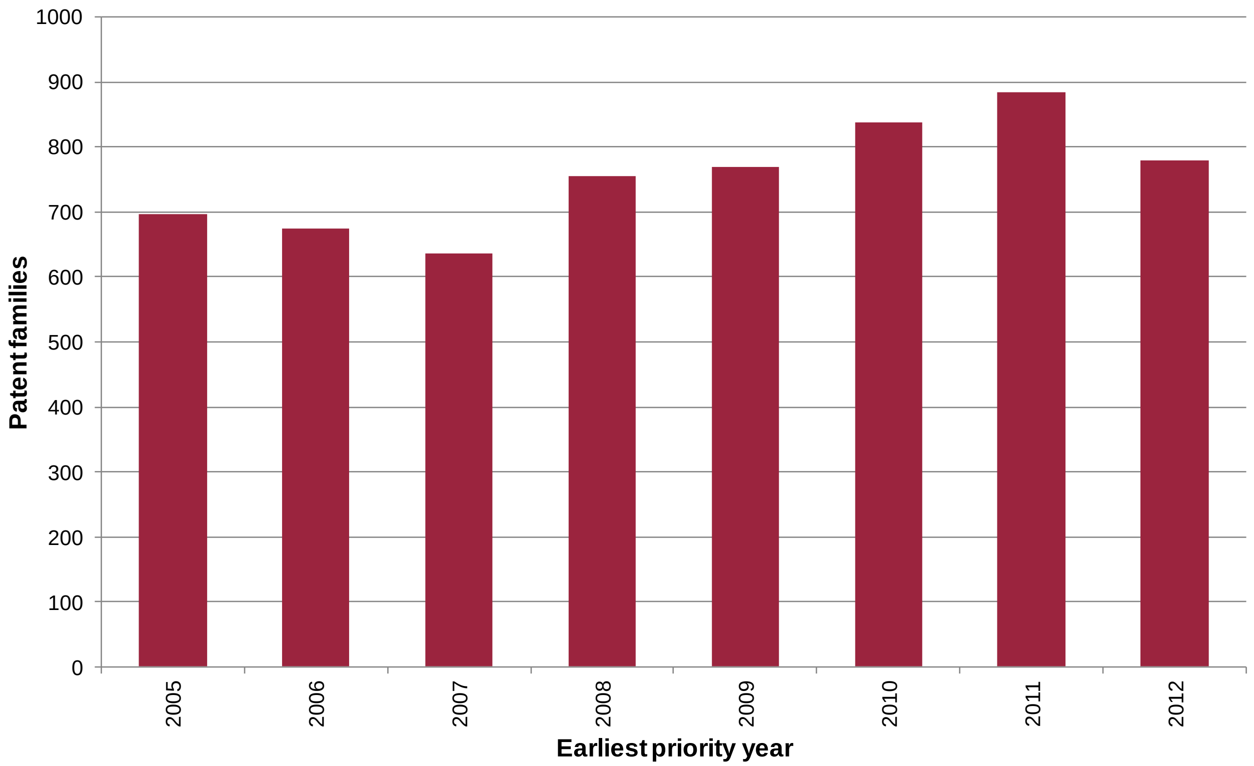

Figure 2: Patent families by priority year (bottom)

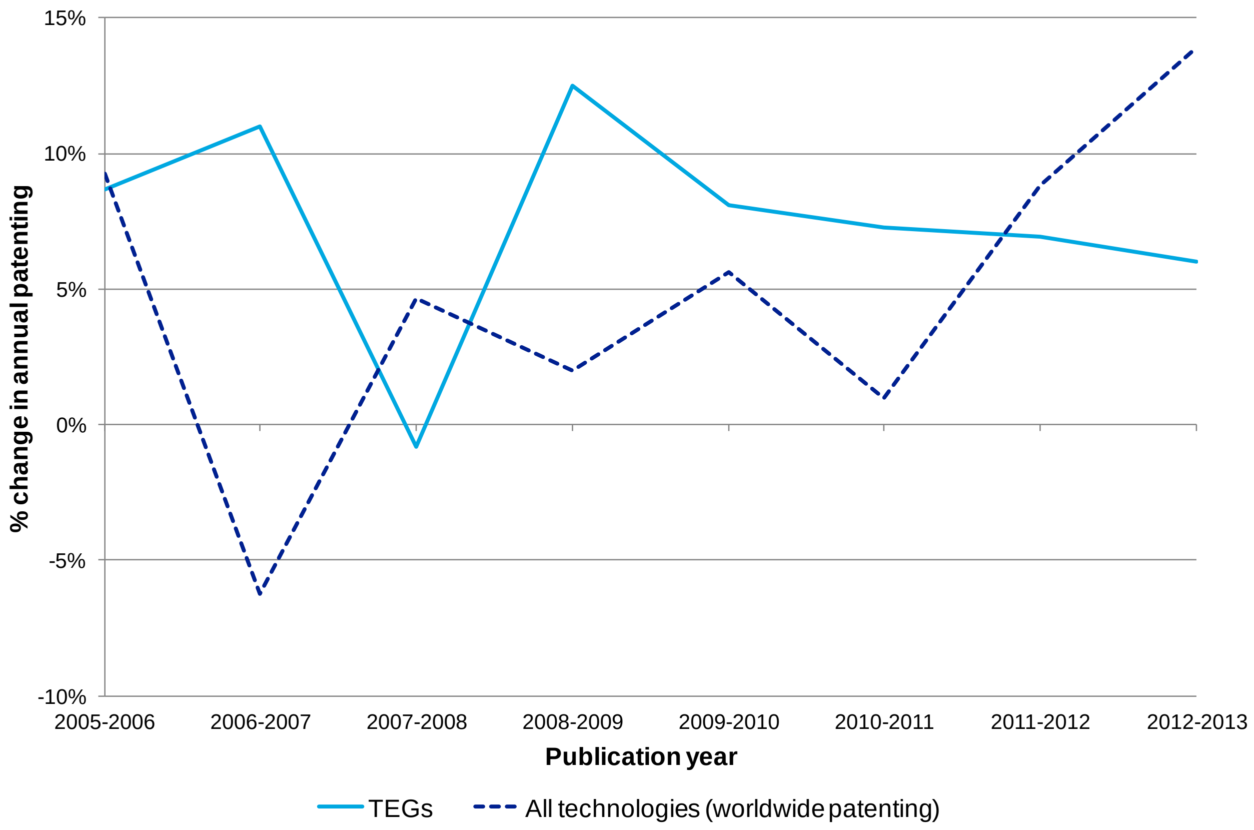

Figure 3: Year-on-year change in TEG patenting compared to worldwide patenting across all technologies

2.3 Geographical analysis

Figure 4 shows the priority country distribution across the dataset with over half of TEG patent families having their first filing in Japan or the USA. Just 1% of TEG patent families are first filed in the UK. Traditionally priority country analysis has been a good indicator of where the invention is actually taking place because many applicants will file patent applications first in the country in which they reside[1], but in recent years drawing firm conclusions from this data is harder because there may be other strategic reasons for an applicant choosing the country of first filing (*e.g.* tax treatment).

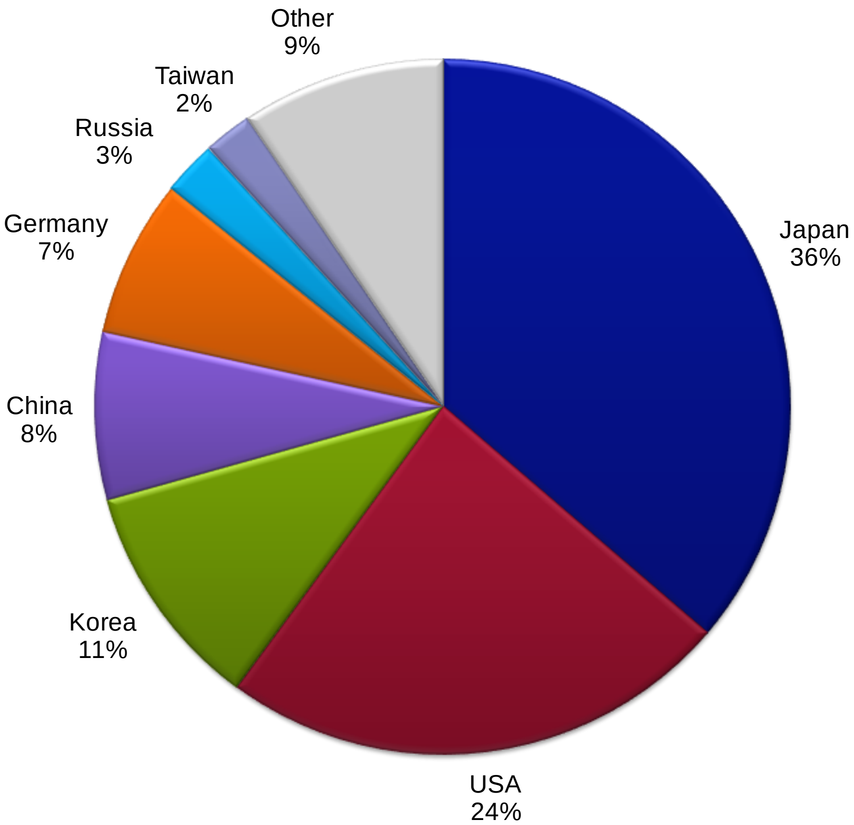

Figure 4: Priority country distribution

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[1] In some countries this is/was a requirement (*e.g.* in the UK this was a requirement until 2005).

The applicant country distribution in Figure 5 shows there is a strong similarity with the priority country distribution shown in Figure 4 and the top five countries (Japan, USA, Korea, China and Germany) account for 87% of all TEG patents.

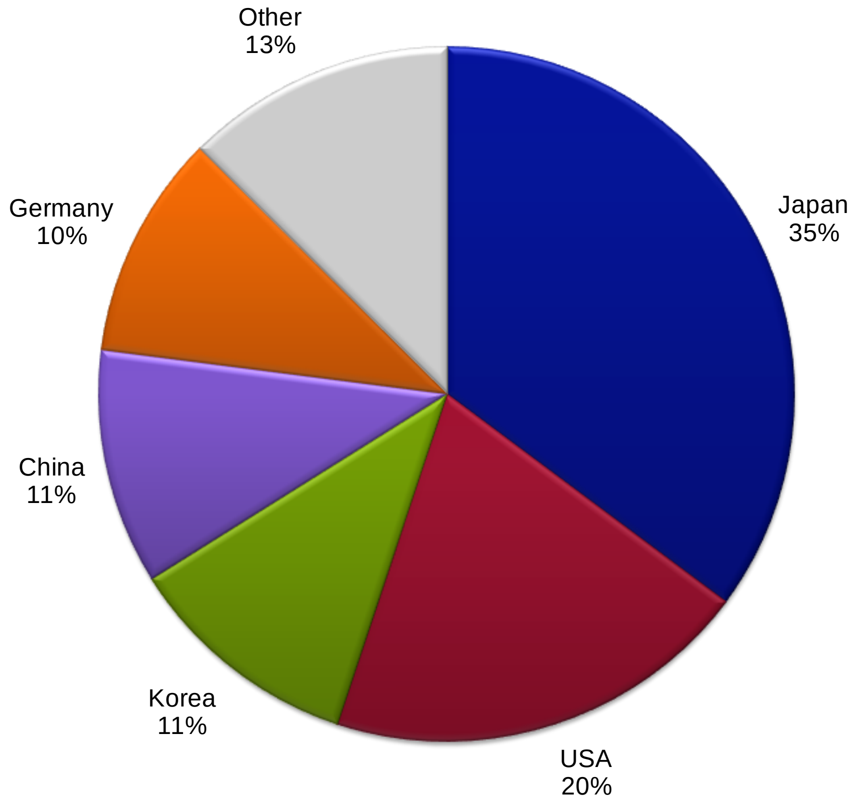

Figure 5: Applicant country distribution

However it is very difficult to draw accurate conclusions from simply presenting data based on the country of residence of patent applicants because there is a greater propensity to patent in certain countries than others. The Relative Specialisation Index (RSI)[2] for each applicant country (Figure 6) has therefore been calculated to give an indication of the level of invention in TEG patenting for each country compared to the overall level of invention in that country.

The priority country distribution shown in Figure 4 and applicant country distribution shown in Figure 5 are dominated by Japan and the USA which suggests that these two countries are relatively specialised in TEGs. However the RSI shown in Figure 6 appears to suggest a slightly different picture. When the RSI is applied, Japan is still ranked 1st, but the USA is ranked 4th, below countries including Australia. The RSI distribution suggests that Australia show much greater levels of patenting in TEGs than expected given their modest absolute levels of patenting.

The UK is ranked 6th with a negative RSI value of -0.10, suggesting that there are fewer TEG patents filed by UK applicants compared to the overall level of patenting from UK applicants across all technology areas. However the UK's RSI ranking of 6th suggests a more positive picture than shown by the UK's ranking in the priority country distribution (11th) and applicant country distribution (8th).

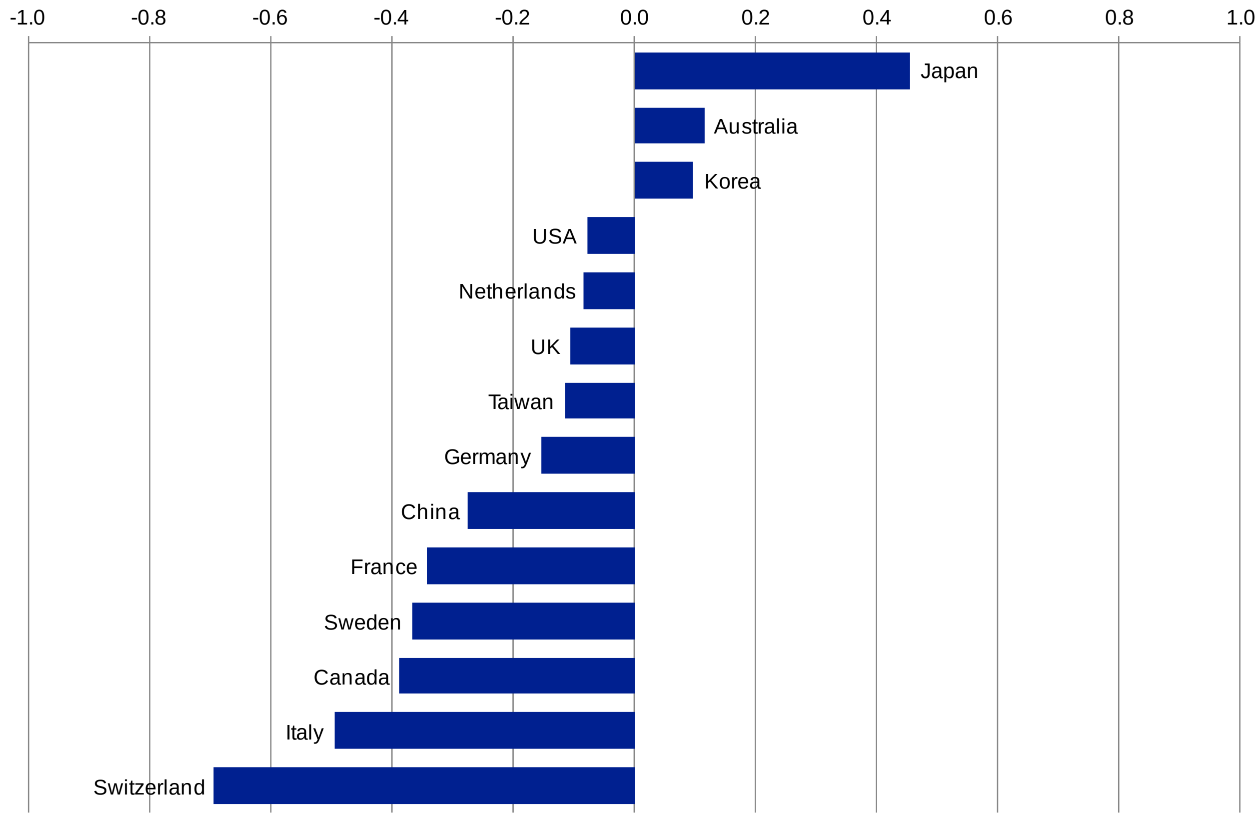

Figure 6: Relative Specialisation Index (RSI) by applicant country

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[2] See Appendix B for full details of how the Relative Specialisation Index is calculated.

Figure 7 shows the countries in which TEG applicants are interested in seeking patent protection. The strong coverage the USA and Japan is expected given the propensity to patent in these countries. UK patents filed at the UK-IPO account for just 0.57% of the dataset but it should be noted that most of the published patents filed via the EPO and WIPO (PCT) routes[3] will also have effect in the UK once granted.

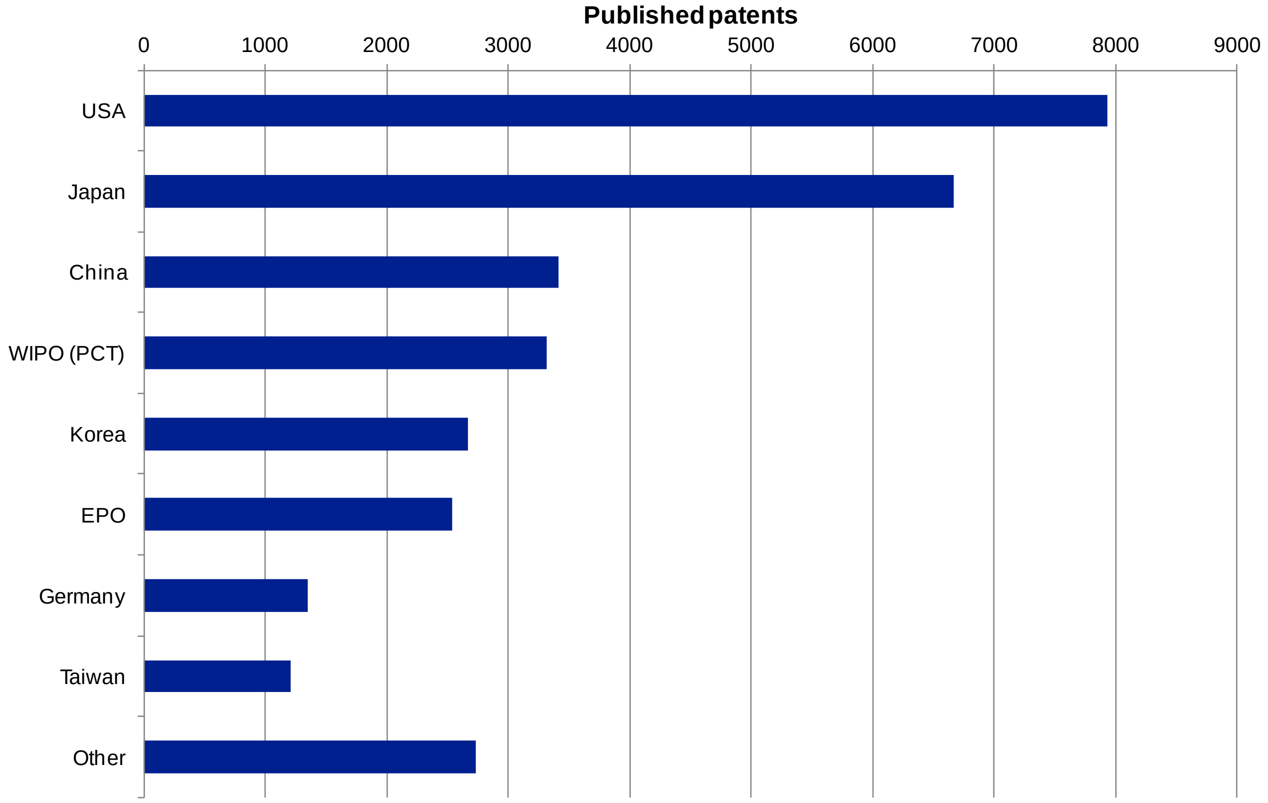

Figure 7: Patent coverage (publication country coverage)

[3] See Appendix A.3 for further details.

Although the KTN is interested in trying to understand the power output and operating temperature range of the TEGs disclosed in these patents, this is impossible due to the inherent way in which patents are drafted.

A patent is a legal document that describes how the invention works and in the UK a patent is granted for an invention that is novel, involves an inventive step[4], is not excluded[5], and is capable of industrial application[6]. Due to computational software limitations, patent landscape analysis cannot be undertaken using the full-text[7] of the patents in the dataset and the text fields that can be analysed is limited to the patent title and abstract.

It is not a legal requirement to disclose the technical specification[8] of a product referred to in a patent application and the full-text description of very few patents contain such information because the ‘quality’ of an end product is not relevant to whether it can be patented or not. The title and abstract of a patent application are even less likely to contain technical specification details of any product disclosed.

In the TEG patent dataset, only 5 of the 8863 inventions (patent families) contain details regarding the TEG power output[9] in the title and/or abstract and only 8 of the 8863 inventions contain details regarding the TEG operating temperature[10]. Macroscopic analysis of this data would not be meaningful.

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[4] Something that is not obvious to the ‘person skilled in the art’.
[5] Excluded inventions in the UK include business methods, scientific discoveries, mathematical methods, mental act, some computer programs etc.
[6] *i.e.* it can be made.
[7] *i.e.* the entire patent specification – consisting of the title, abstract, description, claims and drawings.
[8] For example, the power output, operating temperature range and efficiency of thermoelectric generators.
[9] CN102157672A → 1.03mW; US2008/0083445A1 → 150mW; US2005/0115601A1 → 1W; US2005/0040388A1 → 70W; US2014/0020730A1 → 1kW.
[10] WO2008067815A2 → -123°C; US2005/0115600A1 → -17°C to 40°C; WO2013/119298A2 → 26°C to 226°C; US2008/0083445A1 → 100°C; US2005/0040388A1 → 250°C to 300°C; WO2007/063755A1 → <300°C; PL399296A1 → <400°C; DE102008022802A1 → >400°C.

2.4 Top applicants/inventors

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[11]. Figure 8 shows the top 20 applicants which primarily consists of Japanese companies (14 out of the top 20).

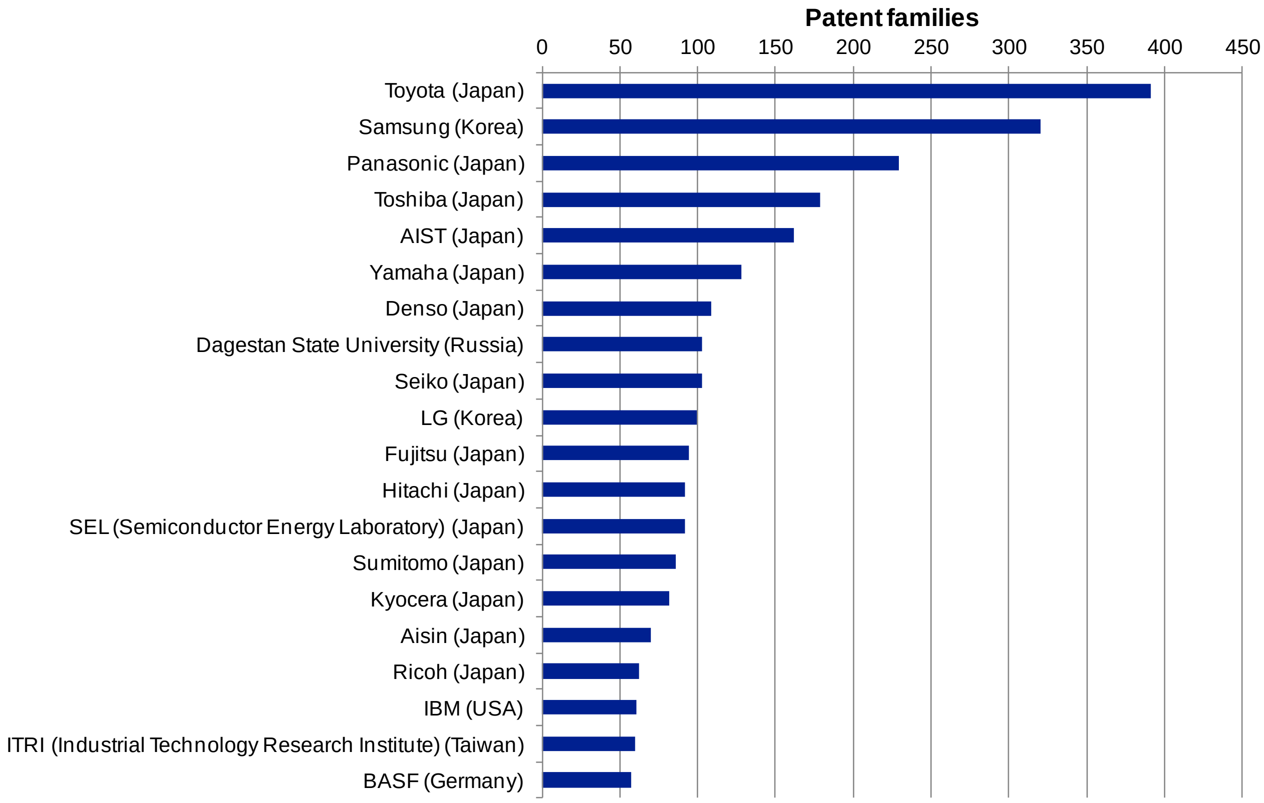

Figure 8: Top applicants

Toyota has the most patent families (391) of any of the applicants in the TEG patent landscape. The inventions that these families seek to protect relate to a variety of different TEG applications with many inventions relating to thermoelectric generation systems for motor vehicles (*e.g.* JP2005051934A), vehicle exhaust gas TEGs (*e.g.* JP2013110218A), thermoelectric materials for seawater temperature difference TEGs (*e.g.* JP2008311247A) and grain oriented ceramics used for solar TEGs (*e.g.* US2003/0013596A1).

For comparison, Samsung have a number of TEG patent applications relating to nanowire TEGs (*e.g.* US2010/0193003A1) and materials used in TEGs (*e.g.* US2013/0299754A1) whereas Panasonic have a number of TEG patent applications relating to small-sized portable TEGs (*e.g.* JP2009218251A) and methods of manufacturing thermoelectric materials (*e.g.* WO2010/007729A1).

AIST (The National Institute of Advanced Industrial Science and Technology) is a Japanese research facility headquartered in Tokyo and is the leading government-funded

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[11] See Appendix A.4 for further details.

organisation in the list of top TEG applicants (162 patent families). Many of AIST's TEG patent applications relate to research into materials for TEGs (*e.g.* JP2014239092A) as well as TEG systems for boats and ships (*e.g.* JP2014195359A) and integrating a TEG into a wristwatch (*e.g.* JP2007103879A). The leading academic patent applicant in the TEG dataset is Dagestan State University in south-west Russia (103 patent families) who appear to specialise in research into thermoelectric batteries.

Figure 9 is a bubble map showing a timeline for the top 20 applicants and shows the filing activity of these applicants in the last 10 years.

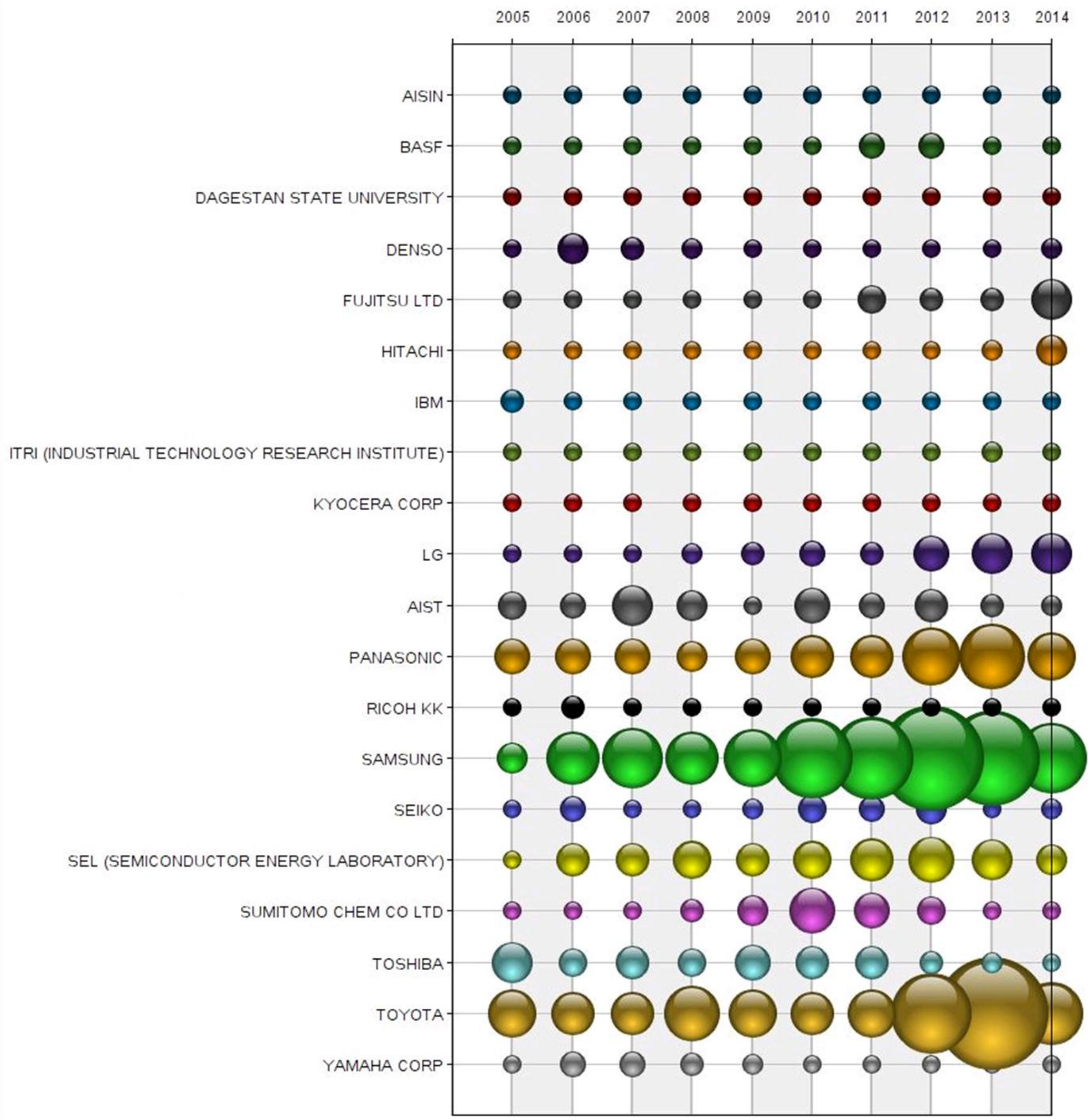

Figure 9: Applicant timeline of published patents by publication year

Figure 10 shows the top 20 inventors in the TEG dataset. Several of the top inventors work for organisations that do not appear in the list of top applicants (Figure 8) including Shanghai Institute of Ceramics and Murata Manufacturing. Shanghai Institute of Ceramics appear to specialise in flexible TEGs (*e.g.* CN202855806U and CN102903839A) and Murata Manufacturing have many patent applications relating to TEGs for use in waste heat management (*e.g.* WO2009/011430A1).

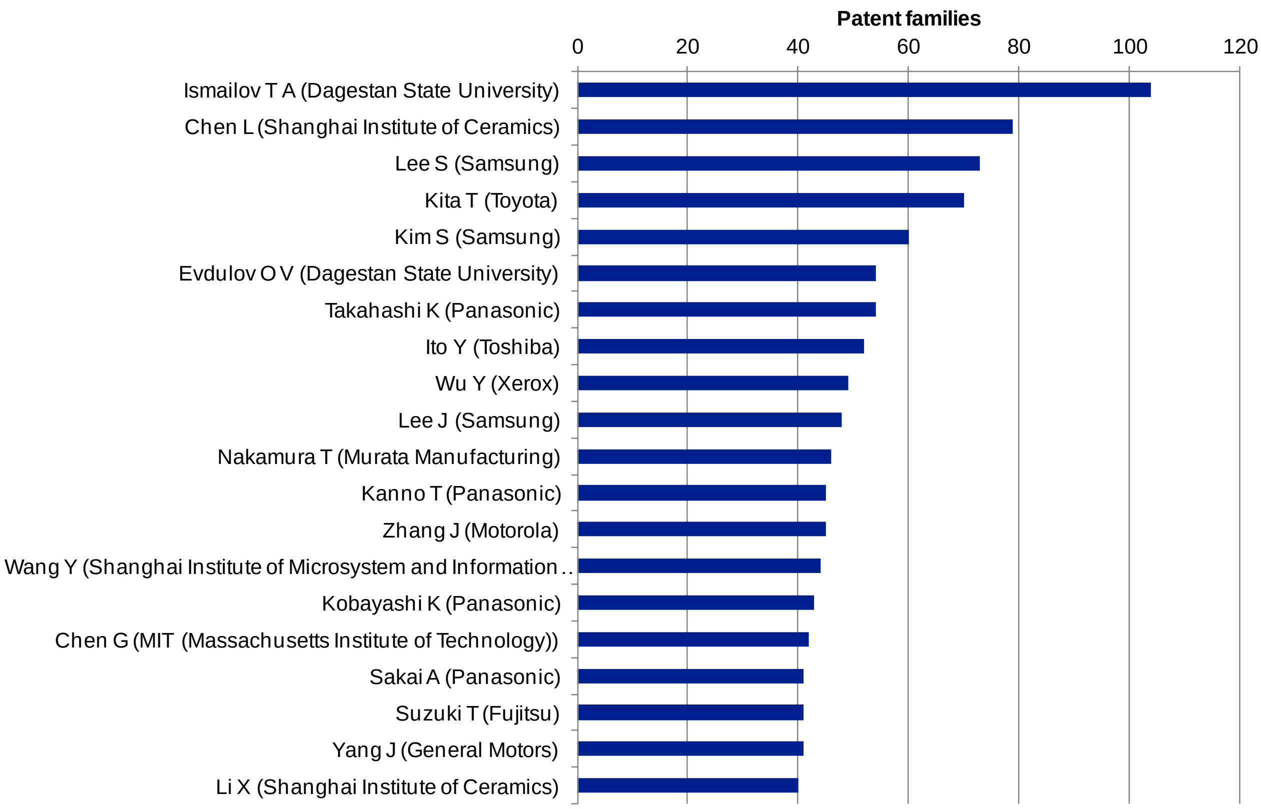

Figure 10: Top inventors

3 Thermoelectric generators – the UK landscape

3.1 UK applicants/inventors

Figure 11 shows that Cambridge Display Technology (CDT) is the top UK applicant for TEG patents with 15 patent families (inventions). CDT is a spin-off from the University of Cambridge, which is also in the top 10 UK TEG patent applicants alongside two other academic institutions, Imperial College and the University of Glasgow. The appearance of Weston Aerospace and BAE Systems is unsurprisingly given one of the common uses of TEGs is in space applications.

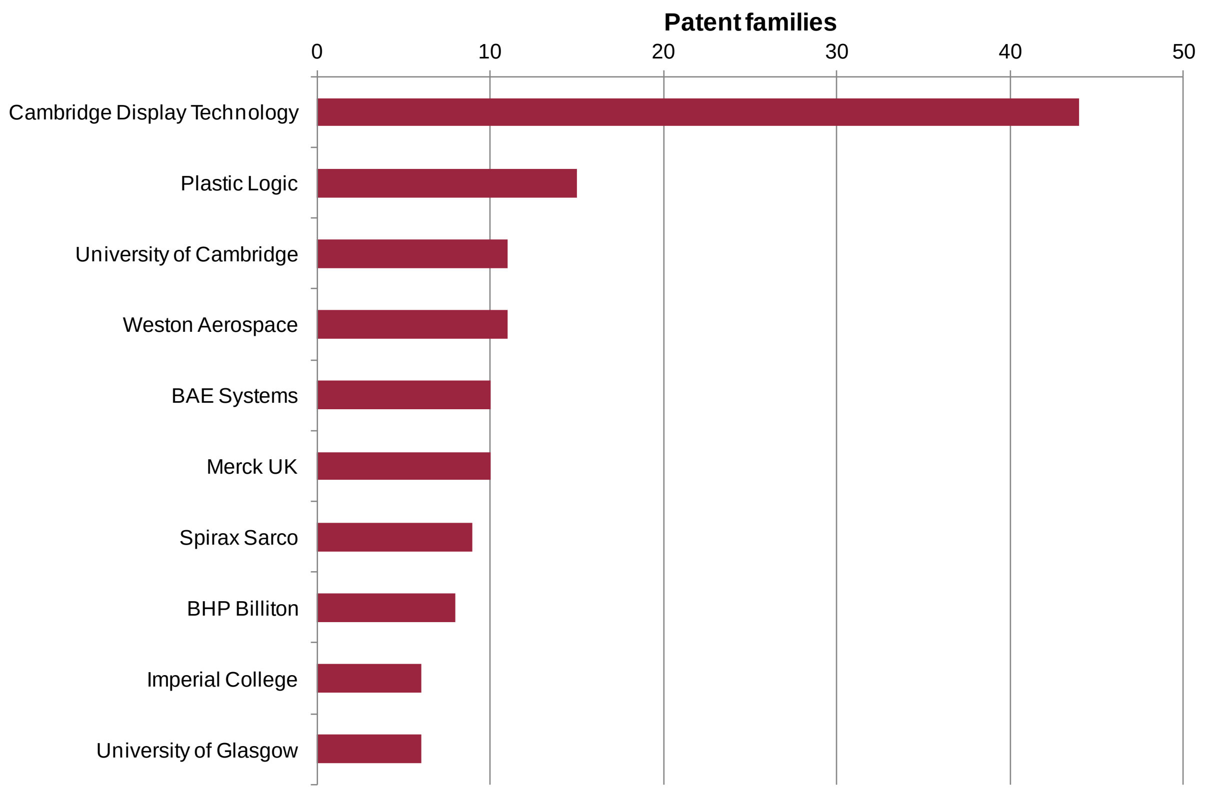

Figure 11: Top UK applicants

Figure 12 shows the top UK inventors. Only one of the top 10 UK inventors (Tavkhelize A) work for non-UK organisations (Borealis Technologies, Gibraltar).

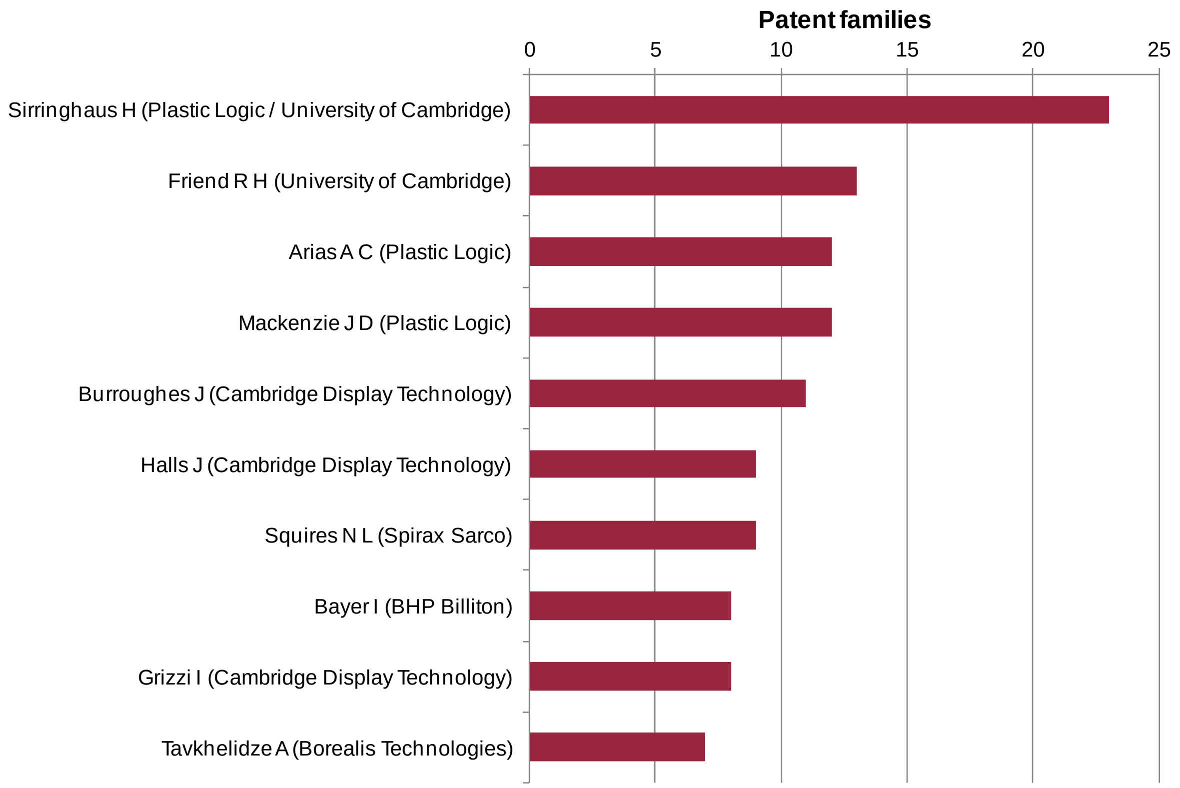

Figure 12: Top UK inventors

3.2 Collaboration

Figure 13 is a collaboration map showing all collaborations between the top UK applicants in the dataset and their collaborators. Each dot on the collaboration map represents a patent family and two applicants are linked together if they are named as joint applicants on a patent application. A collaboration map indicates instances where joint work in solving a problem has resulted in a shared application for a patent.

Cambridge Display Technology (CDT) show collaboration with Sumitomo Chemical, although it should be noted that CDT is now a wholly owned subsidiary of Sumitomo Chemical following a takeover in 2007. Other organisations who have collaborated with CDT include Sumation Co Ltd (Japan), Seiko (Japan), Georgia-Pacific Chemicals (USA) and Panasonic (Japan).

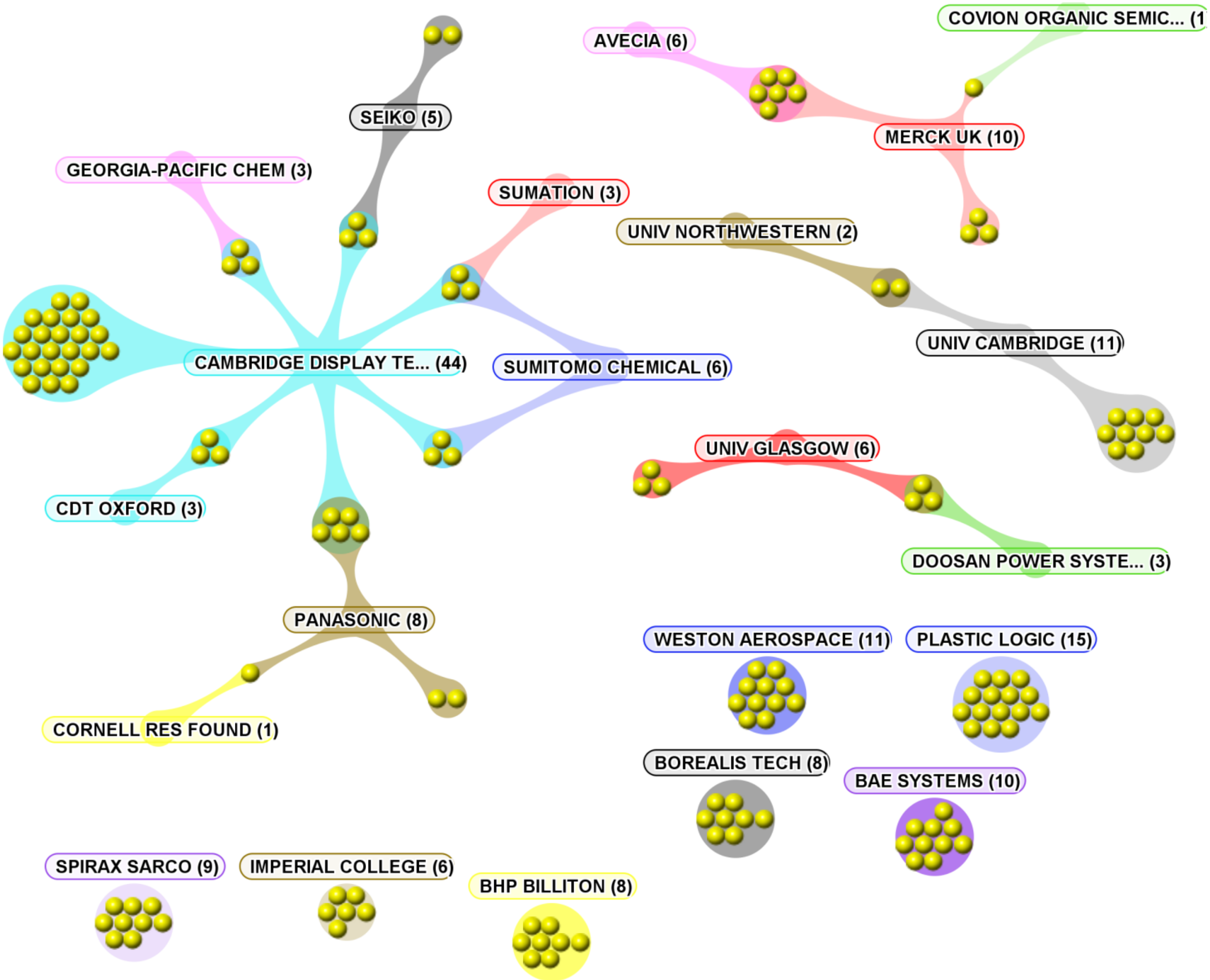

Figure 13: Map of collaborations between the top UK applicants and their collaborators

3.3 How active is the UK?

A subset of the main worldwide TEG patent dataset designed to reflect UK patenting activity[12] was selected. Similar data subsets were created for a number of comparator countries (Japan, USA, China, Germany and France).

Figure 14 shows separate filing trends by comparator country. Japan and the USA are clearly the dominant players in the TEG sector but appear to show a slight decline in patenting activity in recent years whereas there has been a general increase from the other countries considered.

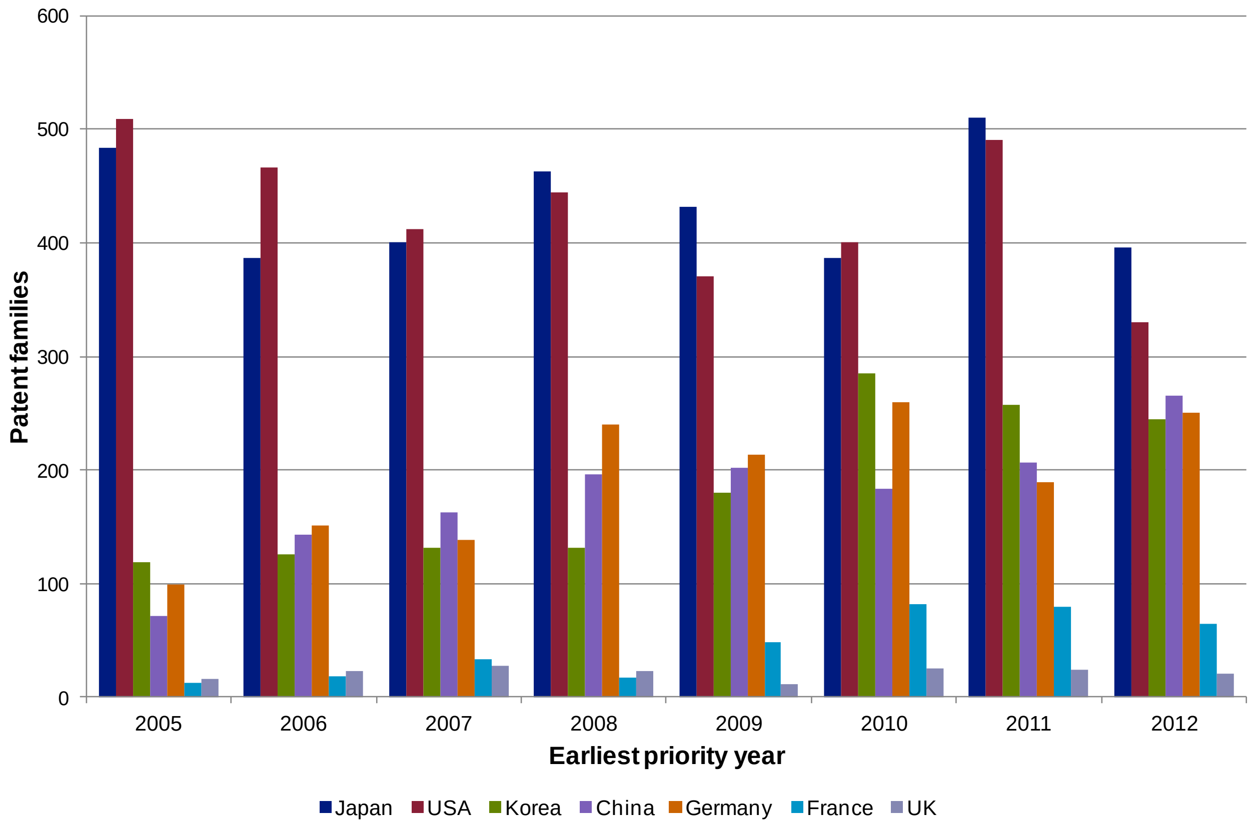

Figure 14: Patenting activity by country (patent families by priority year)

[12] For the purposes of this report, UK patenting activity is defined as either a patent family having at least one application with an applicant with a UK address, a patent family having at least one application with an inventor with a UK address, or a patent family originating in the UK (UK priority).

As discussed previously, there is a greater propensity to patent in certain countries, especially Japan and the USA, so it is difficult to draw accurate conclusions when looking at the 'raw' number of published patents. Hence, Figure 15 shows the annual change in TEG patenting from patenting activity in each comparator country as well as the worldwide year-on-year change in this field.

Patenting activity from Japan and the USA overshadows the data presented in Figure 14 but when the percentage of annual change is plotted in Figure 15 it shows very little growth in patenting activity in these countries (between -8% and 29% for Japan, and -13% and 22% for the USA). This is in contrast with the strong growth seen in China between 2006 and 2008 when TEG patenting activity increased 86% between 2006 and 2007 (92 patent publications in 2006 and 171 in 2007) and then a further increase of 84% between 2007 and 2008 (171 patent publications increased to 314). Strong annual growth well above the worldwide average is also shown for patenting activity from France with four of the nine data points plotted showing an annual year-on-year growth of more than 40%. UK patenting activity showed its biggest increases between 2007 and 2008 (141 patent publications increased to 199) and between 2009 and 2010 (168 patent publications increased to 232).

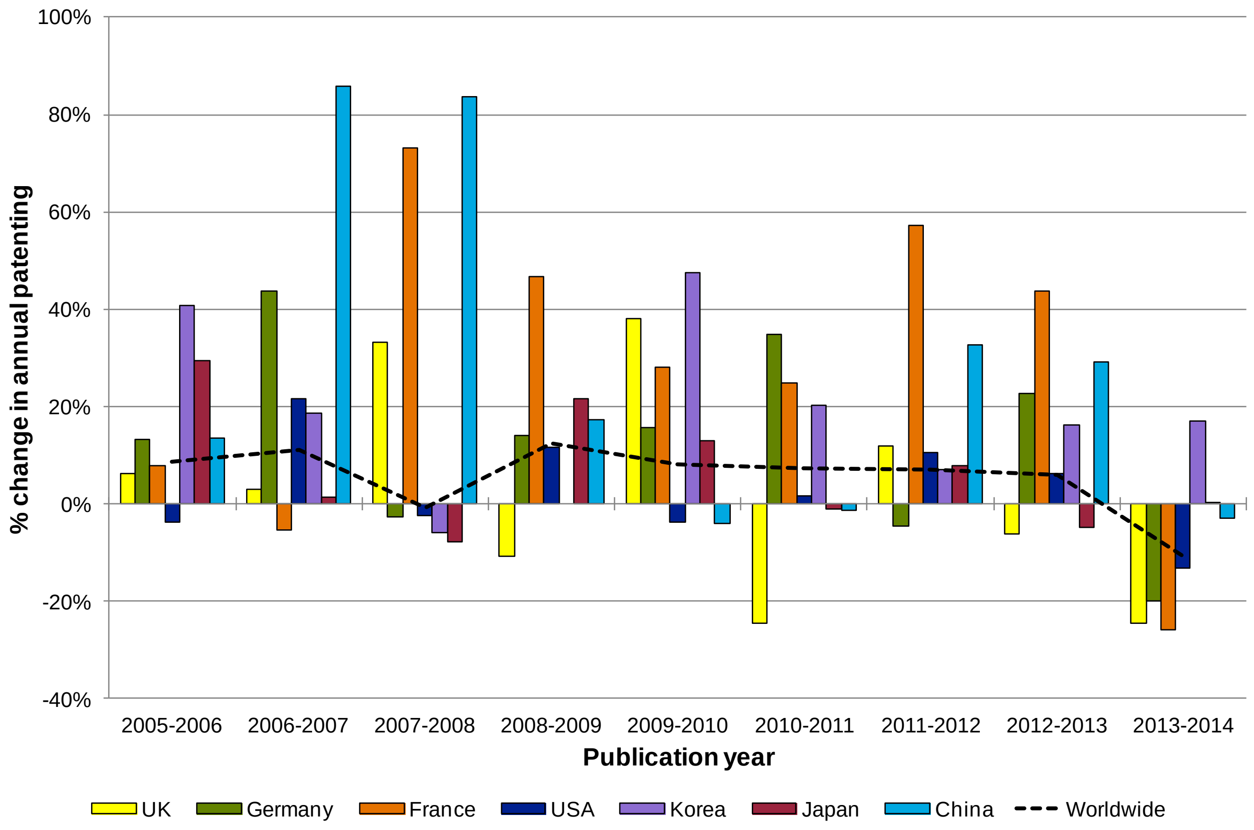

Figure 15: Year-on-year change in TEG patenting activity by country

4 Thermoelectric generators - patent landscape map analysis

In order to give a snapshot as to what the TEG patent landscape looks like, a patent map provides a visual representation of the dataset. Patent families are represented on a patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map[13]. Figure 16 shows the TEG patent landscape map for all TEG patents between 2005 and 2014.

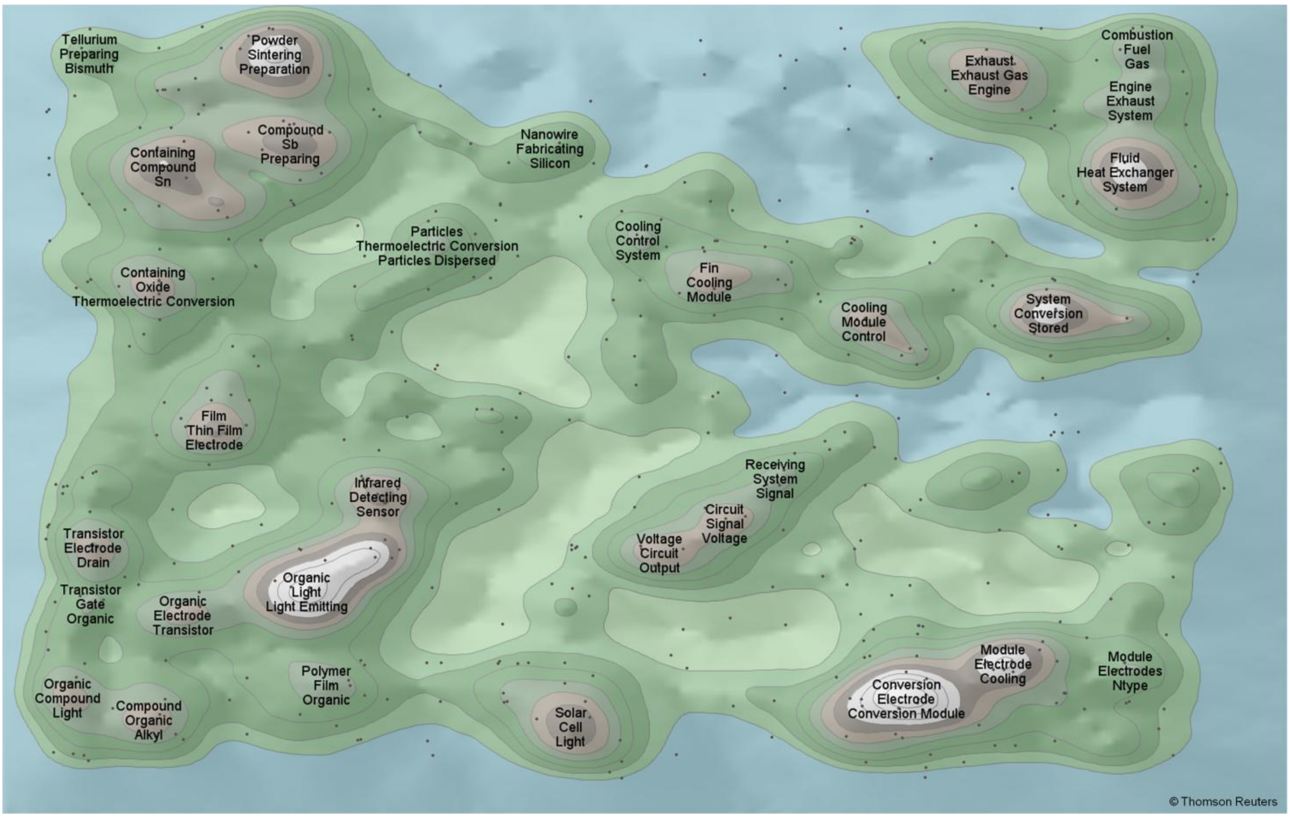

Figure 16: TEG patent landscape map

The largest 'snow-capped peak' in the bottom-left of the map shows that a large proportion of the TEG patent landscape relates to LEDs. This suggests that many inventions relate to the use of TEGs to power light sources, for example stove-mounted lamps[14]. Figure 16 also shows areas of the patent landscape relating to the production of thermoelectric materials (top-left) and using the temperature difference in vehicle exhaust gas to generate power (top-right).

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[13] Further details regarding how these patent landscape maps are produced is given in Appendix C.
[14] See, for example, http://www.stovelite.com/.

The patent landscape map shown in Figure 17 is the same patent map shown in Figure 16, but with the individual TEG patents of five select worldwide applicants highlighted (the top three applicants shown in Figure 8, as well as the top government-funded applicant and the top applicant from academia). Figure 17 visually highlights the previously mentioned TEG patent specialisms from Toyota relating to vehicle exhaust gas TEGs (red dots in the top-right), Samsung relating to nanowire TEGs (green dots) and Panasonic relating to methods of manufacturing thermoelectric materials (cyan dots in the top-left). AIST's specialism for conducting research into materials for TEGs is also clearly shown by the cluster of blue dots in the top-left, as is Dagestan State University's specialism in researching thermoelectric batteries (the cluster of yellow dots in middle-right of the map).

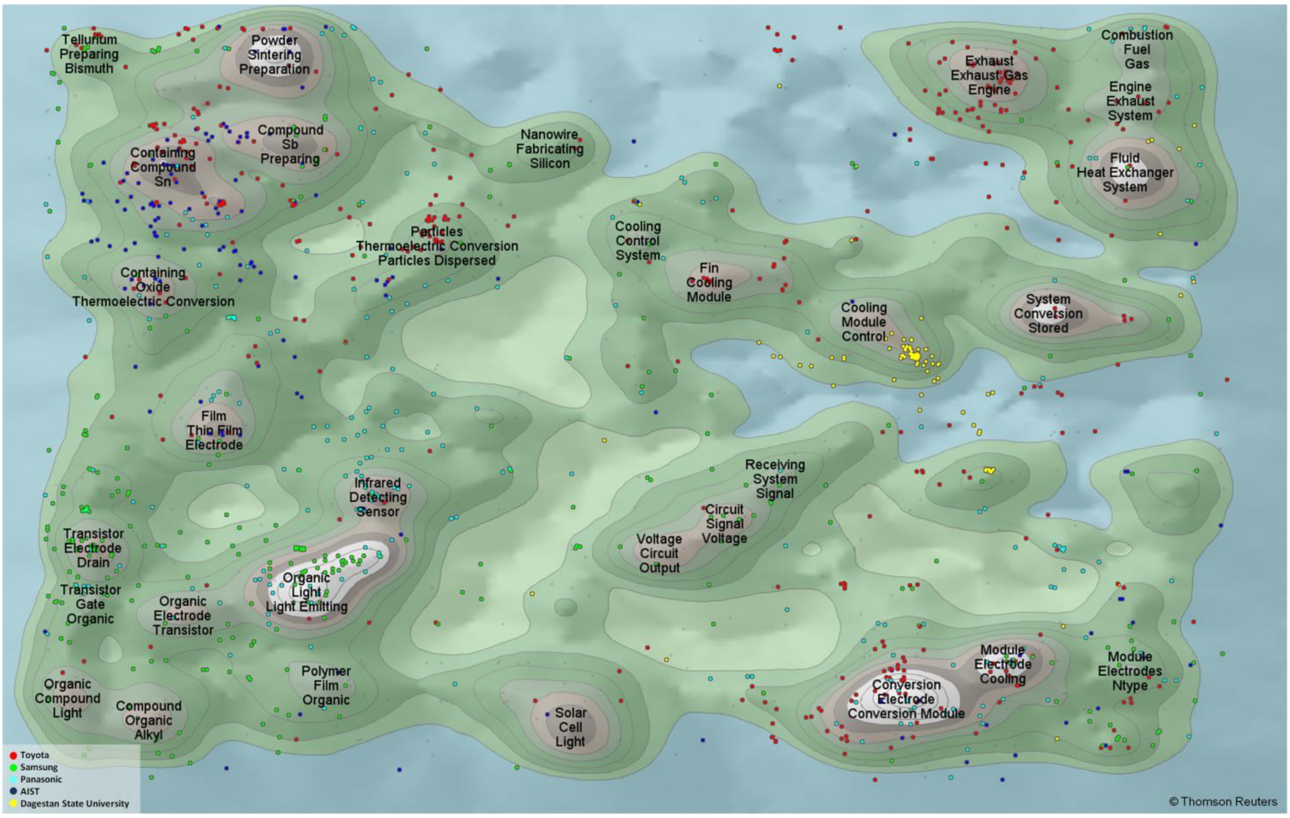

Figure 17: TEG patent landscape map with select top applicants highlighted

The patent landscape map shown in Figure 18 highlights UK patenting activity in red dots. The UK does not appear to be focusing on any one areas of specialism within the TEG patent landscape because there is a wide and even spread of red dots across the whole patent map.

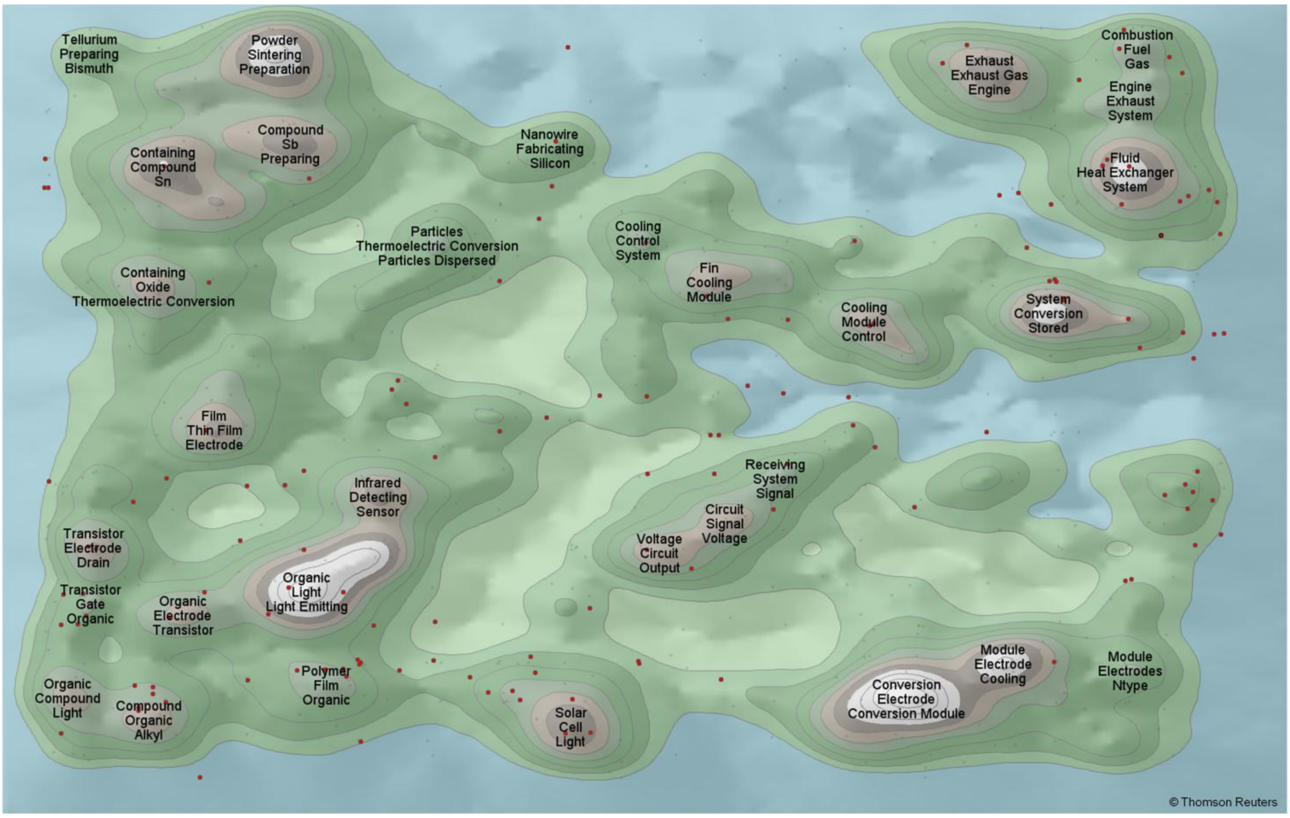

Figure 18: TEG patent landscape map with UK patenting activity highlighted

5 Radioisotope thermoelectric generators – patent analysis

5.1 Overview

The KTN has a specific interest in investigating radioisotope thermoelectric generators (RTGs) so a subset of the main worldwide thermoelectric generator patent dataset was created[15] for further analysis. Due to the small size of the extracted subset, a further manual clean of the data was possible[16] to ensure that all patents in the RTG data subset were directly relevant to RTGs. Table 2 gives a summary of the RTG data subset which contains only 72 published patents between 2005 and 2014 equating to 28 patent families[17].

Table 2: Summary of radioisotope thermoelectric generator patent data subset

Number of patent families	28
Number of patent publications	72
Publication year range	2005-2014
Peak publication year	2013
Top applicant	Caltech (USA)
Number of patent assignees	24
Number of inventors	79
Priority countries	7
IPC sub-groups	77

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[15] The RTG data subset was created by extracting patents that contained relevant keywords in the title and/or abstract of the patent application. These included, but were not limited to the following keywords: *radioactive, radioisotope, plutonium-238, strontium-90, caesium-137, cesium-137, polonium-210, americium-241, curium-244, RTG* and *RITEG.*

[16] By individually analysing the content of the title and abstract of each published patent.

[17] The RTG data subset is too small to undertake patent landscape map analysis because a minimum of 500 records are required to produce a meaningful patent map.

5.2 Filing profile

Figure 19 shows the total number of published RTG patents by publication year. It suggests an increase in recent years but it is hard to draw any firm conclusions on overall trends with such a small number of records in the RTG data subset.

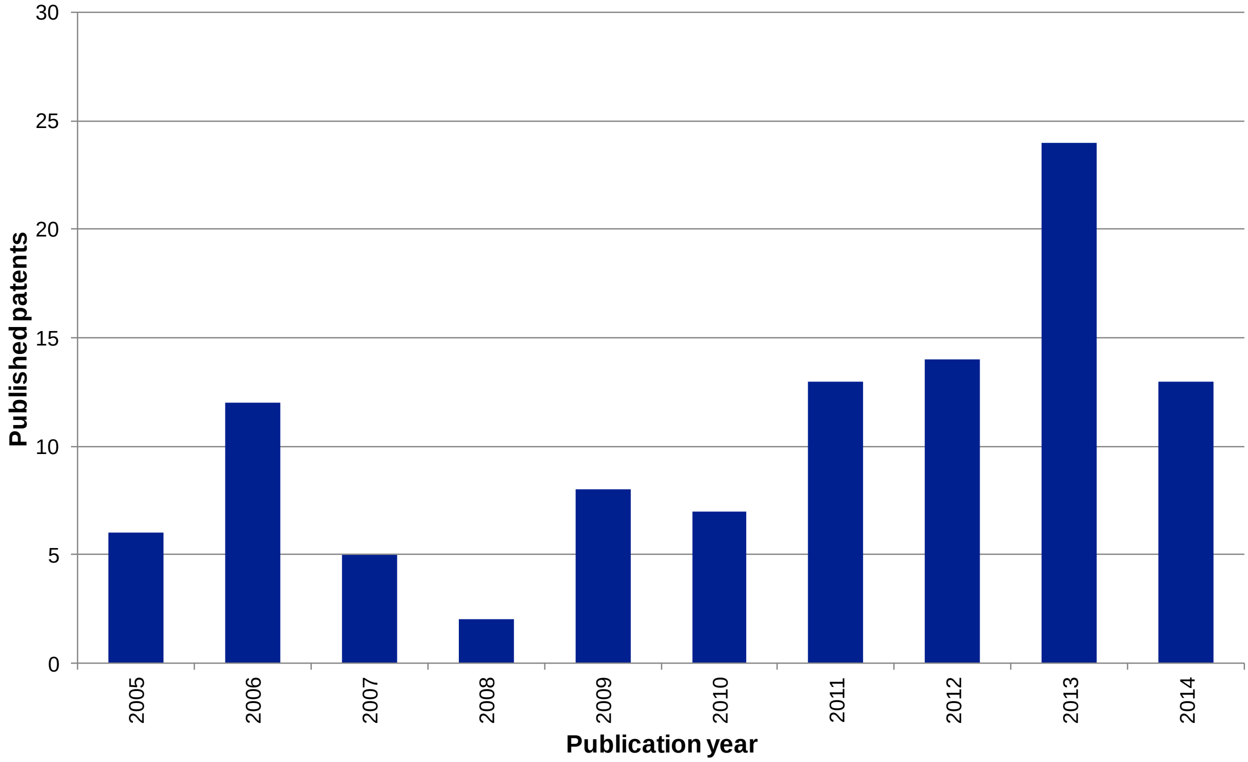

Figure 19: Patent publications by publication year

5.3 Geographical analysis

Figure 20 and Figure 21 respectively show the priority country distribution and applicant country distribution for the RTG data subset. Figure 22 shows the patent coverage for RTG published patents.

In these charts the most noticeable difference between the RTG data subset and the main TEG dataset (see Figure 4 and Figure 5) is the involvement of Japan in RTG patenting. Japan accounts for 36% of TEG patent first filings but only 10% of RTG patent first filings, and 35% of all TEG patents come from Japanese applicants yet there are no RTG patents from Japanese applicants.

There is a noticeable increase in the UK's involvement with 7% of RTG patent first filings in the UK compared to 1% of all TEG patent first filings. Similarly, UK applicants account for 9% of all RTG patents compared to just 1.5% of all TEG patents. The biggest increase however involves the USA; first filings in the USA account for 53% of all RTG patents compared to 24% of all TEG patents, and US applicants account for 54% of RTG patents yet only 20% of all TEG patents.

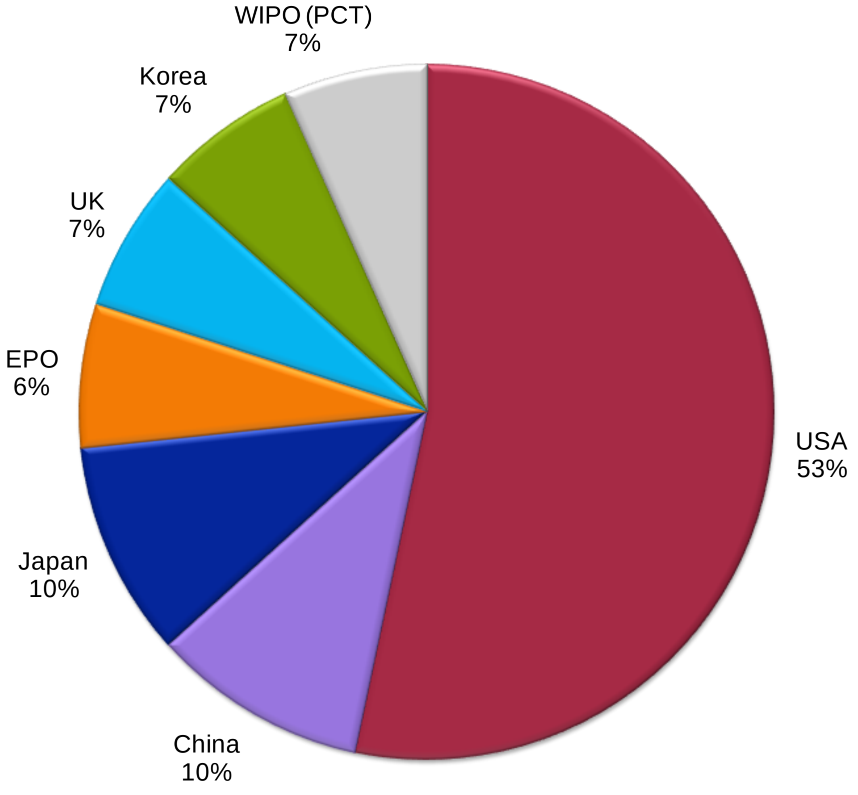

Figure 20: Priority country distribution

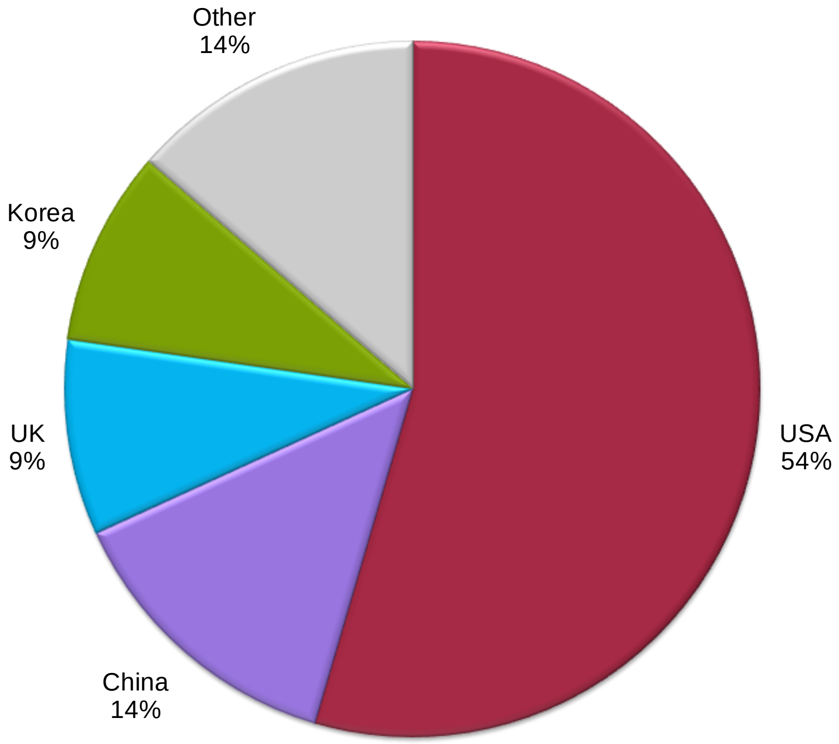

Figure 21: Applicant country distribution

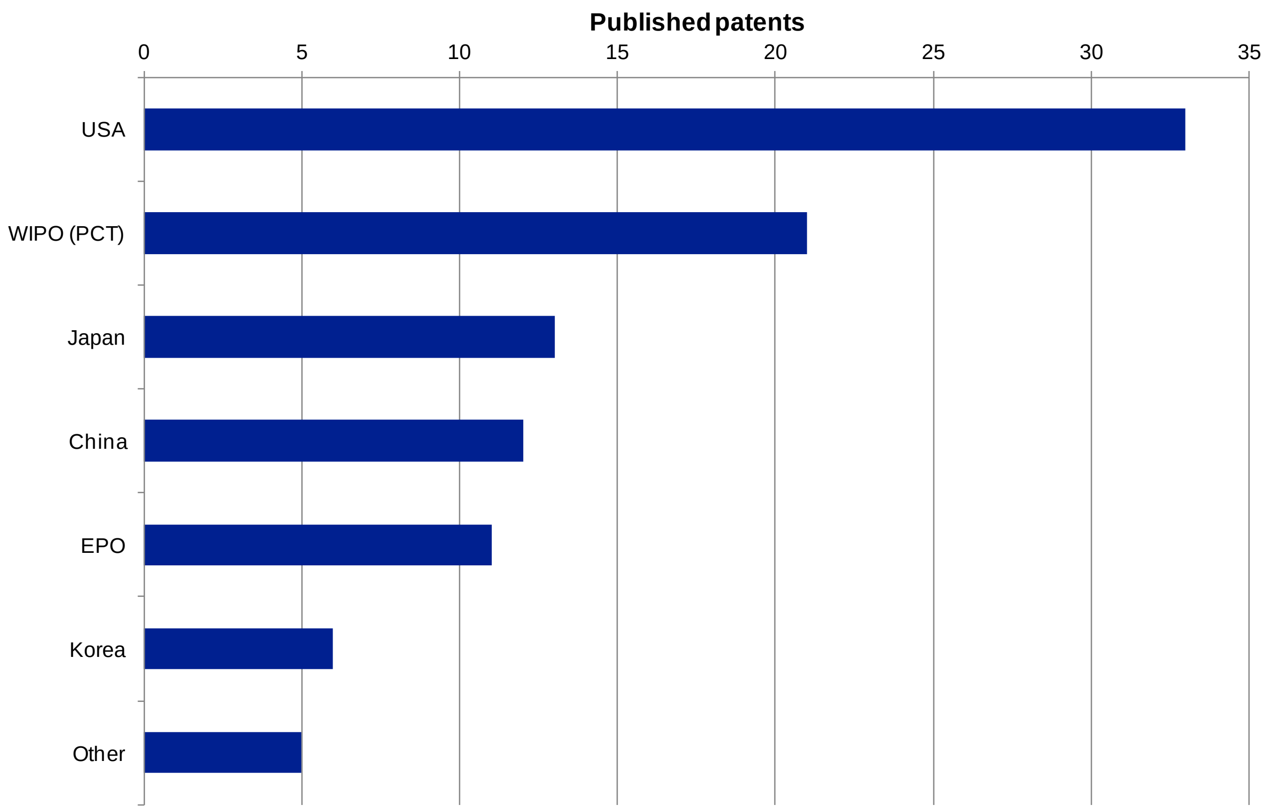

Figure 22: Patent coverage (publication country coverage)

5.4 Top applicants/inventors

Figure 23 shows all RTG patent applicants and Figure 24 shows the top inventors (inventors listed on more than one patent family). Caltech[18] and Michigan State University[19] both have two RTG patent families but Michigan State University's inventions have wider coverage with 19 published patents covering the two patent families compared to just four published patents for Caltech's two inventions. All other RTG patent applicants have just one patent family (one invention) but the coverage for these inventions range from just one published patent to 18 published patents (18 patent family members).

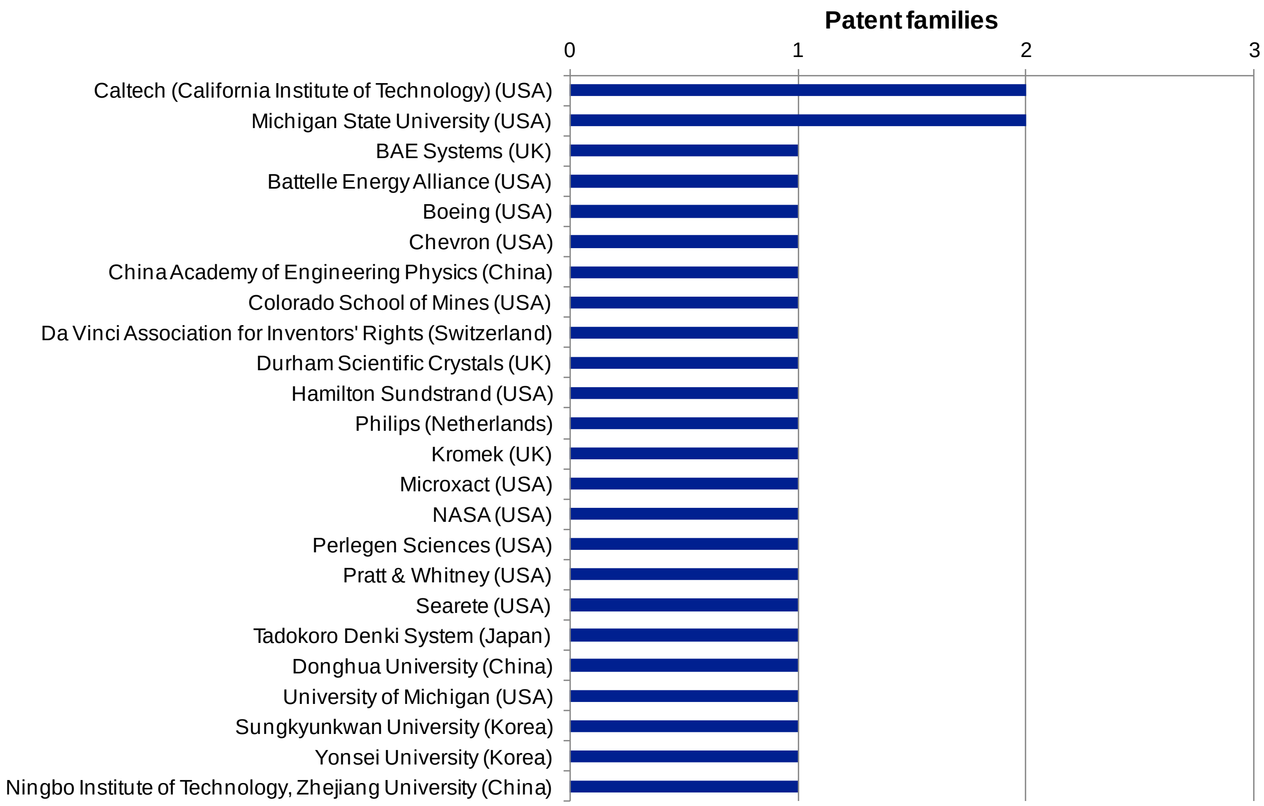

Figure 23: Radioisotope thermoelectric generator patent applicants

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[18] US2003/0066476A1 and WO2011159804A2.
[19] US2005/0076944A1 and US7592535B2.

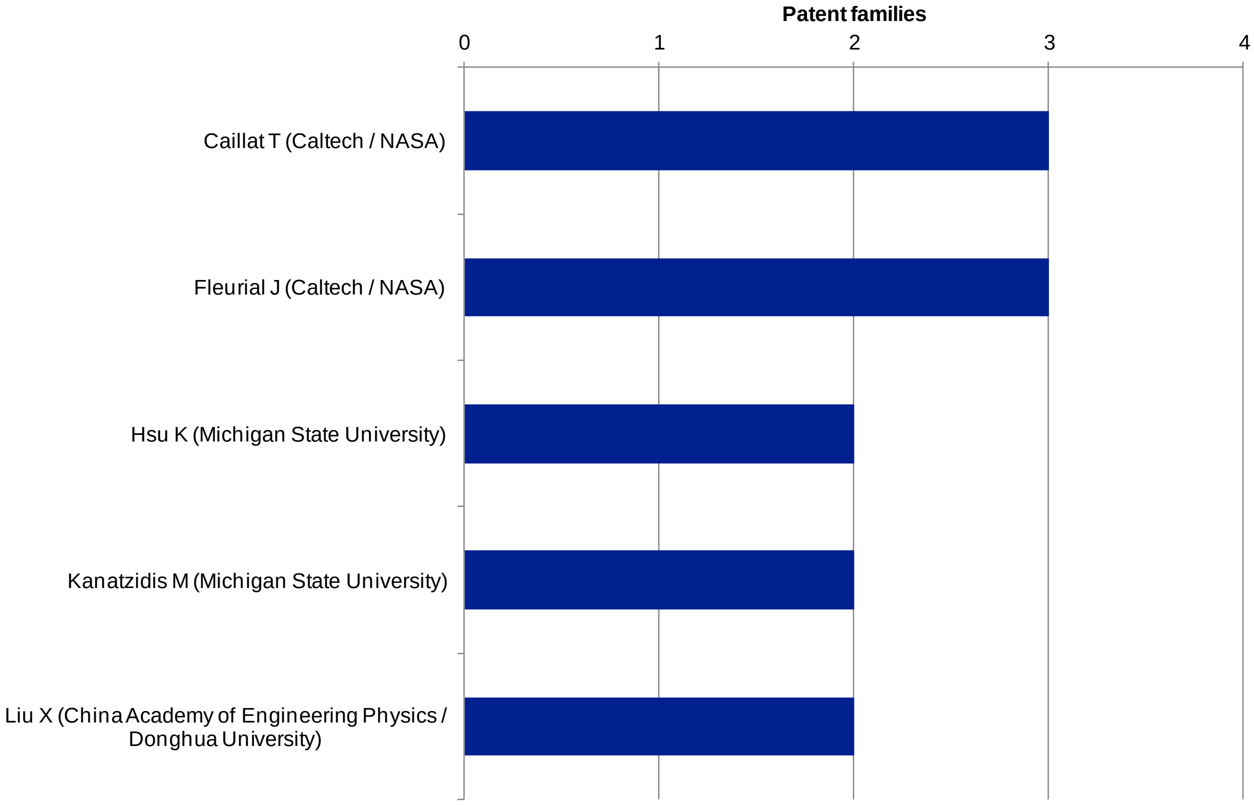

Figure 24: Top inventors

5.5 Collaboration

Figure 25 shows there is very little collaboration amongst the RTG patent applicants. This is not unsurprising given the small size of the RTG data subset.

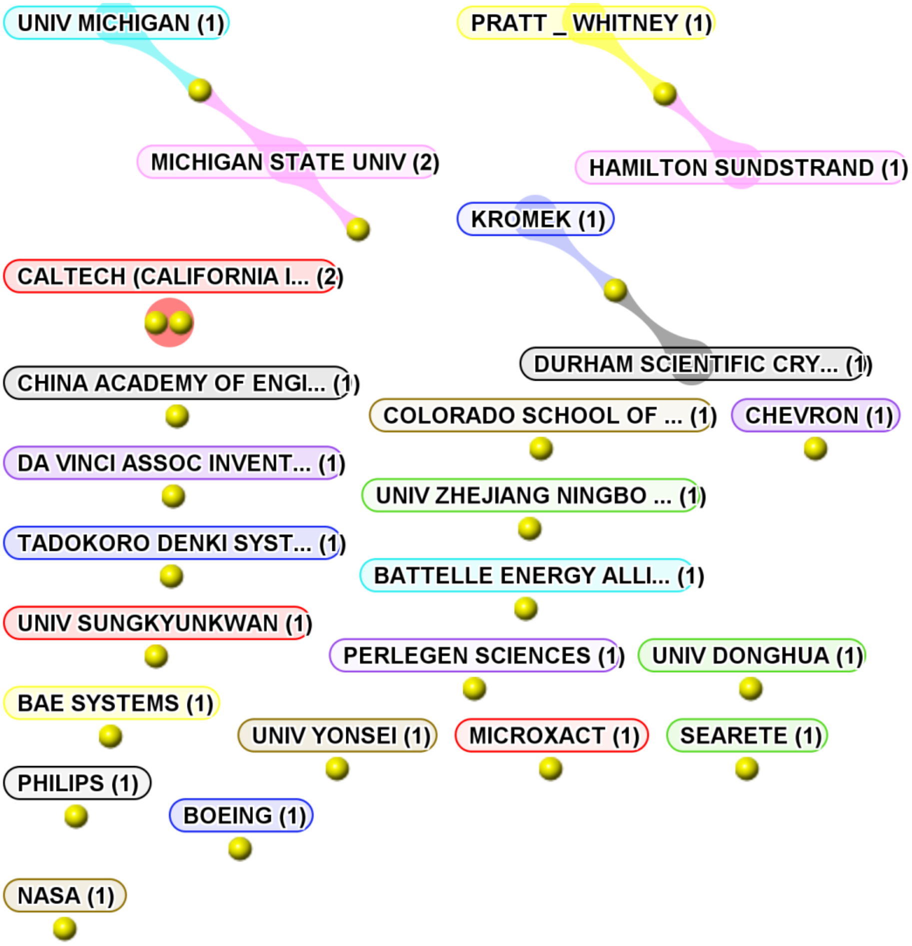

Figure 25: Collaboration amongst RTG patent applicants

6 Conclusions

There are almost 32,000 published patent applications between 2004 and 2013 relating to thermoelectric generators (TEGs), resulting in almost 9000 patent families (inventions). Patenting activity in this field has grown steadily over the past ten years and generally at a level above the annual increase in overall patent publications over the same time period.

Japan and the USA dominate the TEG patent landscape, even when the raw number of patents is adjusted to take into account the greater propensity to patent in these countries. Toyota has the most patent families in the TEG patent landscape, AIST (The National Institute of Advanced Industrial Science and Technology in Japan) is the leading government-funded organisation and Dagestan State University is the leading TEG patent applicant from academia. Cambridge Display Technology is the leading UK applicant and has patent collaboration partners both domestically and internationally.

A subset of radioisotope thermoelectric generator (RTG) patents consists of only 28 inventions (patent families) which are covered by 72 published patent applications. Caltech and Michigan State University are the most prolific RTG patent applicants but both only have two patent families. Japanese patenting activity is negligible in the RTG patent subset, which is dominated by patenting activity from the USA. Although the overall numbers are small, patenting activity from the UK is more noticeable in the RTG subset than in the main TEG dataset.

Appendix A Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) was interrogated using *Thomson Innovation*[20], a web-based patent analytics tool produced by *Thomson Reuters*. This database holds bibliographic and abstract data of published patents and patent applications derived from the majority of leading industrialised countries and patent organisations, *e.g.* the World Intellectual Property Organisation (WIPO), European Patent Office (EPO) and the African Regional Industry Property Organisation (ARIPO). It should be noted that patents are generally classified and published 18 months after the priority date. This should be borne in mind when considering recent patent trends (within the last 18 months).

The WPI database contains one record for each patent family. A patent family is defined as all documents directly or indirectly linked via a priority document. This provides an indication of the number of inventions an applicant may hold, as opposed to how many individual patent applications they might have filed in different countries for the same invention.

A.2 Priority date, application date and publication date

Priority date: The earliest date of an associated patent application containing information about the invention.

Publication date: The date when the patent application is published (normally 18 months after the priority date or the application date, whichever is earlier).

Analysis by priority year gives the earliest indication of invention.

[20] *http://info.thomsoninnovation.com*

A.3 WO and EP patent applications

International patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

Figures for patent families with WO and EP as priority country have been included for completeness although no single attributable country is immediately apparent.

A.4 Patent documents analysed

The dataset for analysis was identified in conjunction with patent examiner technology-specific expertise. A search strategy was developed and the resulting dataset was extracted in February 2015 using keyword searching of titles and abstracts in the *Thomson Reuters* World Patent Index (WPI) and limited to patent families with publications from 2005 to 2014.

The applicant and inventor data was cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation (Ltd, Pty, GmbH *etc*.), or equivalence (Ltd., Limited, *etc*.).

A.5 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[21] produced by *Search Technology* in the USA. The patent records exported from *Thomson Innovation* were imported into *VantagePoint* where the data is cleaned and analysed. The patent landscape maps used in this report were produced using *Thomson Innovation*.

[21] *http://www.thevantagepoint.com*

Appendix B Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patent families in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of technology area specific patents found in each country to the fraction of patents found in that country overall. A logarithm is applied to scale the fractions more suitably. The formula is given below:

$$\log_{10}\left(\frac{n_i/n_{total}}{N_i/N_{total}}\right)$$

where

n_i = number of technology area specific patents in country i
n_{total} = total number of technology area specific patents in dataset
N_i = total number of patents in country i
N_{total} = total number of patents in dataset

The effect of this is to highlight countries which have a greater level of patenting in the specific technology area than expected from their overall level of patenting, and which would otherwise languish much further down in the lists, unnoticed.

Appendix C Patent landscape maps

A patent landscape map is a visual representation of a dataset and is generated by applying a complex algorithm with four stages:

i) **Harvesting documents** – When the software harvests the documents it reads the text from each document (ranging from titles through to the full text). Non-relevant words, known as stopwords, (e.g. "a", "an", "able", "about" etc) are then discounted and words with common stems are then associated together (e.g. "measure", "measures", "measuring", "measurement" etc).

ii) **Analysing documents** – Words are then analysed to see how many times they appear in each document in comparison with the words' frequency in the overall dataset. During analysis, very frequently and very infrequently used words (i.e. words above and below a threshold) are eliminated from consideration. A topic list of statistically significant words is then created.

iii) **Clustering documents** – A Naive Bayes classifier is used to assign document vectors and Vector Space Modelling is applied to plot documents in n-dimensional space (i.e. documents with similar topics are clustered around a central coordinate). The application of different vectors (i.e. topics) enables the relative positions of documents in n-dimensional space to be varied.

iv) **Creating the patent map** – The final n-dimensional model is then rendered into a two-dimensional map using a self-organising mapping algorithm. Contours are created to simulate a depth dimension. The final map can sometimes be misleading because it is important to interpret the map as if it were formed on a three-dimensional sphere.

Thus, in summary, patents are represented on the patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map. Please remember there is no relationship between the patent landscape maps and any geographical map.

Please note that the patent maps shown in this report are snapshots of the patent landscape, and that patent maps are best used an interactive tool where analysis of specific areas, patents, applicants, inventors *etc* can be undertaken 'on-the-fly'.

KTN
the
Knowledge Transfer
Network
Bailey House
4-10 Barttelot Road
Horsham
West Sussex
RH12 1DQ
United Kingdom

@KTNUK

www.ktn-uk.org

Intellectual Property Office

Concept House
Cardiff Road
Newport
NP10 8QQ
United Kingdom

www.gov.uk/ipo