Storytelling with patent data

Energy Series Thought Leadership:
Next Generation Solar

April 2021

Inventions & Innovators powering the Energy Transition
Next generation solar

If you want to see solar in action take a trip to Vegas. From McCarran International drive south along Interstate 15 and just across the border with California in the middle of the Mojave Desert sits the Ivanpah Solar facility. The blinding white light on the receivers of the three solar towers appears almost extra-terrestrial as more than 340,000 mirrors, mounted on 170,000 heliostats that track the path of the sun, focus the solar rays directly onto the towers. This concentrating solar power (CSP) plant with a capacity of 392 MW is the largest of its kind in the US and the second largest in the world after the 510 MW Ouarzazate Solar Power Station in Morocco. CSP plants at their core are thermal, incorporating boilers and steam turbines to generate power with a distinct advantage being that the thermal energy can be stored to provide dispatchable energy. The 110 MW Crescent Dunes CSG project 200 miles northwest of Vegas includes in its design 1.1 GW of thermal energy storage – enough for ten hours of full capacity power. Ivanpah does not include integrated thermal storage but is set up to generate boiler steam before sunrise by burning natural gas.

CSP has its problems, challenged by high capital cost and technical obstacles related to the mechanical components, high operating temperatures and heat transfer fluid design. Crescent Dunes has suffered a number of failures including a major leak in the molten salt thermal storage tank and since being commissioned in 2015 has never achieved its rated capacity. The plant has actually been mothballed since 2019. CSP has its place along with coal, natural gas and nuclear for thermal power generation, but probably the biggest threat for its future as a material part of the solar picture is that photovoltaic (PV) projects are attracting the majority of investment dollars. Drivers behind this include the rapid decrease in price combined with marked power efficiency gains achieved by PV cells over recent years. And many of the PV solar plants under design today are incorporating battery storage to enable dispatchable energy. A good example is the US$1 billion Gemini Solar Project under development on federal land 30 miles northeast of Vegas. Complete with an integrated battery storage system, the first phase is expected online this year and the second in 2022 making it the largest project of its kind in the US.

The dominant PV technology today is the **crystalline silicon-based cell**. Making up somewhere in the region of 90% commercial market share, the benefits include the maturity of the technology, proven reliability & performance from over 50 years of use and availability of the raw material silicon – the second most abundant element in Earth's crust (after oxygen).

In this, the second of a series to put a lens on the invention and innovation being made in critical technologies powering the energy transition, we take a look at next generation solar with a focus on new innovations specific to photovoltaic cells.

- **Thin-film PV Cells:** with about 10% market share and characterised by thin layers of photovoltaic materials deposited onto substrates such as glass or flexible plastic sheet. The principal types include Copper indium gallium selenide (CIGS), Amorphous Silicon and Cadmium Telluride (CdTe).
- **Organic PV Cells:** an emerging category that utilises carbon-based semiconductors. Yet to be commercialised but attracting a lot of interest due to the relatively low cost and manufacturing flexibility. Key challenges to overcome include low power efficiency and short material life.
- **Perovskite PV Cells:** materials with the same crystal structures as calcium titanium oxide (CaTiO3). The first use as a photovoltaic material was in 2009 with rapid progress made in improving power conversion efficiency. Perovskites offer relatively high performance and low production cost potential.

The alternatives are not exclusive to this list of three, but these represent in our view the most interesting to watch. Whether you are an energy supplier, consumer, innovator or investor understanding in which technology areas the inventions are being made and who owns these inventions is the starting point for getting ahead and taking advantage of the changes that are coming.

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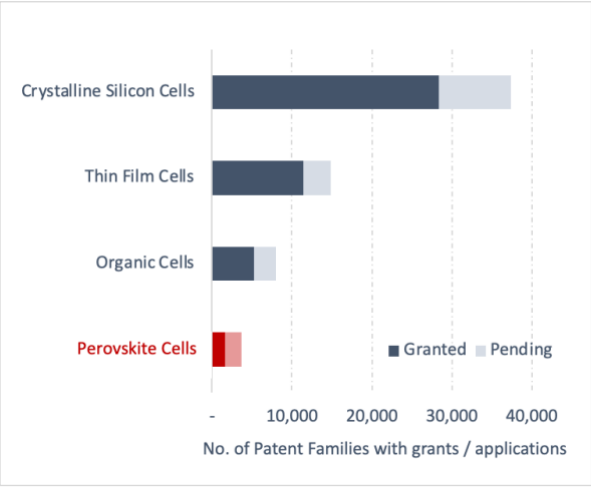
Technology to watch: Perovskite Solar Cells

Although lagging both thin-film and organic solar cells in the scale of inventions protected, the pace of invention in perovskite PV cells has ramped up materially over the last five years. What is striking about perovskite cells are the advances that have been made in improving performance. Reported power conversion efficiencies have increased from around 4% in 2009 to well over 25% today.

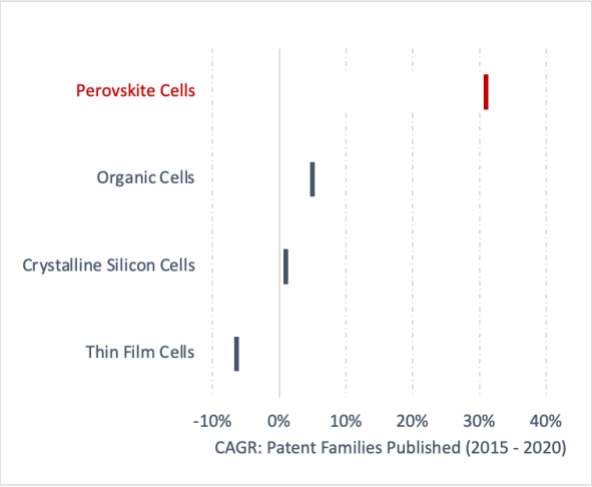
The technology remains at the research stage, but the potential impact is transformational. While costs have come down significantly for the traditional silicon-based cells, they are still sophisticated semiconductor systems with complex and expensive manufacturing processes. The key advantage with perovskite cells is that they are manufactured in solution. The cells can then be painted or printed directly onto any surface to create a film or integrated directly into new and existing infrastructure, buildings, vehicles or products.

The most likely path to first commercialisation of perovskite cells is as part of a tandem cell. By integrating with silicon-based cells, overall module efficiencies of close to 30% have now been reached in the lab. This is exceptional, especially considering that conventional silicon cell efficiency looks to have maxed out at just under 28%. A key challenge in scaling up from the laboratory to commercial applications is improving the cell stability and robustness to ensure long cell life without material performance degradation in normal outdoor environmental conditions.

Number of Inventions: *Global*



The Pace of Invention: *Global*



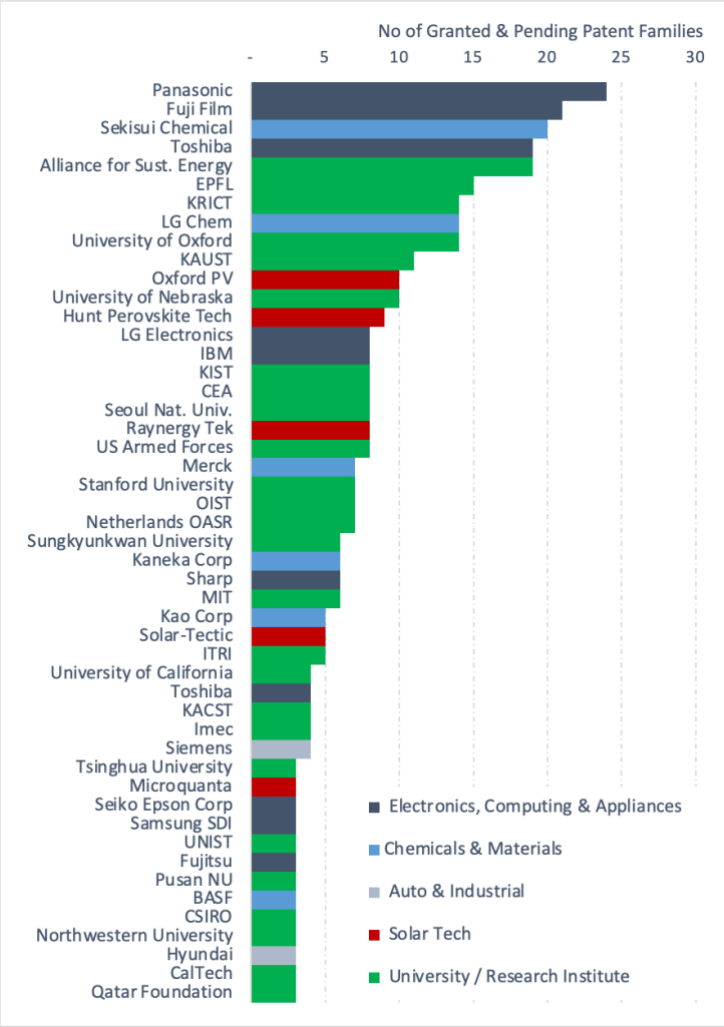
As measured by patent families either granted or pending globally

Thin-film PV cells are readily available today as part of off-grid and mobile systems. More suited to niche applications where the install requires light and flexible or even transparent solar panels. The technology is cheaper but less efficient than conventional silicon-based cells, although there have been reasonable efficiency improvements over recent years with both the CIGS and CdTe type cells. A key challenge is the faster degradation compared to silicon-based cells. Although the pace of R&D in thin-film cells has slowed, companies still active include Panasonic, Fuji Film and Sekisui Chemical.

Organic PV cells, also known as OPVs or plastic solar cells, incorporate organic polymers to convert photons to electricity. A key differentiator versus silicon-based cells is the physical structure. The organic cell compounds, like perovskites, are typically dissolved in an ink solution and printed onto thin plastics or even windows providing better placement flexibility than with crystalline photovoltaics. Low power conversion efficiencies achieved to date is a key weak point. Companies actively exploring to improve efficiency, performance and cell-life include Merck, Samsung, LG Chem and smaller pure-plays like Quebec based start-up Brilliant Matters.

Universities & research institutions are actively pushing forward perovskite solar cell research for inventions protected across the US and Europe.

The Companies: *Number of Inventions Owned Perovskite Photovoltaic Cells – Us & Europe*



The supply side of today's photovoltaic cell market is located in China, with the top three global suppliers JinkoSolar, JA Solar, and Trina Solar based out of Shanghai, Beijing and Changzhou respectively. Chinese innovation in perovskite cells is continuing at pace led by many research institutions and universities. But specific to perovskite cell inventions protected across the key markets of the US and Europe the top innovators are Japanese firms.

In a surprise strategy shift announced earlier this year, major Japanese player Panasonic announced its planned exit from solar cell and panel production by first quarter 2022. Competition from Chinese suppliers was a driving force behind this decision and it follows Panasonic's 2020 exit from its manufacturing partnership with Tesla at the Buffalo, New York solar plant.

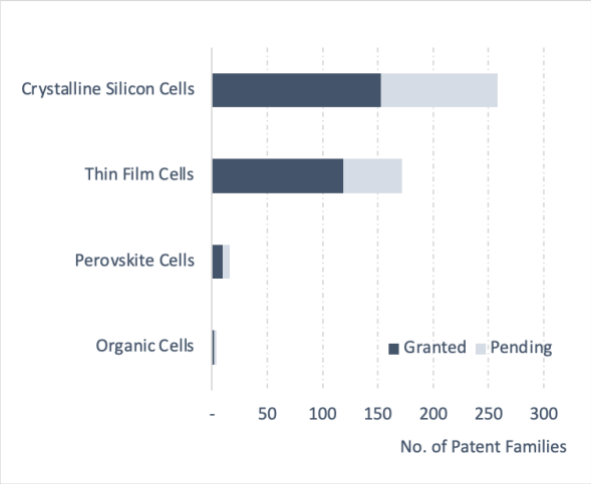
There has been a strong history of collaboration and partnership across Japanese government funded institutions, companies and universities in the space. Panasonic, Toshiba and Sekisu Chemical have each worked on developing cells with support from the New Energy and Industrial Technology Development Organization (NEDO), affiliated with Japan's Ministry of Economy, Trade & Industry. The exit of the leading innovator Panasonic from the solar cell business, leaves a material gap in Japan for advancement of perovskite solar cell research, but is an opportunity for others including research institutes and universities such as the Okinawa Institute of Technology (OIST) to build on progress made to date.

Outside of Japan the innovation landscape for perovskite solar cells is weighted to a relatively large number of universities and research institutions, highlighting the fact that the leap has yet to be made from the laboratory to commercial scale applications. These include the Swiss Ecole Polytechnique Federale de Lausanne (EPFL), Korea Research Institute of Chemical Technology (KRICT), University of Oxford, Saudi Arabi King Abdullah University of Science & Technology (KAUST) and the University of Nebraska.

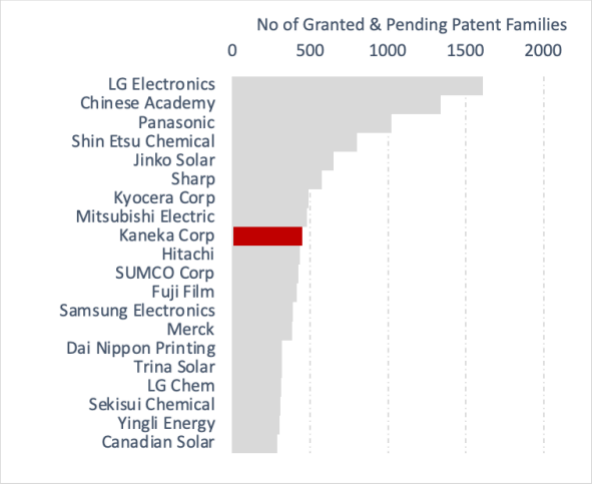
On the radar: Kaneka Corp, driving forward thin-film PV cell research

Japanese chemical company Kaneka Corp has exposure to each of the four solar cell technology types and is a manufacturer and supplier of PV modules globally. Kaneka is known to be pushing the advancement of both organic and thin-film PV technology. The data however shows that thin-film is where the company has been allocating the bulk of its R&D resource, after silicon-based cell innovation.

Number of Inventions: *Global*



The Companies: *Number of Inventions, Global*



As measured by patent families either granted or pending anywhere in the world

Kaneka has partnered on projects with a number of Japanese firms including with Toyota on development of vehicle roof glass solar modules. This aligns closely with its expertise in developing building-integrated modules; its existing product lines including transparent thin film solar cells for windows and roof-tile solar cell modules.

Kaneka's PV module business sits within its PV & Energy management division, part of its Quality of Life Solutions unit. The PV module revenue contribution today is small compared to that from the Material Solutions, Health Care and Nutrition Solutions units combined. Considering the pace of innovation and that Kaneka is one of the top ten owners of inventions specific to silicon, thin-film, organic and perovskite PV cells, we see a strategic push to build a strong foundation and competitive edge in the development of next generation solar tech. This is one to watch.

Next generation solar tech pure-plays to watch

Oxford Photovoltaics: An Oxford University spin-off established in 2010. Has raised close to $140 million in total funding. Backers include Goldwind, a provider of renewable energy solutions in China, and the European Investment Bank. R&D site in Oxford and a manufacturing site near Berlin. Recently set a world record with a 29.52% conversion efficiency with a tandem cell approach of perovskite layered upon a silicon cell. The company has invested €44 million in the expansion of its manufacturing facility, ahead of a planned commercial deployment later this year or early 2022.

Hunt Perovskite Technologies: A recently formed division of Hunt Consolidated, a privately-owned US oil and gas holding company. Developing solution-based perovskite technologies to reduce manufacturing costs and improve cell durability. Has formed a corporate partnership with the Energy Department's National Renewable Energy Laboratory. Currently raising capital and seeking new strategic partners as a way to accelerate the route to commercialisation.

Raynergy Tek: Taipei based Raynergy is focused on development and commercialisation of organic PV cells. This start-up, founded in 2014, is backed by a number of Taiwanese listed companies including Sunplus, PixArt and Fortune Electric. The company has a joint venture in place with Chicago based Polyera, a private electronics company developing flexible Thin-Film Field Effect Transistors (TFTs). Much of the next generation materials R&D research is carried out in the Chicago Innovation Centre

Solar-Tectic: Private company based out of Briarcliff Manor, NY. Developing high efficiency and cost effective tandem solar cells with perovskite active materials. Received grant funding in 2017 from the Strategic Partnership for Industrial Resurgence (SPIR).

Scope Notes

Crystalline Silicon PV Cells:
Crystalline silicon cells belong to the first generation of solar cell technologies and are the most commonly used cell types in commercial solar applications. The scope includes both monocrystalline and polycrystalline silicon cells. Amorphous silicon cells are captured in the thin-film technology area.

Thin Film PV Cells:
Thin film photovoltaics belong to the second generation of solar cell technologies. These cells are made by depositing thin layers of photovoltaic materials onto a substrate (typically plastic, metal or glass), using physical vapor deposition or chemical vapor deposition techniques. The scope includes all thin film technologies, including amorphous silicon, CIGS, CdTe, GaAs and dye-sensitized solar cells.

Organic PV Cells:
Organic photovoltaics belong to the third generation of solar cell technologies. Organic cells are solar cells where the absorbing layer is formed from an organic semiconductor material (OSC). The scope includes both small-molecule OPV cells and polymer-based OPV cells.

Perovskite PV Cells:
Perovskite photovoltaics belong to the third generation of solar cell technologies. Perovskite solar cells include a perovskite-structured compound in the active layer (general formula ABX_3, where A and B are cations, and X is an anion).

For reference & attached: Innovation Lens Snapshots

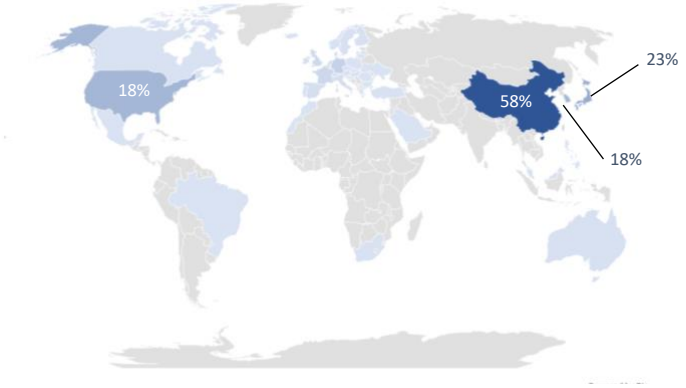
- *Technology Screening: Next Generation Solar*
- *Company Screening: Perovskite Solar Cells*
- *Company Snapshot: Kaneka Corp – Next Generation Solar*

Technology Screening: Next Generation Solar

Technology Areas:

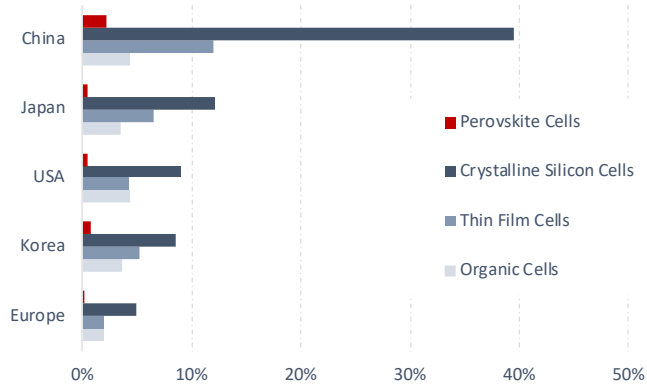
Crystalline Silicon Cells: *Both monocrystalline and polycrystalline silicon cells, 1st generation technology.*
Thin Film Cells: *thin layers of PV materials deposited onto a substrate, 2nd generation technology.*
Organic Cells: *absorbing layer is formed from a carbon-based organic material, 3rd generation technology.*
Perovskite Cells: *Cells with a perovskite-structured compound in the active layer, 3rd generation technology.*

Geographies Protected: *By Country Across all 4 Tech Areas*



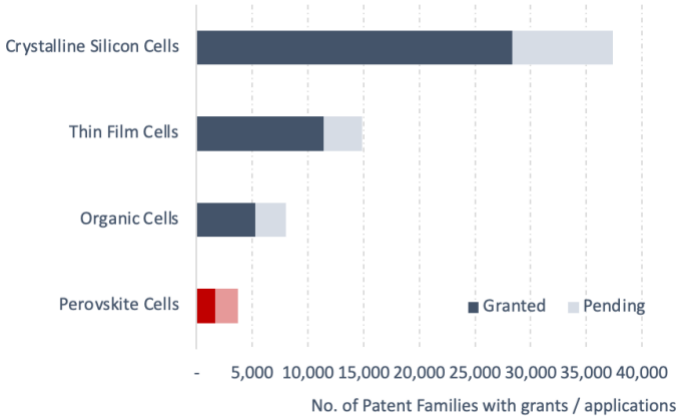
Patent Families with Grants by Country as a Percent of the Total Granted Families

Geographies Protected: *By Key Region / Countries*



Patent Families with Grants by IP5 Region as a Percent of the Total Granted Families

Number of Inventions: *Global*

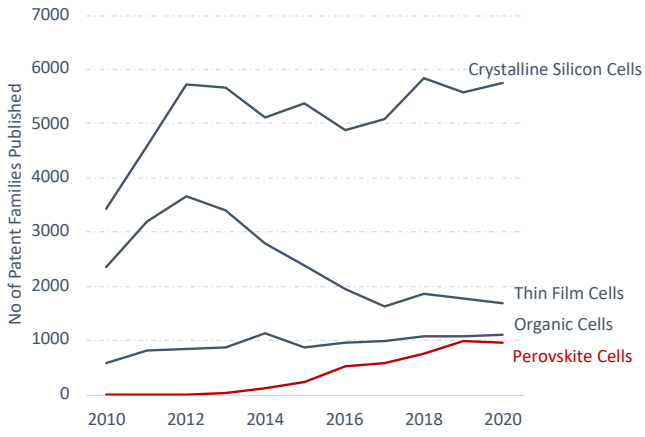


Companies: *Top Ranked by Inventions Owned, Global*

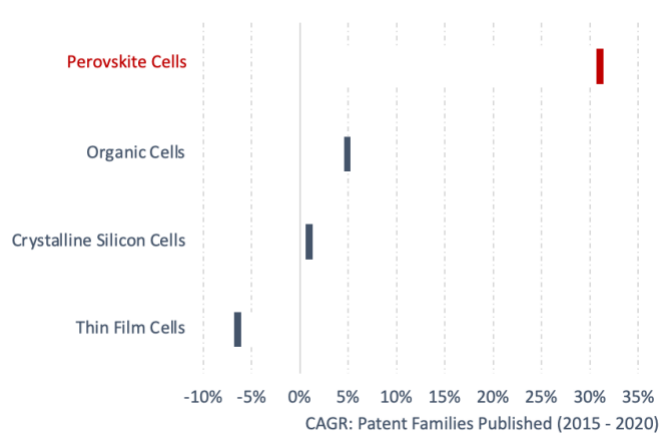
Rank	Organic Cells	Thin Film Cells	Perovskite Cells
1	Merck	LG Electronics	Chinese Academy
2	Chinese Academy	Chinese Academy	University EST China
3	Samsung Electronics	Panasonic	Sekisui Chemical
4	Duksan Holdings	Sharp	Microquanta
5	Sumitomo Chemical	Fujikura	Huazhong University
6	LG Chem	Kyocera Corp	Soochow University
7	Fuji Film	Kaneka Corp	Peking University
8	South China University	Fuji Film	Wuhan UT
9	Samsung SDI	Dai Nippon Printing	Nanjing University
10	Konica Minolta	Sekisui Chemical	Shaanxi Normal University
11	LG Electronics	Jusung Engineering	XI'AN Jiaotong University
12	Cynora GmbH	First Solar	Fuji Film
13	Nanjing University	Canadian Solar	KRICT
14	University EST China	Mitsubishi Electric	Panasonic
15	KRICT	Korea AERI	LG Electronics

Top Owners of Patent Families with grants / applications in the US / Europe

Pace of Invention: *Trendlines, Global*



Pace of Invention: *CAGR 2015-2020, Global*

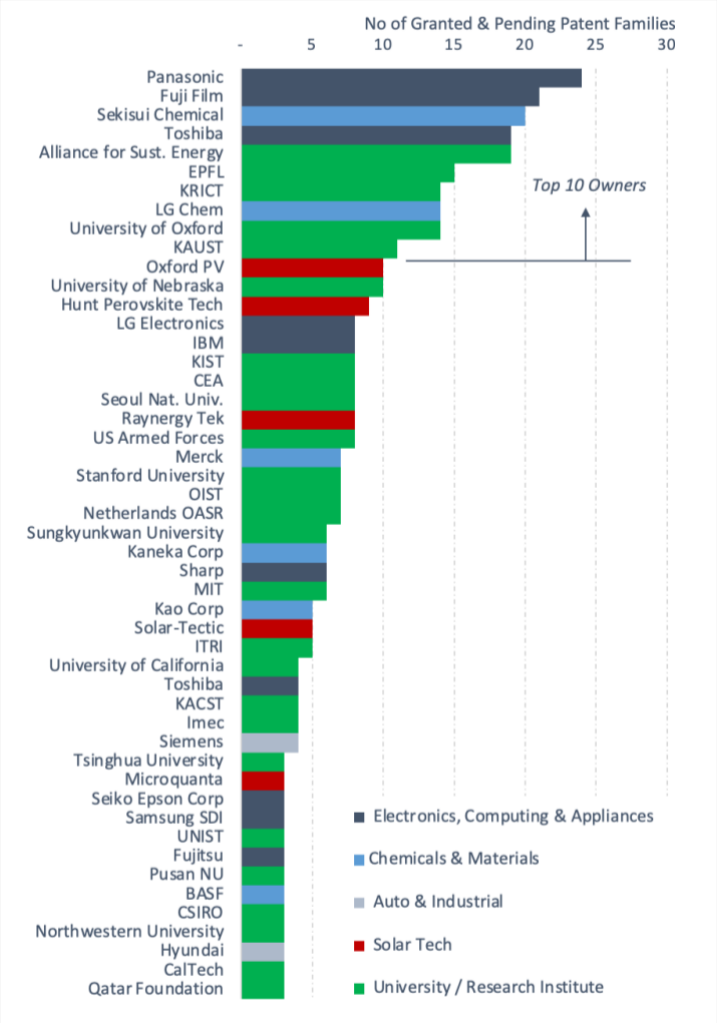


Company Screening: Perovskite Solar Cells

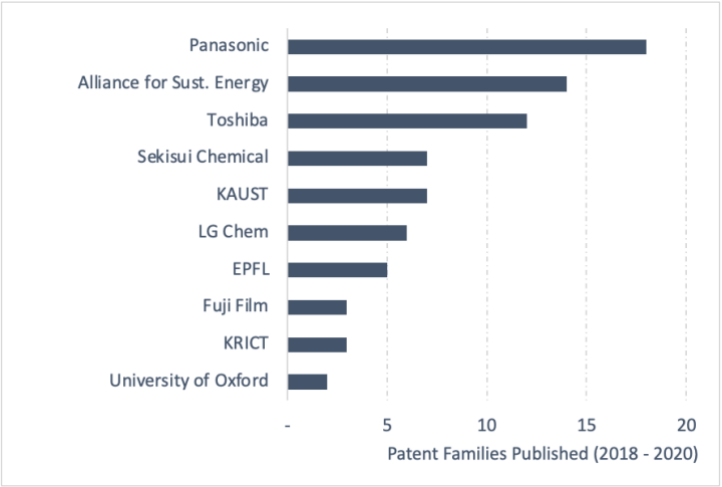
Technology Area: **Perovskite Cells**: *Perovskite cells include a perovskite-structured compound in the active layer (general formula ABX_3, where A and B are cations, and X is an anion). Perovskite photovoltaics belong to the third generation of solar cell technologies.*

Region: **US & Europe** *granted/pending patent families (inventions)*

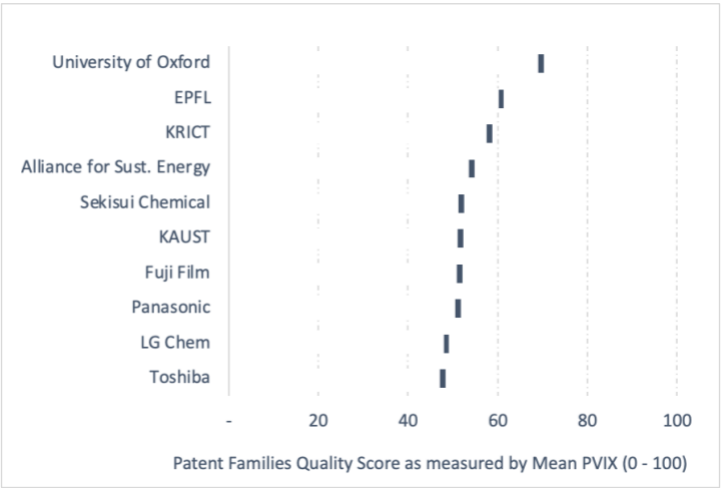
Companies: *No of Inventions Owned, Perovskite Cells*



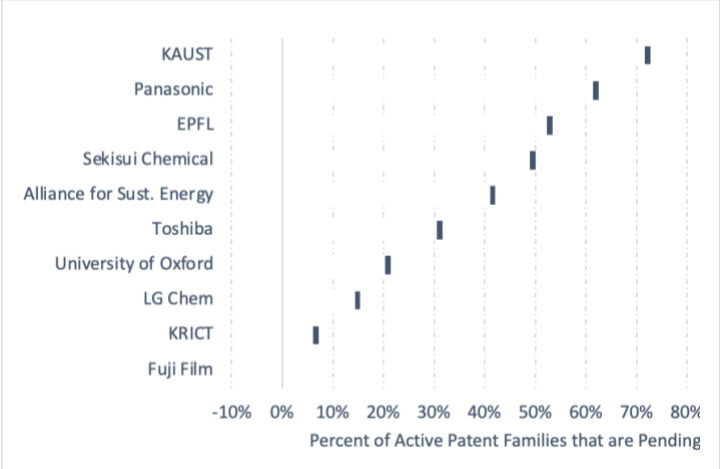
Pace of Invention: *2018-2020, Perovskite Cells*



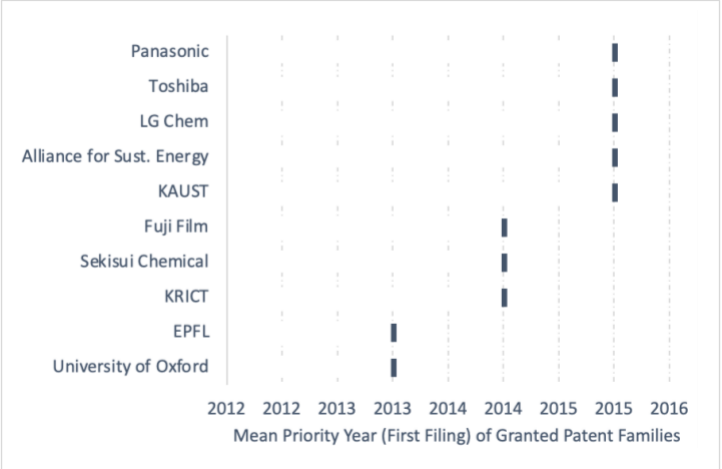
Quality of Invention: *Perovskite Cells*



Invention Pipeline: *Perovskite Cells*



Invention Age: *Perovskite Cells (First Filing Date)*

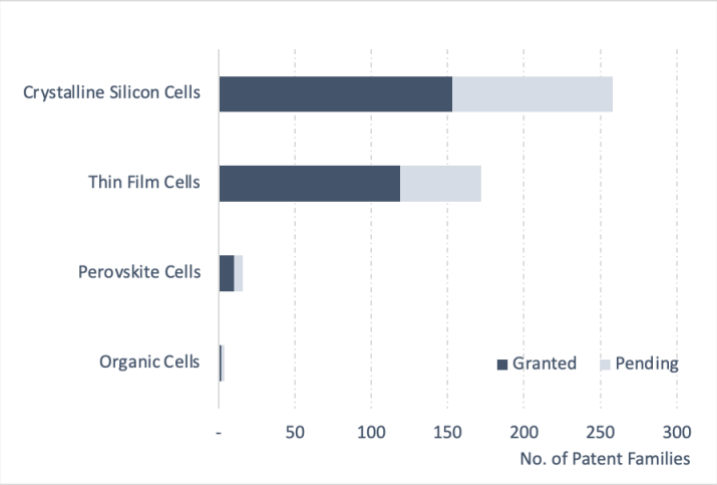


Company Snapshot: Kaneka Corp – Next Generation Solar

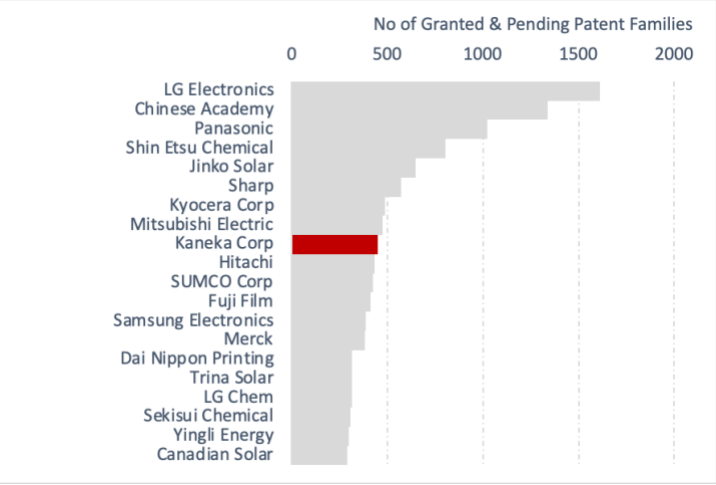
Technology Areas: **Crystalline Silicon Photovoltaics; Thin Film Photovoltaics; Organic Photovoltaics; Perovskite Photovoltaics.**

Region: **Global** *all granted/pending patent families (inventions)*

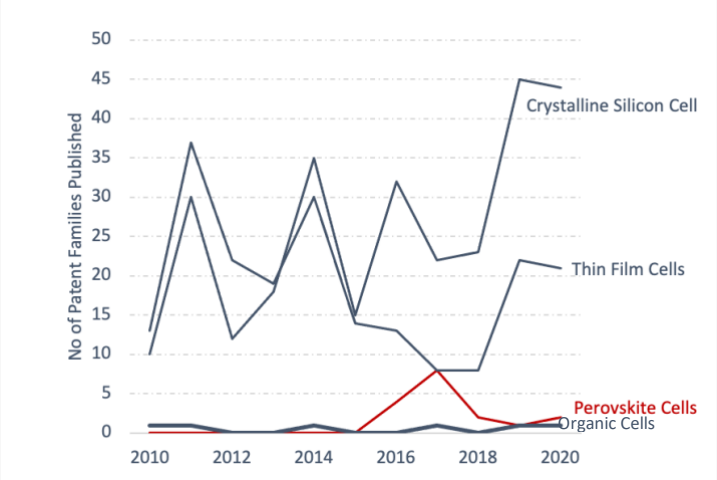
Number of Inventions: Kaneka Corp.



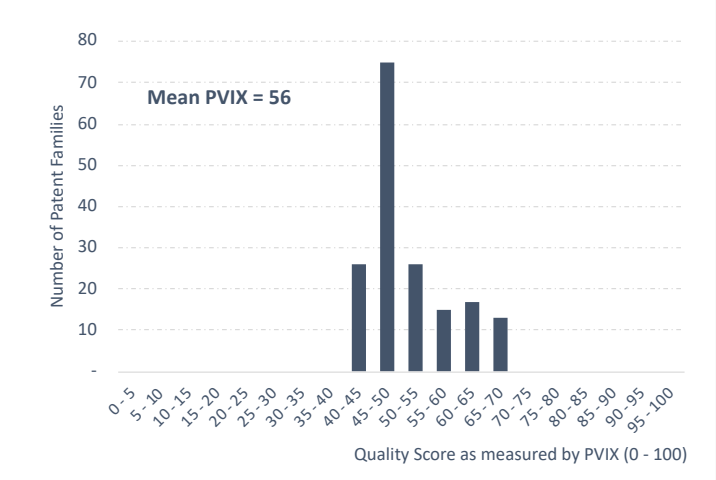
Companies: *Number of Inventions Owned*



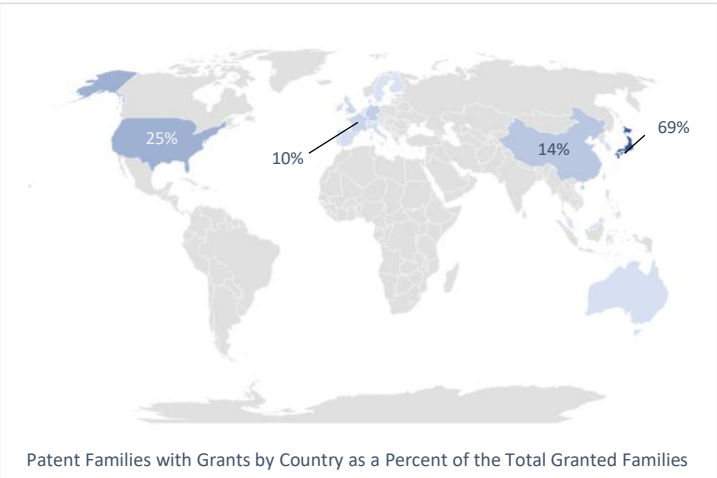
Pace of Invention: Kaneka Corp.



Quality of the Inventions: Kaneka Corp.



Geographies Protected: Kaneka Corp.



Patent Families with Grants by Country as a Percent of the Total Granted Families

Invention Age: Kaneka Corp. *(Expiry Date)*