March 2021

Inventions & Innovators powering the Energy Transition
Next Generation Batteries

Lithium-ion is here to stay. Over the near to medium term this will remain the dominant battery technology for the primary energy transition use case – that is powering electric vehicles. Material investment continues to be made advancing lithium-ion battery chemistry & architecture to improve power density, charge time and cycle life while reducing weight and cost. A key challenge from an ESG perspective is the sustainability risk inherent in the rare earth minerals supply chain, in particular the cobalt supply. This metal is critical to supporting lithium-ion thermal stability and a high energy density but comes at a high social & environmental cost.

There are multiple types of chemistries deployed within the category of lithium-ion batteries. These are differentiated by the cathode material and include $LiCoO_2$, $LiNiCoAlO_2$ and the $LiNiMnCoO_2$ or NMC type which is today the most widely adopted by the electric vehicle industry. Across the space there have been big steps forward, for example with commercialising high nickel low cobalt batteries and with bringing the cost per kwh down, but still work to do to get the cost and performance to a level that makes widespread adoption of electric vehicles a reality. The level of investment in lithium-ion and the fact that many of the companies leading the energy transition have already committed to a lithium-ion strategy just extends its lead over the alternatives. However, this is not a one-horse race. At some point, with diminishing returns, it becomes increasingly difficult to push the limitations of a technology type. Next generation battery chemistries alternative to lithium-ion offer the potential for a step change in power, size, charge time, life, cost and safety all of which are critical to powering the future.

In this, the first 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 batteries exploring three specific alternatives to lithium-ion:

- **Solid-state batteries:** this is the one to watch and closest to making inroads on lithium-ion. Japan has the early mover advantage led by the likes of Toyota and Panasonic but keep an eye on pure plays like the VW-backed, NYSE listed Quantum Scape.

- **Lithium-sulfur batteries:** great potential and lower cost given the use of a sulfur cathode, primary challenge is extending the cycle life. Leading innovators include LG Chem, Bosch and Hyundai.

- **Lithium-oxygen batteries:** also known as lithium-air, has the potential to solve the range anxiety challenge. With the oxygen supplied from the air, the energy density is multiples that of a lithium-ion type battery. Companies leading research & development in the space include Samsung Electronics, Hyundai, Toyota and Honda.

The alternatives are not exclusive to this list of three, but these represent in our view the most interesting to watch given their game-changing potential.

Whether you are an energy supplier, consumer, innovator or investor understanding in which technology areas the inventions are being made and who the owners of these inventions are is the starting point for getting ahead and taking advantage of the changes that are coming.

Welcome to the energy transition!

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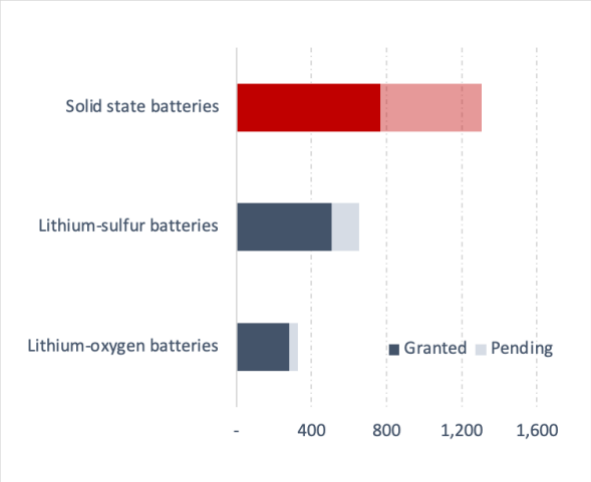
Solid-state is the battery technology to watch

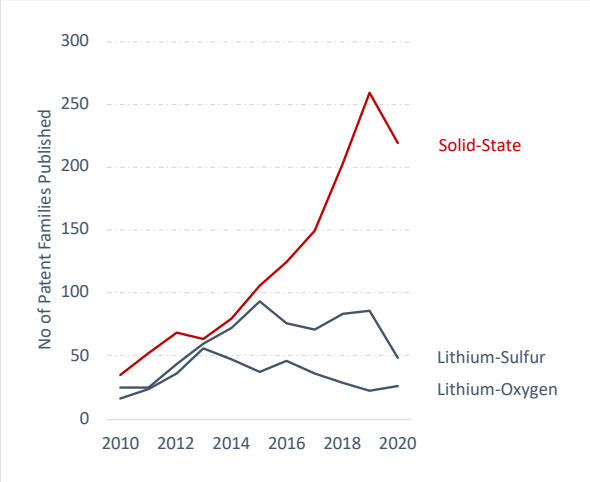
The volume and pace of invention in solid-state battery technology is well ahead of lithium-sulfur and lithium-oxygen both globally and for those inventions that have been registered and protected in the US and Europe.

Solid-state batteries are characterised as the name implies by the use of both solid electrodes and electrolyte. The solid electrolyte improves stability, reduces the risk of thermal runaway eliminating the need for much of the safety protection electronics required for lithium-ion, and importantly are much more tolerant to multiple charging cycles with the promise of longer life. They are safer, lighter and can push the energy & power densities beyond today's limits. The key obstacle today is cost per watt. Given the relative high cost, deployment will likely be weighted to the high-end vehicle market first and extend from there to the broader fleet.

Number of Inventions: *US & Europe*



The Pace of Invention: *US & Europe*



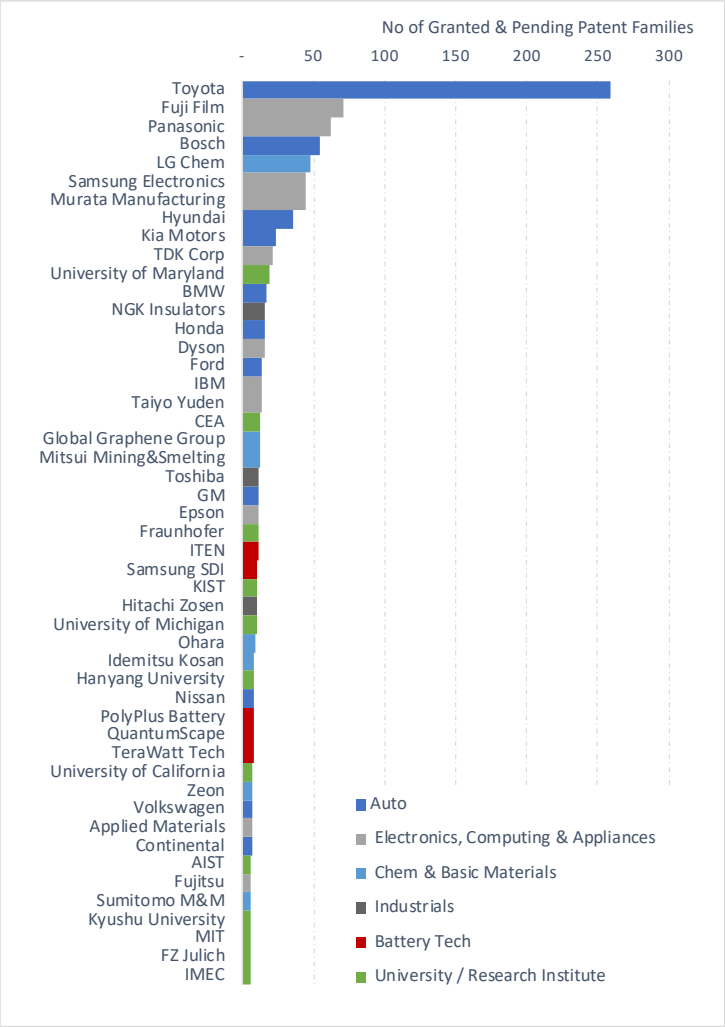
As measured by patent families either granted or pending in the US or Europe.

Lithium-sulfur batteries are characterised by a lithium metal anode and a sulfur cathode. Key advantages are super high energy density and lower cost due to the use of sulfur. The primary challenge to commercialising is that lengthening cycle life has been obtained in exchange for energy density and cost, basically a material science challenge in figuring out the optimal cathode design. Companies leading the charge in lithium-sulfur innovation include LG Chem, Bosch and Oxis Energy, a private UK based pure-play working exclusively on lithium-sulfur science.

Lithium-oxygen, also known as lithium-air, is exciting given the potential for significantly lengthened cycle times or range. Range anxiety for electric vehicle owners is very real and solving it would cement consumer confidence. A lithium metal anode is paired with a carbon-based cathode. The concept is oxidation of lithium at the anode and reduction at the cathode producing Li_2O_2. Because the oxygen is supplied from the air, the energy density is increased by multiples compared to a more traditional battery cell where everything is contained within. The primary challenges to overcome are air purification to avoid unwanted side reactions with nitrogen or water and the cathode design to limit degradation and enable long cycle life. Leading innovators in lithium-oxygen include Samsung Electronics, Hyundai, Toyota and Honda.

Japan is best positioned with an early mover advantage in solid-state batteries over China and Korea.

The Companies: *Number of Inventions Owned Solid-State Battery Tech, US & Europe*



Toyota dominates both in terms of the size of its portfolio of inventions in solid state battery tech and the pace of invention over recent years. Toyota is expected to unveil a prototype this year and to be the first company to introduce a solid-state battery powered vehicle. Partnering with Panasonic, the vision is a car with a range of over 500 kilometres and a recharge time from zero of only ten minutes. The supply chain is already being built out to support a launch. Mitsui Mining & Smelting and Idemitsu Kosan are key players lined up to produce the solid electrolyte with pilot plants expected to be operating at scale this year.

The Japanese government is backing this large-scale investment in solid state batteries, pinning its ambitions on an early mover strategy in the space to gain an advantage over China and Korea which today dominate the existing supply chain. Key state support will be in ensuring companies have access to raw material resource in particular lithium deposits around the world.

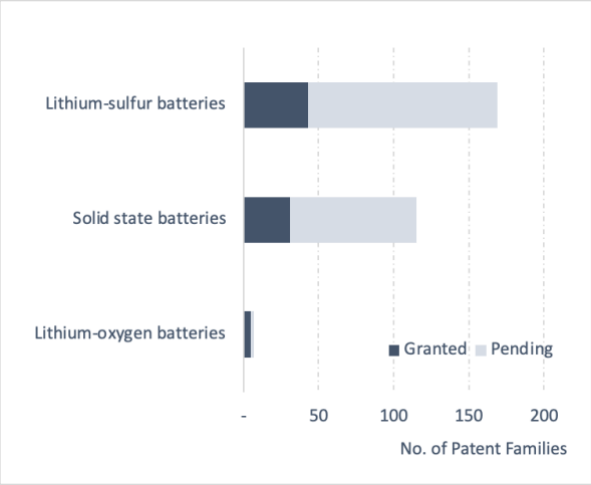
Other Japanese players on the list include Fuji Film, Honda, Taiyo Yuden and Murata Manufacturing – looking at solid state batteries not just for vehicle applications but also for IoT, wearables and consumer electronics.

Korea is in second place after Japan in the solid-state battery space. The Korean strategy is to be a fast follower. The list of key players with inventions protected in the US and Europe include many of the largest and well known Korean firms. LG Chem part of the LG Corp chaebol, Samsung Electronics (and its sister company Samsung SDI), also the major auto firms Hyundai and Kia Motors. The race is on.

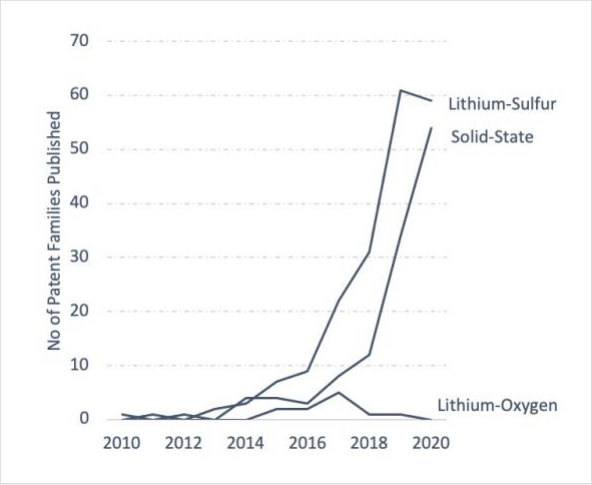
On the radar – LG Energy Solution, a leading supplier of lithium-ion batteries to Tesla, is actively investing in both solid-state and lithium-sulfur technologies

Korea's biggest electric vehicle battery maker LG Chem, through its wholly owned subsidiary LG Energy Solution, has pinned its strategy firmly on conventional lithium-ion battery development. The company is doubling its production capacity in China this year to supply key customer Tesla's Shanghai built Model 3 as well as Tesla factories in the US and Germany. Officially LG Chem has no plans for producing solid-state batteries, but it has been quietly ramping up innovation in the space registering over a four-fold increase in solid-state battery tech inventions from 2018 to 2020. A similar pace of invention is evident for LG Chem in lithium-sulfur battery technology.

Number of Inventions: *Global*



Pace of Invention: *Global*



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

With all the buzz around battery demand growth and LG Chem's electric vehicle battery business unit becoming profitable in 2020 for the first time, the company made the decision to spin-off the battery business into a separate unit. The new company LG Energy Solution split out from LG Chem in December and is planning a listing on the Korean exchange later this year. The IPO is hotly anticipated and expected to be the biggest ever for Korea to date.

Three next generation battery tech pure-plays to watch

Quantum Scape: Inventions specific to solid-state battery tech. San Jose, California based. Backed by Volkswagen, Kleiner Perkins and Bill Gates. The company went public in Nov 2020 via a SPAC and is listed on the NYSE.

Sion Power: Inventions specific to lithium-sulfur but has now shifted to developing lithium-metal battery tech. Headquartered in Tucson, Arizona. Originally spun out from Brookhaven National Laboratory in 1989, remains privately owned and backed by BASF.

PolyPlus: Inventions specific to solid-state and lithium-sulfur battery tech. Berkeley, California based and operating since 1991. Private and supported by a combination of funding from licensing, private investment and government contracts with the Dept of Energy and the Dept of Defense.

For reference & attached: Innovation Lens Snapshots

- *Technology Screening: Next Generation Batteries*
- *Company Screening: Solid State Batteries – Top Owners*
- *Company Snapshot: LG Chem (LG Energy Solution) – Next Generation Batteries*

Technology Screening: Next generation batteries

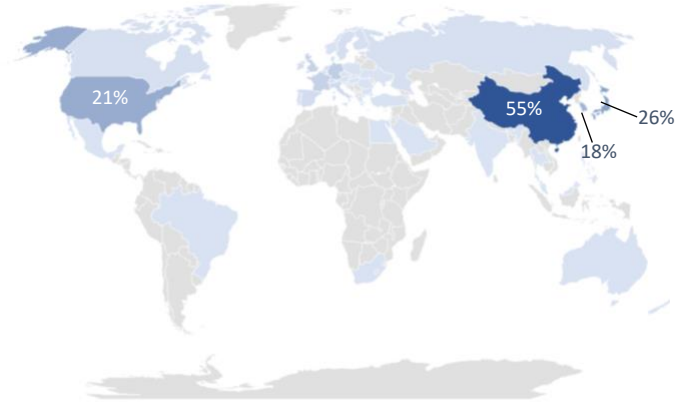
Technology Areas:

Solid-state battery: *Scope includes components, chemical compositions, nano-materials, coatings, method of manufacture, electrolyte material & associated apparatus.*

Lithium-sulfur battery: *Scope includes components such as nano-materials, nano-carbon coatings, organo-sulfur compounds, carbon-sulfur polymers, membranes, separators & catalysts.*

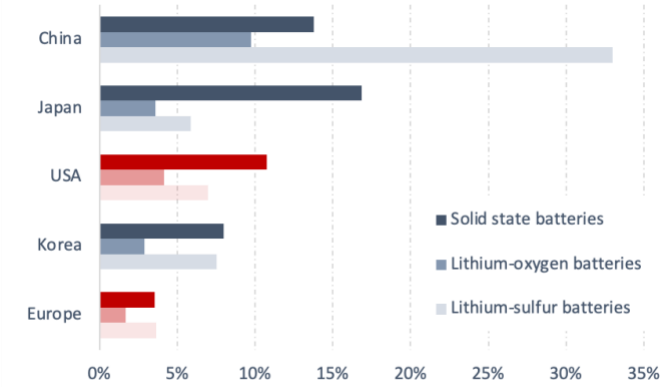
Lithium-oxygen battery: *Scope includes apparatus & features specific to this such as membranes, separators & catalysts - less emphasis on other metal-air inventions unless Li-O_2 chemistry is specifically mentioned.*

Geographies Protected: *By Country across all 3 Tech Areas*



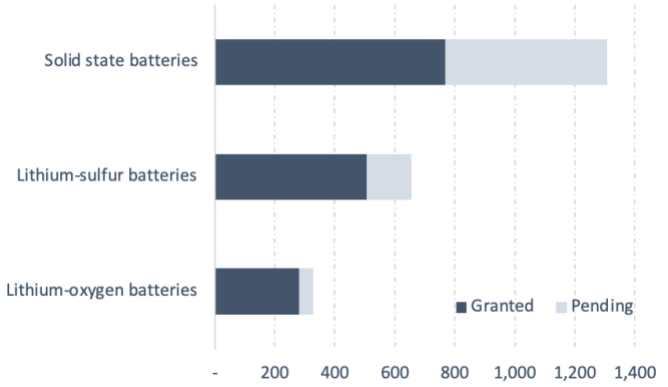
Patent Families with Grants by Country as a Percent of the Total Granted Families

Geographies Protected: *By Key Region / Countries*



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

Number of Inventions: *US & Europe*



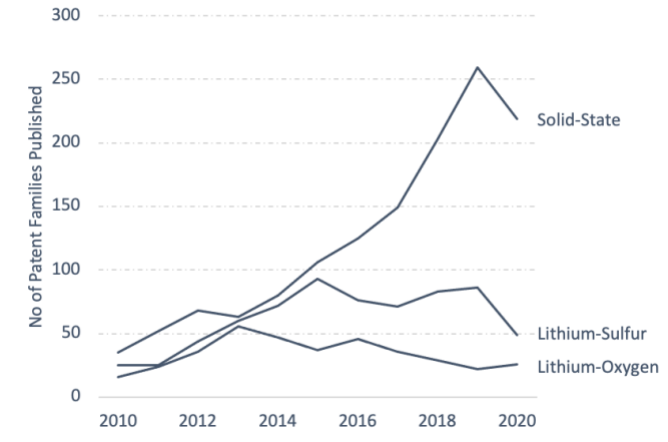
No. of Patent Families with grants / applications in the US / Europe

Companies: *Top ranked by Inventions owned, US & Europe*

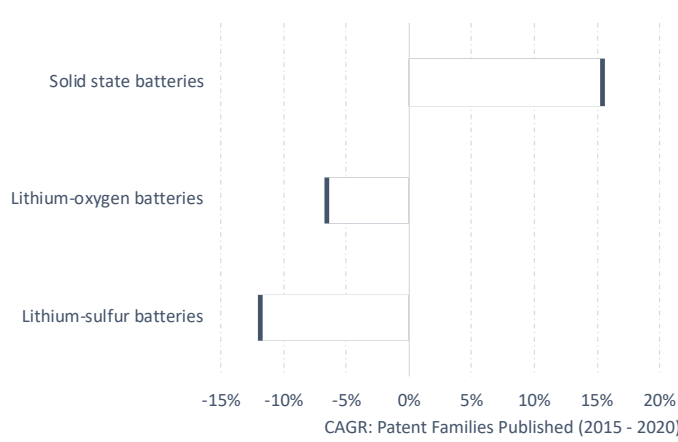
Rank	Solid state batteries	Lithium-sulfur batteries	Lithium-oxygen batteries
1	Toyota	LG Chem	Samsung Electronics
2	Fuji Film	Bosch	Hyundai
3	Panasonic	Oxis Energy	Toyota
4	Bosch	Global Graphene Group	Honda
5	LG Chem	Tsinghua University	University of Chicago
6	Samsung Electronics	Hyundai	Bosch
7	Murata Manufacturing	Sion Power Corp	Kia Motors
8	Hyundai	GM	Panasonic
9	Kia Motors	Foxconn	Praxair Inc.
10	TDK Corp	Toyota	Hanyang University
11	University of Maryland	CEA	Showa Denko KK
12	BMW	University of California	MIT
13	NGK Insulators	Samsung SDI	LG Chem
14	Honda	BASF	BASF
15	Dyson	NGK Insulators	BMW

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

Pace of Invention: *Trendlines, US & Europe*



Pace of Invention: *CAGR 2015-2020, US & Europe*



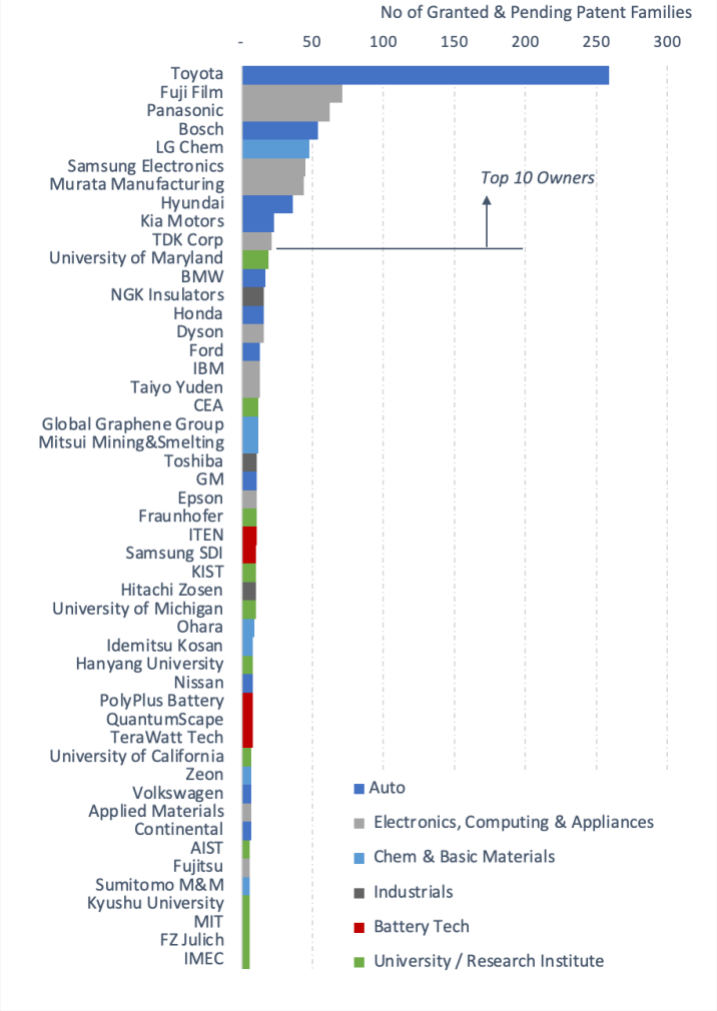
CAGR: Patent Families Published (2015 - 2020)

Company Screening: Solid-state batteries

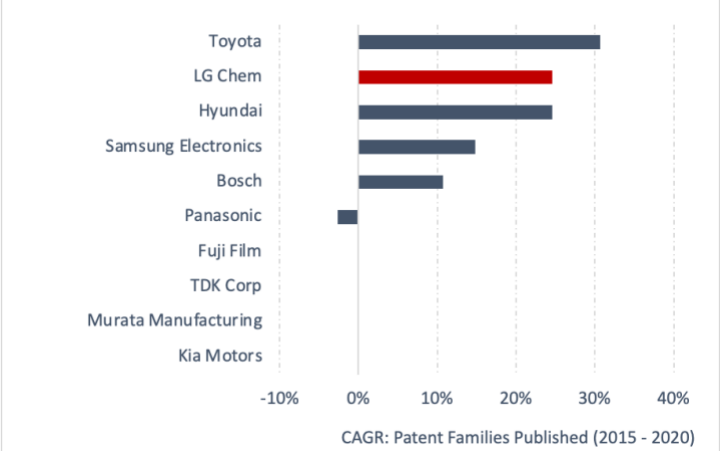
Technology Area: **Solid-state battery**: *Scope includes components, chemical compositions, nano-materials, coatings, method of manufacture, electrolyte material & associated apparatus.*

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

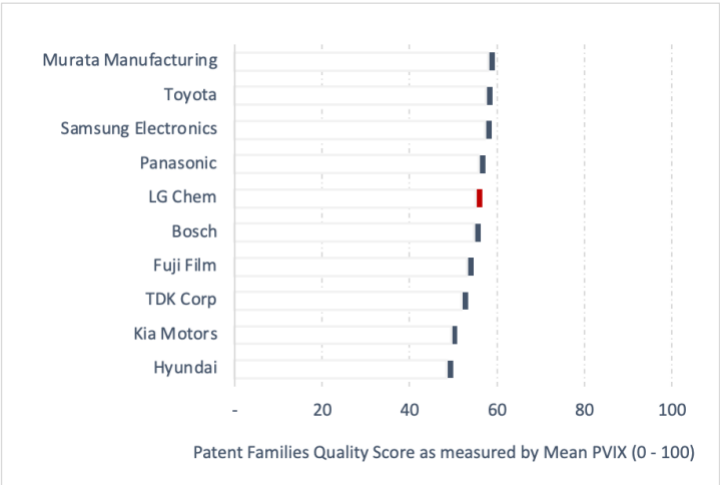
Companies: *No of Inventions Owned, Solid-state Battery Tech*



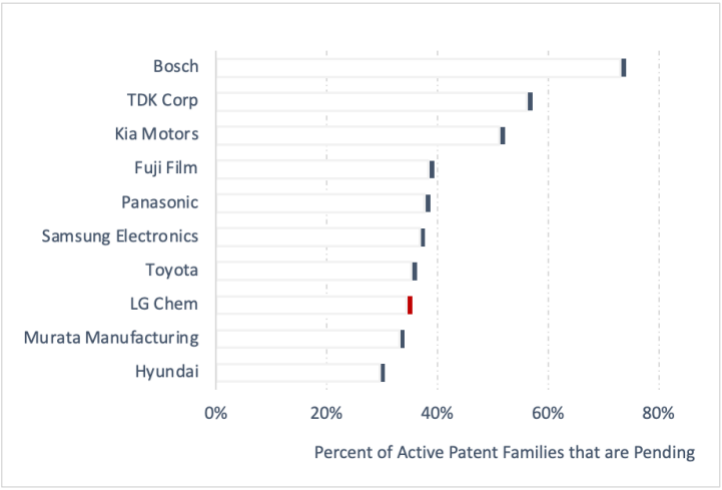
Pace of Invention: *CAGR 2015-2020, Solid-state Battery. Tech*



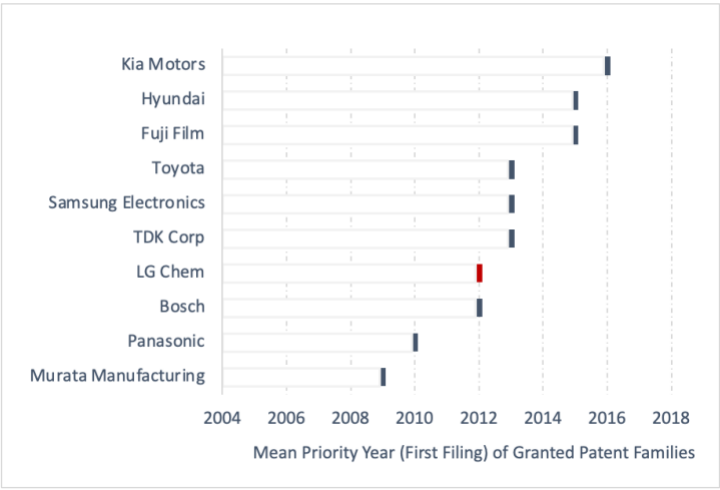
Quality of Invention: *Solid-state Battery Tech*



Invention Pipeline: *Solid-state Battery Tech*



Invention Age: *Solid-state Battery Tech (First Filing Date)*

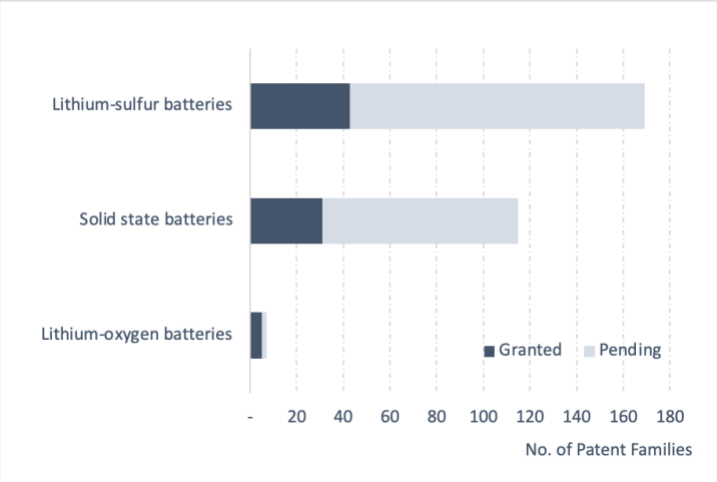


Company Snapshot: LG Chem (LG Energy Solution) - Next gen batteries

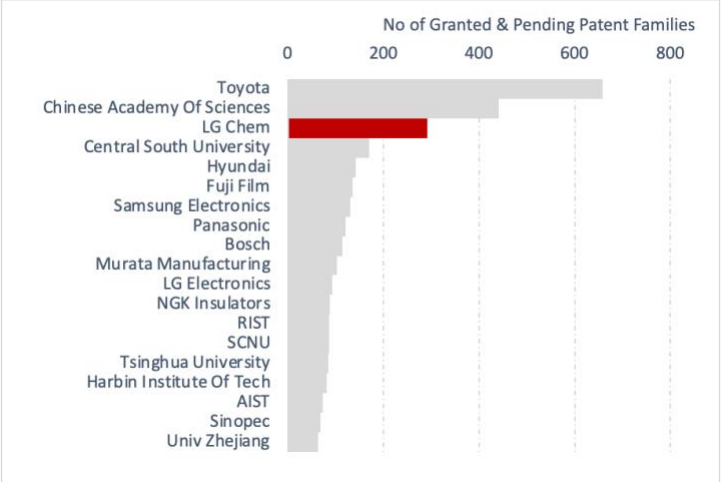
Technology Areas: **Solid-state battery**
Lithium-sulfur Battery
Lithium-oxygen Battery

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

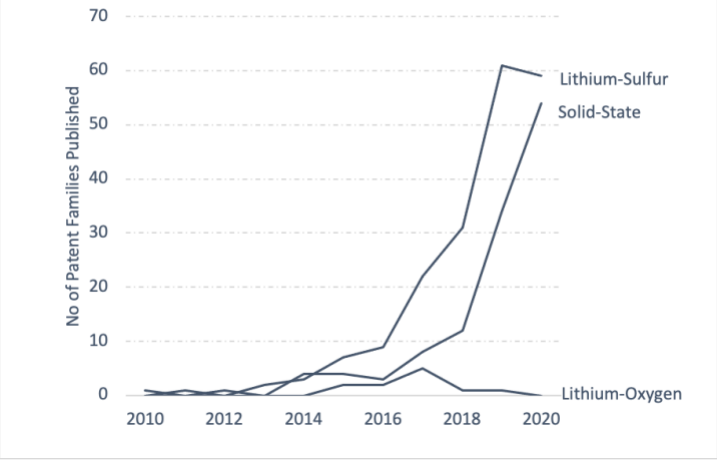
Number of Inventions: *LG Chem*



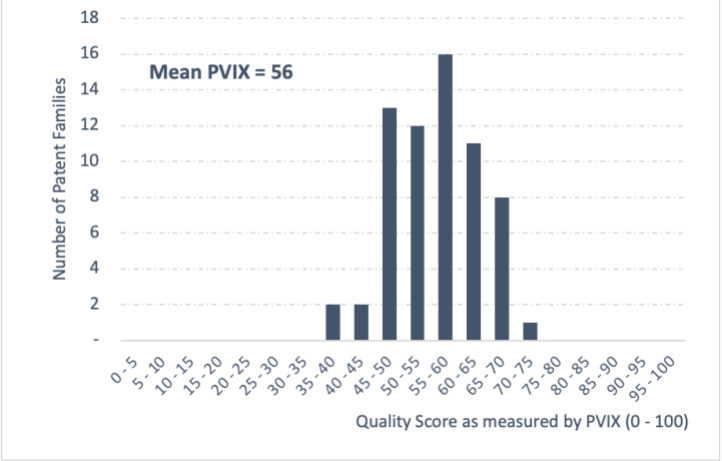
Companies: *Number of Inventions Owned*



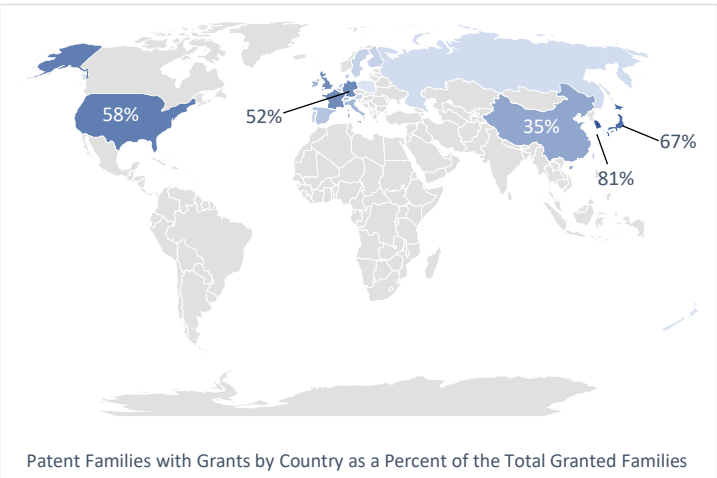
Pace of Invention: *LG Chem*



Quality of the Inventions: *LG Chem*



Geographies Protected: *LG Chem*



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

Invention Age: *LG Chem (Expiry Date)*