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Introduction to Flash Battery – Fast Charging Technology

"I THINK THE BIGGEST INNOVATIONS OF THE TWENTY-FIRST CENTURY WILL BE THE INTERSECTION OF BIOLOGY AND TECHNOLOGY. A NEW ERA IS BEGINNING, JUST LIKE THE DIGITAL ONE ". STEVE JOBS

The challenge to the mobile and electric vehicle industry is allowing fast battery charging. However, the fast charging using current approaches destroy battery cycle life and overall lifetime.

StoreDot has developed Flash Battery, which is a new generation battery based on proprietary multifunction electrode (MFE) that charges fast like a supercapacitor and discharge slow like a battery. This disruptive and patented, groundbreaking technology enables the unique combination of ultra fast charging of smartphone in 60 seconds, an electric vehicle in 5 minutes while improving battery lifetime.

Battery requirements are focused on delivering increased capacity in the same size, extended lifetime and ultra fast charging. Traditionally, battery suppliers have optimized one attribute at the expanse of the other. StoreDot novel technology enables all three requirements simultaneously, without compromising standard battery performance.

This document starts with the description of known technologies, and then elaborates on StoreDot approach and its advantages. The technology covered herein is StoreDot proprietary and is patented.

1. Background – Known technologies

The increasing necessity to develop high performance electrochemical energy storage devices is driven from the rapid demand to portable electronic devices and transportation electrification.

Currently, the dominating energy storage device remains the battery, particularly lithium-ion battery (LiB). LiBs power nearly every portable electronic device, as well as almost every electric car, including the Tesla Model S and the Chevy Volt. Batteries store energy electrochemically, where chemical reactions release electrical carriers that can be extracted into a circuit.

This can be illustrated with the example of the lithium ion battery: during discharge, the energy containing lithium ion travels from the high energy anode material through a separator, to the low energy cathode material (**Figure 1**). The reduction of the lithium releases electrons, which are extracted into an external circuit. When the battery is charged, energy is used to move the lithium ion back to the high energy anode assembly.

Charge and discharge processes in batteries are rather slow. As a result, batteries gain lower power density over time, and gradually lose their ability to retain energy over their lifetime.

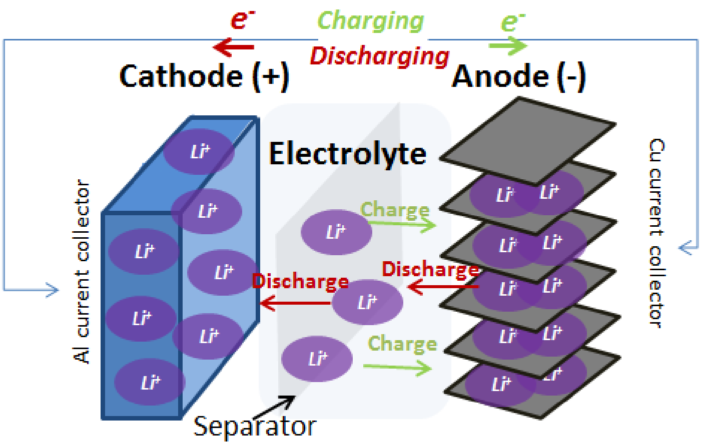

Figure 1. Lithium-ion battery structure

There are several limiting factors for the battery performance. The main limiting component of the LiB is the cathode. The conventional cathode components are based mainly on inorganic compounds, *i.e.* typically transition metal oxides or polyanions, which are electrochemically charged or discharged by de-insertion or insertion of the lithium ions. This charge transfer mechanism limits the capacity (140-170 $mA{\cdot}h{\cdot}g^{-1}$), power density, safety and the cycle life of LiBs. It also has issues related to metal-based inorganic materials such as toxicity, availability of resources and cost.

Organic polymer based energy storage materials are an attractive alternative due to their inherent advantages that include: tunable redox properties and theoretical capacity, potentially high energy and power properties by varied charge transfer mechanisms, along with the added benefits of polymer materials such as environmentally benign, light weight, and mechanic (elastic) properties.

Other disadvantages of LiBs are the graphite anode capacity, which is limited to approx. 340-370 $mA \cdot h \cdot g^{-1}$, and the commonly used organic electrolytes which are flammable, and has a limited ionic conductivity.

On the other hand, supercapacitors (SCs) represent high power, but restricted energy devices. Unlike LiBs, SCs uses a different storage mechanism, and due to that, SCs can be charged quickly, leading to a very high power density, while not losing their storage capabilities during their shelf and cycle life. The main shortcoming of SCs is their low energy density, meaning that the amount of energy SCs can store per unit weight is very small, particularly when compared to batteries. Additionally, the cost of SC materials often exceeds the cost of battery materials due to the increased difficulty in creating high performing SC materials.

In general, the SCs storage principle is divided to two storage mechanisms:

- Electric double layer – Electrostatic storage achieved by separation of charge in a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte. The separation of charge is of the order of a few angstroms (0.3-0.8 *nm*), much smaller than in a conventional capacitor.
- Pseudocapacitance – Faradaic electrochemical energy storage with electron transfer through the double electrical layer, achieved by highly reversible redox reactions, intercalation or electrosorption. The charge transfer that takes places in these reactions is voltage dependent, so a capacitive phenomenon occurs.

The energy of SC is given by:

Eq. 1. $$E=0.5CV^2$$

where E – the energy, C – the capacitance, V – the working electrochemical window.

Thus, as seen in **Eq. 1**, the energy of the device could be increased by two ways: capacitance enhancement, and/or increase of the working voltage. In general, a pseudocapacitor has much higher capacitance than the double layer capacitor due to the Faradic nature of the reactions, and the use of redox active material may enhance the standard double layer capacitance by a factor of 100 depending on the material type and the electrolyte used. Another parameter is the working voltage window of the device. The working window is restricted by the stability of the electrolyte. In general, organic and ionic liquid based electrolytes are better than aqueous based electrolytes due to their enhanced working potential window.

In general, SCs are divided into three families, based on their electrode composition and design:

- Electric double layer capacitors (EDLCs) – usually highly activated carbon electrodes (high specific surface area – $m^2 \cdot gr^{-1}$) and its derivatives, with much higher electrostatic capacitance than Faradaic capacitance.
- Pseudocapacitors – usually use metal oxides or conducting polymer electrodes with high electrochemical capacitance due to reversible redox reactions incorporating one/multiple electron transfer.
- Hybrid capacitors – capacitors with asymmetric electrodes, one of which exhibits mostly electrostatic and the other electrochemical capacitance, such as lithium-ion capacitors.

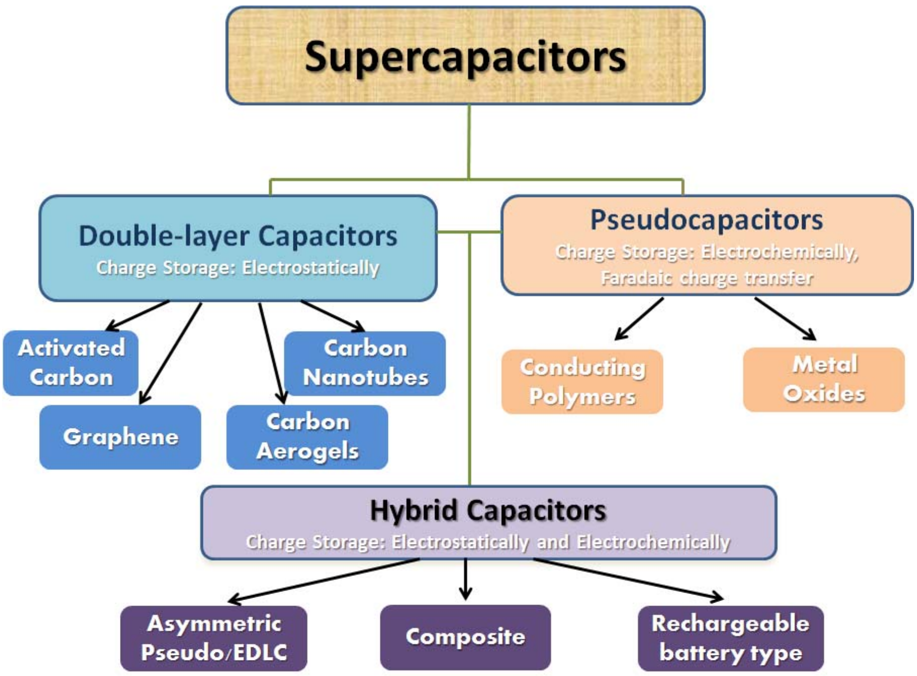

Figure 2. Hierarchical classification of supercapacitors and related types

The power performance of the pseudocapacitors and hybrid capacitors is lower in comparing to the EDLCs due to their slower charging kinetics, however, it is still significantly higher than the power of a battery.

2. Flash Battery: StoreDot's approach based on multifunctional electrodes

In order to develop fast charge and long lasting (in terms of cycle life) energy storage device, with satisfying energy properties, the most intuitive approach would combine two different types of energy storage sources incorporating high energy and high power density devices, without any modification of the intrinsic properties of each device. The method to do so is to combine the properties of SCs (high power) to the properties of LiB (high energy). The primary drawback of this approach is that the power and energy performance is decoupled.

At high current densities, the response is dominated by the SC component, considerably diminishing the energy density of the hybrid device. The sloping potential profile of the SC component during the device discharge is detrimental for most of the applications where a constant power supply is required.

Flash Battery technology is based on the engineering of a proprietary high charging rate and high capacity multifunctional electrode (MFE) to be used as cathode and/or anode in energy storage devices. A combination of both battery-like and supercapacitor-like electrode material components is present within the same electrode, thus, composed of a organic polymer and lithium metal oxide (LiMO) components.

Figure 3 schematically represents the structure of Flash Battery containing MFE design, where the organic material is used as a high power pseudocapacitive component, while the LiMO is used as an energy storage tank, both elements reside within the same cathode. The green and the red arrows indicate lithium ion flow in the electrolyte, which, unlike in most electrolytes used in the market, is dramatically enhanced due to the nature of the proprietary electrolyte, which is much safer than commonly used organic electrolytes. The black arrows within the cathode indicate the charge transfer within the MFE material matrix.

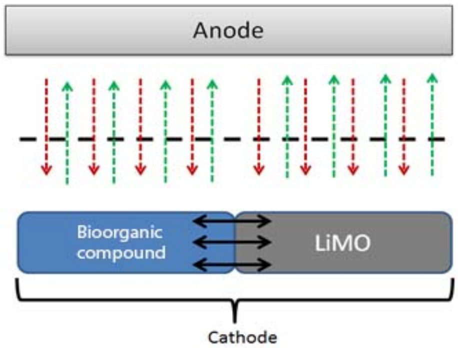

Figure 3. Schematic structure of Flash Battery containing a multifunctional electrode design.

Flash Battery structure in **Figure 3** enables the following fast charging mechanism (see **Figure 4**):

- The organic material is charged first. The organic component has a higher energy level. The voltage rises with applied bias via external charger due to the fast redox reactions. After the organic material charging the external charger can be disconnected (60C charging rate in **Figure 5**)
- Due to the fact that the equilibrium potential of the biomaterial is higher than the equilibrium potential of the LiMO component (**Figure 6**), thermodynamic relaxation mechanism coming into action, inducing the extraction of Li^+ ions from the LiMO component, and intercalation into the anode. The organic component's energy level is decreasing vs. the LiMO component via internal charge transfer (**Figure 4**). This relaxation mechanism is performed while the external charger is already off, and the "user" can be mobile again.
- Recharging may be performed over and over, until both the biopolymer and the LiMO components are fully charged.

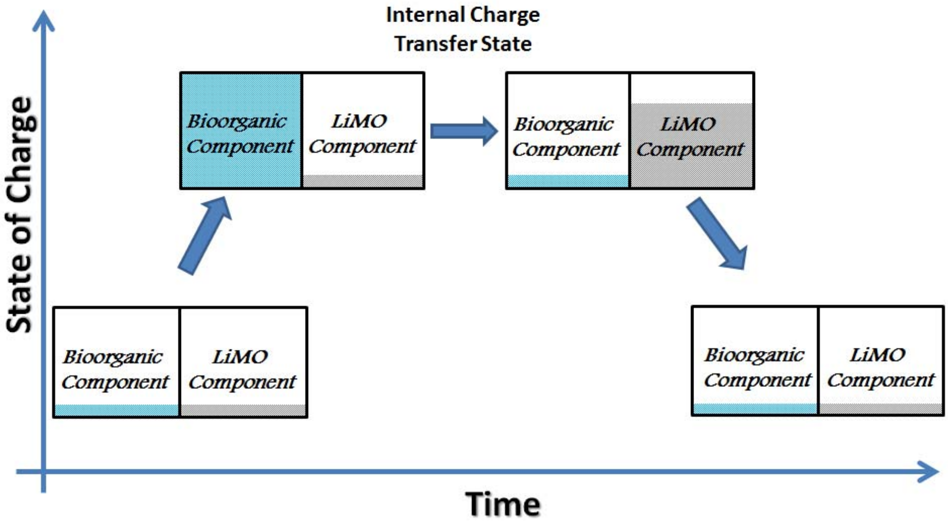

Figure 4. Charging mechanism of the multifunctional electrode structure

Schematic charge/discharge curves of the MFE containing device, with different charging rates are presented in **Figure 5**. At high charging rates (*e.g.* 60C) the only component being charged is the organic, while at low discharging rates (*e.g.* 0.5C) most of the energy is extracted from the LiMO component, having “standard” discharge profile. In addition, due to the fact that the battery continues to be charged during its work, discharging slope gets steeper with time.

In contrast at low charging rates (*e.g.* 0.5C) both components are being charged, each via its redox potential as seen from **Figure 5**.

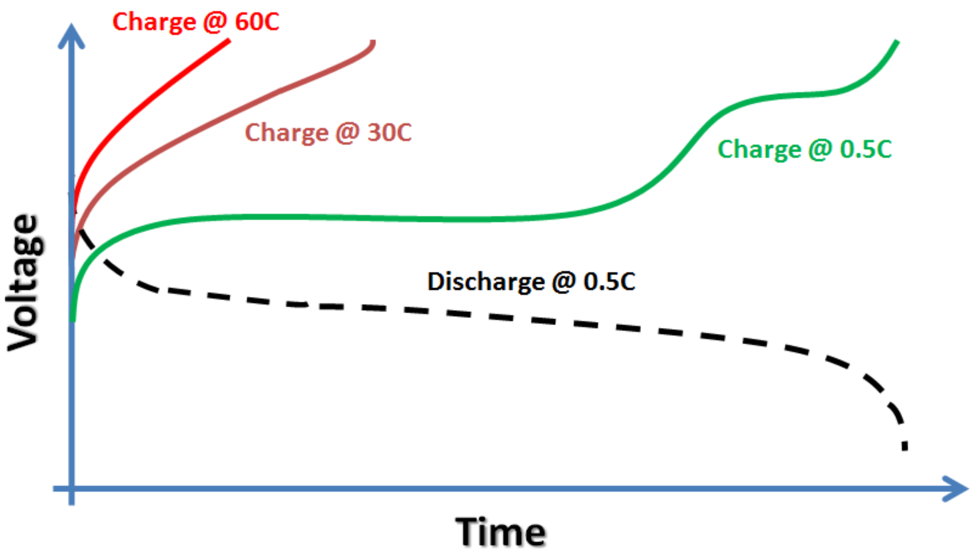

Figure 5. Charge/discharge profiles of the **Flash Battery** containing the multifunctional electrode (MFE) design

As discussed, the LiMO component continues to be charged via the internal charge transfer mechanism, even after external charger being disconnected, as represented in **Figure 6**. During this charge transfer, open circuit potential of the device is changing from higher (non-equilibrium) state to lower (equilibrium) state.

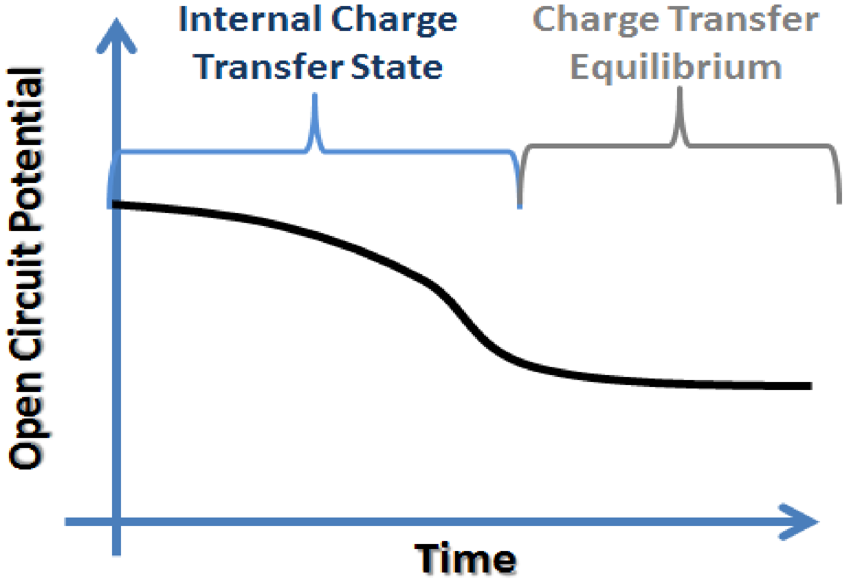

Figure 6. Relaxation mechanism inside the multifunctional electrode structure

Due to their abundance, low toxicity and an easy control of their structure and composition, organic compounds make an ideal material as an electrode. They can be both used "as is" material, or incorporated in conducting polymer matrix, thus making it more robust and more efficient.

3. The advantages of the Flash Battery incorporating MFE structure

Figure 7 demonstrates the main advantages of the **Flash Battery** over standard Lithium-ion battery.

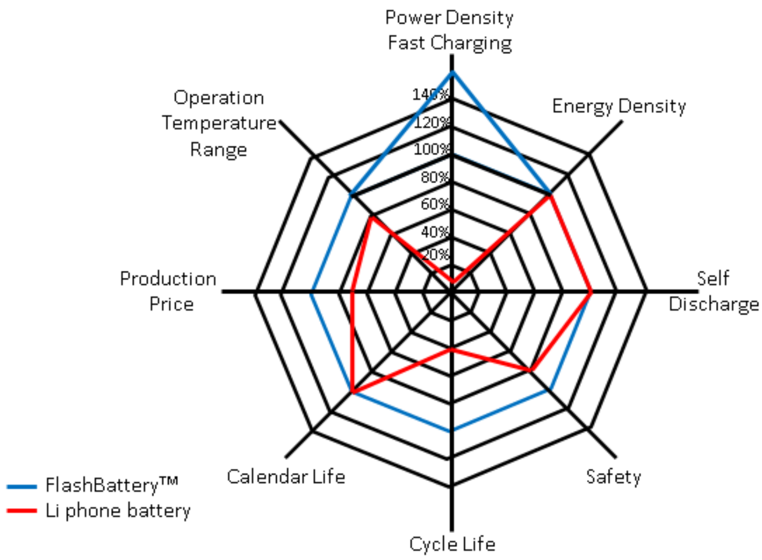

Figure 7. **Flash Battery** performance relative to standard lithium-ion battery

- Enables fast charging of the device
- Enhanced life cycle
- No overcharge, which is one of the most important safety problems with current LiBs
- Using organic compounds with appropriate functional groups having high redox potentials, makes it possible to enhance the energy density of the Supercapacitor component of the MFE.
- Using organic compounds on the anode, together with modifying the electrolyte, reduces the irreversible capacity due to stabilized SEI layer (higher first cycle efficiency), and promotes C-rate (**Figure 8**).

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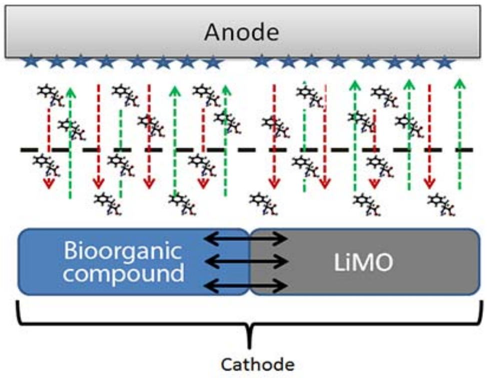

Figure 8. Schematic structure of **Flash Battery** containing multifunction electrode and organic compounds on the surface of the anode (stars) and inside the electrolyte

4. Why organic compounds?

- Similar to a biochemical electron transfer chain, bioorganic molecules are used for their high chemical stability and rapid and reversible redox activity.
- Using organic materials allows incorporation of various appropriate functional groups (*i.e.* amines, carbonyls or esters), leading to a large variety of suitable compounds for our specific purposes. This way, design of multifunctional biomolecule compounds may increase the uptake of lithium ions and its counter ions.
- The use of organic compounds and biopolymers electrodes lowers the overall cost of the battery, due to these materials' cost effectiveness. In addition, in comparison to toxic, polluting heavy metals and inorganic compounds, biomaterials have less environmental influence and less biohazard.
- The synthetic routs developed for our bioorganic materials are straightforward and may be easily manipulated in order to introduce different structures and functional groups, according to the needed application.
- The addition of organic materials to the electrolyte will result in better formation of the SEI (higher first cycle efficiency) and thus larger reversible capacity.

5. **Frequently asked questions**

- Does StoreDot develop charger or fast charging battery? – The StoreDot focus is on Flash Battery that is fast charging **battery**.
- What is the working mechanism of Flash Battery? – Flash Battery is a new generation battery that is based on proprietary multifunction electrode (MFE) that charges like a supercapacitor and discharges like a battery.
- How Flash Battery is different from supercapacitor? – Supercapacitors store energy through accumulation of ions on the electrode surface, have a low energy storage capacity but a very high power density.
  In other words, supercapacitors can be charged quickly, but have low energy densities. Flash Battery unites the advantages of both, supercapacitor and battery technologies, and has unique advantages over supercapacitors: Much higher energy density; Low self-discharge; Flat output voltage; Long-term energy storage.
- Should Flash Battery be used instead of standard battery? – Yes. Flash Battery is the only battery in a mobile device. It replaces the old battery in your smartphone.
- What are the materials of the electrode or the electrolyte? – We are using proprietary electrodes and electrolyte. We are modifying the material of the electrodes with our bioorganic multicomponent nanomaterials to create fast and reversible Faraday-like reactions that interact with both lithium ion and its counter ion in the electrolyte. In parallel, we optimize the electrolyte with small bioorganic compounds in order to improve and stabilize the built solid electrolyte interface (SEI), thus lowering the irreversible capacity.
- What is the role of peptides? – Peptides or other biomolecules enhance the memory effect of the electrodes and enable the fast transport of the ions.
- Is there any heating problem during the fast charging? – No. The internal resistance for charging is very low ~1 *mOhm*.
- What is the maximum charging current? – The maximum current we use during the charging is ~30 *A*.
- What is the life cycle of the battery? – Flash Battery will have up to 5000 cycles.

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- What is the exact performance of demonstrated device? – The initially demonstrated (April 2014) device is equivalent to a battery of ~700-800 *mA·h*. Our goal is to achieve ~2500 *mA·h* in a form factor of smartphone devices.
- Is Flash Battery intended only for Samsung smartphones? – No. Flash Battery is a universal battery technology.
- Why is it 30 *sec* and not 20 *sec*? – Flash Battery can be charged even faster using higher currents.
- How do you plan to increase the energy density? – Using bio-organic materials allows incorporation of various appropriate functional groups, leading to a large variety of suitable compounds for our specific purposes. We are currently working on incorporating additional functional groups in order to achieve multipeak pseudoreactions (having different redox potentials). The incorporation of these functional groups, which possess higher voltage redox reactions into the supercapacitor component of the multifunctional electrode, will result in higher energy density. This is done in parallel to our work on new modified electrolytes, possessing higher electrochemical potential window.
- What will be a price for Flash Battery? – It will be priced at around 2X current lithium ion battery pricing.
- Is there any specific technology needed for a charger system? – No. The charger will be standard portable AC-to-DC technology.
- Can Flash Battery be charged through USB? – Yes, using adaptive pinout of the USB port.
- When will we see the device in the market? – It is expected to reach the market in late 2016.
- Is the technology relevant for electric vehicles? – Yes. Flash Battery technology may be adjusted to electric vehicles and other energy storage applications.
- Is the technology well protected? – Not only the solution of StoreDot based on use of bio-organic compounds is unique, it is as well protected by patents with broad claims not allowing others to use similar technologies even using other small organic molecules. On the other hand, it is quite difficult to replicate our technology due to use of proprietary solutions in synthesis of the bio-organic materials we are using.

- Is fast charging important? – The youtube video (https://youtu.be/9DhJZAhjbcI) and its replicas got several million views in less than two weeks. The reaction to the demonstration of fast charging is very enthusiastic. The most frequent comment to the demo is "Shut up and take my money". StoreDot is also getting many inquiries about the possibility of installing fast charging stations at publicly accessible points (cafes, public transportation, offices, *etc*.) Also, we have received inquiries from leading battery producers with inquiries about a possibility of cooperation in further development of the technology.

"IMAGINE YOUR PHONE IS CHARGED WHILE YOU'RE PUTTING YOUR JACKET ON BEFORE YOU LEAVE THE HOUSE!"