THE BATTERY SHOW NORTH AMERICA

electric & hybrid vehicle technology expo

Divergent Approaches to Solid & Semi-solid Batteries for EVs

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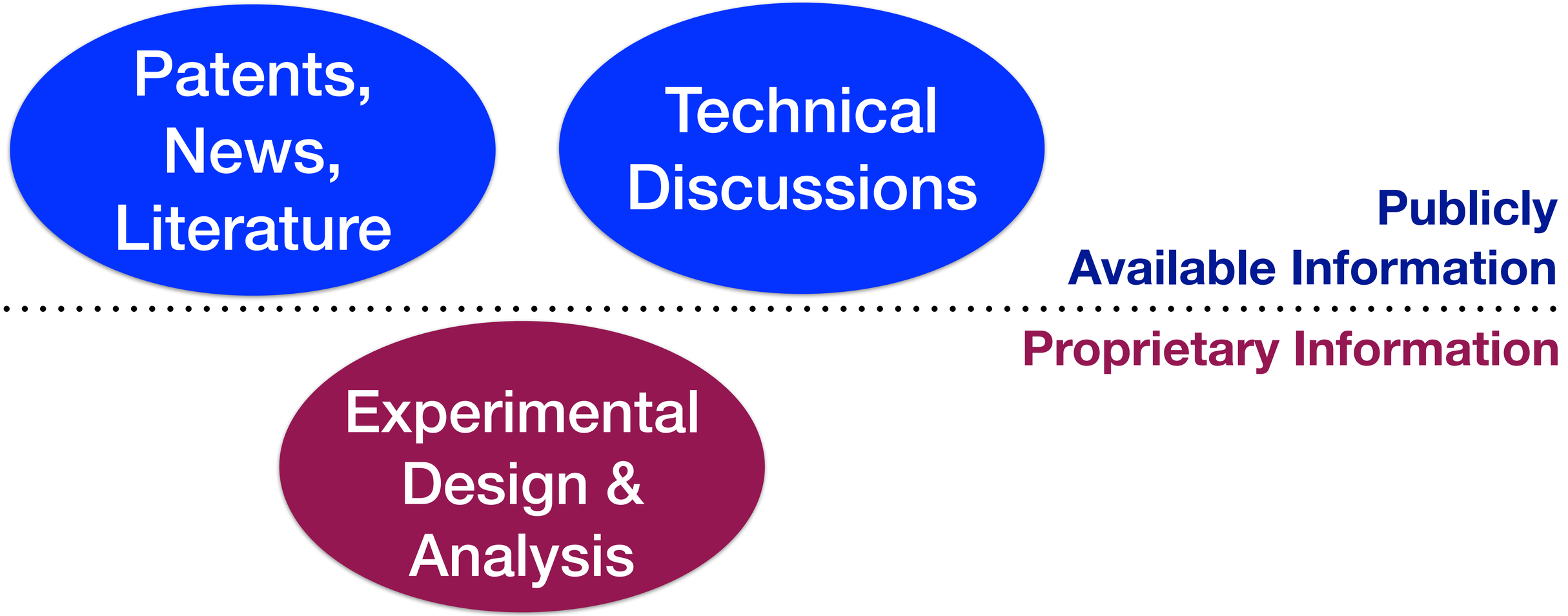
The Climate Tech Product Development Process

	Conceptual product outline	Detailed product definition	Market introduction
Key challenge	• Invent novel products	• Match application needs	• Timely launch of products
Key benefit of our service	• Discovery of under-explored ideas	• Make informed trade-offs: performance / safety / costs	• Situational awareness to accurately dedicate resources

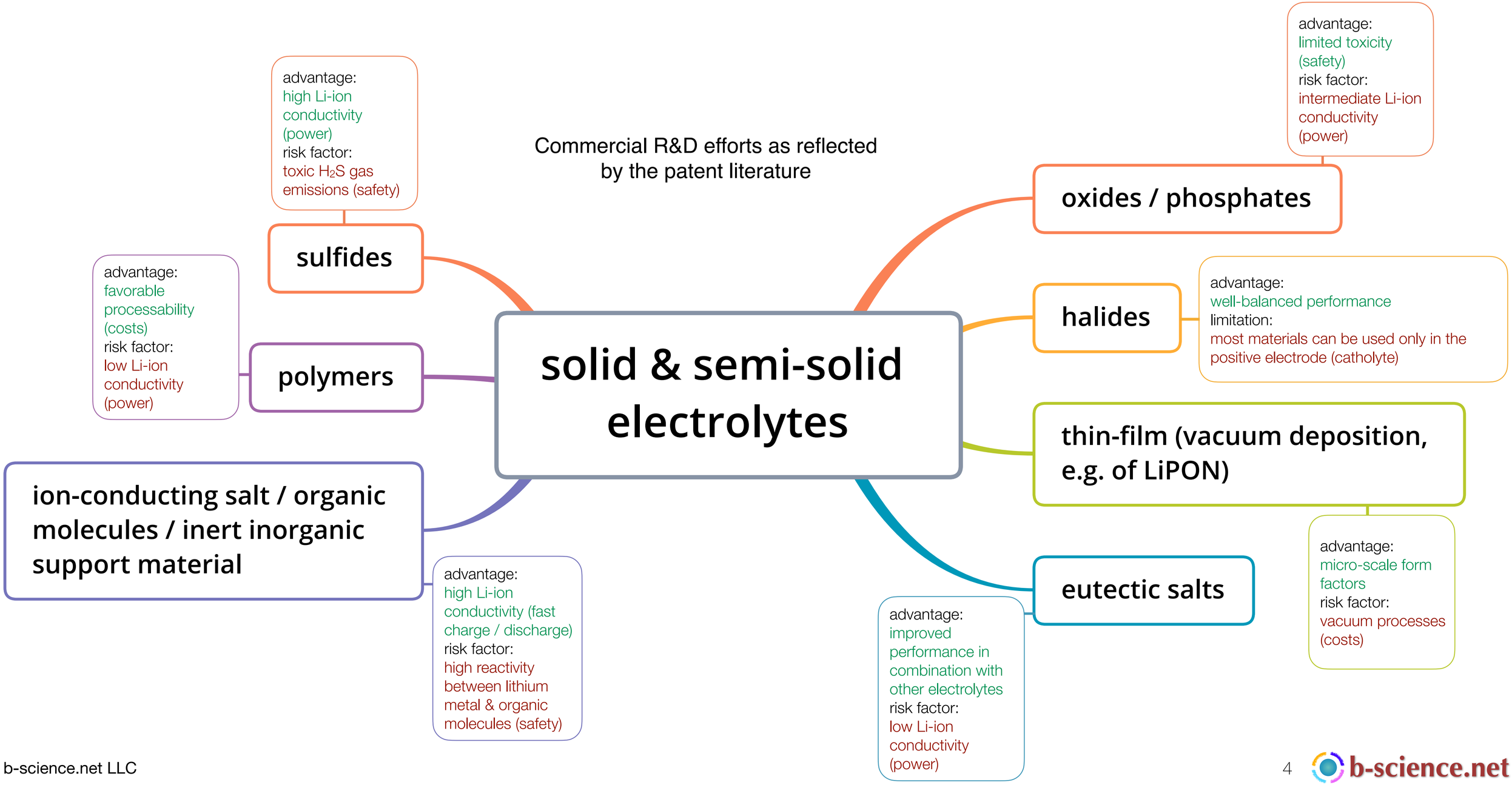
Using ML to Provide Granular Decision-making Support



- We analyze the top 2 domains with the help of our ML framework.

Decision visualization - main solid / semi-solid electrolyte classes

Commercial R&D efforts as reflected by the patent literature



Market entry and time-to-market projections for solid-state / semi-solid battery EVs

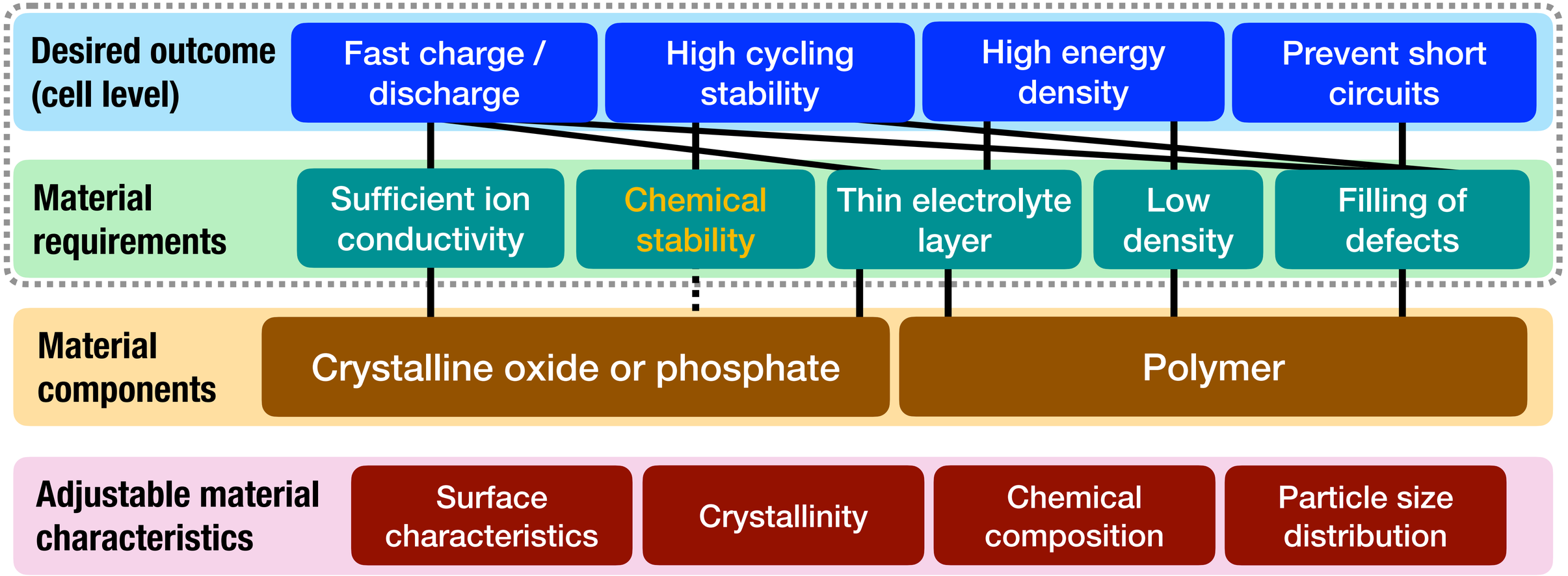
Company	Country	Year	(Prospective) Technology / Partner
Blue Solutions	France	2012	**Polymer**, operation at >60 °C / **Hydro Québec**
Daimler (and other Blue Solutions customers)	Germany	2020	**Polymer**, operation at >60 °C / **Blue Solutions** / **Hydro Québec**
Dongfeng Motor	China	Q1/2022 (cabs)	**Oxide or phosphate & polymer / Ganfeng Lithium**
NIO	China	Q4/2022	**Presumably oxide or phosphate & polymer with >10% liquid content** / probably **WeLion**
Vinfast	Vietnam	2023-2024	JV with **ProLogium (probably phosphate & polymer, bipolar cell architecture)**
Toyota	Japan	by 2025 in hybrids	**Sulfide (possibly mixed with halide) / Panasonic**

Market entry and time-to-market projections for solid-state / semi-solid battery EVs

Company	Country	Year	(Prospective) Technology / Partner
VW	Germany	2025-2026	**Oxide / QuantumScape**
Ford	USA	2027-2030	**Sulfide / Solid Power**
GM	USA	?	Investment in **SES** (**Li metal with liquid / eutectic salt electrolyte**), collaboration with **Honda** (**sulfide**), collaboration with **Posco** (**sulfide** or **polymer**), **GM China: sulfide** or **oxide, bipolar cells**
Chrysler / Stellantis	USA / EU	?	**Evaluation of packs for various solid-state battery types**
Nissan / Renault / Mitsubishi Motors	Japan / France	2028	**Sulfide (bipolar cells)**
BMW	Germany	2030	**Sulfide / Solid Power**
Hyundai Motor / Kia Motors	Korea	2030	**Sulfide / Samsung, LG and/or SK Innovation**

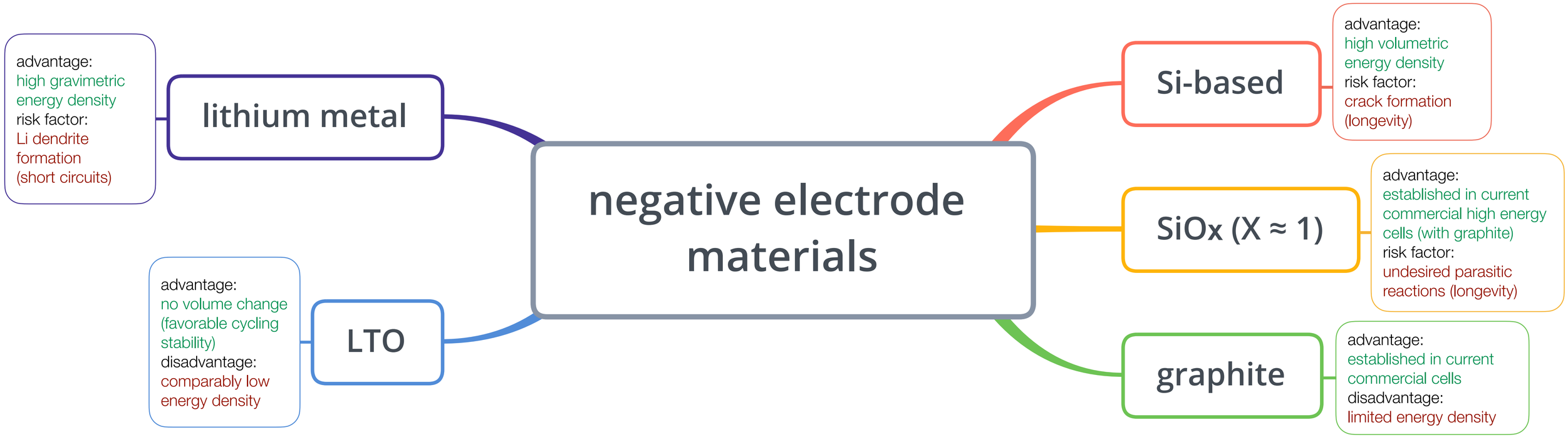
Potential synergies oxides / polymers

(patent filings by Fujifilm, Ganfeng Lithium, ProLogium, Qingtao Kunshan, SVOLT, Toshiba, WeLion)



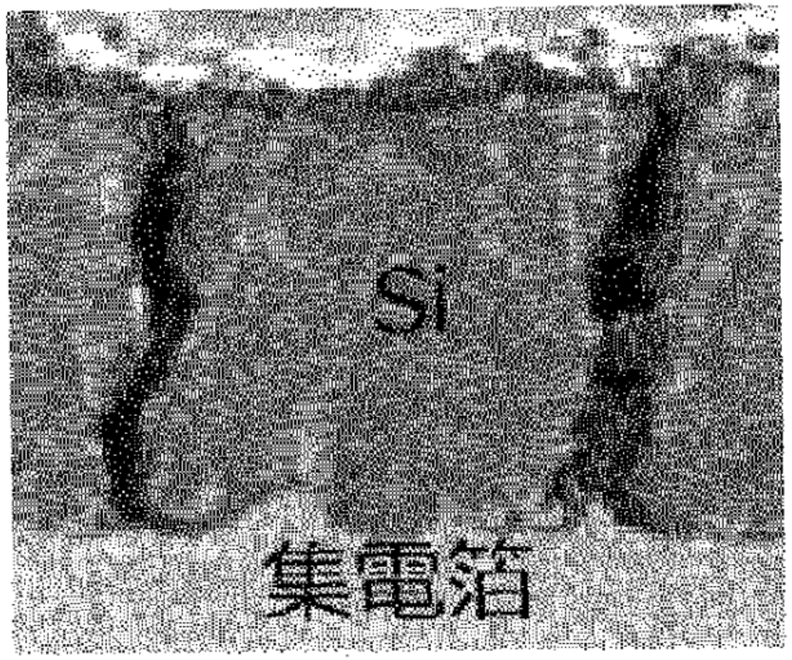
- **Chemical stability depends on choice of specific oxide / phosphate electrolyte, negative and positive electrode materials and has to be sufficient also for polymer.**

Decision tree - negative electrode materials selection (EV applications)



Prospects for comparably low-cost, Si negative electrodes in solid-state Li-ion batteries - Toyota Motor / Panasonic

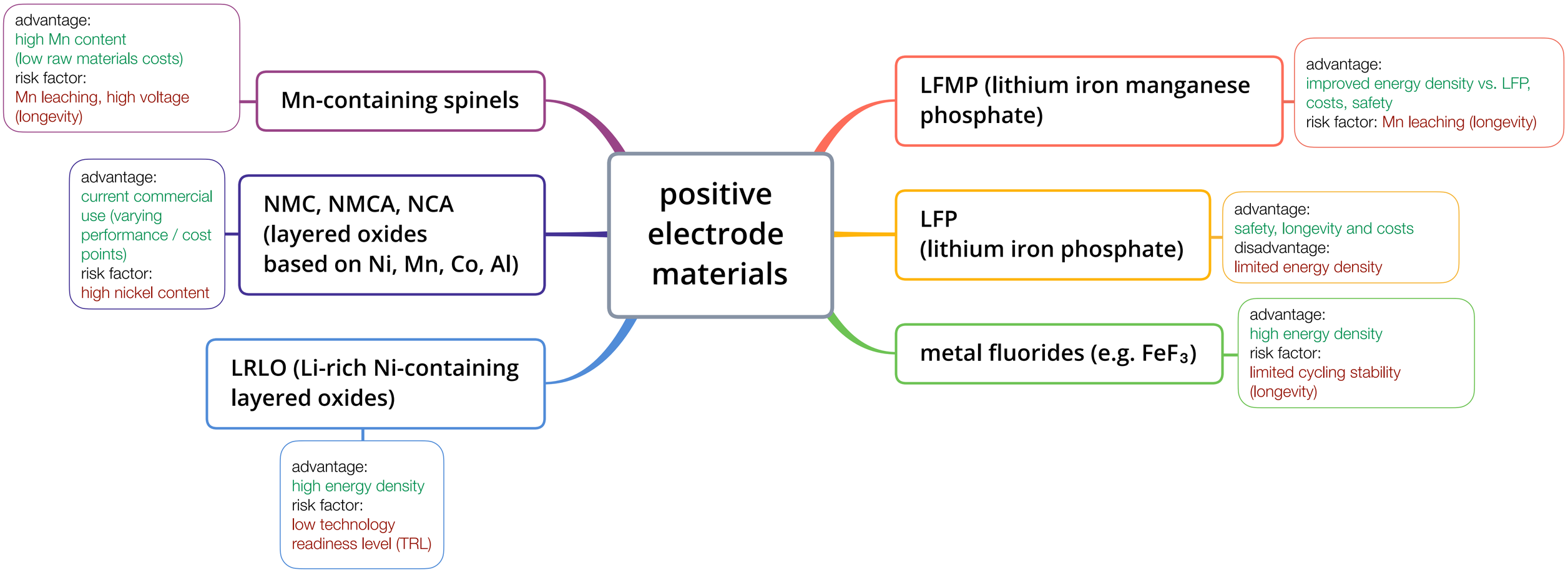
Link to key patent:
Espacenet / Google



集電箔: collector foil

- **Toyota:** formation of vertical pores during first charge under high pressure.
- **Tesla:** holds IP to key components that could serve as basis for implementation of semi-solid or solid cells based on low-cost Si negative electrode, **with dry electrode processing**.

Decision tree - positive electrode materials selection (EV applications)

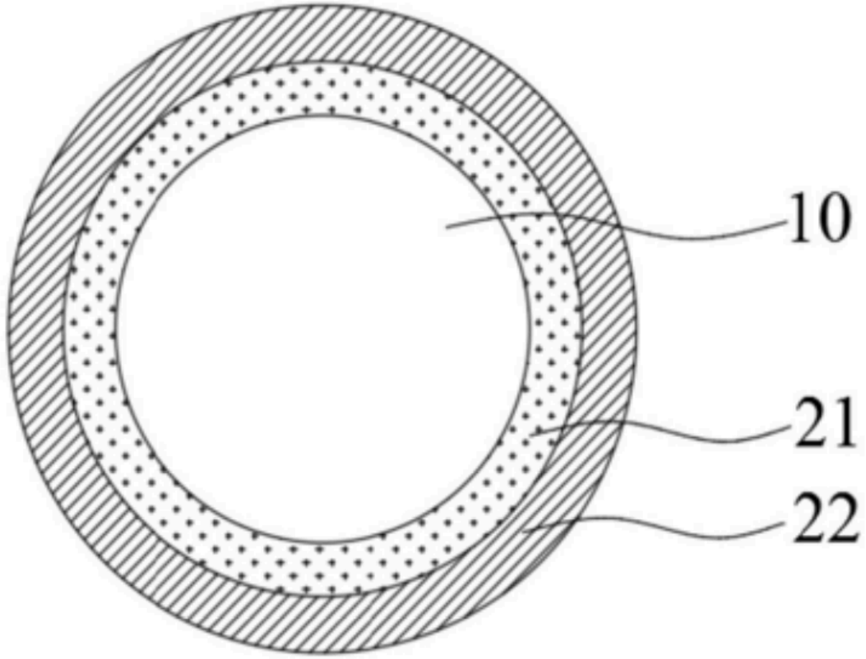


BYD - LFMP (Lithium Iron Manganese Phosphate)

10 - core: a $LiMn_{0.75}Fe_{0.25}PO_4$ core

21 - interlayer: titanium oxide

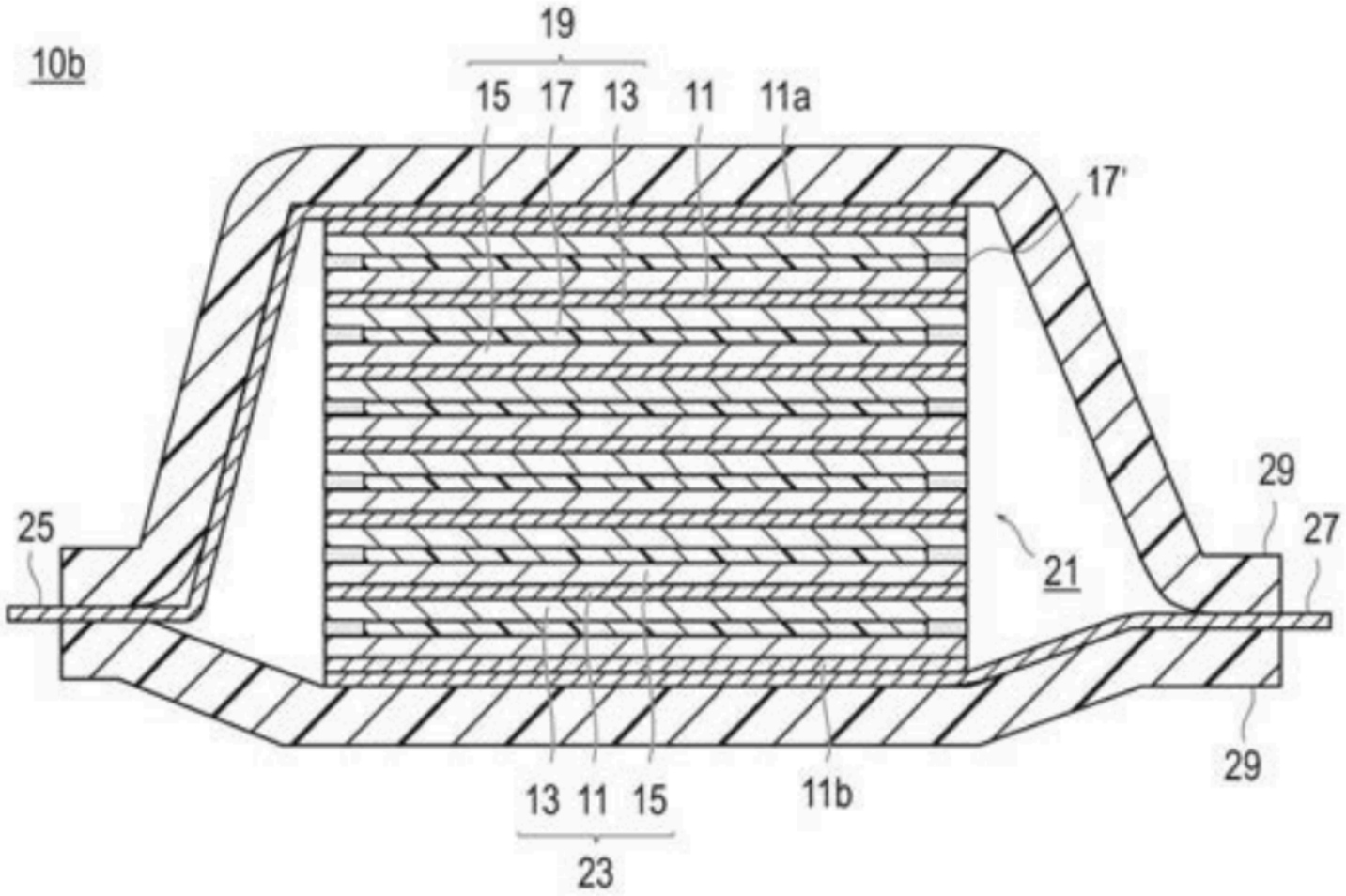
22 - outer layer: carbon



- This material exhibits a specific capacity of 163 mAh/g and a median voltage of **3.72 V** vs. Li^+/Li (LFP: ca. 160 mAh/g, 3.2 V vs. Li^+/Li).
- Use of solid-state electrolyte might reduce Mn-leaching and improve longevity.

Link to key patent: Espacenet / Google

Bipolar cells - Nissan / Renault



Other key players that target bipolar cells:

- **ProLogium**
- **GM**
- **Toyota**
- **Panasonic**

- Solid electrolytes potentially allow for implementation of stacked cells with > 40 V voltage ➔ could allow for energy density / cost savings at pack level.

Link to key patent: Espacenet / Google

(Solid-state) Sodium-ion Batteries

- **Prospects:** Na-ion battery cells have reached similar energy density (160 Wh/kg) as LFP Li-ion batteries, with favorable raw material costs, power, safety.
- **Time to market launch:** upscaling pursued by CATL (China, **commercial production in 2023**, i.e. close to market launch) and Reliance (India, with Faradion, UK).

(Solid-state) Sodium-ion Batteries

- **Key risk factor (as long as there is no cost advantage):** identification of unique selling proposition vs. LFP cells.
- **Solid-state electrolytes:** early stage (lab or pre-pilot, e.g. LiNa, might allow for increased energy density at reduced raw material costs).

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Thanks for your attention!

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