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eXtreme Fast Charging (XFC) era is around the corner – the battery technology to realize XFC much earlier than you presume

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Executive Summary

Authors will first summarize key attributes US DOE (Department of Energy) projected for eXtreme Fast Charging, XFC for short, an initiative kicked off around end of 2017. Then, we present data points of the like attributes based on what NiveauUp's samples deliver, all validated by customer partnership or NiveauUp's own test, to benchmark against those data points suggested by US DOE or their collaborative labs. This explains how the title highlights such a position.

Readers' own judgments may apply to what opportunities and methods may unlock untouched potential of the Lithium-ion (Li-ion for short) process, by sharing what NiveauUp team has achieved. In NiveauUp's own experiences, our proprietary manufacturing process re-constructs more than $1,000 worth of BOM per EV. Overall, the solution starts by pre-treating mostly off-the-shelf materials that make up standard Li-ion batteries, introducing primarily cathode coating [1] and electrolyte refining techniques to convert their properties, in order to stand against the high-rate delithiation reaction during a reduction-oxidation (REDOX for short) reaction. Equally critical, design trade-off decisions were to be made, plus, effectively, working around or overcoming manufacturing scale-up traps early on was needed.

Outcomes of successfully turning common Li-ion battery cells to charge 10X faster, last 3 times longer and weigh lighter at the pack level were demonstrated. By defying industry consensus, not only XFC's merits will be fulfilled, but also a new EV era may just arrive a decade ahead of a broadly assumed timing.

Battery will no longer be, first time ever in its history, EV ecosystem's bottleneck. Stakeholders may be keen to learn this implies changes of pace, only this time, for the better of expediting EVs' mass adoption.

US DOE’s initiatives and NiveauUp’s present positioning

[2] Back in Sept. 2017, the US Department of Energy (US DOE) Office of Energy Efficiency and Renewable Energy (EERE) issued, on behalf of the Vehicle Technologies Office (VTO), a funding opportunity targeting the development electric vehicle systems that can recharge rapidly at high power levels. Batteries for Extreme Fast Charging (XFC) had since emerged to become an acronym for more and more people in the EV industry to talk about.

As the initiatives progressed, the engaged technical communities also started publishing information regarding specially designed material structures, technical or engineering methodologies, and novel technology development to make recommendation to the industry how XFC batteries can or may be realized for commercialization.

As in the sub-section 1.3, NiveauUp would proclaim ourselves to be, most likely, the first operational entity in the market to offer “commercialization-ready” XFC batteries. In this paper, we would like to share our views by benchmarking if validated data are available, or forecast the potential feasibility according to the trajectory of our proven development in the working. Whereas, “commercialization-ready” means NiveauUp has submitted XFC battery samples to EV manufacturers or objective third parties with equivalent capabilities to test and validate desired battery’s attributes. With such proofs of performance, Authors might refute, or deny, some reference papers since the XFC initiatives started, in the case when we found their suggestions or analysis, based upon our implementation, not supposed to produce what NiveauUp team has achieved, though in their own future or follow-on works, XFC capabilities might still be achieved otherwise.

Fast charging batteries’ technical challenges as barriers for EVs’ adoptions

[3] One known market barrier for EV adoption is their relatively slow recharge times compared to refueling internal combustion engine vehicles, which weighs in to be the key contribution to the commonly quoted term, “range anxiety”. Current state of the art in battery technology significantly sacrifices battery range, cost, or battery cycle life when higher charge rate conditions are applied. As a contrast, there are industry leaders’ opinions pointing to ‘price points’ to outweigh the ‘range’ as the main barrier [4]. As a balancing act, Authors endorse strongly that XFC technology must be cost sensitive to justify itself right in the stage of its initial introduction.

XFC use cases for consumers

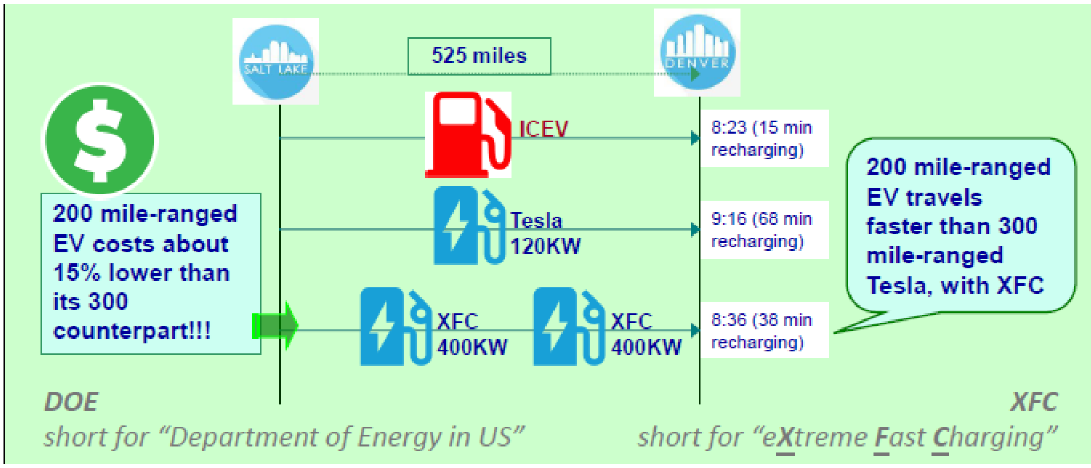
Authors believe the availability and potentials of XFC batteries will bring three popular use cases to propel consumers’ EV adoption.

We also suggest what practical considerations are required in order to harmonize the above use cases, together with XFC, to drive the holistic benefits across the EV ecosystem.

Mitigation of range anxiety

Among various use cases evaluated by US DOE [5], Figure 1 illustrates to best meet the balancing act scenario, a 300~500 mile range and let's call it a case of "long-haul charging" modality.

Figure 1: **US DOE’s Range Use Case for “XFC vs. Tesla vs. ICEV”**



Re-classifying EVs' price points

Following what was illustrated in Figure.1, say 1/3 of the battery in a Tesla equivalent EV can be reduced, that's more than 15% to be taken away from a total EV cost (base models' BOM only), in exchange of getting at a minimal three(3) times faster charging than a Tesla charging. This new kind of EV can travel faster than a Tesla in a 300~500 miles of range.

"Opportunity charging" modality (in an urban scenario)

"Opportunity charging", before this paper, is a charging modality only applicable to e-bus for fast charging between stops [6] and lift folks' fast charging between work shifts [7]. We may expand such an "opportunity charging" modality to much broader urban and metropolitan use scenarios where XFC's user experience won't be inferior to ICEV's. Authors would like to re-define the term "opportunity charging" as follows.

"Opportunity charging for an EV permits batteries to be charged, in a very short period of time (a few minutes), for just a sufficient range to reach the next destination where less competition for a charging facility or a lower cost of charging is provisioned. As long as EVs' batteries can take faster charging, this charging modality offers flexibility for both EV owners and charging service providers to optimize their assets and resources, e.g. service re-pricing, reducing the frequency to queue in front of the popular public charging points, … Etc."

Objective settings to harmonize the above-mentioned needed usability

To harmonize the above-mentioned merits, the net premium, after including XFC batteries, shall be at least lower than the 15% reduction at the total cost level, to justify a new breed of EV. Authors will elaborate, as follows, factors of how XFC battery technology will differentiate their design objectives and performance from their conventional predecessors.

Validated data of (NiveauUp's) "commercialization-ready" samples' against DOE's estimated targets (in performance as well as timeline aspects)

Authors' company, NiveauUp Inc., is a battery technology startup. We have continuously sampled battery cells to customers. Their validated performance serves as benchmarks against DOE's projected targets according to key attributes as shown in Table 1, which concludes the "commercialization-ready" status is not self-proclaimed for a marketing purpose.

In addition, NiveauUp's samples last at least 3 times longer than the standard cells for standard life-cycling tests and far more than 500 cycles under various, specific, fast charging conditions.

US DOE suggests XFC battery cost most likely will start at a multiple of 2.2 times of the standard conventional battery [8]. NiveauUp's premium factor fares lower than 10% higher.

Table 1: Initial XFC performance targets set by DOE against the qualification data of NiveauUp's samples (in performance as well as timeline aspects)

Key Attributes	Cell Capacity (Ah)	Energy Density (Wh/Kg)	Pack "Specific" Energy Density*	Charging Rate/Times (C-Rate/minutes)**
DOE's Initial XFC 2020 targets [9]	2	180 =a	a x 06~0.7 [9]	6/10
DOE's Projected XFC 2028 targets [10]	TBD	250	TBD	4/15
vs.				
NiveauUp's deliverable by end of 2017	10	>180 =b	likely b x 0.7 &up	10/6
NiveauUp's projection by end of 2019	10+	>200 =c	likely c x 0.7 &up	6/10

*Multipliers applied for estimating the pack specific energy density have been, in EV history, between 0.6 and 0.7 ranges [11]. Assumption of NiveauUp technology's low thermal contribution to achieve 0.7 and up remains to be an ongoing joint work of customer partnership on the day of the paper submission.
**NiveauUp's charging SoC window is 0~90%, and the industry status quo is 10~80%.

Opportunities to unlock full potential of Li-ion process

In our opinions, "faster charging improves uniformity", a very essential scientific insight, poses the most significant opportunity available from the research community. Professor William Chueh of Stanford University published a series of papers [12;13] to promote its potential, and the physical and chemical phenomena have been captured between 0.6C and 3C rate.

Successfully as well as luckily, NiveauUp team re-structured the conventional Li-ion process and turned it into a manufacturing platform of next generation, by leveraging mostly toolsets now deployed by the mainstream.

Then, we may reasonably anticipate piggyback opportunities on such groundwork. For example, we may target to over drive 4.7V or up [14] as the cut-off voltage, while the industry has been capped by 4.35V for years. Equation (1) can be applied to calculate the potential gain to realize this opportunity. NiveauUp team will acknowledge its first checkpoint by implementing the 4.4V as the cut-off specification well before end of 2019.

Equation (1) - E: Energy Density, R: Resistance, V_2 is the target cut-off voltage; V_1 is the currently capped cut-off voltage. The net gain is 16.7% after applying 4.7 and 4.35 to V_2 & V_1 respectively, to expect additional pack design benefits as the operational voltage approaches 5V.

$$\text{\% of Gain in } \Delta E = (V_2^2/R - V_1^2/R) \; / \; (V_1^2/R) \qquad (1)$$

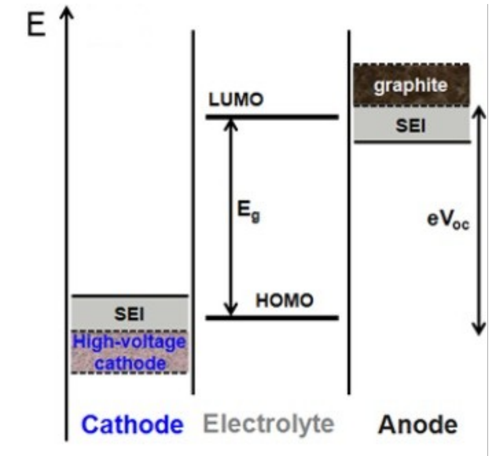
There will be more side opportunities open for grabs and Authors will share what they are, later in this paper.

Approaches which NiveauUp applied, endorsed by (validated) results or rational projections

Battery design has been an industrial puzzle taking decades of collective efforts globally to reach its status quo. Very easily, experts can name typically 8 to 10 dimensional performance objectives, e.g. energy density (volumetric and weight), power density, cost, charging times, cycle life, safety, operating temperature ranges, operating voltage ranges, thermal (heat dissipation), … Etc. to achieve the status quo performance before additional advantages brought by the new technology can be proclaimed as a mainstream breakthrough.

[15] is the one among many papers to examine how the formation of SEI (Solid Electrolyte Interphase) is being set up or what SEI design considerations are required to handle specific process issues to facilitate a stable XFC process. SEI-related contents will repeat themselves many times in this section and sub-section 4.1, and by having this paper to serve as a preface, Authors are skipping the verbiages of the technical details and directing the focus on Figure 2. The crown, for almost all battery engineers to chase, are to widen the energy gap (short for Eg) in between LOMO (short for Lowest Unoccupied Molecular Orbital) and HOMO (short for Highest Unoccupied Molecular Orbital) layering over the electrodes inside a battery.

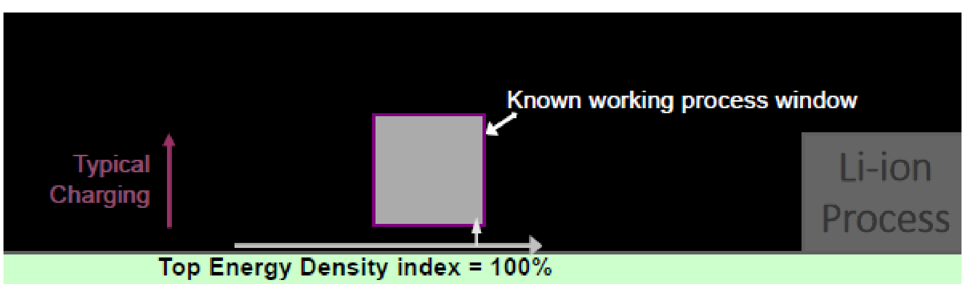
Figure 2: **To widen the stability window maximally by the forming optimal SEI layers on the electrodes** [16]



With that universally agreed definition across the 8 to 10 attributes of “breakthrough”, Authors plotted a general illustration to show two (2) dimensional status quo of concerns in this paper, energy density vs. charging times, as in Figure 3. Readers shall keep in minds that all remaining 6 to 8-dimensional objectives have their respective minimal targets that a battery breakthrough shall perform equal to or better than their conventional counterparts do.

Figure 3 also indicates a stable manufacturing process window which confines conventional battery technology allowed for commercial acceptance within the whole complexity of Li-ion process. That confined process window shifts, i.e. energy density improvement, moves forwards in a single digit percentage year over year during the past decades, and it will continue so in years to come.

Figure 3: **A manufacture-able process window known to the status quo ecosystem within the whole complexity of Li-ion process by highlighting charging rate vs. energy density**



The following sub-sections pinpointed the major design strategies or tactics NiveauUp team applied to produce a commercialization-ready eXtreme Fast Charging (XFC) battery, and what validation have been demonstrated.

Cathode coating

Study [1] lists many computational models, and therefore, many potential cathode coating methods may be considered depending upon what the effects battery designers intended to achieve.

That is easier to say than done, nevertheless. A most recently published paper demonstrated many positive results after practicing the ZrO2 coating on $LiNi_{0.5}Mn_{1.5}O_4$ cathode, except “the electrochemical performances are still partly limited by both interfacial resistances at the beginning of charge and electrolyte diffusivity, particularly under higher rate cycling conditions” [17].

NiveauUp team has controlled interfacial resistances well by the coating methods of choice and is able to set up a process mechanism design to over-drive the operating voltage potential. It will either be disclosed as a patent or remain as a trade secret. In sub-section 4.1, Authors will confer again the possible roles of alternate cathodes’ for the future.

Electrolyte refining

Electrolyte refining process has been proprietary across almost the whole industry; however, EV industry leader, Tesla, did file a patent to target a charging rate up to 2C, just recently [18].

Authors are unable to provide benchmarking analysis. To achieve a low-impedance delithiation acceleration reaction, 10C in NiveauUp’s case, it is an essential objective for XFC process.

Given its significance to construct XFC batteries, this sub-section is written down to keep readers’ attention regardless.

Extremely low thermal uniformity

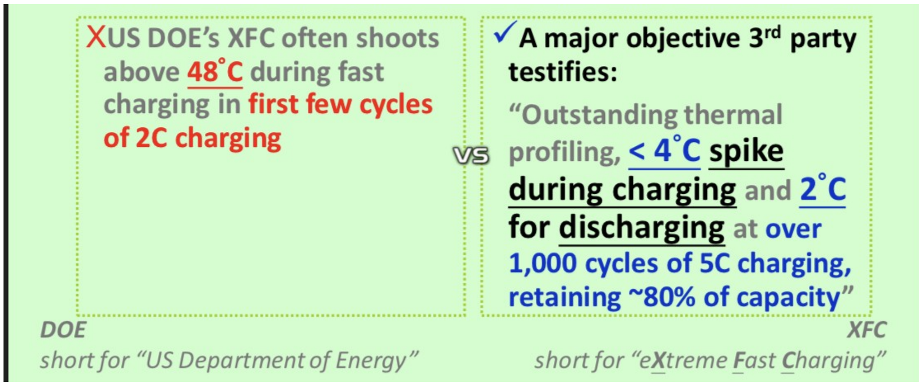
US DOE has long highlighted thermal implication as a major barrier to deploy XFC in their mid of 2017 study. In early cycles, the cell has a peak temperature frequently spiking above 48°C, with large temperature variations across surfaces of cells, thus affecting life and performance [19]. The fast charging condition was 2C rate. Authors summarized the condition on the left of Figure 4.

To be noted, Argonne Lab published every quarter about the progress in improving the temperature rise and other attributes at a half-cell or a coin cell scale [20]. It is however far from feasible to translate the experimental data into what the actual commercialization-ready attributes may turn out to be. In Figure 4, Authors would still apply the data from [19] as the benchmarking reference.

NiveauUp team, still depending upon the off-the-shelf materials, and in order to harmonize technologies mentioned in sub-section 3.1 and 3.2, pre-treated all actors involved in the fast charging reactions to amend the corresponding properties for fitting in the desirable process window depicted by Figure 2.

NiveauUp team managed to assemble samples for a major objective third party who has the XFC testing capabilities. The right of Figure 4 summarizes the testimony. (The test target is a 3Ah cell, or in NiveauUp’s own definition, made by a pre-Generation 0 technology) .

Figure 4: **Thermal Implication between US DOE’s initial study and NiveauUp’s testified results**



Authors would therefore refute another research published after XFC initiatives started. [21] recommended notions of "The optimal temperature for cycle life increases with charge rate & energy density" and "Raising charging temperature is an effective method to eliminating lithium plating", which do not fit in NiveauUp's XFC design architecture, or were not deemed as the critical roots for NiveauUp's XFC implementation.

Cycling life & SoC (State of Charging) profiling of charging/discharging

"The New Mythbusters: Slow Charging May Not Make Batteries Last Longer" was once the news title of Professor Chueh's work [12;22]. Researchers from the University of Illinois at Chicago and Lawrence Berkeley National Laboratory advanced the subject research further [23]. Remarkably, a recent publication [24] has progressed to analyze a key fast charging property - lithium intercalation, at 1C rate. We expect the follow-on research to scale up the scope to pattern 10C rate, and, if possible, to include the interactive effects with the formation of SEI and subsequently other actors in the process reactions. More works need to be done if XFC battery's commercialization is the end objective, to be concise.

In contrast, NiveauUp team took a short cut.

Relying more on try-and-errors and hands-on learned from previous works and side projects, NiveauUp aimed directly to re-construct SEI structure to allow a longer CC (constant current) charging mode switching to CV (constant voltage) to aggregate to a 90% of SOC (status of charging) much faster. The tactic has been switching the constant charging mode to the constant voltage mode by a lagged time stamp (Figure. 4). E.g., Standard charging for the comparable capacity of a cell NiveauUp uses for XFC charging test is likely to switch from CC to CV at 3 minutes, at a typical charging rate, then it has a very long tail in CV mode. In our profile, the switch takes place at a little over 4 minutes, and aggregates the capacity to 90% in a total of about 6 minutes. Our XFC also has a very short CV tail. Figure 5 (a) and (b) illustrate this example.

Figure 4: **Switching constant current (CC) mode charging late and shorten the constant voltage (CV) mode to aggregate mote energy storing during fast charging**

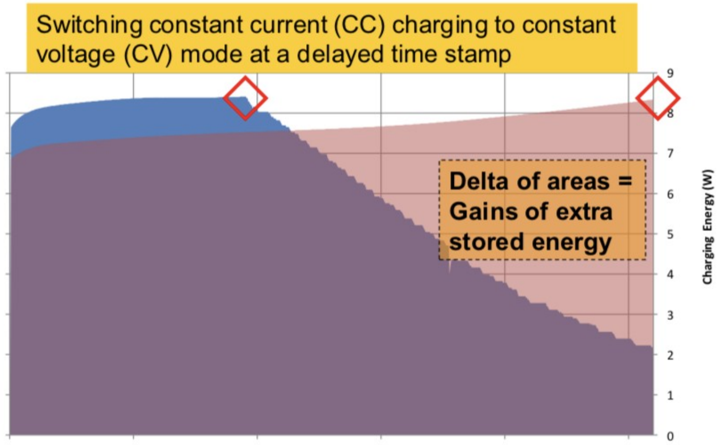
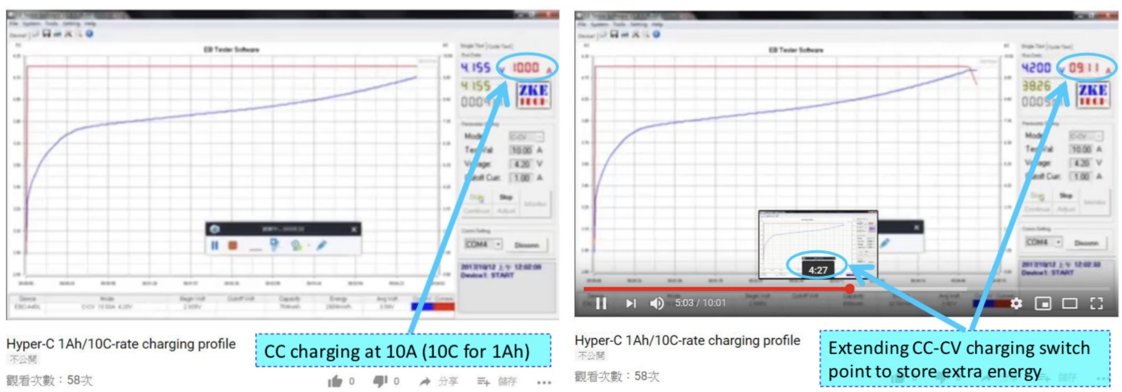


Figure 5 (a)/(b): **(a-left) An ongoing CC mode charging; (b-right) NiveauUp's XFC charging switches it at seconds past 4 minutes for a comparable cell**



With the above, NiveauUp has a two-folded product qualification plans for the cycling life: 1). At least 500 cycles of continuous charging and discharging between SoC (State of Charging) windows of 0 and 90% for any specified charging rates between 30- and 6-minute charging times, and 2). At least 2,000 cycles of the standard charging rate identical to the conventional battery, but the SoC window remains as 0 to 90%, whereas the conventional battery mostly stays between 10 to 80%, and sub-section 3.5 will elaborate how this unique advantage will add benefits to the ecosystem.

For readers to comprehend more easily, NiveauUp selects a less complicated statement, "3 time's longer life" to describe the subject attribute.

Finally and above everything else, what the profile indicated is something to defy the common sense as XFC can not only feasibly have a later CC-CV switching timestamp than the standard charging, but echo the opening remarks of this sub-section "The New Mythbusters: Slow Charging May Not Make Batteries Last Longer".

Bonus ranges up for grabs now

Unlike NiveauUp, a couple of other battery actors seek to embed silicon into the graphite anodes, or design a novel anode compound, to boost the energy density together with faster charging capabilities.

Authors created Table 2: What XFC may gain in terms of a 5-min charging, to offer an objective comparison by taking into accounts technology maturity and performance expectation, then normalized today's 5-min charging as the base (line 1), the total range of a 200-mile range EV will get about 220 miles for a 5-min charge. NiveauUp's XFC battery will get more than 310 miles (line 2) – NiveauUp's wider SOC window being explained in the above sub-section. Ideally & theoretically to achieve its optimum, in another two years from now, XFC with silicon-enriched anodes will get up to 385 miles (line 3), based upon sources of information from their respective recent updated online claims.

Table 2: **What XFC may gain in terms of a 5-min charging**

Anode -a	**Extra range**	**Base Range (in Miles)**	**SoC window -d**	**5-min Charging gives**	**Availability**
Gr	0	200, conventional batteries	10~80%	~20 miles	Yes
Gr	0	180, NiveauUp XFC -b	0~90%	>130 miles	Yes
Si/Gr	40 miles [25]	220, w/ Si-enhanced anodes –c	up to 75% [26]	up to 165 miles	Pre-EV trial -e

Remarks:

a. "Gr" stands for graphite, "Si/Gr" stands for the mix of silicon & graphite.

b. 10% energy density trade-off

c. Assume 5% of energy density trade-off, then add the extra range boosted by silicon-enhanced anodes.

d. This sets a range of SoC charging window allowing the charging source to inject.

e. "in lab development based upon the upcoming validation for the consumer application"

Authors have gracefully declared a commercialization-ready sampling for mobile/consumer devices' validation as the "pre-EV trial", and therefore the conditions apply to two of NiveauUp's peers as follows.

StoreDot de-committed the launch schedule to be only able to start its first sales of the flash batteries for mobile devices in 2019 [27].

Enevate admitted that Electric vehicles (EVs) have some of the most stringent battery requirements of any application: extreme temperatures, …, fast charging, and most of all, high energy density by both weight and volume. Batteries with Enevate's HD-Energy® technology are "currently under development in the lab" [28].

Authors exclude industrialization–ready batteries enhanced by a new "titanium niobium oxide" anode from Toshiba, for their volumetric energy density of 350 Wh/L [29] to be launched in 2019 will address a niche application segment rather than the mainstream.

Authors also exclude Samsung [30]. It is still far from feasible to translate the presented test data into what the actual commercialization-ready attributes may turn out to be, for the same reason as described in sub-section 1.3 for Argonne Lab's reporting data.

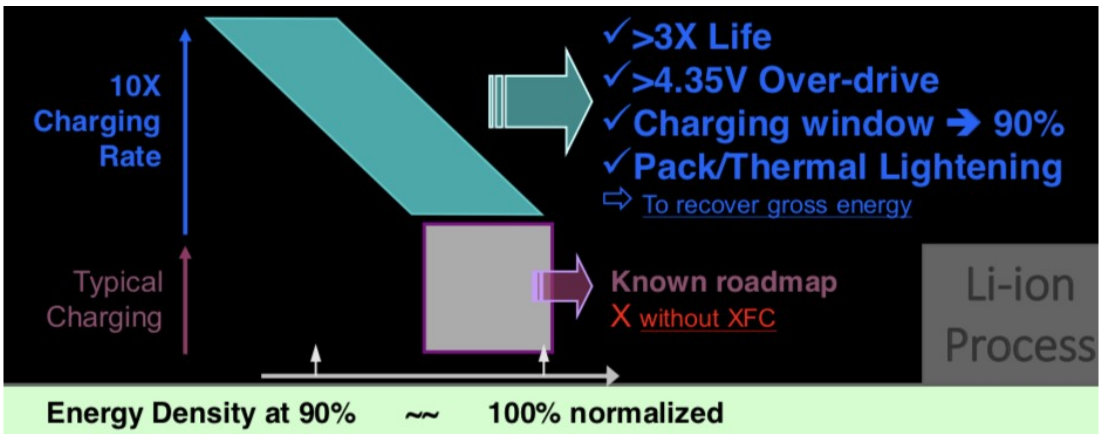
In sub-section 4.1, Authors will pinpoint other alternates than silicon-enhanced anodes for the sake of enhancing the energy density.

Level-up of a new Li-ion process window

In this sub-section, Authors provide an overview of what NiveauUp team's efforts contribute - achieving to construct a manufacture-able process window in the whole complexity of Li-ion process NiveaUp team has optimized the battery performance in a variant combination of attributes to defy what the industry peers may intuitively and collectively presume otherwise. See Figure 6.

In NiveauUp's XFC implementation, about a 10% range of energy density at cell levels has been traded-off to gain as high as 10C rate (6-minute charging), longer cycling life, higher operating voltage, wider SoC charging windows, and thermal optimization to lighten pack weights, all of which would contribute to recover the gross systems energy density, and probably with surplus.

Figure 6: **A new manufacture-able process window in the Li-ion process complexes not only realize XFC but also offer unique advantages in other performance attributes**



XFC era around the corner

Authors are calling for a thought-shift to adjust the electrification infrastructure in order to accommodate the earlier than expected arrival of XFC, since "battery", for the first time in its history, will not become EV ecosystem's bottleneck. ICEV'S infrastructure relies solely on gas refuelling networks; we can optimally mix and match the depot charging as the base, which the ICEV infrastructure can't counter, aided by XFC to serve "opportunity" and "long-haul" charging, thus lifting EV owners from their present constraints in the foreseeable future.

An XFC fork on the industry roadmap

Analysis [31] pointed the conditions that the graphite anode is the rate-limiting electrode for fast charging in NMC811/Graphite pouch cells. The effective N/P ratio falls below 1.0 at high charging rates, which also causes lithium plating. While NiveauUp team is studying if there are tactical implementations to resort to, we'd, however, develop an alternate path to keep the energy density incremented without losing XFC capabilities.

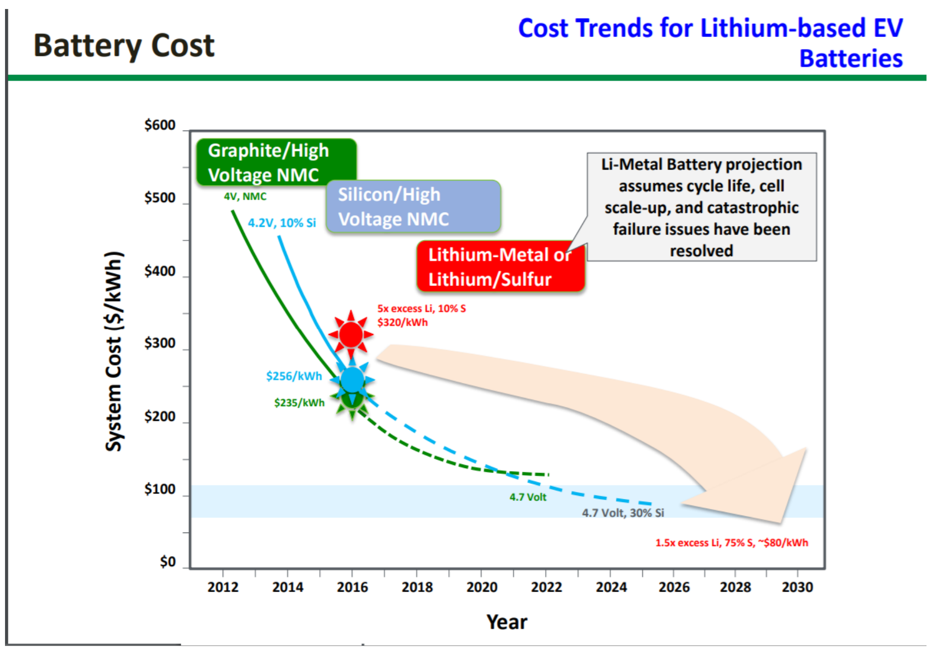
NiveauUp's XFC process achieves highly stable graphite-electrolyte interface to profile fast charging. Research [32] suggested examples of potential candidates with higher operating voltages are the spinel $LiNi_{0.5}Mn_{1.5}O_4$ (∼4.7V), olivine $LiCoPO_4$ (∼4.8V), and layered $LiNi_{1-y-z}Mn_yCo_zO_2$ to reversibly extract/insert more lithium.

Also pointed by the above research – "Although the cathode–electrolyte interface is presently not stable above∼4.3V as the cathode REDOX energy lies below the HOMO (short for Highest Unoccupied Molecular Orbital), as depicted in Figure 2, of the electrolyte, it could potentially be circumvented by forming an optimum SEI on the cathode surface and thereby raising it above the HOMO of the electrolyte". Our team has overcome the challenge that any efforts made to make the cathode–electrolyte interface operable at higher voltages through electrolyte composition and/or additives should be compatible with the graphite anode [14;32]. Across the industry, the present optimal upper operating voltage caps at 4.35V. Our XFC process has stabilized at 4.35V, and observed no issues in qualifying 4.4V. From the industrialization point of view, the next challenge will be 4.45V and we will not expect the off-the-shelf supplies might suffice. Raising the cut-off from 4.35V to 4.5V, though, will only gain 7% for the cell level density; however, getting the operating voltages by another . 15V closer to 5V, the system designers may take the benefit on the pack and system sides.

Forward looking, NiveauUp would consider cathode alternates besides NMC/622, while NMC/622 with XFC merits (over-drive operating voltages and a charging SoC window of 90%) can well challenge the NMC/811, which will not support XFC. We may take the above hypothesis, but a practical one, into the industry roadmap discussion.

Before the XFC initiatives kicked off, Vehicle Technologies Office (VTO) of US DOE published an industry roadmap by factoring the cost learning and projected technology progress into Figure 7. [33]

Figure 7: **Cost Trends for Lithium-based EV Batteries (a direct copy from VTO, US DOE)**

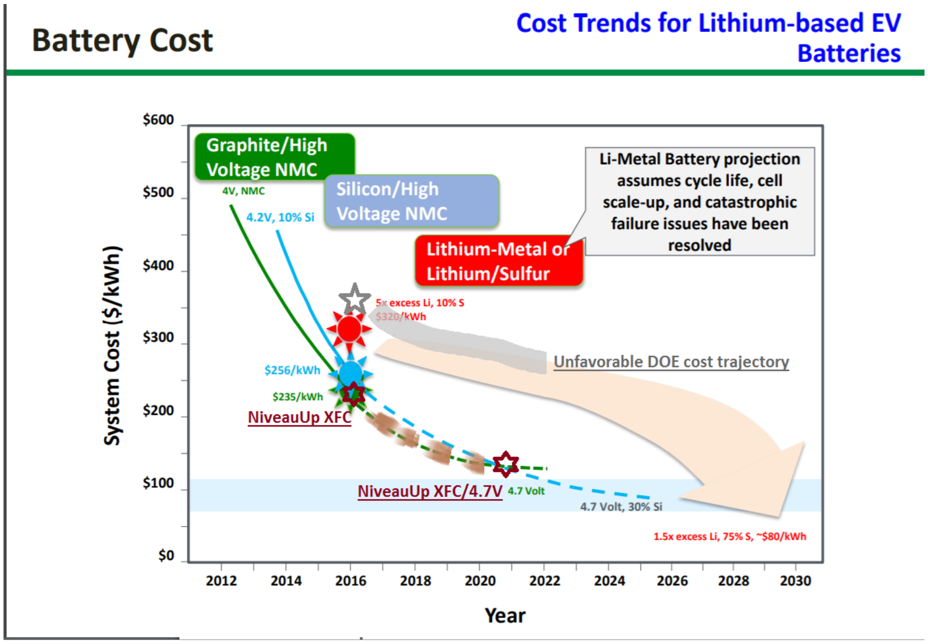


By plugging in what XFC, based upon what NiveauUp delivered and what US DOE's initial study suggested, we concluded the Figure 8.   .

As mentioned in sub-section 1.3, US DOE suggested an XFC cell would start to cost at more than 2.2 times of a standard conventional cell, which is marked as the grey star. Assume its future development has a projected parallel trajectory like other technologies (the grey curve), there will never be a favourable cost trend ready for consumers' adoption by 2028.

As summarized sub-section by sub-section in section 3, NiveauUp's XFC battery costs would be roughly in line with the conventional cells' at the systems level, which Authors inked the curve and pointers in purple in Figure 8. In contrast, the latter (conventional battery) will not support EV with XFC capabilities.

Figure 8: **Overlaying the hypothetical trajectory of DOE's XFC and validated data of NiveauUp's XFC (and extended by the above hypothesis) on Figure 7**



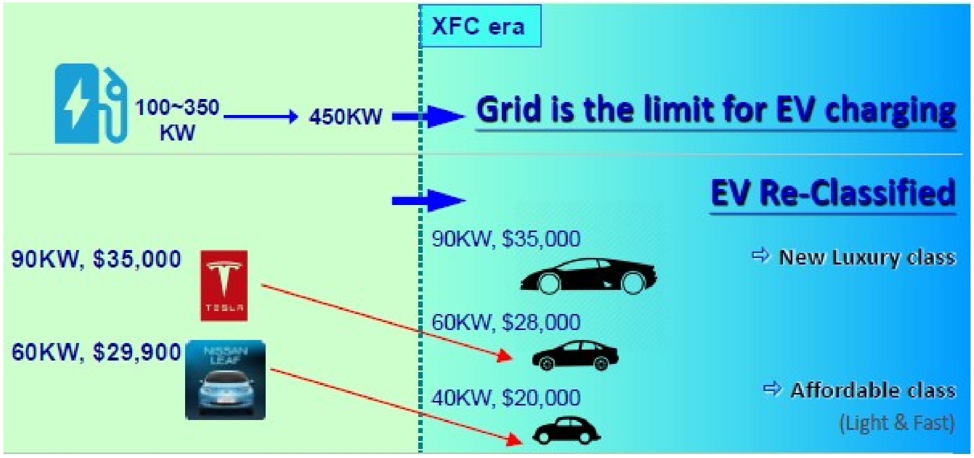
At present, NiveauUp's XFC battery is able to jump above what capped the conventional cells' operating voltages at 4.35V, which shows a potential to gain 7% on energy density upon reaching 4.5V according to Equation (1). The closer of the operating voltages to 5V, the more designers may take additional cost and performance advantages at the system level.

EVs' re-classification (and re-pricing)

With what the alternative industry roadmap suggested NiveauUp believes we may re-classify EVs according to various battery contents and built in with XFC. Almost no EV use cases will depart for their next journey with a low charging level. EVs' mile ranges do not need to couple exactly with their ICEVs' equivalent classification, since ICEV may from time to time depart with their fuel tanks close to empty. So again, please contemplate, an XFC-supported EV may mingle charging modalities of the depot, opportunity, and long haul, with the aid of modernized navigation technology to optimize their electrification consumption and the end-to-end charging cost.

The bottom half of Figure 9 shows the concept of base model prices to pair with their respective re-classification once EVs have built-in XFC batteries.

Figure 9: **XFC's impacts to charging infrastructure and EVs' classification**



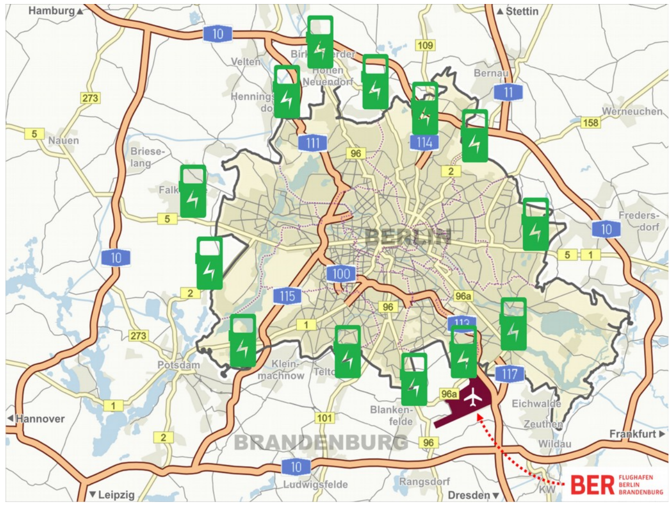
Economics of electrification charging

Typical charging service complexes either relied on in the electrical grid, referred to as the BAU or business-as-usual case, or had onsite solar photovoltaic (PV) generation and/or energy storage. Study [34] found systems that were BAU had better financial performance than systems with onsite solar photovoltaic (PV) generation and/or energy storage, due to the higher capital costs that could not be fully recovered.

XFC-supported EV may promote a use scenario, as shown on the upper half of Figure 9, to upgrade today's highest 450KW powered charging stations to a level that the electrical grid is the limit. Charging service providers' can leverage such a future scenario to collect upside profitability.

Furthermore, coupled with the provisioning of the "opportunity charging" modality for XFC-supported EV, which can contribute a sufficient range by charging in the minutes-timeframe as elaborated in sub-section 1.2.3, city planners and charging service providers together may consider installing such grid-level capable charging stations or facilities in the main roads entering or exiting the cities. It will be a paradigm shift to offload the tedious and costly construction works within the limited city space and upgrade the whole metropolitan's EV charging infrastructure. Figure 10 chooses Berlin road plan as an example to locate the grid-level charging facilities.

Fig 10: **Berlin road plan as a hypothetical reference in setting up grid-level charging facilities to offload city's tasks in deploying the electrification infrastructure**



Side notes: Is there a Role Model for Battery Startups?

The battery is an industry overwhelmed by Elon Musk outrageous comments: “When somebody has like some great claim that they've got this awesome battery, you know what, send us a sample. Or if you don't trust us, send it to an independent lab, where the parameters can be verified. Otherwise, STF. [35]” By achieving XFC’s commercialization-ready status, Authors would try to contribute some lessons learned, a little more than insignificantly, about how NiveauUp team excluded us from the “Otherwise”.

When Authors tried googling “Research Innovation Lean Startup”, [36] popped up on the top of the search. Then we read it, and found it hard to describe NiveauUp’s situations. MVP (minimum viable product) is a partial but unlikely essential among various Innovation Acceleration Models the paper suggested. But Eric Ries, author of The Lean Startup said “DEVELOP AN MVP” is a core component of Lean Startup methodology [37].

It is more of a self-reflection of NiveauUp’s own experiences. Authors would further emphasize, first, “trying to take a good catch of the MVP” might just be the most critical among everything else and, second, the battery development, or ventures of the Deep Tech [38] nature, shall set much more stringent rules for preserve and pivot, than the non-Deep Tech ones.

MVP for battery technology development

Please do not just interpret MVP (minimum viable product) literally. In the battery development, “minimum viable “proven process” might just well be a better definition in the “context” of the technology nature - minimum viable process missions itself to close gaps between laboratory and manufacturing scale-up. This is why Authors stated previously that “trying to take a good catch of the MVP” might just be the most critical.

What has been mentioned in section 3 ended to set up a platform to initially deploy mostly off-the-shelf materials for various MVP battery makings. Such an MVP (minimum viable proven process) approach worked during NiveauUp team’s two-plus years of product prototyping. Limiting the process variables helped determine and cure the process’ intrinsic failure mechanisms, or a jargon called potential Failure Mode and Effects Analysis (pFMEA) these days, in the early stage of NiveauUp’s XFC technology development.

Many of NiveauUp's peer and preceding startups fell in the traps of being unable to do the same, i.e. discover and cure pFEMA early enough, which would eventually disturb the manufacturing's scaling-up, to cost/cause themselves long delays or fails. If debugging is unavoidable, do it early rather than late.

NiveauUp's sequence of technology development might be a reverse of the majority of the battery startups by starting small – trying to aim (take a good catch of) MVP as accurately as we can, yet its result should also deserve its fair shares of recognition.

Science (Research) is the daughter of technology [39]

(Inspired by Matt Ridley's writing, Authors mimicked titles of sub-section 5.2 and 5.3, and a partial portion of contents, from the book.) [40]

> *"Technology comes from technology far more often than from science. And science comes from technology too. Of course, science may from time to time return the favour to technology."*

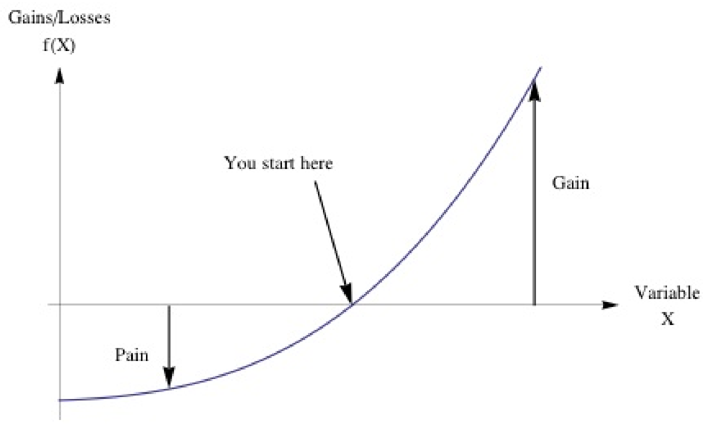
When in a commercialization stage, Authors would argue the "science" quoted in the above statement can be fairly substituted by "research". Authors would also agree what Nassim Taleb has insisted - the story of technology is a story of rules of thumbs, learning by apprenticeship, chance discoveries, trial and error, tinkering [41]. In NiveauUp's case, our team has been practiced all of the above on their jobs or from side projects throughout the years, with a probable exception for the "chance discoveries". Stanford University, on the academic side, and NiveauUp team, on the commercialization side, leverage the physical as well as chemical characteristics of "fast charging improves uniformity" to stride forwards in parallel.

To this point, allow Authors to offer two philosophical, but also scientific, angles of contemplating the development journey of NiveauUp's technology.

1). "Things Are Better Than We Think": adding some flavours to the chance discovery, I'd like to quote from the popular book title "Factfulness: Ten Reasons We're Wrong About the World – and Why Things Are Better Than You Think" [42]. It certainly defies people's consensus, and what puzzled the industry for decades, the fact that we may manoeuvre to get the high rate electrical charging by facilitating REDOX (reduction-oxidation reaction) process and its interactions with interfaces.

2). "**ASYMMETRY (of large gains vs. small loss)"** [43]: Here is one of Nassim Nicholas Taleb's conversations about antifragility. Allow Authors to make an analogy and declare that NiveauUp team captures an asymmetry between gains (they need to be large) and errors (small or harmless – trading off a small cell level energy density with the net loss to be compensated at the gross system level, in NiveauUp's XFC case). Figure 6 illustrated those respective gains – cycle life, operating voltages, thermal advantages, and higher charging SoC limitation. It is from such asymmetry that luck and trial and errors (and chance discoveries) produce results collectively. Figure 11 re-depicts Mr. Taleb's ASYMMETRY concept.

Figure 11: **The driver is the asymmetry (or convexity) of payoffs - the payoff is a function of gains and errors, and not in the "luck" part**



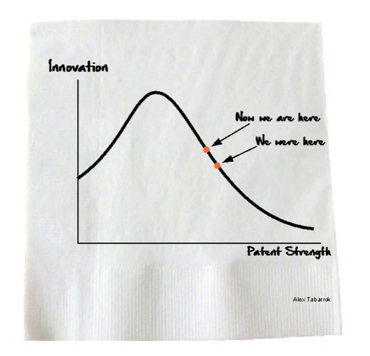
From “Patent scepticism” to “Right-sizing the patent portfolio” based on probabilities of realization

Many firms use patents as barriers to entry, suing upstart innovators who trespass on their intellectual property. In the battery industry, many battery startups responded to this barrier on two fronts - to differentiate their technology from the incumbents’ as well as creating barriers to entry for the startups to emerge after them. It easily becomes an arms’ race in creating the “patent thicknets”, while the process of product realization as complex as the battery might not earn its deserved resources.

NiveauUp team is against the notion of creating a "patent thicket" to be a battery startup’s priority. We believe what we did demonstrated a balance act

Alex Tabarrok drew a convex, curved graph to illustrate and point that a little intellectual property is better than none, but a lot is a bad thing (see Figure 12, [44]). NiveauUp, as our trade-secret backed product development progressed to be commercialization-ready proven, shall start filing the patents to strengthen our intellectual property portfolio, being a for-profit business entity. In NiveauUp case, as mentioned previously in this paper, early debugging of process’ intrinsic failure mechanism set up the manufacturing process baseline. This baseline process can serve as the technology platform to back future advance development, e.g. we are now migrating from XFC Generation 0 (MVP) to Generation 1, and we may enhance the patent portfolio for either defensive or offensive purposes based on the successful odds of product realization as our team’s development evolves.

Figure 12: **Tabarrok's curve - a little intellectual property is better than none, but a lot is a bad thing**



Learning from the past three years of XFC battery development, self-examined by the above thought processes, NiveauUp will carry on by avoiding repeating mistakes a rather high number of predecessors made in the battery development history [45].

Conclusions

Onwards with NiveauUp's journey beyond the technology's commercialization-ready stage, Authors look forward to stakeholders of the EV and eVTOL ecosystems to embrace the earlier-than-expected arrival of eXtreme Fast Charging (XFC) batteries. XFC is a complicated technology but its realization might prove to be easier than presumed among all non-conventional, or advanced technology choices, which people are discussing enthusiastically, a testimony that NiveauUp's 3-year journey is here to make.

Therefore, we wish the message of "eXtreme Fast Charging (XFC) era can arrive earlier than most people think" could entice the technical community's broad echoing after reviewing this publication.

Acknowledgment

Authors are most grateful to the two most influential EV stakeholders of the global standing. For a span of over 12 months, they assisted NiveauUp team to validate our samples' capabilities, and as such, I am able to generate contents for this paper.

Notes

NiveauUp has been a self-funded for-profit entity. We did not receive any public grants. Authors would therefore appreciate the readers to accept that benchmarking against validated data together with how NiveauUp chooses to refute or endorse what other XFC papers said may provide sufficient guides for the community, if not complete, to implement XFC, though what those papers suggested may produce the XFC battery on their own paths in the future.

Authors, therefore, shared test data but no laboratory data.

NiveauUp's XFC development, so far, accumulates a count of 20+ trade secrets, and we are planning to apply four (4) patents to cover two generations of ongoing technology development.

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	BJ Perng, Founder and CEO of NiveauUp Inc., is a serial entrepreneur who involved in several internet startups based in Taiwan. Taking with him the lean startup practice, he founded NiveauUp Inc. and launched several battery MVPs (minimum viable products), the first of its kind in the battery development history. It might prove to be the first commercialization-ready, as well as affordable, eXtreme Fast Charging (XFC) battery, well ahead of what industry consensus would presume in time-to-market. Mr. Perng holds a Master of Engineering from Cornell University, majoring in Electrical Engineering with a minor in manufacturing engineering.
	Alex Fang, Technical-side Founder. He leads a stealth team made up by talents of a mix of overlapped and distinct core skills, for a gross of 50+ years. Alex designs the overall MVP (minimum viable proven process). "Hacking" together with the associates to develop chemical recipes have been things they do for a living, as well as fun. These "side" projects, as well as their own deep experiences accumulated over the years have now collectively given birth to the "commercialization-ready" eXtreme Fast Charging (XFC) batteries ahead of all others. Mr. Fang holds a BS, Chemical Engineering, from National Taiwan University of Technology and Sciences.