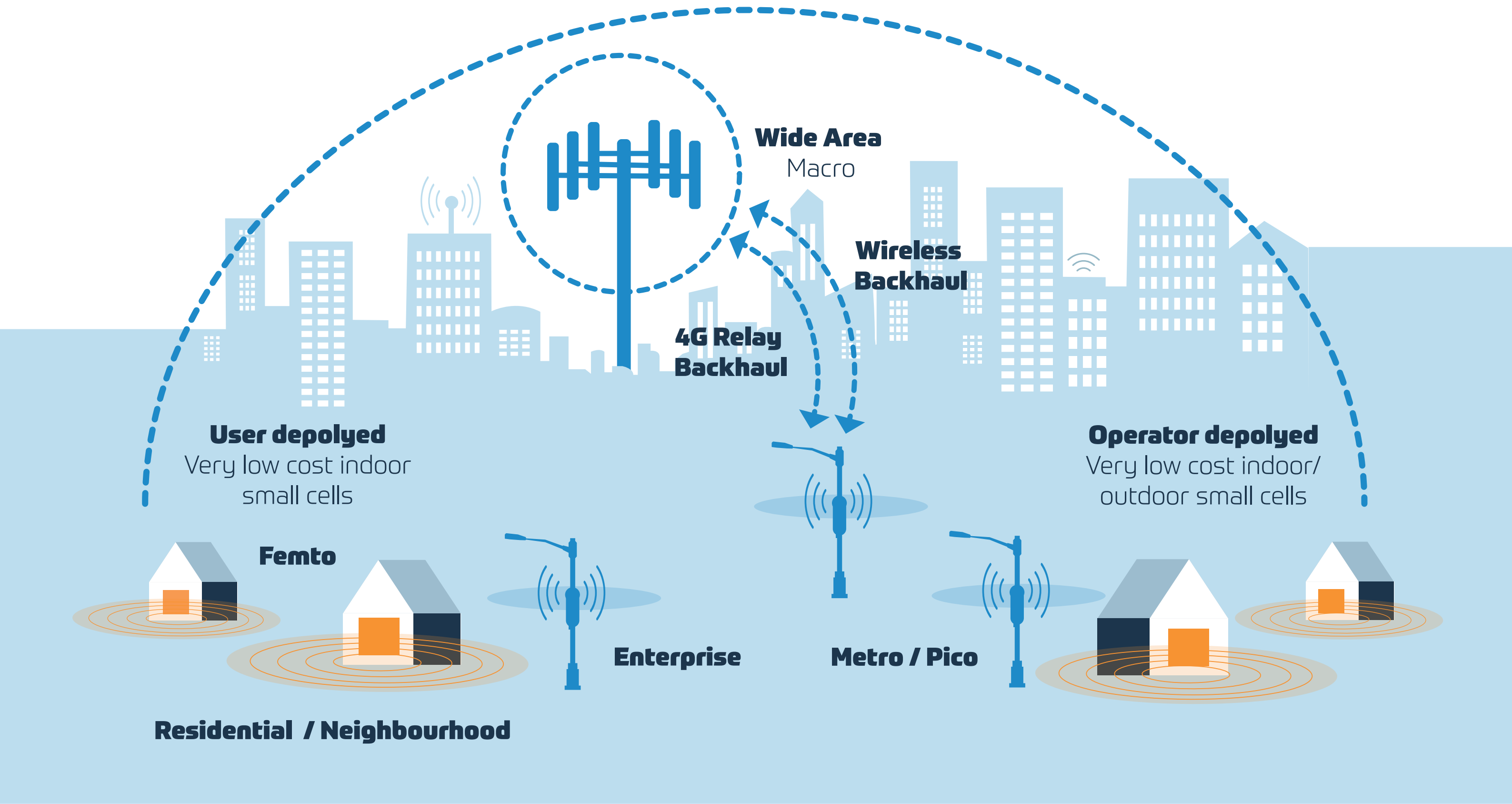
Powering **5G Small Cell** in Smart City Context

White Paper



L7 DRIVE

Electric Drive Made Simple

LuxTurrim 5G

Electric Drive Made Simple

0. Abstract

L7 Drive Ltd. from Finland has been pioneering an intelligent power backup solution design in an ecosystem project, developing and demonstrating a fast 5G network based on smart light poles with integrated antennas, 5G base stations, sensors, screens and other devices. This joint project opens up new digital services and business opportunities for a real smart city.

Key Challenges:

Smart cities require a digital service infrastructure to improve safety, energy efficiency, air quality, transportation efficiency and quality of living. However, the capacity of present mobile networks will be far too insufficient due to the increased number of users and new digital services built and planned.

The problem can only be solved by using small cell 5G radio frequency technology and higher frequencies. This requires a dense network of antennas, setting new requirements for the network infrastructure and the blending of network infra with city infra.

New requirements include an intelligent power backup approach, as 5G network slicing and latency sensitive applications and modern IoT use cases will need to comply with the power backup regulations from 1 to 3 hours, depending on the application mix. In developing regions, backup times up to 6 hours are required.

This white paper elaborates the power solution design and requirement framework from a number of different perspectives that L7 Drive Ltd. has learned to be relevant in the intelligent power backup domain.

1. Megatrends and New Requirements for Powering 5G Small Cells in a Smart City Infrastructure

5G Small Cell deployment may be a few years away, yet it is already proving to be a major disrupter of the status quo. In preparing their networks to handle the massive demands for more bandwidth, new applications, lower latency and ubiquitous coverage, Mobile Network Operators (MNO) have begun the process of cell densification in their existing 4G networks. The result is a significant increase in the number of small cells being installed already at present.

The current efforts however represent a small percentage of the millions of new small cells that will be needed to deliver the much-anticipated promises of 5G and its most prominent use cases: Smart City, autonomous vehicles, robots, remote surgery etc.. As small cell deployment continues to increase, MNOs are facing a host of fundamental challenges, including how to deliver power and power backup to each individual node without breaks.

Between 2019 and 2025, new non-residential small cell deployments are expected to grow at a compound annual rate of 36%, to reach almost 13 million 5G nanocell base stations installed by 2024 in addition to current 3G and 4G small cells. A recent survey indicated that 40% of operators are expected to deploy between 100 and 350 small cells per square kilometer (indoors and outdoors) in the areas they densify. While estimates regarding the degree of small cell density vary, the consensus is that MNOs will require more than 10 small cells per current macro cell in urban areas to densify their networks in the next evolutionary phase.

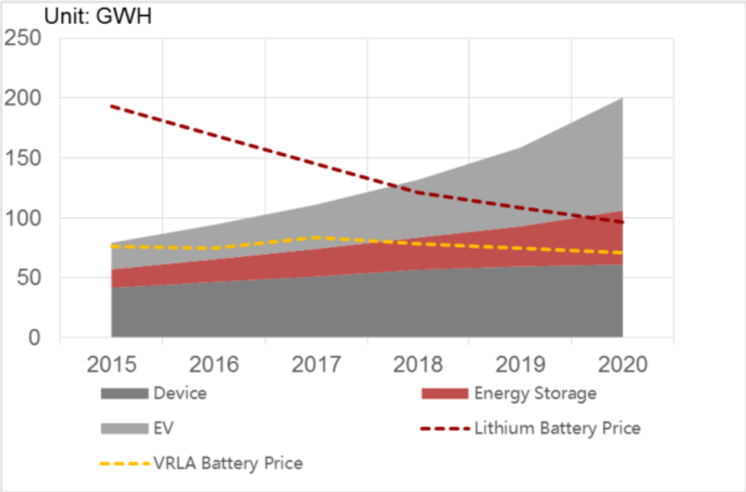
As the need for ubiquitous, high-density coverage increases, small cells must move closer to subscribers (humans or things) in order to support new higher-frequency wireless services and stricter signal quality requirements. This will involve locations that are more discreet and compact, such as lamp posts, utility poles and street furniture including signs.

The advanced capabilities of 5G small cells mean additional power requirements. Increased data traffic requires more computational power. Although massive Multiple Input Multiple Output (MIMO) can help to improve spectral efficiency, power efficiency is generally lower and as a consequence, a typical 5G small cell requires approximately 300 watts of power as is the industry consensus today. The challenge is how to get power to a large number of small cells in a cost-effective and repeatable way that supports fast, efficient rollouts and 100% uptime. In the 5G era, the requirements for service continuity, reliability of the power supplies and backup power for small sites are increasing. Given the criticality of 5G availability, the regulatory framework in developed urban metropolises requires 15 to 360 minutes of backup power per small cell site. In developing regions with diesel powered power generation, the backup power requirement is up to 600 minutes.

In parallel with 5G introduction, the battery industry is gradually migrating to lithium based chemistries due to a number of motivational drivers:

1.1 Replacement of Lead with Lithium

Lithium-ion (Li-ion) batteries have been developing for about two decades. With the rapid application of electric vehicles, especially in recent years, the cost of Li-ion batteries has dropped rapidly. The capital expenditure (CAPEX) is expected to be the same as that of lead-acid batteries by 2021. Li-ion batteries, with their long cycle life, high discharge rate, small size and low weight, become the best choice to replace lead-acid batteries in the telecom energy sector.



Data source: CBIA, CAAM, Huawei Search

1.2 Evolution from Traditional Passive Lead-acid Batteries to Intelligent Lithium-ion Batteries

The AI algorithm and advanced power and electronic conversion technology evolution have created intelligent Li-ion battery systems, featuring real-time monitoring of the state of charge (SOC) and state of health (SOH), current equalisation in parallel connection, dynamic voltage boosting, application security in high/low temperature scenarios, and an intelligent anti-theft function.

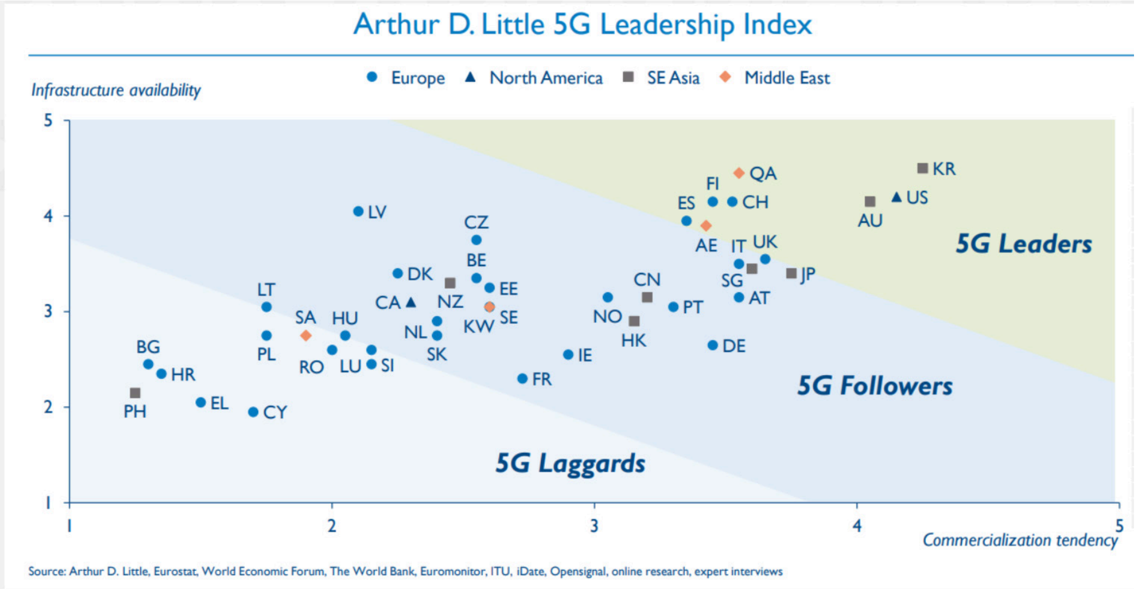
1.3 Battery Application from Power Backup to Power Backup and Grid Optimiser

When intelligent Li-ion batteries perform 5G small cell power backup as their primary task, they can, as their secondary task, optimise load peaks, price peaks and frequency harmonisation in main grid without jeopardising their primary task.

With its excellent cycle and rate performance, intelligent Li-ion batteries can provide major benefits for energy operators. These include intelligent peak clipping, reduced customer electricity fees through off-peak power consumption and implementation of a refined configuration to cope with short-term power backup at high discharge rate.

Advanced energy operators with Intelligent Active Li-ion Power Banks installed across 5G and Smart City infrastructure nodes see an increasing opportunity to provide Energy as a Service to MNOs. In this value proposition, the MNO is partnering with an energy operator so that the energy operator is the owner of the power backup resources and offers the power for the infrastructure as a fail safe service. Additionally the energy operator can, at its own expense, configure the battery backup capacity to override its primary task in order to serve its secondary task for peak clipping and grid optimisation.

Regionally the 5G rollouts are forecasted to take place as follows:



South Korea, US, Australia, Qatar, UAE, UK, Switzerland and Finland are the early adopters and trailblazers for other regions that will adopt the technology later.

The installed base of small cells is forecasted to evolve as shown in the following key findings related to market dynamics:

- The installed base of small cells to reach **70.2m in 2025**.
- Densification initially led by APAC and North America, with Europe lagging as it works to address commercial, technical and regulatory barriers.
- Massive annual growth **(36%)** in the rate of new non-residential deployments of small cells, led by urban and enterprise small cells.
- 5G cell deployments overtaking 4G by 2024. The total installed base of 5G or multimode small cells in 2025 is predicted to be **13.1m**, over one-third of the total in use.
- A stronger emphasis on virtualisation, notably for 5G and multimode 4G/5G small cells. Virtualized systems will grow at a CAGR of **52% to reach 57%** of the total in 2025.

- The vast majority of new deployments expected to be in dense or hyperdense environments by 2025.
- Strong support from operators for the deployment of 5G small cells as their **5G capacity layer where LTE remains the coverage layer.**

2. New Business Opportunities and Use Cases for Smart City Ecosystems

As stated above, due to the increased demand for ubiquitous, high-density coverage, small cells must move closer to subscribers (humans or things) in order to support new higher-frequency wireless services and stricter signal quality requirements. This will involve locations that are more discreet and compact, such as lamp posts, utility poles and street furniture including signs.

Since late 2018, L7 Drive has contributed to Nokia driven Smart City experimental ecosystem called LuxTurrim5G+. LuxTurrim5G+ is a Nokia Bell Labs driven ecosystem project, developing and demonstrating fast 5G network based on smart light poles with integrated antennas, base stations, sensors, screens and other devices. This joint project opens up new digital services and business opportunities for a real smart city.

Key Challenges:

Smart cities require a digital service infrastructure to improve safety, energy efficiency, air quality, effectivity of transportation efficiency and quality of living.

However, the capacity of present mobile networks will be rather inadequate due to the increased number of users and new digital services built and planned.

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Project Goals and Results:

The project objectives are: To develop and pilot key technical solutions and a concept for smart light pole based 5G infrastructure together with business and service innovations; to create an open access ecosystem for digital services; and and to pilot services on navigation, information sharing, advertisement, weather monitoring and smart lighting.

Key Project Characteristics:

Highly multi-disciplinary joint R&D project developing composite and antenna materials, smart light pole design, miniaturised 5G base stations and integrated sensors.

The project creates novel digital services, business models and ecosystem. Within the framework of Smart City Poles, the most interesting and novel use cases with significant business opportunities in the long run from L7 Drive's perspective are **Operations & Maintenance , Intelligent Battery Backup, Grid optimisation, Peak clipping and cost optimisation of the grid improvements.**

2.1 Operations & Maintenance of a Smart City Pole

On a closer analysis of the Smart City Lighting Pole design, the first conclusion is that it converts from a simple metal pole construct with a lamp to a IoT system: smart light poles with integrated antennas, base stations, sensors, screens and other devices constitutes a loosely coupled IoT system with tens of subsystems. The first question for runtime governance is the question of Operations & Maintenance (O&M). O&M involves the functions, duties and labour associated with the daily operations and normal repairs, replacement of parts and structural components of the Smart City Pole. It also includes other activities that are required to preserve the Smart City Pole so that it continues to provide acceptable services and achieves its expected life.

There are two alternatives for the O&M approach:

1. Each IoT subsystem in the pole has its own O&M, or
2. The pole O&M control is a shared functionality and service of the pole, that each IoT subsystem is using as a O&M service and common interface between the pole and the internet.

In the LuxTurrim5G+ experiment the hypothesis is that only one O&M control is the right thesis to be investigated in field tests during 2020. Instead of each of the 10+ subsystems with their own silo O&M, the governance of one pole and network of thousands of poles, in terms of efficiency, is optimised if only one point of O&M control is provided and the pole controller is preinstalled to each pole prior to commissioning. The detailed pole controller design is discussed later in this document in chapter 3.

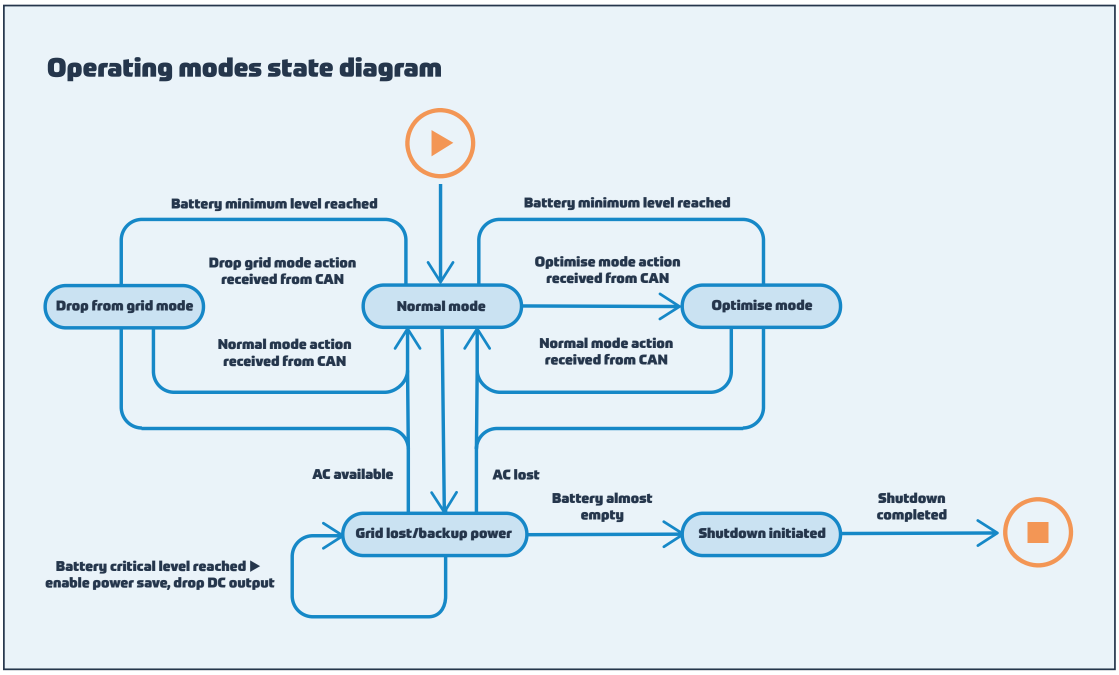
2.2 The Intelligent Battery Backup of a Smart City Pole

The regulatory framework around small cell radios requires spare power to be available for a duration of 15 to 360 minutes to cover power outages sufficiently. In earlier multilayer 3G/4G networks, the typical approach was to use macro layer with large lead-acid batteries during a power outage and shut down the small cell layer. This approach allowed only voice minutes and SMS messages to be available, as the packet data traffic had to be limited and deprioritized. In case of 5G and streaming data with low latencies, as in real time steering of traffic, vehicles and security systems (video surveillance, public audio), small cell layer has to have its own power backup solution to satisfy the following:

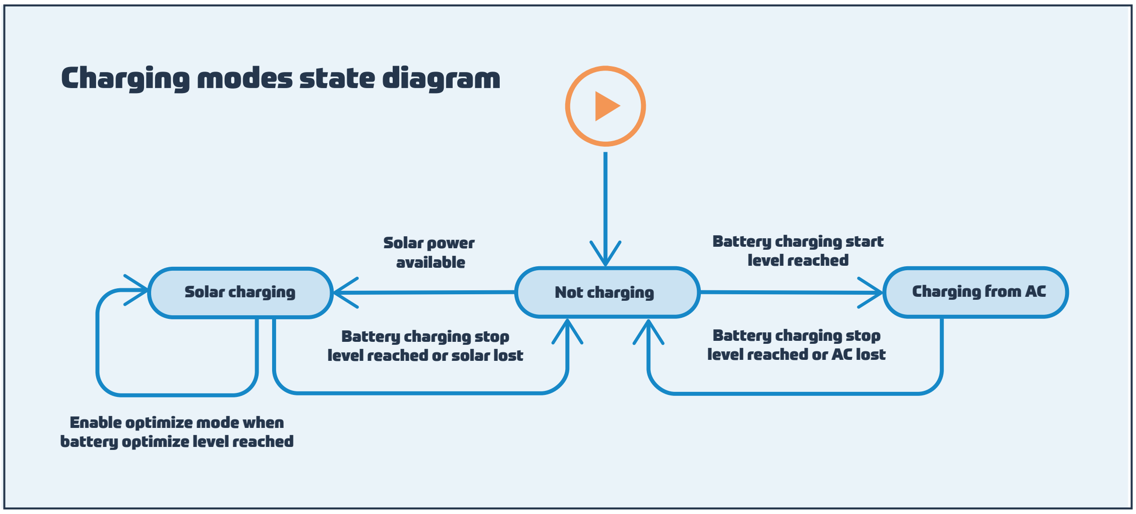
- the regulatory standards, and
- the standards of availability set by the Smart City service providers.

Lighting, screens, loudspeakers, cameras, radars, pole controllers all need to have their specific safe mode operation during abnormalities and blackouts of the grid. Safe mode regulations are currently being formulated, but the general consensus opinion is that a minimum of 15 minutes has to be secured during safe mode.

For the Smart City Pole trials, L7 Drive initially, and later Neutral Host Operator, will broadcast commands to change the pole's operating status per pole, or per group of poles, along the following Intelligent Battery Backup use cases:



In case of renewable energy (solar) sources the use case is as follows:



2.3 Grid Optimisation and Peak Clipping with Smart City Pole Energy Storages

Grid optimisation and peak clipping scheme is a novel manifestation of Energy as a Service, in the context of a large cumulation of Smart City Poles. The energy utility operators can utilise thousands of small intelligent lithium-ion battery storages as the source of elasticity and spare capacity in a number of optimisation use cases. It suits well to 5G infrastructure, where a novel concept of slicing is deployed for the first time in telecom history. The concept of network slicing is considered a key mechanism for 5G networks. Network slicing enables 5G networks to serve vertical industries that possess widely different service needs in terms of latency, reliability, capacity and domain specific extra functionalities. In 5G, network slicing is implemented by exposing isolated partitions of network resources and services. From a powering point of view, slicing can be implemented in a similar manner by exposing agreed partition of the cumulative battery capacity to special purposes of the energy operator without jeopardising the primary purpose of backup batteries. In this scenario, the energy operator owns the backup batteries as an augmented resource to its grid. In agreement with a tele operator or a Neutral Host party, the energy operator is liable for providing grid power, backup power and backup power duration as per agreed terms with the tele operator. In addition, the energy operator is motivated to oversize the batteries sufficiently to serve its own optimisation needs.

The most prominent optimisation cases are **clipping of peak loads and peak prices, maintenance of power balance in the grid and hedging against abnormal weather conditions.**

In the case of **peak clipping**, when the hourly price or load is forecasted to peak, the energy operator can command the Smart City Pole network to use backup batteries only for given duration of the peak. During this mode, the primary purpose of the batteries can not be compromised, therefore the capacity can only be used up to the limit of their primary purpose. Peaking grid load normally means the utilisation of fossil fuels. Thus running the grid in this peak clipping mode is a sustainability act as well. From a temporal perspective, ramping up a fossil power plant is far slower than activating an elastic web of backup battery energy reserve.

Maintenance of power balance in the grid is critically important for smooth grid operation. The electricity consumption is the sum of all the loads connected to the grid, so it is constantly fluctuating. The level of consumption also changes over longer periods, hourly, daily and seasonally. Changes also occur in production over short and long periods.

It is the responsibility of the market operators to plan and balance their production and consumption in advance. The plans, however, always deviate from what actually happens. As the party responsible for the system, it is the grid operators' task to take care of the balance between consumption and production during each hour.

The balance between consumption and production at any given moment is indicated by the frequency of the electricity grid. The frequency falls below the nominal value of 50 Hz when consumption is greater than production. Correspondingly, the frequency exceeds the 50 Hz value, when production is greater than consumption. The frequency is allowed to fluctuate between 49.9 and 50.1 Hz in normal state.

The grid operator ensures the balance between consumption and production by activating regulating bids from the balancing power markets and by reserving capacity. The grid operator acquires different reserve products that react to changes in consumption and production at different times. Smart City Pole batteries define one such reserve resource for grid balancing purposes.

In the case of hedging against abnormal weather conditions, the grid operator activates Smart City Pole batteries to be pre charged to full capacity prior to the forecasted abnormal weather conditions. The upcoming storm can cut out the grid, but IoT poles with lighting, video surveillance and 5G can still operate in safe mode until the grid is back in operation.

3. New Solutions and Technology Selections

From Pole to Smart Pole

Modern Smart Poles will be hosting multiple subsystems and features. Besides the 5G radio, the pole may host surveillance cameras, radars, weather sensors, pollution sensors, AV devices, street lighting etc. These subsystems make the distinction between normal poles and Smart Poles. The Smart Pole is the sum of its subsystems. For the Smart Pole to be turned into a reliable, manageable and attractive infrastructure for these subsystems, they must be more than just empty metal shells. The vast number of Smart Poles will be operating under severe conditions all over the world. In order to manage and maintain the network of poles, the pole itself has to be a smart component as well.

Thermal monitoring and control

The pole control system monitors the temperature and moisture in several locations inside the pole. This information is collected to a cloud based monitoring system. The temperature information from inside the poles is critical for designing the pole assembly for different geographical locations, as the thermal requirements for the components will vary significantly based on their geographical locations. The poles will also be equipped with a smart ventilation system that can be controlled remotely. There are several priority modes for operating the fan. In normal conditions, the ventilation system will hibernate to save energy. When the temperature inside the pole rises over a certain point, the ventilation system will be used to cool down the pole. The ventilation can also be used to control the moisture level inside the pole and prevent condensation inside. Furthermore, the ventilation system can also be used to direct the waste heat of the components to defrost the ice formation in the water exit vents. The direction of the airflow can be changed so that it can be used to clean the intake air filter. This will provide a significant cost reduction in infrastructure maintenance.

From Lead-acid to Lithium

The transition from lead-acid batteries to lithium-ion is inevitable when creating a modern Smart Pole infrastructure. The energy density of lead-acid batteries is low, which means that the required amount of energy storage capacity can not fit inside the Smart Pole. Due to the vast number of backup units required, the investment in batteries will be significant. Therefore it is necessary to consider modern solutions, where the battery system can contribute in different energy optimising actions to divert some of the investment away from simple backup towards more efficient electricity infrastructure.

Passive-Active Power Backup scheme

Traditionally the backup battery has been a passive component just waiting for a blackout. Turning the battery from passive to active means that instead of just waiting for a blackout, the battery will become an active component contributing to the everyday operation of the pole. However, this will set a completely new requirement for the cyclic durability of the battery. The traditional lead-acid batteries may only complete 10-30 full cycles during their lifespan. In an active system, they may face several cycles a day. Li-ion battery cells are able to provide very high cyclic endurance at low DOD (Depth of Discharge) cycles. However, in normal Li-ion battery packs, the voltage unbalance between the individual cells will cause the pack level capacity to degrade much faster than identical single cells would do in an ideal circuit. The Battery Management System (BMS) is supposed to balance the voltages between the cells, but most BMS systems are unable to do that at sufficient level, especially if the charge-discharge cycles are not full. The new L7 Drive battery backup system is the first system to completely eradicate the unbalance problem and remove the traditional BMS from a Li-ion battery system, resulting in a remarkable increase in the cyclic lifespan of the battery pack. This enables a cost effective way of turning the battery pack into an active part of the Smart Pole.

Remote monitoring and control of the battery system

As stated above, backup battery of the past was a passive subsystem waiting for a grid failure as the trigger to activate a battery-based powering of the host system. In the IoT era, the state of the power backup is monitored continuously and DOD cycles can be optimised along the same principles as explained above in the Active Power Backup Scheme section. Continuous monitoring of battery state and active lifespan optimisation leads to extended cycle life of the battery and total cost of ownership benefits. Initial analysis in Smart City Pole use shows that an optimised solution design can reach a lifetime of 7+ years. Further experiments will elaborate on the cycle life and lifetime in greater detail. With an extended lifespan and primary and secondary powering business cases, the cumulative justification to invest in power backup subsystem is becoming very lucrative.

Sustainability aspects

The strong sustainability megatrend is forcing IoT solution providers to clearly articulate how the sustainability megatrend manifests itself in novel IoT system designs. In the case of a Smart City IoT Pole, the arguments are split into the following themes;

- solar and windmill utilisation;
- manufacturing and battery waste management; and
- grid peak clipping.

Renewable energy resources such as solar power plants and windmills fit well into Smart City Pole powering concept. The intelligence of cloud-based monitoring and control logic can select the optimal supply source from alternative energy supplies, based on sustainability algorithms. Priorities for power sourcing can be set so that if solar/windmill power is available, the grid is cut out partially or completely until renewable energy is not rationally available on an hourly basis anymore. The key issue in this framework is to decide, whether the solar panels or windmills are installed in every pole, or if semi centralised power plants on rooftops in a city would make more business sense and provide renewable energy for a group of poles. This topology aspect is a topic for further experiments. UN sustainability development goals aim to increase the use of renewable energy sources, as stated in its goal number 7, “By 2030, increase substantially the share of renewable energy in the global energy mix”. L7 Drive solution is thus contributing towards the achievement of this goal.

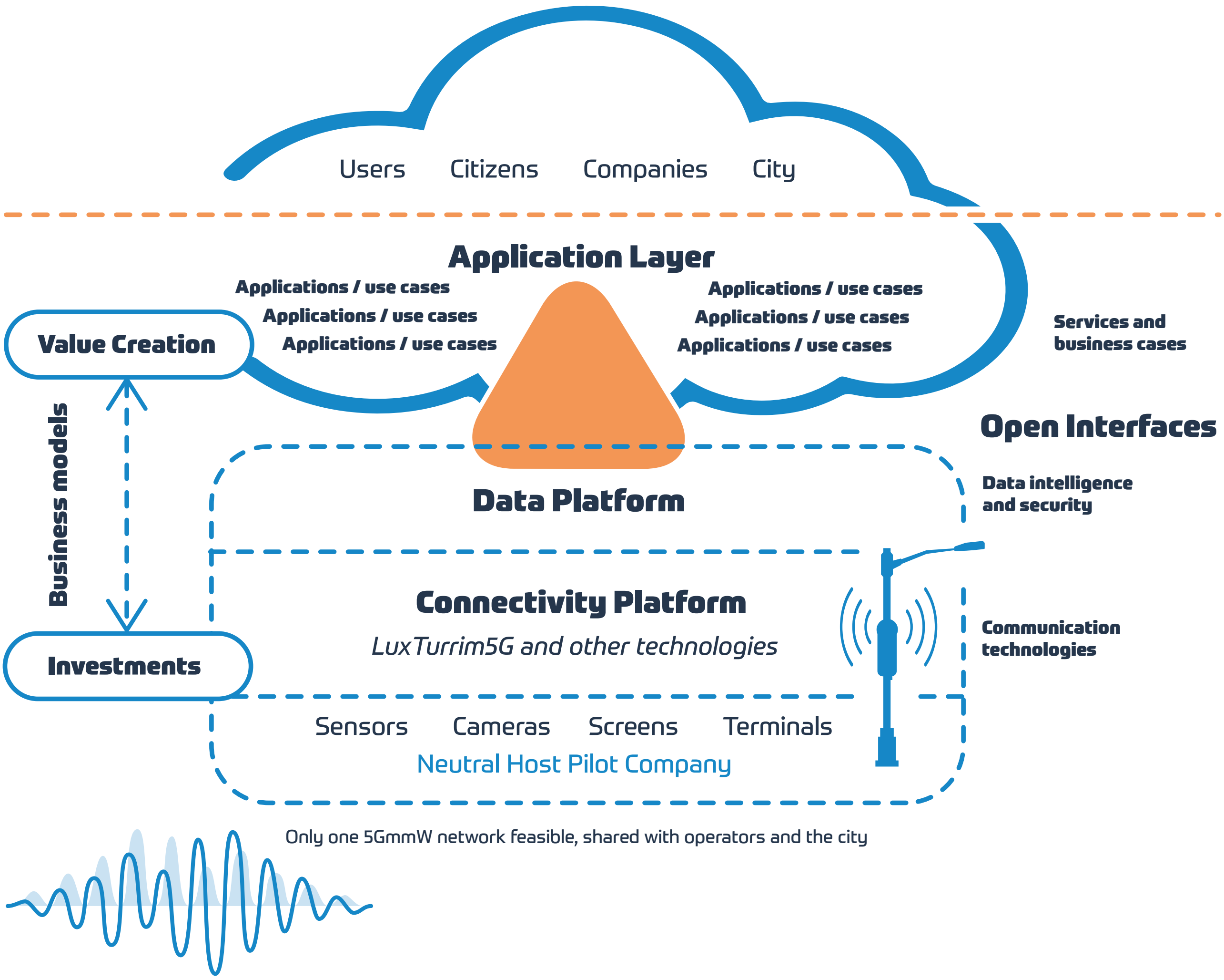
Second sustainability aspect is related to manufacturing and battery waste management. The manufacturing of cells is a major energy intensive phase in the production process. Obviously the longer the life cycle, the less is the energy demand of the manufacturing process. Thus long life cycle contributes directly to sustainability in a positive manner. Secondly all batteries contain a number of heavy metals and toxic chemicals. Disposing them in accordance with sustainability standards varies by battery type. Recycling is the key method to reuse the ingredients of different battery types. Current regulations stipulate recycle and return rates above 70%. Li-ion batteries contain high-grade copper, aluminium and transition metals, such as cobalt and nickel. The amount and type of transition metals contained depends on the active materials of the battery. To prevent a future shortage of cobalt, nickel, and lithium, and to enhance the sustainability of these technologies, recycling processes for lithium-ion batteries must develop further. These processes have to recover not only cobalt, nickel, copper, and aluminium, but also a significant share of lithium from the used battery cells. Recycling processes today recover approximately 25% to 96% of the materials of a lithium-ion battery cell, depending on the separation technology. The LiFePO4 batteries used in the L7 Drive system do not contain the problematic cobalt or nickel. In combination with effective recycling processes and an extended 7 year lifespan, the Li-ion power bank for Smart City Poles has a clear advantage over currently used lead-acid batteries.

Peak load clipping is contributing to the UN sustainability development goals as well. Peak supply for energy and power is typically generated with fossil fuels such as coal or oil. With a wide deployment of Smart City Poles, the peak load clipping is directly minimising the need for fossil fuel usage with elasticity in grid demand side of balance.

Old School Operations & Maintenance - Smart Operations & Maintenance on Big Data Platform

Traditionally O&M of a mobile network has been divided into domains of preventive and corrective activities. Preventive maintenance is aimed at reducing the risk of faults and at maintaining the predetermined tolerance limits. Experience and statistics are used in order to judge how often the preventive work has to be performed. Corrective maintenance consists of activities for correcting any faults which occur. Faults may be, for example, detected by alarms, complaints from customers or from checks during preventive maintenance work. Any faults discovered are reported to the operating statistics system.

In the new framework of Smart City IoT Poles, a new approach is required due to the diversity of sensor systems and diversity of roles related to preventive actions and corrective responses. The prominent approach in the Smart City context is to introduce a new mediator in the overall business system called Neutral Host. Neutral Host is in charge of the overall collection, integrity and curation of the Smart City Infrastructure data as defined in the following diagram.



In this approach Neutral Host is in charge of:

- Connectivity Platform Operations, Maintenance and Repair standards
- Data Platform with IoT data integrity assurance, curation and control based on raw IoT data and aggregated combinations of IoT datasets. Control commands towards IoT subsystems are orchestrated via Neutral Host instead of individual IoT subsystem providers with their diverse control systems by silo brands.

Advanced Backup Power Considerations and Use Cases

The dense network of Smart City Poles opens up two interesting dimensions relating to business cases. Firstly, assuming that the Smart City Pole network is large enough, it brings along the investment requirement for the modernisation of mains cabling. This costly requirement can be avoided by using the L7 Drive power backup system, which is able to configure the mains input based on the typical power instead of the peak power. This reduces the cost of mains modernisation greatly. The mains modernisation cost avoidance is a further justification for the wide adoption of the Smart Power backup solution.

Secondly, the oversizing of energy storage capacity in each Smart Pole is creating an interesting possibility for grid operators to satisfy their demand for the grid elasticity. Grid operators increasingly seek to optimise the peaks by hourly price while simultaneously avoiding fossil fuel use and/or AC frequency fluctuation due to unbalanced supply or demand. In this business case, the grid operator is tempted to propose that the energy from grid, renewable sources and battery backup network is available for IoT subsystems, including the 5G radio, as a service. In this scenario, the grid operator, as the first objective, guarantees power to IoT poles with 1-3 h backup time as a value proposal to IoT operators. As a secondary objective, the grid operator uses the cumulus of pole batteries as a source of elasticity without compromising the primary objective. In this mode, the grid operator seeking to optimise the grid, is forcing the Smart City Pole network to charge or discharge the batteries as a part of the total optimisation of hourly price, fossil fuels usage and AC grid balance. Based on the weather information, the grid operator can prepare for storms and rough weather by forcing the batteries to fully charge just in time prior to rough weather.

4. L7 Drive Solution Description

Battery pack structure

Li-ion battery cells have a low nominal voltage between 3 - 4V depending on the exact chemistry of the active layers. This voltage is too low to be used in any applications that drive significant loads. The obvious solution has always been to connect several battery cells in series in order to achieve high enough voltage for the particular use case (typically 48V in telecom applications). However, the series connection of Li-ion cells generates several problems. Some of the issues, such as the over- and under-voltage protection of each individual cell, can be solved with a good quality Battery Management System (BMS), but some fundamental challenges will always remain as long as there are any series connections.

The most significant issue is the accumulation of voltage and State Of Charge (SOC) unbalance between the individual cells, causing both capacity- and cycle life reduction as well as complicating the SOC calculation. Typically, the unbalance between the series connected cells within the battery pack is causing very significant reduction in perceived battery capacity already before there is any actual damage in any of the individual cells. Even a good BMS is only able to effectively balance cells when they are charged to a very high SOC (usually 98% and above). Repeatedly charging Li-ion cells this full will have a negative effect on the cycle life of the cells.

In a system, where the backup battery is used as an active component to serve several other purposes besides the actual backup power, the demand for cycle life is very high and the instances, when the battery will be charged full to enable cell balancing, are few. A typical cycle will not have a high Depth Of Discharge (DOD), since a significant part of the battery capacity must always be reserved for covering the necessary backup time, but the number of cycles may become very high, depending on the application. This type of duty cycle does not age the cell very fast, but it is the most challenging for balancing the cells voltage and SOC.

It is inevitable that some unbalance between the cells will be generated over time. Even if the cells are completely identical, which is never the case, they will not be subjected to equal conditions inside a battery pack. The position of the cell inside the battery pack creates temperature differences between the individual cells. Generally, the cells in the centre of the pack retain the heat generated during charge/discharge cycles and are less exposed to ambient temperature compared to cells on the outer edge of the pack. The temperature difference between the cells is causing variation in the internal resistance, which leads directly to voltage and SOC variation between individual cells.

Also, the BMS itself may slowly create unbalance between cells, even though its purpose is exactly the opposite. This is due to the fact that the BMS system usually obtains its power from the respective battery cell that it is monitoring. It is especially problematic during the downtime, when the only power keeping the BMS alive is coming from the battery itself.

If the battery pack is constantly operated and kept at the ideal SOC between 30 - 85%, the BMS is not able to accurately determine the SOC of the individual cells, and therefore is unable to balance the cells. Over time this accumulation of unbalance is significantly limiting the available capacity of the pack and causes deterioration of individual cells.

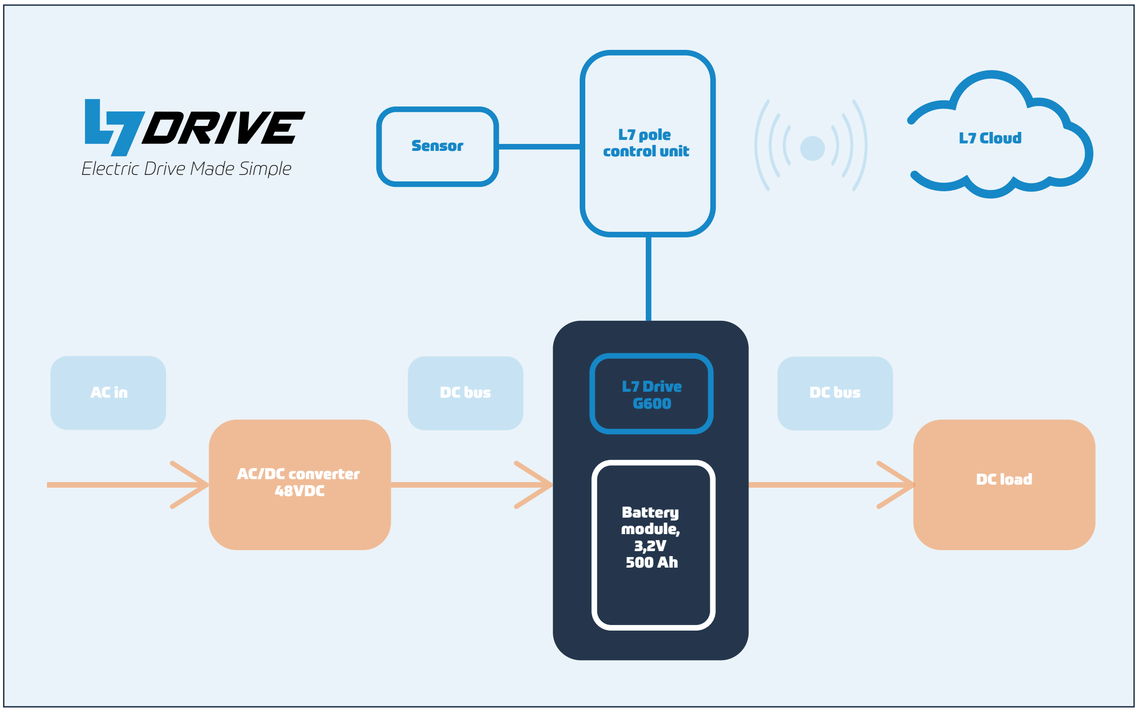
L7 Drive solution

The basic idea behind the L7 Drive technology is to avoid series connection of lithium-ion battery cells. By avoiding the series connection, it is possible to completely avoid the complicated issue of unbalance and balancing of the individual cells. Without the balancing issue, there is no need for a traditional BMS either. When the cells are connected parallel, not in series, the voltage of the whole battery pack will remain the same as the nominal voltage of an individual cell (3,2V with LFP, 3,6V with NMC).

L7 Drive has developed a novel DC-DC converter technology that is able to efficiently step up the nominal voltage of a single cell to 48 volts. The DC-DC conversion is bi-directional and the unit is able to manage both charging and discharging of the pack with all the required battery management features, like controlling the minimum and maximum voltages of the pack to avoid under- and over-voltage of battery cells. The DC-DC unit is also able to precisely adjust the power output and input to charge and discharge the battery pack, which allows the pack to turn into an active component in the energy management system.

The peak clipping functionality can easily be implemented by limiting the maximum power from the grid to a certain value and, when more power is required, the rest of it can be extracted from the battery pack. When the load is lower than the desired maximum grid power, the DC-DC can charge the battery with the excess power available.

The picture below indicates how the L7 Drive battery backup system is integrated in the 48V DC bus of a telecom system:



Key Benefits of the L7 Drive Smart City Pole energy backup solution

- Significant improvement in battery cycle life and reliability with parallel connected cells
- Full control of the battery power through DC-DC converter, critical feature in peak clipping and other smart energy use cases
- Stable voltage, independent of the SOC of the battery
- Remote monitoring and control of the battery system
- Remote monitoring and control of the Smart Pole, which allows efficient O&M
- Thermal management of the battery pack allows operation also in both cold and hot climate

Parallel connection

The concept of parallel connection of Li-ion battery cells is old, but not as well studied as the properties of a series connection. It is known that in both cases the differences between the individual cells have an effect on their behaviour as a pack. To get a deeper understanding of how cells behave under different conditions in parallel connection, L7 Drive commissioned VTT Technical Research Centre of Finland (VTT) to carry out an extensive research project for testing the effects of parallel connection to the cycle life of the cells. Furthermore, some extreme tests with mixed packs of cells with different age and State Of Health (SOH) were performed to understand how the pack behaves under the most extreme conditions.

The results of the study were encouraging, and some even surprising. Whereas the series connected pack is always limited by the weakest cell (lowest capacity/highest internal resistance), in parallel connection the load is distributed between the cells based on the characteristics of each cell. This means that the stronger cells will carry a larger portion of the load and allow the weaker cells to perform according to their respective characteristics. This phenomenon allows the weak cells to have a longer lifetime than they otherwise would have, even if used as an individual cell. Consequently, the weak cells are not compromising the operation or cycle life of the other cells in the pack, nor the performance of the pack as a whole.

In series connection, the performance of all cells is limited by the weakest cell in chain, and the same weak cell will always encounter the same load demand as all other cells. This will lead to a downward spiral, where the weakest cell continues to get worse with accelerated speed, limiting the lifetime of the complete pack. When that one weak cell finally gives up, the whole series connected pack seizes to operate. Even very small differences in cell characteristics when they are new will multiply over time, which will compromise the whole pack.

As the current load is, by nature, divided between the cells according to their respective characteristics in parallel connected pack, there is a theoretical risk that under rare extreme conditions most of the current is directed through one cell, or a small group of cells, which would cause serious overload and heat accumulation in that cell or the group.

This scenario was studied carefully with following results:

Dangerous deviation in cell current was only discovered, when a factory new cell was introduced in a pack with 4 other cells that were in the end of their life, and the pack was cycled with over 1C current (C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity). Another important find was, that the higher the number of cells connected in parallel, the less deviation in current between the cells was discovered.

To prevent the dangerous current deviation between cells, a new type of variable resistive element was deployed in series with each individual cell in the parallel connection. This element is serving two main purposes; as a fuse disconnecting the cell from the pack in case of a fatal cell failure while leaving the rest of the pack operational, and as a current limiter in the case of a severe overcurrent, restoring the current load balance between the cells. When the current returns to a normal level, the resistive element will also return to its normal state. This novel system was found to be very effective. L7 Drive has filed a patent application based on this method.

The conclusion of this study is, that the parallel connection is an ideal way to extend the Li-ion battery pack lifetime and capacity. A properly configured parallel connected battery pack is able to outperform a series connected battery pack in safety, reliability and lifespan.

Thermodynamic aspects and general requirements

Building a nano cell network access to premises is a major challenge. Traditionally, backup batteries of the base stations have been installed in an environmentally controlled space. In the era of nano stations, this is no longer possible. The backup batteries must be installed in varying locations and environments close to the 5G radios. This means installation in light poles, bus stops, public buildings etc. It is well known, that Li-ion cells have a rather narrow operating temperature window. Typical acceptable temperature range is about -20°C - +50°C for discharge and 0°C - +50°C for charge. Charging at subzero temperatures is not possible without an active temperature control method.

The L7 Drive battery backup system is equipped with insulation and battery heating system that is capable of maintaining a temperature difference of +40°C to the surrounding environment. This allows the battery to operate in the arctic regions. The Smart Pole is also equipped with a ventilation system that can be used to cool down the battery pack. The internal heating of the battery pack is minimised by maximising the battery capacity. When the battery capacity is high enough, it is possible to keep the C-rate low during both charge and discharge, thus preventing excess heat formation. The maximum charge/discharge rate of the cells in L7 Drive Smart Pole system is approximately 0,3C. This eliminates the internal heating of the cells almost completely, especially when using LFP chemistry, which is not as susceptible to heating during operation compared to NMC cell chemistry. This integrated thermal management system allows installation of batteries in a wide range of ambient temperatures outside of an environmentally controlled location. This is a significant cost saving factor in building the infrastructure.

5. Total Cost of Ownership & Benefit Considerations

In framework of viewpoints presented in the previous sections of this document, direct and indirect benefits for infrastructure operators are obvious. Investment and business case analysis and calculations should therefore include quantified marginal impacts of L7 Drive smart Li-ion battery backup solution. Direct marginal benefits come from increased lifetime expectancy, cost reduction, space saving and lower weight. Indirect marginal benefits relate to Smart City safety and enhanced competitiveness for the attraction of talents and business campuses.

Direct marginal benefits in Total Cost of Ownership calculation are divided into non-recurring items and annually recurring items. Based on the research institute VTT laboratory cycle tests in 2019, L7 Drive solution in Smart City Pole use have a replacement period of 7-15 years. This translates into less labour effort required to replace units and less cost in the waste management phase. The space required for Li-ion battery is only 37% of a similar lead-acid unit. The weight of a Li-Ion unit is only 26% of a lead-acid unit of similar capacity. Space and weight constraints in a Smart City Pole exclude practically all battery chemistries other than Li-Ion. Cell cost comparison between the battery chemistries is speculative. As the electric vehicle industry is growing vigorously around the world, it is estimated that the global Li-ion battery demand will reach 3000 GWh in 2030. Therefore, the cost of Li-ion batteries will decrease rapidly. The cost of Li-ion batteries and lead-acid batteries is expected to be the same by 2021.

The Energy as a Service scenario introduces a whole new business case for the Smart City Neutral Host operator. In this scenario, an alternative energy operator is providing guaranteed power and energy as a subscription service. This cuts out energy related jobs and assets from a Smart City and utilises the same assets in the energy operator business case with extra capacity dimensioning (30% - 50%) as a marginal investment. Simulations of this business case are the subject of business development programs of interested energy grid operators.

The indirect marginal benefits to be quantified in this business case are the annually recurring cumulative items. Assuming that a Smart City can offer a higher standard in security, safety, air quality control, fast 5G networks and modern innovative sentiment, it is becoming a differentiating factor and transforms a forerunner city into a center of gravity for talents and business campuses. This translates into more jobs and taxes for the city. Indirect benefits justify infrastructure modernisation and thus they should be qualitatively and quantitatively defined in respective investment calculations.

6. Summary

In summary, this paper has elaborated megatrends and new use cases in the battery backup industry space. Evolution is forcing the industry to move from passive lead based battery chemistry to lithium based active intelligent IoT power backup subsystems. L7 Drive is a clear forerunner in this transition phase. The innovation in the L7 Drive solution is based on a patented special method of parallel coupling of cells and a novel DC-DC conversion technology. This approach cuts out a large part of standard Battery Management System tasks, especially in the domain of intra battery temperature management. This innovative L7 Drive solution interlocks perfectly with the uninterrupted power requirement of the Smart City Pole and its IoT subsystems. Additionally, the L7 Drive solution can actively contribute to secondary requirements related to power grid optimisation. This slicing of intelligent battery backup system into primary and secondary purposes, is perfectly complementary towards similar novel network slicing in 5G network. Ongoing experiments with industry ecosystems will provide proof for the overall concept, which will lead to an emerging boom of replacing conventional lamp posts with Smart City Poles in pioneering metropolitan cities.