Green Li-Ion Batteries through Electrode Electroless Deposition

LIFE Project Number

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Deliverable C.2

COMMERCIALISATION EVALUATION

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Contents

OVERVIEW

Objectives

A key objective of this LIFE+ demonstration is that the plant design offers real potential as a large scale industrial/commercial model. Hence it is important to define suitable benchmarks as the outset and to assure that these are referenced against the project performance and economics.

Methodology:

The evaluation method for industrialization and commercialization potential will develop along two axes:

- Industrial/technical: whose goal is to check the scalability of the equipment and added cost for cathode active material of the solution for large volume productions. The most important benchmark is the added cost of the solution to the stand indicator in this direction.
- Commercialization potential and evaluation of economic feasibility of the large scale industrial solution. Porter's five forces and SWOT analysis are tools commonly used by companies to conduct analyses and make strategic decisions. Each of the models seeks to define the company's position in the market. The major distinction is that Porter's five forces are used to analyze the competitive environment within an industry, often focusing on external forces, while a SWOT analysis tends to look more deeply within an organization to analyze its internal potential. Porter's five forces are also generally more of a micro tool, while SWOT analysis is comparatively macro.

  A SWOT analysis focuses on analyzing the strengths, weaknesses, opportunities and threats to a business. It is a bird's-eye view meant to flesh out the viability of a concept from the inside out. The SWOT analysis is often considered a more macro review, as it can give a sense of whether an objective is attainable and helps identifying competitive advantages and disadvantages. For these reasons the LIFE+GLEE technology industrialization and commercialization potentials has been carried out through SWOT analysis.

  Several market entry strategy scenarios will be develop thereof to be submitted to management and, if applicable, to Partners.

Expected results:

- Assessment of the replication potential of the technology within European context.
- Commercialization Evaluation Report underlining recommendations for replication (size, number, location, typical partners).

REPLICATION POTENTIAL OF THE TECHNOLOGY

Scalability

The plant:

The LIFE+ GLEE pilot plant is located in the Solvay Specialty Polymers HQ of Bollate (Milan), one of the most advanced Research & Innovation centers in the Solvay group. The GLEE plant covers an area of nearly 300 sqm and includes two cisterns which contain the solution needed by the process, a reactor where the chemical reaction occurs, and a filter which divides the powder from the liquid phase, allowing for treatment in the drier at the end of the process. All this equipment is protected by the Glove Box, a structure which prevents the operators' contact with any of the agents used during the process. The whole plant is monitored by an automated system which simplifies the activities while granting improved safety. The plant dimensions allow a daily production of approximately 1 kg of CAM which is an amount sufficient to manufacture 50 small batteries. While this plant is mainly dedicated to internal and external testing and evaluation, the LIFE+ GLEE process can be easily scalable to hundreds of times the size by replicating the process with larger equipment and/or multiple lines. Thanks to the low complexity level of the process (neither high pressure/special gases nor high temperatures are required) the plant can be easily scalable and replicated with competitive costs.

A detail of necessary investment for the replication of multiple lines (3 lines) and a single line with higher capacity production will be discussed in the next chapters. Both these scenarios endow a production of batteries similar to a small industry (100000 battery packs per year, 40Ah capacity, 60 cells per battery). The same figures will be used to analyze the overall costs for battery productions.

Added costs

Introduction

The replacement of NMP by water is a tremendous opportunity to reduce cost in the production of lithium ion batteries. The cost of water is negligible compared to that of NMP; water is not flammable and does not produce flammable vapors; and water is environmentally benign. The NMP substitution with water will reduce costs mainly thanks to:

1) Intrinsically lower costs of the solvent NMP vs. water
2) Plant reduction costs and labor costs
3) Improved performance of the battery

These three contributions will be analyzed separately in the next chapters and our conclusions will be given and discussed.

Costs reduction thanks to NMP substitution (based only on solvent costs)

The actual cost for batteries production is around 300 Eur/kWh. The targets (Lux Research Report, http://www.luxresearchinc.com/) for most of the battery producers are to reduce these costs to 150 Eur/kWh (target 2017) and 100 Eur/kWh (target 2020) by adopting incremental innovations. In this first scenario we assume that the only costs reduction is due to solvent substitution and we do not take into account plant costs and personnel costs that will be analyzed in detail in the next chapters.

The LIFE+GLEE technology can play an important role in costs reduction with plant investments lower than state of the art machineries. Our first cost reduction estimation is based on the difference in price simply due to solvent substitution. The costs reduction for current technology and projections for 2017 and 2020 are reported in table 1. Briefly our study indicates that for each kWh of battery produced with the GLEE technology there is a costs reduction of 0.3% with the state of the art technology and this cost reduction will increase up to 1% in 2020.

This first scenario is merely a calculation of the money saved by replacing the solvent NMP with water and does not take into account all the environmental benefits, the overall sustainability and greening impact of the technology and the better working environment which are taken into account in the LIFE+GLEE eco-profile and in the socio-economic impact. Moreover this costs reduction does not take into account the further costs reduction that will results from performance improvements. These benefits will be analyzed in detail in the next chapter.

	NMP costs % per kWh	**Water costs % per kWh**	**GLEE costs save (%)**
Actual cost (300 Eur/kWh)	0.4	0.1	0.3
Target cost 2017 (150 Eur/kWh)	0.9	0.2	0.7
Target cost 2020 (100 Eur/kWh)	1.3	0.3	1.0

Table 1: costs of batteries Eur/kWh (actual, 2017 and 2020), costs of NMP and water impact on the battery costs and GLEE costs reduction.

Costs reduction based on different plant investments

The Argonne National Laboratory is the world-wide reference in term of batteries cost studies since more than 10 years now. In September 2011 it published a report on the “Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles” and a related “Battery Performance and Cost model (BatPaC” excel tool. The BatPac model is now at its 3rd version, released on 21/12/2015, so for our calculations we used updated and reliable costs estimation tool.

The cost of the designed battery is calculated by accounting for every step in the lithium-ion battery manufacturing process (fig.1).

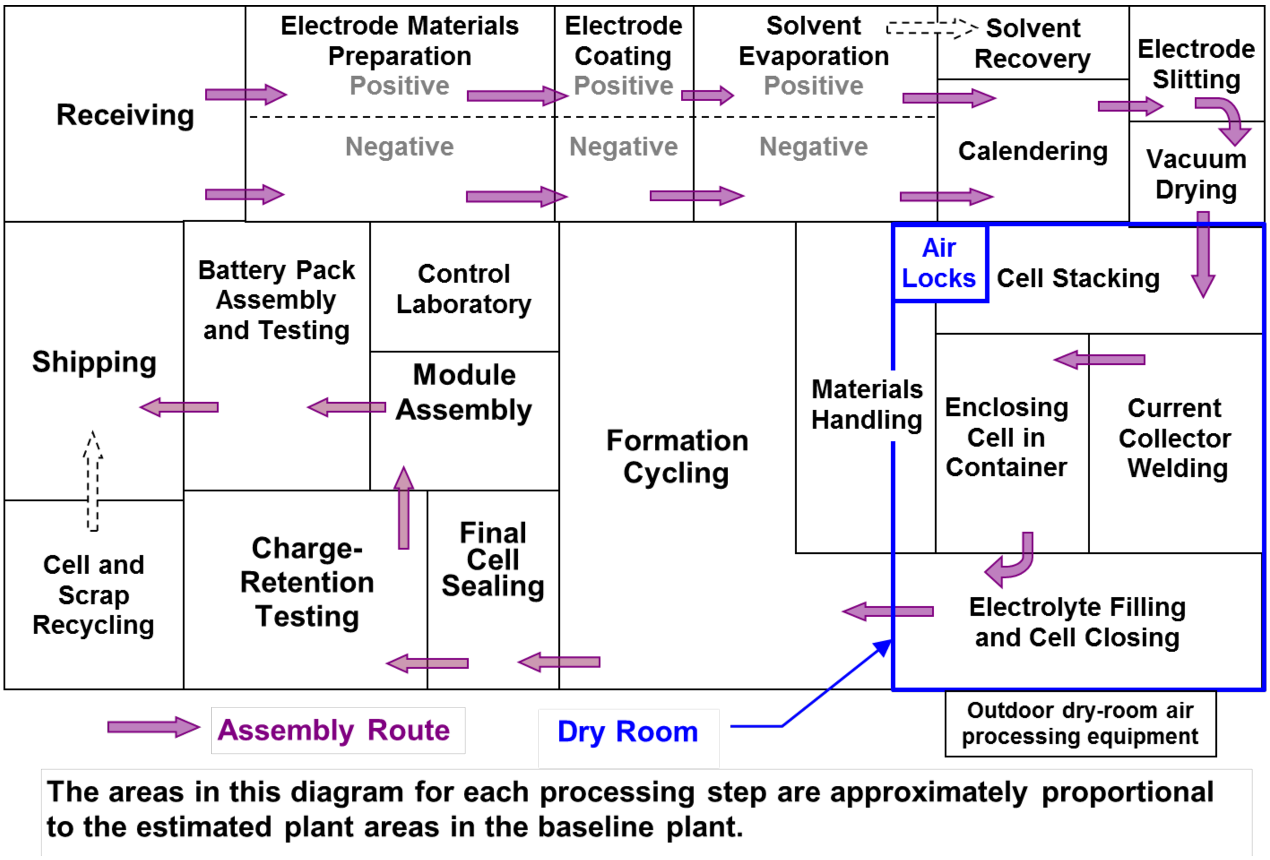

Fig.1 Definition of the different cell process steps in BatPaC

We used the BatPac tool to establish manufacturing cost base line with the following characteristics:

- 100,000 battery packs per year, 50-kW battery power, 40-Ah capacity, 60 cells per battery
- Operating year: 300 days with three 8-hr shifts per day

BatPaC enables to extract a cell cost breakdown; it is shown in fig. 2. It is important to highlight that the overall manufacturing cost of the cell represents 24% of the whole cell cost (7% direct labor + 5% variable overhead and 12% depreciation). BatPaC also enables to go deeper into the cost analysis by providing a breakdown of the process cost at the different steps and from the fig. 3 we can see that the process perimeter addressed by the LIFE+GLEE project represents around 33% of the global process cost (24% material + 9% Electrode processing).

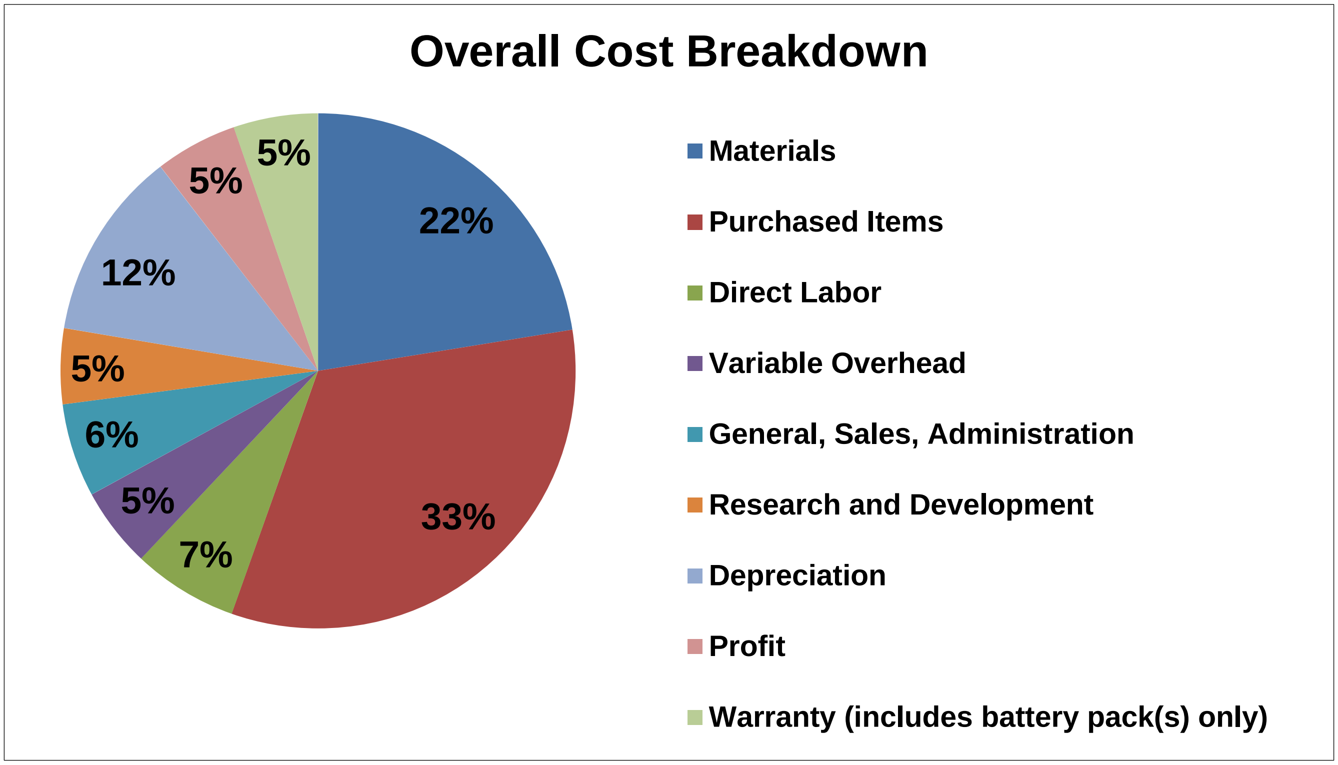

Fig.2: Cell cost breakdown.

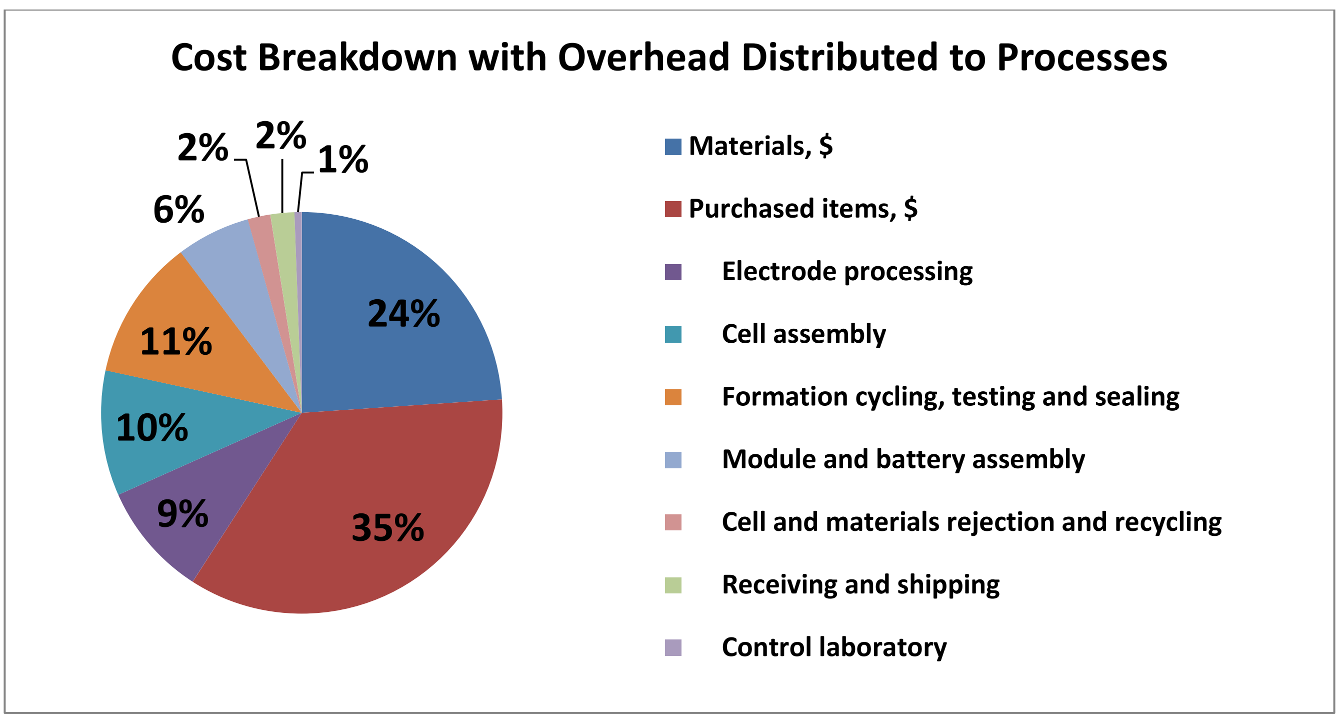

Fig.3: Process cost breakdown.

The GLEE process has lower costs related to infrastructure devoted to correctly manipulate NMP which include explosion proof system, environment management system, solvent recovery column, re-purification system, safety and health systems.

The BatPac tool provides specific costs for the equipment for NMP solvent recovery for the cathode manufacturing and direct labor. These costs are compared directly with two different scale-up solutions for the LIFE+GLEE process. A multiple cathode active material coating line (3 lines) and a single line both with reactors capacity capable to provide cathode active material sufficient for the estimated annual production are considered in this analysis. All the costs related to the GLEE plant are real costs estimated during the pilot plant construction. The direct labor costs are calculated by considering that three small fully automated plants will require 4.5 FTE (10800hours/year) while a single medium size plant will require only 3FTE (7200 hours/year). The cost for an FTE is assumed to be 80000 Eur.

In table 2 the plant costs and the direct labor costs (hours/year and Eur) are summarized.

	Solvent recovery line	GLEE (3 small plant)	GLEE (1 medium size plant)
Plant costs MEur	5	1.7	1
Direct labor (hours/year)	10800	10800	7200
Direct labor (Eur/year)	360000	360000	240000
Investment costs saving MEur	benchmark	3.3	4
Direct labor costs saving Eur/year	benchmark	0	120000

Table 2: plant and labor costs

Moreover physics make water much easier to remove than NMP as can be seen by data reported in table 3:

Property	NMP	Water
Heat of Vaporization at 100°C (kJ/mol)	50.6	40.7
Boiling point (C°)	204.3	100
Vapor Pressure at 40°C(mm Hg)	1.0	55.3

Table 3: comparison of physical properties of water and NMP

All in all cost of electrode processing could be cut up to 5 Eur/kWh-usable primarily due to fast drying of water (i.e. higher solids loading, lower drying T, lower air flow rate & higher volatility than for NMP) and no solvent recovery costs. This represents a costs reduction per kWh of 2% at the actual costs and will represent up to 5% costs saving in 2020.

Costs reduction thanks to improved performance

The costs of a battery are strictly related to its performance. In fact the price of a battery is commonly referred to the battery energy or power and it is usually referred as price/kWh. One of the goal of the LIFE+GLEE project is to demonstrate that the coating process not only endows the possibility to use cathode active material in aqueous environment but it also gives further benefits in terms of performance improvements with respect to the state of the art batteries prepared using the toxic solvent NMP.

During the bench scale feasibility of the project we demonstrated at small battery scale an increase in performance at medium C-rate from 50 mAh/g to 120 mAh/g which represent a factor of 2.4 with respect to an uncoated cathode prepared in aqueous environment and a performance improvement of around 10% compared to a standard cathode. This performance improvement will reflect directly in a reduction of the cost of the battery expressed in Eur/kWh and thus we expect that this is the major goal of the project.

We can then assume that the costs reduction for batteries prepared using this innovative technology will reduce the costs up to 10% by increasing the battery performance in terms of capacity retention and cycle life.

Conclusions

Overall conclusions

The LIFE+GLEE technology thanks to the low complexity level of the process (neither high pressure/special gases nor high temperatures are required) and the easy scalability of the plant can be replicated with competitive costs.

The main identified costs reductions are related to 1) NMP replacement 2) plant investments/labor costs and 3) performance improvements. The NMP replacement itself was estimated to bring a cost reduction from 0.3 % to 1% per kWh of battery produced. Additional costs saving for cathode production by using the LIFE+GLEE aqueous based process has been estimated to be up to 5 Eur/kWh; this value take into account both investment and annual labor costs. This represents another costs saving from 2 to 5%.

The improvements in battery performance with respect to standard cathode manufacturing could bring another 10% of costs saving. The overall impact of the technology is potentially high as it does not only bring production costs reduction but also all the environmental benefits that are underlined in the LIFE+GLEE project eco-profile.

COMMERCIALISATION EVALUATION

SWOT analysis

A SWOT analysis (alternatively SWOT matrix) is a structured planning method used to evaluate the strengths, weaknesses, opportunities and threats involved in a project or in a business venture.

- Strengths: characteristics of the business or project that give it an advantage over others.
- Weaknesses: characteristics that place the business or project at a disadvantage relative to others.
- Opportunities: elements that the business or project could exploit to its advantage.
- Threats: elements in the environment that could cause trouble for the business or project.

In the next pages the strengths, weaknesses, opportunities and threats related to LIFE+GLEE projects will be analyzed in detail and risk mitigation actions/solutions will be proposed.

Strengths:

- NMP substitution: LIFE+GLEE is targeted at elimination from the large scale and rapidly growing Li-ion battery manufacturing process of a chemical which is hazardous for the health of the living things exposed. The European Community REACH regulation encourages progressive substitution of NMP in all applications.
- Costs reduction: the substitution technology proposed in the LIFE+GLEE will enable the use of water based green solvents which, in addition to not carrying toxic risks for living beings, reduces the cost of manufacturing process by making redundant the sophisticated solvent recovery and re-purification processes. Additional costs for cathode production that become unnecessary by using THE LIFE+GLEE aqueous based process are schematically depicted in Fig. 4.

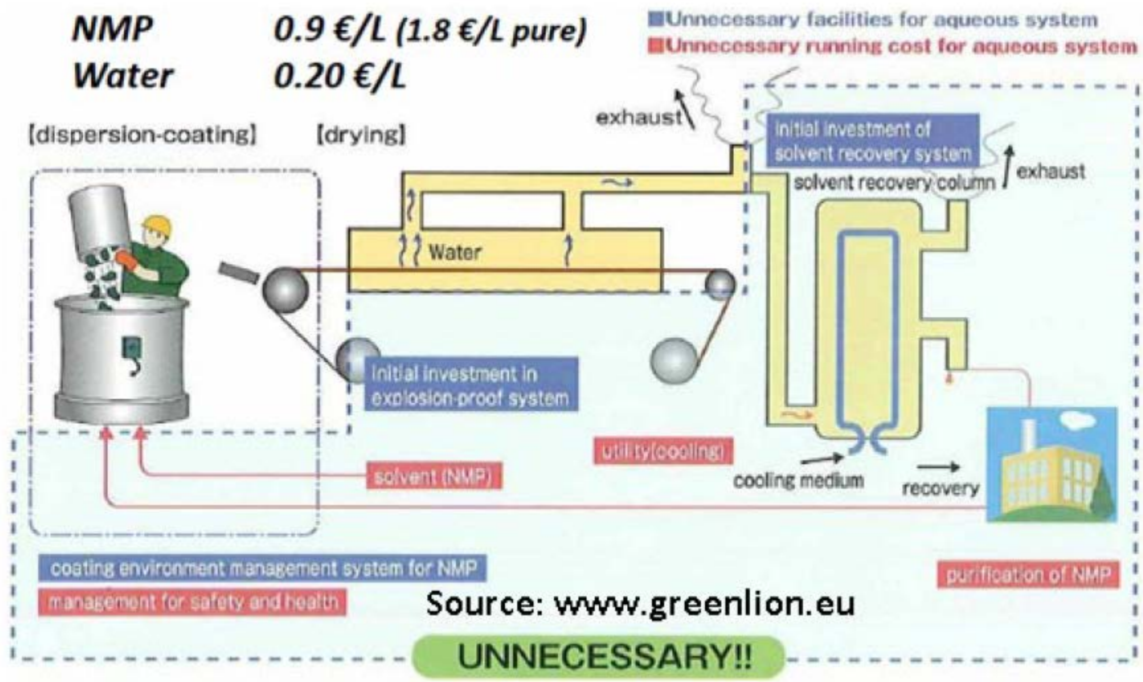

Fig. 4: additional costs for cathode production that become unnecessary by using THE LIFE+GLEE aqueous based process.

- Technical advantage: stability and better electrical performance. LIFE+GLEE process increases battery capacity at high discharge rate.
- Better working environment. The replacement of NMP with water assures a better working environment for all cathode manufacturing line operators.
- 1° mover position. Solvay is 1° mover in this technology and has a strong IP position on the coating process.
- In the field of advanced energy storage cells Solvay is a leader in the development and supply of binders, separators and other materials for Li-ion battery makers and this is the basis of its specialize expertise in this field.
- Today's Li-ion manufacturing processes continue to use a complex wet slurry process that involves mixing, coating, drying, solvent recovery, and so forth… The use of aqueous process simplify this process as explained in the previous chapter (no need of explosion proof system, environment management system, solvent recovery column, re-purification system, complex safety and health systems)

Weaknesses:

- Solvay is not an active material producer or a battery manufacturer thus will need partners to successfully commercialize this technology
- Toxicity of the reducing agent (i.e. formaldehyde).
- PVDF based latex could require post heating treatment to improve the adhesion of the electrode to the current collector. This treatment could increase processing costs.

Opportunities:

- PVDF latex: SSP has a family of PVDF latices in its portfolio that are ready to use in combination with CAM.
- LIFE+GLEE technology licenses to material and battery manufacturers
- Major Li-ion developers are scaling up manufacturing capacity aggressively, even in the face of existing overcapacity (the U.S. DOE estimated global utilization at 22% in 2014).
- Battery market is growing enormously and a battery consumption rate is doubling every three years.
- Transportation will see no significant adoption of next-generation batteries before the late 2020s –until then, Li-ion will dominate, evolving to become advanced Li-ion.

Threats:

- The LIFE+GLLE process adds one step (coating) to the raw cathode active material production. This could bring additional costs to the raw material producers or battery manufacturers.
- Reducing solution has been developed by an external company then availability could become a problem if the request increases.

Risks mitigation:

- Solvay is in the battery market since many years and then the organization could support well this new business opportunity.
- Substitution of toxic reducing agent with non-toxic chemicals.
- If the value proposition is sufficiently strong the cathode active material producer or the battery manufacturer could accept this.
- It will be important to evaluate other suppliers in the market entry strategy.
- Solvay is developing new amorphous PVDF lattices with low melting point and higher molecular weight to achieve high level of adhesion without requiring post heating treatment.