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Title: **2020 cathode materials cost competition for large scale applications and promising LFP best-in-class performer in term of price per kWh**

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Abstract Summary:

See PDF below

2020 cathode materials cost competition for large scale applications and promising LFP best-in-class performer in term of price per kWh

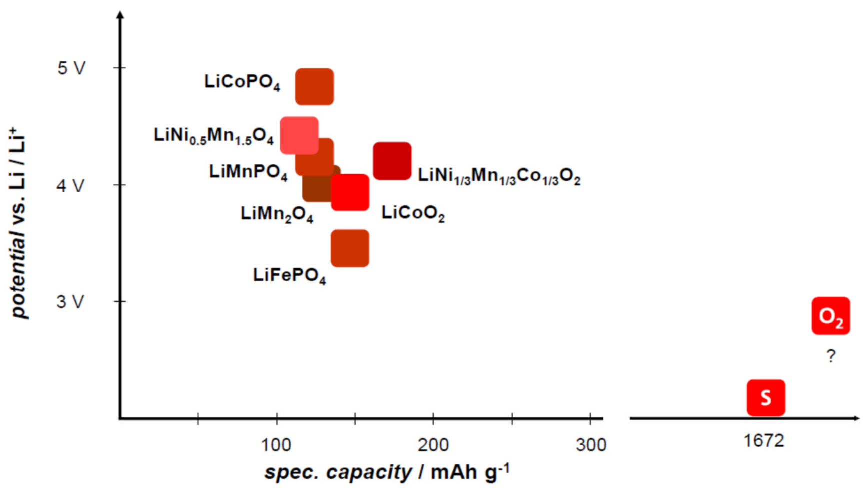
1. Introduction

The goal of this paper is to compare the cost structure of the Lithium Iron Phosphate cathode material in its position in terms of price/cost performance for mass industrialization in regard with other current cathode materials used for EV or ESS: LMO, NCA and NMC. The study integrates also LCO cathode although this material is not used for EV or ESS but, due to its massive usage in portable electronics, this material is still a reference cathode material for LIB to make a comparative study.

2. LIB cathode materials - State of the art

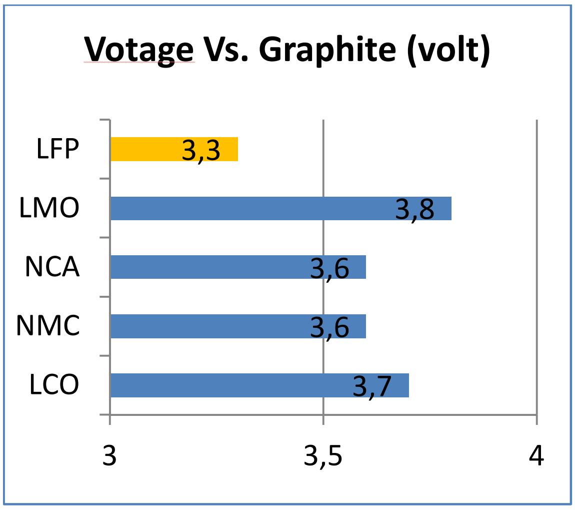
2.1. Performance of materials

Promising and existing cathode materials are mapped below in terms of voltage and specific capacity.

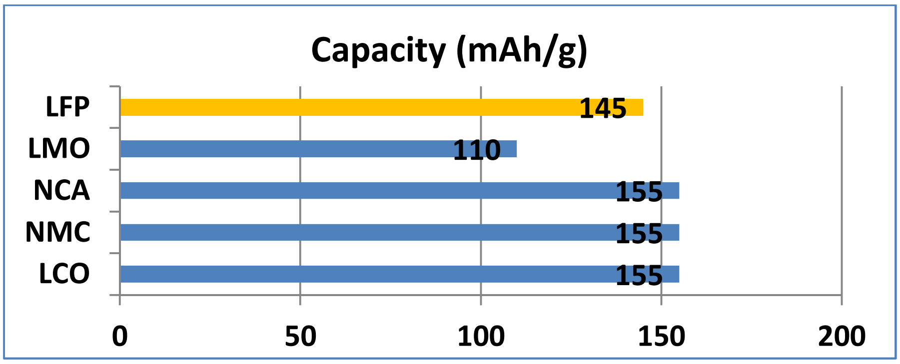


Source : Franhaufer

To highlight electrochemical performance in application, real potential and specific capacity of the five selected materials for this study are defined below :



Source : beLife



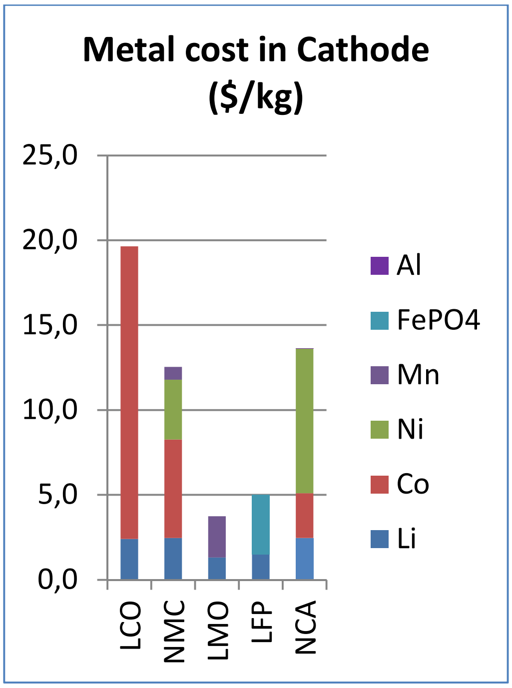
Source : beLife

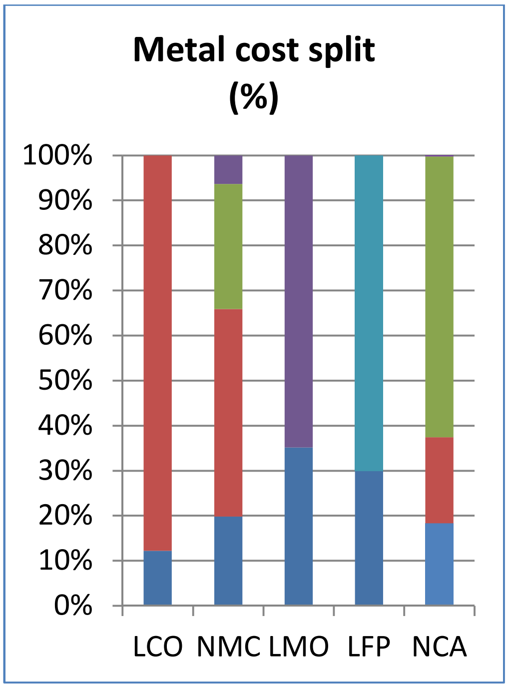
At cathode material level, NMC and NCA has a significant advantage in terms of kg/kWh for EV or ESS applications. They show a benefit of 17 % compared to LFP and 34% to LMO.

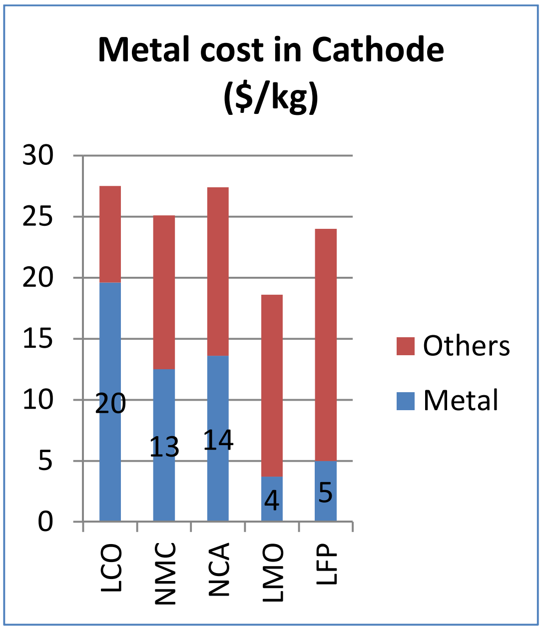
	mAh/g	Volts	**kg/kWh**
LCO	155	3,7	1,74
NMC	155	3,6	1,79
NCA	155	3,6	1,79
LMO	110	3,8	2,39
LFP	145	3,3	2,09

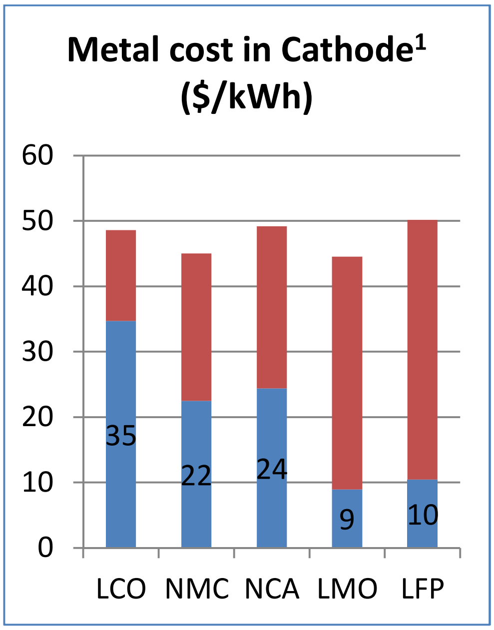
2.2. Metal cost in cathode (H2 2012)

Nota bene : Phosphorus is not a metal even if in this report the term metal includes all chemical elements constituting cathode materials : lithium, cobalt, nickel, manganese, iron but also phosphate



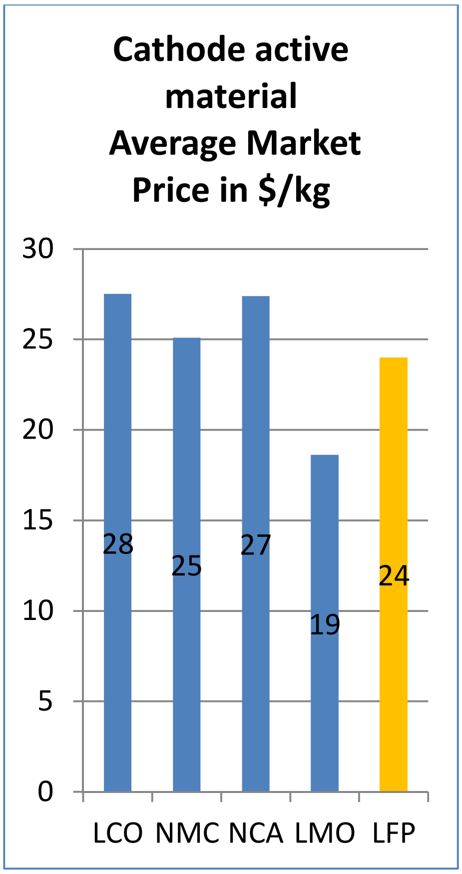


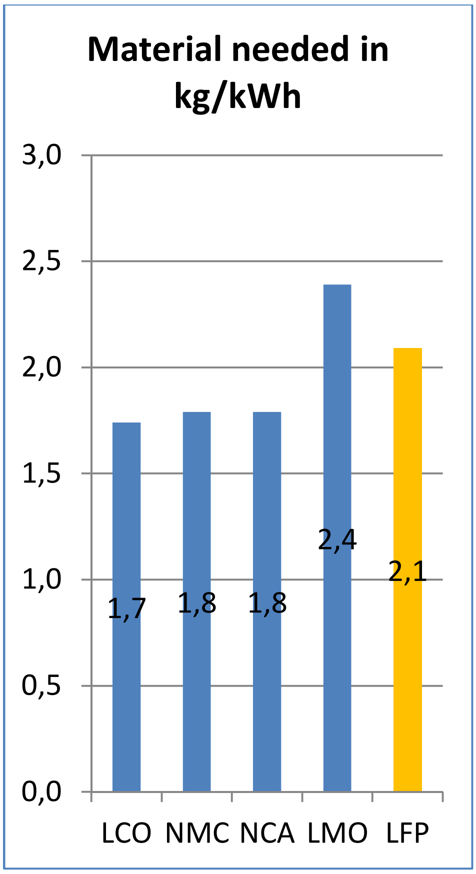




1- Before cell & pack process Yield

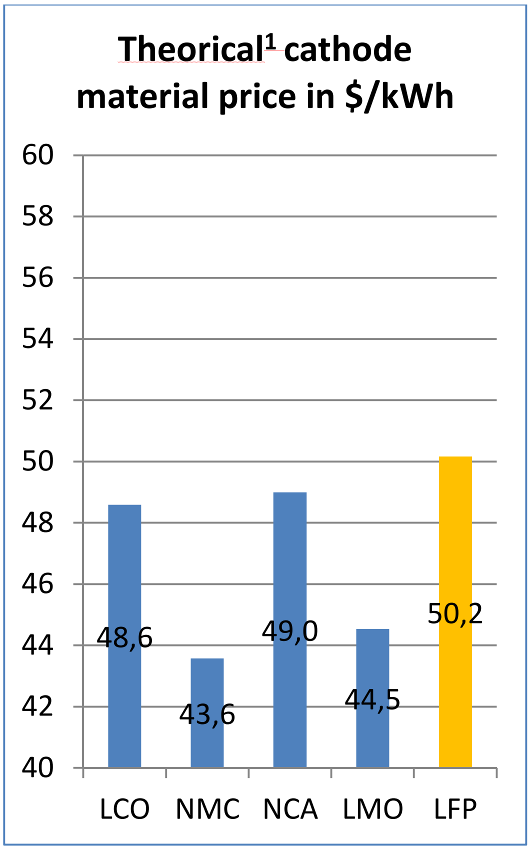
2.3. Cost of cathode materials (H2 2012)

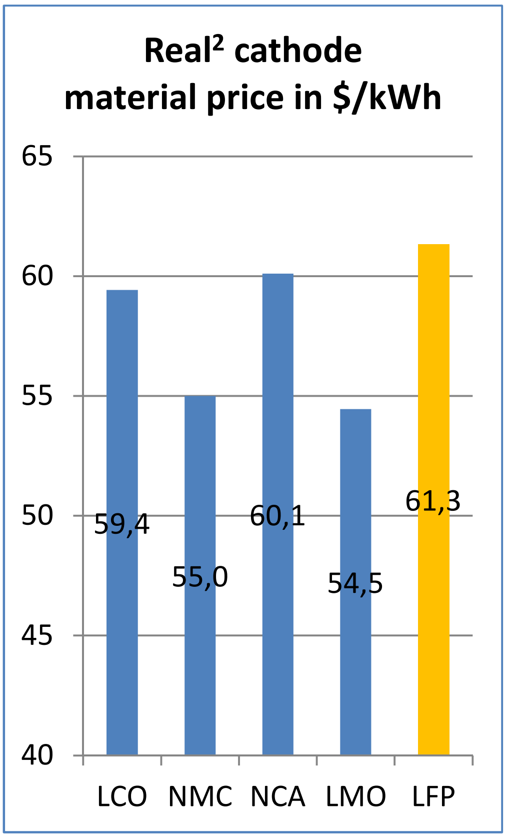




Actual average market price is directly linked with the technological maturity and the global worldwide available capacity for each cathode material and also largely driven by the level of competition.

Latecomers like LFP but also NMC subject to continuous improvements will become more and more competitive in comparison with LCO, NCA and LMO as shown later in the chapter describing prices forecast up to 2020.





1- Before cell & pack process Yield

2- After cell process yield (94%) and Pack process Yield (87%)

Only few mass productions for high quality LiFePO4+C AG patented LFP materials were up to the agenda in H2 2012.

Based on the above cathode competiting materials in $ per kWh, a full production cost below 20 $/kg is a first minimal target for LFP producers to move towards a competitive price under 50 $/kWh at pack level.

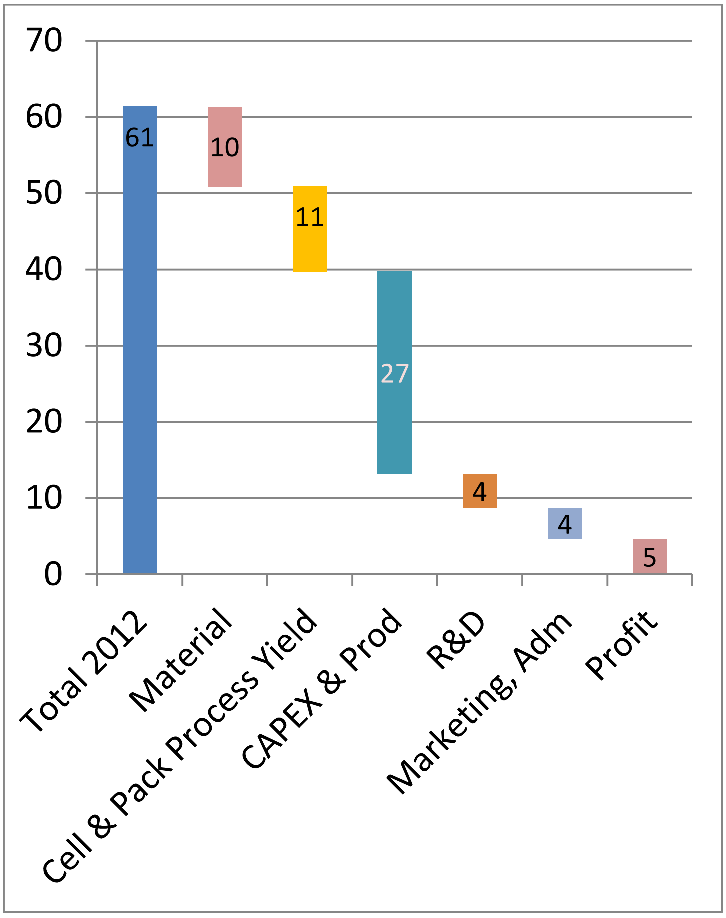
3. Detailed costs for LFP production end of 2012 – Gross Estimation

3.1. Rationales

- Assuming at least 1,000 tons per year of production
- Capacity: 140 mAh/g
- Voltage (Versus Graphite) : 3.3 volts
- Material costs:
  - Li_2CO_3: 6.4 $/kg
  - $FePO_4$: 3.5 $/kg
- R&D cost: 7%
- Marketing & Adm: 7%
- Profit: 7.5%
- Gross Margin: 21.5%

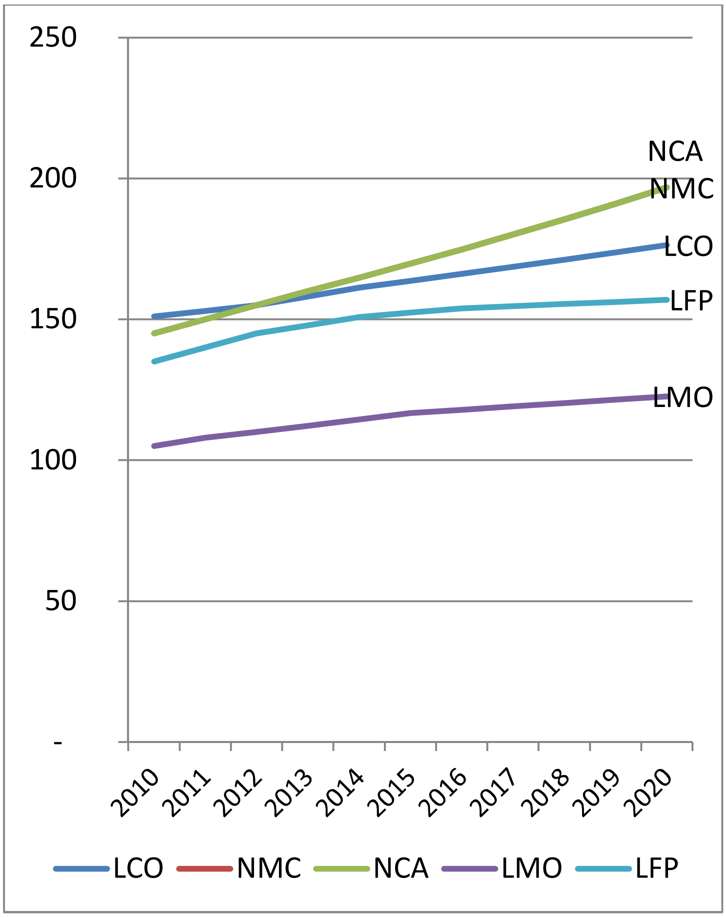
⇨ LFP cathode price ± 24 $/kg

3.2. LFP price in $/kWh at pack level (H2 2012)



4. Cathode material price forecasts 2012 – 2020

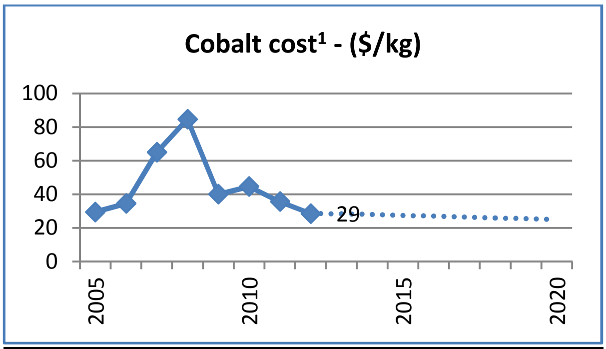
4.1. Specific energy increase in mAh/g

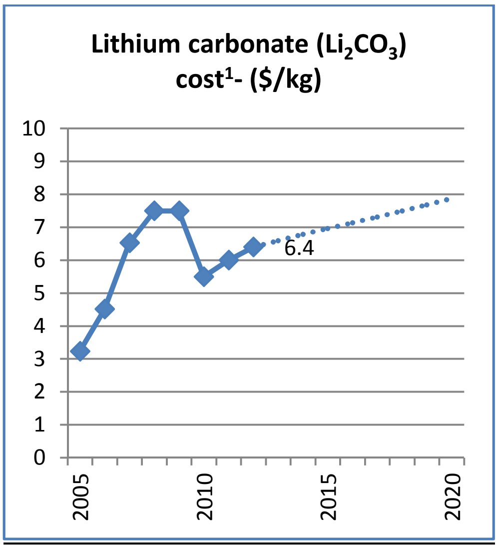


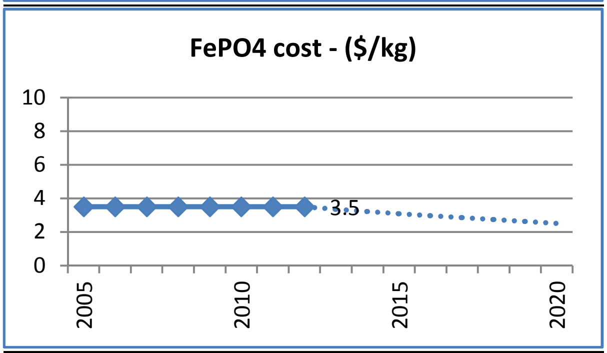
2012 – 2020 Average growth rate:

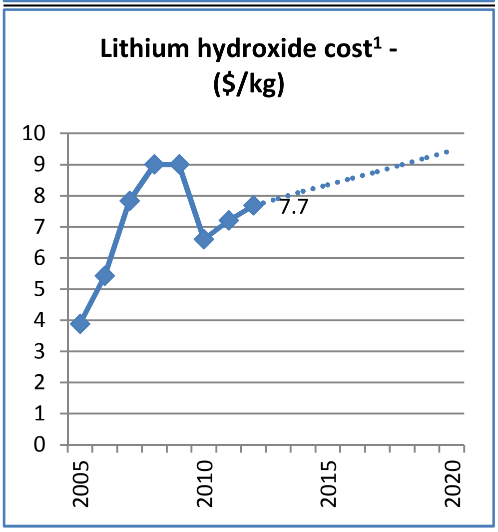
LCO: +1,7% - NMC: + 3%, - LMO: +1,4% - LFP: +1% - NCA: +3%

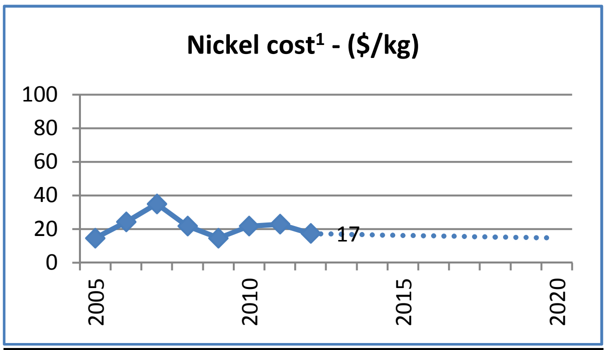
4.2. Raw materials











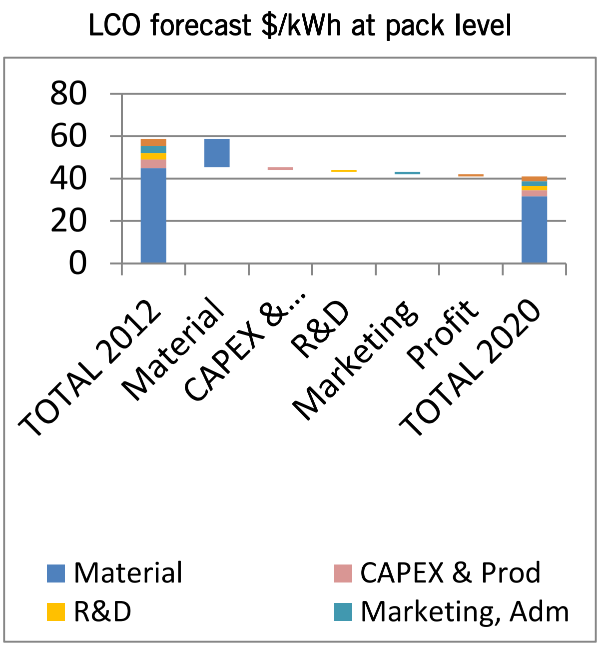
Source: LME, CDI, AVICENNE, Internal

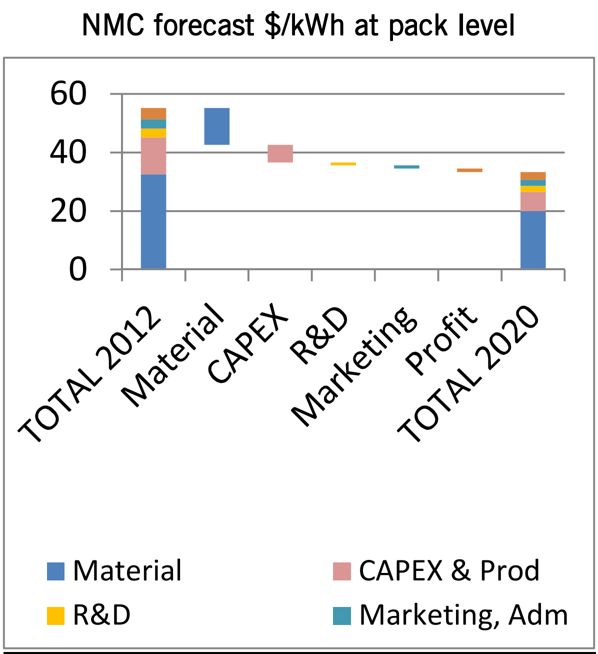
Source: FMC, Rockwood, SQM, Internal

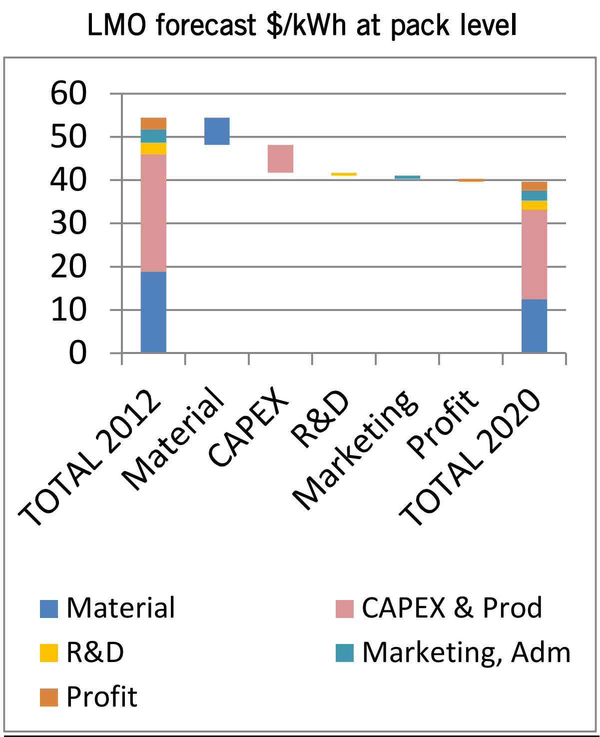
Note: 1- Battery grade average

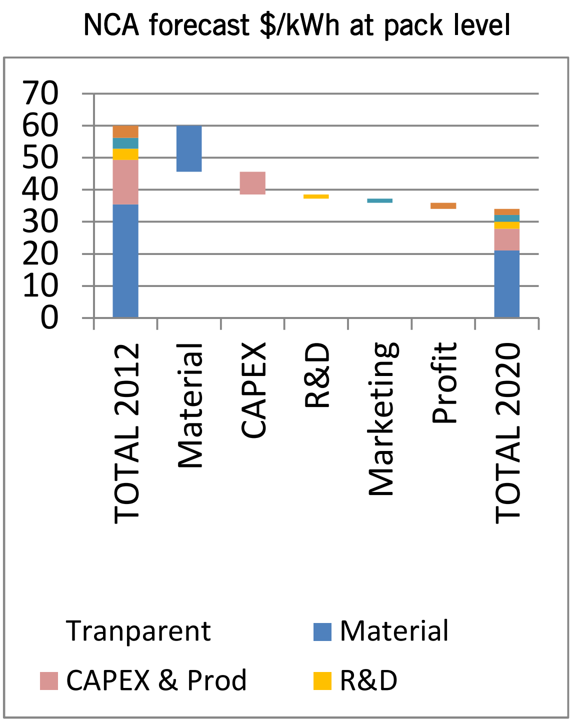
Manganese cost: stable at 4$/kg Mn over the concerned period.

4.3. Forecast 2020 in $/kWh at pack level per cathode material







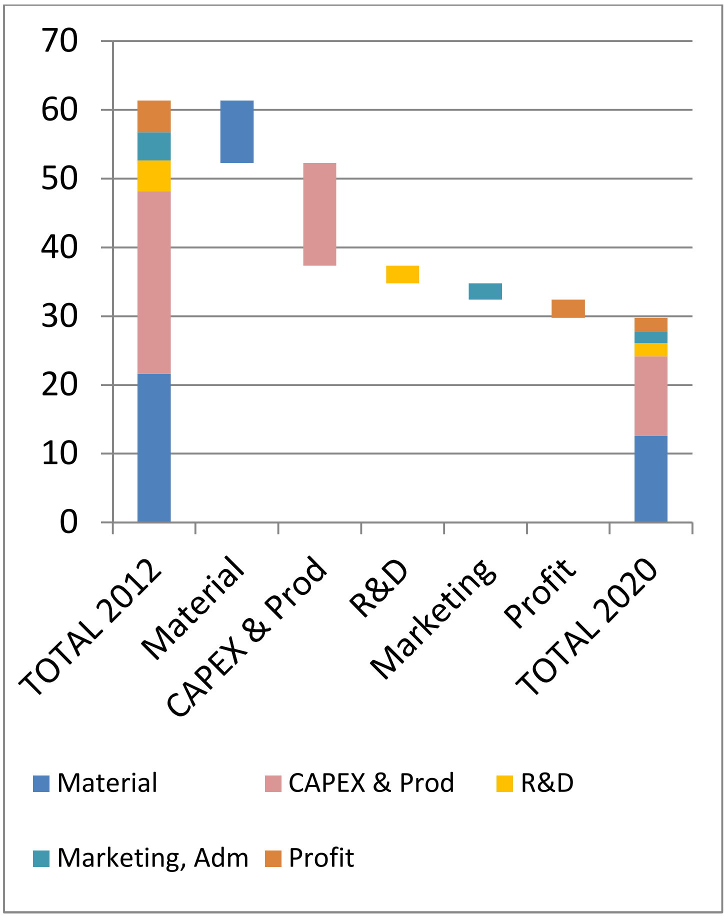


4.4. Forecast 2020 in $/kWh at pack level for LFP

4.4.1. Rationales

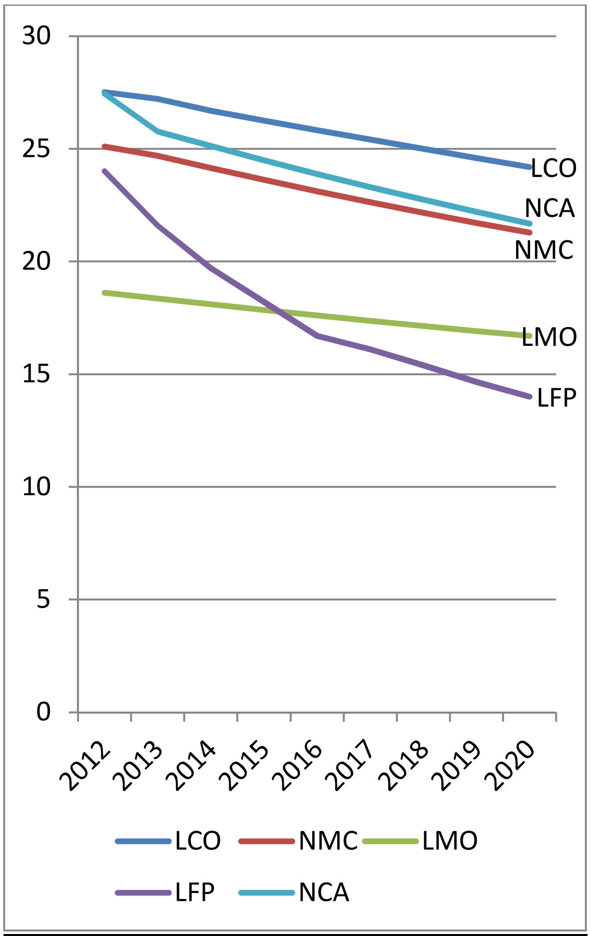
- Material price
  - Li: +3% per year from 2012 to 2020
  - Ni: -4% per year from 2012 to 2020
- Capacity: +1% per year from 2012 to 2020
- Capex & production cost: from 13$/kg to 6$/kg (-9% per year)
- Cell process yield: from 94% to 95%
- Pack process yield: from 87 to 95%

4.4.2. Forecast at pack level

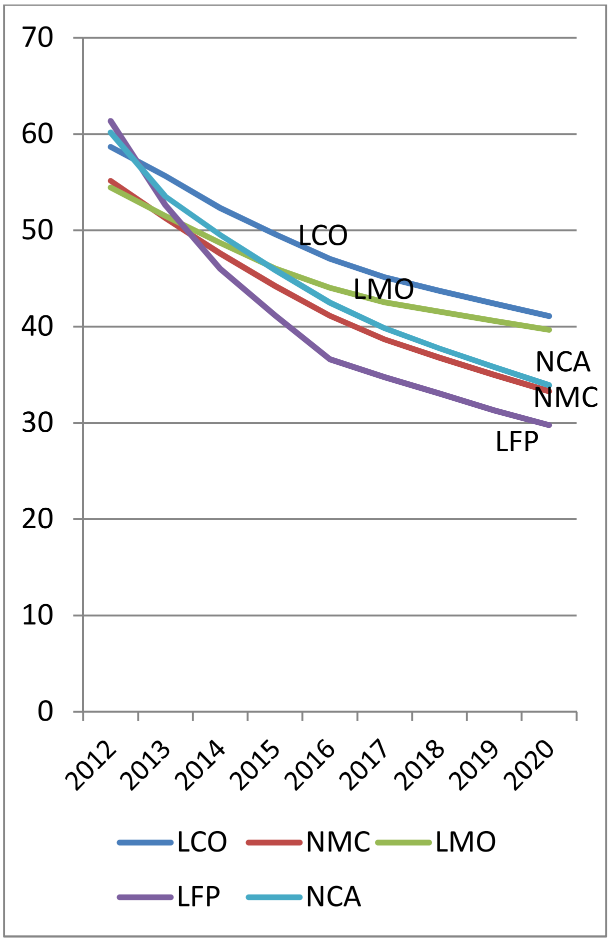


5. Conclusion

Cathode price forecast ($/kg)



Cathode price forecast ($/kWh) at pack level



Under usual reserve for long-term assumptions and in conclusion :

By 2020, LFP and its further evolutions will be comptetitive with the future generation NCM material specifically designed for full EV and probably become the bes-in-class in term of $/kWh but - linked with its lower specific energy capacity and voltage - will be more dedicated to large storage applications.

Acronyms:

LIB : Lithium Ion Battery
EV: Electrical Vehicle
ESS: Energy Storage System
LCO: LiCoO2
NMC: $Li(Ni_{0,33}Mn_{0,33}Co_{0,33})O_2$ or eq.
LMO: $LiMn_2O_4$
LFP: $LiFePO_4/C$ or eq.
NCA: $Li(Ni_{0,8}Co_{0,15}Al_{0,05})O_2$

With the support and advice of :