# Soft sensors to assess the energy consumption in the formation of lead-acid batteries

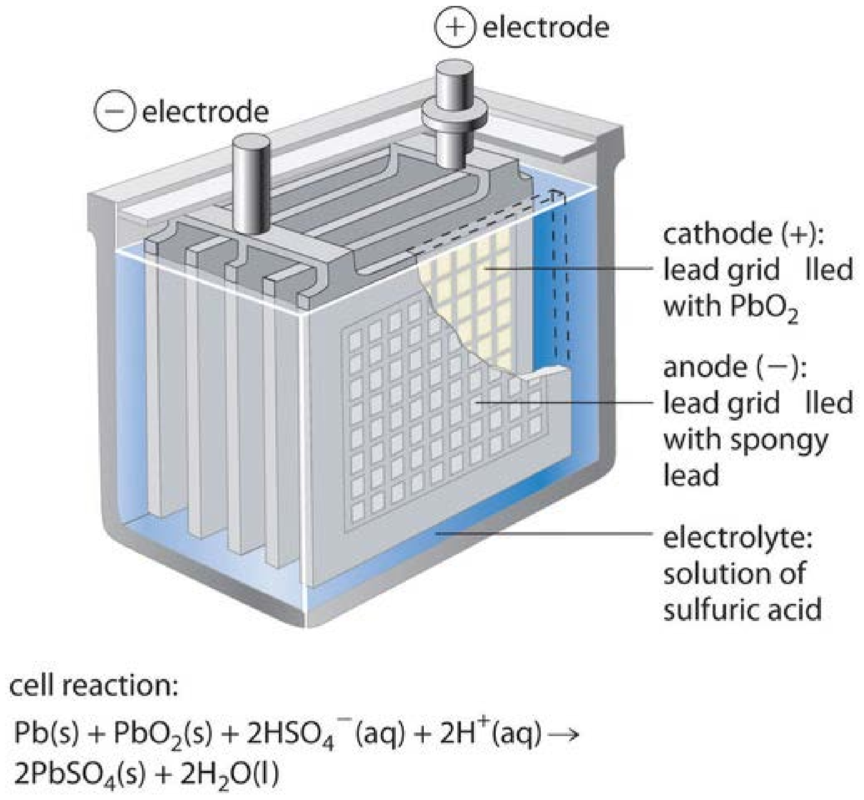
Dr. Alexis Sagastume and Dr. Juan José Cabello

Universidad de la Costa, Colombia

# Introduction

Lead-acid batteries:

- Energy intensive products;
- Essential for different economic activities;
- Limited discussion on how to assess energy consumption in battery manufacturing.

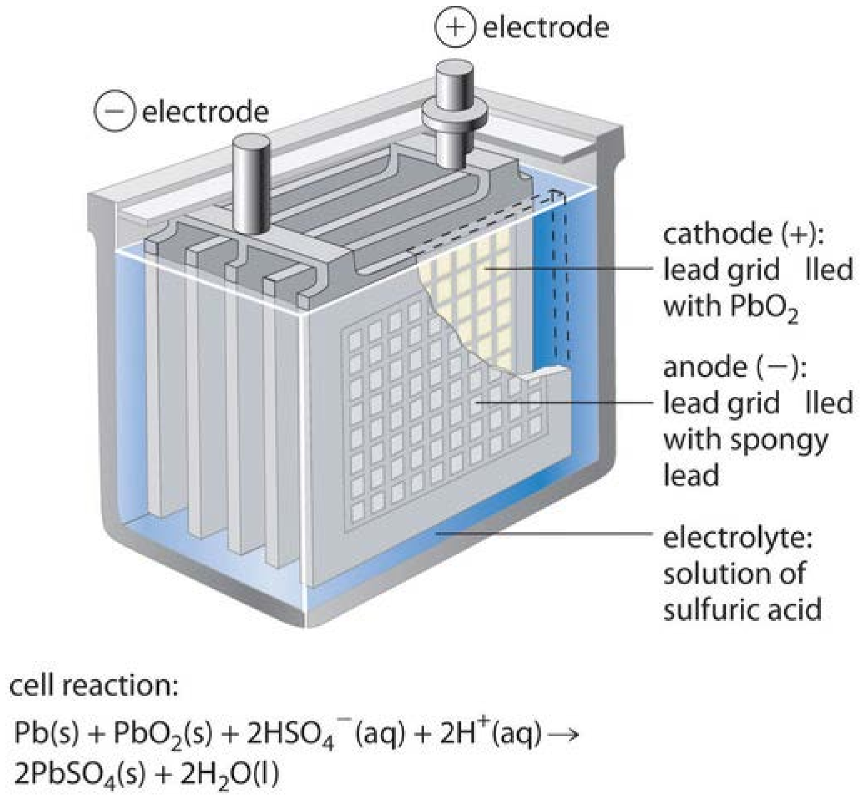



Source:
https://chem.libretexts.org/Textbook_Maps/General_Chemistry_Textbook_Maps/Map%3A_Chemistry%3A_The_Central_Science_(Brown_et_al.)/20%3A_Electrochemistry/20.7%3A_Batteries_and_Fuel_Cells

# Introduction

Lead-acid battery manufacturing:

- Grid manufacturing;
- Battery assembly;
- Battery formation: account for >50% of electricity used in battery manufacturing.




Source: https://chem.libretexts.org/Textbook_Maps/General_Chemistry_Textbook_Maps/Map%3A_Chemistry%3A_The_Central_Science_(Brown_et_al.)/20%3A_Electrochemistry/20.7%3A_Batteries_and_Fuel_Cells

# Battery formation

- Battery formation: defines the lifespan and the overall performance of battery;
- Intermittent charge regime (ICR): main algorithm used to control the electric current and voltage during battery formation;
- Intermittent charge regime (ICR): Requires de use of sensors for V, A, etc.

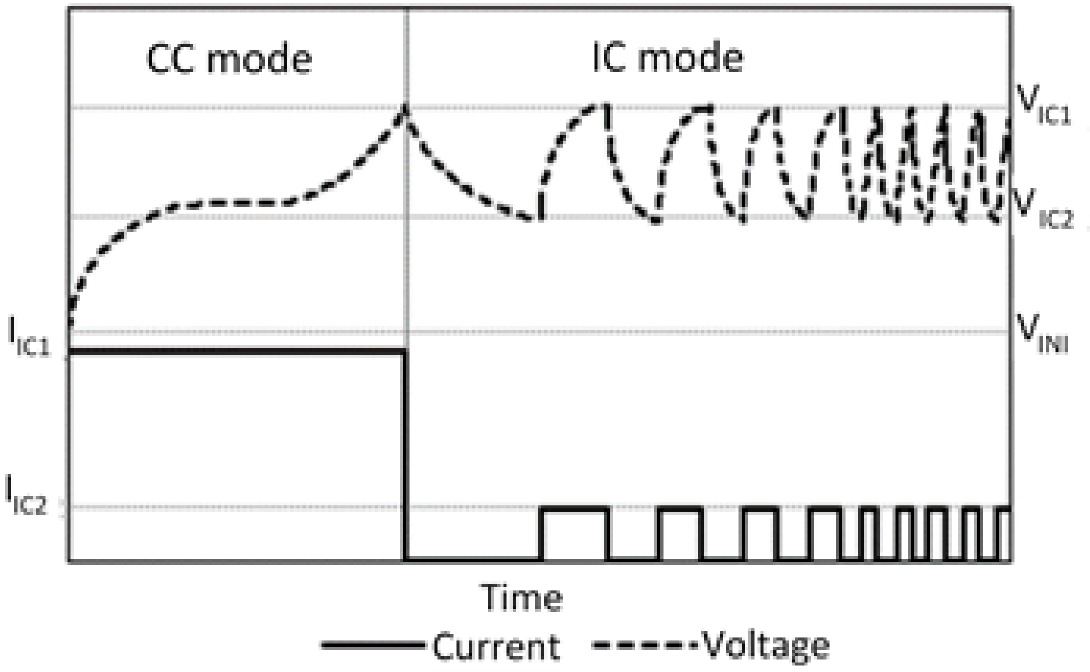



Fig. 1. Intermittent charge regime algorithm of battery formation.

# Battery formation

Formation circuit:

Energy balance battery batch subcircuit:

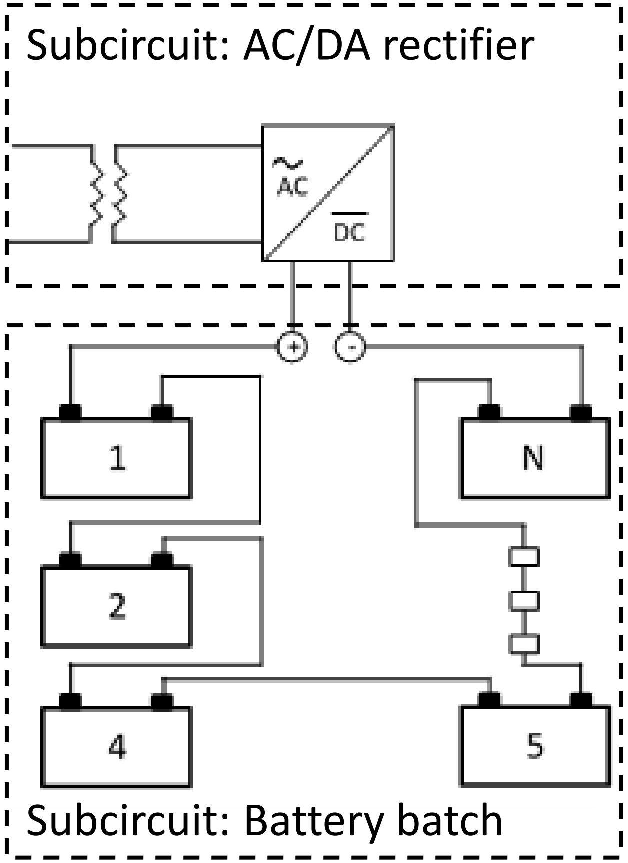
$$E_{BB} = E_{BF} + E_{LC} + E_{LB}$$

$E_{BB}$ – Electricity supplied to the battery batch subcircuit

$E_{BF}$ – Electricity used in the formation process

$E_{LC}$ – Energy loss in wires and connectors

$E_{LB}$ – Heat loss of the exothermal reactions




**Battery formation circuit**

# Battery formation

- $E_{BB}$ is calculated from measures of the current and voltage during battery formation:

$$E_{BB} = \int_0^t p(t) \cdot dt = \int_0^t V_{DC}(t) \cdot I_{DC}(t) \cdot dt$$

$$\downarrow$$

$$E_{BB} = \sum_{i=1}^{n} V_{DCi} \cdot I_{DCi} \cdot t$$

p – Power supply (W)

$V_{DC}$ – Voltage (V)

$I_{DC}$ – Current in the power supply line (A)

# Soft sensors (SSs)

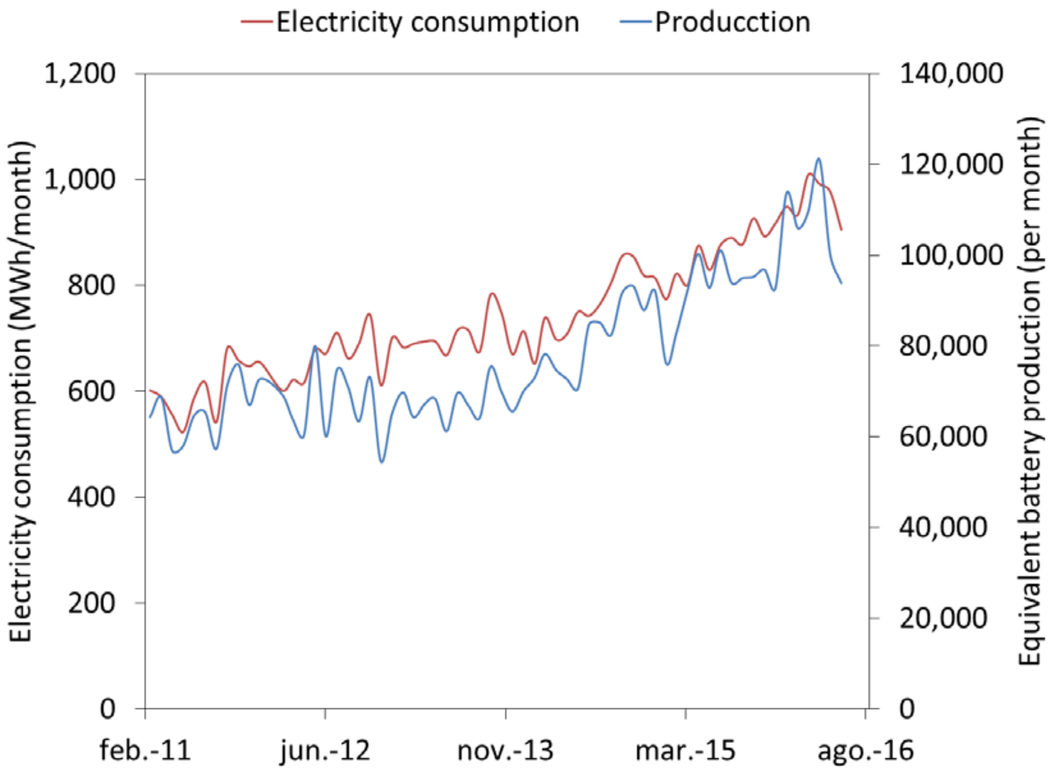
Some parameters are either too difficult or too costly to assess with sensors and instrumentation.

The development of SSs, based on available measures of other parameters, to be used in either statistical models or with natural laws and principles, are an alternative in this case.

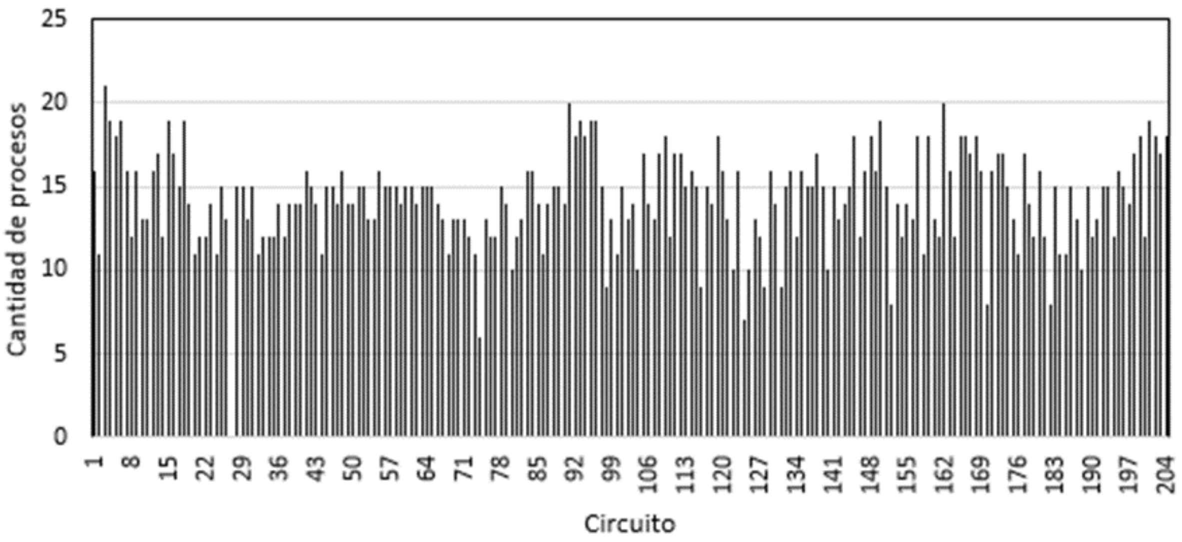
# Case study

Battery plant:

- Battery production increased a yearly average of 14% in the last years;
- Electricity consumption shows a similar growing trend;
- Battery formation → 53% of the overall electricity consumption (i.e. 480 MWh/month) ;



# Case study




- 204 battery formation circuits
- Batch of 18 batteries.
- Over 200 battery models
- 10,286 formation batches measured in the study.
- Random sample of 2,902 batches (98% confidence interval), used to develop different tools.

# Case study: Energy efficiency of battery formation

- Energy Performance Indicator (EnPI): ratio between electricity supplied to the battery batch subcircuit and the equivalent batteries:

$$\mathrm{EnPI} = \frac{\mathrm{E_{BB}}}{\mathrm{Q_B}}$$

Where:

$E_{BB}$ – Electricity supplied to the battery batch subcircuit

$Q_B$ - equivalent battery

# Case study: Energy efficiency of battery formation

Given the different battery models manufactured (i.e. different sizes and capacities), the concept of equivalent production (ISO, 2014), is used :

$$Q_B = P \cdot k_b$$

Where:

$Q_B$ - equivalent battery

P – Produced batteries

$k_b$ – Battery electric charge coefficient

# Case study: Energy efficiency of battery formation

- Battery electric charge coefficient:

$$k_{b-j} = \frac{C_{b-j}}{C_{bmin}}$$

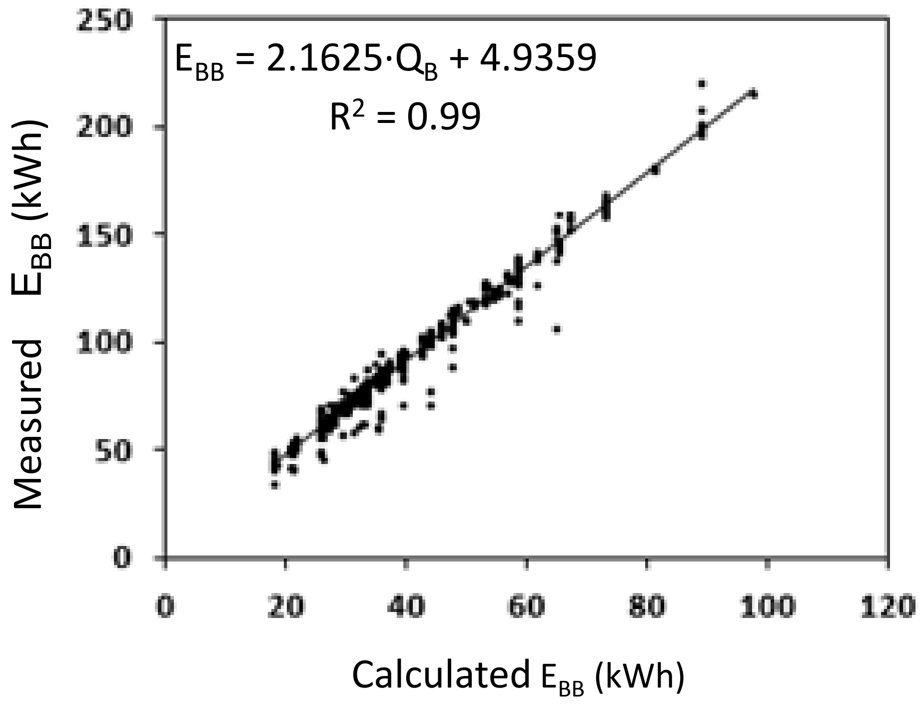
Where:

$C_{b-j}$ – Electric charge of the j^th^ battery model

$C_{bmin}$ – Electric charge of the smaller battery model

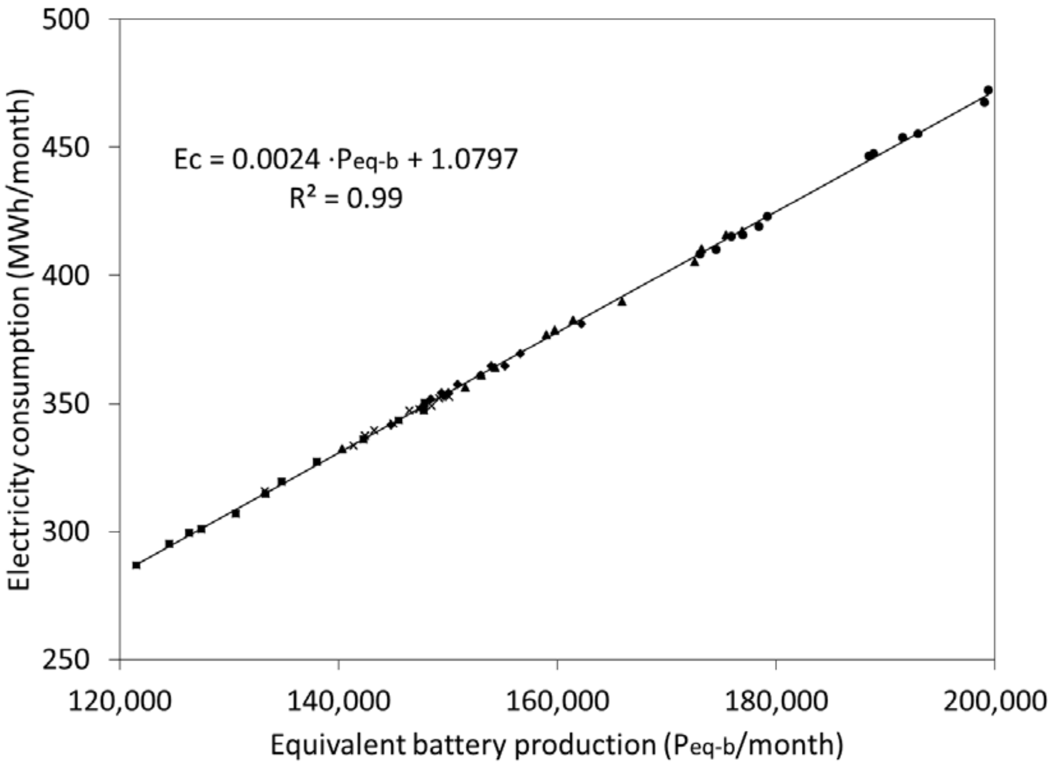
# Case study: EnPI

- It is not possible to measure the electric loss in the AC/DC rectifier.
- The measures make to control the formation algorithm can be used to calculate $E_{BB}$.



# Case study: Energy baseline

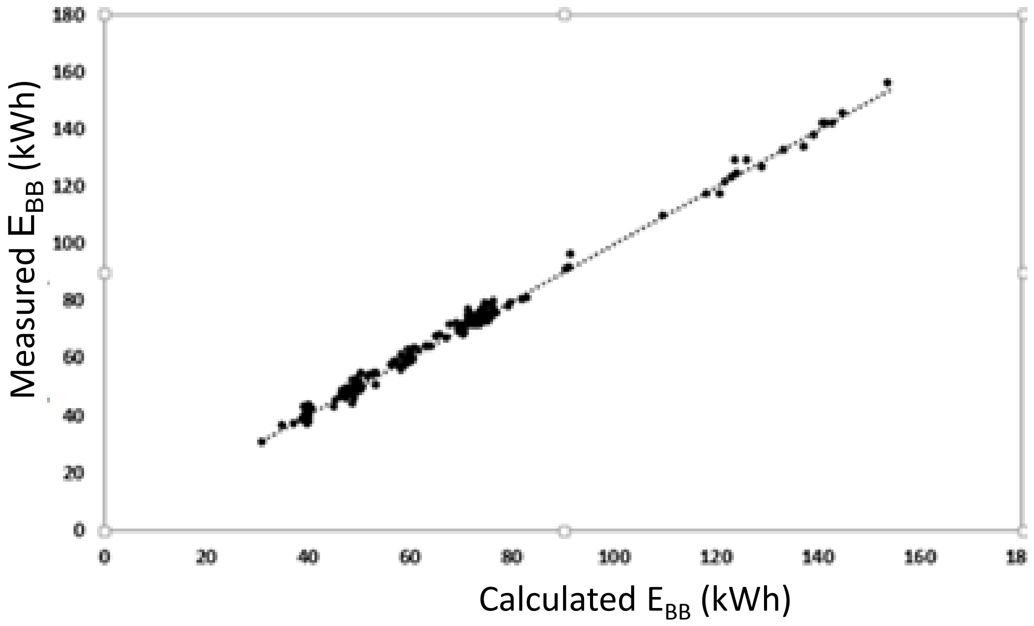
Energy baseline: to forecast electricity consumption as a function of battery production (recommended by ISO 50001)



# Case study: Soft sensor

Soft sensor:

- Developed to calculate $E_{BB}$ and the EnPI with measurements from the battery batch subcircuit.
- Calibrated by using direct measures from a network analyzer



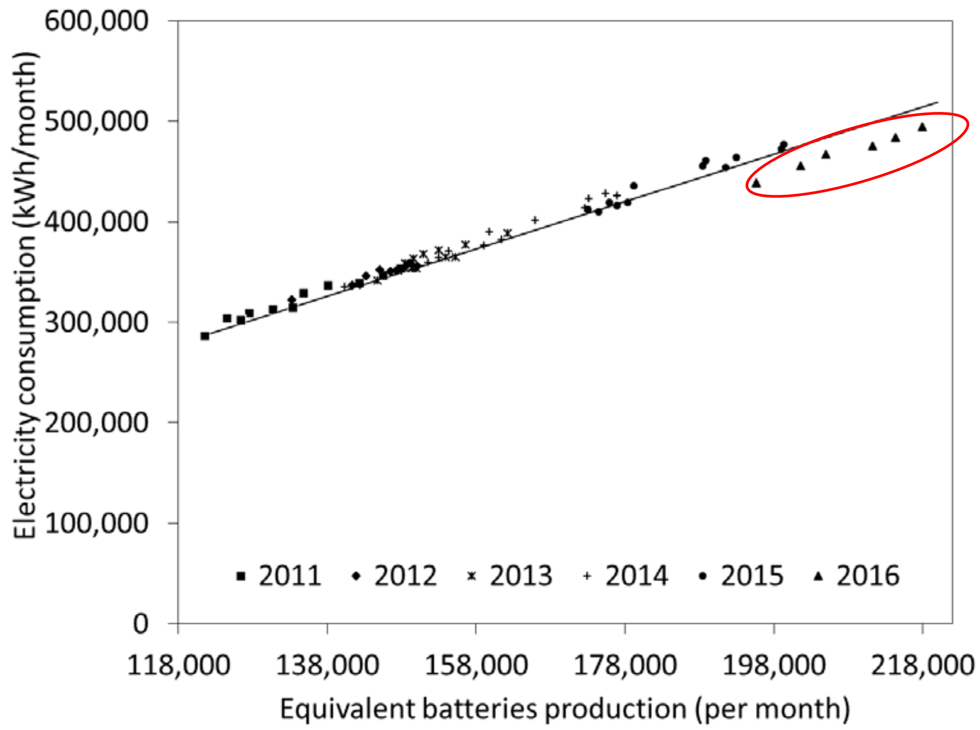
# Case study: Implementation (January - May, 2016)

EnPI: allows to assess trends of electricity efficiency at different levels:

- Formation circuit level: allows to quickly identify efficiency loss and malfunctioning of sensors on the formation circuits → Rapid implementation of corrective measures.
- Operational staff level: measures the EnPI for the formation processes developed by each operative staff team → Rapid detection of malpractices.
- Management level: measures the monthly average EnPI of the formation section → support the process of decision making by the plant managers.

# Case study: Results

- Battery production increased in 2016
- Electricity consumption of battery formation increased in 2016
- Electricity consumption of battery formation decreased some 3 to 5% as compared to the calculations from the energy baseline.
- Average savings of 20,6 MWh/month were achieved
- Six months implementation → savings of 124,1 MWh.



Thank you