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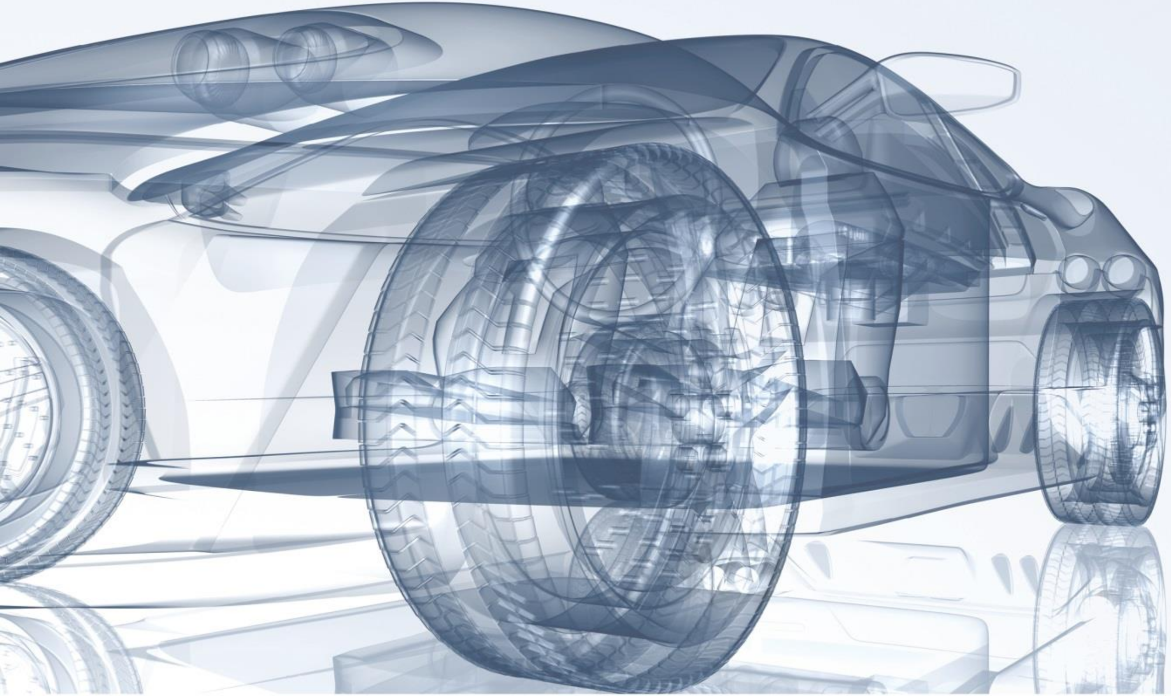

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Electrochemical Capacitor Powered Automated Guided Vehicles (AGVs)

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Presenter: Toshihiko Furukawa United Chemi-Con/Nippon Chemi-Con Group

Contents

1. Introduction

- Improve efficiency of manufacturing and warehousing
- Reduce labor cost
- Provide overall economic benefit
- Electro Chemical Capacitor energy technology was implemented
  1) Over 1,000,000 cycles
  2) Maintenance free
  3) Safe and environmentally friendly
- Maximum carry-able weight is approx.,500Kg (System: 50Kg)
  1) 30m/min,20m/min(medium speed), 4m/min (low speed)
  2) The original energy technology was 65Ah Pb-battery
  3) Magnetic tape guide

2. The basic System

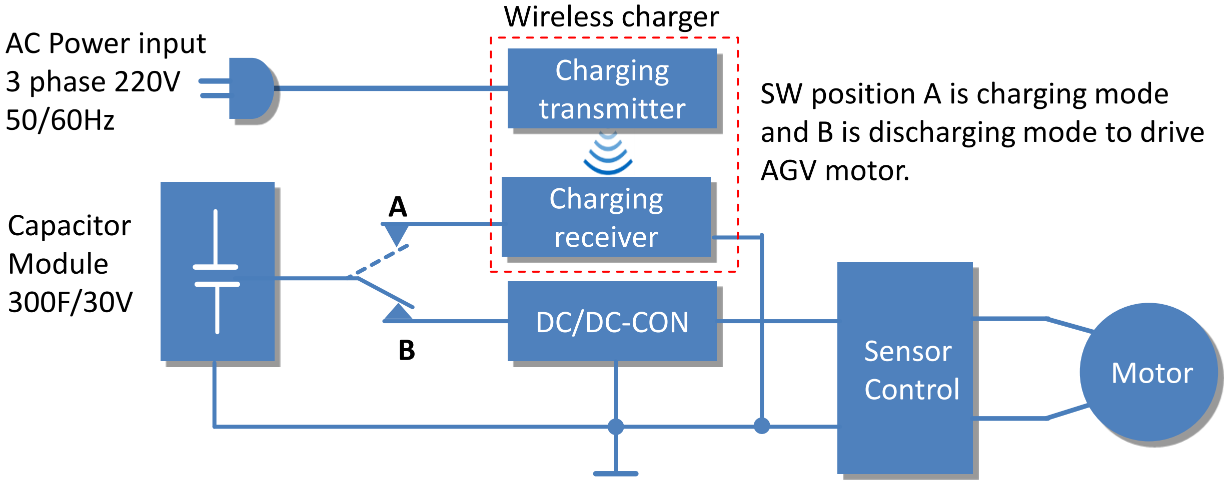

Figure 1: Block diagram of the capacitor energy storage system used to power the AGV. Wireless charging takes place at a base station in the factory. Switch position **A** is for charging the capacitor module and position **B** is for AGV operation.

3. Electrochemical Capacitor Powered AGV

Maximum carry-able weight is approx.,500Kg (System: 50Kg)

1) 30m/min,20m/min(medium speed), 4m/min (low speed)

2) CAP module was designed to provide 2.5 round trip (93m)

3) Average load of 325Kg

Wireless charging receiver

DC motor to drive AGV is mounted under this

Figure2. Photograph of capacitor-powered AGV located at the Nippon Chemi-Con factory in Nagaoka, Japan.

Figure 3: Electrochemical capacitor module used to power the AGV. Twelve model DXE 3600-F Nippon Chemi-Con electrochemical capacitors are connected in series. The module is rated at 30 V and can deliver ~100 kJ (28 Wh) with discharge to 15 V.

3.1 Driving profile of round trip

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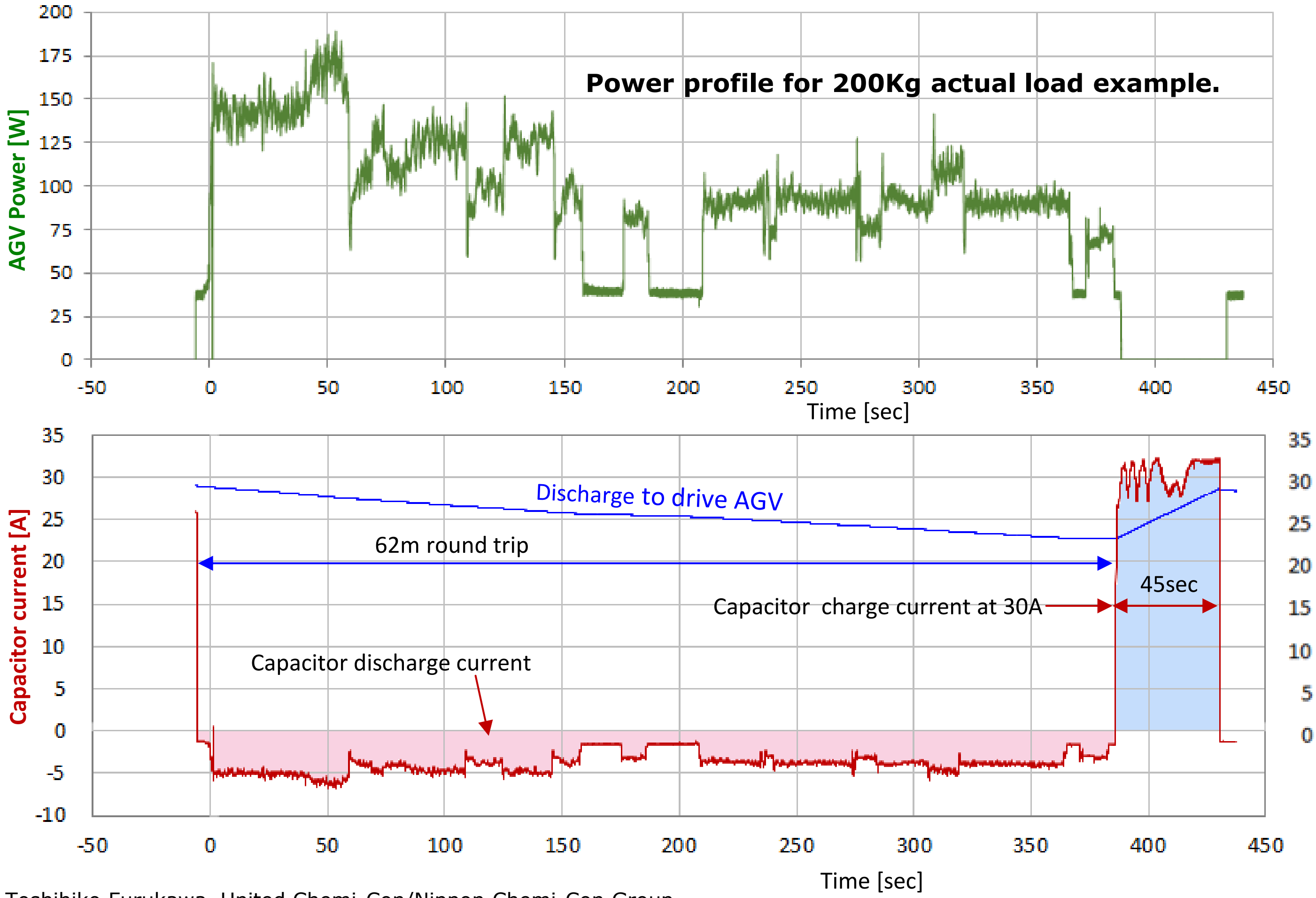

Figure-4. AGV power profile is shown in the upper graph and capacitor module voltage and current is shown in the lower graph. With 30-A current, the capacitor module is charged from 22.5 V to 28 V in ~45seconds (blue shaded region).

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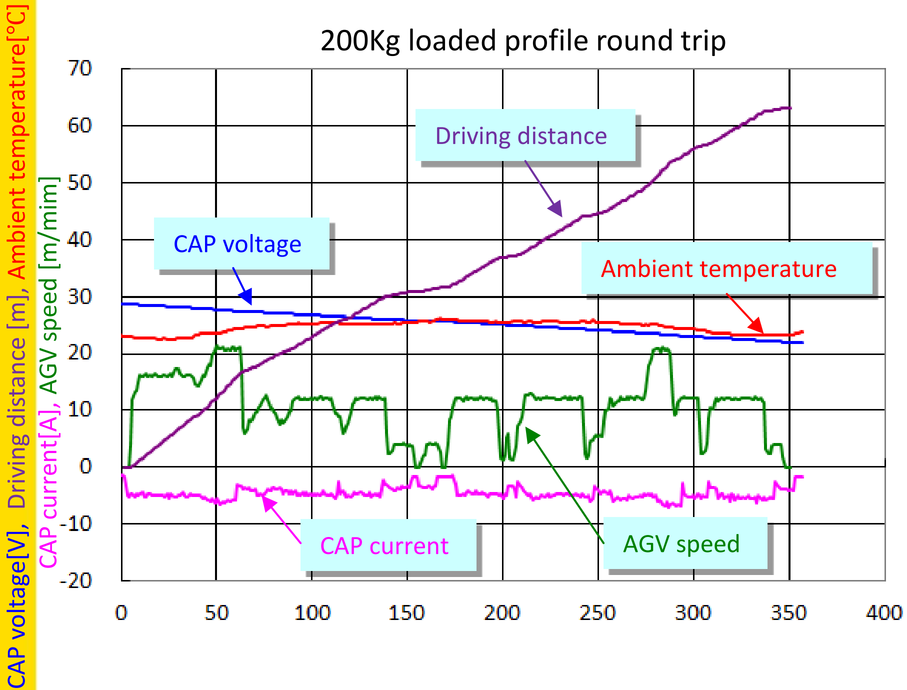
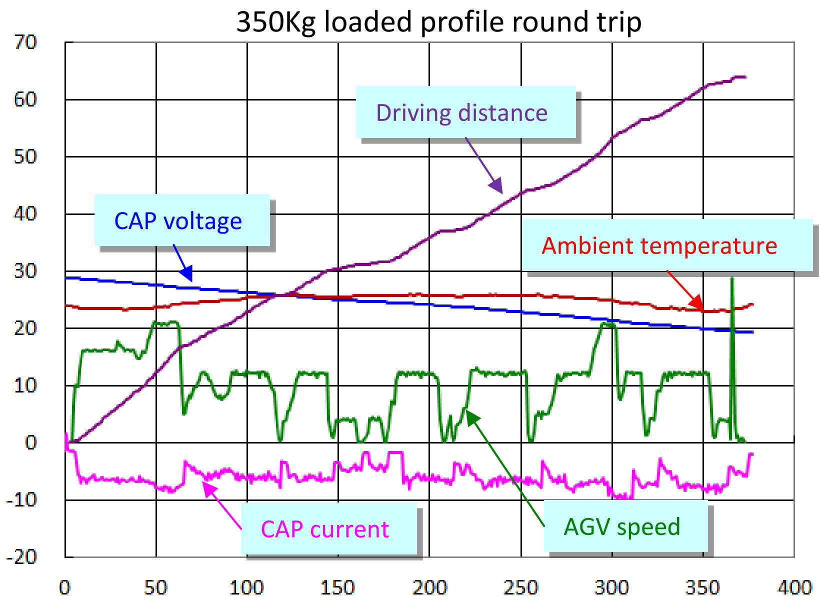
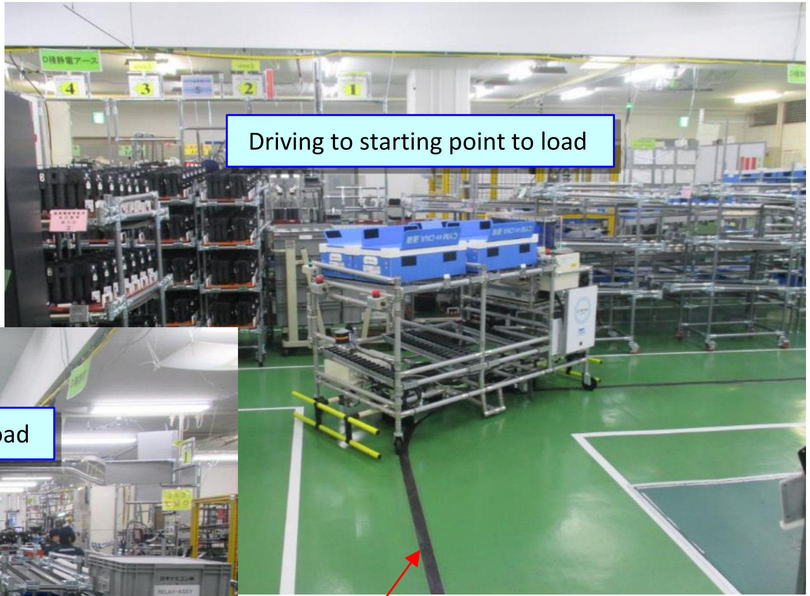
3.2 Loaded profile comparison examples of 200Kg vs 350Kg





2.3 AGV is working in Nippon Chemi-Con Nagaoka manufacturing facility



Magnet tape to guide

4. Life Analysis

4.1 Cycle life at room temperature

4.2 Cycle life at Elevated Temperature

4.1 Cycle life at room temperature

The life expected for an AGV is 10 years during which time its energy storage system may be charge/discharge cycled 350,000 times. Assuming continuous AGV operation seven-day-a-week with four charge/discharge cycles every hour.

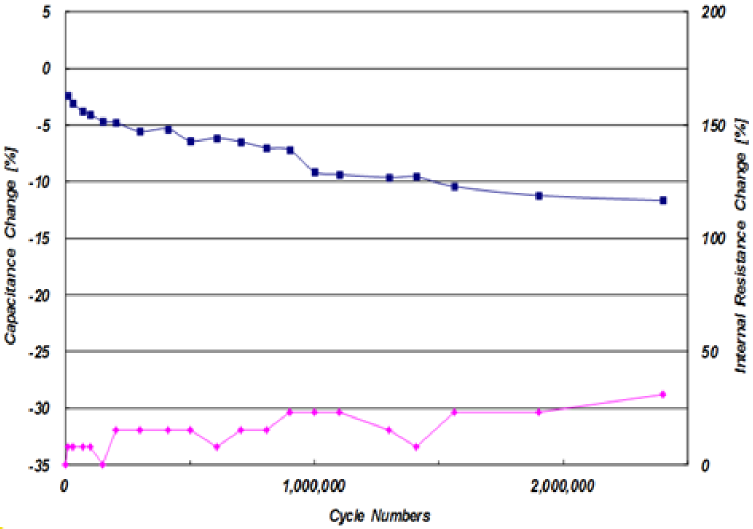


Figure 5: Room-temperature electrochemical capacitor cycle-life. As shown, stored energy fade was <12% after 2,000,000 cycles. Source: Nippon Chemi-Con electrochemical capacitor test data similar to the type used in the AGV.

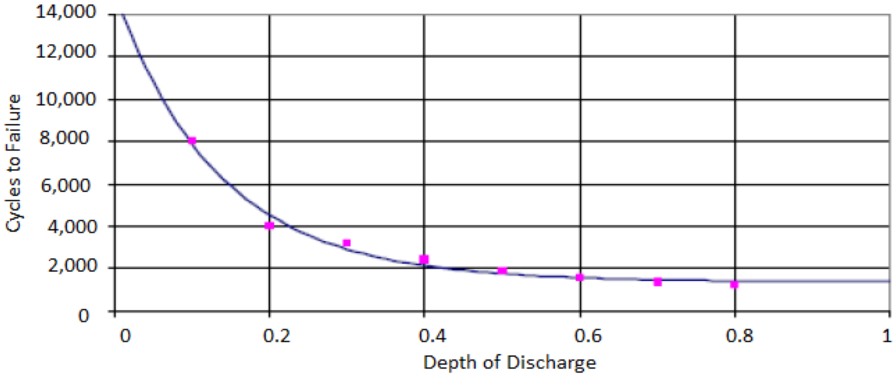


Figure 6: Typical cycle life performance of a lead acid battery at room-temperature, which shows that high cycle life requires shallow depths of discharge. However, this correspondingly reduces its effective energy density.
Source:
http://www.powerthru.com/documents/The%20Truth%20About%20Batteries%20%20POWERTHRU%20White%20Paper.pdf

4.2 Cycle life at Elevated Temperature

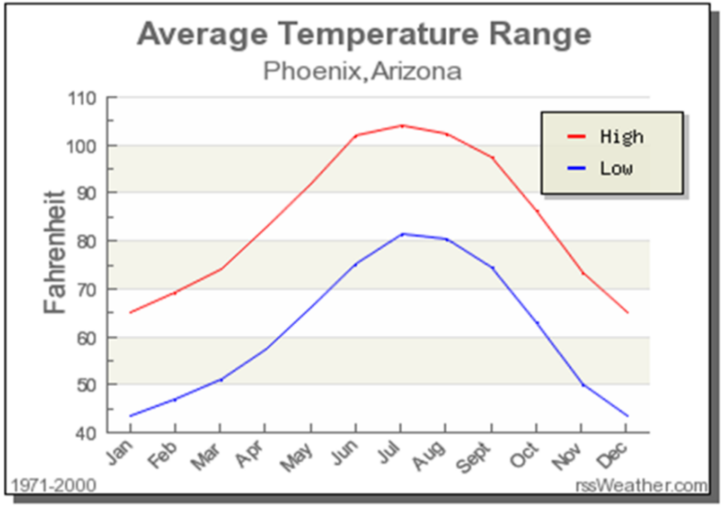


Figure 7. Average temperature distribution for YR 1971 to 2004
Source:[2] http://www.rssweather.com/climate/Arizona/Phoenix

Electrochemical capacitors(ECs) has strong temperature dependability. Some warehouse space may have the high temperature environment. **Figure 7** shows average high and low temperatures over one year in Phoenix, Arizona, USA, a local known for its hot climate. As shown, the average high temperature peaked at 104F (40℃) in July. ECs life should be considered for environment with additional self heating, ΔT caused by heat power of I*ESR.

The calculated self heating:

$$\Delta T = \left(7.5\ {}^{o}C/_{W}\right) * (10.3\ A)^2 * (0.27\ mOhm) = 0.2\ {}^{o}C$$

ΔT can be ignored in ECs life calculation.

Table I: Approximation of the Figure 7 average high-temperature plot. During one year (8760 hours), 3600 hours would be at 20 ℃, 2280 hours at 30 ℃, and 2880 hours at 40 ℃.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Highest (℃)	18.3	20.8	23.5	28.3	33.3	38.9	40.1	29.1	36.3	30.2	22.9	18.3
Approximation (℃)	20			30		40				30	20	

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Predicted life

Table II. Life estimates at each of the three temperatures of the simplified temperature profile. Also listed is R_n, which is the ratio of time at each temperature T to the time in one year. *1) Rn=3,600/8,760=0.41 of year.

Month	Jan.-Mar. Nov.-Dec.	Apr-May, Oct.	Jun.-Sep.
Estimated Number of hours (Ln)	3600 hrs	2280 hrs	2880 hrs
Ambient temperature (≒cell temperature)	20 ℃	30 ℃	40 ℃
Life at each stress Ln (⊿C : -30%)	120,500	88,140	65,760
Ratio to total hours (Rn)	0.41	0.26	0.33

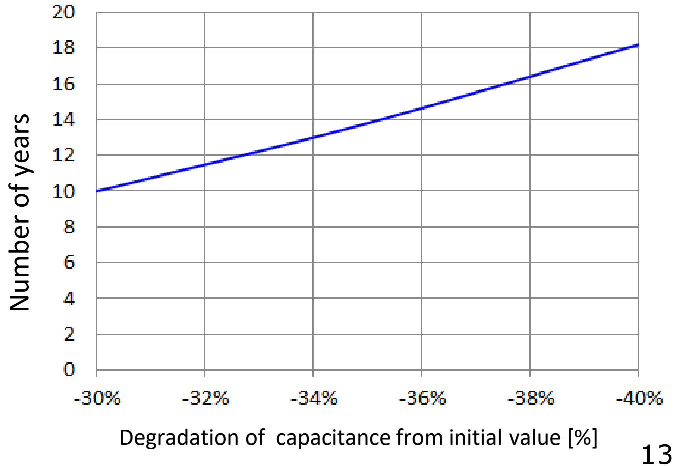
The typical way to calculate the life under different ambient temperatures is to apply the Miner's Rule, which describes cumulative damage when different levels of stress are applied. For life predictions the rule is described as:

$$\frac{1}{L} = \sum_{n=1}^{n} \frac{Rn}{Ln}$$

At -30% of capacitance:

$$L = \frac{1}{\left(\frac{0.41}{120500} + \frac{0.26}{88140} + \frac{0.33}{65760}\right)} = 87{,}950\ hours \approx 10\ years$$

At -40% of capacitance: ≈ 18 years



5. Economic Discussion

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Advantage of EC's powered AGV system is a long term cost performance.

- ❖ **Maintenance free, No replacement**
- ❖ **Over million cycle life, >2 million cycles**
- ❖ **Rapid charge in second level, 45 sec charge**

Table III: Cost comparison of the two energy storage technologies. Costs have been converted to US dollars.

TECHNOLOGY	Storage device cost ($)	Charger cost ($)	Maintenance cost ($)
Electrochemical capacitor	1,100[3)]	5,500[3)]	0
Lead-acid battery	650[1)]	420	830[2)]

[1)] Battery life is assumed to be 1.5 years. Labor costs for battery change-out are included.
[2)] Labor costs are associated with battery swapping and charging that is assumed to occur each day.
[3)] Wireless charger and Capacitor module are expensive.

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Running costs comparison ECs vs Pb-Battery

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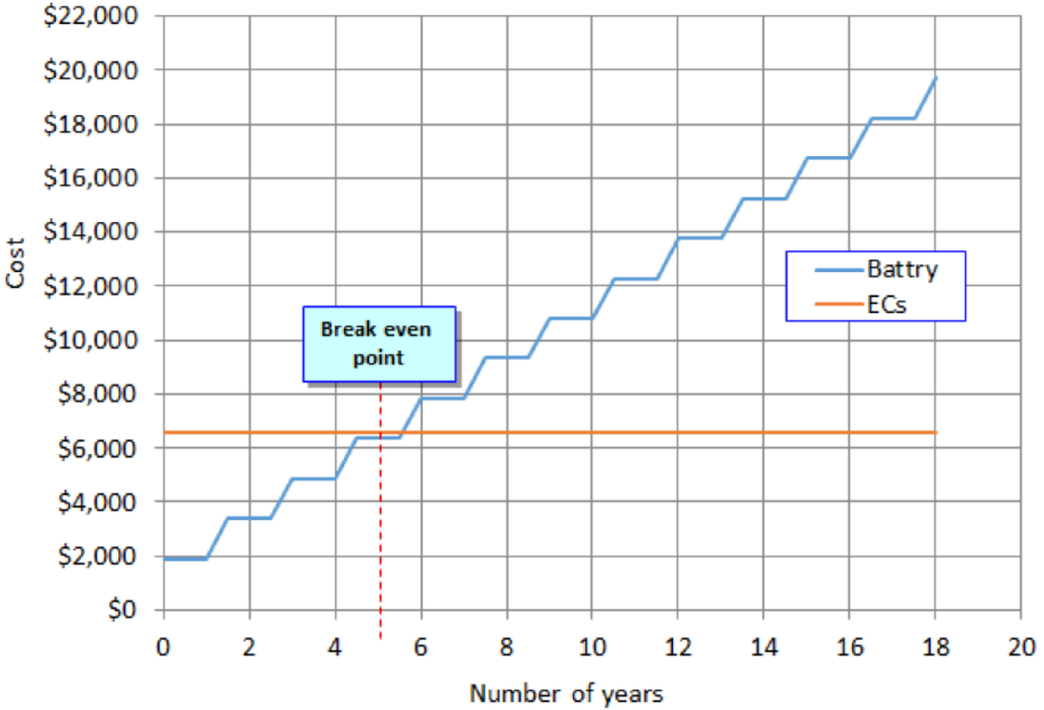

Figure 8: Predicted running cost for two energy storage systems used in an AGV—one using electrochemical capacitors and the other using lead acid batteries. The capacitor is wirelessly charged and operates maintenance-free for 18 years. Thus, its sole cost is the initial purchase. The battery, on the other hand, needs daily maintenance plus replacement every 1.5 years

The practical example of cost comparison at the user

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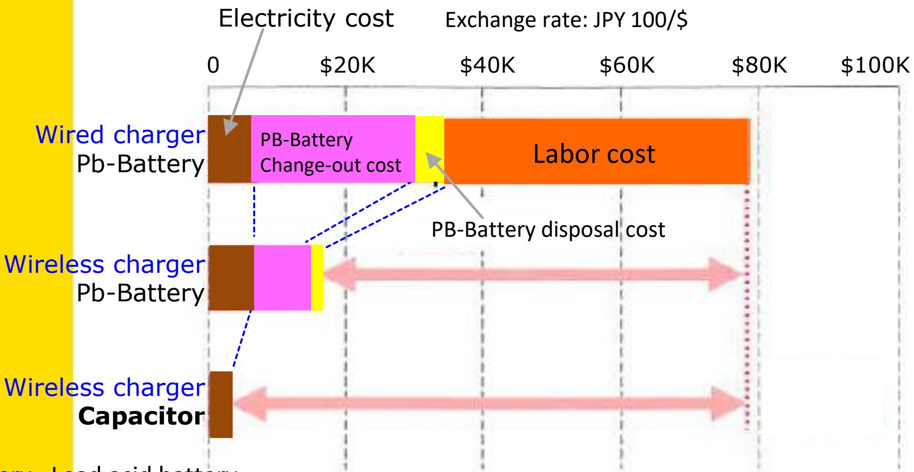
Source: AGV wireless charger system development and EDLC by Y.Tsuruda, DAIHEN Corporation presented at The Committee of Capacitor Technology/The Electrochemical Society of Japan on June-23rd 2017

- **AGV system: 1ton carriable 9 systems**
- **Operating hours: 8 hours, 3 shift, 24 hours continuous**
- **Charger station: 4 locations**



Pb-Battery : Lead acid battery

Figure 9. Operating cost comparison

Translated in English from the original version of Japanese

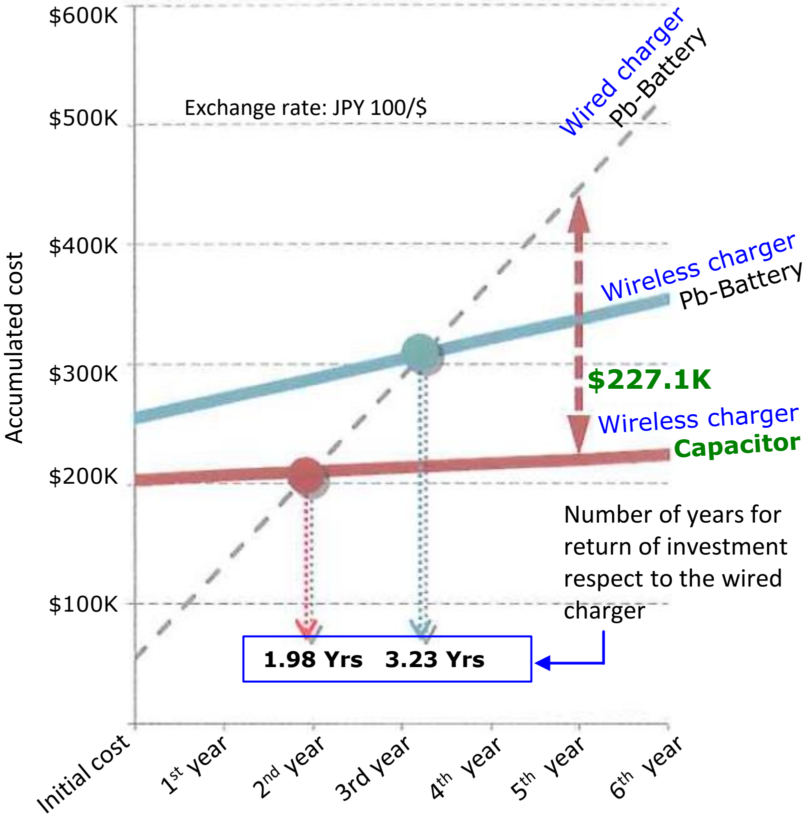


Figure 10. Return of Investment

Translated in English from the original version of Japanese

6. Summary

- **AGVs powered by Electrochemical Capacitors have lower long-term ownership costs than those powered by batteries.**

- **24 hours continuous operation could make less than 2 years return of investment.**

- **The cost break even point of batteries vs Capacitors for 8hrs/day operation could be 5 years or less.**

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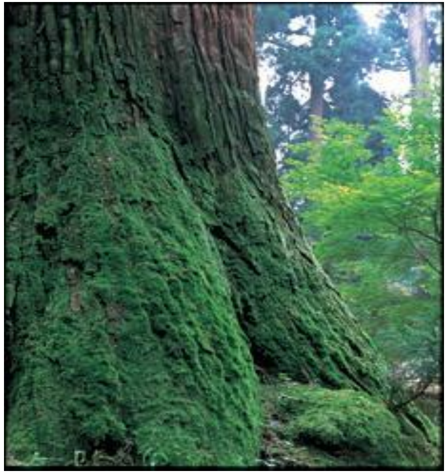

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