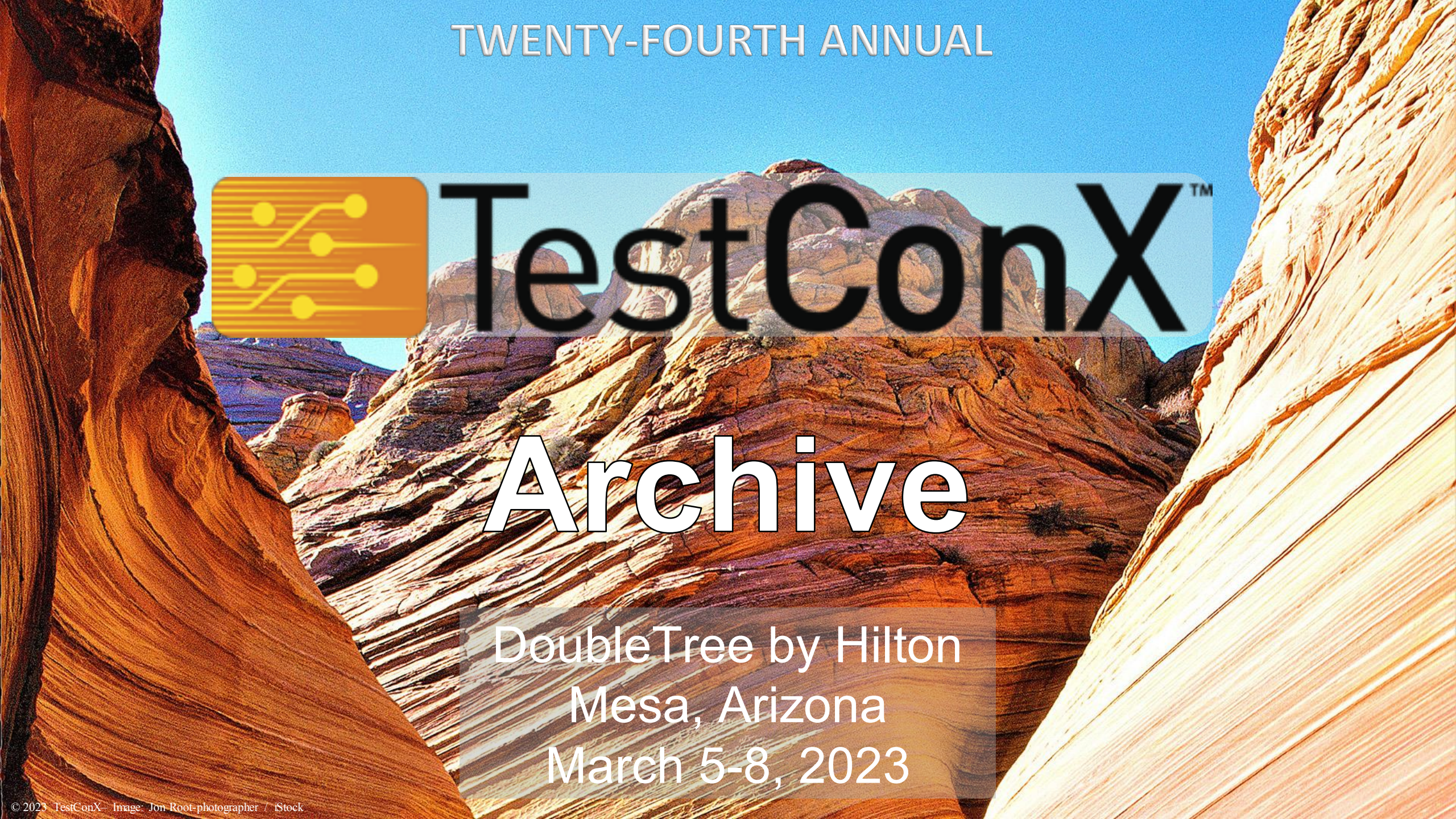

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Li-ion Cell Formation and Test Overview

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Taras Dudar
Texas Instruments

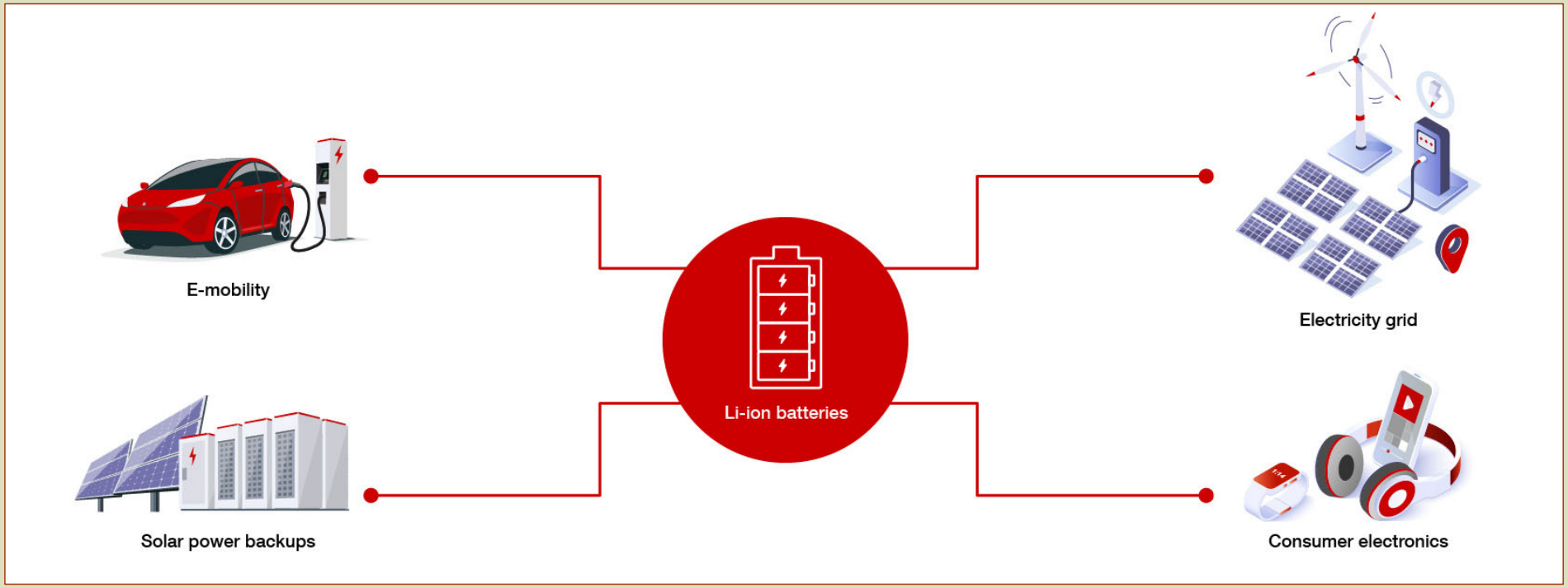
Mesa, Arizona • March 5–8, 2023

Agenda

Contents

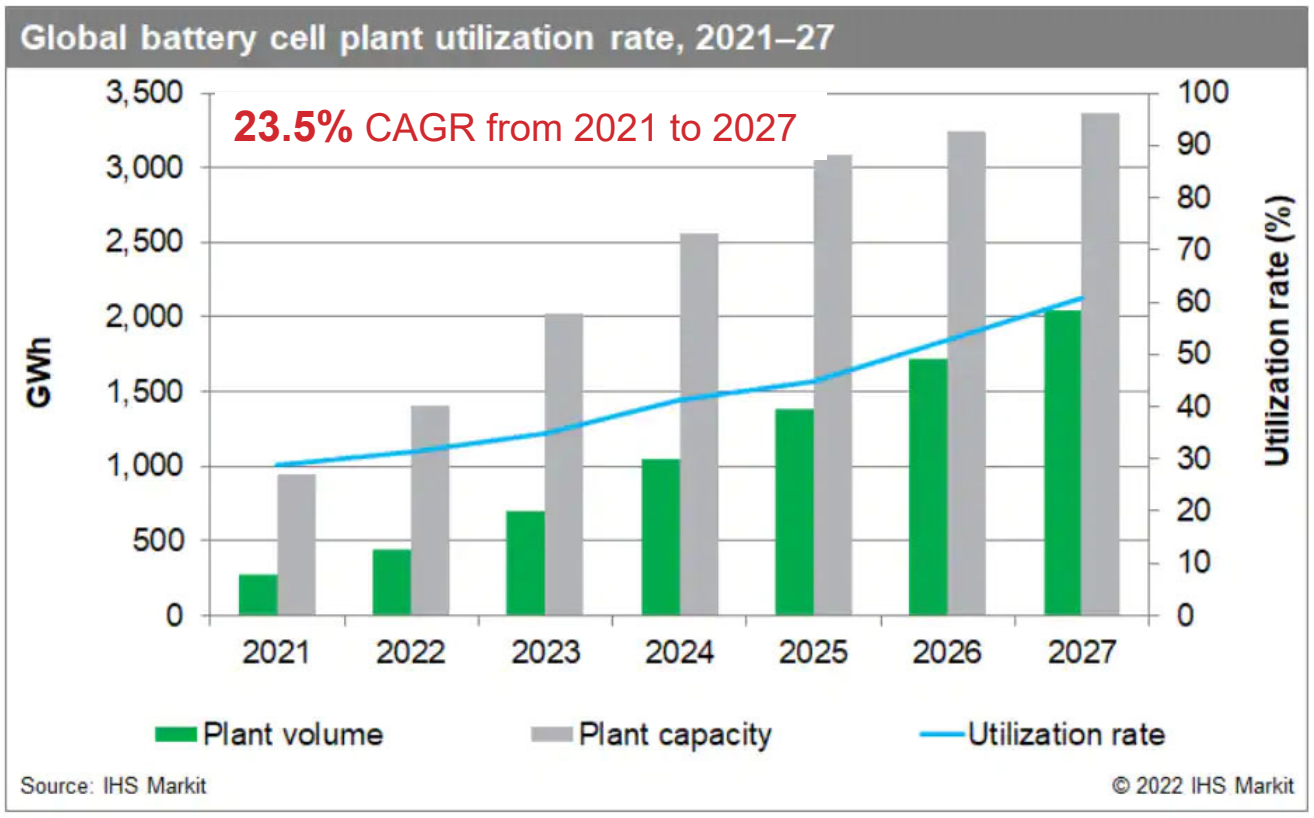
- Li-ion battery applications and manufacturing process
- Test requirements
- Methods to reduce cell production cost

Li-ion Battery Applications



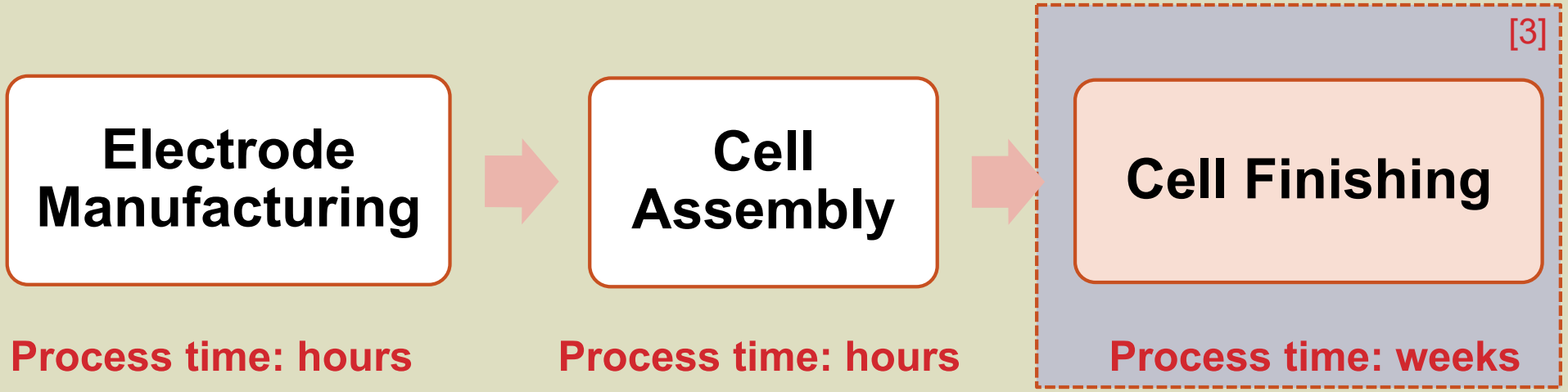
Source: Texas Instruments

Li-ion Battery Production Growth



Source: www.spglobal.com

Li-ion Cell Manufacturing Process



Cell finishing takes **longest time,** and can cost about **~30%** of the total manufacturing cost [3].

Cell Finishing - Formation, Aging and Test

[5]

Formation

- Precise charge & discharge control
- Duration: 24h
- DC internal resistance test (DCIR)
- Battery test system(BTS)
- *Equipment cost: ~$100M

Aging

- Cells undergo high temperature & normal temperature aging
- Open circuit voltage (OCV) is measured at regular intervals to estimate self-discharge rate
- Duration: 3weeks
- *Equipment cost: ~$15M

End-of-line Test

- Charge & discharge cycling, self discharge measurement, internal short check, pulse test
- Duration < 24h
- BTS
- *Equipment cost: ~$9M

Duration: Aging> Formation > Test

Cost: Formation> Aging> Test

*Study by the Aachen University, Germany

For approx. 25Ah, 45M cells/y, 4GWh/y annual capacity

Li-ion cell formation and test overview

BTS Specifications for >1Ah Cells

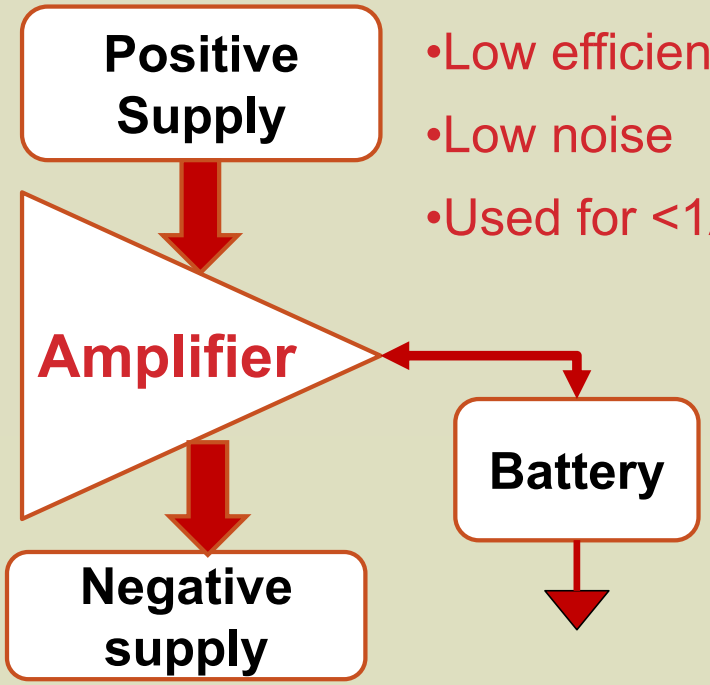
- Output voltage range : 0V to 5V
- **Bidirectional output current**
  Typical ranges : 10A/50A/100A/200A
- **High channel count**
- **Smooth constant current (CC) to constant voltage (CV) mode transition**
- **Current & voltage regulation < ±0.02% of full scale range**
- Measurement accuracy: ±0.02% of Full-Scale at ±5°C
- **High energy recycling efficiency >70%**

Picture of a BTS

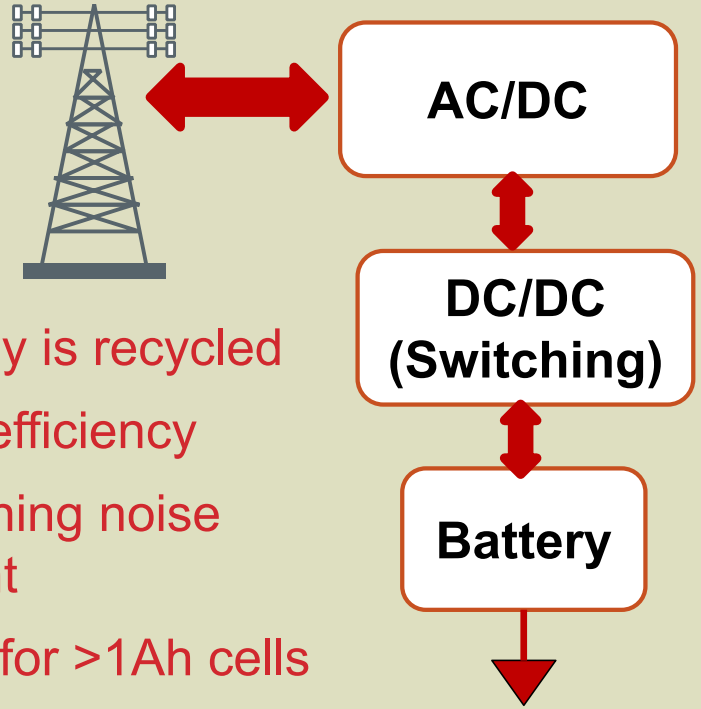
Why not ATE for battery manufacturing?

Using semiconductor ATE DC supply

- No energy recycling
- Low efficiency
- Low noise
- Used for <1Ah cells



Battery testing using BTS



- Energy is recycled
- High efficiency
- Switching noise tolerant
- Used for >1Ah cells

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Li-ion cell formation and test overview

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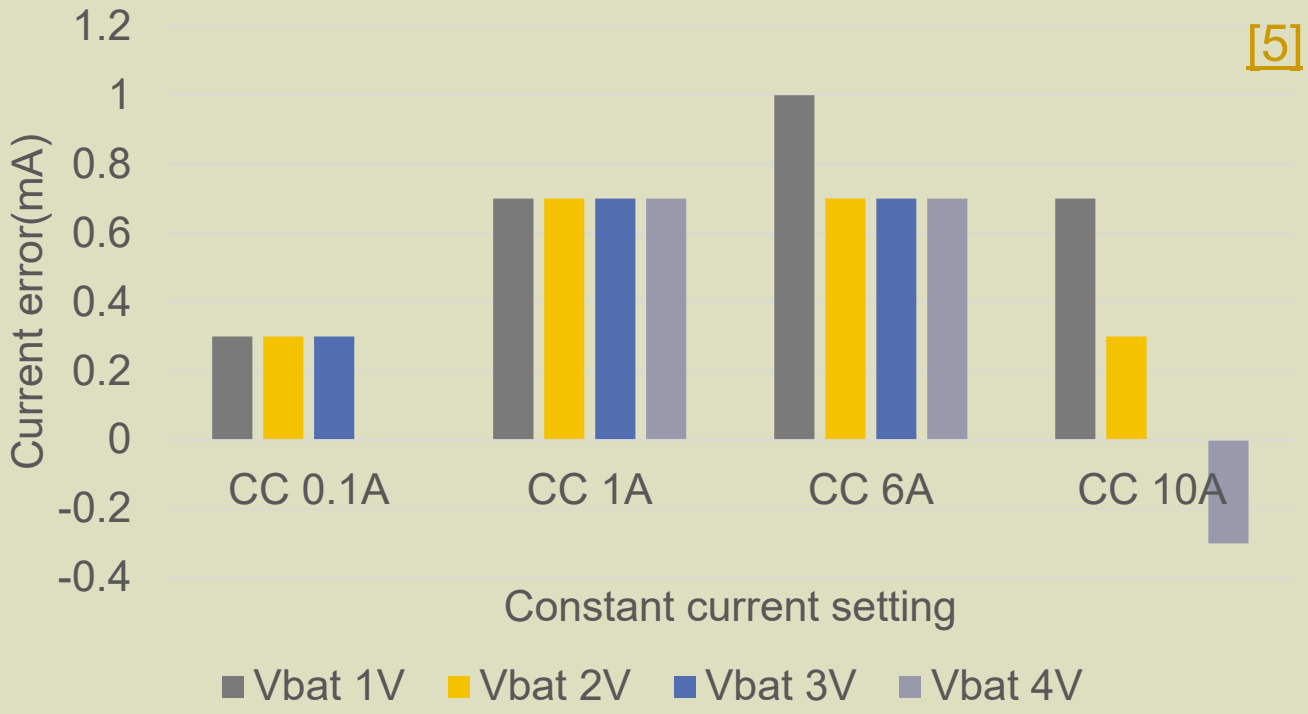
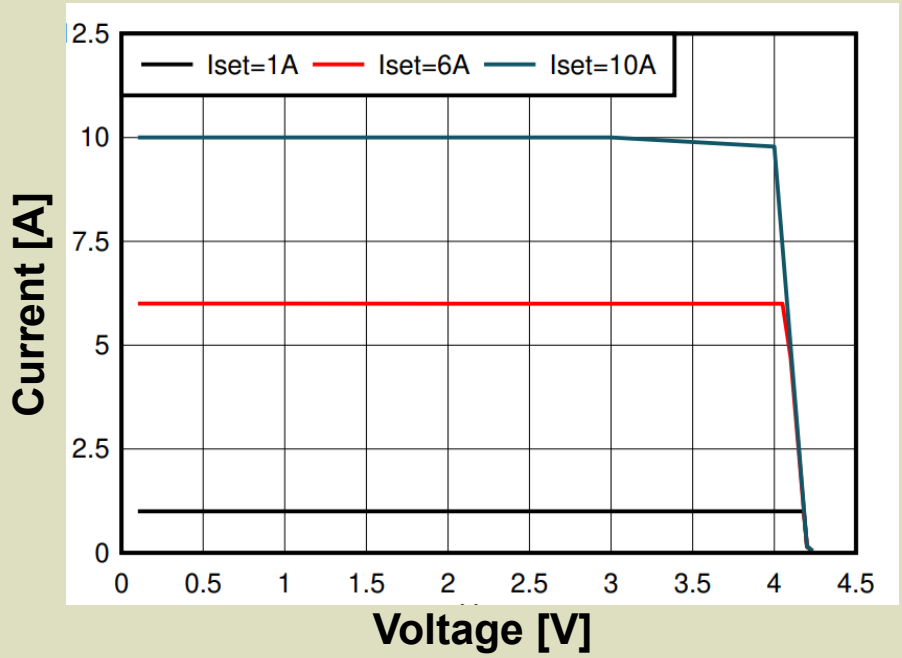
10A BTS Reference Design

Current regulation error is <± 1mA (0.01% of Full scale)

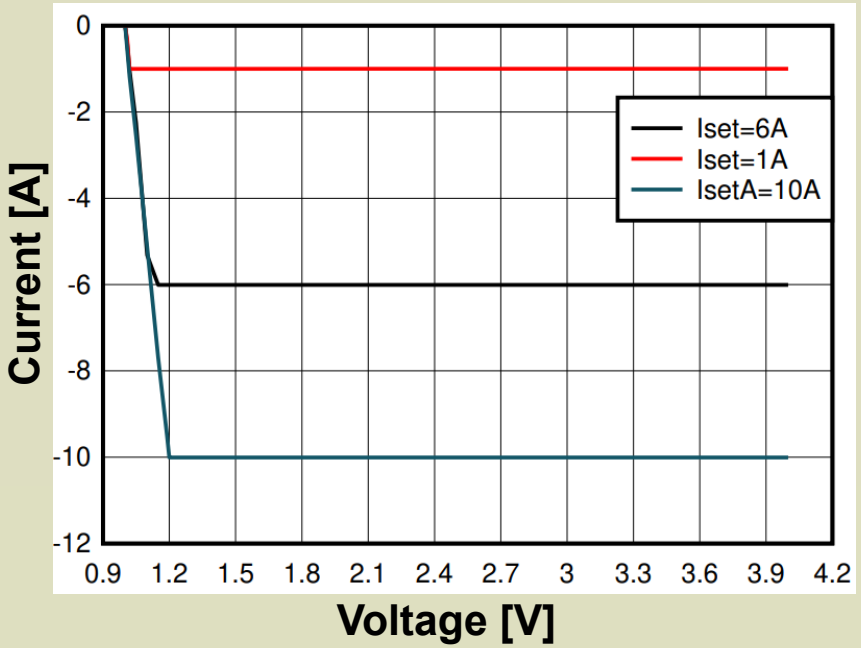


CC to CV transition

Charge Mode



Discharge Mode



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Li-ion cell formation and test overview

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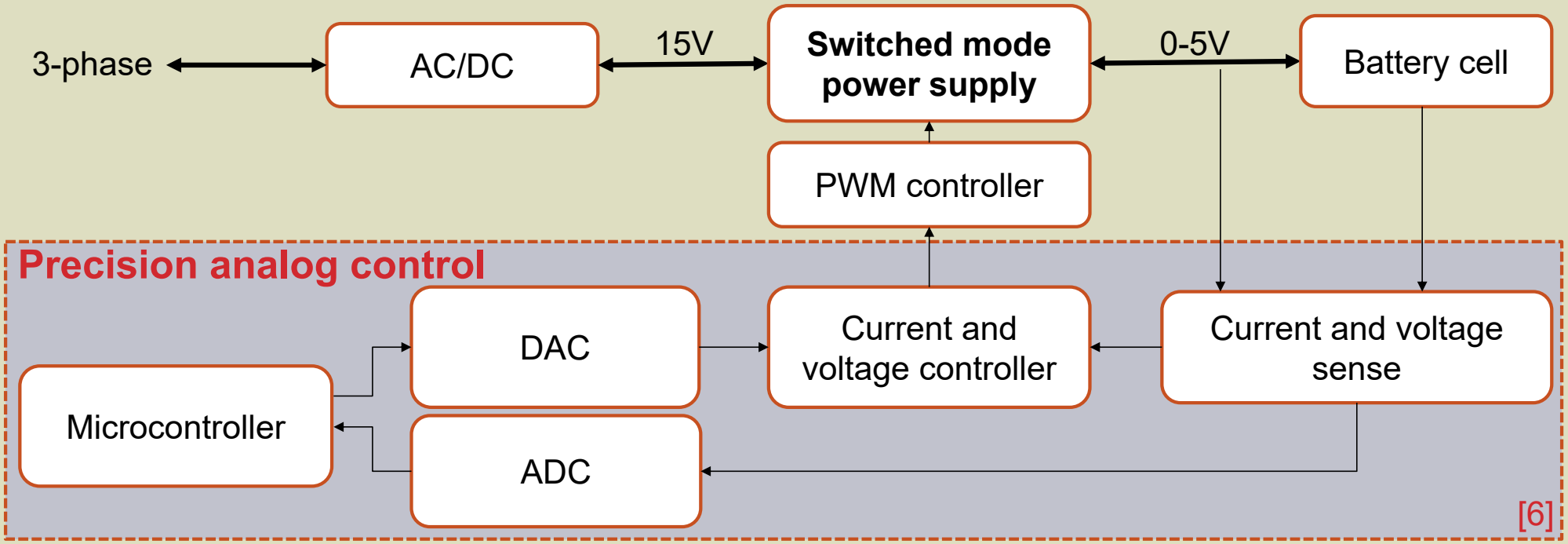
Methods to Reduce Cell Production Cost

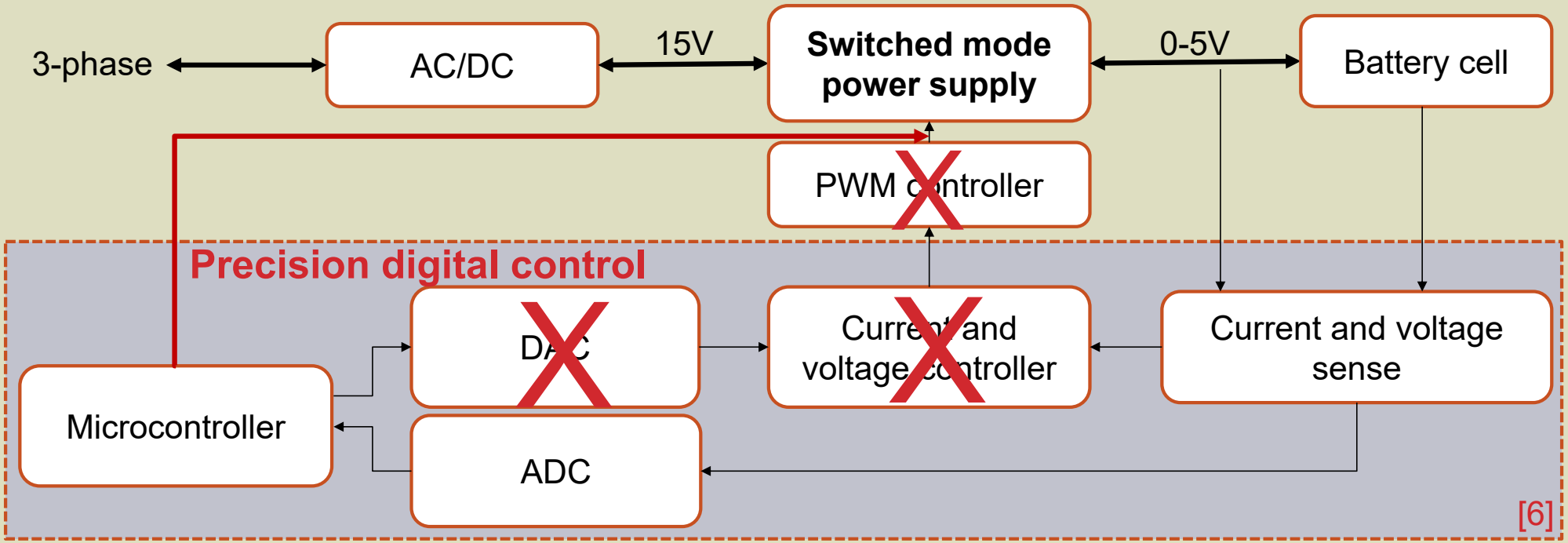
- **Reducing cost of the BTS**
- **Reducing the process time** by integrating of more features in the BTS
- **Reducing energy cost** by improving energy recycling efficiency

Analog Feedback Loop BTS



High precision 14-18b resolution ADC and DAC are used

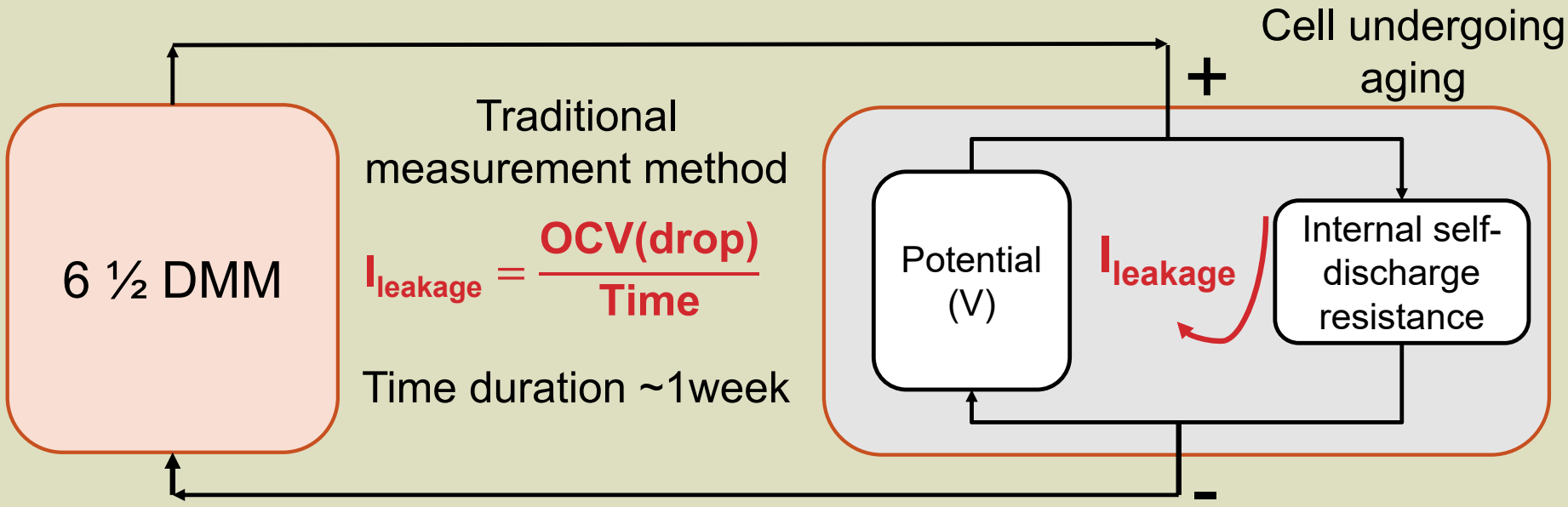
Digital Feedback Loop BTS



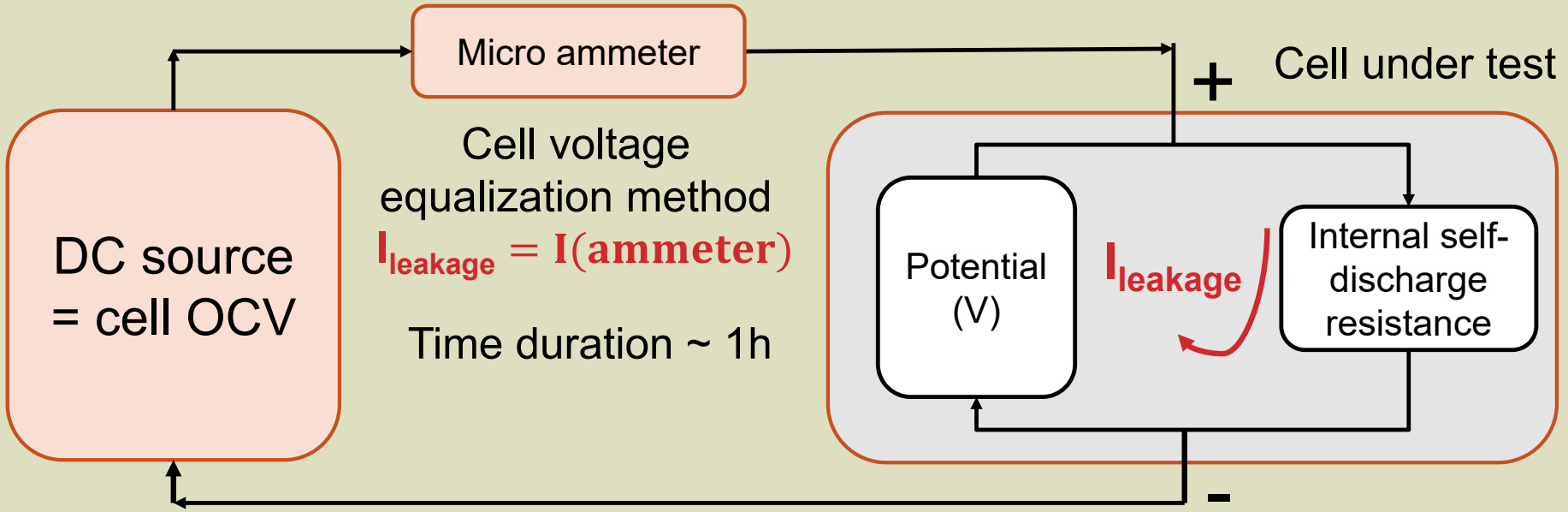
Digital control brings about 30% equipment cost reduction[7]

What is the self-discharge rate of the battery?

Self-discharge is leakage current ($I_{leakage}$) within the cell.



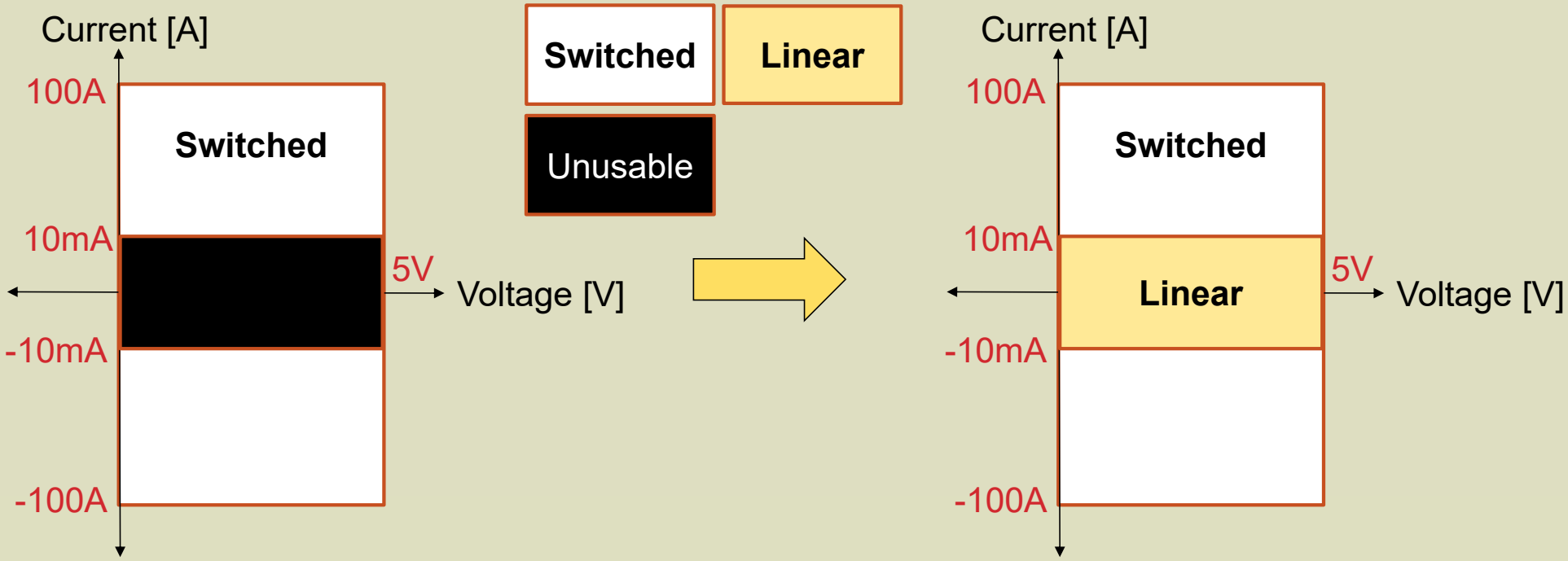
Direct Self Discharge Measurement



[8]

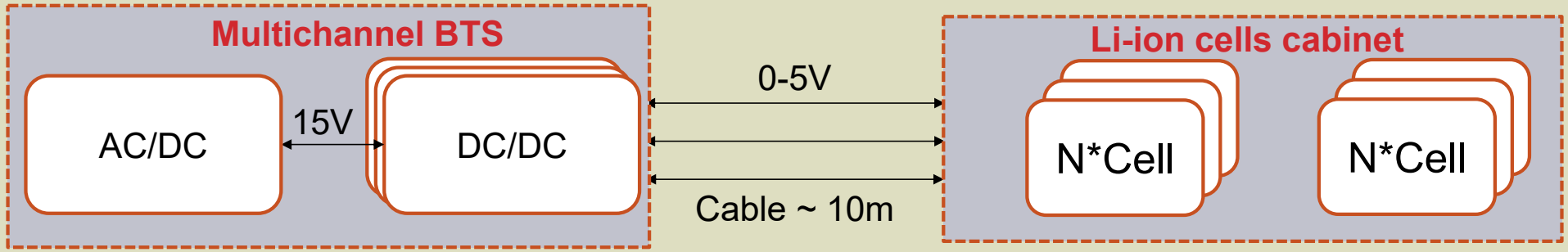
Self discharge can be measured during formation to remove bad cells

BTS for Self Discharge Measurement

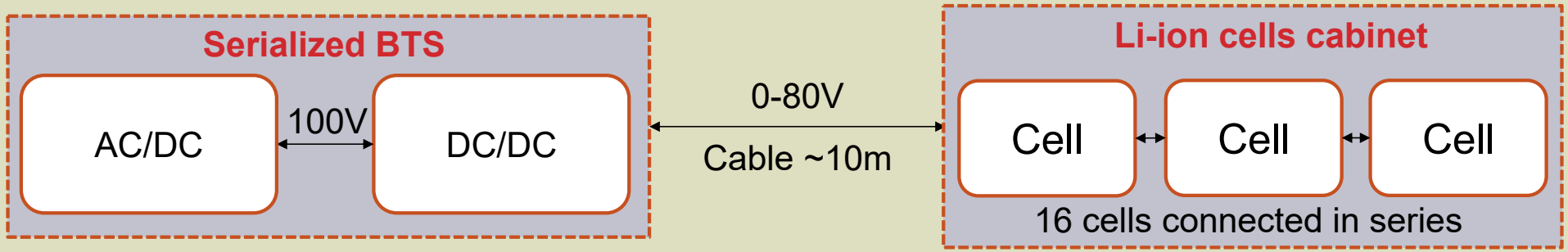


Proposed BTS for self-discharge rate measurement

Improving Efficiency



Losses in the cables reduces power supply efficiency by more than 10%



Lower losses in the power cables improves efficiency by more than 10%

Summary

- **Formation, aging and test** take the **longest time,** becoming the **bottleneck** of the production line. It could cost about 30% of total manufacturing cost[2].
- **Formation requires highest capital investment** because of slow charging and discharging. A semiconductor ATE should not be used for high power battery testing because energy recycling is not supported.
- **Digital feedback loop** reduces cost of the BTS.
- **Integration of linear mode** in BTS enables early detection of bad cells.
- **Serialized BTS** improves the power supply efficiency by more than 10%

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