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Energy Harvesting for Micromobility Systems

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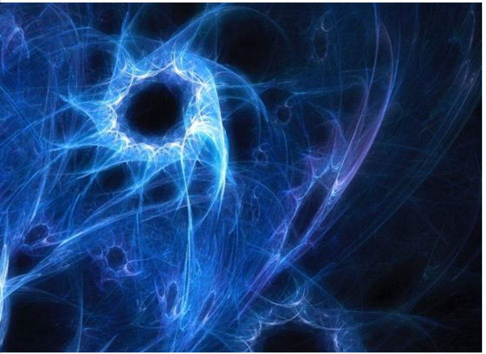
November 4, 2019

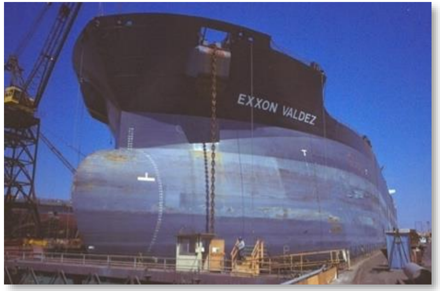


Exponent Overview

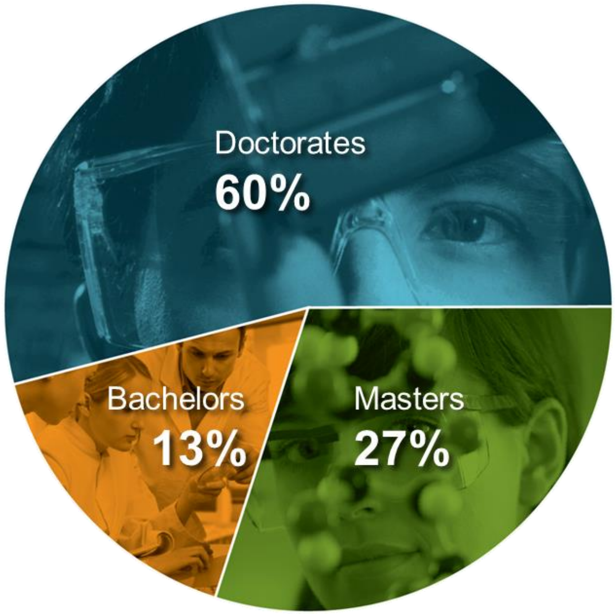
Who We Are

Exponent is a multi-disciplinary engineering and scientific consulting firm that brings together more than
90 different disciplines to solve important **engineering, science, regulatory**, and **business** issues facing our clients

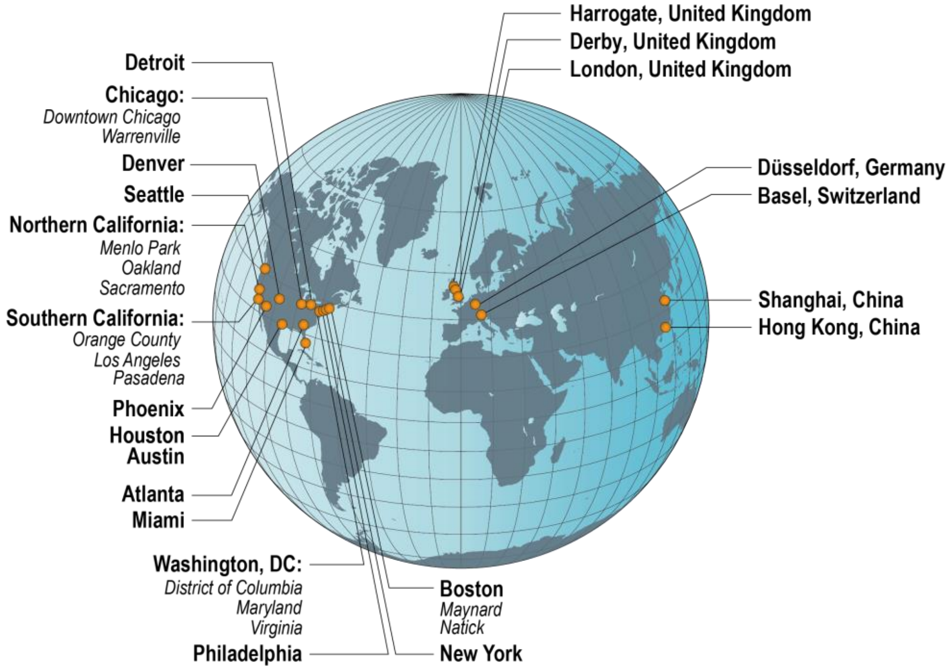



Consulting Staff



Exponent Offices



PROJECTS

Engineering Sciences

- Biomedical Engineering
- Electrical Engineering & Computer Science
- Mechanical Engineering
- Materials & Corrosion Engineering
- Polymer Science & Materials Chemistry
- Thermal Sciences

Environmental Sciences

- Ecological & Biological Sciences
- Environmental & Earth Sciences

Health

- Chemical Regulation & Food Safety
- Health Sciences

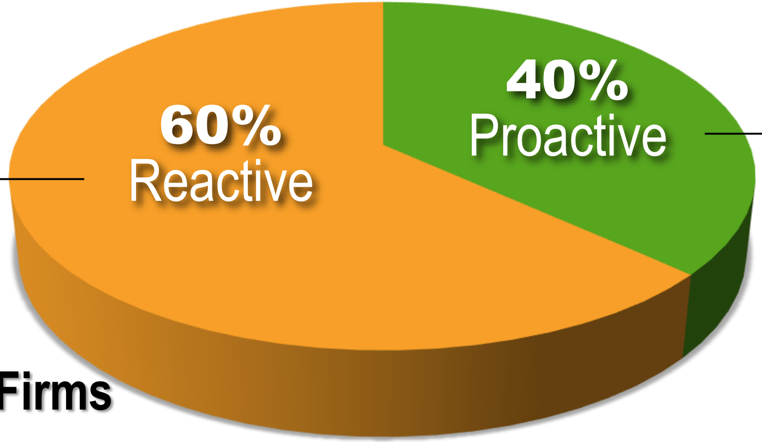
Transportation

- Biomechanics
- Human Factors
- Statistical & Data Sciences
- Vehicle Engineering

Infrastructure

- Buildings and Structures
- Civil Engineering
- Construction Consulting

Exponent's Business Today



Corporations/Law Firms

1) Litigation Support
2) Insurance Investigations
3) Product Recalls
4) Regulatory Actions

Corporations

1) Design Consulting
2) Regulatory Submissions
3) Risk Management
4) Product and Process Improvement
5) Research and Development

EHIOS Outline

- Introduction to Micromobility
- Energy Harvesting for Micromobility
- Energy Storage Challenges
- Conclusion

Introduction – Growth of Micromobility

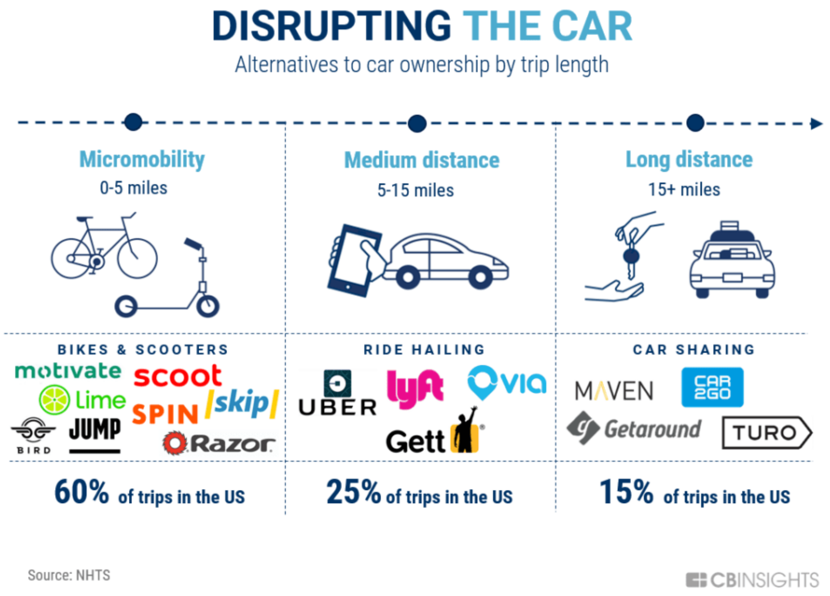
<u>Dock-less rides</u>

2018: estimated 84 million trips taken in America

- Electric scooters (E-scooters)
- Electric bicycles (E-bikes)

<u>Docked rides</u>

2018: estimated 19,106,000 Citi Bike rides in NYC alone



*https://www.cbinsights.com/research/disrupting-cars-car-sharing-scooters-ebikes/

Introduction – Micromobility Regulations

- "Guidelines for Regulating Micromobility"
  - National Association of City Transportation Officials (NACTO)
    - 82 DOTs in US and Canada
- Consumer Product vs. Shared Use Fleet Vehicle
- CPSC Public Law "107-319"
  - ebike engine wattage – 20 mph
  - e-scooter weight bearing standard – 15 mph
- UL approval
- On-board GPS
- Local regulations on labeling, safety codes
  - Brakes, reflectors, etc.

Introduction – Micromobility Battery Regulations

- Plan for charge, storage, and disposal of batteries
- Reporting and mitigating of incidents
  - Tampering, accidents, thermal events
- Spec for battery management system (BMS or BMU)
  - Information in UI
- How to ID at-risk vehicles and how to handle
- Instructions to subcontractors on collection and charging
- 24 hours to disable and remove all vehicles for equipment failure of "unknown scale"

NACTO

Introduction – Available Alternative Power Sources

Power available from energy sources

Energy Source	Characteristics	Harvested Power
Light	Outdoor Indoor	100 mW/cm^2 100 μW/cm^2
Thermal	Human Industrial	60 μW/cm^2 ~1-10 mW/cm^2
Vibration	~Hz–human ~kHz–machines	~4 μW/cm^3 ~800 μW/cm^3
RF	GSM 900 MHz WiFi	0.1 μW/cm^2 0.001 μW/cm^2

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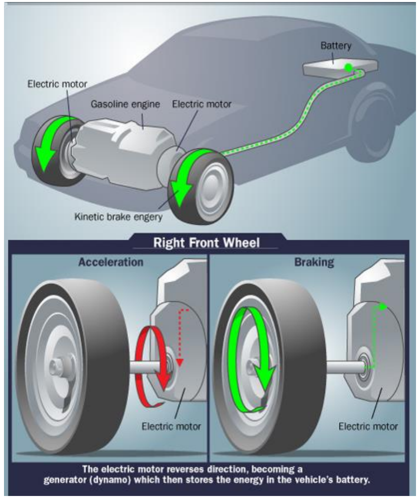
Texas Instruments

*https://gigaom.com/2013/11/21/energy-harvesting-chips-the-next-big-thing-for-a-connected-world/

Additionally for mobility:

- Regenerative braking “Regen”

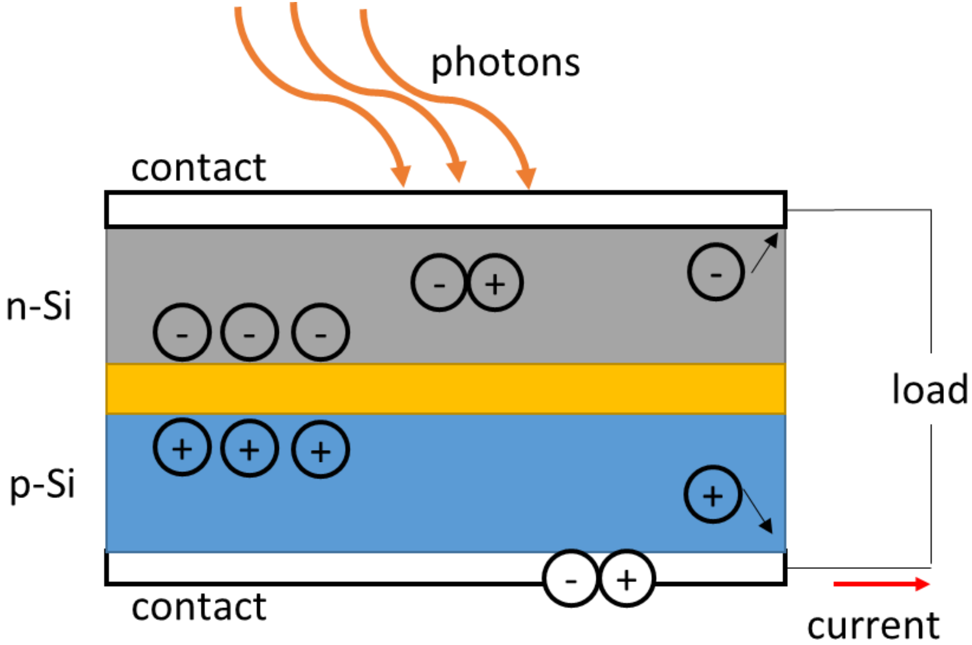


*https://www.quora.com/How-does-regenerative-braking-work

Energy Harvesting for Micromobility - Solar

Basic solar cell - PV effect

- p-n junction creates E-field
- Photon generates e-h pair
- Charges separate due to E-field
- Carriers go to external circuit



Energy Harvesting for Micromobility - Solar

Solar technology efficiency though increasing generally has a max of ~25% for retail components

Therefore due to space constraints solar is generally limited to docking systems to manage locking and comms but not battery charging.

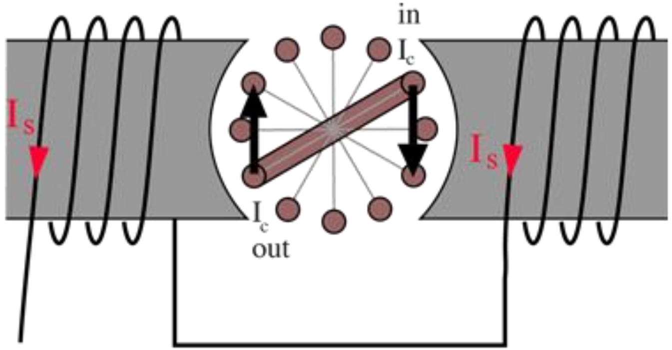
Citibike example, NYC

Bluebikes Bike Share – Cambridge MA

Energy Harvesting for Micromobility – Regen

Basic Regen

- Motor converts electric/magnetic energy into mechanical energy
  - i.e. induction motor
- When torque applied motor acts as electrical generator
  - Drag braking
- Counter-electromotive force
  - Slower to fully break



Energy Harvesting for Micromobility – Regen

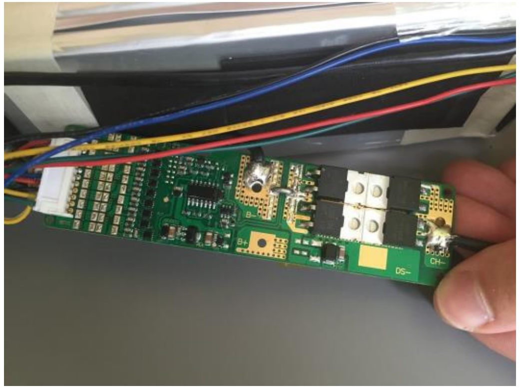
Regenerative braking

- Common on electric cars - rare on electric bikes
- Bike and rider weight low compared to car
- Less energy to be captures by braking
- Average terrain about 10% further distance per battery charge for e-bike[1]
- 1-2% for e-scooter[2]

1 - https://www.electricbike.com/regenerative-brakes/
2 - https://electric-scooter.guide/guides/electric-scooter-regenerative-brakes/

Energy Storage Challenges - Introduction

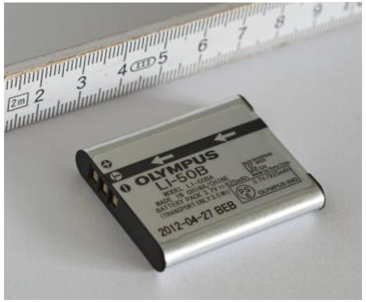
18650 cell
4.2 V max
1500-3500mAh

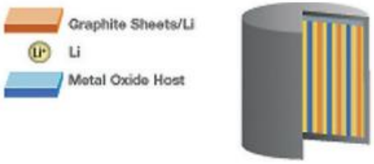


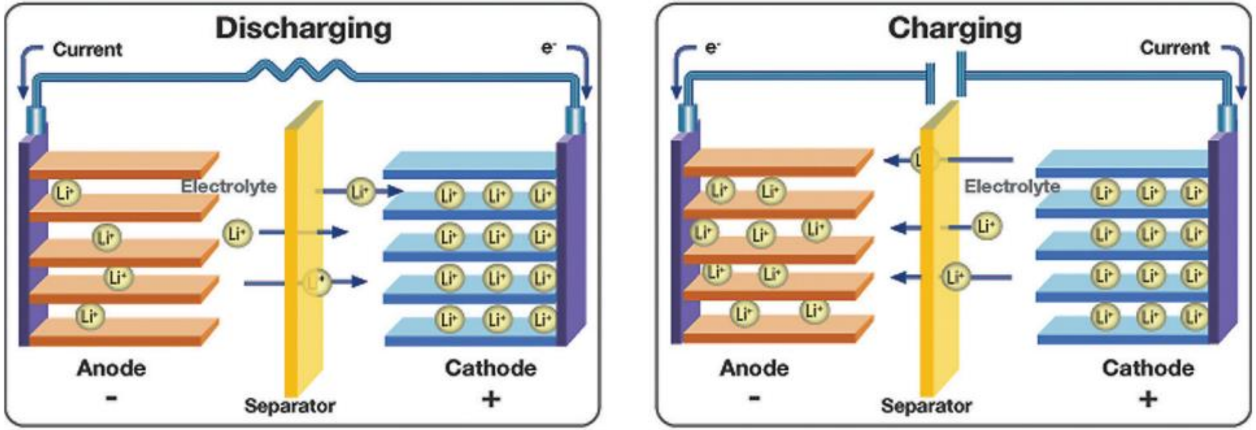
Battery Management System

Li-ion battery pack
~36-48V
~13-40Ah

Energy Storage Challenges – Li-ion Cells







*http://www.spectroscopyonline.com/techniques-raman-analysis-lithium-ion-batteries

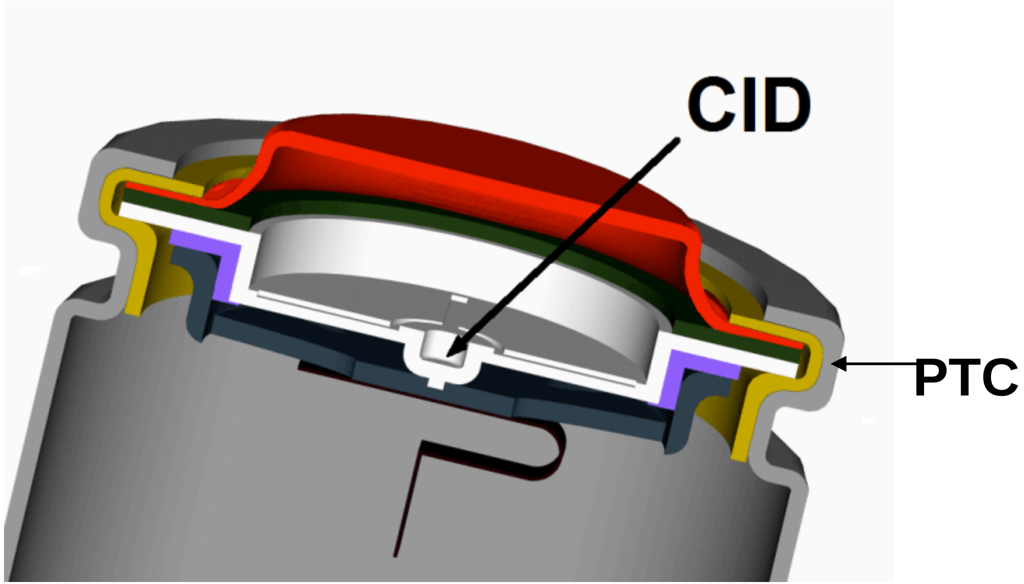
Energy Storage Challenges – Li-ion Cells

Internal cell protection for 18650

Current Interrupt Device CID
- Pressure valve
- Scored vent
- Opens pole

Positive Temperature Coefficient PTC
- Conductor
- Resistance increases with temp
- Limits current

Counterfeit issues
- Missing PTC / CID
- High capacity 12000mAh

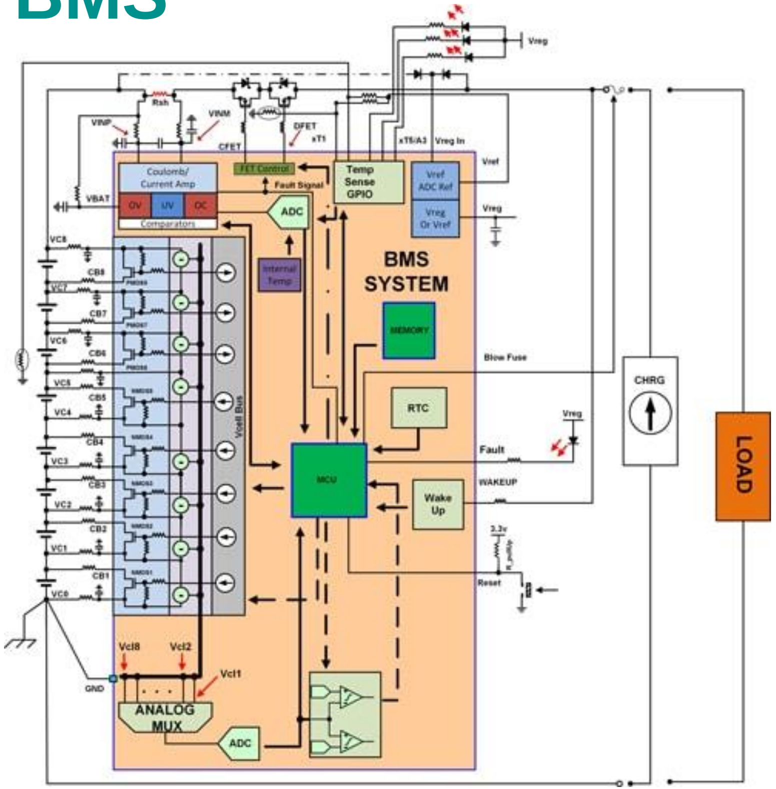


*https://www.electricbike.com/inside-18650-cell/

Energy Storage Challenges – BMS

BMS performs the following functions

- Charge/discharge control
  - Damage to battery internals
- Levels of charge
  - User info
- Cell balance
  - Maintain equal state on each cells
- Communications



*https://www.electronicdesign.com/power/look-inside-battery-management-systems

Energy Storage Challenges – Famous incidents

Boeing 787 Dreamliner

- APU overheat and fire
- Single cell failure
- Grounded

*Sky News

Boeing 787 Dreamliner - unrelated

- Fire in emergency locator transmitter
- Single cell failure

Energy Storage Challenges – Famous incidents

Samsung Galaxy Note 7
- New battery design
- Damage at separator
- 1 million recalled units

https://www.theverge.com/2016/10/9/13218730/samsung-galaxy-note-7-fire-replacement-fourth-virginia

Energy Storage Challenges – E-bike and E-scooters

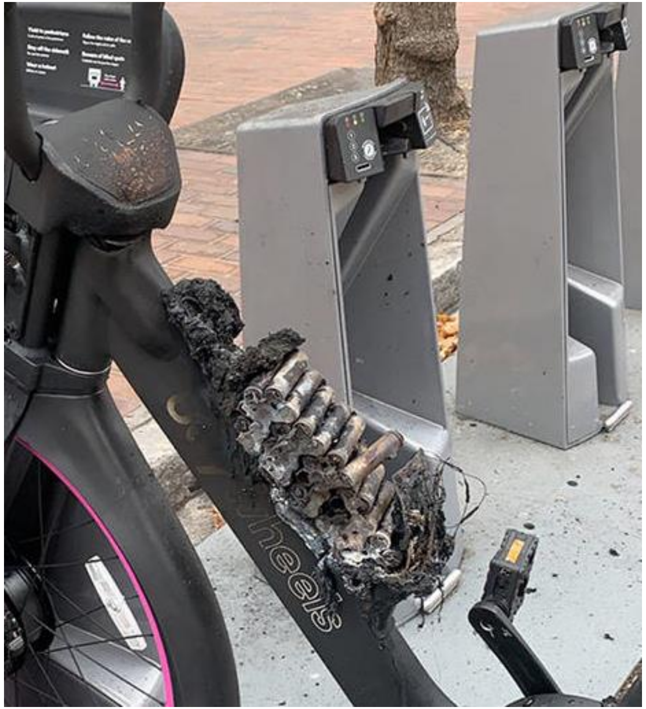
Lyft E-bike
- Possible fire at battery module

*https://www.sfexaminer.com/news/lyft-electric-bike-catches-fire-in-sf/

Lime E-scooter
- Fire at storage warehouse
- Reported building electrical problem

*https://www.spokesman.com/stories/2019/oct/07/numerous-lime-scooters-damaged-in-spokane-valley-w/

Energy Storage Challenges – Failure Mechanisms



Heating

Shorting
- Conductive path - anode to cathode

Environmental conditions
- Moisture
- Ambient temperature

Abuse
- Impacts
- Penetration

…*Thermal runaway*

Energy Storage Challenges – Failure Mechanisms

Energy Storage Challenges – Thermal Runaway

Thermal Runaway

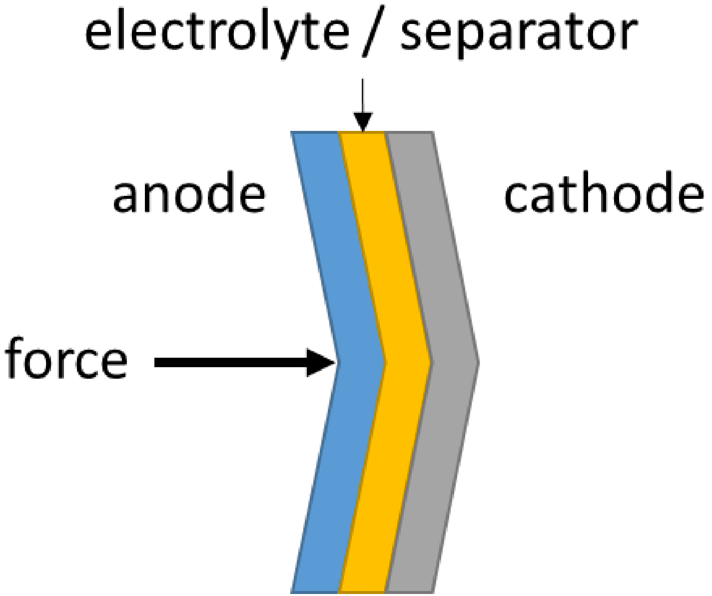
- Catastrophic violent release of energy
- Up to 500°C
- Internal chemicals react and ignite
- Venting with ignited gases

flickr/Garycycles8

Energy Storage Challenges – Abuse

<u>Abuse</u>

- External pressure
- Hot spots
- Concentrated E-fields
- Separator failure



Energy Storage Challenges – Abuse

*https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2016/January-February-2016/Features/ESS/Lithium-Ion-conundrum

Energy Storage Challenges – Moisture

<u>Moisture</u>

Cell level

- Oxidation of internal metal contacts

Module level

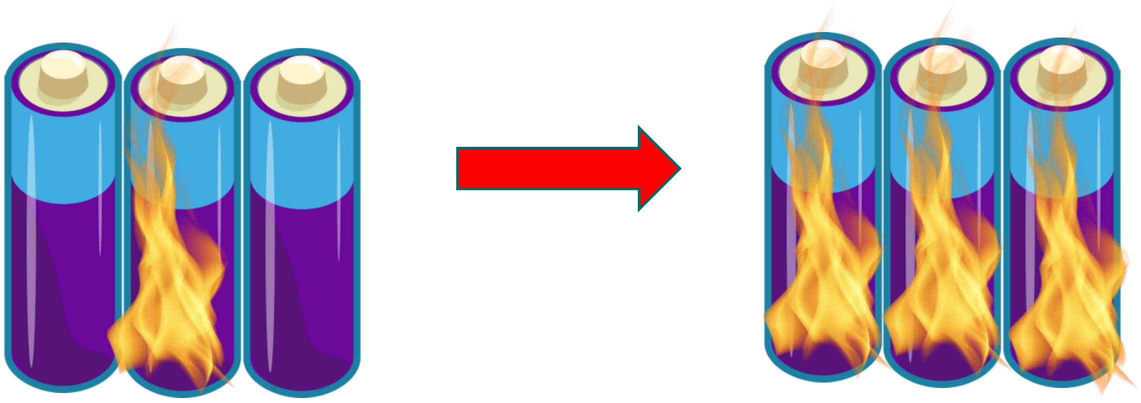
- Damage to BMS and components
- Corrosion / heat
- Conductive paths

Energy Storage Challenges – Adjacent Heat

<u>Ambient temperature</u>

Failure in single cell leads to thermal runaway in neighboring cells

Failure in single pack or module leads to thermal runaway in neighboring packs



Conclusion

- Micromobility is aggressively growing
- Energy technology is key
  - Energy harvesting, battery charging, storage, and safety
- 1 in 1,000,000 failure modes must be considered
  - CID, PTC, BMS, Flame Retardant Materials
- Failures due to internal defect or external factor must be quickly identified and mitigated