Some investigations into

Battery-powered trams

and other catenary-free solutions

Anna Chang

Wolfson School of Mechanical, Electrical and Manufacturing Engineering
Loughborough University, UK

Loughborough University

#InspiringWinners since 1909

About Loughborough

- The Times and Sunday Times **University of the Year** 2019.
- **University of the year** at the Whatuni Student Choice Awards 2018
- In 2018, **Best in the UK for Student Experience** - Times Higher Education Student Experience Survey, 5th time since 2009
- **Ranked 4th in the 2019** Guardian University League table. It ranked 30th in Britain in 2014.
- **Loughborough** is **renowned** in the UK for its sports. World's largest **university**-based sports technology research group.
- **UK top 3 for Mechanical Engineering and in the UK top 10 for Electronic and Electrical Engineering**

About Anna Chang

- Wolfson School of Mechanical, Electrical and Manufacturing Engineering – Smart Cities EPSRC Grant
- ***Energy Utilisation to Improve Light Rail Development***
- Specifically on tramways, **their development and cost,** and in particular on the gap between **engineering, economics**, and **socio-political** players
- and the costs of prolonged decision-making.

EPSRC

Engineering and Physical Sciences Research Council

About Anna Chang

- Transferable skills: Strategic Management, Change Management, Business Process Re-engineering, Marketing, PR, Project Management.

GOLD PEAK

Regional Marketing Manager

NXT Plc

Regional Licensing Manager

UK Ministry of Defence Speech & Sound Technology

Jardine Matheson | Dairy Farm

Regional Accounts Director

Revamp private labels for No Frills and First Choice brand across 7 countries

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

Loughborough University

The objective

To develop a model of a tram route on which to test various combinations of power supply and battery technology

Model must give a realistic overview of the typical power usage on a typical route

But need not examine the power requirements in great detail – a “helicopter view”

Nottingham Express Transit

March 2004

15 Bombardier Incentro AT6/5

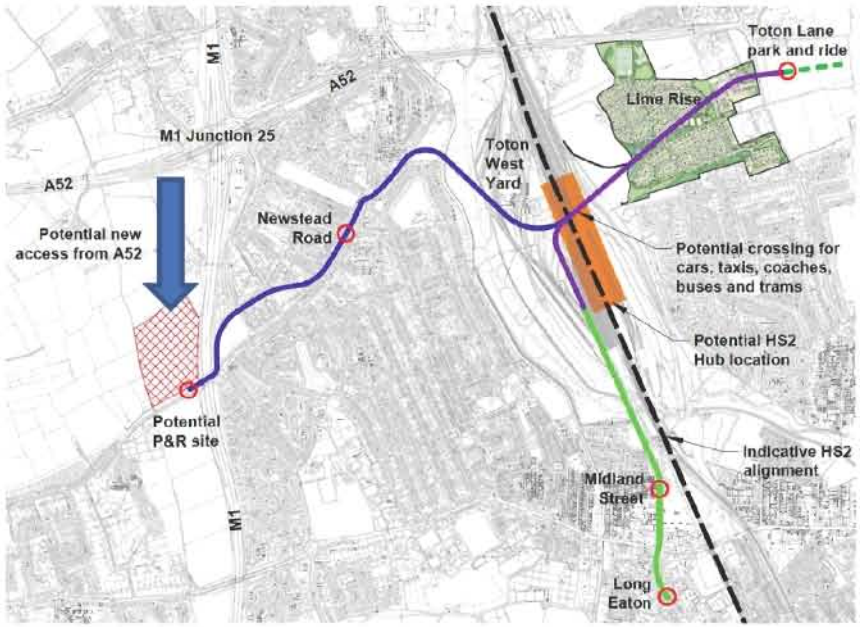
22 Alstom Citadis 302

32km (20 miles)
2 lines , 50 stations

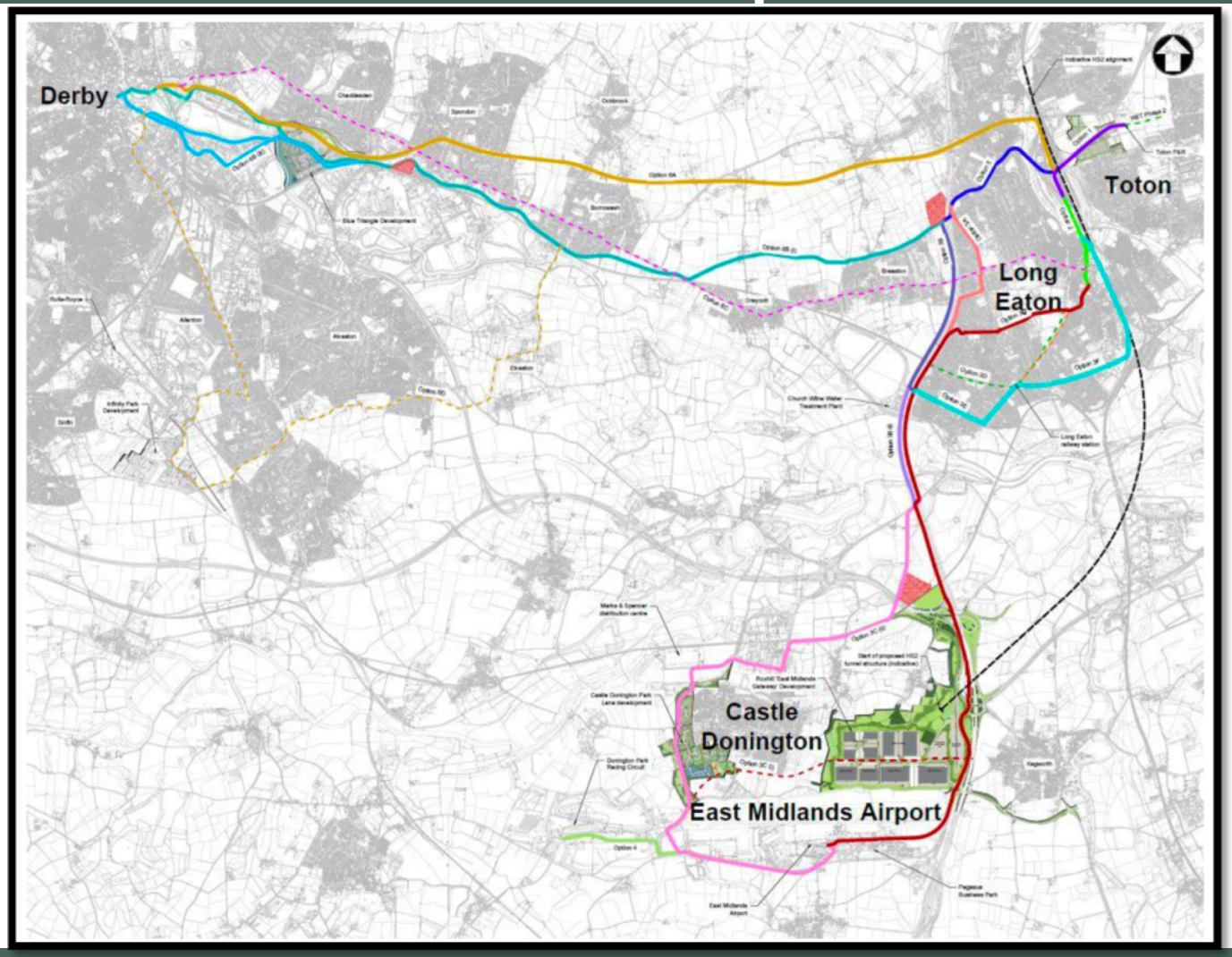
Ridership: 18.8 million (2018/19

EXTENSION TO HS2 HUB

- 1.6km extension from Toton P&R
- 4 mins journey time
- Route alignment through proposed Lime Rise development west of Toton Lane
- Interface with HS2 Hub / station



All HS2 Route Options



EAST MIDLANDS AIRPORT OPTIONS

Option	Route length from Toton P&R	No. of stops	Journey times from HS2	% segregated	Capital cost £m from Toton P&R
EMA via East Midlands Gateway	14.4 – 15.9km	10-13	24-28 mins	81 - 97	346
EMA via Castle Donington	18.2km	13	33 mins	81 - 91	388

DERBY OPTIONS

Option	Route length from Toton P&R	No. of stops	Journey times from HS2	% segregated	Capital cost £m from Toton P&R
A52	15.8km	5	18 mins	95	682
Former canal corridor	16.5km	14	28 mins	76 – 92	402

Power from catenary / OLE

- Traditional, tried-and-tested technology
- Problems
  - Cost of installation – wires, substations, energy supply
  - Cost energy supply in operation
  - Visual intrusion and equipment in street
  - Risks
    - loss of power
    - Icing
    - Danger of live wires
    - Danger of collapse of OLE

Power from Battery/wireless trams

- Risk and uncertainty with new technology
- Safety Risks – known, can be contained
  - Fire through overheating
  - Spontaneous fire
  - Spillage in the event of an accident
- Newer technologies can be very safe
- Cost – always an issue

Other new technologies

- Other new technologies are emerging -
  - Super capacitors
  - Hydrogen fuel cells
  - Hybrid energy storage – batteries/supercaps
- Risk and uncertainty with new technology
- Cost – always an issue

Issues with batteries

- Space – where to fit them
- Mass
  - Ideally keep them low down
  - Difficult with low-floor trams
  - Better with tram-train
- Power rates – charge / discharge
- Energy / capacity
- Performance in service – speed, acceleration
- Lifetime and replacement costs

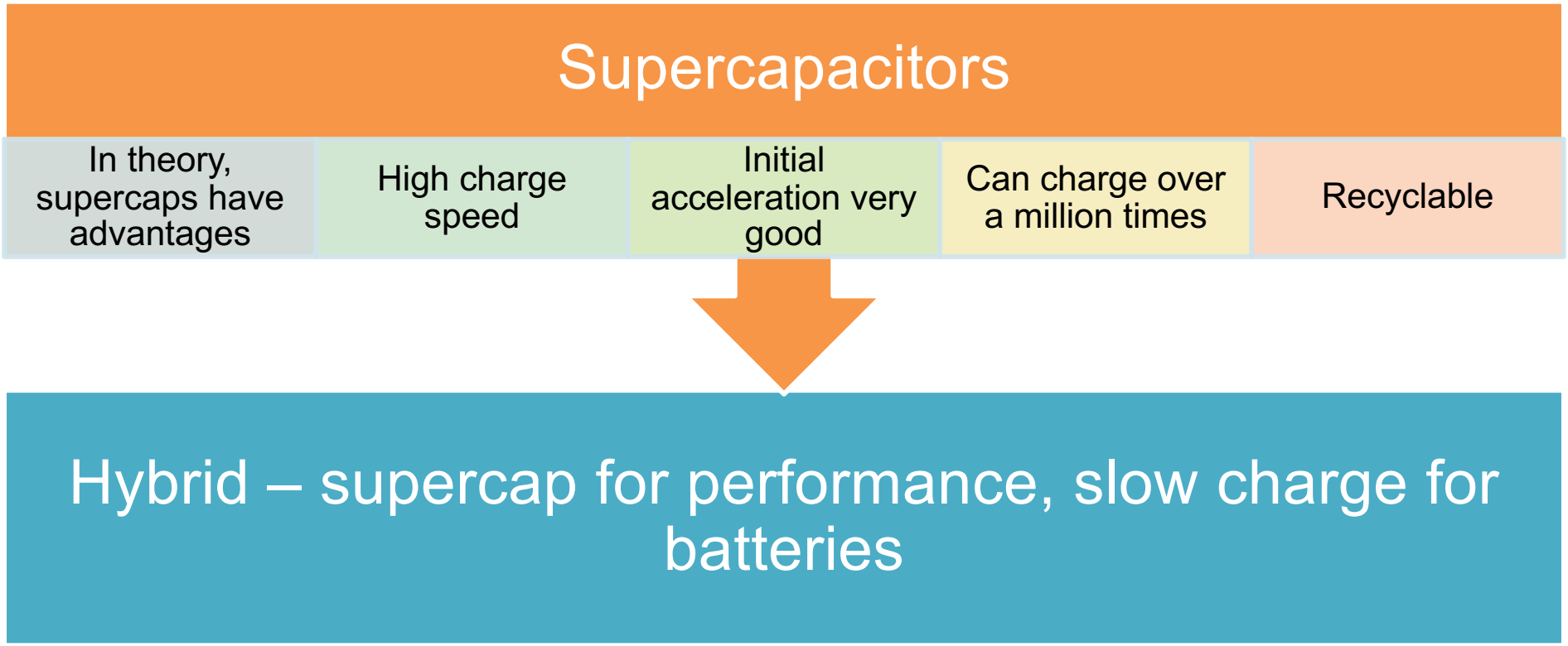
FLOOR FRAME
AND TYPICAL AVAILABLE SPACES

FLOOR FRAME AND TYPICAL AVAILABLE SPACES

16 PAIRS OF SEATS BACK-TO-BACK WITH POWER ELECTRONICS BETWEEN, OVER MOTOR BOGIE

ROOF-MOUNTED POWER ELECTRONICS AND HVAC EQUIPMENT

How to tackle these issues



Comparison of energy and power densities of battery and supercapacitor

	Energy Density (Wh/kg)	Power Density (W/kg)
Battery	210	200
Supercapacitor	1.33	11000

Source: https://ieeexplore.ieee.org/document/7455088

Comparison of supercapacitors and lithium-ion batteries

Function	Supercapacitor	Lithium-ion Battery
Charging period	1 - 10 s	10 - 60 min
Cycle period	30000 h	Approximately 500
Cell voltage	2.3-2.85V	3.7-4.0V
Specific Energy (Wh/kg)	2 - 5	100 - 200
Specific Power (W/kg)	> 10000	1000 - 3000
Cost per Wh ($/Wh)	20	0.5 - 1
charge temperature	-40 - 65 ℃	0 - 45 ℃
discharge temperature	-40 - 65 ℃	-20 - 60 ℃

https://ieeexplore.ieee.org/document/7455088

Battery and Supercapacitor cell characteristics

Specifications	Battery	Supercapacitor
Nominal Voltage (V)	3.2	2.7
Nominal Capacity (Ah)	2.6	NA
Rated Capacitance (F)	NA	2000
Energy Storage (Wh)	8.32	2.03
Weight (kg)	0.0805	0.36
Energy per Weight (Wh/kg)	103.35	5.64

Source: https://ieeexplore.ieee.org/document/7177105

Lithium is difficult to extinguish

Risk Mitigation

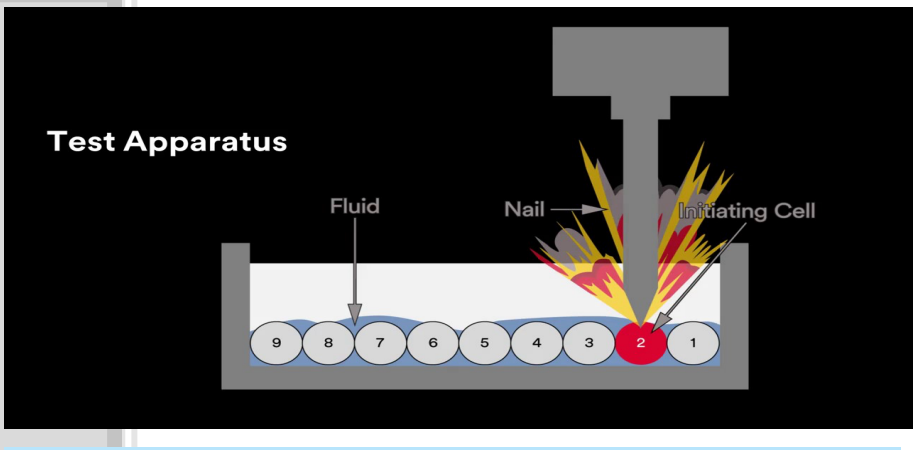
- Detect the heat
- Apply cooling or switch it off
- Battery Management System (BMS)

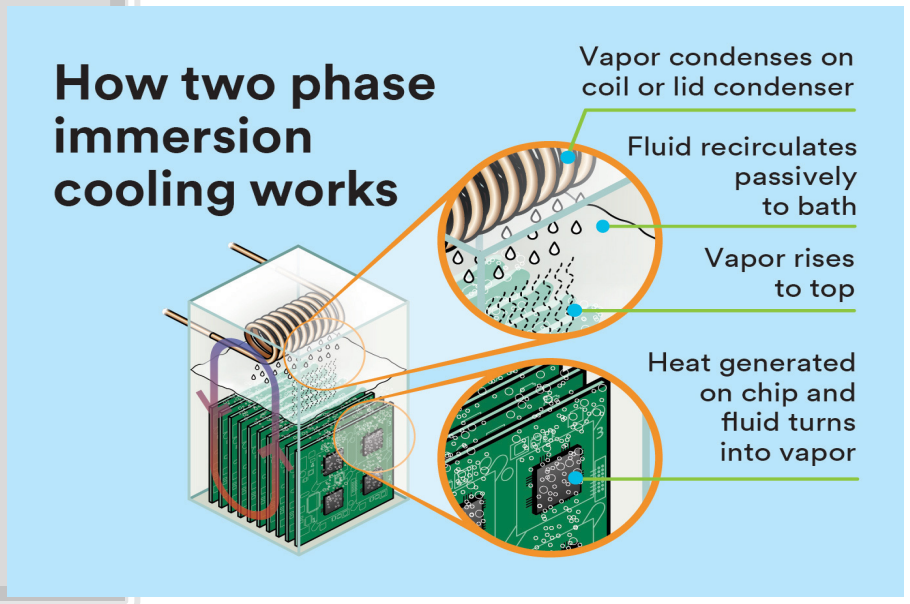
Energy from impact damage or mishandling

–> BMS can have failure

3M™ Novec™ Engineered Fluids

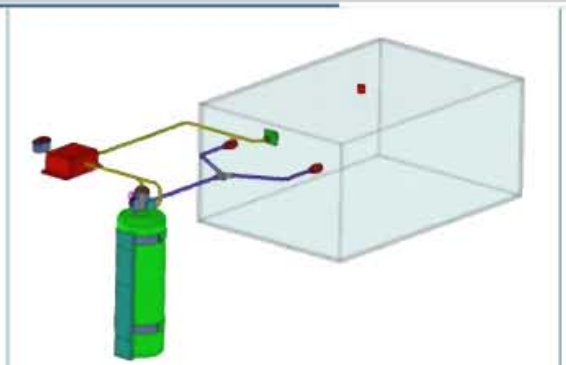
- Can be use on high-speed electric trains to wind turbines to electric drive motors
- Can precisely control electrical voltages on a large scale





Source: https://www.3m.com/3M/en_US/novec-us/applications/immersion-cooling-of-power-electronics/

Composed of fire extinguishing device host, quick start valve, CPU intelligent controller, sensor (temperature, flame, etc.), connecting cable, control switch, fire extinguishing agent conveying pipeline and so on.



Automobile lithium battery box fire extinguishing device. Compulsory on full electric buses use in China

Our outstanding campus

Largest single site green campus in the UK