Electrification of Road Transport

Myths, Truths and the Way Ahead

I-SEE, Bath, April 2019

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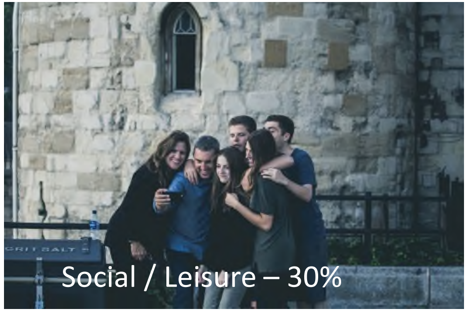
Transport is essential to our personal and business lives

Moving People


Social / Leisure – 30%


Shopping / Personal – 25%


Work / Business – 25%


Education – 15%

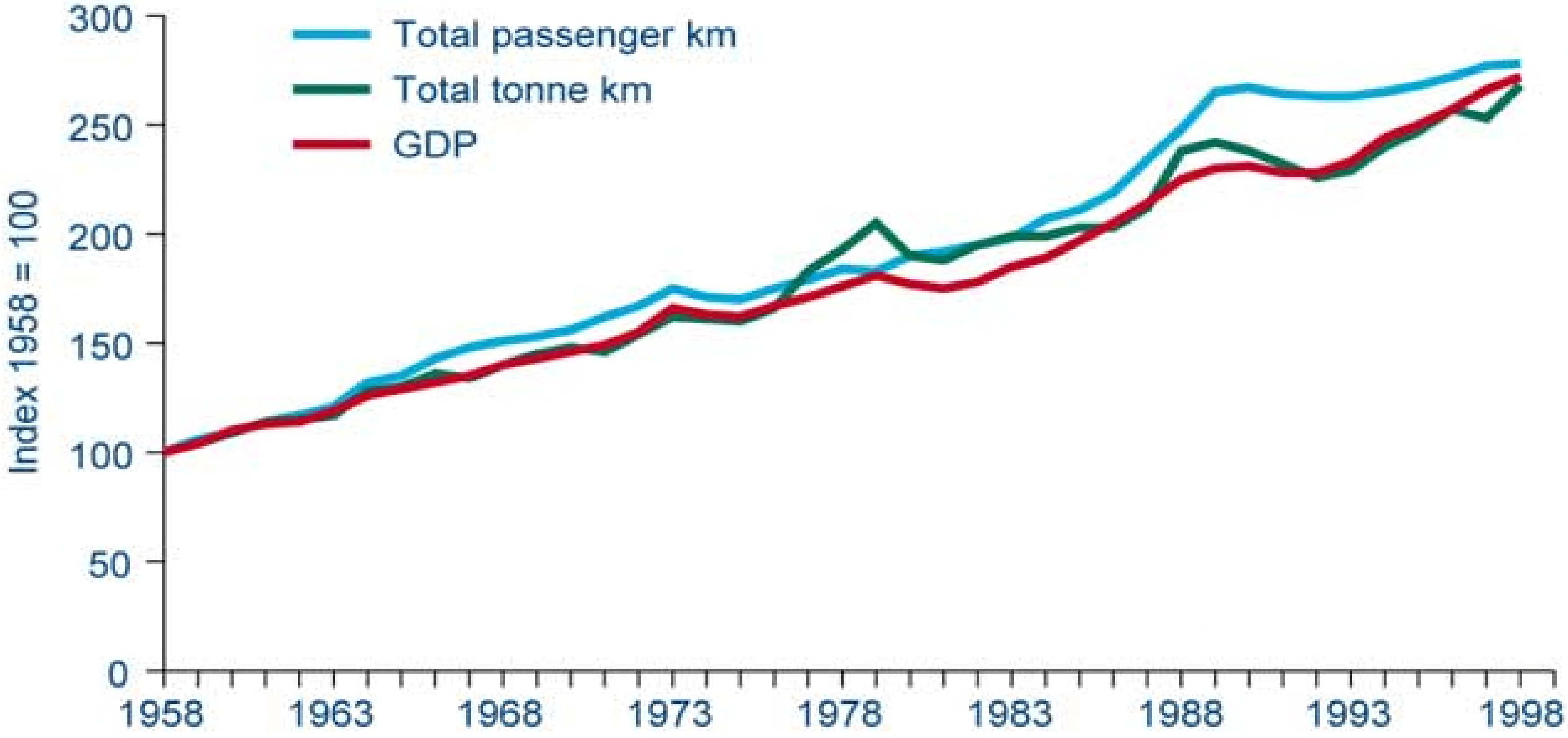
Moving Goods


Industrial


Domestic

Source: UK Department for Transport National Travel Survey 2014

Transport is strongly correlated to economic growth



Source: DfT Transport 10 year plan 2000

But transport growth comes at a cost

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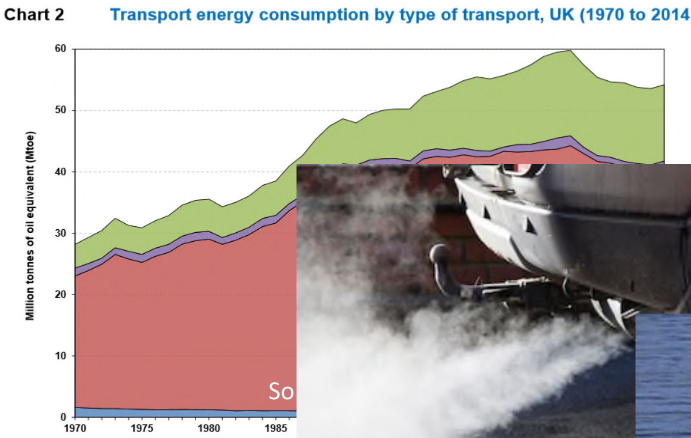

Energy Demand

Air Quality

Climate Change

Congestion

Accidents

What can we do about it ?

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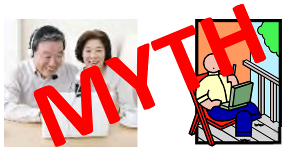
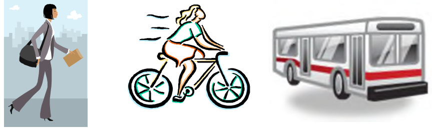
Manage Demand

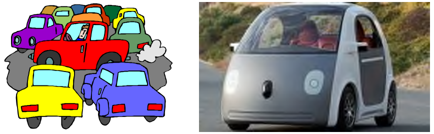
- Travel Less



- Use best transport mode



- Manage transport network



Improve Technology

- Reduce vehicle mass and drag

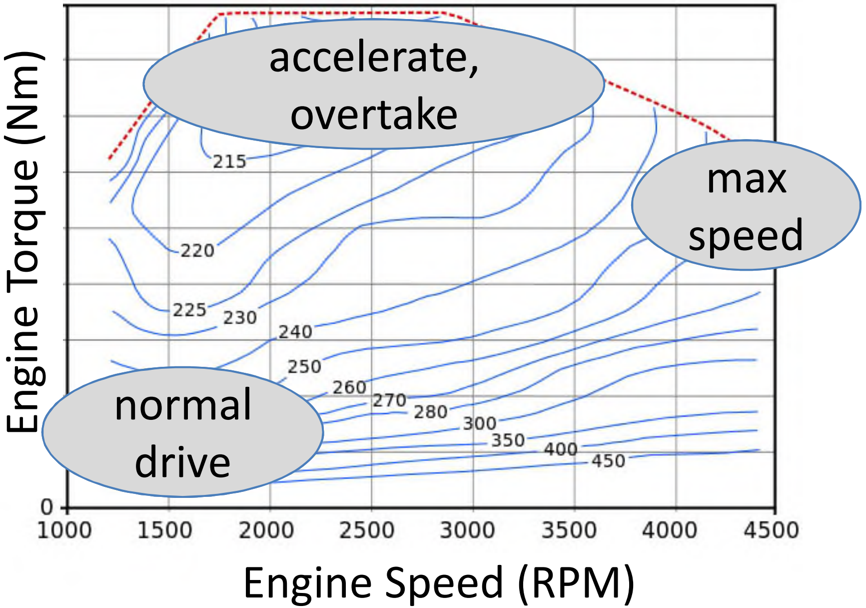
- Improve powertrain
- Reduce carbon in fuel

What's wrong with conventional cars ?

Typical 5 seater family car (Renault Captur)

- Average power in use (NEDC) 6bhp
- Smallest engine available is 88bhp

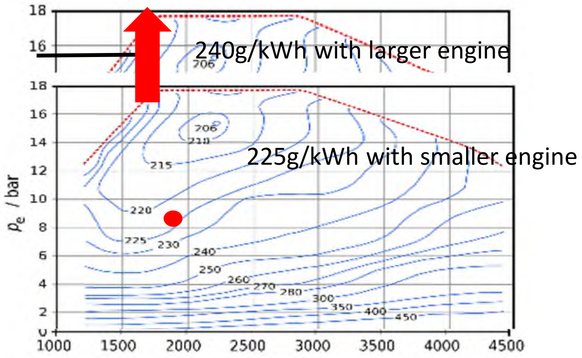
Speed (mph)	20	30	50	70
Power (bhp)	1.6	3.2	9.1	21



Adding electric motors and batteries allows:

Engine downsizing with electric used to deliver transient acceleration

Torque fill
with motor



Engine stop when not required

Electric drive at low speed / load

Electric drive to pumps, fans and air conditioning – more efficient

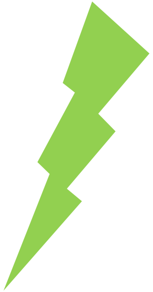
Captures braking energy for re-use later

Store as electricity
Not lost as heat

Electricity as primary fuel source in place of hydrocarbons

Zero tailpipe emissions
Lower CO_2/kWh

(Depends on grid
Generation mix)



Degrees of Electrification

	Engine	Motor	"Battery"
Conventional	100kW Full transient	Starter motor Stop/start	12V 3kW, 1kWh
Mild Hybrid	90-100kW Full transient	3-13kW Torque boost / re-gen	12-48V 5-15kW, 1kWh
Full Hybrid	60-80kW Less transient	20-40kW Limited EV mode	100-300V 20-40kW, 2kWh
PHEV	40-60kW Less transient	40-60kW Stronger EV mode	300-600V 40-60kW, 5-20kWh
REEV	30-50kW No transient	100kW Full EV mode	300-600V 100kW, 10-30kWh
EV	No Engine	100kW Full EV mode	300-600V 100kW, 20-60kWh

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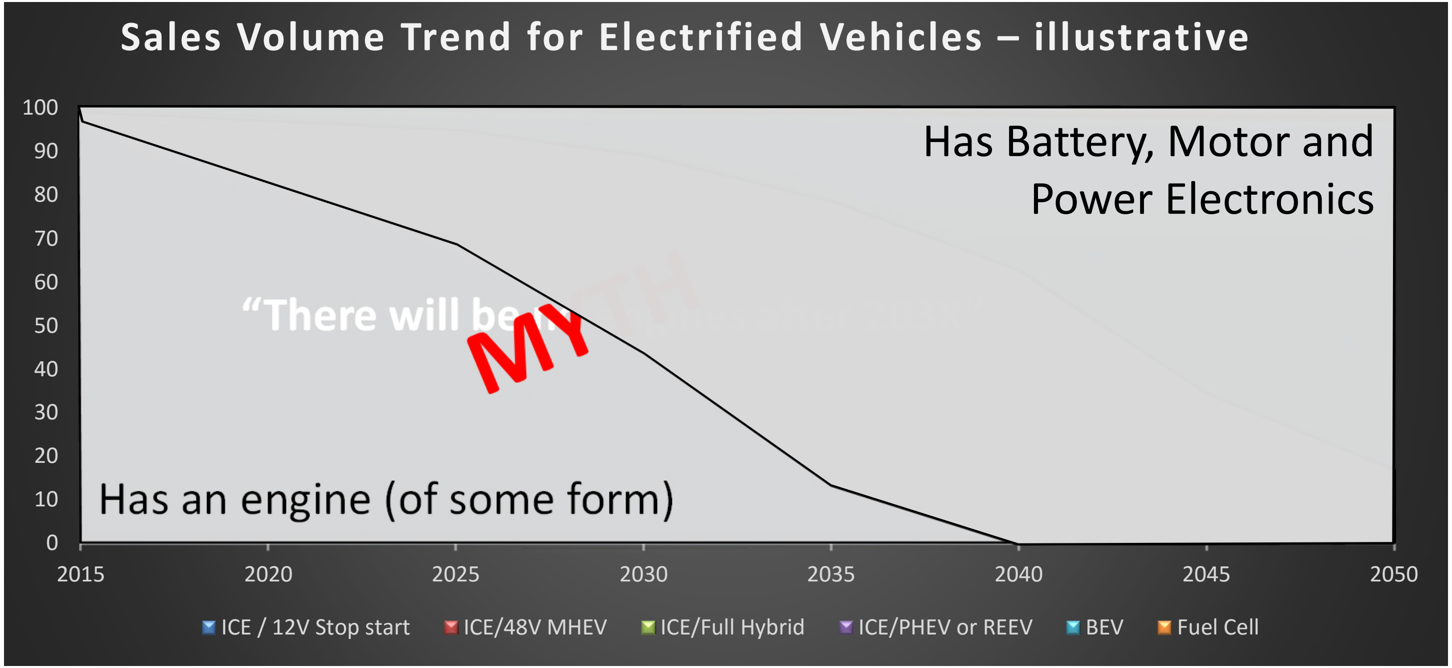
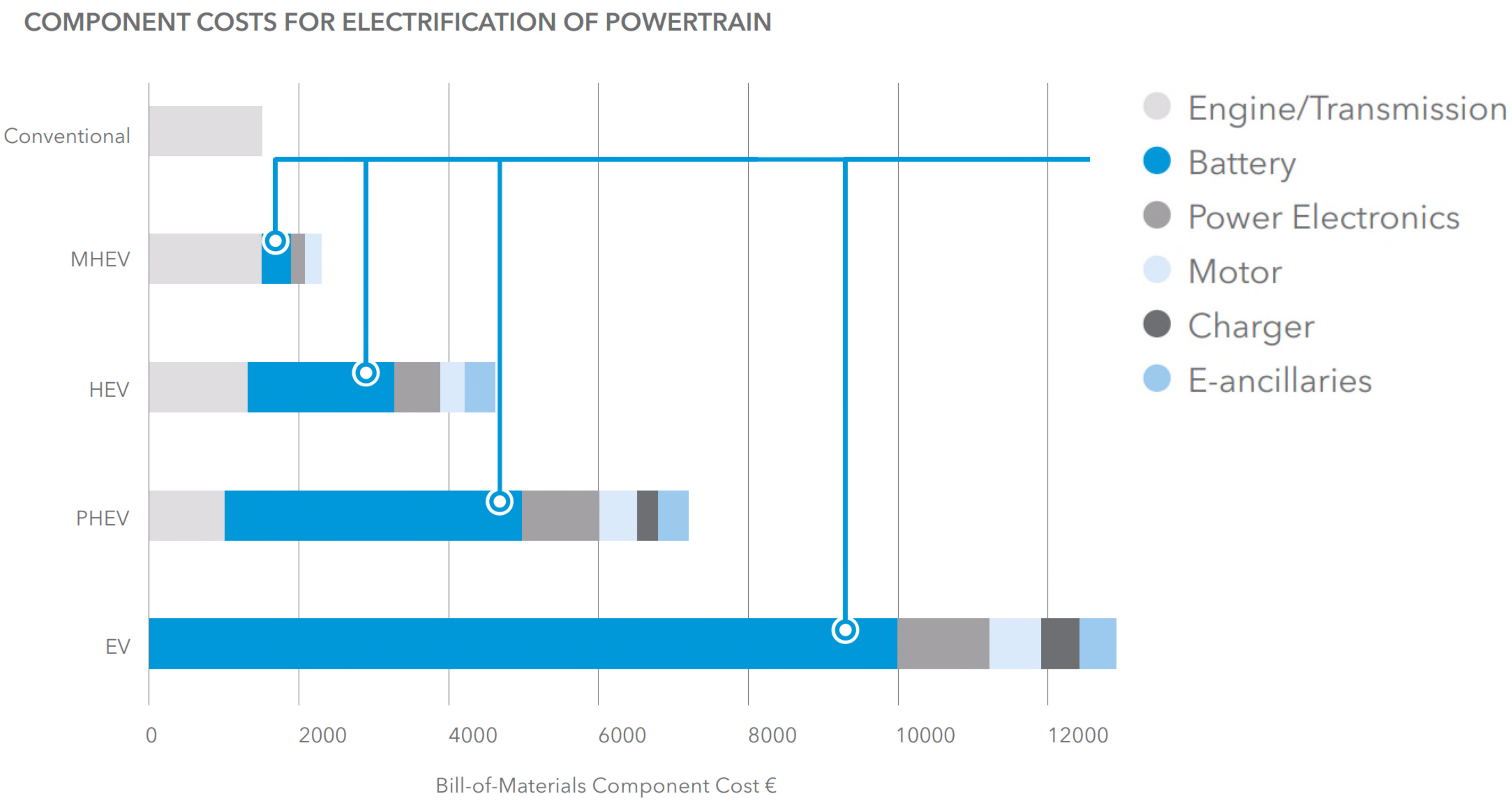
Electrification will not happen overnight…



- Market for engine components and systems still exists until at least 2035, and aftermarket until 2050
- But value will diminish
- Market for motors, power electronics and battery systems grows quickly
- Easiest to enter market whilst small

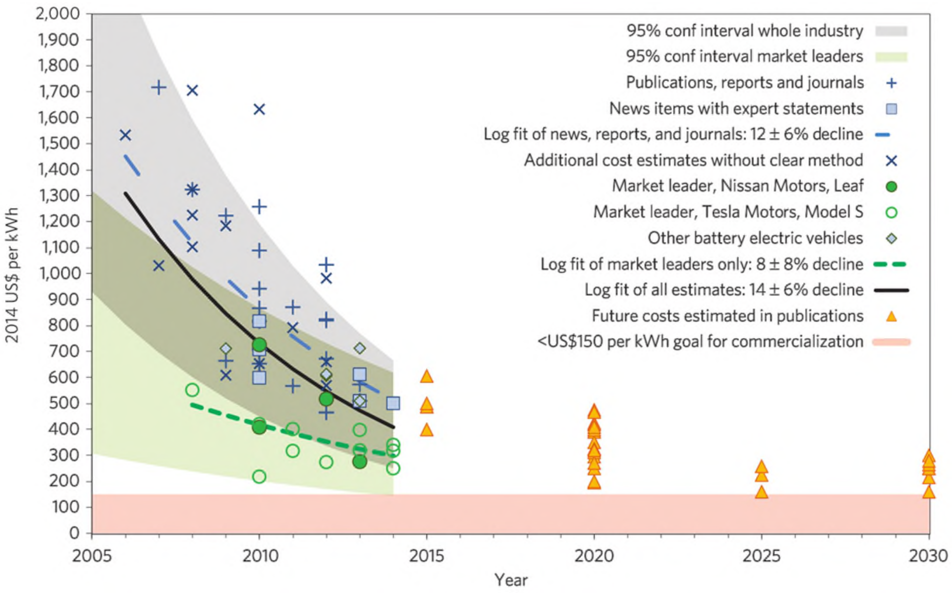
Source: Illustrative only – no basis in peer reviewed data !

Biggest challenge for commercialization is battery cost

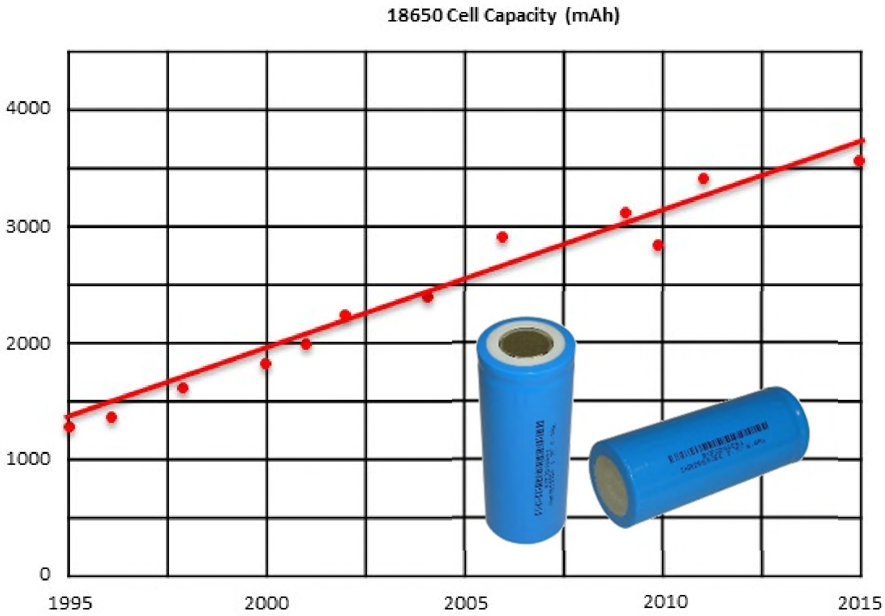


Lithium Ion batteries are improving rapidly

- Costs have fallen dramatically due to technology, production volume and market dynamics
- Pack cost fallen from $1,000/kWh to <$250/kWh in less than 8 years

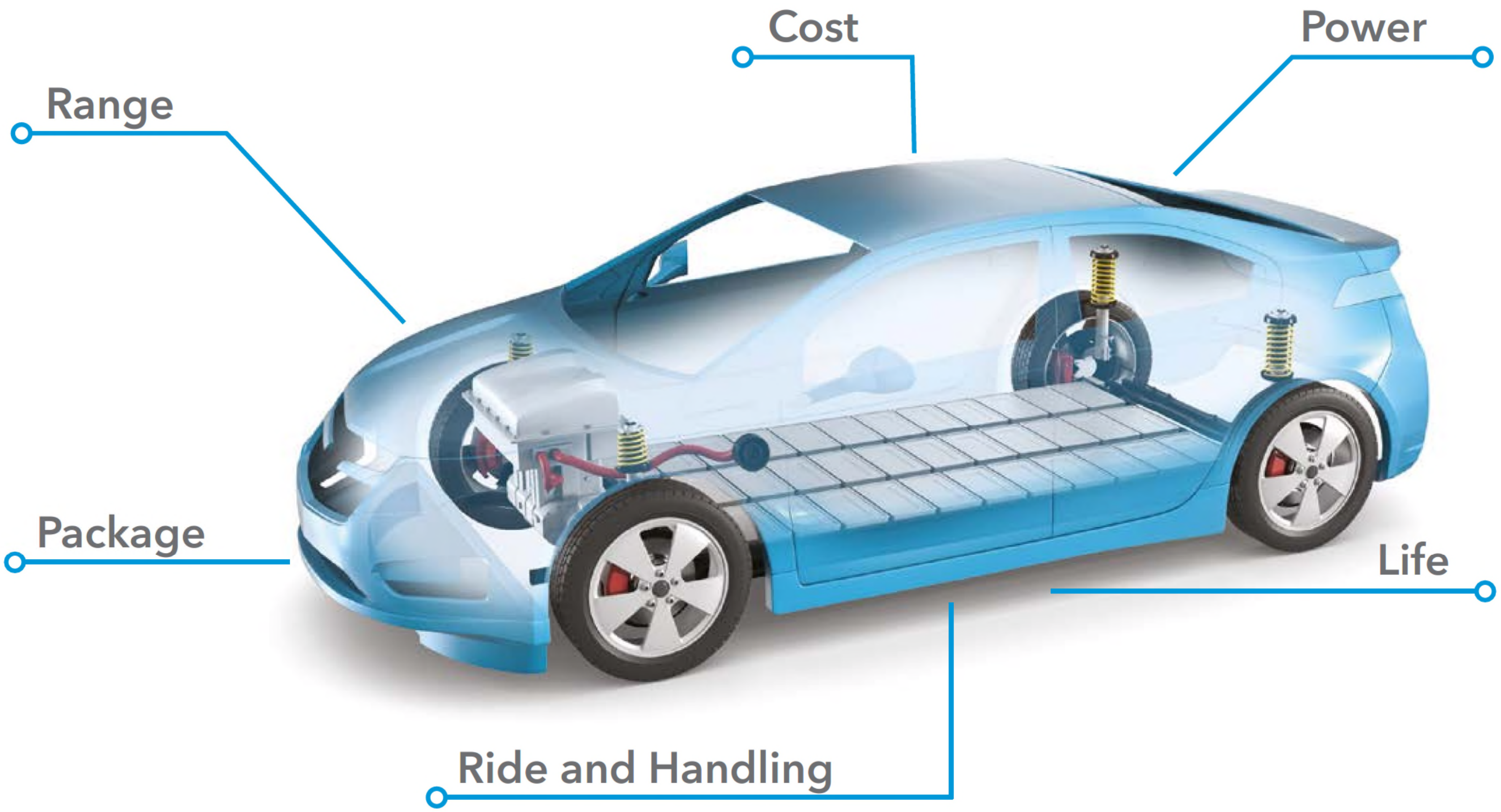


Nykvist et al 2014



- Volumetric energy density is increasing due to better materials and cell structure
- Doubled in 15 years
- Requires continued innovation to continue

The battery is the defining component of the electric vehicle



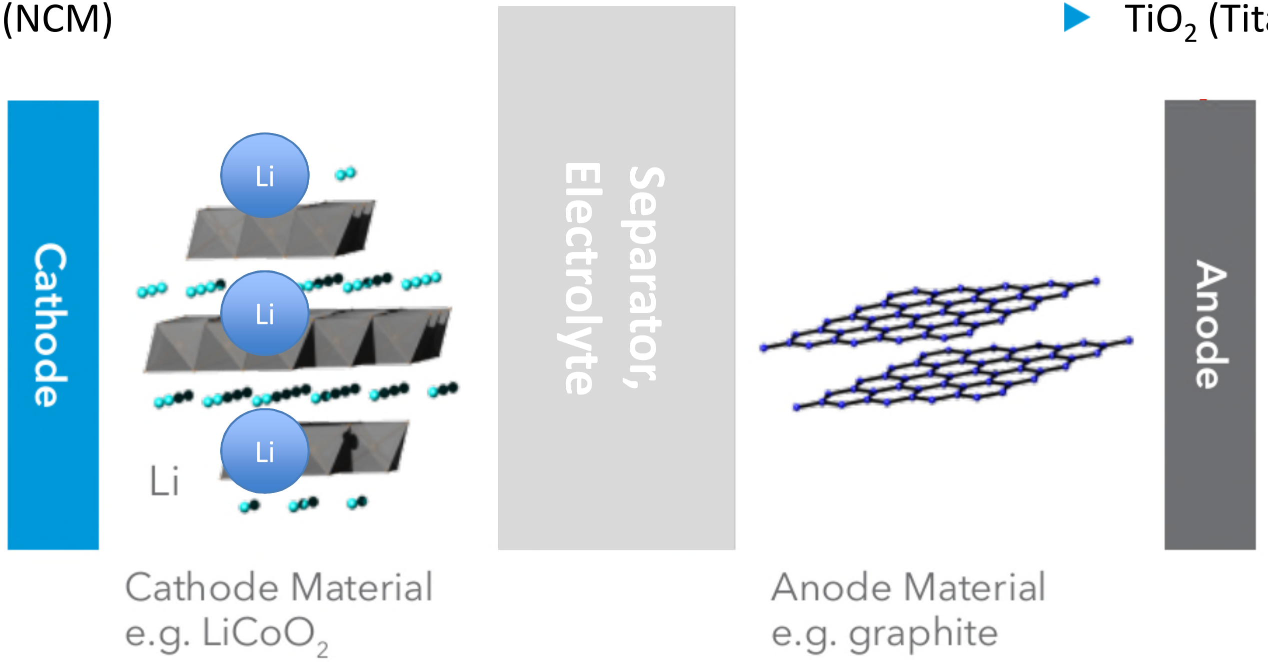
How a Lithium-ion cell works - structure

Cathode

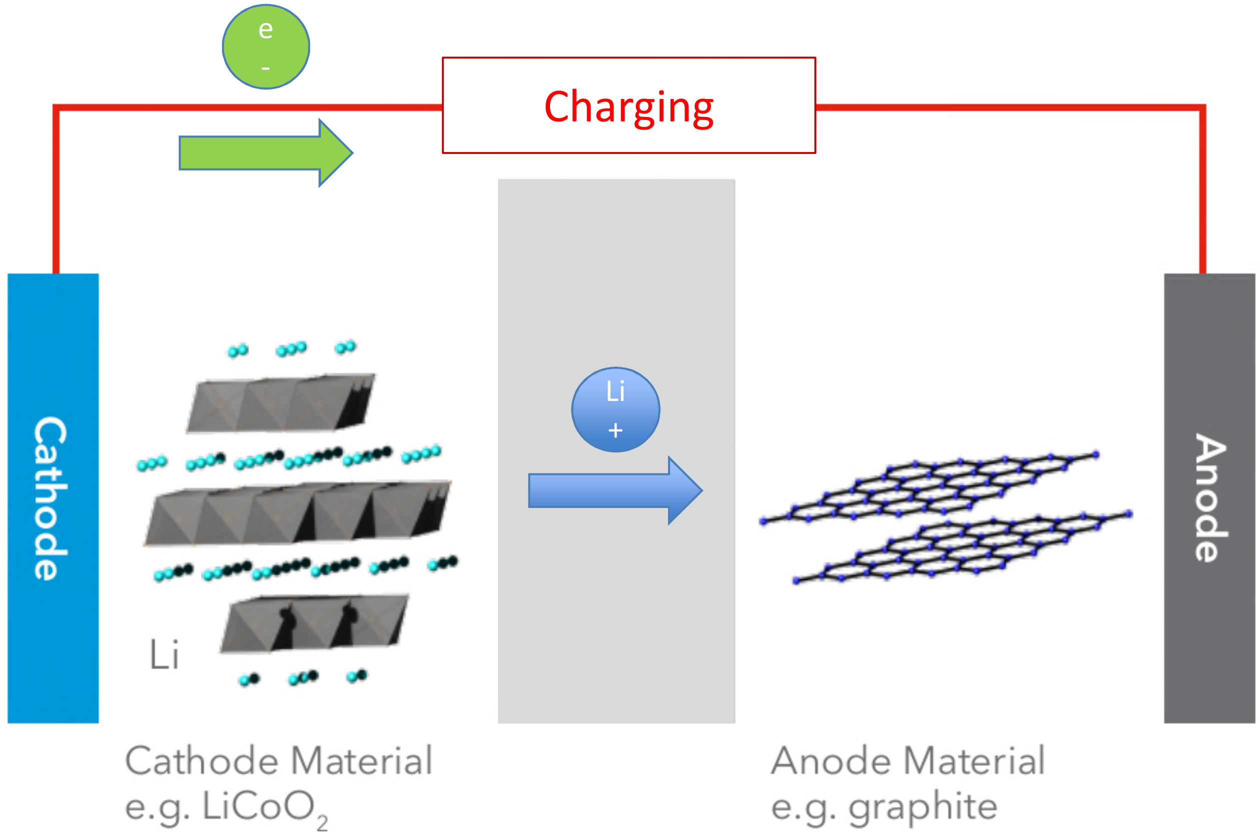
- $LiCoO_2$ (LCO)
- $LiNiCoAlO_2$ (NCA)
- $LiNiCoMnO_2$ (NCM)
- $LiFePO_4$ (LFP)
- LiNiMnO (LMO)

Anode

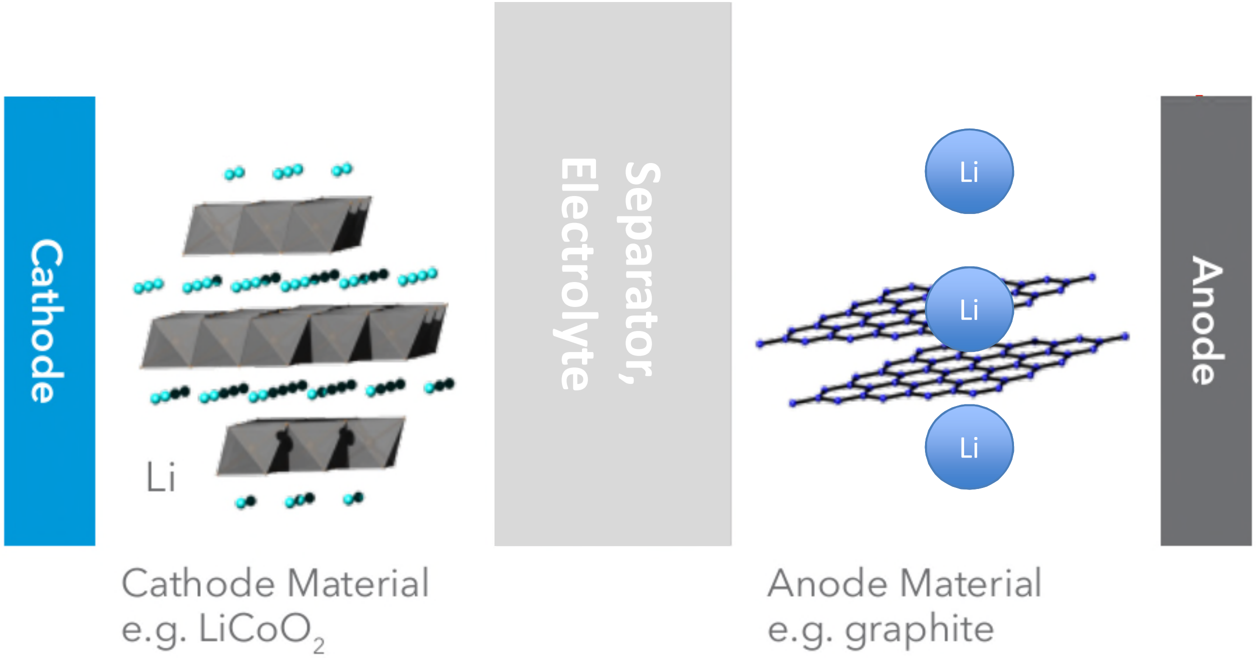
- Graphite (+ Graphene ?)
- Silicon + Graphite
- TiO_2 (Titanate)



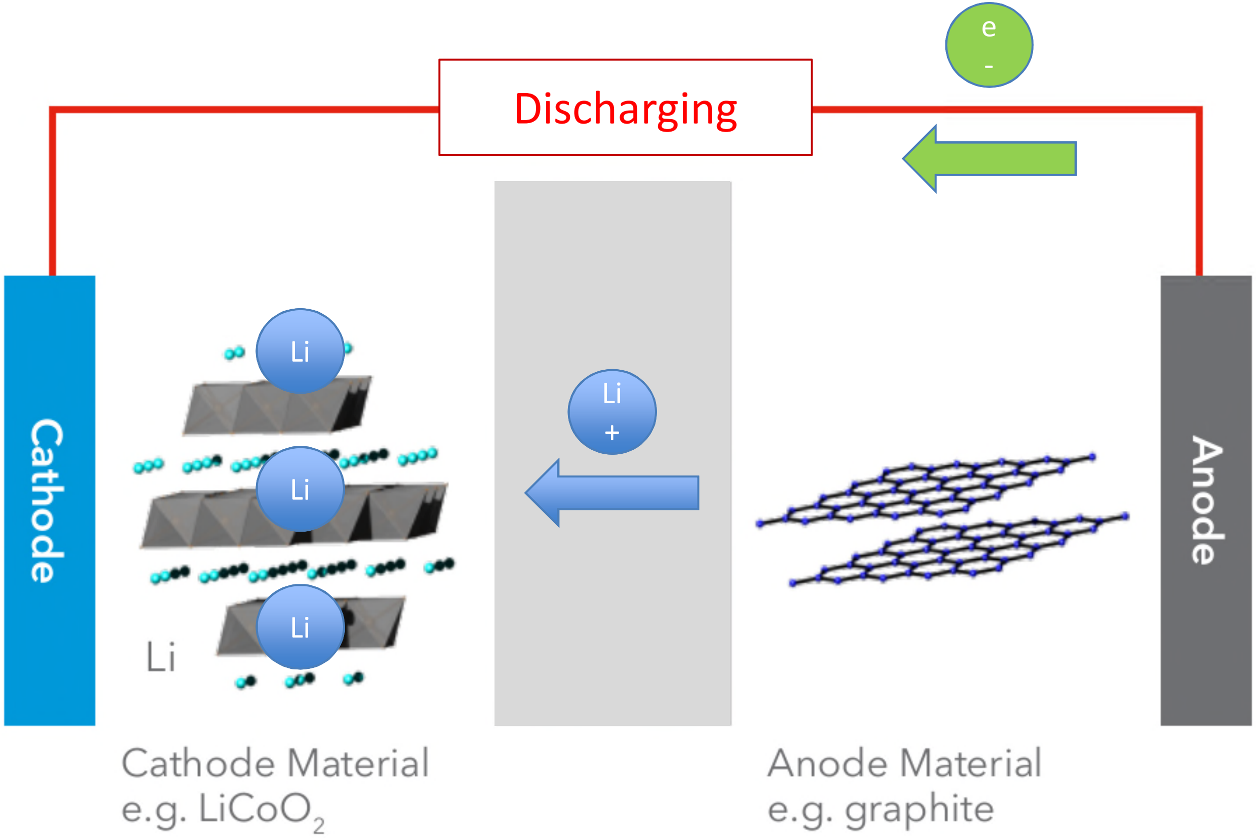
How a Lithium-ion cell works - charging



How a Lithium-ion cell works - charged

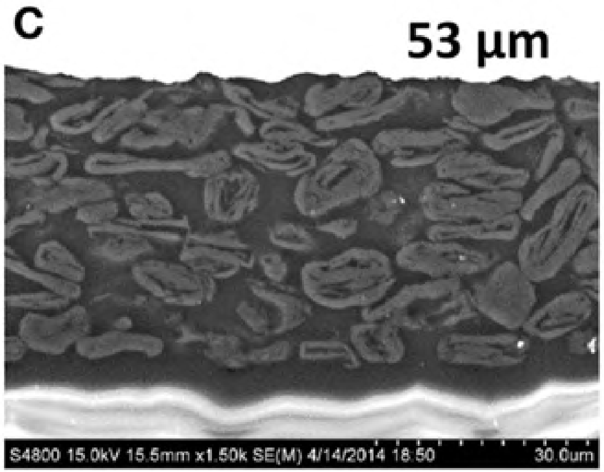


How a Lithium-ion cell works - discharging

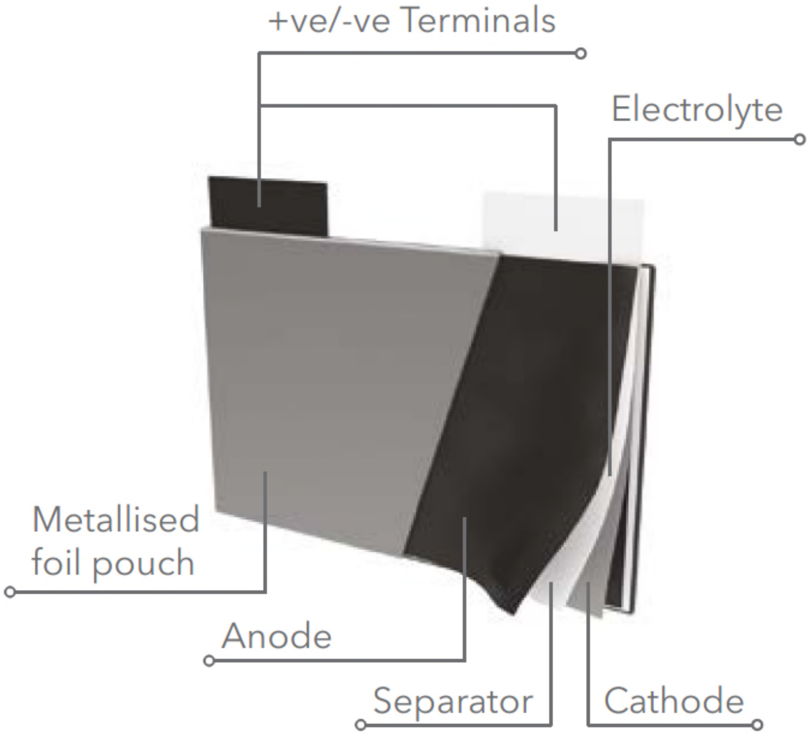


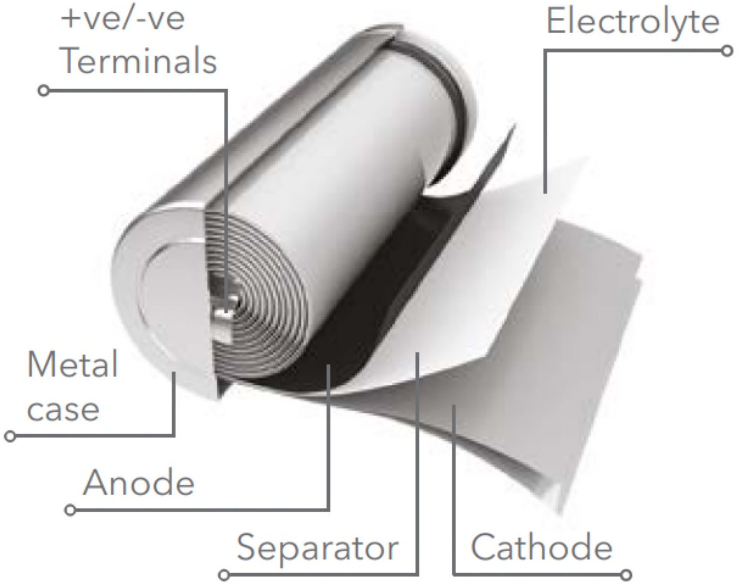
Electrode construction

Sheng et al. Front Energy Res 5 December 2014



Automotive cell construction





Automotive pack construction

Lithium-ion cell

e.g. pouch or cylindrical cell

As a single unit, a '**cell**' performs the primary functions of a rechargeable 'battery'. Cells come in varied formats:

- Cylindrical Cells
- Pouch Cells
- Prismatic Cells

Module

e.g. module for pouch cells (Nissan Leaf)

A '**module**' is formed by connecting multiple 'cells', providing them with a mechanical support structure and thermal interface and attaching terminals. Modules are designed according to cell format, target pack voltage and vehicle requirements.

Pack

e.g. pack for pouch cells (Nissan Leaf)

A '**pack**' is formed by connecting multiple 'modules' with sensors and a controller and then housing the unit in a case. Electric vehicles are equipped with batteries in a 'pack' state which are connected to the powertrain.

Typical EV battery weighs 400-800kg and fits under car floor

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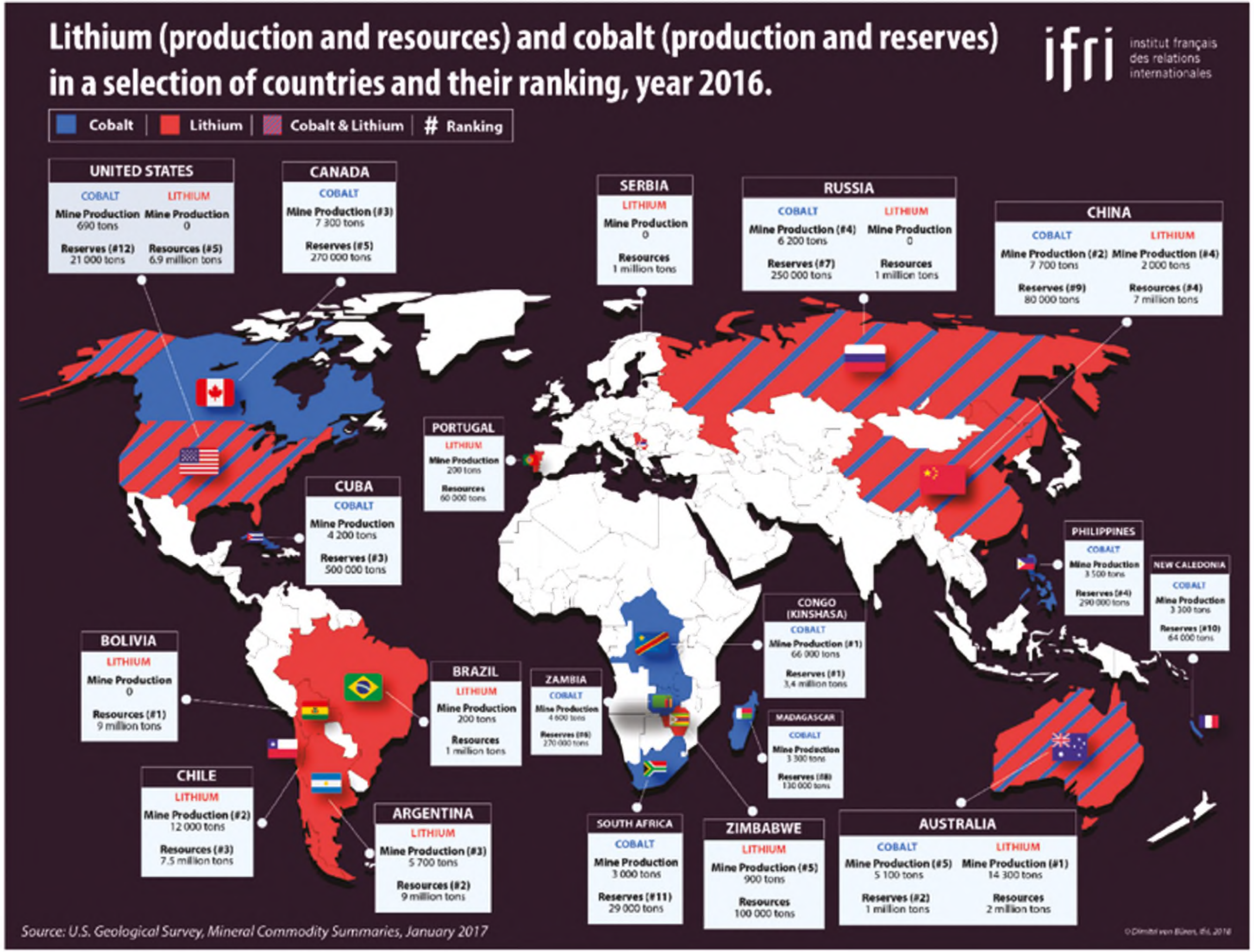
Mineral supplies, and their sustainability must be considered



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"There isn't enough raw material to make all these batteries"

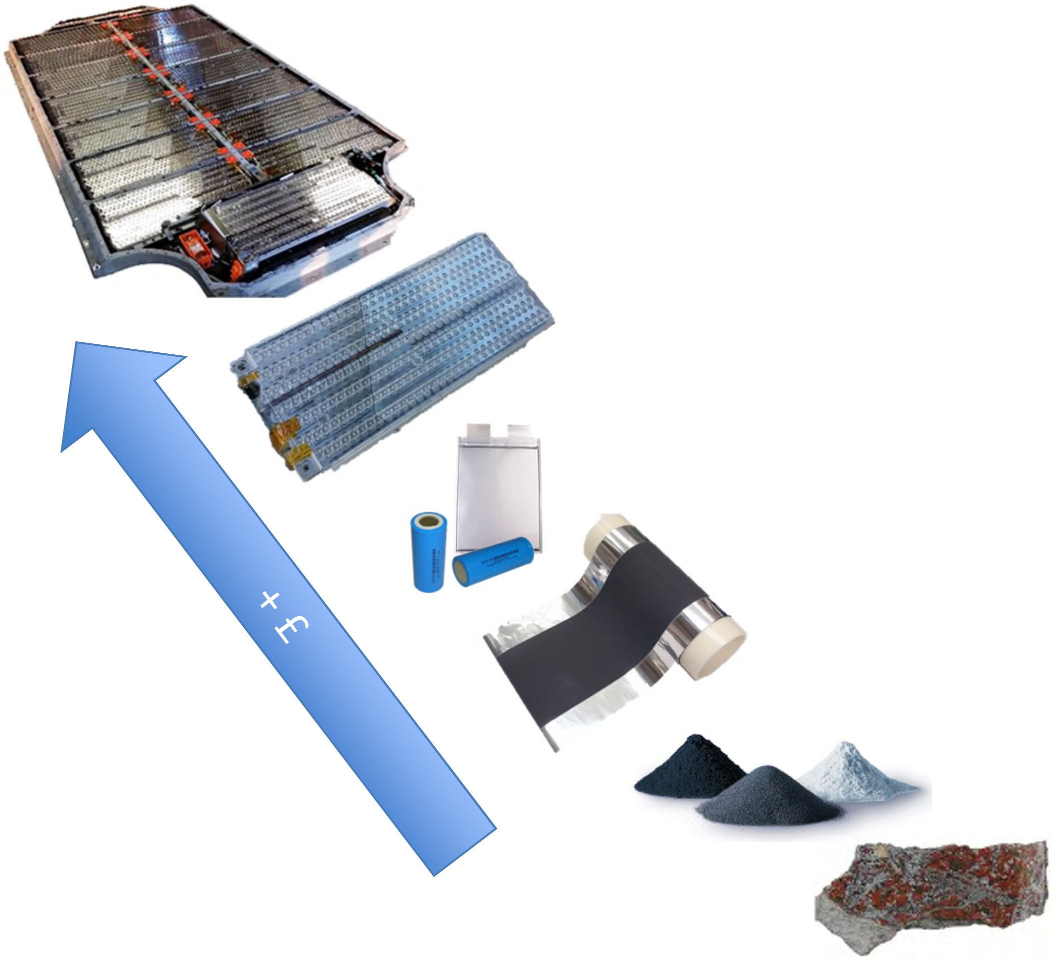
MYTH

But we will see imbalance of supply and demand

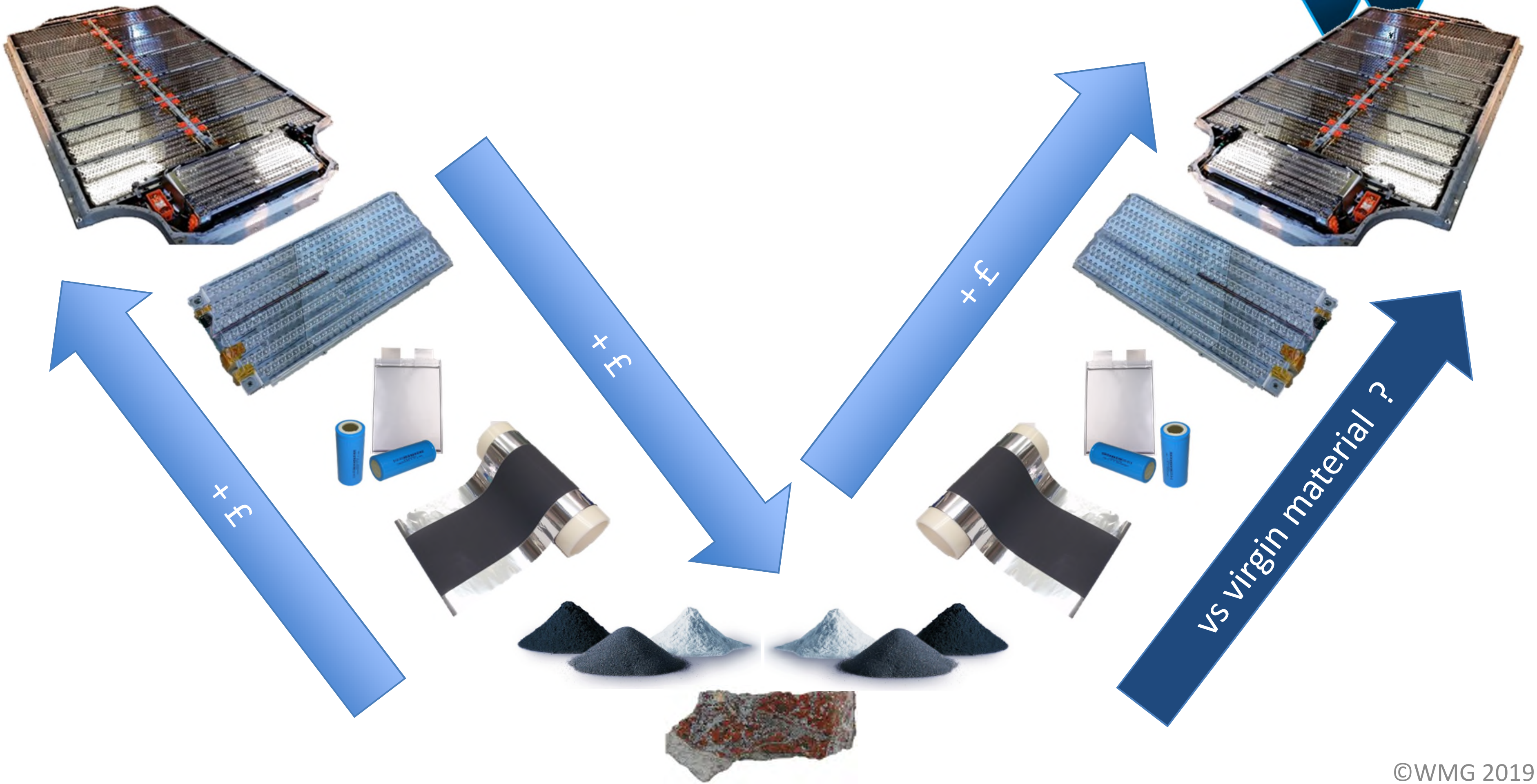
And ethics and sustainability of sourcing will be important

Image credit: Institut francais des relations internationales (ifri)

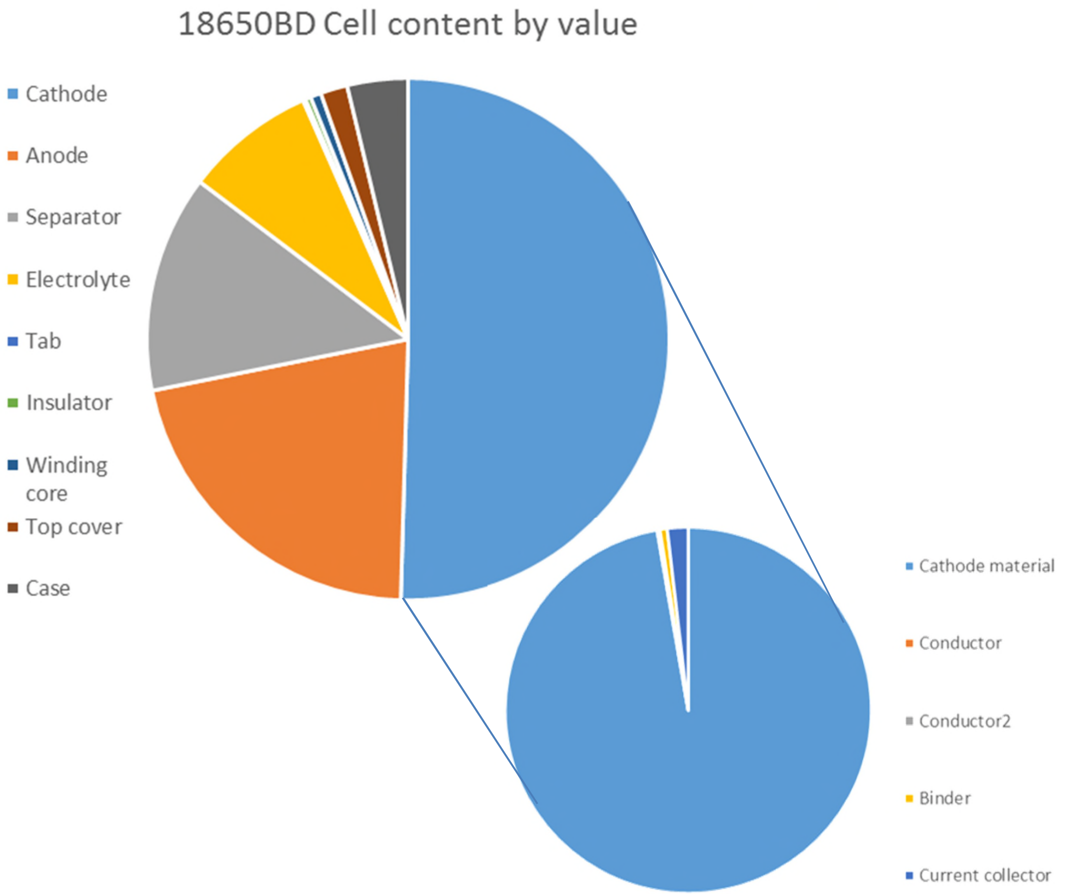
Value is added at every stage of the manufacturing process



Recycling should retain maximum value



Typical EV battery weighs 400-800kg and contains valuable materials



Data source: ITRI, Taiwan, 2015

Commonly recovered:

- Cobalt
- Nickel
- Copper
- (Manganese)

Not recovered:

- Graphite
- Electrolyte
- Aluminium

An EV is only as clean as the energy used to charge it…

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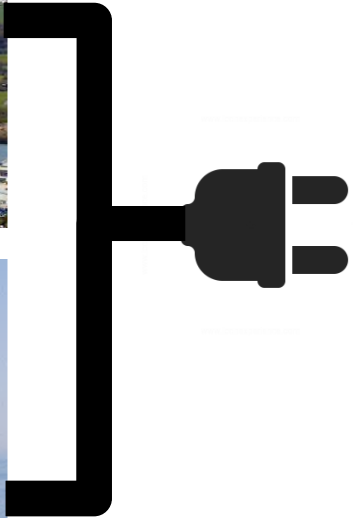


Zero Emission

Electricity is only as clean as the process to make it

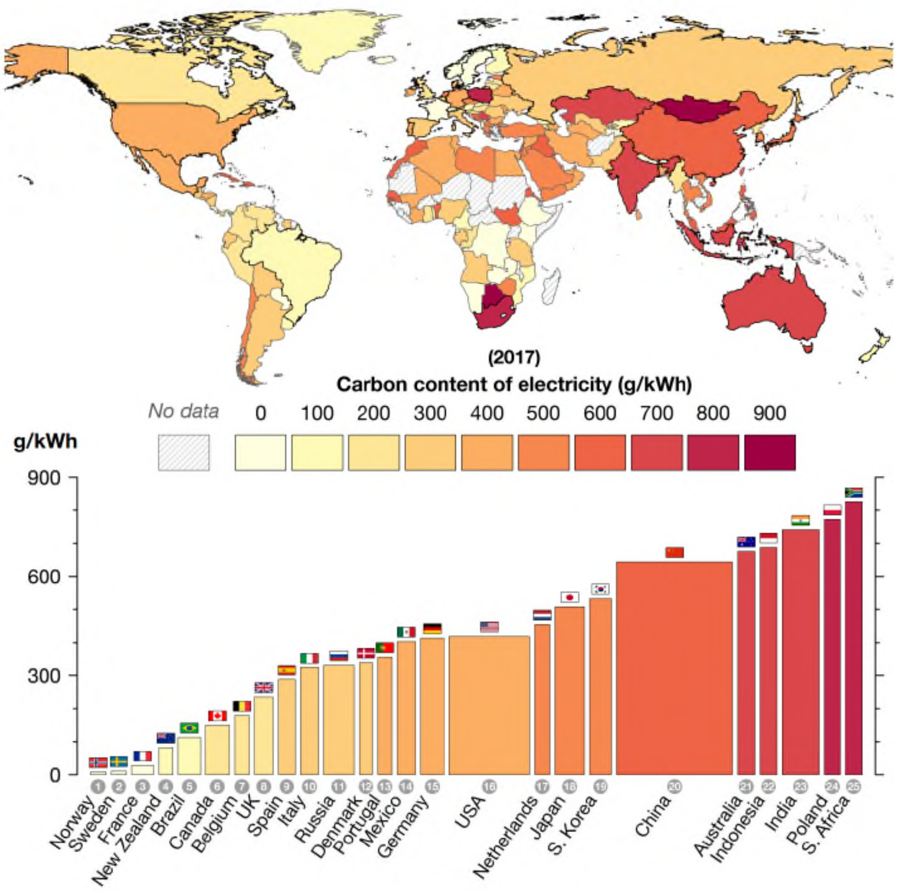
Generation type determines CO_2/kWh:

- Nuclear 5g/kWh
- Wind 5g/kWh
- Photovoltaic 30-60g/kWh
- Gas 500g/kWh
- Coal 800-1000g/kWh

And mix varies by time of day and time of year:

- UK Summer avg: 340g/kWh
- UK Winter avg: 450g/kWh

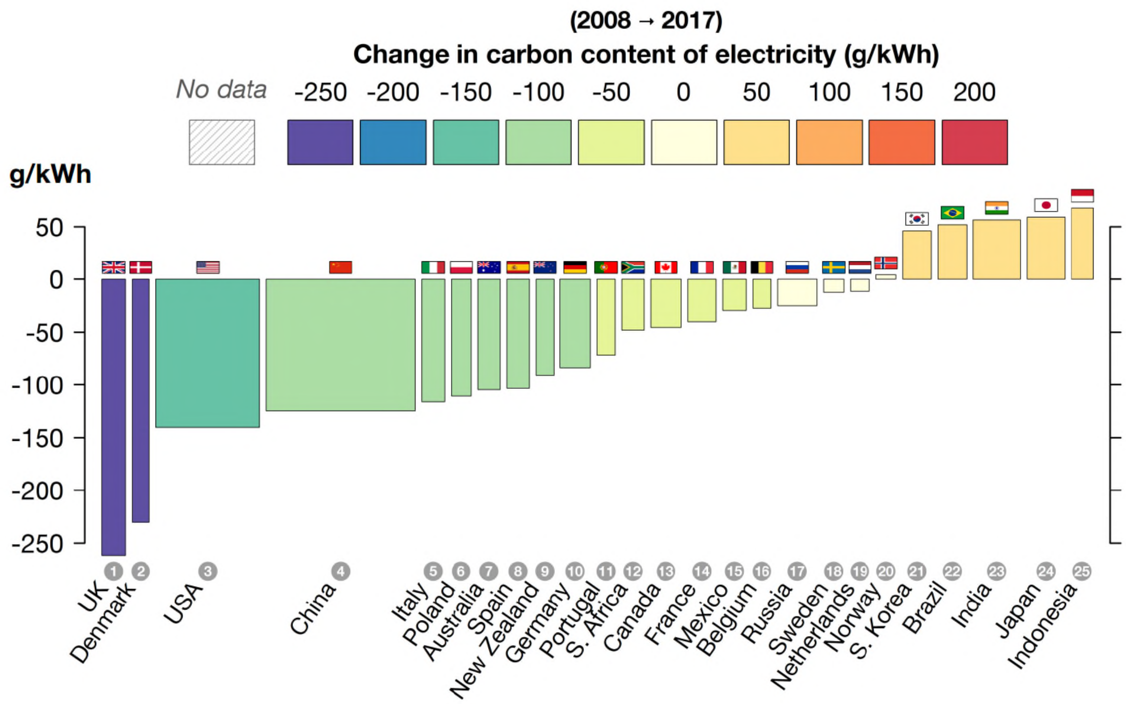
- UK July min: 150g/kWh
- UK July max: 410 g/kWh

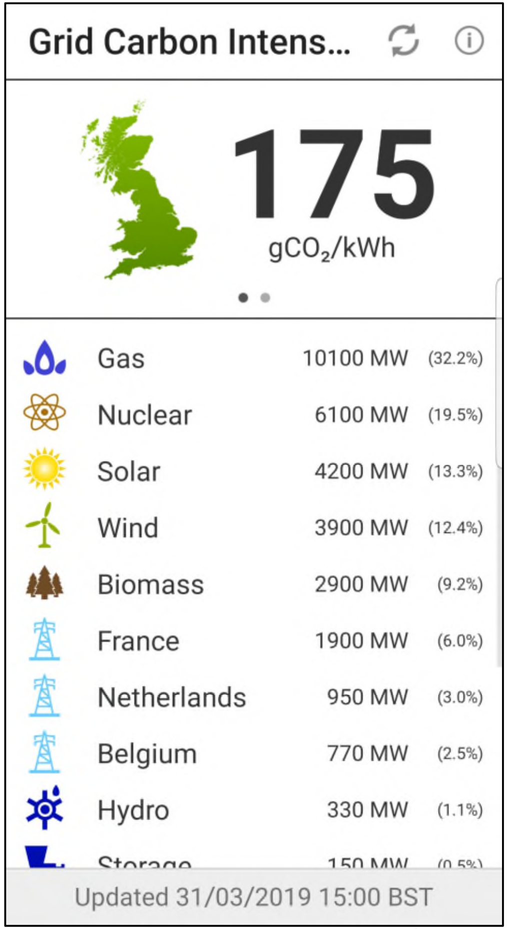


Source: FUELINST – Data for 2014

Source: Energy Revolution A Global Outlook, E4Tech December 2018

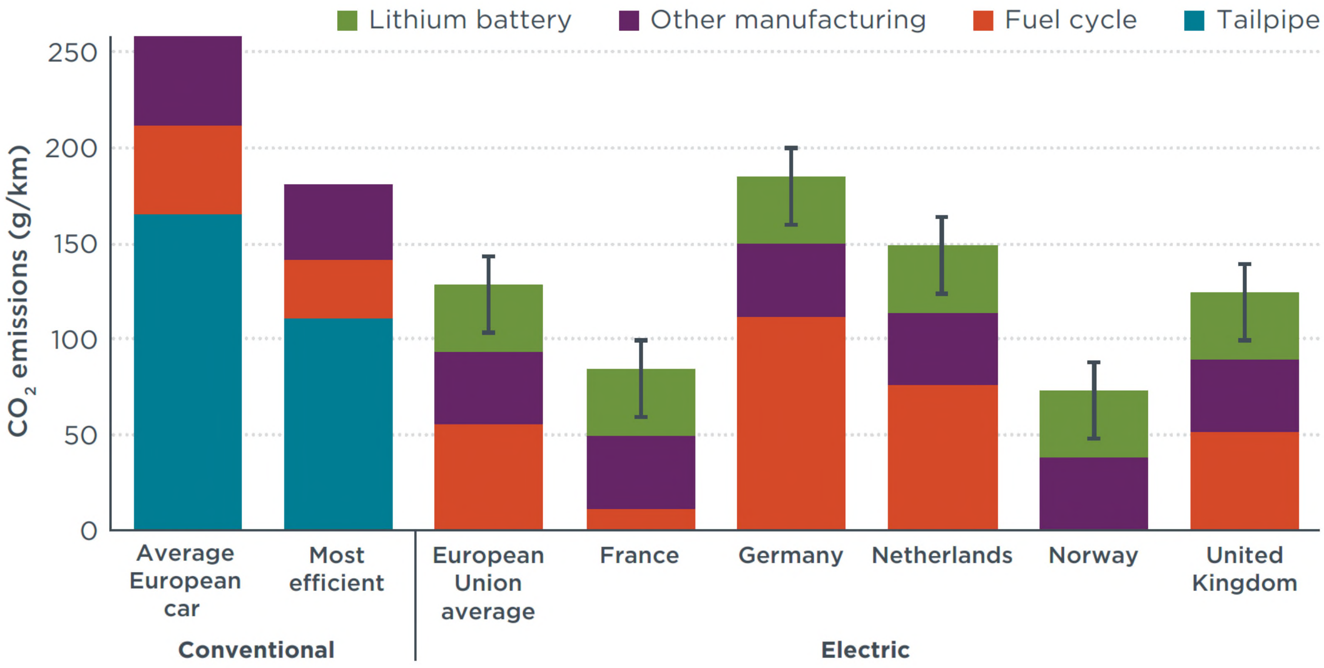
Electricity CO_2/kWh improving with use of nuclear, gas, solar and wind





Source: Energy Revolution A Global Outlook, E4Tech December 2018

EVs take more energy to manufacture, but use less through lifetime

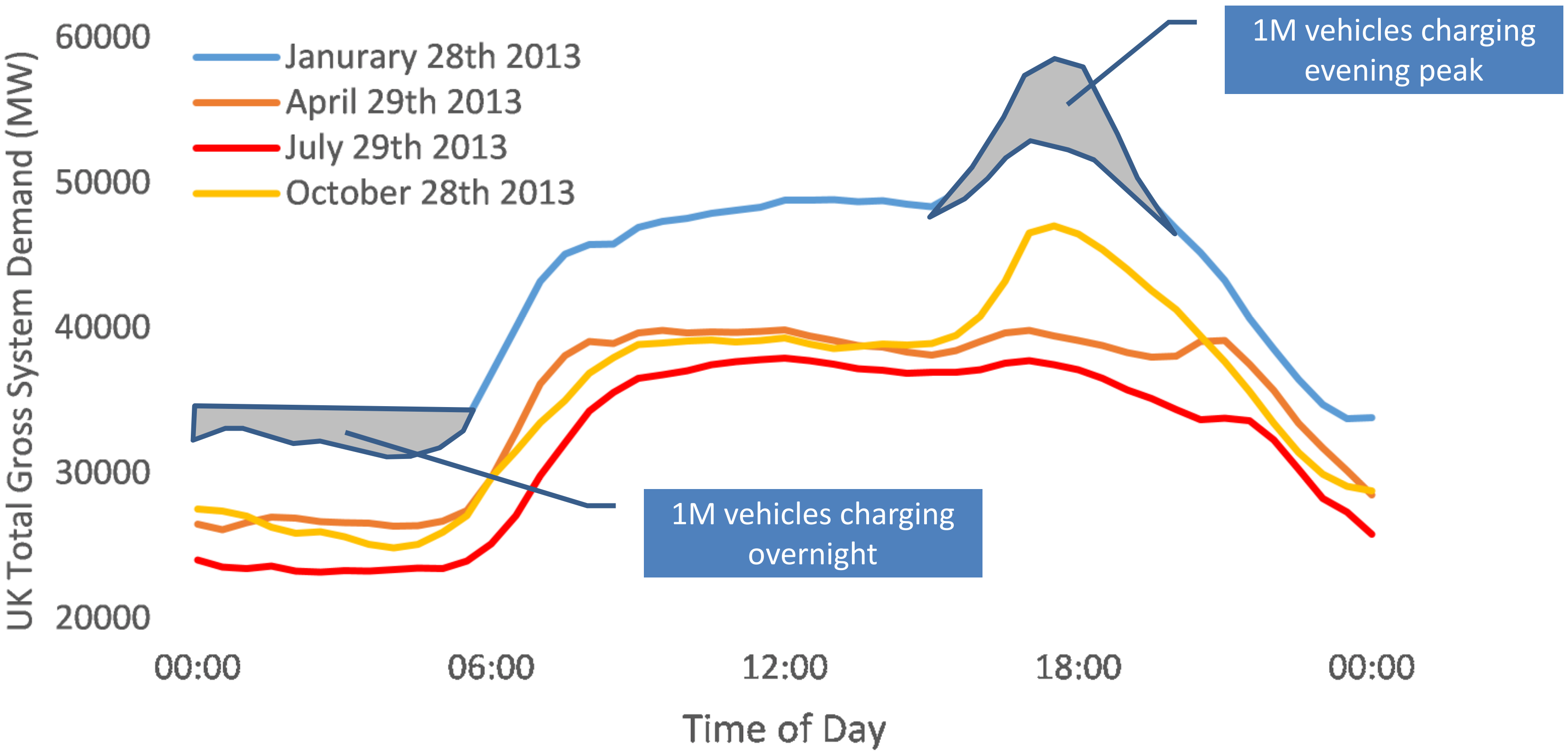


Source: ICCT – Effects of battery manufacturing on electric vehicle lifecycle greenhouse gas emissions– Feb 2018

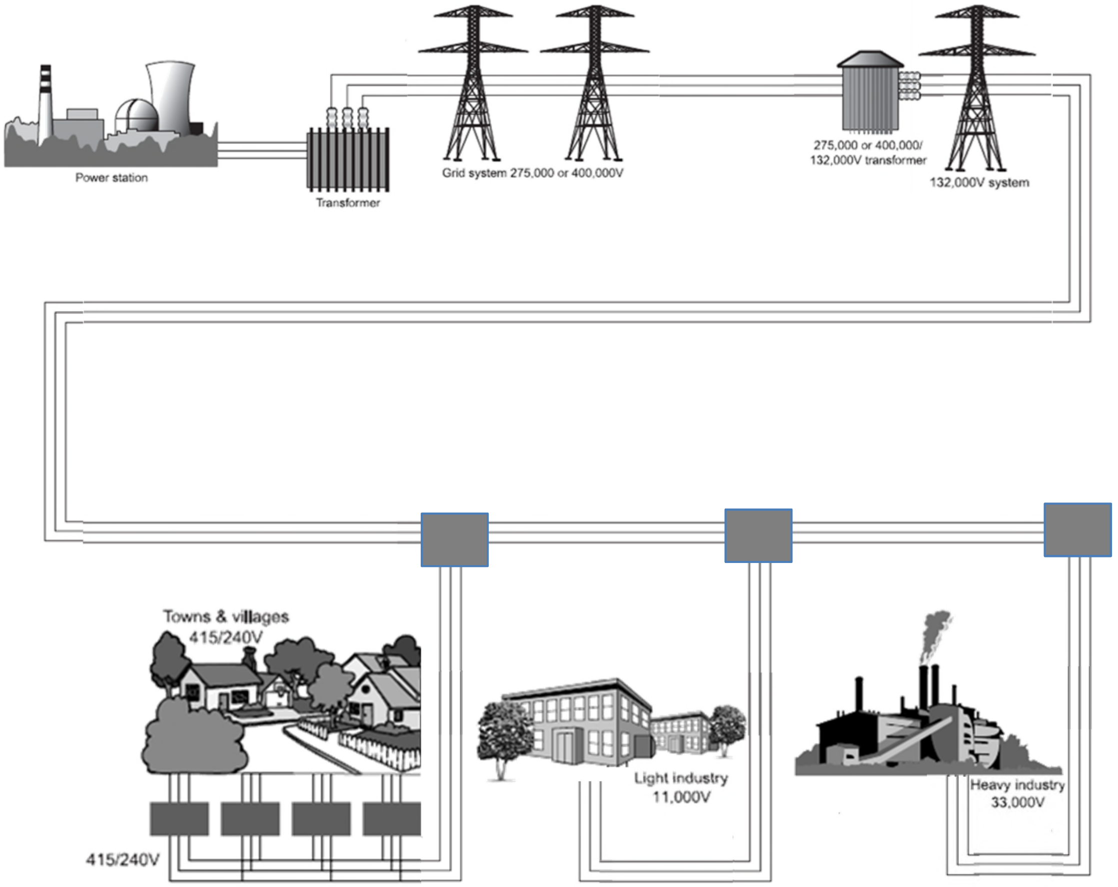
"All our electricity comes from coal – so electricity is dirtier than diesel" MYTH

"EV's make more greenhouse gases than normal cars because of the energy to build them" MYTH

Have we got enough electricity ?



Electricity distribution network will be challenged by electrification



- Generation and high voltage distribution "Grid" within capacity as long as charging times managed

- Reinforcement may be needed for:
- House wiring/fusing
- Neighbourhood wiring
- Local substations
- Motorway services
- Workplace parking

Research and the future

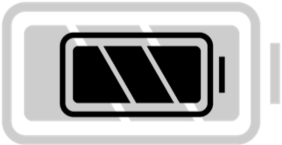
Battery Roadmap – 15-20 year timescale

Cost

Now $130/kWh (cell)
$280/kWh (pack)

2035 $50/kWh (cell)
$100/kWh (pack)

Energy Density



Now 700Wh/l,
250Wh/kg (cell)

2035 1400Wh/l,
500Wh/kg (cell)

Power Density

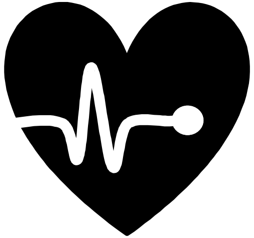
Now 3 kW/kg (pack)

2035 12 kW/kg (pack)

Safety

2035 eliminate thermal runaway at pack level to reduce pack complexity

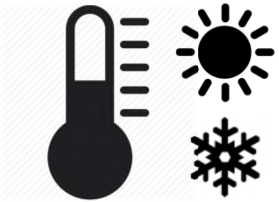
1st Life



Now 8 years (pack)

2035 15 years (pack)

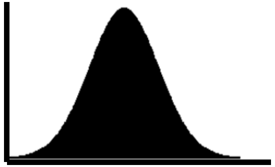
Temperature



Now -20° to +60°C (cell)

2035 -40° to +80°C (cell)

Predictability



2035 full predictive models for performance and aging of battery

Recyclability

Now 10-50% (pack)

2035 95% (pack)

We need new battery materials and new supply chains for them

- **Materials**
- Cells
- Packs
- Vehicles

- Short to medium term
  - Li-Ion cathode improvements
  - Silicon / graphene anodes
  - Binders / solvents
  - Electrolyte additives / solid electrolytes
  - Separator materials

- Longer term
  - Sodium Ion chemistries ?
  - Lithium Sulfur ?
  - Lithium metal anodes ?

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We need innovation in cell format and construction to optimize system

Materials

Cells

Packs

Vehicles

- Cell format
  - Cylinder
  - Pouch
  - Prismatic
  - Size, materials, aspect ratio
  - Joining features

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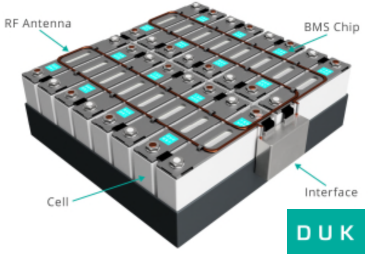
- Smart cells
  - Integrated cooling features (high power)
  - Fire suppression measures
  - Distributed BMS with integrated sensors ?



Module and pack design must improve for cost and performance

Materials
Cells
Packs
Vehicles

- Modules
  - Design for manufacturing / disassembly
  - Cell cooling arrangements
  - Cell welding (non-welded ?)
  - Design for end of life

- Packs
  - BMS systems to maximise life and SoC utilisation
  - Cooling and heating arrangements
  - Structural integration with vehicle
  - Crash structural considerations
  - Fire propagation limitation

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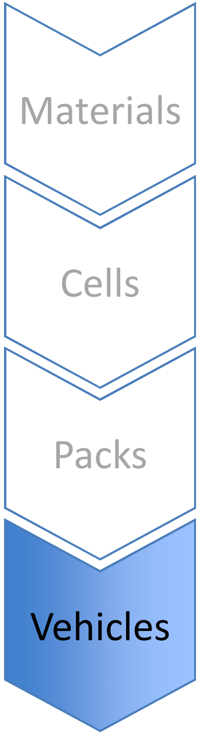
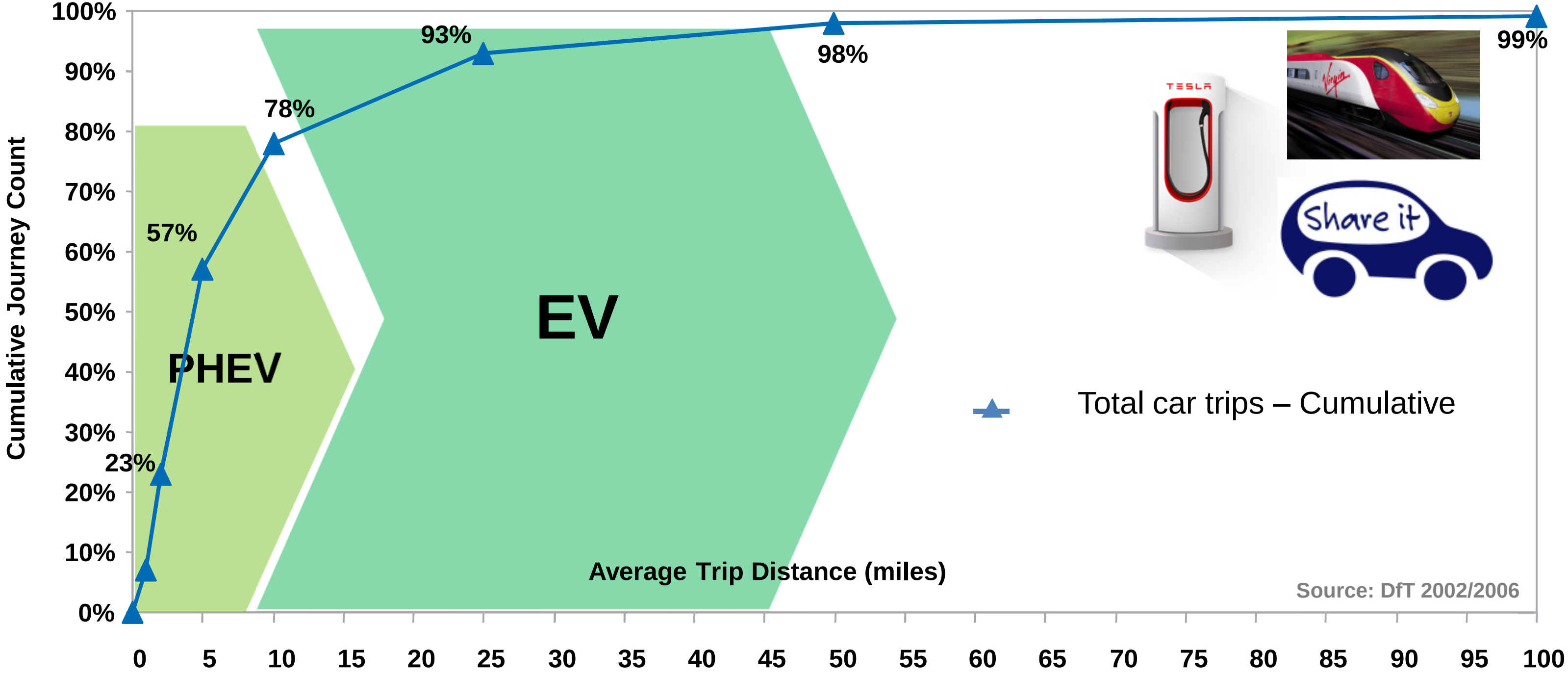
Vehicle concepts will evolve towards smaller batteries





- For PHEV, the battery should be large enough for typical daily mileage
  - As small as possible for cost and packaging => 20-40 miles
- For EV, 100 miles (real world) covers 98% of usage.
- Fast charge, car-share or alternative mode for remaining 2% of journeys

Vehicle concepts will emerge around smaller vehicles

Materials

Cells

Packs

Vehicles

L – Segment vehicle concepts from many manufacturers




Electric personal transport





Thank you

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