Vehicle Electrification & Recyclability

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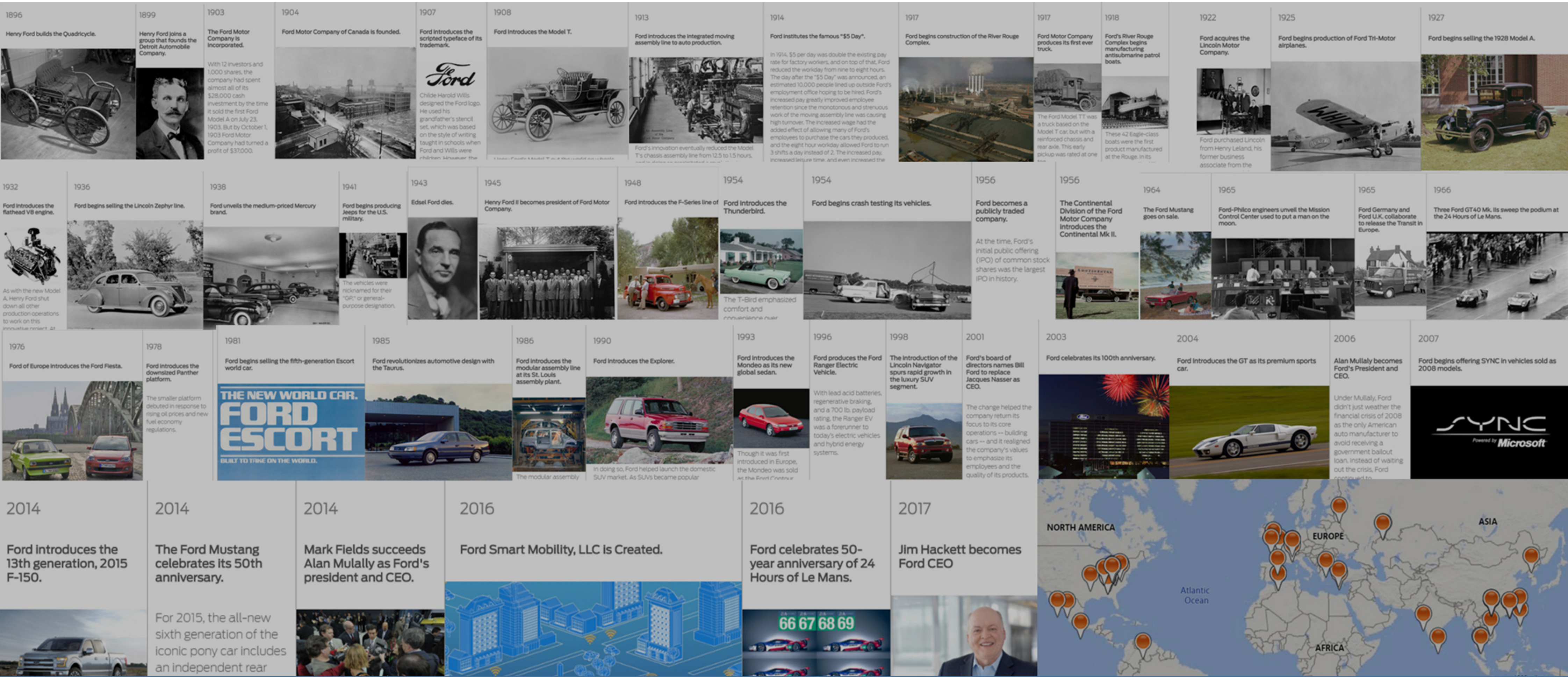


Ford is more than **a century of passion in Automotive Industry !**

Today, **199 000 employees** in **61 plants & facilities** across the globe,

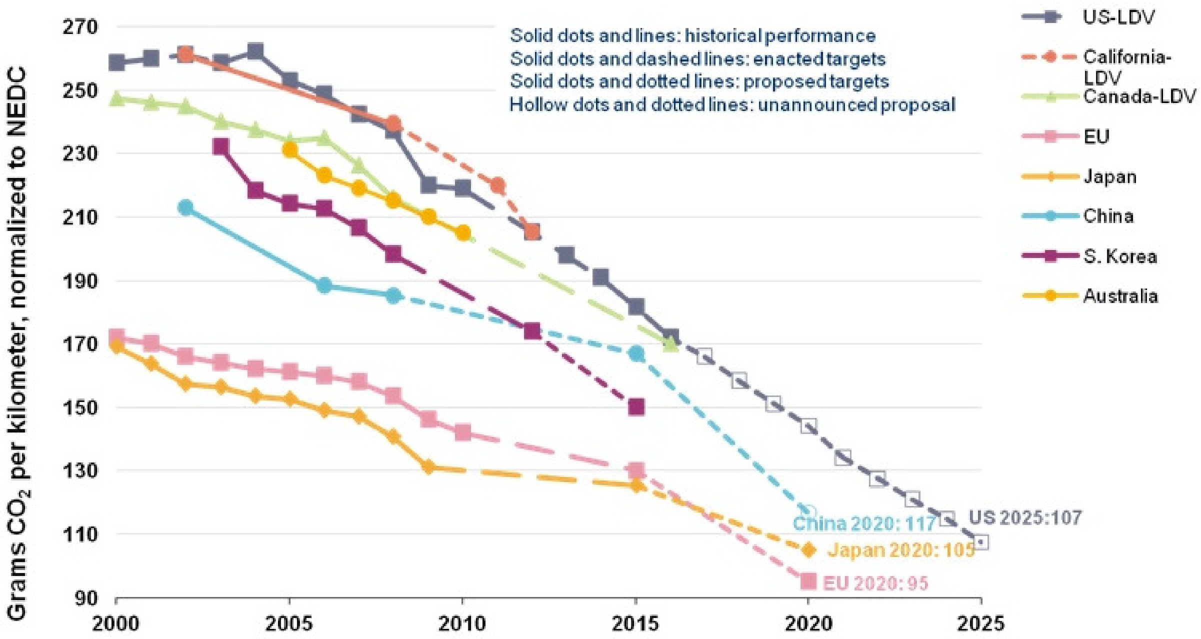
are producing **6 Mil. vehicles** annually, distributed through **12 000 dealerships**,

making **$160 Bil.** Revenue

What sustainability means to Ford - (Video)

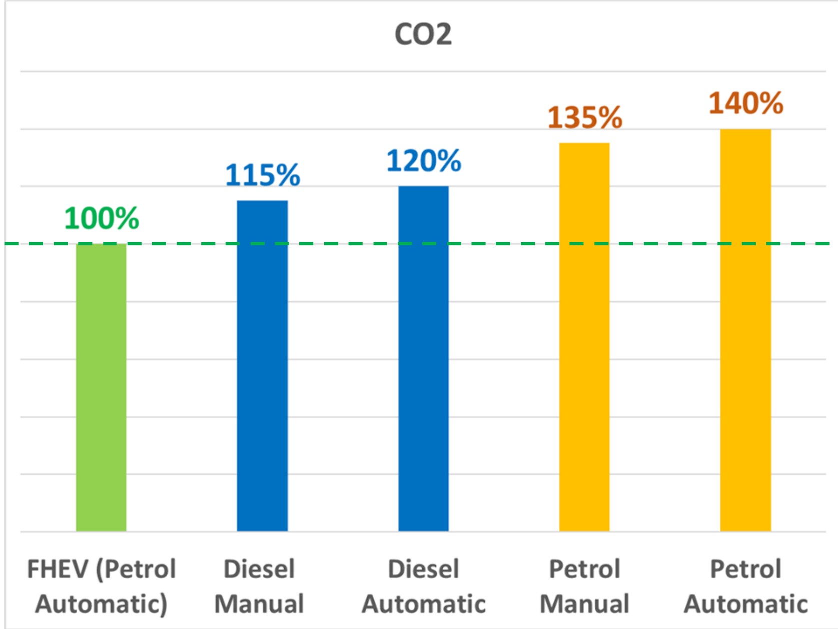
https://www.youtube.com/watch?v=Gy24EejkOjc

Why Electrification ?



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

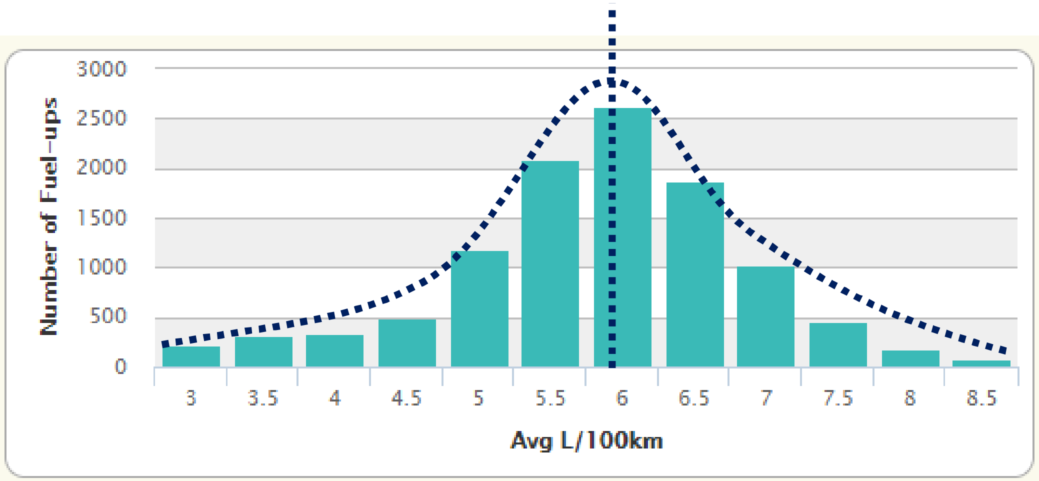
Source: ICCT

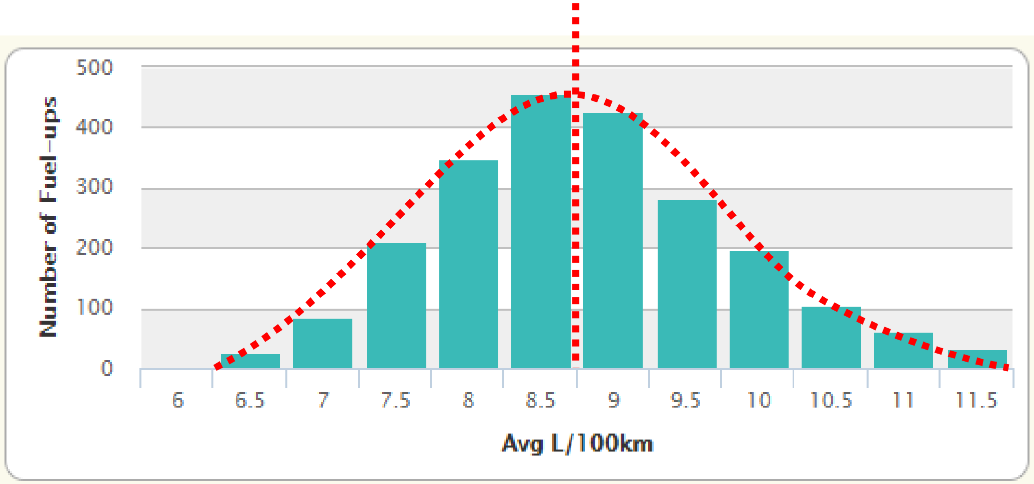


HYBRID **DIESEL** **PETROL**

- Diesel : 95 g Co2/ km → 3.5 L /100 km - Petrol : 95 g Co2/ km → 4 L /100 km
- Mild Hybrid **(mHEV) : 10% FE** | Full Hybrid **(FHEV) : 30% FE** | Plug-In Hybrid **(PHEV) : 80% FE**
- Full Electric **(BEV) : No Fuel consumption**
- CO2 target can not be met without electrification

Hybrid vs Conventional Powertrains in Real World





Ford Fusion Full **Hybrid** : Av. **5.7** L/100

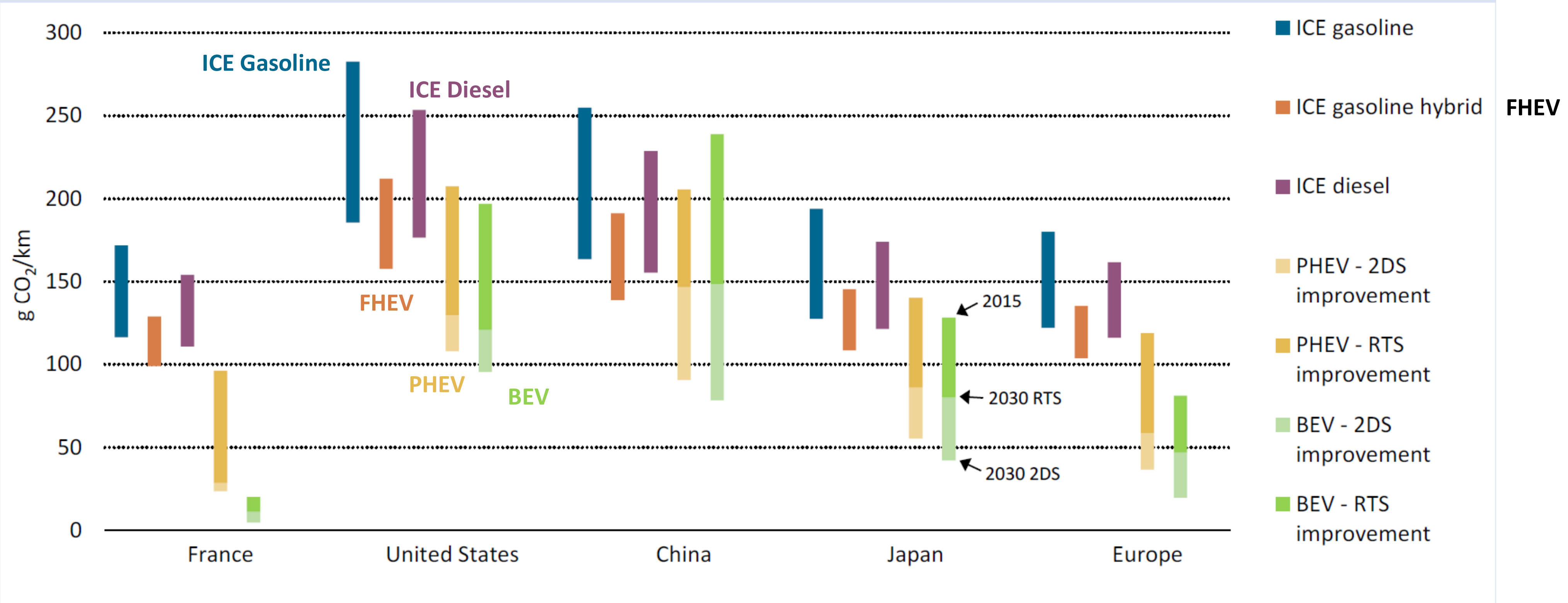
132 g CO2/ km

Ford Fusion Normal **Petrol** : Av. **8.8** L/100

205 g CO2/ km

Large sample size statistics (> 1 Mil. km) reported by customers in US on Ford Fusion show Fuel Economy on Full Hybrid 25% to 30% better than Similar Petrol Engine

Well-to-wheel CO2, Battery Full Electric vs Conventional Powertrains

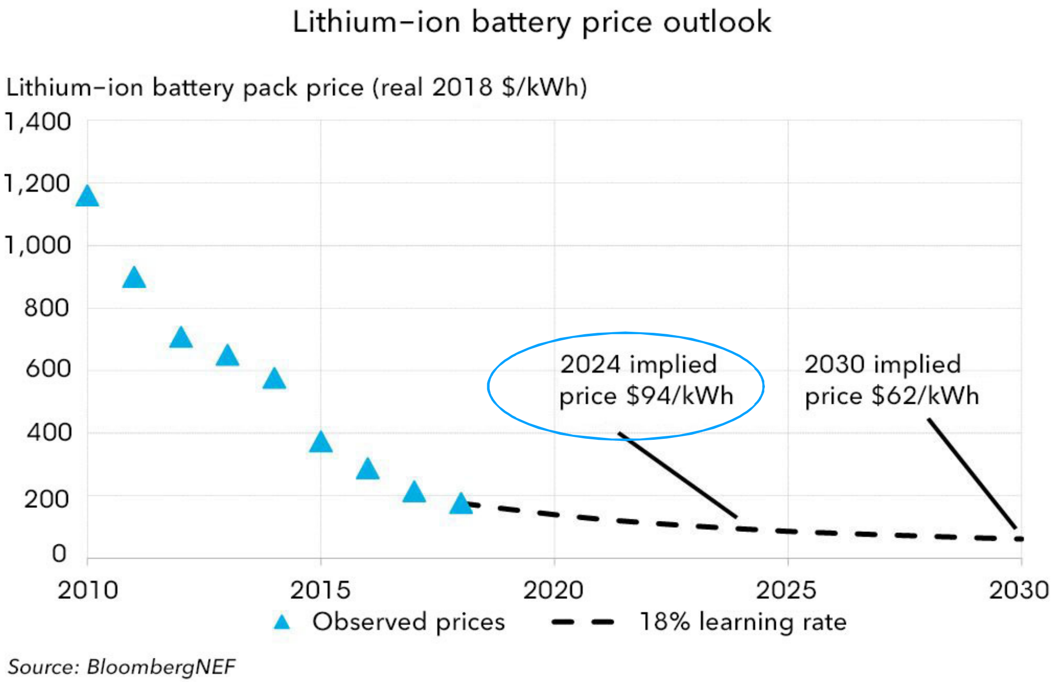


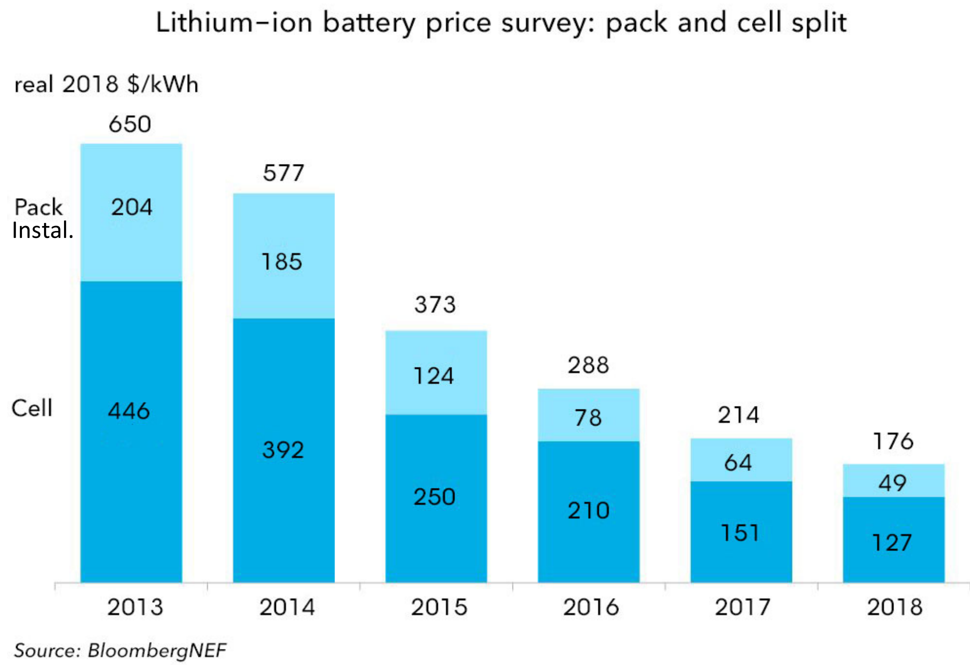
RTS : Current Technology Ref.
2DS : 2 °C decarburization

Source : Global EV Outlook 2017 – International Energy Agenda

BEVs & EVs in general are key to deliver significant CO2 reduction, especially under decarburization plan of power generation industry

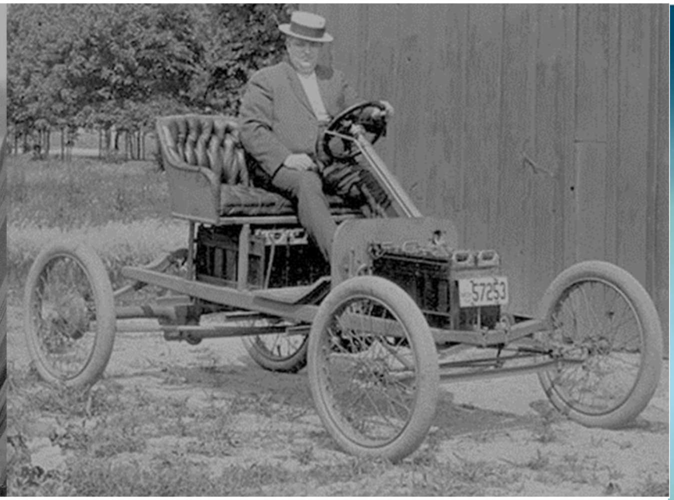
Battery cost, key cost for EVs, is dropping significantly



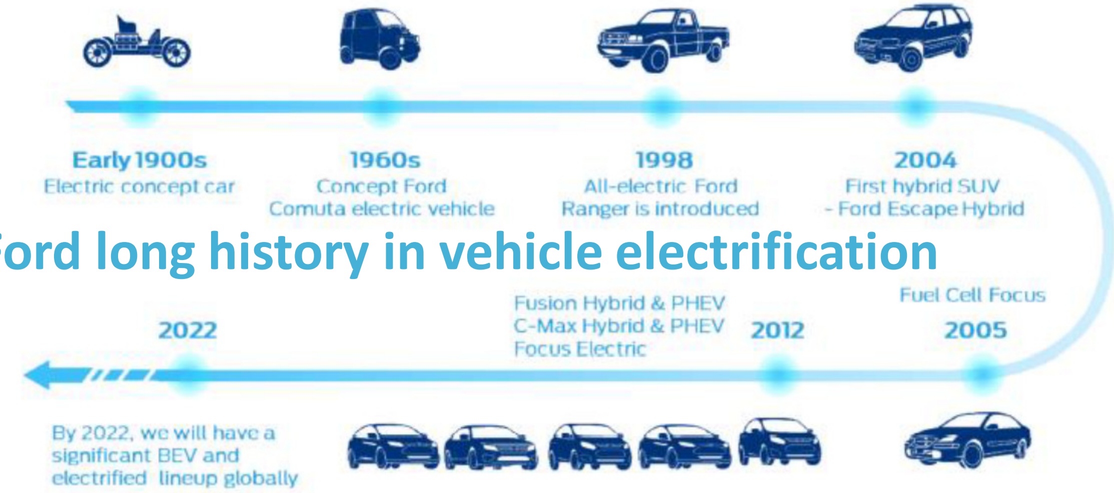


Learn more @ : https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

The cost of EV battery cells dropped dramatically in recent years.
Total battery **pack price / kWh** is expected to **drop below $100 in next 5 years**

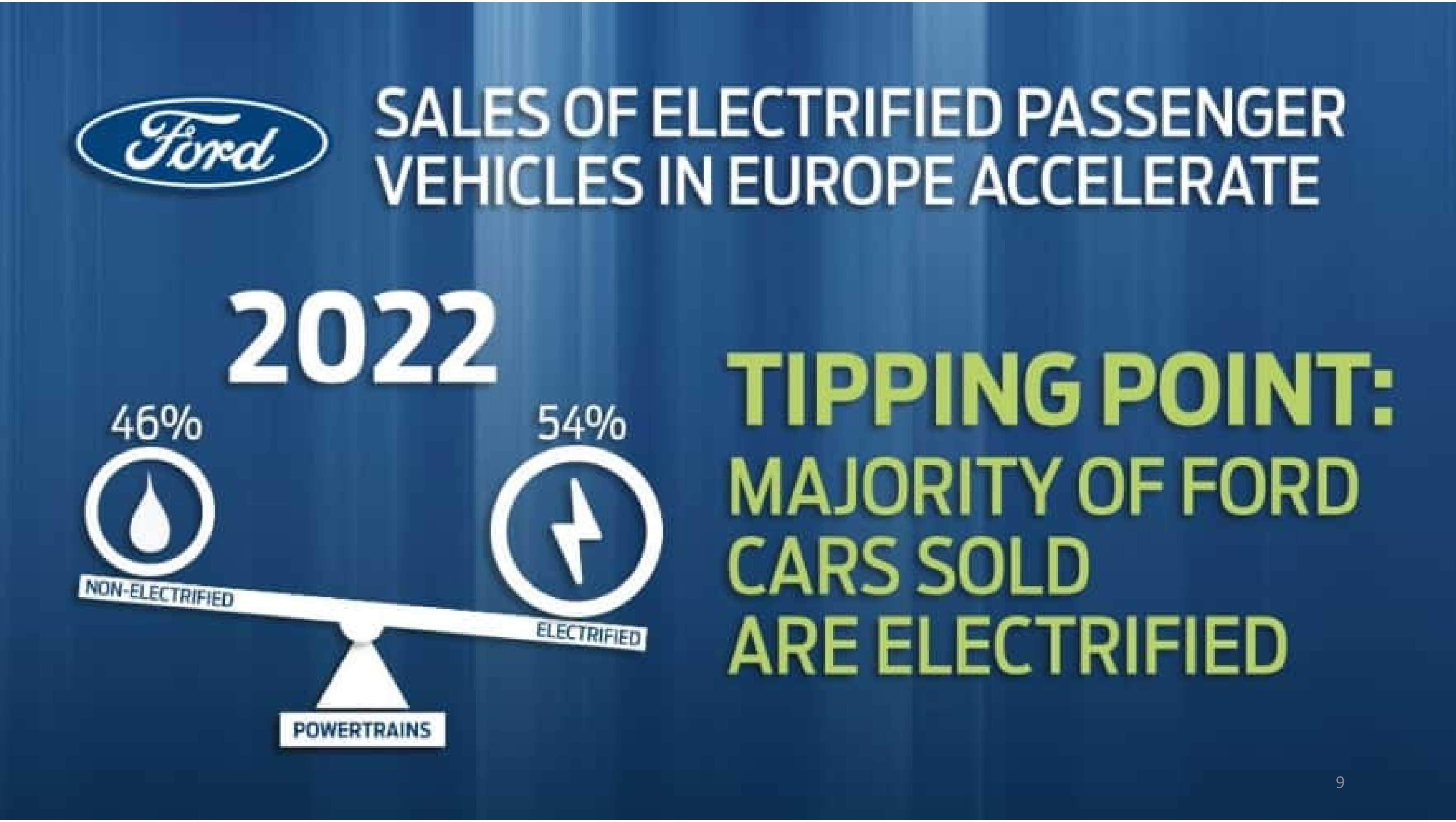


Ford long history in vehicle electrification



MEB platform shared by Ford & VW

- Ford has a **long history in vehicle Electrification**
- Today, **Electrification became the only sustainable way forward in automobility.**
- **Ford & Volkswagen alliance was created** to make this major change affordable to masses !


SALES OF ELECTRIFIED PASSENGER
VEHICLES IN EUROPE ACCELERATE
2022
46%
54%
NON-ELECTRIFIED
ELECTRIFIED
POWERTRAINS
TIPPING POINT:
MAJORITY OF FORD
CARS SOLD
ARE ELECTRIFIED

ELV & Recyclability, Re-use, Recovery

EU DIRECTIVE 2000/53/EC

The End-of-Life Vehicles ELV DIRECTIVE 2000/53/EC

- The ELV Directive 2000/53/EC was introduced to :
  - Limit the quantity of waste arising from vehicles;
  - Increase rates of reuse, recycling and recovery of ELVs and their components, through appropriate treatment, vehicle design and production;
  - Incorporate of recycled materials into vehicle design; and
  - Limit the toxicity of ELVs through restrictions on the use of hazardous substances in new vehicles (Lead, Cadmium, Mercury and Hex-Chrome) .

EU ELV Targets :

By 1st January 2006

- Reuse and recovery: minimum of 85%
- Reuse and recycling: minimum of 80%

By 1st January 2015

- Reuse and recovery: minimum of **95%**
- Reuse and recycling: minimum of **85%**

Applying several typical processes, a car can be recycled and legal quota of 85% for Recycling and 95% for Recovery can be achieved

Pre-treatment

and minimum dismantling acc. to Annex 1 of ELV 2000/53/EC

1%
(non-metallic re-use)

4%
(fluids / tires)

Shredding

ASR*

PST (e.g. SiCon process)

Fe-scrap NF-Metals

75%
(incl. metals from pre-treatment + dismantling)

Application depends on applied technology and market demands

Material for Recycling	~5%
Material for Energy Recovery	~10%
Disposal: Landfill	max 5%

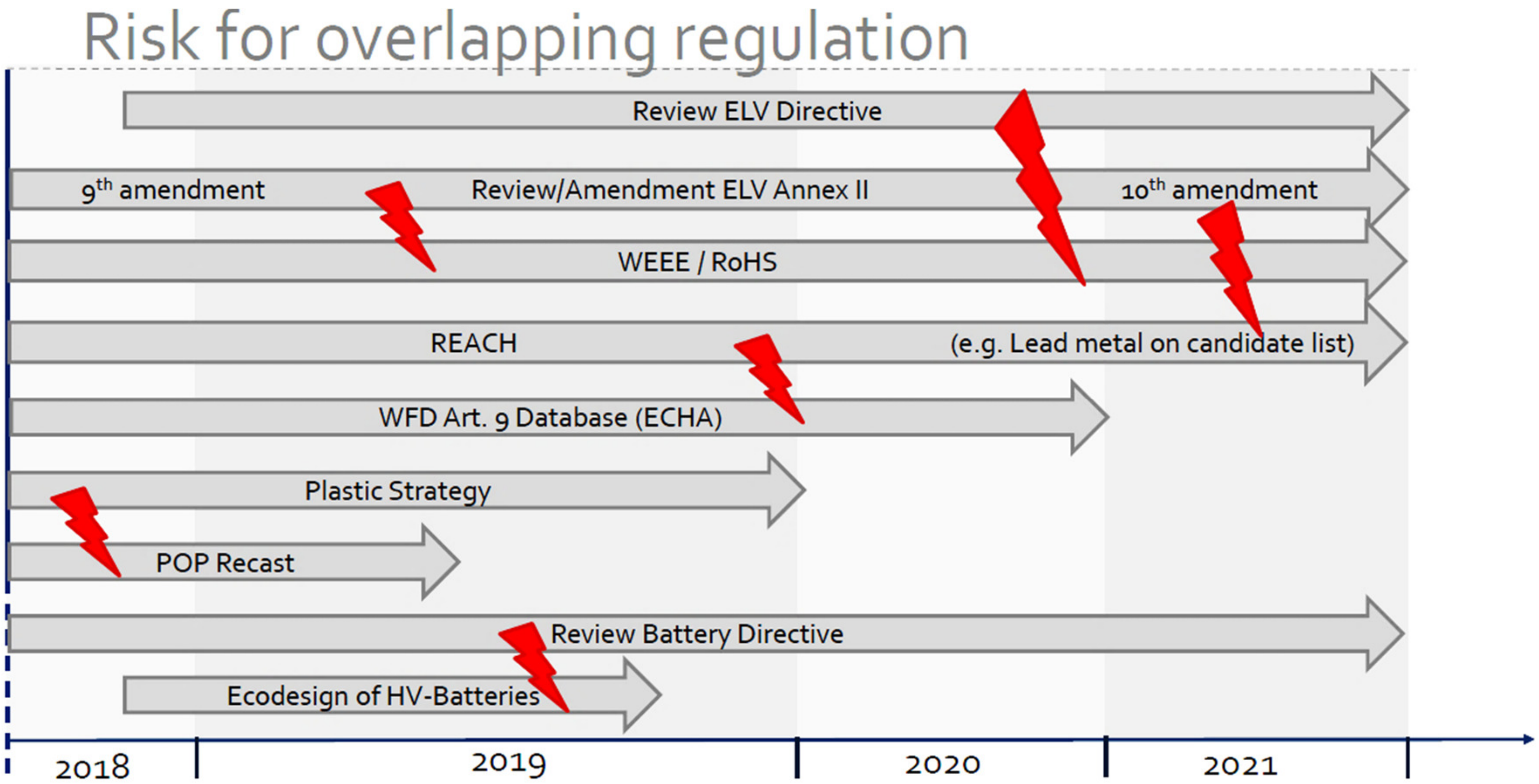
Recycling Quota: $\sum \approx 85\ \%$

Recycling and Recovery Quota: $\sum \approx 95\ \%$

Source ACEA
*ASR: Automotive Shredder Residue

- 85 % achieved through Pre-treatment, Shredding and material recycling
- 10 % additional recovery is achieved through heat energy generation

Automotive Electrification makes Recycling legislation more complex

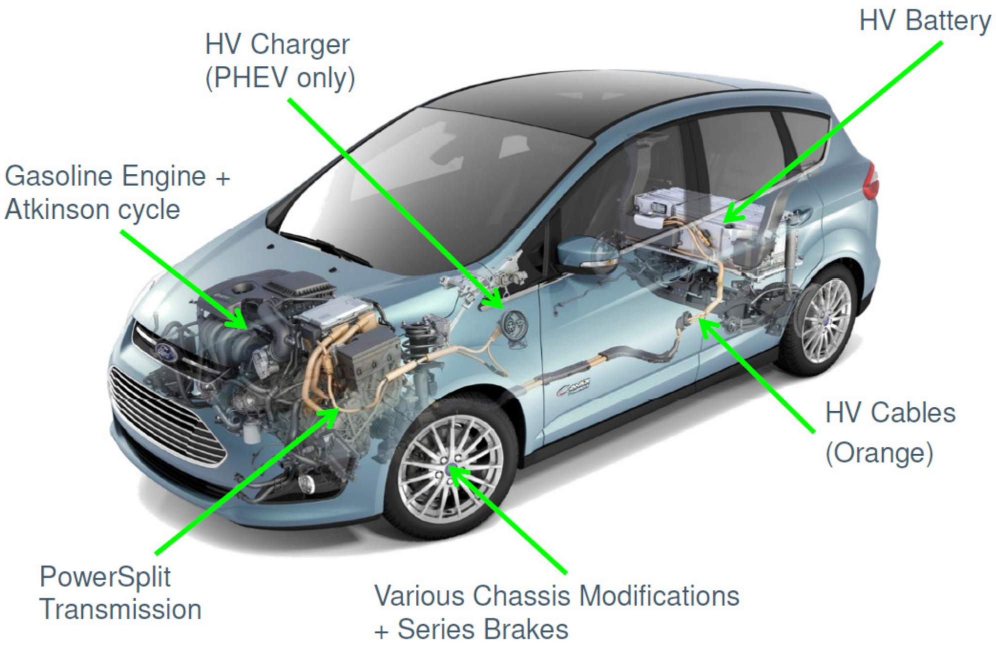


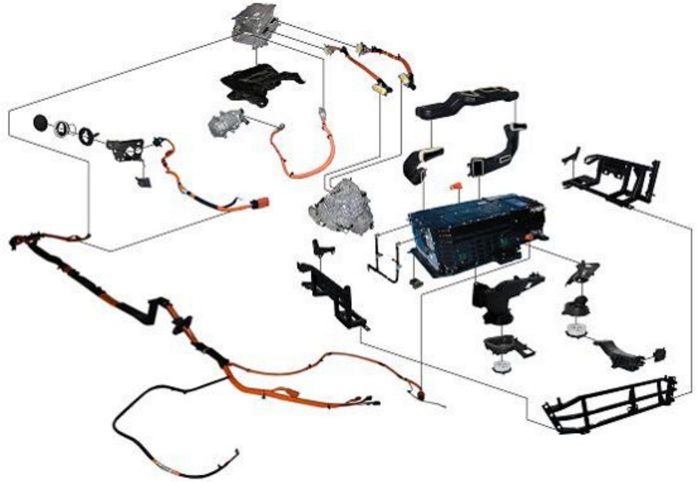
Source ACEA

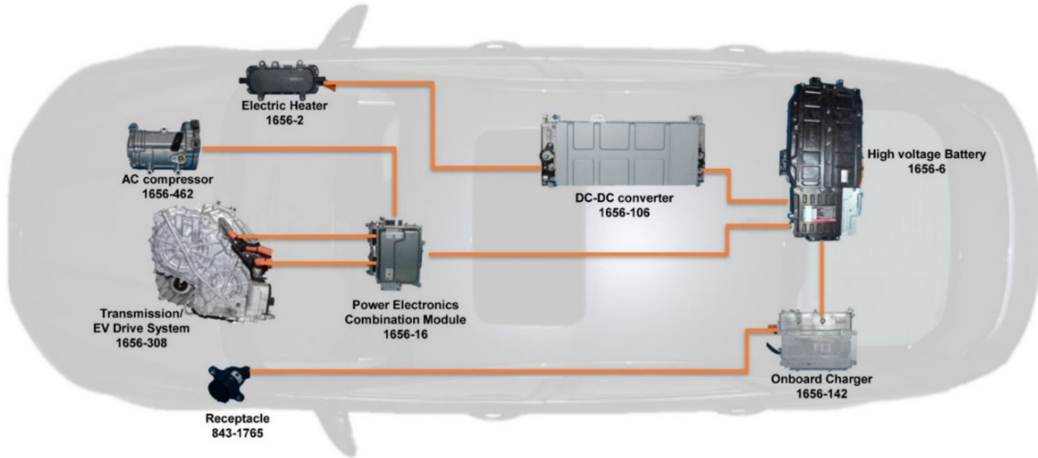
- **With Electrification, there is a high risk of overlapping regulation (WEEE/RoHS, Battery Ecodesign, etc…)**

ELV & Recyclability, Re-use, Recovery applied to Electrification

Electrified vehicle content



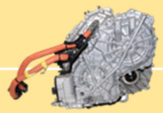
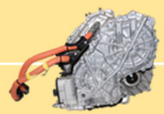
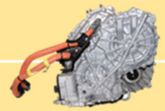
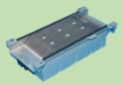
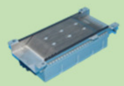
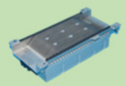
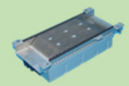




Key components of vehicle electrification are :

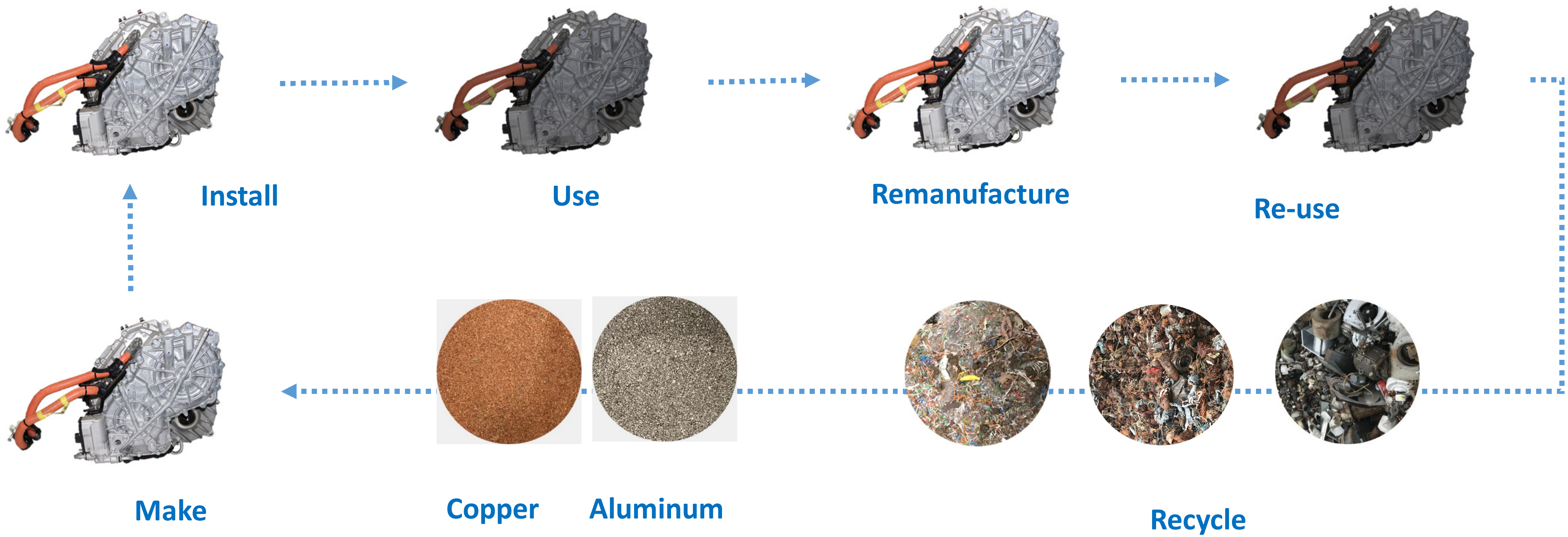
- **HV Battery , Charger , Wiring, Inverter & Motor Controler, DCDC converter , Transmission, eMotor, Thermal management system**

Key Electrification components

	mHEV	FHEV	PHEV	BEV
Internal Combustion Engine				
eDrive				
Generator	Part of ICE			
ISC (Inverter & Controler)				
DC/DC converter				
Charger				
Battery				
% Total PT weight added	+5%	+30%	+75%	+85%

Focus is on recycling key new Electric parts. Wiring & Cooling will follow existing standard process for similar parts.

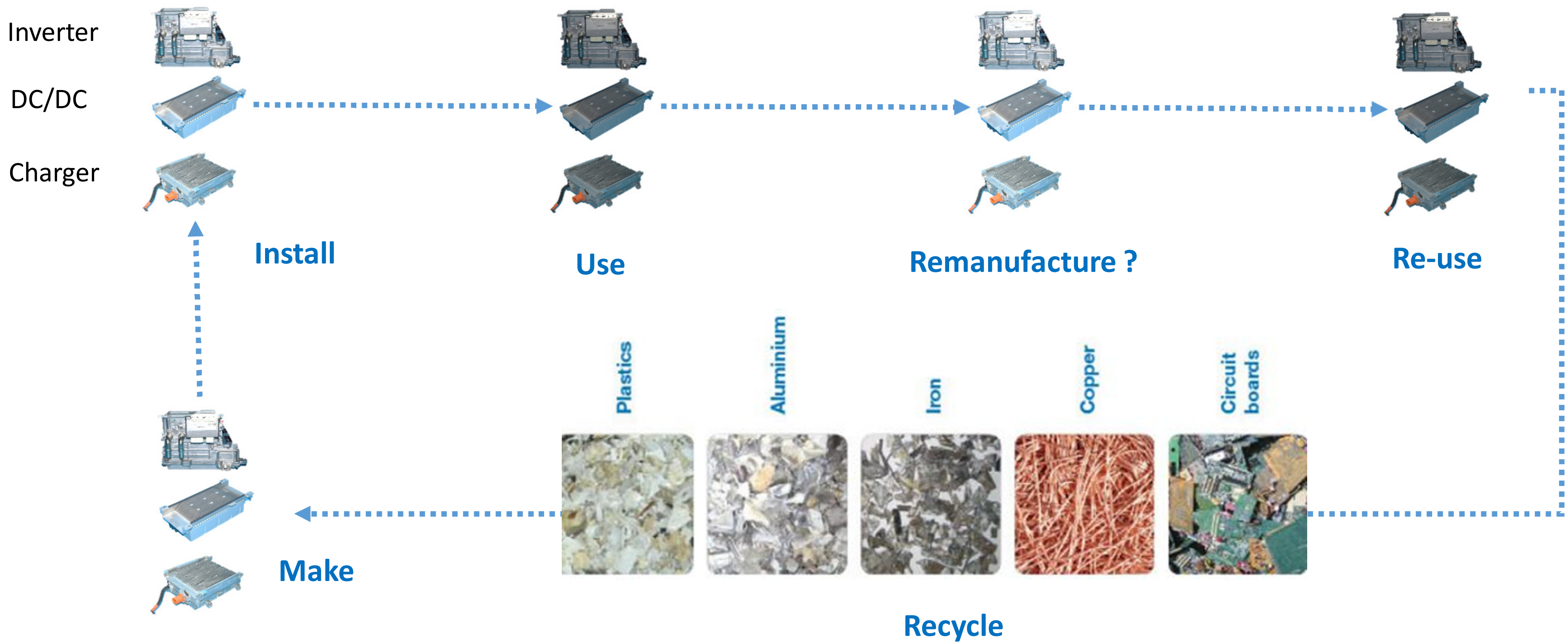
Recycling eDrive components



Source https://engineeredrecycling.com/

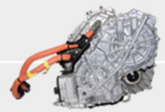
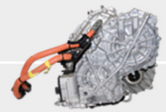
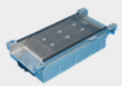
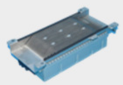
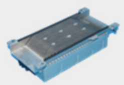
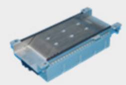
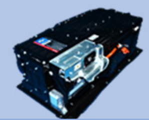
- Content of eDrive is made of aluminum (Casing) , steel (Gears) and copper (eMotor)
- Recycling process of eDrive could follow the vey well known eMotors process. Given the amount of involved copper content, dismantling process will be used by some recyclers to enable effective recovery of copper .

Recycling Electronic controllers



- Electronic modules will follow similar processes as current **Engine control unit** or other **vehicle eModules.**
- They may join the mature **eWaste recycling processes** knowing the nature of their content (Al. casing + PCB).
- Given the high involved masses and maturity of eWaste of recycling process, these parts will be **very attractive for recycling . The high durability of these parts and relatively high cost, the re-use will be significant.**

Recycling Lithium Batteries

	mHEV	FHEV	PHEV	BEV
Internal Combustion Engine				
eDrive				
Generator	Part of ICE			
ISC (Inverter & Controler)				
DC/DC converter				
Charger				
Battery				
% Total PT weight added	+5%	+30%	+75%	+85%

Key battery cell components :

a) Cathode
b) Anode
c) Electrolyte
d) Separator
e) Can

a) Cylindrical

b) Prismatic

c) Pouch

Positive electrode (Cathode)
Lithium Nickel Manganese Cobalt Oxide ("**NMC**", $LiNi_xMn_yCo_zO_2$)
Lithium Nickel Cobalt Aluminum Oxide ("**NCA**", $LiNiCoAlO_2$)
Lithium Manganese Oxide ("**LMO**", LiMn2O4)
Lithium Iron Phosphate ("LFP", **LiFePO4**)
Lithium Cobalt Oxide (LiCoO2, "**LCO**")

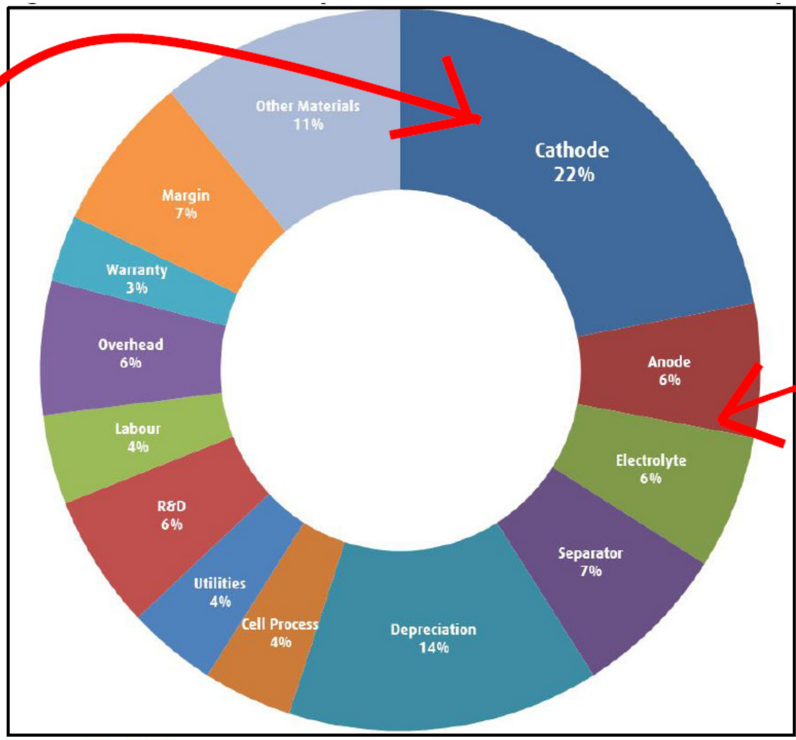
Negative electrode (Anode)
Graphite
Lithium Titanate ("**LTO**", $Li_4Ti_5O_{12}$)
Hard Carbon
Tin/Cobalt Alloy
Silicon/Carbon

Electrolyte	
Salts	Lithium Hexafluorophosphate ($LiPF_6$)
	lithium tetraborate ($LIBF_4$)
	Lithium bis-(oxalato)borate (LiBOB)
	Lithium hypochlorite (LiClO)
Organic solvent	Ethylene Carbonate ($C_3H_4O_3$)
	Dimethyl Carbonate, ($C_3H_6O_3$)
	Diethyl Carbonate ($C_5H_{10}O_3$)
	Propylene Carbonate ($C_4H_6O_3$)

Separator
PVDF (Polyvinylidene fluoride)

Battery cell cost breakdown

Cathode=22% of battery costs and includes raw materials, manufacturing, coatings

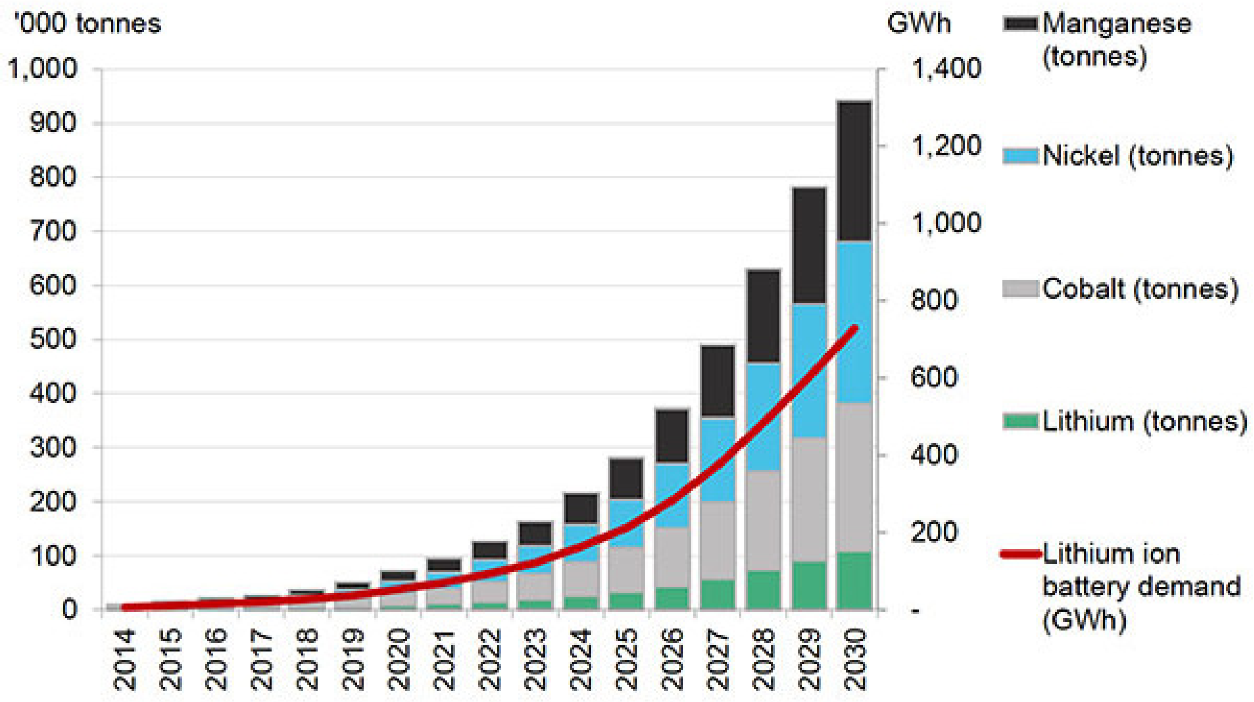


Source: U.S. DOE

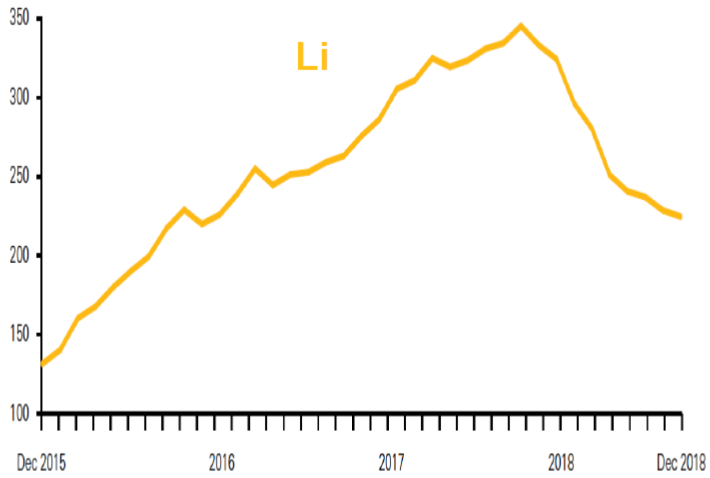
Anode, electrolyte and separator make up another 19% of the cost

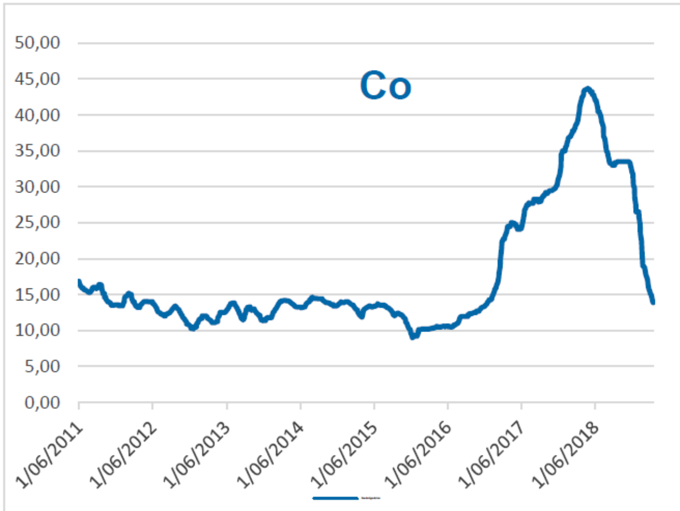
Cathode represents 22% of estimated battery cost.
Anode and separators represent 19%

Global demand of Li-Ion battery materials



Source: Bloomberg New Energy Finance





Global demand of Lithium Ion battery content in increasing exponentially, creating instability in raw material prices. Recycling is a key element to balance increasing need and stabilize prices

Recyclable Materials in different Li-Ion battery types

Recyclable materials in different lithium-ion battery types

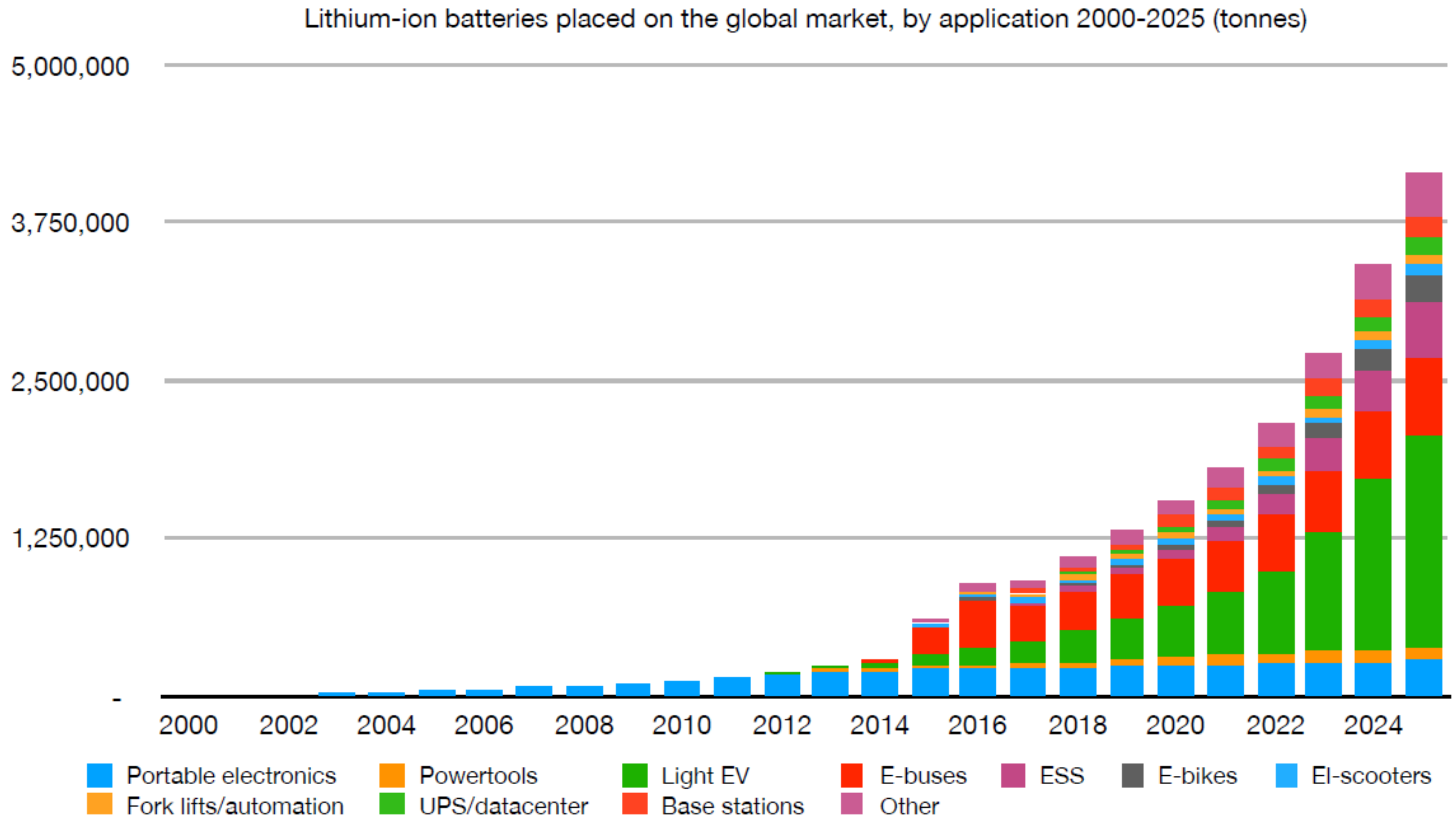
Material	USD/kg	% Content in a cylindrical cell (18650)							
		NCM111	NCM523	NCM622	NCM811	NCA	LFP	LMO	LCO
Casing									
Steel	0,29	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Aluminium	1,8	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Current collectors									
Aluminium	1,8	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Copper	6,0	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%
Anode material									
Graphite	1,2	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%
Cathode material									
Manganese	2,4	6.1%	5.5%	3.6%	1.8%			19.4%	
Lithium	70,0	2.3%	2.3%	2.3%	1.9%	2.3%	1.4%	1.2%	2.3%
Cobalt	30,0	6.5%	3.9%	3.9%	1.9%	2.9%			19.3%
Nickel	12,0	6.5%	9.7%	11.6%	15.4%	15.6%			
Aluminium	1,8					0.4%			
Iron	0,4						11.3%		
Total value per kg		**5.42**	**5.02**	**5.19**	**4.77**	**5.32**	**1.97**	**2.26**	**8.30**

Source: Circular Energy Storage

Trend in Battery Cell Cathode Chemistry is clearly in favor of NMC 811 (80% Ni, 10% Mn, 10% Co) . It has the best balanced attributes

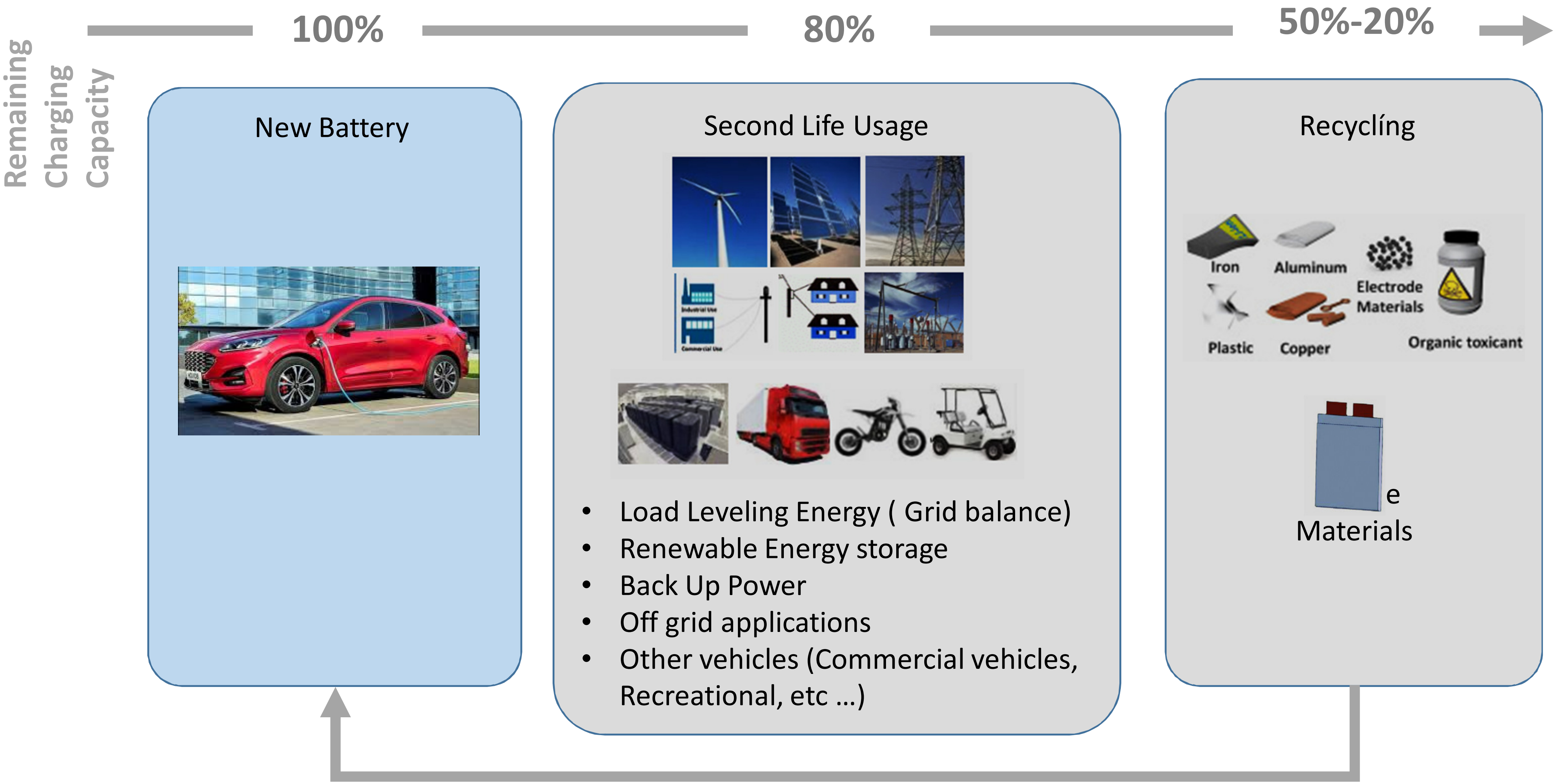
NMC 811 will lead into drop of Cobalt content by 50% which may reduce the attractiveness for recovery

Lithium Battery in global market for different applications



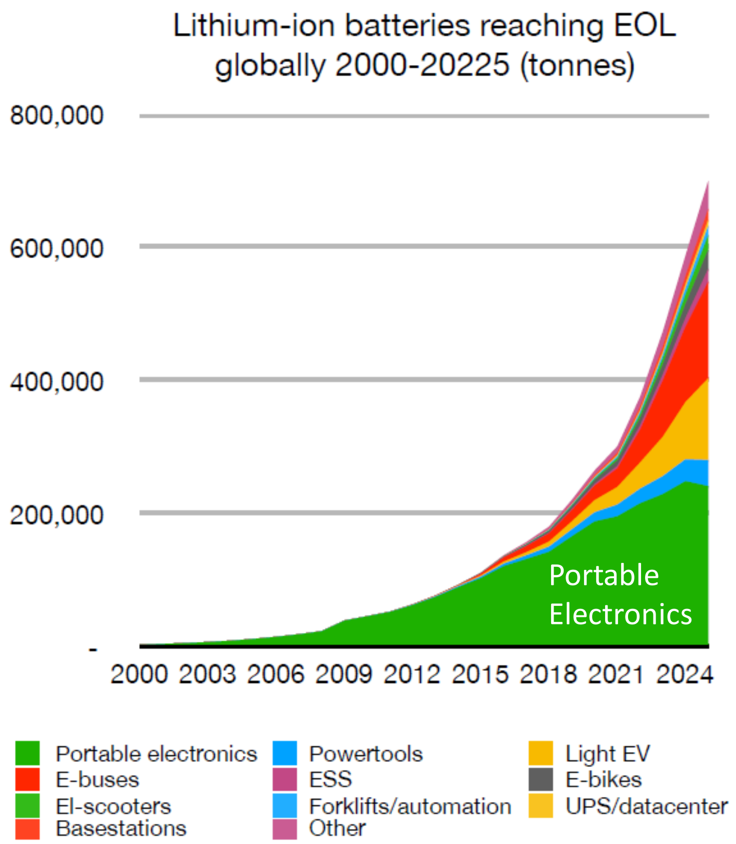
Source: Circular Energy Storage

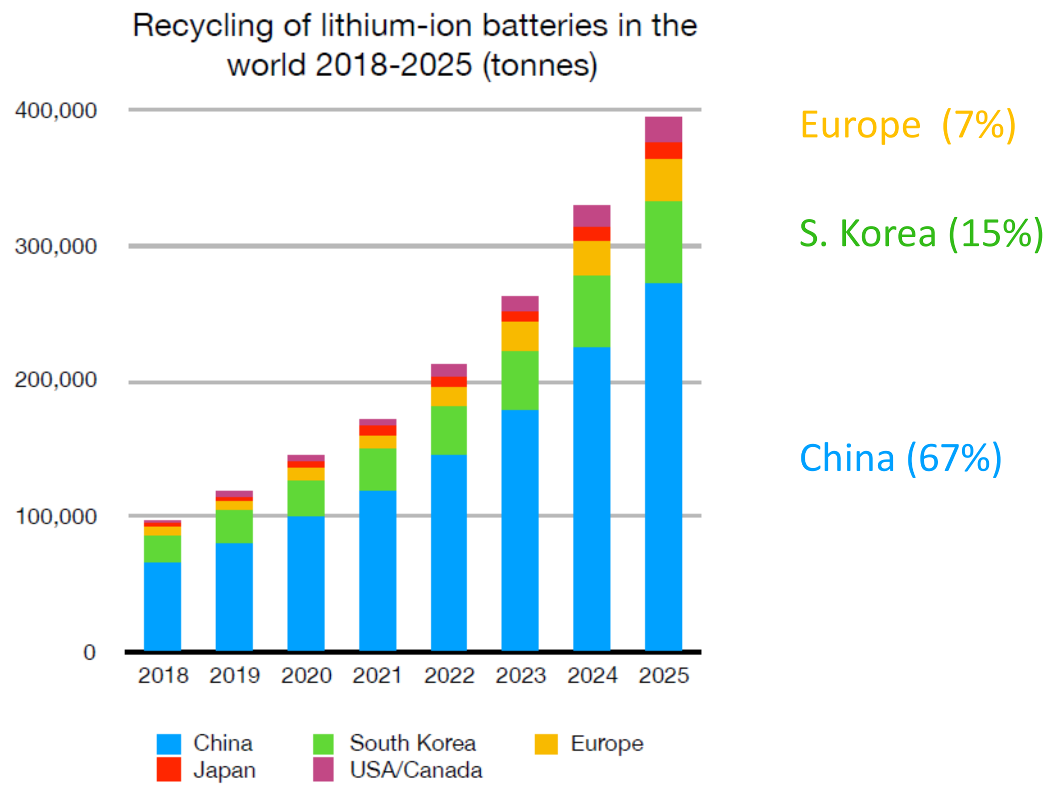
Lithium Ion battery technology is shared by several applications and industry sectors. EVs are the most significant user today.



EV Battery Recycling Strategy

Status on Li-Ion Battery recycling



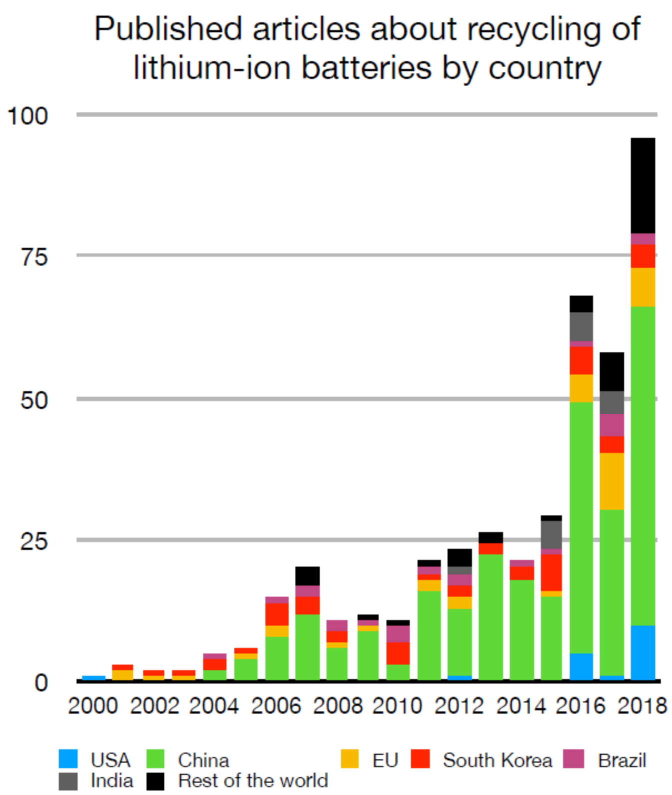


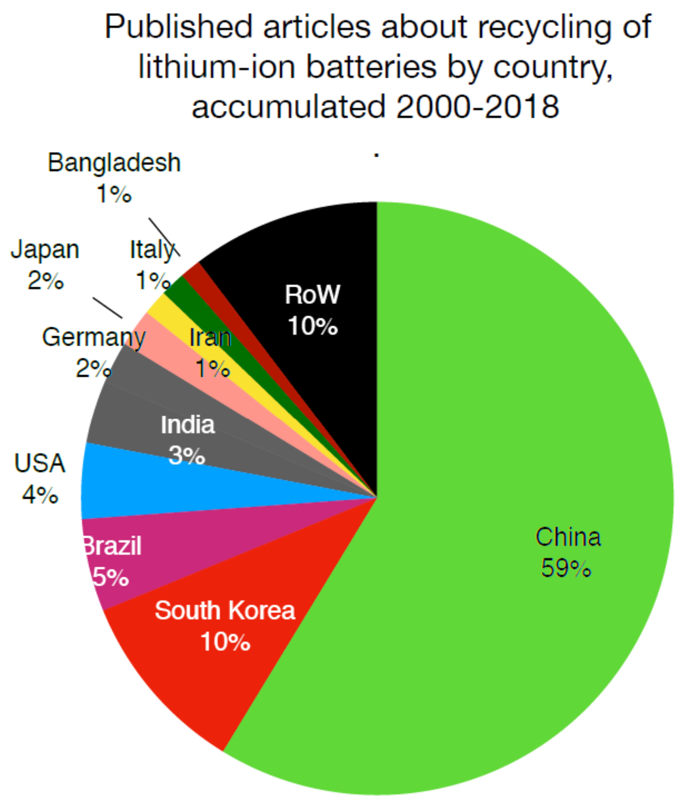
China & S. Korea represent 82% of total recycled Lithium Batteries

Source: Circular Energy Storage https://circularenergystorage.com/

- Today, there are over 50 companies around the world which recycle lithium-ion batteries.
- Most of them are located in China and South Korea. These **2 countries represent 82% of total recycled** batteries (67% China & 15% S. Korea) . Europe is in 3rd position with 7% .

Research in Battery Recycling



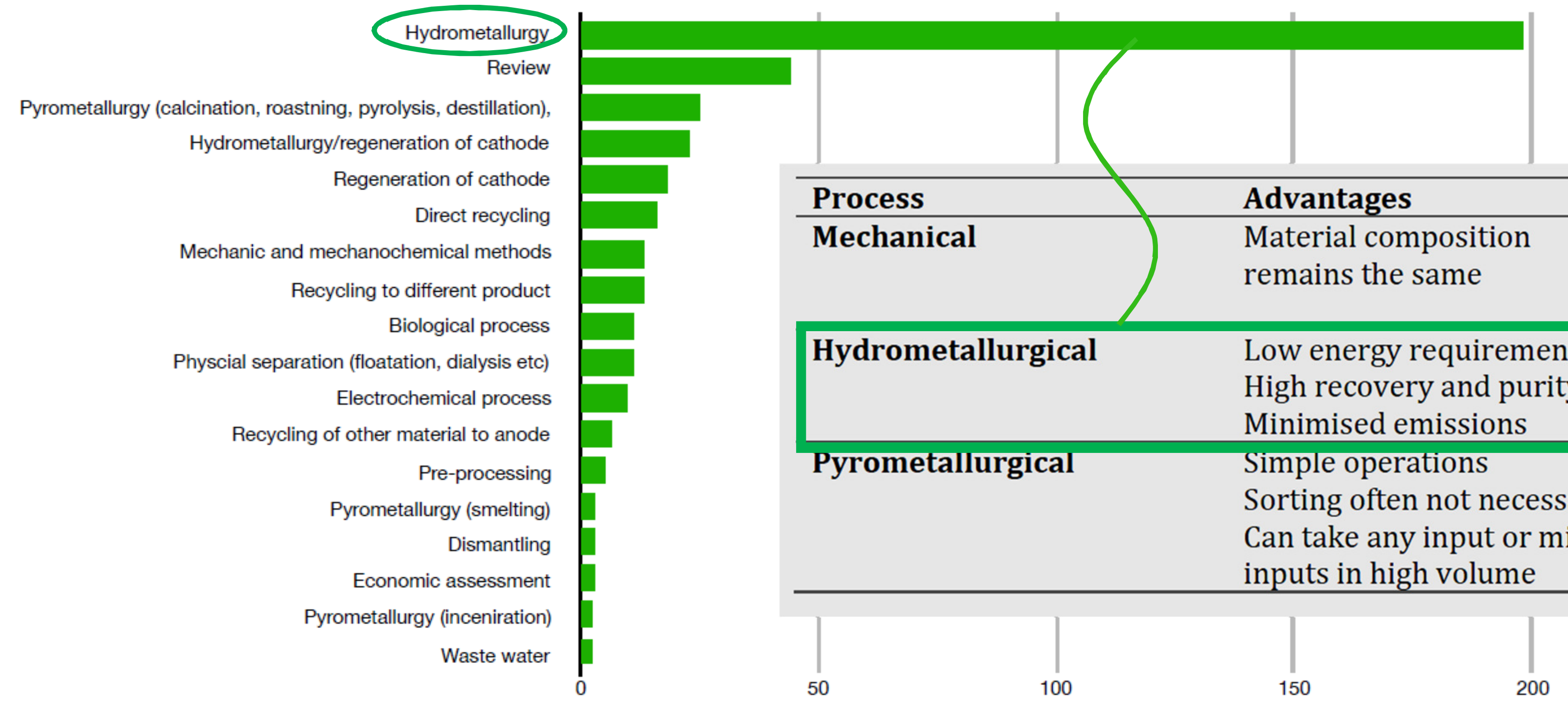


Source : Circular Energy Storage https://circularenergystorage.com/

As per recycling activity, most of the research on Lithium battery recycling is conducted in China (60% of the publications) and South Korea (10% of published articles)

Overview of Li Battery recycling methods

Primary focus in published research about lithium-ion battery recycling

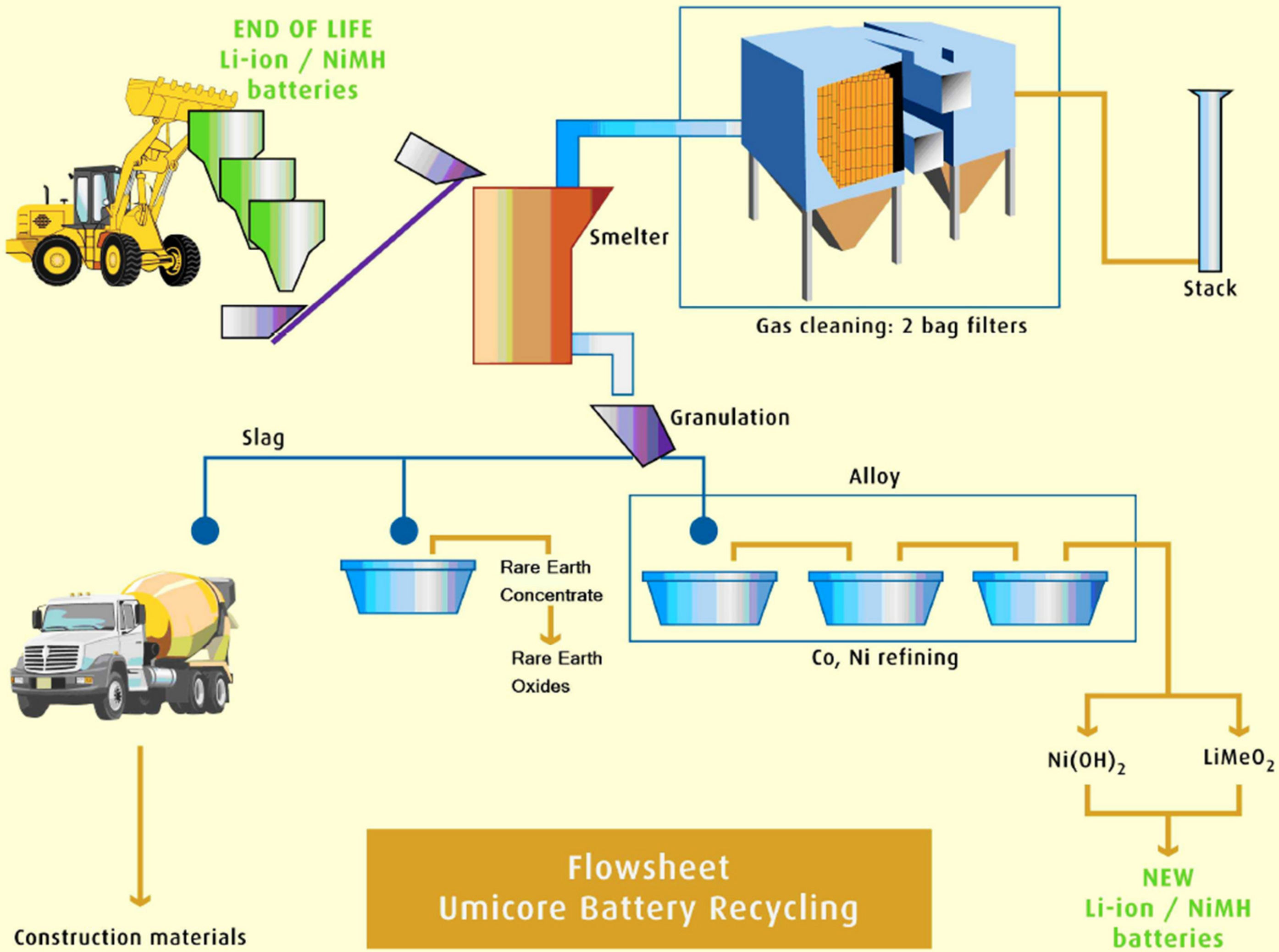


Process	Advantages	Disadvantages
Mechanical	Material composition remains the same	High energy requirements Risk of explosion Requires uniform feed
Hydrometallurgical	Low energy requirements High recovery and purity Minimised emissions	Gas treatment required Wastewater produced Sensitive to process input
Pyrometallurgical	Simple operations Sorting often not necessary Can take any input or mix of inputs in high volume	Lithium cannot be recovered Plastic/paper not recovered High energy requirements High emissions control

Source : Circular Energy Storage

There are 3 main recycling processes used for Lithium Ion Batteries. Mechanical, Hydrometallurgical and Pyro metallurgical. A combination of parts of each processes can be also found in recycling industry.
Research intensity shows a clear trend in favor of Hydrometallurgy which enables high material recovery and purity.

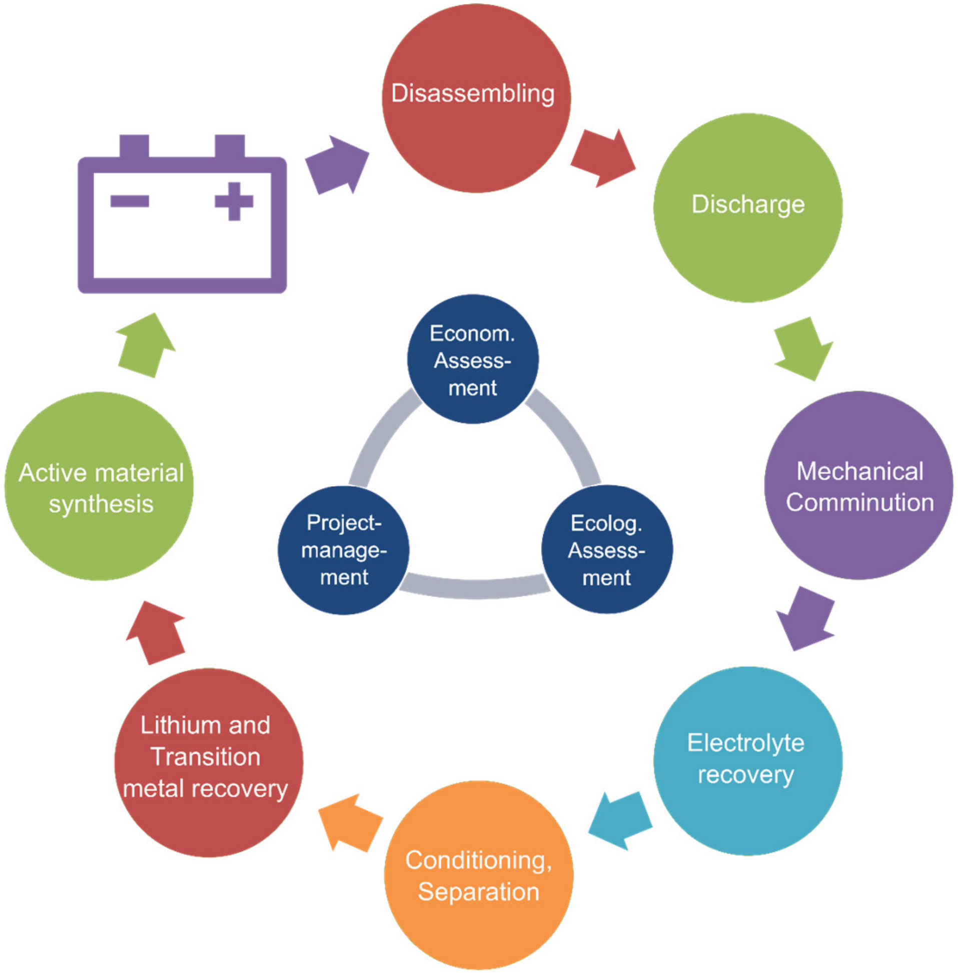
Umicore Pyro-Metallurgical process



Umicore process is actually a combined pyro- and hydrometal. recycling process

- Advantages :
  - Recycles different types of batteries (LiB , NiMH)
  - Simple process
  - Recovers Cu, Fe, Co, Ni and Mn
  - Close loop recycle as Umicore is supplier of cathode materials
- Disadvantages
  - Does not recover as Aluminum and Lithium for battery re-use but for construction materials
  - Does not recover Electrolyte
  - Recovers less than 70% of total material.

Duesenfeld Mechanical-Hydrometallurgical recycling process



Duesenfeld process was developed by a joint German Research institutes.
It uses a combined Mechanical, and hydrometallurgical processes.

- Advantages :
  - Recovers 85% to 96% of Battery materials
  - Recovers all noble materials Cu, Fe, Co, Ni, Mn, Li, Al
  - Recovers Electrolyte
  - All recovered materials can be reused in high value products such batteries
  - More Co2 efficient than Pyro-Metal.
- Disadvantages
  - Recycles only Lithium batteries
  - Uses complex processes
  - New process not enough return of experience

Value for money to be assessed (No information available)

https://www.youtube.com/watch?v=wxCFDWMPu38

Eco-friendly method of recycling EV batteries

Duesenfeld Battery Mechanical-hydrometallurigcal recycling process (Video)

Thank You !

That’s it !