WORLD MATERIALS FORUM

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Future trends on critical materials

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June 2018

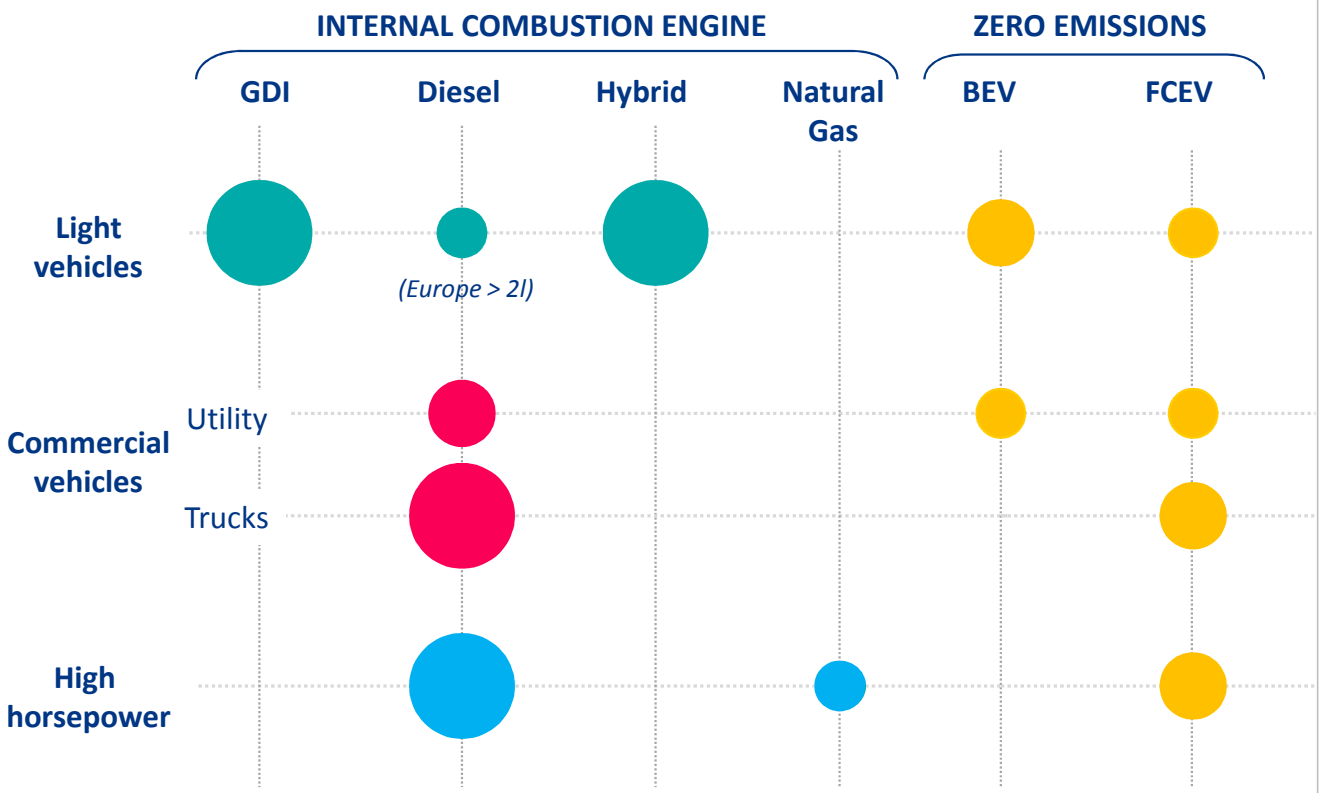
Agenda

1. Energy mix evolution
2. Critical raw material availability
3. Necessary investments
4. Take away

Agenda

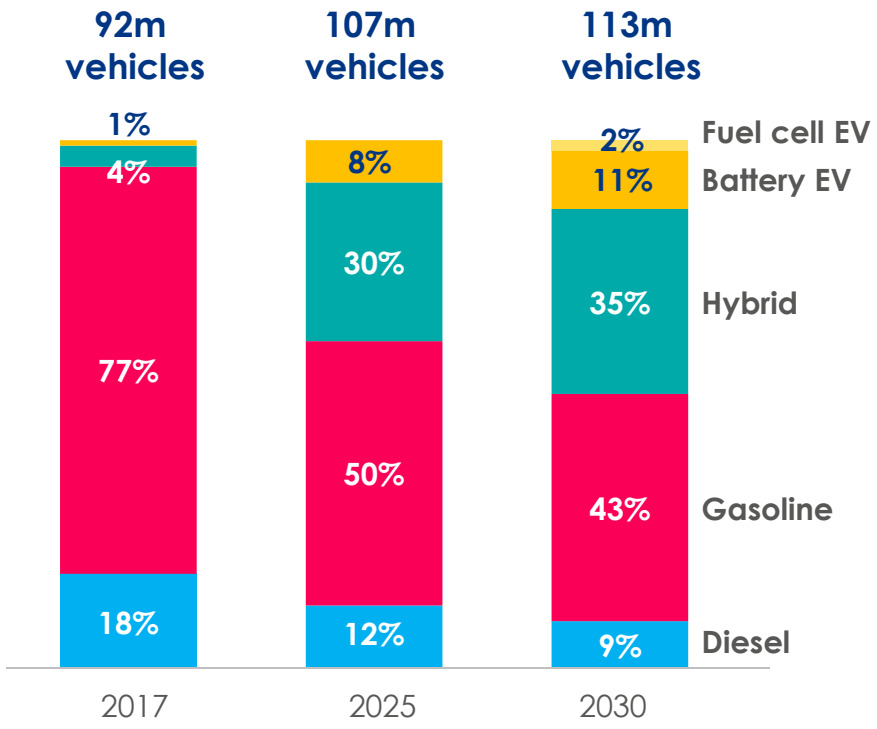
1	**Energy mix evolution**
2	Critical raw materials availability
3	Necessary investments
4	Take away

Relative importance of powertrain driven by regulation, use cases and cost



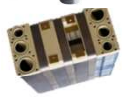
- Stringent regulations and new technology breakthroughs
- All markets getting emissionized including China and India Commercial Vehicles, High Horsepower engines & Industry
- Nearly 50% of the market will be electrified by 2030
- Smart Cities will drive new mobility requirements

Powertrain mix assumptions
Light vehicles



- **Pure ICE powertrains drop from 95% in 2017 to 52% in 2030**
- **Diesel powertrain decline might accelerate further**
- **Fuel cell is the unique zero emissions alternative**
- **High regional variation in EV take up by 2025**
  - US around 5%
  - China and Europe above 12%

Battery Electric Vehicle and Fuel Cell Electric Vehicle in 2030
Complementary zero emission solutions

	FUEL CELL		BATTERY VEHICLE	
	500 Km range	300 Km range	500 Km range	300 Km range
	€7,500	€6,900	€10,200	€5,400
Energy storage	5 kg  Hydrogen tank	3 kg  Hydrogen tank	100 kWh  Li-ion battery	40 kWh  Li-ion battery
Energy conversion	Valves  Fuel cell stack 100 kW  DC/DC Converter  Li-Ion Battery 1.6 kWh 		DC/DC Converter  On-board charger 	
Drivetrain	Electric Motor 		Inverter 	

- **Practicality should be taken into consideration**
  - Charging time on BEV: from 45mn to 2 hours
  - Filling time for FCEV: 3 minutes
- **Range cost is the strong differentiating point**
  - €1,200 to 2,200 (depending on the range of the vehicle) for extra 100 km on BEV
  - €300 for extra 100 km on FCEV
- **Fuel Cell Electric Vehicles are cheaper for ranges over 350 km and better when filling time is critical**

Agenda

1	Energy mix evolution
2	**Critical raw material availability**
3	Necessary investments
4	Take away

Impact of new powertrains on critical materials by 2030

Material	Usage	Reserves (KT, est.)	Production (KT, 2017)	Additionnal requirements for electrified powertrains (KT, 2030)	Criticality
Lithium	Batteries	40,000	200	125	**+**
Nickel	Batteries	74,000	2,400	600	**++**
Cobalt	Batteries	7,000	127	83	**+++**
Platinum	Fuel Cell	70	0.227	0.04	**+**

Agenda

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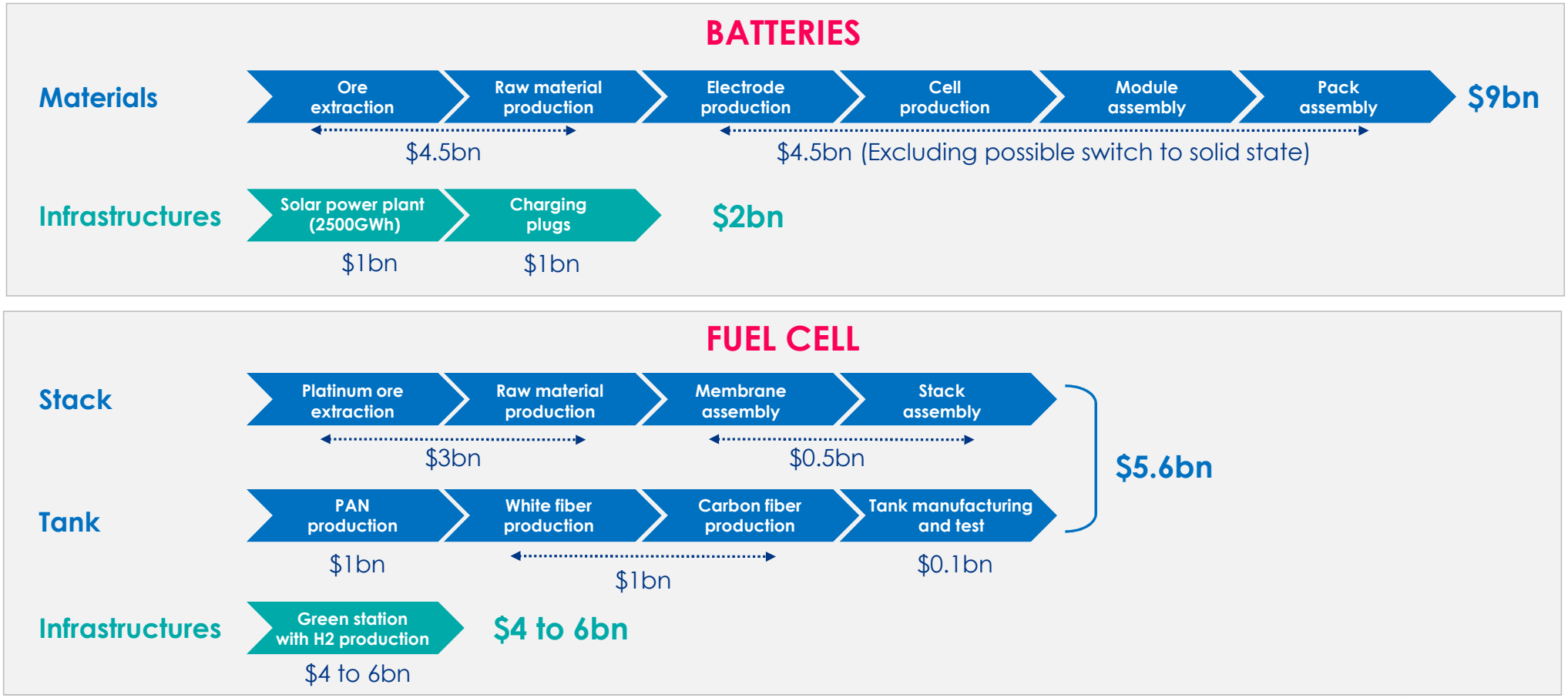
2	Critical raw material availability
3	**Necessary investments**
4	Take away

Investments in $bn per million vehicles produced/year and per million vehicles park for infrastructure



Agenda

1	Energy mix evolution
2	Critical raw material availability
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4	**Take aways**

Take aways

- **Powertrain electrification is a strong trend of future mobility**

- **BEV will grow fast but hurdles like technology effectivity, costs and use cases might slow it down. It might become an opportunity for Fuel Cell vehicles, the only zero emission alternative.**

- **Critical raw materials shouldn't be an issue until 2030 but will have to be managed beyond. Material recycling will be key to support the electrification growth**

- **Huge public and private investments will be requested for BEV and FCEV respectively**
  - $9bn and $5.6bn per 1 million vehicle produced per year for bill of materials
  - $2bn and $5bn for infrastructure per additional 1 million vehicles on the market


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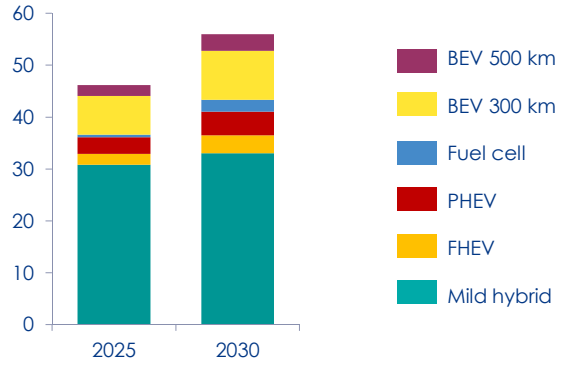
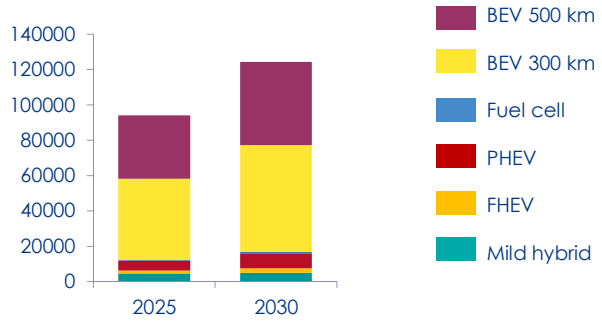
Batteries
Lithium is not critical thanks to important reserves

Electrification market (millions)



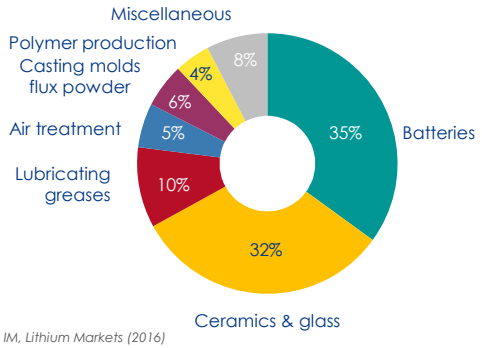
Lithium consumption (tons)



Relevant impact

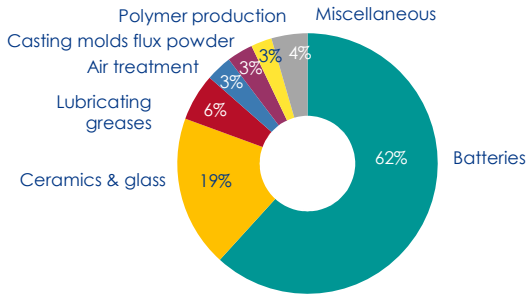
- **According to scenarii, the consumption of Lithium dedicated to Light Vehicles in 2030 could represent from half or even tend to the total current production volume (200,000 tons)**
- **Batteries could represent more than half of the consumption in 2030**
- **Reserves of lithium are not critical : around 40Mt**
- **However we can expect huge portion of recycled lithium by 2030 and other technologies will certainly emerge like Na based batteries for non mobility application which could de-stress the lithium market**

Current market



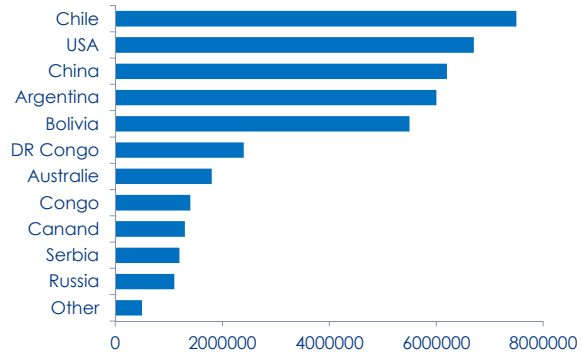
Source: IM, Lithium Markets (2016)

Market outlook (2030)*



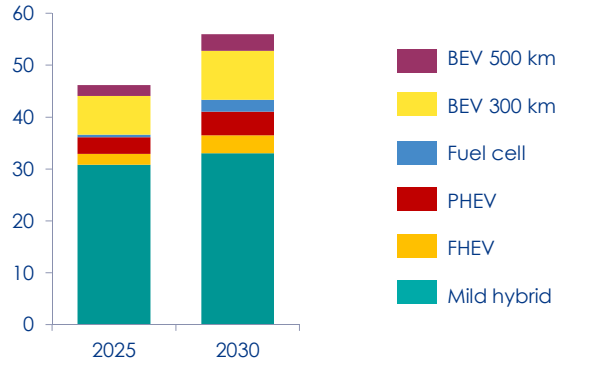
**: Non automotive consumption considered as unchanged*

Estimated reserves (tons)

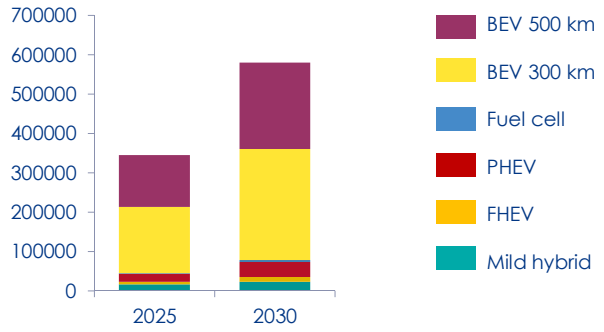


Batteries: Nickel resources are not critical even with higher ratio of nickel in batteries but investments in mines will be needed

Electrification market (millions)



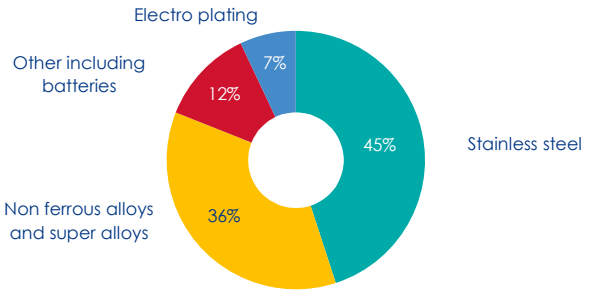
Nickel consumption (tons)



Nickel production will have to significantly increase

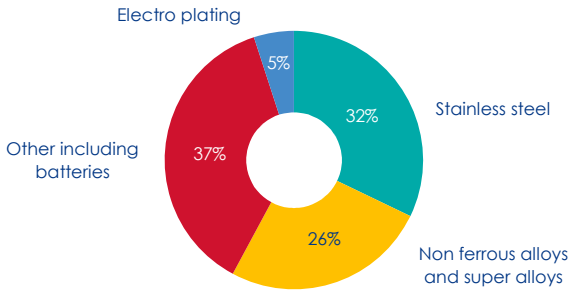
- **With NMC 811, share of Nickel in battery will increase from around 0,4 kg / kWh to around 0,8 kg /kWh**
- **Nickel reserves are close to 74,000,000t**
- **Consumption is currently around 2,400,000t per year but automotive batteries will need additional 600 000t by 2030 and more beyond**
- **Only 40% of the resources can be used for battery-grade**
- **Current mines shouldn't be able to absorb mid-term demand**

Current market



Source: Handelsbanken Capital Market

Market outlook (2030)*



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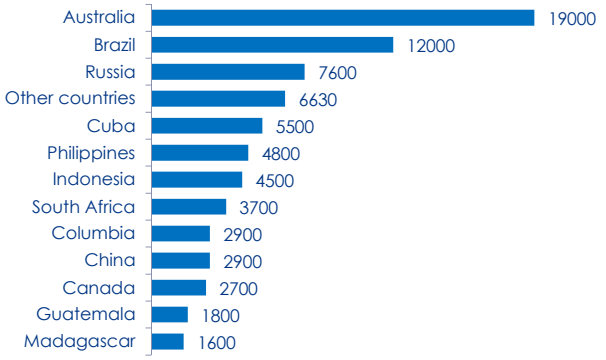
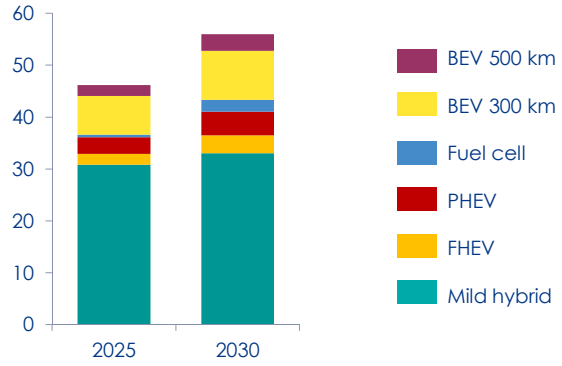
Estimated reserves (k tons)

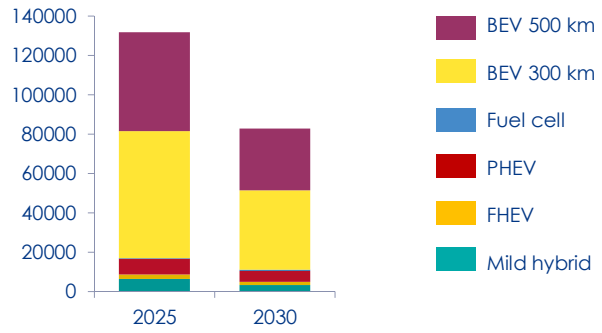


Batteries: Cobalt is not critical by 2030 (except location of mines) but will have to be managed beyond

Electrification market (millions)



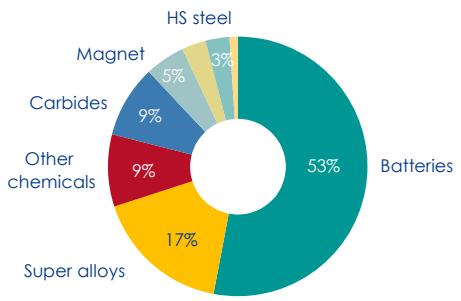
Cobalt consumption (tons)



An impact which has to be managed

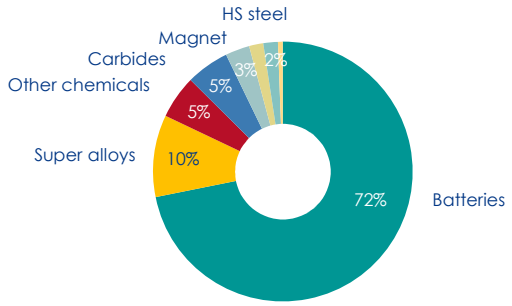
- **Cobalt is at 95% a by-product of Nickel or Copper**
- **The consumption of cobalt will double between 2017 and 2025 to reach 250,000t but will be decrease between 2025 and 2030 thanks to battery chemistry improvement. It should increase again after 2030 due to higher electrified cars volumes**
- **Global reserves (7,000,000t) are sufficient for 2030 but over 50% of the production is located in unstable countries (Congo)**
- **Cobalt is 100% recyclable in end of life Li-Ion batteries but the network is not existing today**

Current market



Source: CRU & Cobalt Blue Holdings

Market outlook (2030)*



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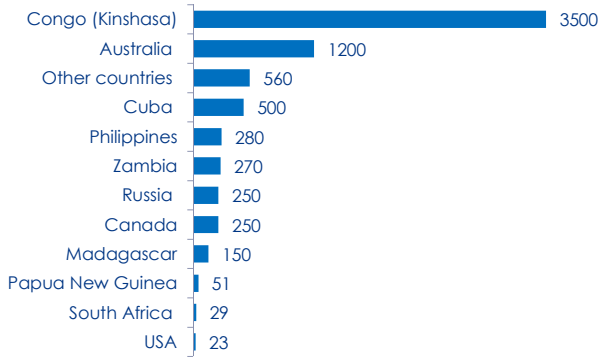
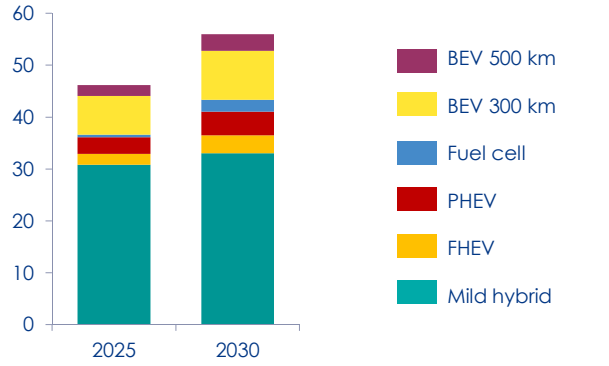
Estimated reserves (k tons)

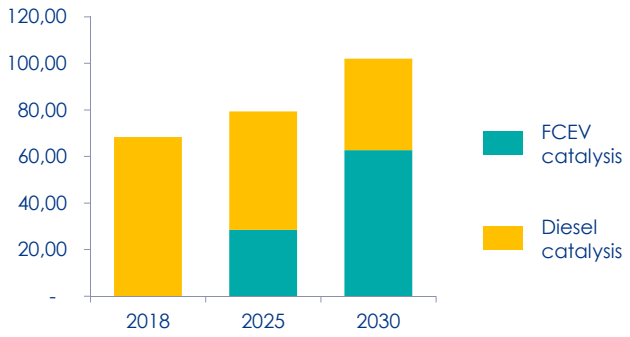


Fuel cells
Platinum consumption will not jeopardize the production

Electrification market (millions)



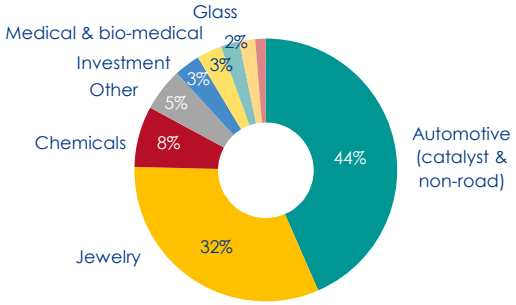
Platinum consumption (tons)



Higher consumption but full recyclability

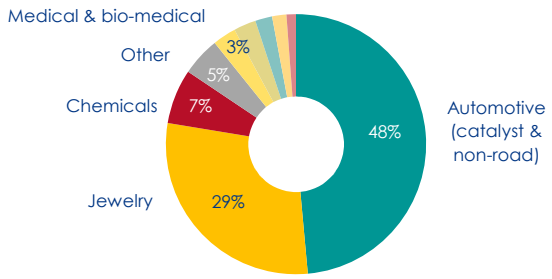
- **The lowering Diesel volumes will not balance the rising material needs for catalysis in Fuel Cells**
- **At the opposite of Diesel Catalysis, Platinum used in Fuel Cell is 99 % recyclable. 25 % of current WW Platinum consumption is coming from recycling.**
- **Around 30g of platinum for 100kW fuel cell in 2030.**
- **Current Platinum consumption (227t among which 68,4 for automotive catalysis) versus reserves (70,000t) is not critical today and shouldn't be beyond 2030**

Current market



Source: World Platinum Investment Holding

Market outlook (2030)*



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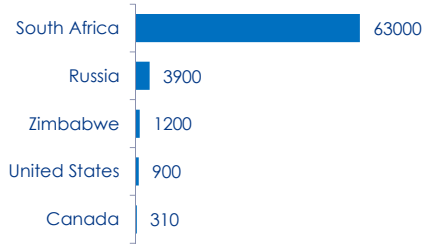
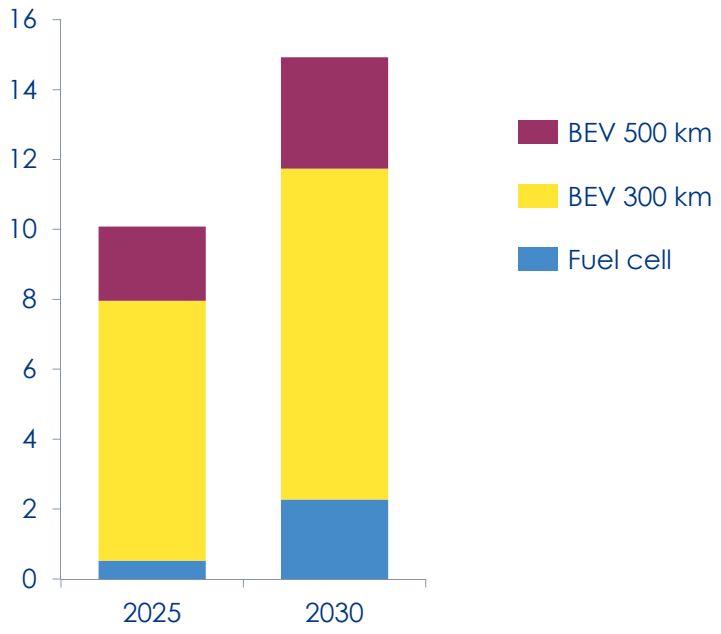
Estimated reserves (tons)



Batteries
€65bn private investments for production will be necessary by 2030

Electrified market in million vehicles

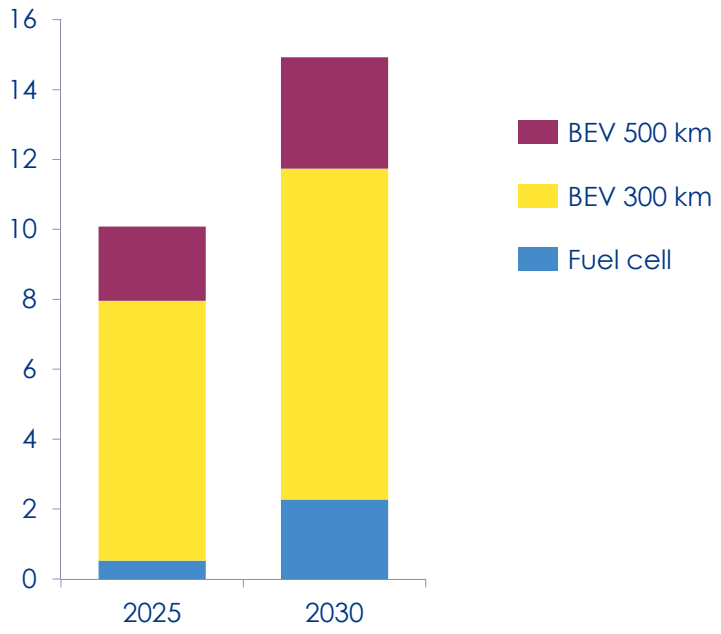


- Around 800GWh of batteries will be necessary to power electrified vehicles in 2030 which means around €65bn investment

- Tesla and Panasonic are currently investing more than $4bn to power 500,000 vehicles/year of 100kWh energy
- High technology disruption risk of the battery chemistry
- CapEx per million vehicles : €4.5bn for BEV with mid range autonomy

Fuel Cell
Carbon fiber production will double to feed hydrogen tanks in 2030

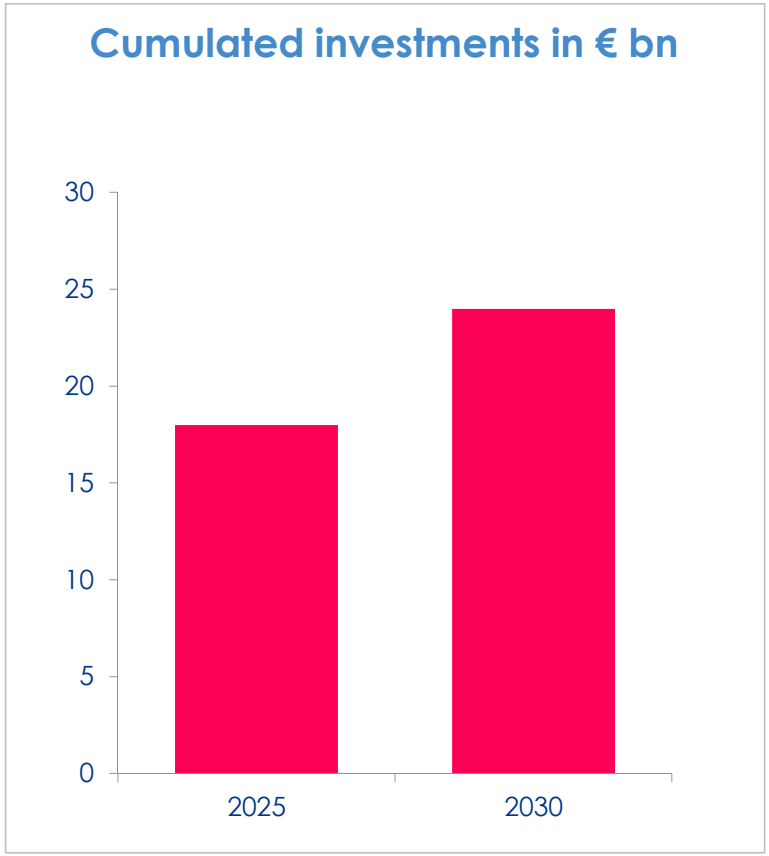
Electrified market in million vehicles



- High pressure tanks (700 bars) are necessary to store hydrogen in the cars

- Carbon fiber will be used to reduce the weight
- If we consider 2% of the total car production dedicated to Fuel Cell in 2030 (around 2.2 million vehicles) 88,000t of carbon fiber will be necessary to produce hydrogen tanks meaning to double the current production
- CapEx per million vehicles : €1.15bn

Plugs for electric and plug-in vehicles
€25bn of public infrastructures (plugs) investments by 2030



- **Close to €25bn investments by 2030 including cost decrease over time by around 50%**
- **Fast charging stations>22kW represents 5% in volume**

- **Occupation rate assumption: 15% for slow charging and 30% for fast charging**
- **Around 6.5 million charging points by 2030**
  - 45% in Europe
  - 35% in China
  - 20% in US
- **CapEx per million vehicles : €0.9bn BEV vehicle park**

Fuel Cell
Hydrogen stations will require €17bn investment by 2030

- Fuel cell vehicle park should be around 3 million by 2030
- Each vehicle will do 20,000 km/year and consume 1kg H2/100km ➔ 600,000t of hydrogen
- 11,000 autonomous and green hydrogen stations able to deliver 200 kg of hydrogen (used at 75% of their capacity) will have to be built and will cost each around €1.5m, so in total €17bn investment
- CapEx per million vehicles on the park : €5.5bn