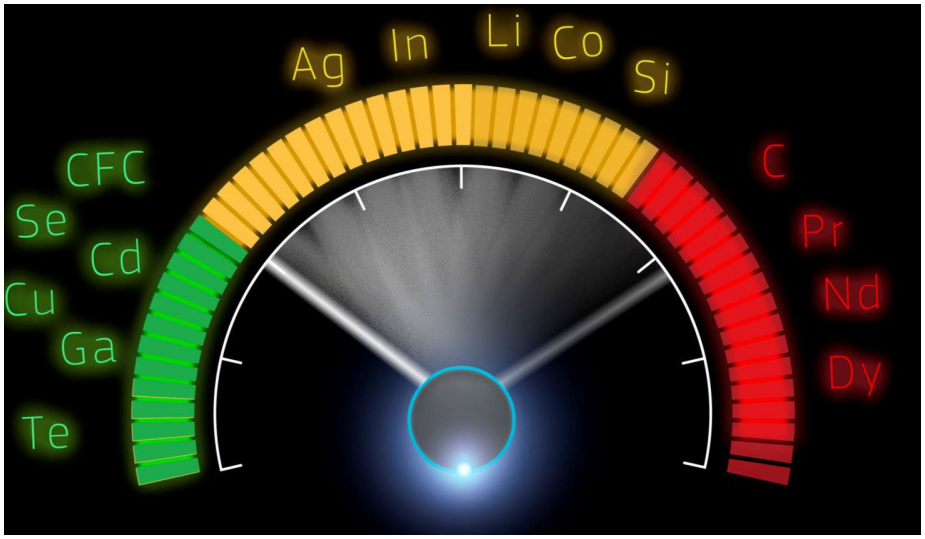
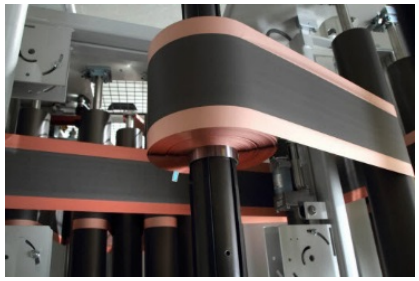




2nd EU CRITICAL RAW MATERIALS EVENT
12th NOVEMBER 2018, BRUSSELS

Didier Bloch, Etienne Bouyer
CEA Grenoble

Vehicle electrification: a challenge for the strategic material supply

INTRODUCTION

Serious concerns are manifested…

2016 https://www.economist.com/news/business/21688386-amid-surge-demand-rechargeable-batteries-companies-are-scrambling-supplies

« Lithium ? The world's hottest commodity » Clean Energy – an increasingly precious metal » The Economist

11th July 2017 https://www.ecowatch.com/koch-brothers-electric-cars-2456866524.html

Koch Brothers Launch Attack to Kill Electric Cars

« Electrical vehicles are much more toxic for humans than the average level of other vehicles »

« Fueling U.S. Forward », NGO dedicated to « educate the public on value and potentialities of American energy »

16th September 2017 **Electrical vehicles are they really « clean » ?**

http://www.liberation.fr/futurs/2017/09/16/les-voitures-electriques-sont-elles-vraiment-propres_1596551

ADEME emphasises that *«throughout its entire lifecycle, energy consumption of an EV [Electrical vehicle] is close to that of a diesel vehicle»*. This is due to the fact that an electric vehicle requires twice as much energy to its manufacture than for a thermal engine vehicle. One of the most energy-intensive step is the battery assembly.

INTRODUCTION

Serious concerns are manifested…

1st February 2018

« An electrical vehicle generates carbon nearly as much as a diesel engine »

http://www.liberation.fr/planete/2018/02/01/metaux-rares-un-vehicule-electrique-genere-presque-autant-de-carbone-qu-un-diesel_1625375

In his last publication, «The war of rare metals » (2017), Guillaume Pitron denounced « the hidden side of both energy and digital transitions ».

How to distinguish the true from the false ?

What is the reading grid ?

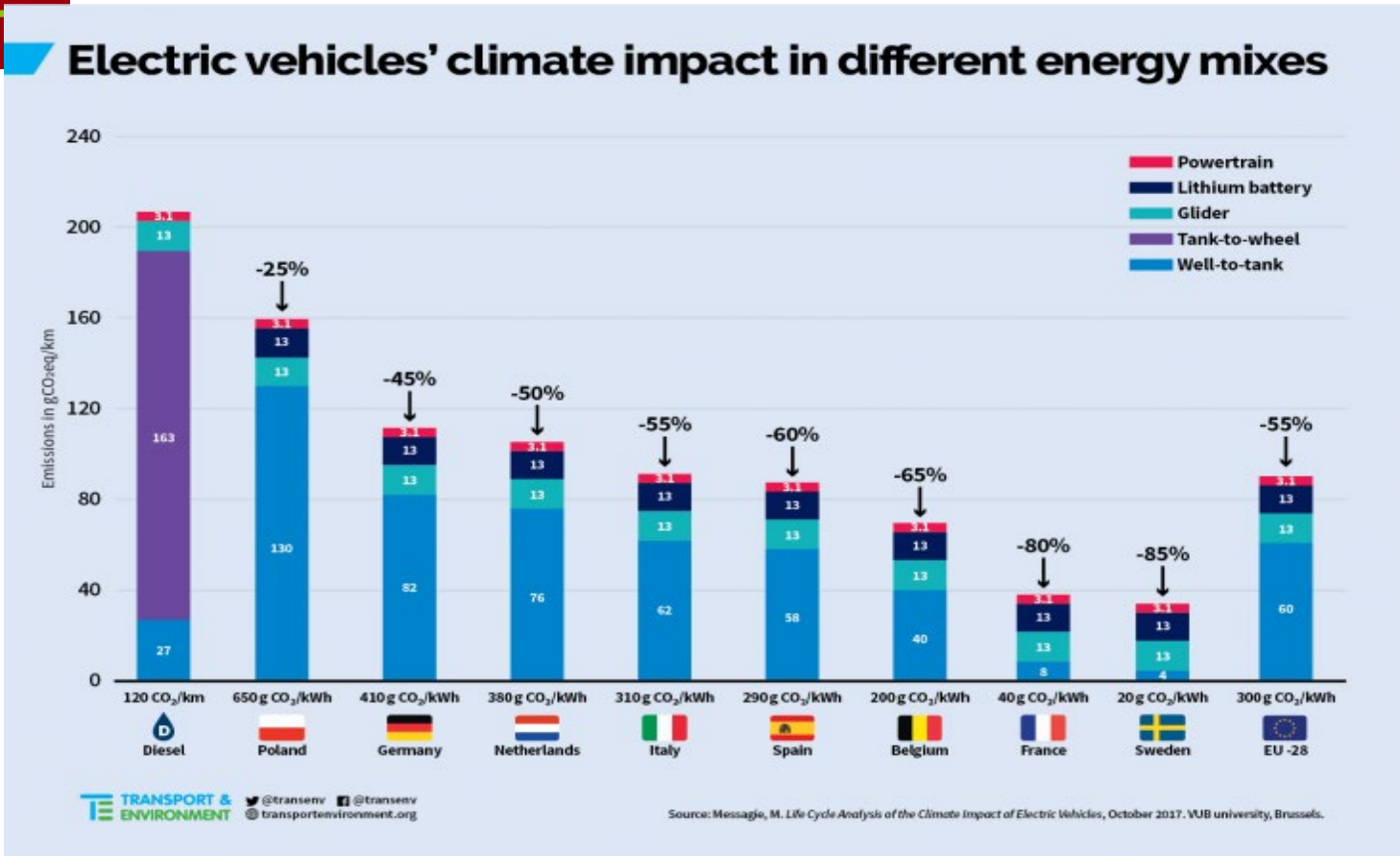
CEA READING GRID: PRIORITIES & FINAL GOALS FOR ENERGY STORAGE

CEA missions in the « energy transition » framework

- Contribute to reduce GHG emission
- Improve energy independence by limiting fossil energy consumption
- Contribute to improve energy and material resources efficiencies all along the life cycle
- Contribute to national (& European) industry development

EV “not clean?”
Carbon footprint on the whole life cycle

http://www.automobile-propre.com/france-voiture-emet-80-pourcent-co2-en-moins-thermique/



While older studies reported mixed results and even negative concerning CO_2 emission during EV lifecycle, a recent academic study published by the NGO « Transport & Environment » set the record straight.

Life cycle: in France, EV emit 80 % CO_2 less than thermal engine vehicle

Life Cycle Analysis of the Climate Impact of Electric Vehicles Dr. Maarten Messagie – Vrije Universiteit Brussel

KEY ADVANTAGE

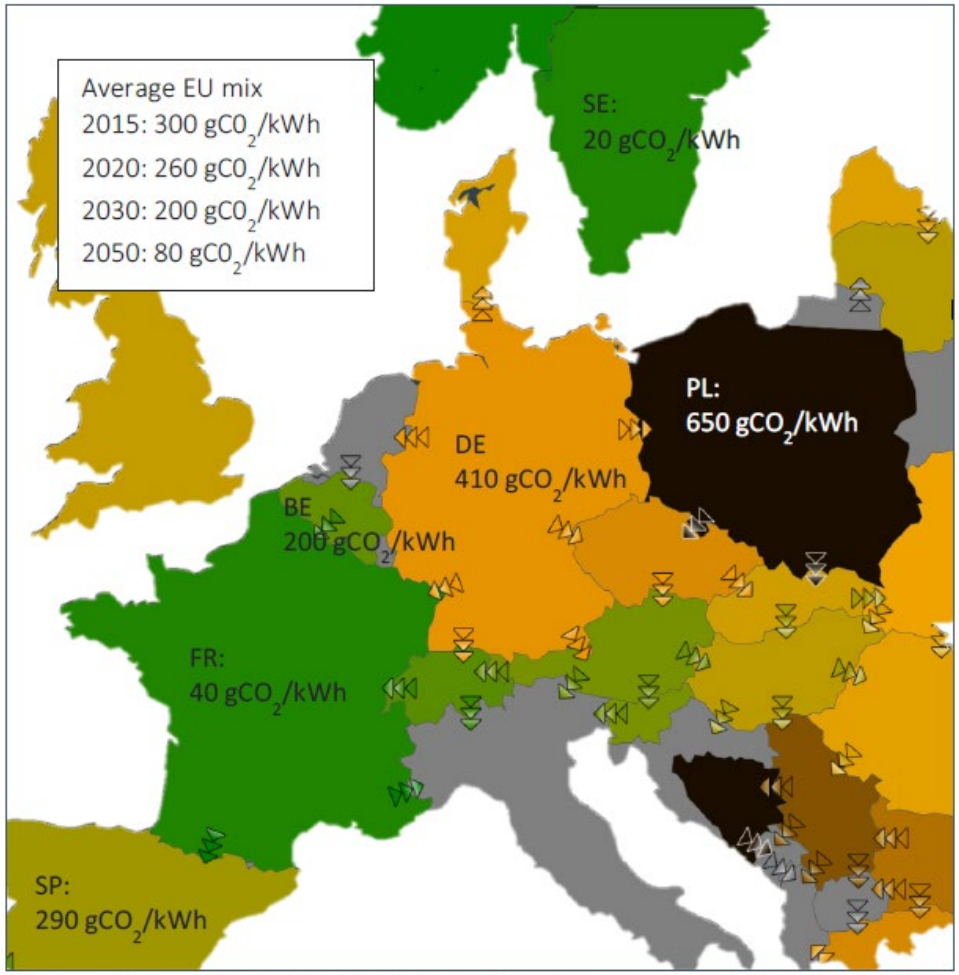


Figure 6: carbon footprint of European member states in 2015, and prognosis of EU mix in 2015, 2020, 2030 and 2050. Based on data from [21]

https://www.transportenvironment.org/sites/te/files/publications/TE%20-%20draft%20report%20v04.pdf

70% of the impact of the EV originates from the electricity mix.

15% originates from the vehicle production.

WHAT THE GIGAFACTORY PANASONIC/TESLA LOOKS LIKE ?

Battery: 75-100 kWh embarked

GIGAFACTORY PANASONIC- TESLA (SPARKS, NEVADA)

The second world's largest footprint

By 2020 the company plans to ramp up production to build as many as 500,000 vehicles per year

- **Investissement: 5 B$** (Panasonic/Tesla)
- **6500 employees**

WHICH MARKET SHARE (2040) ?

1 billion personal-use vehicles wolrdwide

If 50 kWh embarked per vehicle ➔ 50 TWh

1000 Gigafactories of 50 GWh each !!!

Possible ? Realistic ?

"Worldwide market prospects for Li Ion batteries are overwhelming: from about 85 GWh in 2016 to a forecasted 550 GWh by 2025 [= 10 gigafactories = 1% world market@ 50 kWh/vehicle], an exciting market potential driven by vehicle electrification and to a lesser extent by a steady growth in portable electronics and energy stationary storage accounting for +/- 30 GWh"

file:///C:/Users/db122678/Downloads/Report_Batteries%20Workshop_January%2011%2012.pdf

WHICH MARKET SHARE IN 2030 ?

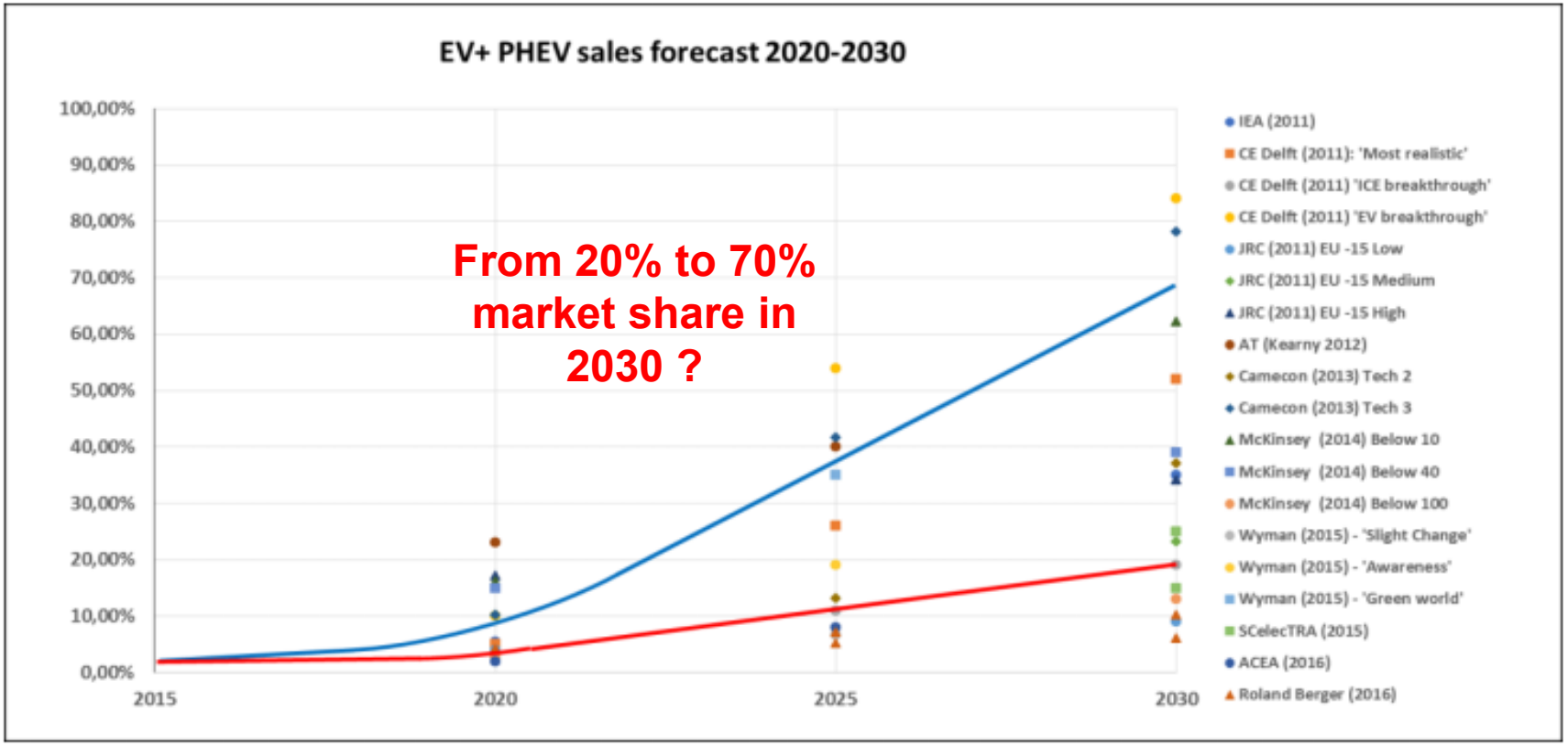


Figure 5: *Overview of recent market forecasts for Europe in literature[27], and market share projections for electric and plug-in hybrid vehicles (new sales). Lower curve: perseverant market scenario based on CO2 targets achieved with a focus on technology improvements and hybridization of ICE-based vehicles. Upper curve: expected development under assumption of reaching major technological breakthrough for EVs (Battery technology:*

Large uncertainties: to shape its own opinion !

AS A RESULT, FOR FRANCE

around 20% of the french stock of privately-owned « electrified » in 2030 (?) [5-6 millions vehicles]

i.e. 1 vehicle in 2 is sold from 2023

(fleet renewal rate 6%/y, if 3% during 7 years ➔ 21%)

MATERIALS IN LI-ION BATTERIES

MATERIAL QUANTITY & TYPE DEPEND ON:

- Market share taken by EV
- **Type of EV**
- Type of battery

Which electrified vehicle ?

- « full electric » vehicle (battery 40-100 kWh) ?

- « mild hybrid » vehicle (battery with few kWh, few km autonomy in full electric mode) ?

- « PHEV » (plug-in hybrid electric) vehicle (battery with several kWh, around 60-80 km autonomy in full electric mode) ?

What kind of electrified vehicle?
Car manufacturers & Europe

November 2017

Increase autonomy

Fast charging up to 3 min

		Current (2014/ 2015)	2020	2030
Performance targets for automotive applications				
1	Gravimetric energy density [Wh/kg]			
	pack level	85-135	250	> 250
	cell level	90-235	400	> 400
2	Volumetric energy density [Wh/l]			
	pack level	95-220	500	> 500
	cell level	200-630	750	> 750
3	Gravimetric power density [W/kg]			
	pack level	330-400	470	> 470
	cell level		700	> 700
4	Volumetric power density [W/l]			
	pack level	350-550	1.000	> 1.000
	cell level		1.500	> 1.500
5	Fast recharge time [min] (70-80% ΔSOC)	30	15	3
6	Battery life time			
	Cycle life to 80% DOD [cycles]		1.000	5.000
	Calendar life [years]	8-10	15	20

SET PLAN AND TARGETS https://setis.ec.europa.eu/system/files/integrated_set-plan/action7_issues_paper.pdf

FAST CHARGING???

Considering at any one time 10000* vehicles are charging in a (fast) charging station, it means…

350 kW x 10000 = 3500 MW to deliver…

… the equivalent of **3 nuclear power plants at full capacity**… in full day, at times where the grid is often already saturated…

Over and above the necessary copper, ohmic losses in the charger, installation cost …

Fast charging for few Tesla, but what about mass-market electric vehicles ??

*http://www.automobile-propre.com/eon-veut-deployer-10-000-bornes-rapides-europe-dici-2020/

TENSIONS ON COBALT !!

19th October 2017

In one of the clearest signs of a tight cobalt market, Volkswagen has failed to secure a long-term supply of cobalt used in electrical vehicle batteries.
The German carmaker last month put out a tender seeking a five-year supply of the strategic metal at a fixed price. But people familiar with the deal said the offer was well below market prices.
Cobalt has more than doubled in price from a year ago, when it was trading around $12 a pound, to its current $27.10 a pound as of last Thursday.

"They're being arrogant because they're automotive and they're used to doing it," said a cobalt trader quoted in the Financial Times. "They completely misjudged the contents of the tender. There's no point negotiating - it's not even a discussion point."
Over 60 percent of cobalt is mined in the Democratic Republic of the Congo - raising concerns about stability of supply. The big producers are Glencore and China Molybdenum, along with thousands of artisanal miners who mine the metal and send it to China. Amnesty International has said the process involves child labour.
According to the FT, the VW tender requires the supply of 80,000 to 130,000 tonnes of cobalt, in a market whose total supply is just over 100,000 tonnes a year.

In July of this year Glencore signed a deal to sell up to 20,000 tonnes of cobalt to Chinese battery maker Contemporary Amperex Technology Co Ltd. (CATL). VW would buy the batteries from CATL, in an effort to lock in supply of the metal used in lithium-ion EV batteries.
The same month Chinese-owned Volvo said all its car models launched after 2019 would be electric or hybrid. Tesla and BMW are also said to be looking for cobalt supplies, though no tenders have been issued, the FT said.

https://www.electricvehiclesresearch.com/articles/12978/vw-fails-to-secure-long-term-cobalt-supply-for-electric-vehicles

COBALT

Co market price (London Metal Exchange)

LME COBALT

Trading summary | Current year summary | Price graph | Average prices | Contract specs | Reports

HISTORICAL PRICES GRAPH

MATERIALS IN LI-ION BATTERIES

MATERIAL QUANTITY & TYPE DEPEND ON:

- Market share taken by EV
- Type of EV
- **Type of battery**

WHAT BATTERY TYPE?

Li-Ion?

Post Li-Ion?

Li-Sulfur?

Hybrid Supercapacities ?

Hybrid systems?

Full organic batteries?

Li-metal?

Na- Ion ?

Solid state batteries ?

Lithium-Air ?

Mg- Ion ?

Al- Ion ?

WHICH TYPE OF LI-ION BATTERY (CATHODE MATERIALS) ?

http://www.visualcapitalist.com/critical-ingredients-fuel-battery-boom/

Cathode Type	Chemistry	Metals	Example Use
NCA	**$LiNi_{0,8}Co_{0,15}Al_{0,5}O_2$**	**Nickel, Cobalt, Aluminum**	**EV's**
LCO	$LiCoO_2$	**Cobalt**	Apple iPhone
LMO	$LiMn_2O_4$	Manganese	Nissan Leaf
NMC [111]	**$LiNi_{0,33}Mn_{0,33}Co_{0,33}O_2$**	**Nickel, Manganese, Cobalt**	**EV's**
LFP	$LiFePO_4$	Iron phosphate	Stationnary ?

WHICH BATTERY TYPE ?

$LiNi_xMn_yCo_zO_2$ (NMC)/Electrolyte/Graphite

5 materials for which the question may arise

- **Lithium**
- **Cobalt**
- **Nickel**
- **Manganese**
- **Graphite**

WHICH BATTERY TYPE?

$LiNi_xMn_yCo_zO_2$ (NMC)/Electrolyte/Graphite

$Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$ (NMC 111) : Nickel, Manganese, Cobalt (20,4 %)

$Li[Ni_{0,6}Mn_{0,2}Co_{0,2}]O_2$ (NMC 622) : Nickel, Manganese, Cobalt (12,2 %)

$Li[Ni_{0.8}Mn_{0.1}Co_{0.1}]O_2$ (NMC 811) : Nickel, Manganese, Cobalt (6 %)

An obvious solution for EV/PHEV in the coming years: « NMC-Graphite »

NMC 111, NMC 622 or NMC 811 ??

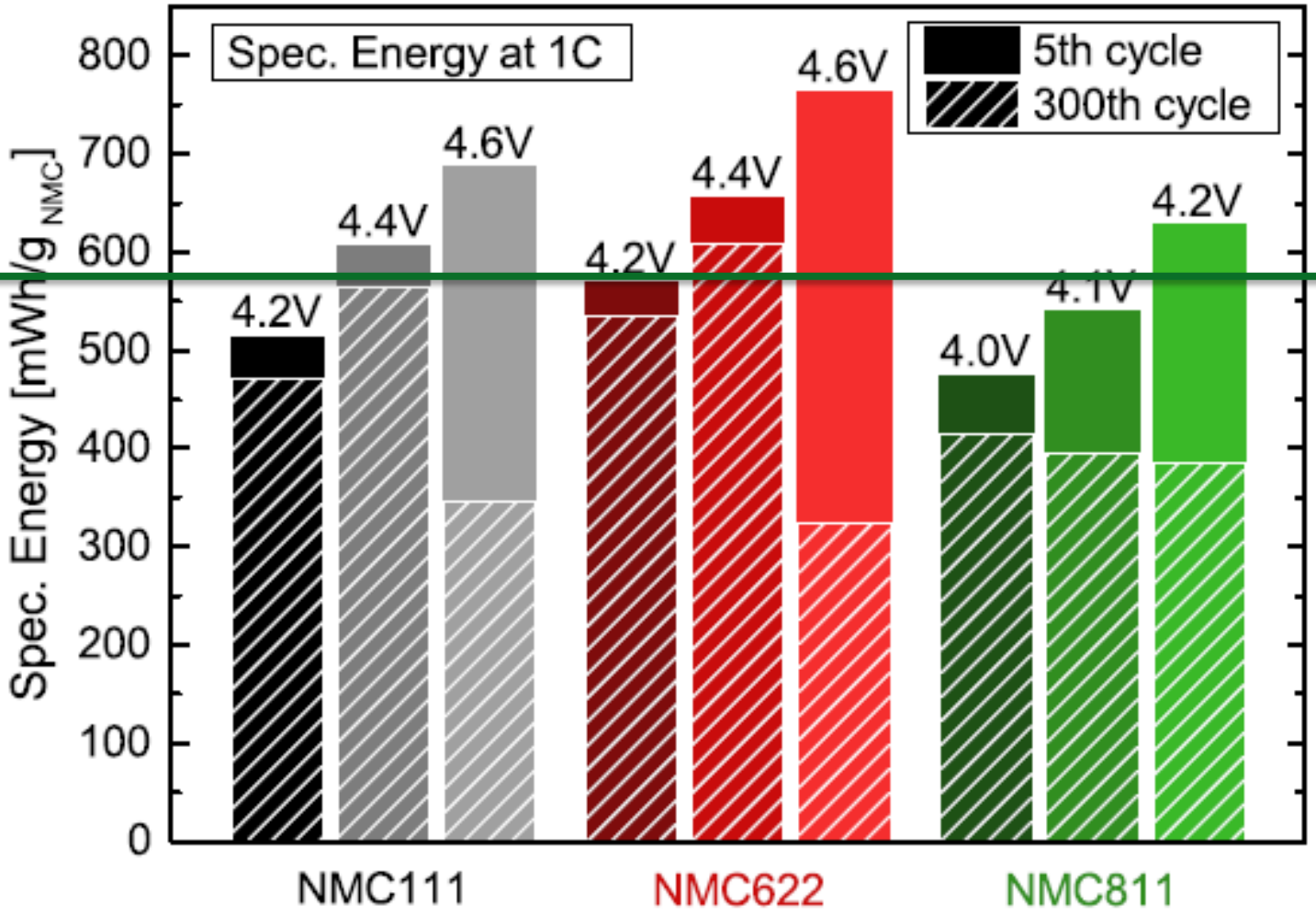
Which best possible compromise performance/cost ??

http://www.visualcapitalist.com/critical-ingredients-fuel-battery-boom/

WHICH MATERIAL QUANTITY?

Journal of The Electrochemical Society, **164** (7) A1361-A1377 (2017)

~ 570 Wh/kg NMC



WHICH MATERIAL NEED PER VEHICLE?

Journal of The Electrochemical Society, **164** (7) A1361-A1377 (2017)

"Lithium Ion battery Supply chain considerations: analysis of Potential Bottlenecks in Critical materials" Joule 1 229-243 October 11, 2017

Calculation basis: 570 Wh/kg of NMC, i.e. 1,754 kg/kWh of NMC compound

Cobalt (%)	kg/kWh	BEV (50 kWh)	PHEV (10 kWh)
NMC 111 (20,36%)	0,357 kg/kWh	17,85 kg	3,57 kg
NMC 622 (12,16%)	0,213 kg/kWh	10,65 kg	2,13 kg

Lithium (%)	kg/kWh	BEV (50 kWh)	PHEV (10 kWh)
NMC 111 (7,2 %)	0,122 kg/kWh	6,1 kg	1,22 kg
NMC 622 (7,2 %)	0,122 kg/kWh	6,1 kg	1,22 kg

Nickel	kg/kWh	BEV (50 kWh)	PHEV (10 kWh)
NMC 111 (20,2%)	0,354 kg/kWh	17,7 kg	3,54 kg
NMC 622 (36,3%)	0,636 kg/kWh	31,8 kg	6,36 kg

WHICH STOCK ?

Geological resources: known deposits likely to be exploited

Geological reserves: exploitable resource from both technical and economic points of view

Resources and reserves can differ significantly between them and they both evolve with time

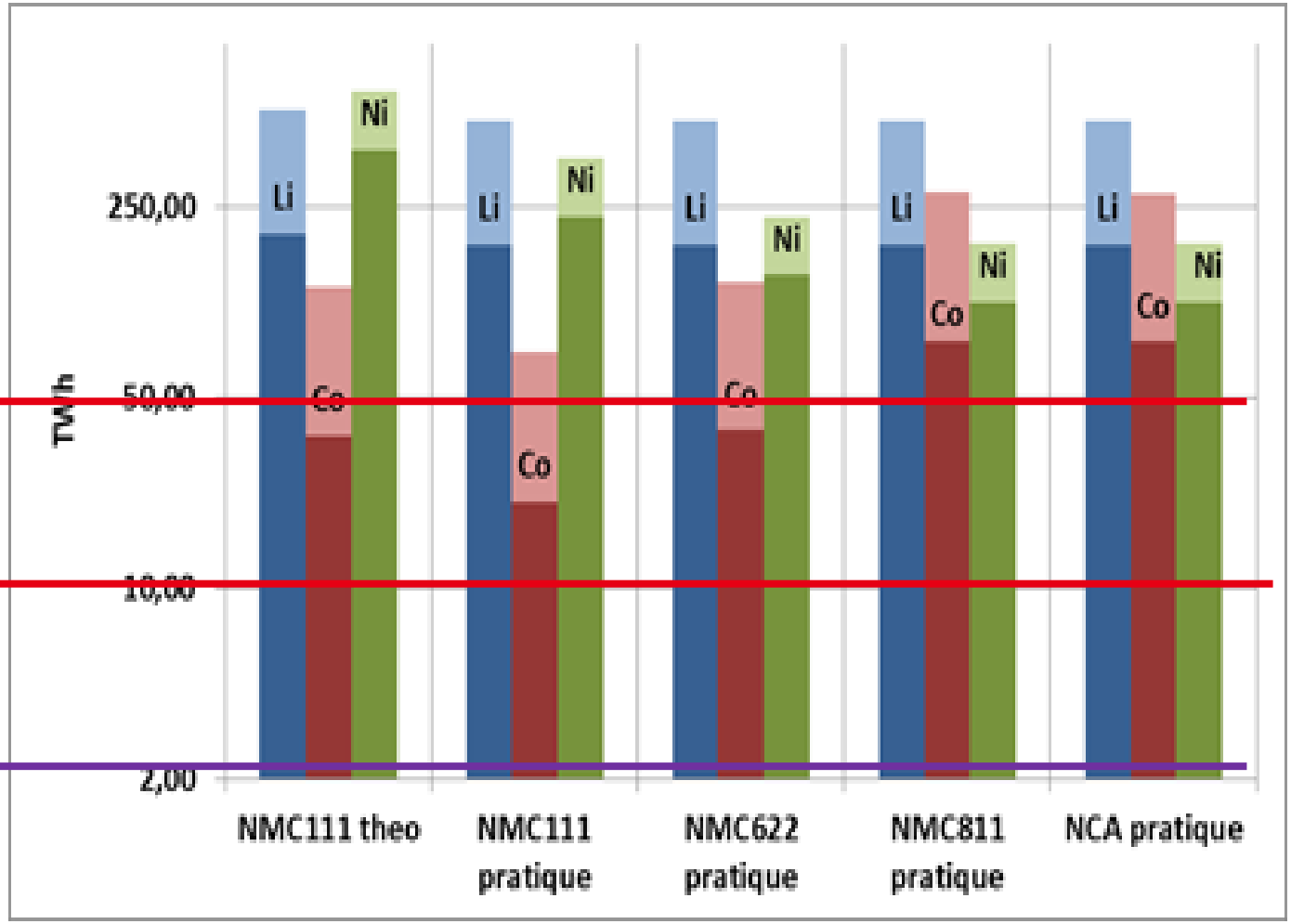
http://www.ifri.org/fr/publications/etudes-de-lifri/transition-energetique-face-defi-metaux-critiques-une-domination-de

MATERIAL RESERVES/RESOURCES

World vehicle fleet
Full electrified **EV** (50 kWh embarked per vehicle) : 50 TWh). (1 MM vehicles)

World vehicle fleet PHEV
(10 kWh embarked per vehicle) : 10 TWh. (1 MM vehicles)

European vehicle fleet
fully electrified **PHEV** (10 kWh embarked per vehicle) : 2 TWh. (200 M vehicles



Results:

- **Impossible task for EV 50 kWh except if there are substitutes to both Co and Ni**
- **Complicated, although not impossible with PHEV 10 kWh but efficient recycling needed**

CONCLUSIONS : THE FACTS

- China represents in 2016 88 % of the offer and 58% of the demand for the rare earth, and has the near monopoly for Co extraction (in DRC)
- China, thanks to a farsighted strategy (« mineral nationalism ») has the leadership and the control of the complete value chain
- Europe lag behind but realize the stakes

CONCLUSIONS: ACTS ?

Need to implement in Europe

- Production chain for adapted electric vehicles

  ➔ Full electric vehicles ? Hybrid PHEV ?

- Production chain for batteries

  ➔ With low content of critical materials

- Efficient recycling chain (collection & recovery)

  ➔ Cobalt, copper, nickel, lithium,…

Numerous Public or Private Research actors to mobilize around this critical challenge for Europe

Europe has at its disposal a broad competencies and the necessary attractiveness

DE LA RECHERCHE À L'INDUSTRIE

cea

MAKE YOUR OWN MIND !

DE LA RECHERCHE À L'INDUSTRIE

cea

Thank you

Commissariat à l'énergie atomique et aux énergies alternatives
17 rue des Martyrs | 38054 Grenoble Cedex
www.cea-tech.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019