

Hidrojen ve Enerji Depolama

Barış Sanlı

Bilkent Enerji Politikaları Araştırma Merkezi

Yaşar Üniversitesi Enerji Sohbetleri - 11 Mart 2021 / barissanli.com

Bu sunumdaki tüm görüşler kişisel görüşler olup hiçbir kurum/şirket/dernek ya da Bilkent EPRC'ye atfedilemezler. Görüşlerde yanlış var ise bunlar şahsi hatalardır. Bu sunumdaki görüşler yatırım amacı ile kullanılamaz.

Ana soru

Hidrojen ve enerji depolama gelecek enerji denkleminde ne şekilde ve ne kadar yer alacak?

Bazı birimler

- **Hidrojen**

- 33 kWh/kg -> 11 m³
- 1 m³ doğalgaz -> 10.64 kWh
- Elektrolizör verimliliği %60 : 55kWh elektrik -> 1 kg H₂

- **Depolama**

- Pil enerji depolar -> kWh
- Depolama sistemleri hem anlık hem de süreli kapasite verir
 - 1 saat 5 kWh veren sistem : 5kW/5kWh
- Yoğunluk: Wh/kg, Wh/l

Battery Type	Cost \$ per Wh	Wh/kg	Joules/kg	Wh/liter
Lead-acid	\$0.17	41	146,000	100
Alkaline long-life	\$0.19	110	400,000	320
Carbon-zinc	\$0.31	36	130,000	92
NiMH	\$0.99	95	340,000	300
NiCad	\$1.50	39	140,000	140
Lithium-ion	\$0.47	128	460,000	230

Neden

- **Hidrojen**

- Dekarbonizasyonu zor olan sektörlerde bir alternatif olabilir mi?
- Gaz sistemlerinde batık maliyet
- Elektrik-gaz entegrasyonu için ideal

- **Depolama**

- Tüm enerji sistemlerinde kritik
- Enerji güvenliği tanımının parçası (doğalgaz depo, stratejik petrol stokları)
- Elektrik üretim tarafında su rezervi ile depolama

Elektrik sisteminin özelliđi

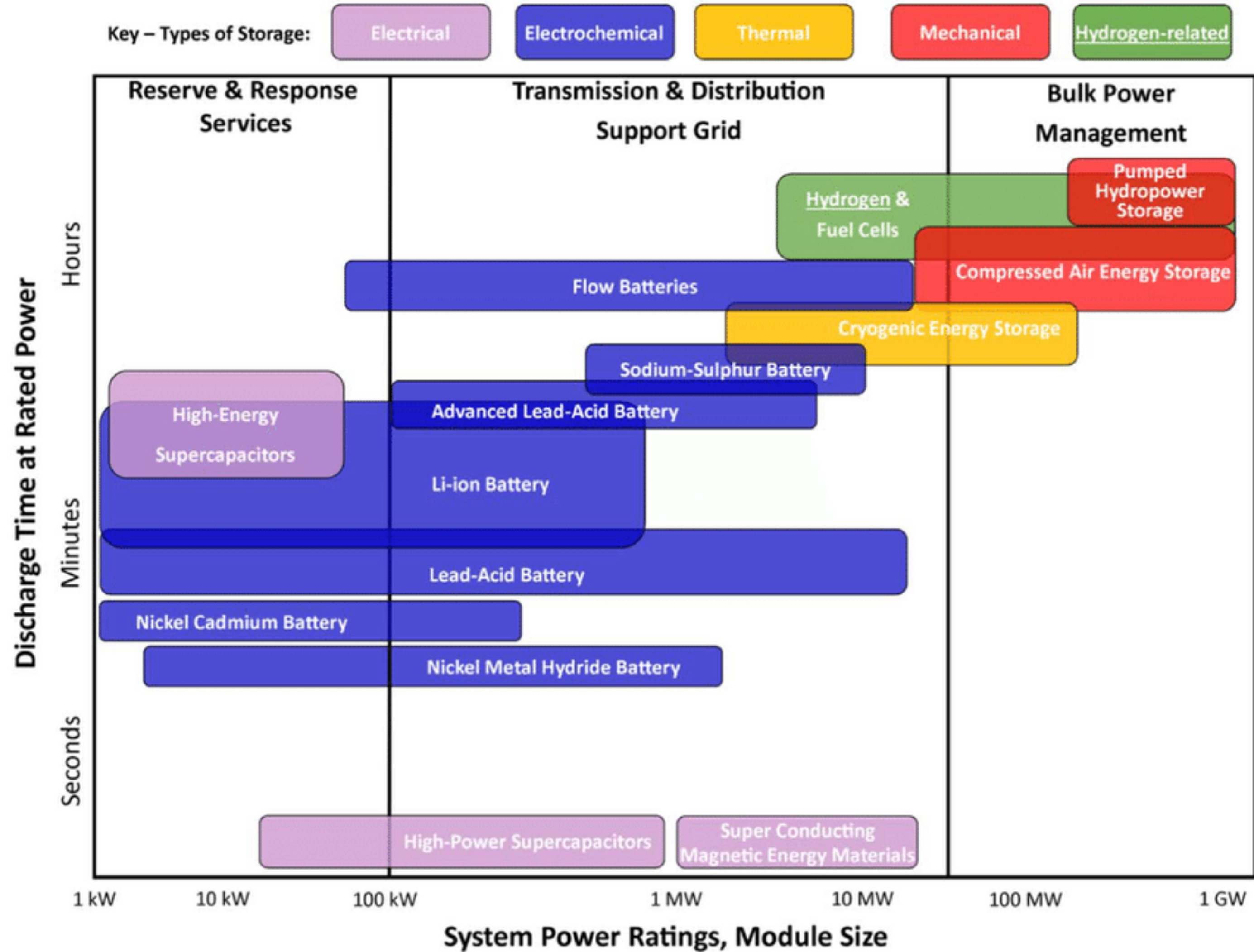
- **Tüketici yönetir**

- Tüm elektrik sistemi tüketim etrafına örülü
- Tüketici istediđi zaman tüketir, üretim buna uyar
- Elektrik anlık dengelenir.

- **Elektrik bir hizmetler bütünü**

- Üretme/tüketme
- Yedekte durma, sistem dengeleme
- Kesinti durumunda devreye girip sistemi ayađa kaldırma

Depolama türleri

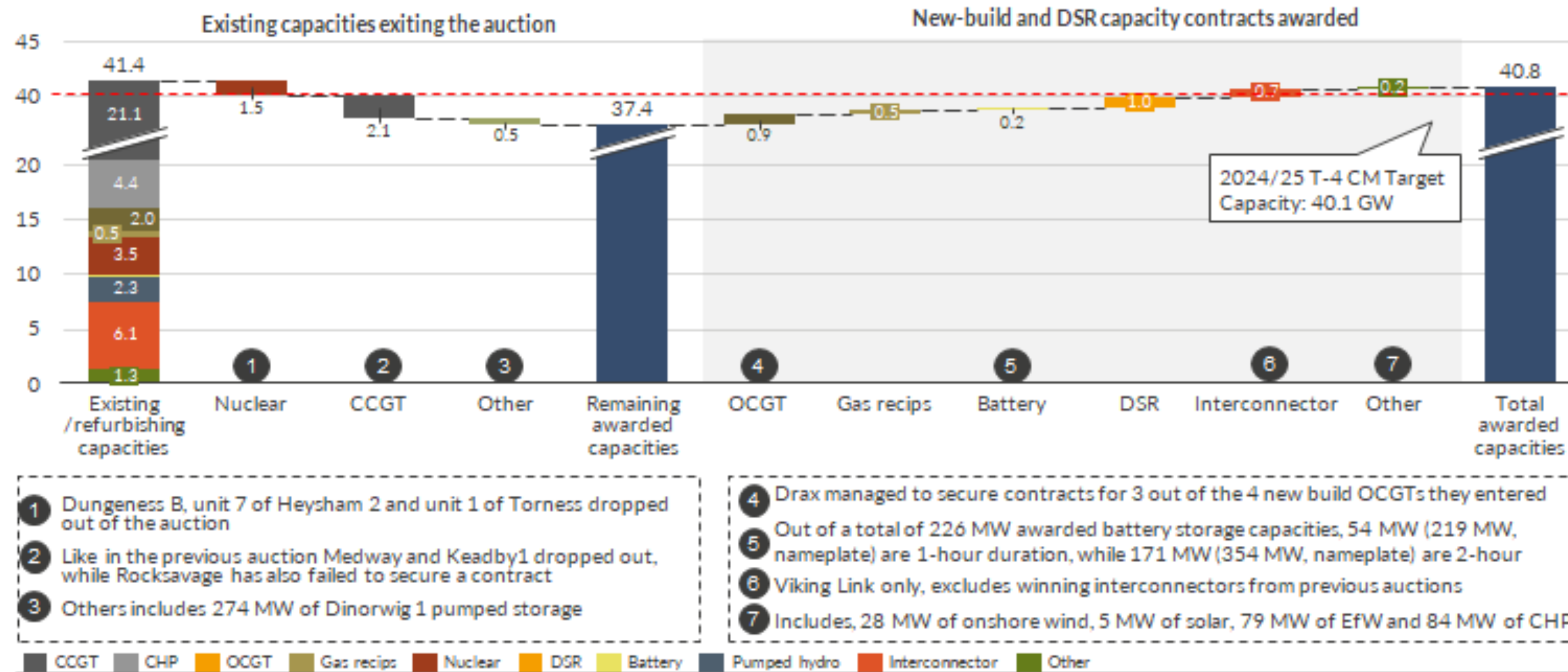


İngiltere kapasite piyasası ve piller

The 2024/25 T-4 CM auction cleared at £18.0/kW, procuring 40.8GW of capacity including 3.4GW new build

AURORA

2024/25 T-4 breakdown of awarded capacities by technology
GW de-rated



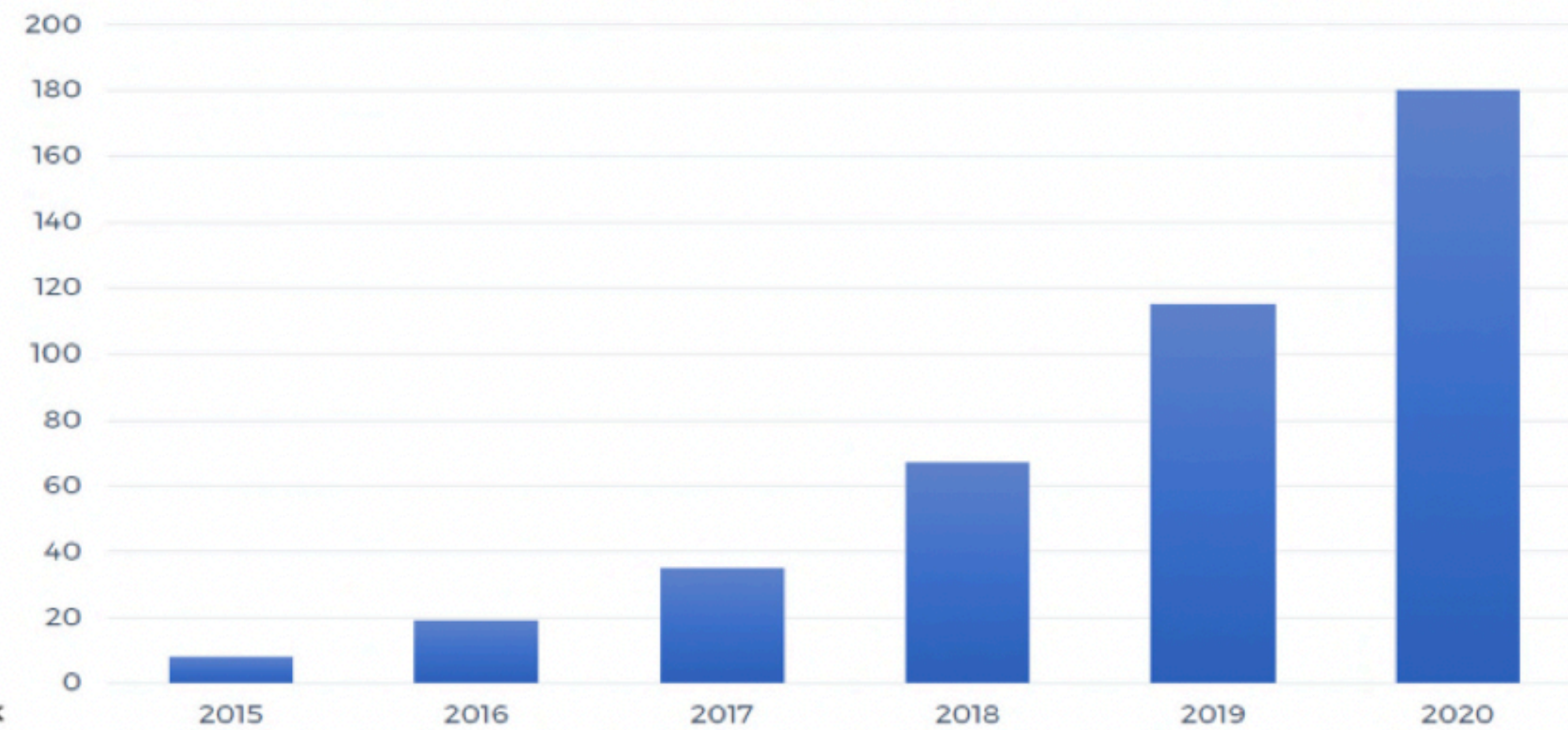
Sources: Aurora Energy Research, National Grid

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Depolama - Mega fabrikalar

Build-out of battery megafactories (>1 GWh), 2015–2020

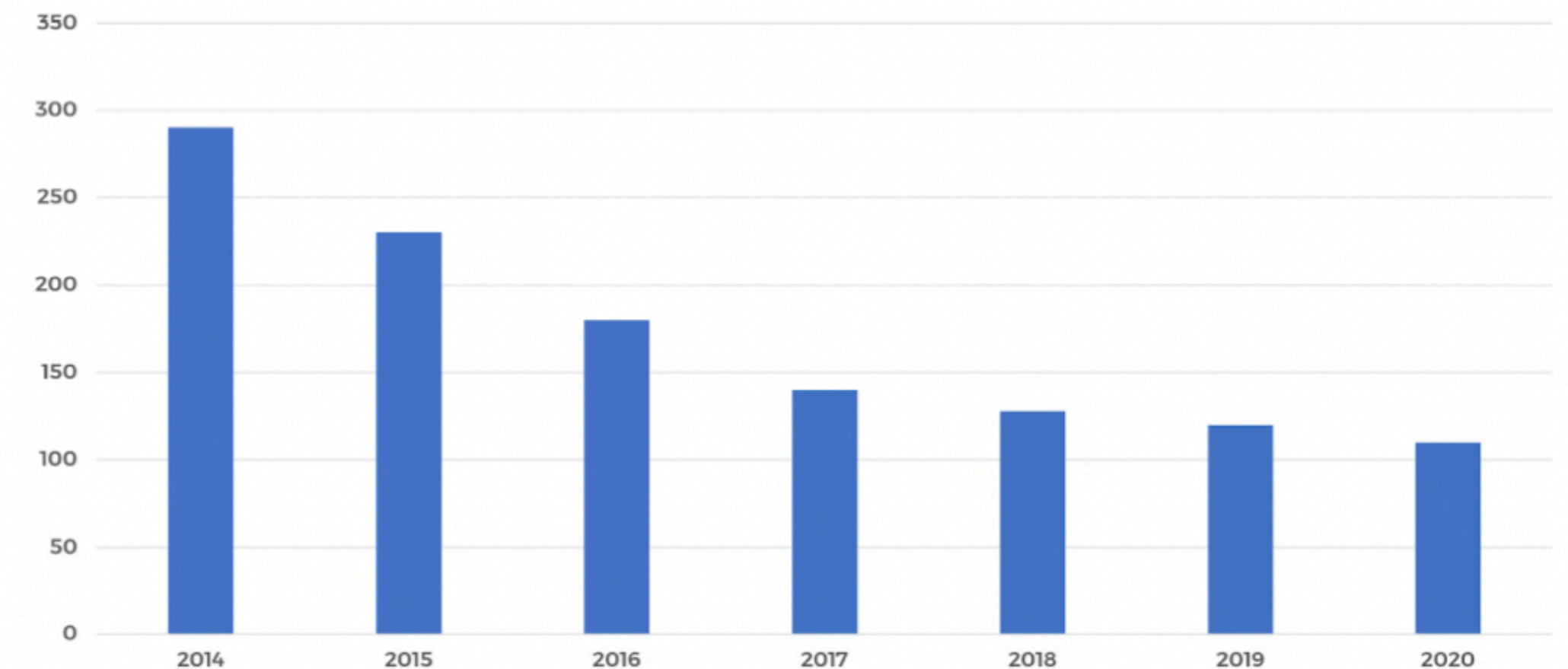
The build out of EV battery megafactories / gigafactories since 2015 (> 1GWh)



Source: Benchmark Mineral Intelligence.

Declining cost of lithium-ion batteries used in electric vehicles (\$/kWh), 2014–2020

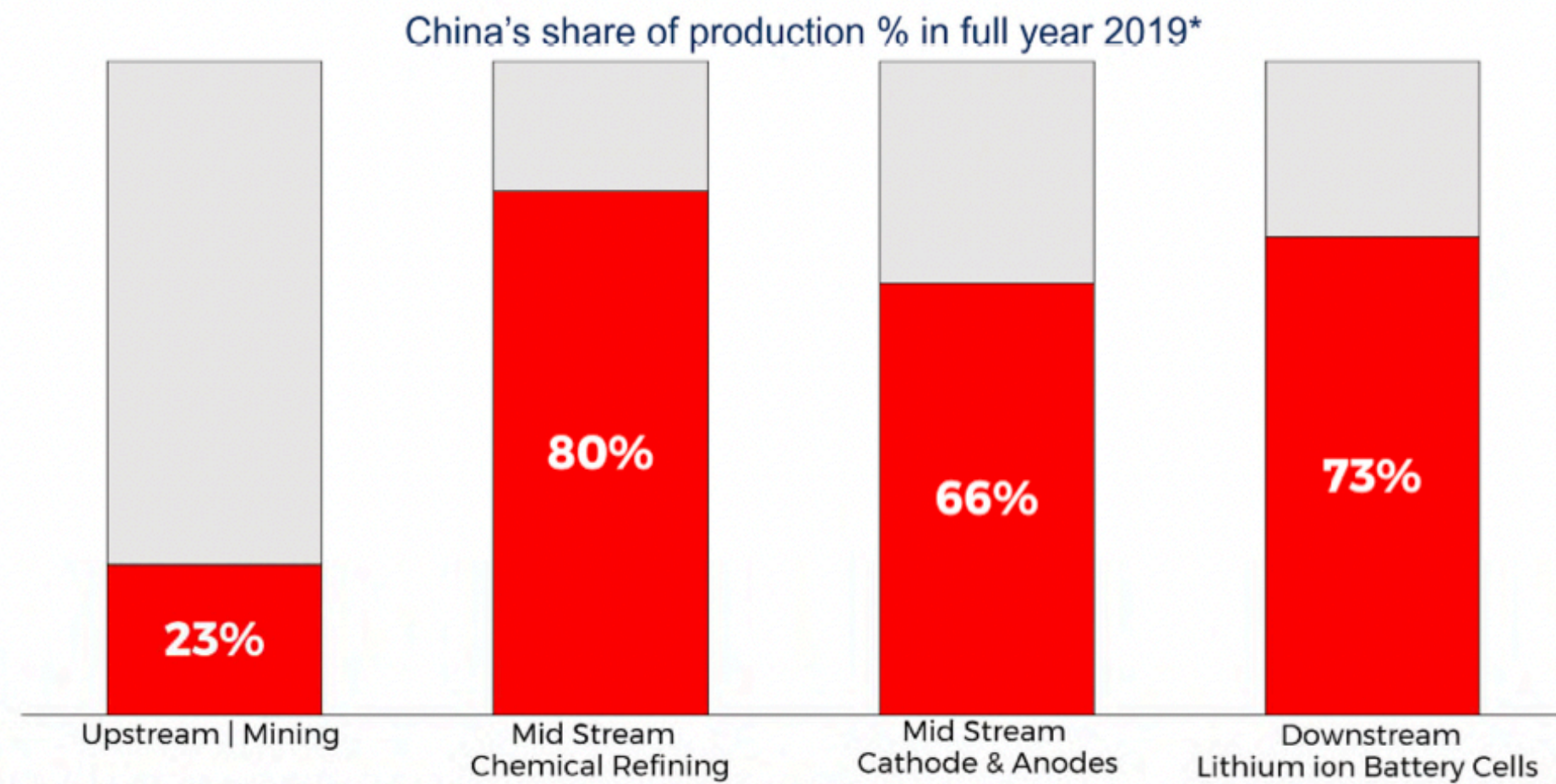
Lithium ion cell price, Large contract, Automotive, \$/kWh



Source: Benchmark Mineral Intelligence.

Depolama - Çin'in payı

Share of China's lithium-ion battery manufacturing produced domestically in 2019



*Lithium, Cobalt, Nickel, Graphite, Manganese, Cathode, Anode, Cells accounted for in calculations

Source: Benchmark Mineral Intelligence

Source: Benchmark Mineral Intelligence. Data account for production of lithium, cobalt, nickel, graphite, manganese, cathode, anode.

Current and potential future supply chains

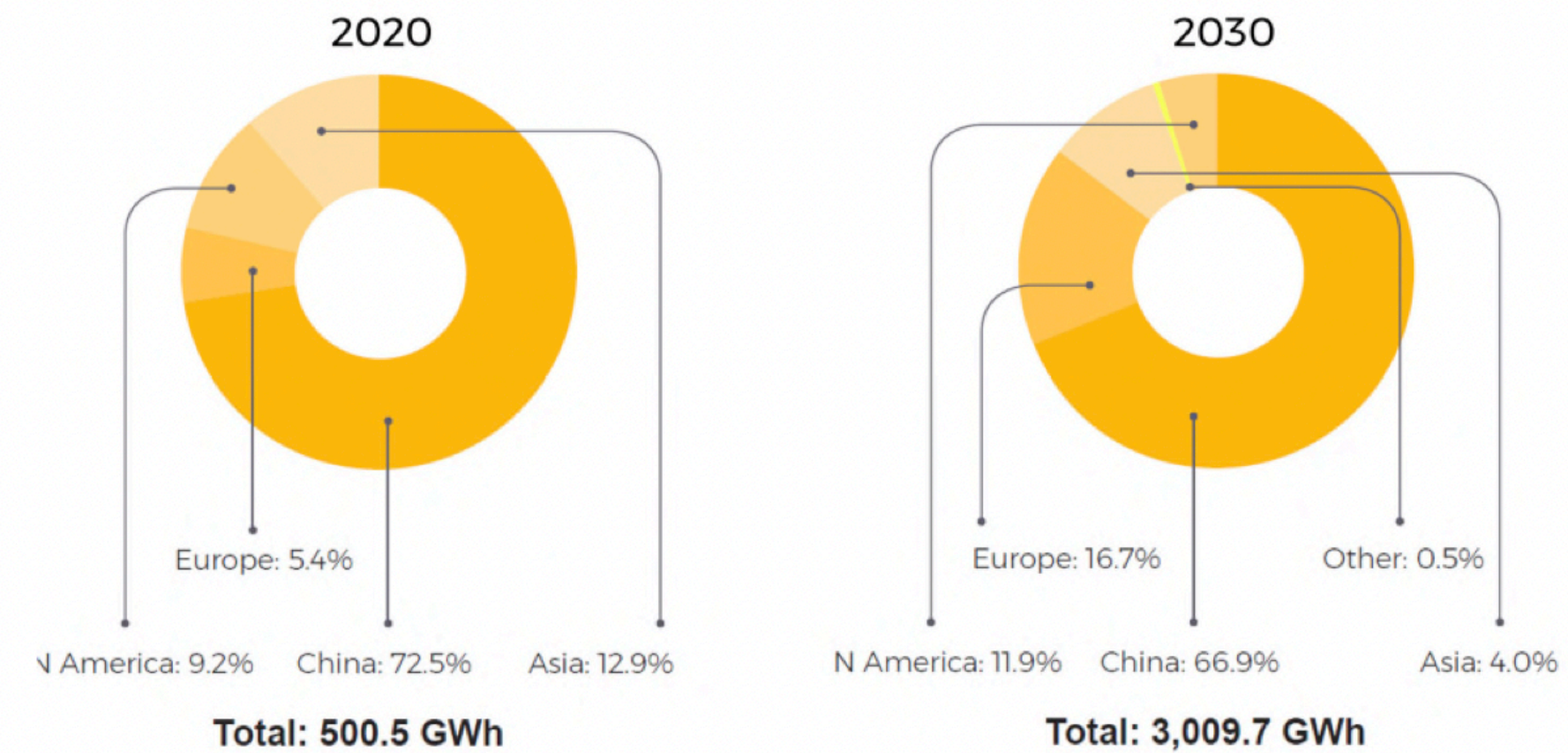
Current sample Supply Chains for Europe and North America focus on global mining and Asian refining of cathode materials

Growth of battery supply chains allows future sourcing to optimized, reducing shipping and working capital requirements, while reducing political risk



Source: Benchmark Mineral Intelligence.

Lithium-ion battery cell capacity in 2020 and planned for 2030

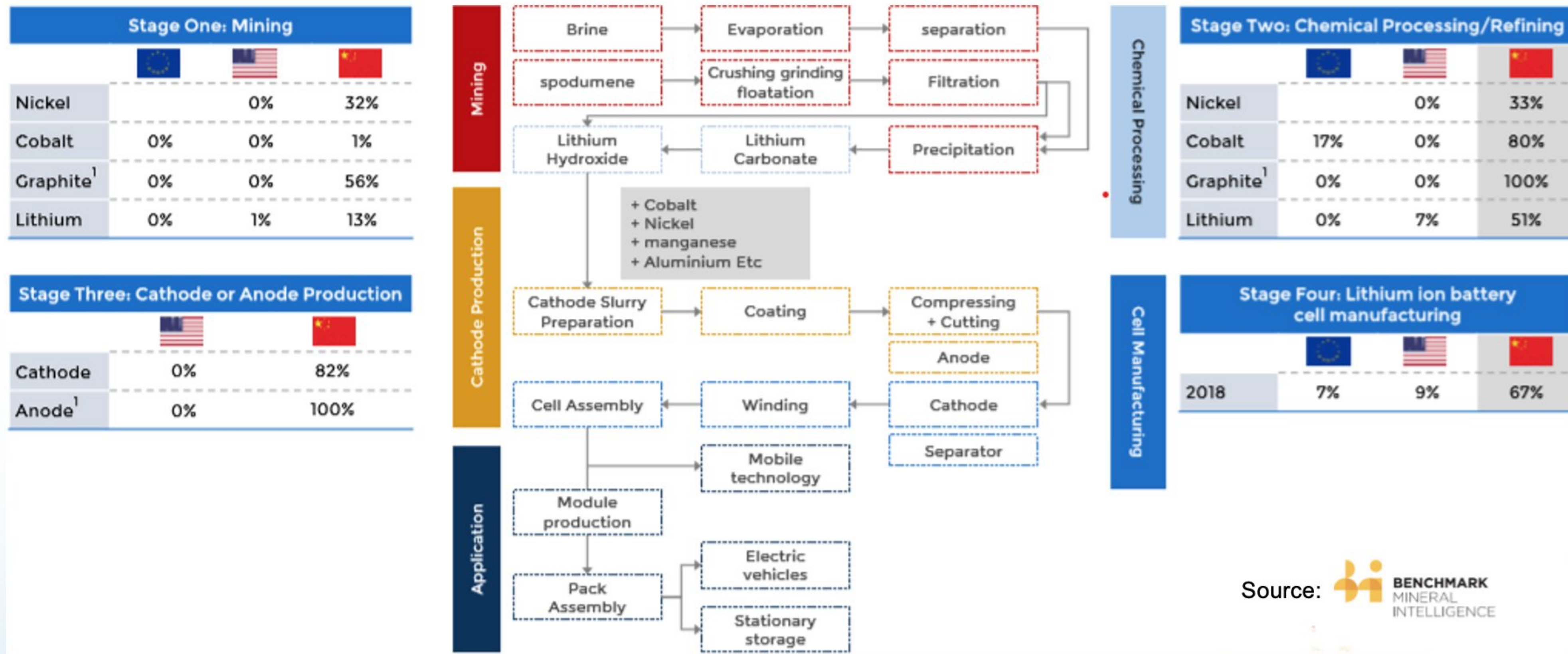


Source: Benchmark Mineral Intelligence.

Çin'in NTE tedarik zincirindeki payı

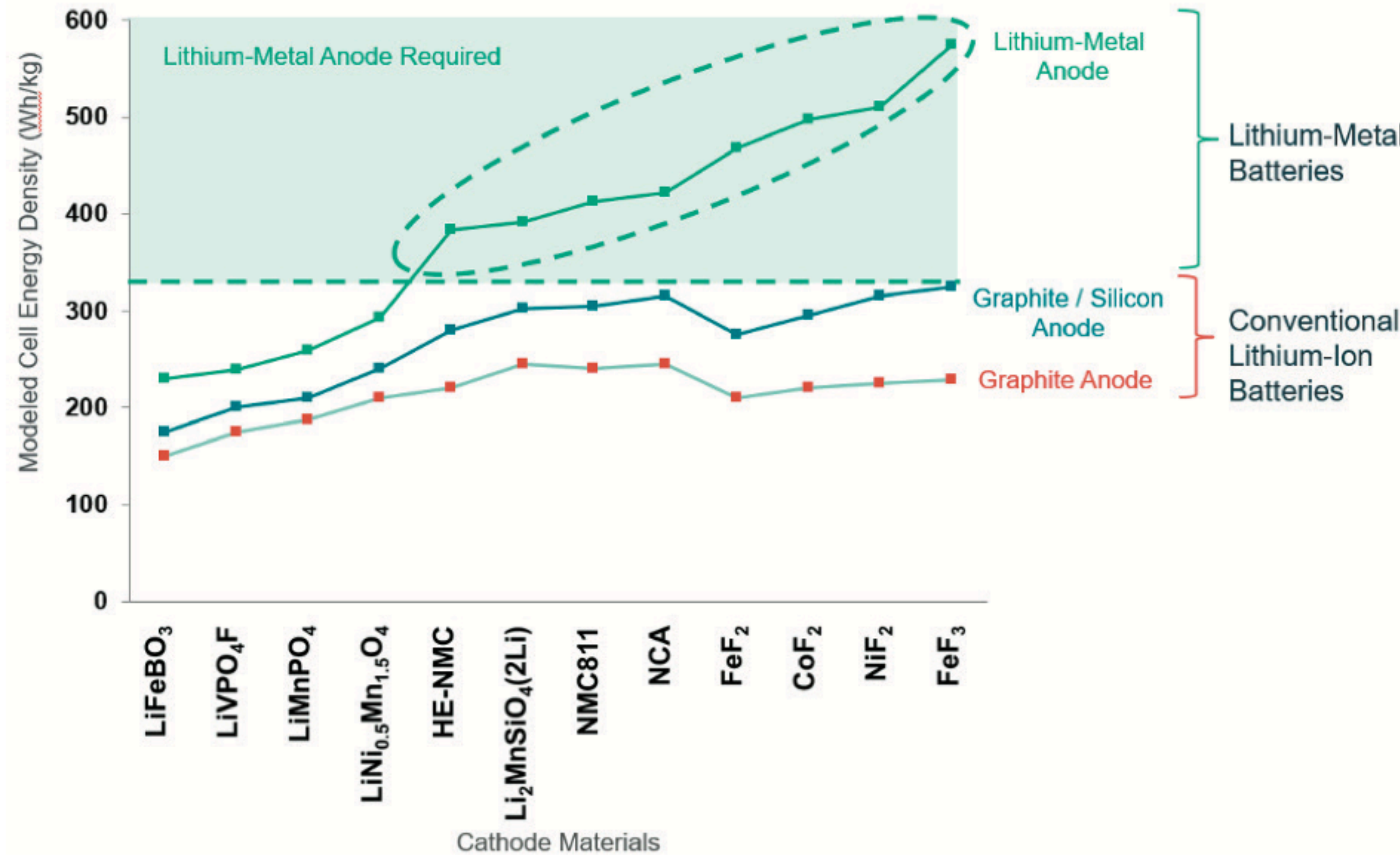
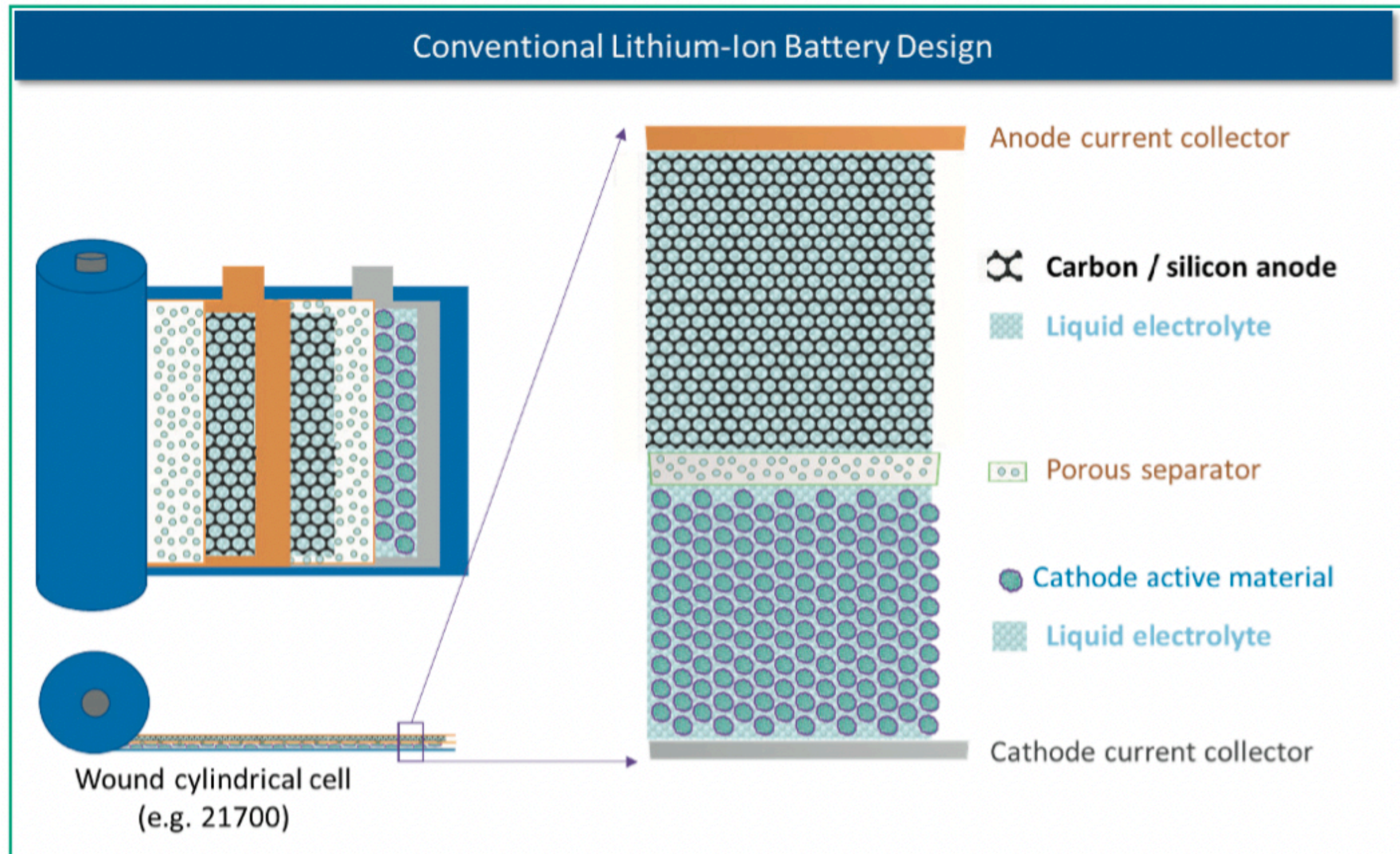


China's Supply Chain is leading

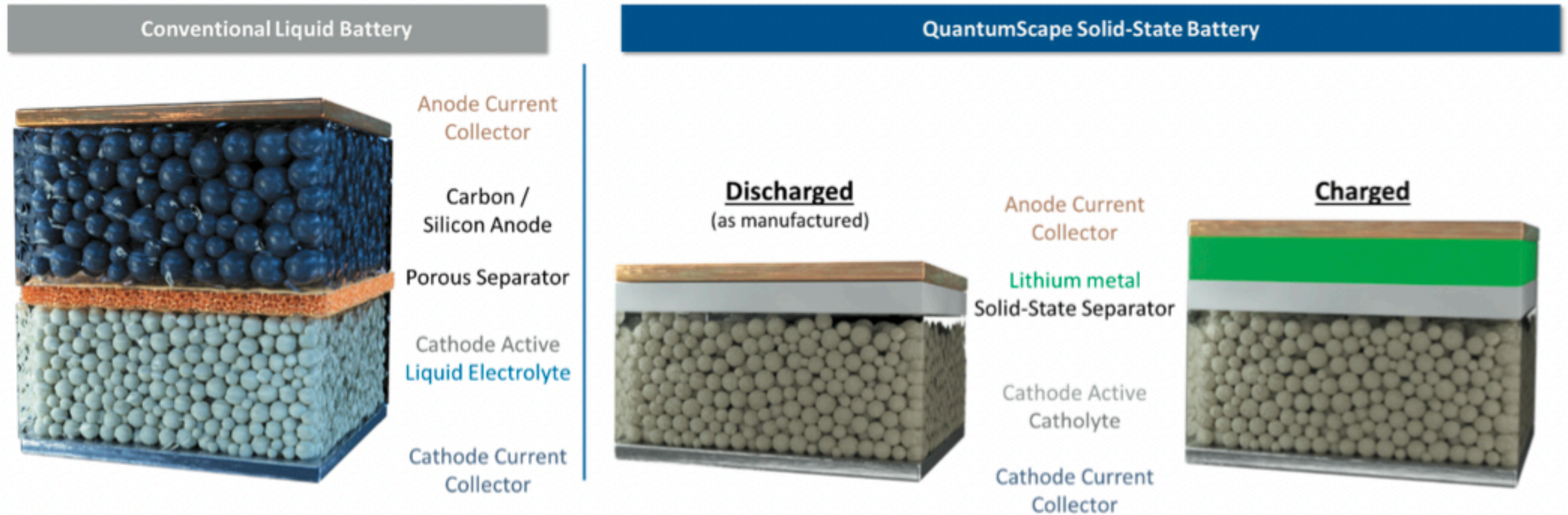


Source: BENCHMARK MINERAL INTELLIGENCE

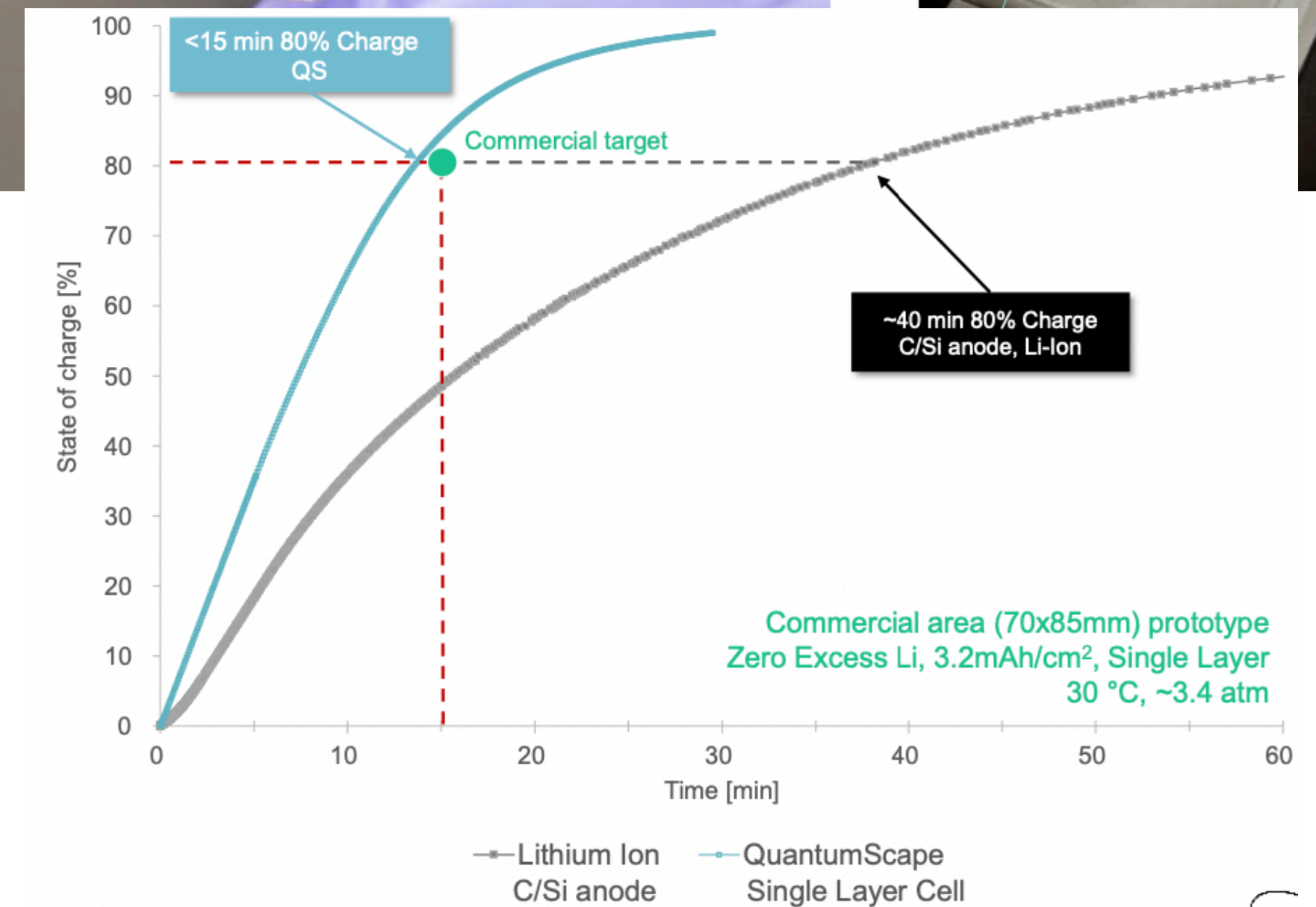
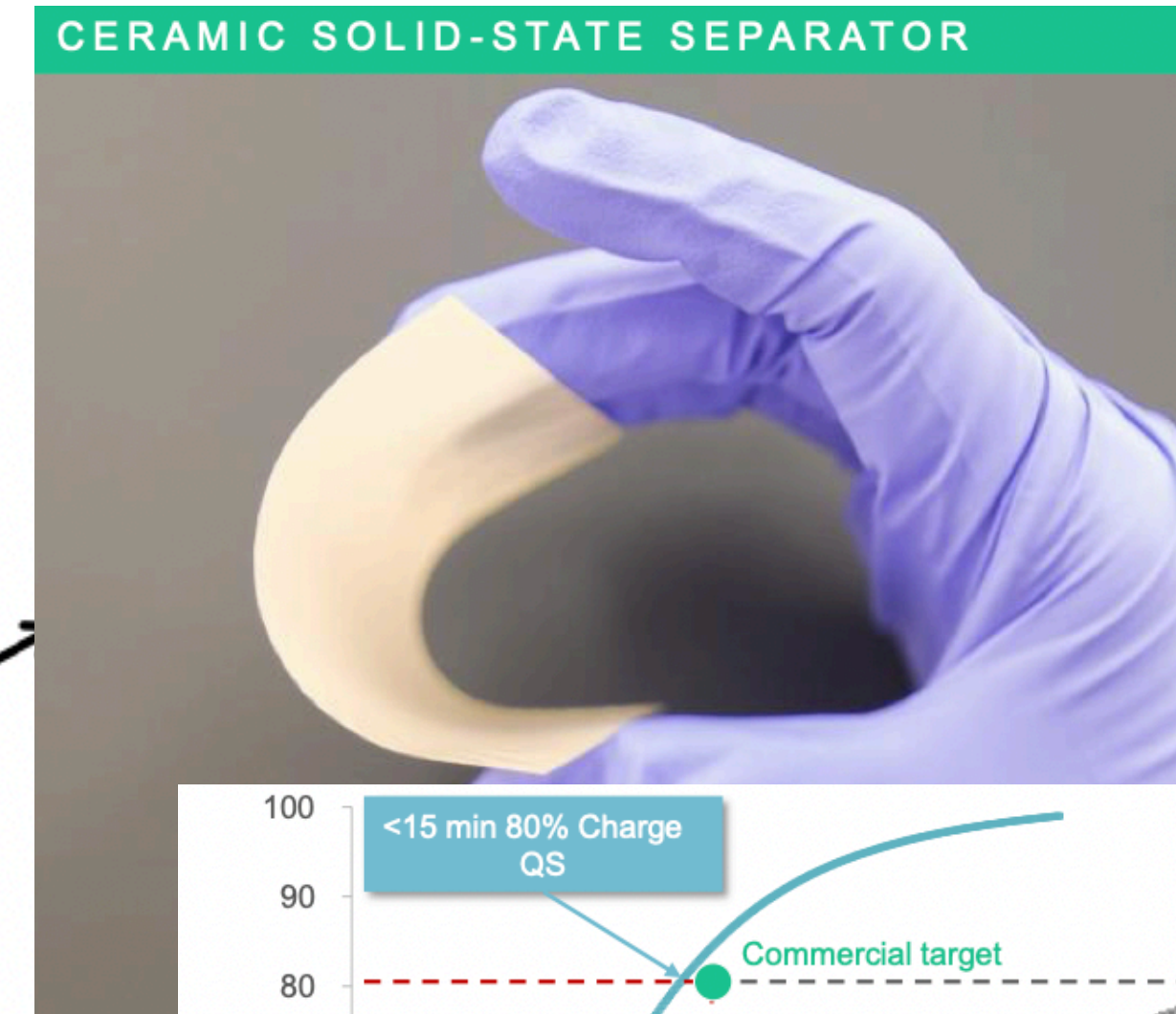
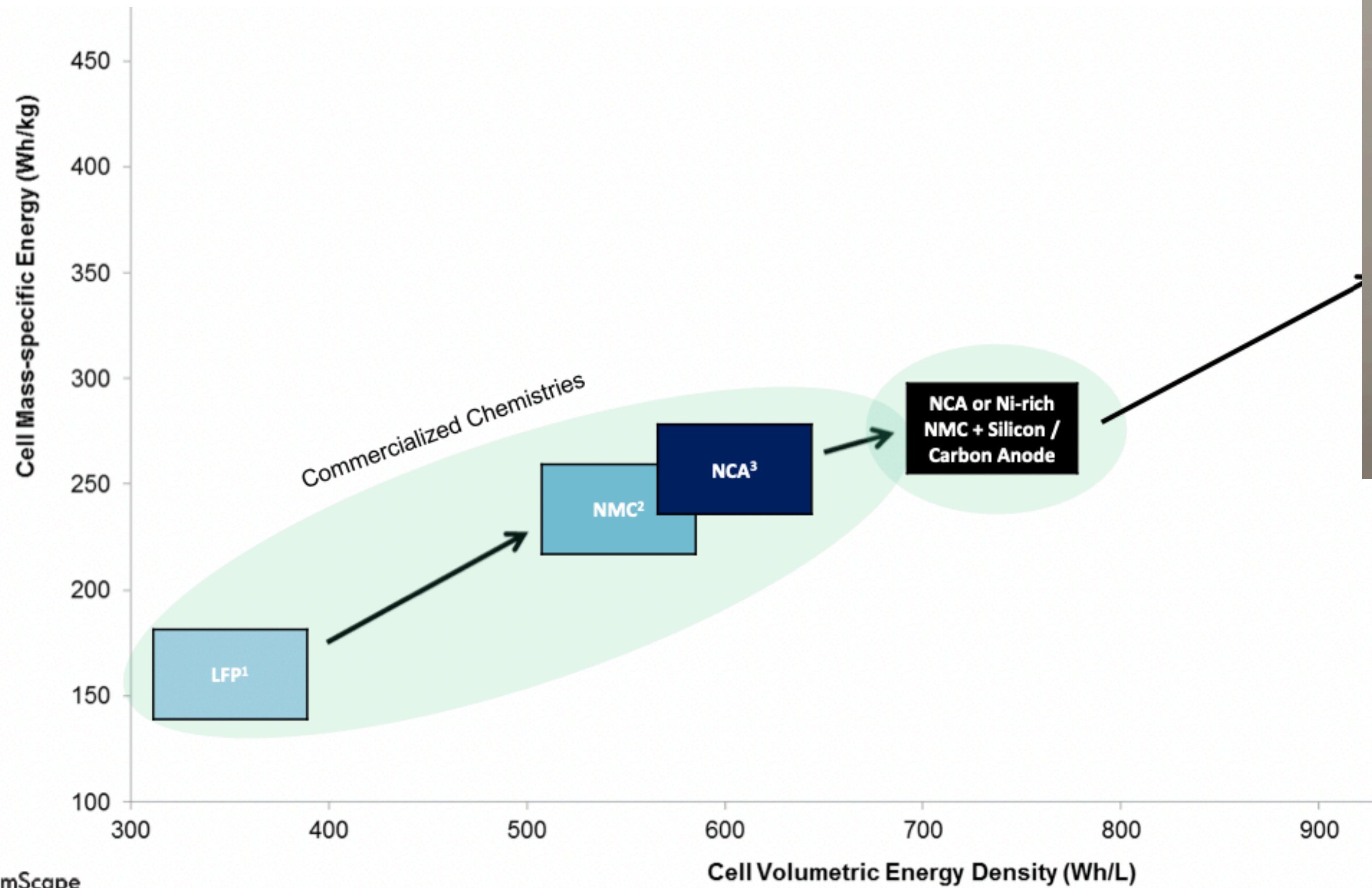
Mevcut Lityum Ion Pil Tasarımı



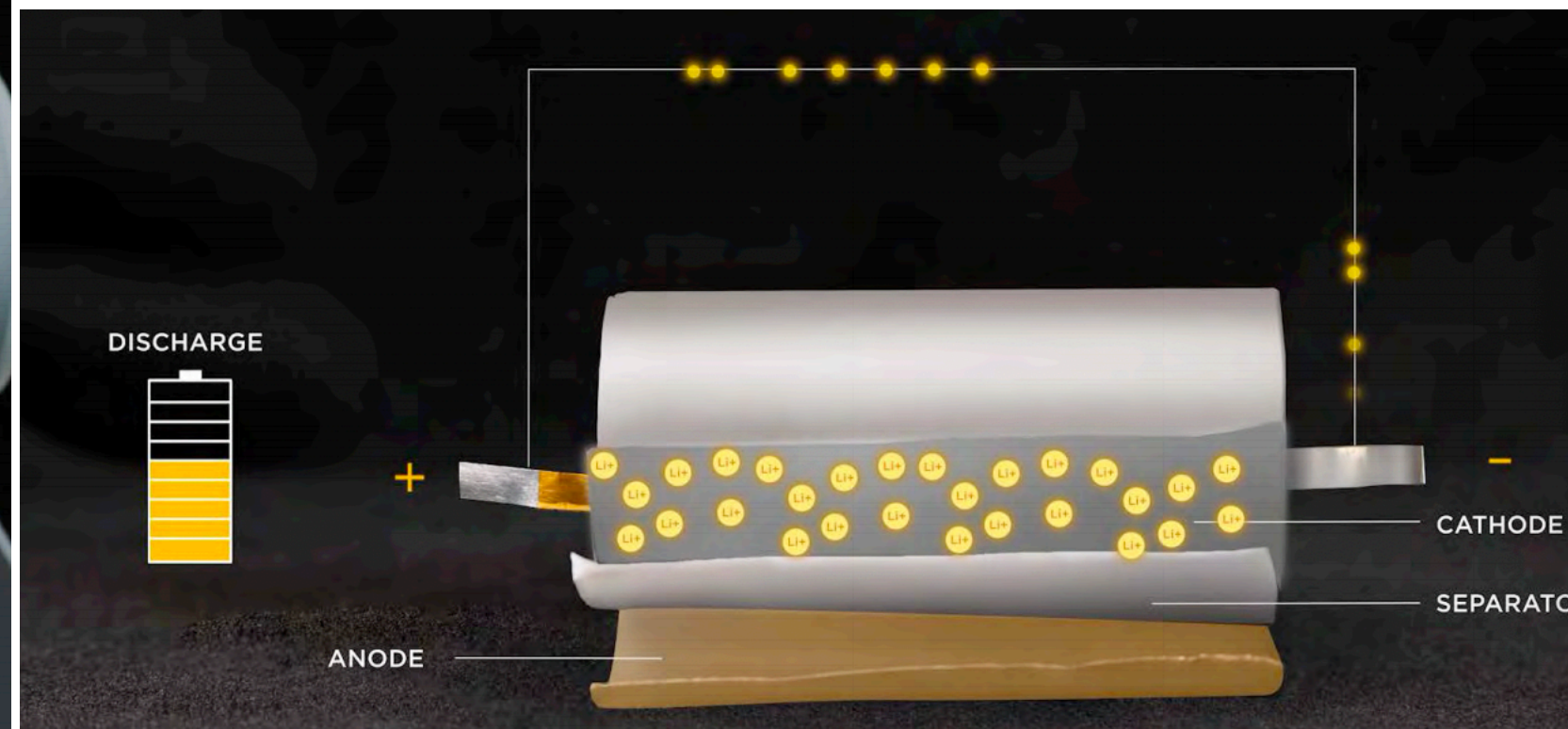
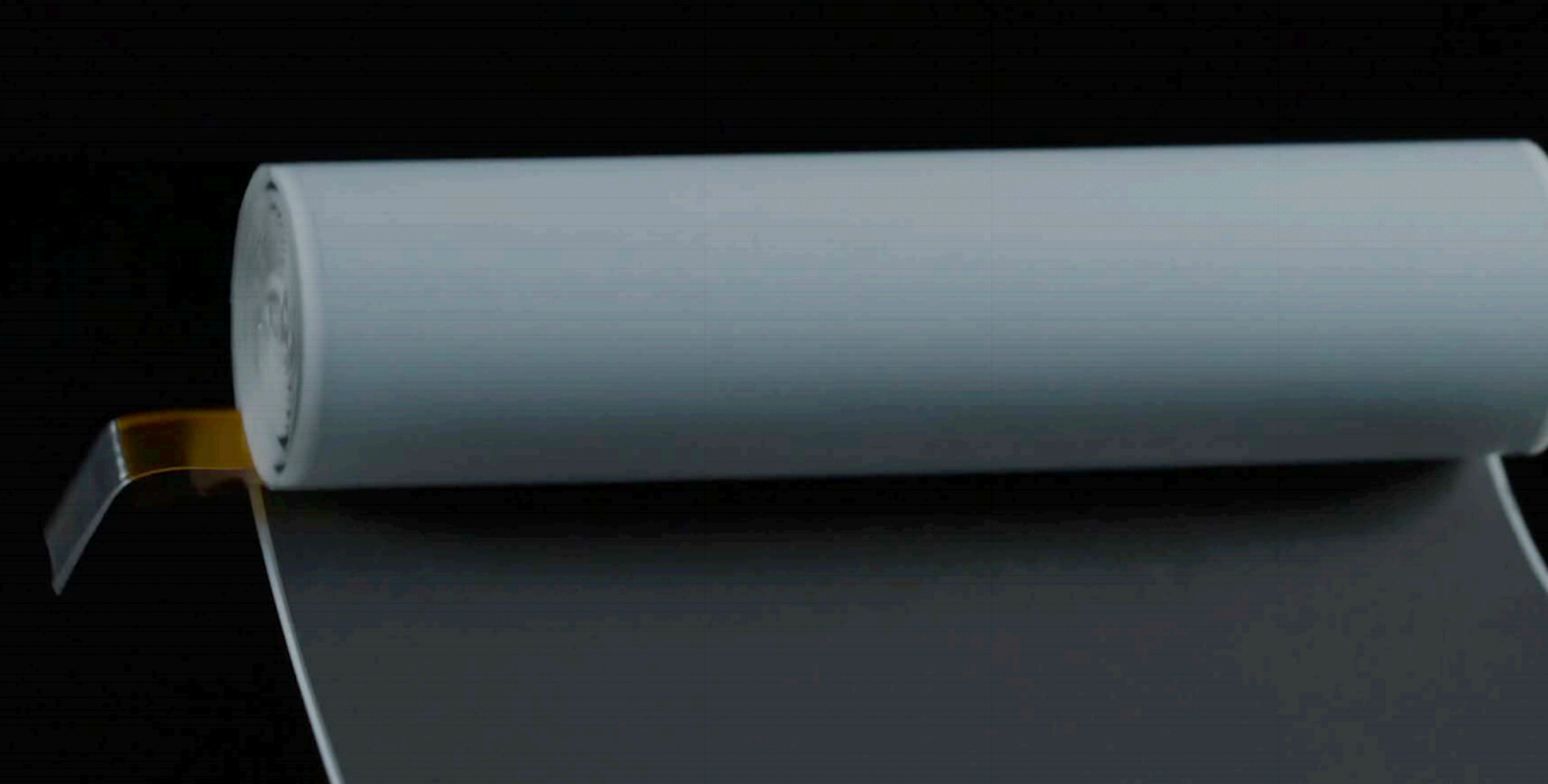
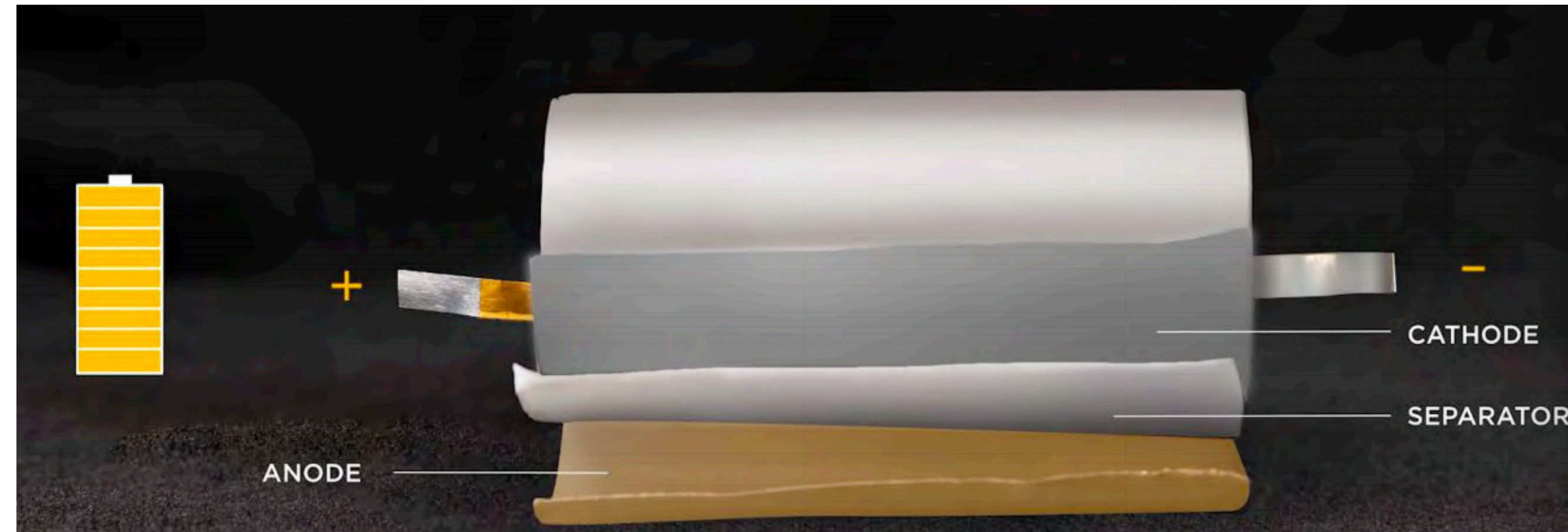
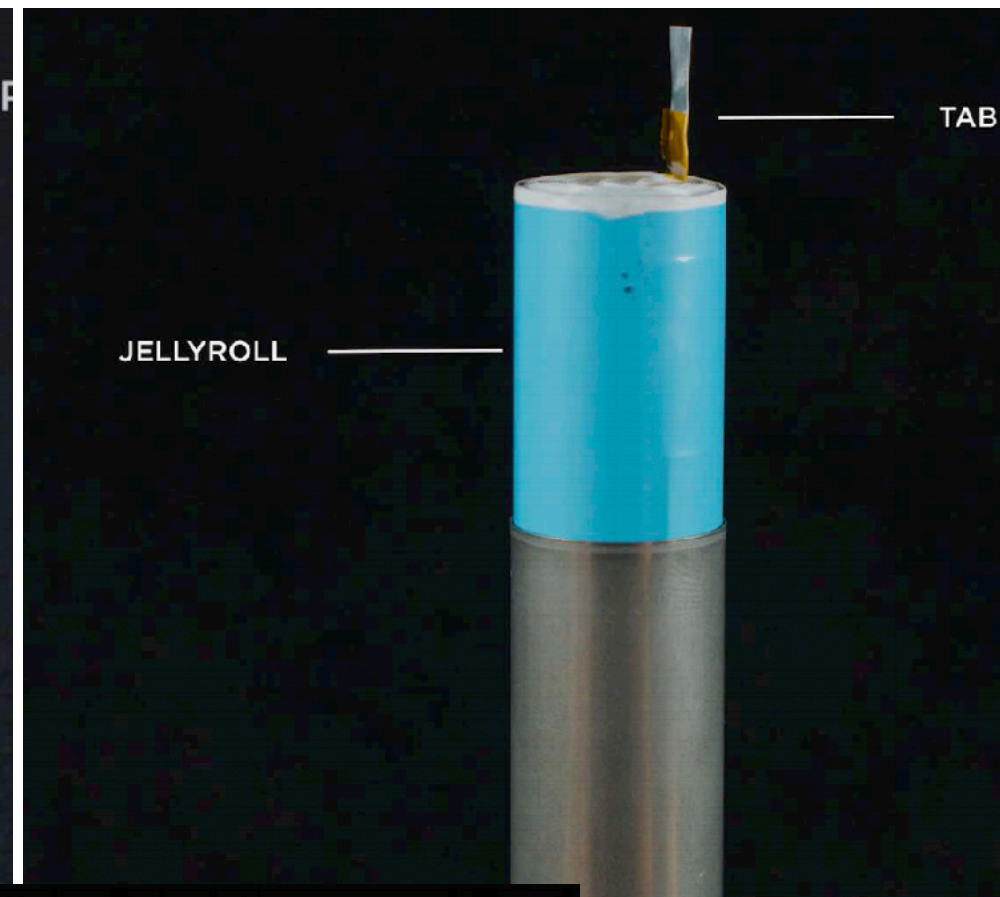
Katı hal piller



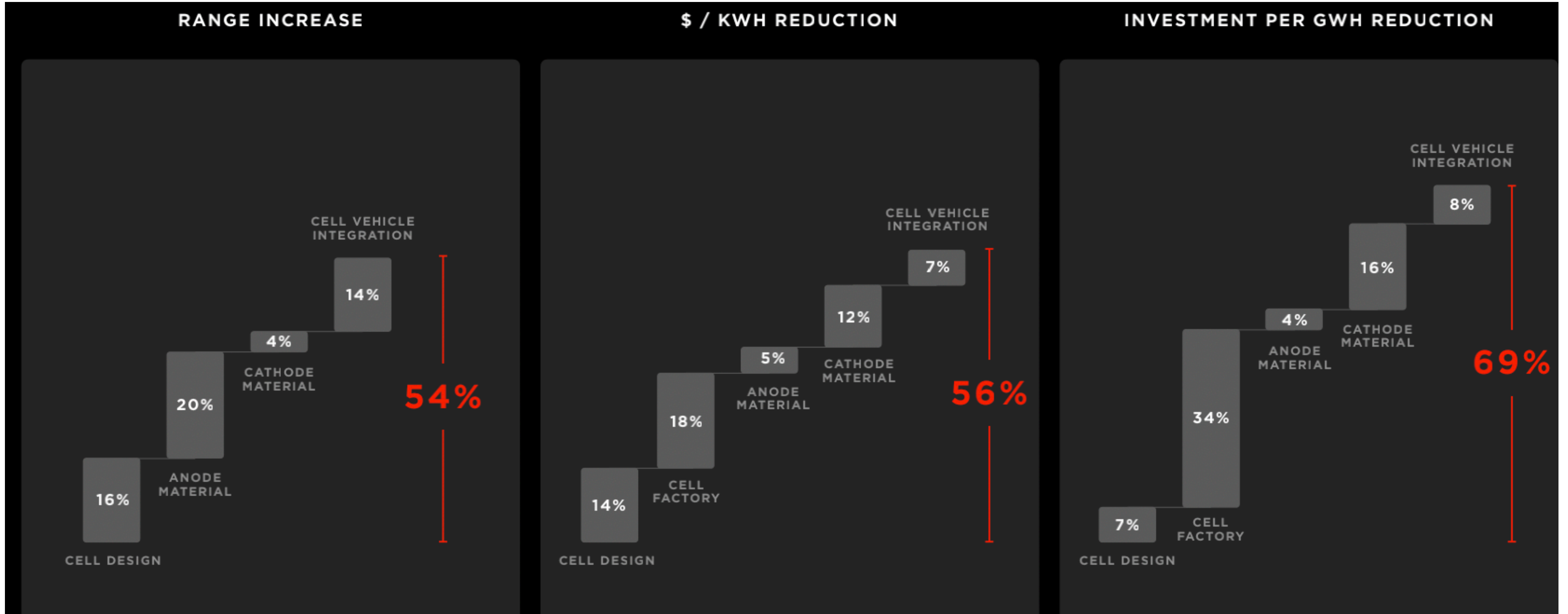
Katı hal piller



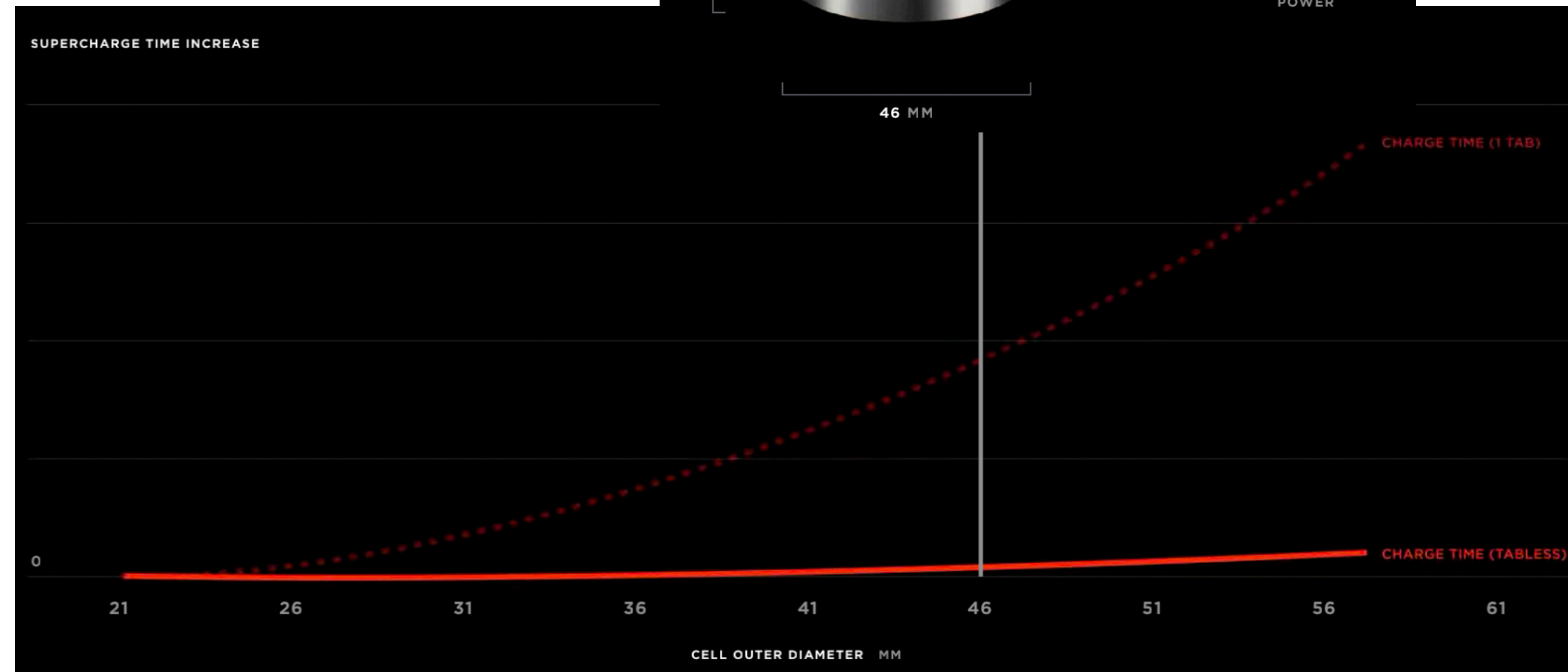
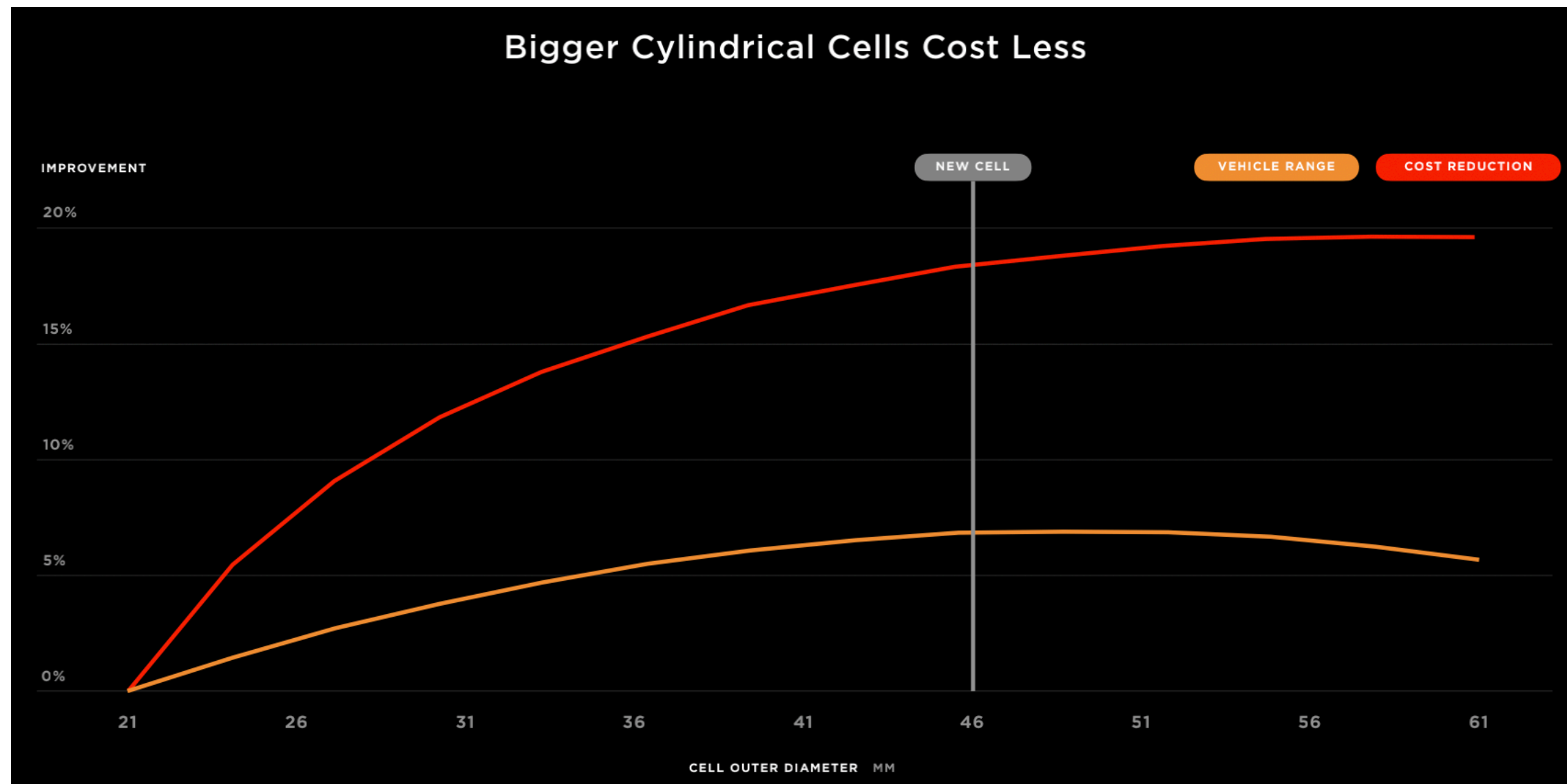
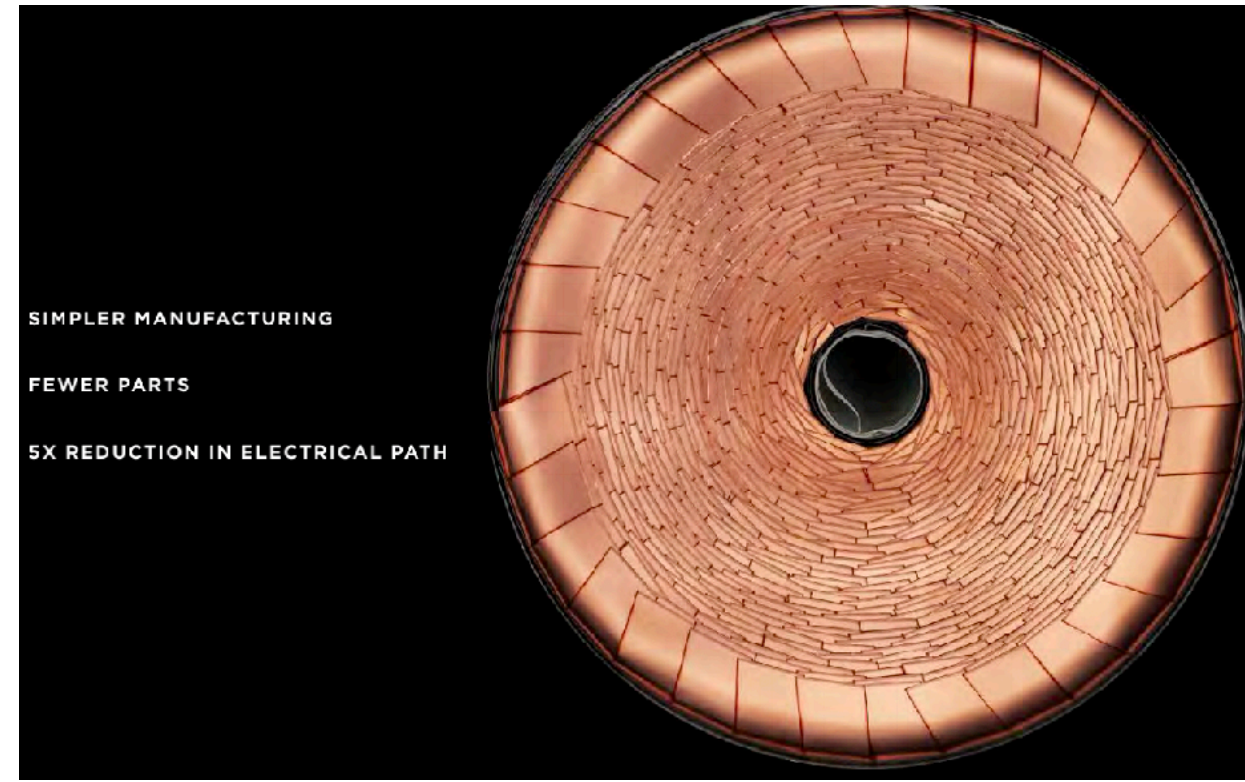
Tesla Pil



Tesla Pil

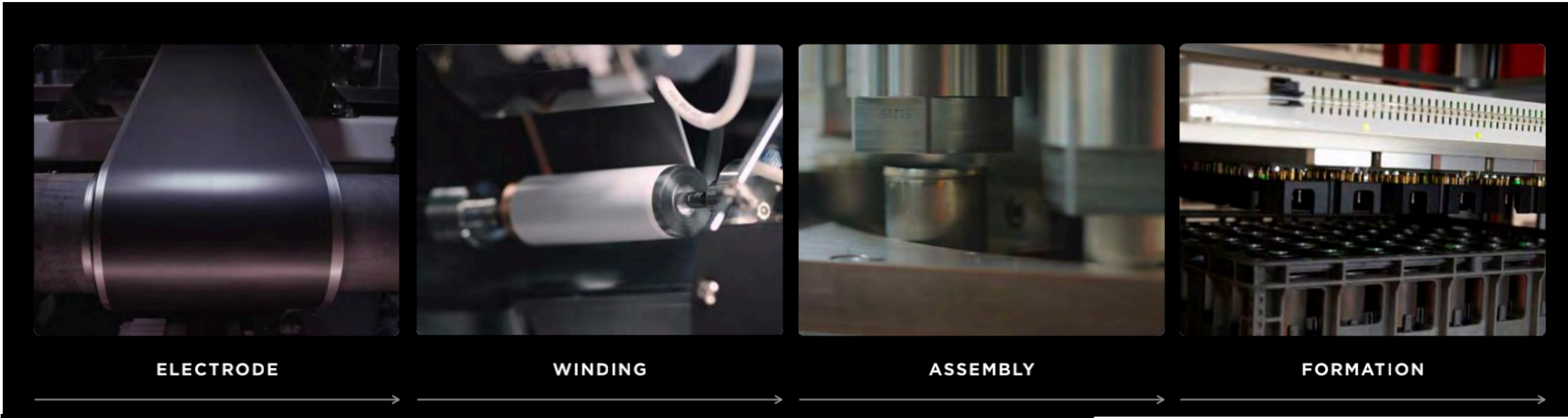


Tesla Pil



<https://www.tesla.com/2020shareholdermeeting?redirect=no>

Tesla Pil - Üretim



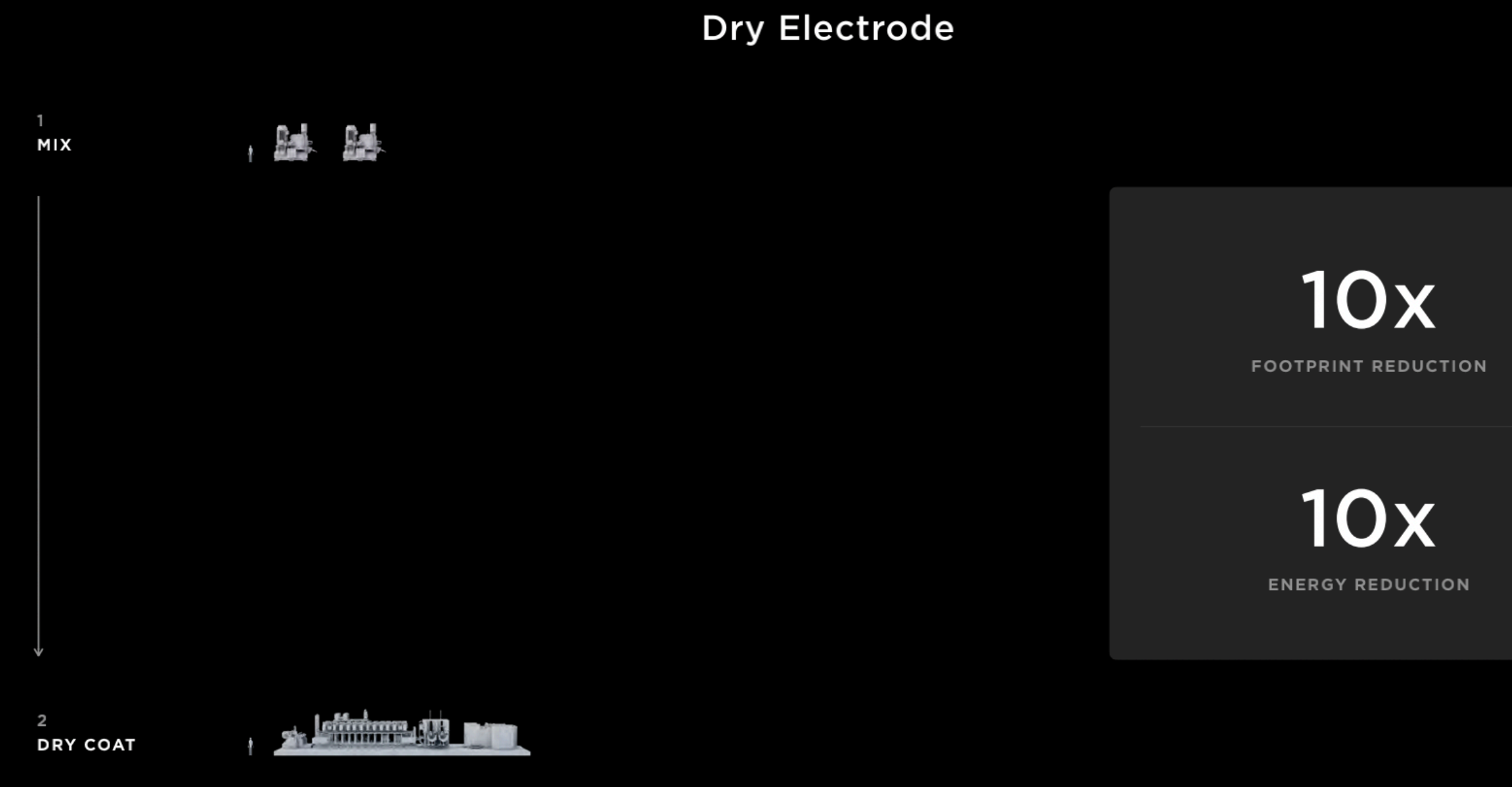
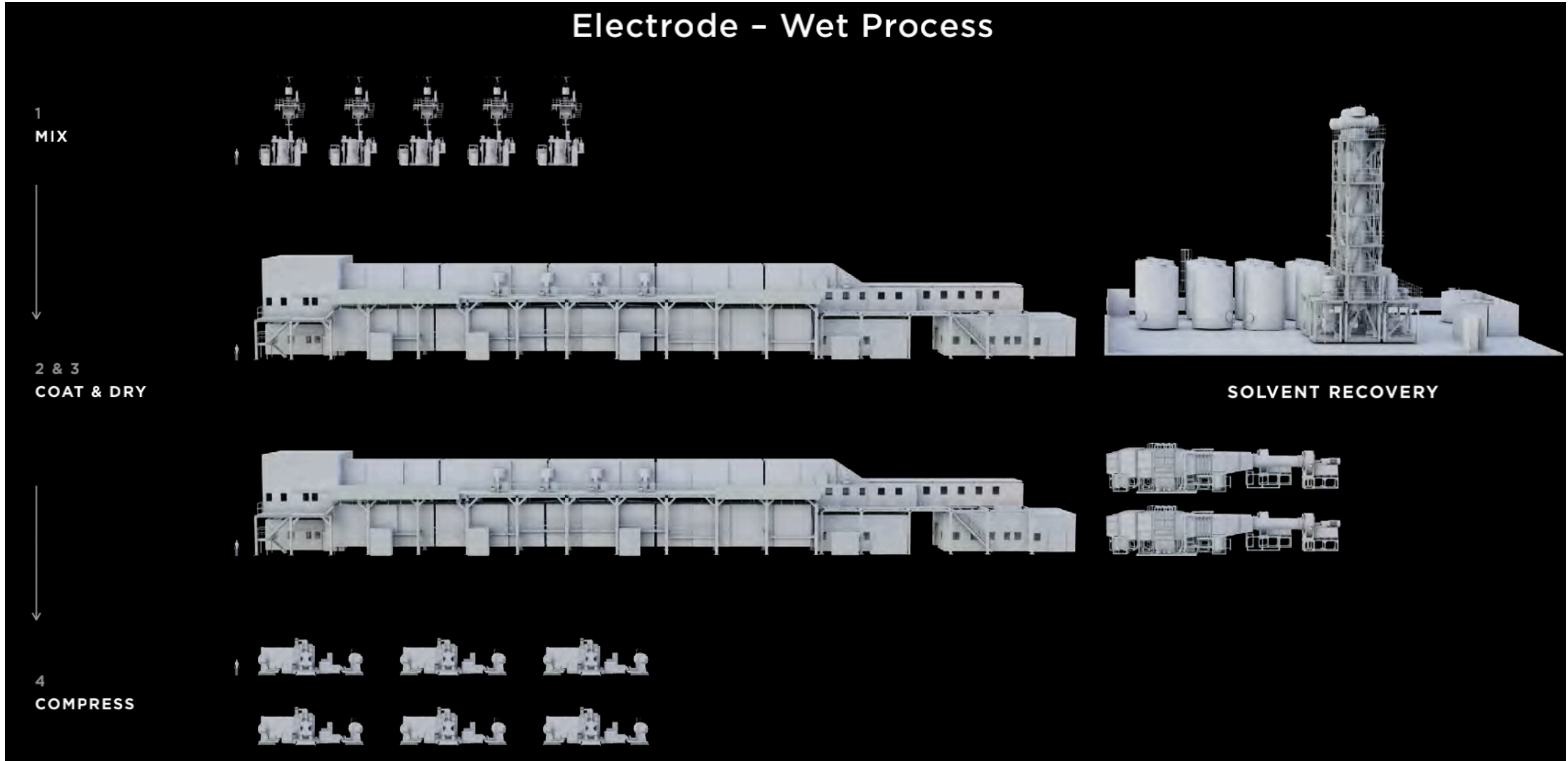
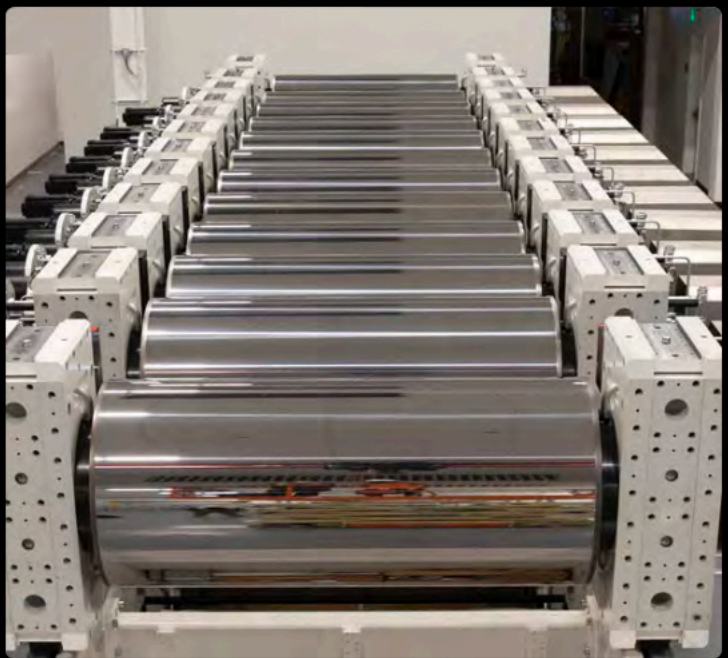
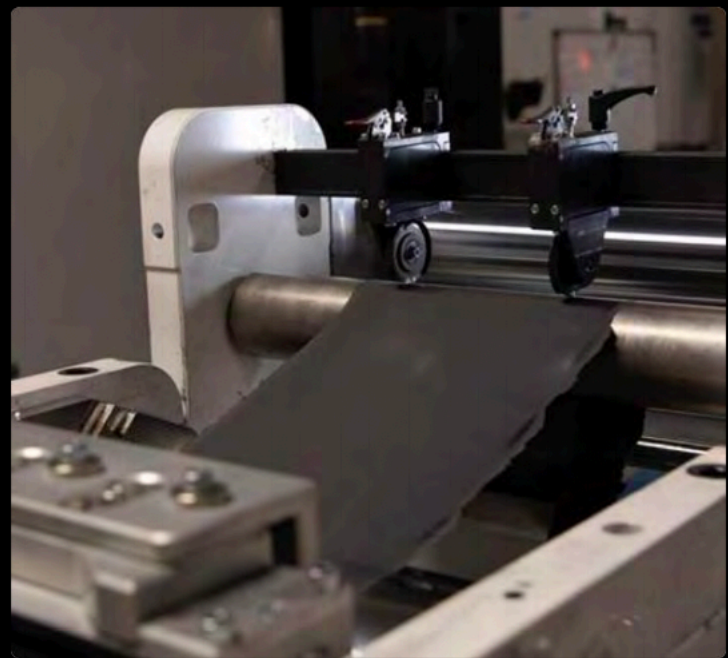
Powder Into Film



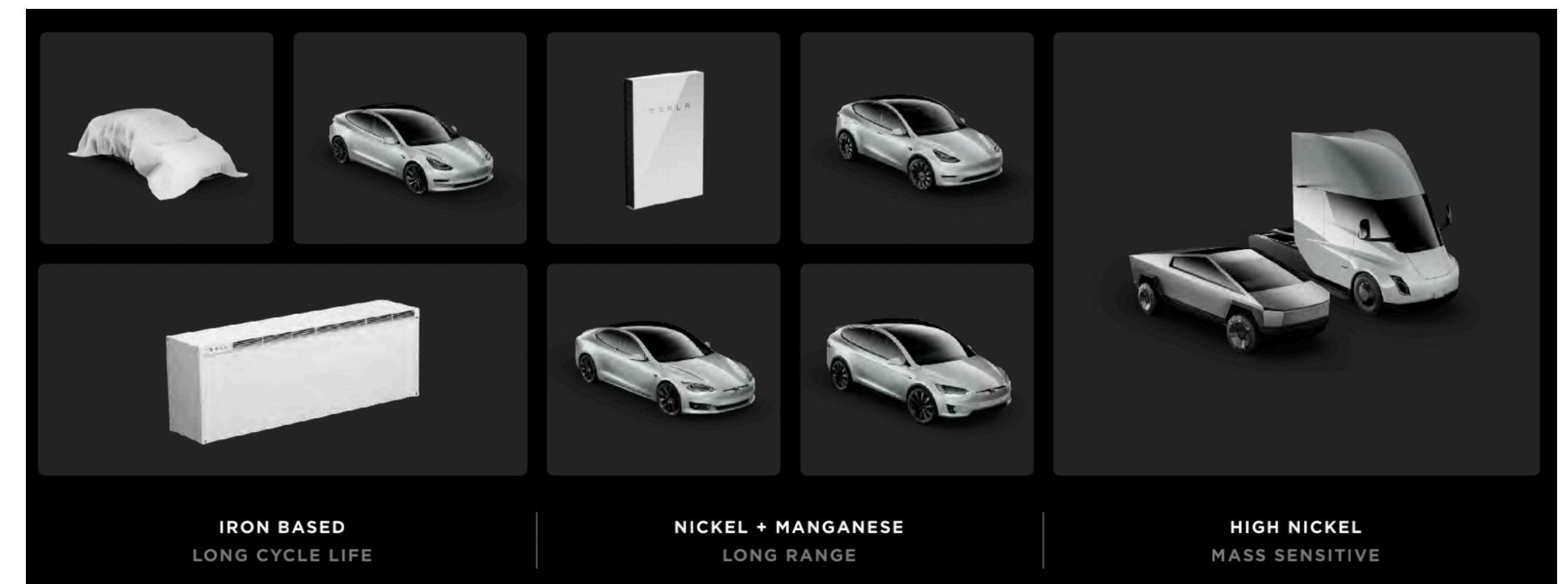
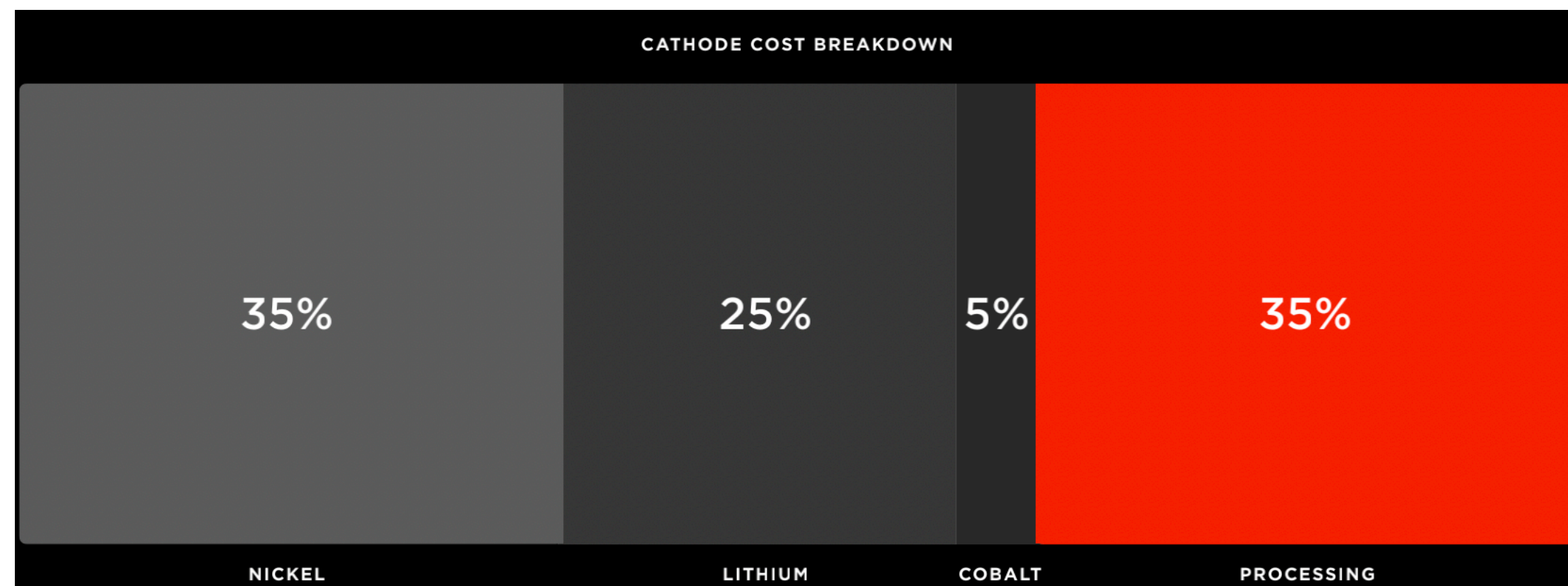
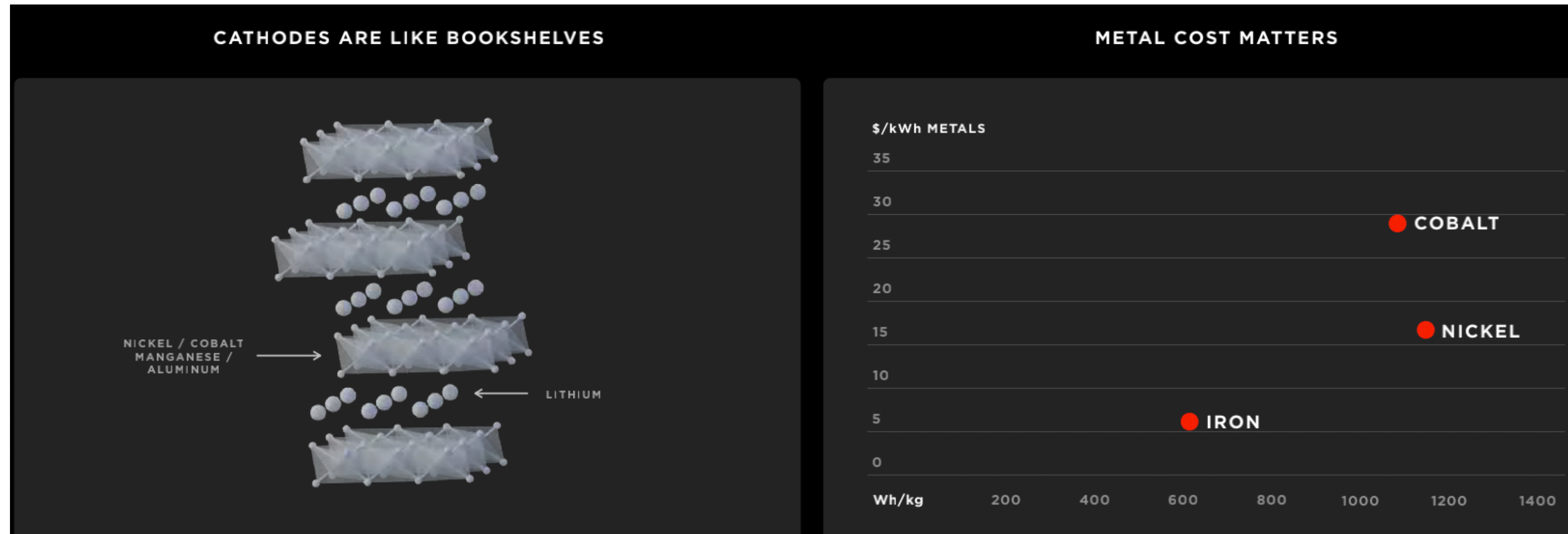
BENCH

LAB

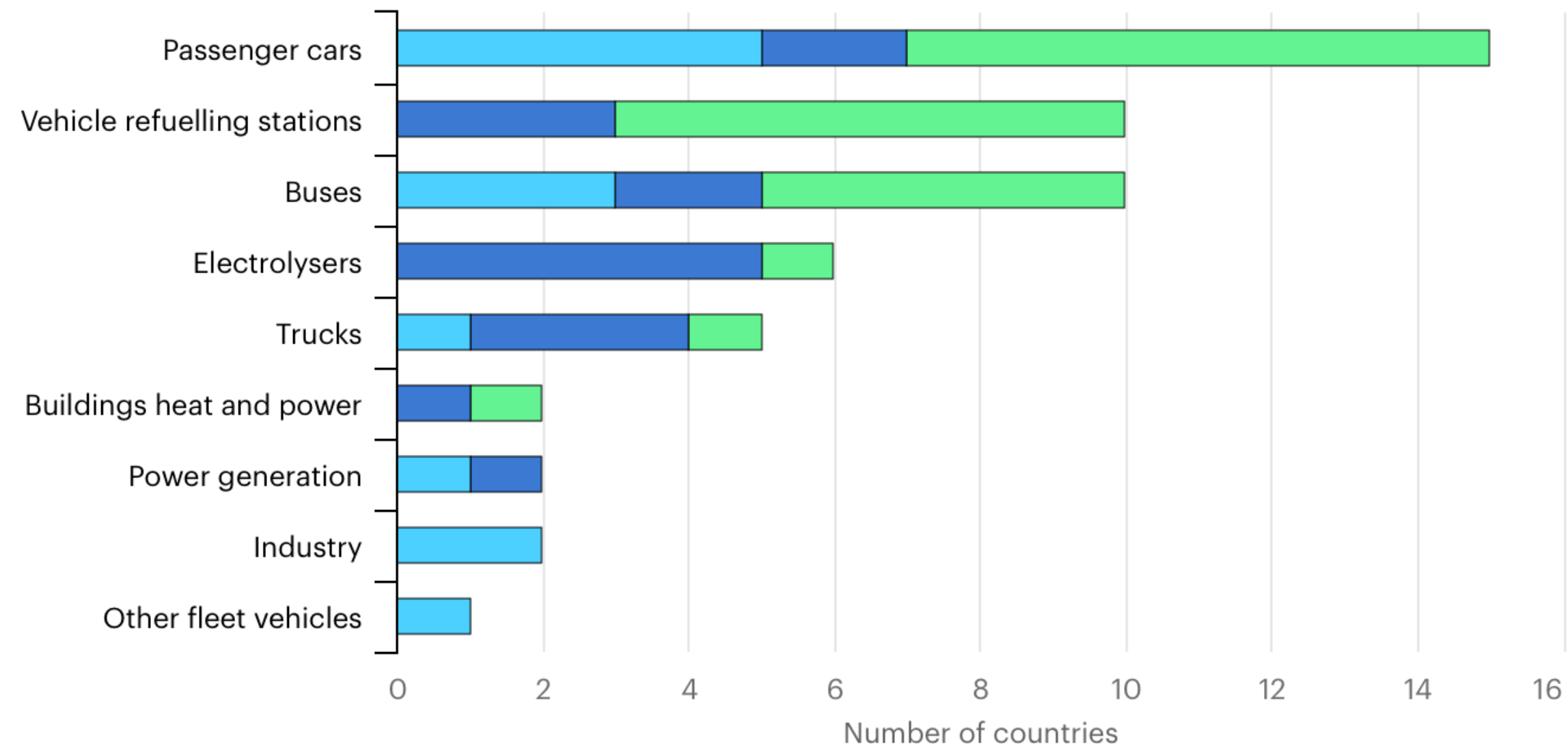
PILOT



Tesla Pil - Katot



Hidrojen destek alanları

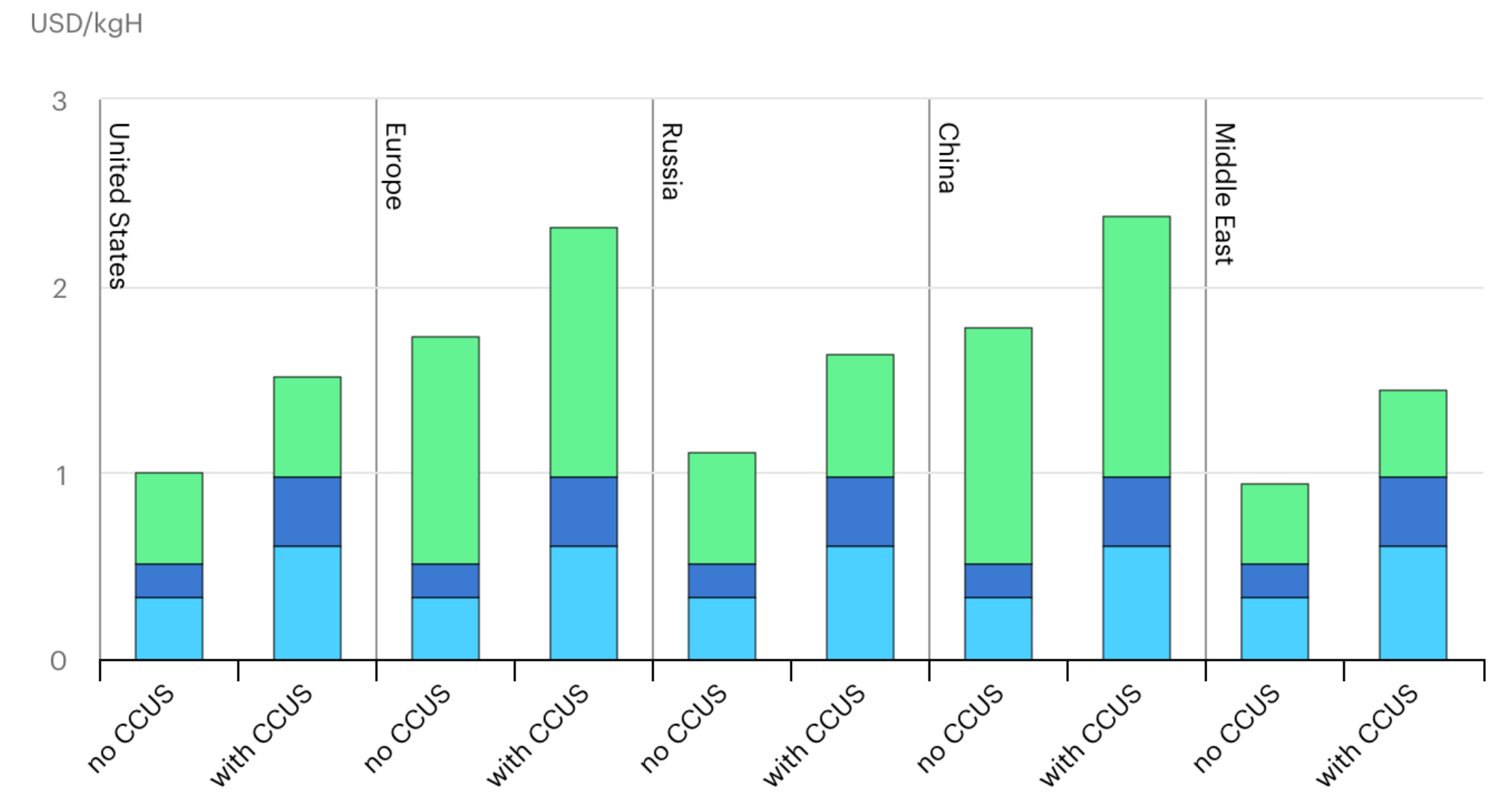


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● Incentives without targets ● Targets without incentives ● Combined incentives with targets

Hydrogen production costs using natural gas in selected regions, 2018

Open ↗

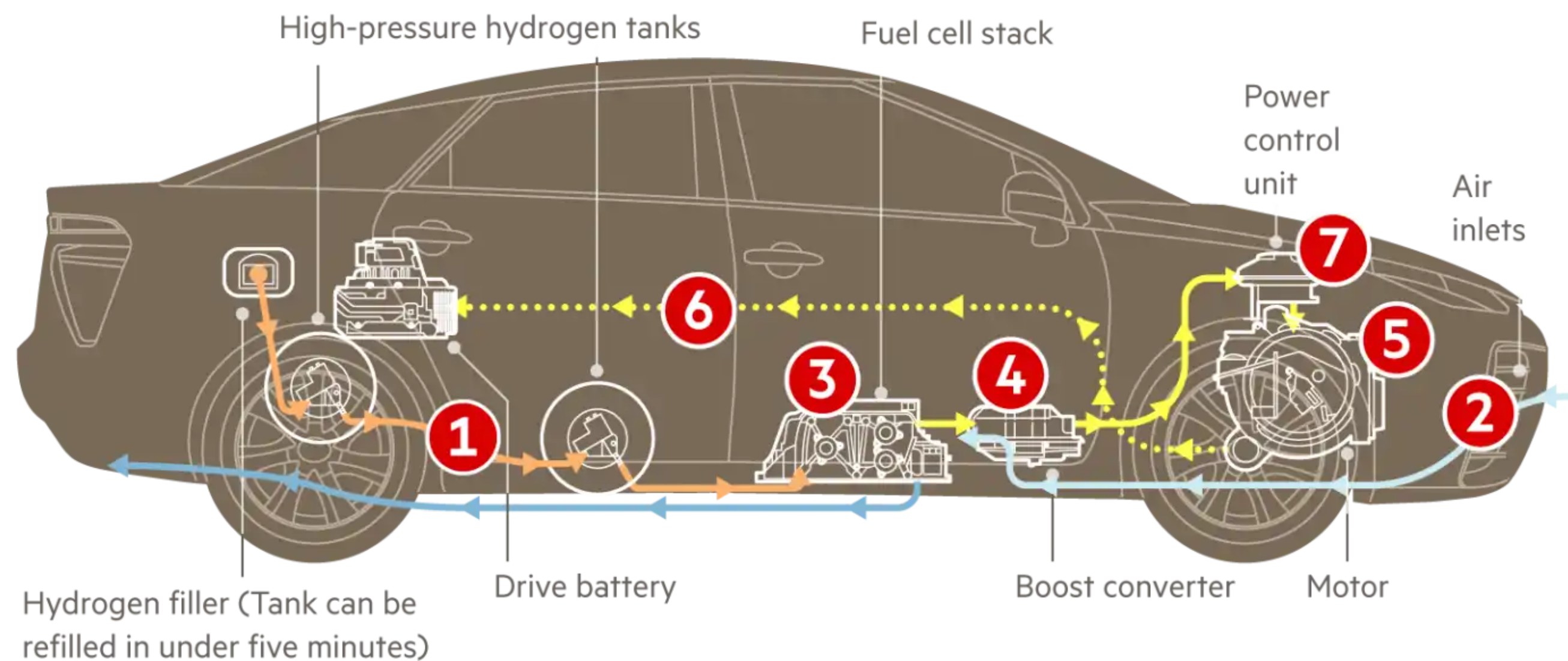


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● CAPEX ● OPEX ● Natural gas

Hidrojen Yakıt Hücresi

How the Mirai works: the drive train



- 1 The stack of 370 fuel cells is supplied with hydrogen gas from two internal tanks ...
- 2 ... and oxygen from the inlets at the front of the car
- 3 The reaction in the cell stack generates an electrical current
- 4 The current's voltage is increased by a boost converter. This means fewer fuel cells and a smaller motor are needed, allowing a reduction in weight
- 5 The electric motor drives the car's wheels. When the car is coasting or braking the motor acts as a generator
- 6 The extra electricity generated by the motor is stored in a drive battery, which can be added to the fuel cells' output during acceleration
- 7 The power control unit oversees fuel cell power output and drive battery discharge and recharge depending on driving conditions



Graphic: Ian Bott

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<https://www.ft.com/content/a1325d48-6c76-4b6f-81e8-2be504c21791>

Elektrolizör türleri

	Alkaline	PEM	AEM	Solid Oxide
Operating temperature	70-90 °C	50-80 °C	40-60 °C	700-850 °C
Operating pressure	1-30 bar	< 70 bar	< 35 bar	1 bar
Electrolyte	Potassium hydroxide (KOH) 5-7 molL ⁻¹	PFSA membranes	DVB polymer support with KOH or NaHCO ₃ 1molL ⁻¹	Yttria-stabilized Zirconia (YSZ)
Separator	ZrO ₂ stabilized with PPS mesh	Solid electrolyte (above)	Solid electrolyte (above)	Solid electrolyte (above)
Electrode / catalyst (oxygen side)	Nickel coated perforated stainless steel	Iridium oxide	High surface area Nickel or NiFeCo alloys	Perovskite-type (e.g. LSCF, LSM)
Electrode / catalyst (hydrogen side)	Nickel coated perforated stainless steel	Platinum nanoparticles on carbon black	High surface area nickel	Ni/YSZ
Porous transport layer anode	Nickel mesh (not always present)	Platinum coated sintered porous titanium	Nickel foam	Coarse Nickel-mesh or foam
Porous transport layer cathode	Nickel mesh	Sintered porous titanium or carbon cloth	Nickel foam or carbon Cloth	None
Bipolar plate anode	Nickel-coated stainless steel	Platinum-coated titanium	Nickel-coated stainless steel	None
Bipolar plate cathode	Nickel-coated stainless steel	Gold-coated titanium	Nickel-coated Stainless steel	Cobalt-coated stainless steel
Frames and sealing	PSU, PTFE, EPDM	PTFE, PSU, ETFE	PTFE, Silicon	Ceramic glass

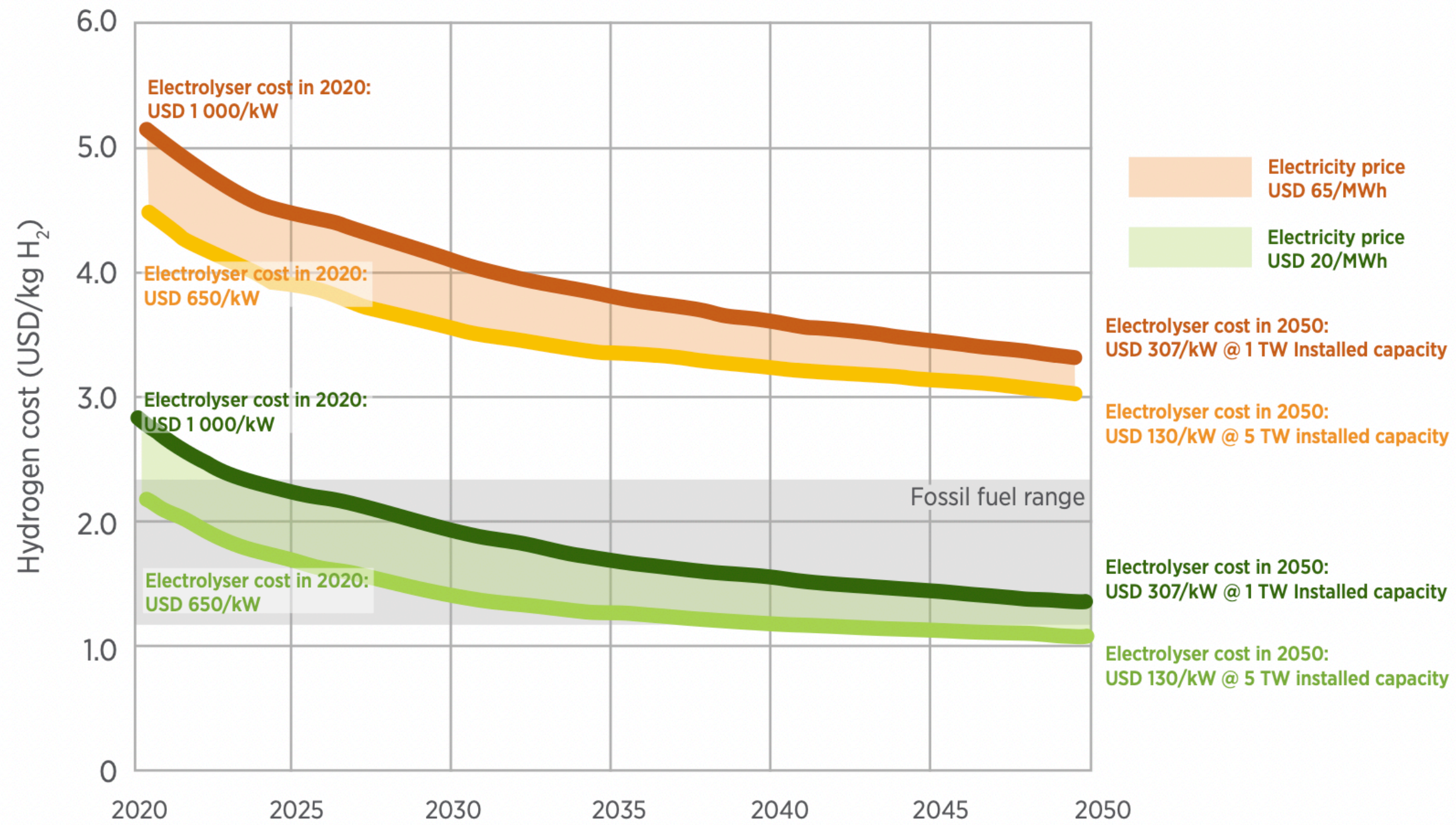
Note: Coloured cells represent conditions or components with significant variation among different companies. PFSA = Perfluoroacidsulfonic; PTFE = Polytetrafluoroethylene; ETFE = Ethylene Tetrafluorethylene; PSF = poly (bisphenol-A sulfone); PSU = Polysulfone; YSZ = yttrastabilized zirconia; DVB = divinylbenzene; PPS = Polyphenylene sulphide; LSCF = La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-δ}; LSM = (La_{1-x}Sr_x)_{1-y}MnO₃; § = Crofer22APU with co-containing protective coating.

	2020				2050			
	Alkaline	PEM	AEM	SOEC	Alkaline	PEM	AEM	SOEC
Cell pressure [bara]	< 30	< 70	< 35	< 10	> 70	> 70	> 70	> 20
Efficiency (system) [kWh/KgH ₂]	50-78	50-83	57-69	45-55	< 45	< 45	< 45	< 40
Lifetime [thousand hours]	60	50-80	> 5	< 20	100	100-120	100	80
Capital costs estimate for large stacks (stack-only, > 1 MW) [USD/kW _{el}]	270	400	-	> 2 000	< 100	< 100	< 100	< 200
Capital cost range estimate for the entire system, >10 MW [USD/kW _{el}]	500-1000	700-1400	-	-	< 200	< 200	< 200	< 300

Note: PEM = Polymer Electrolyte Membrane (commercial technology); AEM = Anion Exchange Membrane (lab-scale today); SOEC = Solid Oxide Electrolysers (lab-scale today).

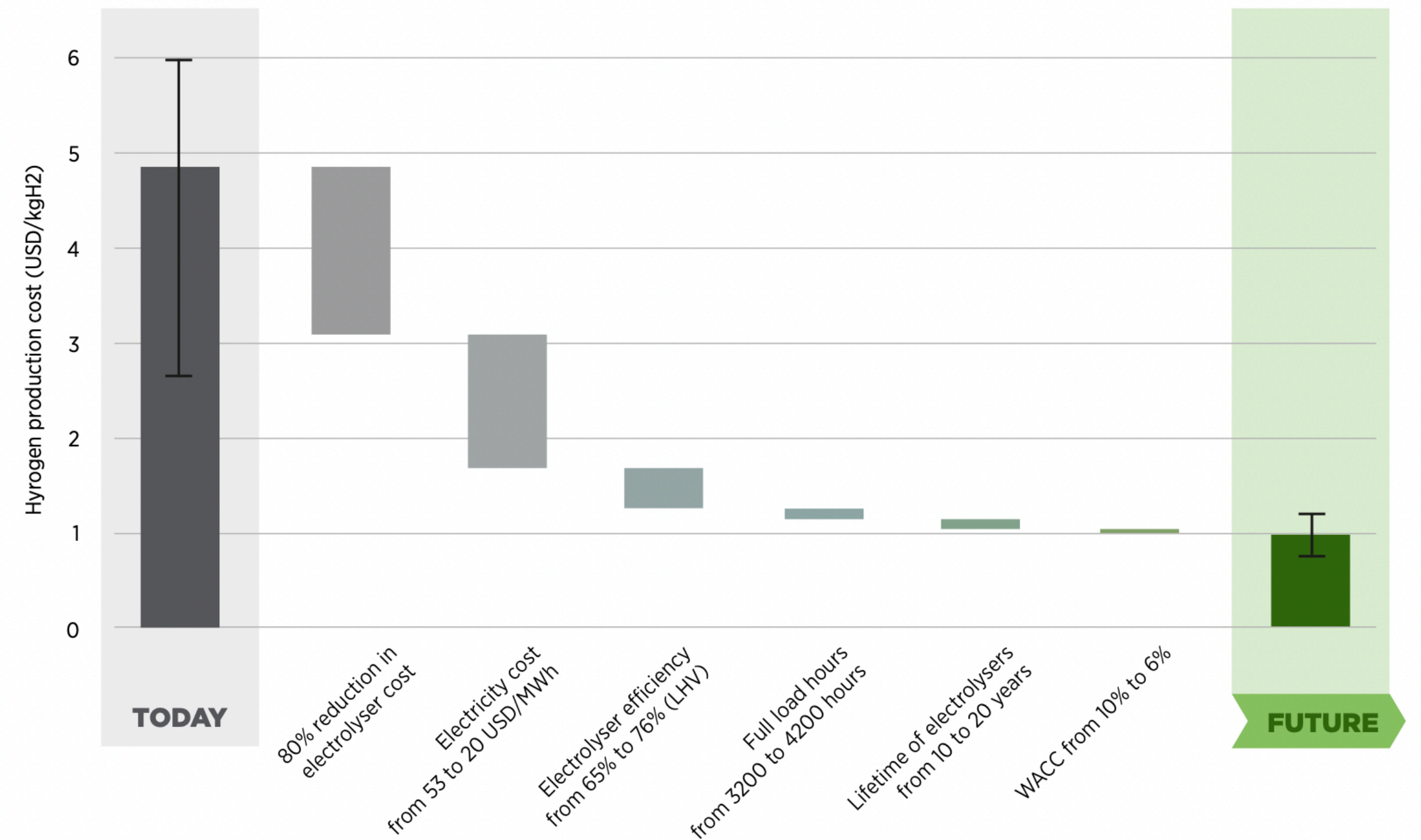
Based on IRENA analysis.

Elektrolizörlerde maliyet düşüşü



Note: Efficiency at nominal capacity is 65%, with a LHV of 51.2 kilowatt hour/kilogramme of hydrogen (kWh/kg H₂) in 2020 and 76% (at an LHV of 43.8 kWh/kg H₂) in 2050, a discount rate of 8% and a stack lifetime of 80 000 hours. The electrolyser investment cost for 2020 is USD 650-1000/kW. Electrolyser costs reach USD 130-307/kW as a result of 1-5 TW of capacity deployed by 2050.

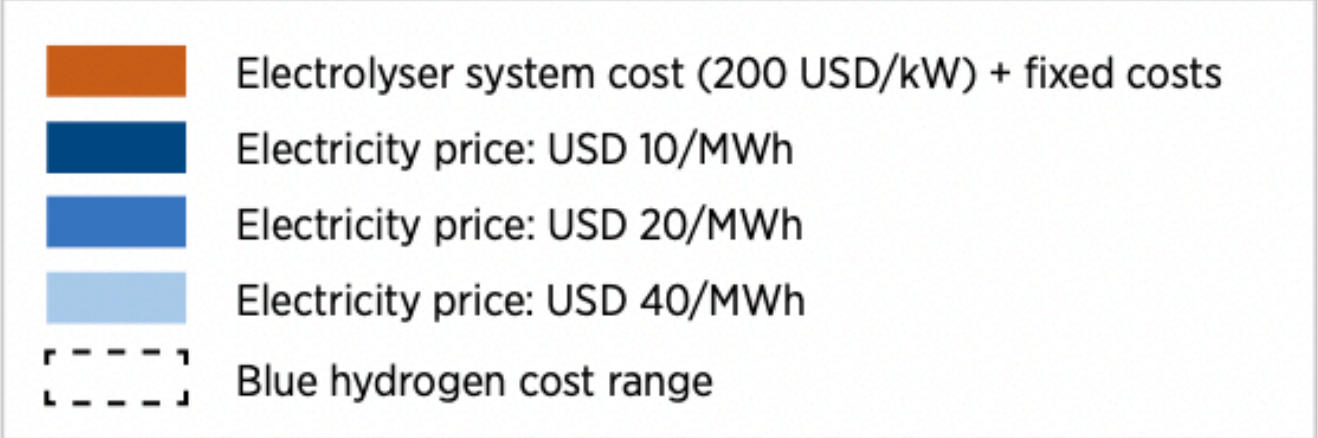
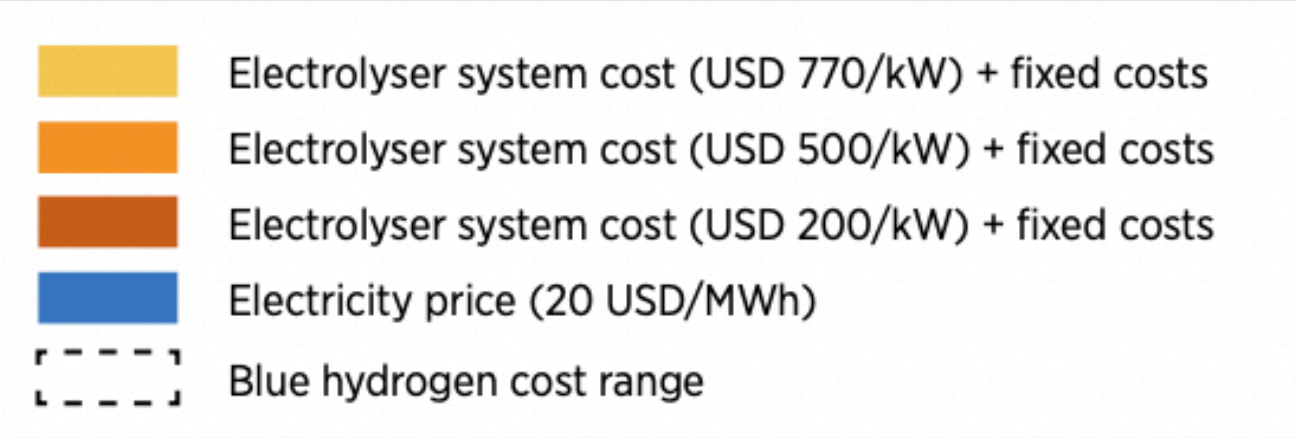
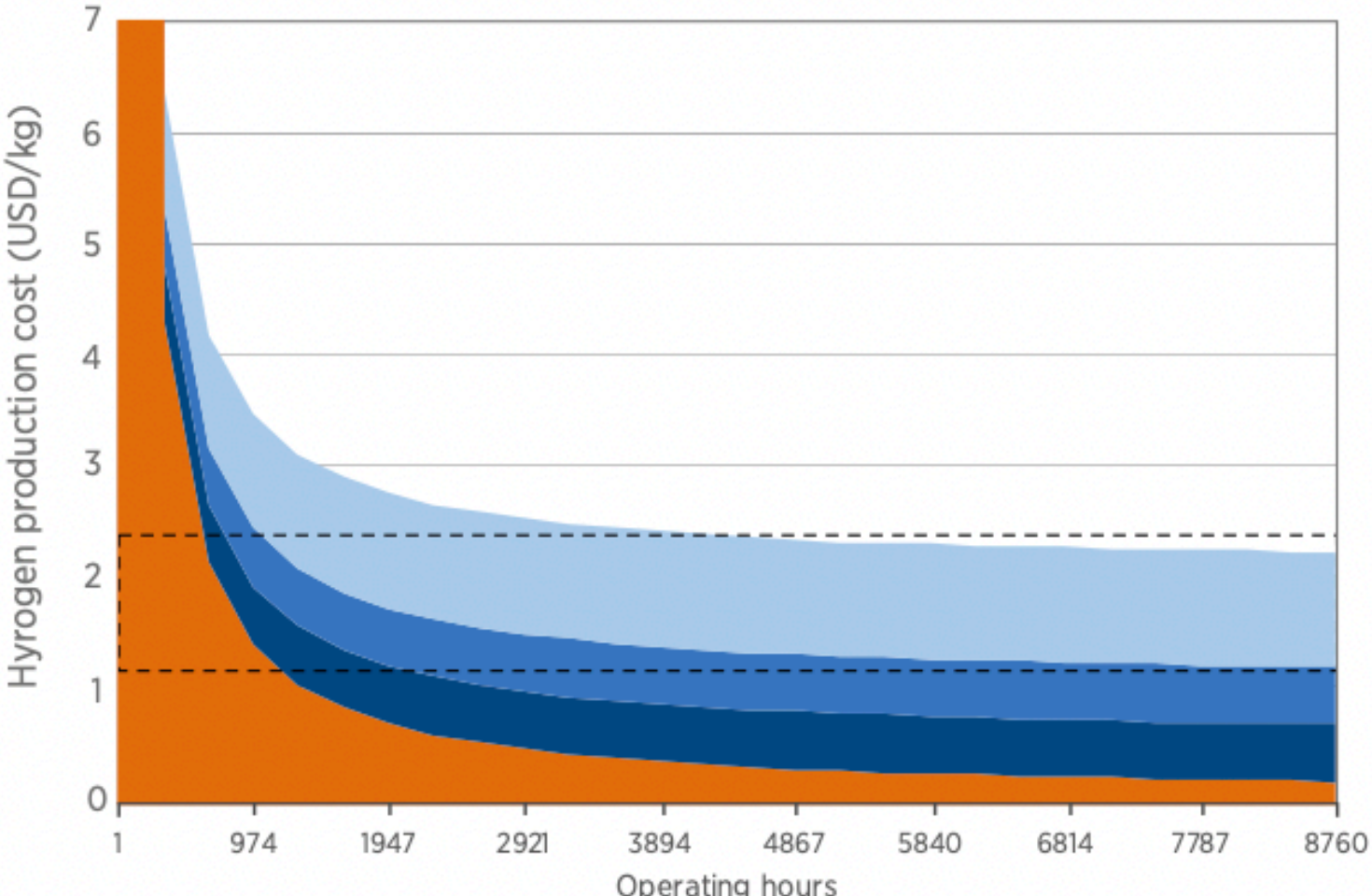
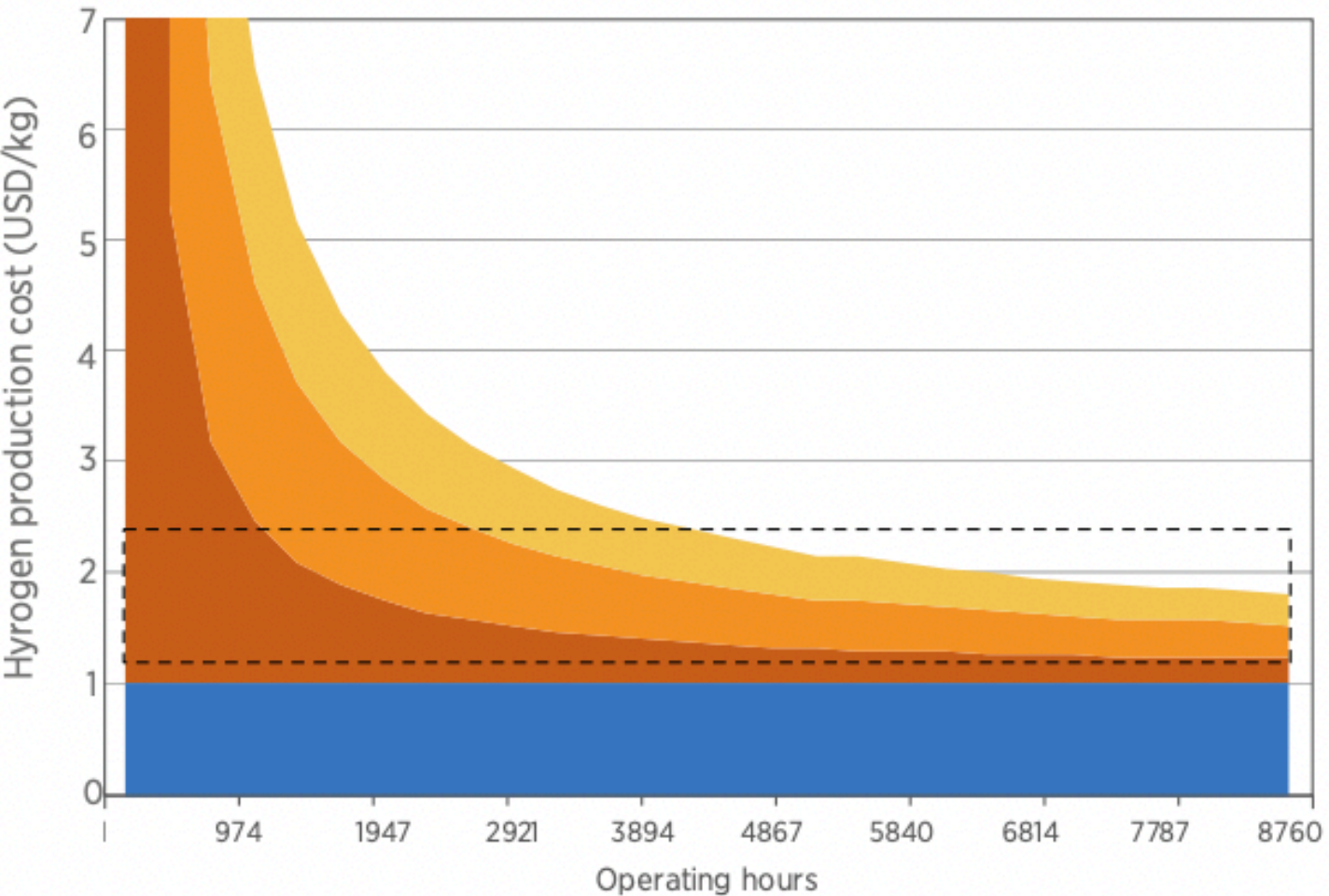
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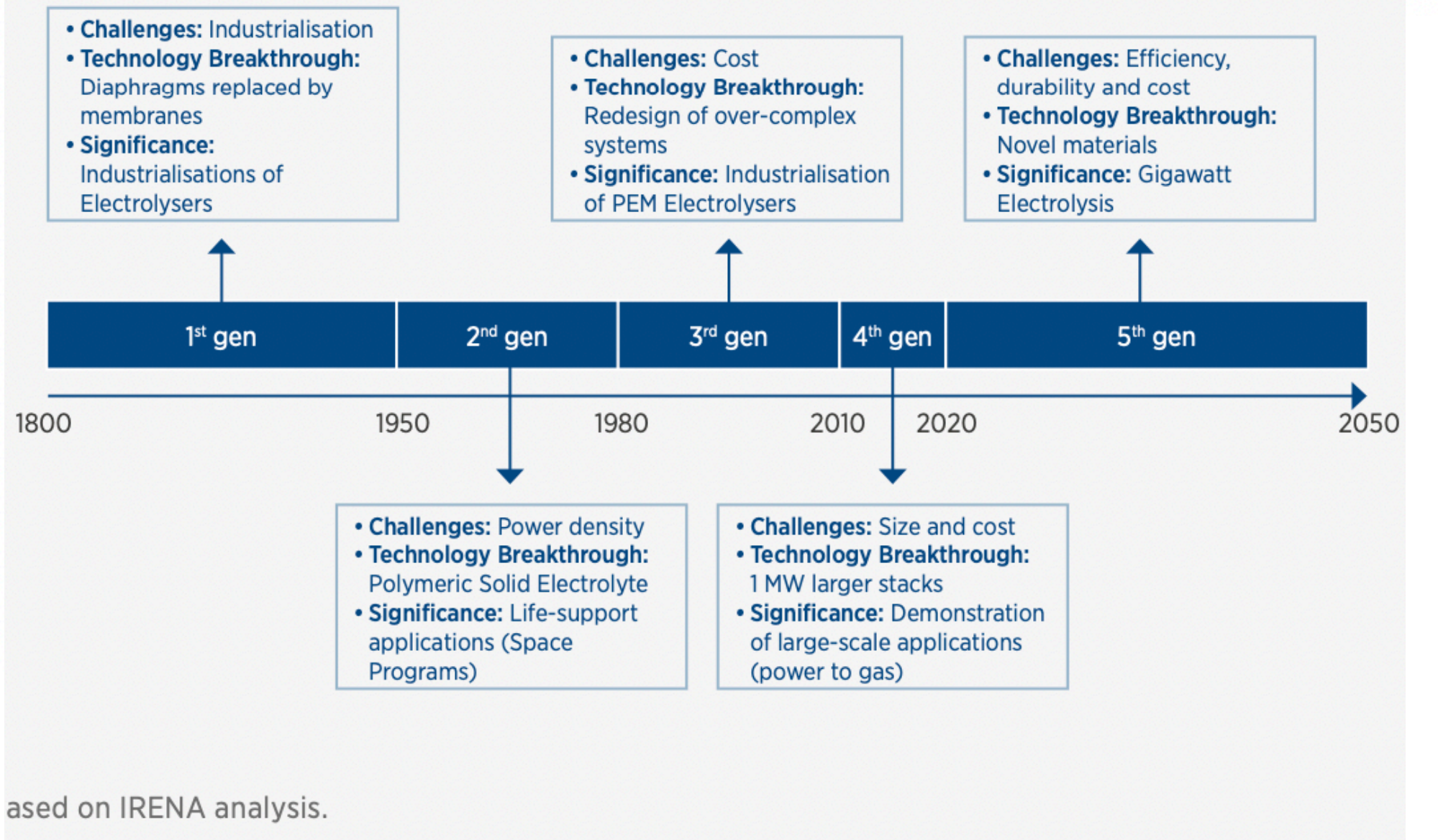
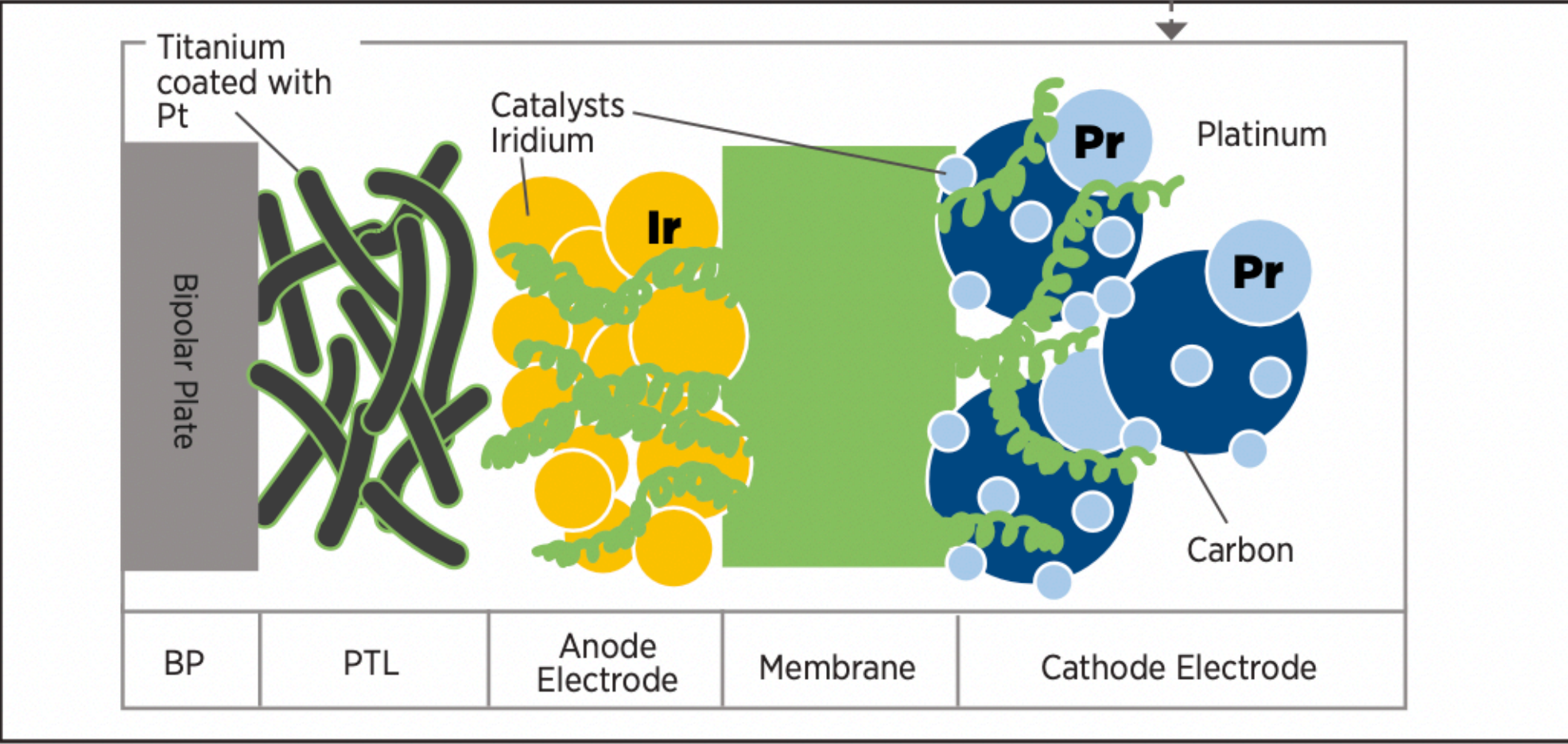
Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value - LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high risk). 'Best' signifies investment of USD 130/kW, efficiency of 76% (LHV), electricity price of USD 20/MWh, full load hours of 4200 (onshore wind), and a WACC of 6% (similar to renewable electricity today).

Based on IRENA analysis

Elektrolizörlerde maliyet düşüşü



CELL LEVEL

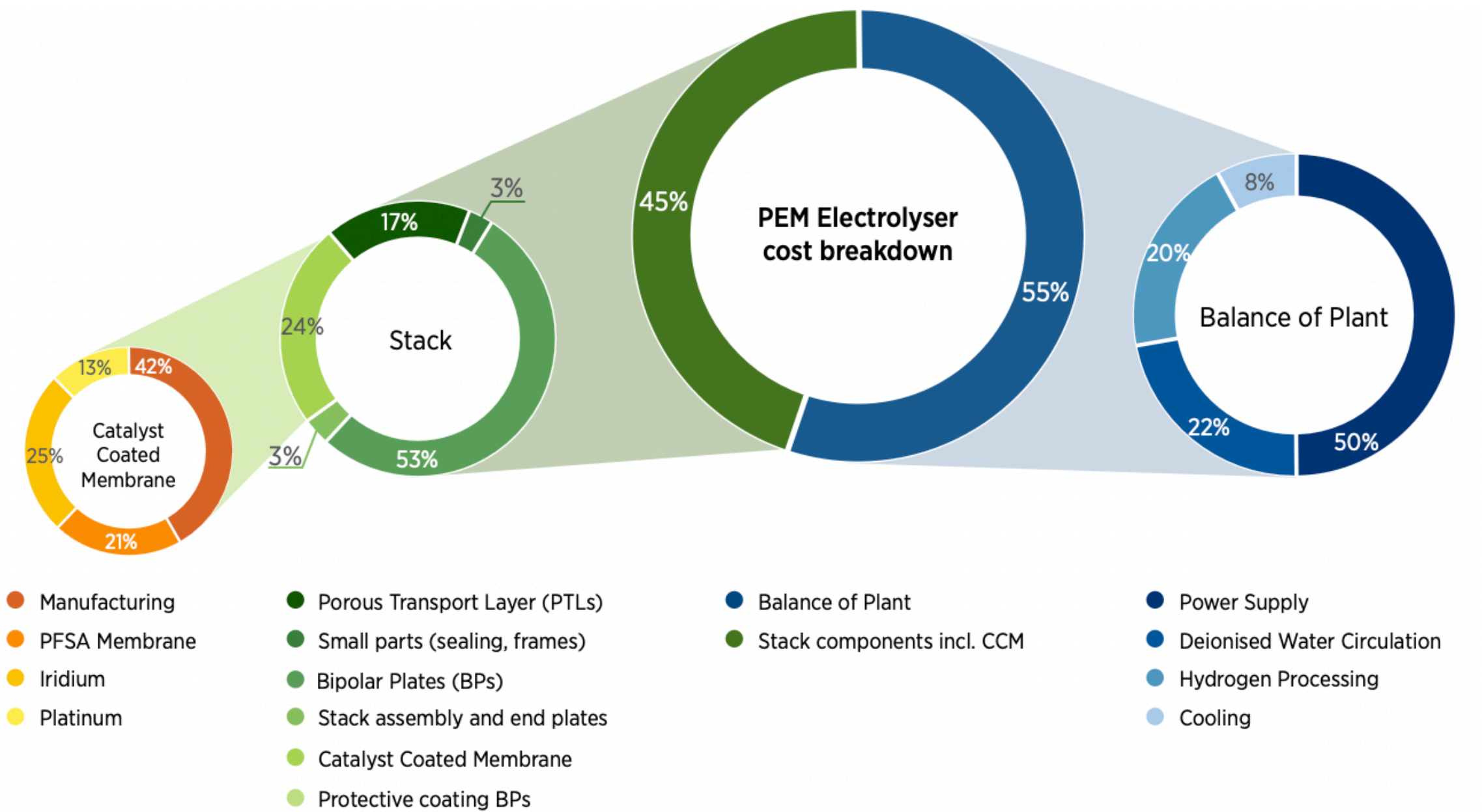


Note: Efficiency at nominal capacity is 65% (with an LHV of 51.2 kWh/kg H₂), the discount rate 8% and the stack lifetime 80 000 hours.

Based on IRENA analysis.

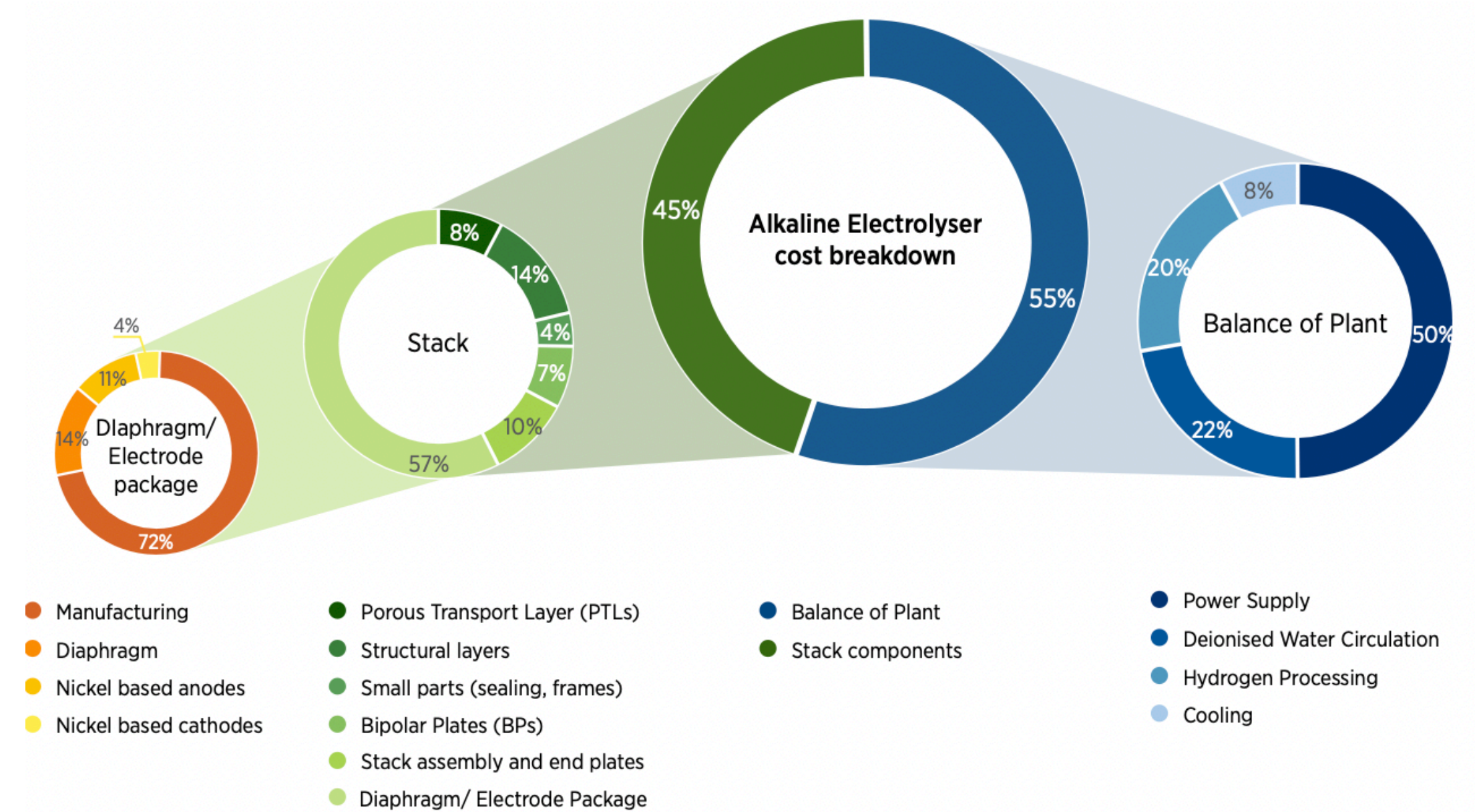
ased on IRENA analysis.

Elektrolizörlerde PEM ve Alkaline maliyet bileşenleri



Note: The specific breakdown varies by manufacturer, application and location, but values in the figure represent an average.

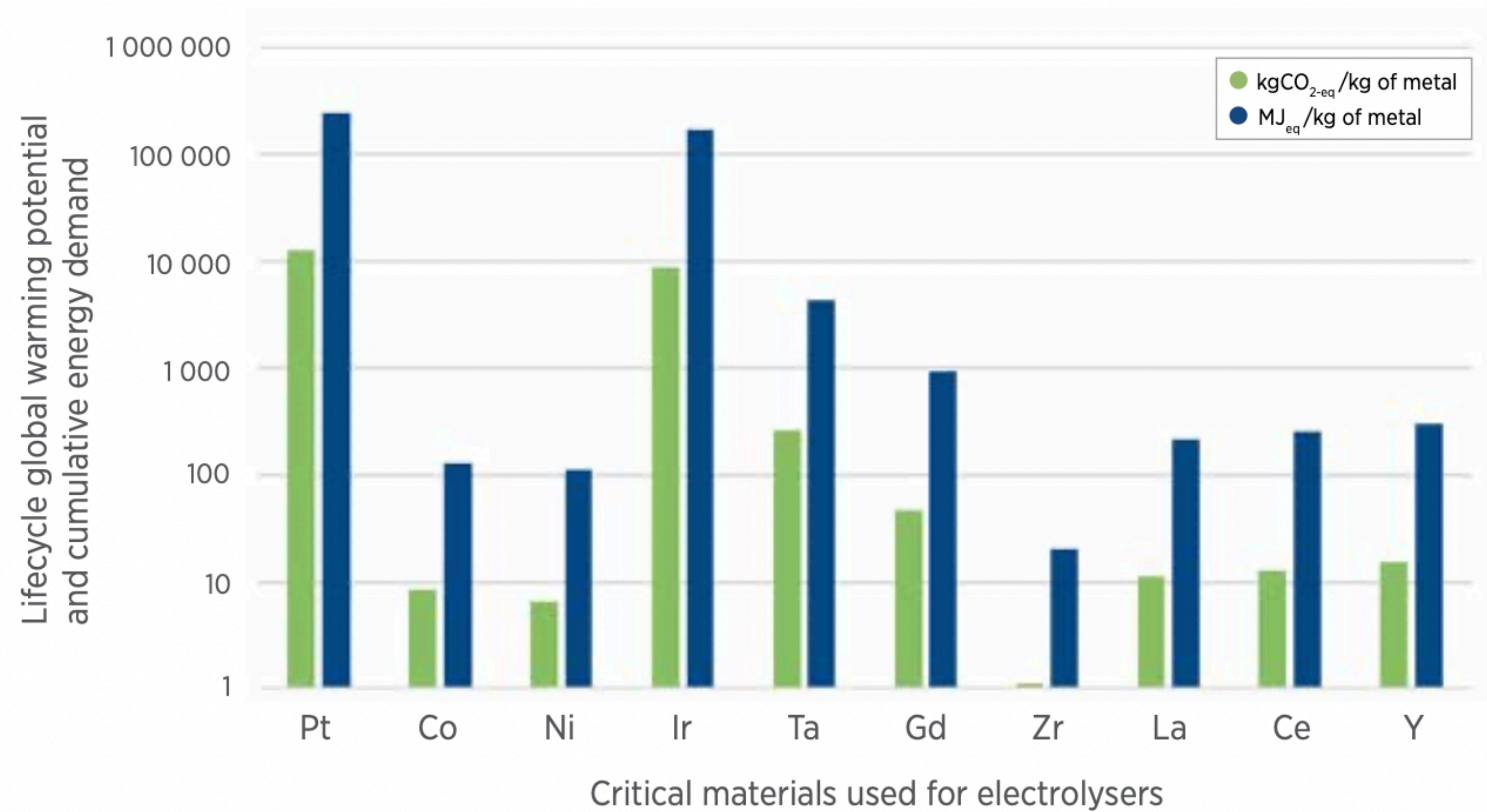
Based on IRENA analysis.



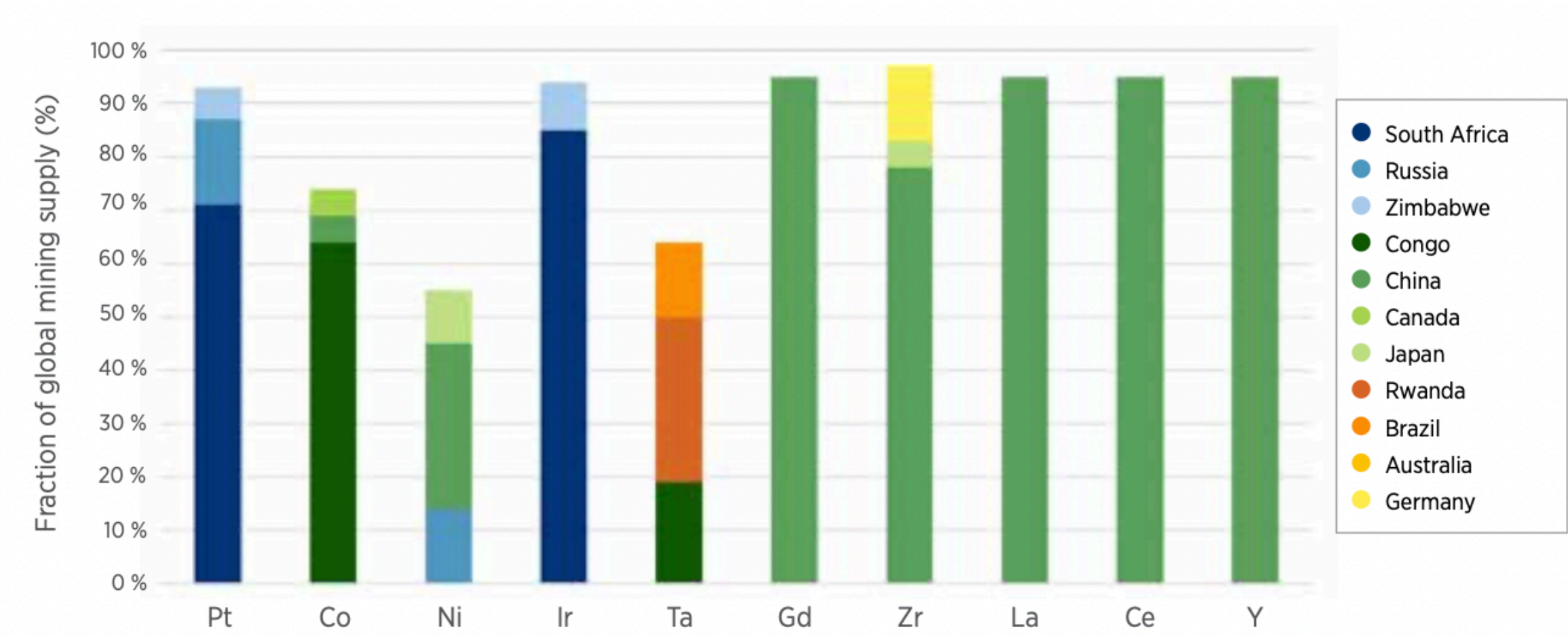
Note: The specific breakdown varies by manufacturer, application and location, but values in the figure represent an average.

Based on IRENA analysis.

Elektrolizörlerde kritik madenler

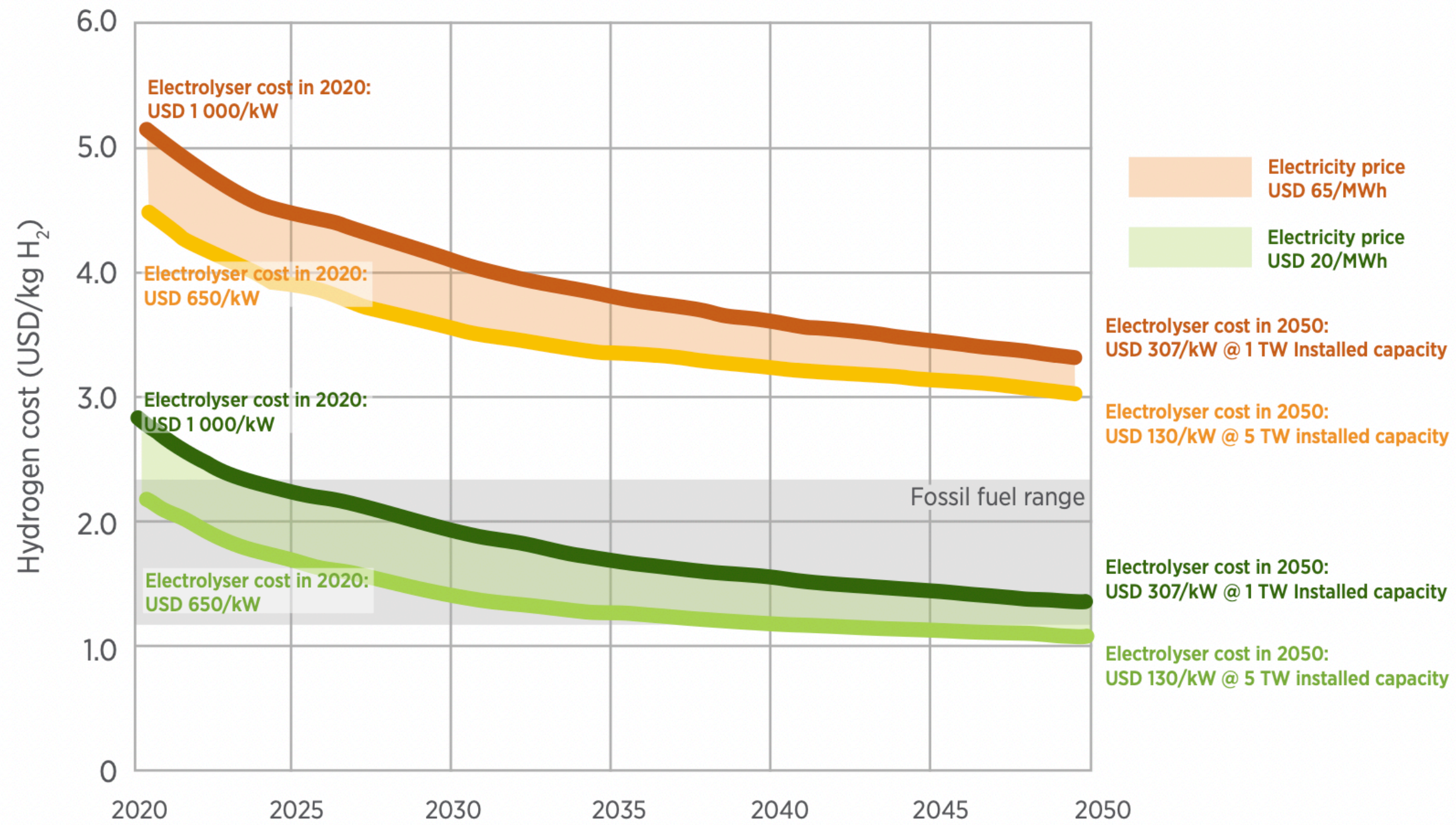


Source: Nuss and Matthew, 2014.



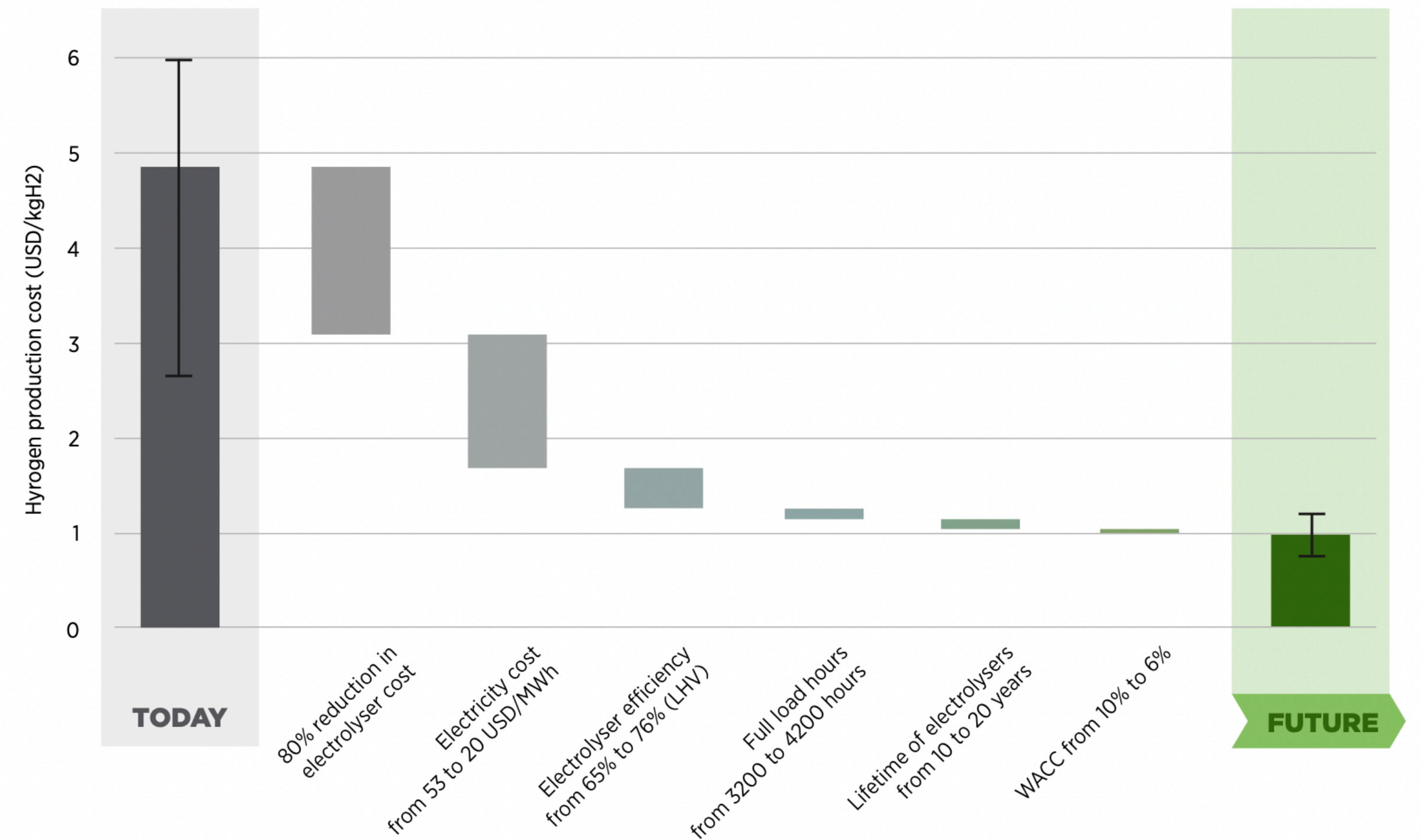
Source: European Commission, 2020.

Elektrolizörlerde maliyet düşüşü



Note: Efficiency at nominal capacity is 65%, with a LHV of 51.2 kilowatt hour/kilogramme of hydrogen (kWh/kg H₂) in 2020 and 76% (at an LHV of 43.8 kWh/kg H₂) in 2050, a discount rate of 8% and a stack lifetime of 80 000 hours. The electrolyser investment cost for 2020 is USD 650-1000/kW. Electrolyser costs reach USD 130-307/kW as a result of 1-5 TW of capacity deployed by 2050.

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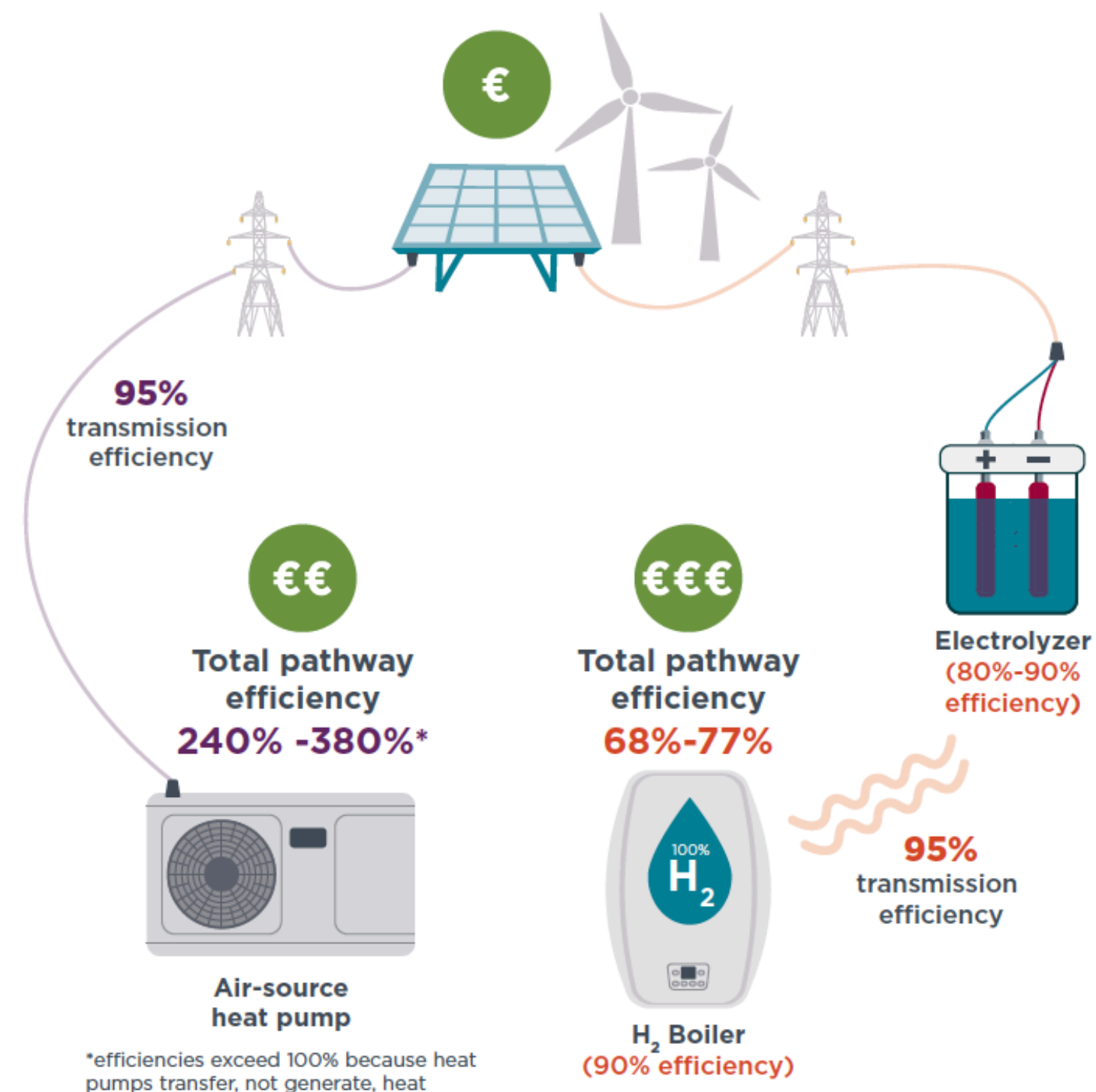


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Based on IRENA analysis

Hidrogen dođru tercijh mi?

Air-source heat pumps will be more energy efficient and cost effective than using hydrogen boilers to heat single-family homes in the EU in 2050



In 2050, it will be **55% cheaper** for a single family home in the EU to use renewable electricity in **heat pumps** vs. renewable electrolysis hydrogen in a **boiler**.

December, 2050

Single-family household
XXXXXX XXX
XXXXX EU Member State

Annual Energy Cost: Heat Pump

Heat Pump Installation (Annuitized).....	€225
Maintenance.....	€12
Cost of Renewable Electricity.....	€342 (Wind and Solar Energy)
Total	€579

December, 2050

Single-family household
XXXXXX XXX
XXXXX EU Member State

Annual Energy Cost: Hydrogen Boiler

Boiler Installation (Annuitized).....	€49
Maintenance.....	€98
Cost of Renewable Electrolysis.....	€1124
Hydrogen (from Wind and Solar Energy)	
Total	€1271

teşekkürler

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