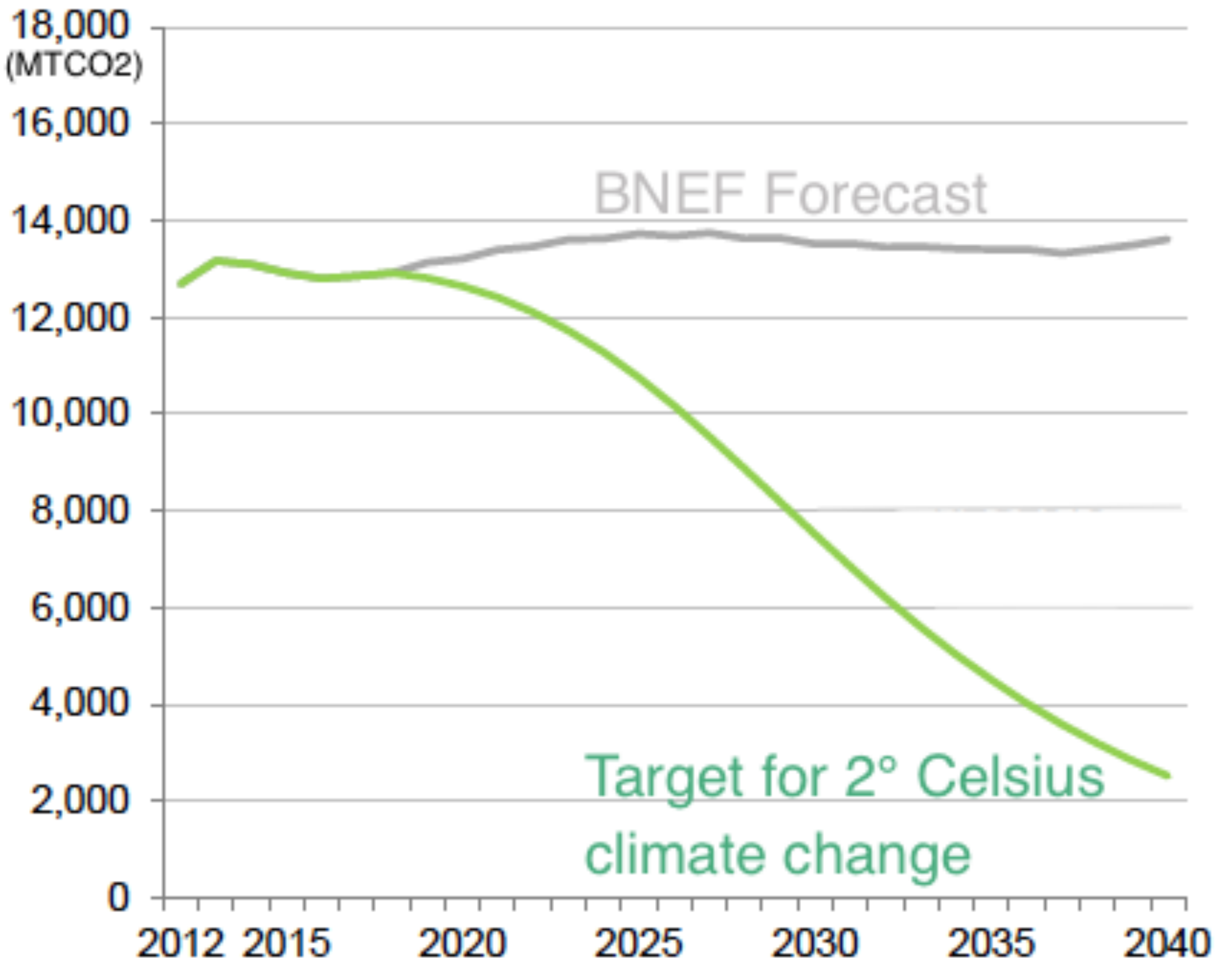
The Progress of Batteries

How innovation in energy storage will push society to new forms of organization and productivity.

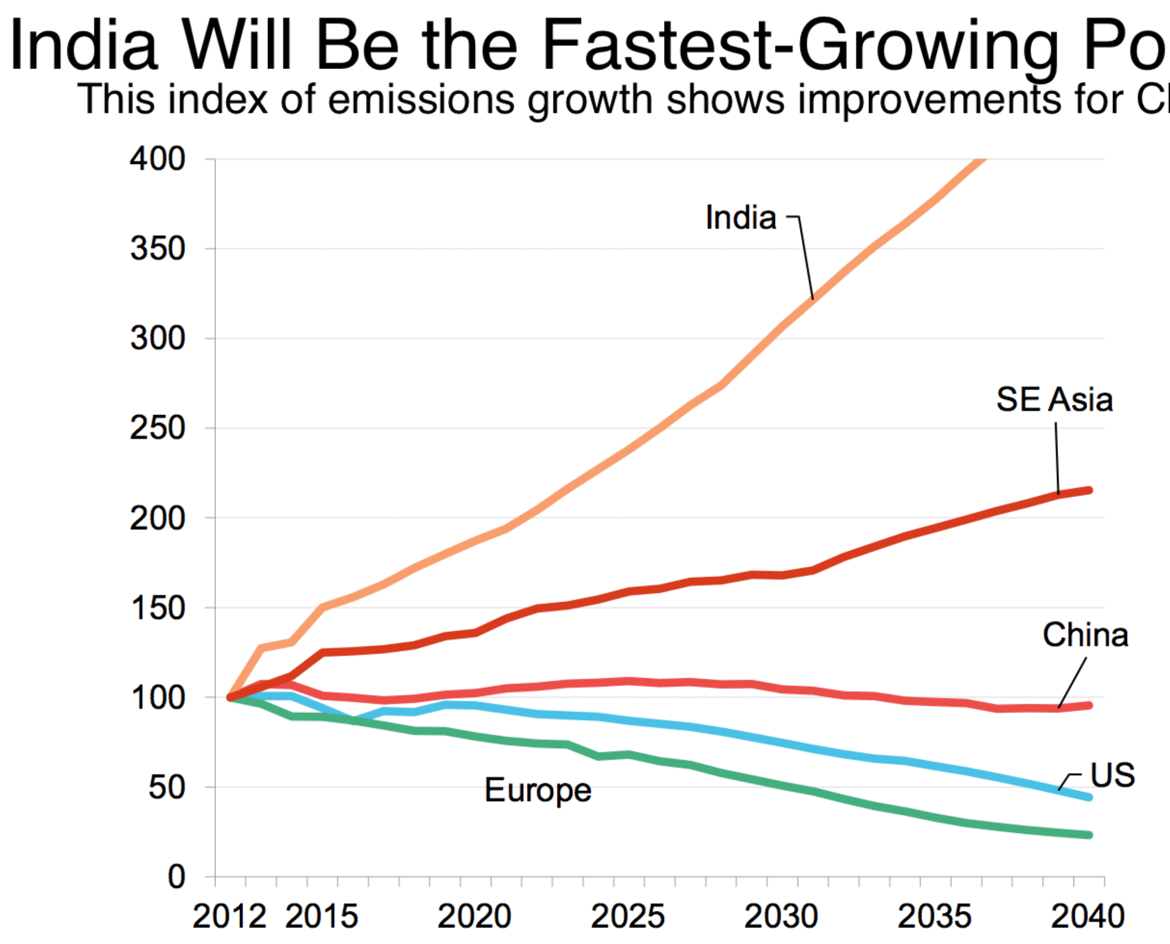
Elkington

Global warming is a huge world issue



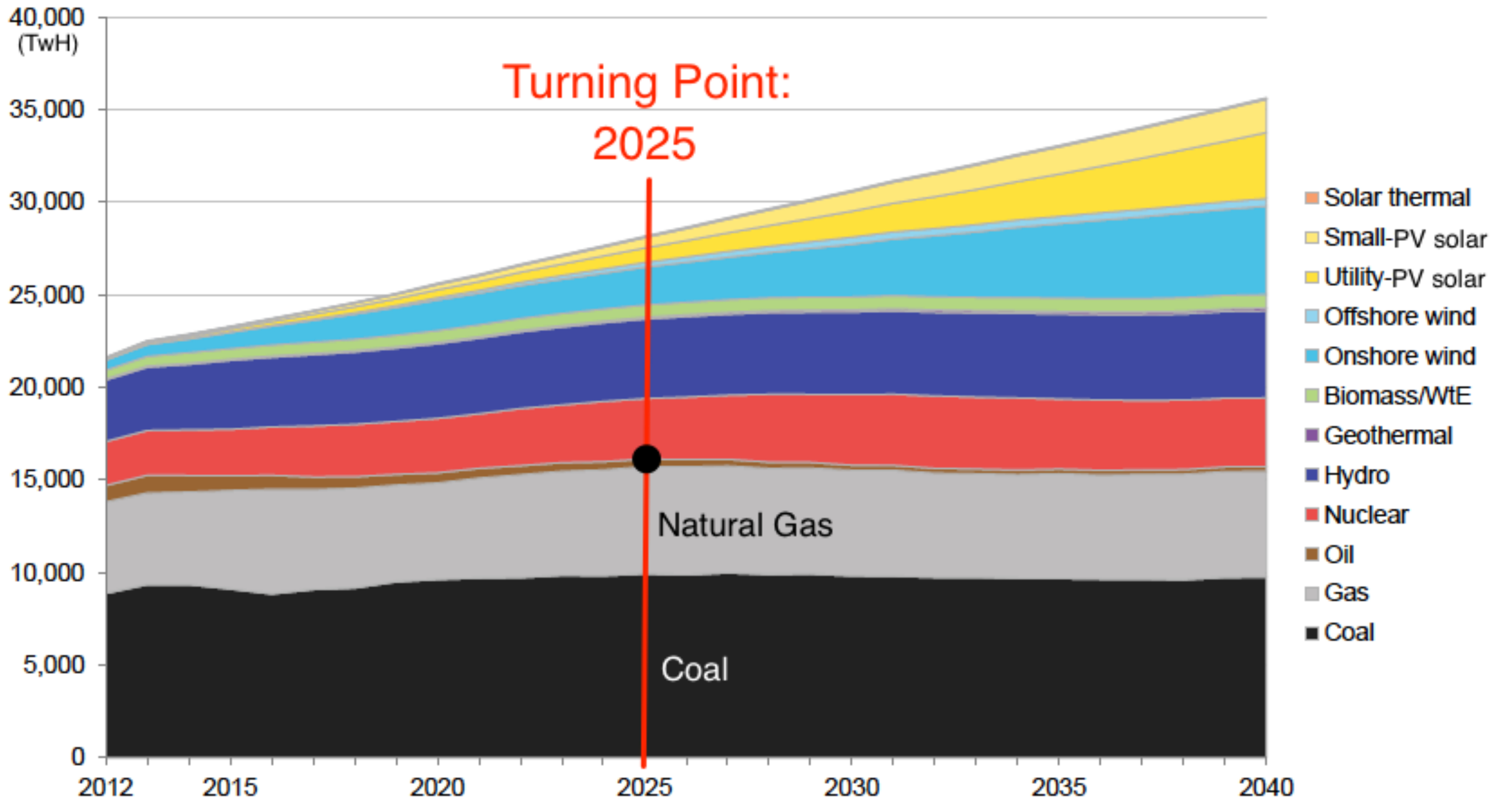
Source: BNEF

There still remains policy and technology issues to address



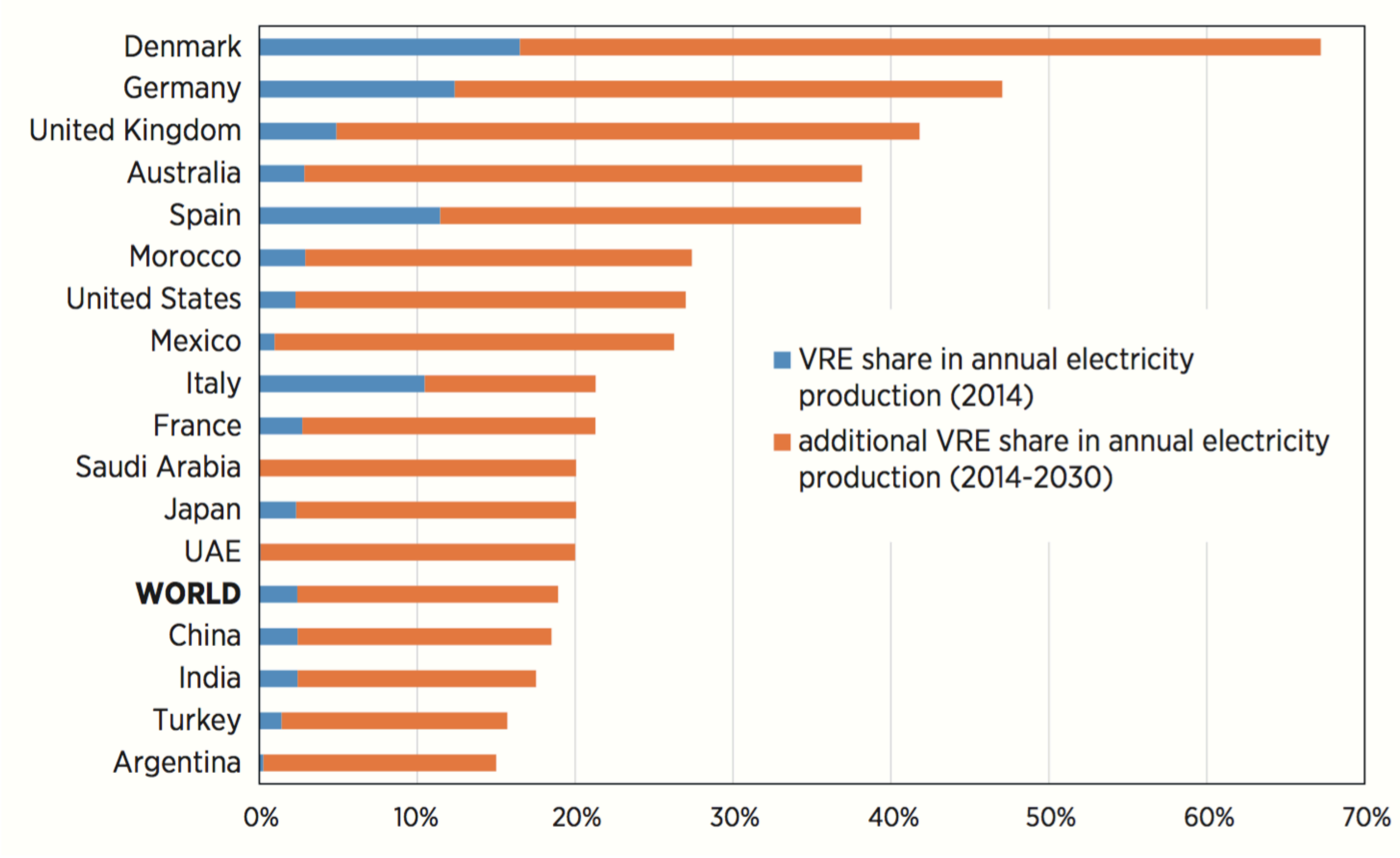
Source: BNEF

Growth in fossil fuels appears to be leveling off



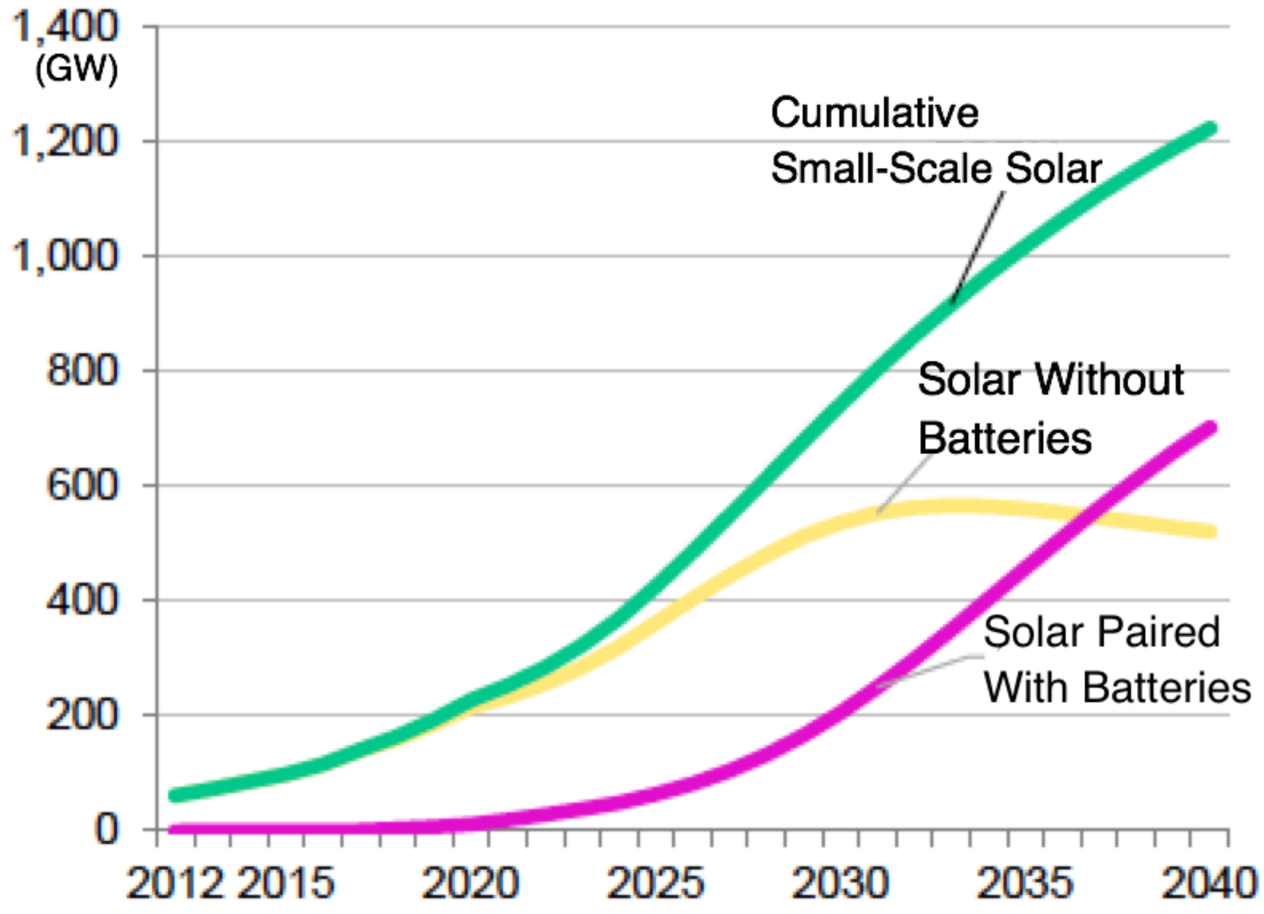
Source: BNEF

Global Variable Renewable Energy Production



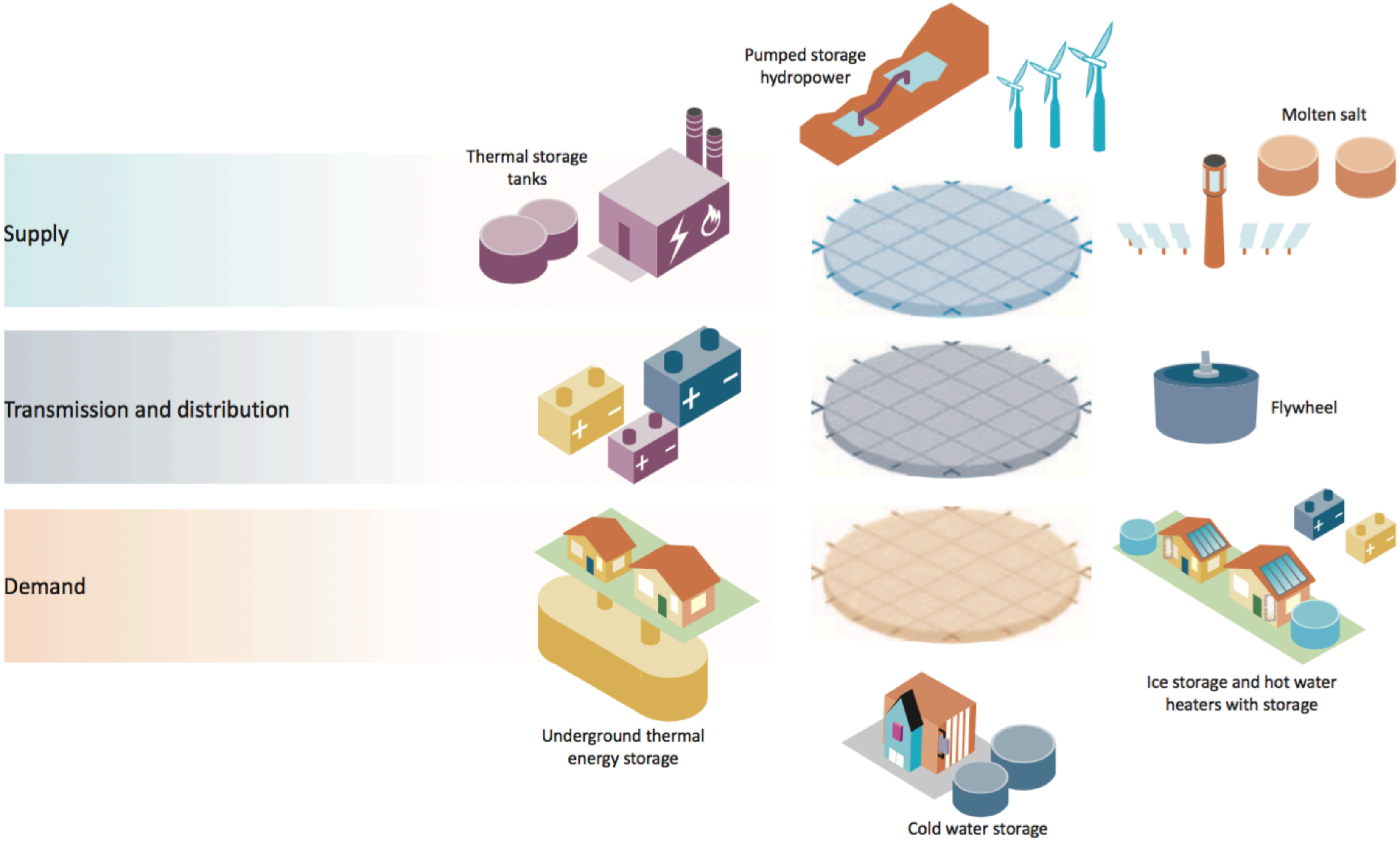
Source: EIA (Energy Information Administration)

Solar paired with batteries is becoming the standard



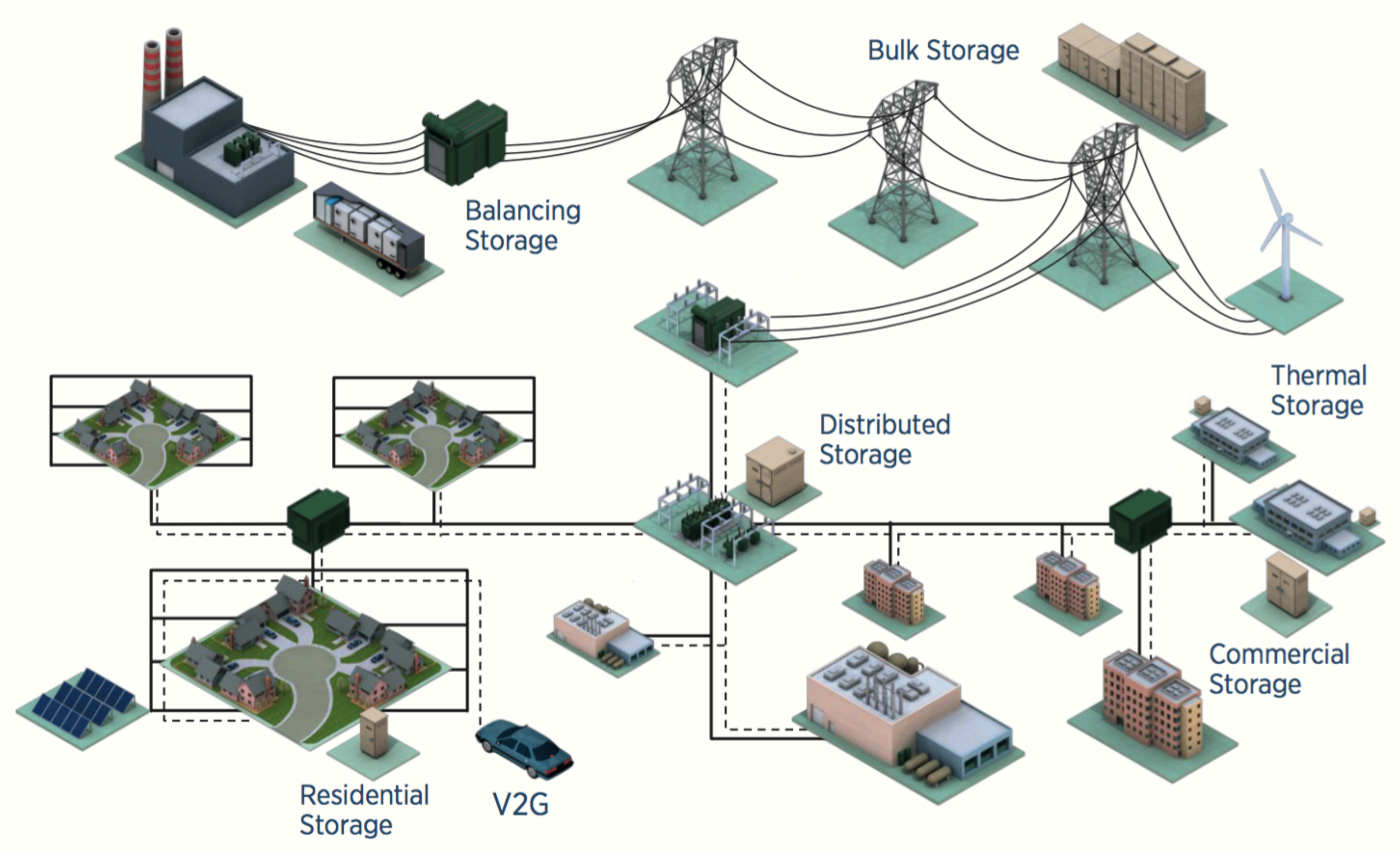
Source: BNEF

Power Networks for Tomorrow



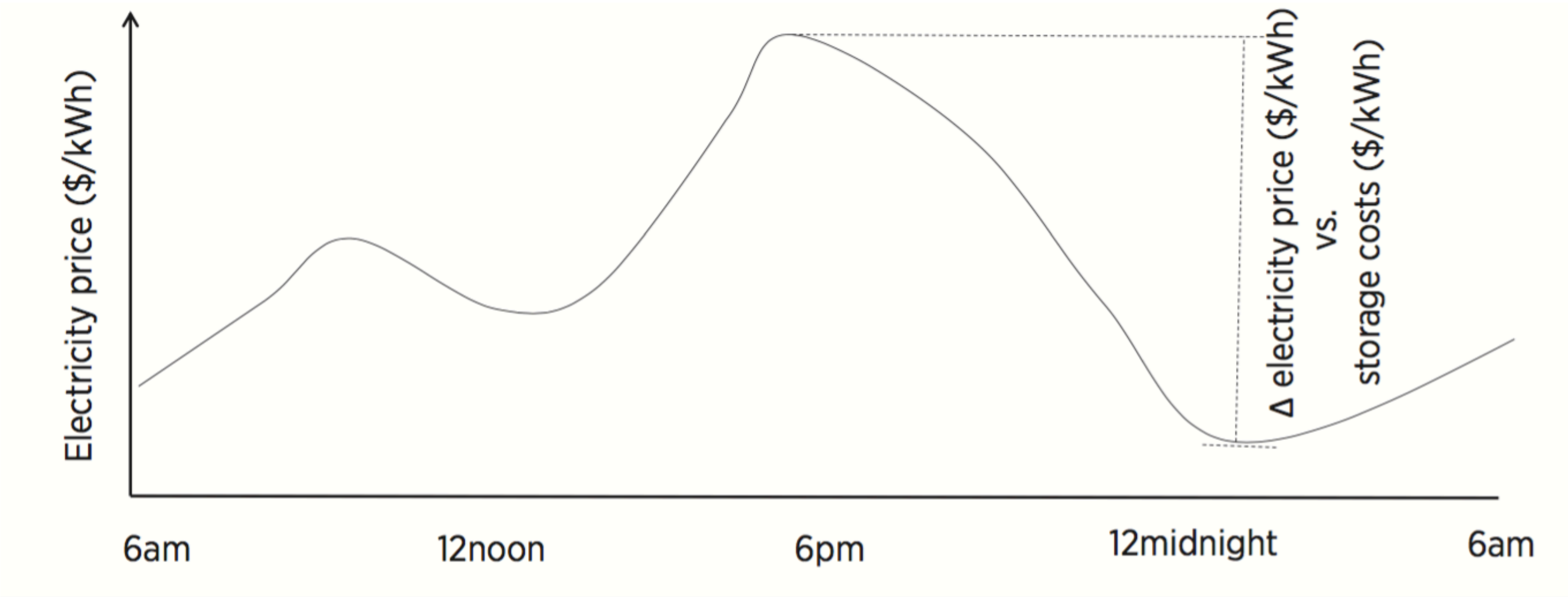
Source: modified from EIA (Energy Information Administration) (2012), "Electricity storage: Location, location, location.....and cost", Today in Energy, Washington, DC, United States, www.eia.gov/todayinenergy/detail.cfm?id=6910.

Connections within the power network



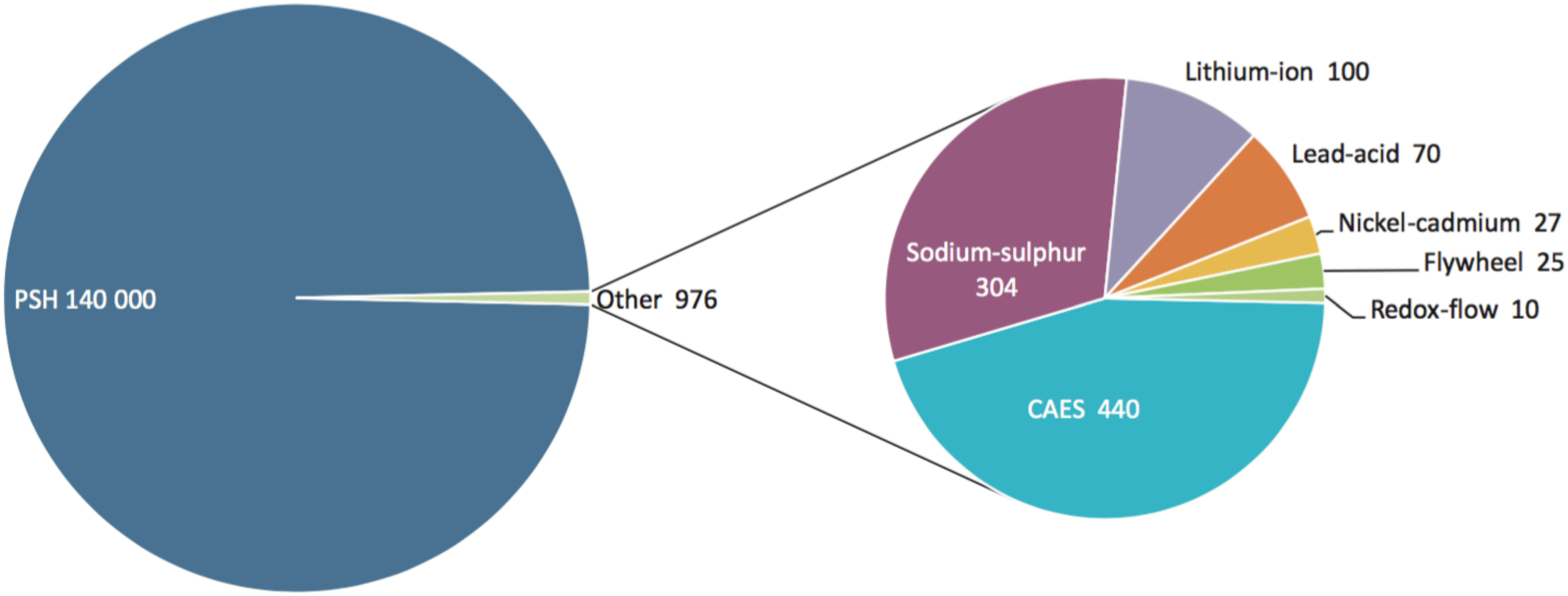
Source: modified from EIA (Energy Information Administration) (2012), "Electricity storage: Location, location, location.....and cost", Today in Energy, Washington, DC, United States, www.eia.gov/todayinenergy/detail.cfm?id=6910.

Use of electricity on the power network throughout the day



Source: EIA (Energy Information Administration)

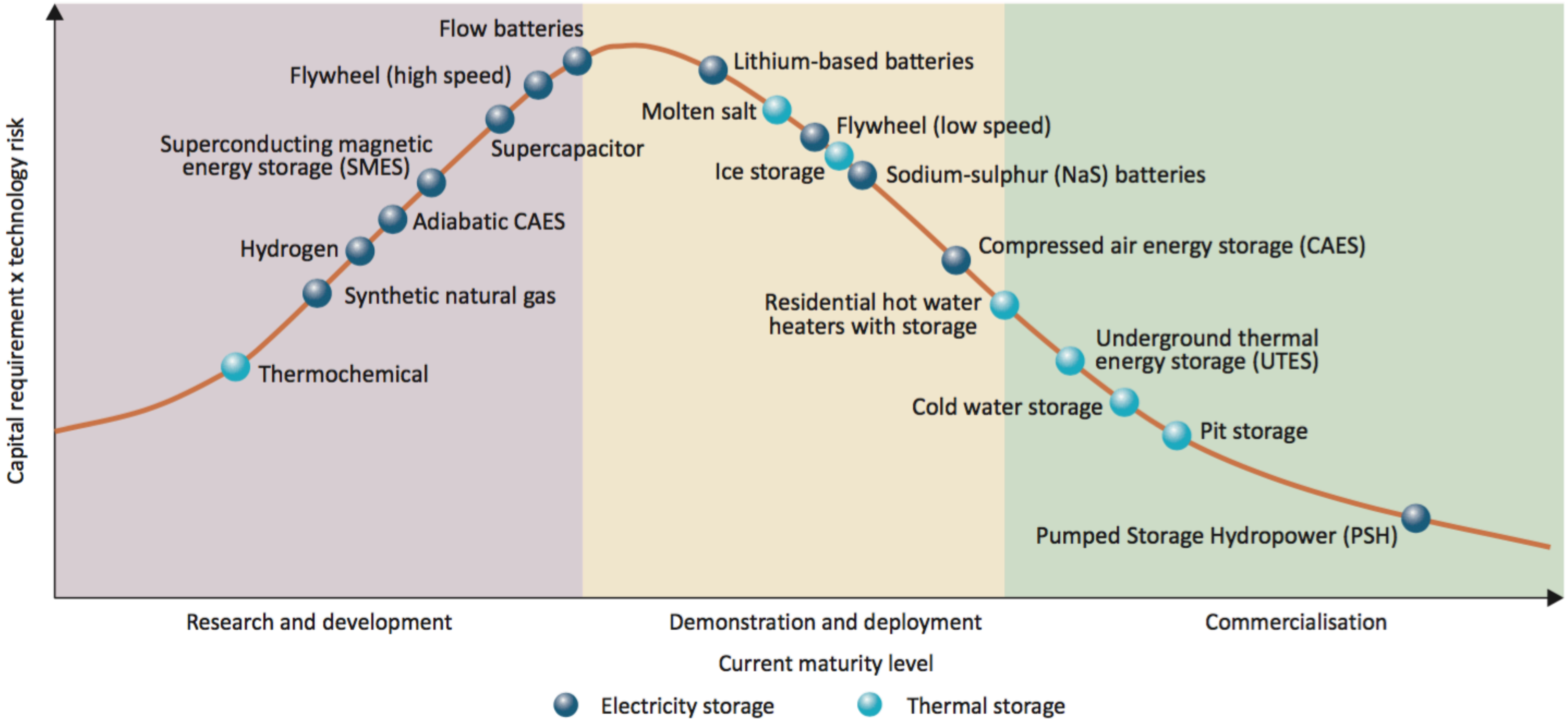
Division of battery types in use today



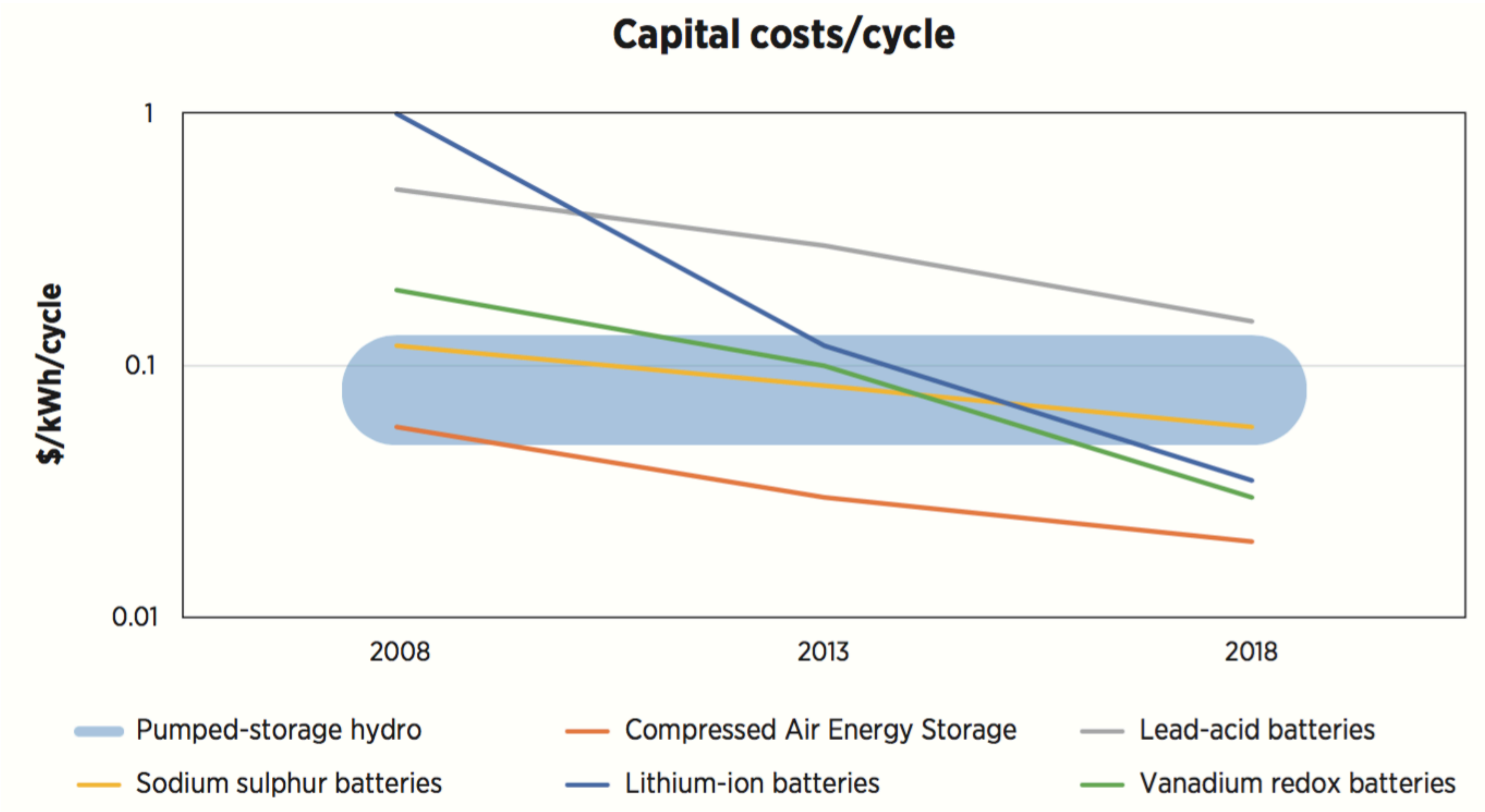
Note: PSH = Pumped-storage hydroelectricity

Source: EIA (Energy Information Administration)

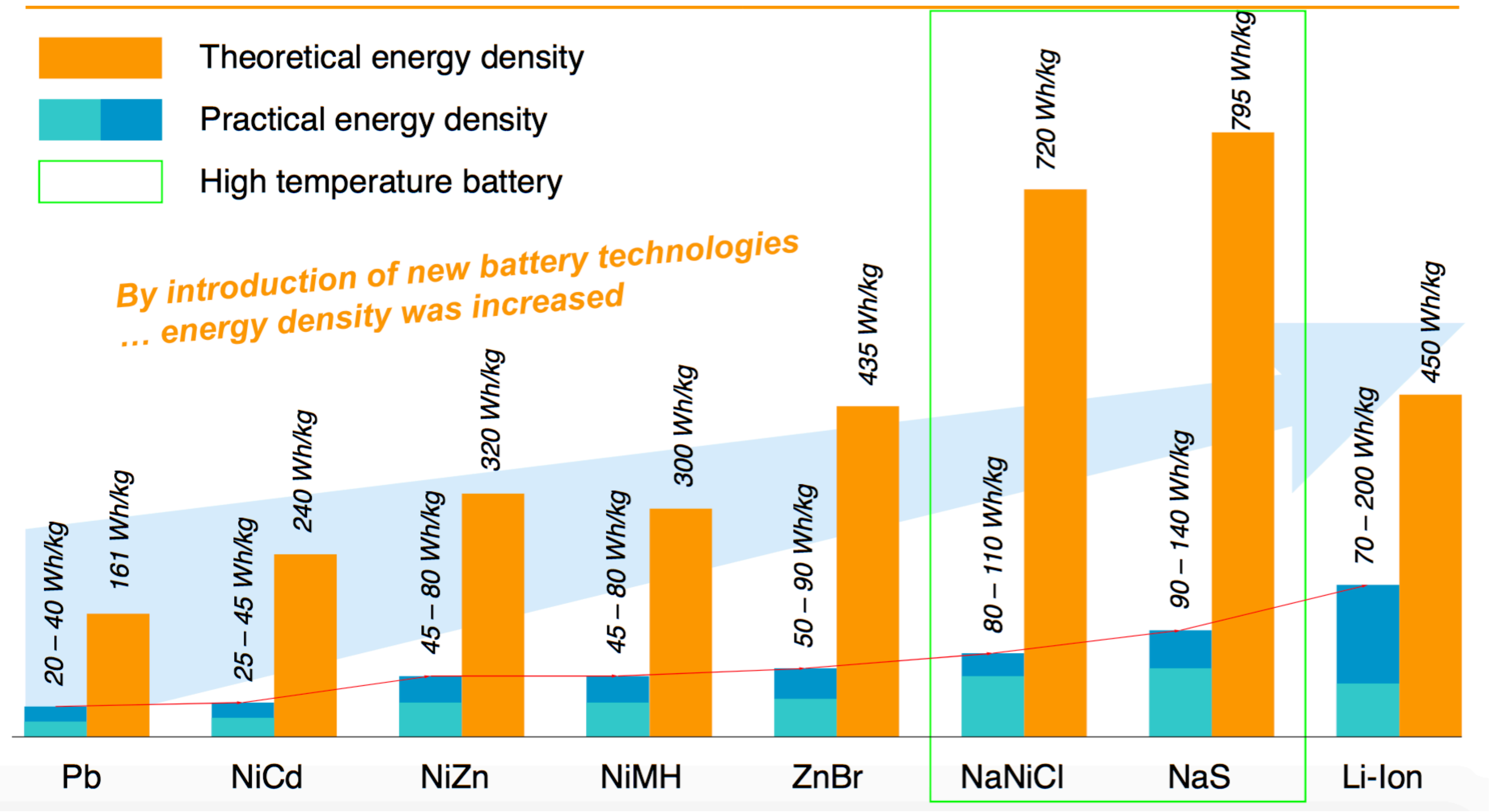
Distributions of battery technologies



Costs of battery technologies



Comparison of energy densities of batteries



Applications of battery technologies

Application	Description	CAES	Pumped Hydro	Flywheels	Lead-Acid	NaS	Li-ion	Flow Batteries
Off-to-on peak intermittent shifting and firming	Charge at the site of off peak renewable and/ or intermittent energy sources; discharge energy into the grid during on peak periods	◐	◐	○	●	●	●	●
On-peak intermittent energy smoothing and shaping	Charge/discharge seconds to minutes to smooth intermittent generation and/or charge/discharge minutes to hours to shape energy profile	○	◐	◐	●	●	●	●
Ancillary service provision	Provide ancillary service capacity in day ahead markets and respond to ISO signaling in real time	◐	◐	◐	◐	◐	◐	◐
Black start provision	Unit sits fully charged, discharging when black start capability is required	◐	◐	○	●	●	●	●
Transmission infrastructure	Use an energy storage device to defer upgrades in transmission	○	○	○	●	●	●	●
Distribution infrastructure	Use an energy storage device to defer upgrades in distribution	○	○	○	●	●	●	●
Transportable distribution-level outage mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short term distribution overload situations	○	○	○	◐	●	●	●
Peak load shifting downstream of distribution system	Charge device during off peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peak	○	○	○	●	●	●	●
Intermittent distributed generation integration	Charge/Discharge device to balance local energy use with generation. Sited between the distributed and generation and distribution grid to defer otherwise necessary distribution infrastructure upgrades	○	○	○	●	◐	◐	◐
End-user time-of-use rate optimization	Charge device when retail TOU prices are low and discharge when prices are high	◐	◐	○	◐	◐	◐	◐
Uninterruptible power supply	End user deploys energy storage to improve power quality and /or provide back up power during outages	○	○	◐	●	●	●	●
Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid	○	○	○	●	●	●	●

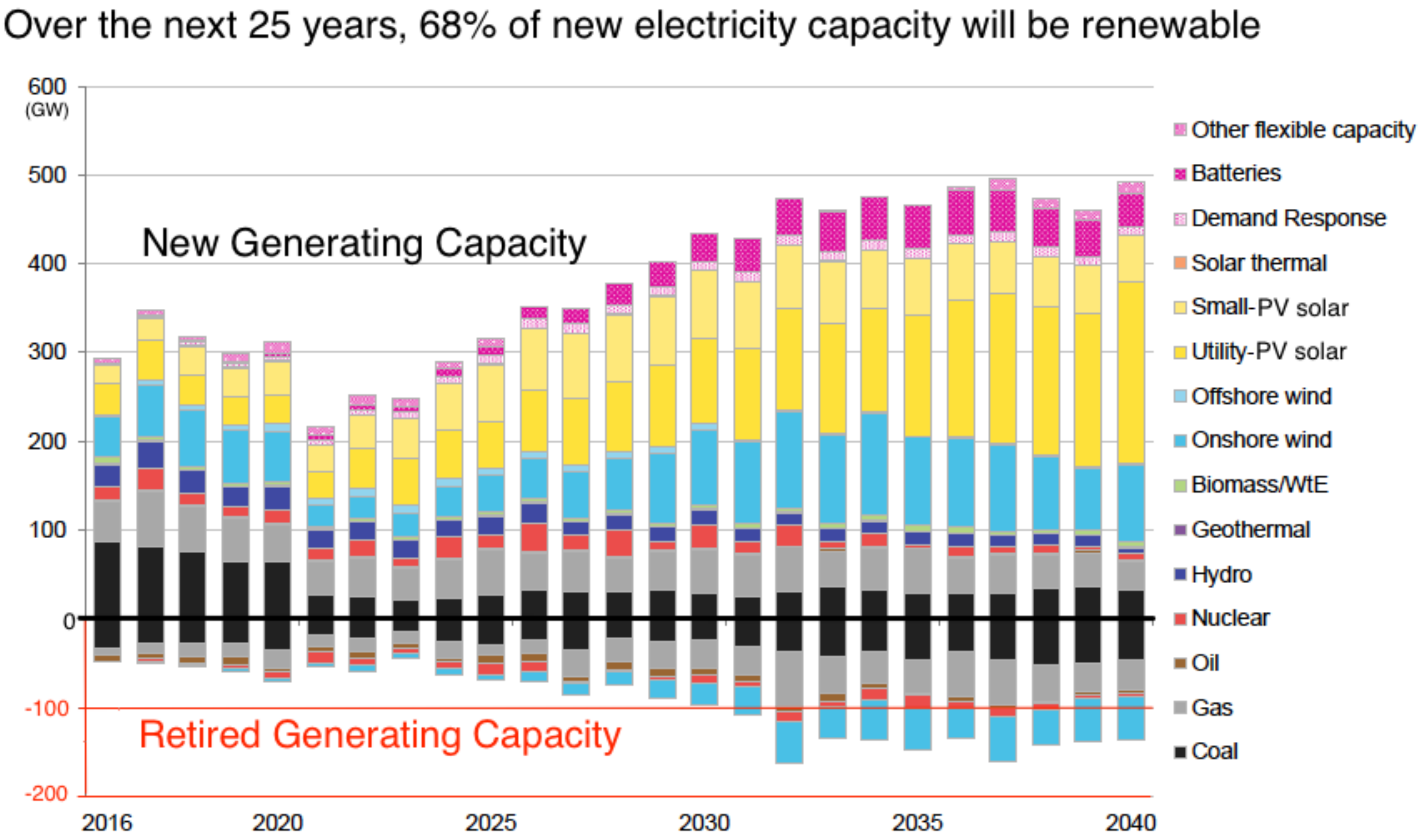
Definite suitability for application ● ; Possible use for application ◐ ; Unsuitable for application ○

Power segments open to innovations in batteries

Bulk energy services	Ancillary services	Transmission infrastructure services	Distribution infrastructure services	Customer energy management services
Electric energy time-shift (arbitrage)	**Regulation**	Transmission upgrade deferral	Distribution Upgrade Deferral	Power quality
Electric supply capacity	Spinning, non-spinning, and supplemental reserves	Transmission congestion relief	Voltage Support	**Power reliability**
	Voltage support			**Retail electric energy time-shift**
	Black start			Demand charge management

Boxes in red: Energy storage services directly supporting the integration of variable renewable energy

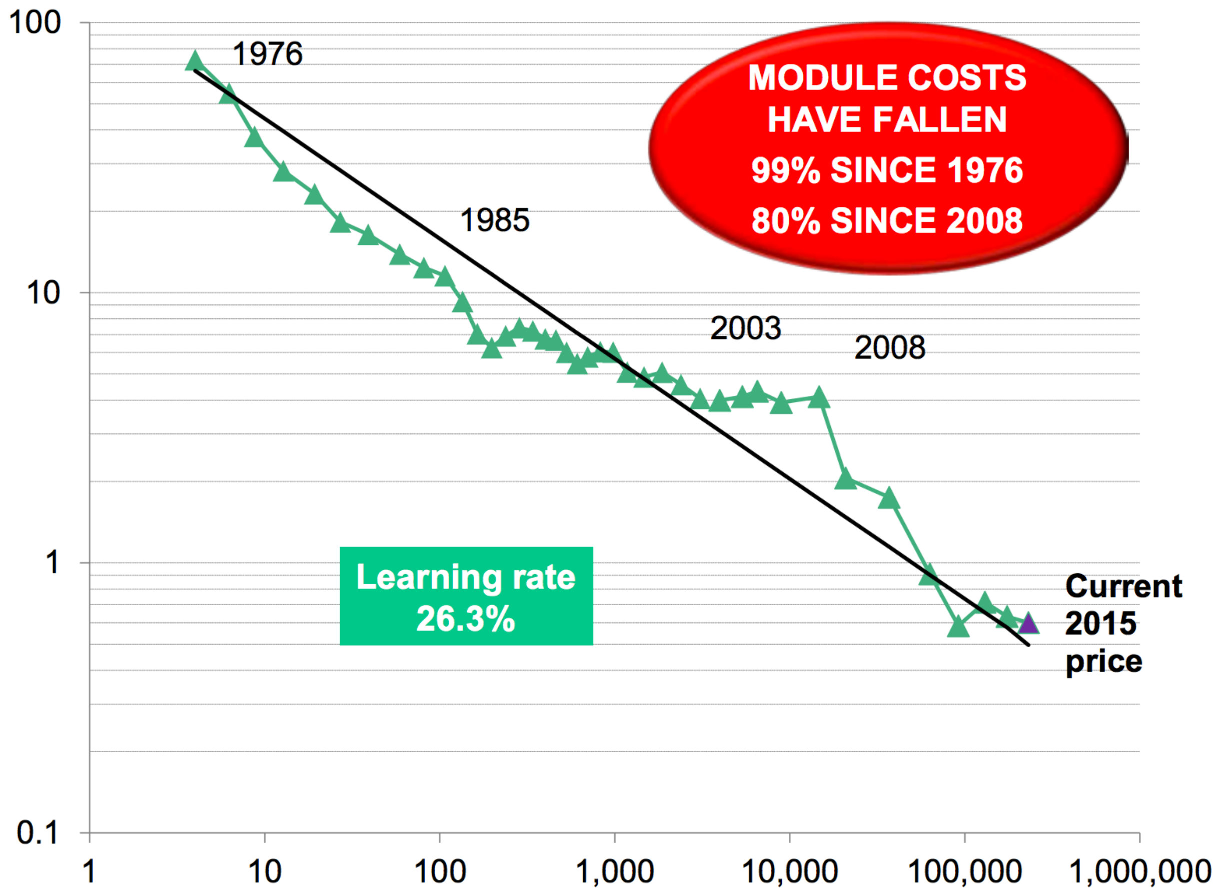
Solar is trending up



Source: BNEF

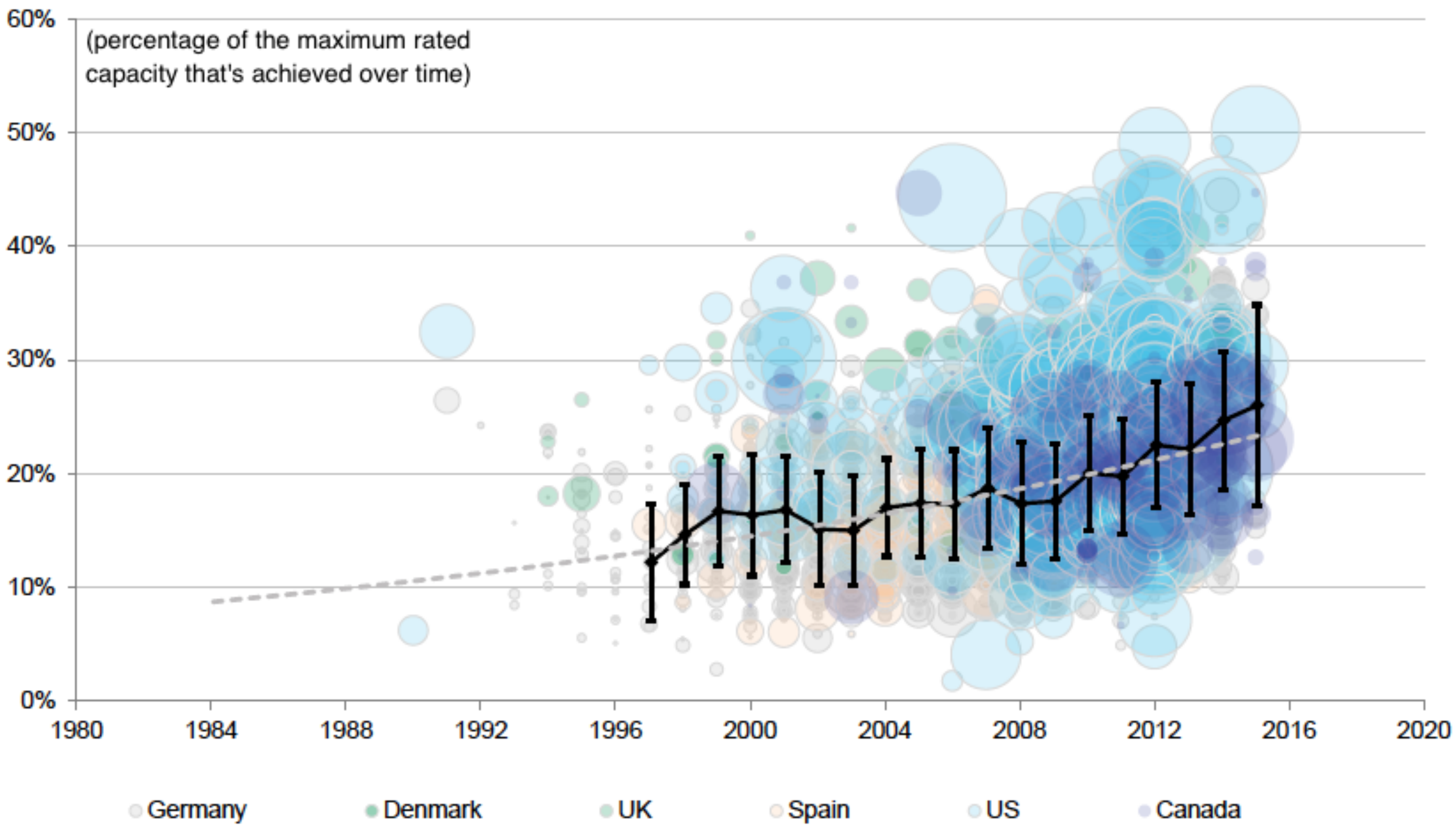
Growth in solar is being driven by falling costs

Every time the world's solar power doubles, the cost of panels falls 26%



Source: BNEF

Wind power is catching up too



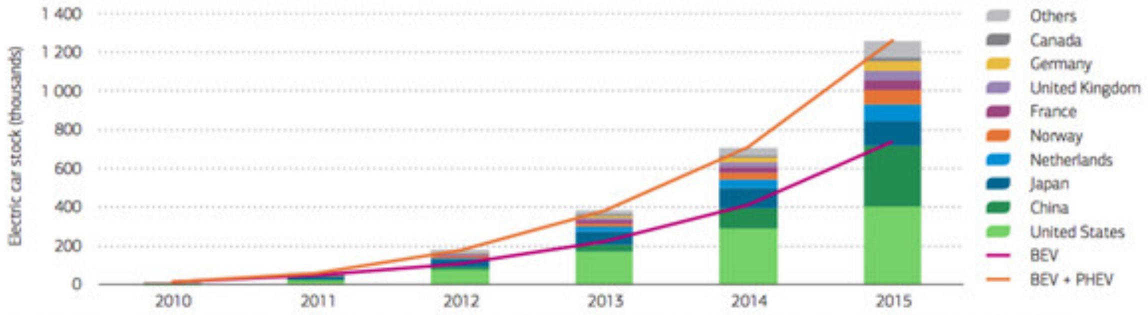
Source: BNEF

Electric vehicles and batteries

Electric vehicles

The year 2015 saw the global threshold of 1 million electric cars[1] on the road exceeded, closing at 1.26 million. In 2014, only about half of today's electric car stock existed. In 2005, electric cars were still measured in hundreds. 2015 also saw more than 200 million electric two wheelers on the road, and 170 000 buses, primarily in China.

Evolution of the global electric car stock, 2010-15

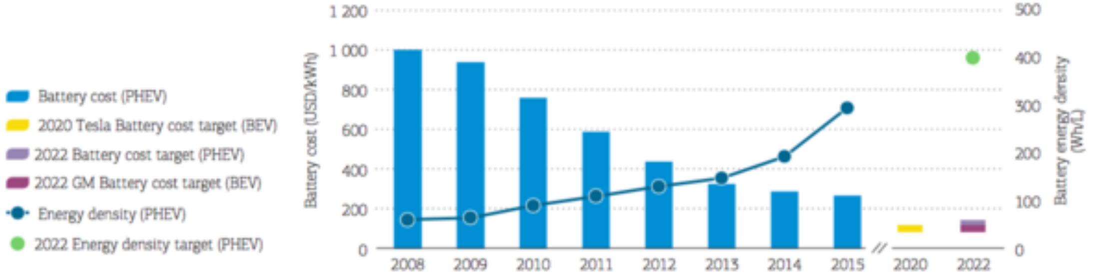


Key point: The uptake of electric cars has been growing since 2010, with a BEV uptake slightly ahead of PHEV uptake. 80% of the electric cars on road worldwide are located in the United States, China, Japan, the Netherlands and Norway.

Battery technology improvements

Since 2008, battery costs were cut by a factor four and battery energy density had a fivefold increase. Technological developments hold the promise to continue to deliver improvements in the forthcoming years.

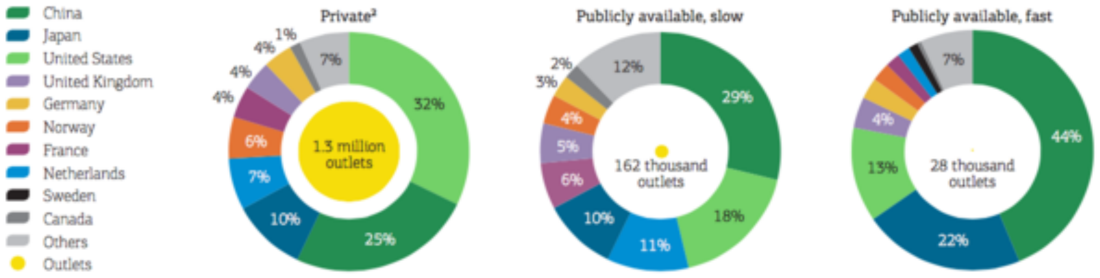
Evolution of battery energy density and cost



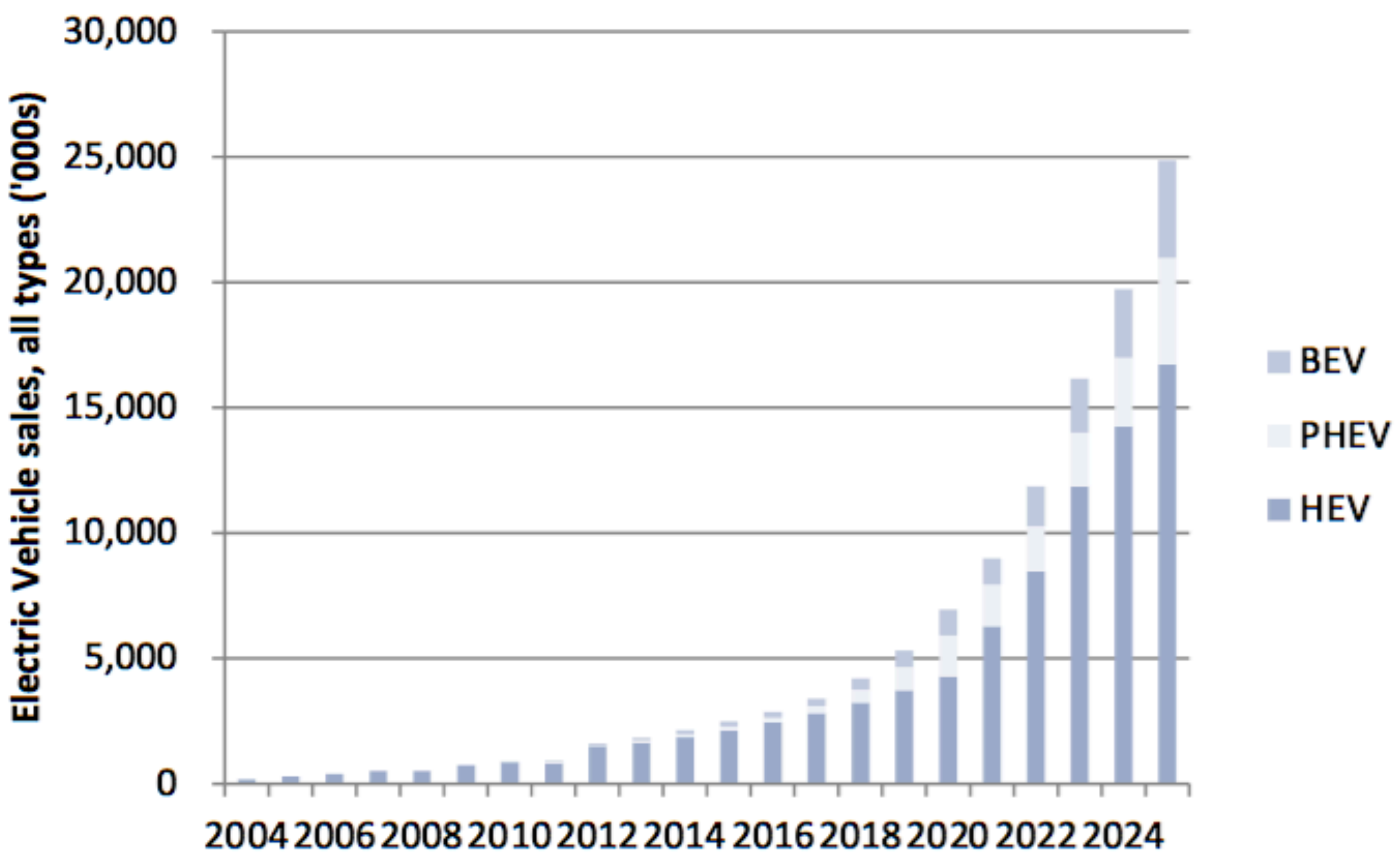
Charging infrastructure

There are an estimated total of 1.45 million electric car charging points worldwide in 2015. Publicly accessible charging facilities have been following the growth trend of the electric car stock in the past year.

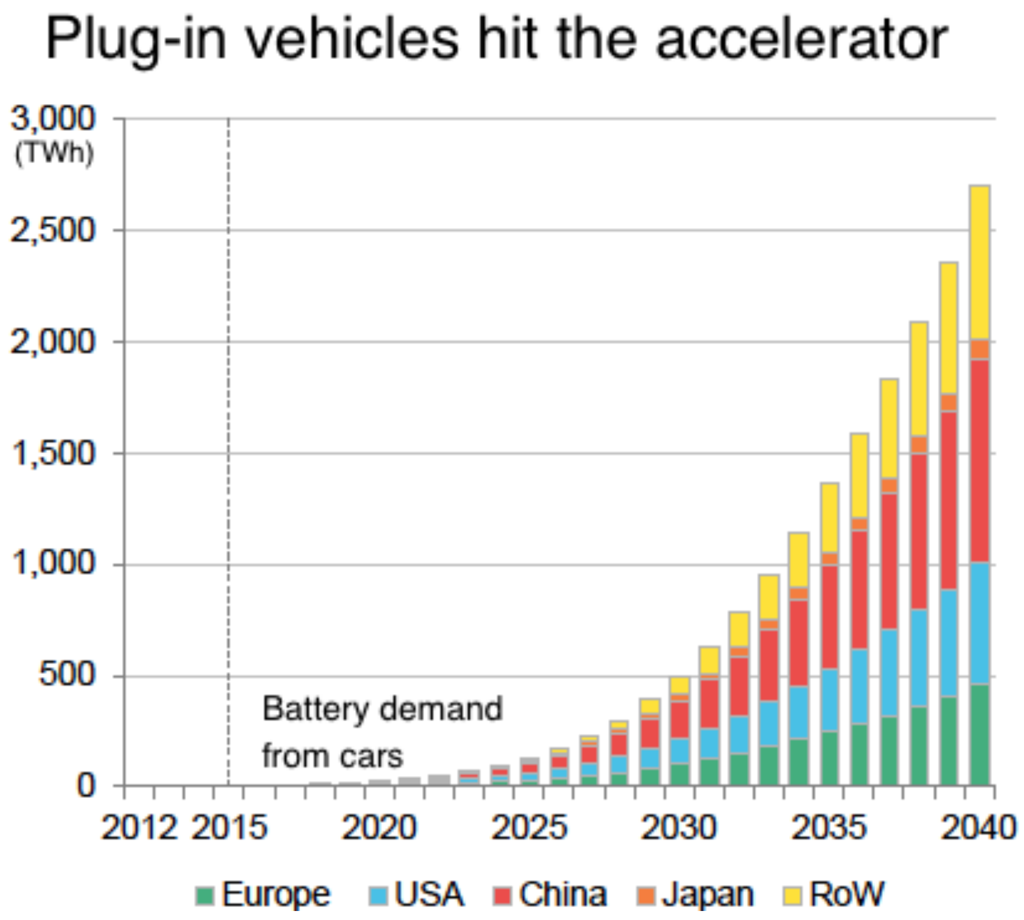
Geographical distribution of the 2015 stock of EVSE outlets by charger type

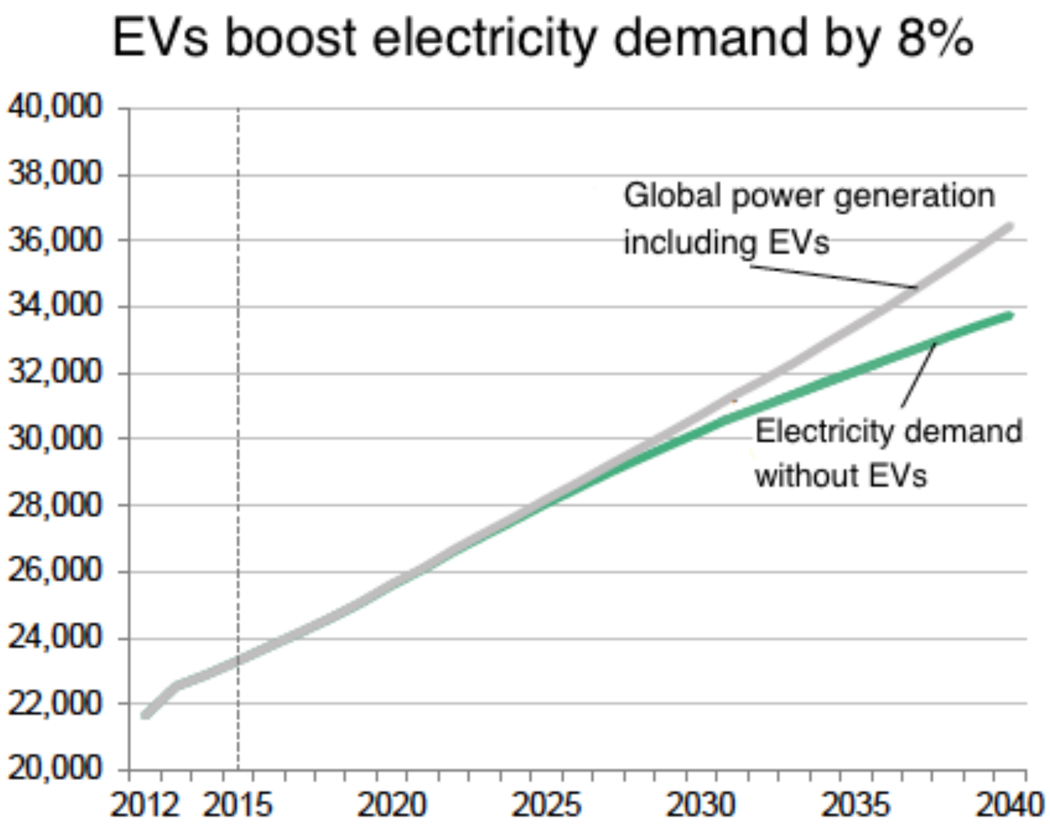


Growth of electric vehicle sales



Electric vehicles will affect demand on the power grid



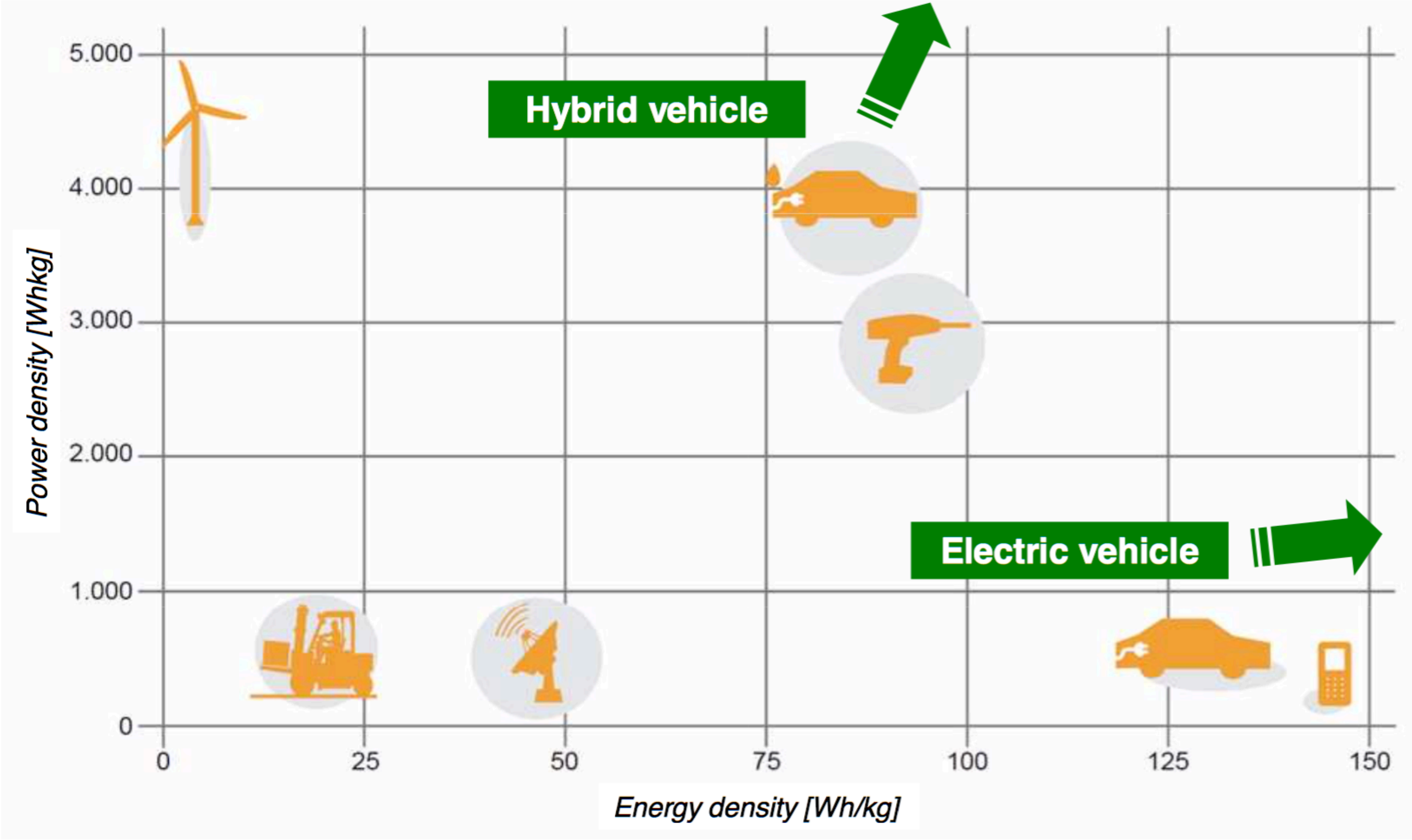


Source: BNEF

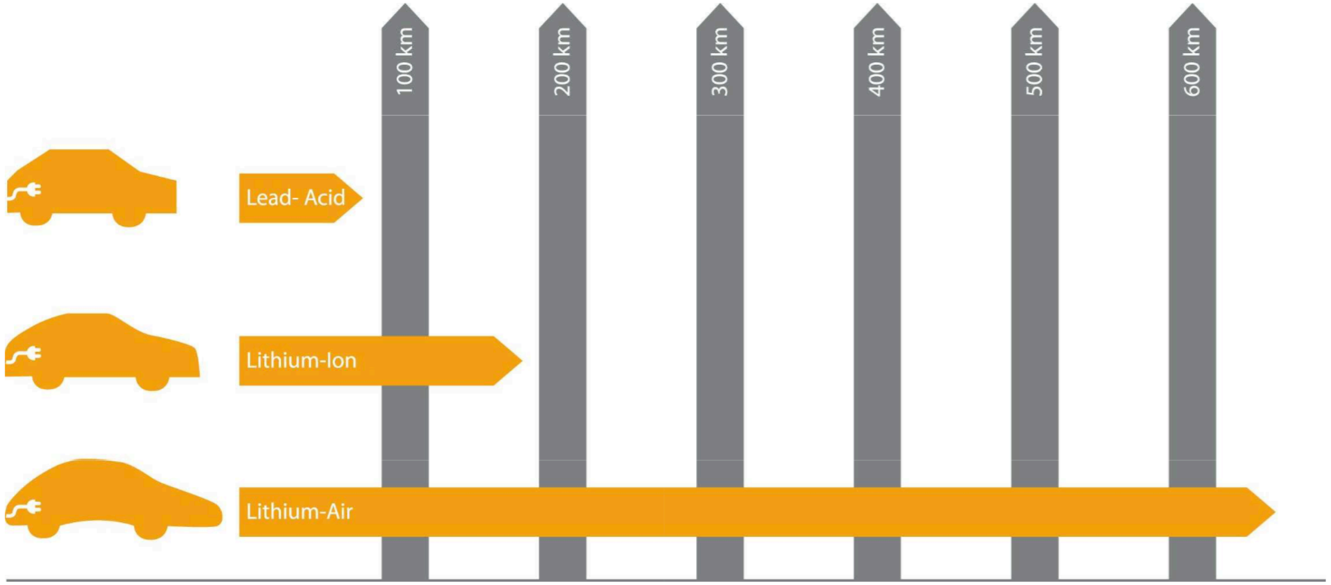
Types of Electric Vehicles

1. Plug-in Hybrid Electric Vehicle (PHEV): PHEV’s have both electric and conventional motors, but are distinct from HEVs in that they can be recharged from an electric outlet via a plug (e.g. Chevy Volt).
2. Hybrid Electric Vehicle (HEV): HEV’s are capable of storing charge (usually only in small amounts), and they do not plug into an electric outlet, but instead are recharged by a separate internal combustion engine which is the principal power source (e.g. Toyota Prius).
3. Battery Electric Vehicle (BEV): BEV’s are fully electric vehicles that do not contain a combustion engine. Their battery packs and driving ranges between recharges tend to be much larger than other EVs since they do not have auxiliary power sources such as an internal combustion engine (e.g. Tesla Model S).

Advantages of Hybrids versus Electric Vehicles



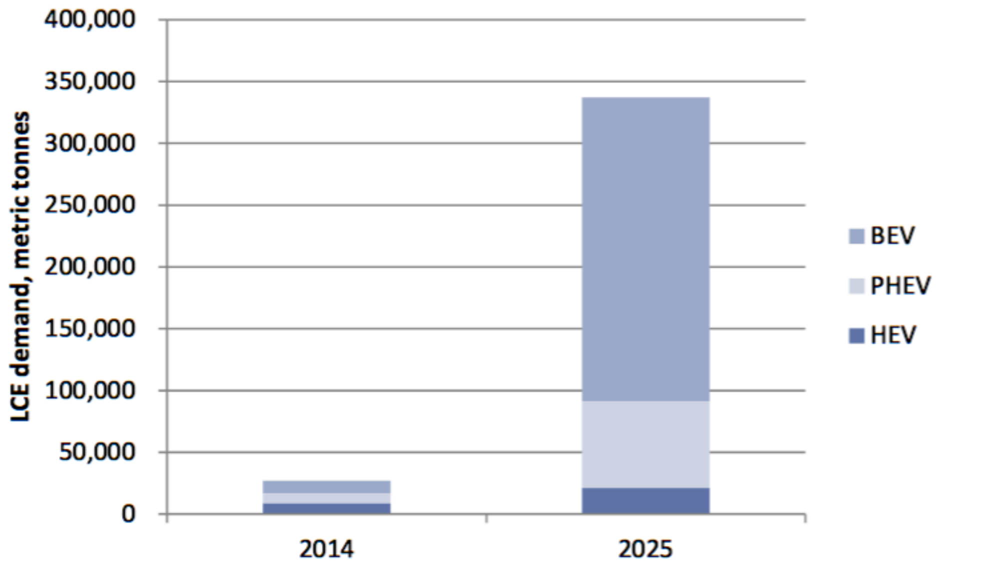
Impact of Batteries on Electric Vehicles



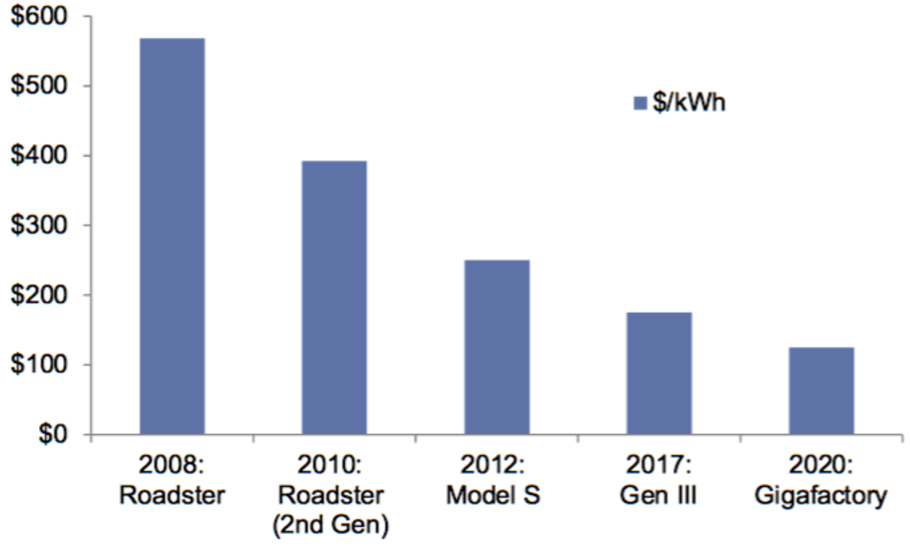
Model	Type	Battery Size	LCE Required	Range
2016 Ford Fusion Hybrid	HEV	1.4 kWh	1.3kg	-
2016 Chevy Volt	PHEV	18.4 kWh	16.6kg	53 mi
2016 Nissan Leaf S	BEV	24.0 kWh	21.6kg	84 mi
2016 Tesla Model S	BEV	70.0 kWh	63.0kg	240 mi

Assumes 0.9kg LCE per kWh for all batteries. Actual ranges generally vary from 0.7-1.3kg per kWh
HEVs usually do not guarantee electric only range

Impact of Batteries on access to Electric Vehicles



Note: Assumes 70kWh batteries in all BEVs and 3.5% global BEV adoption in 2025



Note: Battery costs referenced above are Tesla specific

Decreasing battery costs and further battery efficiencies is driving the price down to the targeted $150/kWh level seen as the tipping point for broad commercialization of electric vehicles.

Conclusions

1. The increase in global renewable energy use will increase demand of batteries that can store energy for variable use rates
2. Future battery technologies remain far out; however, progress in batteries for electric vehicles has been accelerating
3. The power grid has many points where batteries can boost efficiency and adapt the network for variable renewable energy