

#EnergyProspectives

Energy Prospectives

Michael Liebriech

Fundación
Naturgy 

 **IESE**
Business School
University of Navarra

Global Trends in Clean Energy and Transportation

Naturgy/IESE Energy Prospectives
Madrid, 14 March 2019

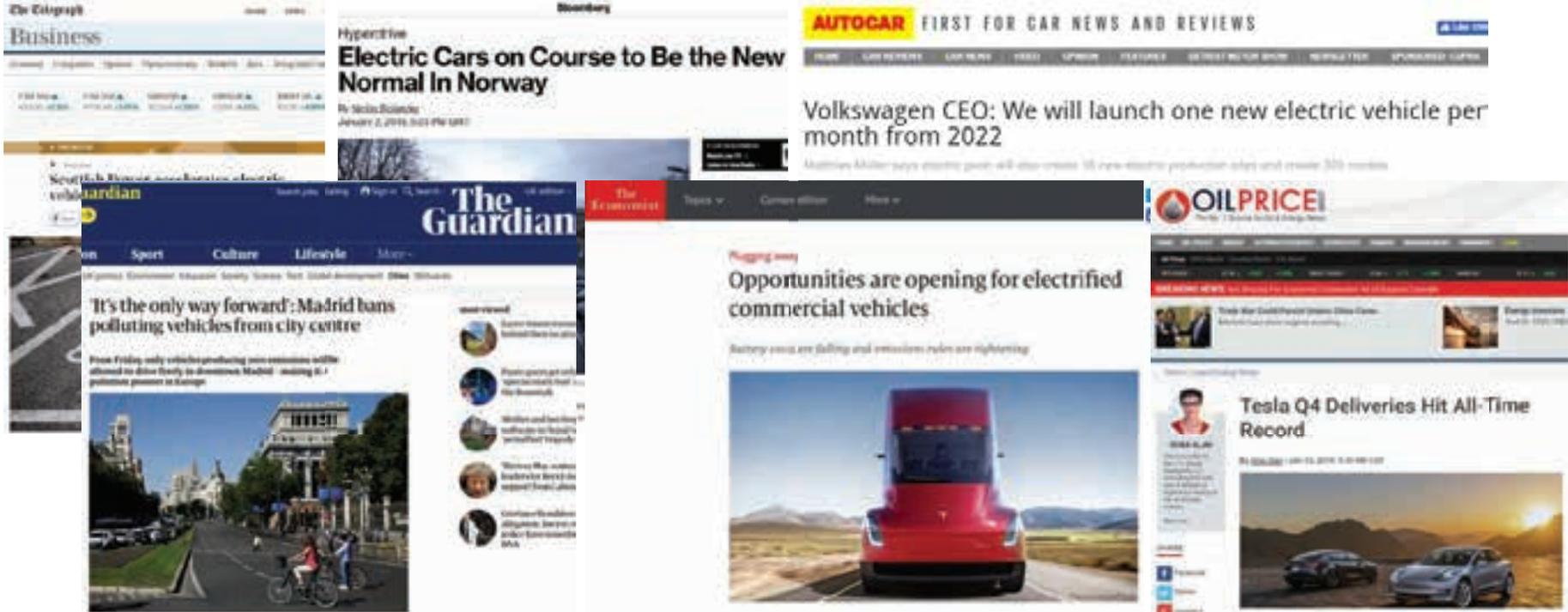
Michael Liebreich
Founder and CEO
Liebreich Associates

Clean energy news flow



Source: Independent; Cleantechnica, Oilprice.com, Businessgreen; FT; Bloomberg; BBC

EV news flow



Source: Telegraph; Oilprice; Bloomberg; Economist; Autocar; The Guardian

Solar and wind are not taking over the world

“

The great hope for a quick and sweeping transition to renewable energy is wishful thinking.

”

Vaclav Smil

*Distinguished Professor Emeritus in the Faculty of Environment
at the University of Manitoba in Winnipeg, Manitoba, Canada*



Image: Wikimedia Commons

Wind and solar are not taking over the world

“

Today, solar and wind make up just 0.8% of global energy. In a quarter century, solar and wind will produce less than 4% of global energy

”

*Bjørn Lomborg
visiting professor at the Copenhagen Business School
President of the Copenhagen Consensus Center
4 February 2018*



Image: Lomborg.com

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
will be wind and solar



1/3 of vehicles will be
electric



Economy will be 1/3 more
energy productive

Images: Tesla, Wallpaper Mania, Cleantecnica

2040: Welcome to the Three-Third World

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1/3 of electricity
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energy productive

Images: Tesla, Wallpaper Mania, Cleantechica

Global clean energy investment and capacity installations 2004 – 2018

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179 GW

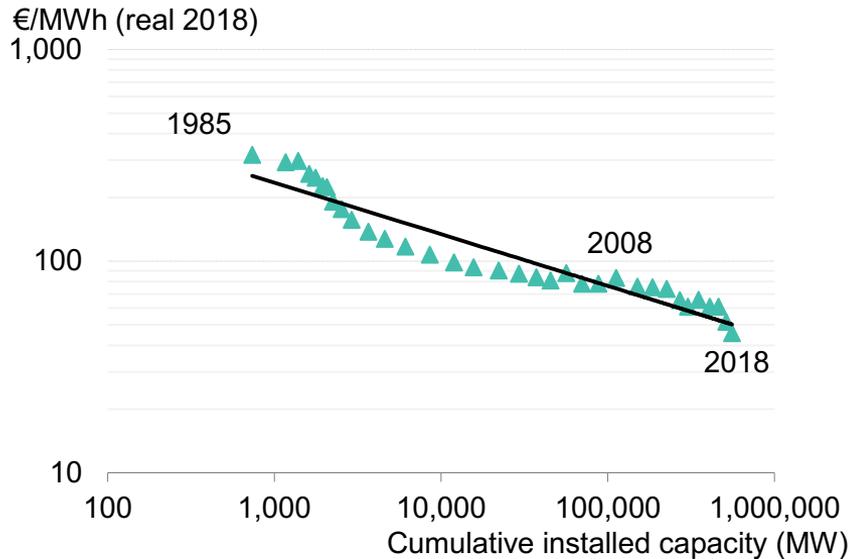


Note: Total values include estimates for undisclosed deals. Includes corporate and government R&D, and spending for digital energy and energy storage projects (not reported in quarterly statistics). Includes large hydro.

Source: BNEF, IRENA

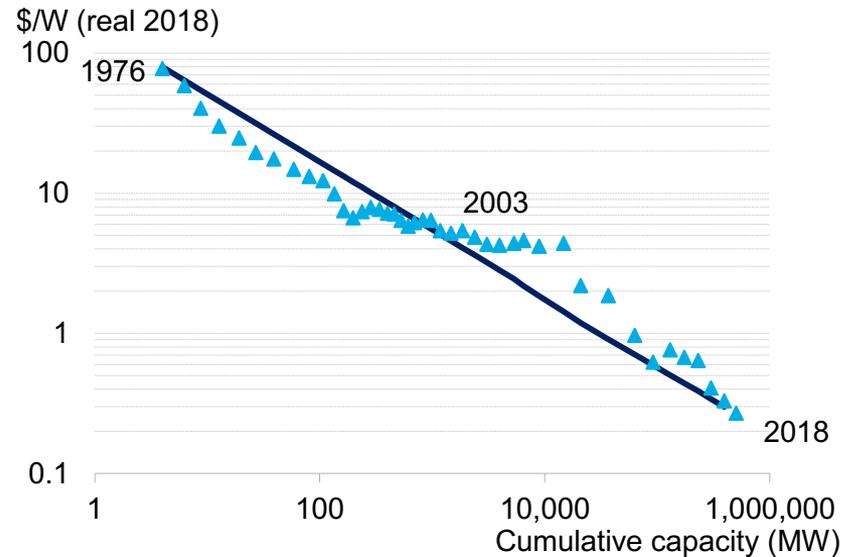
Wind and solar experience curves

Wind – learning rate 15%



Note: LCOE in real 2017

Solar – learning rate 24-29%



Source: BNEF

Solar scale-up 2005 – 2018

2005

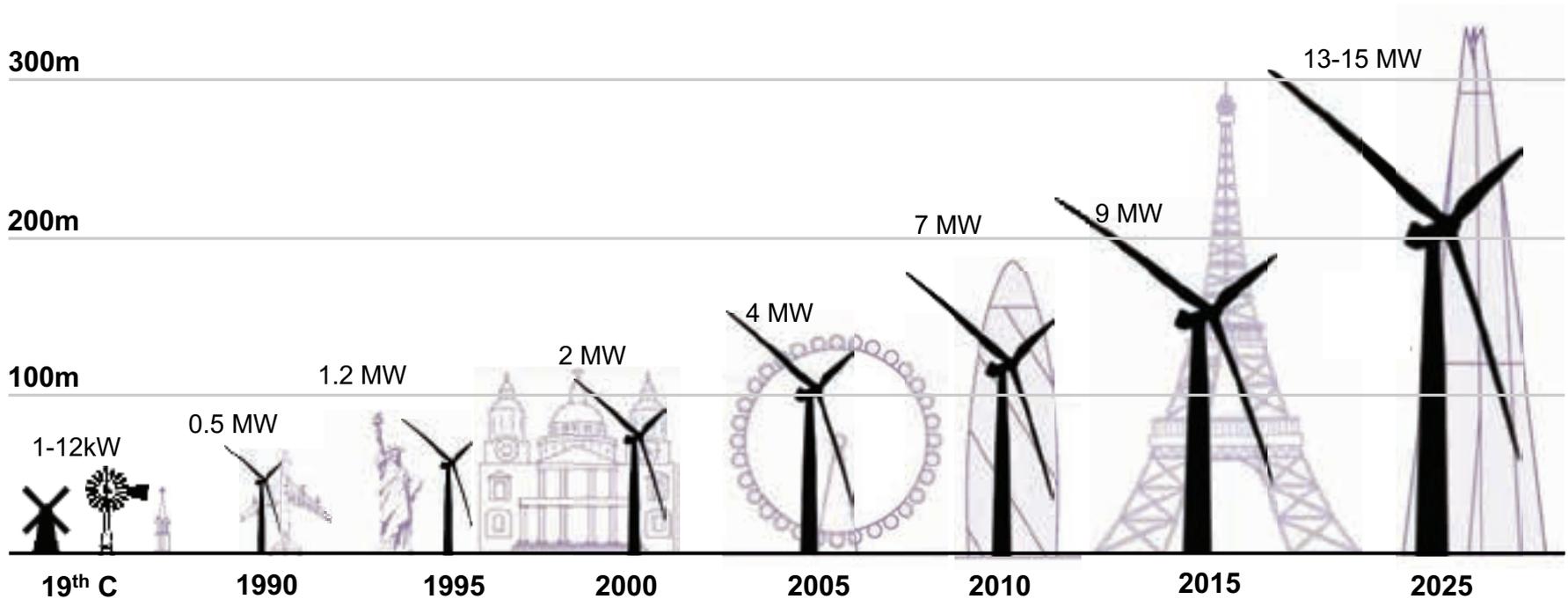


2018



Images: Nissan; Enel Villanueva solar plant

Evolution of wind turbine heights and output



Sources: Various; Bloomberg New Energy Finance

Unsubsidised clean energy world records 2011

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Solar PV



Country: Spain
Bidder: Various
Signed: 2010
Construction: 2012

US\$ 17.0 c/kWh

Onshore wind



Country: USA
Bidder: Various
Signed: 2010
Construction: 2012

US\$ 8.0 c/kWh

Offshore wind



Country: UK
Bidder: SSE
Signed: 2009
Construction: 2011

US\$ 17.0 c/kWh

Note: images are illustrative only

Source: Various manufacturers and project developers

Unsubsidised clean energy world records 2015

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Solar PV



Country: UAE
Bidder: AQWA
Signed: January 2015
Construction: 2017

US\$ 5.8 c/kWh

Onshore wind



Country: USA
Bidder: Various
Signed: 2015
Construction: 2016

US\$ 4.5 c/kWh

Offshore wind



Country: Horns Rev, Denmark
Bidder: Vattenfall
Signed: Feb 2015
Construction: 2017

US\$ 12.1 c/kWh

Note: images are illustrative only

Source: Various manufacturers and project developers

Unsubsidised clean energy world records 2018

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Solar PV



Country: Mexico
Bidder: Enel
Signed: Nov 2017
Construction: 2018

US\$ 1.97 c/kWh

Onshore wind



Country: Mexico
Bidder: Neoen
Signed: Nov 2017
Construction: 2019

US\$ 1.77 c/kWh

Offshore wind



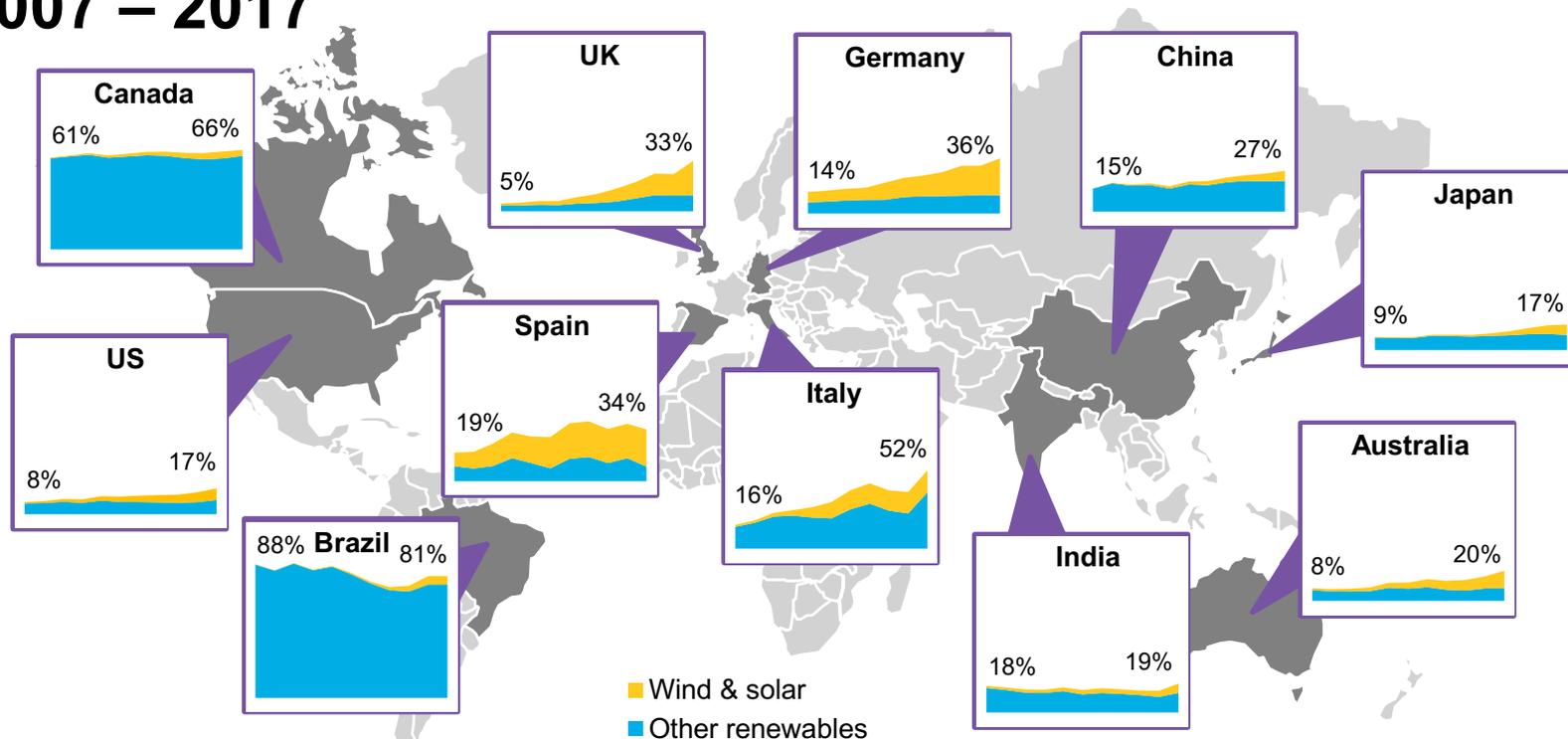
Country: Denmark
Bidder: Vattenfall
Signed: 2016
Construction: 2022

US\$ 5.3 c/kWh

Note: images are illustrative only

Source: Various manufacturers and project developers

RE proportion of power generation 2007 – 2017

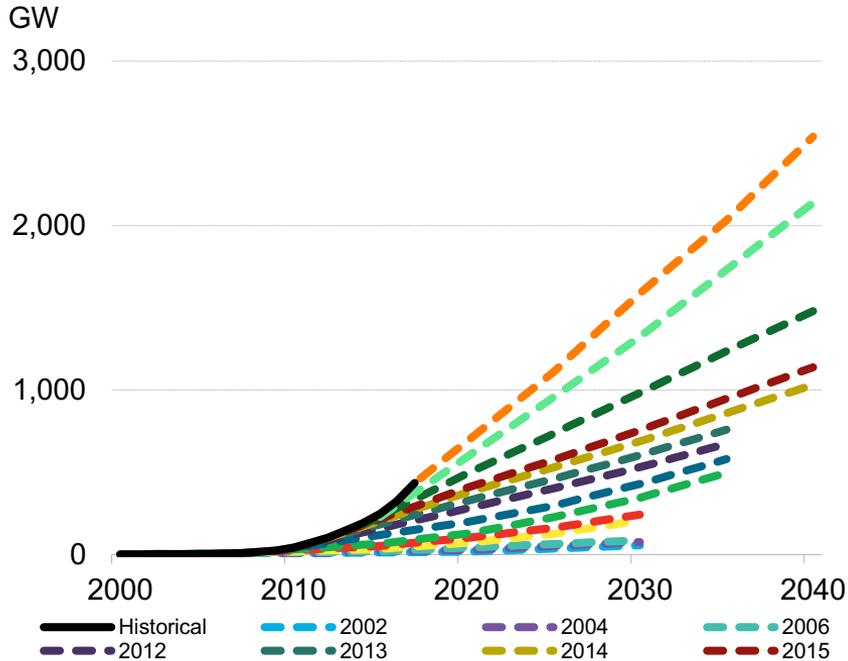


Note: Calculated as GWh renewable production / GWh consumption

Source: Liebreich Associates; BNEF; BP

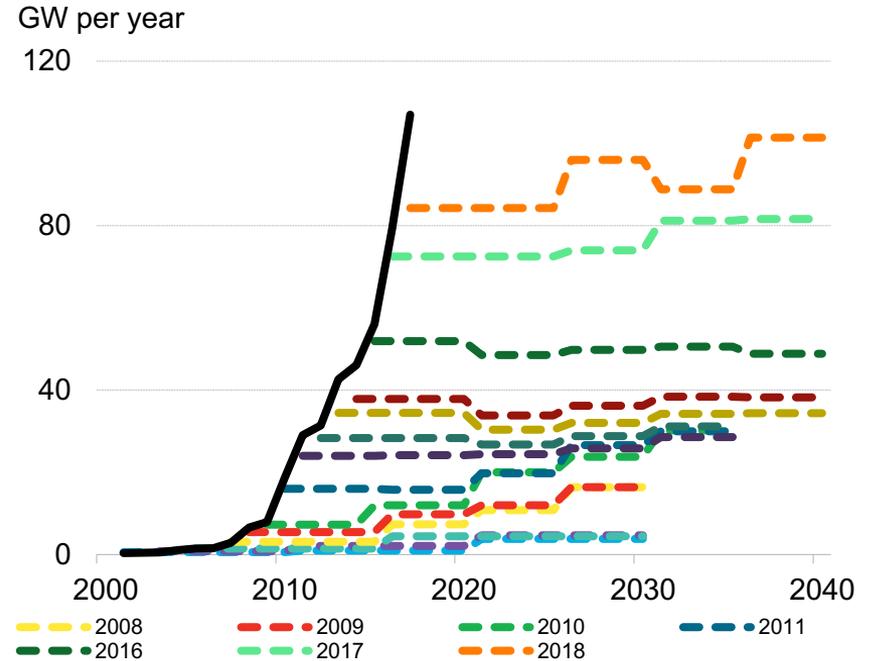
IEA solar capacity forecast evolution

Global cumulative solar installations



Note: 2002-2009 Reference, 2010-2018 New Policies Scenario

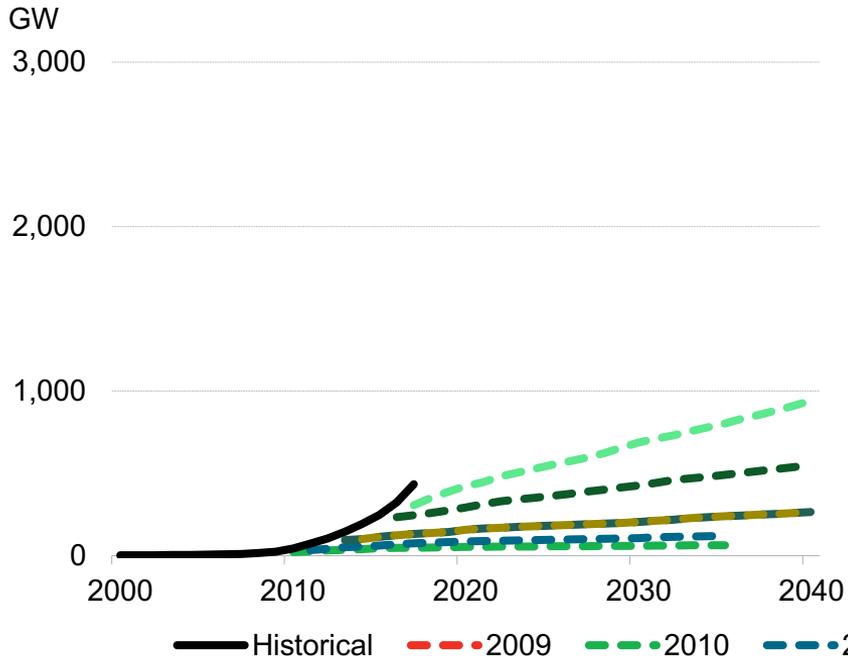
Annual solar additions



Source: IEA World Energy Outlook

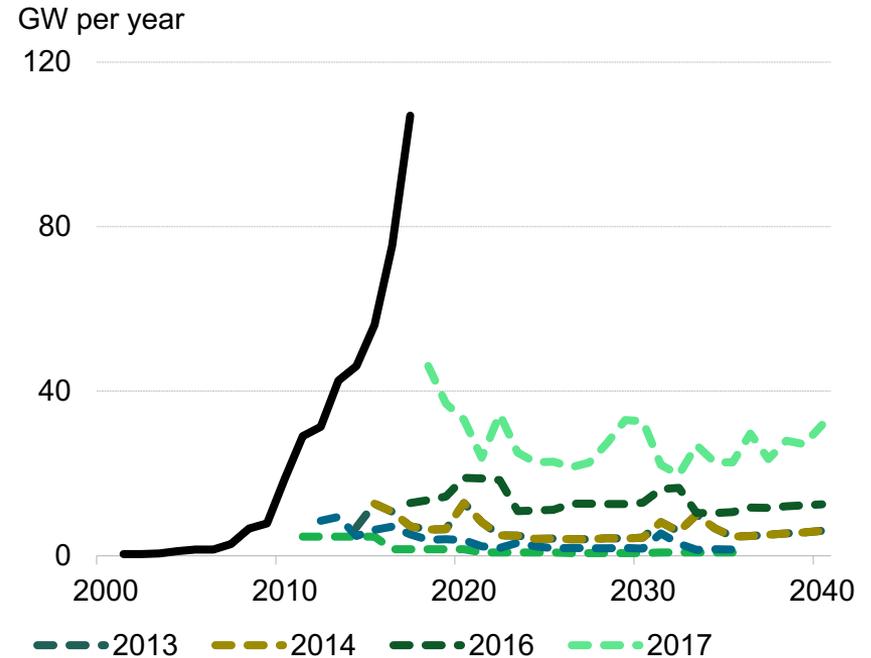
EIA solar capacity forecast evolution

Global cumulative solar installations



Note: Reference scenario

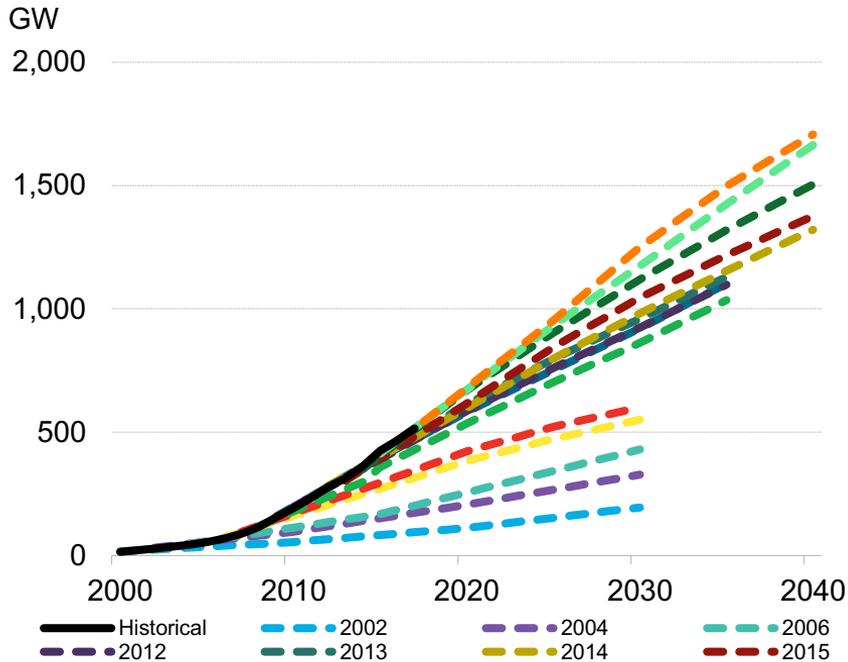
Annual solar additions



Source: EIA International Energy Outlook

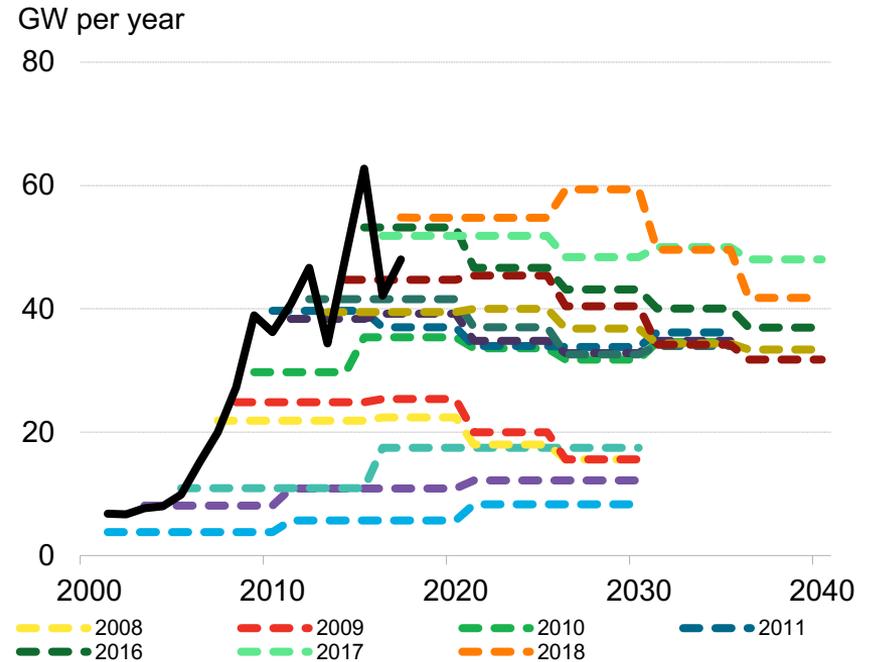
IEA wind capacity forecast evolution

Global cumulative wind installations



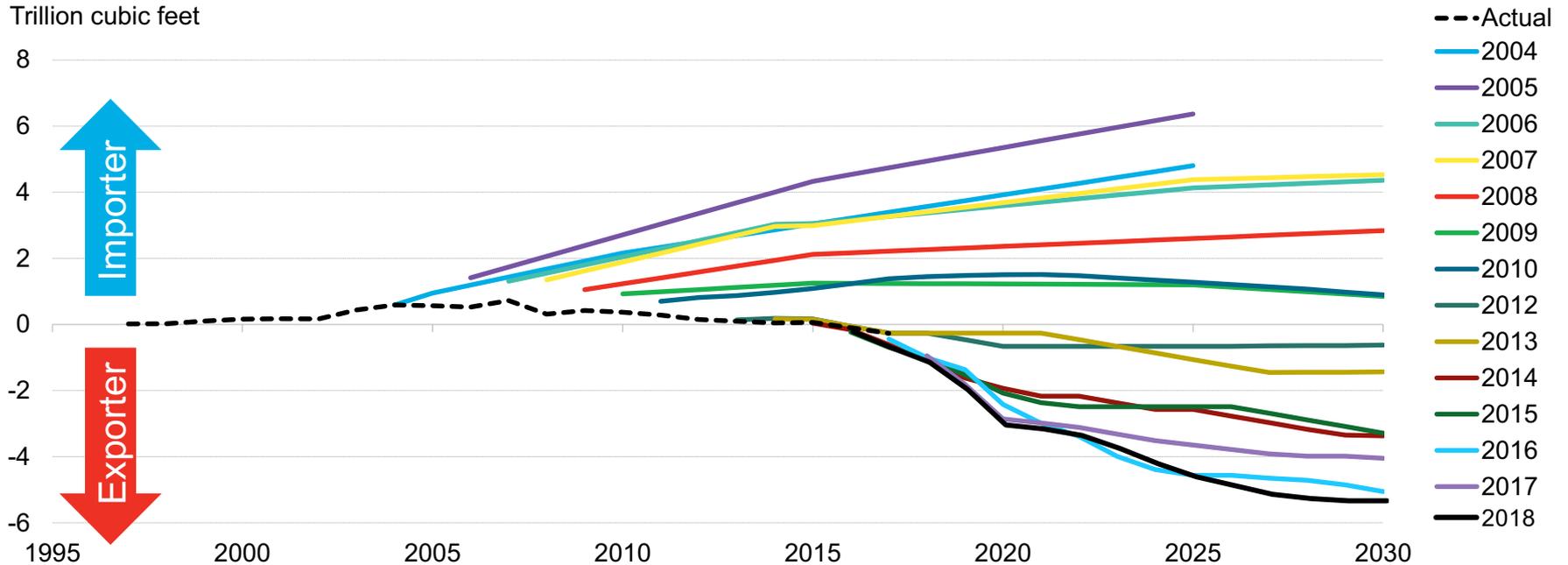
Note: 2002-2009 Reference, 2010-2018 New Policies Scenario

Annual wind additions



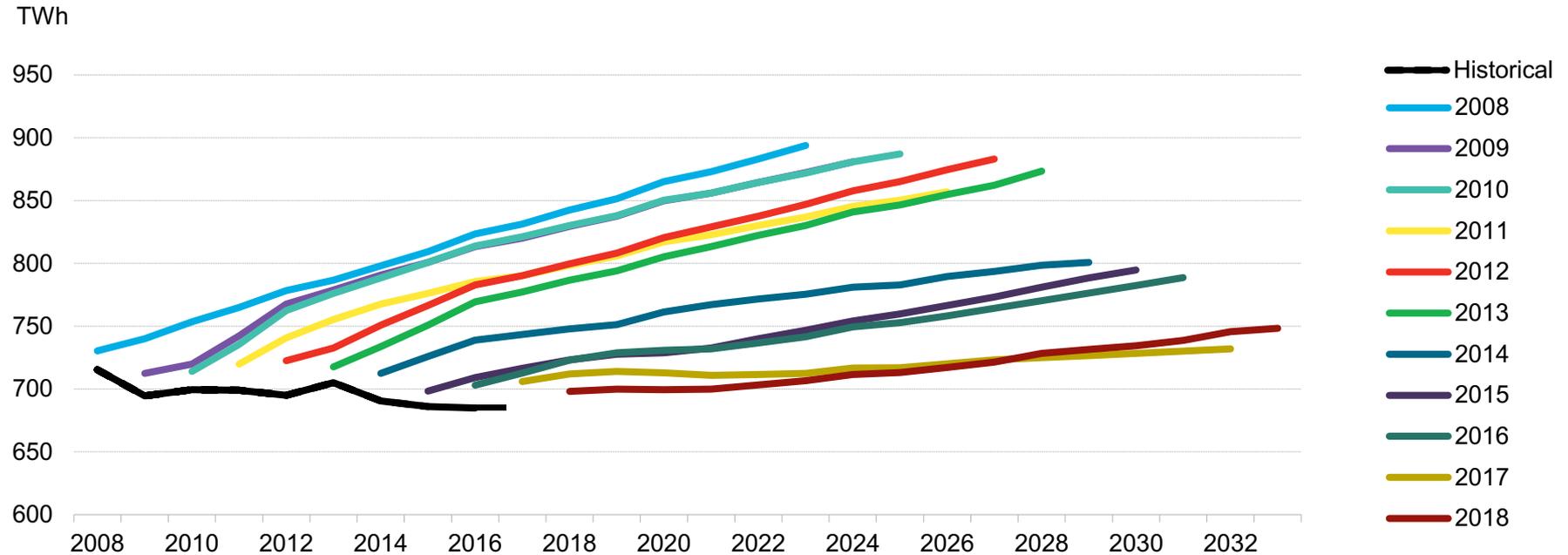
Source: IEA World Energy Outlook

US Projected net imports of LNG 1997-2030



Source: EIA AEO; BNEF

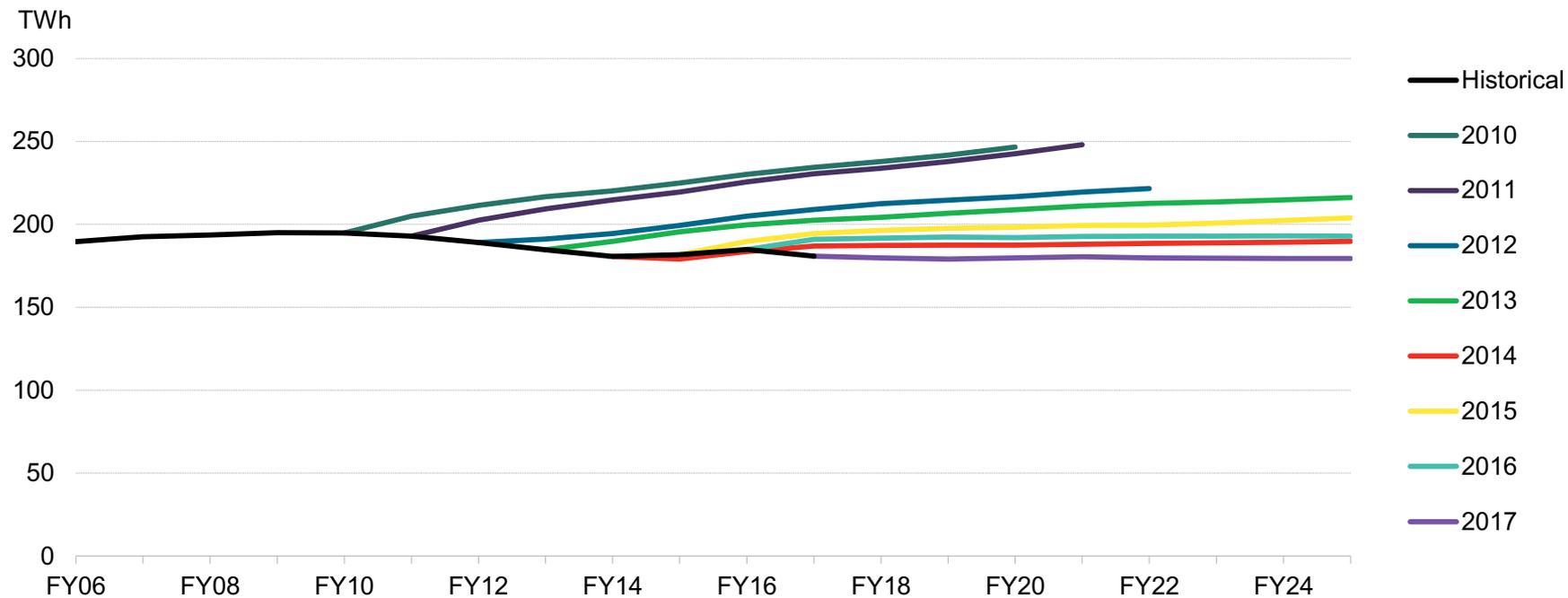
PJM net energy forecasts



Note: Excludes ATSI, DEOK and EKPC

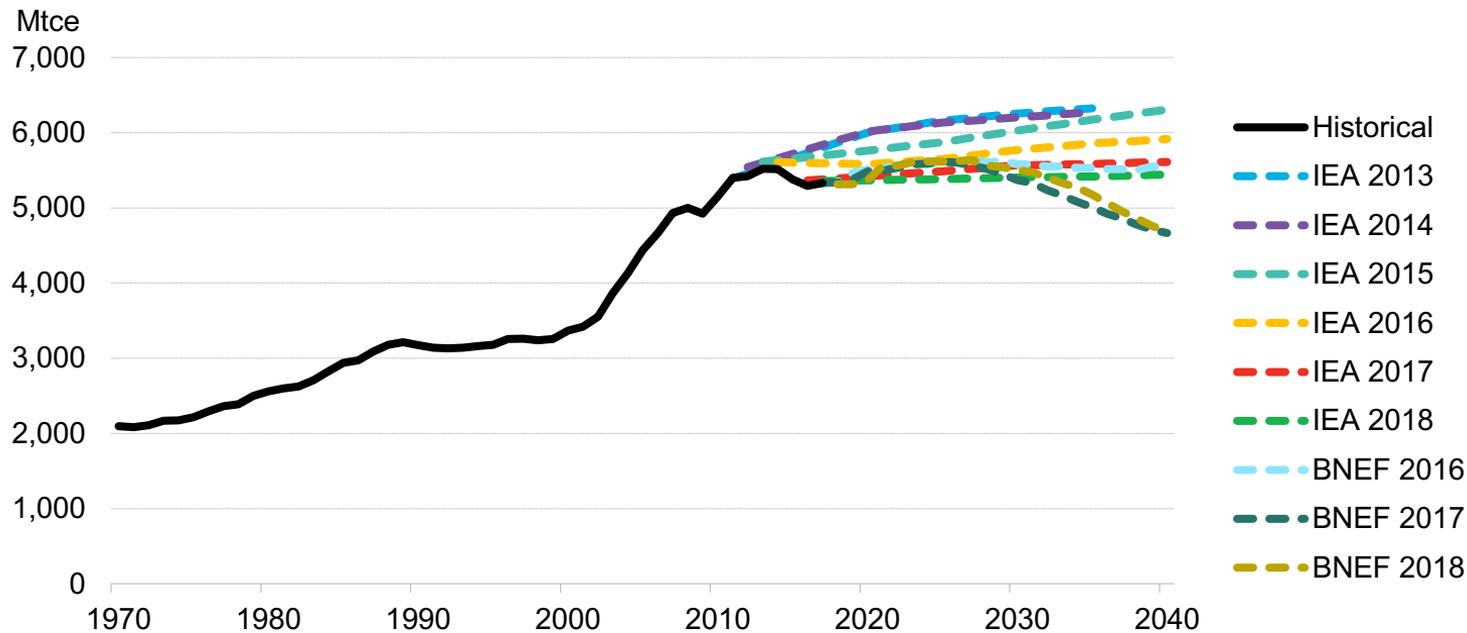
Source: PJM

Australian electricity demand



Source: AEMO

Global coal demand forecasts



Note: Using IEA NPS scenarios

Source: IEA; BP; Liebreich Associates

Price of renewable energy in India

“

The cost of solar power is now cheaper than coal in this country.

”

*Piyush Goyal
Minister of State for Power, Coal, New &
Renewable Energy and Mines, India*

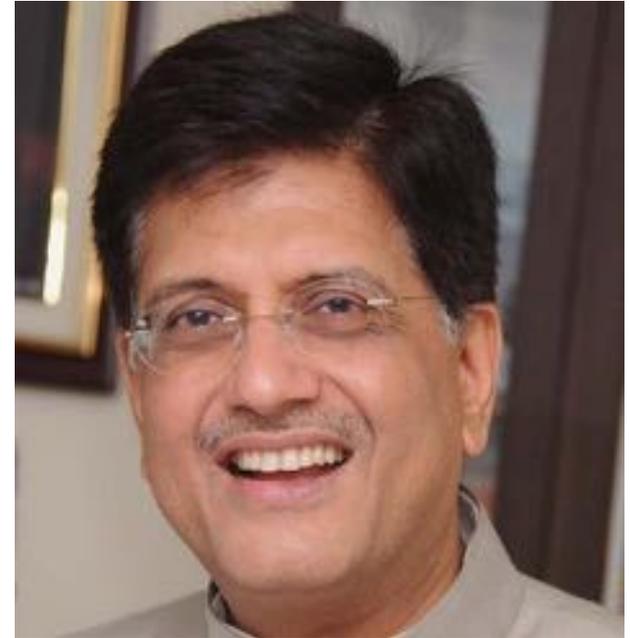
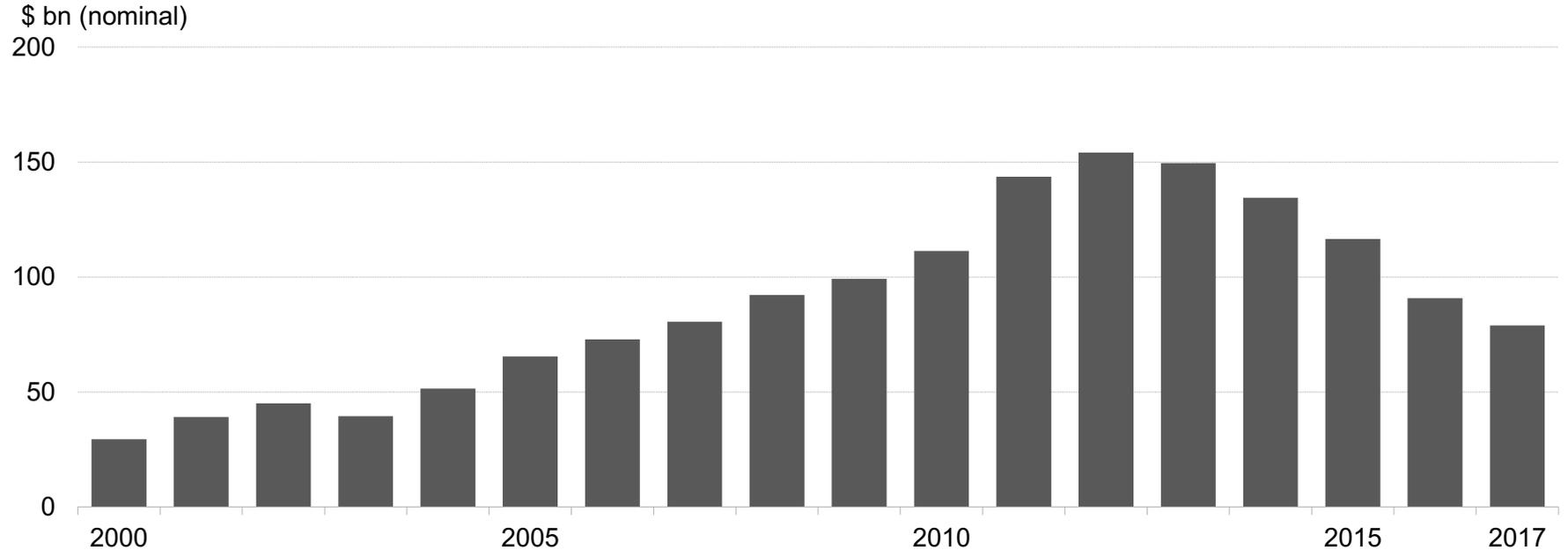


Image: Twitter

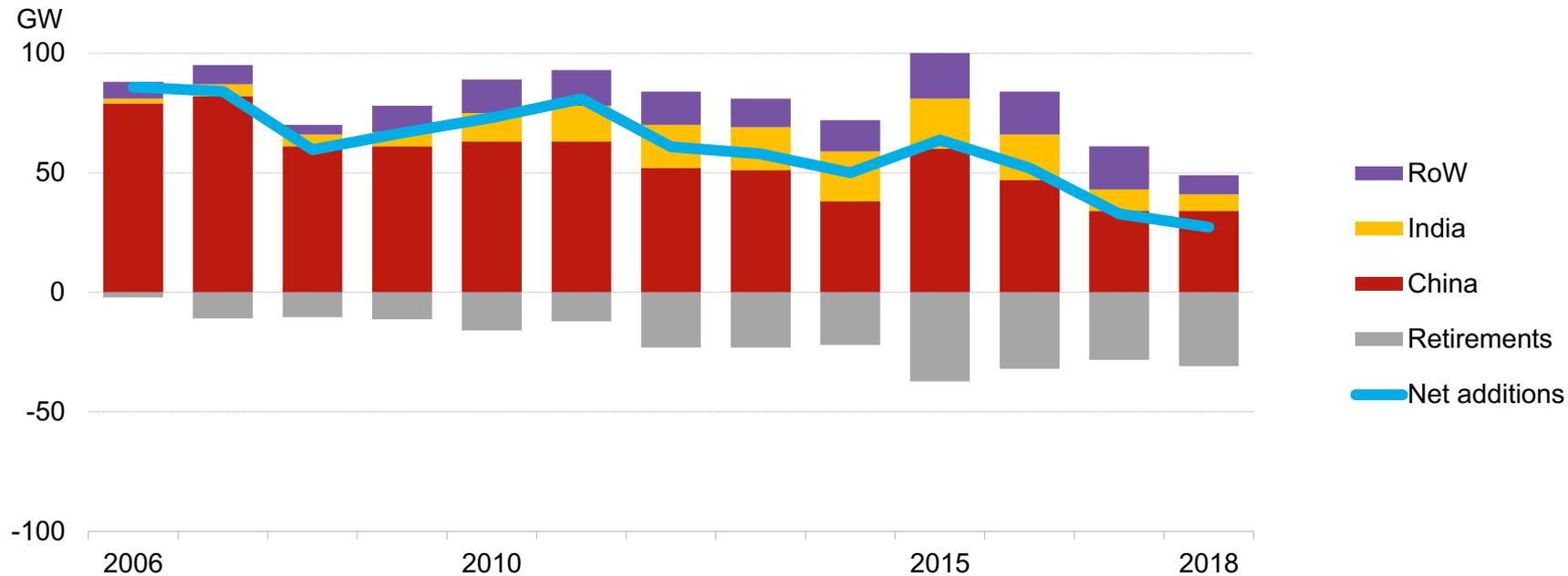
Global investment in coal supply 2000 – 2017

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Source: IEA

Net new coal generation capacity 2006 – 2018



Source: Liebreich Associates; Coalswarm

“

This is coal - don't be
afraid, don't be scared!

”

*Scott Morrison
Prime Minister of Australia*



Image: Bloomberg

Trump digs coal

July 2017

LIEBREICH
Associates

“

Everybody was saying, well, you won't get any mining jobs. We picked up 45,000 mining jobs

”

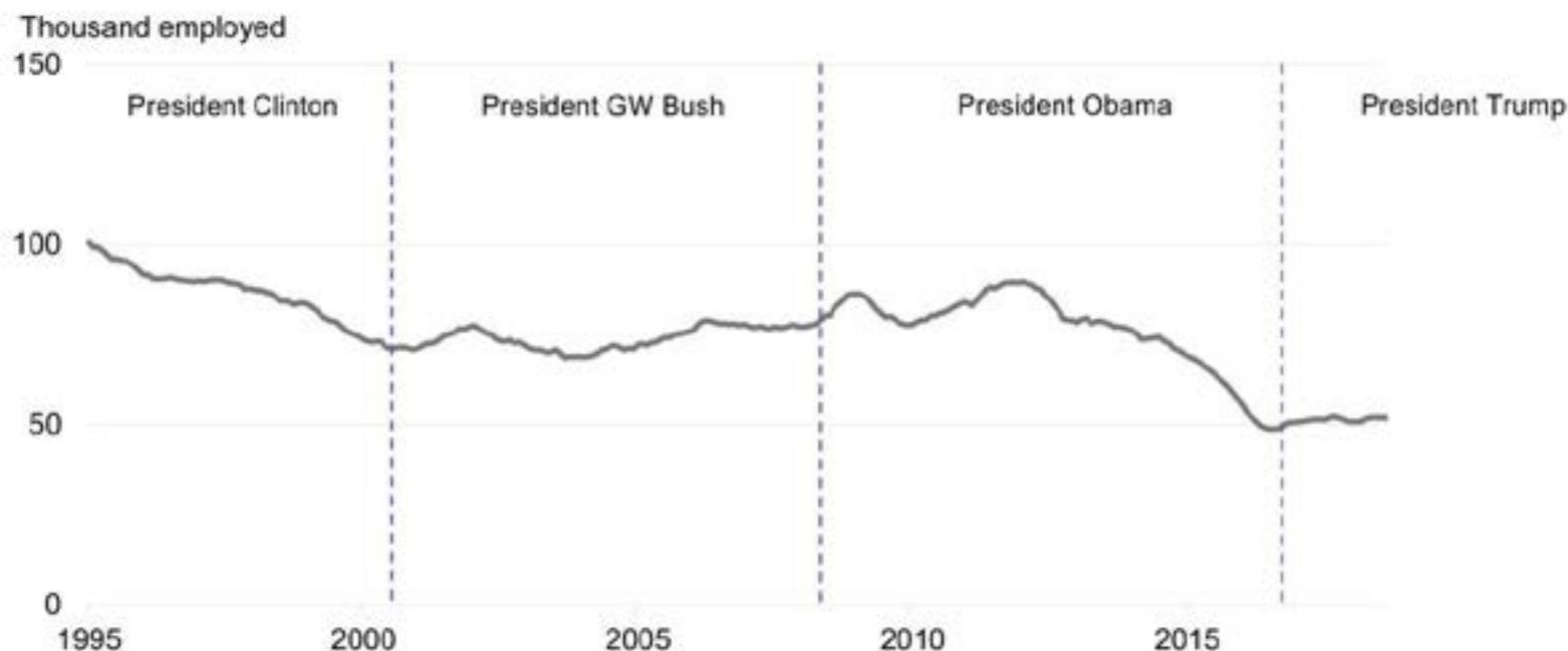
*Donald Trump
US President*



Image: Mark Lyons/Getty Images

US coal mining monthly employment Jan 1995 – Jan 2019

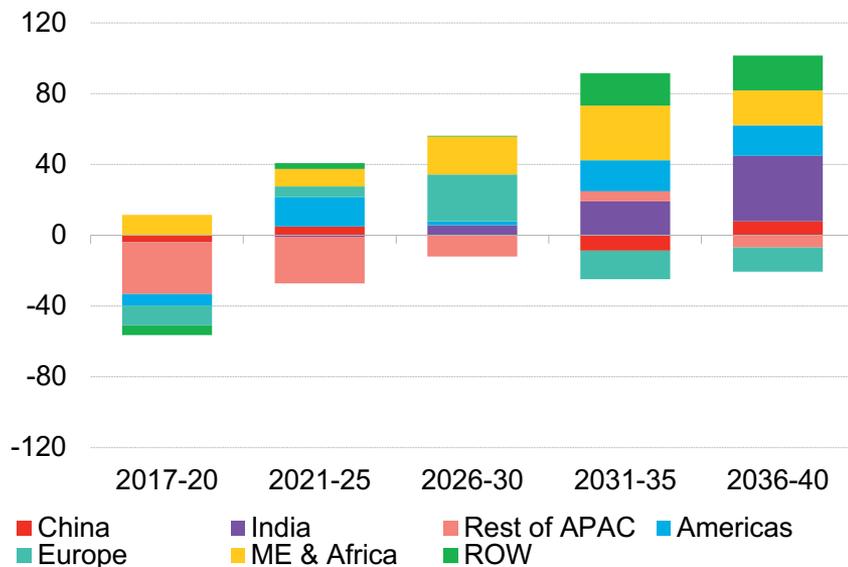
LIEBREICH
Associates



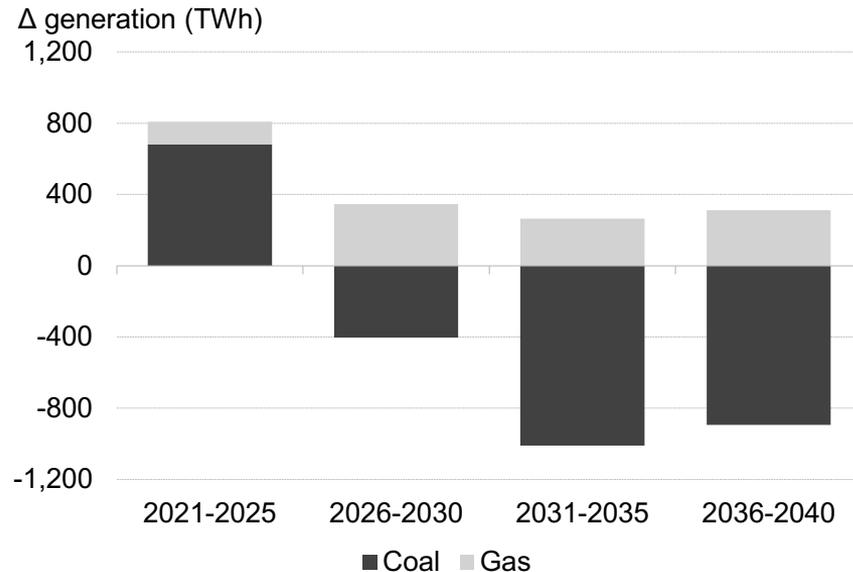
Source: U.S. Bureau of Labor Statistics

Gas plays an important role, but increasingly for flexibility only

Incremental change in gas consumption

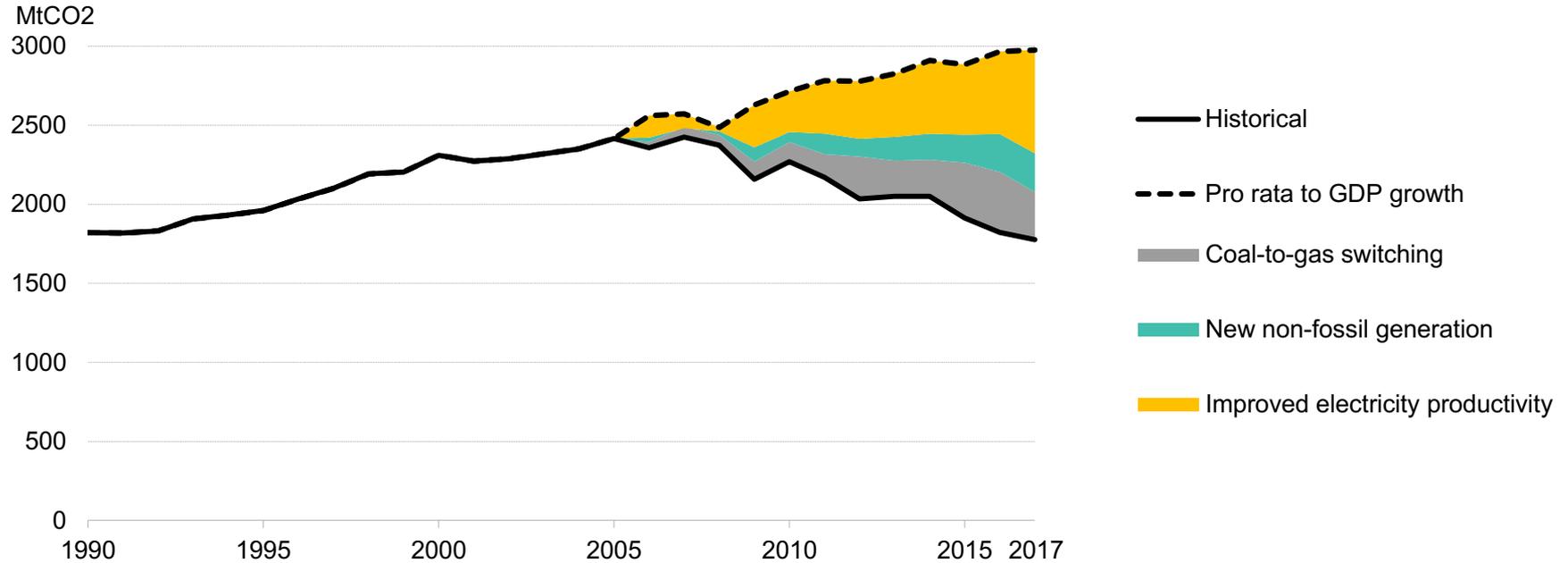


Incremental change in generation



Source: BNEF

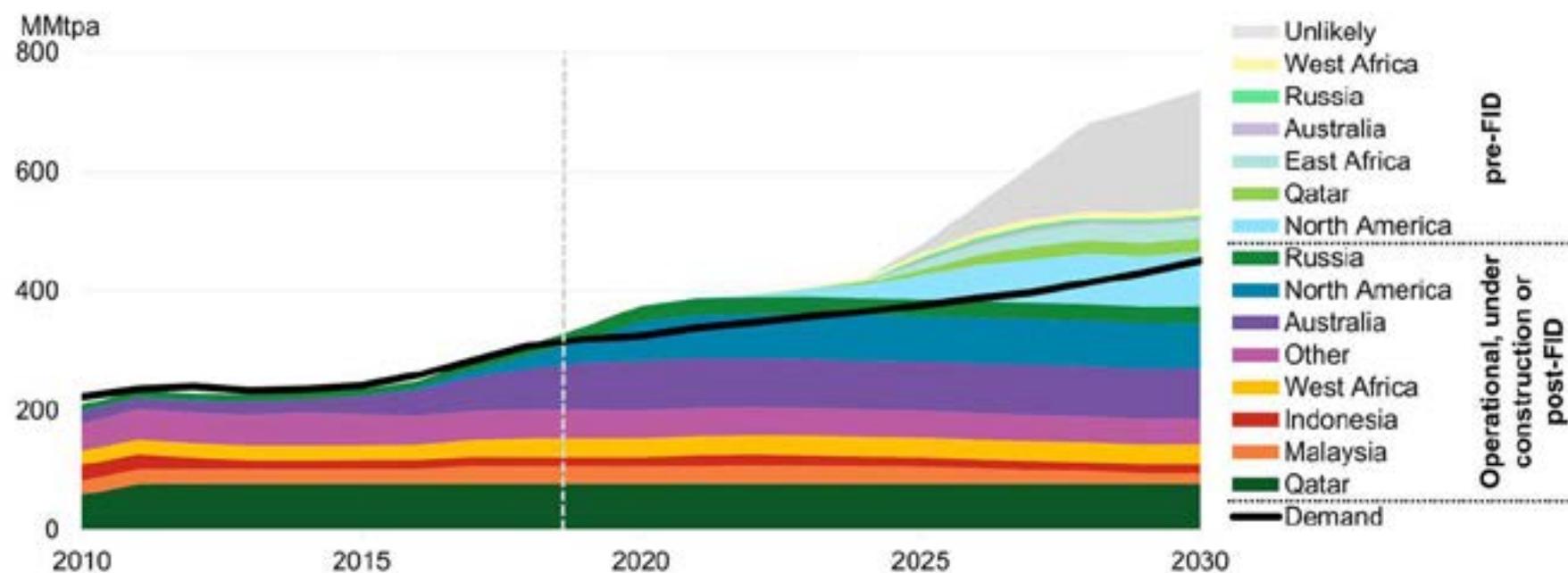
US electricity CO2 emissions 1990 – 2017



Note: 2017 figures are estimates; new non-fossil generation includes nuclear uprates

Source: EIA; Liebreich Associates; FRED

LNG export capacity by country/region



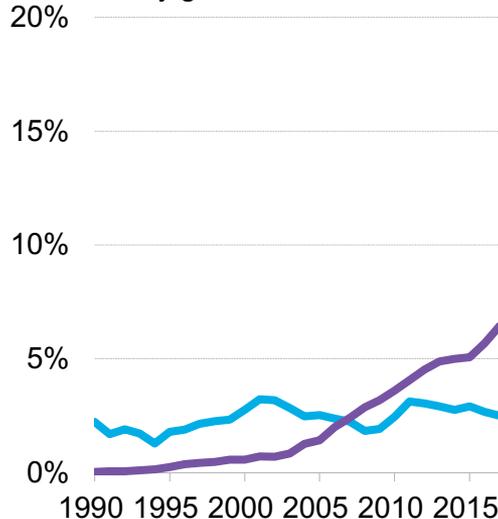
Note: Pre-final investment decision projects with <50% chance of success are included under unlikely

Source: BNEF

Nuclear vs. non-hydro renewable generation in selected countries 1990 – 2017

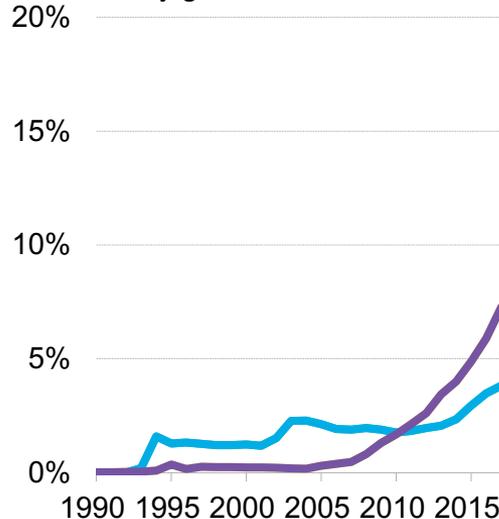
India

% electricity generation



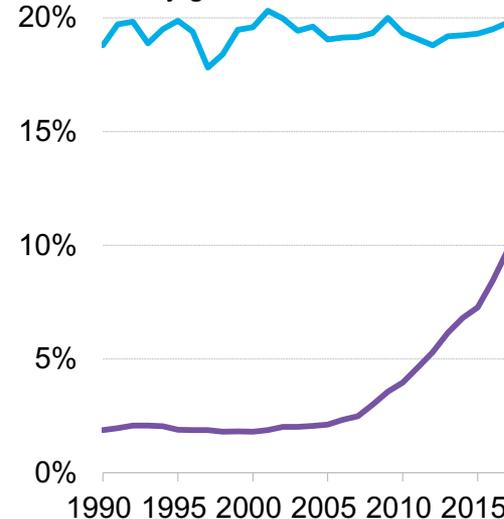
China

% electricity generation



U.S.

% electricity generation



— Nuclear — Non-hydro renewables

Source: BP; Liebreich Associates

Wind and solar are not taking over the world

“

Today, solar and wind make up just 0.8% of global energy. In a quarter century, solar and wind will produce less than 4% of global energy

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*Bjørn Lomborg
visiting professor at the Copenhagen Business School
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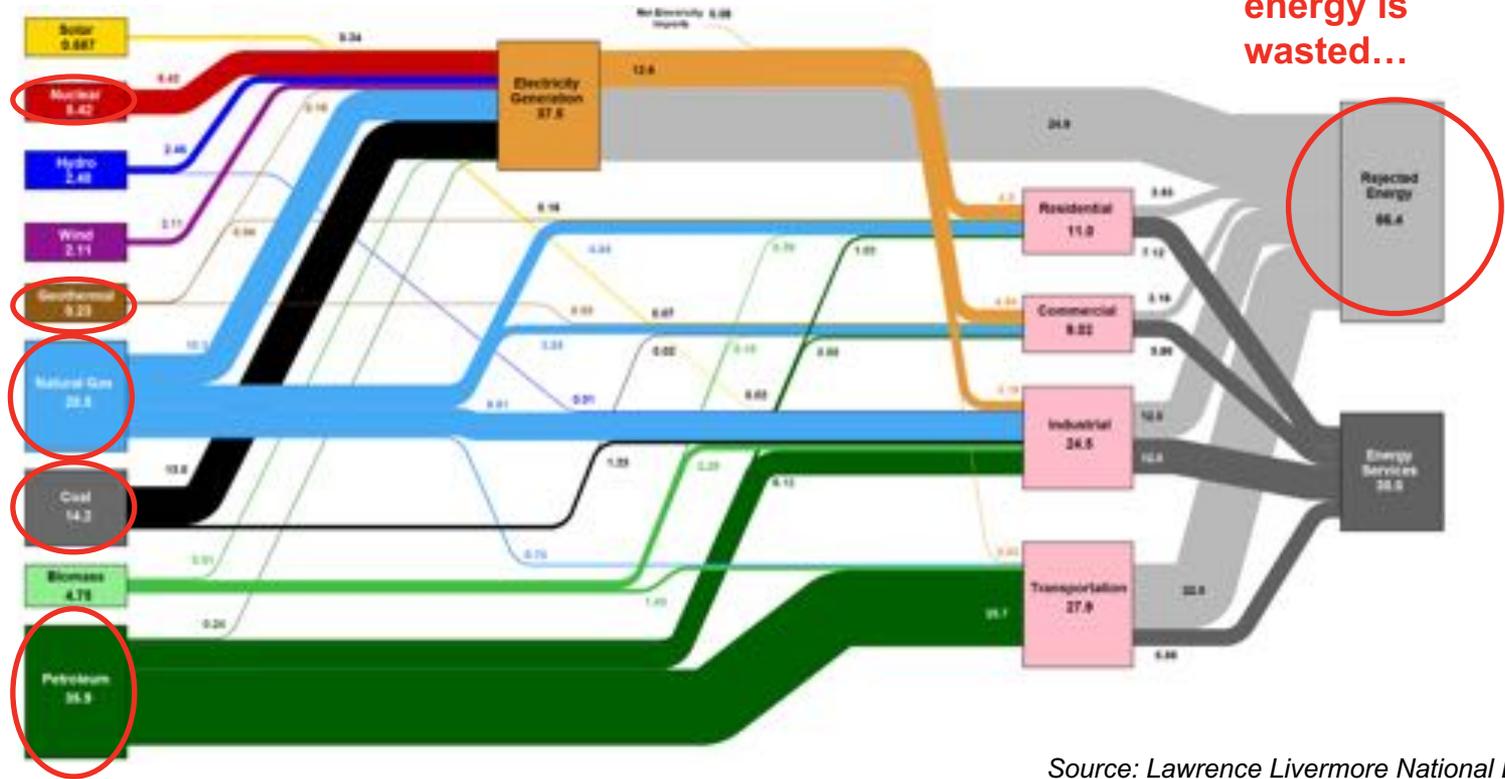
Image: Lomborg.com

Sankey for the U.S. in 2016

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Associates

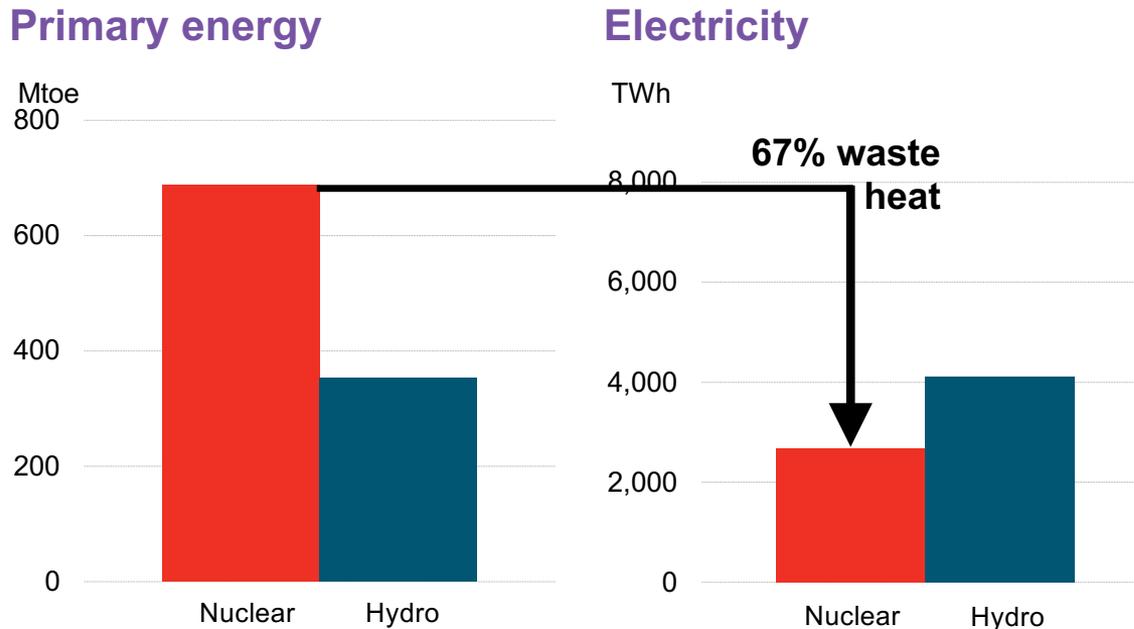
68% of primary
energy is
wasted...

...almost all
of it from
coal, oil, gas
and nuclear



Source: Lawrence Livermore National Lab

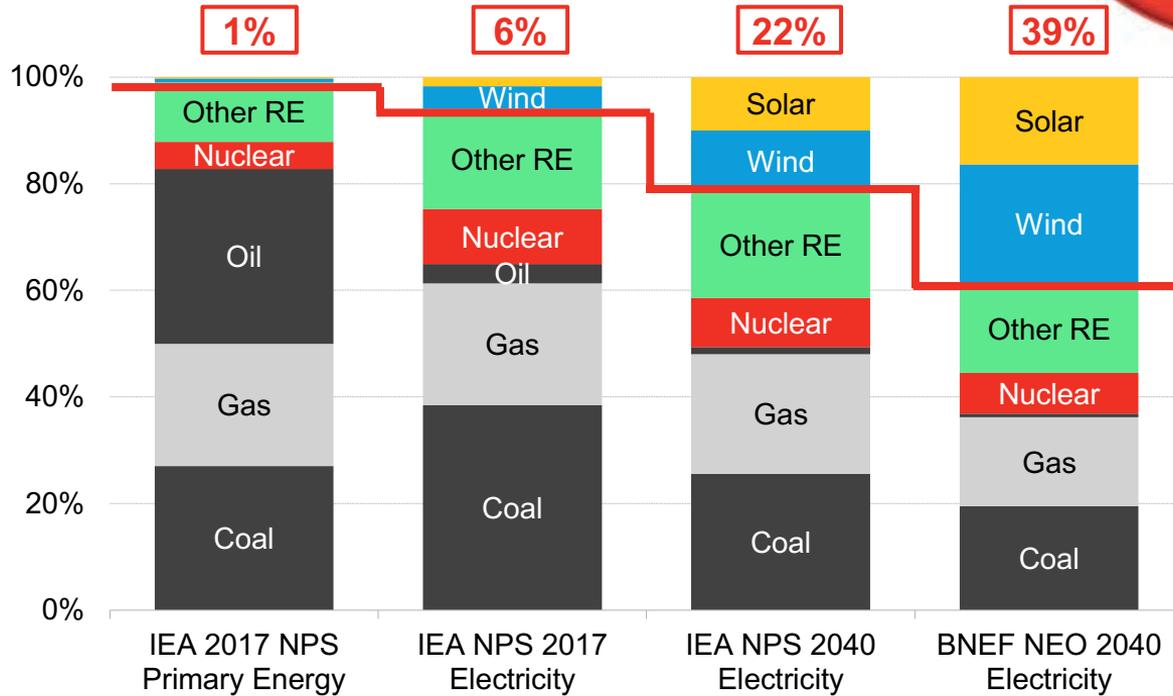
Primary energy, final consumption and electricity generation



Source: IEA WEO2018; Liebreich Associates

Wind and solar contribution to global power generation

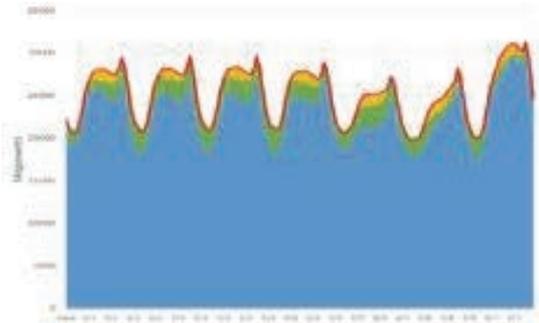
By 2040
20 to 39% of power globally will be from variable sources



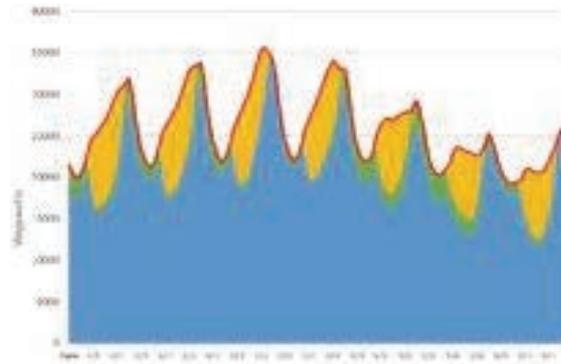
Source: BNEF NEO 2018; IEA WEO 2018; Liebreich Associates

Evolving structure of power supply California

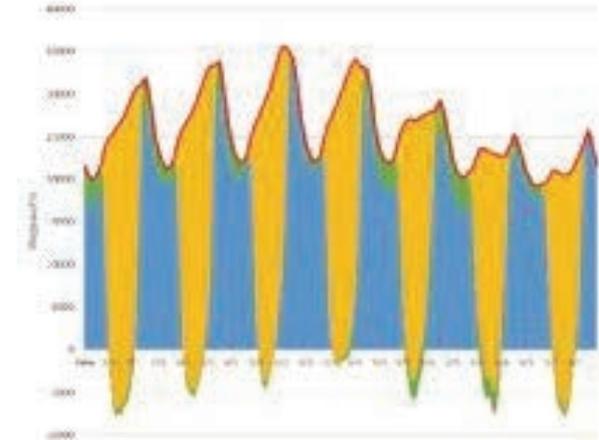
First week of May 2012
(actual)



First week of May 2017
(actual)



First week of May 2030
(modelled)



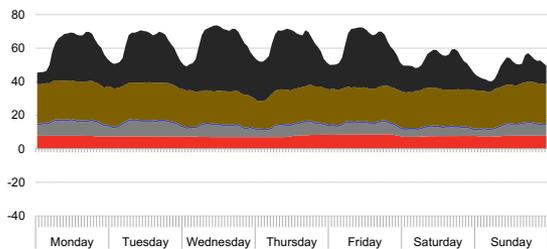
■ Solar ■ Wind ■ Net Load ■ Demand

Source: CAISO OASIS; CPUC; LS Power; CESA; BNEF

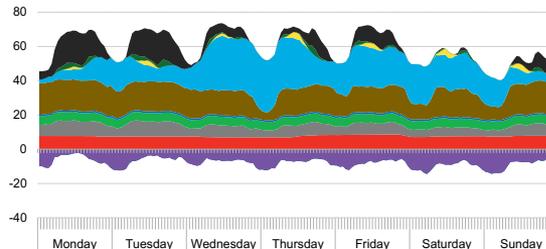
Evolving structure of power supply

Northern Europe

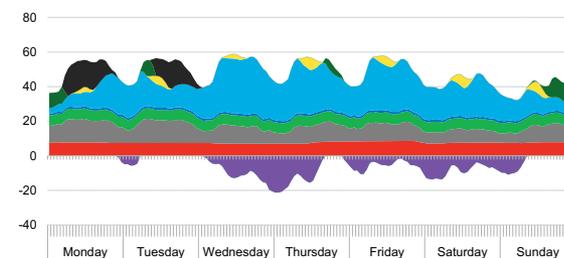
Past – winter



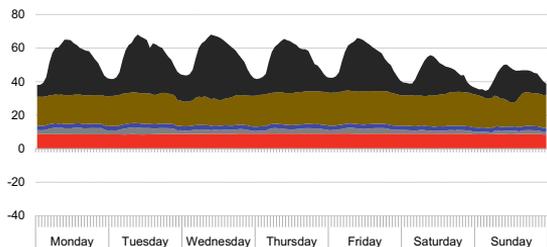
Current – winter



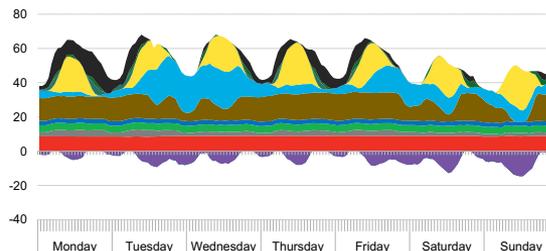
Future – winter



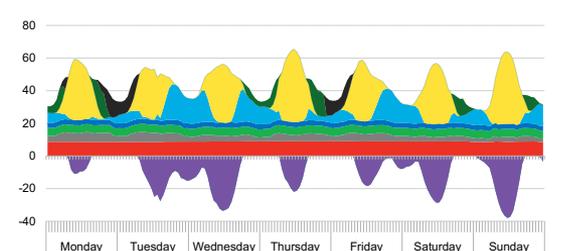
Past – summer



Current – summer



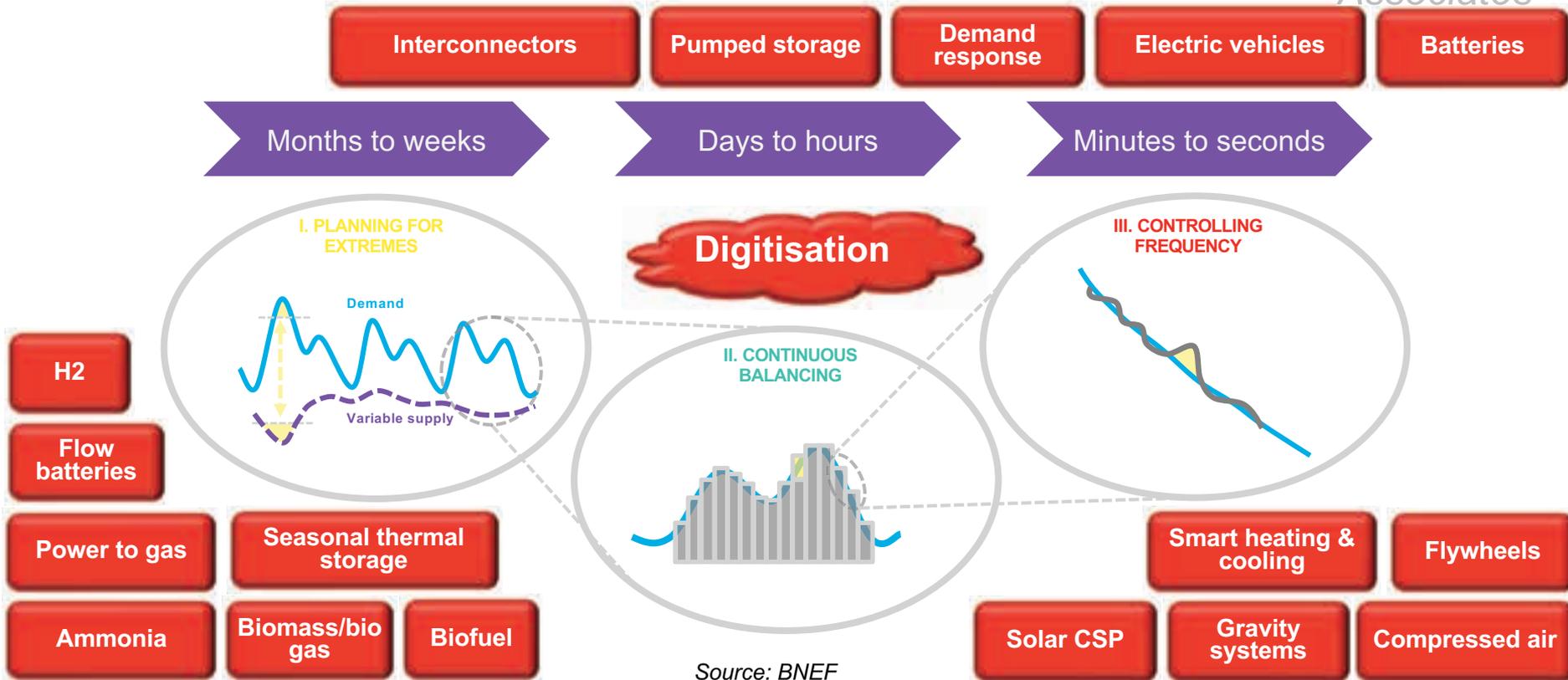
Future – summer



■ Peaking fossil
 ■ Baseload fossil
 ■ Nuclear
 ■ CHP
 ■ Hydro
 ■ Baseload RE
 ■ Solar
 ■ Wind
 ■ Pumped hydro generation/Storage
 ■ Imports
 ■ Exports/curtailment/DR

Source: BNEF

Balancing the grid



2040: Welcome to the Three-Third World

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Associates



1/3 of electricity
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1/3 of vehicles will be
electric



Economy will be 1/3 more
energy productive

Images: Tesla, Wallpaper Mania, Cleantecnica

The future of transportation – EVs

“ Prices on electric cars will continue to drop until they're within reach of the average family. ”

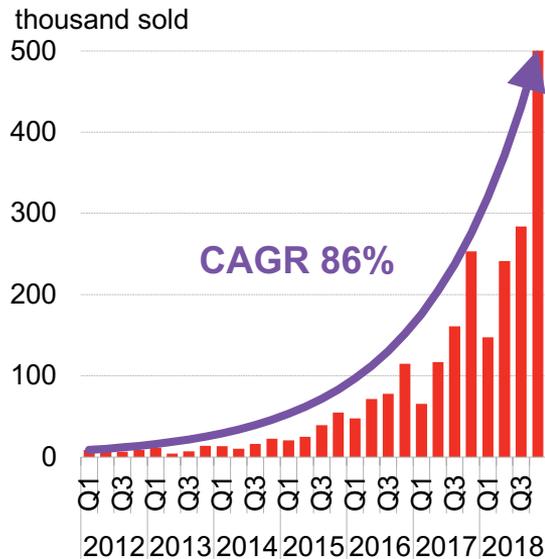


*The Washington
Post, 1915*

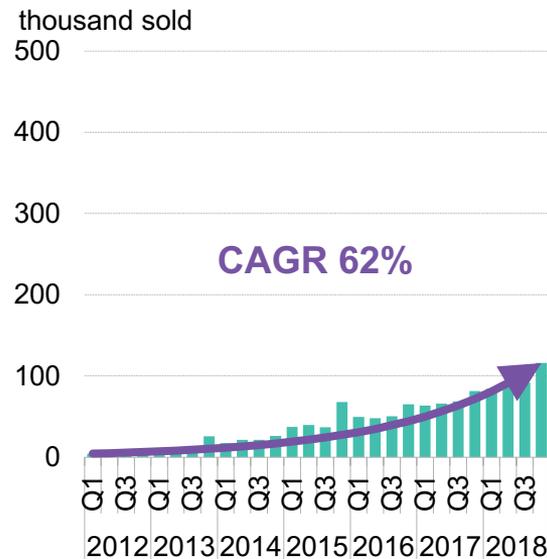
Image: Tesla; Detroit Electric, courtesy of EVASD

Quarterly EV sales by region Q1 2012 – Q4 2018

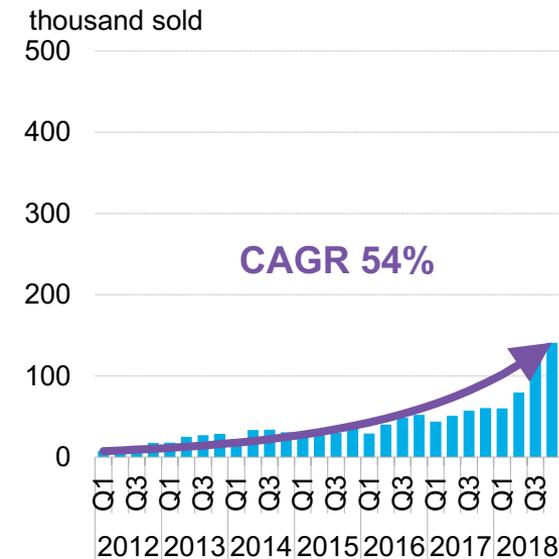
APAC



EMEA



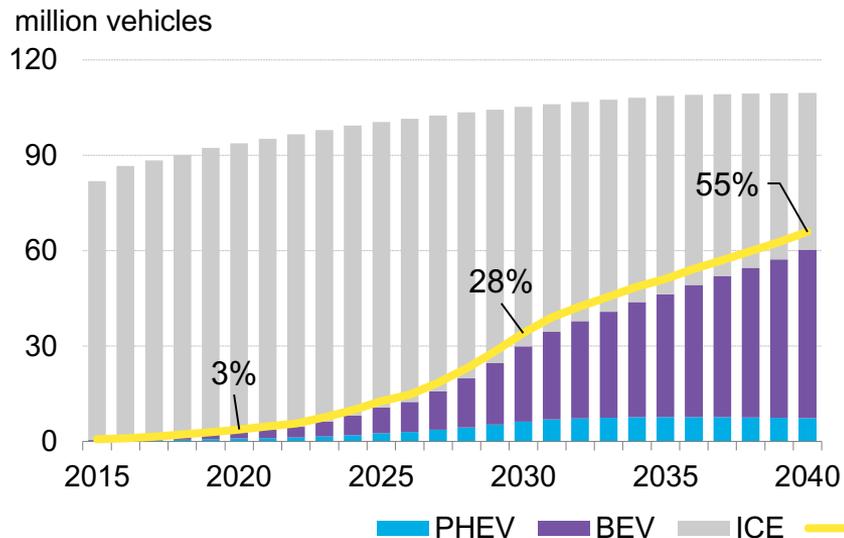
AMER



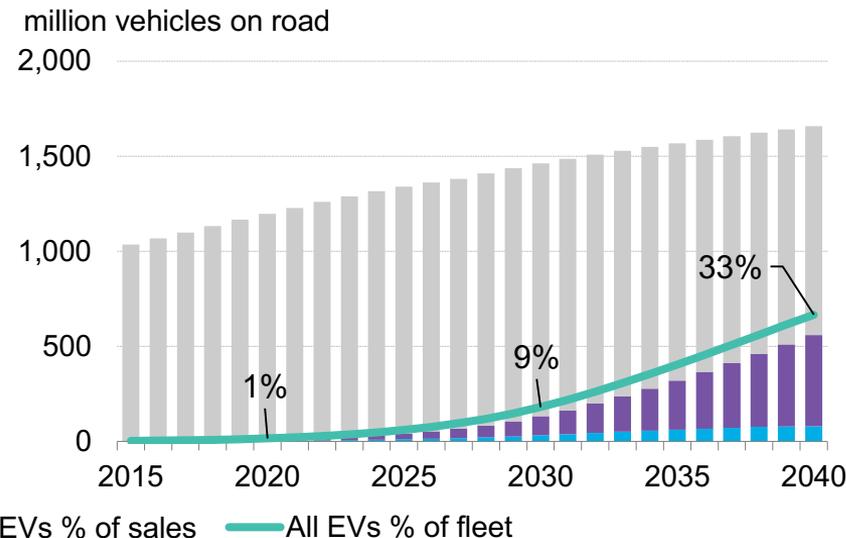
Source: BNEF

BNEF electric vehicle outlook to 2040

Annual global light duty vehicle sales

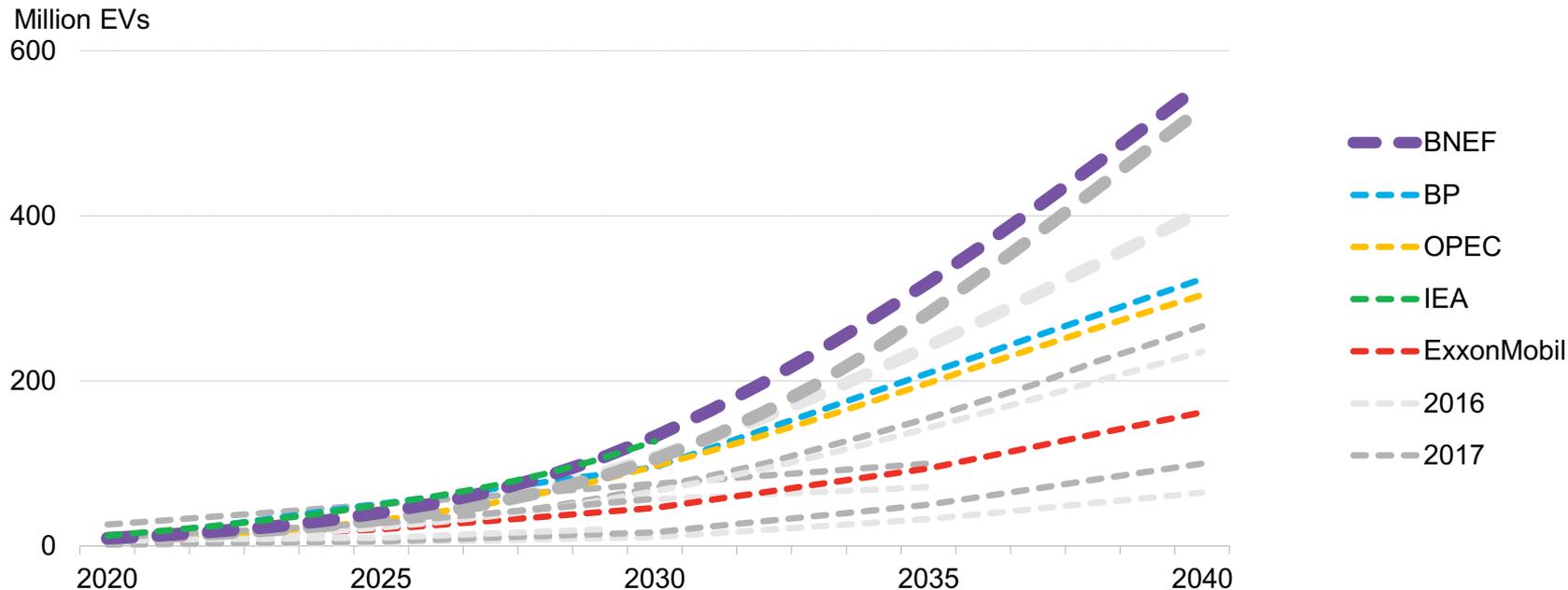


Global light duty vehicle fleet



Source: BNEF EVO 2018

Global EV fleet forecasts by various organisations – 2018

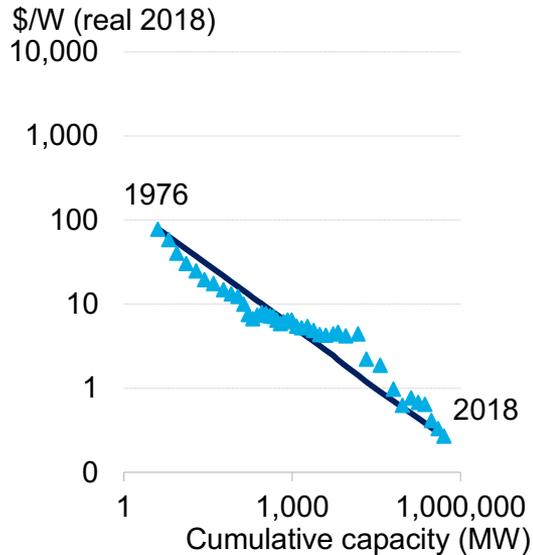


Notes: IEA values are base case. ExxonMobil and IEA forecasts prior to 2018 include BEVs, PHEVs and FCVs; all other forecasts include just BEVs and PHEVs.

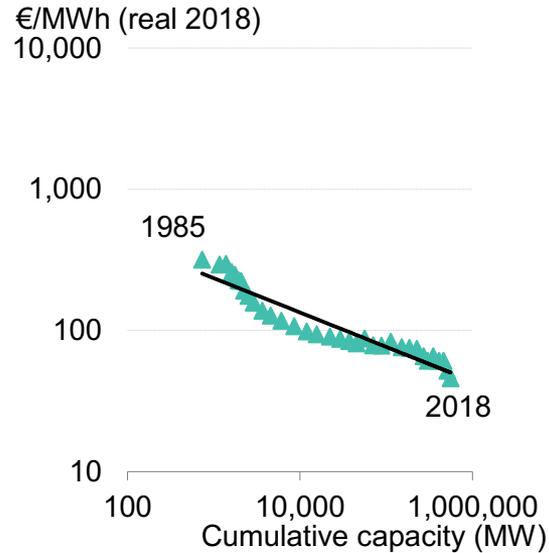
Sources: BNEF; BP; Exxon Mobil; OPEC; IEA

Experience curves

Solar – learning rate 28.5%



Wind – learning rate 15%



Batteries – learning rate 20%



Source: BNEF

US medium BEV price breakdown, share of battery costs and ICE price



Source: BNEF EVO 2018

Shanghai, China

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Associates



Image: Michael Liebreich

Delhi, India

LIEBREICH
Associates



Image: Newsclick India

Paris, France

LIEBREICH
Associates



Image: DENNIS/Creative Commons

London, UK

LIEBREICH
Associates



Image: HHRCA

Madrid, Spain

LIEBREICH
Associates



Image: Majadahonda; Plume Labs



Dieselgate

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Associates



Image: Flickr

Dieselgate



Image: Jassen Todorov/National Geographic

Global EV model availability

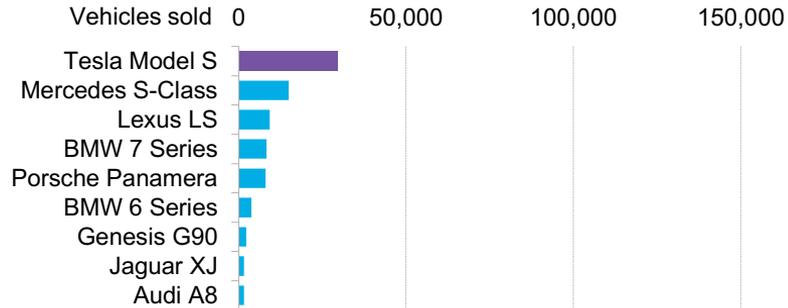
LIEBREICH
Associates



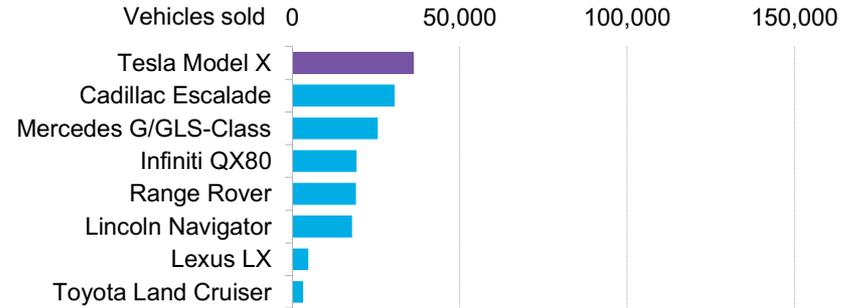
Source: BNEF EVO 2018

US car sales 2018

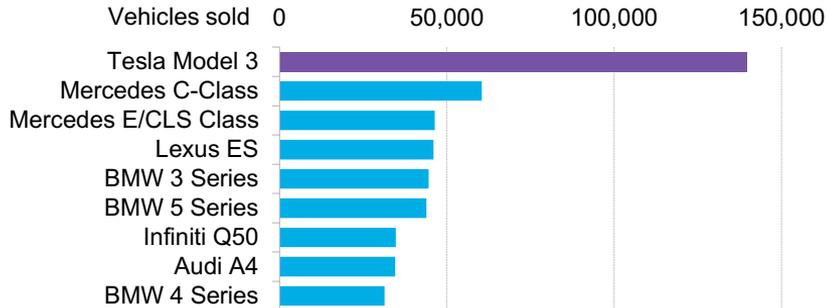
Large luxury cars



Luxury SUVs



Small & midsize luxury cars



Next up...



Source: Cleantechnica; Liebreich Associates; Business Insider

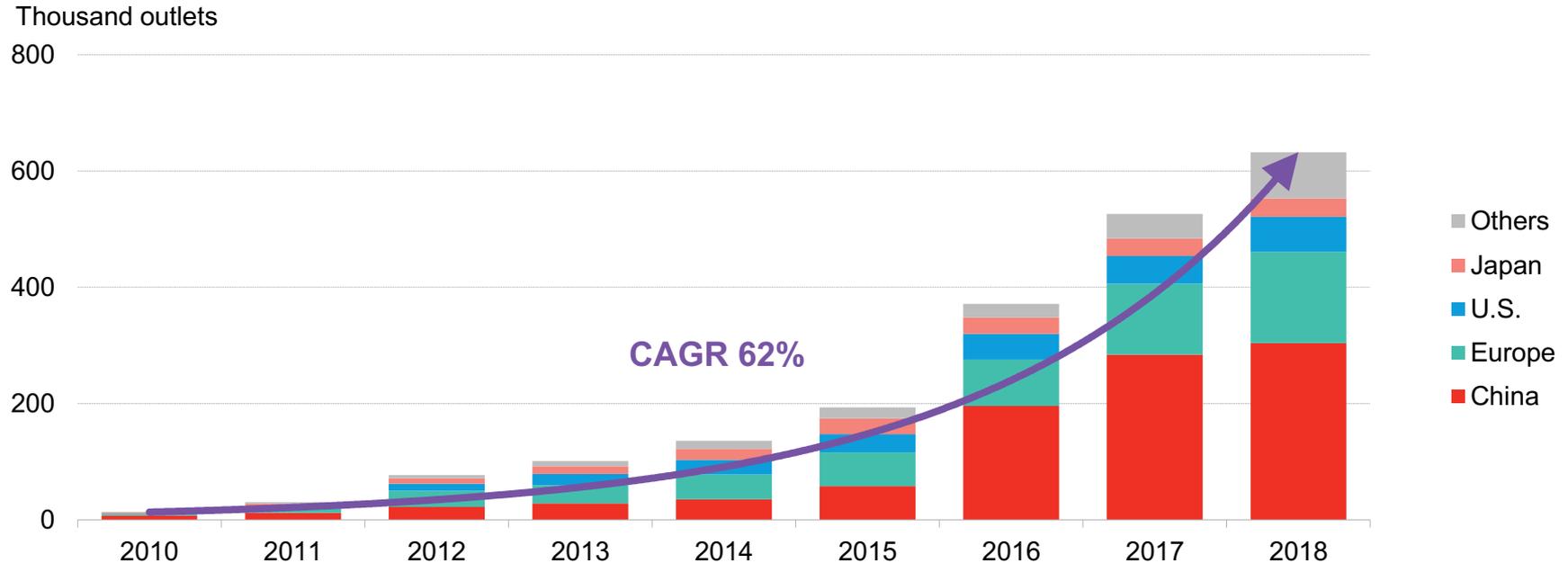
Dyson electric car prototype?

LIEBREICH
Associates



Image: GQ; Royal College of Art

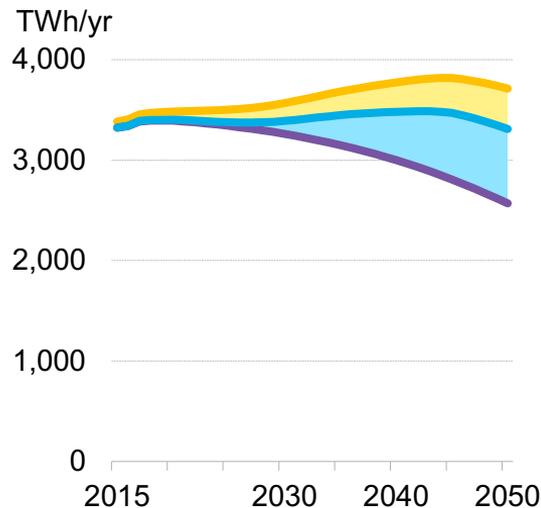
Public EV charging points installed globally 2008 – 2018



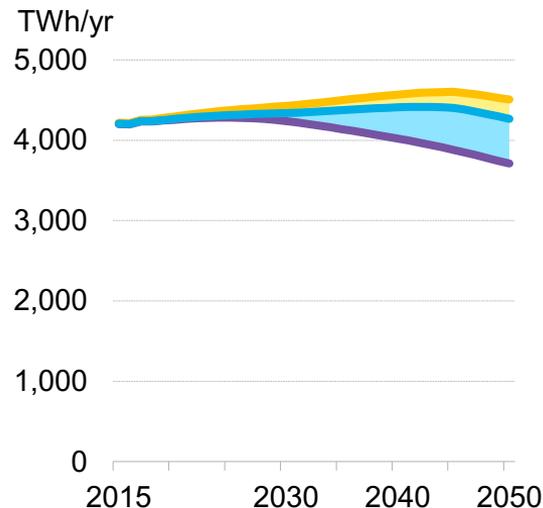
Source: BNEF EVO 2018

Impact of EVs on power demand

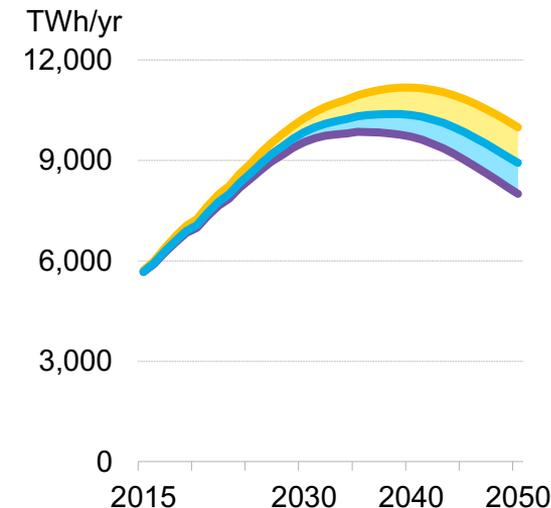
Europe



U.S.



China

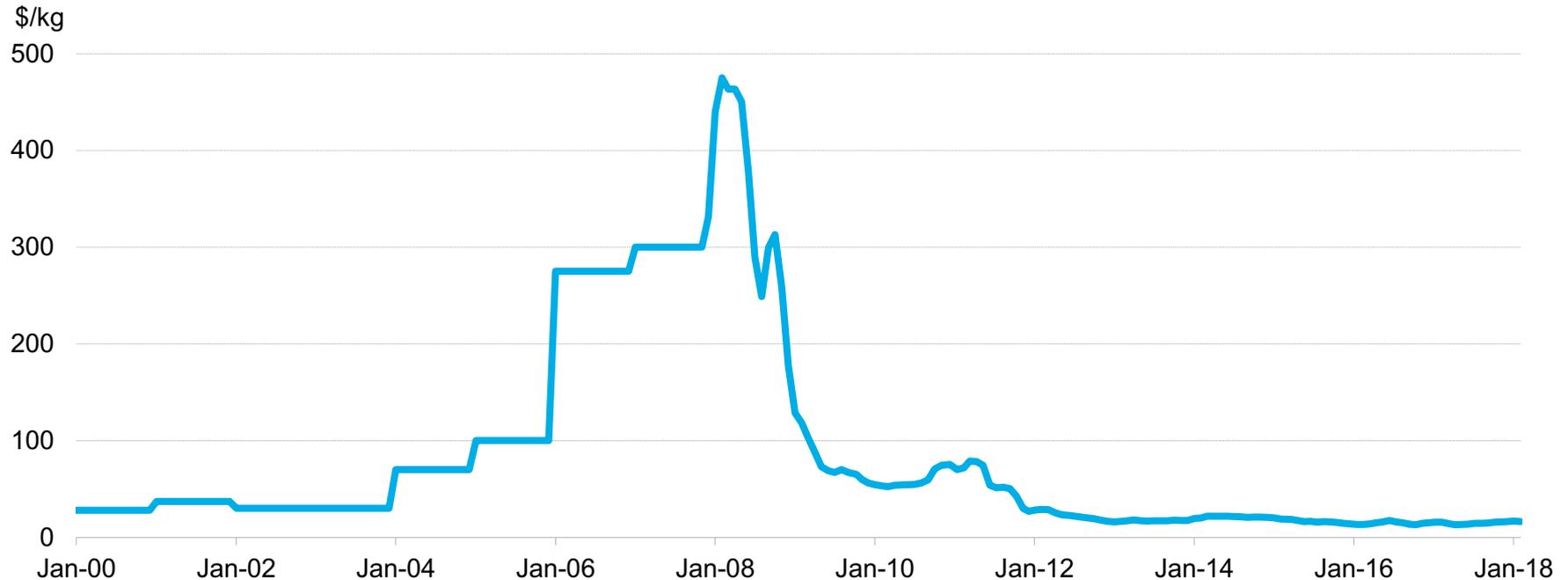


— Gross demand — Rooftop PV — Net demand — Net demand + EV — EV demand

Note: EV demand includes light duty vehicles only; Europe and US EVs are 19% of the fleet by 2040; Chinese EVs are 28% of LDV fleet by 2040

Source: BNEF NEO 2018; Liebreich Associates

Spot price of solar-grade silicon, year 2000 – February 2018

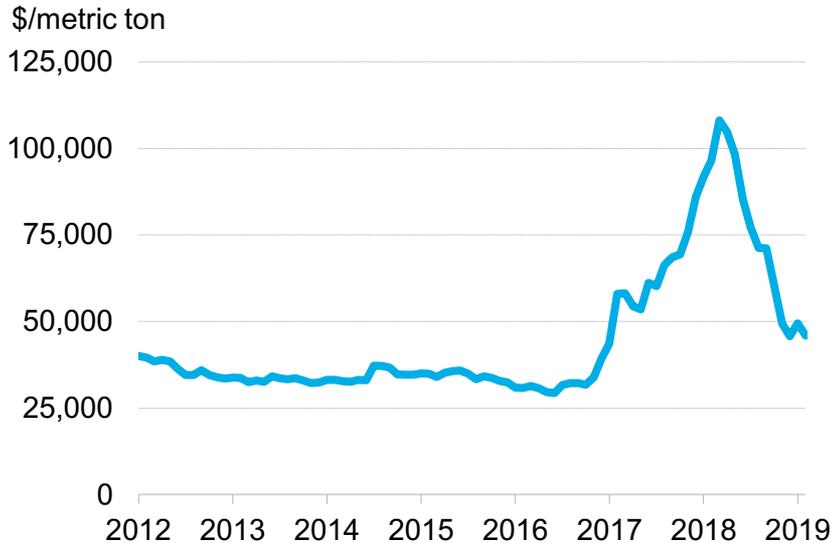


Notes: Annual data 2000-07 from various industry sources. Data November 2007–May 2009 based on a 3-point moving average of actual spot deals. Consistent monthly data collection using the Spot Price Index began in May 2009.

Source: Various, BNEF

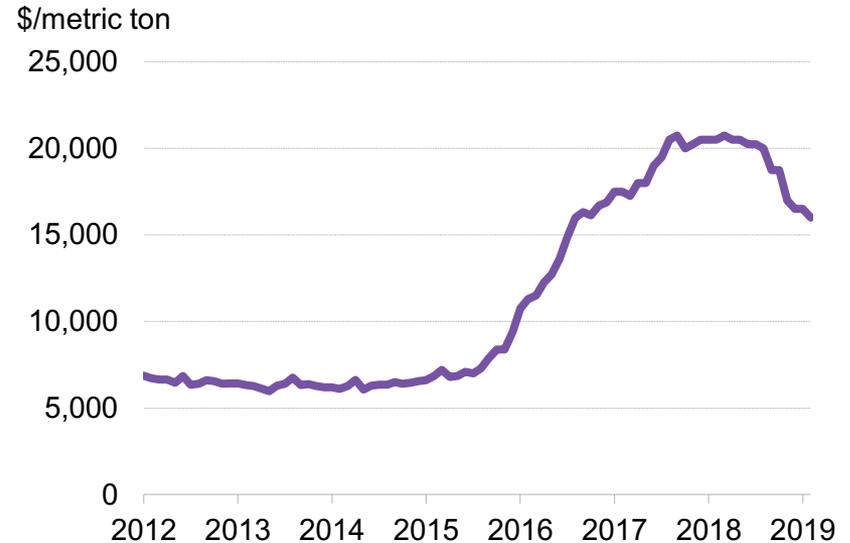
Cobalt and lithium prices

China Shanghai Cobalt



Note: Data up to Feb 2019

Asia Lithium Hydroxide

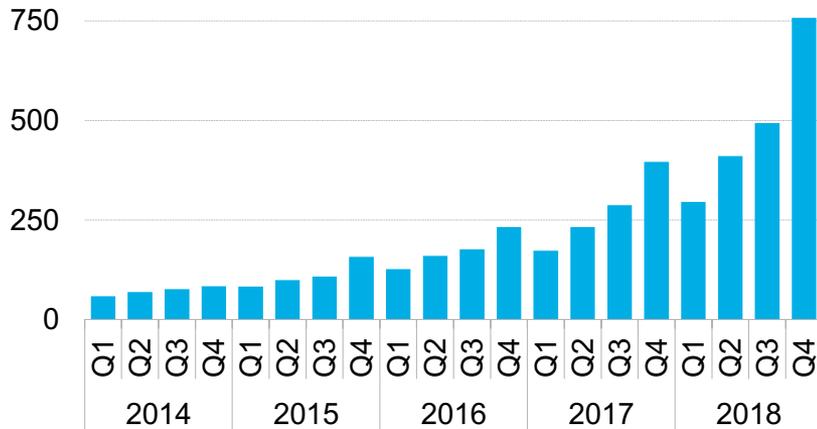


Source: Antaika Information Development Co., Bloomberg; Benchmark Mineral Intelligence; BNEF

Global BEV vs. FCV sales

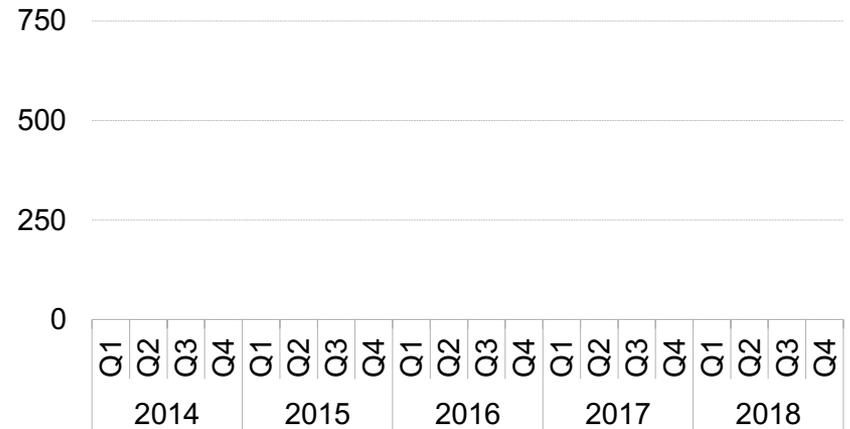
Battery electric vehicles

Thousand units
1,000



Fuel cell vehicles

Thousand units
1000



Source: BNEF

Hydrogen fuel cell vs battery vehicles

LIEBREICH
Associates

Tesla Model 3



Toyota Mirai



Price:	\$49,000	\$57,500
Curb weight:	1,730 kg	1,850 kg
Range:	310 miles	312 miles
Refuel time, motorway:	50 minutes – 200 miles	10 minutes – 300 miles
Refuel time, home:	1 minute	N/A
Drive train moving parts:	17	> 200
Wind-to-wheel efficiency:	> 61%	< 32 %

Images: Tesla; Toyota; Source: Liebreich Associates

Hydrogen fuel cell vs battery vehicles

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Images: Tesla; Toyota; Source: Liebreich Associates

Not just cars going electric – buses

LIEBREICH
Associates



Images: Thomas Jouley; BYD; Proterra

Not just cars going electric – commercial vehicles



Images: Tesla; Starship Technologies; Ehang; Zunum; Daimler; Dpost; UPS/Arrival

Not just cars going electric – 2 & 3 wheelers

LIEBREICH
Associates



Images: Toyota; Omastar ; Kalkhoff; Jetson; Harley Davidson

Not just cars going electric

LIEBREICH
Associates



Image: Pon Equipment

Not just cars going electric – ships

LIEBREICH
Associates



Images: Alf Kare Aesobo; Kongsberg; Enercon

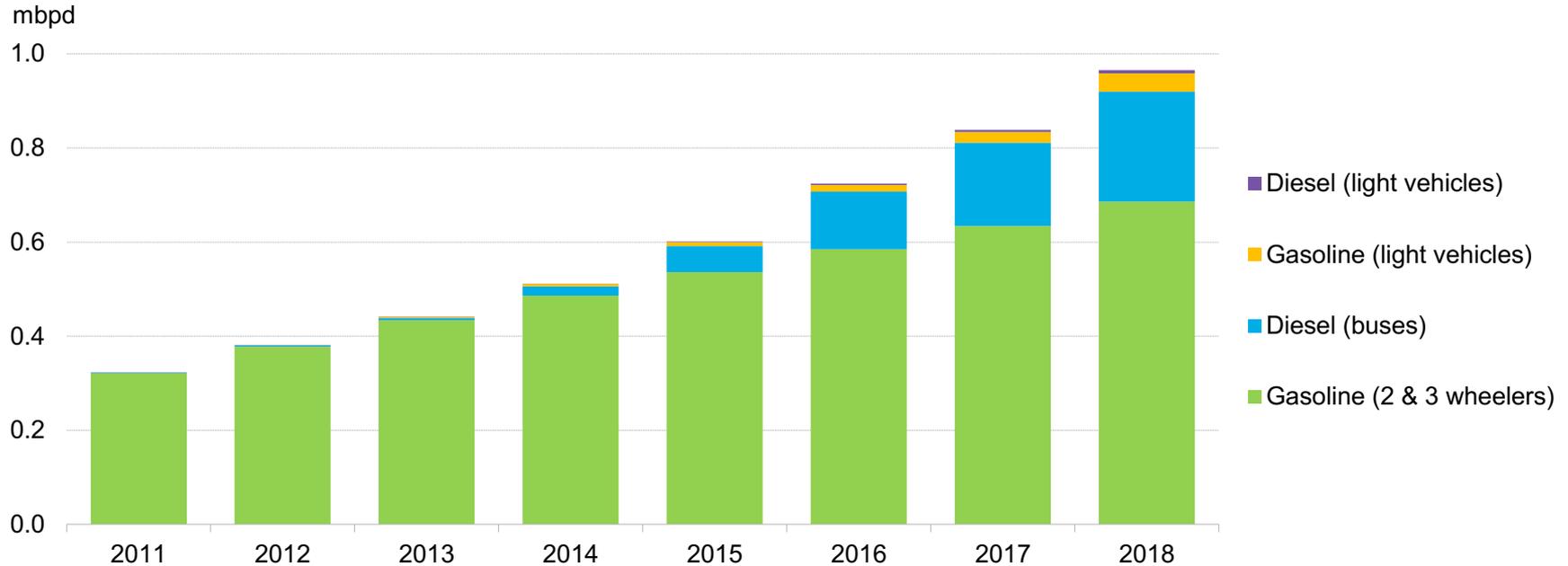
Not just cars going electric

LIEBREICH
Associates



Images: Pipistrel; Ehang; Lilium; Airbus; Zunum; NASA

Cumulative oil displacement by electric vehicles



Source: BNEF; Liebreich Associates

European oil majors power sector moves, 2011 – 2018

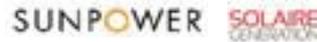
LIEBREICH
Associates

Technology

Generation

Trading and retailing

EV charging



Source: BNEF; Companies

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
will be wind and solar



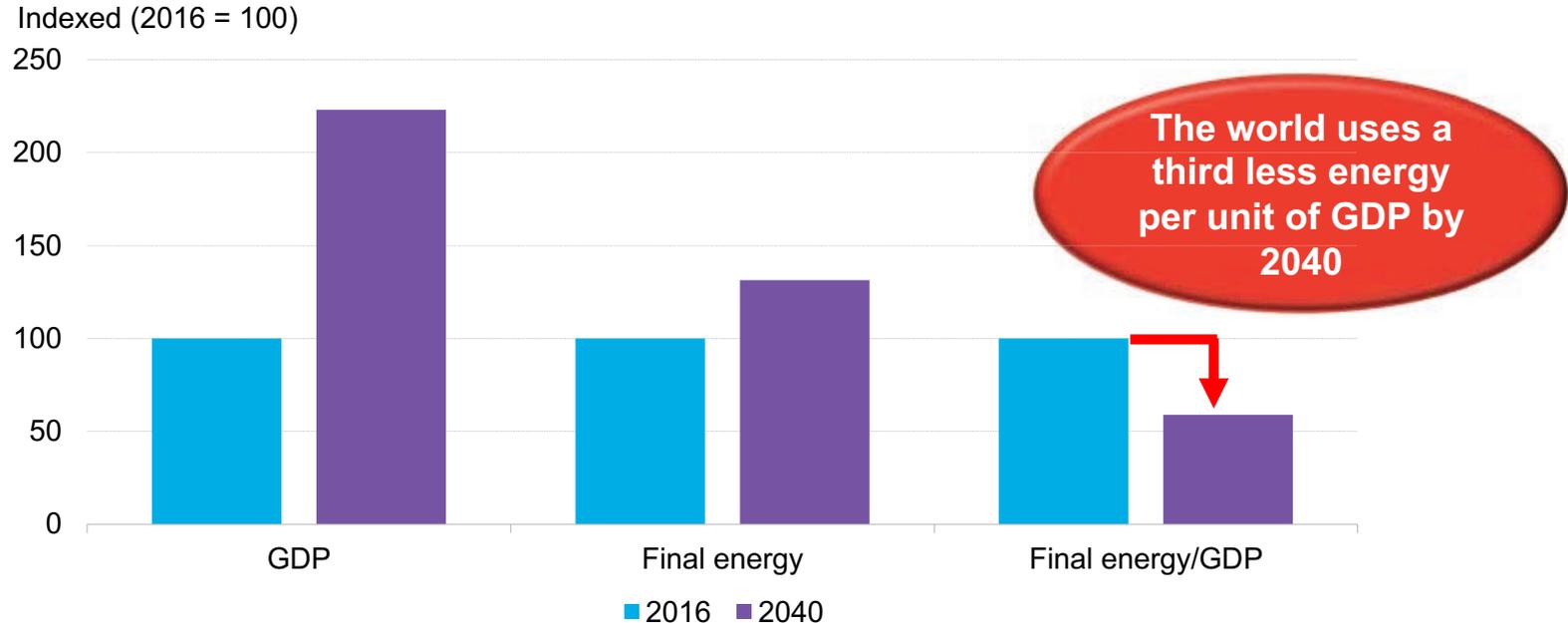
1/3 of vehicles will be
electric



Economy will be 1/3 more
energy productive

Images: Tesla, Wallpaper Mania, Cleantechnica

World GDP, final energy and energy intensity by 2040



Note: Using IEA New Policies Scenario

Source: Liebreich Associates; IEA

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
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1/3 of vehicles will be
electric

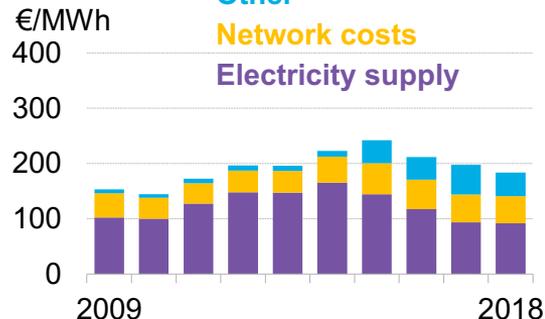


Economy will be 1/3 more
energy productive

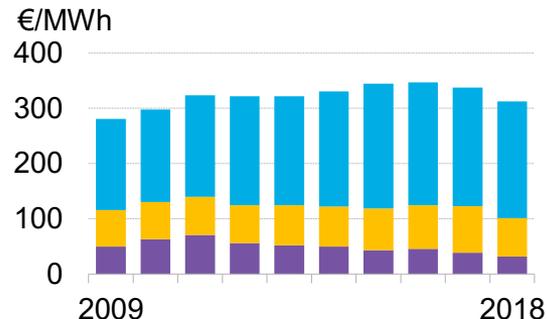
Images: Tesla, Wallpaper Mania, Cleantecnica

Residential electricity prices by cost segment

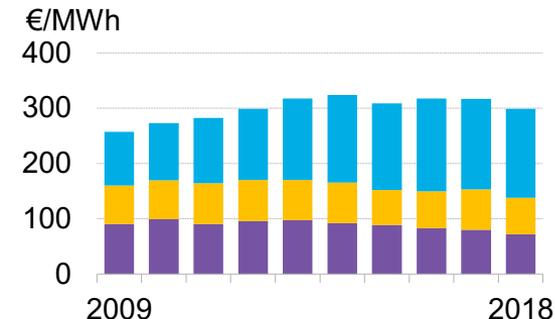
U.K.



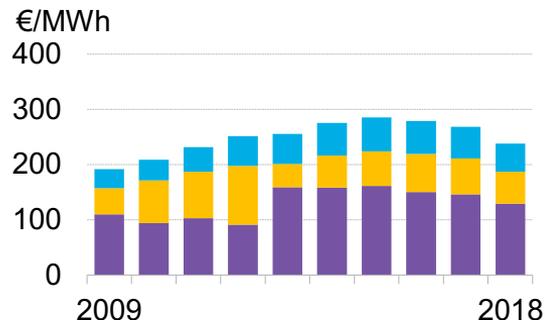
Denmark



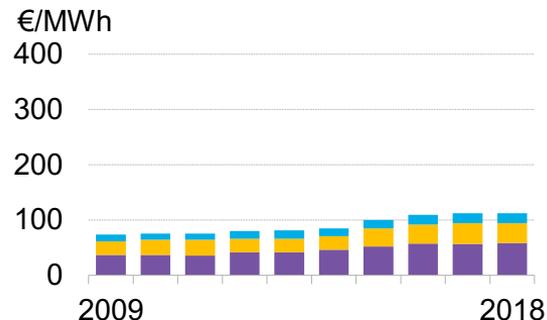
Germany



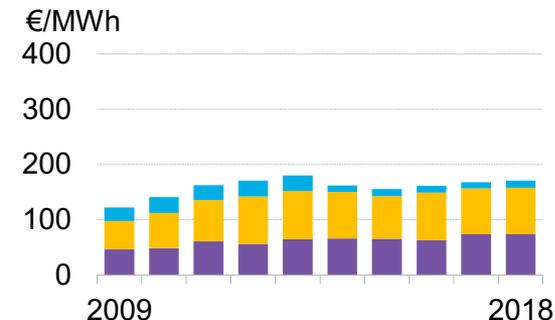
Spain



U.S. (average)



Australia

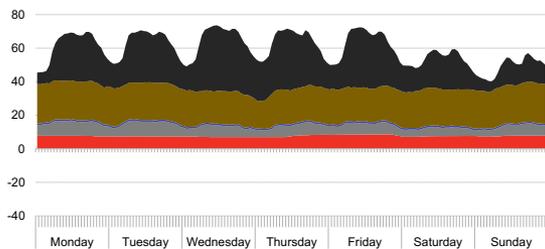


Note: Australian data excludes the carbon price repealed in 2014. EU data only available until H1 2018. Other includes taxes, levies and FITs.

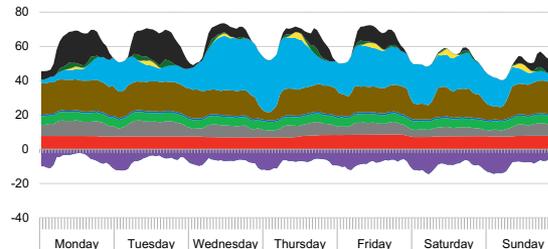
Source: EIA; AEMC; Eurostat; BNEF; Liebreich Associates

Evolving structure of power supply Germany

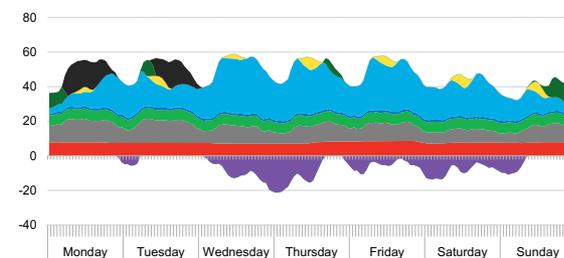
Past – winter



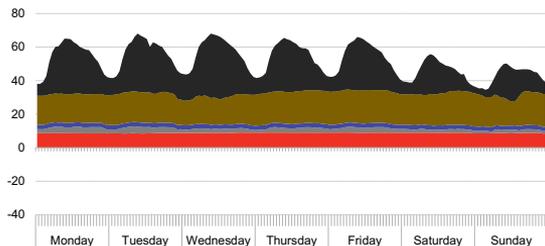
Current – winter



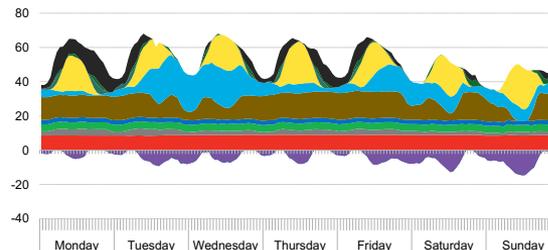
Future – winter



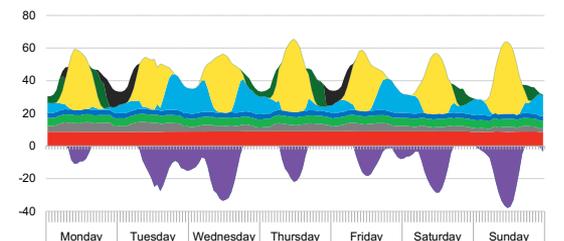
Past – summer



Current – summer



Future – summer



■ Peaking fossil ■ Baseload fossil ■ Nuclear ■ CHP ■ Hydro ■ Baseload RE ■ Solar ■ Wind ■ Pumped hydro generation/Storage ■ Imports ■ Exports/curtailment/DR

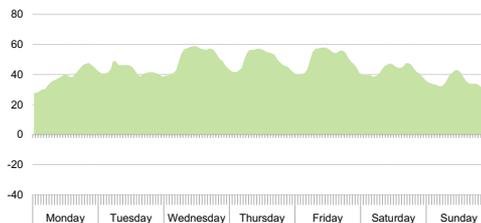
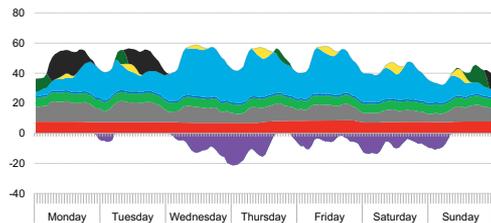
Source: BNEF

Future power supply

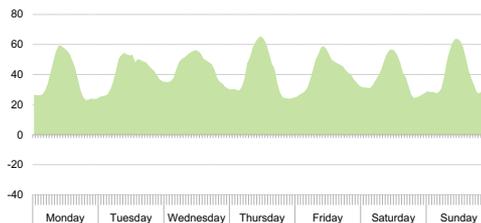
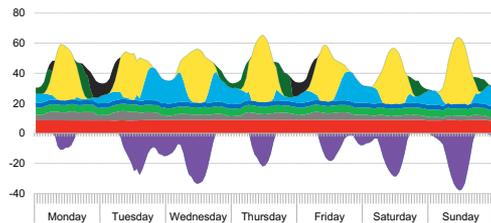
Total generation

Low carbon generation

Winter



Summer



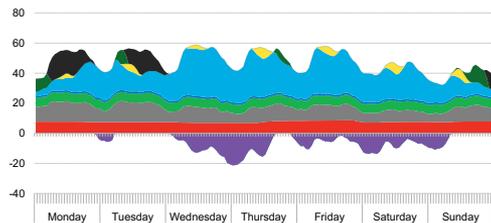
Peaking fossil
 Baseload fossil
 Nuclear
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 Hydro
 Baseload RE
 Solar
 Wind
 Pumped hydro generation/Storage
 Imports
 Exports/curtailment/DR

Source: BNEF

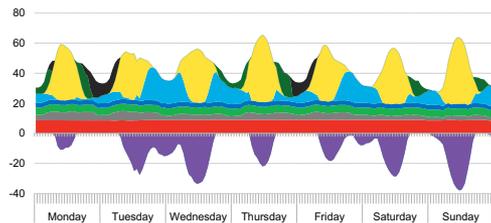
Future power supply

Total generation

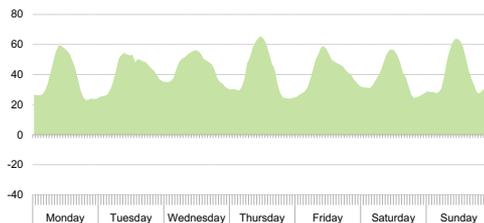
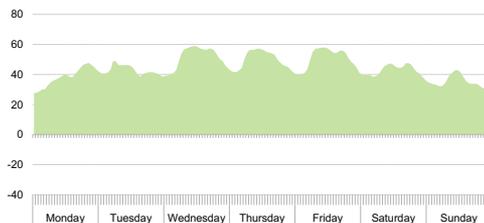
Winter



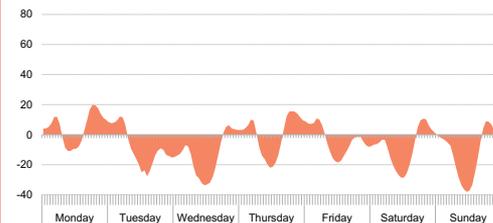
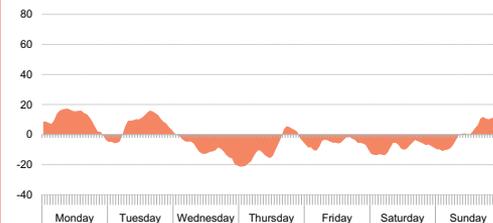
Summer



Low carbon generation



Flexible generation



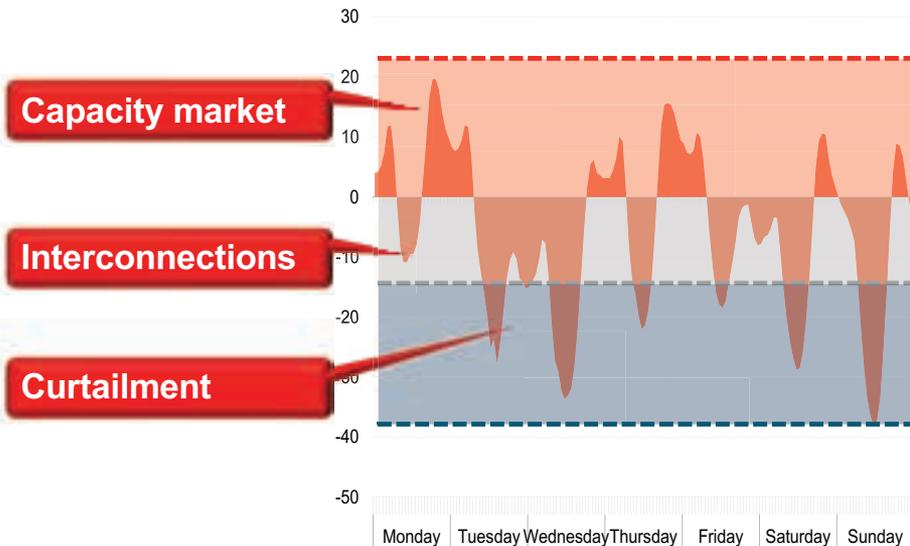
■ Peaking fossil ■ Baseload fossil ■ Nuclear ■ CHP ■ Hydro ■ Baseload RE ■ Solar ■ Wind ■ Pumped hydro generation/Storage ■ Imports ■ Exports/curtailment/DR

Source: BNEF

The future of power market regulation

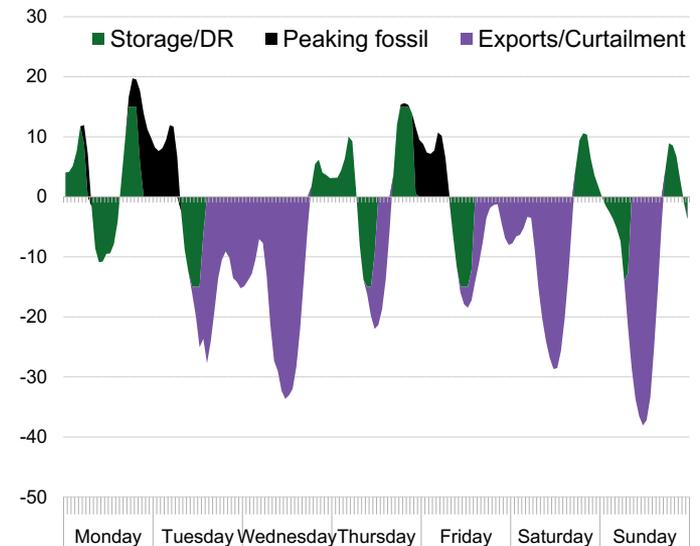
Option A: Capacity markets

“Central planning lite”



Option B: Demand-Led

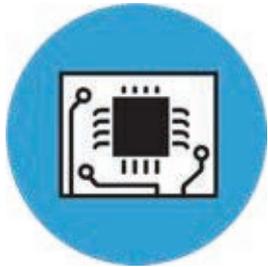
“Telecoms deregulation lite”



Source: BNEF

Digitisation of infrastructure

LIEBREICH
Associates



**Ubiquitous
chips and
sensors**



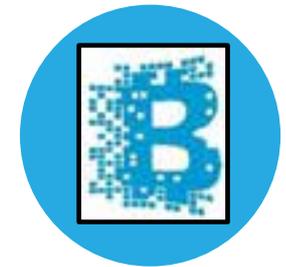
**Ubiquitous
communications**



**Ubiquitous
processing and
storage
(cloud to
network edge)**



**Ubiquitous
Artificial
intelligence and
machine
learning**



**Ubiquitous
Blockchain
(distributed
ledgers and
smart contracts)**

Source: BNEF; Liebreich Associates



The world must achieve
greenhouse gas neutrality
some time in the second half of
the century



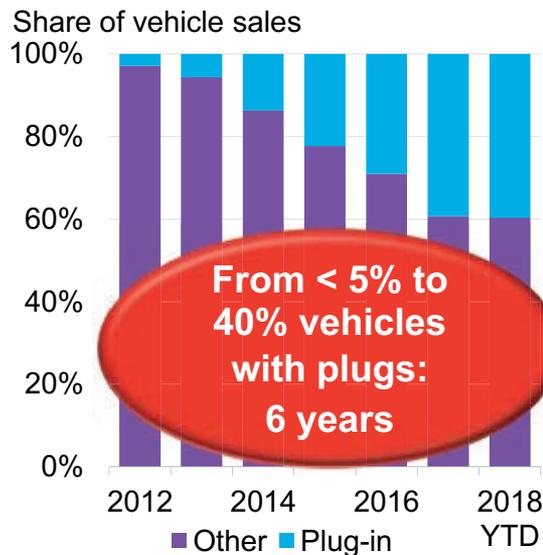
*Paris Agreement
December 2015*



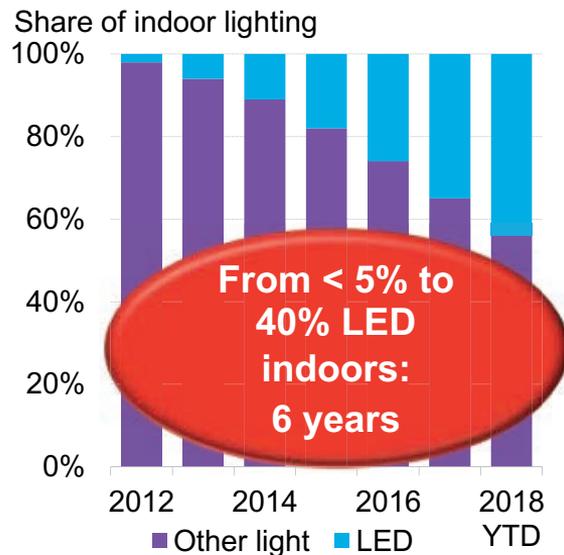
Image: UNFCCC

Speed of energy transition

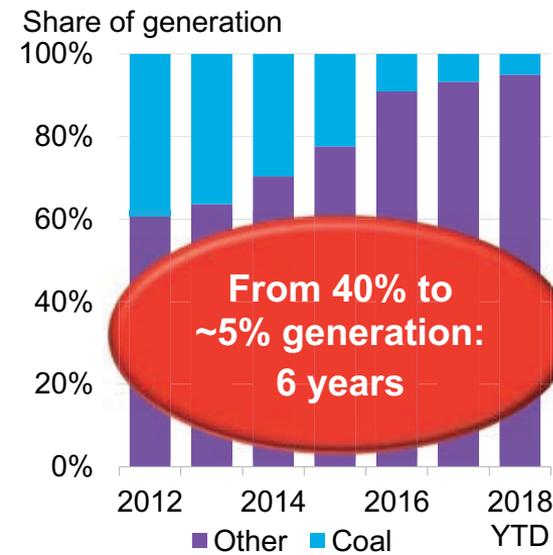
Vehicle sales in Norway



Indoor lighting worldwide



Electricity in the UK

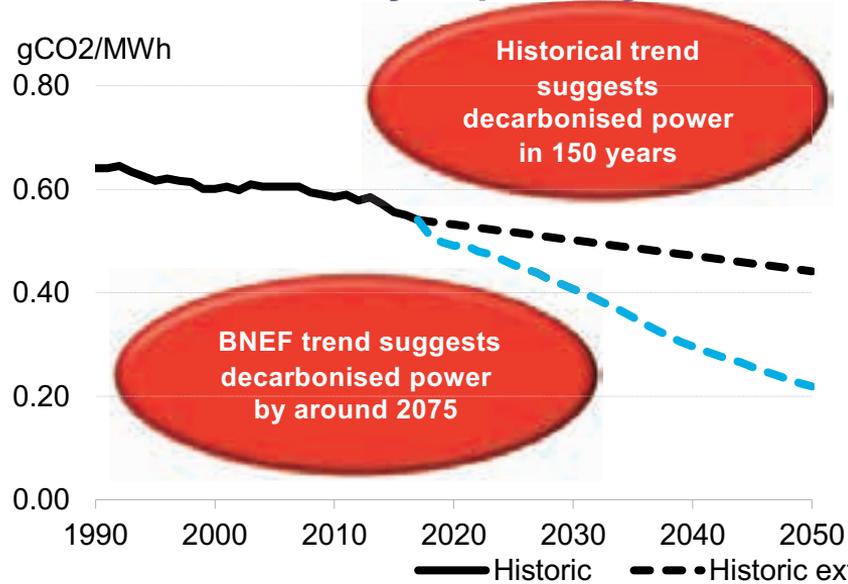


Note: YTD runs up to Sep 2018

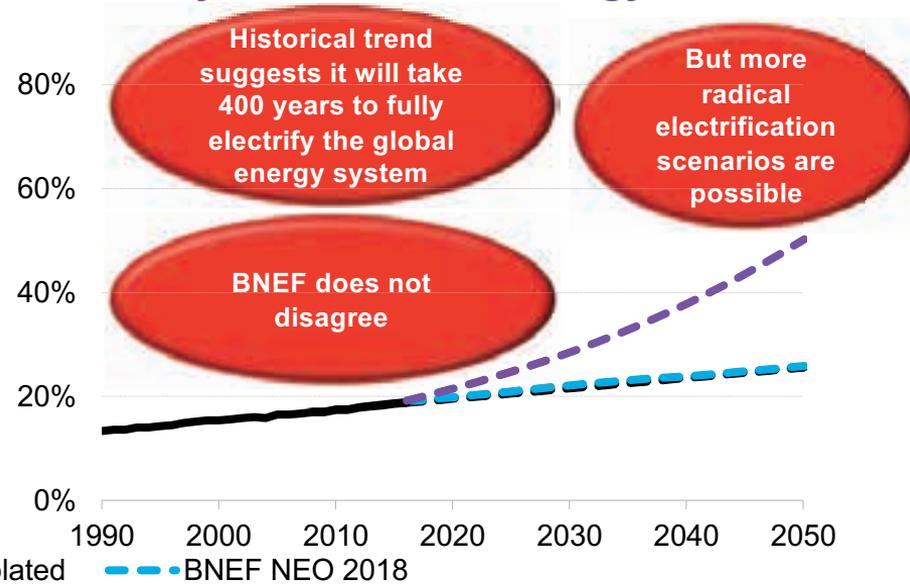
Source: Liebreich Associates; OFV AS; BP; IEA

Are we decarbonising the global energy system fast enough?

Emissions intensity of power generation



Electricity share in final energy



Source: BNEF NEO 2018; IEA WEO 2017; Liebreich Associates

Beyond the Three-Third World

Shipping/air/freight



Manufacturing



Chemicals



Agriculture



Heat



Energy access



Images: Bloomberg New Energy Finance, Tesla, Wallpaper Mania, Cleantecnica; Wikipedia Commons

Thanks!

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