

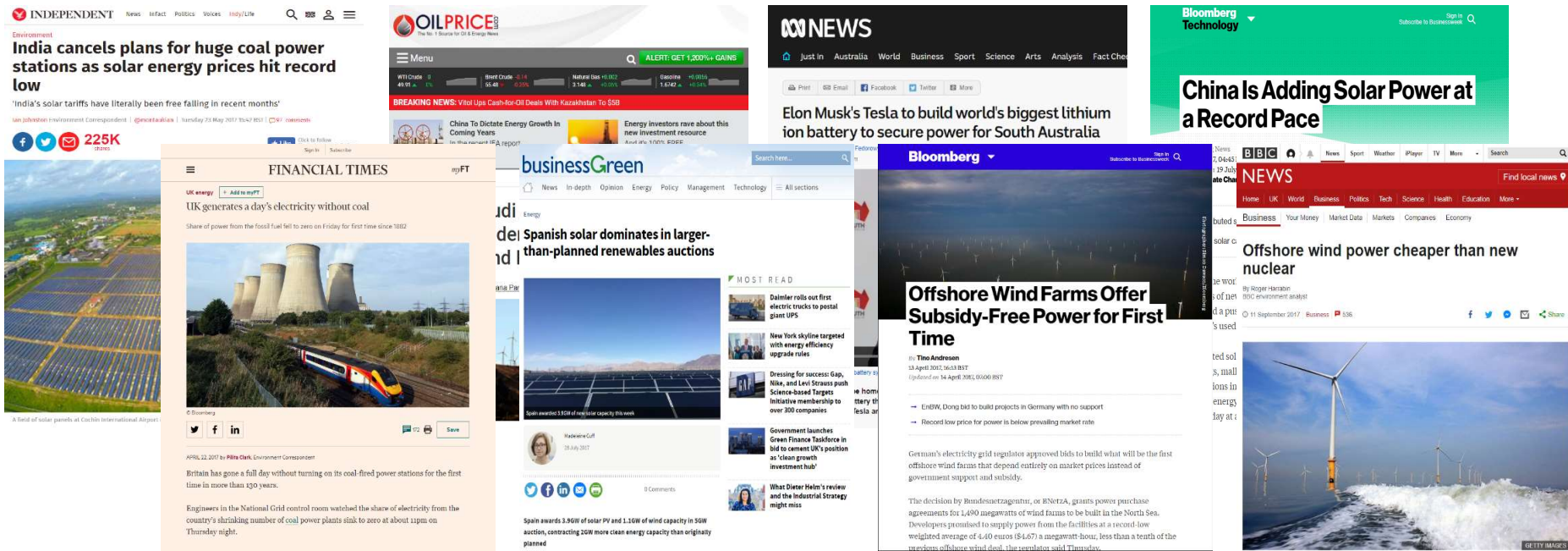
Global Trends in Clean Energy and Transportation

Smart Energy Day, 31 August 2018
Fondation The Arc, Sion

Michael Liebreich
Founder and CEO
Liebreich Associates

Clean energy news flow

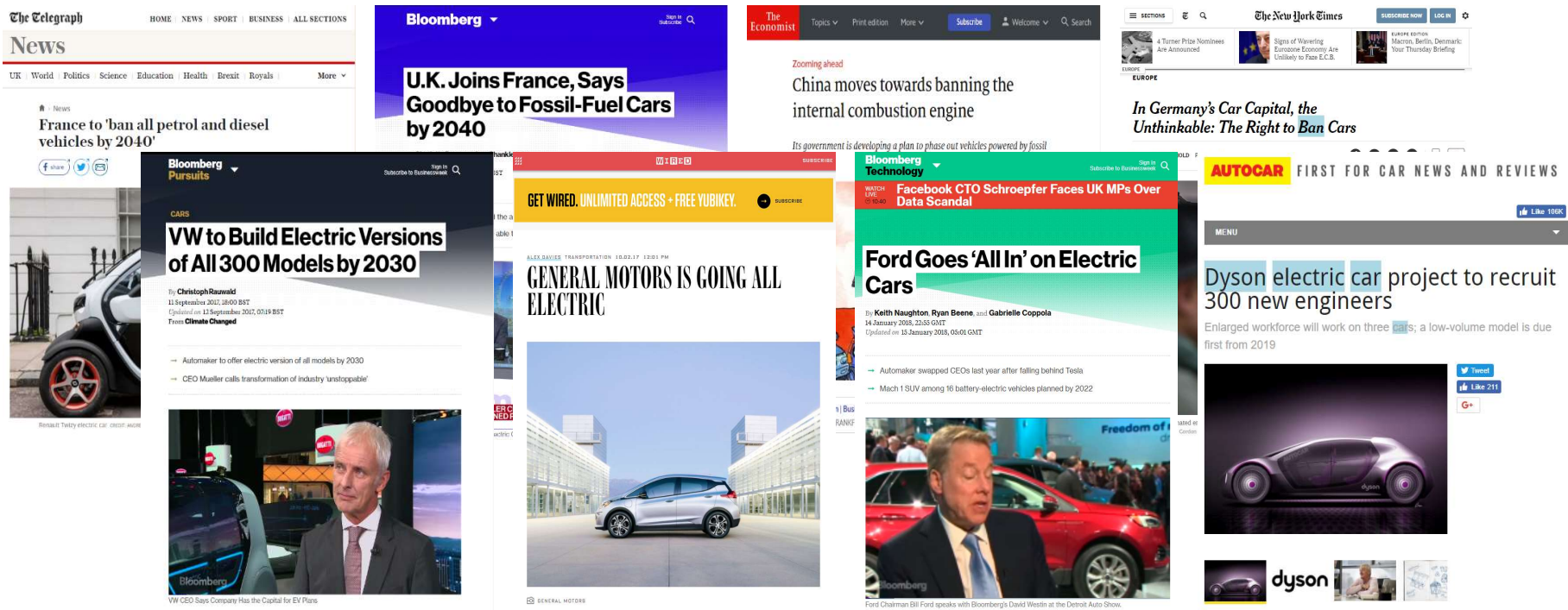
LIEBREICH Associates



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

EV news flow

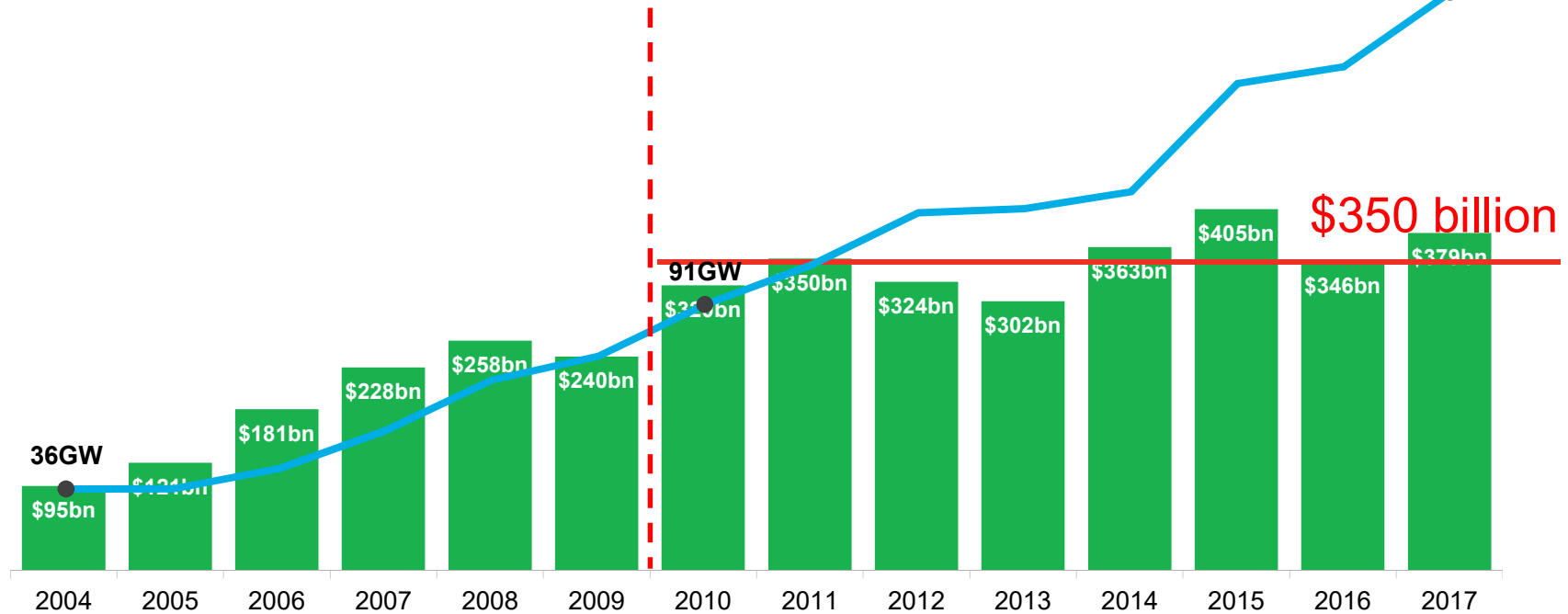
LIEBREICH Associates



Source: Telegraph; Bloomberg; Economist; Autoca; Wired; New York Times

Global new clean energy investment and capacity installations 2004 – 2017

LIEBREICH Associates
175 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

Solar and wind are not taking over the world

LIEBREICH
Associates

“

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

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
will be wind and solar



1/3 of cars and light trucks
will be electric



1/3 more energy-productivity
of the global economy

Images: Liebreich Associates; Images: Tesla, Wallpaper Mania, Cleantecnica

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Unsubsidised clean energy world records 2011

LIEBREICH
Associates

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

LIEBREICH
Associates

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

LIEBREICH
Associates

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

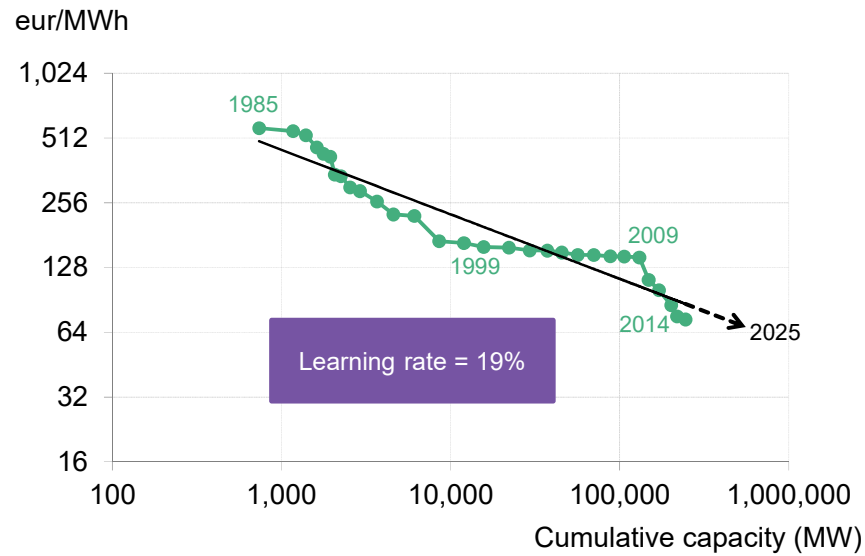
US\$ 5.3 c/kWh

Note: images are illustrative only

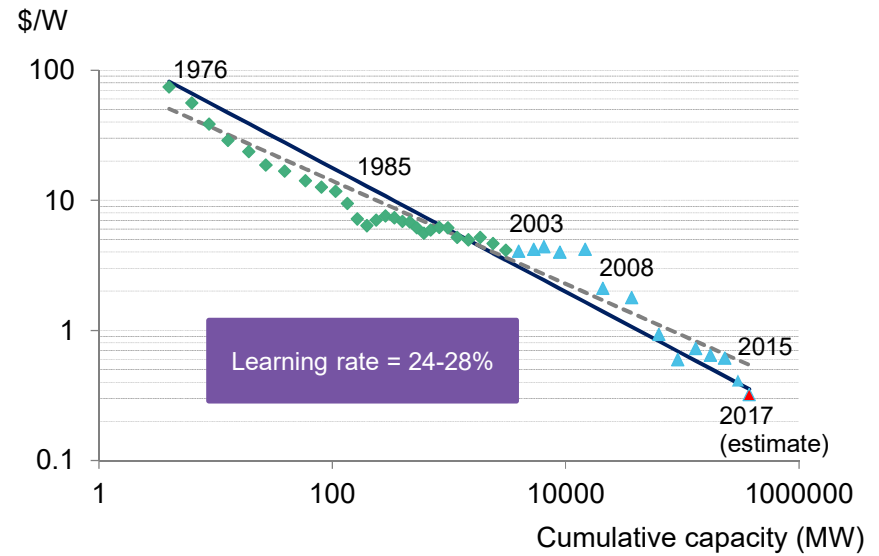
Source: Various manufacturers and project developers

Wind and solar experience curves

Wind



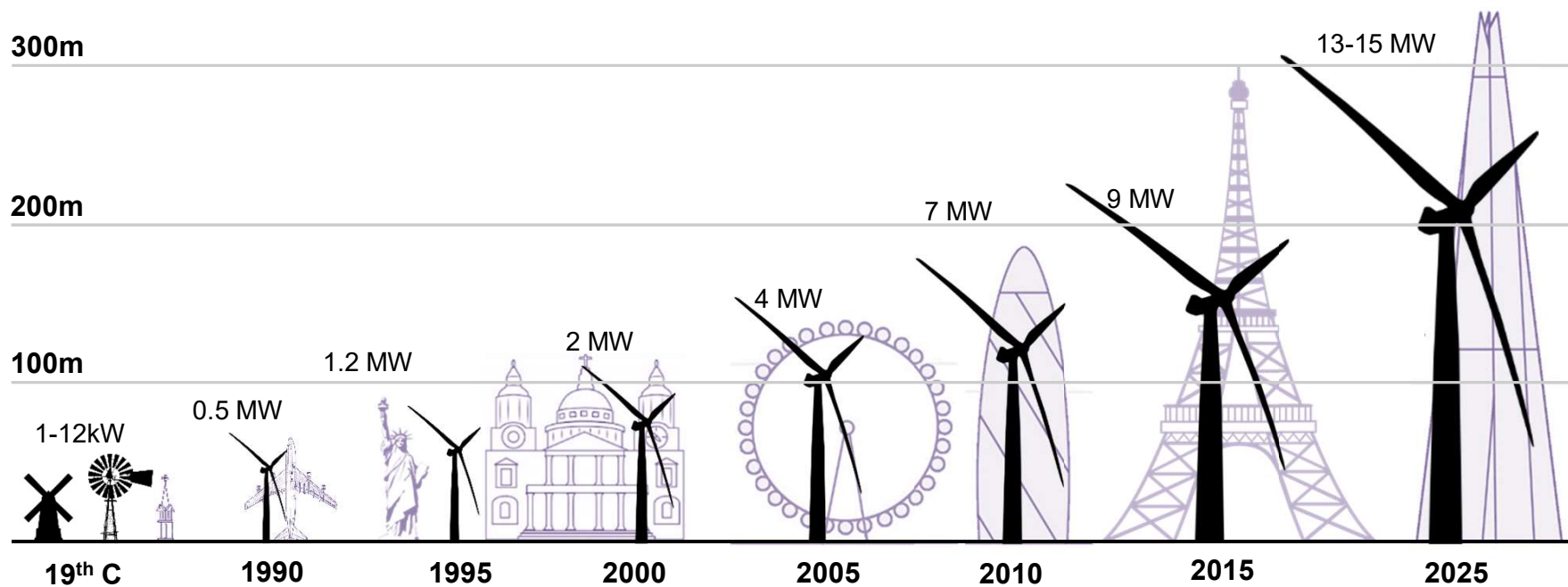
Solar



Source: BNEF

Evolution of wind turbine heights and output

LIEBREICH Associates



Sources: Various; Bloomberg New Energy Finance

Solar scale-up 2005 – 2017

LIEBREICH
Associates

2005



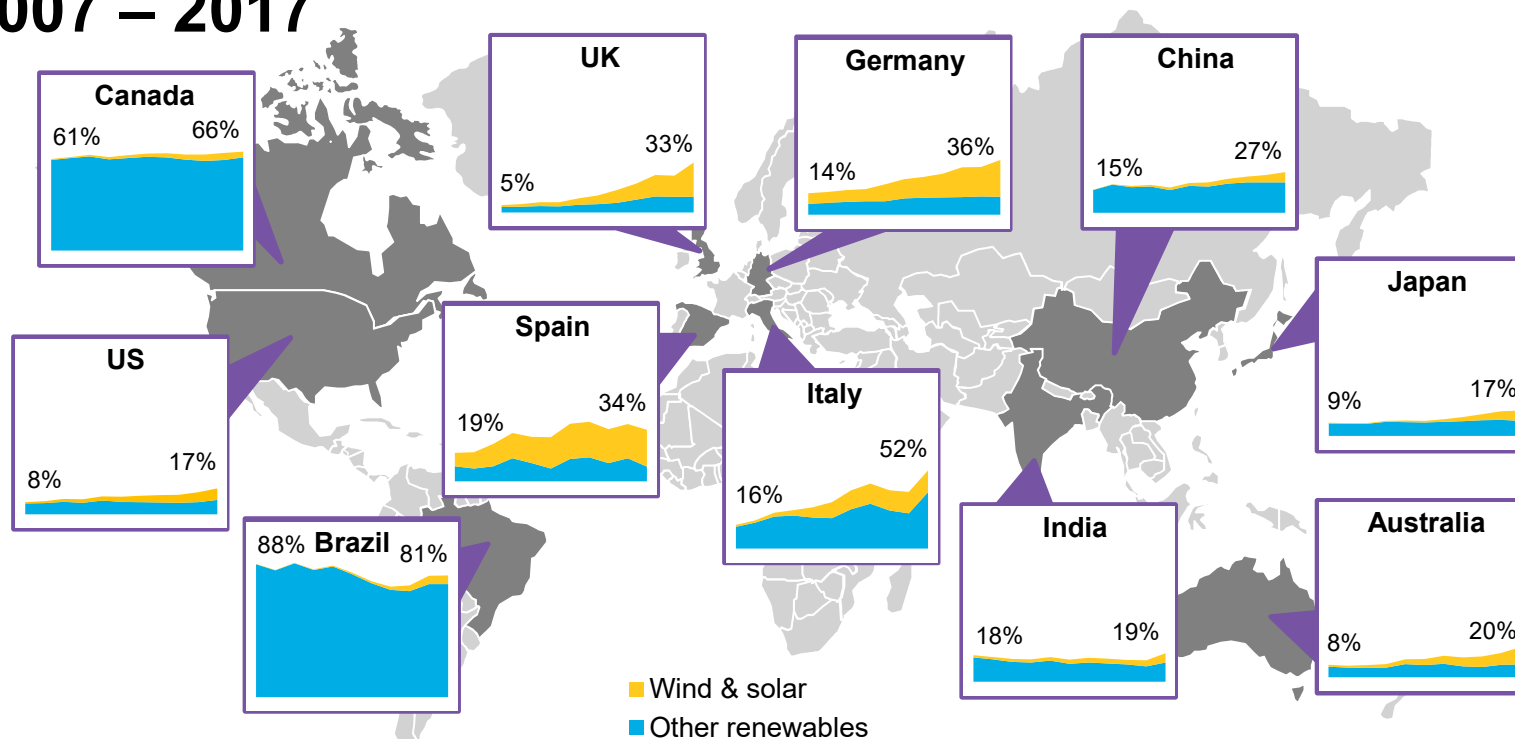
2018



Images: Nissan; Enel Villanueva solar plant

RE proportion of power generation 2007 – 2017

LIEBREICH
Associates



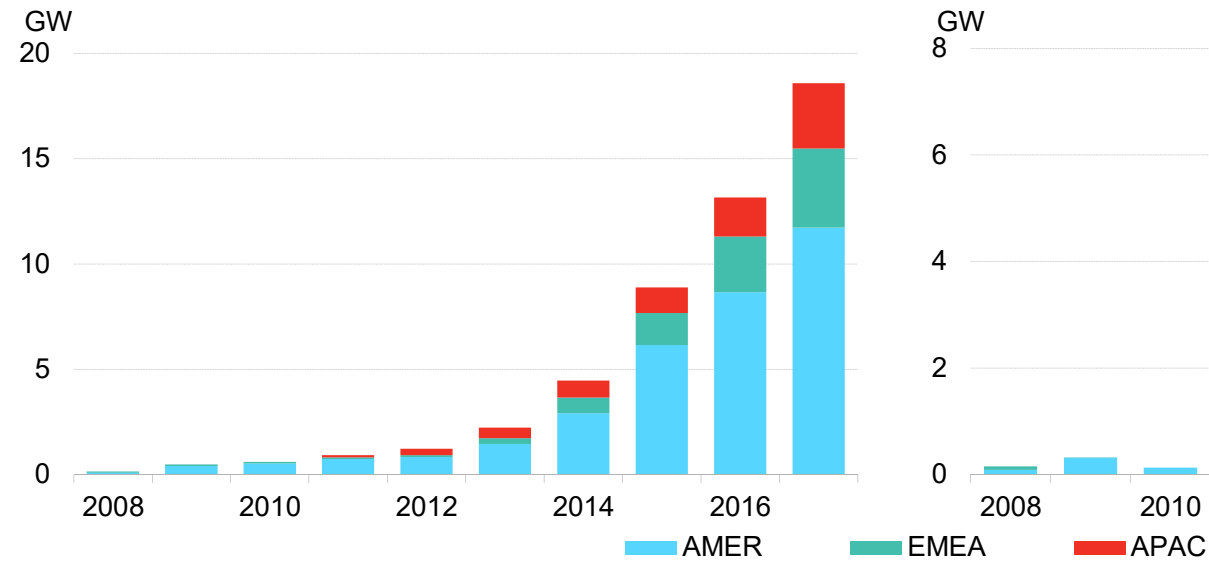
Note: Calculated as GWh renewable production / GWh consumption

Source: Liebreich Associates; BNEF; BP

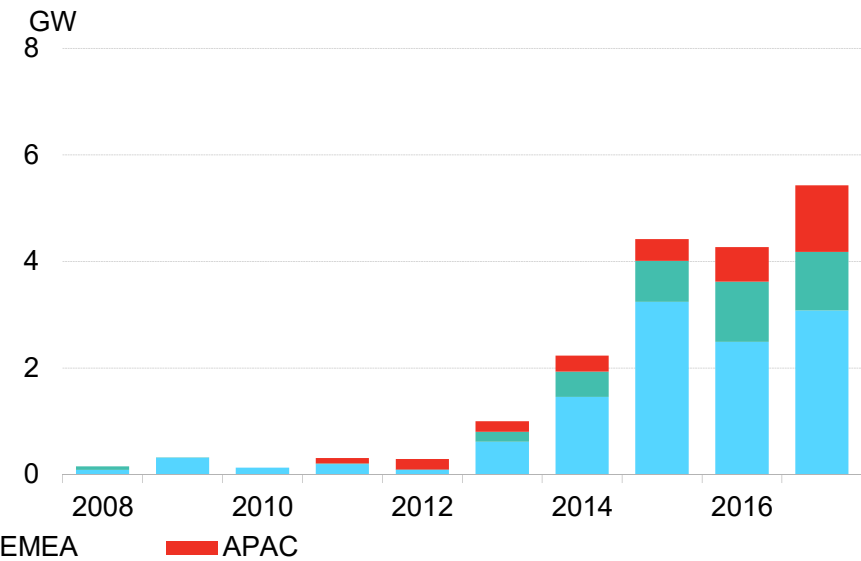
Global corporate PPA volumes

LIEBREICH
Associates

Cumulative



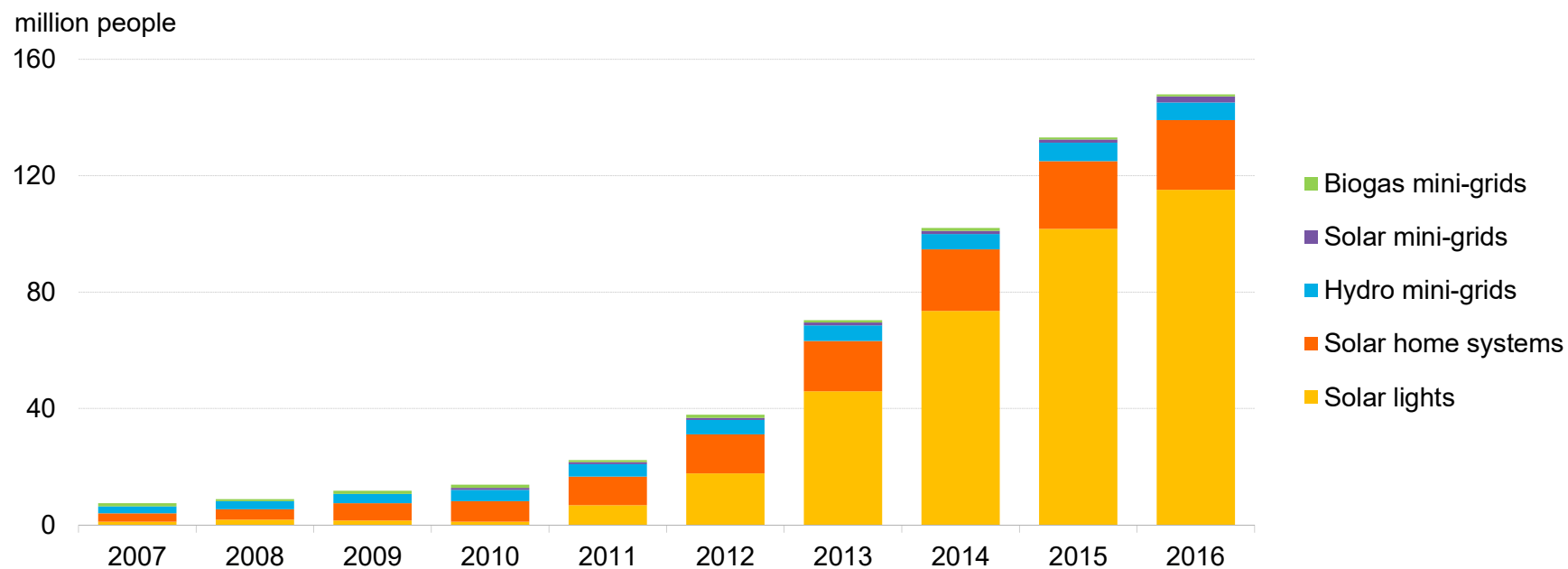
Annual



Source: BNEF

Global off-grid renewable energy users 2007 – 2016

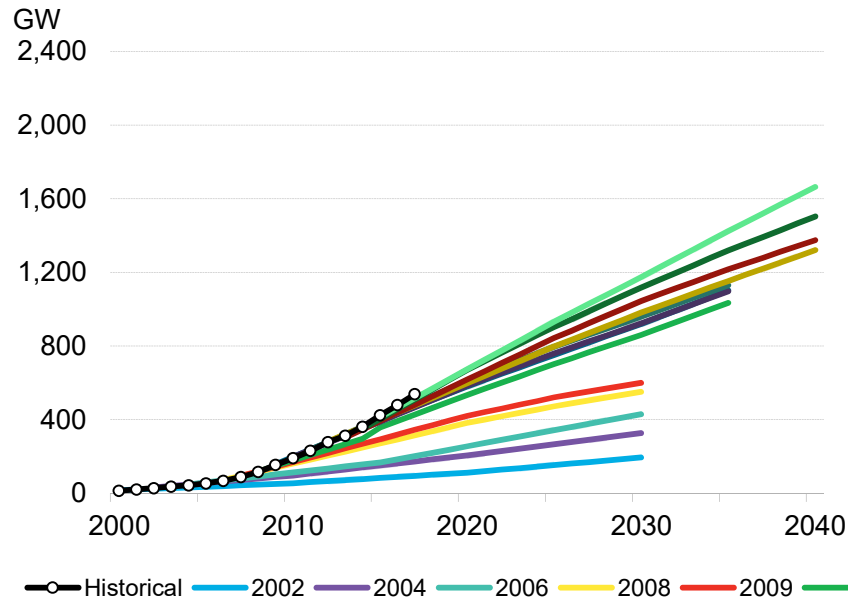
LIEBREICH
Associates



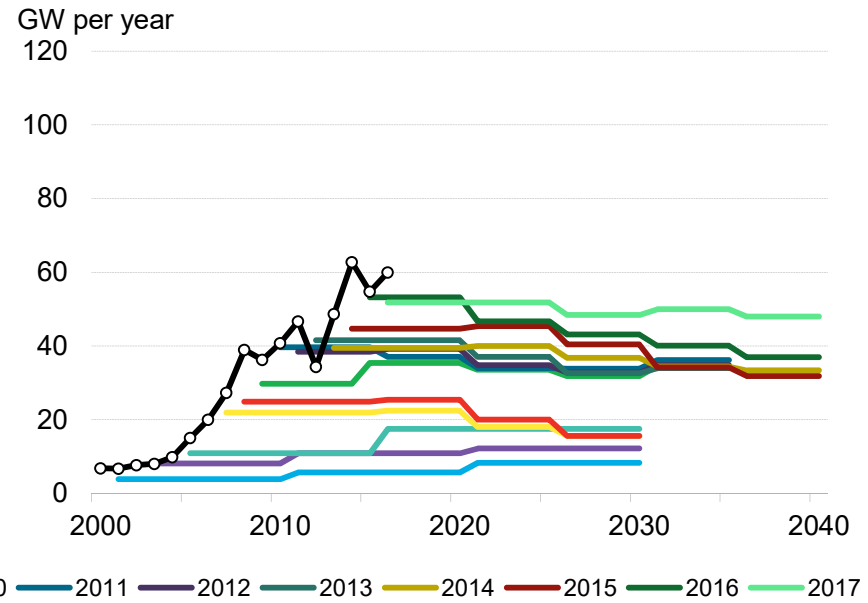
Source: IRENA

IEA wind capacity forecast evolution

Global cumulative wind installations



Annual wind additions

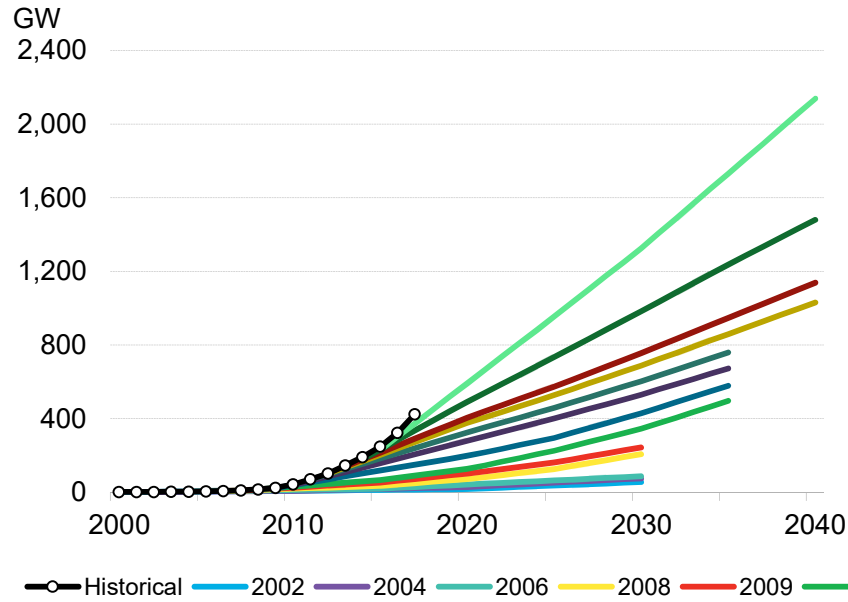


Note: 2002-2009 Reference, 2010-2017 New Policies Scenario

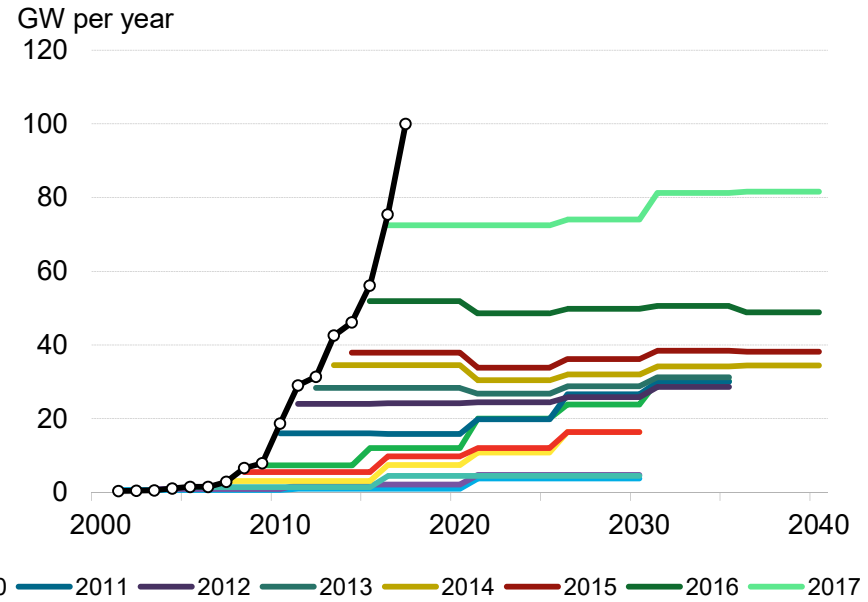
Source: IEA World Energy Outlook

IEA solar capacity forecast evolution

Global cumulative solar installations



Annual solar additions

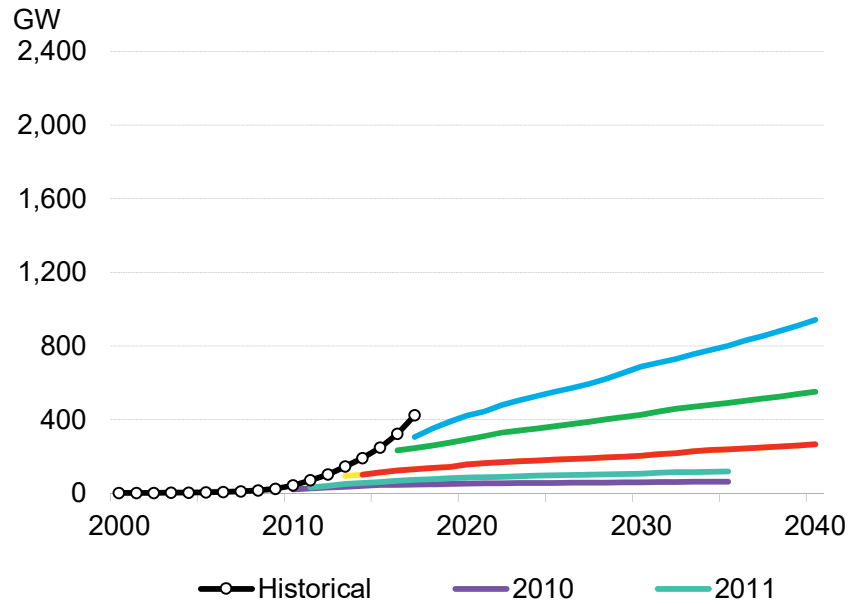


Note: 2002-2009 Reference, 2010-2017 New Policies Scenario

Source: IEA World Energy Outlook

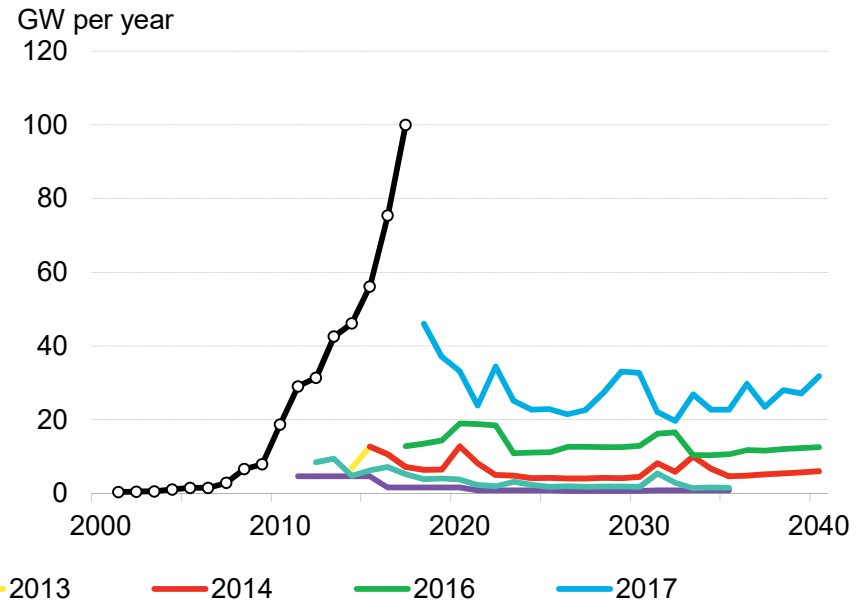
EIA solar capacity forecast evolution

Global cumulative solar installations



Note: Reference scenario

Annual solar additions

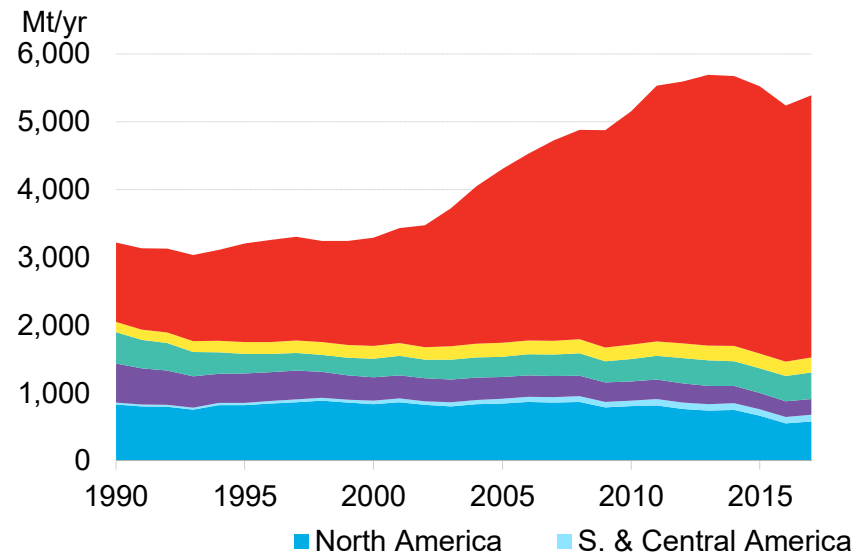


Source: EIA International Energy Outlook

Coal has peaked

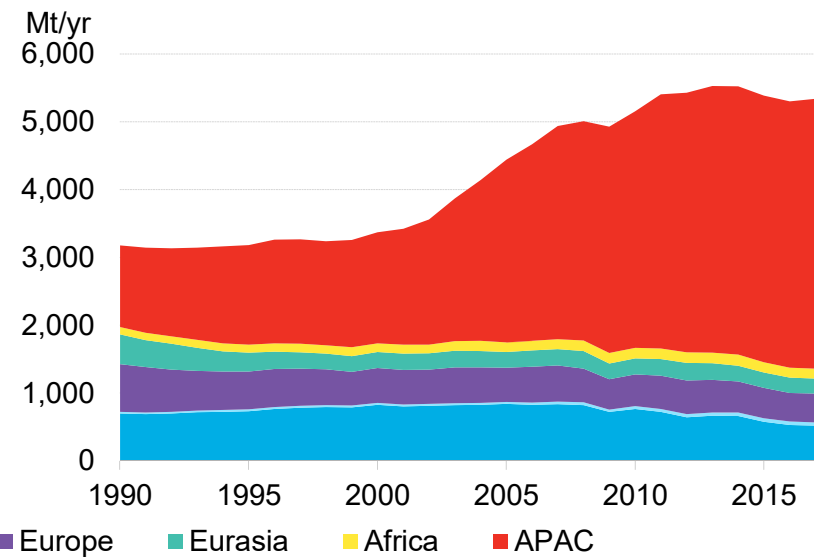
LIEBREICH Associates

Coal production



Note: Adjusted to standard coal equivalent

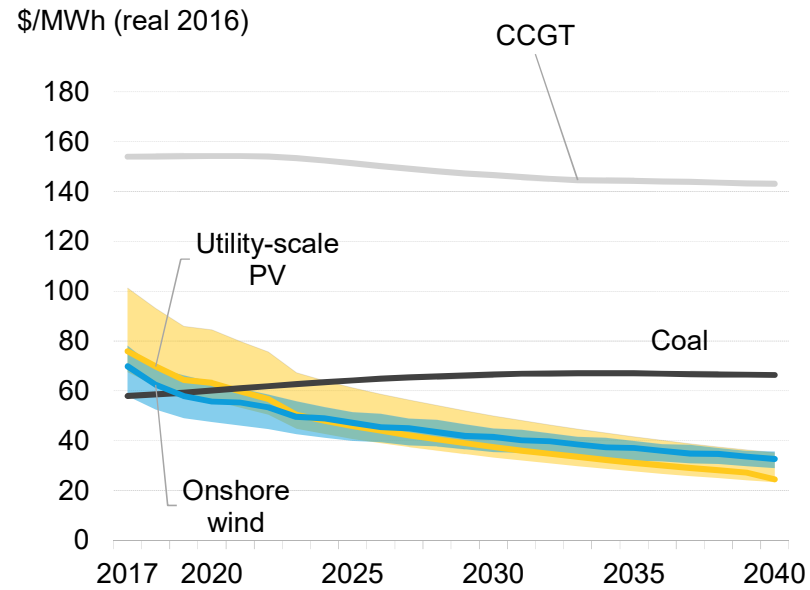
Coal consumption



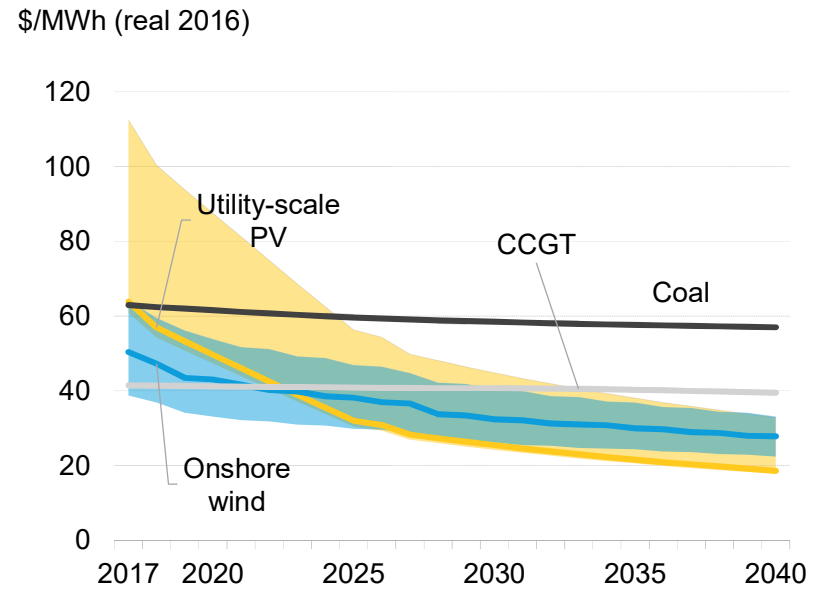
Source: Liebreich Associates; BP Statistical Review

Tipping point 1: new vs new

China



U.S.

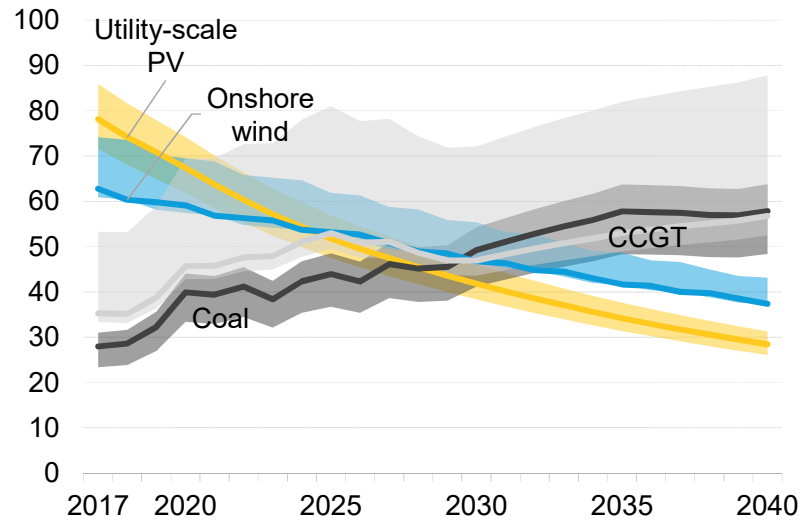


Source: Bloomberg New Energy Finance, *NEO 2017*

Tipping point 2: new vs existing

Germany

\$/MWh (real 2016)



China

\$/MWh (real 2016)

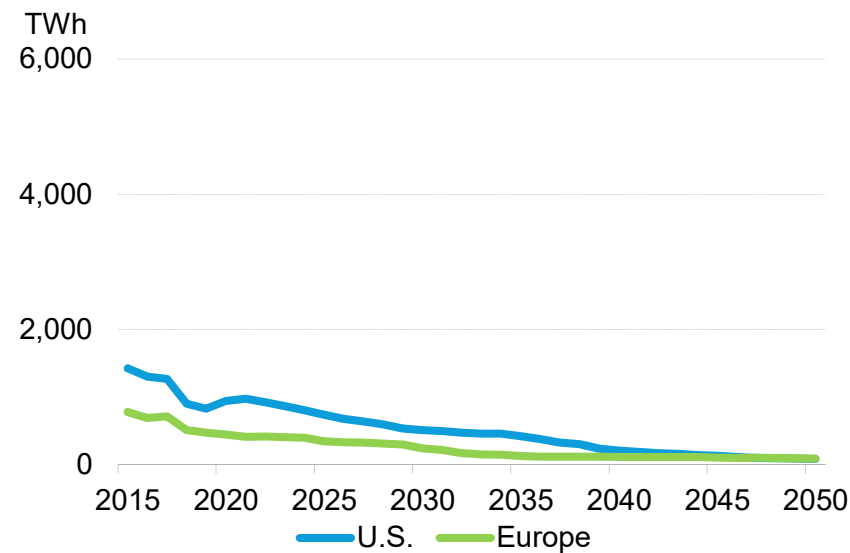


Source: Bloomberg New Energy Finance, *NEO 2017*

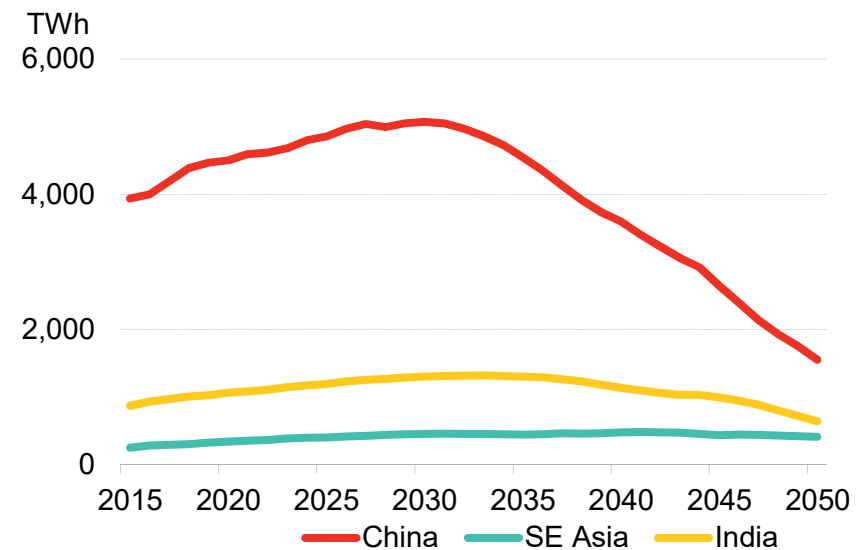
Poor outlook for coal in U.S., Europe and China

LIEBREICH Associates

Coal generation – U.S. and Europe



Coal generation – Asia



Source: BNEF NEO 2018

Trump on US coal

July 2017

LIEBREICH
Associates

“

And you know all the people that were saying the mining jobs? Well we picked up 45,000 mining jobs in a very short period of time. Everybody was saying, well, you won't get any mining jobs. We picked up 45,000 mining jobs

”

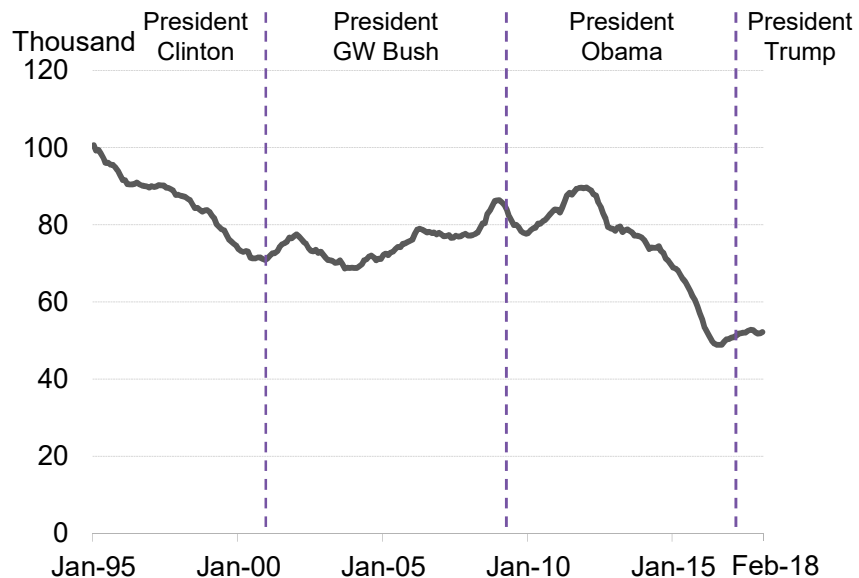
*Donald Trump
US President*



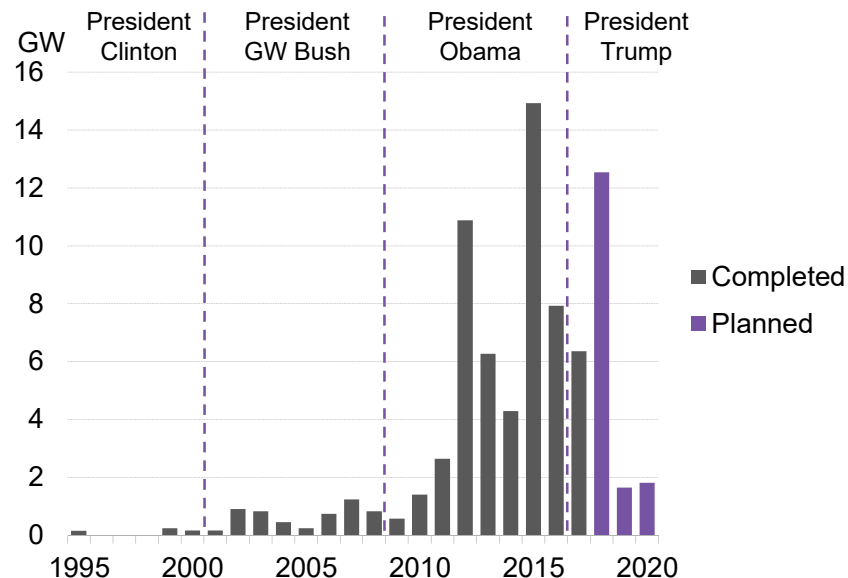
Image: Mark Lyons/Getty Images

The market's response to Trump on coal

US coal mining employment



US coal-fired power plant retirements

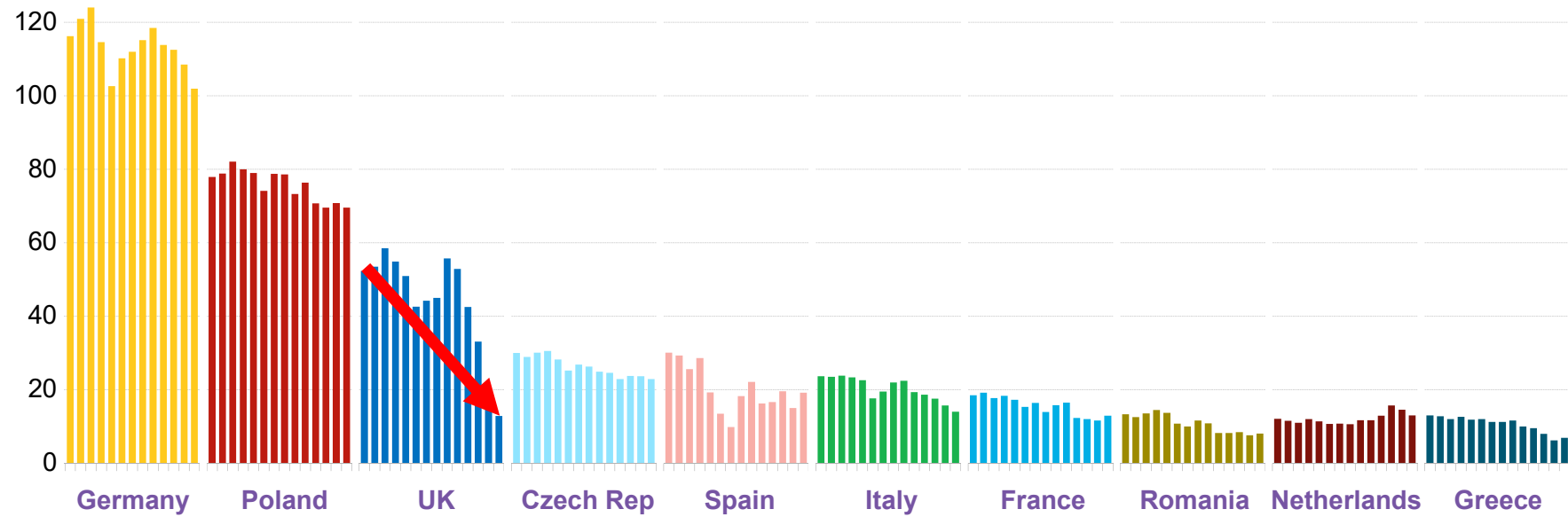


Source: EIA; BNEF; Liebreich Associates; US Federal Reserve

EU member state coal consumption 2004 – 2017

LIEBREICH
Associates

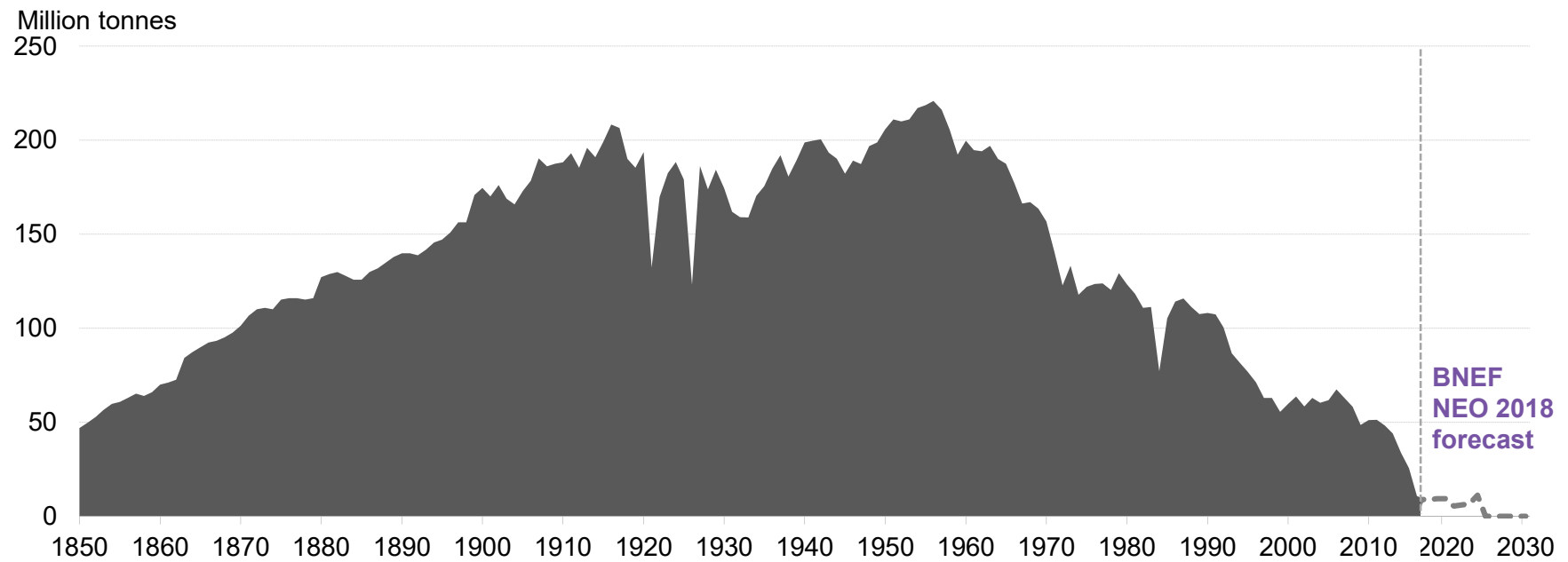
Mt per year
140



Source: BP Statistical Review

UK coal consumption 1850 – 2030

LIEBREICH
Associates



Source: BEIS, Prof. David Rutledge, BNEF; Liebreich Associates

Some people are not wrong but misleading

LIEBREICH
Associates

“

Solar and wind is taking over the world. We hear it all the time. Only it is wrong - now 0.6%, 2040 2.9%.

”

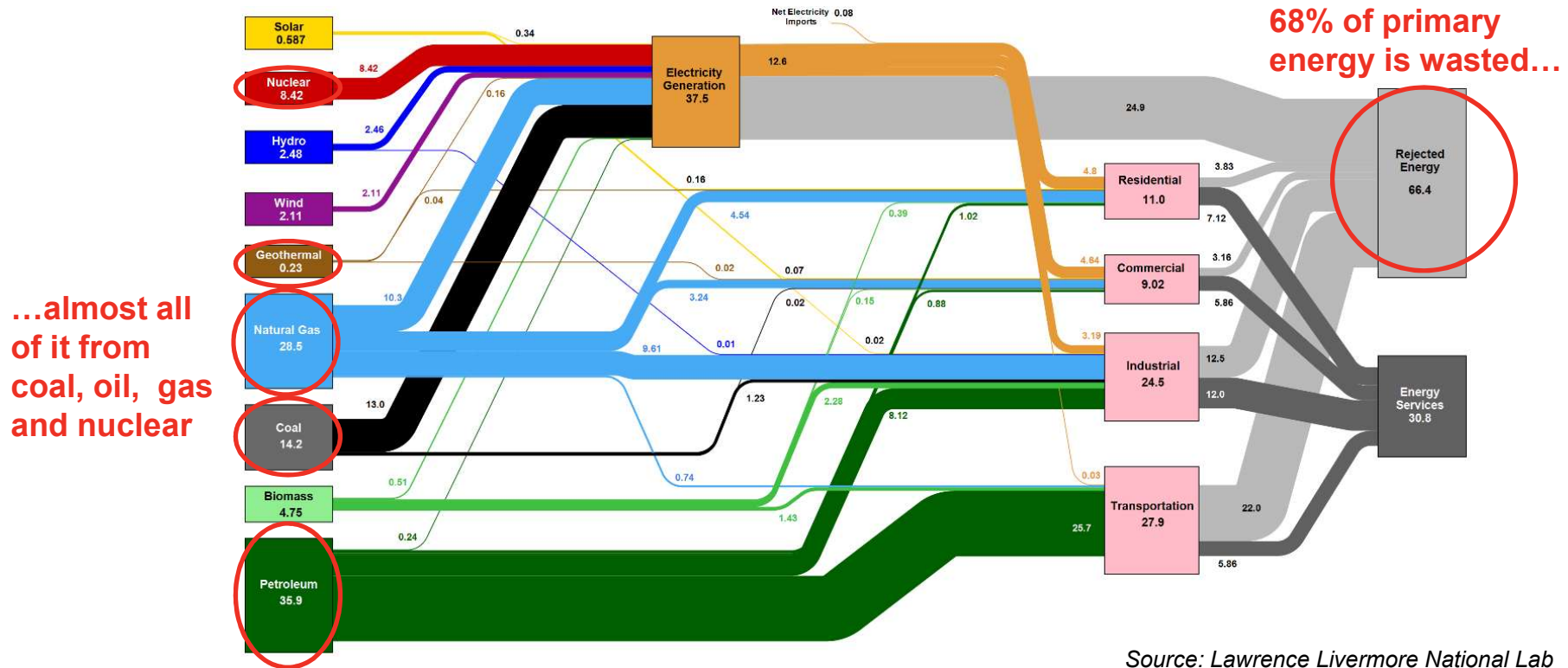
*Bjørn Lomborg
visiting professor at the Copenhagen Business School
President of the Copenhagen Consensus Center*



Image: Lomborg.com

Sankey for the U.S. in 2016

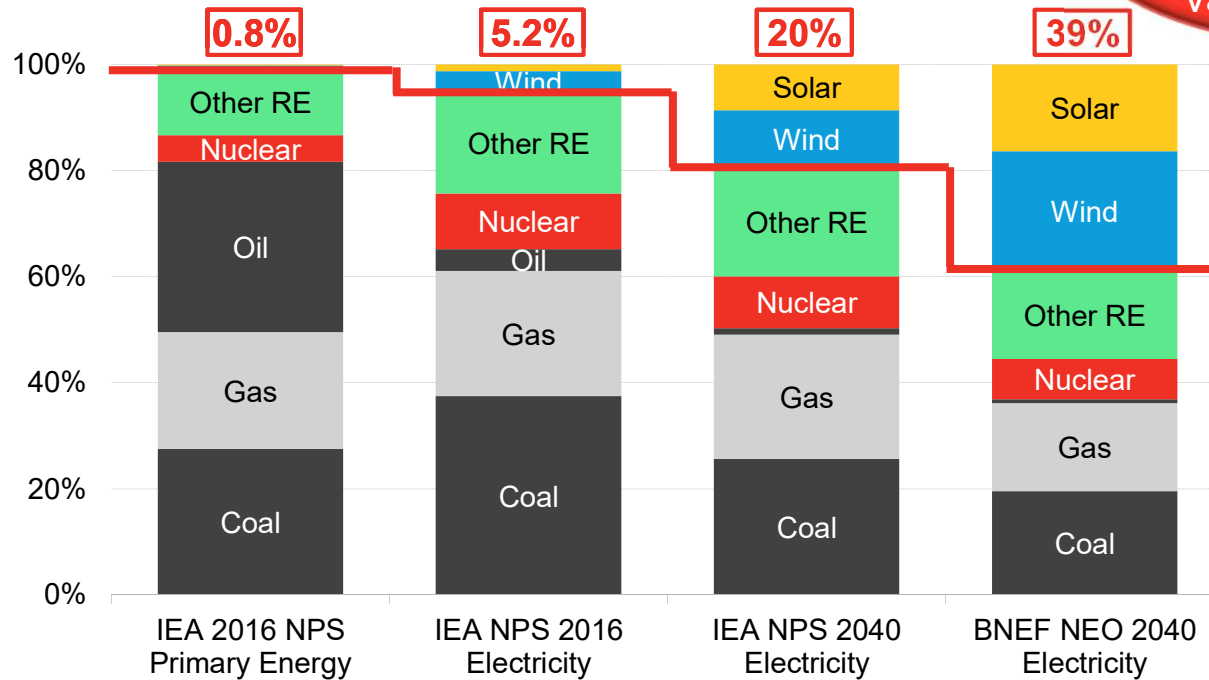
LIEBREICH Associates



Source: Lawrence Livermore National Lab

Wind and solar contribution to global power generation

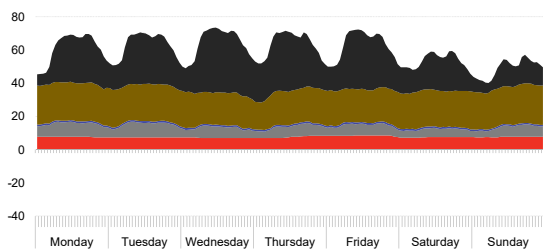
By 2040
20 to 39% of power globally will be from variable sources



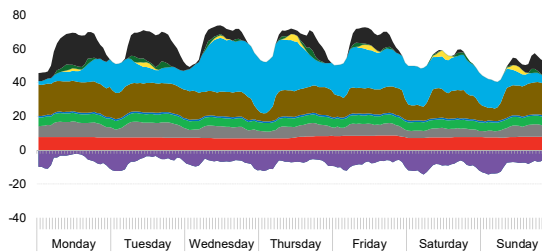
Source: BNEF NEO 2018; IEA WEO; Liebreich Associates

Evolving structure of power supply Germany

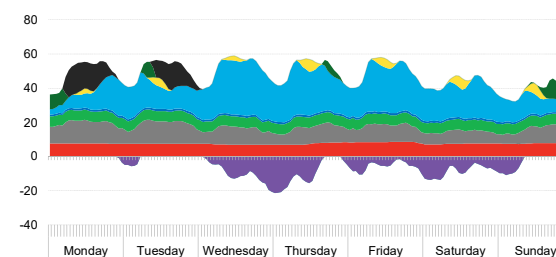
Past – winter



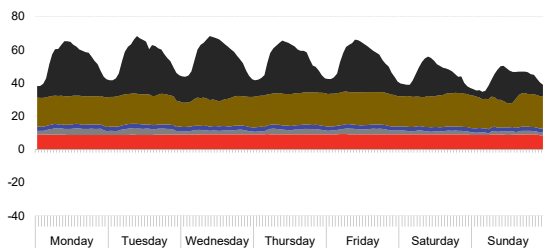
Current – winter



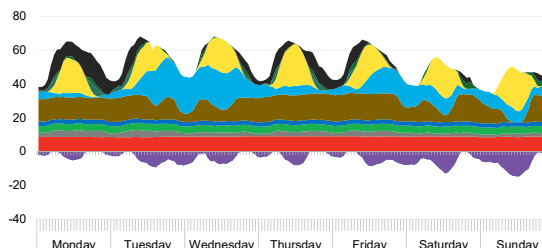
Future – winter



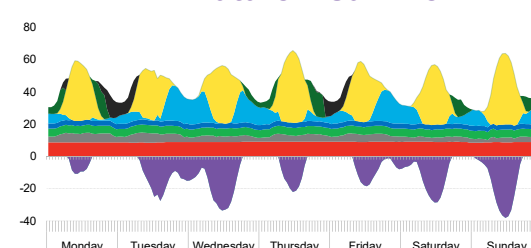
Past – summer



Current – summer



Future – summer



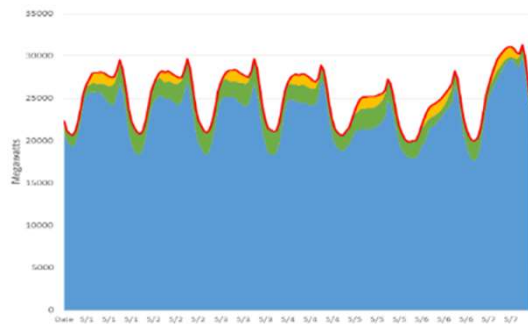
■ Peaking fossil ■ Baseload fossil ■ Nuclear ■ CHP ■ Hydro ■ Baseload RE ■ Solar ■ Wind ■ Pumped hydro generation/Storage ■ Imports ■ Exports/curtailment/DR

Source: BNEF

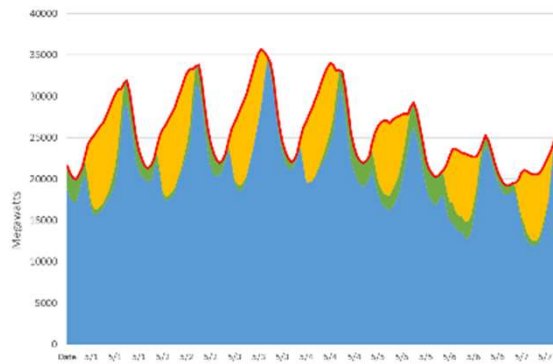
Evolving structure of power supply California

LIEBREICH
Associates

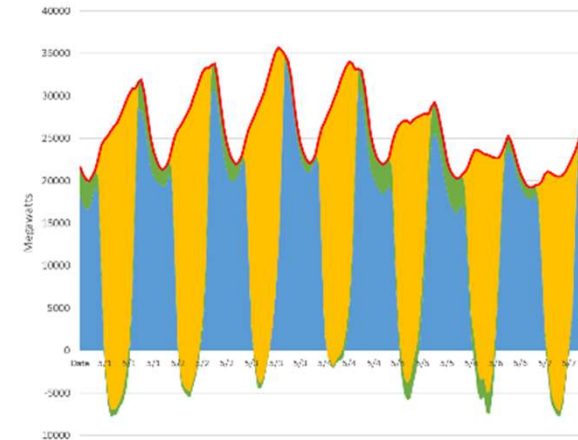
First week of May 2012
(actual)



First week of May 2017
(actual)



First week of May 2030
(modelled)

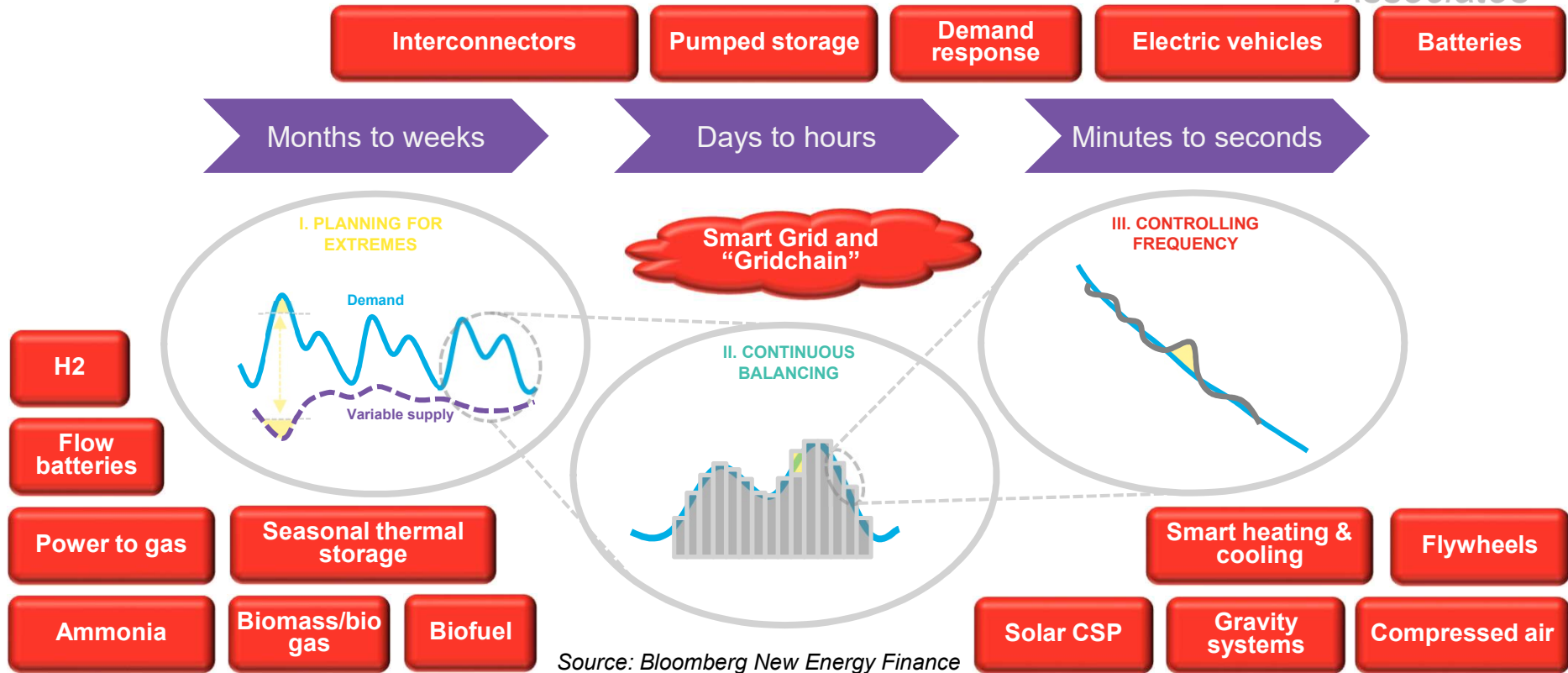


■ Solar
 ■ Wind
 ■ Net Load
 ■ Demand

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

Balancing the grid

LIEBREICH Associates



Source: Bloomberg New Energy Finance

Intermittency costs

LIEBREICH
Associates

UKERC
UK Energy Research Centre

“

At 30% penetration, UK-relevant
balancing and reliability costs less
than £10/MWh

”

*UK Energy Research Centre
The Costs and Impacts of Intermittency – 2016 Update*



The costs and impacts of intermittency – 2016 update

A systematic review of the evidence on
the costs and impacts of intermittent
electricity generation technologies

Philip Heptonstall, Robert Gross, Florian Steiner February 2017

Image: UKERC

Intermittency costs



The costs of integrating 50% percent wind and solar PV into the German power system could range between 5 to 20 EUR/MWh.



The Integration Costs of Wind and Solar Power
Dec 2015

The Integration Costs of
Wind and Solar Power

An Overview of the Debate on the Effects of Adding Wind
and Solar Photovoltaic into Power Systems

BACKGROUND

Agora
Energiewende



Image: Agora

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
will be wind and solar



1/3 of cars and light trucks
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1/3 more energy-productivity
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Images: Liebreich Associates; Images: Tesla, Wallpaper Mania, Cleantecnica

ICE and electric vehicle fleet

LIEBREICH
Associates

Cars and light trucks in use
worldwide, mid 2018
1.4 billion

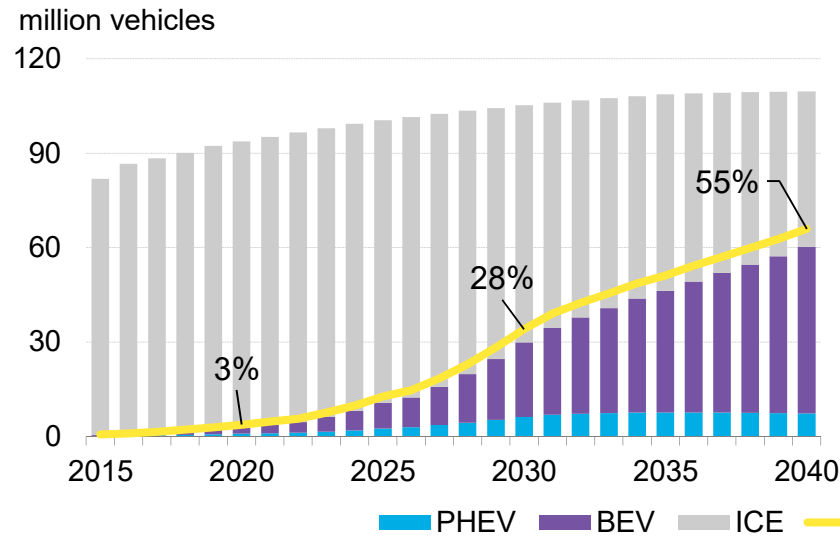


Electric vehicles in use
worldwide, mid 2018:
4.0 million

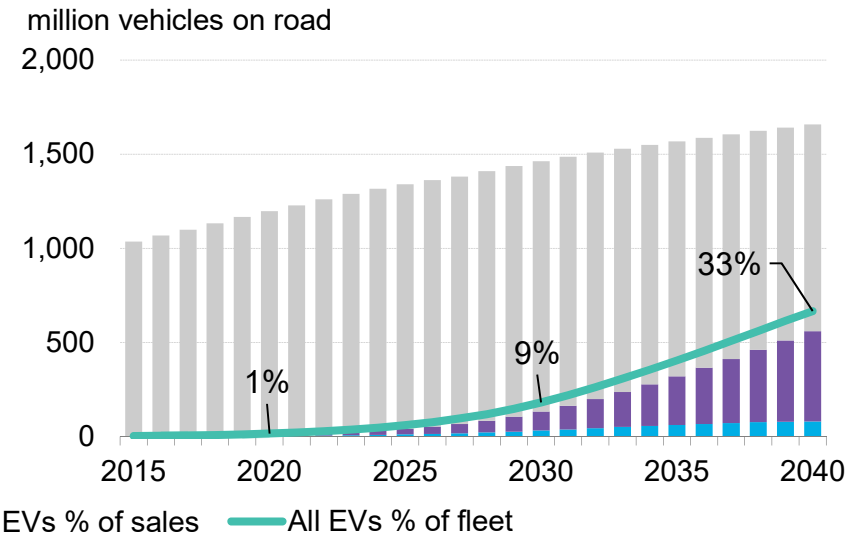
Source: Liebreich Associates, International Organization of Motor Vehicle Manufacturers

BNEF electric vehicle outlook to 2040

Annual global light duty vehicle sales



Global light duty vehicle fleet

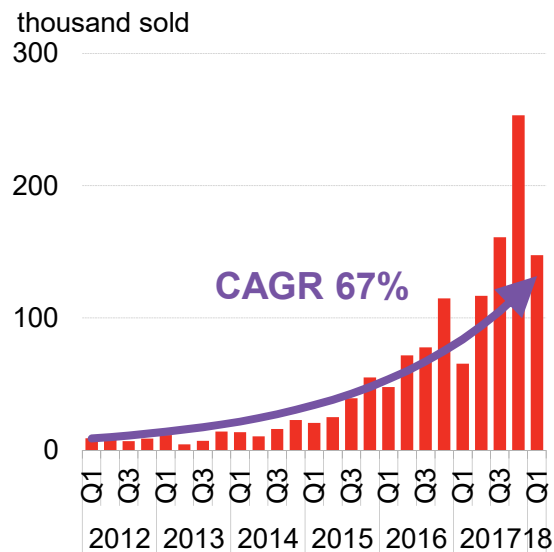


Source: BNEF EVO 2018

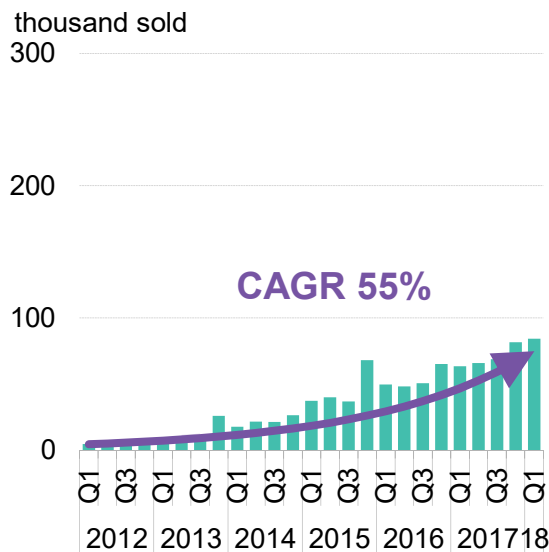
Quarterly EV sales by region Q1 2012 – Q1 2018

LIEBREICH
Associates

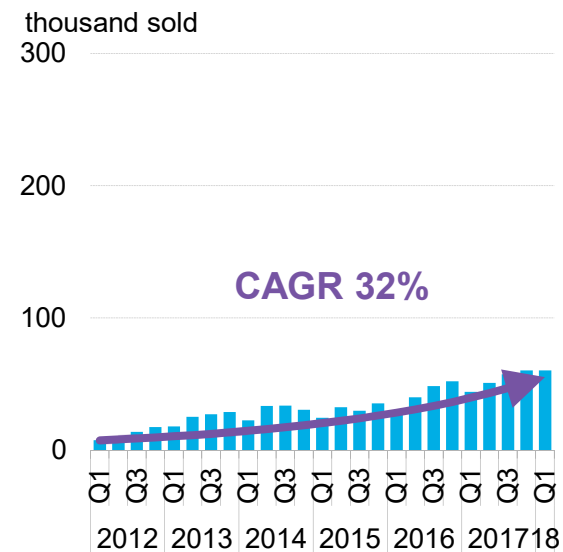
APAC



EMEA



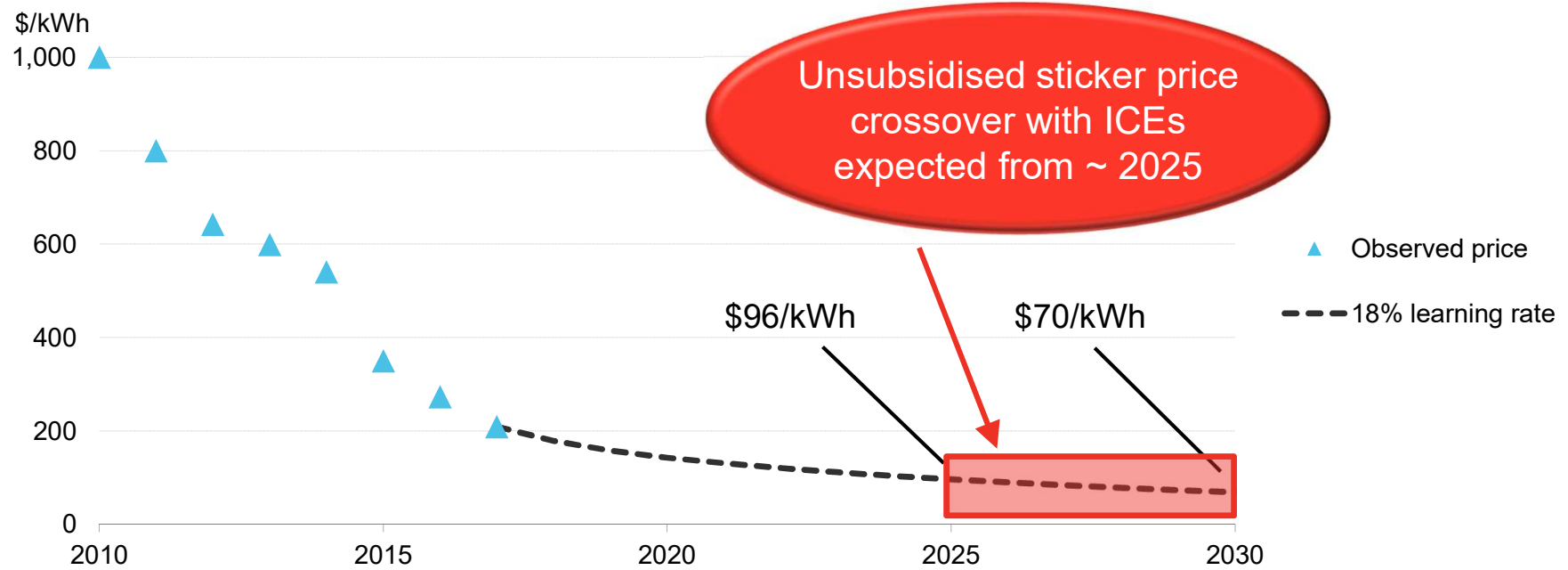
AMER



Source: BNEF

Battery pack costs to fall another 70% by 2030

LIEBREICH Associates



Source: BNEF EVO 2018

London, UK

LIEBREICH
Associates



Image: HHRCA

Not just cars going electric

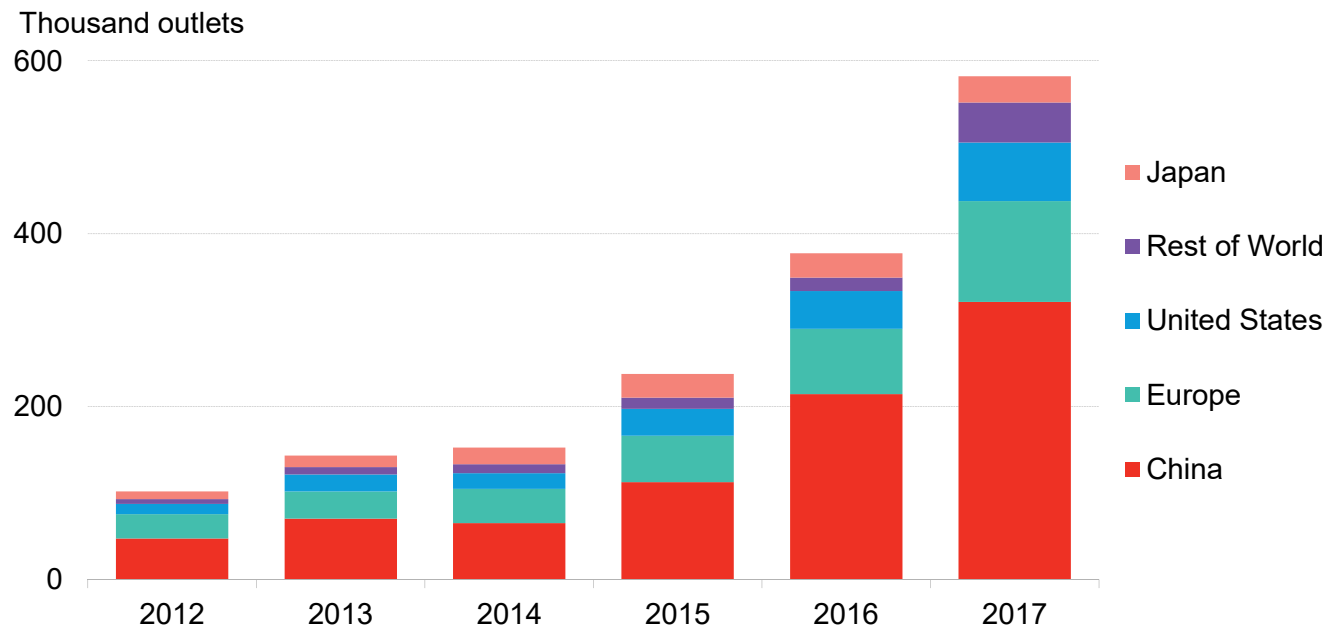
LIEBREICH
Associates



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

Public EV charging points installed globally

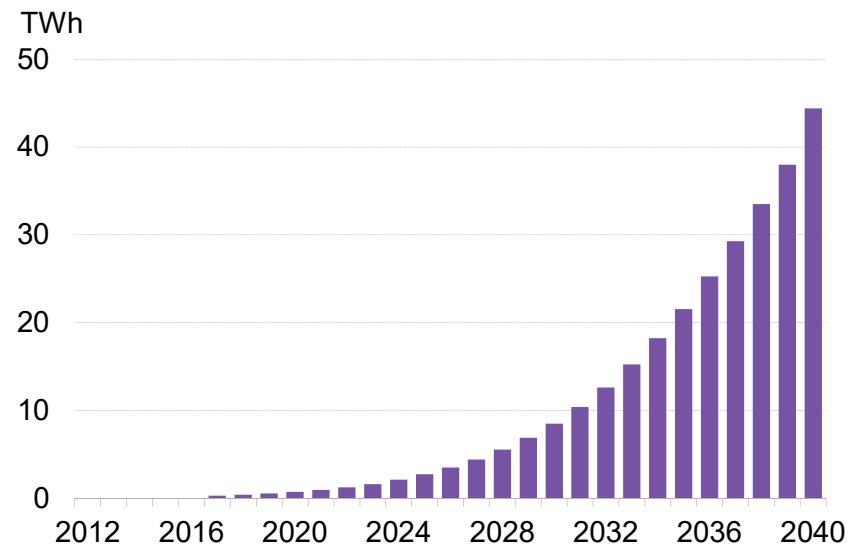
LIEBREICH Associates



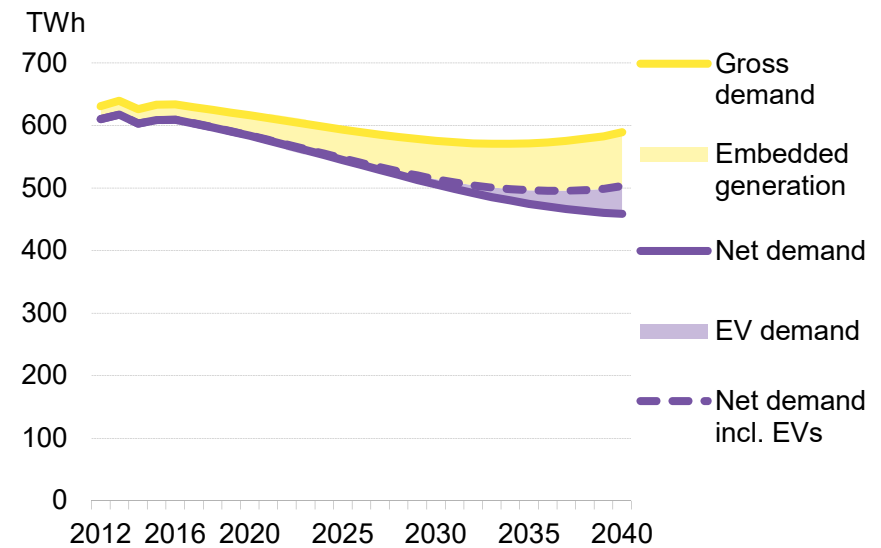
Source: BNEF EVO 2018

Can the power system handle it?

EV electricity demand in Germany



Total electricity demand in Germany

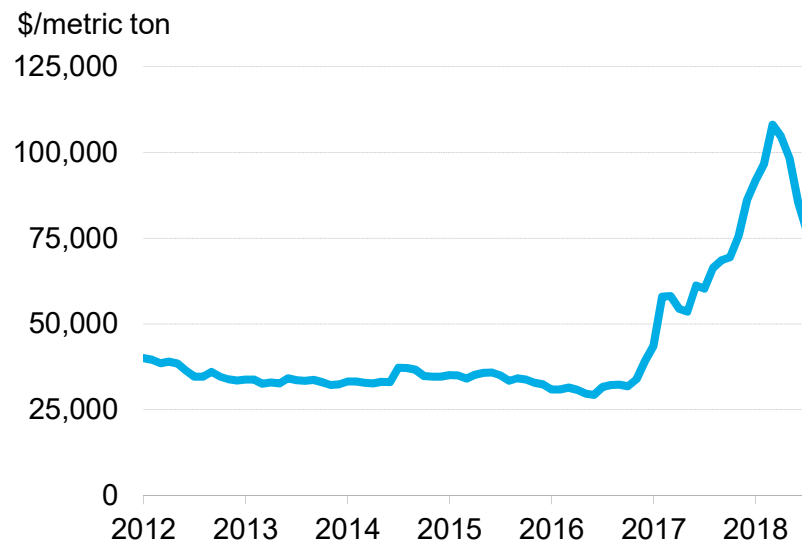


Source: BNEF

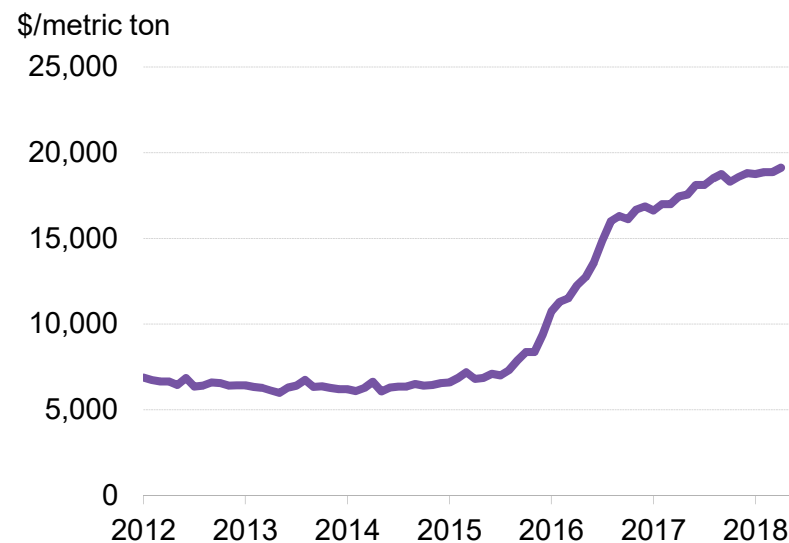
Cobalt and lithium prices

LIEBREICH
Associates

China Shanghai Cobalt



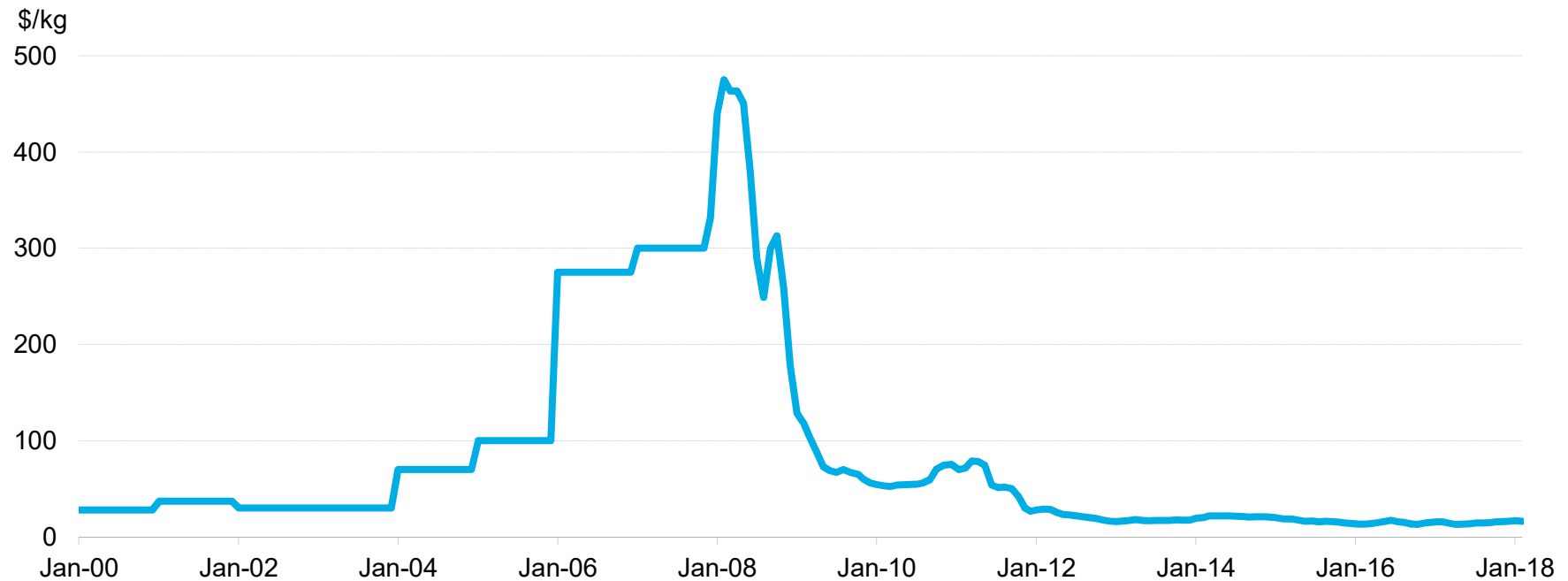
Lithium Hydroxide



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

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

LIEBREICH
Associates

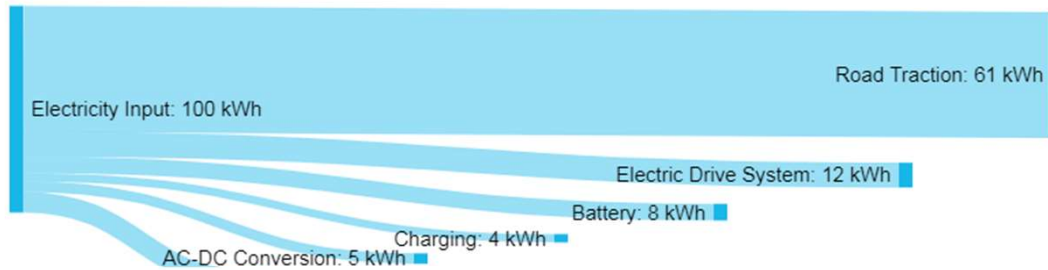


Notes: Annual data 2000-07 from various industry sources. Data November 2007–May 2009 based on a 3-point moving average of actual spot deals. Consistent monthly data collection using the Spot Price Index began in May 2009.

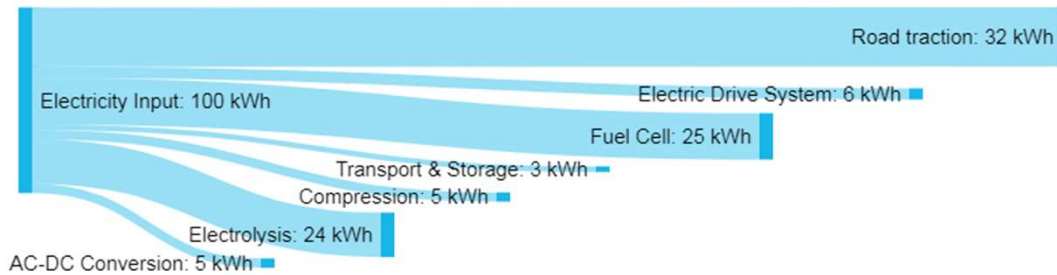
Source: Various, BNEF

BEV and H2FC efficiencies compared

LIEBREICH Associates



BEV
“Wind-to-wheel”
efficiency
61%



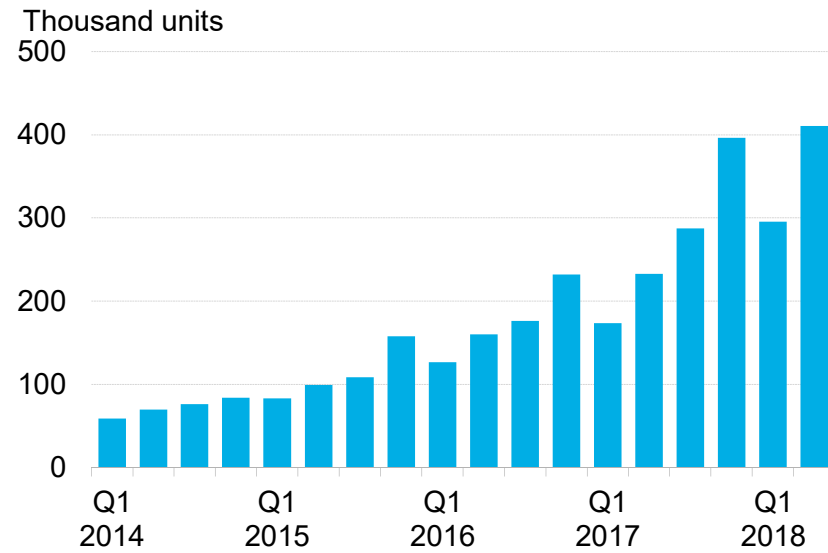
FCV
“Wind-to-wheel”
efficiency
32%

Source: Bloomberg New Energy Finance

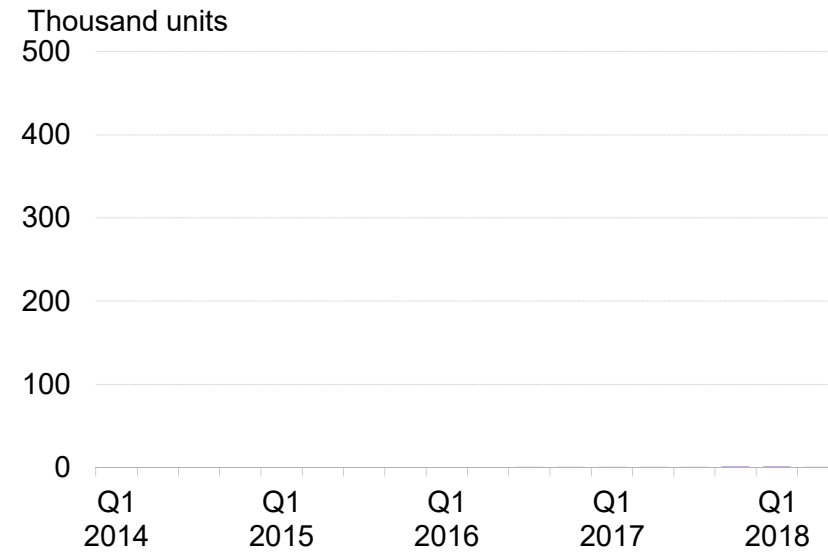
Global BEV vs. FCV sales

LIEBREICH
Associates

Battery electric vehicles



Fuel cell vehicles



Source: BNEF

2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
will be wind and solar



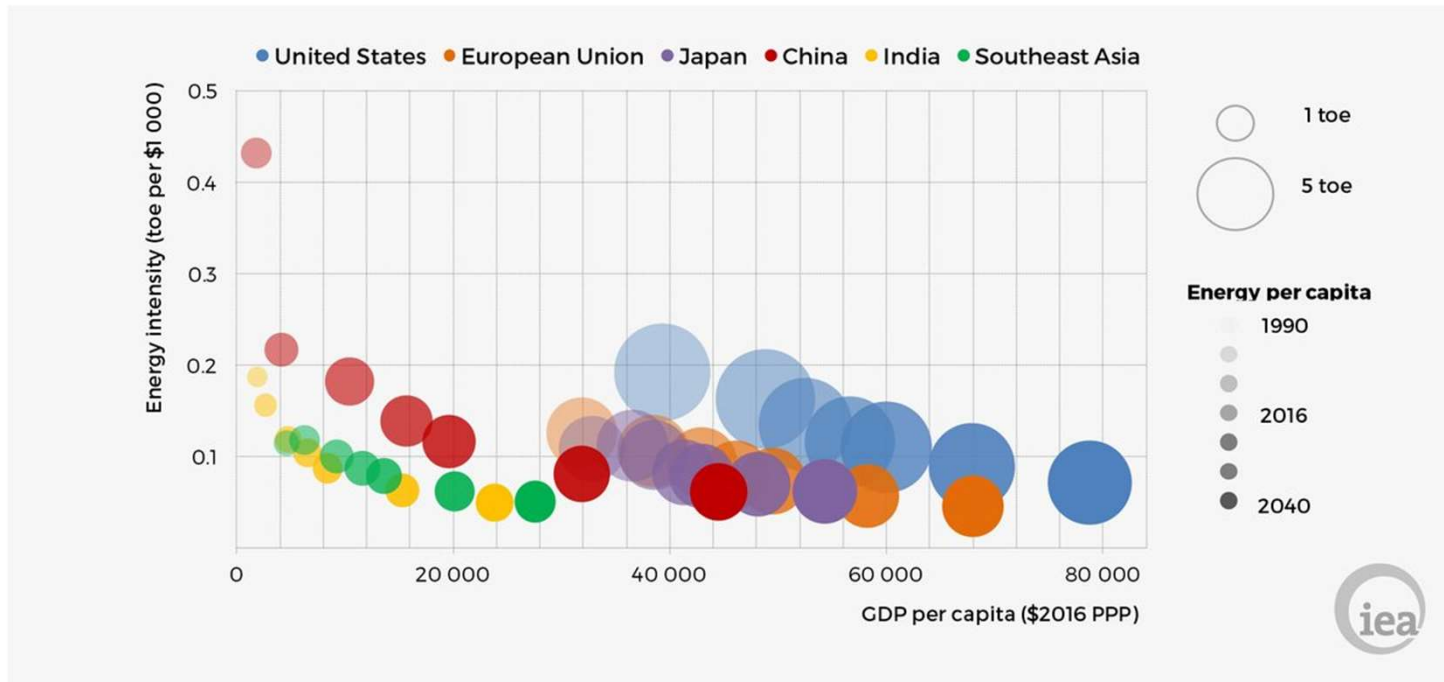
1/3 of cars and light trucks
will be electric



1/3 more energy-productivity
of the global economy

Images: Liebreich Associates; Images: Tesla, Wallpaper Mania, Cleantecnica

Energy intensity and energy use per capita – historic and future trend



2040: Welcome to the Three-Third World

LIEBREICH
Associates



1/3 of electricity
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1/3 more energy-productivity
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Images: Liebreich Associates; Images: Tesla, Wallpaper Mania, Cleantecnica

Paris

LIEBREICH
Associates



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



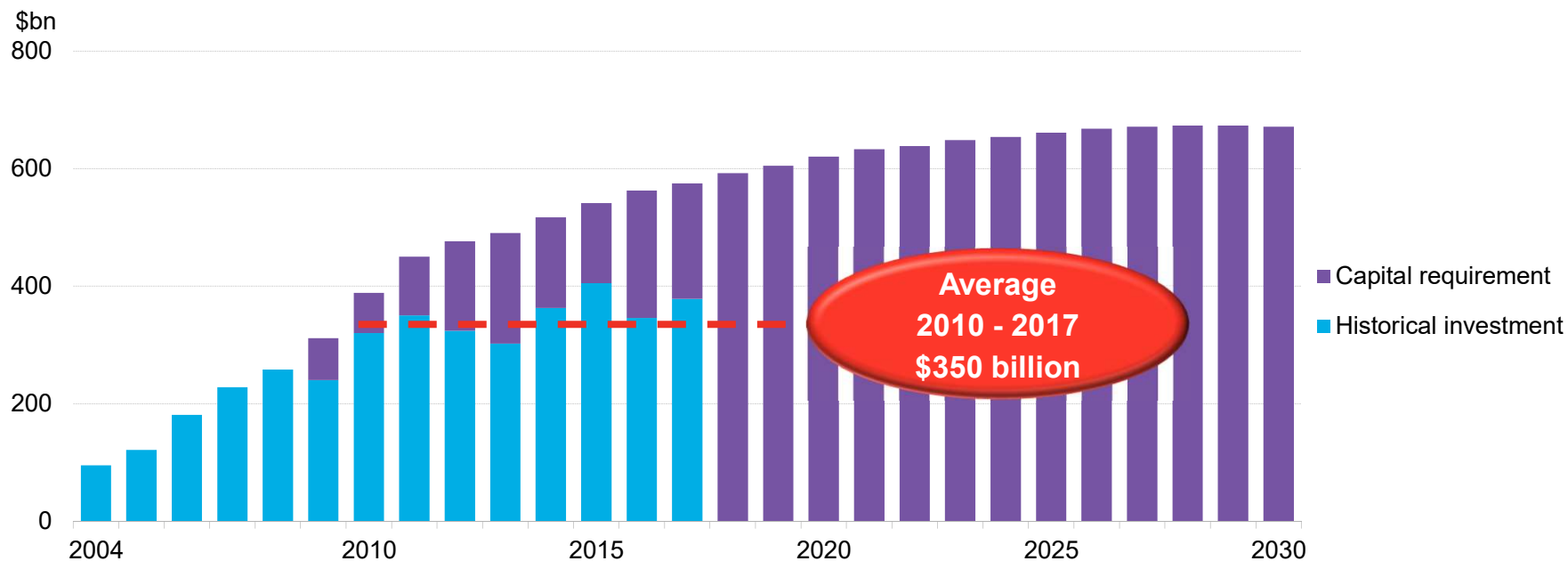
*Paris Agreement
December 2015*



Image: UNFCCC

Clean energy capital requirement to 2030

LIEBREICH Associates

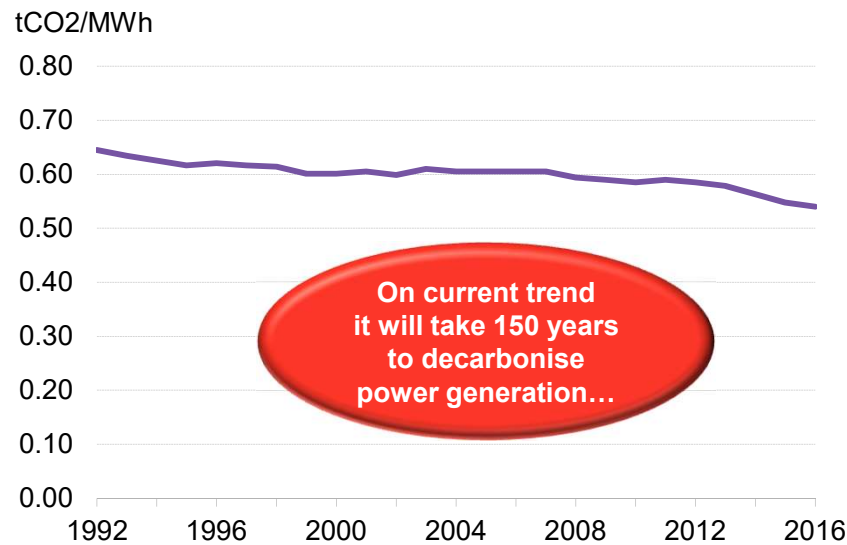


Note: Total values include estimates for undisclosed deals. Includes corporate and government R&D. Includes large hydro.

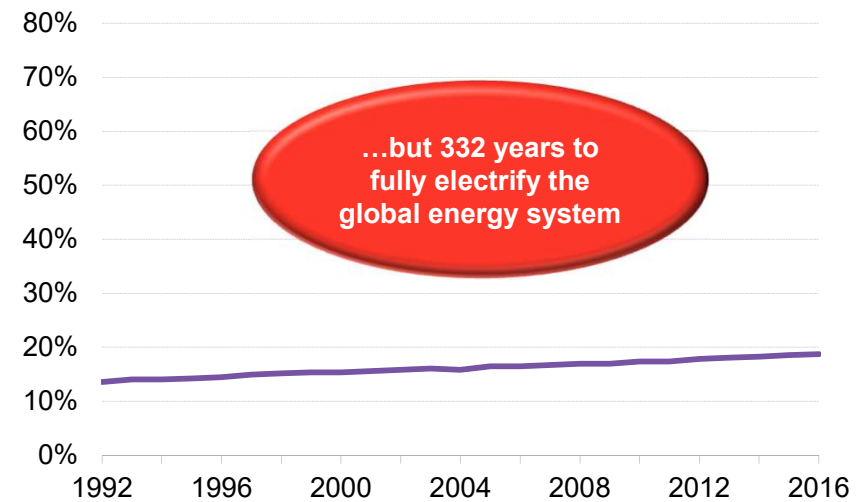
Source: BNEF

Decarbonising the global economy through zero-carbon electricity

Emissions intensity of power generation



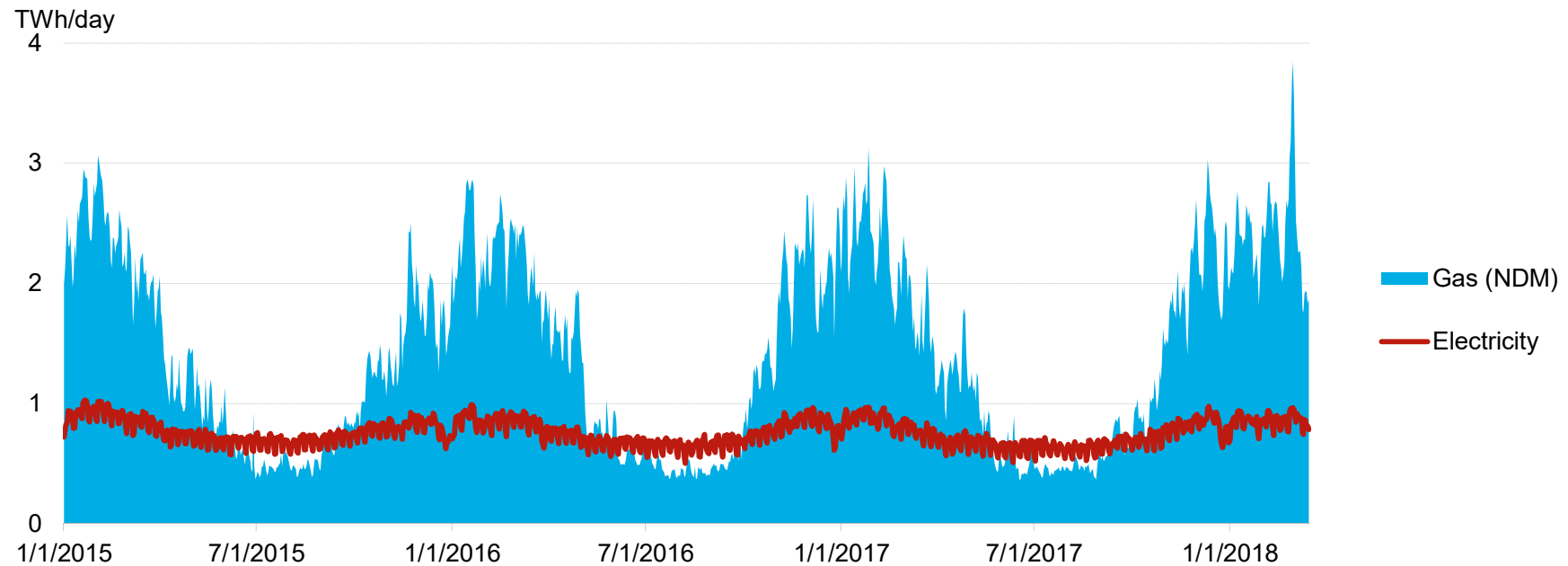
Electricity share in final energy consumption



Source: BNEF; Liebreich Associates; IEA

UK winter electricity and gas demand 2015 – 2018

LIEBREICH
Associates



Note: Non-daily metered (NDM) component is comprised of gas meters not measured on a daily basis, e.g. domestic, small business, and a proportion of commercial, public administration, agricultural and some industrial facilities.

Source: National Grid; Liebreich Associates

Innovation in heat is cool

LIEBREICH Associates



Images: Naked Energy; Climeon; Danfoss; SaltX; Sonnen; Radbot; Optiwatt; PassivSystems; Sunamp; Solidpower

The “house of the future”, Brütten

LIEBREICH
Associates



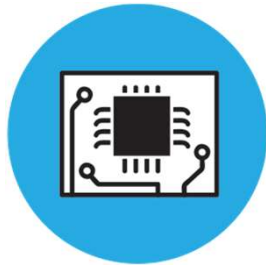
Self-sufficient in
heat and power
throughout the
year

Requires just 1
hour of sun per
day in summer

Image: Evangeline de Macedo, René Schmid Architekten AG

Digitisation of infrastructure

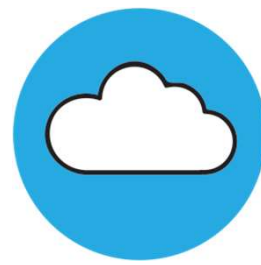
LIEBREICH
Associates



**Ubiquitous
chips and
sensors**



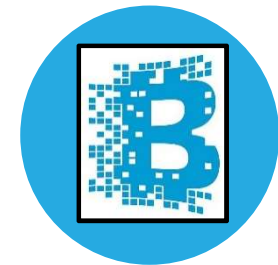
**Ubiquitous
communications**



**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

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Associates

Thanks!

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