The World Nuclear Industry Status Report 2019

(WNISR2019)

www.WorldNuclearReport.org

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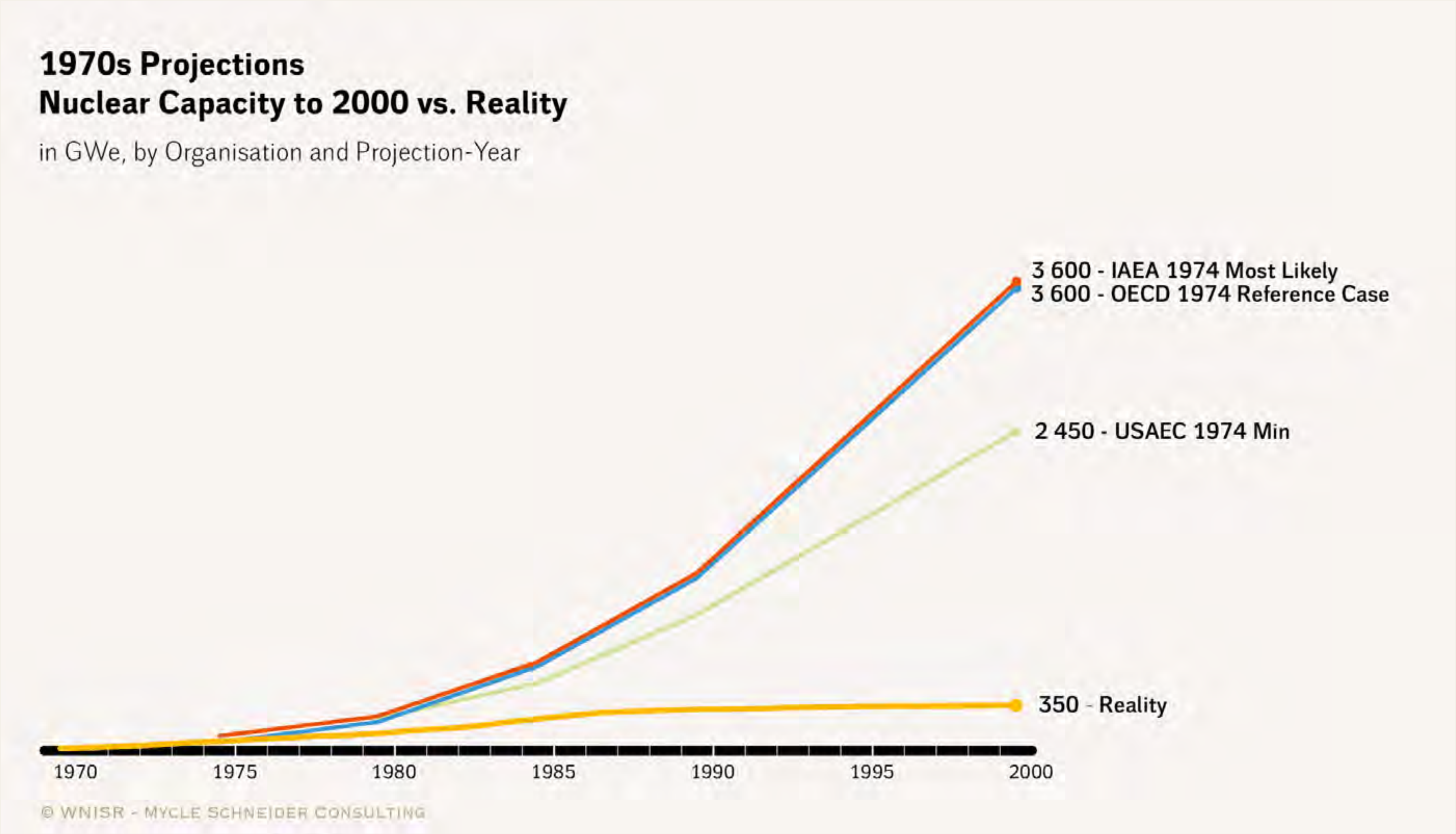
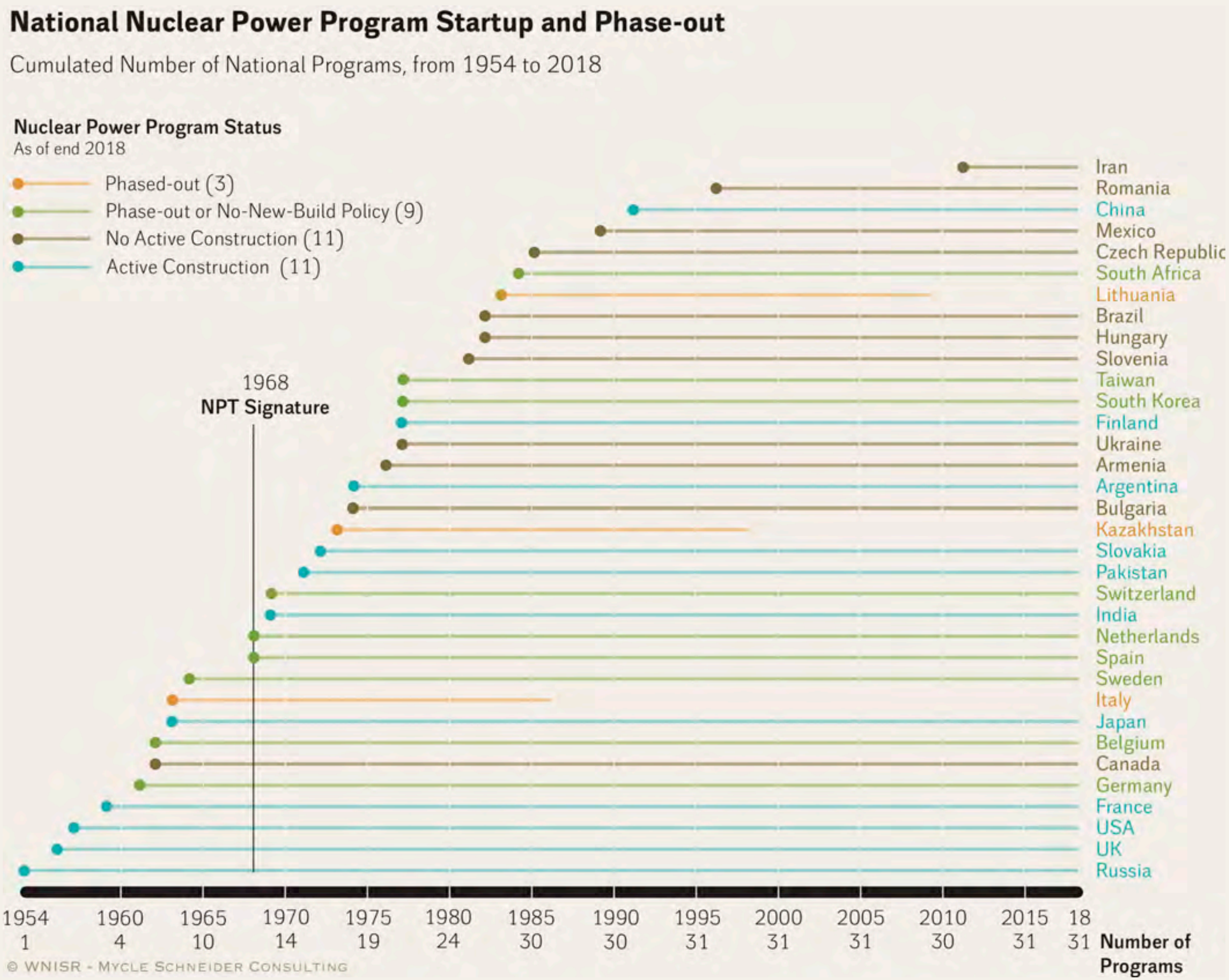
Centre de Recherches Internationales (CERI) de Sciences Po, Paris

GLOBAL OVERVIEW – FORECASTING VS. REALITY



Sources: Klaus Gufler, "Short and Mid-term Trends of the Development of Nuclear Energy", June 2013


National Nuclear Power Program Startup and Phase-out
Cumulated Number of National Programs, from 1954 to 2018
Nuclear Power Program Status
As of end 2018
Phased-out (3)
Phase-out or No-New-Build Policy (9)
No Active Construction (11)
Active Construction (11)
1968
NPT Signature
Iran
Romania
China
Mexico
Czech Republic
South Africa
Lithuania
Brazil
Hungary
Slovenia
Taiwan
South Korea
Finland
Ukraine
Armenia
Argentina
Bulgaria
Kazakhstan
Slovakia
Pakistan
Switzerland
India
Netherlands
Spain
Sweden
Italy
Japan
Belgium
Canada
Germany
France
USA
UK
Russia
1954 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 18
1 4 10 14 19 24 30 30 31 31 31 30 31 31
Number of Programs
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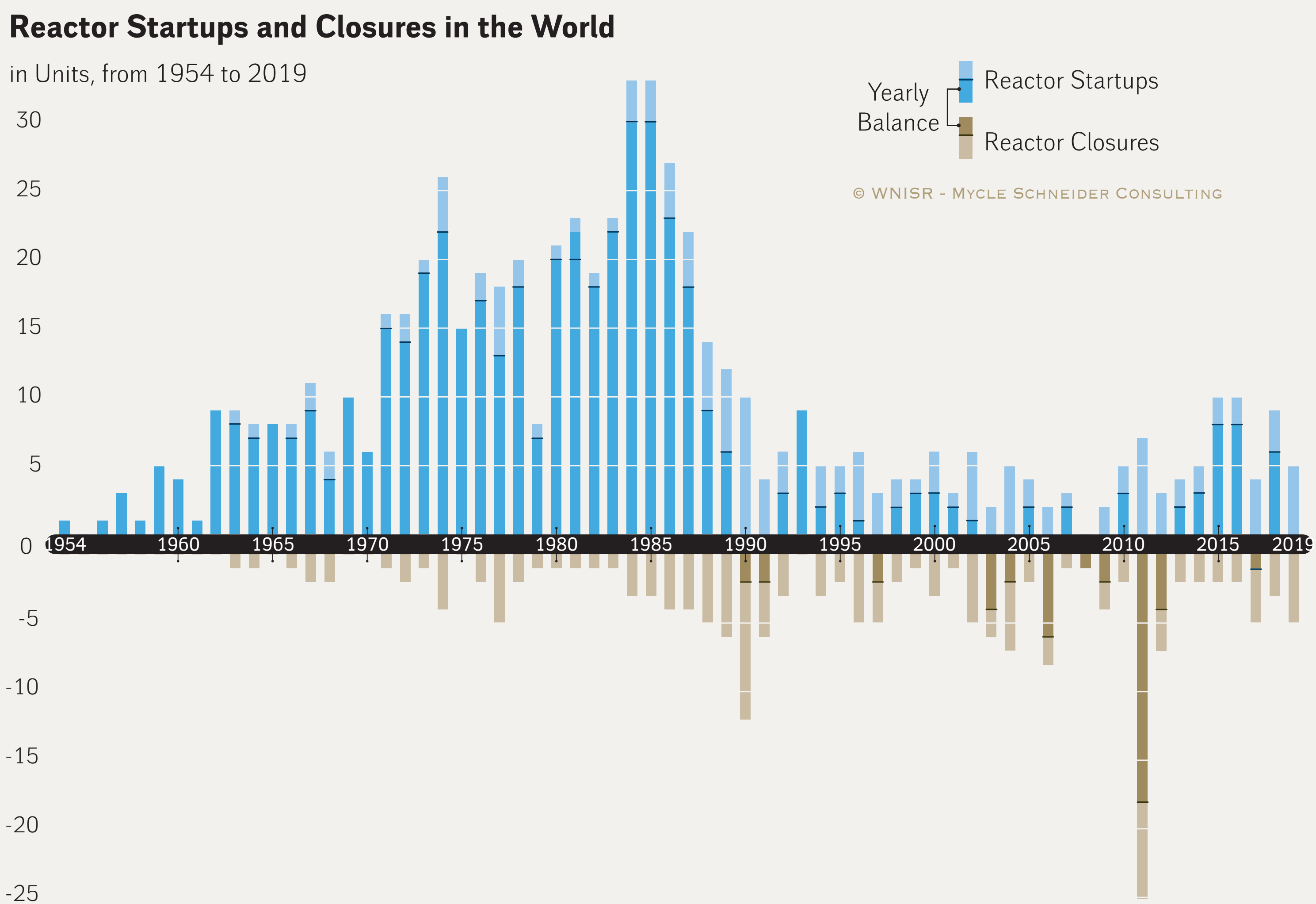
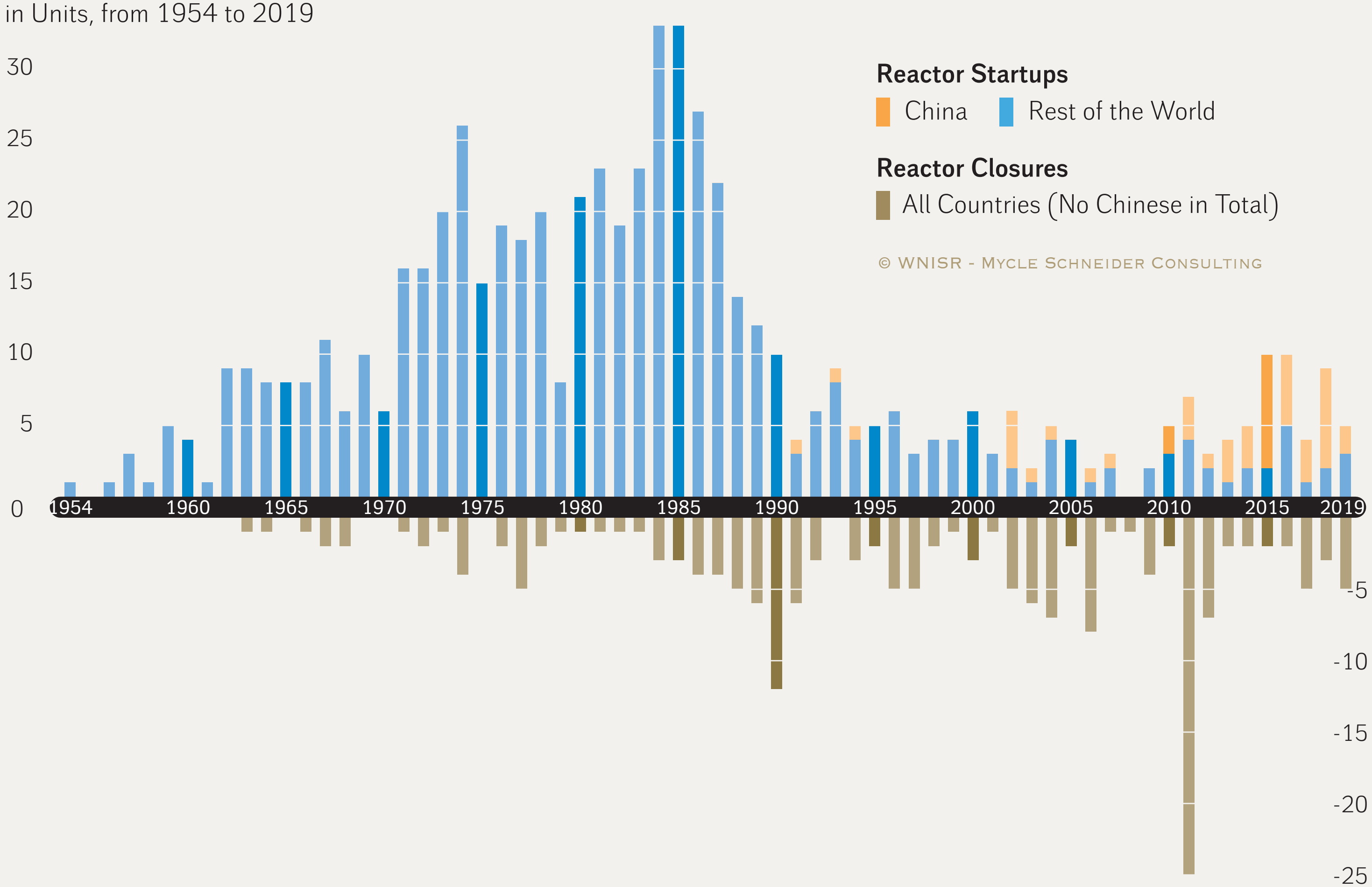
WNISR2019 GLOBAL OVERVIEW – STARTUPS AND CLOSURES



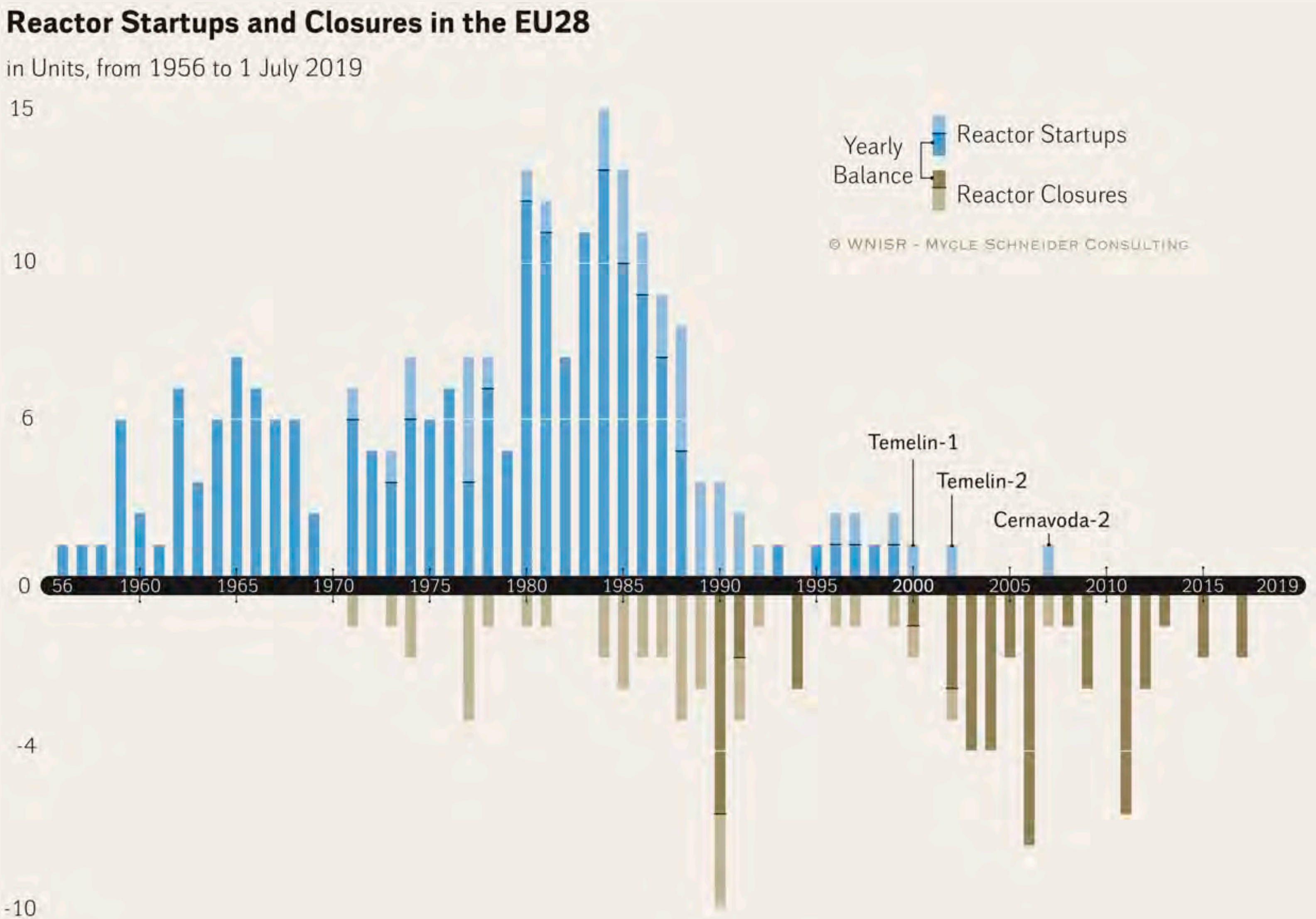
Sources: WNISR, with IAEA-PRIS, 2020

Reactor Startups and Closures in the World

in Units, from 1954 to 2019



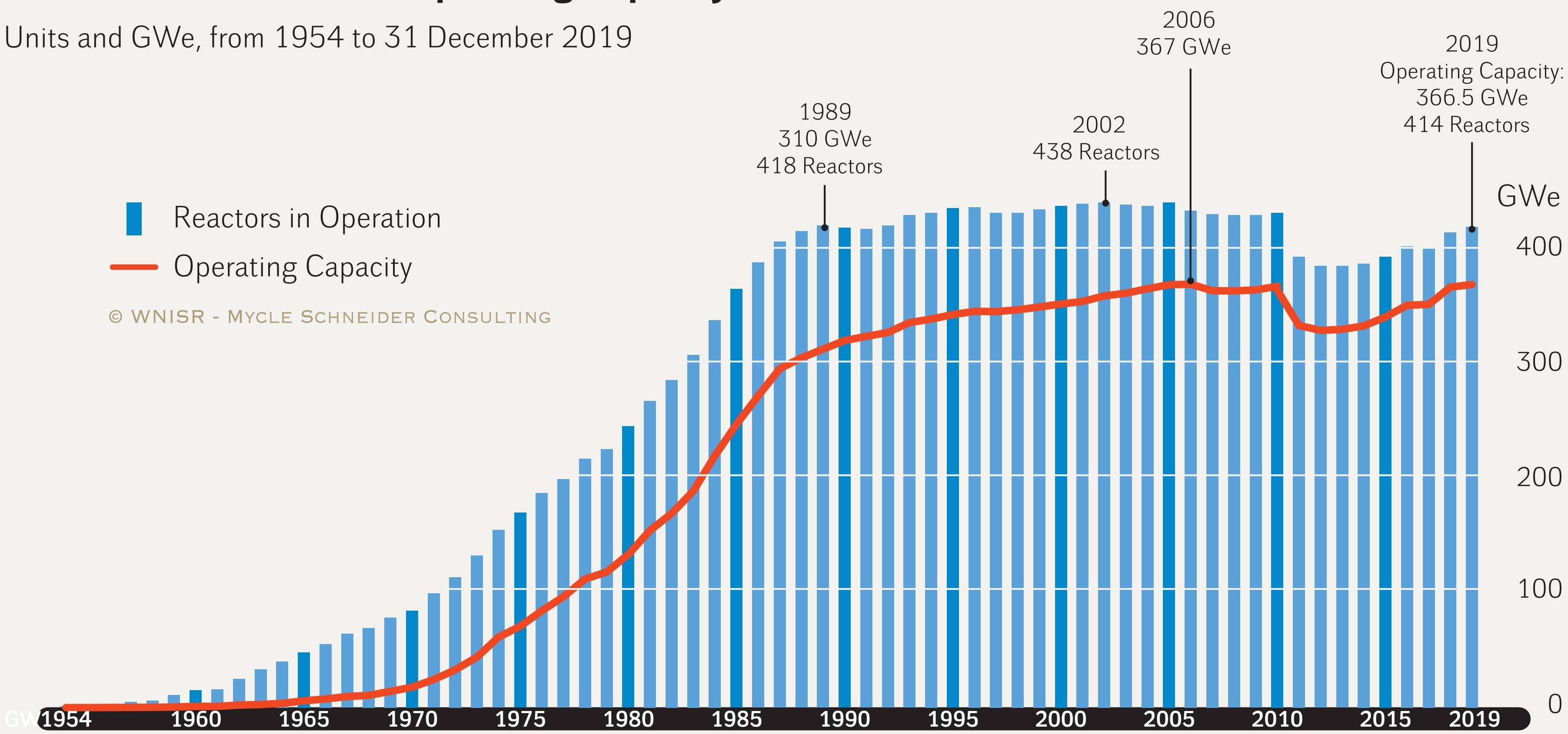
Sources: WNISR, with IAEA-PRIS, 2020



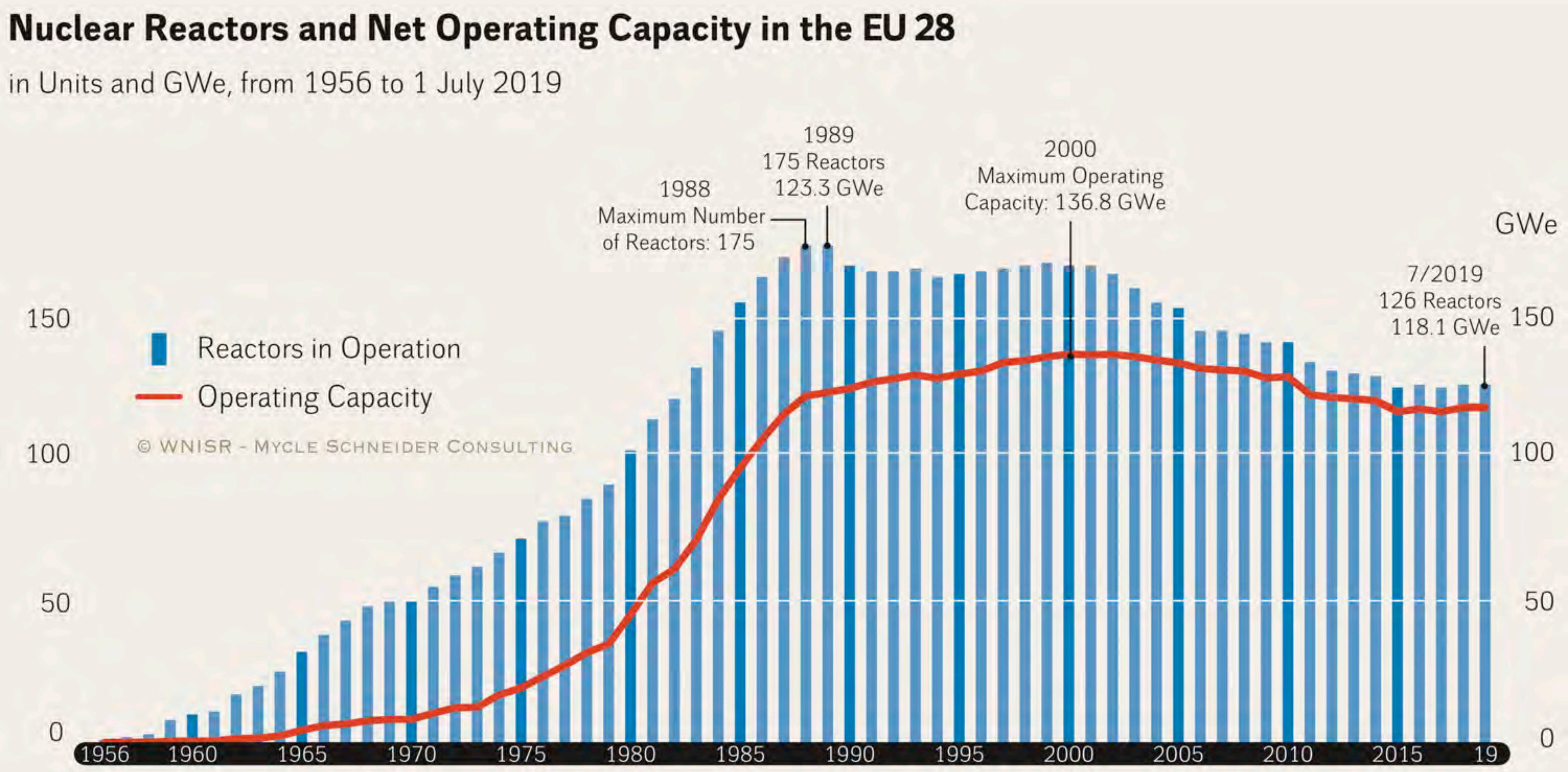
Sources: WNISR, with IAEA-PRIS, 2019

Nuclear Reactors and Net Operating Capacity in the World

in Units and GWe, from 1954 to 31 December 2019

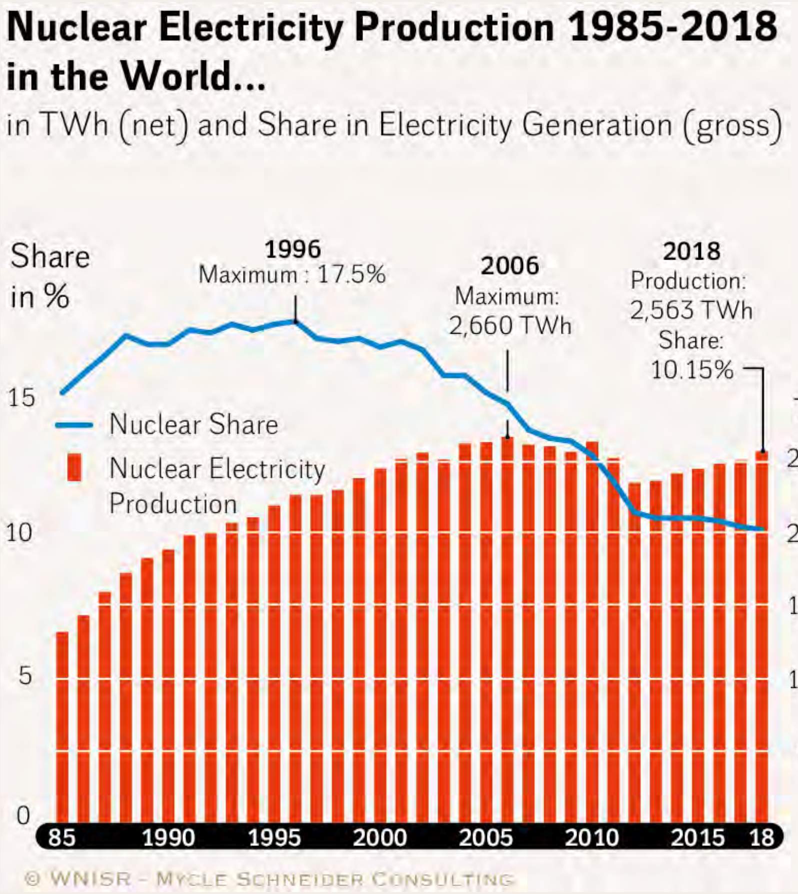


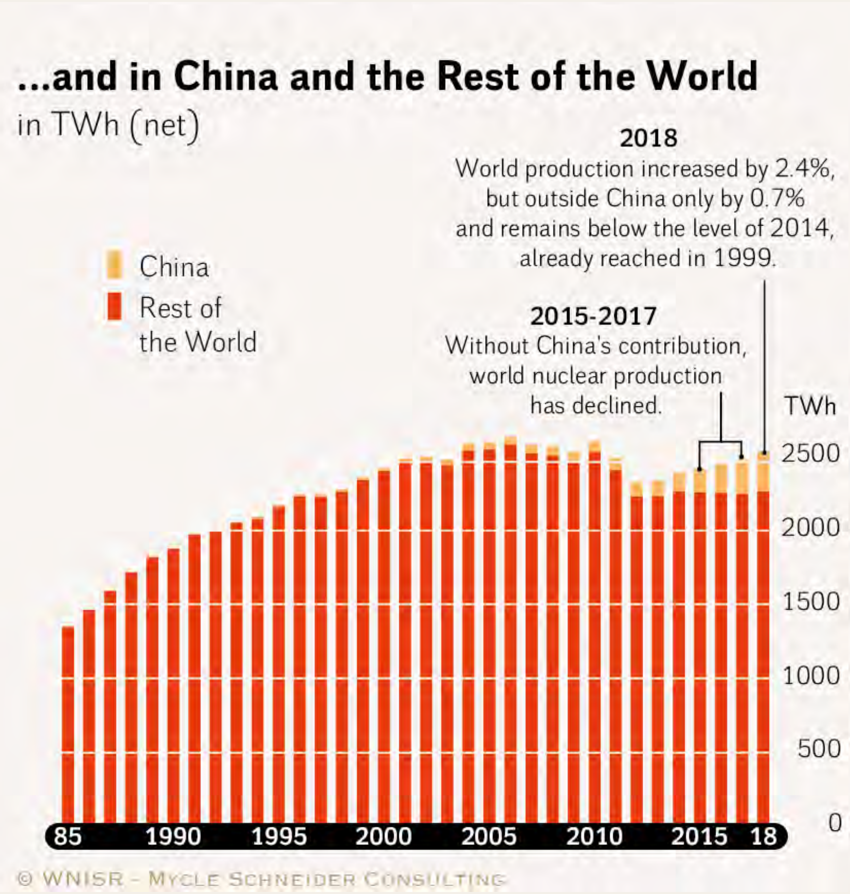
Sources: WNISR, with IAEA-PRIS, 2020



Sources: WNISR, with IAEA-PRIS, 2019

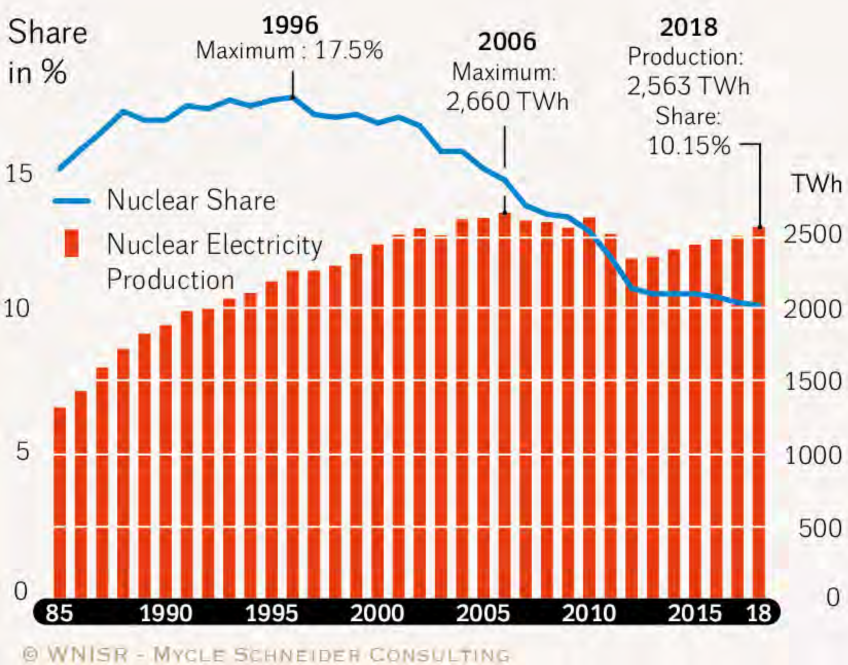
 GLOBAL OVERVIEW – ROLE OF NUCLEAR POWER



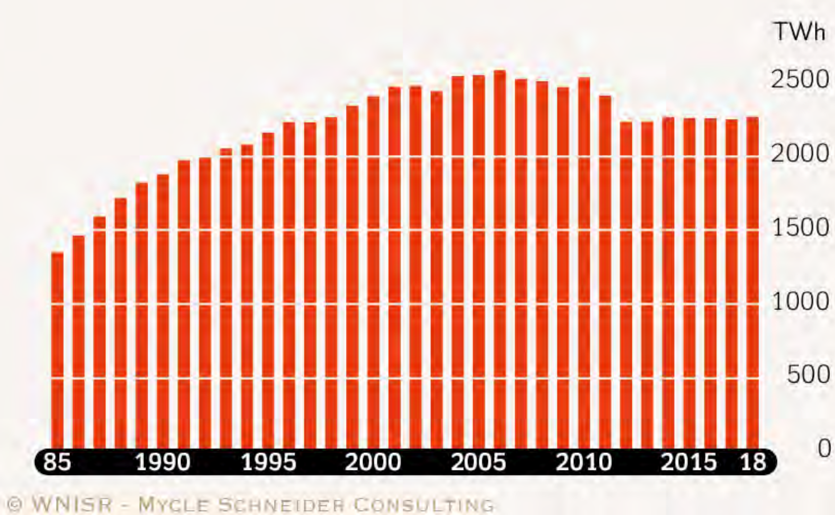


Sources: IAEA-PRIS, BP, 2019

Nuclear Electricity Production 1985-2018 in the World...
in TWh (net) and Share in Electricity Generation (gross)

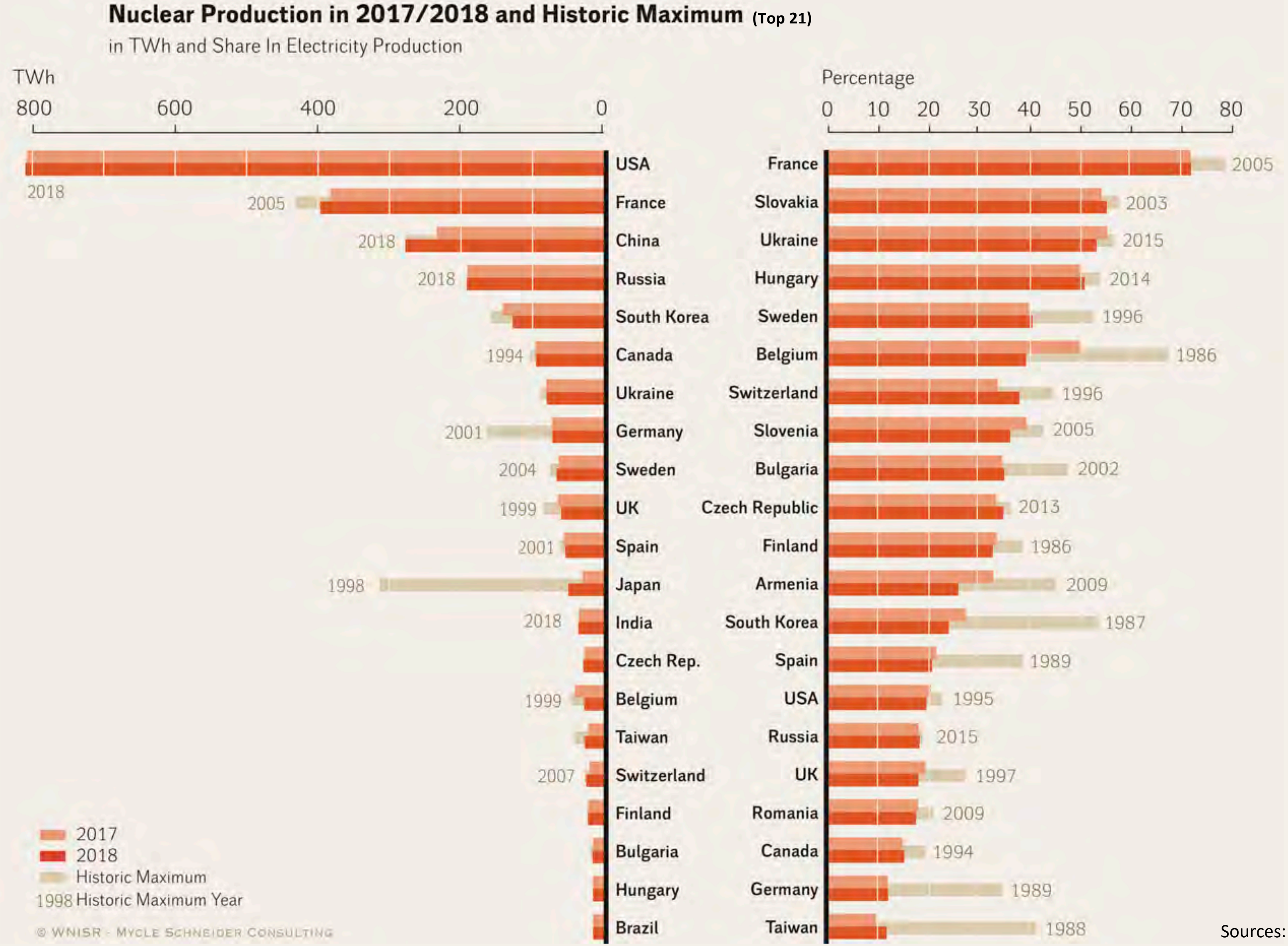


...and in China and the Rest of the World
in TWh (net)

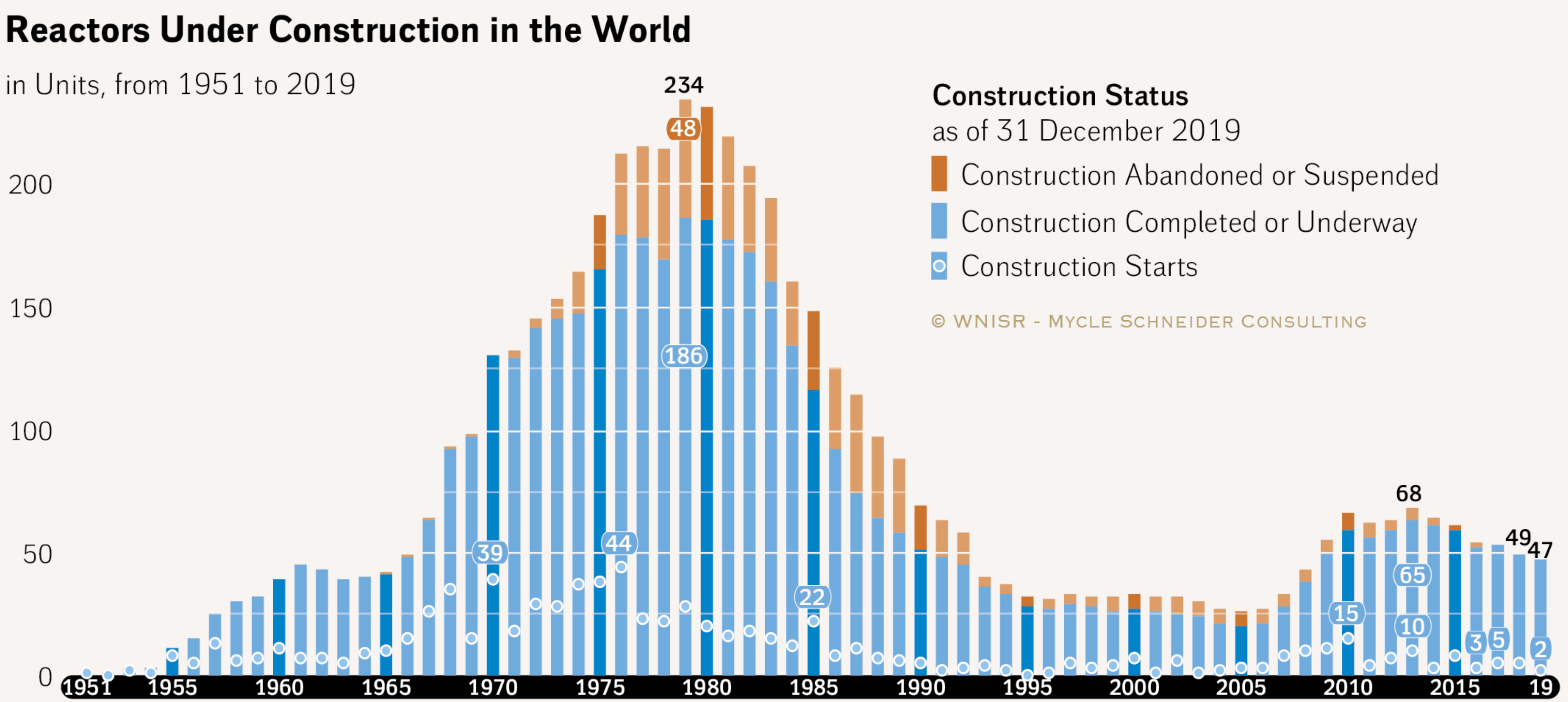


Sources: IAEA-PRIS, BP, 2019

WNISR2019 GLOBAL OVERVIEW - NUCLEAR ELECTRICITY GENERATION



Sources: IAEA-PRIS, BP, 2019



Sources: WNISR, with IAEA-PRIS, 2020

WNISR2019 GENERAL OVERVIEW — CONSTRUCTIONS

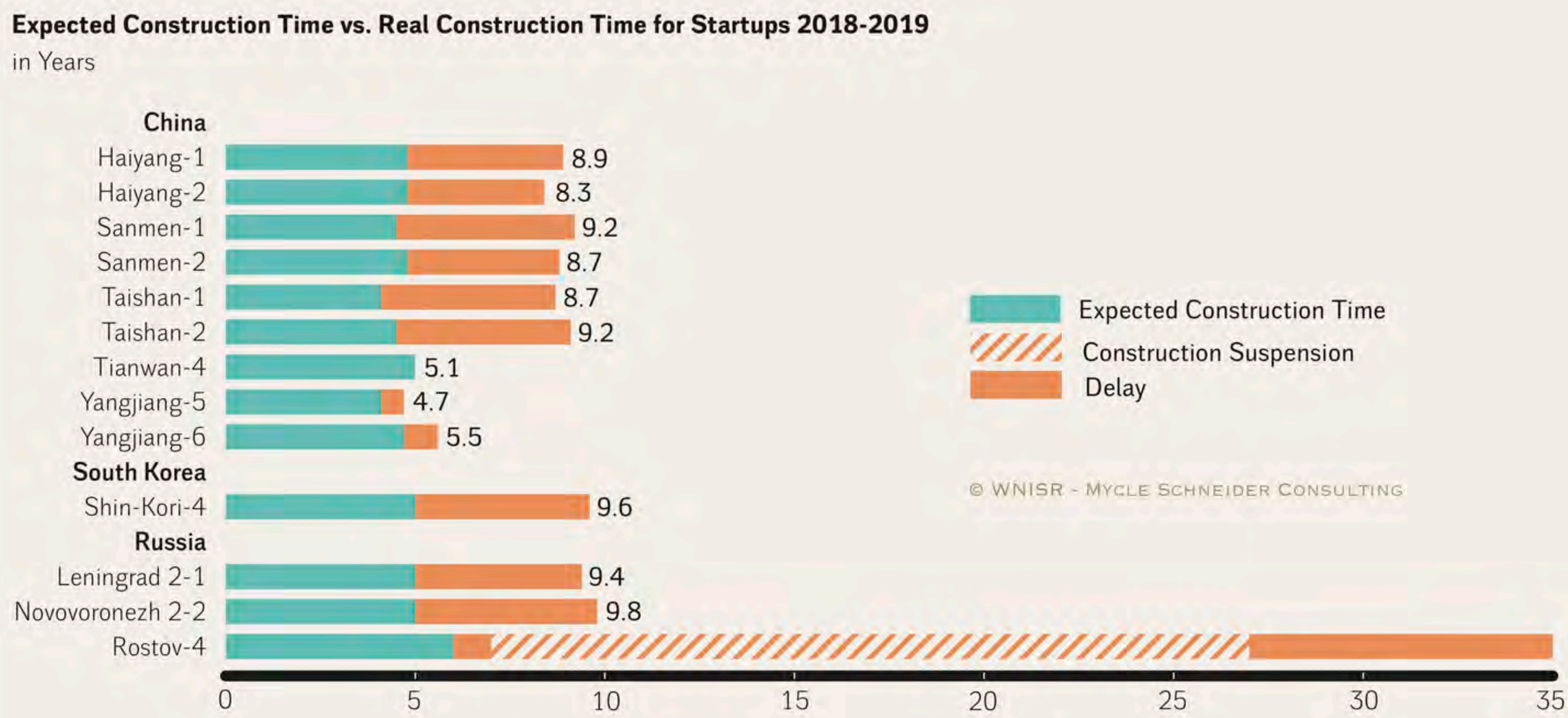
Country	Units	Capacity (MW net)	Construction Starts	Grid Connection	Units Behind Schedule
China	10	8 800	2012 - 2017	2020 - 2023	2-3
India	7	4 824	2004 - 2017	2019 - 2023	5
Russia	5	3 379	2007 - 2019	2019 - 2023	3
UAE	4	5 380	2012 - 2015	2020 - 2023	4
South Korea	4	5 360	2012 - 2018	2019 - 2024	4
Belarus	2	2 218	2013 - 2014	2019 - 2020	1-2
Bangladesh	2	2 160	2017 - 2018	2023 - 2024	0
Slovakia	2	880	1985	2020 - 2021	2
USA	2	2 234	2013	2021 - 2022	2
Pakistan	2	2 028	2015 - 2016	2020 - 2021	0
Japan	1	1 325	2007	?	1
Argentina	1	25	2014	2021	1
UK	1	1 630	2018	2025	0
Finland	1	1 600	2005	2020	1
France	1	1 600	2007	2022	1
Turkey	1	1 114	2018	2024	0
Total	**46**	**44 557**	**1985 - 2019**	**2019 - 2025**	**27-29**

Sources: Compiled by WNISR, 2019

GENERAL OVERVIEW — CONSTRUCTIONS

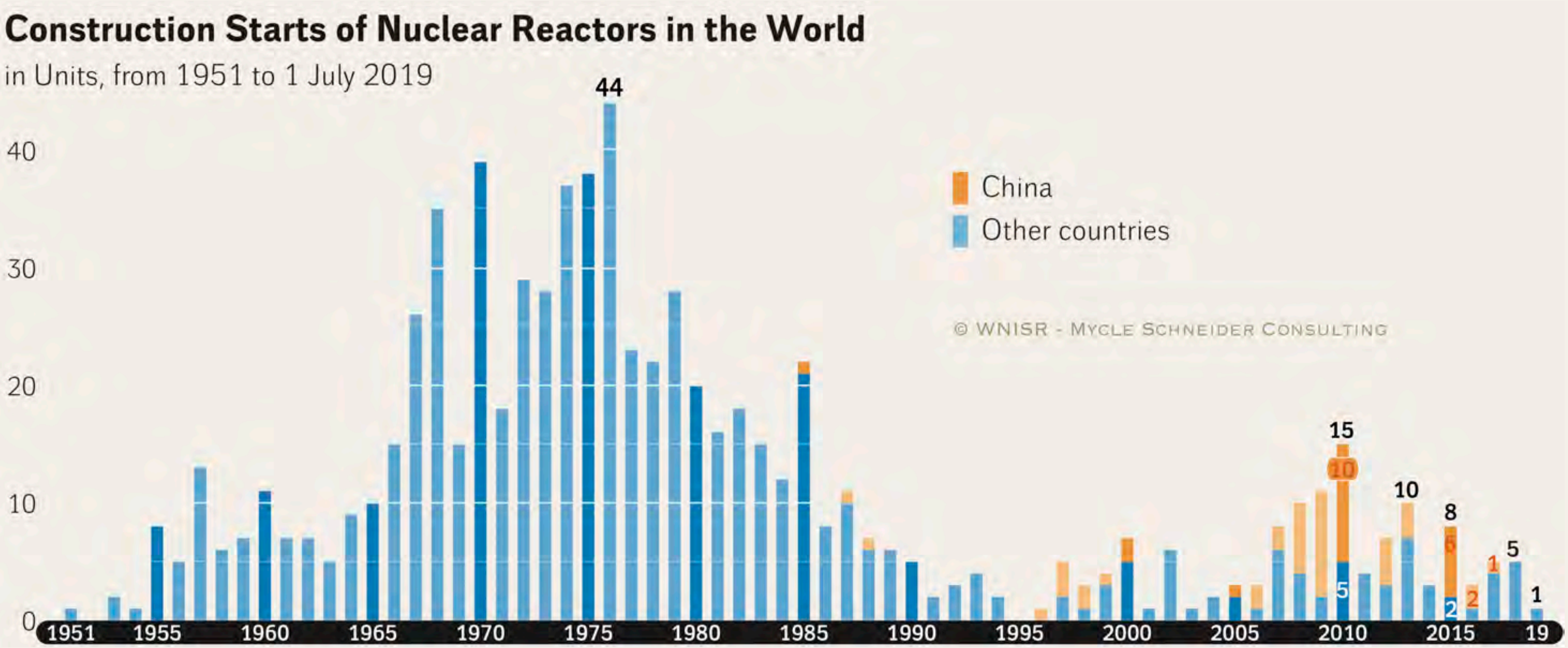
Construction Times of 63 Units Started-up 2009-7/2019				
Country	**Units**	**Construction Time (in Years)**		
		Mean Time	**Minimum**	**Maximum**
China	37	6.0	4.1	11.2
Russia	8	22.2	8.1	35.0
South Korea	6	6.0	4.1	9.6
India	5	9.8	7.2	14.2
Pakistan	3	5.4	5.2	5.6
Argentina	1	33.0	33.0	
Iran	1	36.3	36.3	
Japan	1	5.1	5.1	
USA	1	43.5	43.5	
World	63	9.8	4.1	43.5

Sources: Compiled by WNISR, 2019



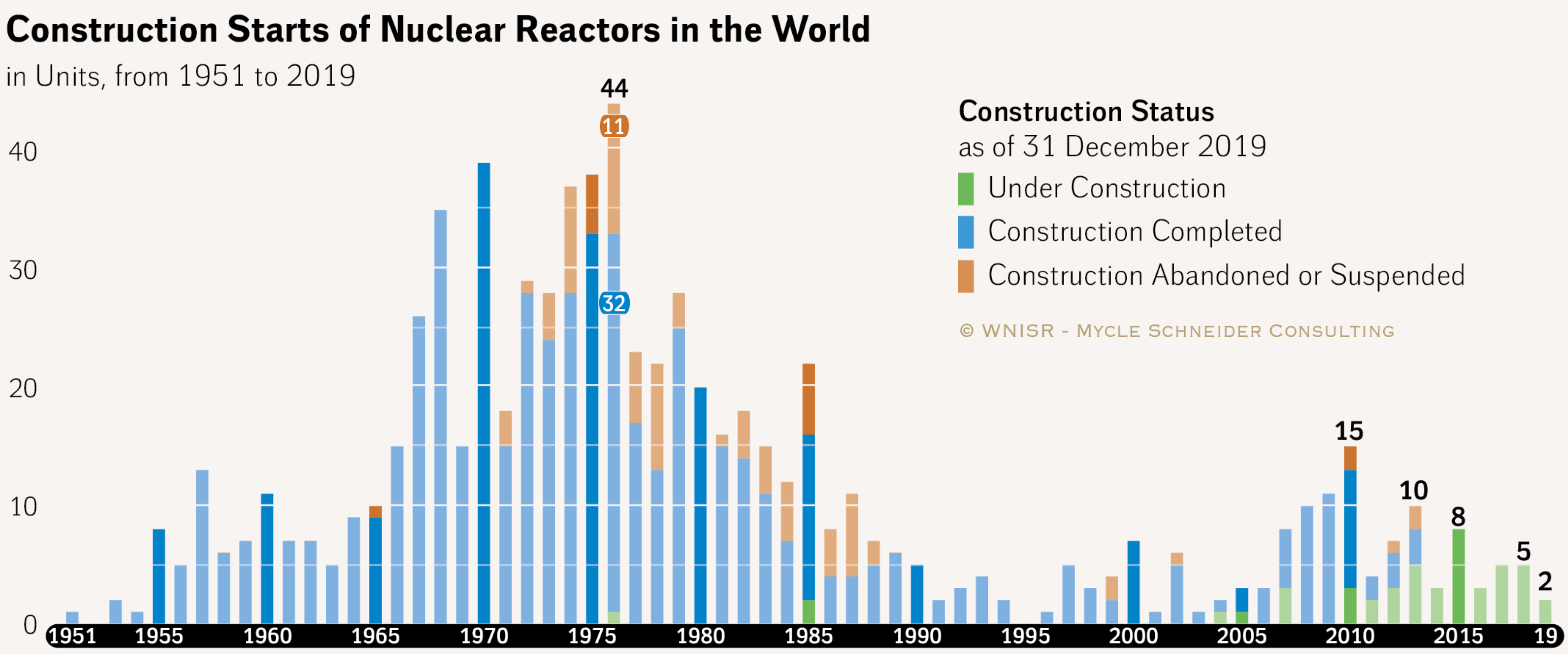
Sources: WNISR, with IAEA-PRIS, 2019

WNISR2019 GLOBAL OVERVIEW – CONSTRUCTIONS STARTS & CHINA



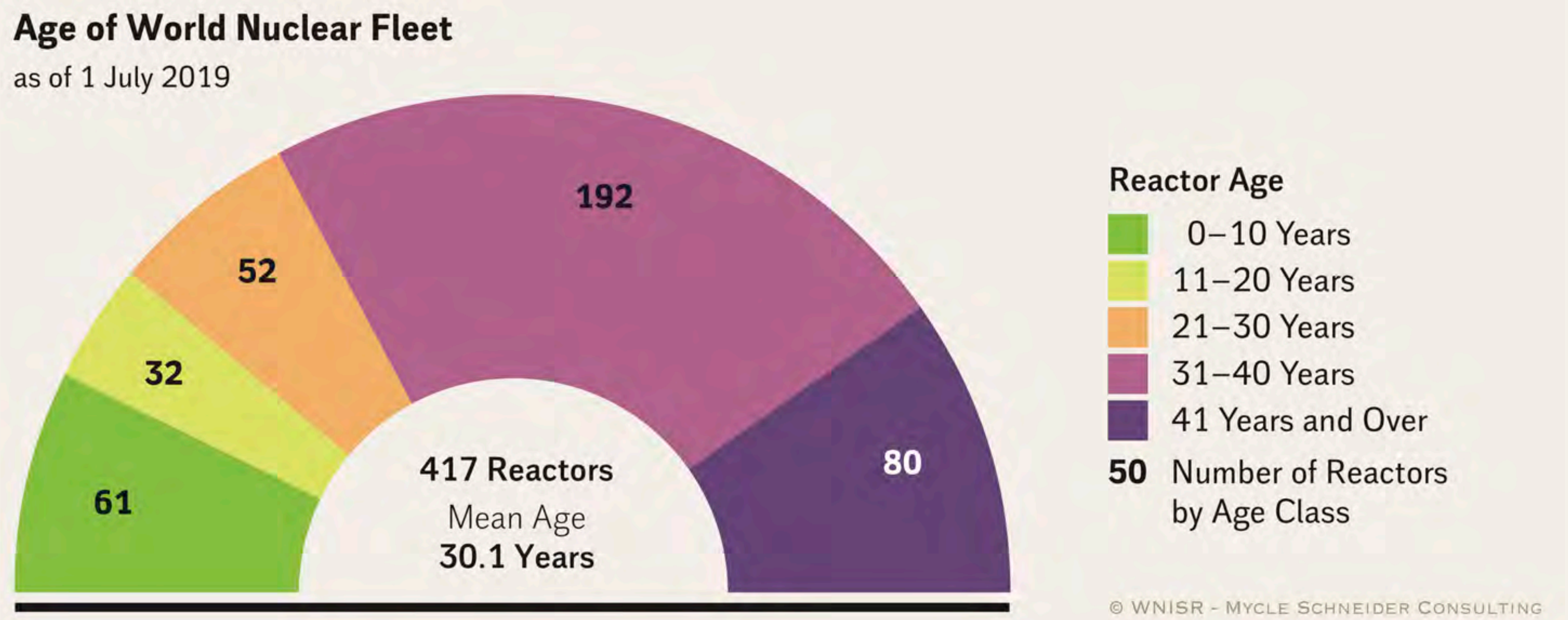
Sources: WNISR, with IAEA-PRIS, 2019

WNISR2019 GLOBAL OVERVIEW – CONSTRUCTIONS STARTS WORLD...

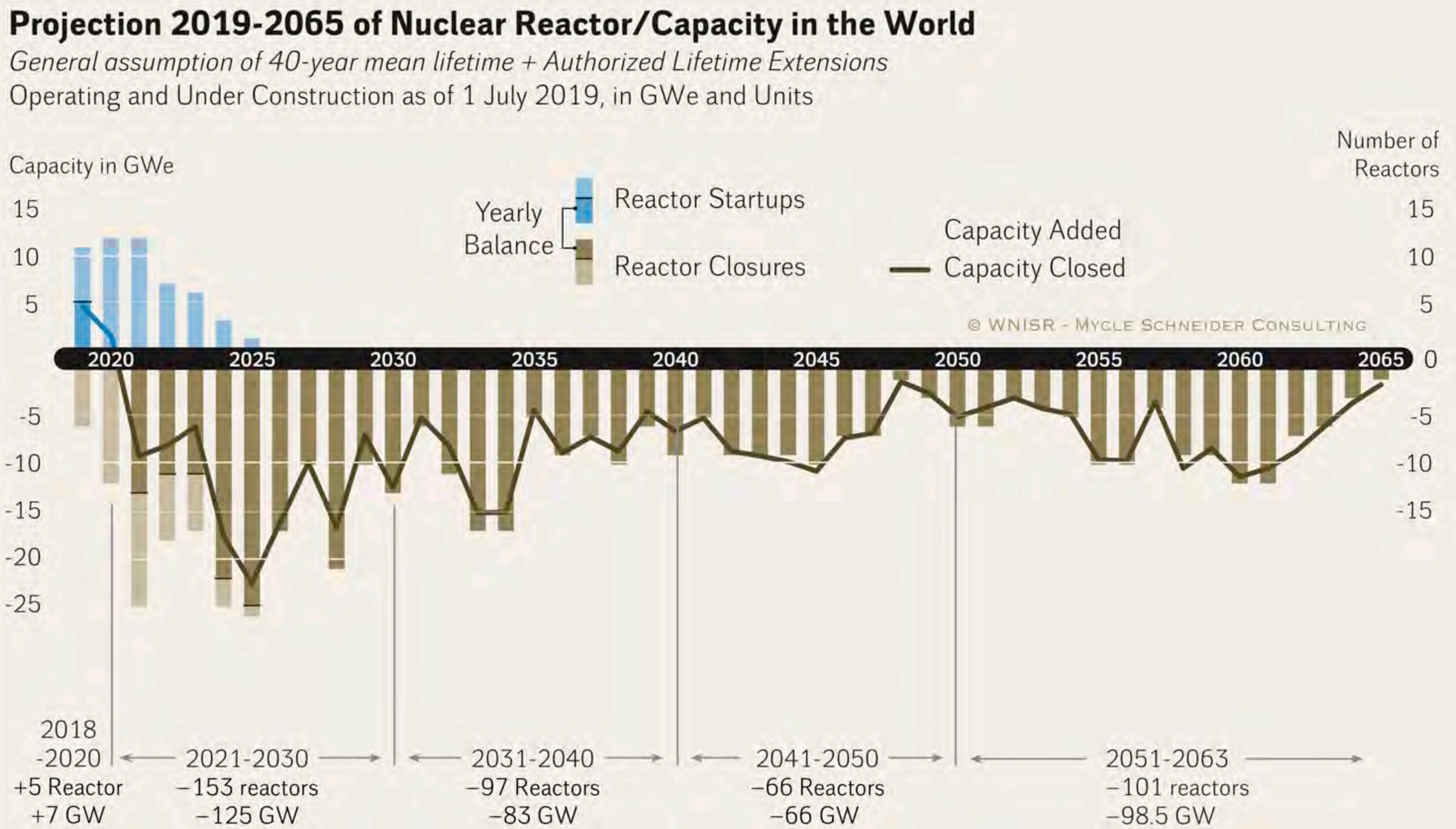


Sources: WNISR, with IAEA-PRIS, 2020

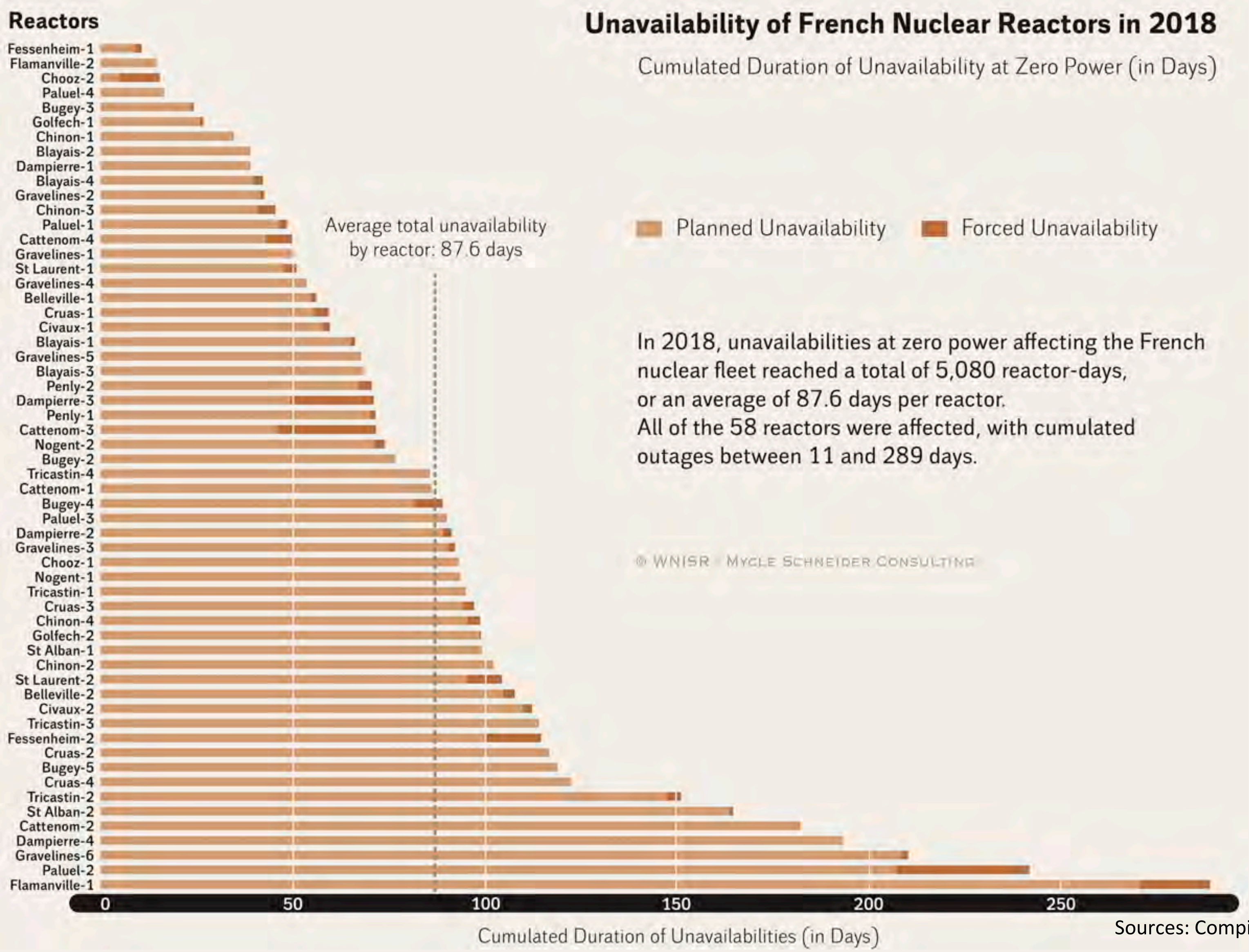
WORLD FLEET - OPERATING AGE



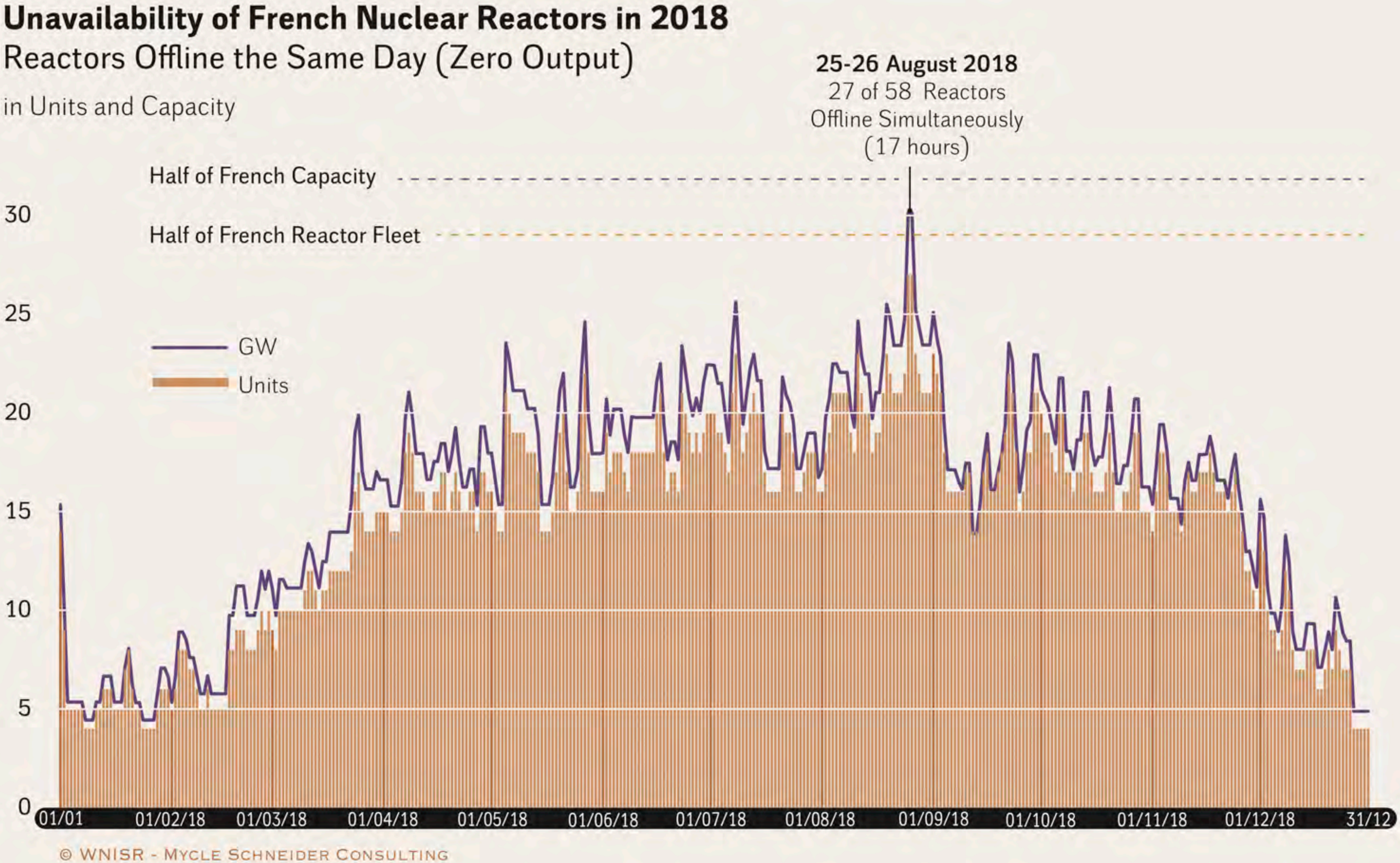
Sources: WNISR, with IAEA-PRIS, 2019



Sources: Various sources, compiled by WNISR, 2019



Sources: Compilation from RTE, 2019

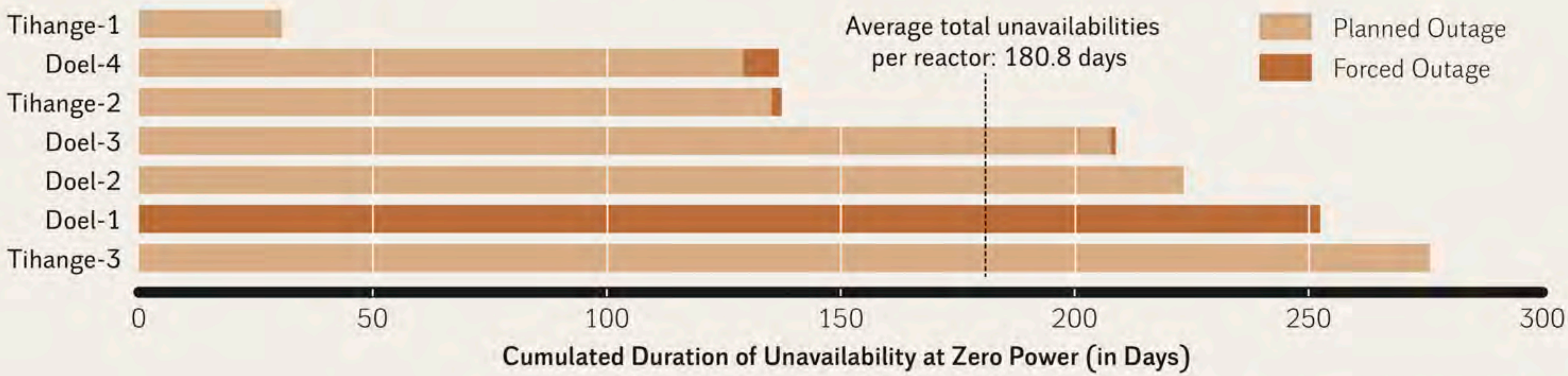


Sources: Compilation from RTE, 2019

Unavailability of Belgian Nuclear Reactors in 2018

Total Unavailabilities in Days per Reactor

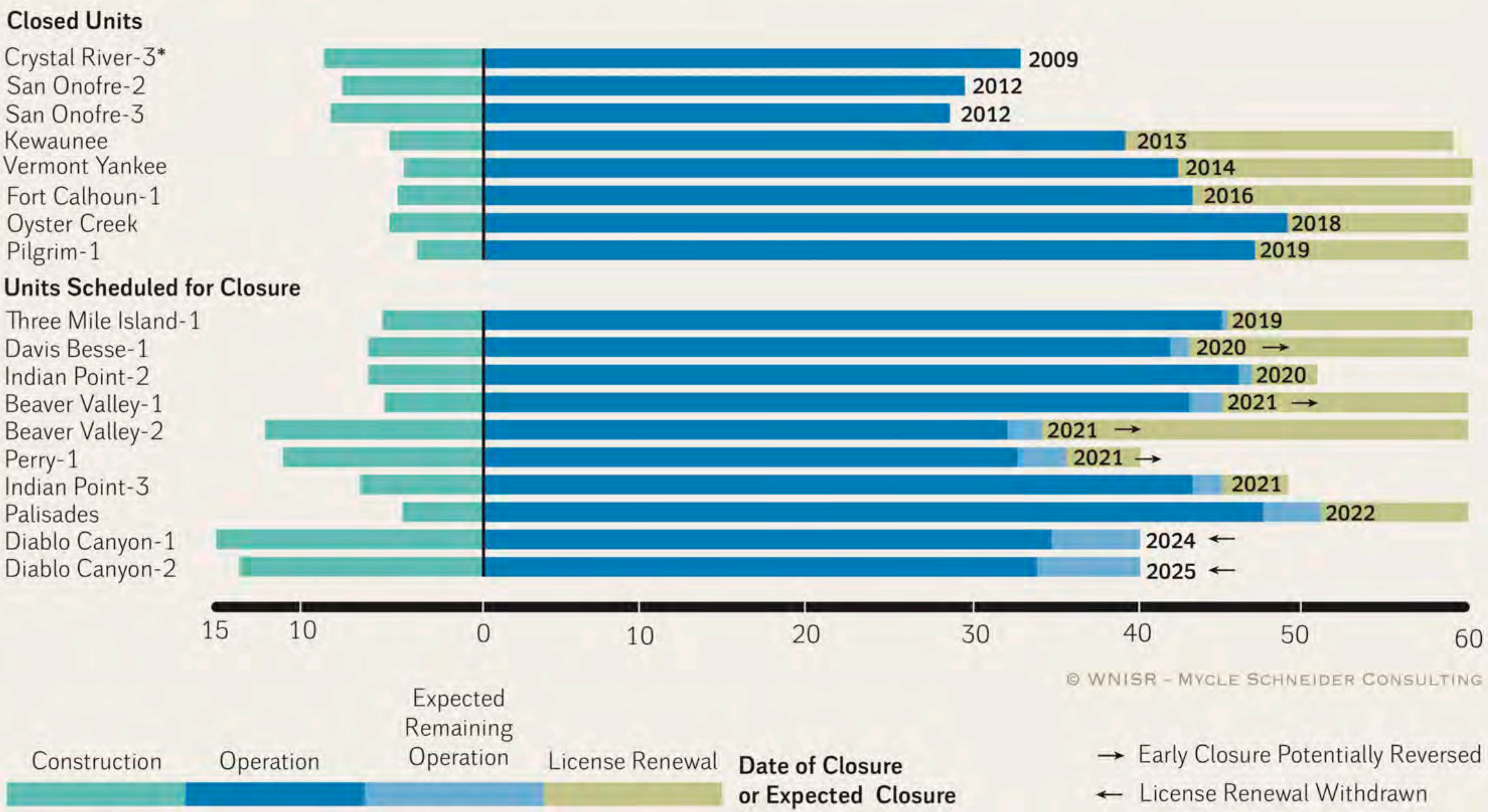
In 2018, unavailabilities at zero power affecting the Belgian nuclear fleet reached a total of 1,265 reactor-days, or an average of 180.8 days per reactor.
All of the 7 reactors were affected, with cumulated outages between 31 and 276 days.



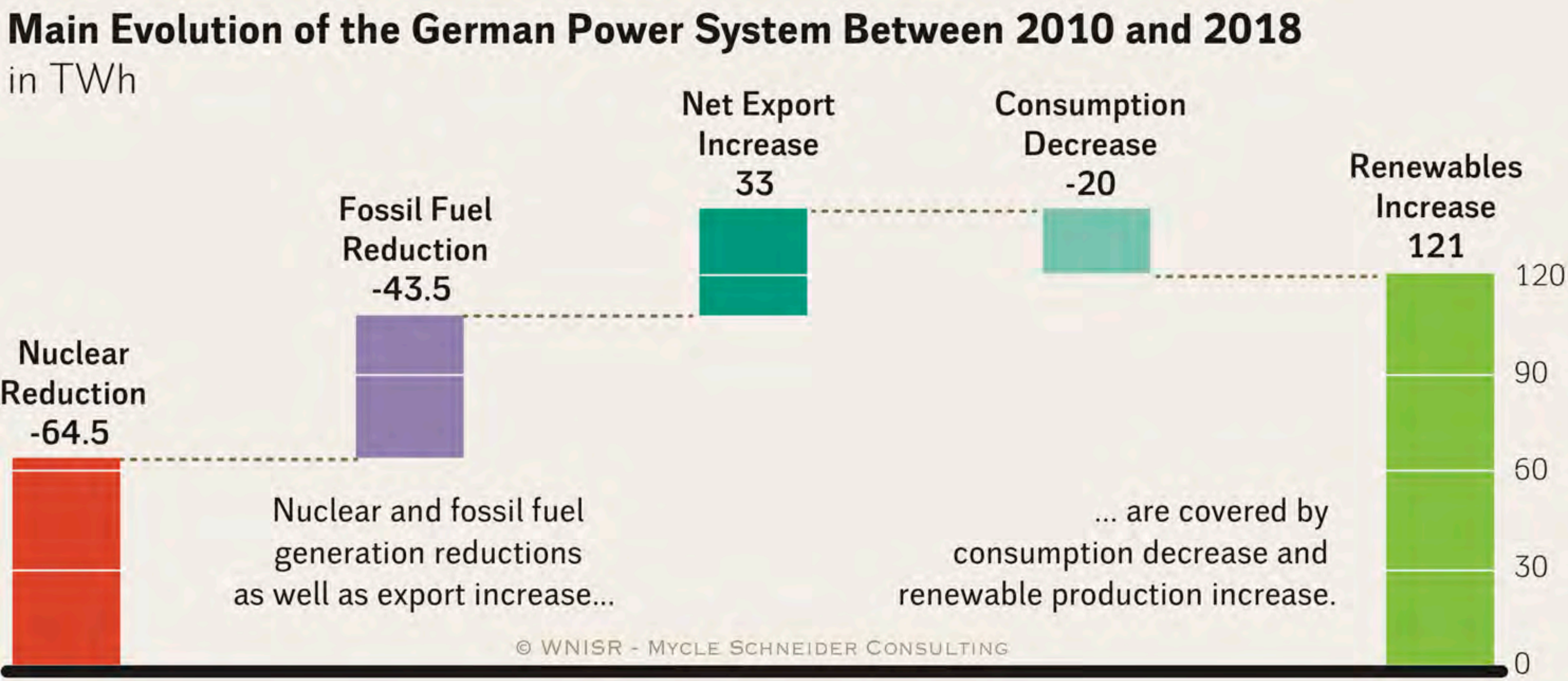
Source: ENTSO-E and Engie Transparency Platforms, 2019

Timelines of 18 U.S. Reactors Subject to Early-Retirement 2009–2025

as of 1 July 2019

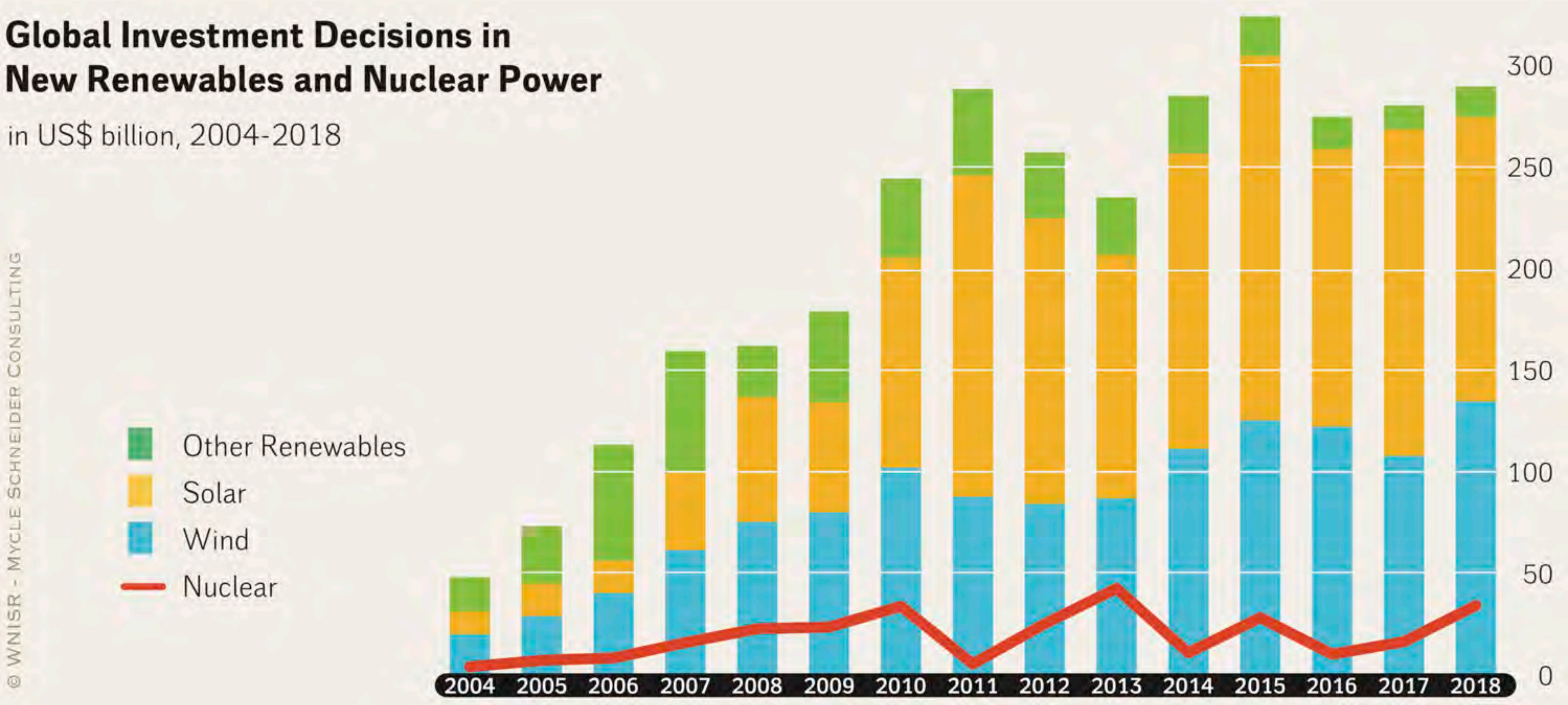


Sources: Various, compiled byWNISR, 2019

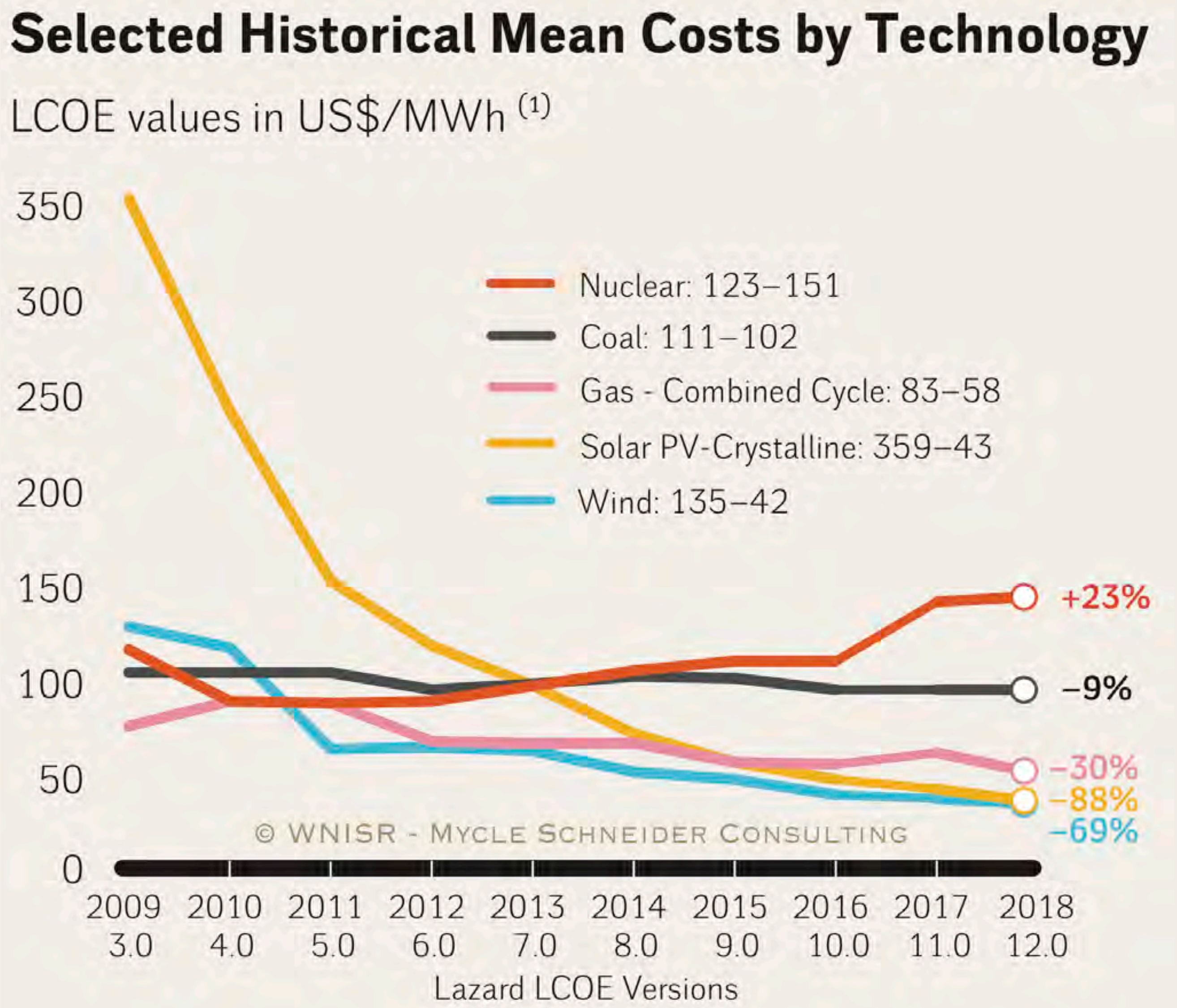


Sources WNISR, based on AGEB 2019

 NUCLEAR POWER VS. RENEWABLES DEPLOYMENT

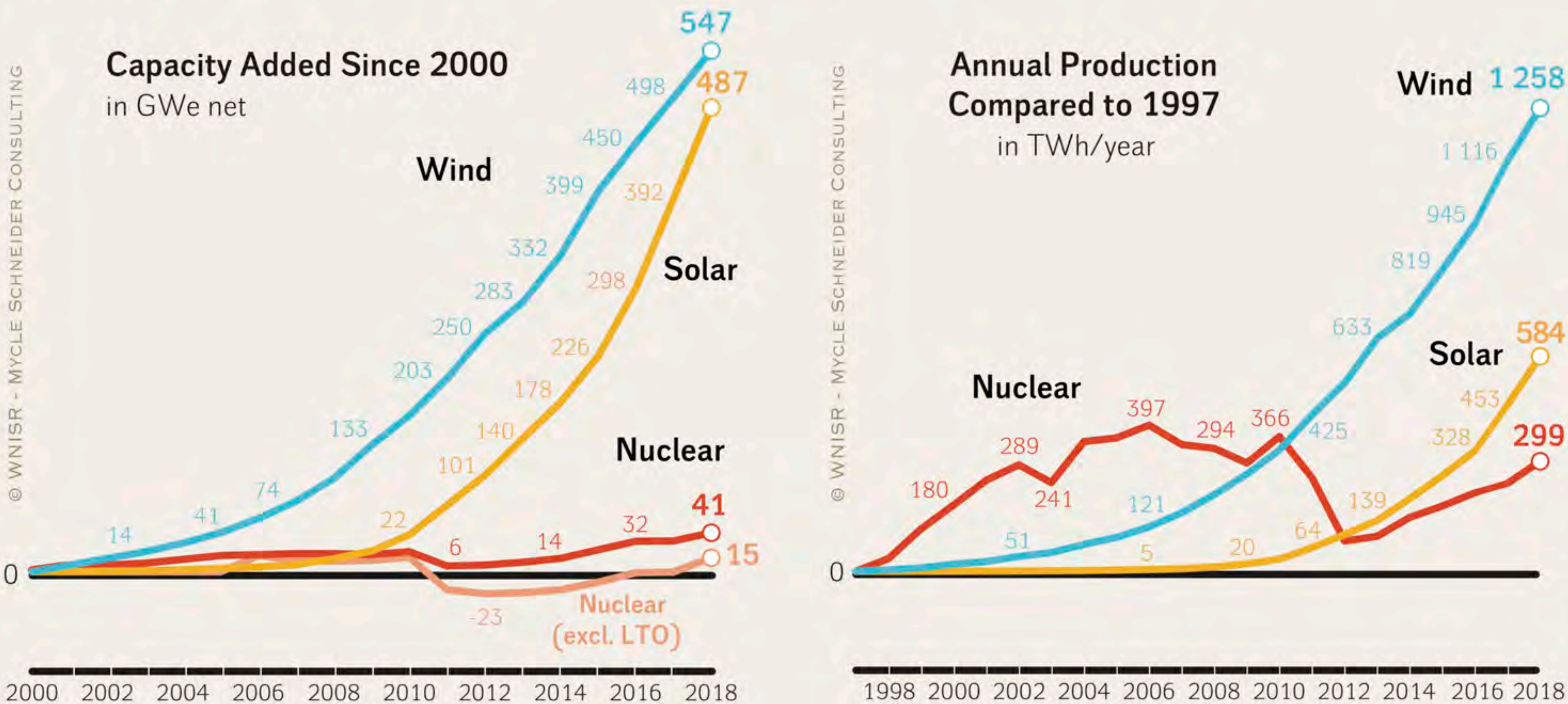


Sources: *FS-UNEP/BNEF 2019 and WNISR Original Research*



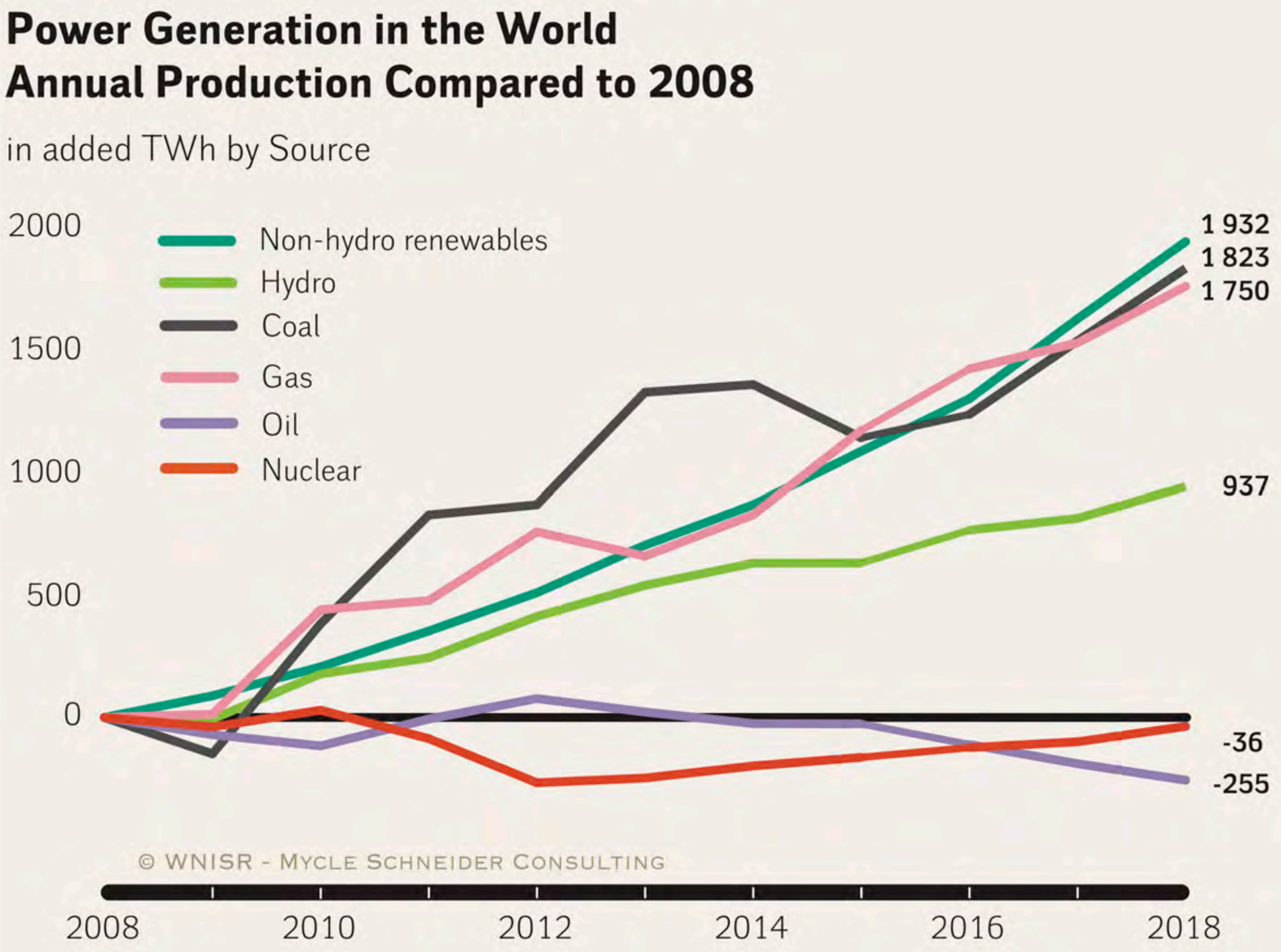
Sources: Lazard Estimates, 2018

Wind, Solar and Nuclear Developments: Installed Capacity and Electricity Production in the World



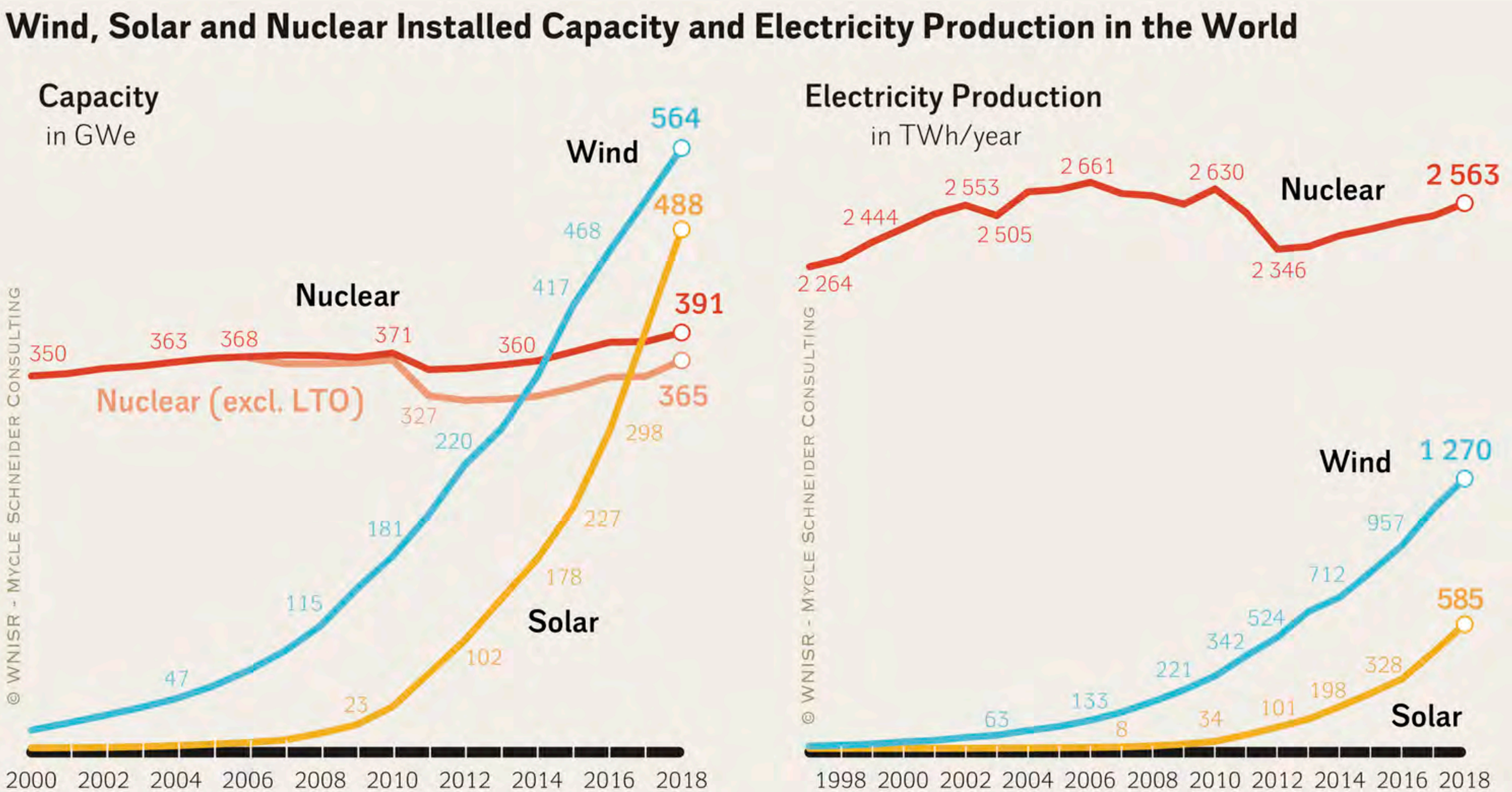
Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT

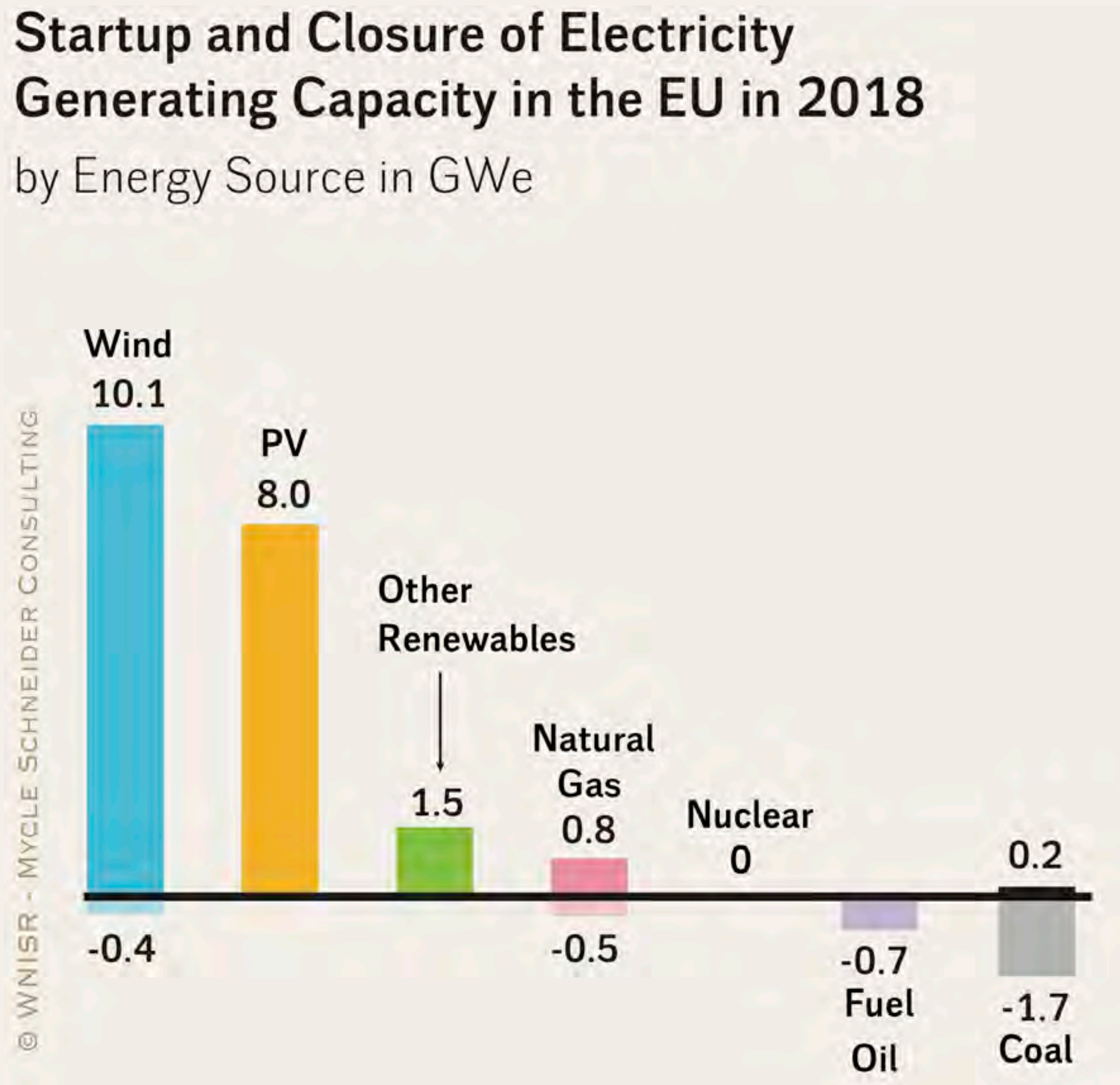


Sources: BP Statistical Review 2019

WNISR2019 NUCLEAR POWER VS. RENEWABLES DEPLOYMENT

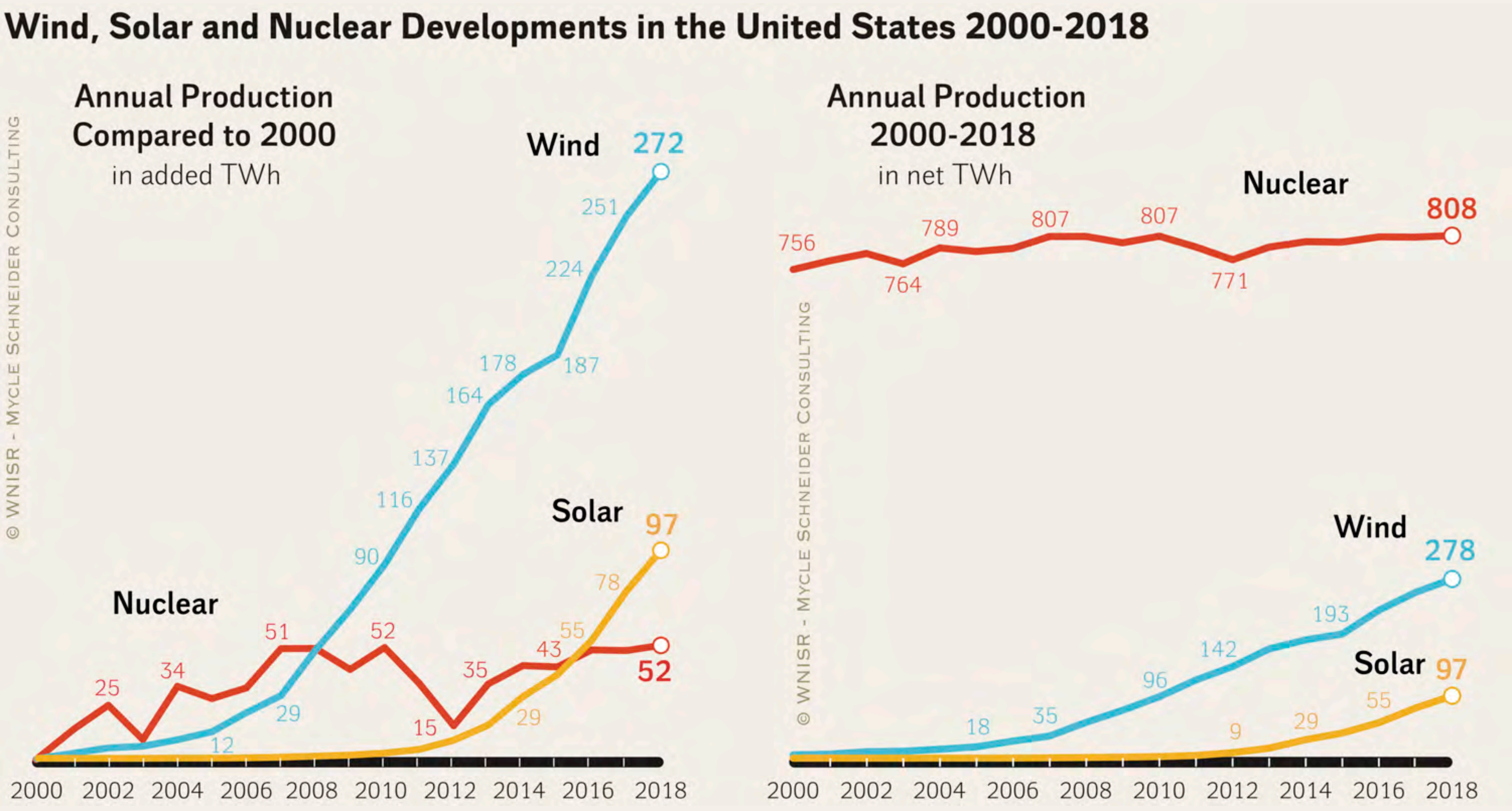


Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019



Sources: WindEurope, WNISR, 2019

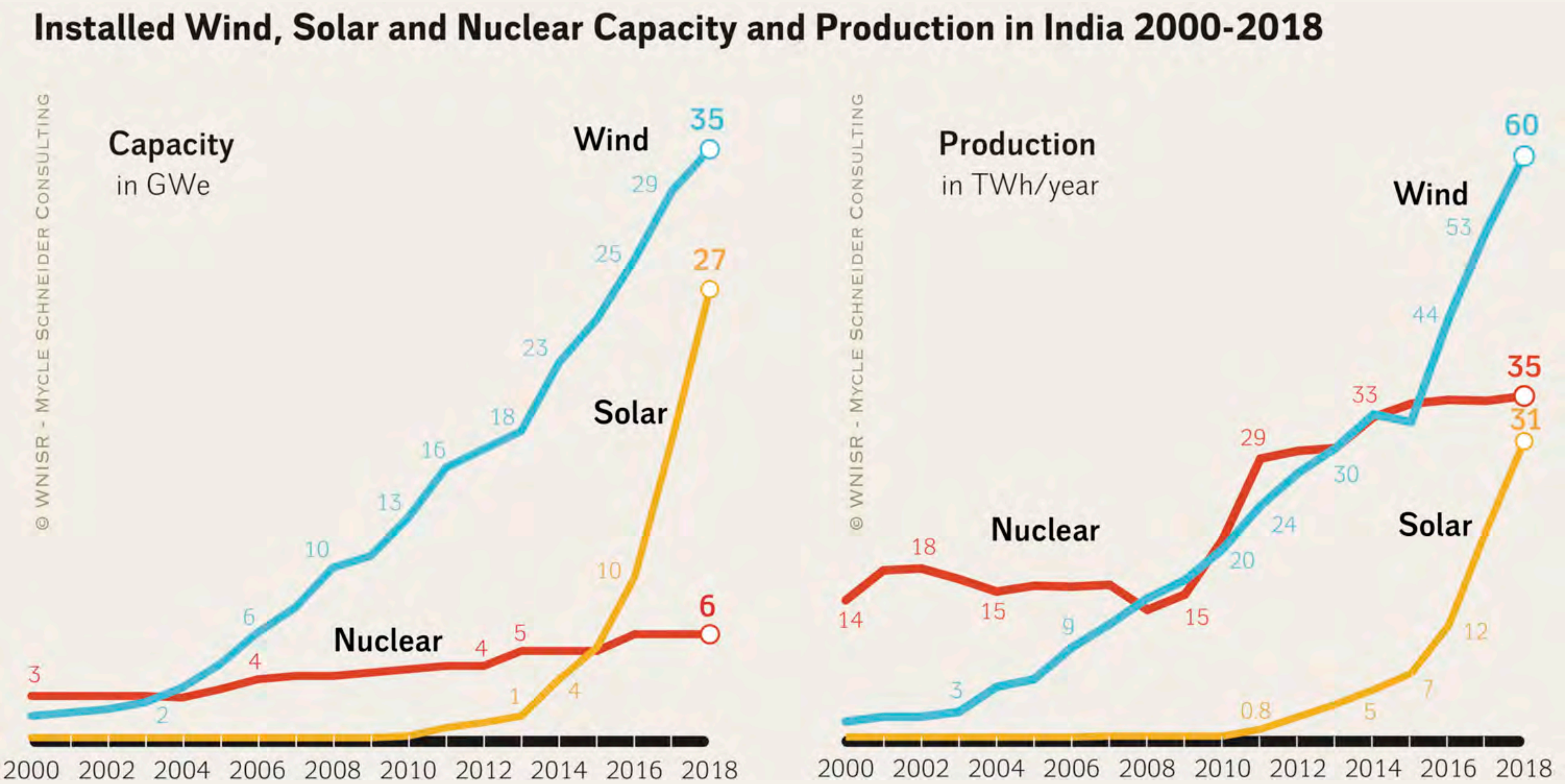
WNISR2019 NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: BP, 2019

Sources: BP, 2019

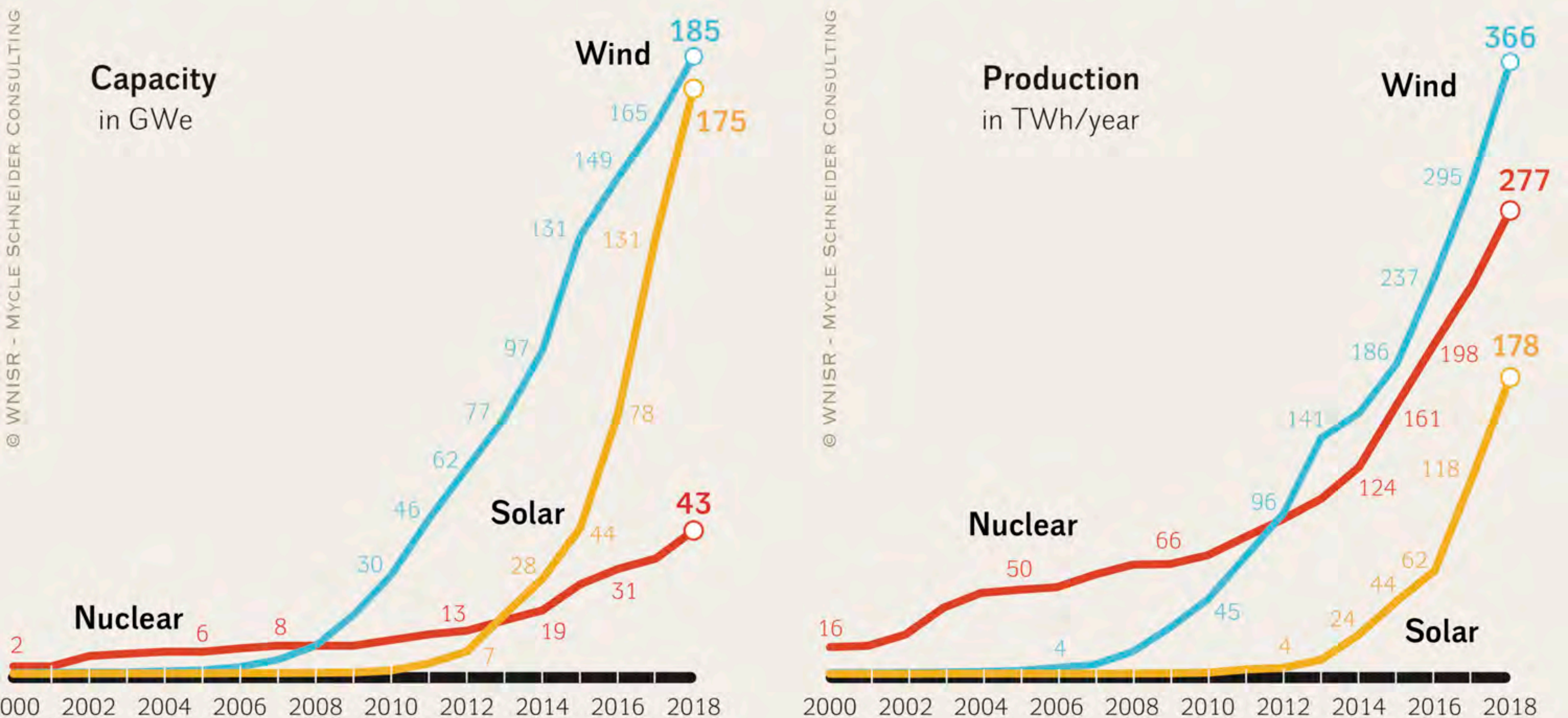
NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT

Installed Wind, Solar and Nuclear Capacity and Production in China 2000-2018



Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019

Climate Change and Nuclear Power

Summary of *World Nuclear Industry Status Report 2019 chapter* (worldnuclearreport.org), pp. 218–256, 24 Sep 2019

Amory B. Lovins, Cofounder and Chairman Emeritus
Rocky Mountain Institute, www.rmi.org, ablovins@rmi.org

Sciences Po, Paris, 09 Jan 2020, by videoconference

Criteria for comparing nuclear power with other options

- Building coal-fired power stations paid attention to *cost but not carbon*
- Defending nuclear plants paid attention to *carbon but not cost*
- Protecting climate requires avoiding the most carbon at the least cost in the least time, paying attention to *carbon, cost, and time—not just carbon*
- **Costly or slow options will avoid less carbon per € or per year than cheaper or faster options could have done, making climate change worse than it could have been.** A low-carbon but costly or slow choice thus *reduces and retards* climate protection

A simple analytic framework for comparing the climate-effectiveness of different ways to save or make electricity is at www.rmi.org/decarb. A lay summary of the thesis is at https://www.forbes.com/sites/amorylovins/2019/11/18/does-nuclear-power-slow-or-speed-climate-change/.

Mind the logical gap

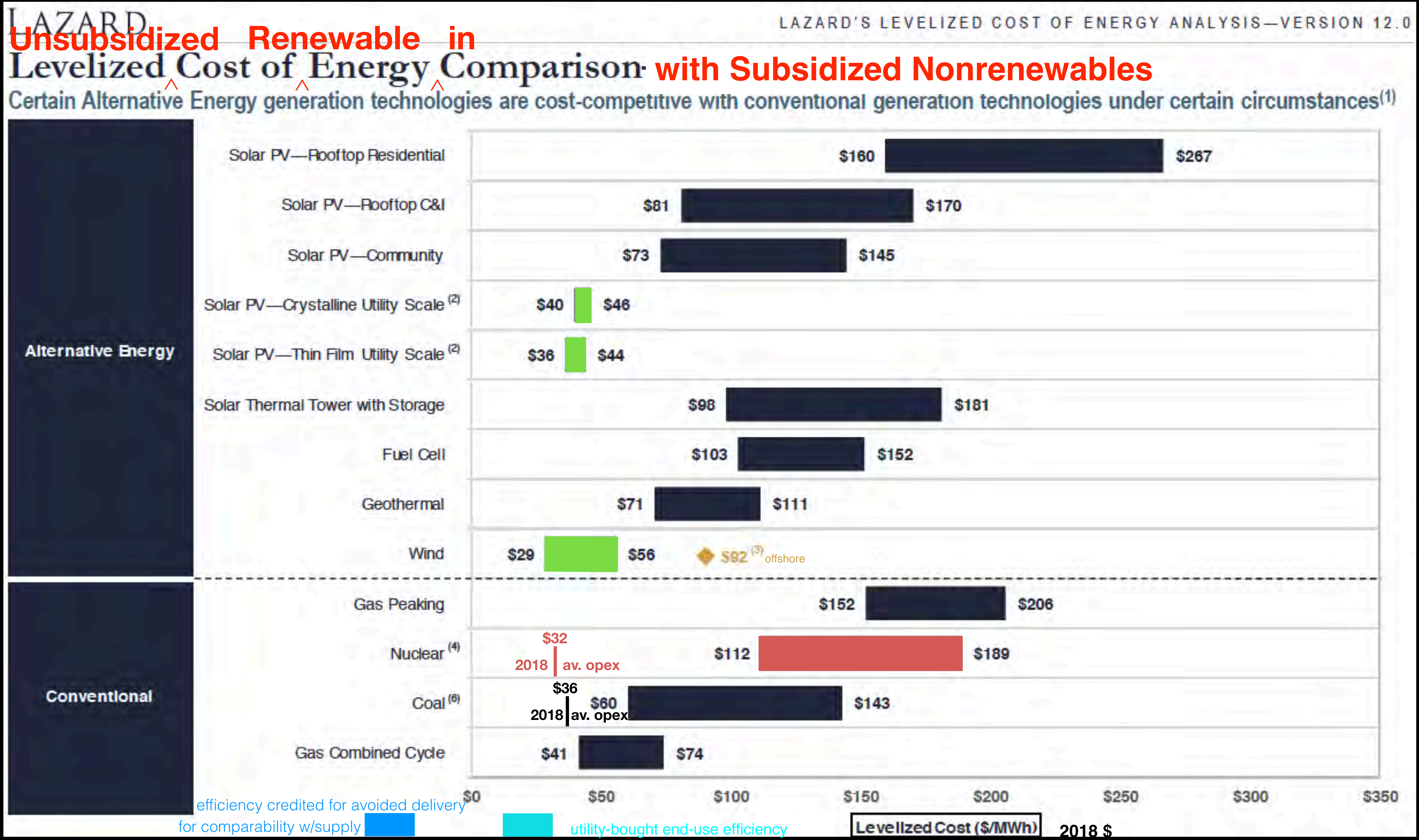
- People are hungry
- Hunger is urgent
- Caviar and rice are both food
- Therefore caviar and rice are both vital to reducing hunger

When solving a problem needs money and time, both finite, we must understand *relative cost and speed* to choose effective solutions.

Climate opportunity cost

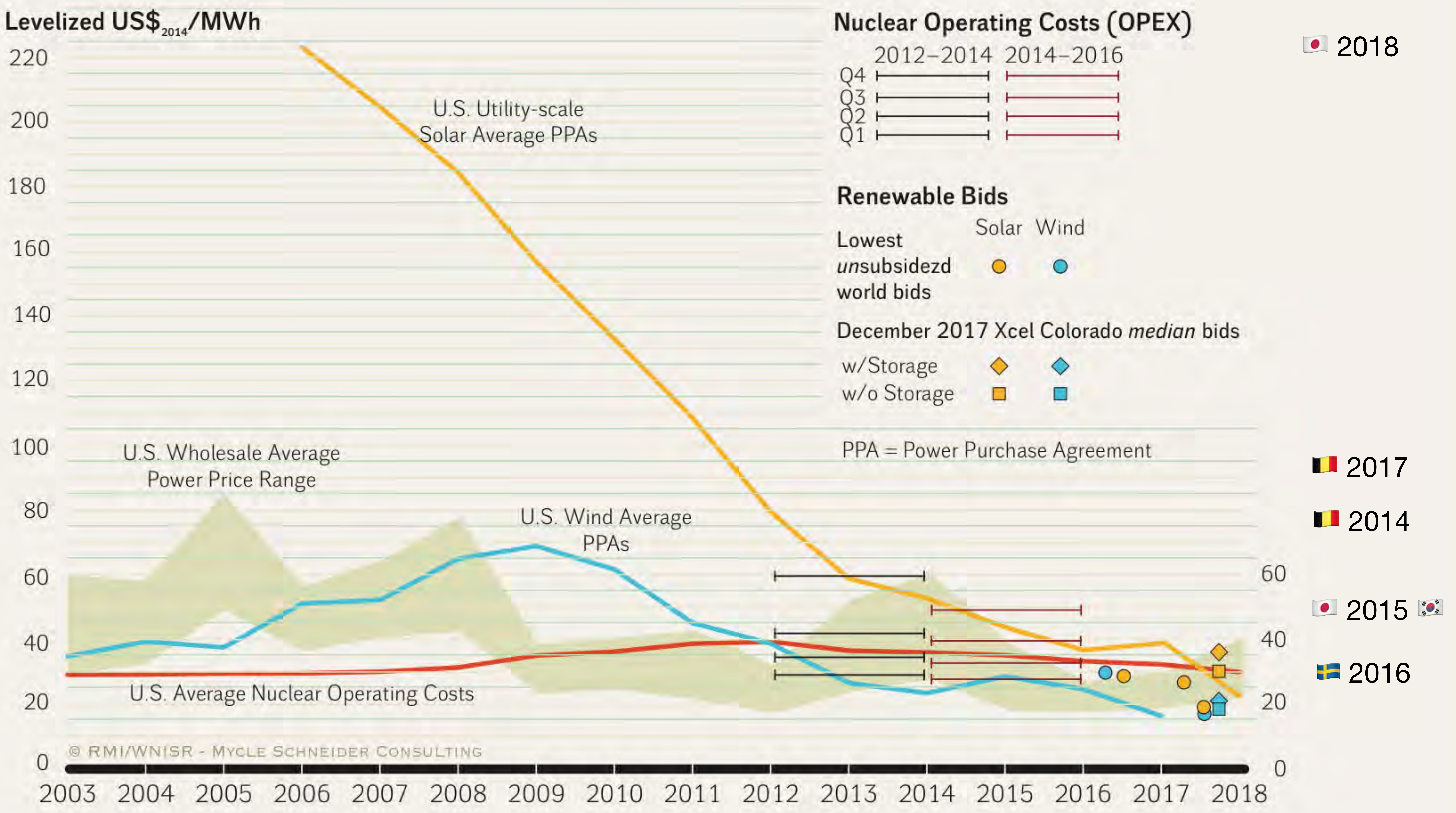
- You can buy only one thing with the same money at the same time.
- Nuclear and fossil-fueled generation compete with renewables and efficiency to meet the same finite demand for electrical services, so each kWh met by one resource is lost to its competitors.
- Since new or often even existing nuclear plants can no longer win in the marketplace, their owners often seek and get from politicians major new subsidies or preferences—misdescribed as “not forcing nuclear out of the market,” “not taking nuclear off the table,” or “keeping the nuclear option open.” Success displaces renewables and efficiency.
- Every kWh of nuclear output forced into walled-garden markets in which renewables (and efficiency) are forbidden to compete slows the growth, hence the cost reductions, of those zero-carbon competitors.

Lazard's November 2018 view of new US electricity resources' costs



Renewable Electricity vs. Nuclear Operating Costs U.S./World

in US$/MWh *World Nuclear Industry Status Report 2019*, www.worldnuclearreport.org, Fig. 49. PPAs; LBNL. Nuclear opex: NEI.



Closing distressed reactors can generally save money *and* carbon

- US nuclear opex in 2014–16 (latest NEI data) averaged >5¢$_{2014}$/kWh for the top 25 units, >4¢/kWh for the next 25; closing the plant saves that opex + any new subsidy
- Utilities buy efficiency at average (not lowest) costs ~2–3¢/kWh—can be <1¢/kWh
- So closing a top-quartile-cost reactor *and* reinvesting its saved opex (as could be required) can buy ~*2–3*+ kWh of carbon-free substitutes—1 kWh to replace the nuclear electricity, the rest to displace fossil-fueled generation, saving *more* CO_2
- Thus coal plants should be closed to save CO_2—*and* high-opex (most) nuclear plants should also be closed to save money whose reinvestment can save even more CO_2
- US evidence shows efficiency and renewables can scale up to replace closed reactors within 1–3 years, then save even more carbon for longer
- PG&E, FOE, NRDC, unions, et al. agreed that orderly closure of Diablo Canyon would save money *and* carbon while improving grid operation; it will be replaced by zero-carbon resources acquired by competitive auction, saving the most carbon per dollar
- *We must track not just the carbon but also the money…and the years*

A B Lovins, "Closing Diablo Canyon Nuclear Plant Will Save Money and Carbon," *Forbes*, 22 Jun 2016, www.forbes.com/sites/amorylovins/2016/06/22/close-a-nuclear-plant-save-money-and-carbon-improve-the-grid-says-pge; —, "Do Coal and Nuclear Generation Deserve Above-Market Prices?," *El. J.* **30**(6):22–30 (Jul 2017), http://dx.doi.org/10.1016/j.tej.2017.06.002 (see also Oct & Dec *El. J.* issues' exchanges with two Exelon-funded critics), preprint at https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2017/07/ElJ6May2017_preprint.pdf

Nuclear *vs.* modern-renewable per-capita deployment speed (–2015)

This misleading graph (Science, 5 Aug 2016) implies nuclear is"much faster"…

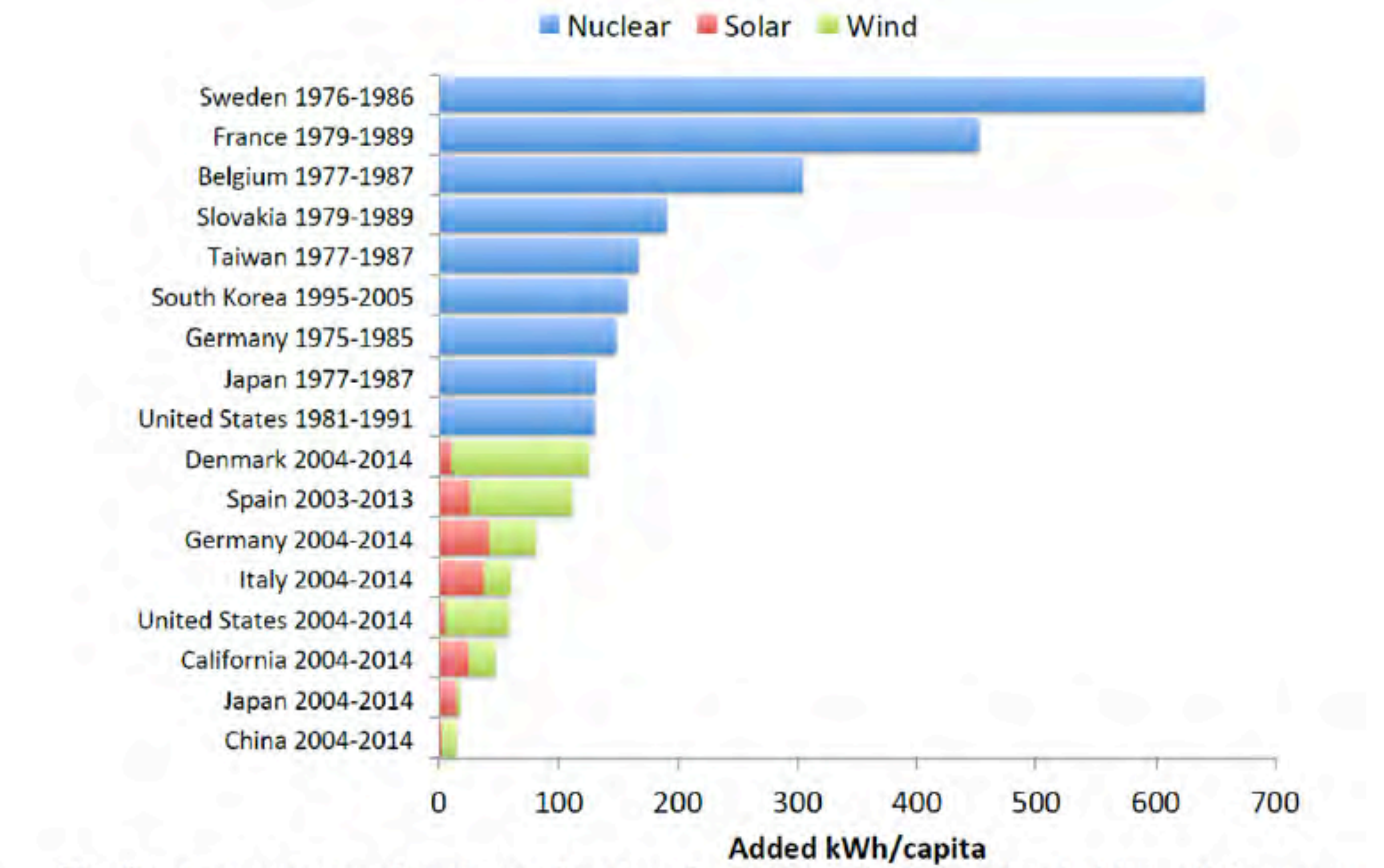
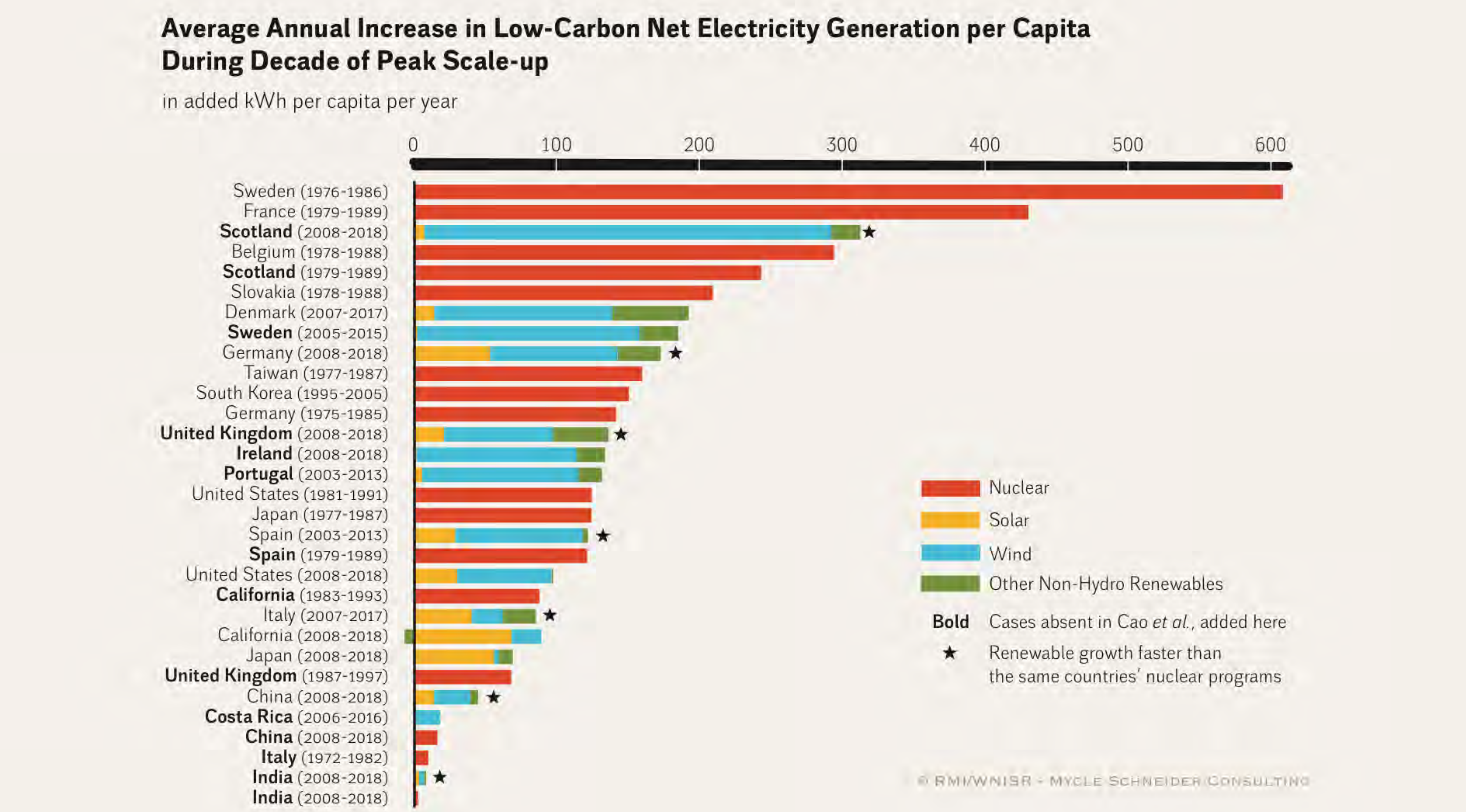


Fig. S2. Average annual increase of carbon-free electricity generation in kilowatt-hours per capita during decade of peak scale-up. Same graph as Fig. 2 in the main text. All generation data from (*S4*), except California renewables generation from (*S1*). All population data from (*S5*). See Tables S1 and S2.

Source: Junji Cao *et al.*, "China-U.S. cooperation to advance nuclear power," *Science* **353**:547–8, 5 Aug 2016, doi: 10.1126/science.aaf7131, from Supplementary Materials at www.sciencemag.org/content/353/6299/547/suppl/DC1; see also A. Lovins, "Nuclear power: deployment speed," *Science* **354**:1112–1113 (2 Dec 2016), https://doi.org/10.1126/science.aal1777, and sources on the following slide.

Nuclear *vs.* modern-renewable per-capita deployment speed (–2018)

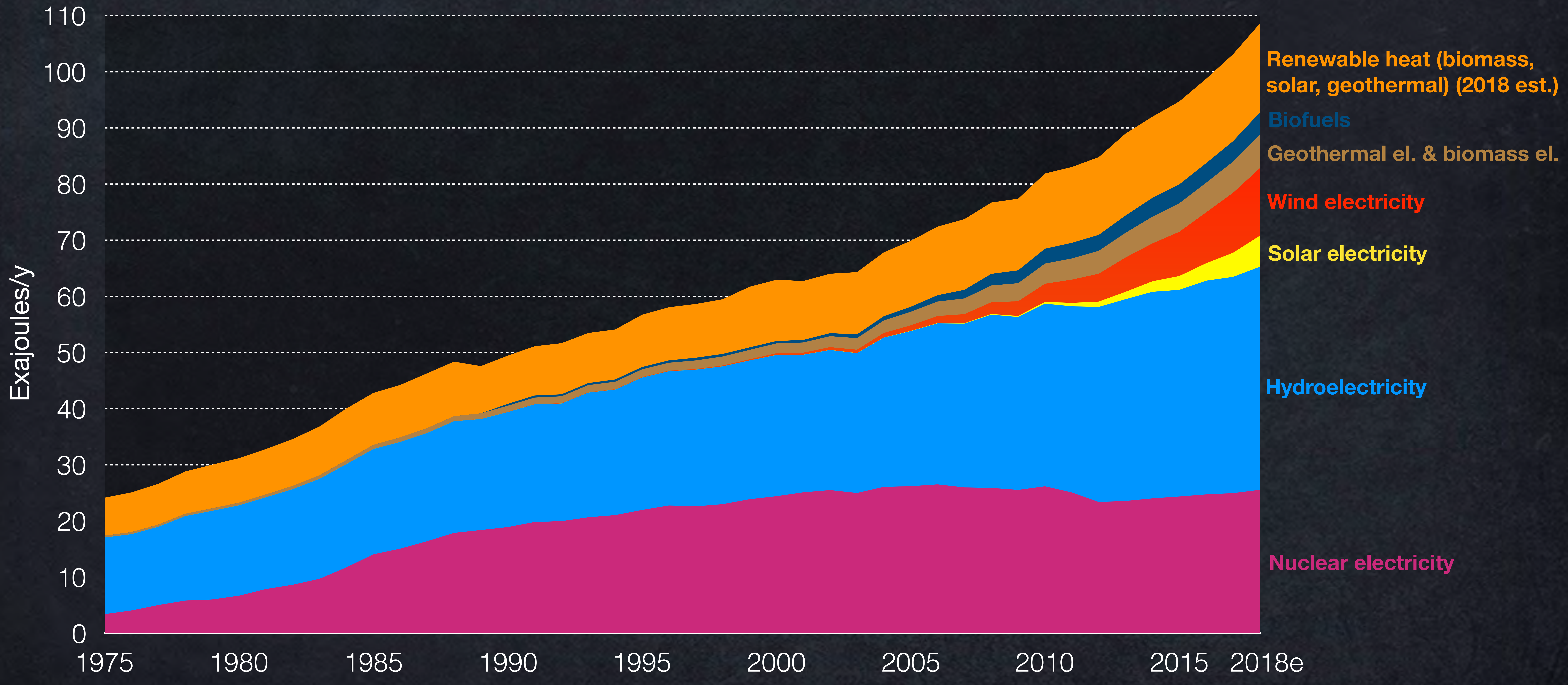
…but even using the same deeply flawed methodology and the same data source yields a very different answer when omitted cases are included and errors corrected.



Redrawn from A. Lovins, Corrigendum to "Relative deployment rates of renewable and nuclear Redrawn from Lovins, Corrigendum to "Relative deployment rates of renewable and nuclear power: a cautionary tale of two metrics," *Energy Res. Soc. Sci.* **38** (2018) 188–192], https://doi.org/10.1016/j.erss.2018.08.001; see also original analysis in A. Lovins *et al.*, "Relative deployment rates…," *Energy Res. Soc. Sci.* **38:**188–192, 22 Feb 2018, https://doi.org/10.1016/j.erss.2018.01.005.

Carbon-free global final energy is 28% and accelerating

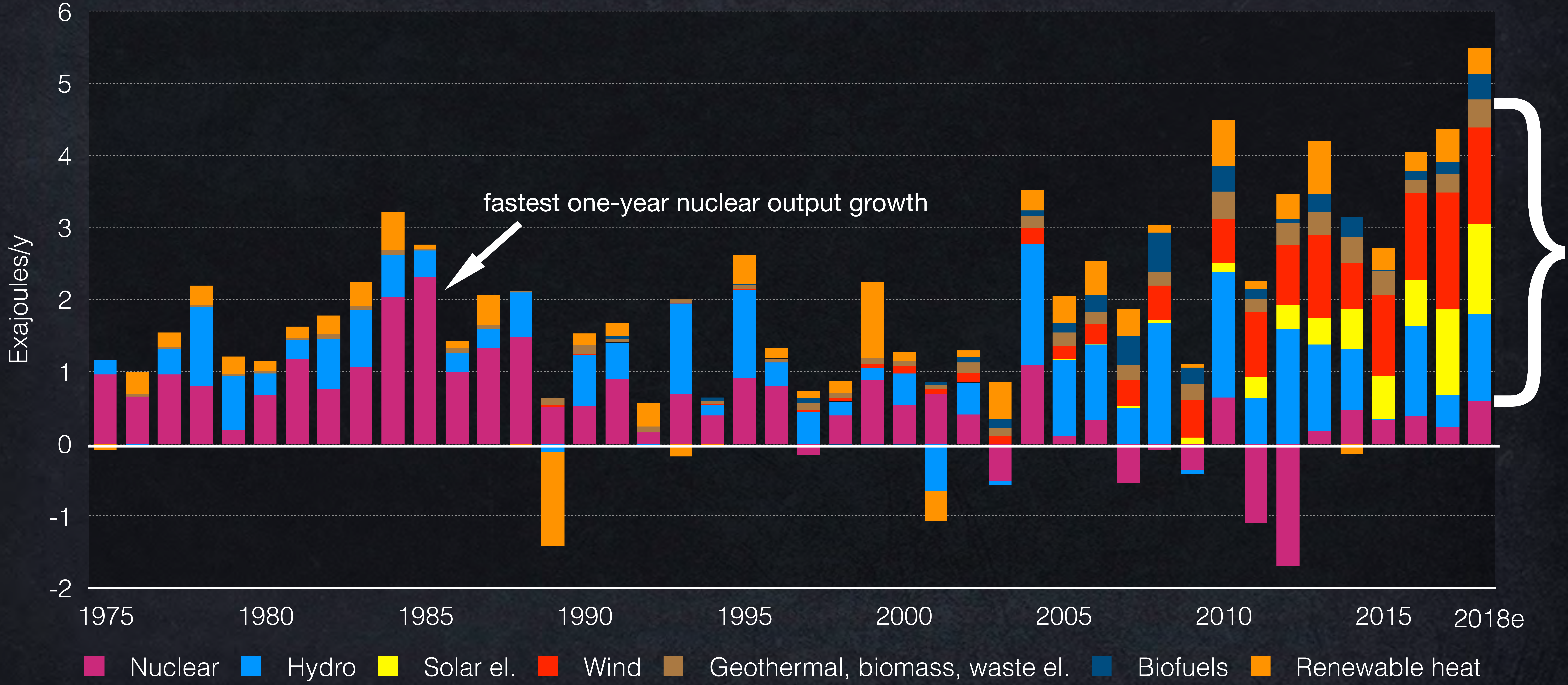
Global total final commercial energy consumption from non-fossil-fuel sources, 1975–2018e



Sources: BP *Statistical Review of World Energy 2019* for all resources, except renewable heat (excluding traditional biomass) from IEA online database, verified within ~1% from IEA *WEO 2018* Figure 6.6 by subtracting BP "biofuels" from IEA "other renewables." (BP does not appear to show renewable heat, while IEA aggregates biofuels with biomass. BP's biofuels data begin in 1990.) REN21 *Global Status Report 2019* draws very similar renewable heat data from IEA and reports its total as 4.2% of 2017 TFEC, comprising 89% biomass, 9% solar, and 2% geothermal. We extrapolate renewable heat total from 2017 to 2018 by using its average annual growth rate during 2014–17.

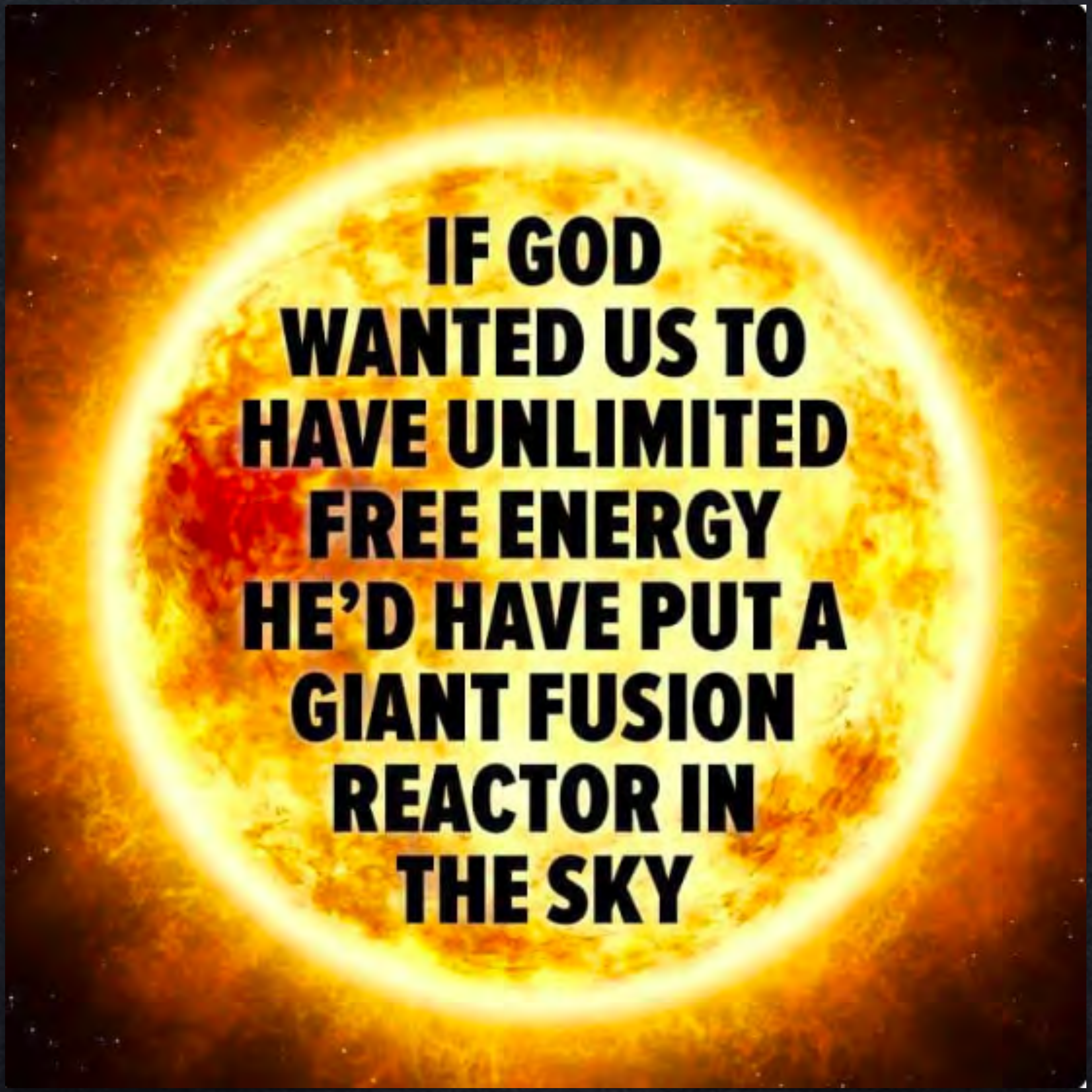
Modern renewables: the new engine of carbon-free growth

Modern renewables are conventionally all renewables less hydro >50 MW; this graph doesn't distinguish small hydro



Sources: BP *Statistical Review of World Energy 2019* for all resources, except renewable heat (excluding traditional biomass) from IEA online database, verified within ~1% from IEA *WEO 2018* Figure 6.6 by subtracting BP "biofuels" from IEA "other renewables." (BP does not appear to show renewable heat, while IEA aggregates biofuels with biomass. BP's biofuels data begin in 1990.) REN21 *Global Status Report 2019* draws very similar renewable heat data from IEA and reports its total as 4.2% of 2017 TFEC, comprising 89% biomass, 9% solar, and 2% geothermal. We extrapolate renewable heat total from 2017 to 2018 by using its average annual growth rate during 2014–17.

Clean watts are obvious; negawatts are invisible but bigger



Conclusions

- For the first time the average age of world nuclear fleet exceeds 30 years.

In 2018

- Nuclear power added 9 GW to the world's power grids to reach a record 370 GW, while renewables added a record 165 GW (wind and solar cumulate >1,000 GW total);
- Nuclear power generation increased by 2.4%, wind by 29%, solar by 13%;
- 10 of 31 nuclear countries generate more power with renewables than with nuclear.

In 2019

- Nuclear construction down to a trickle with 2 starts vs. 15 in 2010;
- 5 Startups / 5 Closures

- Construction times average 10 years over the past decade.
- The costs of new nuclear have *increased* by 26%, while solar costs *decreased* by 89% and wind by 70%.
- Fighting the climate emergency requires to invest into effective strategies combining *speed* and *competitive cost* to drastically reduce emissions. Nuclear power turns out not only the most expensive, but the slowest option to generate "low-carbon" electricity and to provide essential energy services.

Contact: mycle@worldnuclearreport.org www.WorldNuclearReport.org

About the Author

Photo: ©Nina Schneider

Mycle Schneider works as independent international consultant on energy and nuclear policy. He is the initiator and Convening Lead Author of the *World Nuclear Industry Status Reports* and Founding Board Member and Spokesperson of the International Energy Advisory Council (IEAC). He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, USA. In 2010-2011, he acted as Lead Consultant for the Asia Clean Energy Policy Exchange, implemented by IRG, funded by USAID, with the focus of developing a policy framework to boost energy efficiency and renewable energies. Between 2004 and 2009 he has been in charge of the Environment and Energy Strategies Lecture of the International Master of Science for Project Management for Environ-mental and Energy Engineering at the *Ecole des Mines* in Nantes, France.

From 2000 to 2010 he was an occasional advisor to the German Environment Ministry. 1998-2003 he was an advisor to the French Environment Minister's Office and to the Belgian Minister for Energy and Sustainable Development.

Mycle Schneider has given evidence or held briefings at national Parliaments in 15 countries and at the European Parliament. He has advised Members of the European Parliament from four different groups over the past 30 years. He has given lectures or had teaching appointments at over 20 universities and engineering schools in more than 10 countries.

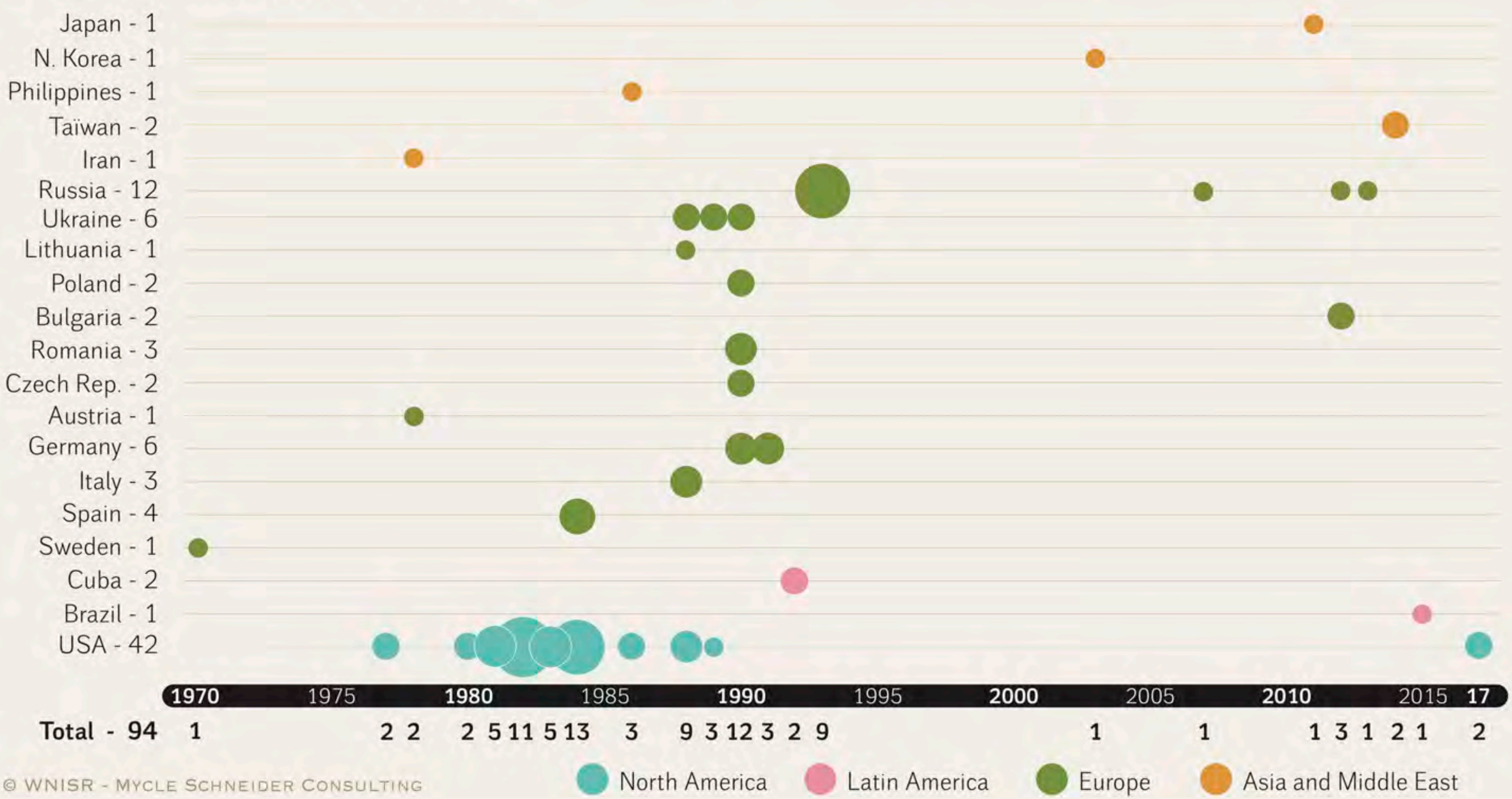
Mycle Schneider has provided information and consulting services to a large variety of clients including international institutions and organizations, think tanks and NGOs.

In 1997 he was honoured with the *Right Livelihood Award* ("Alternative Nobel Prize").

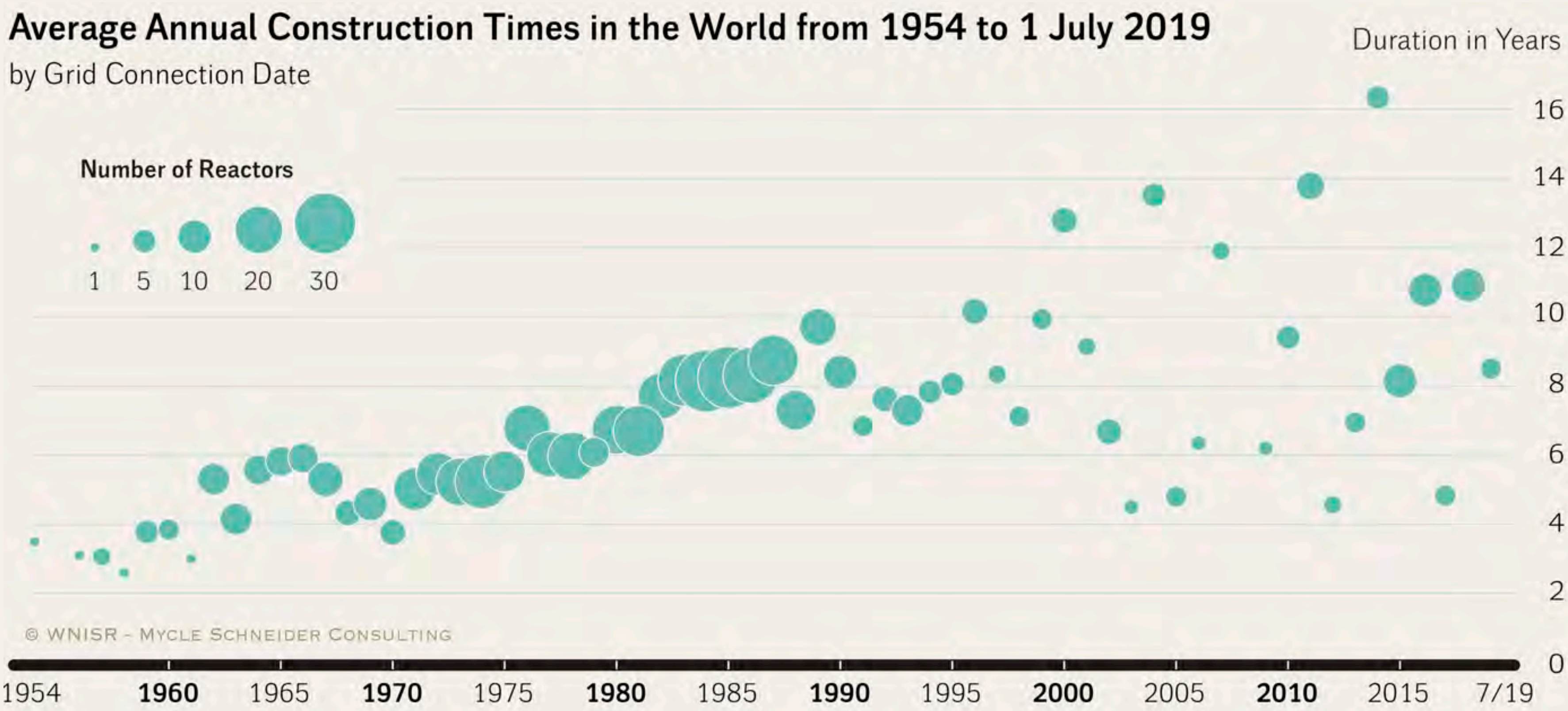
WNISR2019 CONSTRUCTION STARTS AND CANCELLATIONS

Abandoned Reactor Constructions from 1970 to 1 July 2019

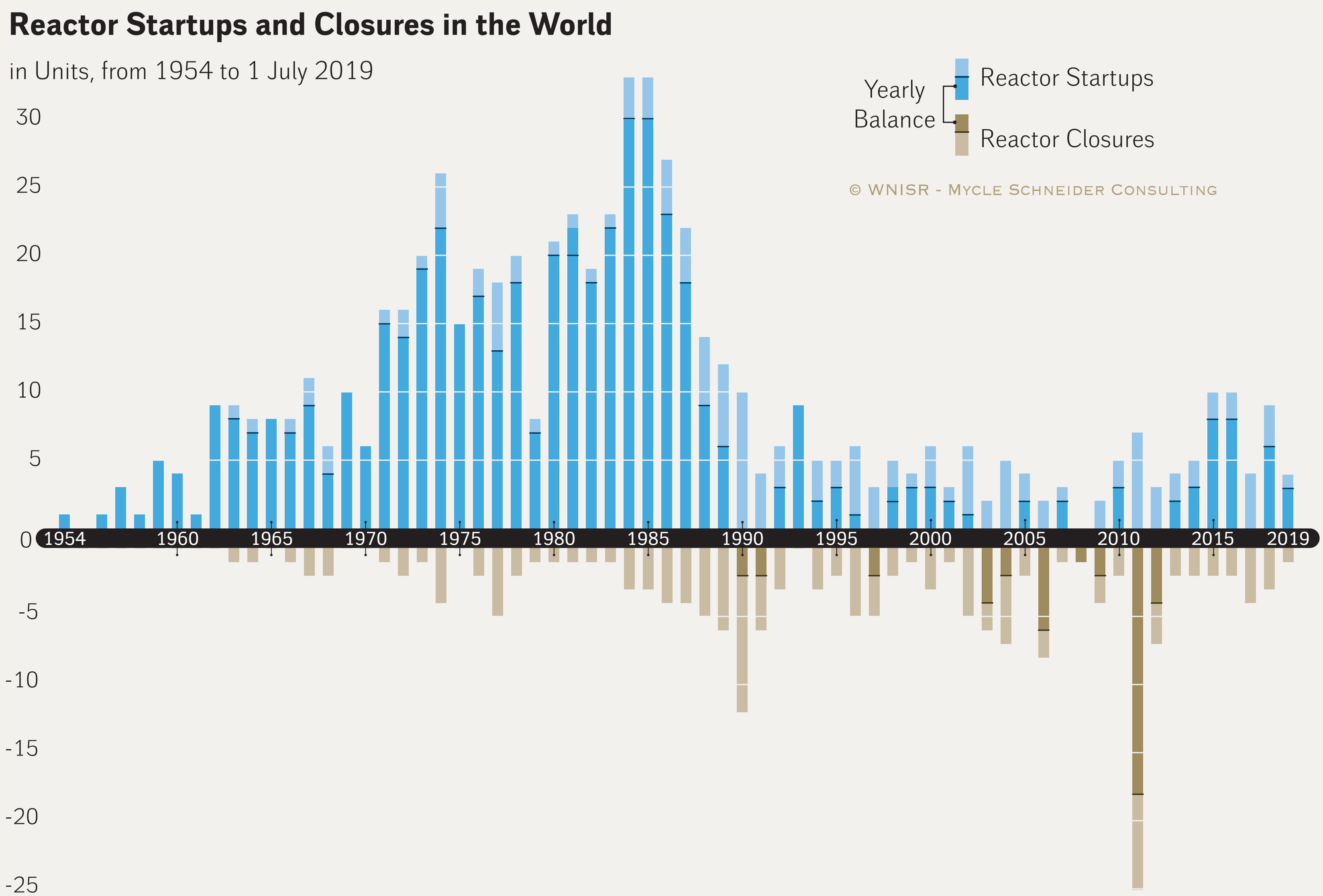
in Units by Cancellation Year and Country



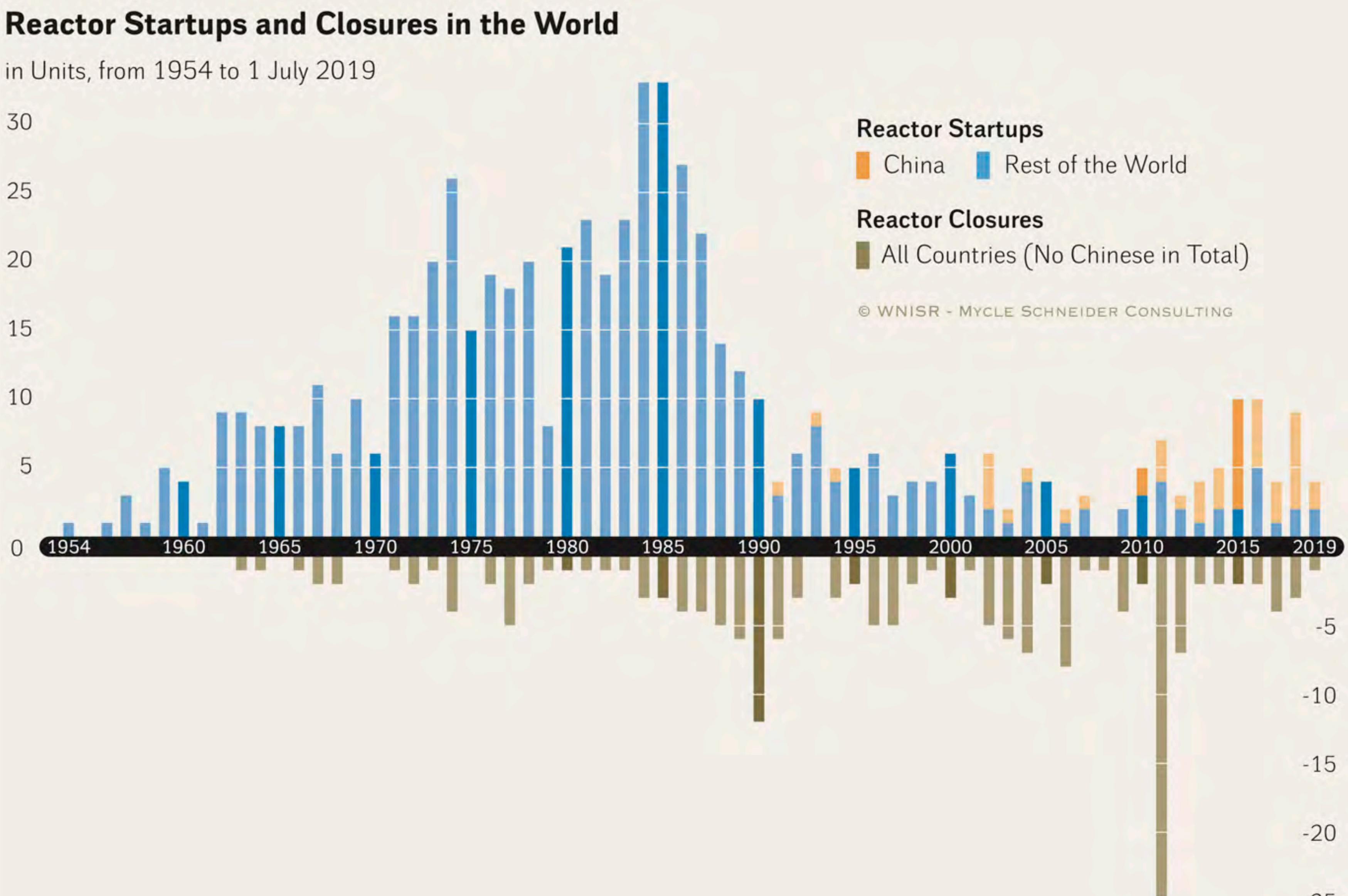
Sources: WNISR, with IAEA, and various sources, 2019



Sources: WNISR, with IAEA-PRIS, 2019

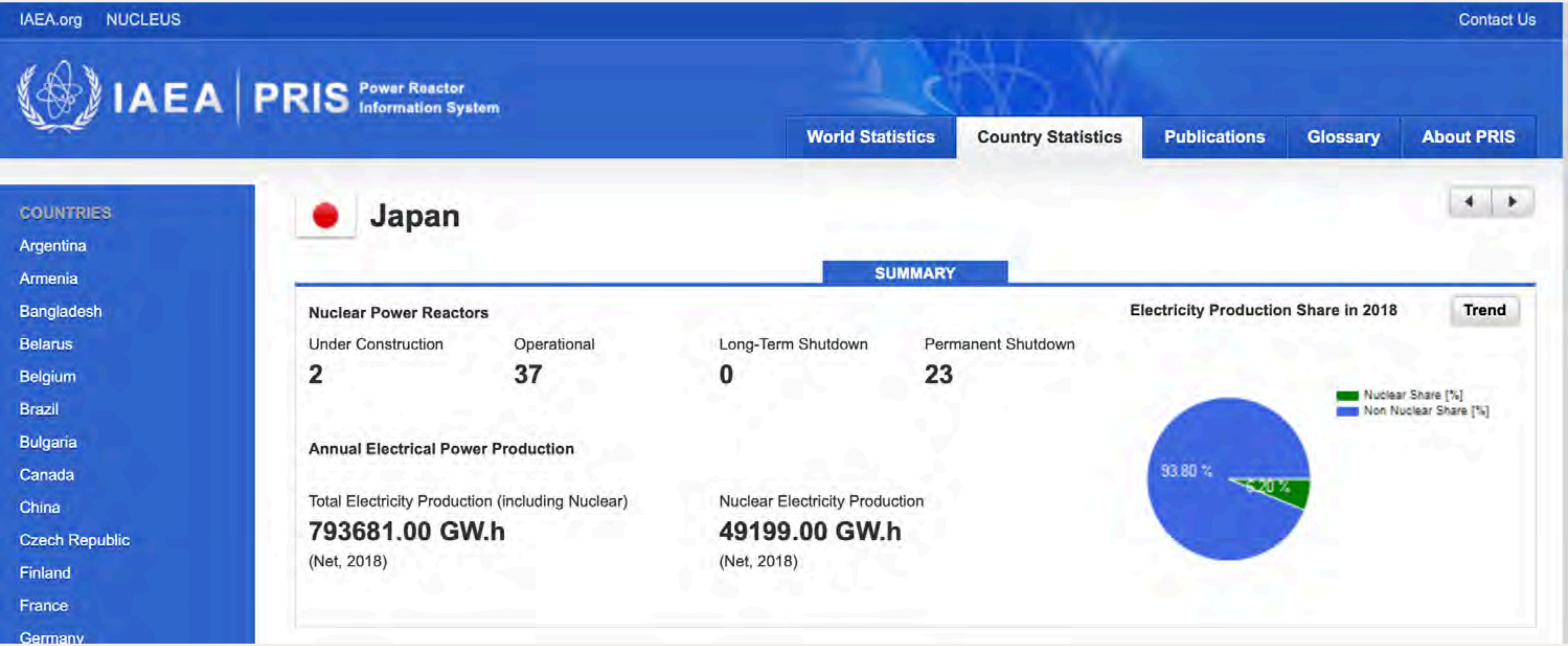


Sources: WNISR, with IAEA-PRIS, 2019

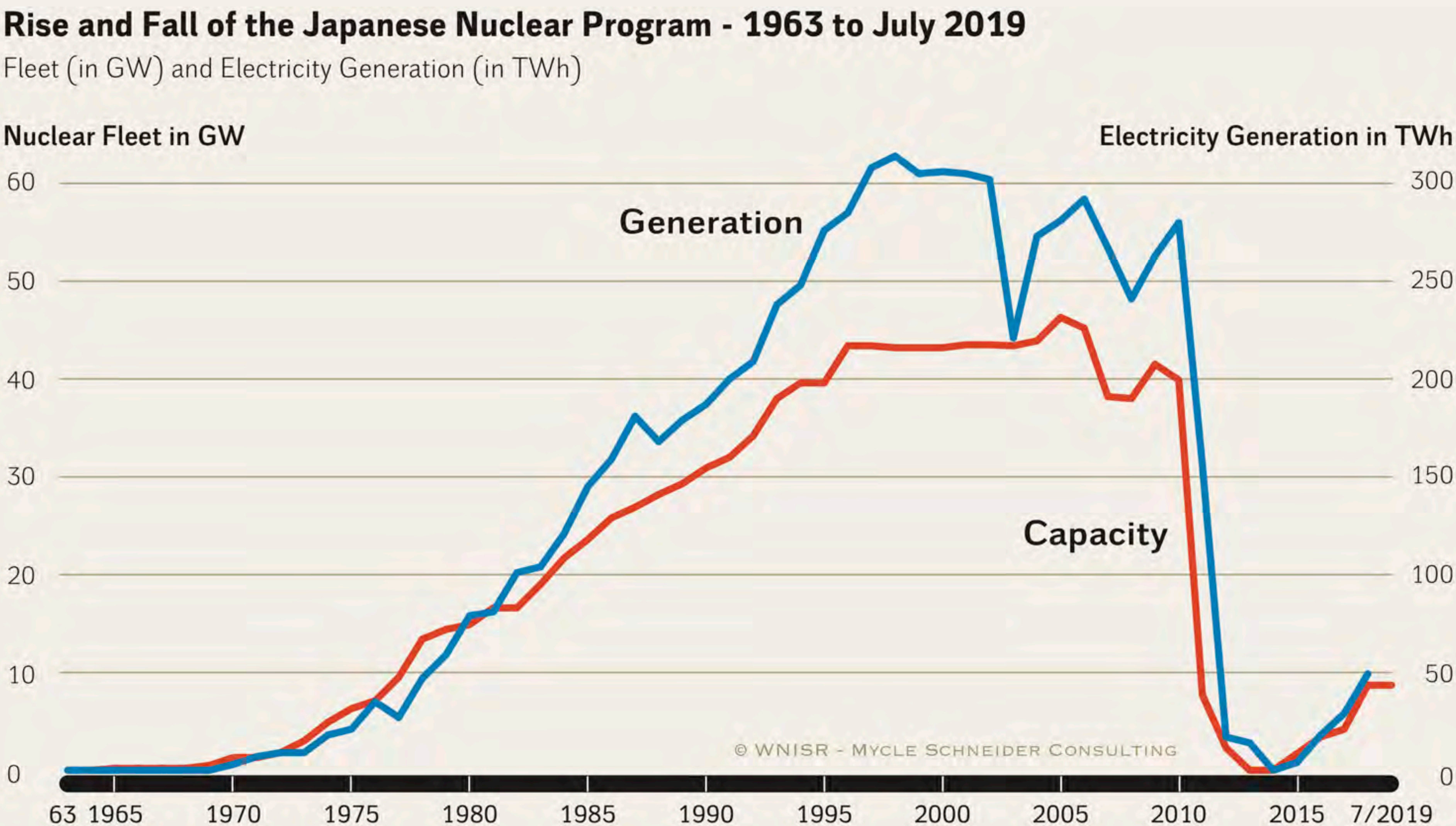


Sources: WNISR, with IAEA-PRIS, 2019

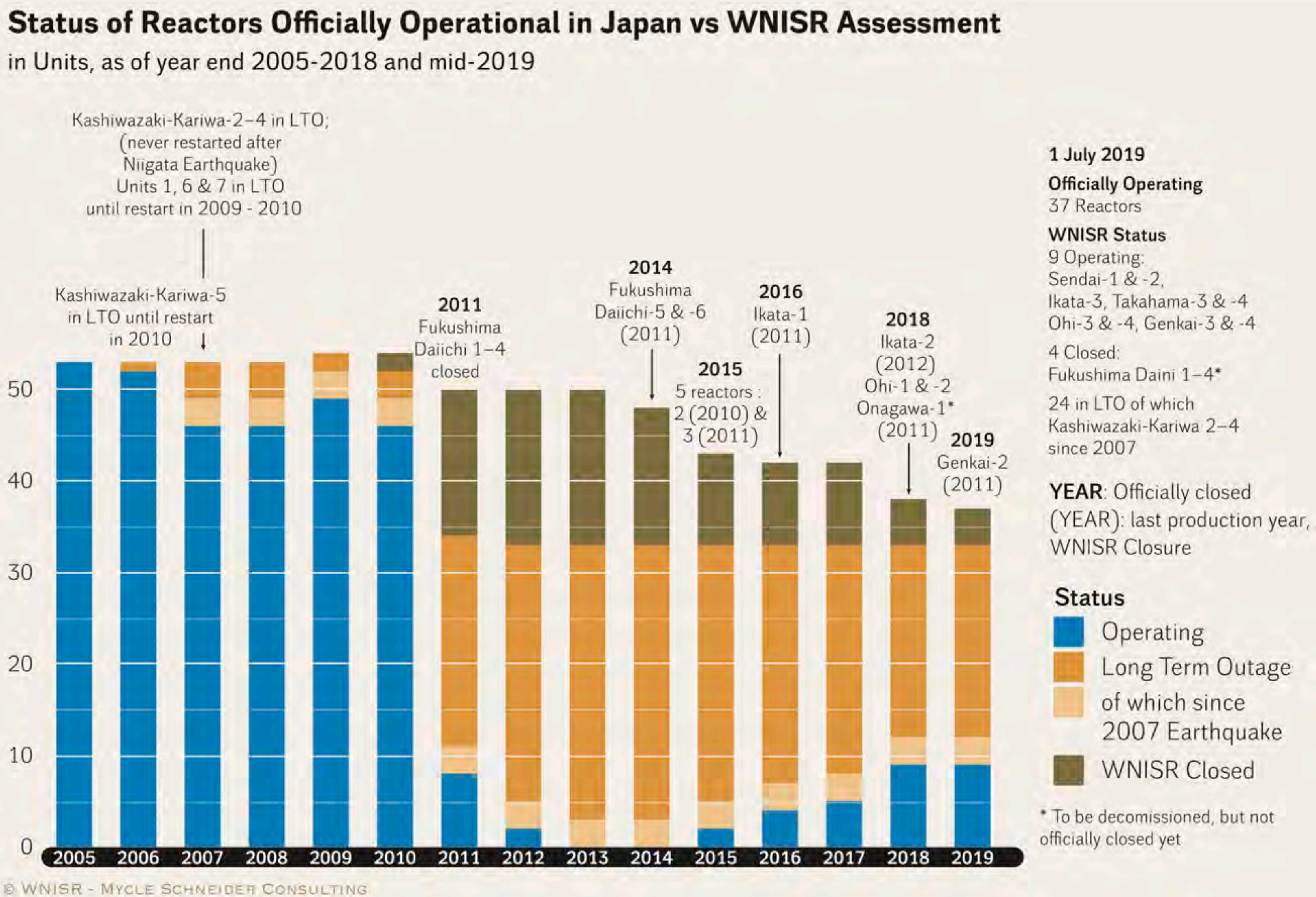
WNISR2019 MISLEADING IAEA STATISTICS



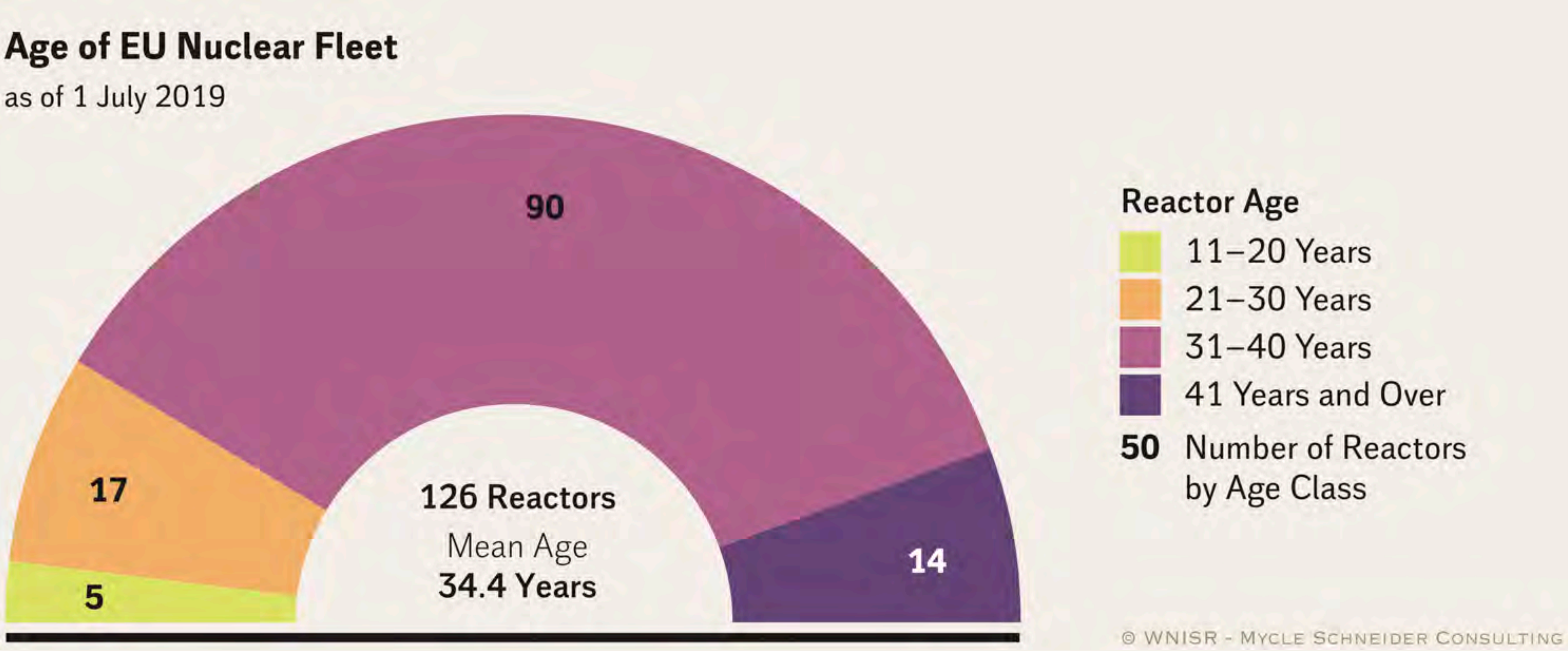
Source: IAEA-PRIS, screenshot 2 October 2019



Sources: WNISR, with IAEA-PRIS, 2019

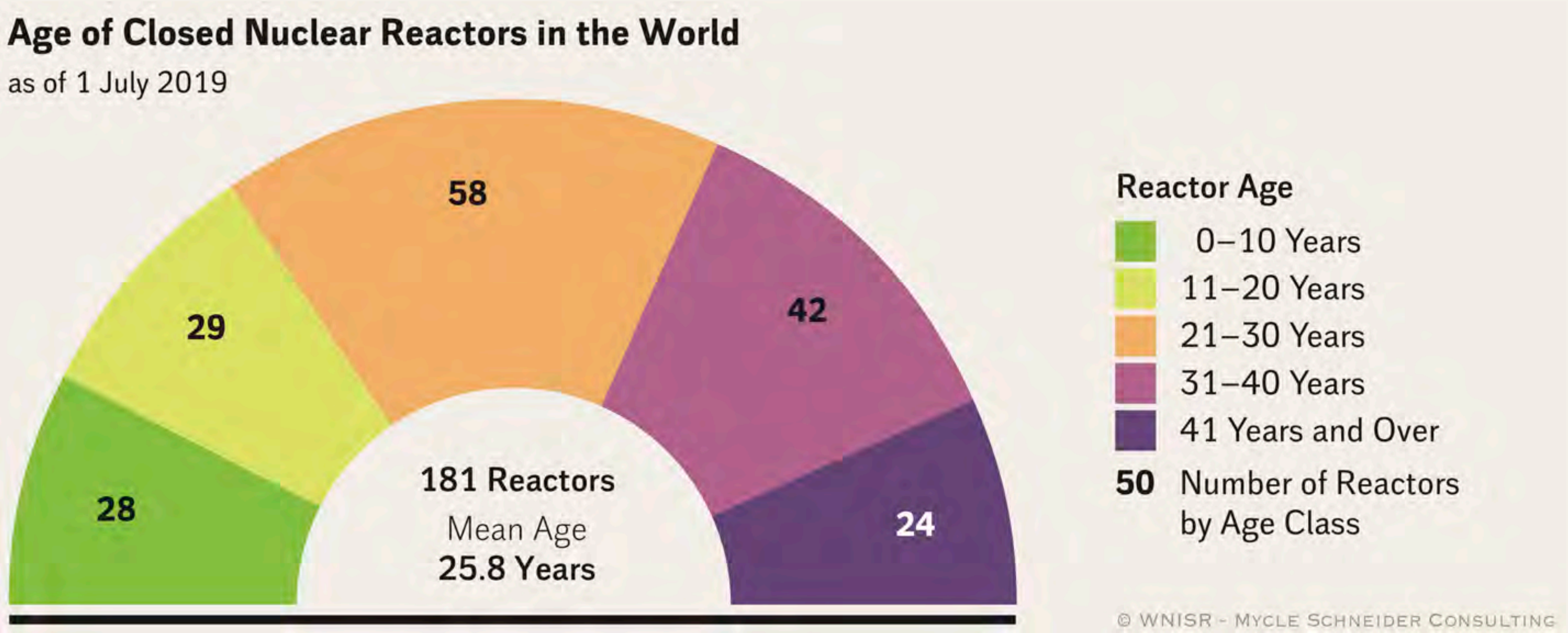


Sources: WNISR, with IAEA-PRIS, 2019



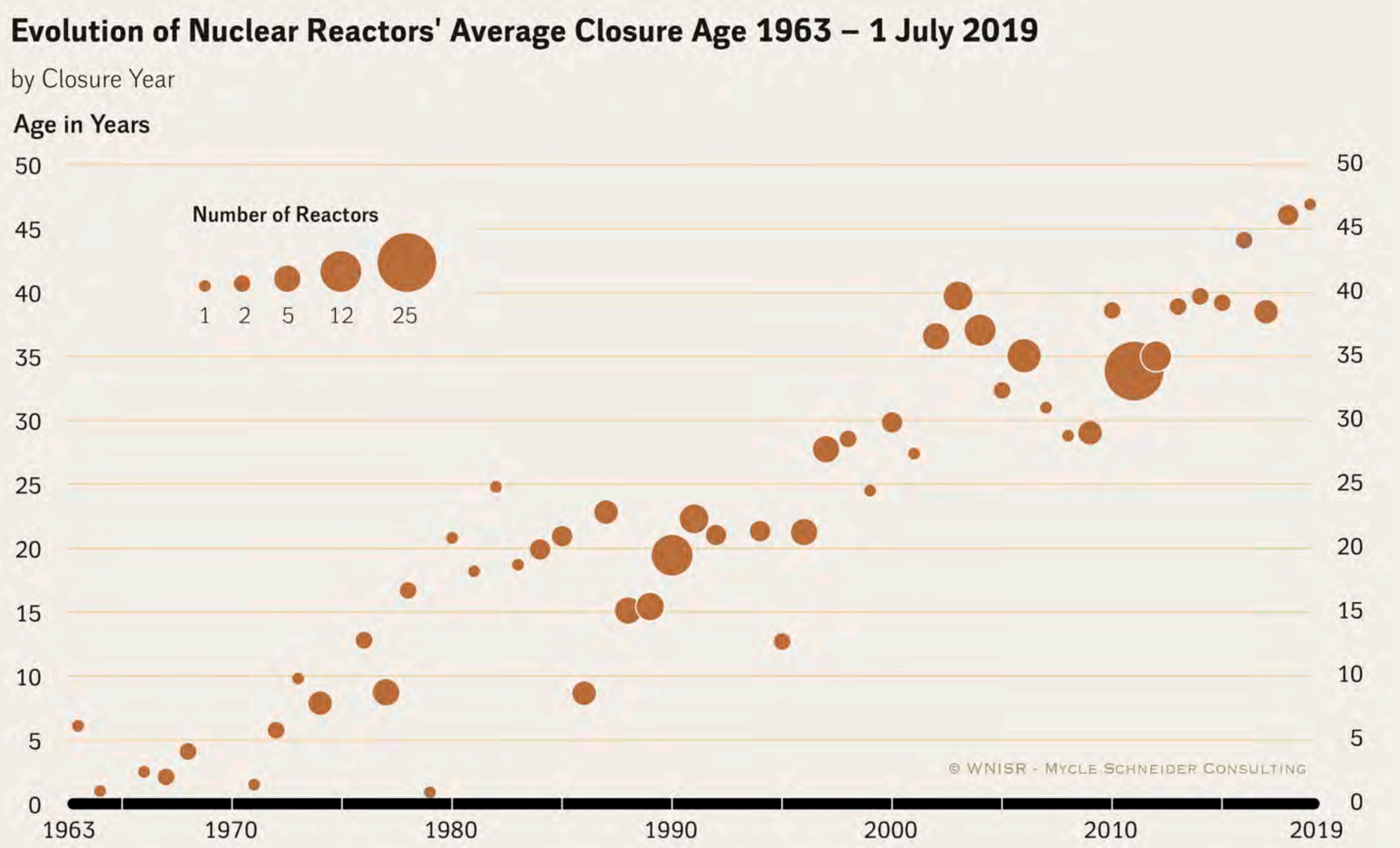
Sources: WNISR, with IAEA-PRIS, 2019

WORLD FLEET – CLOSED REACTORS AGE

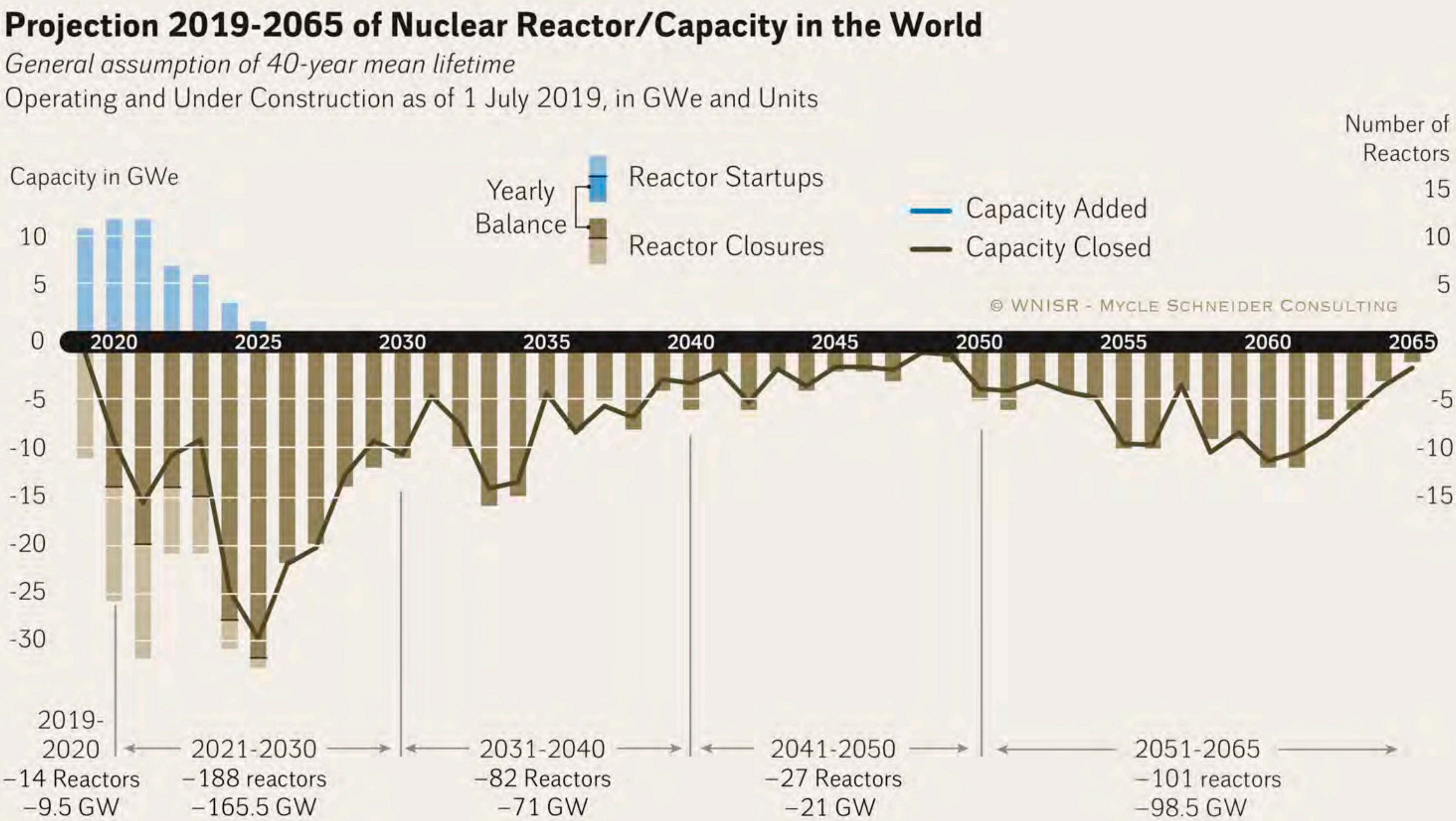


Sources: WNISR, with IAEA-PRIS, 2019

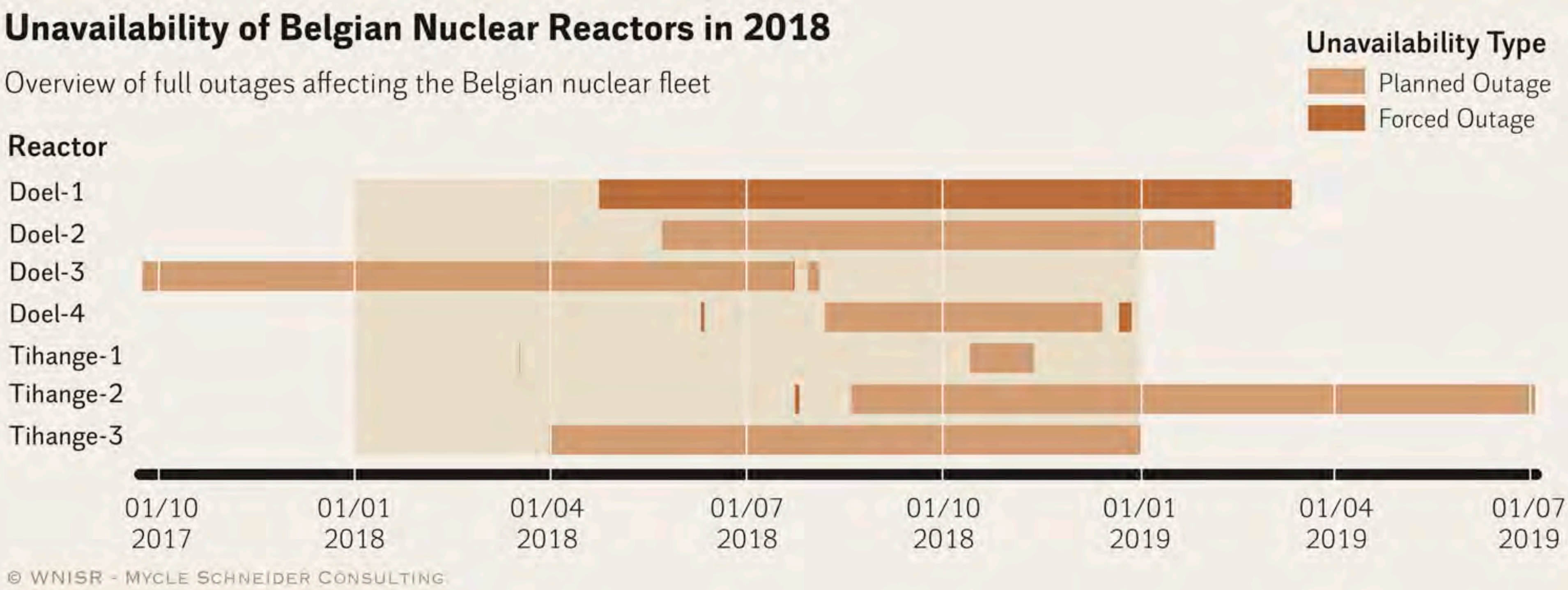
WNISR2019 WORLD FLEET – CLOSED REACTORS AGE



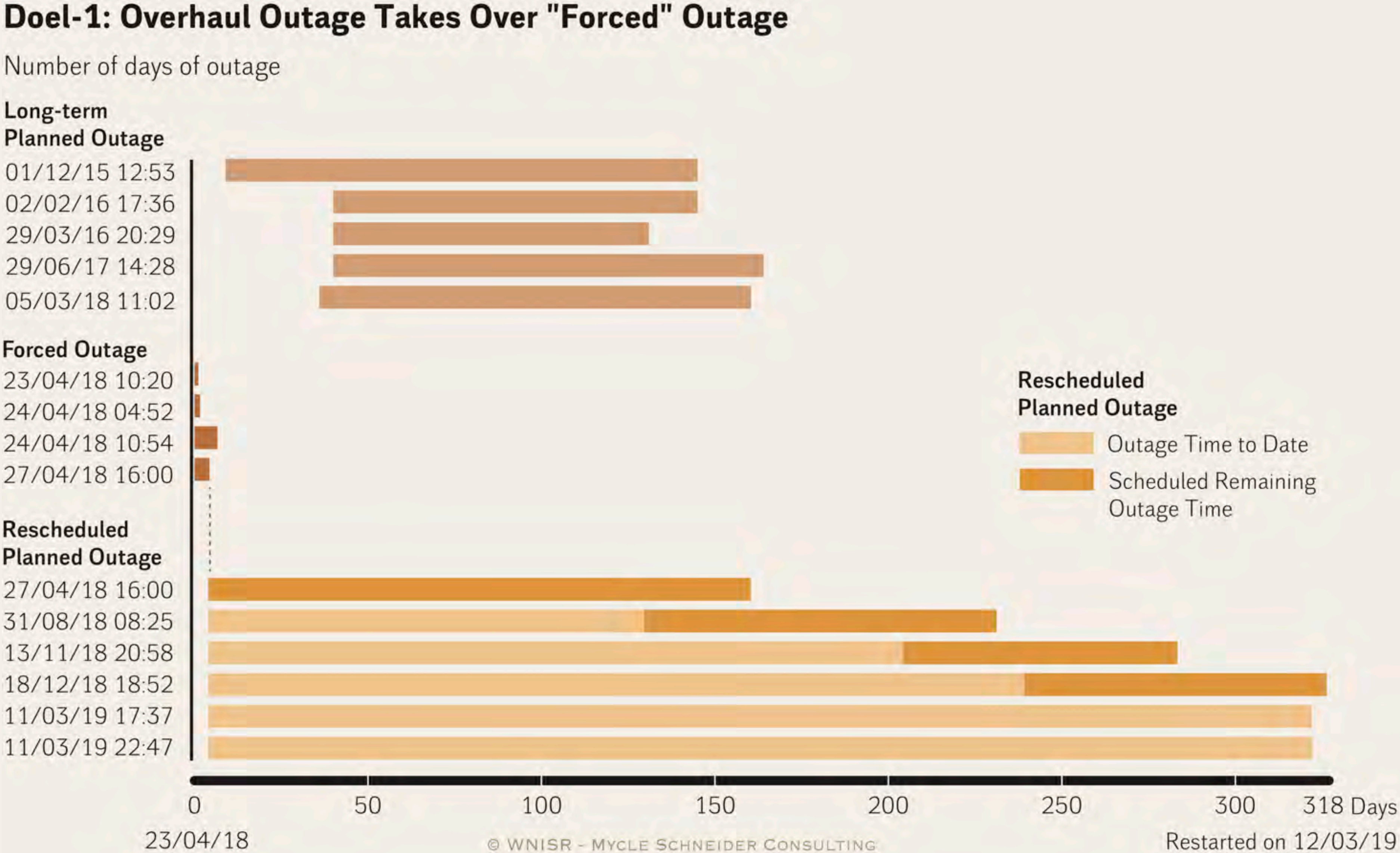
Sources: WNISR, with IAEA-PRIS, 2019



Sources: Various sources, compiled by WNISR, 2019



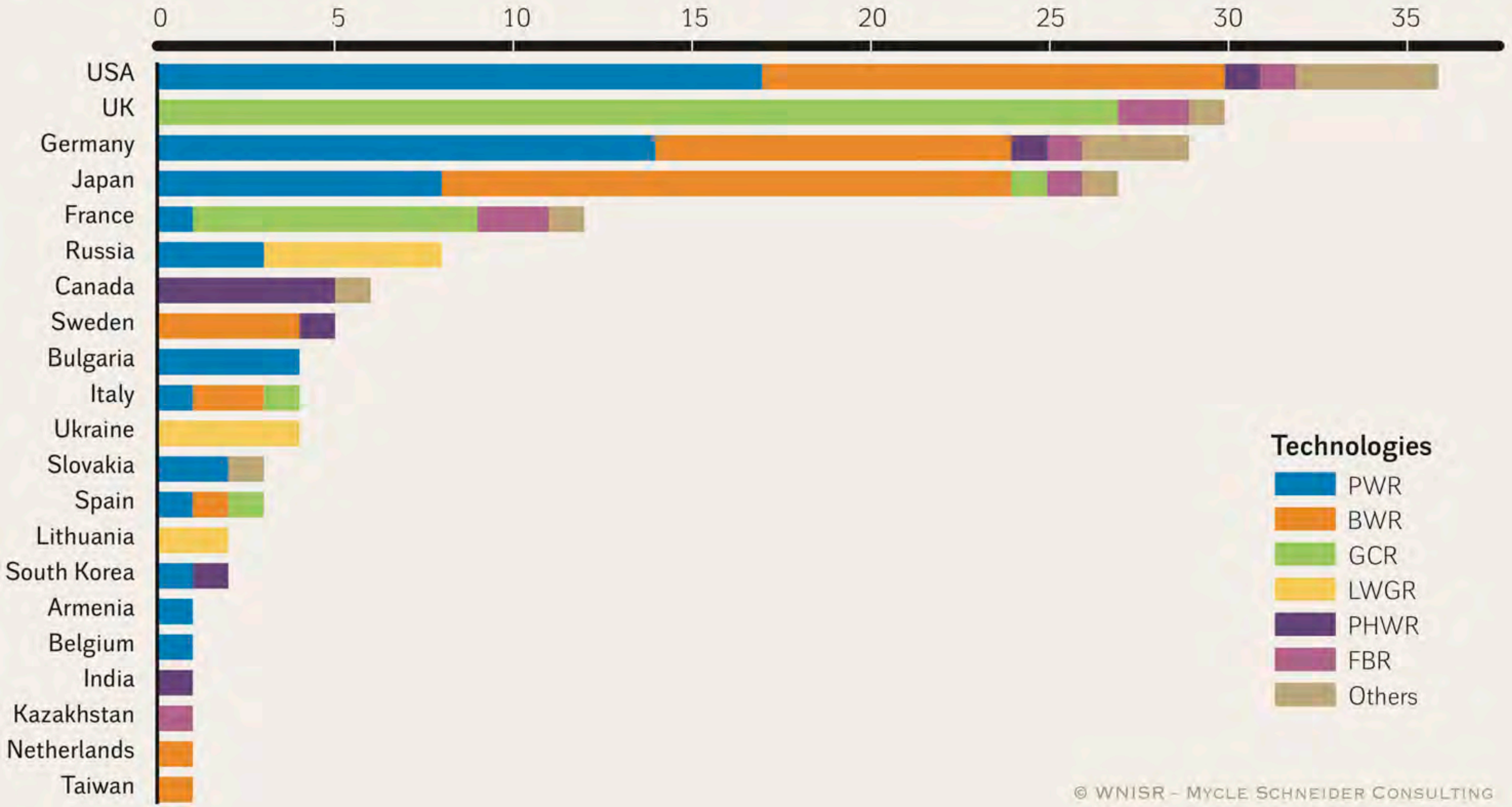
Source: ENTSO-E and Engie Transparency Platforms, 2019



Source: Engie Transparency Platforms, 2019

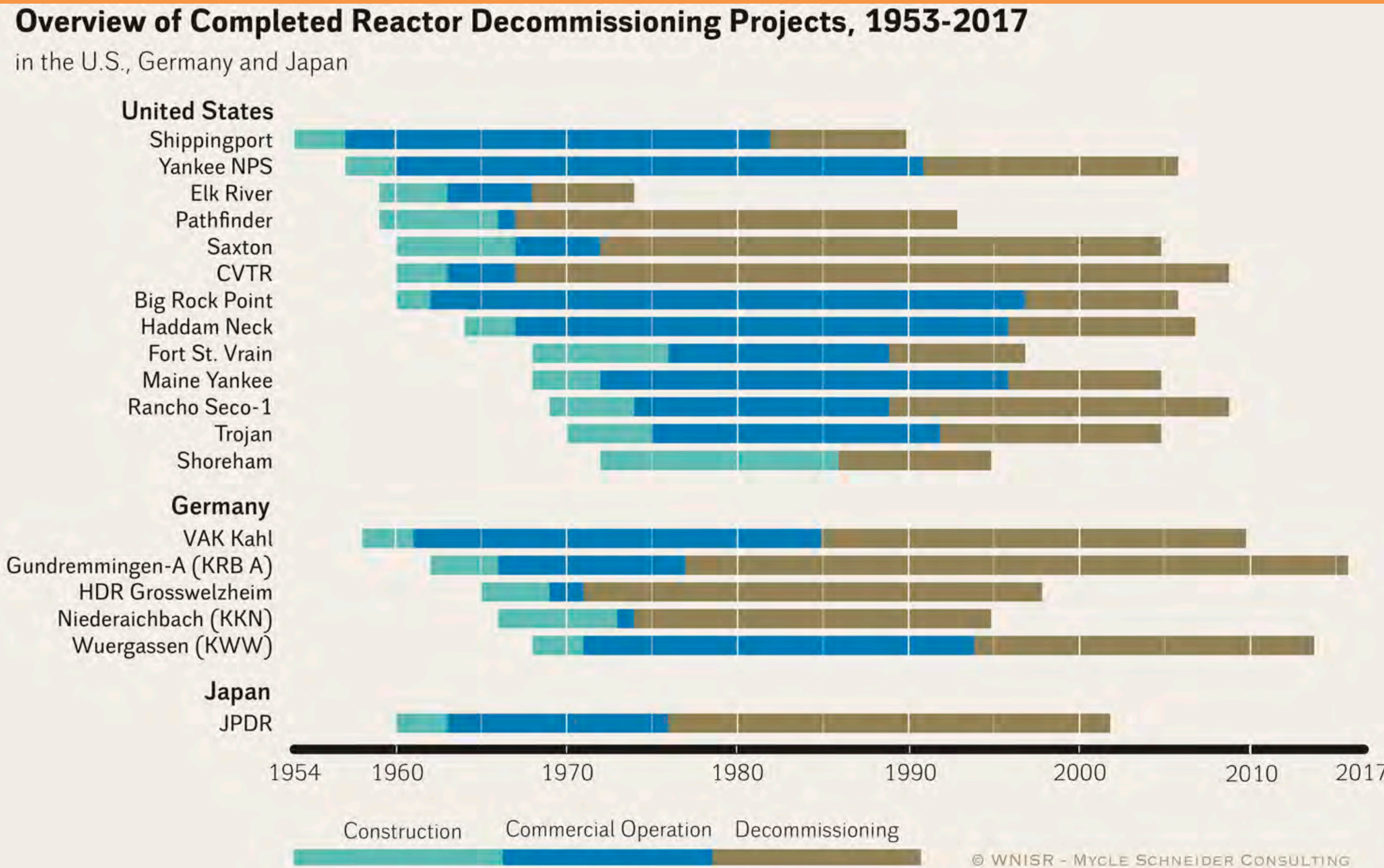
Closed Reactors Worldwide by Country and Reactor Technology

in Units, as of 1 July 2019



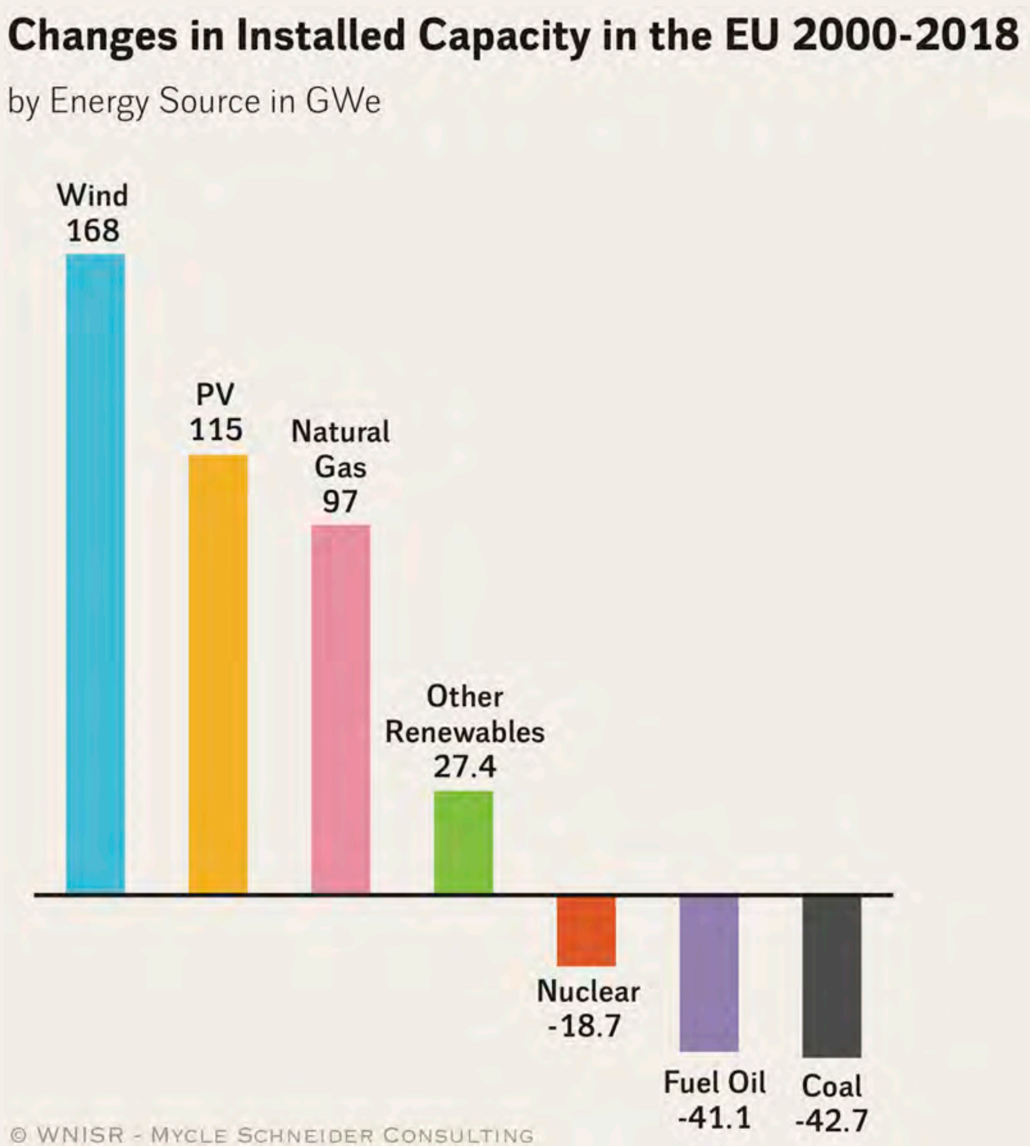
Sources: WNISR, with IAEA-PRIS, 2019

WNISR2019 NO CHANGE SINCE WNISR2018: 19 DECOMMISSIONED



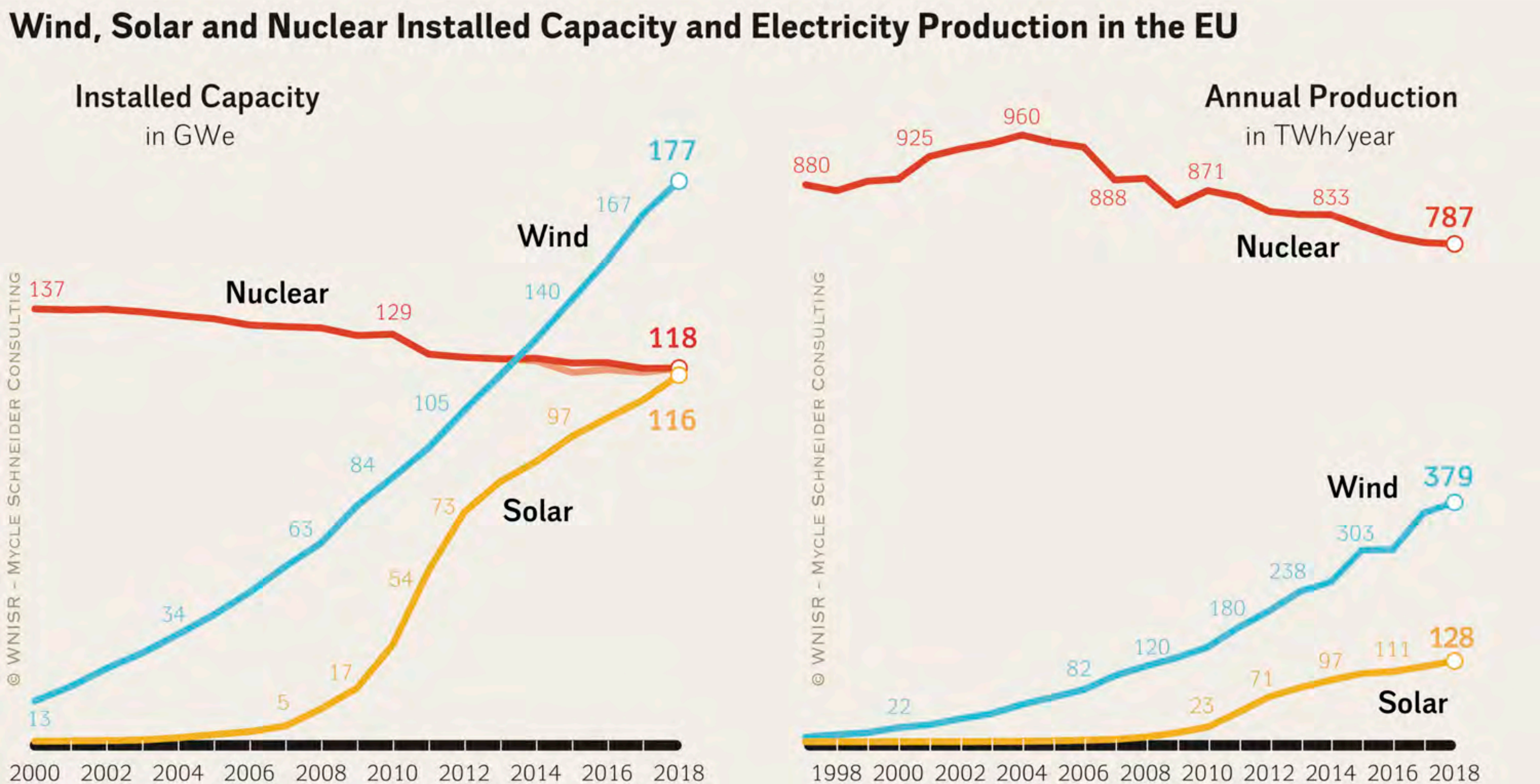
Sources: WNISR, with IAEA-PRIS, 2019

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



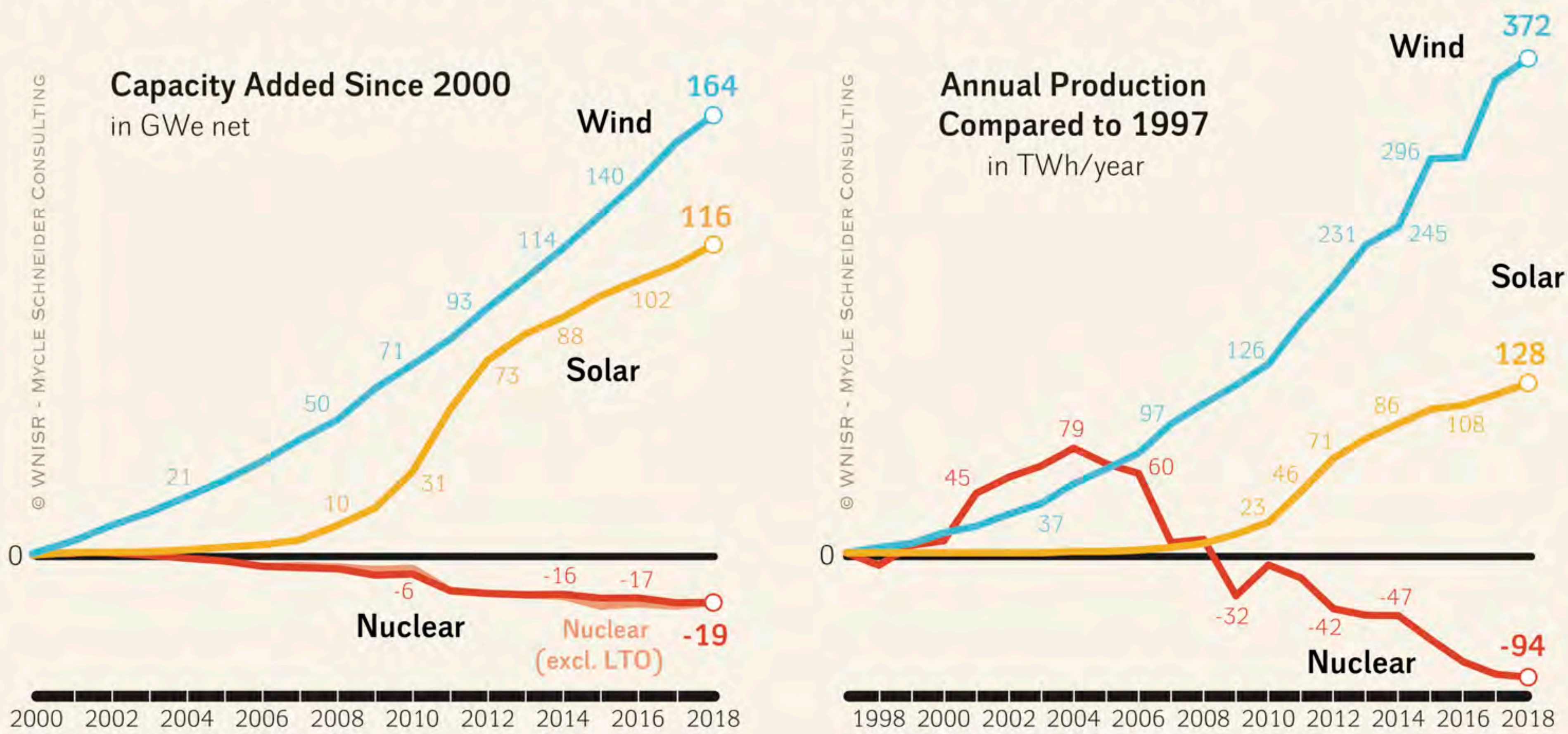
Sources: WindEurope, WNISR, 2019

WNISR2019 NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019

Wind, Solar and Nuclear Developments: Installed Capacity and Electricity Production in the EU



Sources: WNISR, IAEA-PRIS, BP Statistical Review 2019