Global Launch Event

The World Nuclear Industry Status Report 2022

(WNISR2022)

www.WorldNuclearReport.org

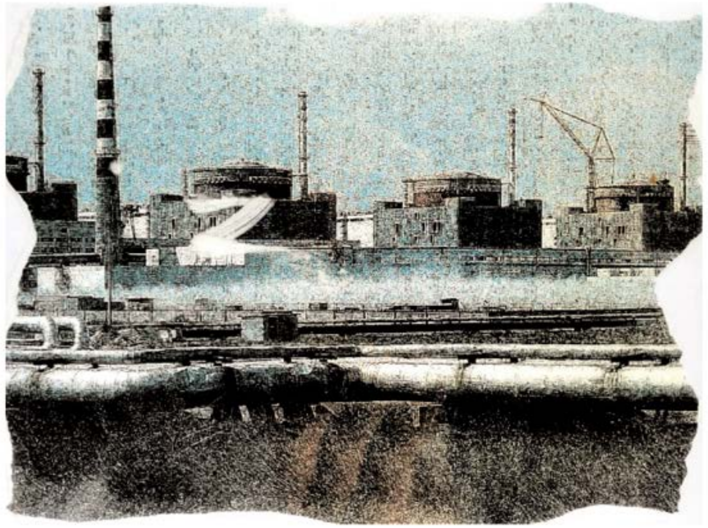
Hosted by Heinrich Boell Foundation, Berlin

Berlin (Germany), Paris (France), London (UK), Vancouver (Canada), Nagasaki (Japan)
5 October 2022

International, Interdisciplinary Team for a Multi-Indicator Analysis

A Mycle Schneider Consulting Project
Paris, October 2022

The World Nuclear Industry
Status Report 2022



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The World Nuclear Industry
Status Report 2022

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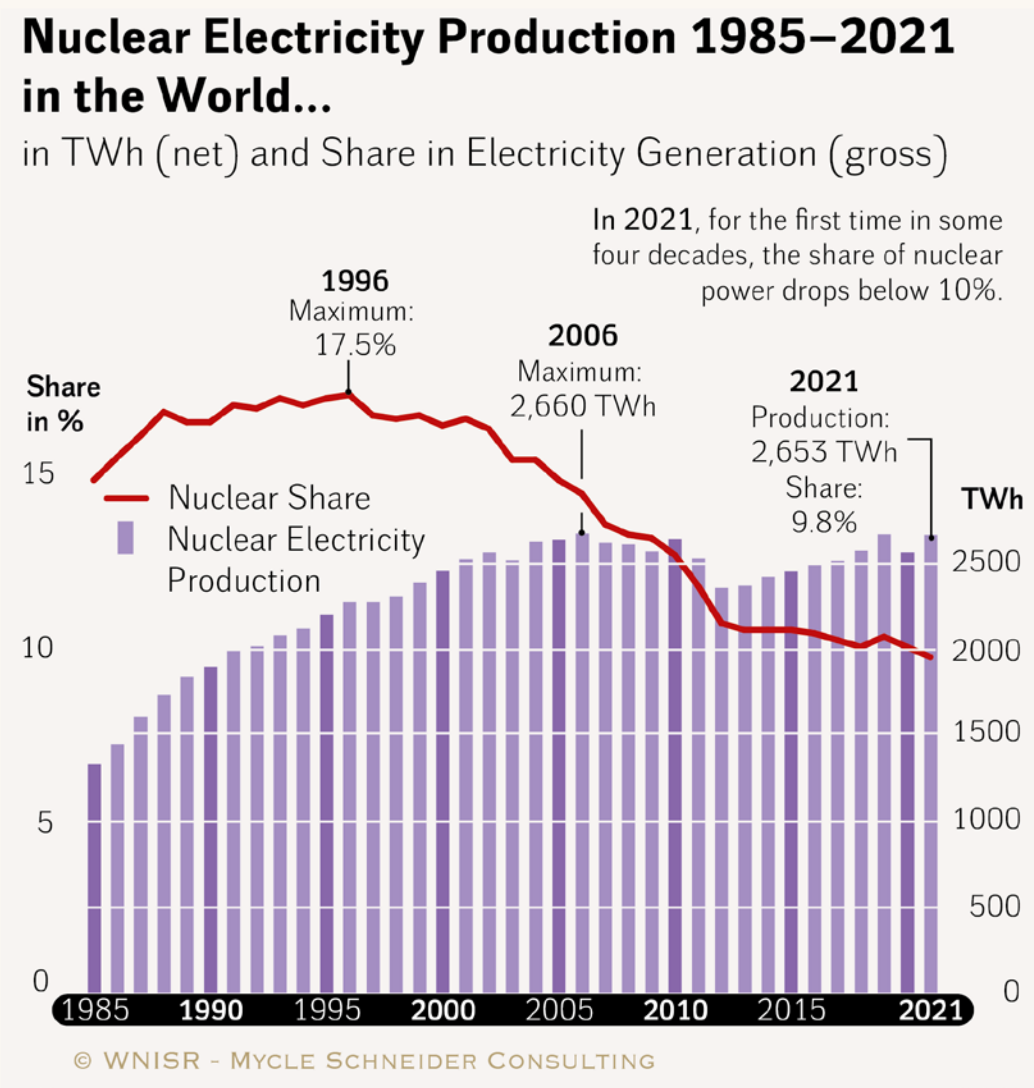
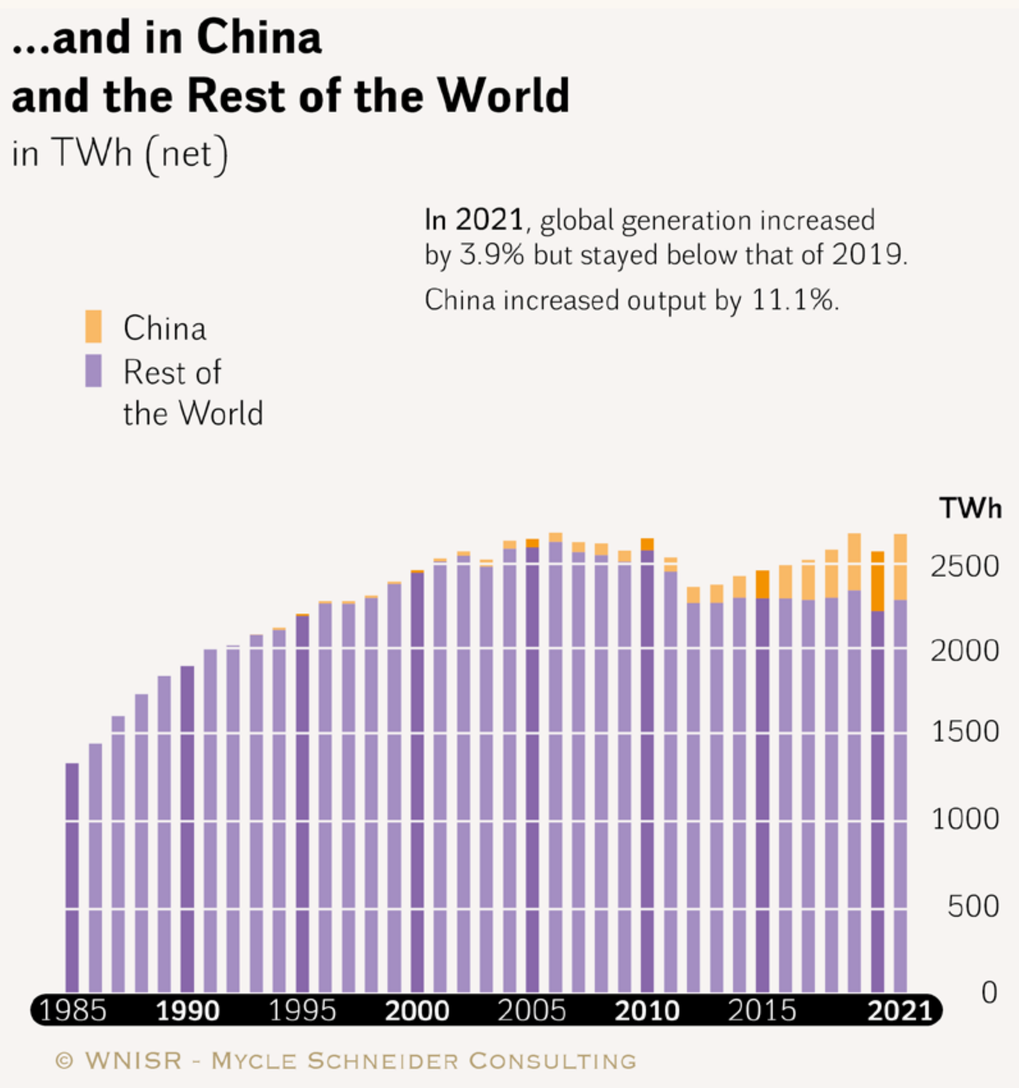
Between 2004 and 2009, he has been in charge of the Environment and Energy Strategies Lecture of the International Master of Science for Project Management for Environmental and Energy Engineering at the *Ecole des Mines* in Nantes, France.

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 16 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 10 countries.

GLOBAL OVERVIEW – ROLE OF NUCLEAR POWER



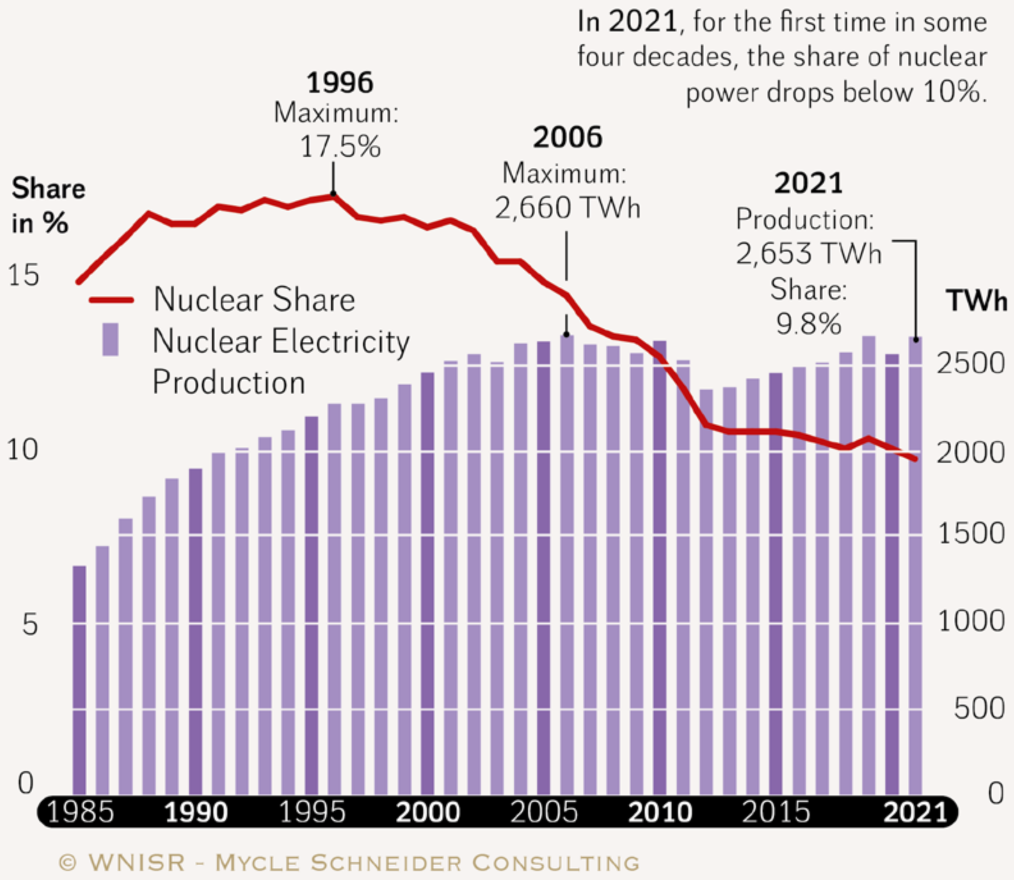


Sources: WNISR, with IAEA-PRIS and BP, 2022

GLOBAL OVERVIEW – ROLE OF NUCLEAR POWER

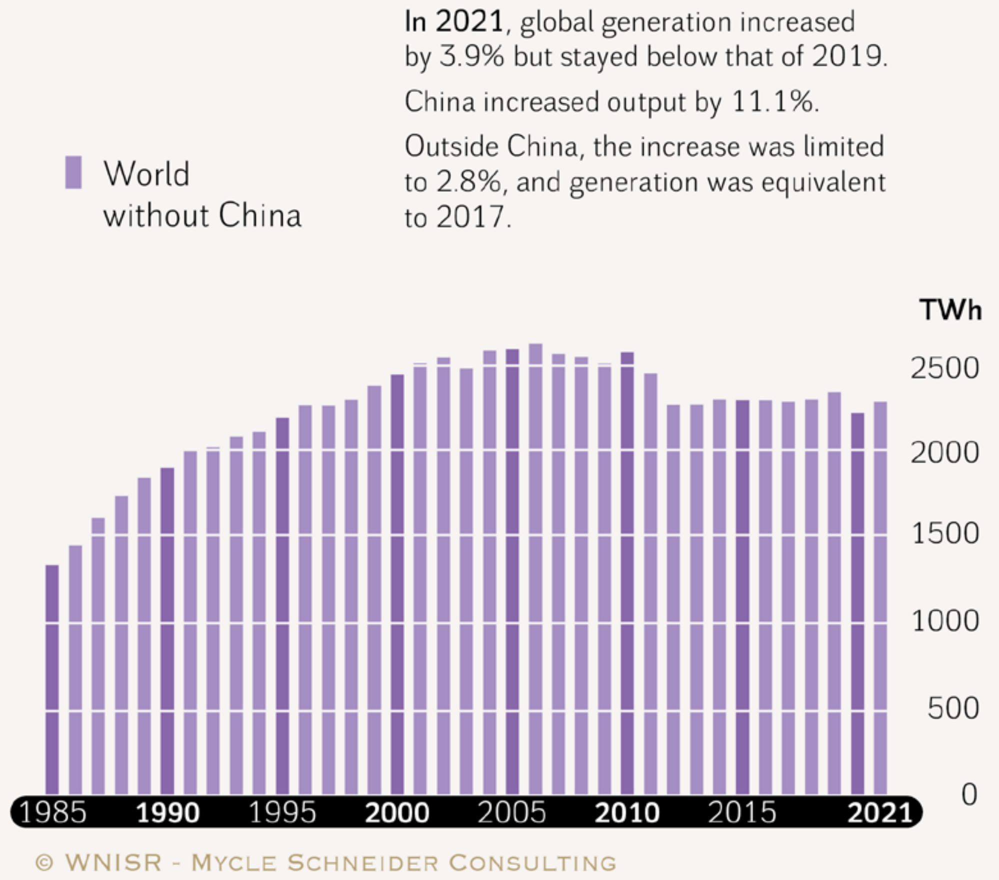
Nuclear Electricity Production 1985–2021 in the World...

in TWh (net) and Share in Electricity Generation (gross)



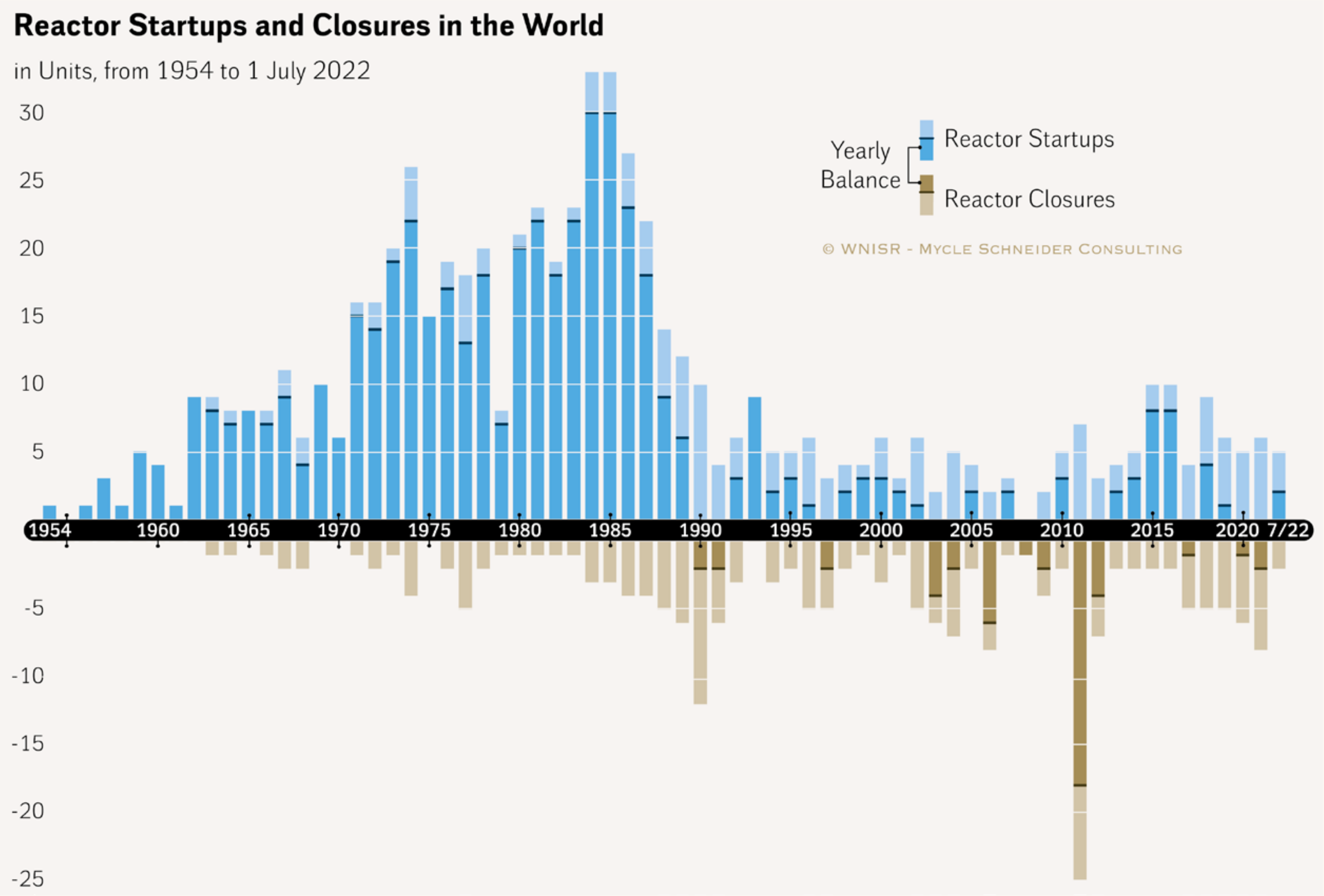
...and in China and the Rest of the World

in TWh (net)



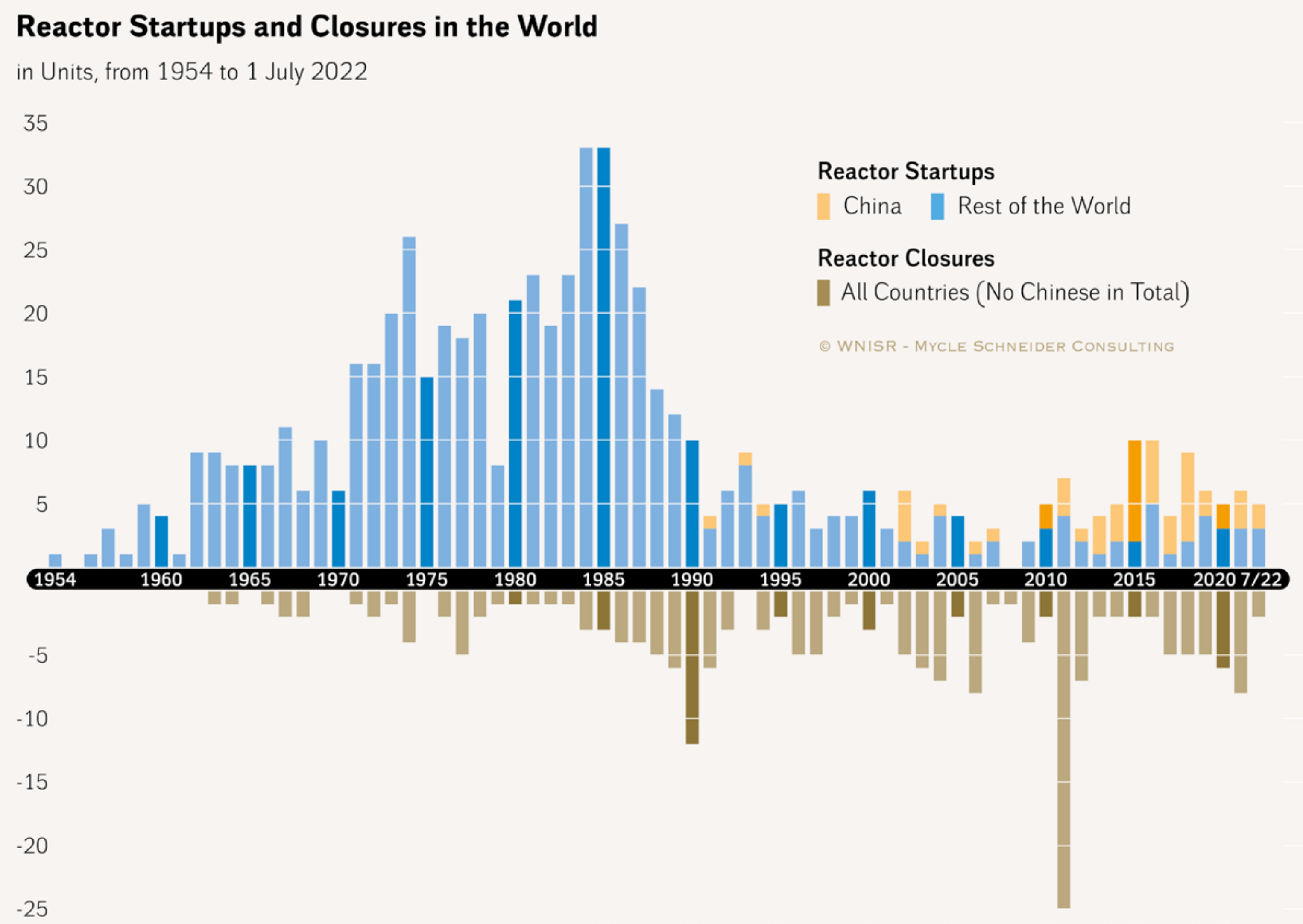
Sources: WNISR, with IAEA-PRIS and BP, 2022

GLOBAL OVERVIEW – STARTUPS AND CLOSURES WORLD



Sources: WNISR, with IAEA-PRIS, 2022

GLOBAL OVERVIEW – STARTUPS AND CLOSURES WORLD AND CHINA



2002–2021

World

- 98 Startups,
- 105 Closures

China

- 50 Startups
- No Closure

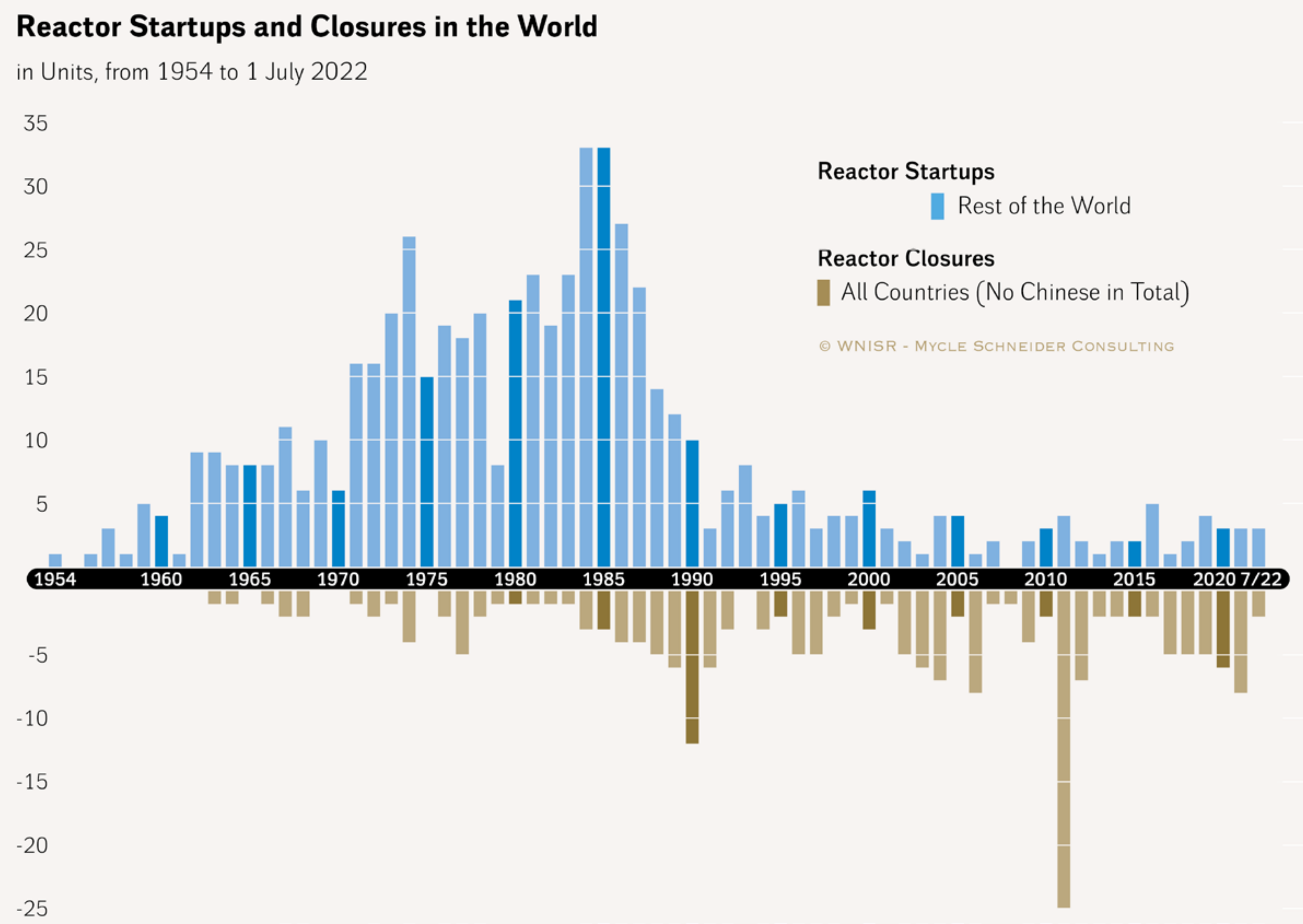
World Outside China

- 48 Startups
- 105 Closures

Net Balance –57

Sources: WNISR, with IAEA-PRIS, 2022

GLOBAL OVERVIEW – STARTUPS AND CLOSURES WORLD OUTSIDE CHINA



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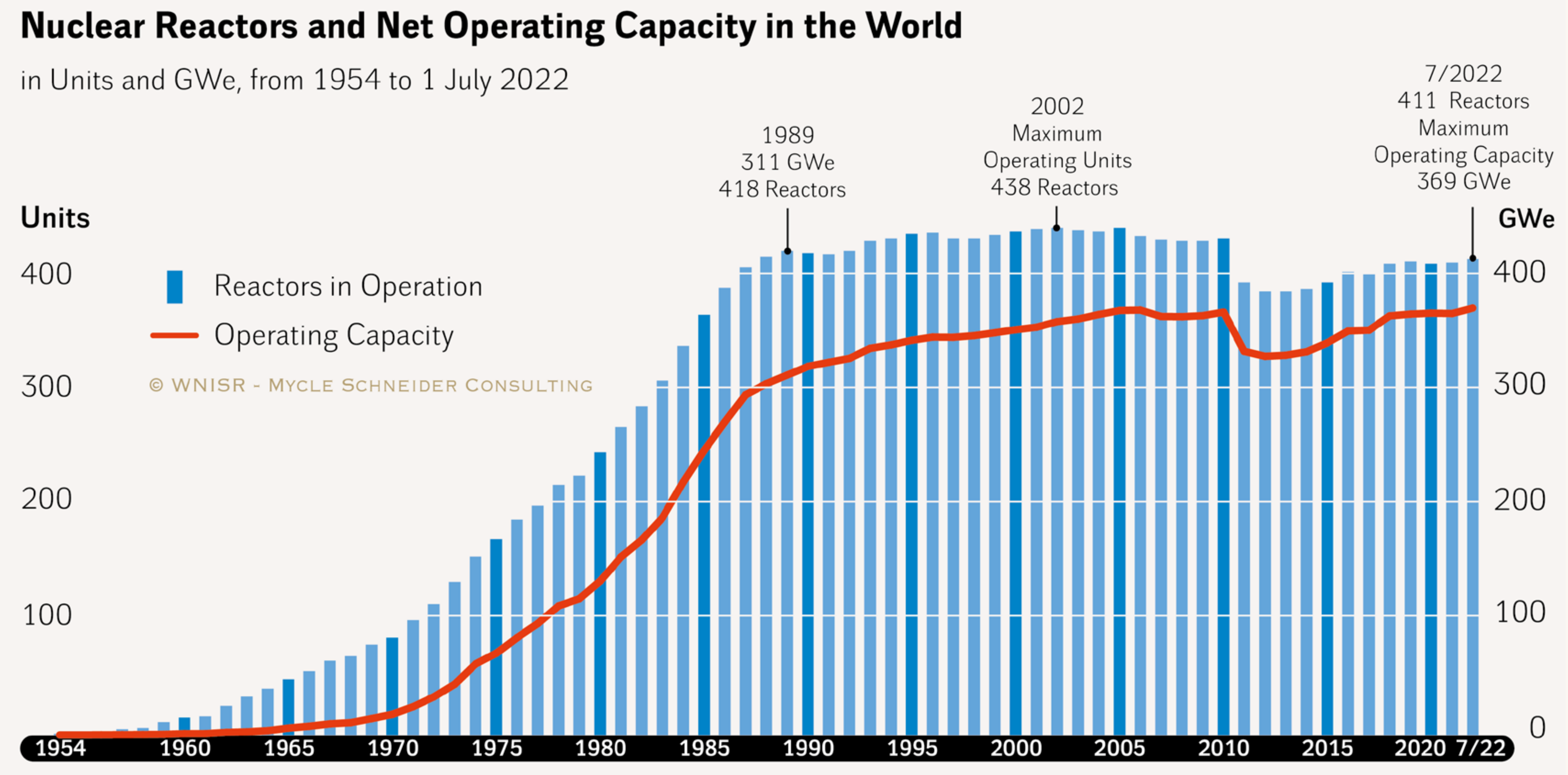
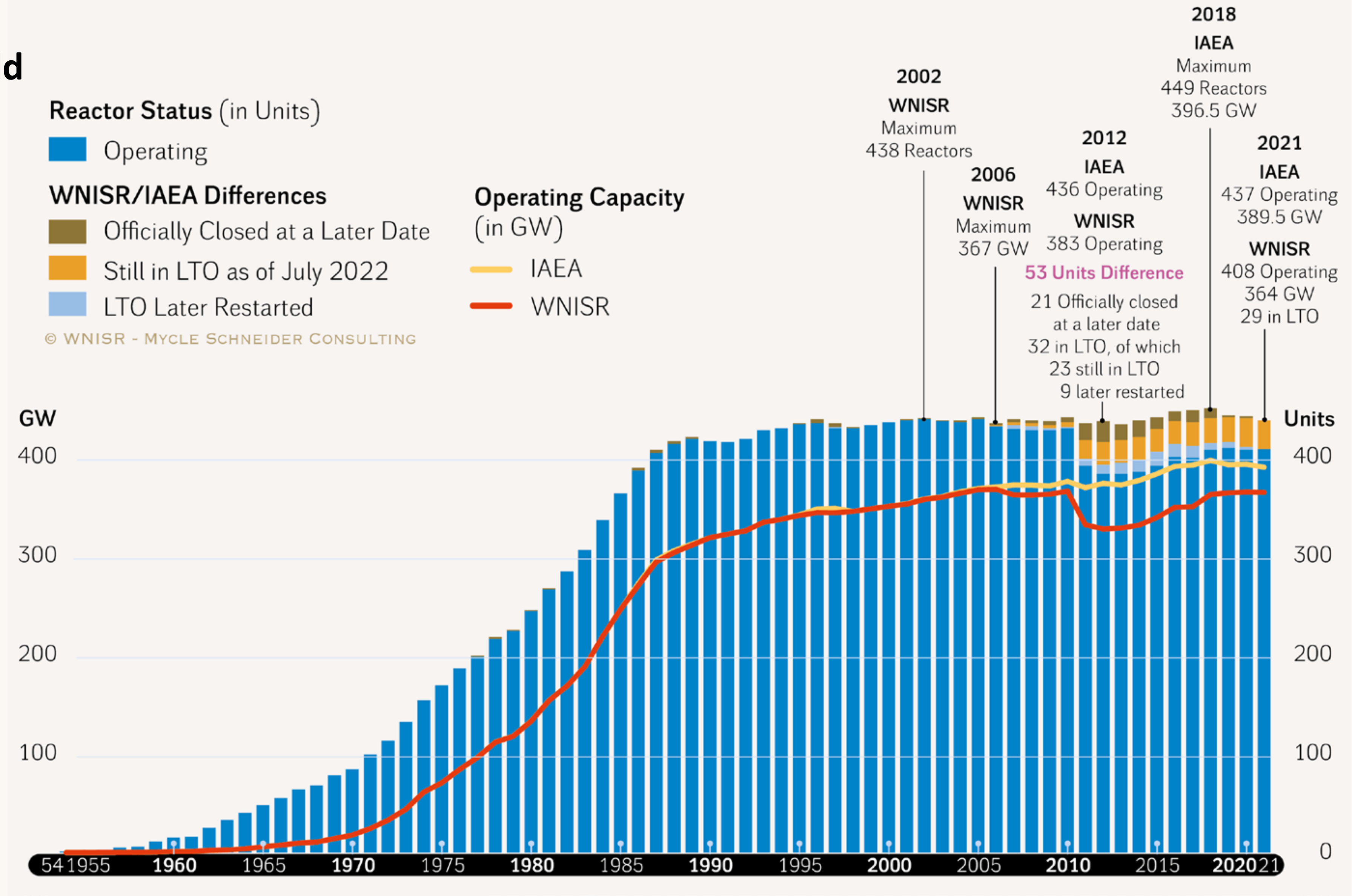


Sources: WNISR, with IAEA-PRIS, 2022

GLOBAL OVERVIEW — WHAT DOES « OPERATING » MEAN?

Nuclear Reactors in the World
IAEA "in Operation"
vs.
WNISR Analysis
In Units and in GW
as of year end 1954–2021



Sources: WNISR and IAEA-PRIS, 2022

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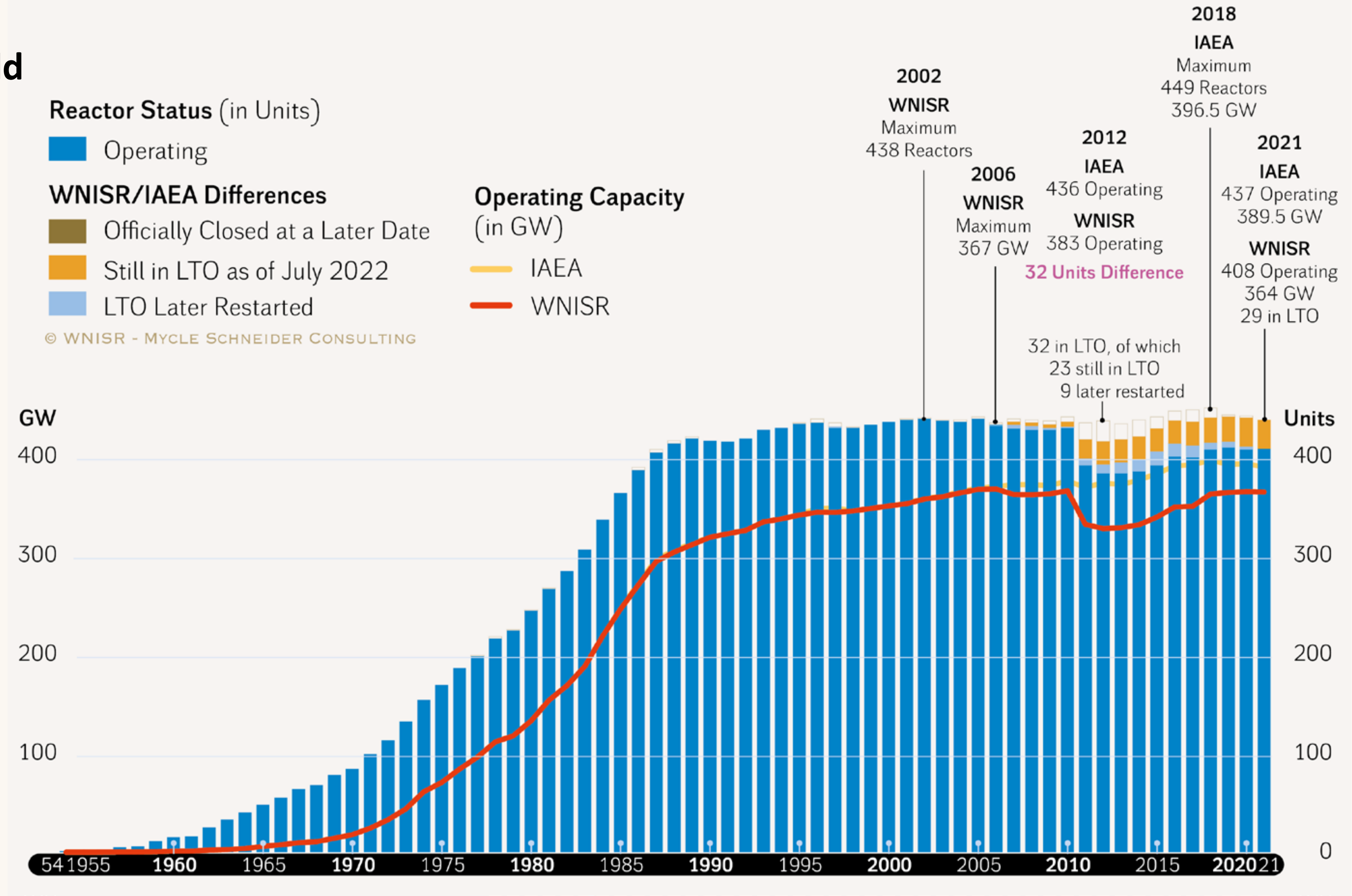

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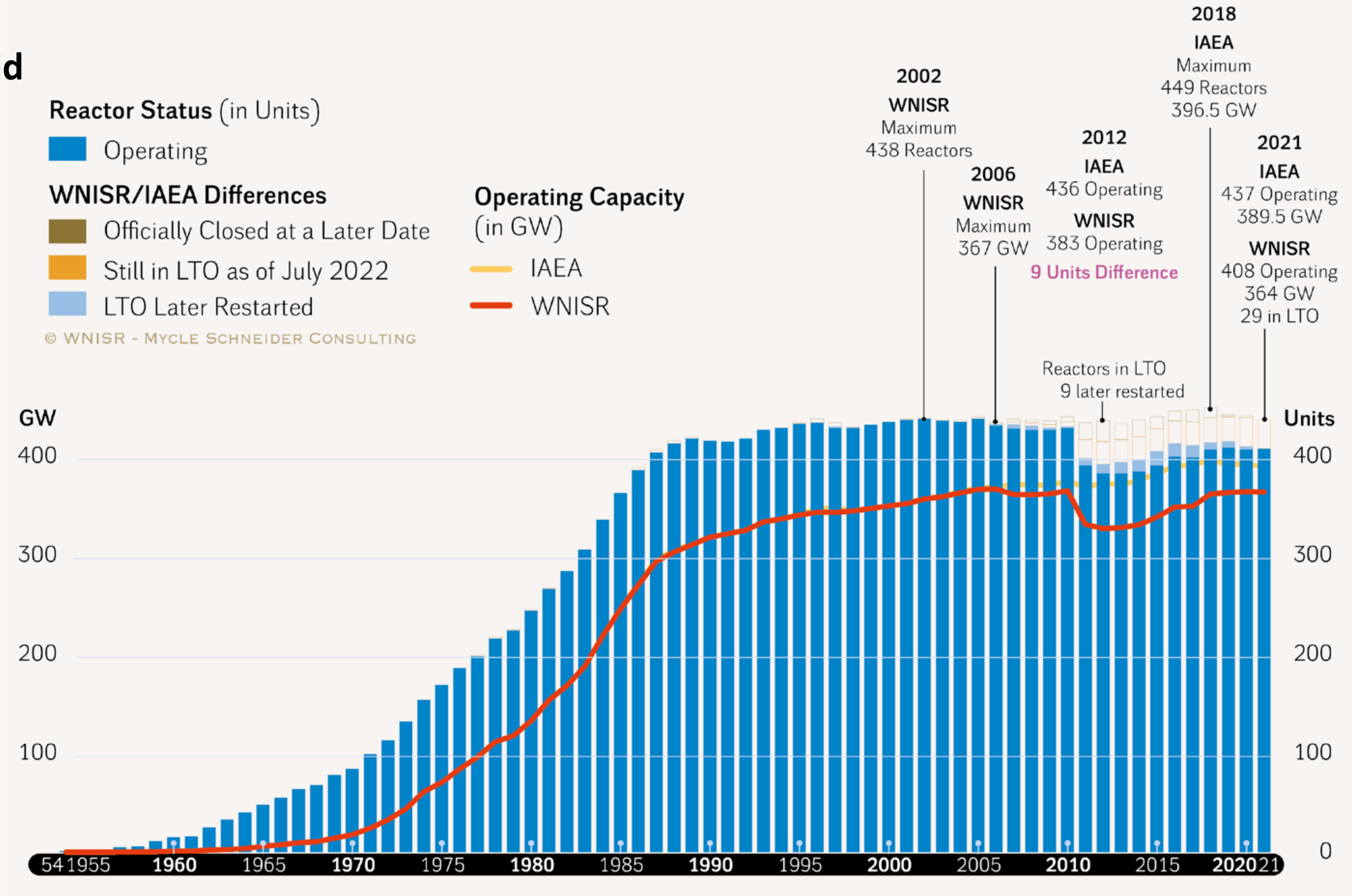

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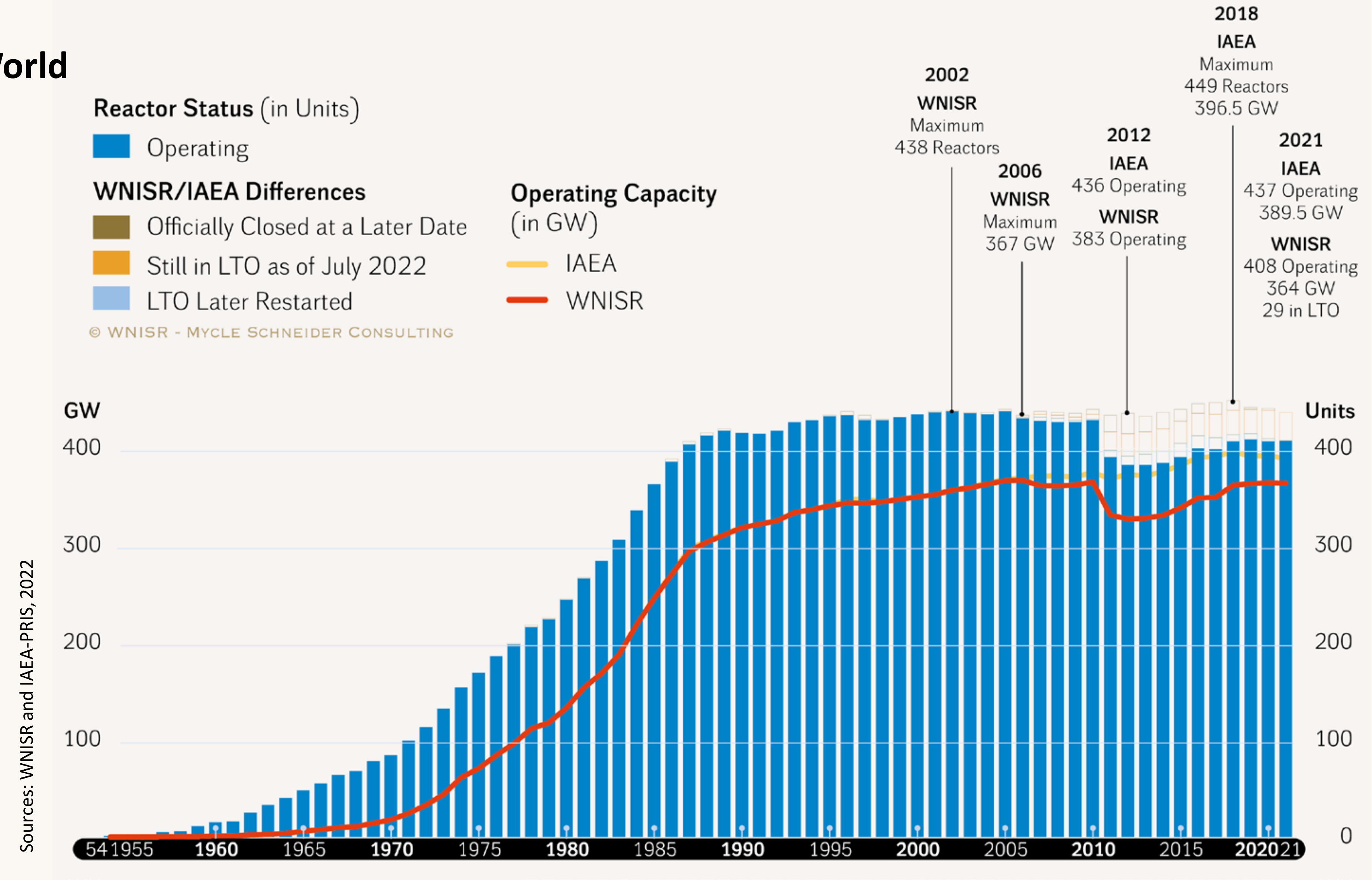
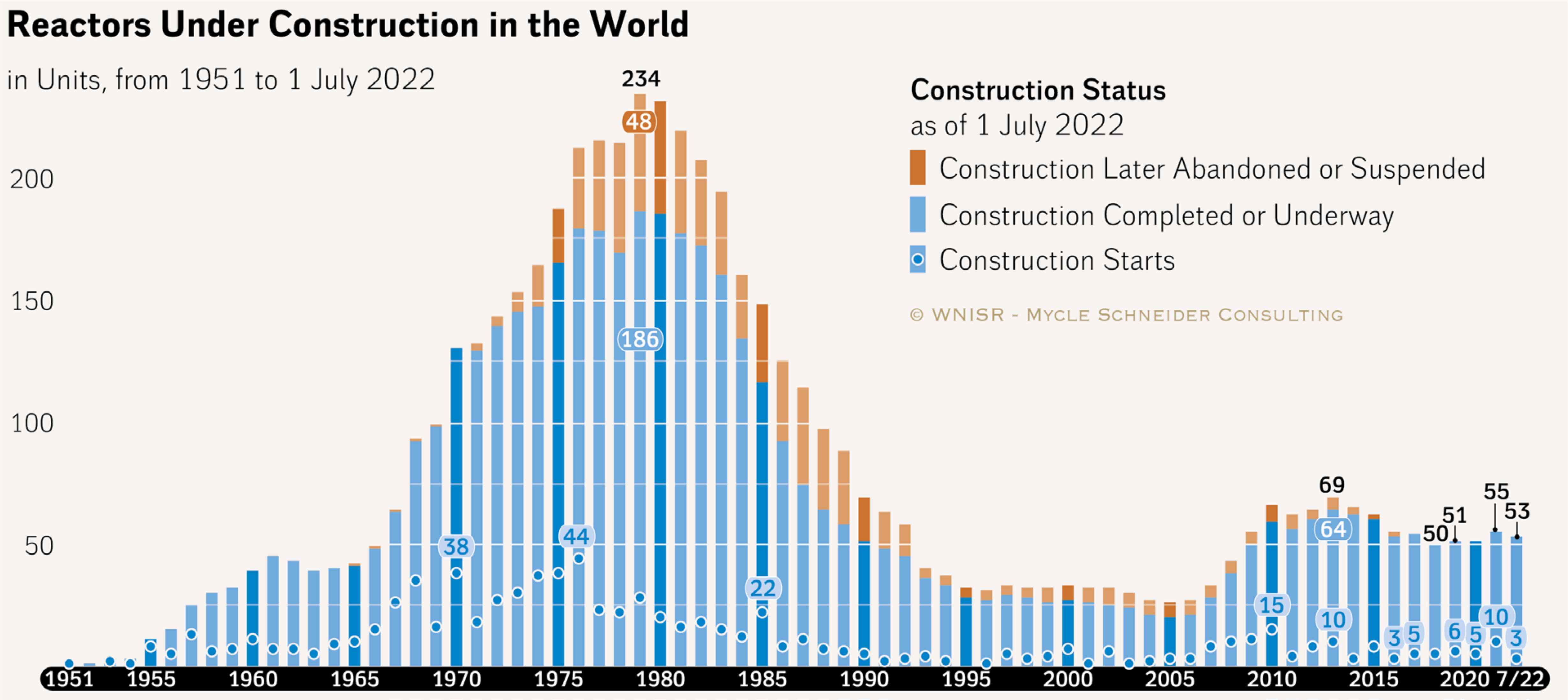


GENERAL OVERVIEW — CONSTRUCTIONS

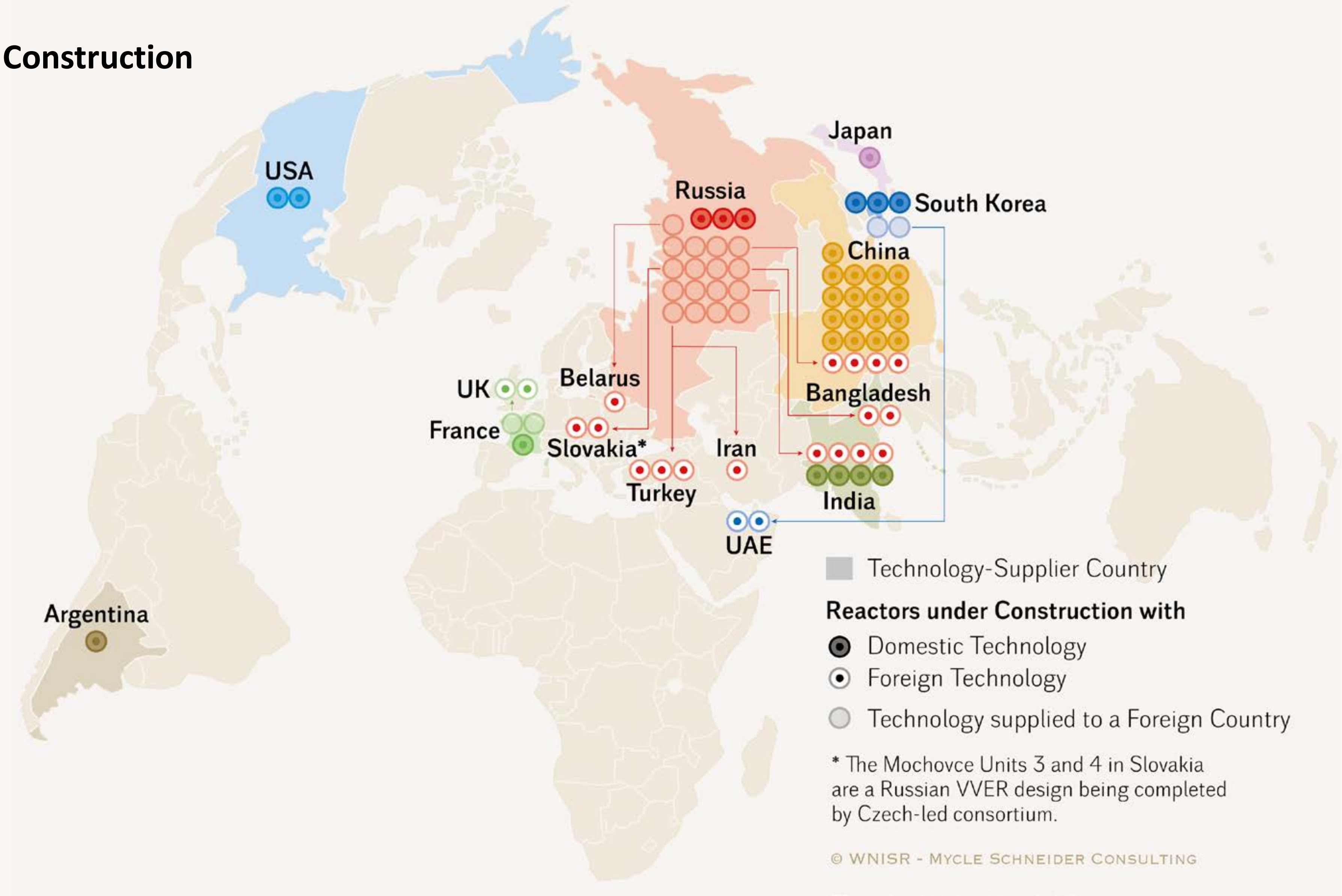


Sources: WNISR, with IAEA-PRIS, 2022

Nuclear Power Reactors Under Construction

By Technology Supplier Country

As of 1 July 2022



Sources: WNISR, with IAEA-PRIS, 2022

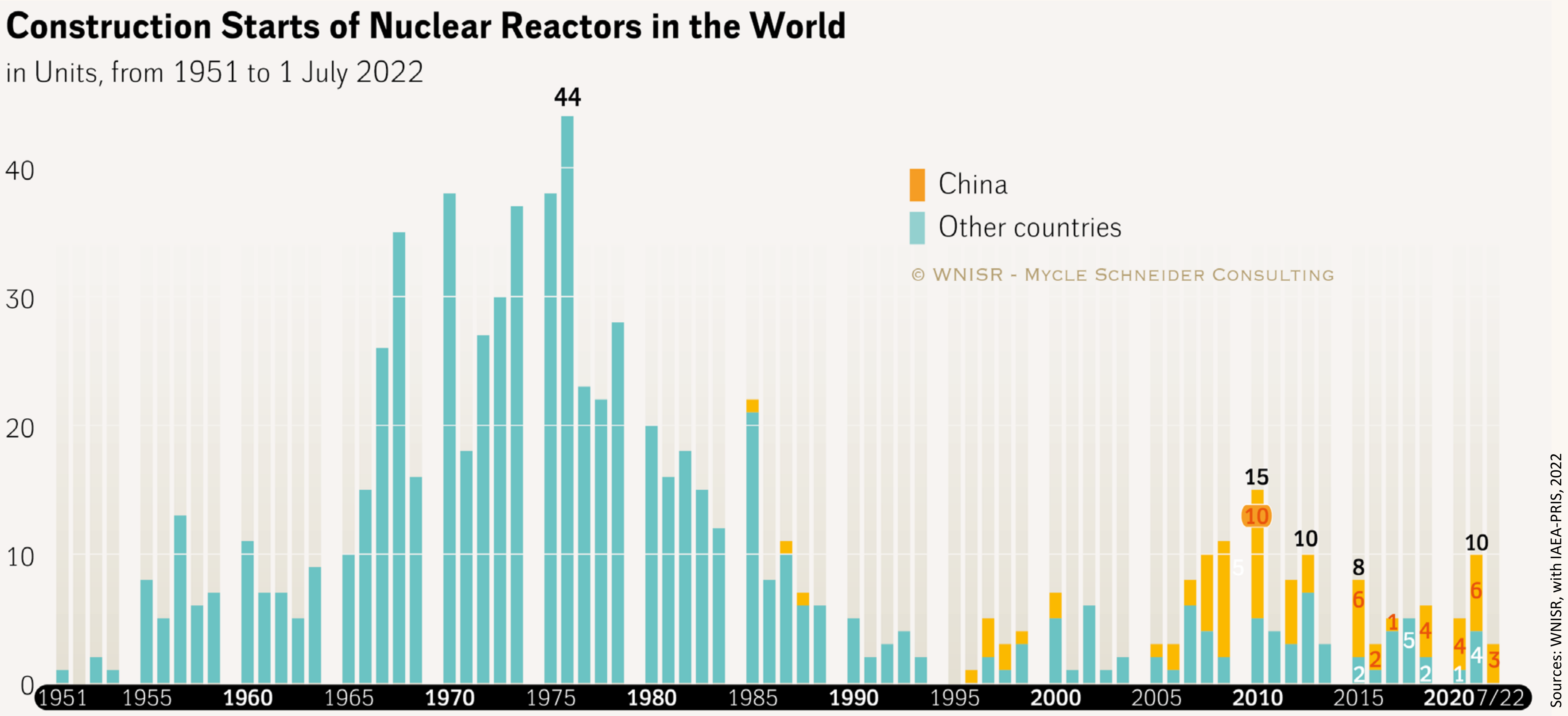
GENERAL OVERVIEW — UNDER CONSTRUCTION, HALF OF PROJECTS DELAYED

Nuclear Reactors Under Construction (as of 1 July 2022)

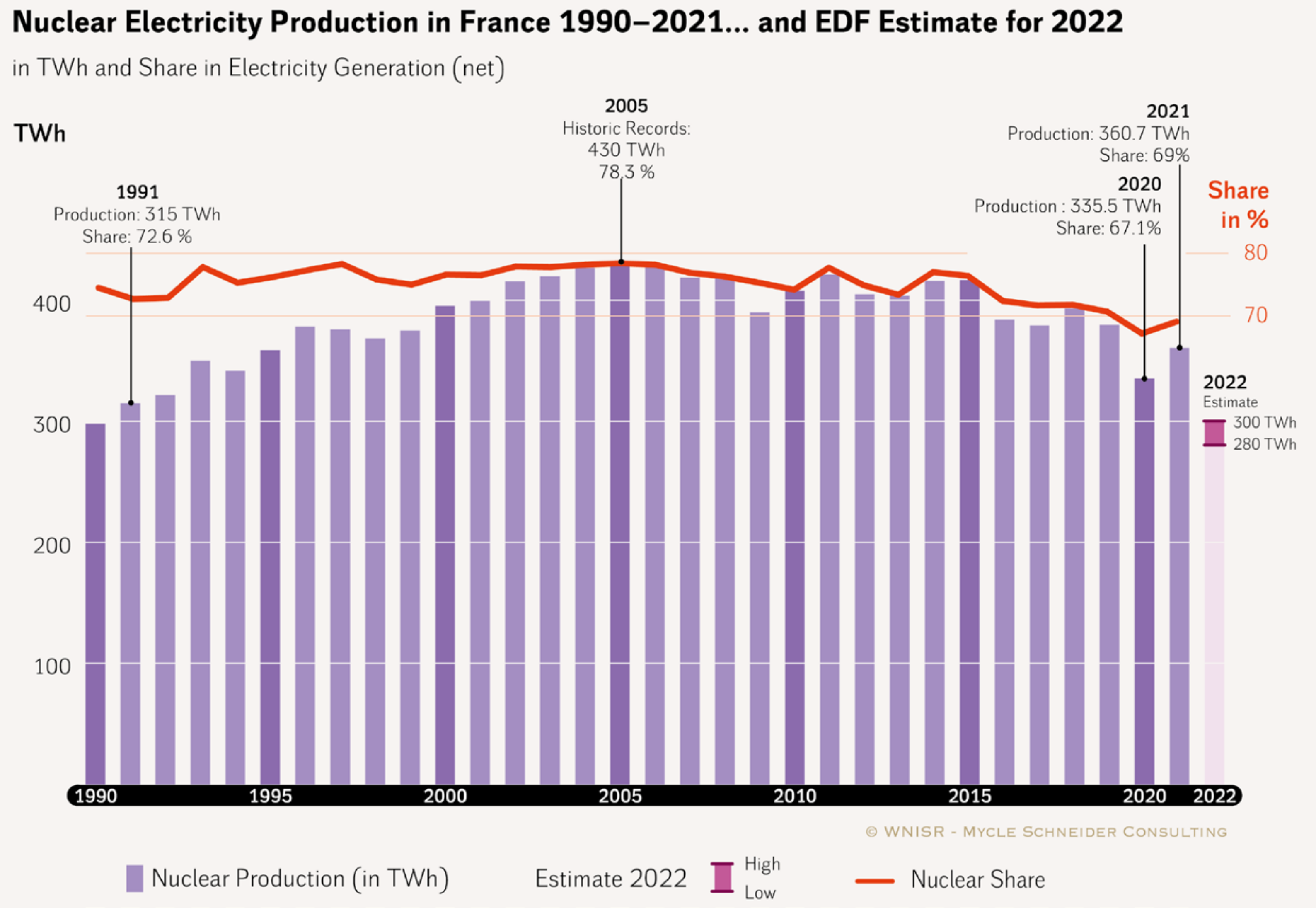
Country	Units (Domestic Design)	Other Vendor	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	21 (17)	Russia: 4	20 932	2012 – 2022	2022 – 2028	3
India	8 (4)	Russia: 4	6 028	2004 – 2021	2023 – 2027	6
Russia	3 (3)	–	2 650	2018 – 2021	2023 – 2026	
South Korea	3 (3)	–	4 020	2013 – 2018	2023 – 2025	3
Turkey	3 (0)	Russia: 3	3 342	2018 – 2021	2024 – 2026	1
Bangladesh	2 (0)	Russia: 2	2 160	2017 – 2018	2023 – 2024	
Slovakia	2 (0)	Russia: 2	880	1985	2022 – 2023	2
UAE	2 (0)	South Korea: 2	2 690	2014 – 2015	2023	2
U.K.	2 (0)	France: 2	3 260	2018 – 2019	2027 – 2028	2
U.S.	2 (2)	–	2 234	2013	2023	2
Argentina	1 (1)	–	25	2014	2027	1
Belarus	1 (0)	Russia: 1	1 110	2014	2022	1
France	1 (1)	–	1 630	2007	2023	1
Iran	1 (0)	Russia: 1	974	1976	2024	1
Japan	1 (1)	–	1 325	2007	2025?	1
Total	53		53 260	1976 - 2022	2022 – 2028	26
Total per Vendor Country: Russia: 20 - China: 17 - South Korea: 5 - India: 4 - France: 3 - USA: 2 - Argentina: 1 - Japan: 1						

Sources: WNISR, with IAEA-PRIS, 2022

GENERAL OVERVIEW — CONSTRUCTION STARTS WORLD OUTSIDE CHINA

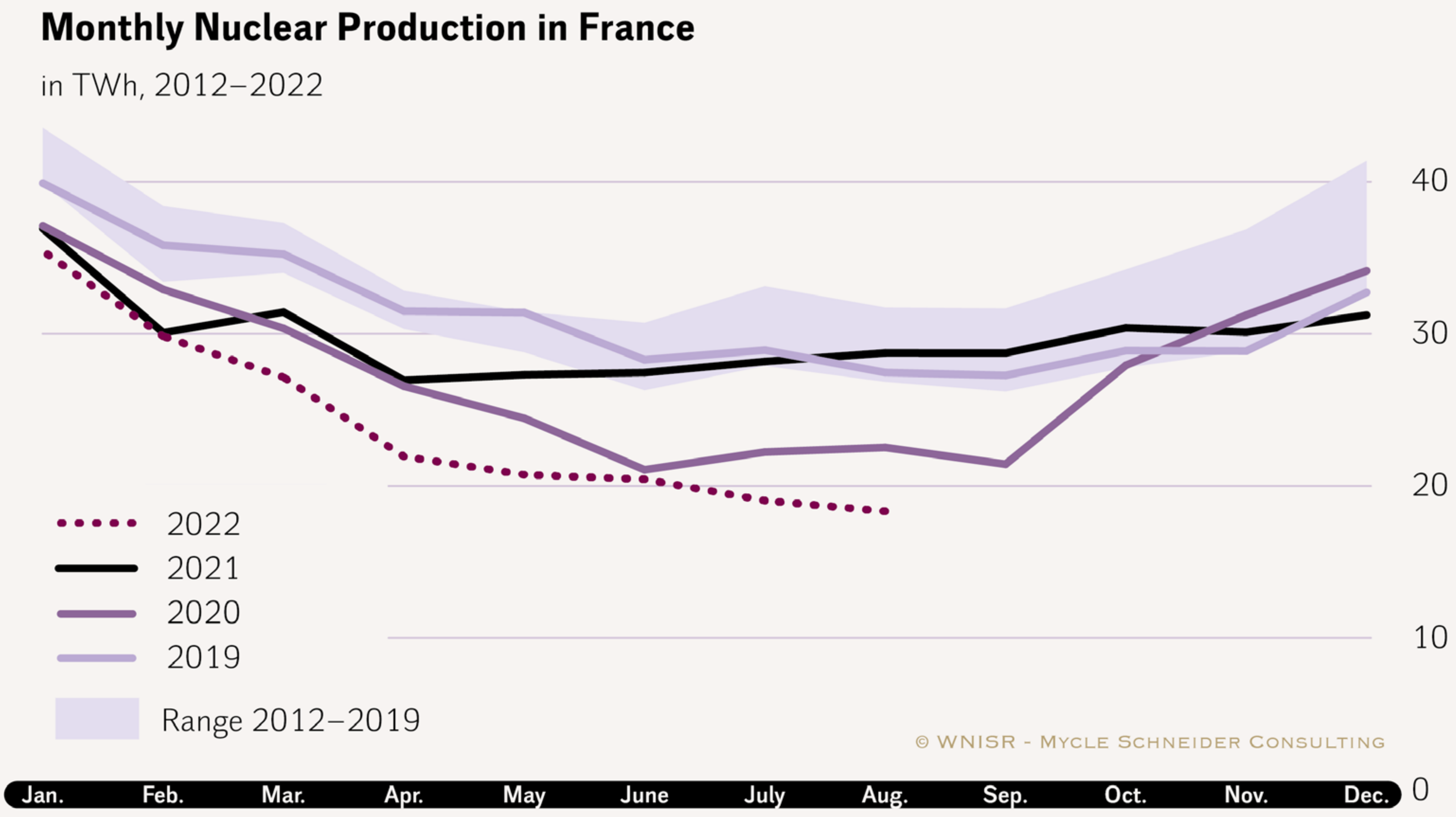


FRANCE FOCUS



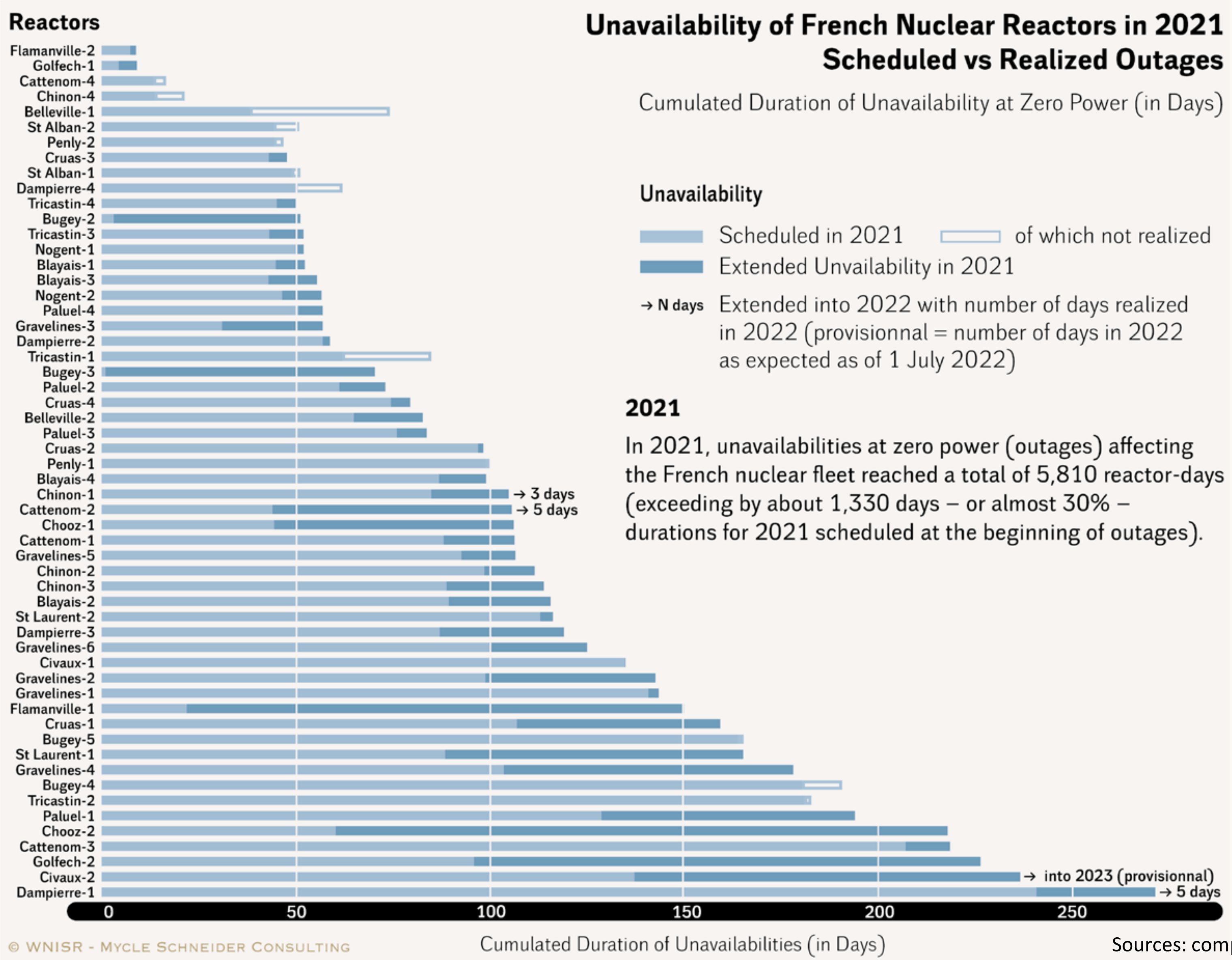
Sources: RTE, and EDF, various dates

FRANCE FOCUS – MONTHLY NUCLEAR PRODUCTION



Sources: RTE and EDF, 2021–2022

FRANCE FOCUS – UNAVAILABILITIES



Sources: compiled by WNISR, with EDF and RTE Data, 2021–2022

Tatsujiro Suzuki — suzukitatsu@nagasaki-u.ac.jp

Tatsujiro SUZUKI is Vice Director, Professor at the Research Center for Nuclear Weapons Abolition at Nagasaki University (RECNA), Japan. Before joining RECNA, he was Vice Chairman of the Japan Atomic Energy Commission (JAEC) of the Cabinet Office from January 2010 to March 2014. Until then, he was Associate Vice President of the Central Research Institute of Electric Power Industry in Japan (1996-2009), Associate Director of MIT's International Program on Enhanced Nuclear Power Safety from 1988-1993 and a Research Associate at MIT's Center for International Studies (1993-95). He is a member of the Advisory Board of Parliament's Special Committee on Nuclear Energy since June 2017. He is also a Council Member of Pugwash Conferences on Science and World Affairs (2007-09 and from 2014~). Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).

FUKUSHIMA STATUS REPORT: Onsite Challenges

- **Fuel Debris Removal**, last planned to start with Unit 2 by 2021, had been delayed by "about one year due to the spread of COVID-19" and was delayed again following transmission loss of the camera mounted on a remotely operated vehicle. **There is no new timeline for debris removal**.

- **Contaminated Water Management**. Various measures have reduced the influx of water from up to **500 m3/day to about 130 m3/day**. An equivalent amount of water is partially decontaminated and stored in 1,000-m3 tanks. Thus, a new tank is still needed almost every week.
  - About **1.3 million m3** of treated water are stored **in 1,020 tanks**. As of 28 July 2022, capacity saturation had reached 96 percent, so the existing tanks would be full by summer or fall of 2023.
  - The safety authority agreed to operator TEPCO's plan to release the contaminated water into the ocean. Close to three quarters of the water would have to be treated again, then **the water would be diluted by a factor of 100 (or more) before being released via a one-kilometer-long sub-seabed tunnel.** The operation would take at least three decades. The plan remains widely contested, including overseas.

FUKUSHIMA STATUS REPORT: Offsite Challenges (1)

- **Evacuees.** As of March 2022, **about 32,400 residents** of Fukushima Prefecture were still living as evacuees; the number decreased from a peak of close to **165,000** in May 2012. In June 2022, for the first time, the evacuation order was lifted for a district designated as "difficult-to-return" zone (an area with high levels of radiation). The evacuation order was also lifted for part of **Okuma city** that hosts the Fukushima plant. **Only 3.6 percent of the residents returned**.

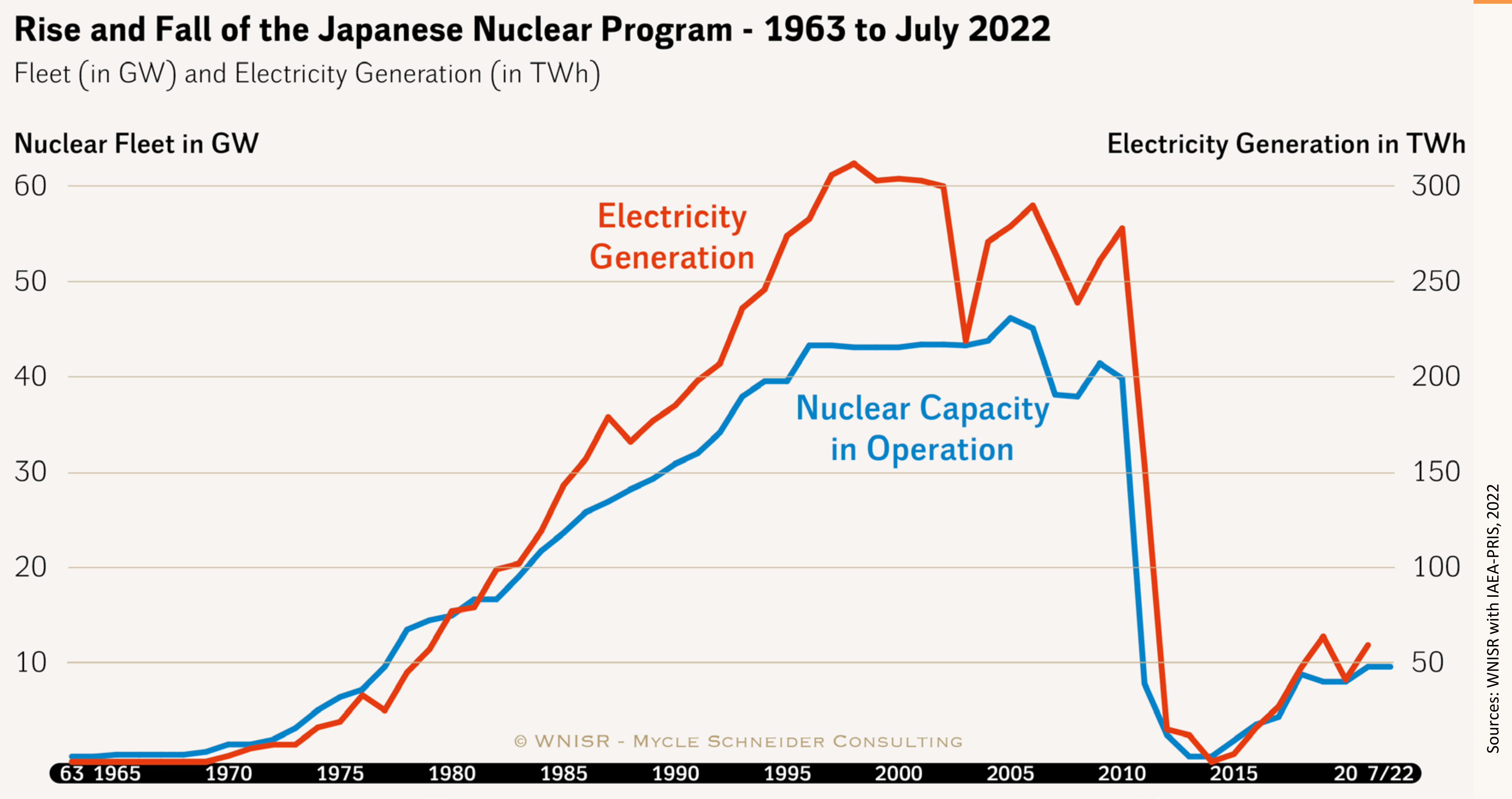
- **Food Contamination**. According to official statistics, a total of **41,361 samples** were analyzed in FY2021, of which **157 samples (30 more than a year earlier and 0.4 percent of total)** exceeded the legal limits.

- **Decontamination and Contaminated Soil Management**. The contaminated soil in the temporary storage area in Fukushima Prefecture is currently being transferred to intermediate storage facilities in eight areas. As of the end of August 2022, a total of **about 13.3 million m^3 of contaminated soil** had been transferred to such interim storage facilities.

FUKUSHIMA STATUS REPORT: Offsite Challenges (2)

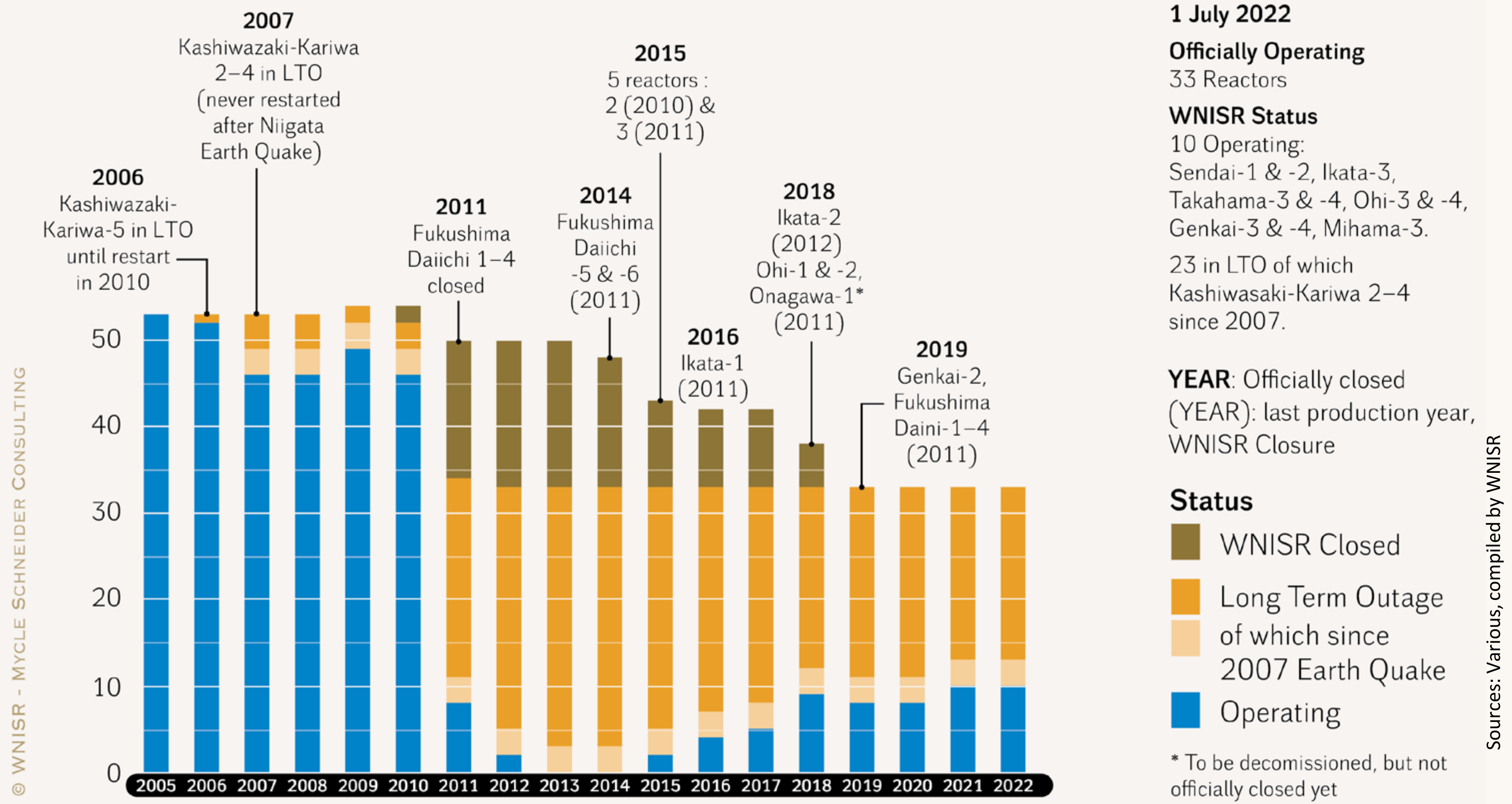
Health Issues and Legal Cases.

- In a first-of-a-kind procedure, in January 2022, **a group of six men and women, diagnosed with thyroid cancer as children, filed a class action** suit against TEPCO, seeking US$5.4 million in compensation.
- In March 2022, Japan's **Supreme Court ordered TEPCO to pay** compensation to **3,700 people impacted by the disaster** but ruled out government responsibility for the catastrophe in a separate June-2022 judgement.
- In July 2022, the **Tokyo District Court ordered four former executives of TEPCO to pay 13 trillion yen (US$95 billion)** in damages to the company. The case was brought by TEPCO shareholders, and the ruling was the first time a court has found former executives responsible for the nuclear accidents.


Rise and Fall of the Japanese Nuclear Program - 1963 to July 2022
Fleet (in GW) and Electricity Generation (in TWh)
Nuclear Fleet in GW
Electricity Generation in TWh
60
50
40
30
20
10
300
250
200
150
100
50
Electricity Generation
Nuclear Capacity in Operation
© WNISR - Mycle Schneider Consulting
63 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 20 7/22
Sources: WNISR with IAEA-PRIS, 2022

Status of Reactors Officially Operational in Japan vs. WNISR Assessment

in Units, as of year end 2005–2021 and mid-2022



JAPAN FOCUS — UPDATE

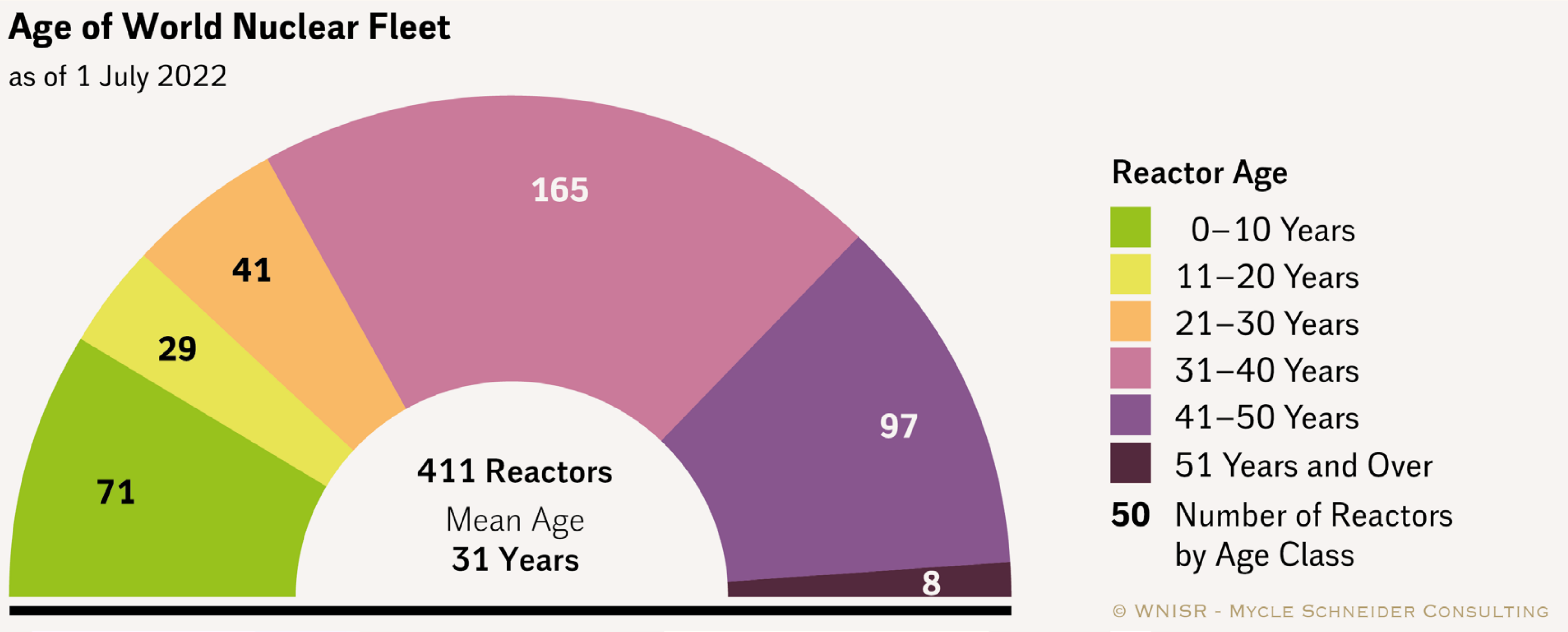
- One additional reactor was operating compared to WNISR2021 (none was slated for closure). **Nuclear generation increased by 42.2 percent but to provide 7.2 percent of the country's electricity**. However, as of July 2022, **only seven of ten licensed units generated power**.
- In an unprecedented ruling, **a Hokkaido District Court prohibited the restart of the only three reactors on the island** due to concerns about spent fuel storage safety and protection levels against tsunamis.
- **Prime Minister Kishida** announced on 14 July 2022, that he had asked METI to have up to nine nuclear reactors operational this winter. On August 24, 2022, Prime Minister Kishida, in his speech at the GX (Green Transformation) Council, stated that **the government should consider building a new generation of nuclear reactor.**
- Although this has been interpreted as **a "new phase" of Japan's nuclear energy policy**, PM Kishida confirmed again at the press conference on 31 August 2022, that **the policy of "reducing dependence on nuclear power as much as possible" remained unchanged.**

Alexander Wimmers, Berlin - awi@wip.tu-berlin.de

Alexander James Wimmers is a research associate of the AT-OM research group at the Workgroup for Economic and Infrastructure Policy (WIP) at the Berlin University of Technology (TU Berlin), Germany. Before joining WIP, he worked as a consultant for renewable energy markets at a renowned energy consulting firm in Berlin. He holds an MSc in Business Administration and Engineering (Wirtschafts-ingenieurwesen) from RWTH Aachen University.

His current research focuses on the political economy of nuclear power, from new build, operation and decommissioning to nuclear waste management. He is a member of a long-term research project on nuclear decommissioning in cooperation with the University of Basel.

WORLD FLEET — OPERATING AGE



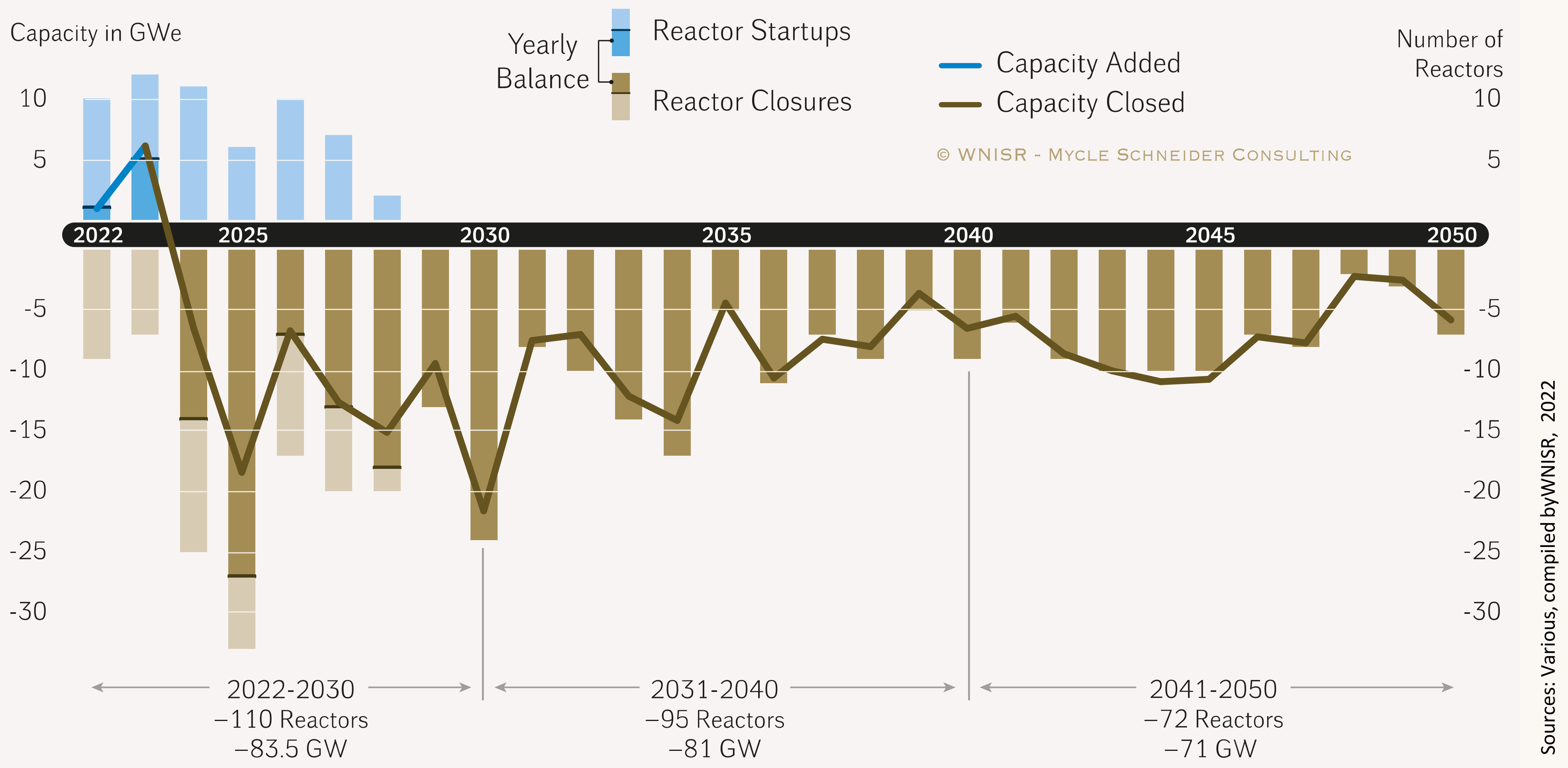
Sources: WNISR, with IAEA-PRIS, 2022

WORLD FLEET – THE PLEX PROJECTION

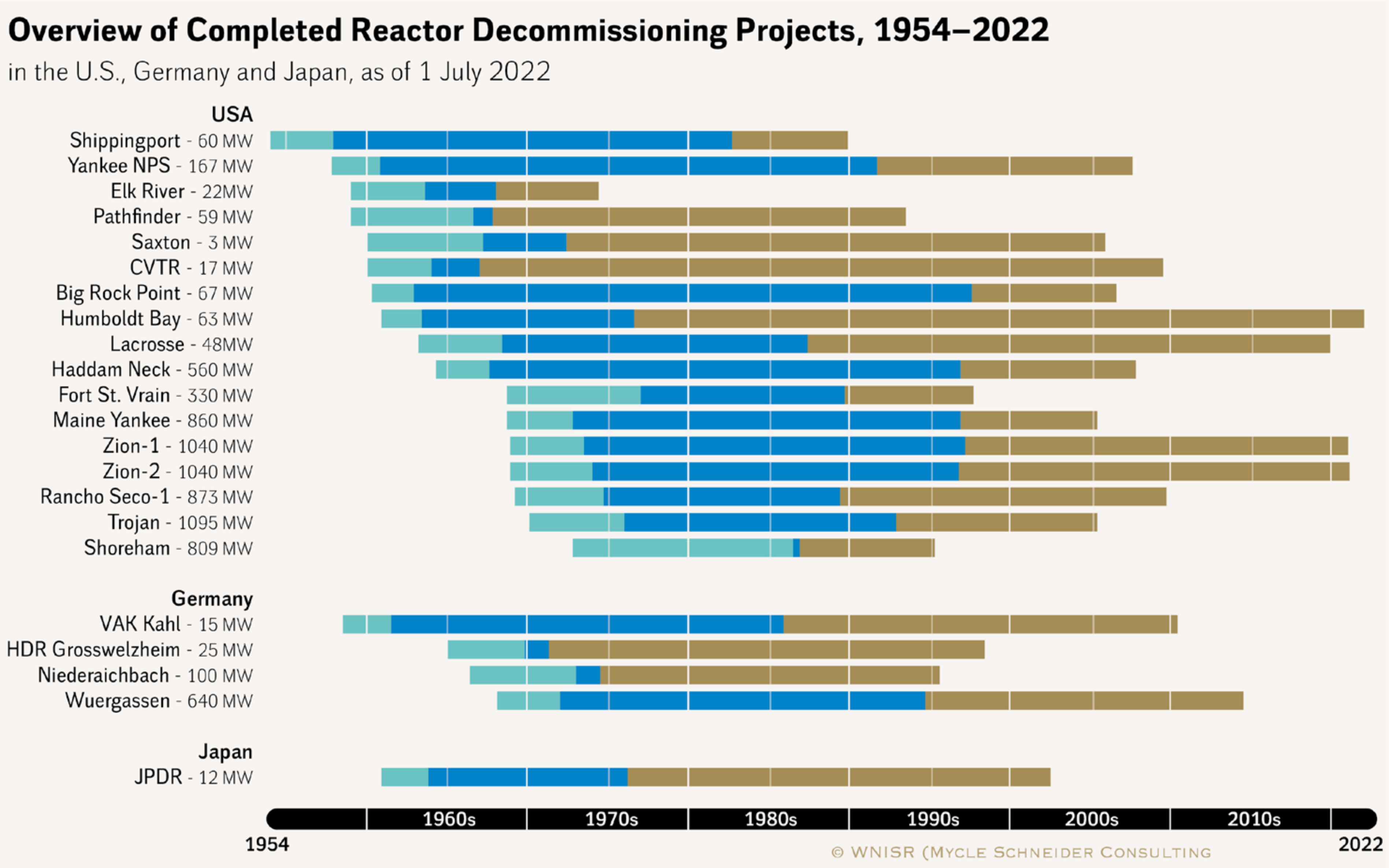
Projection 2022–2050 of Nuclear Reactors/Capacity in the World

General assumption of 40-year mean lifetime + Authorized Lifetime Extensions

Operating and Under Construction as of 1 July 2022, in GWe and Units

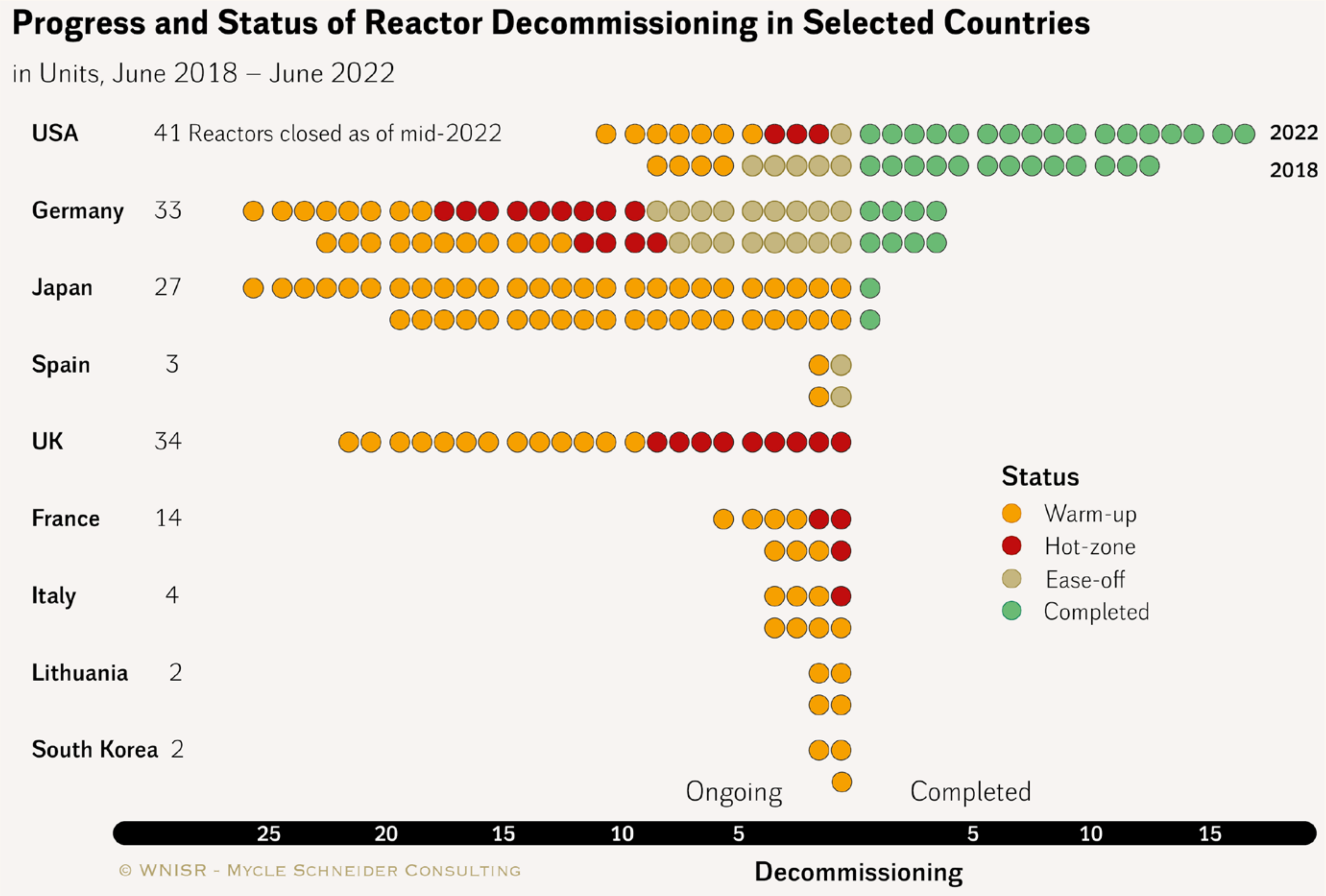


DECOMMISSIONING — HISTORY OF DECOMMISSIONING



Sources: Various, compiled by WNISR, 2022

DECOMMISSIONING – LITTLE PROGRESS SINCE 2018



Sources: Various, compiled by WNISR, 2022

CONCLUSIONS

NPP Rheinsberg in Germany, in decommissioning since 1995.
Photo: Alexander James Wimmers, September 2022

- Decommissioning remains an underestimated and often overlooked issue in the nuclear system
- Decommissioning projects often experience delays, often due to unexpected occurrences (e.g., additional contamination), resulting in decommissioning sometimes lasting longer than actual operation
- Final costs for decommissioning and liability in parts unresolved – thus the question of whether accumulated funds (provisions or external) will suffice

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M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Professor at the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada. He received his Ph.D. in theoretical physics from Boston University. Ramana is the author of "The Power of Promise: Examining Nuclear Energy in India" (Penguin Books, 2012) and co editor of "Prisoners of the Nuclear Dream" (Orient Longman, 2003). He is a member of the International Panel on Fissile Materials (IPFM), the International Nuclear Risk Assessment Group (INRAG) and the Canadian Pugwash Group. He is the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

SMRs – Continued Delays

- **Argentina**

  Carem-25 construction start 2014, with projected date of fuel loading in 2017; current estimate: 2027

- **China**

  HTR-PM construction start 2012; projected to be constructed in "50 months"; actual time – 109 months.

- **Russia**

  KLT-40S construction start 2007; projected to be constructed in 3 years; actual time – 13 years

SMRs – Reactor Design Delays

- **France**

  Nuward to be ready by 2030;
  Earlier example of Antares HTGR design, projected in 2009 to be ready for deployment in 2021 - abandoned

- **India**

  AHWR 2000 projection: operating by 2011; no current construction plans

- **USA**

  NuScale 2008 projection: electricity generation by 2015-16; current: 2029-30?

SMRs – High Costs of Construction

- **Diseconomies of scale**

  - Nuclear power is already costly

Design	Cost Estimate ($/kW)
CAREM (Argentina)	$17,000/kW
Micro Modular Reactor (Canada)	$15,000/kW - $30,000/kW
ACP 100 (China) & HTR-PM	$6000/kW (twice estimate for Hualong-One)
SMART (South Korea)	$10,000/kW
NuScale (462 MWe, USA)	$11,515/kW

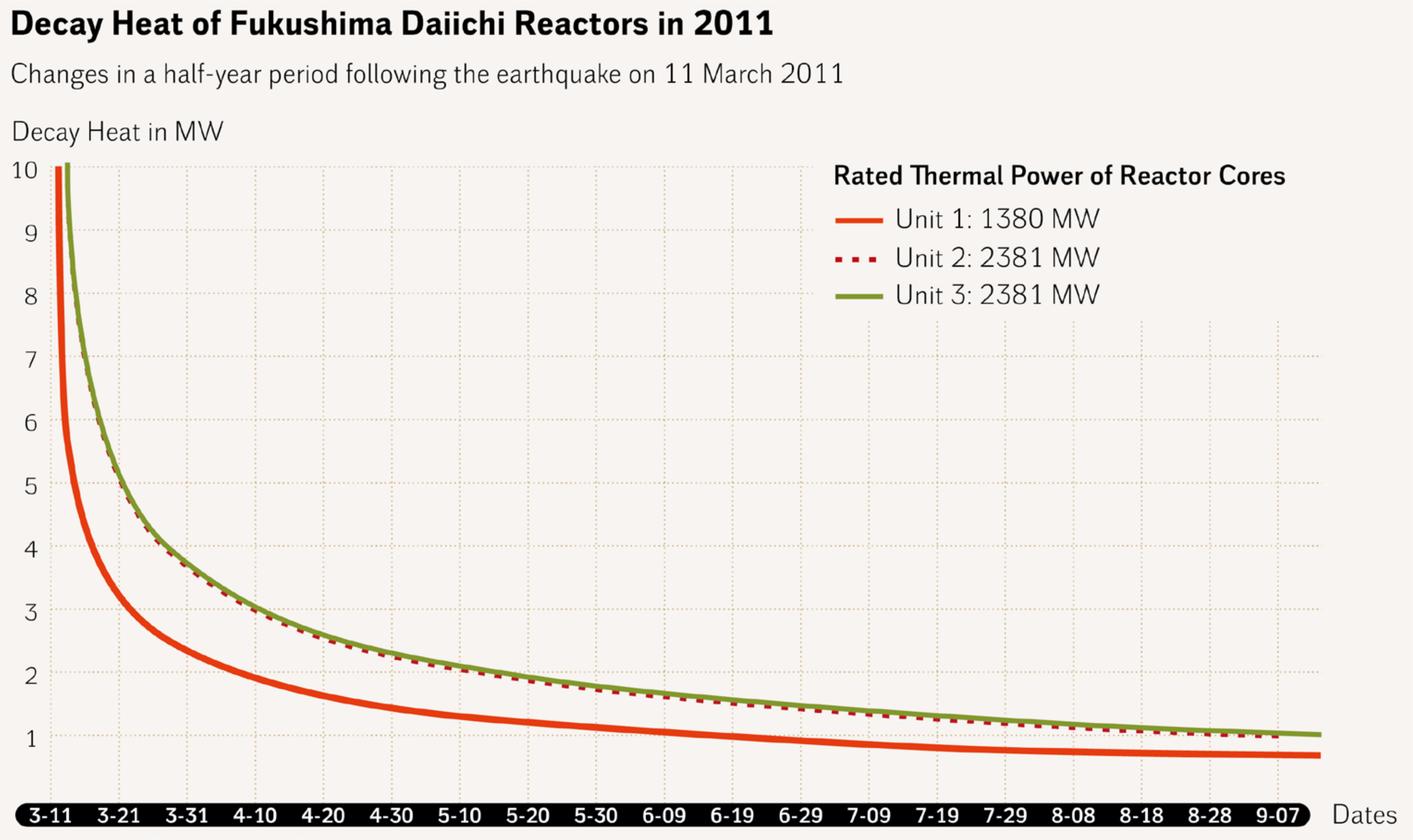
Michael Sailer is working as an Independent Consultant. He is Former Chairman of the Reactor Safety Commission (RSK) of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and Former CEO of Öko-Institut, Darmstadt, Germany.

Christoph Pistner is Head of the Division of Nuclear Engineering & Facility Safety of the Öko-Institut. He received his Ph.D. in Physics at the Darmstadt University of Technology (TUD). He is Vice Chairman of the RSK and of the Committee on Plant and Systems Engineering (AST) of the RSK. He is also member of the board of the Research Association for Science, Disarmament and International Security (FONAS).

NUCLEAR POWER AND WAR - INTRODUCTION

- International treaties: nuclear facilities should not be attacked in principle.
- Unprecedented, an operating nuclear power plant under attack by tank shelling and eventually being occupied by enemy forces.
- Limited literature addressing the effects of war on nuclear power plants and other nuclear facilities.
- Decay heat is the cause of melting of a reactor core.
- No fundamental difference whether the disruption of cooling is caused by an accidental event or by deliberate destruction.

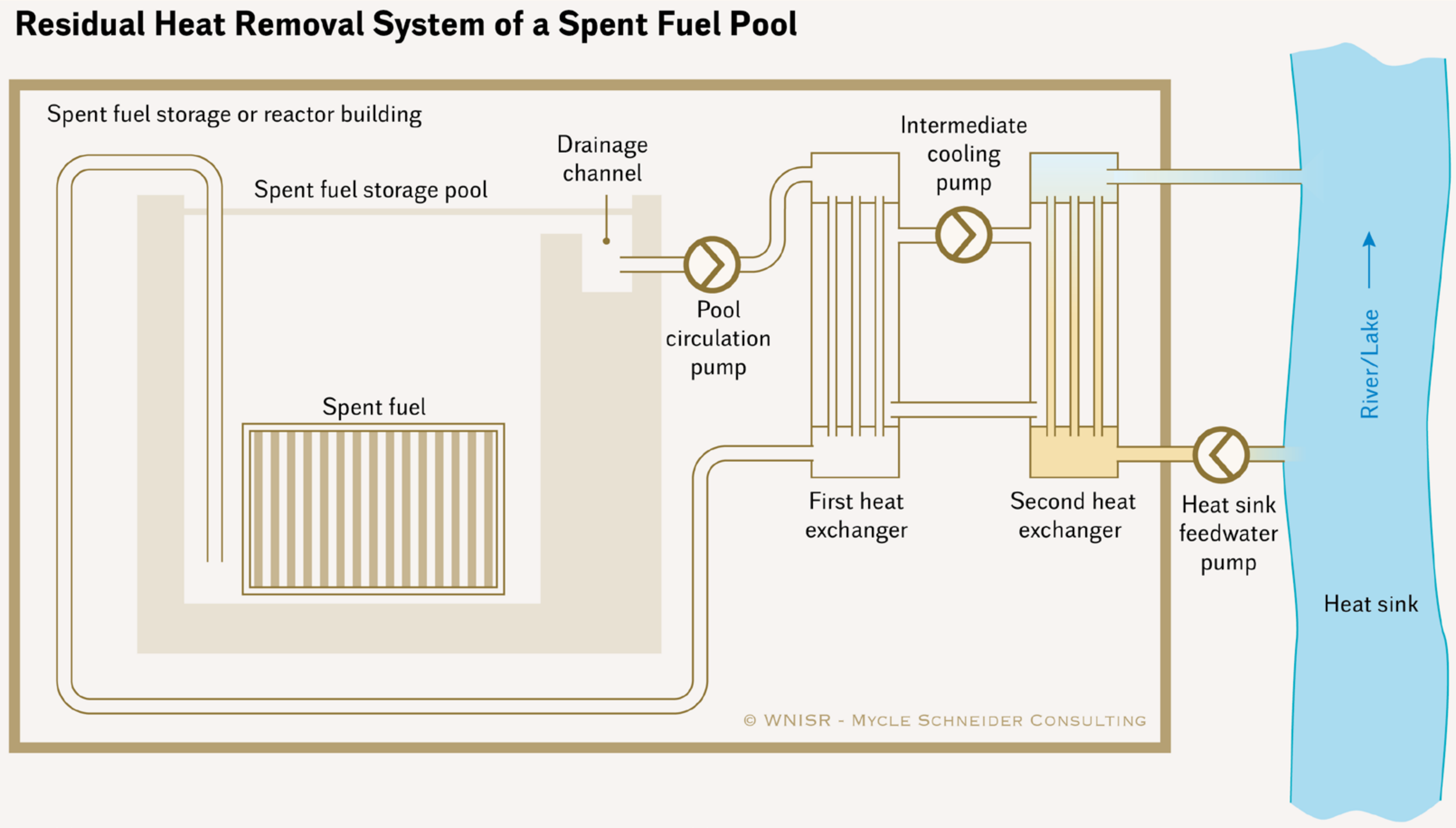
NUCLEAR POWER AND WAR — DECAY HEAT



NUCLEAR POWER AND WAR – CORE AND SPENT FUEL COOLING

- Nuclear power plants are complex industrial facilities. Their safe operation depends on a stable environment.
- Unlike most other types of power plants, the safety of a nuclear power plant depends on continuously functioning cooling systems.
- The decay heat generation cannot be stopped and therefore requires continuous cooling even after the reactor has been shut down.
- Colling is required for the reactor core as well as for spent fuel pools.
- Effective cooling chains must be available with the capacity to dissipate the entire residual heat generated.

NUCLEAR POWER AND WAR – COOLING CHAINS



NUCLEAR POWER AND WAR – VULNERABILITIES

- Nuclear power plants face several specific vulnerabilities:
  - Direct Destruction – Intentional or Unintentional
  - Power Supply
  - Cooling Water Supply
  - Infrastructure
  - Staff
  - Maintenance, Inspection
  - Emergency response
- These vulnerabilities are also addressed by the “seven indispensable pillars of nuclear safety and security” defined by the IAEA

NUCLEAR POWER AND WAR – PROTECTION

- The design of the reactor buildings varies greatly depending on national regulations and the type of reactor.
- Truly bunkered reactor buildings are found only at a few sites worldwide.
- Many safety systems are located outside the reactor building in other buildings (like command and control, power supply, and cooling chains).
- Some infrastructure impacting nuclear safety is located outside the power plant site, from overhead power lines to staff housing, communities in which staff and their families live, and suppliers of indispensable materials.

NUCLEAR POWER AND WAR – RELEASE MECHANISMS FOR REACTOR CORES

- In an **operating nuclear power plant**, residual heat generation is so high that the lack of removal leads directly to core meltdown.
- During core meltdown, hydrogen is formed, which can explode under appropriate conditions and can significantly damage the reactor building.
- The delay until the start of meltdown can range from significantly less than one hour to several hours.
- A core meltdown is also possible when the reactor is shut down. The delay between cooling failure and core meltdown increases.

NUCLEAR POWER AND WAR – RELEASE MECHANISMS SPENT FUEL POOLS

- When a **spent fuel storage pool** loses its cooling function, water heats up. Eventually, fuel elements stand partly or wholly uncovered.
- No longer immersed in water, fuel elements heat up, become increasingly leaky, may produce hydrogen, and can catch fire in air.
- The timescale of these processes ranges from days to many weeks.
- Time sequences accelerate significantly when war-induced destruction leads to unrepairable water escape from the pool.
- Radioactivity releases may vary widely, depending on the retention effect of building structures, the level of damage to the structures, and what mitigating measures are carried out in time.

NUCLEAR POWER AND WAR – CONCLUSIONS

- No nuclear power plant in the world has been designed to operate under wartime conditions.
- The key challenge is to always maintain continuous cooling of the reactor core and the spent fuel pool, even after the shutdown of the reactor.
- The operation of a nuclear facility requires the availability of motivated, rested, skilled staff that are likely under severe stress in a war situation or under military occupation.
- Personnel from outside, required for the supply of spare parts, specialist interventions, maintenance operations and repairs, might not be willing to enter a war zone or get permission or access to the facility.

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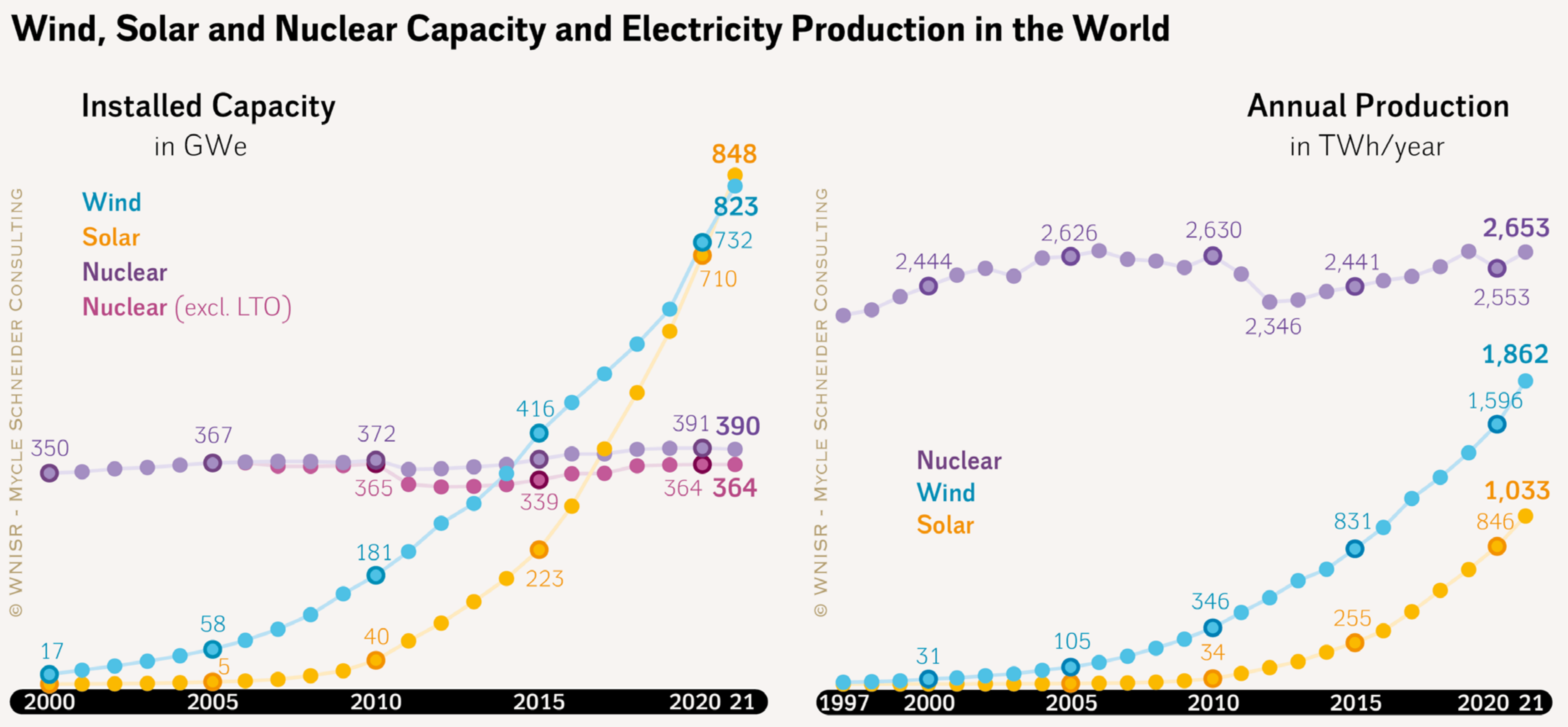
Antony Froggatt joined Chatham House in 2007 and is Deputy Director and a Senior Research Fellow in the Energy, Environment and Resources Department. He has worked as an independent consultant for 20 years with environmental groups, academics and public bodies in Europe and Asia. His most recent research projects are understanding the energy and climate policy implications of Brexit, climate risk (particularly in China), and the technological and policy transformation of the energy sector. Since 1992 he has been the co-lead author of the World Nuclear Industry Status Report, a now annual independent review of the nuclear sector.

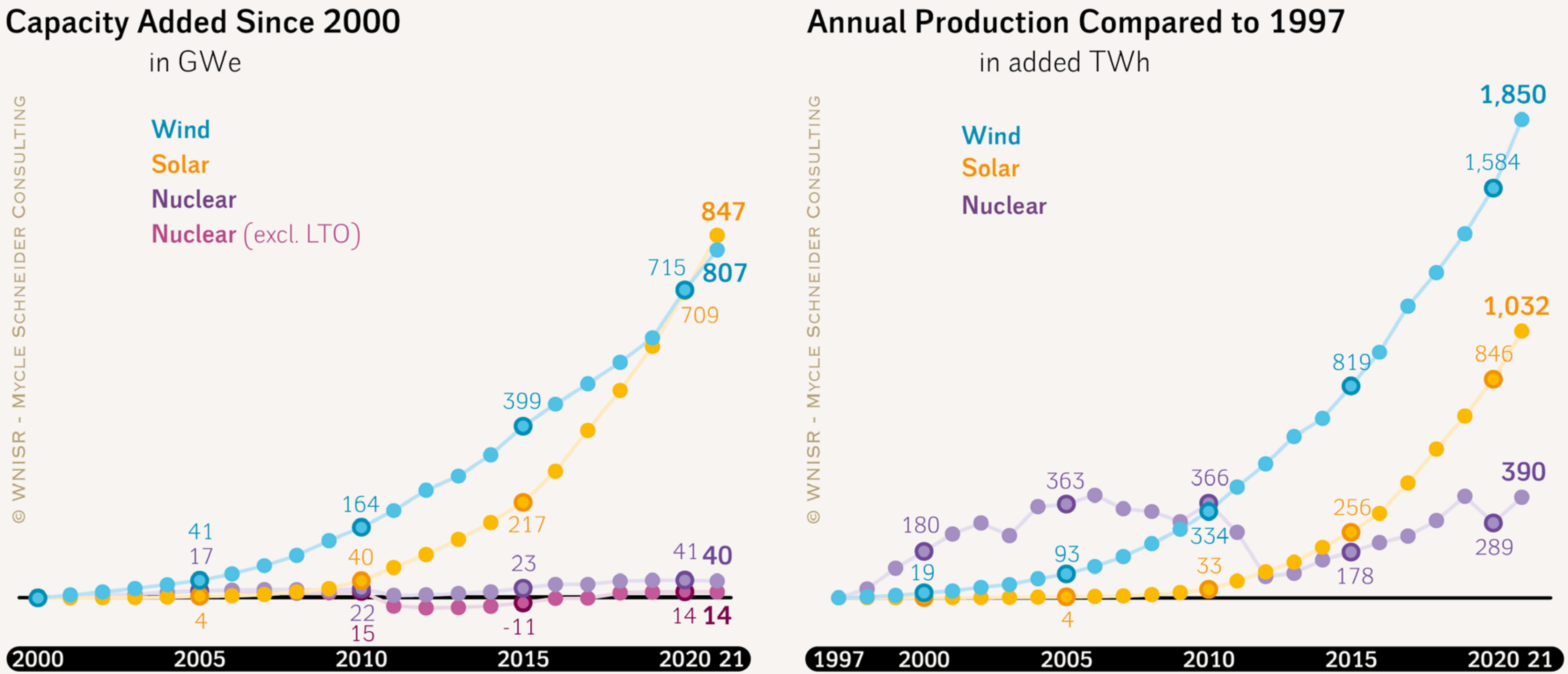
NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

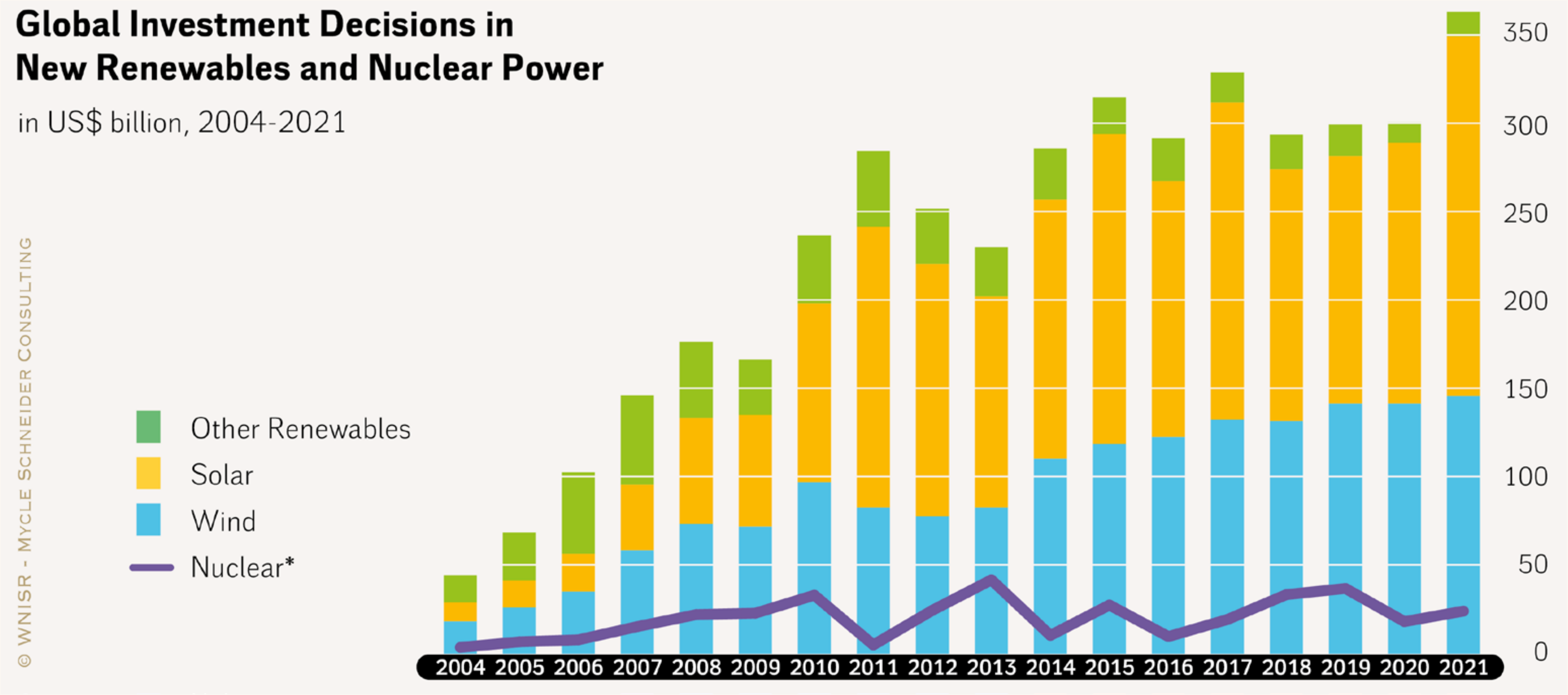
NUCLEAR POWER VS. RENEWABLES DEPLOYMENT

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



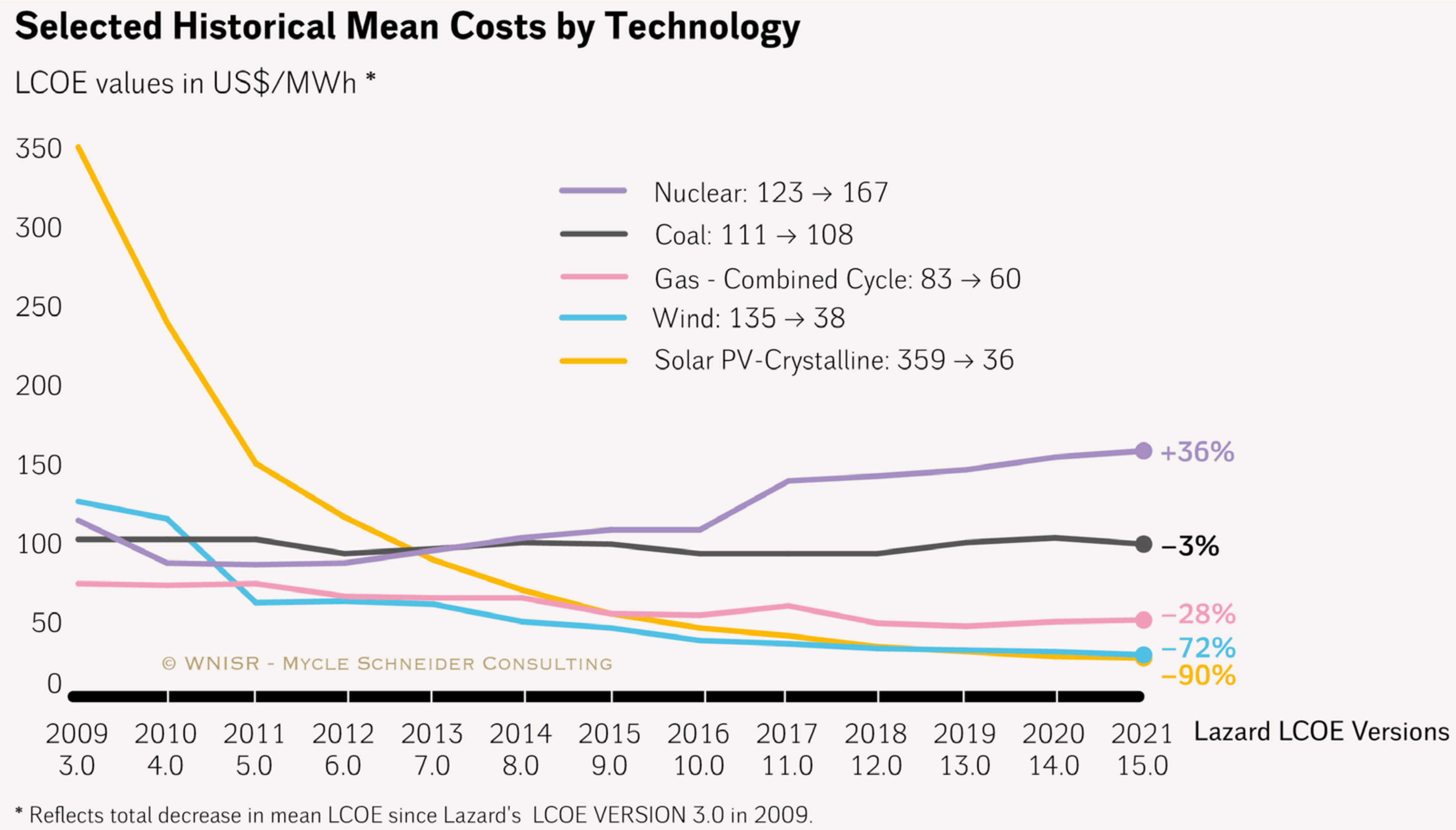
Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – INVESTMENT DECISIONS



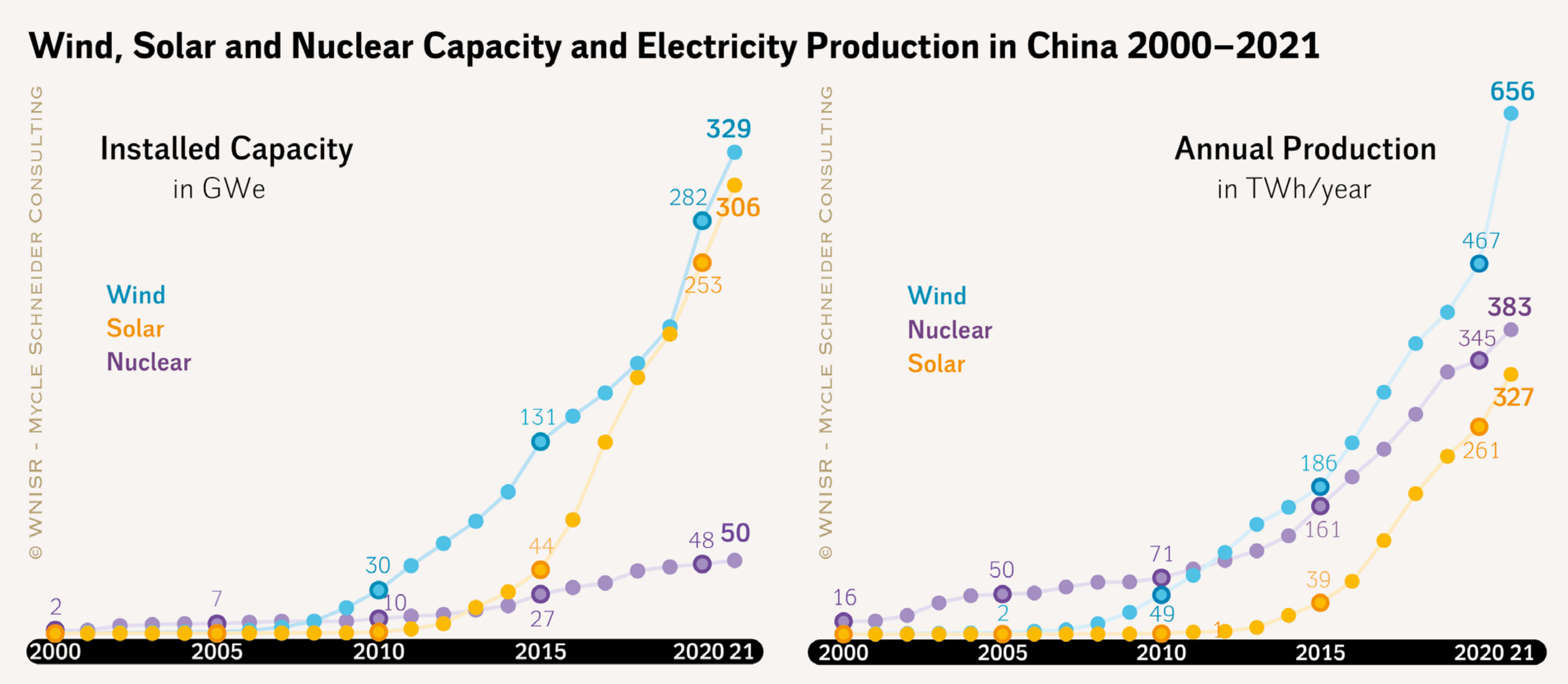
Sources: REN21 and WNISR Original Research, 2022

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – GENERATION COSTS 1



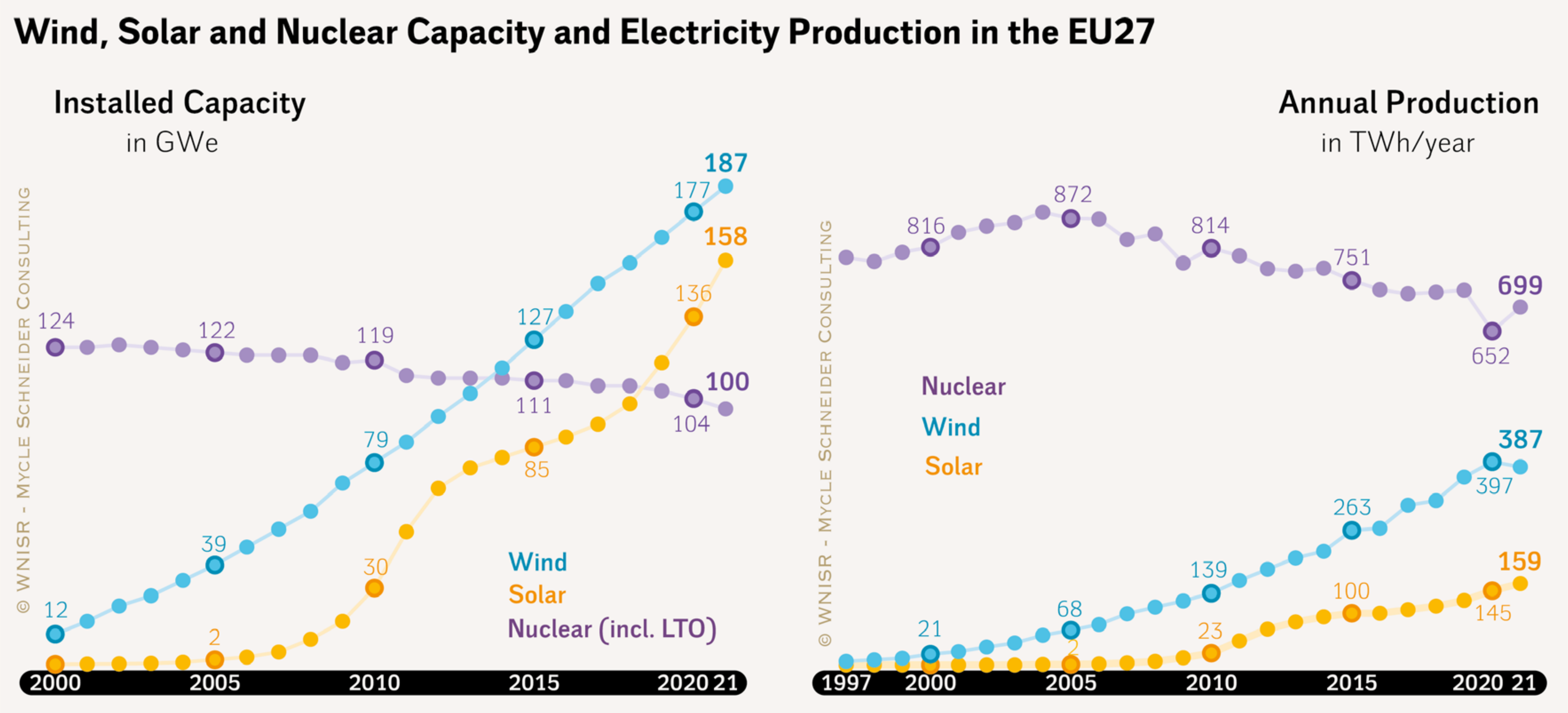
Source: Lazard Estimates, 2021

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



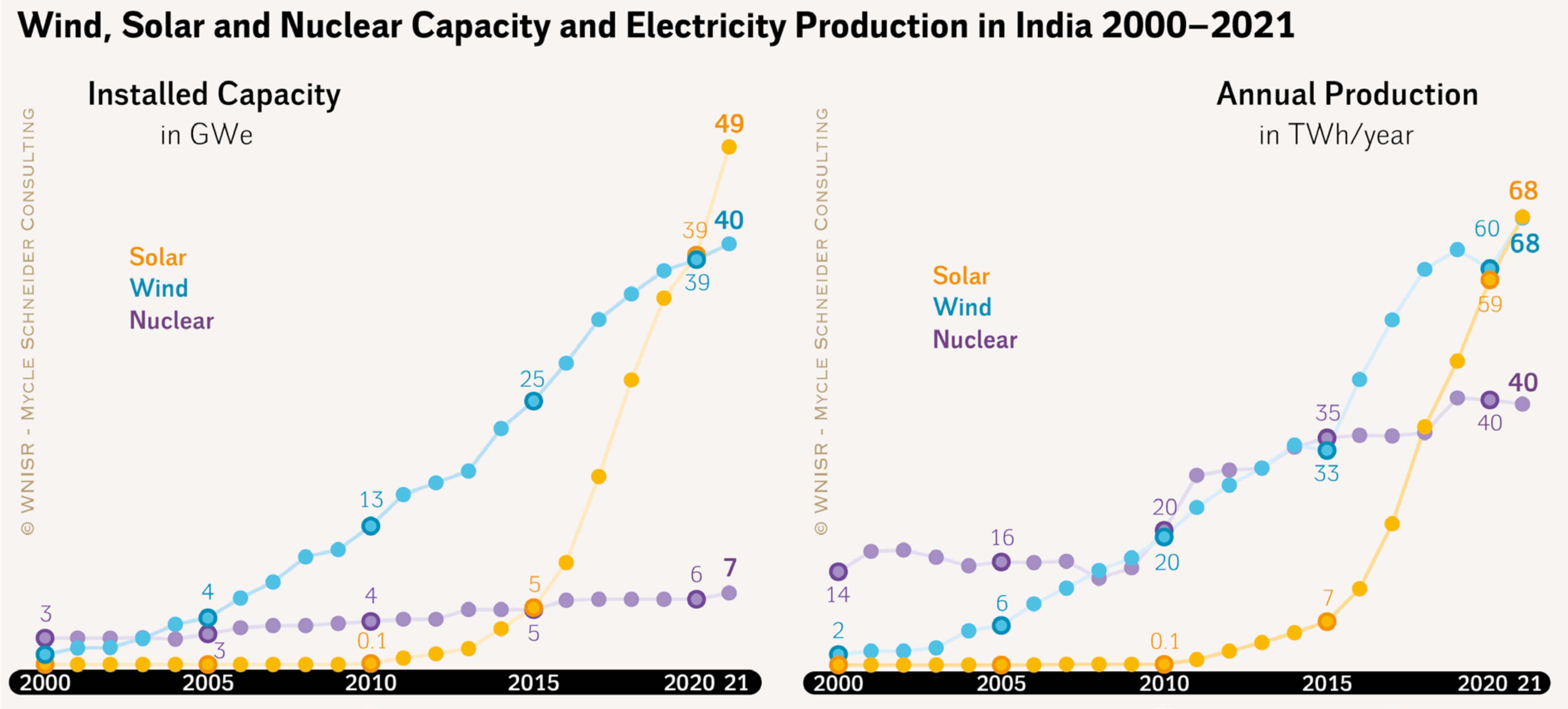
Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



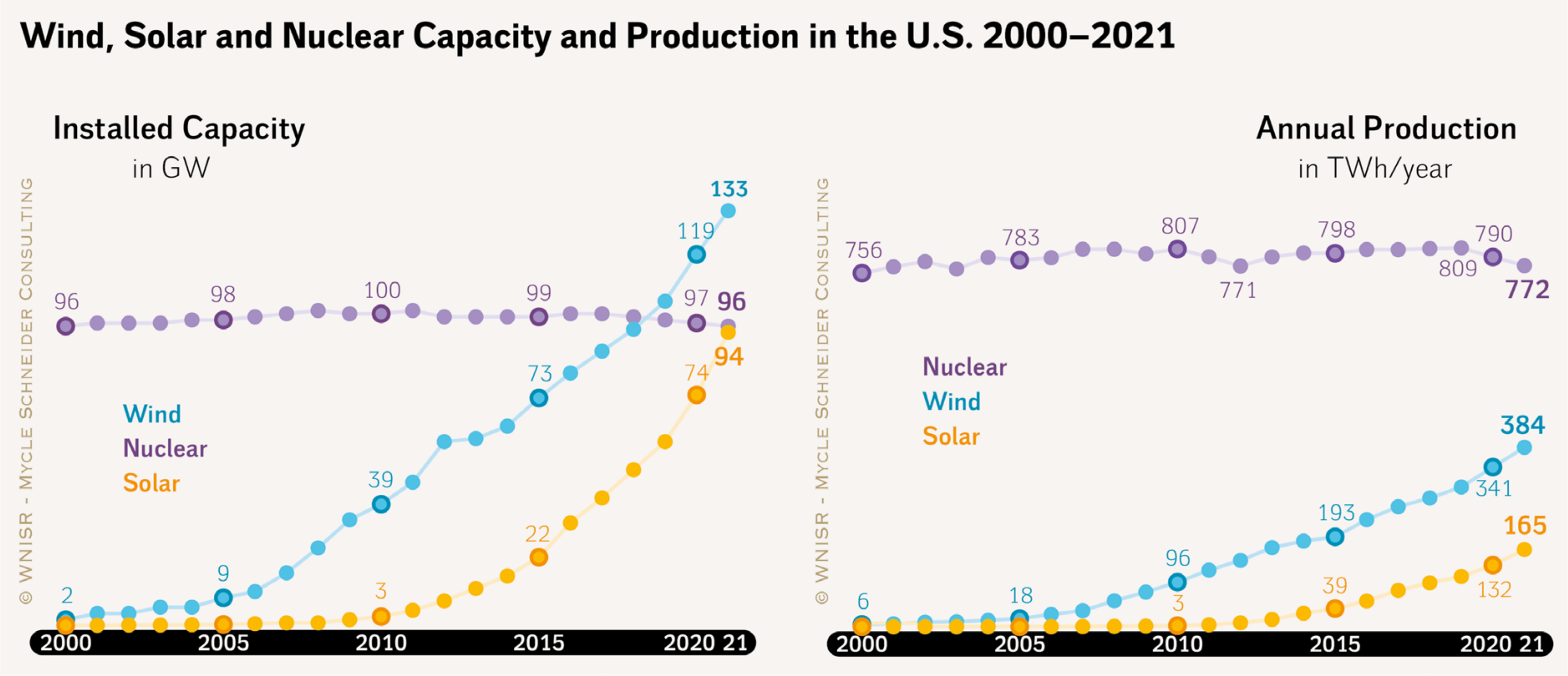
Sources: WNISR with IAEA-PRIS, IRENA, Ember, 2022

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – INDIA



Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – USA

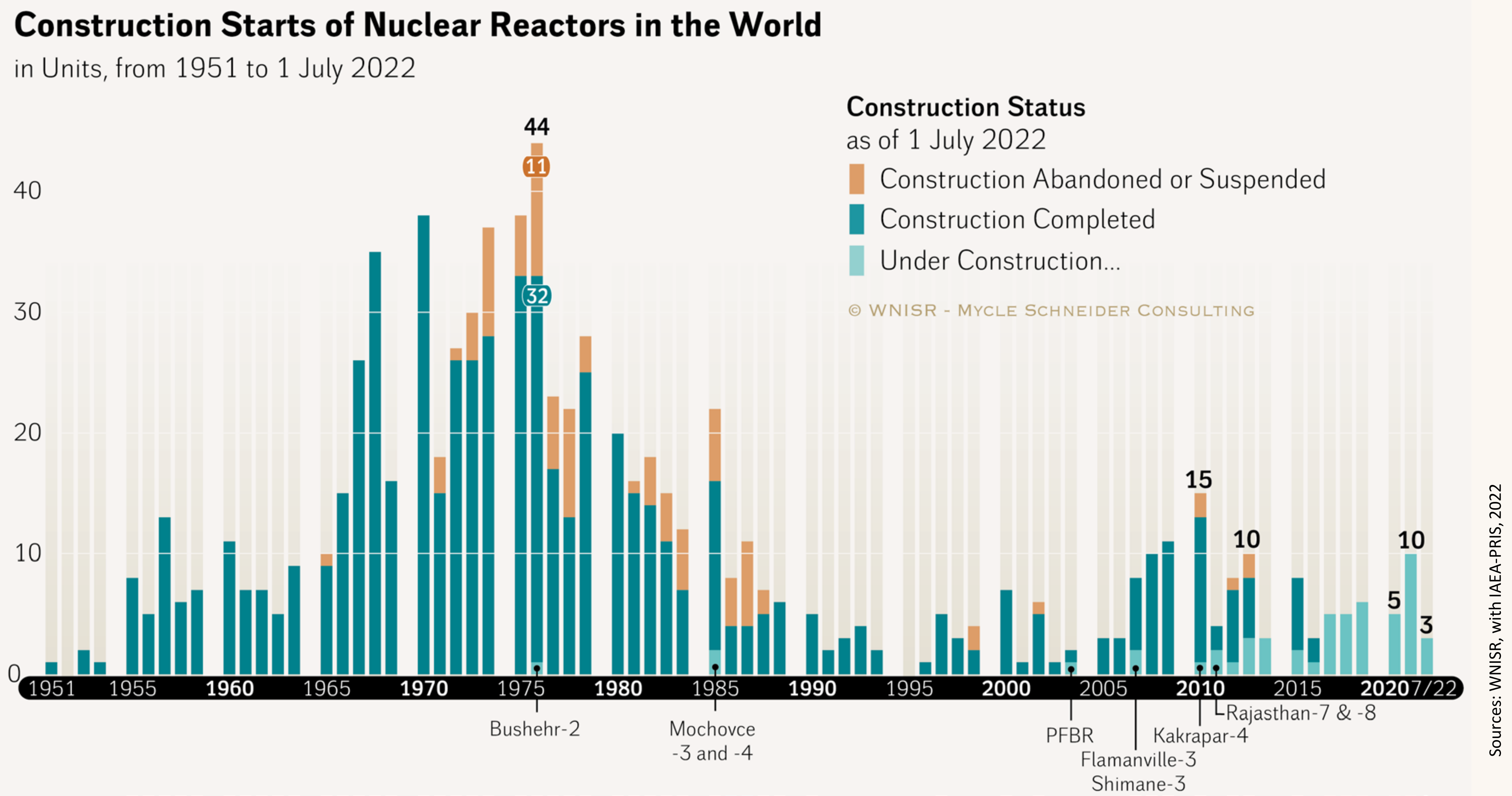


Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

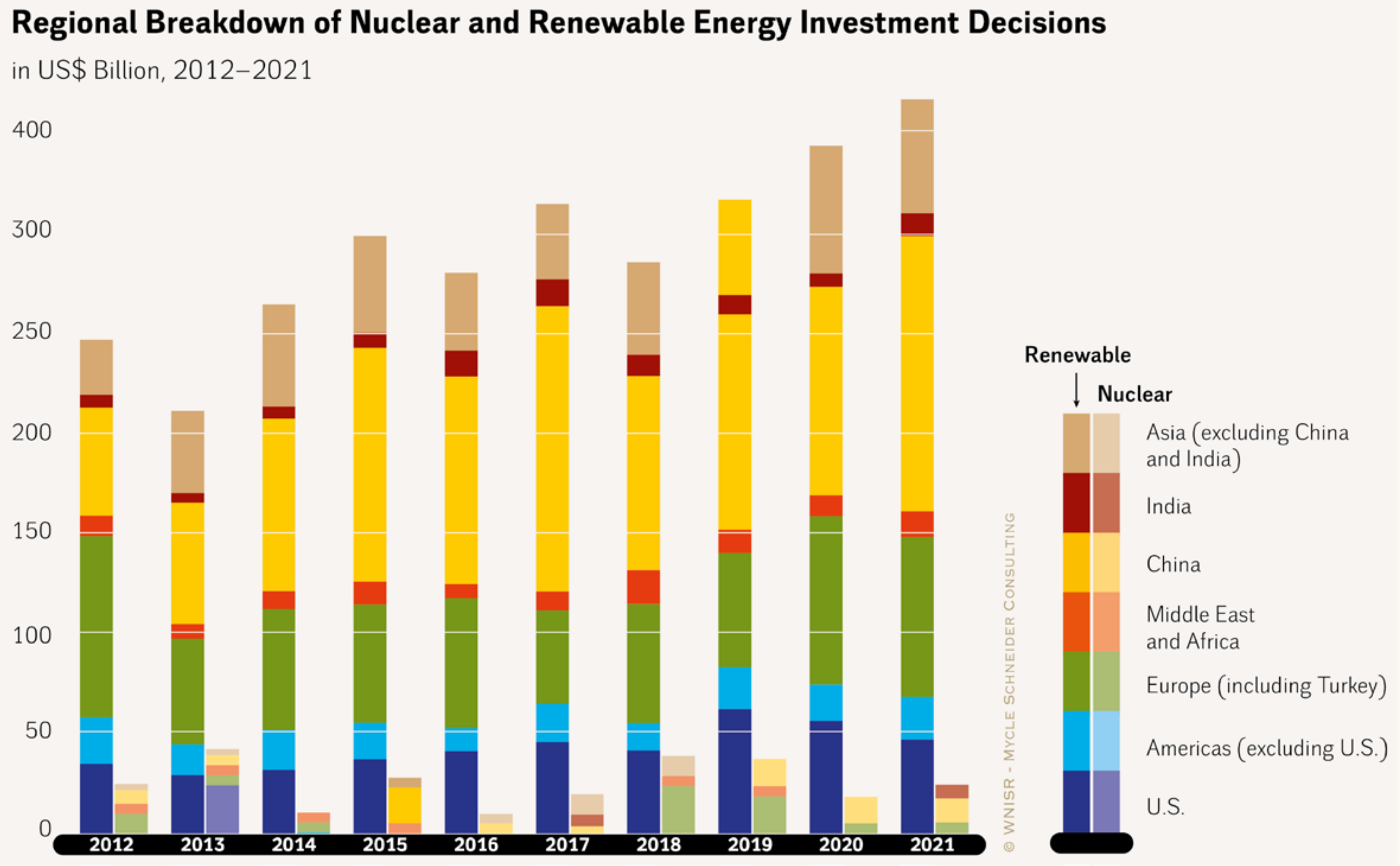
CONCLUSIONS

- For the first time in four decades, the share of nuclear power in commercial electricity dropped below 10 percent while combined solar and wind generated more than 10 percent, thus for the first time ever exceeded nuclear power.
- Five EU countries operate Russian designed reactors and are heavily dependent on Russian manufactured nuclear fuel assemblies incl. Bulgaria, Czech Republic, Finland, Hungary, Slovakia.
- Nuclear newbuild is mainly driven by China domestically and Russia abroad (as of mid-2022):
  - China is building 21 units at home but none abroad.
  - 20 units of Russian design are being built, 3 at home and 17 in seven foreign countries, incl. in Bangladesh, Belarus, China, India, Iran, Slovakia, and Turkey.
- The Russian dominance of the international suppliers market—there is no buyers market—raises the question of international governance, as Russia is also a key player in the International Atomic Energy Agency (IAEA).

GENERAL OVERVIEW — CONSTRUCTION STARTS WORLD



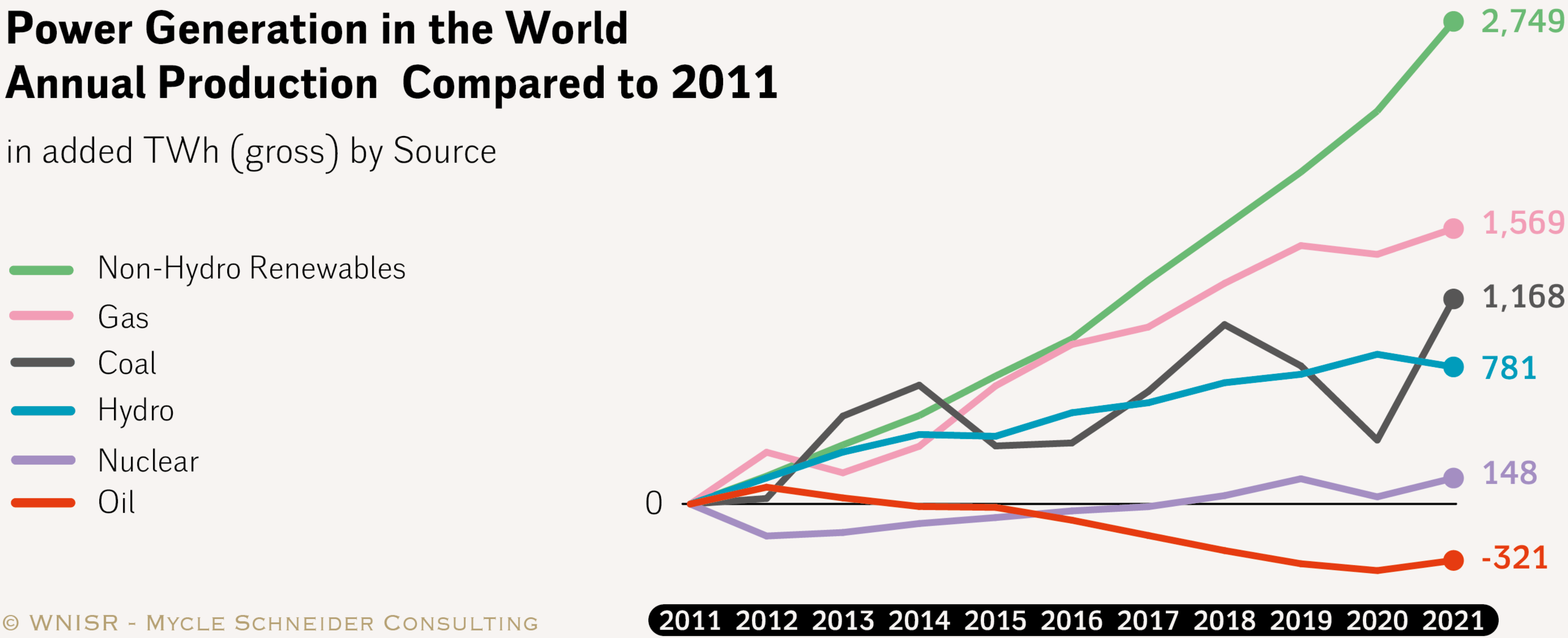
NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: BNEF/UNEP and WNISR Original Analysis, 2022

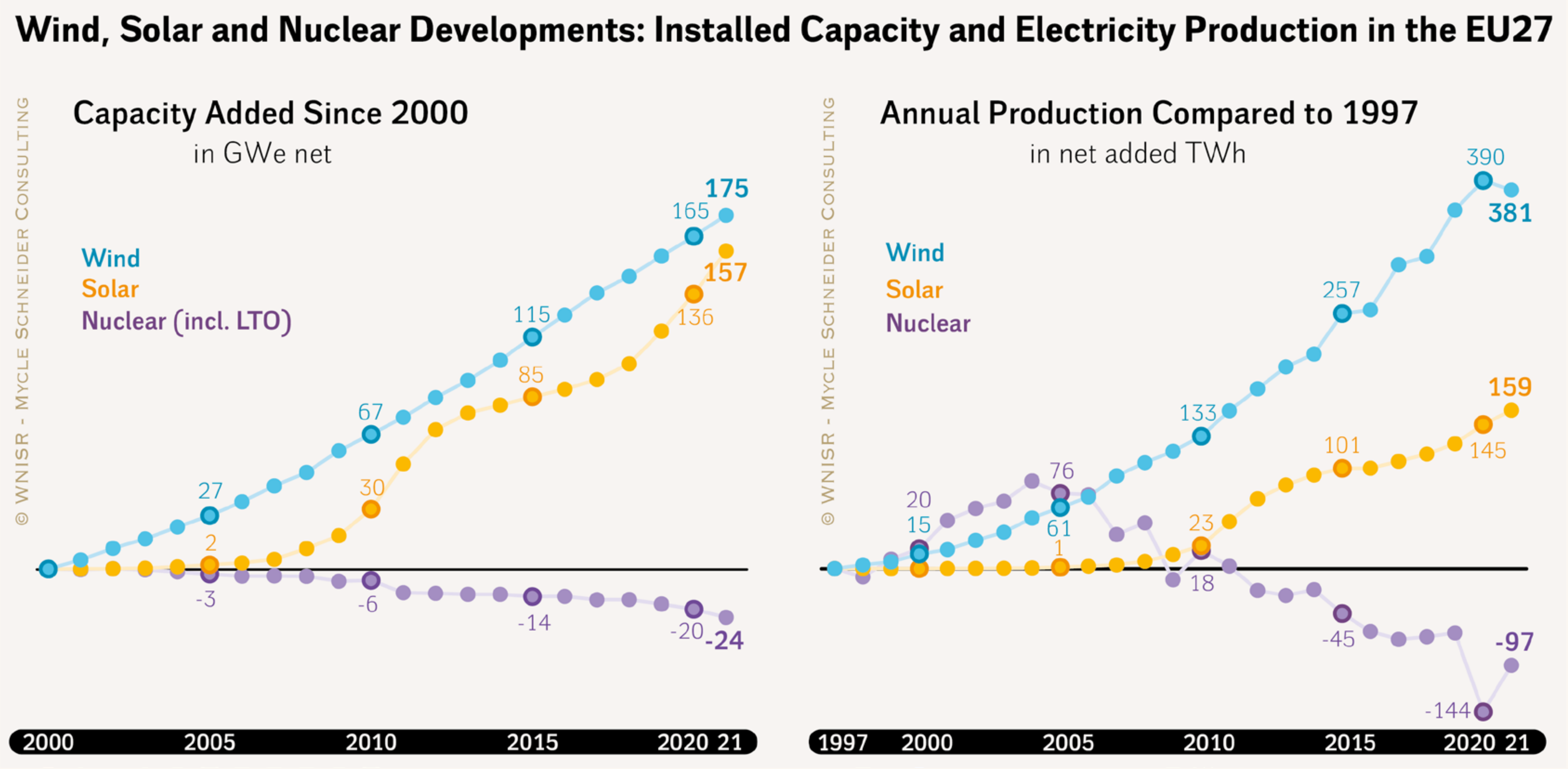
Power Generation in the World
Annual Production Compared to 2011

in added TWh (gross) by Source



Sources: BP Statistical Review, 2022

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT



Sources: WNISR with IAEA-PRIS, IRENA, Ember, 2022