Global Launch Event

The World Nuclear Industry Status Report 2023

(WNISR2023)

www.WorldNuclearReport.org

Co-hosted by

German Federal Office for the Safety of Nuclear Waste Management (BASE), Friedrich Ebert Stiftung, and Heinrich Böll Stiftung

Brussels (Belgium), Syracuse (U.S.), Johannesburg (South Africa), Nagasaki (Japan), Cambridge (U.S.), Vancouver (Canada)
6 December 2023

International, Interdisciplinary Team for a Multi-Indicator Analysis

A Mycle Schneider Consulting Project
Paris, December 2023

The World Nuclear Industry
Status Report 2023

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Former Editor, *Nuclear Intelligence Weekly*

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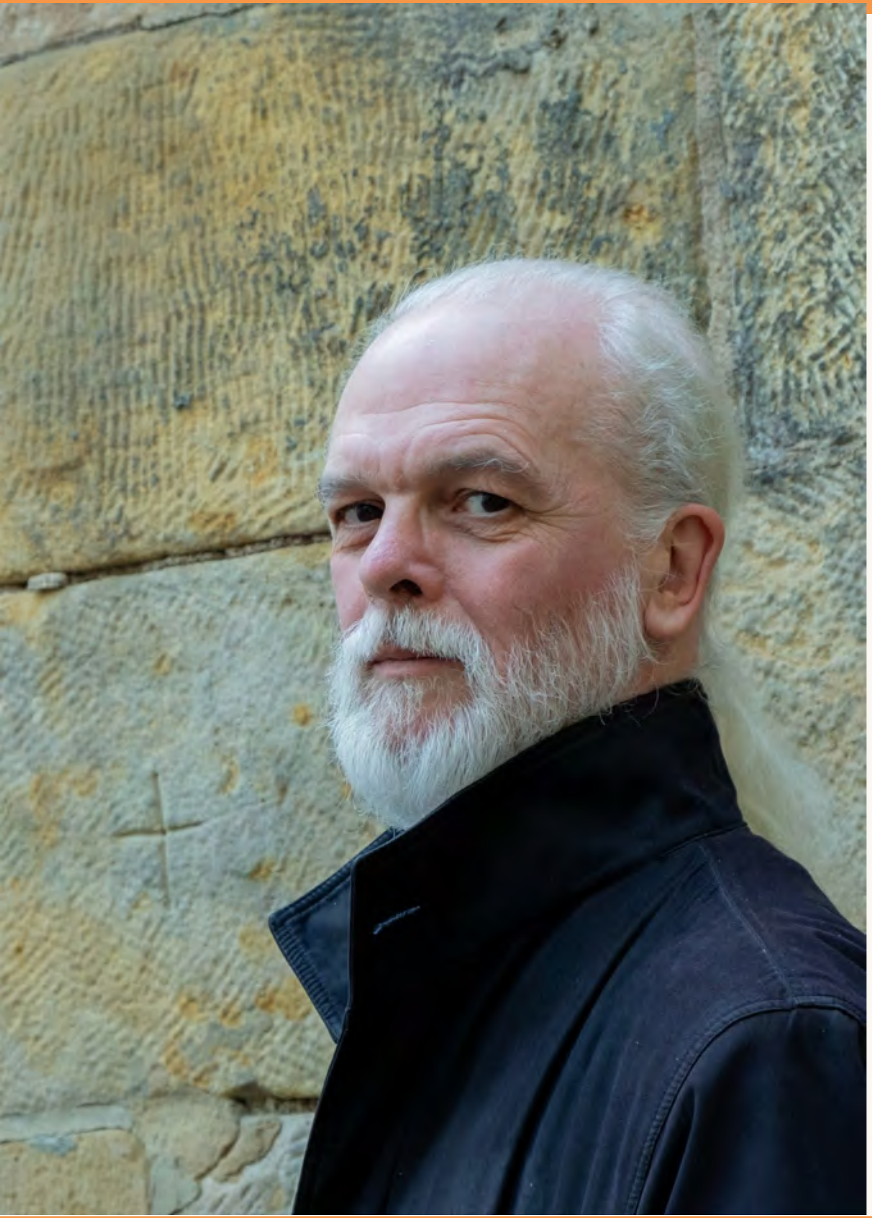


Mycle Schneider works as independent international consultant on energy and nuclear policy. He is the initiator, coordinator and publisher of the World Nuclear Industry Status Reports. He is a Founding Board Member and the Spokesperson for the International Energy Advisory Council (IEAC). He is a Founding Member of the International Nuclear Risk Assessment Group (INRAG) and a member of the International Nuclear Security Forum (INSF), based at the Stimson Center, USA. He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, USA.

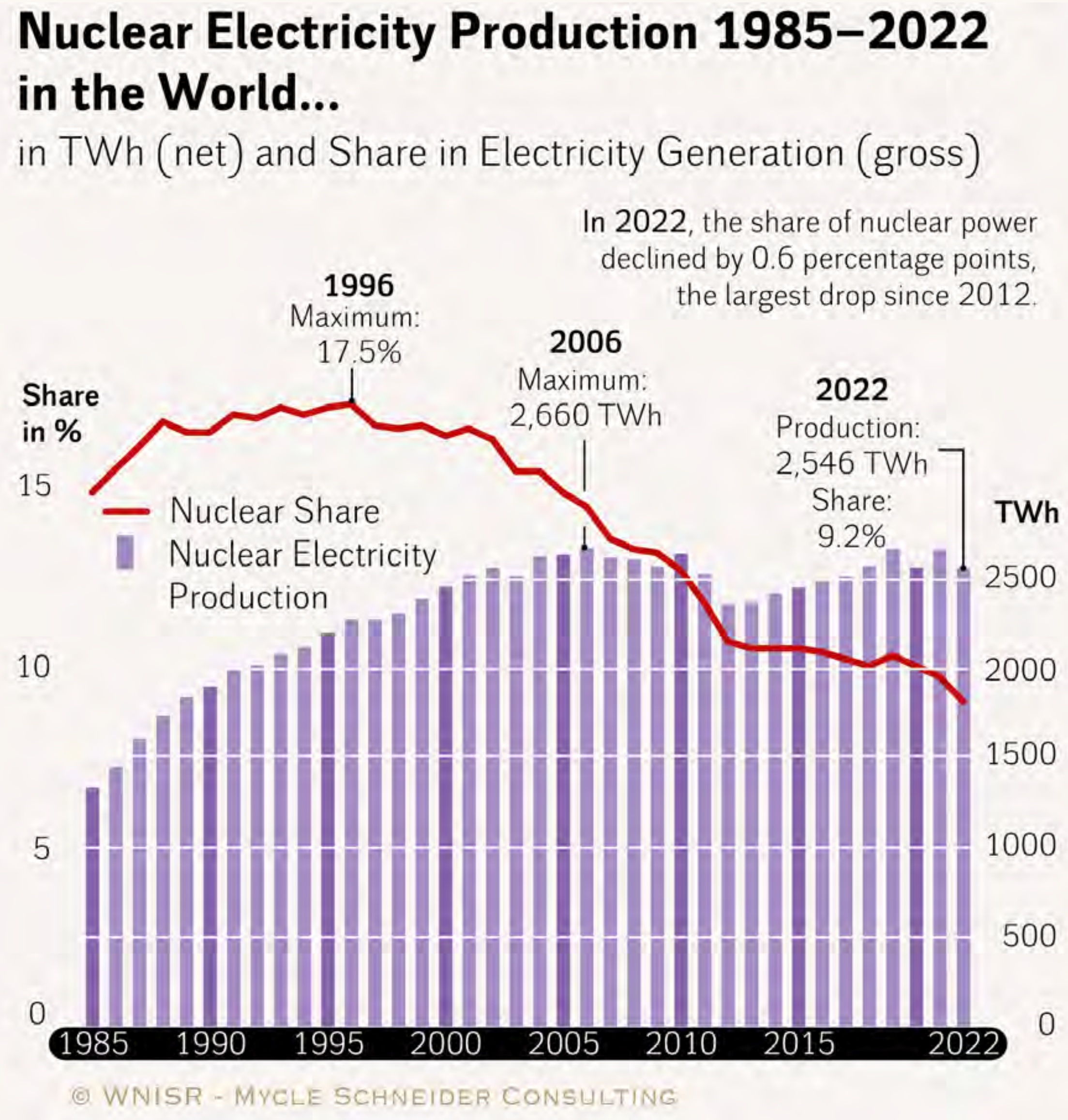
Between 2004 and 2009, he has been in charge of the Environment and Energy Strategies Lecture of the International Master of Science for Project Management for Environmental and Energy Engineering at the *Ecole des Mines* in Nantes, France.

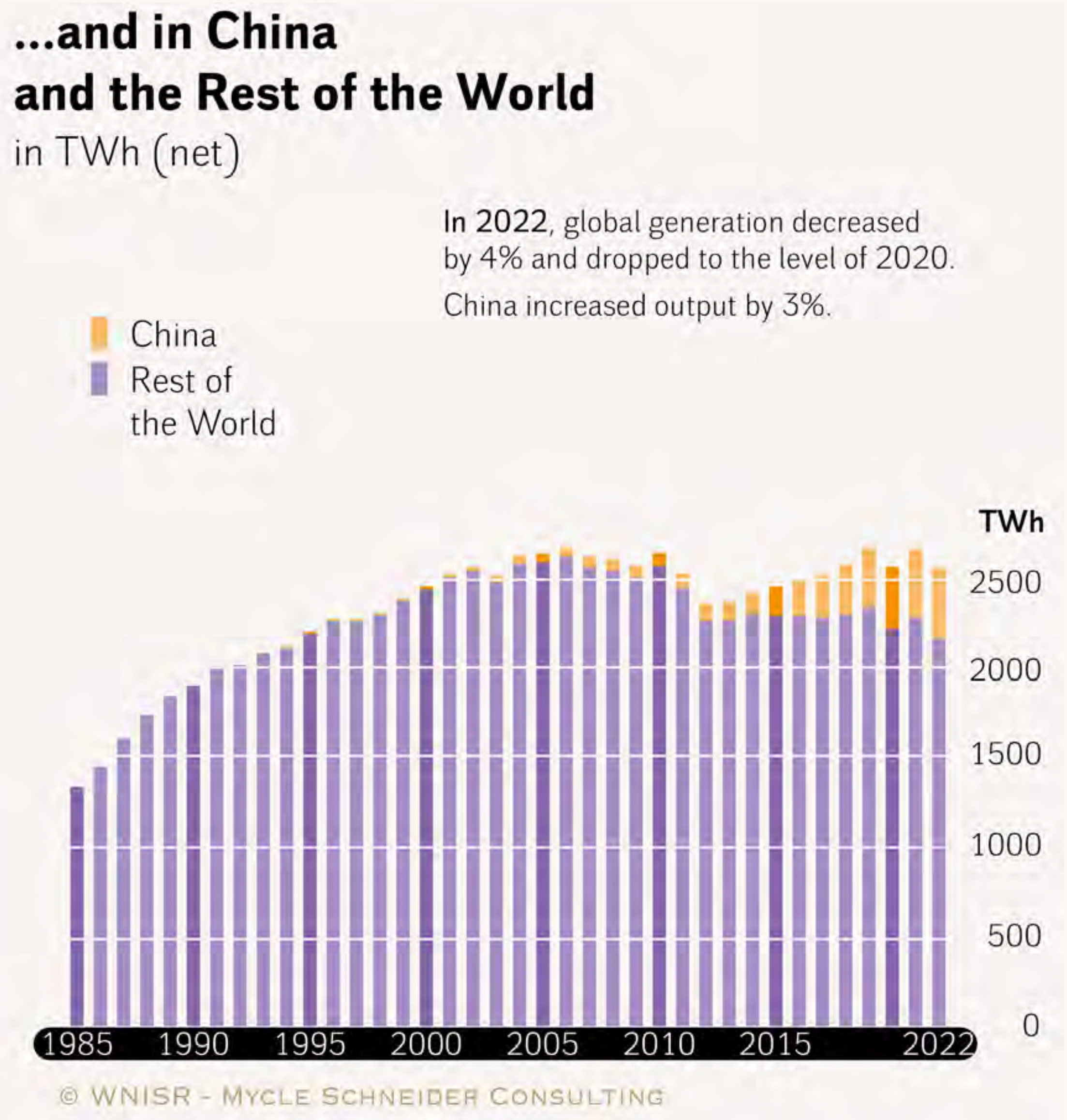
From 2000 to 2010, he was an occasional advisor to the German Environment Ministry. 1998–2003, he was an advisor to the French Environment Minister's Office and to the Belgian Minister for Energy and Sustainable Development.

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.

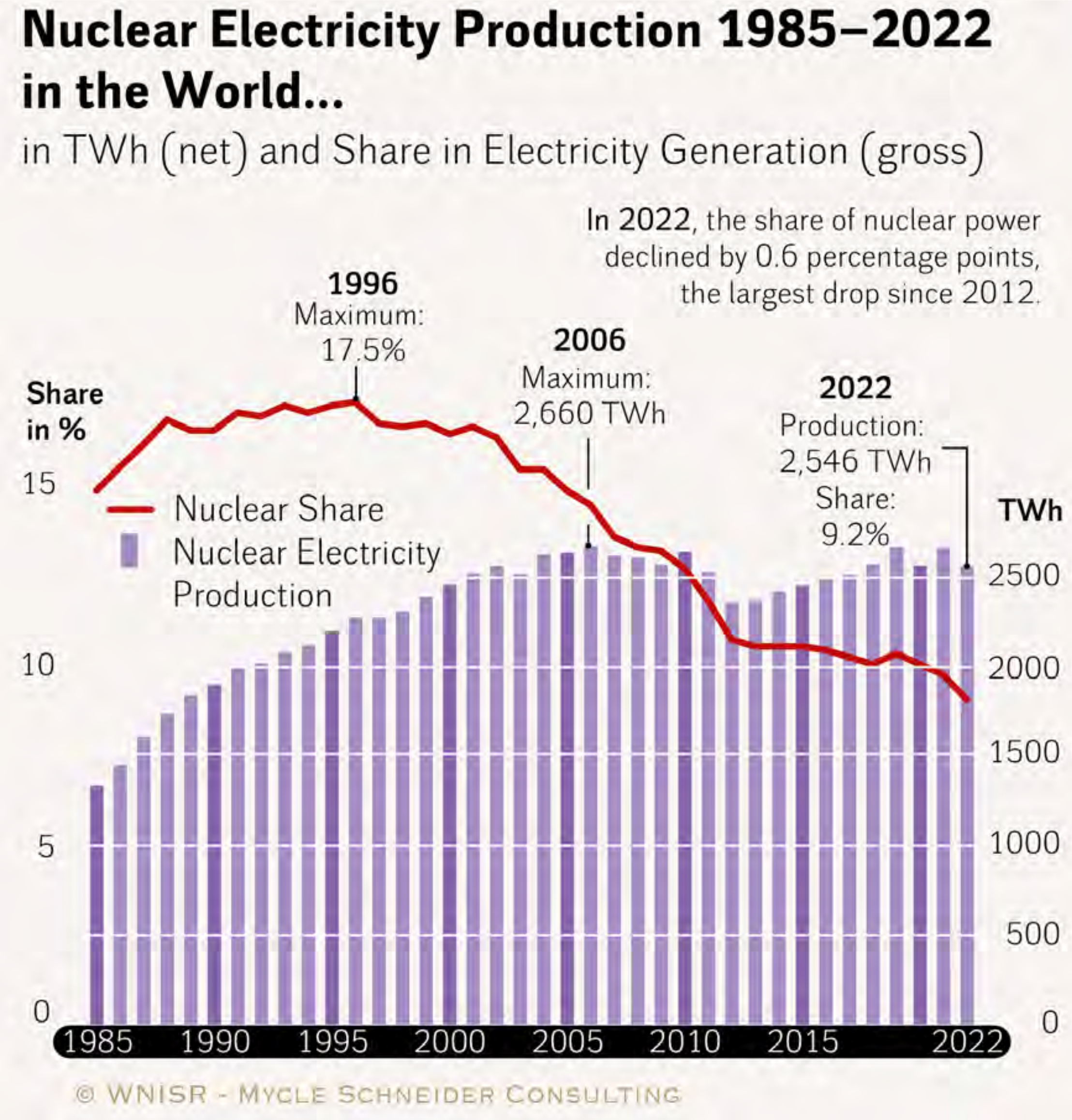
GLOBAL OVERVIEW – Role of Nuclear Power

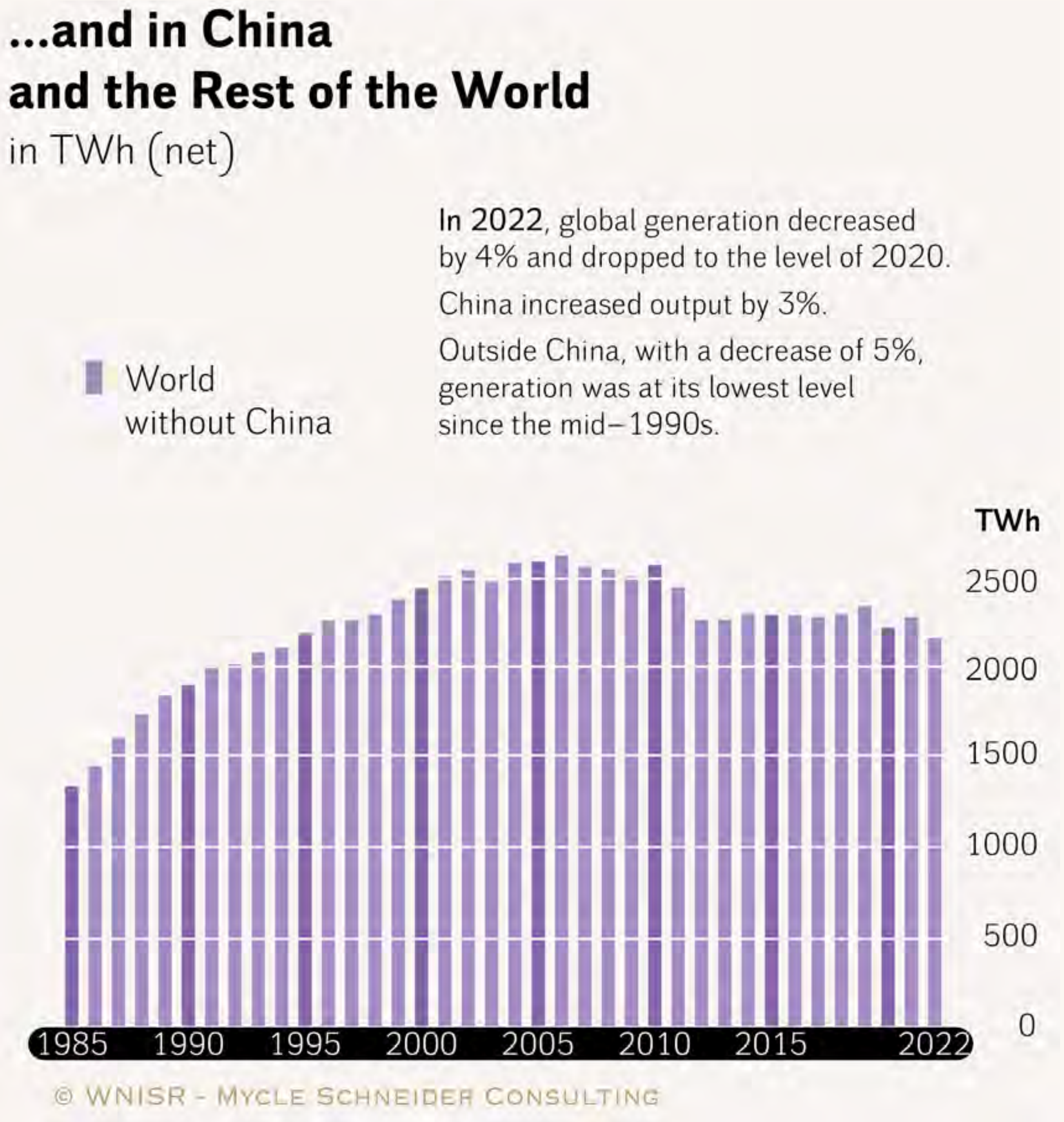




Sources: IAEA & Energy Institute, 2023

GLOBAL OVERVIEW – Role of Nuclear Power



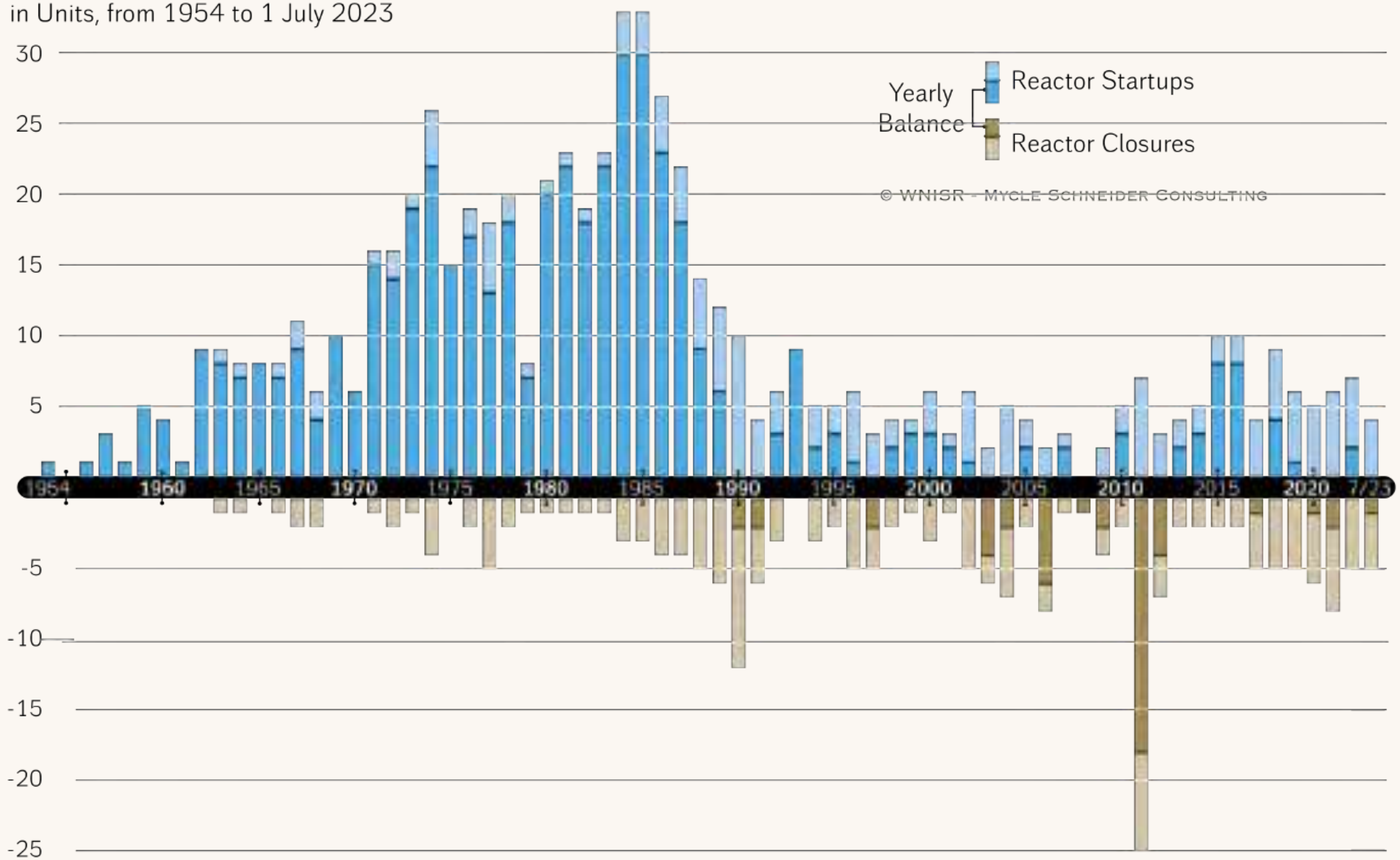


Sources: IAEA & Energy Institute, 2023

GLOBAL OVERVIEW – Startups and Closures World

Reactor Startups and Closures in the World

in Units, from 1954 to 1 July 2023



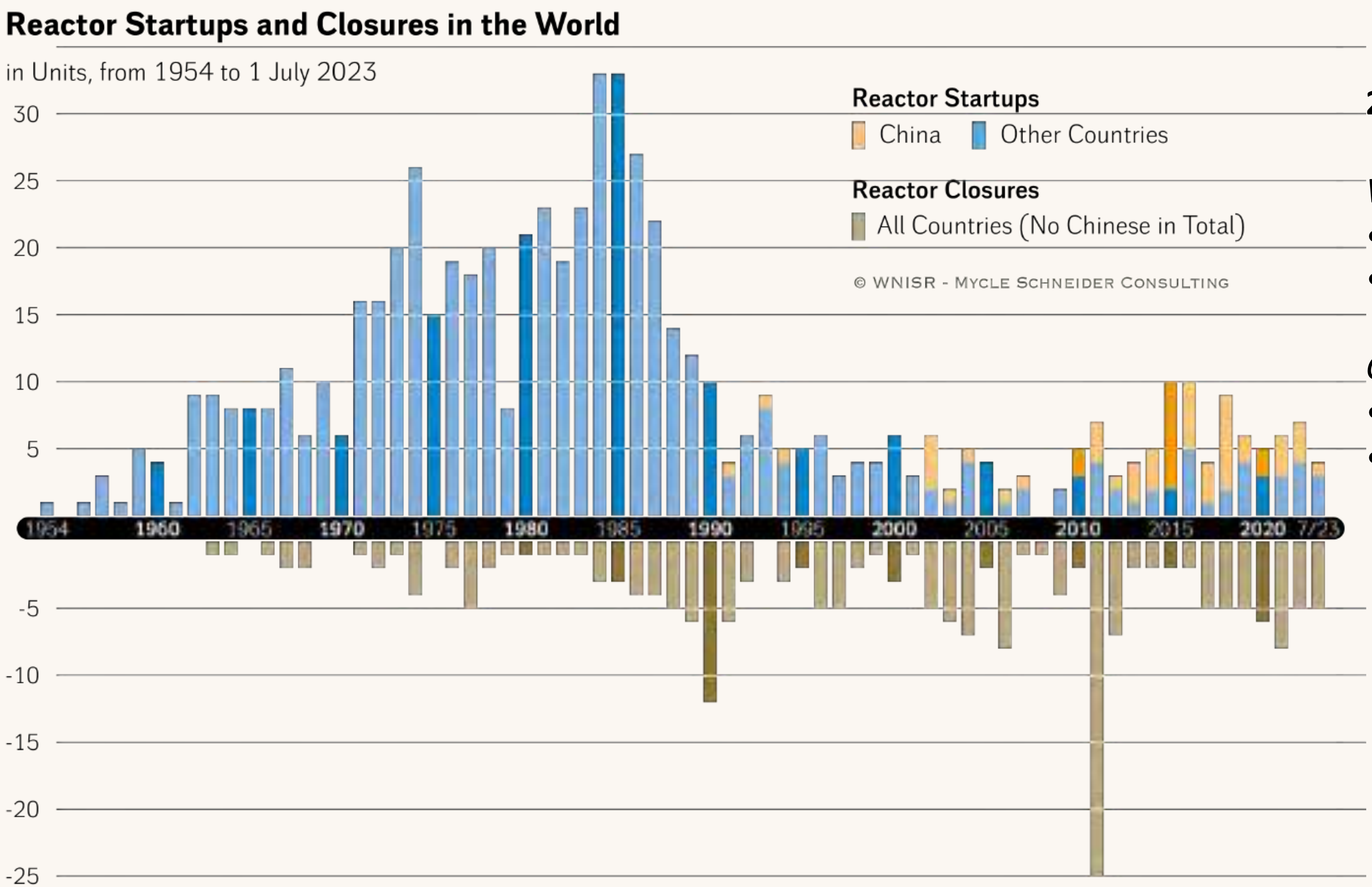
Sources: WNISR and IAEA-PRIS, 2023

2003–mid 2023

World

- 103 Startups
- 110 Closures

GLOBAL OVERVIEW – Startups and Closures World and China



Sources: WNISR and IAEA-PRIS, 2023

2003–mid 2023

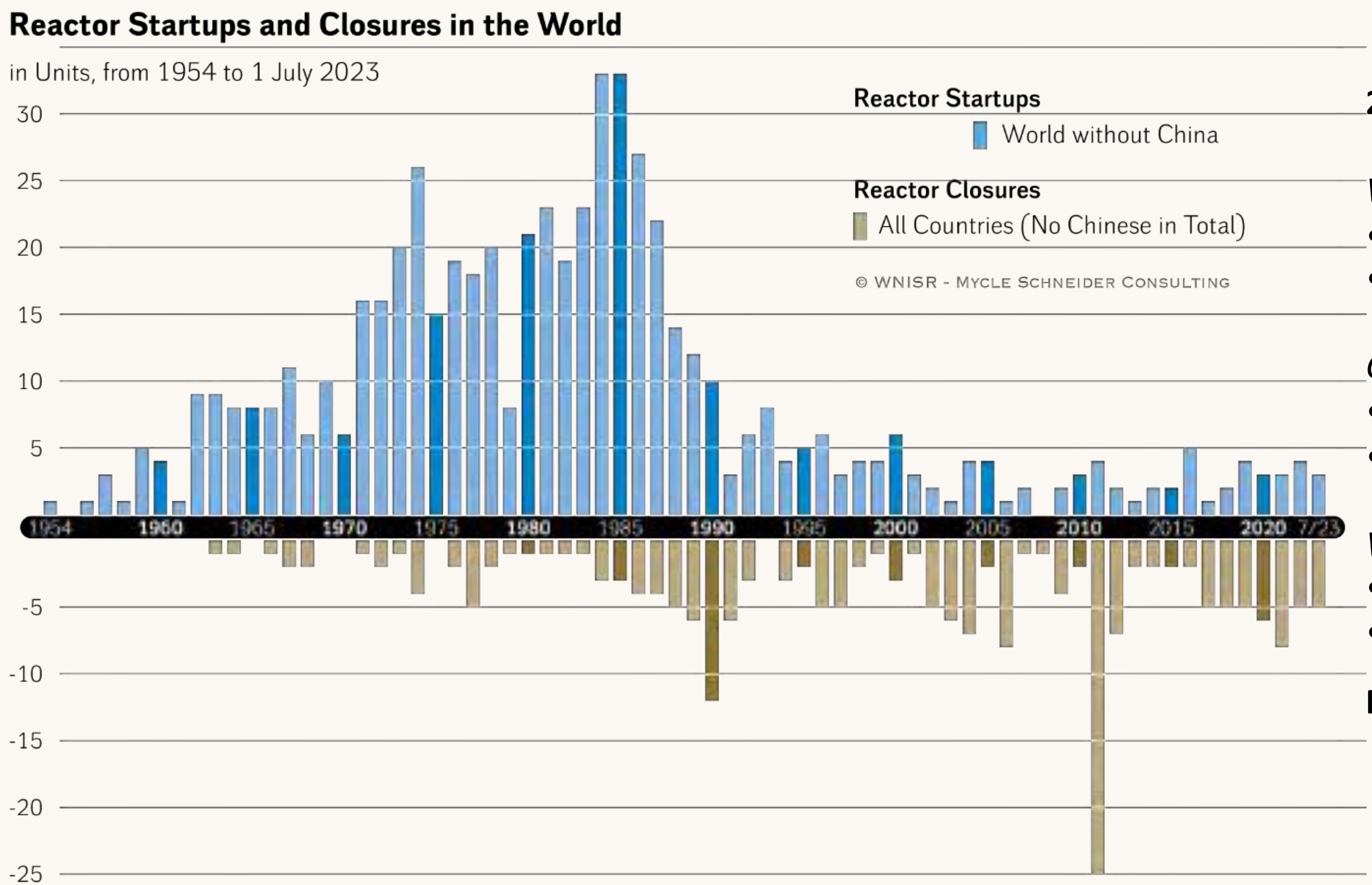
World

- 103 Startups
- 110 Closures

China

- 50 Startups
- No Closure

GLOBAL OVERVIEW – Startups and Closures World Without China



Sources: WNISR and IAEA-PRIS, 2023

2003–mid 2023

World

- 103 Startups
- 110 Closures

China

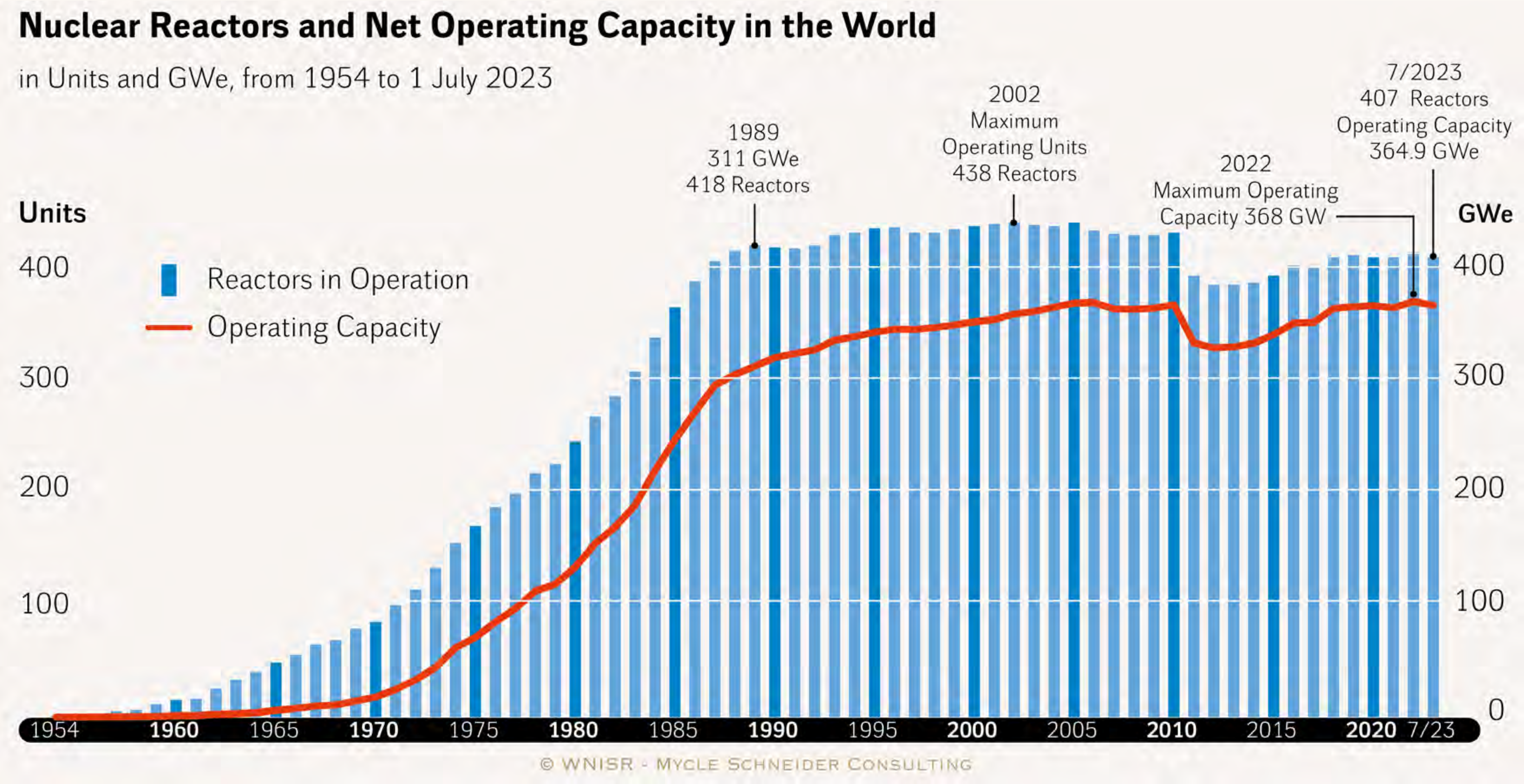
- 50 Startups
- No Closure

World Outside China

- 53 Startups
- 110 Closures

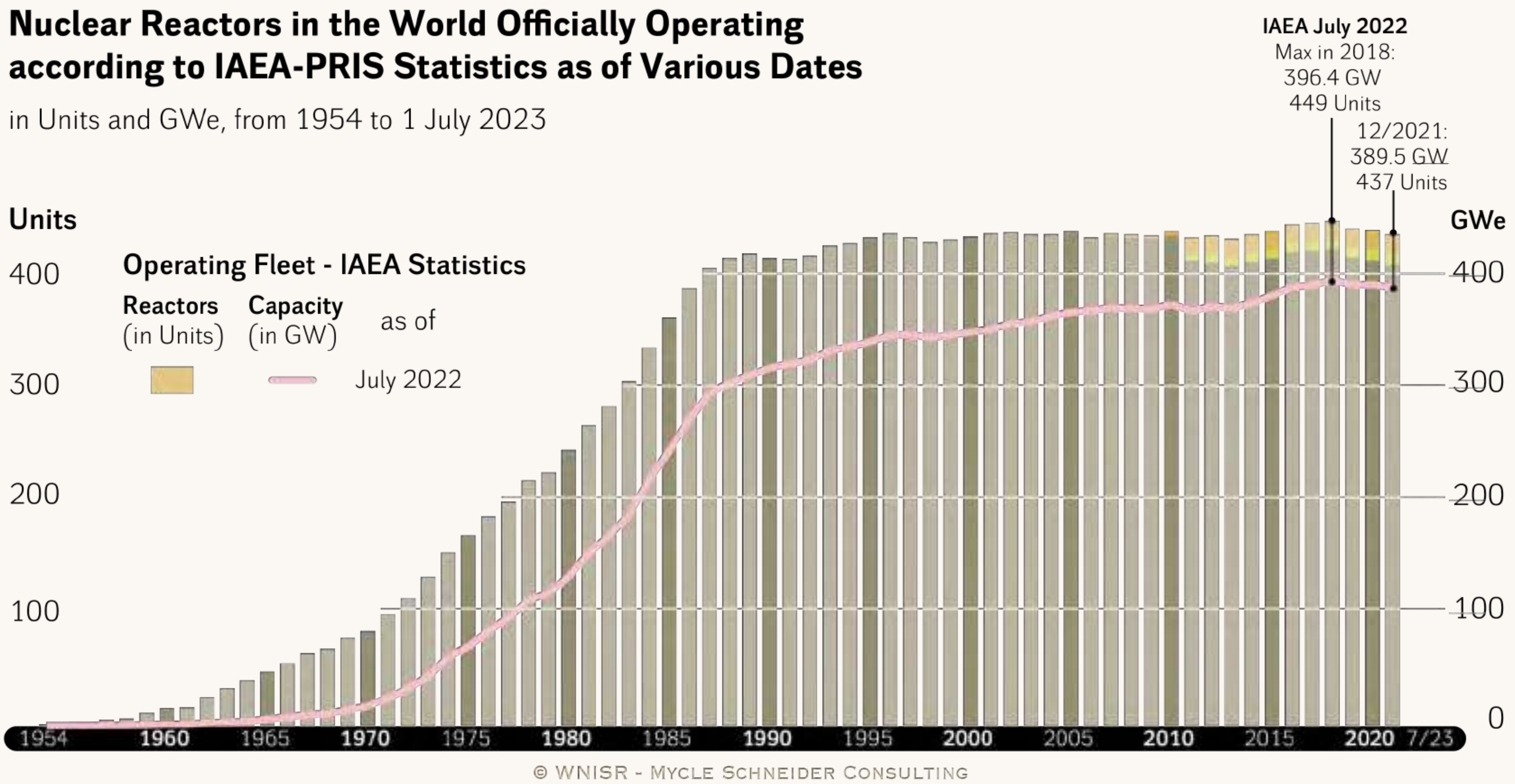
Net Balance -57

GLOBAL OVERVIEW – World Fleet



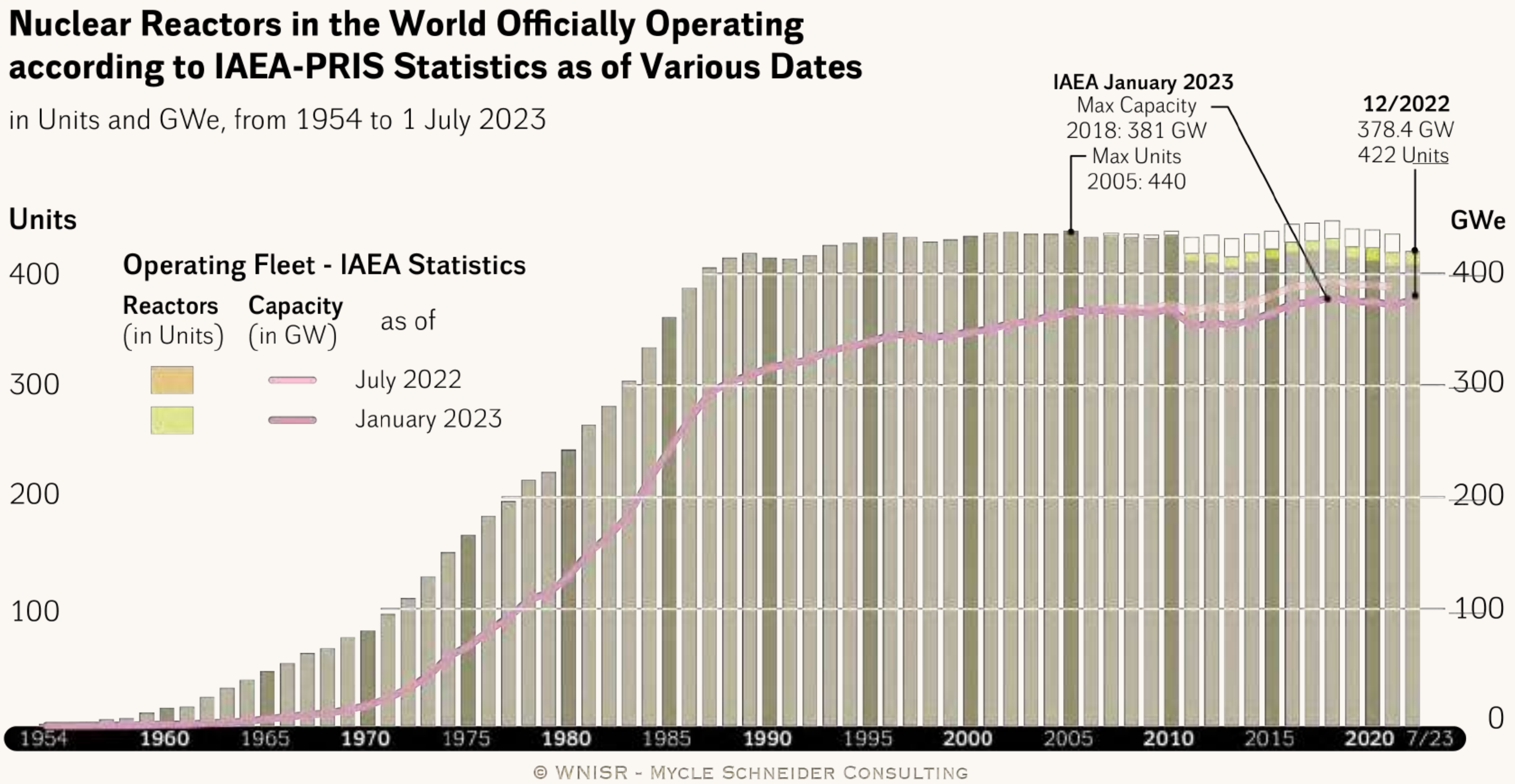
Sources: WNISR and IAEA-PRIS, 2023

GLOBAL OVERVIEW – Revised Statistics – World Fleet



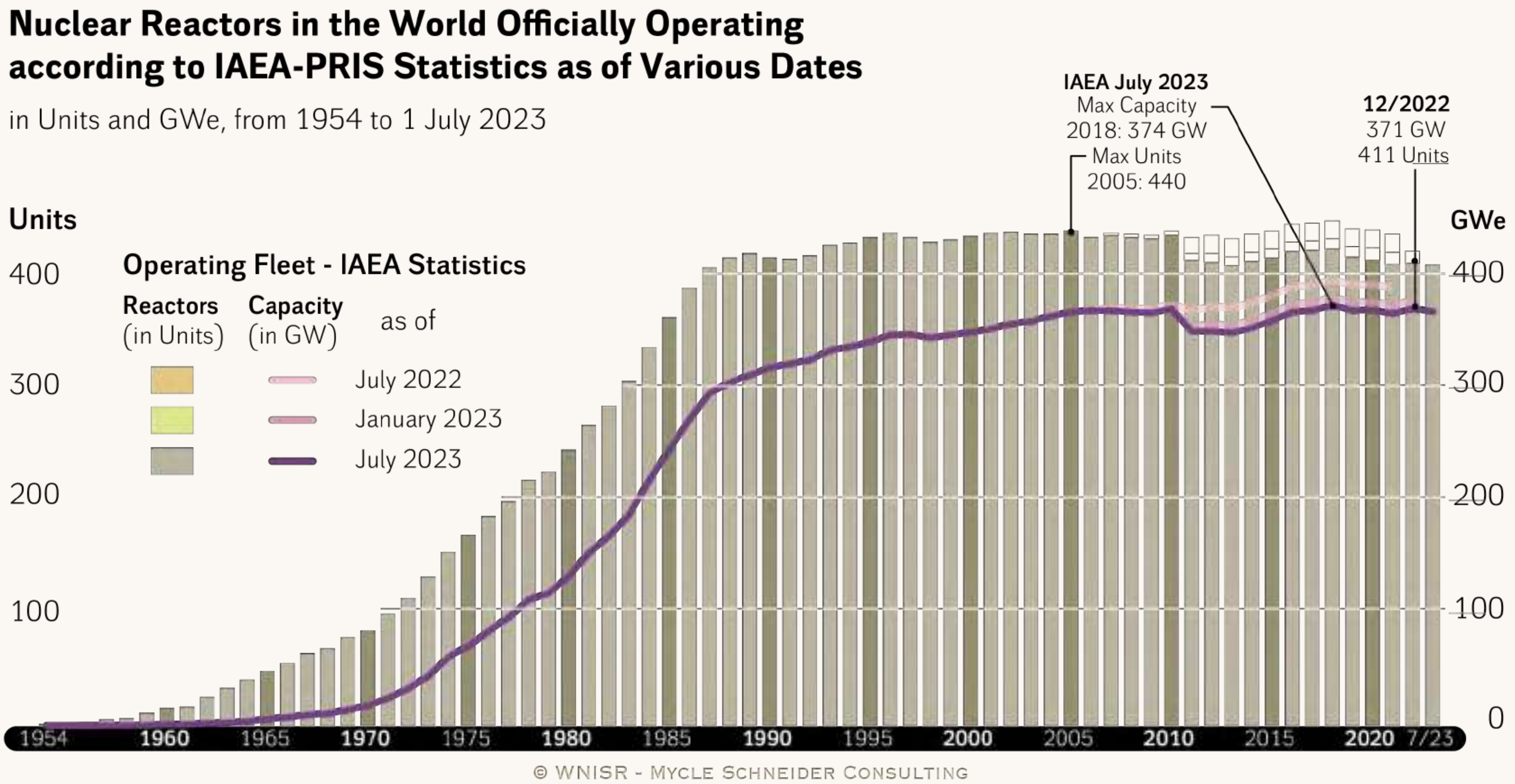
Sources: WNISR and IAEA-PRIS, 2023

GLOBAL OVERVIEW – Revised Statistics – World Fleet



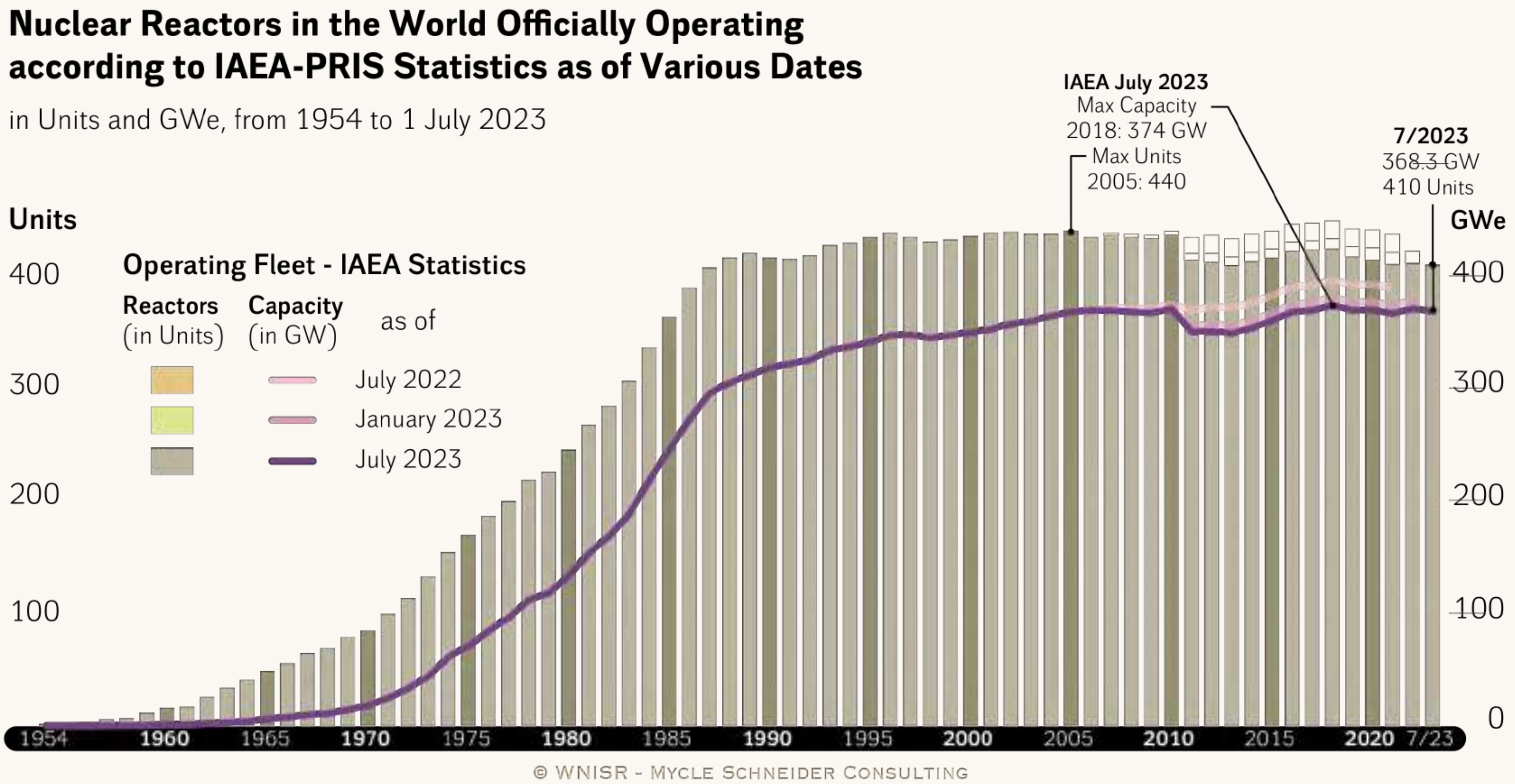
Sources: WNISR and IAEA-PRIS, 2023

GLOBAL OVERVIEW – Revised Statistics – World Fleet



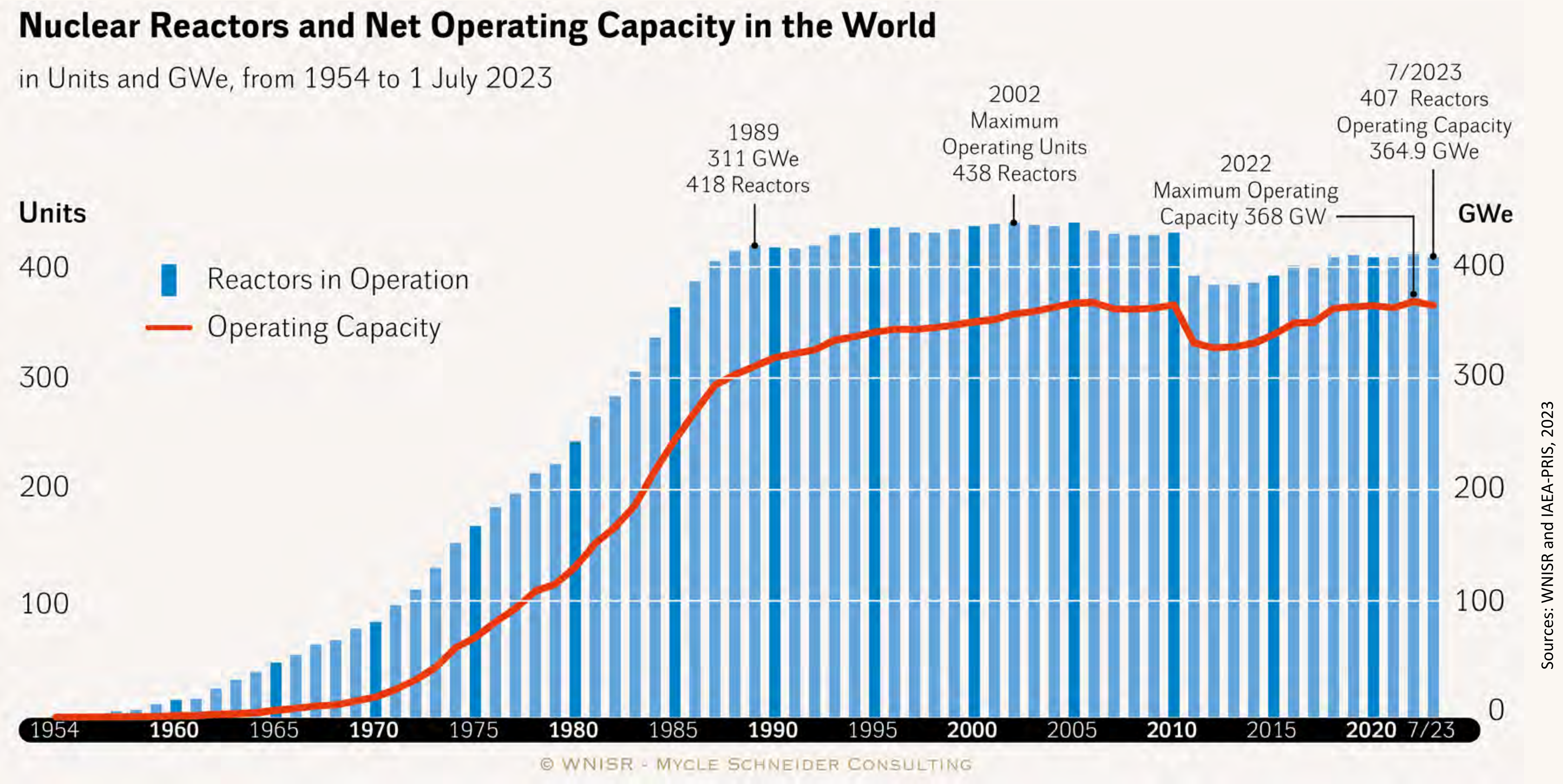
Sources: WNISR and IAEA-PRIS, 2023

GLOBAL OVERVIEW – Revised Statistics – World Fleet

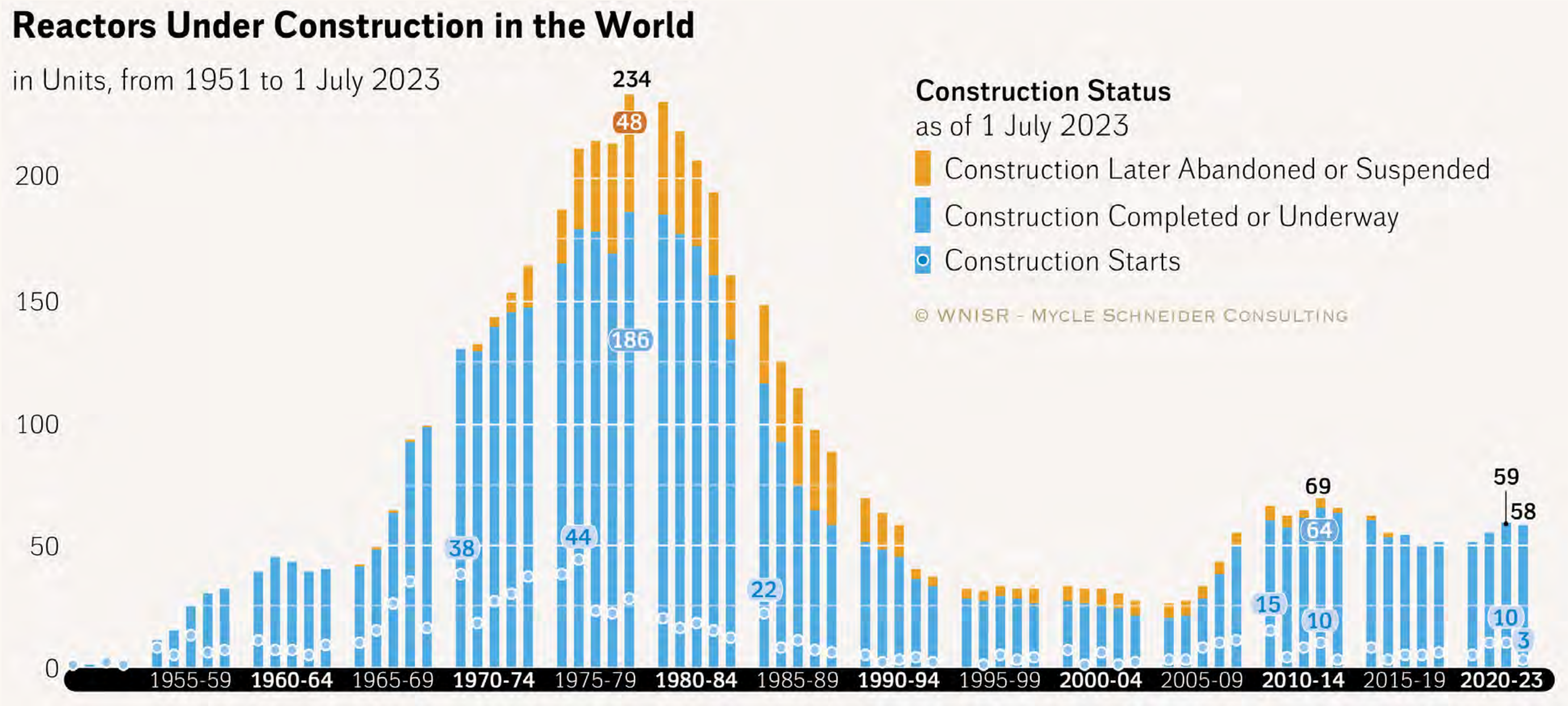


Sources: WNISR and IAEA-PRIS, 2023

GLOBAL OVERVIEW – World Fleet

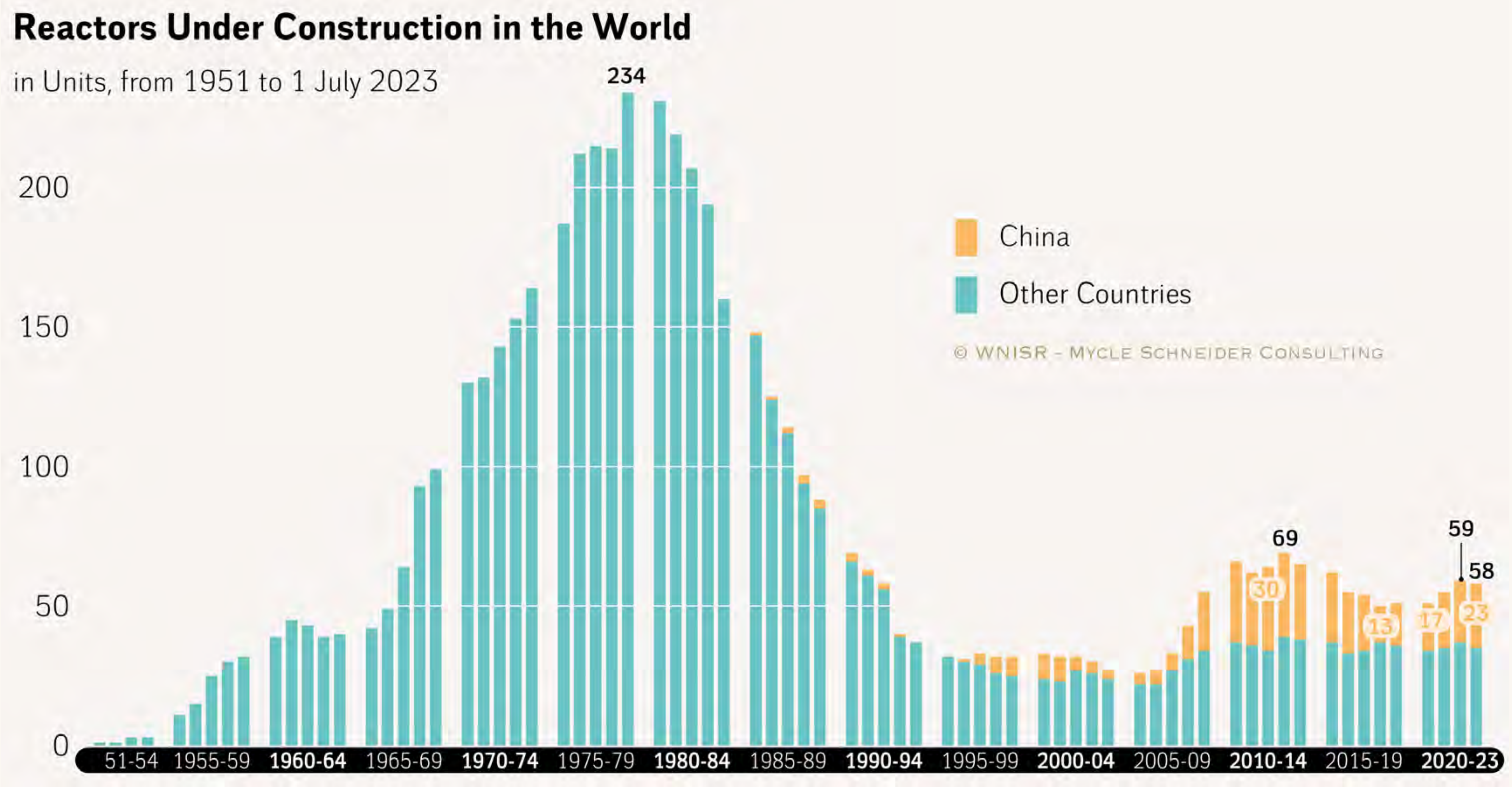


GLOBAL OVERVIEW — CONSTRUCTIONS



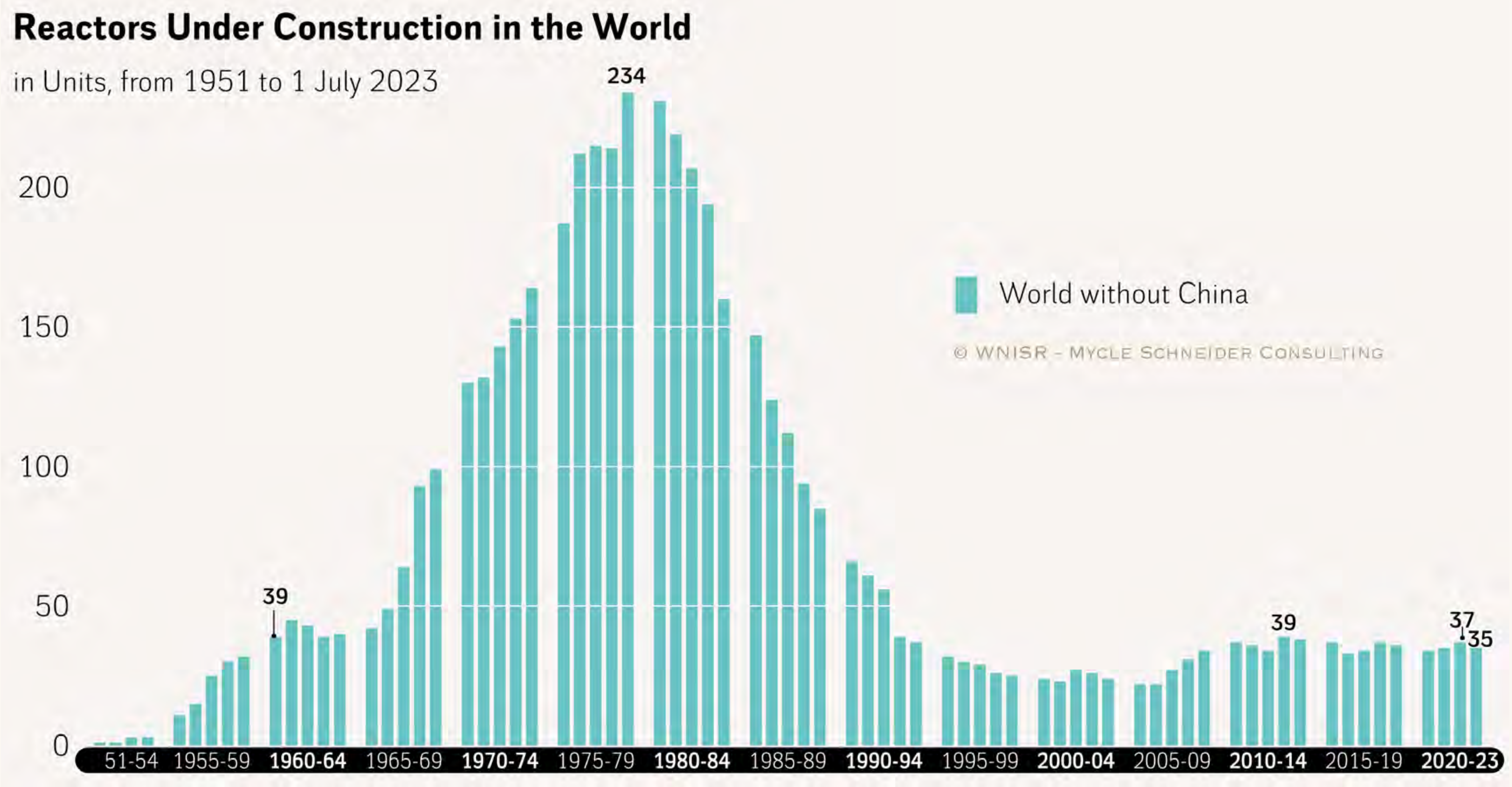
Sources: WNISR, with IAEA-PRIS, 2023

GLOBAL OVERVIEW — CONSTRUCTIONS IN CHINA AND ELSEWHERE



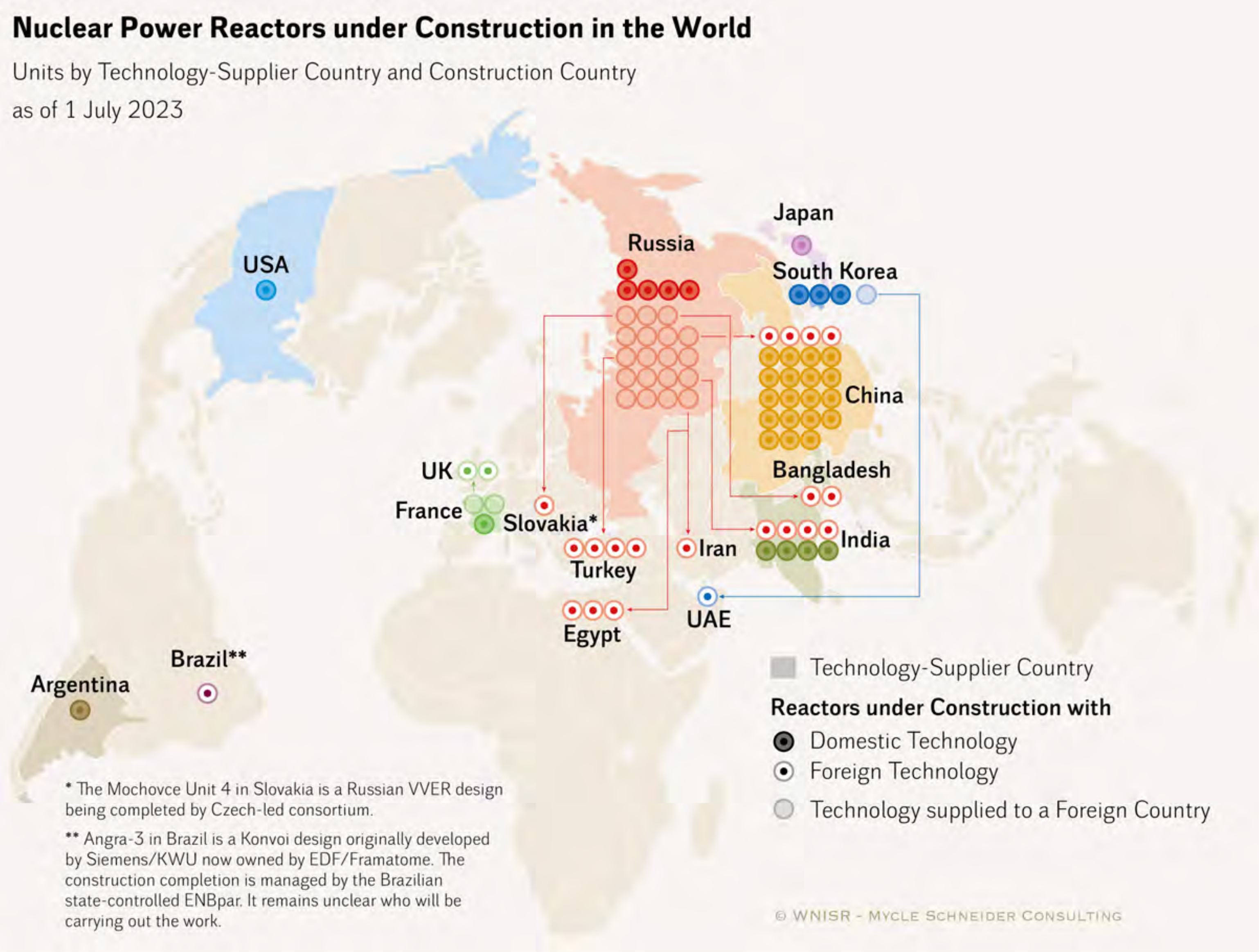
Sources: WNISR, with IAEA-PRIS, 2023

GLOBAL OVERVIEW — CONSTRUCTIONS WORLD WITHOUT CHINA



Sources: WNISR, with IAEA-PRIS, 2023

GLOBAL OVERVIEW — CONSTRUCTIONS: CHINA AT HOME, RUSSIA ABROAD



Sources: WNISR, with IAEA-PRIS, 2023

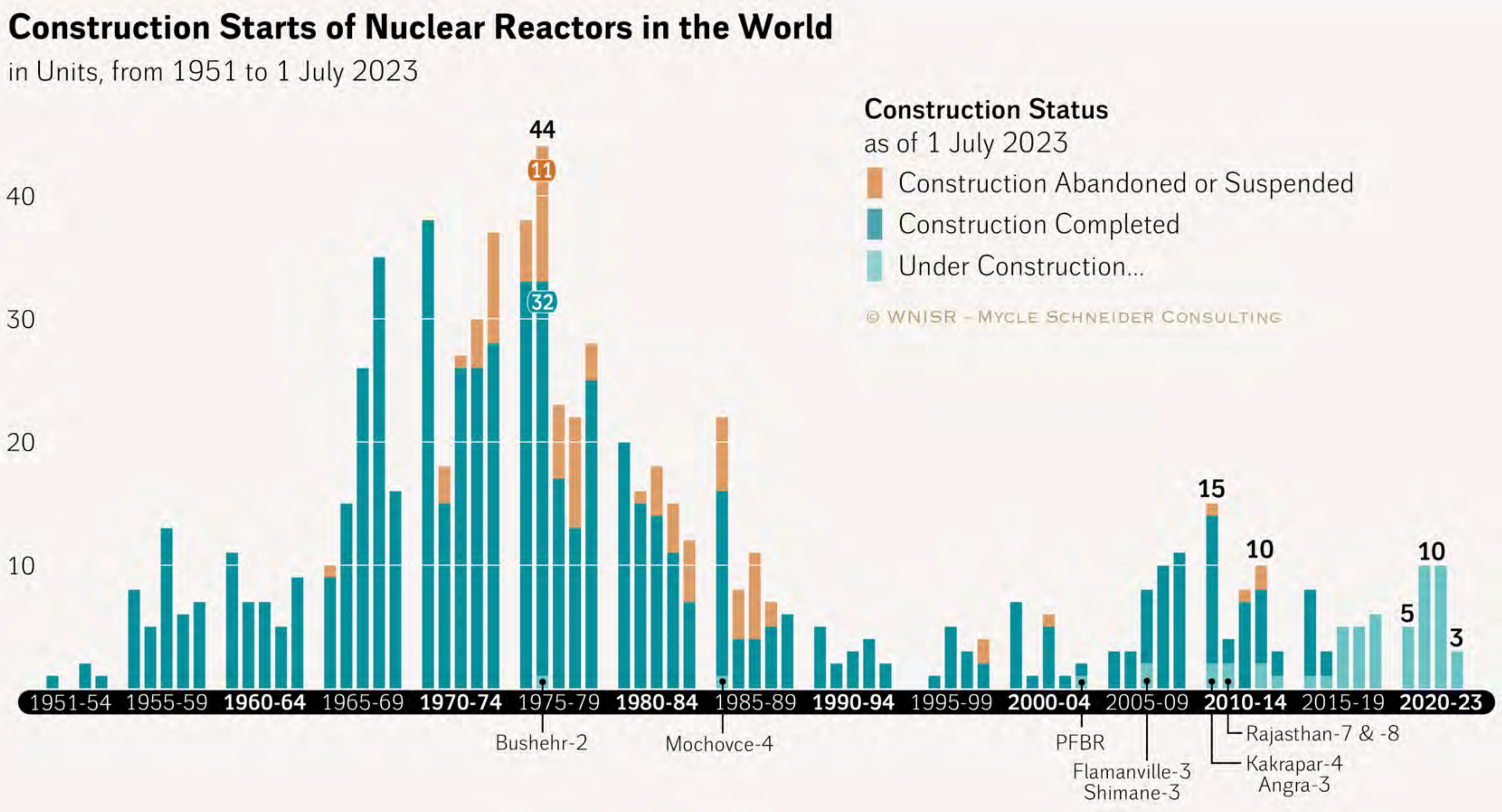
GLOBAL OVERVIEW — CONSTRUCTIONS, RUSSIA DOMINATES

Nuclear Reactors Under Construction (as of 1 July 2023)

Country	Units (Domestic Design)	Other Vendor	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	23 (19)	Russia: 4	24 408	2016 – 2023	2023 – 2028	1
India	8 (4)	Russia: 4	6 028	2004 – 2021	2024 – 2027	6[(a)]
Russia	5 (5)	–	2 810	2018 – 2022	2025 – 2027	2
Turkey	4 (0)	Russia: 4	4 456	2018 – 2022	2024 – 2027	1
Egypt	3 (0)	Russia: 3	3 300	2022 – 2023	2028 – 2030	-
South Korea	3 (3)	–	4 020	2013 – 2018	2024 – 2025	3
Bangladesh	2 (0)	Russia: 2	2 160	2017 – 2018	2024	1
UK	2 (0)	France: 2	3 260	2018 – 2019	2027 – 2028	2
Argentina	1 (1)	–	25	2014	2027	1
Brazil	1 (0)[(b)]		1 340	2010	2028?	1
France	1 (1)	–	1 630	2007	2024	1
Iran	1 (0)	Russia: 1	974	1976	2024	1
Japan	1 (1)	–	1 325	2007	2025?	1
Slovakia	1 (0)	Russia: 1[(c)]	440	1985	2024	1
UAE	1 (0)	South Korea: 1	1 310	2015	2023	1
USA	1 (1)	–	1 117	2013	2023	1
Total	58		58 603	1976 – 2023	2023 – 2030	24
Total per Vendor Country: Russia: 24 - China: 19 - India: 4 – South Korea: 4 - France: 3 - USA: 1 - Argentina: 1 - Japan: 1						

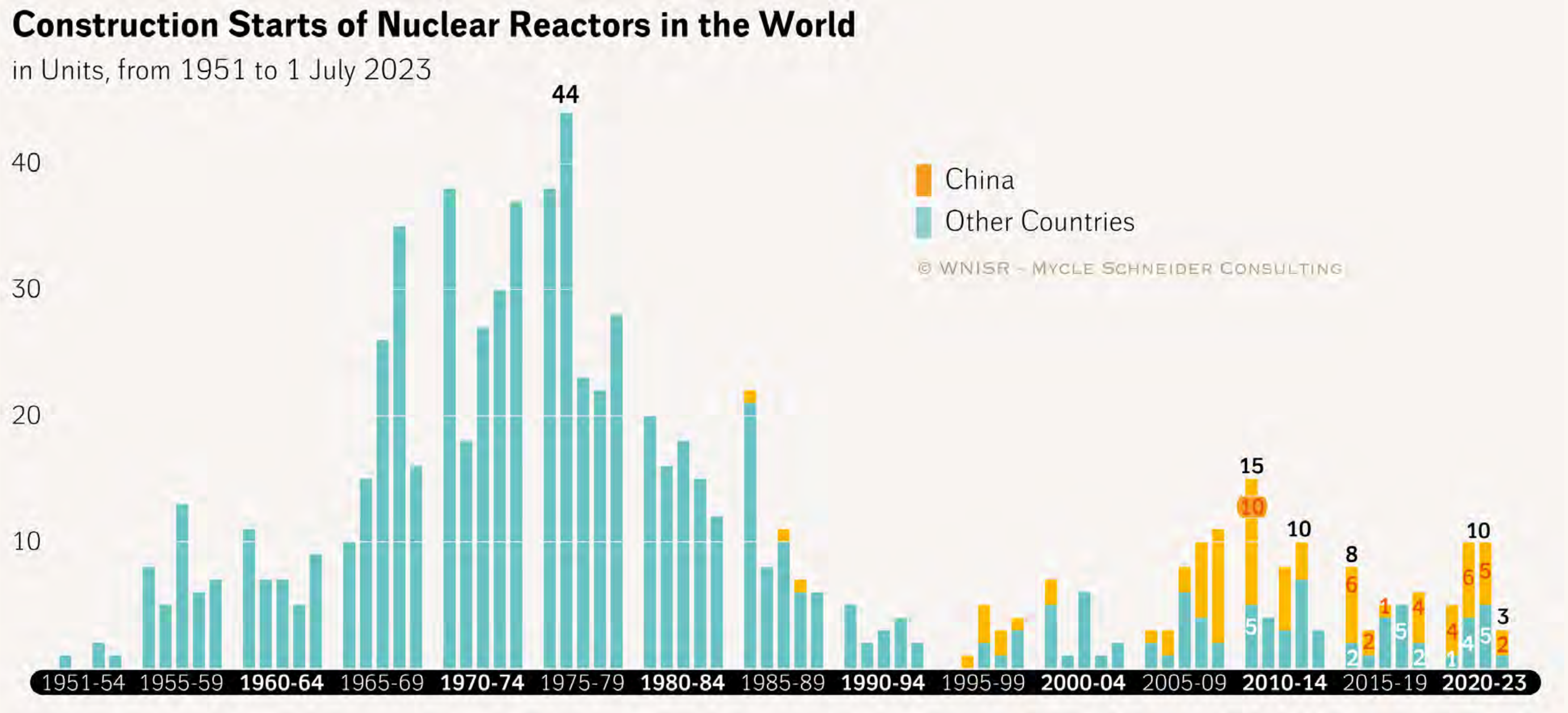
Sources: WNISR, with IAEA-PRIS, 2023

GENERAL OVERVIEW — Construction Starts in the World



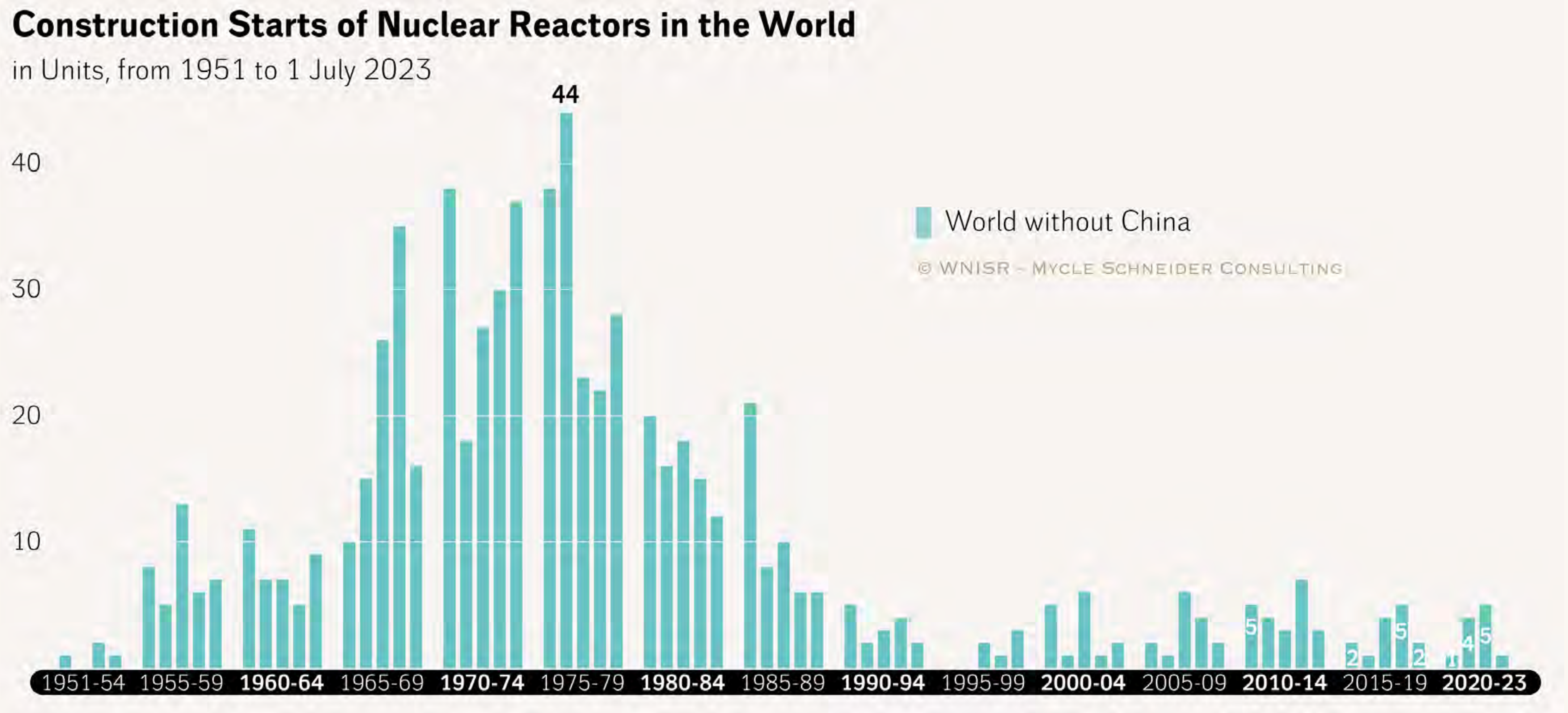
Sources: WNISR and IAEA-PRIS, 2023

GENERAL OVERVIEW — Construction Starts in China and Elsewhere



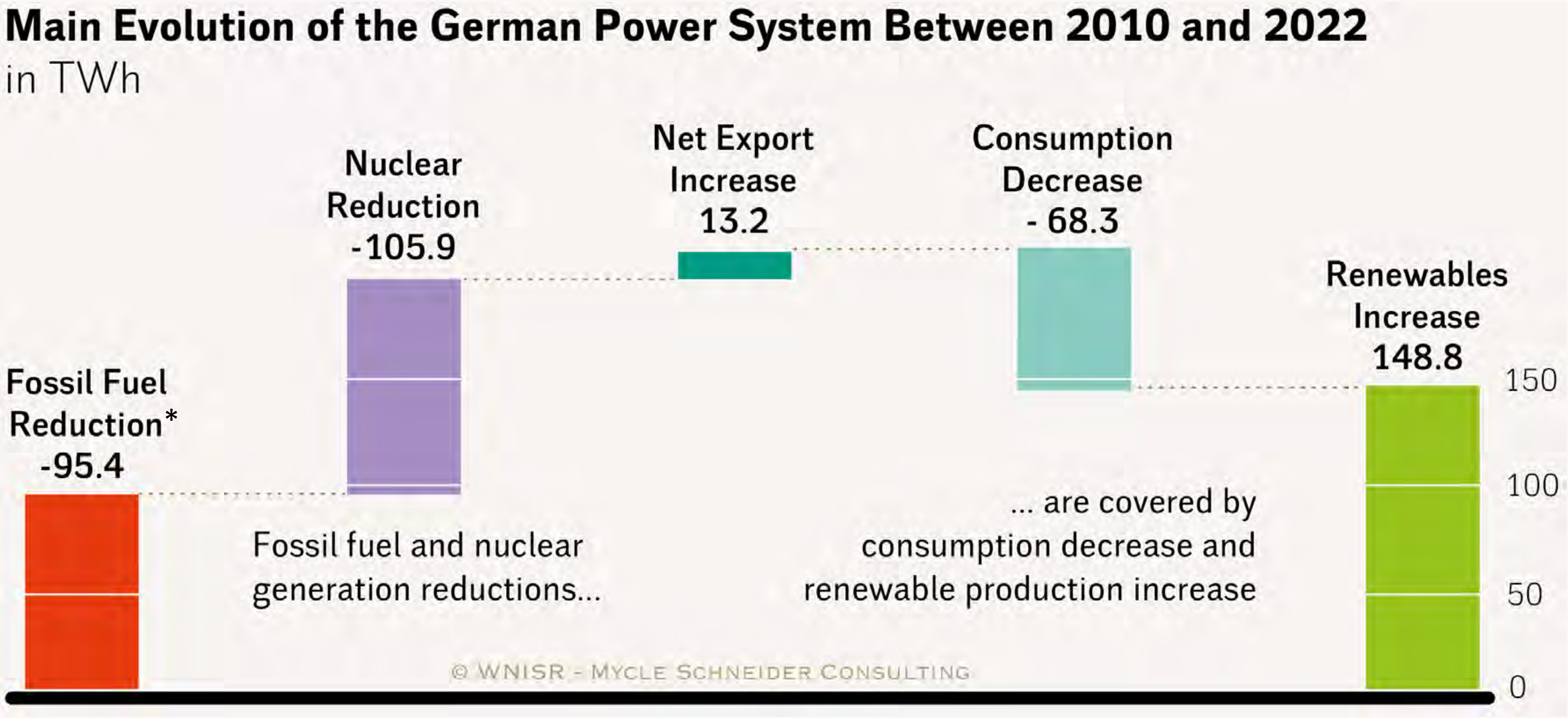
Sources: WNISR, with IAEA-PRIS, 2023

GENERAL OVERVIEW — Construction Starts World Without China



Sources: WNISR, with IAEA-PRIS, 2023

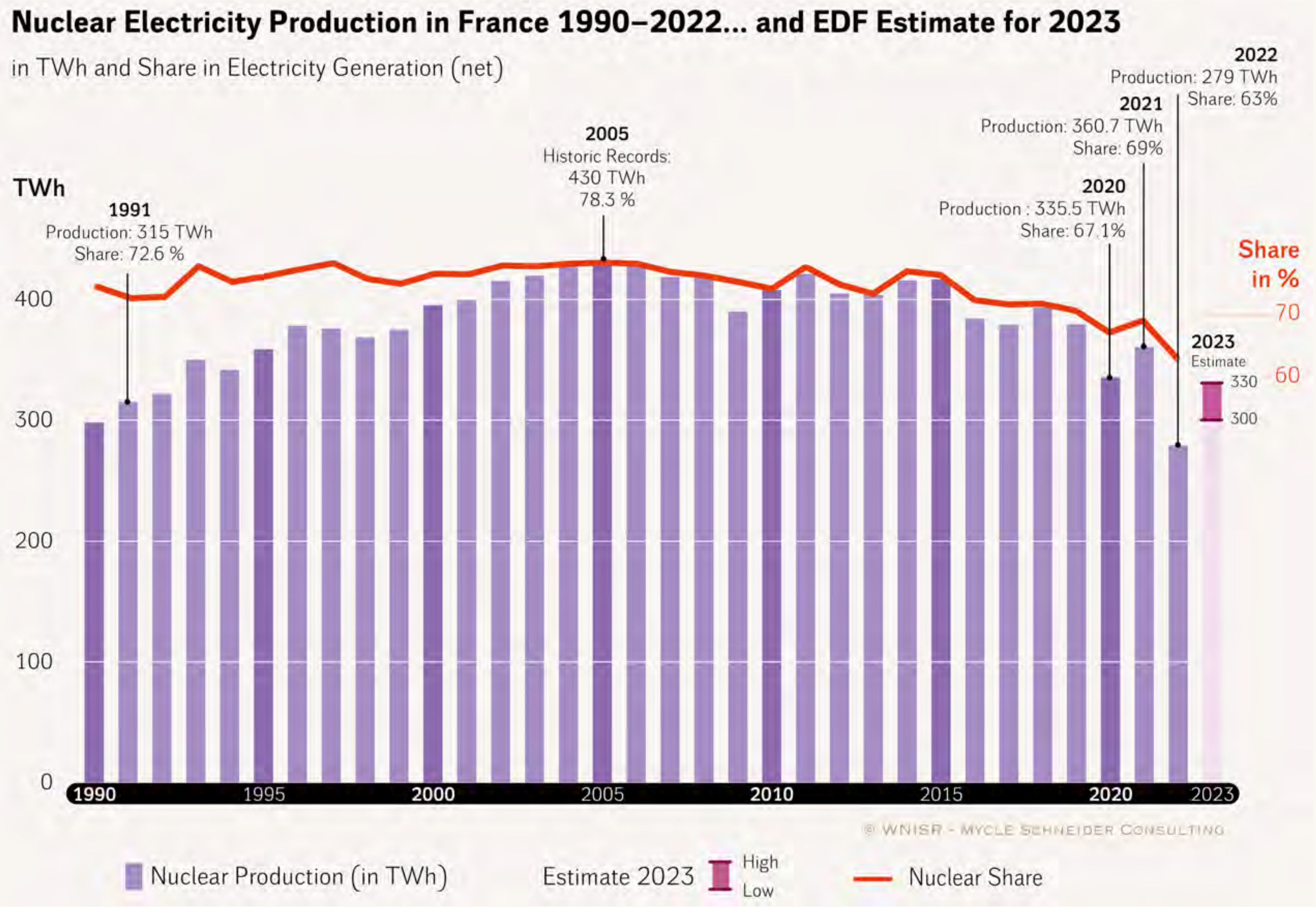
+Renewables -Consumption = -Nuclear *AND* -Fossil Fuels



*Lignite -20% Hard Coal -45% Natural Gas -10%

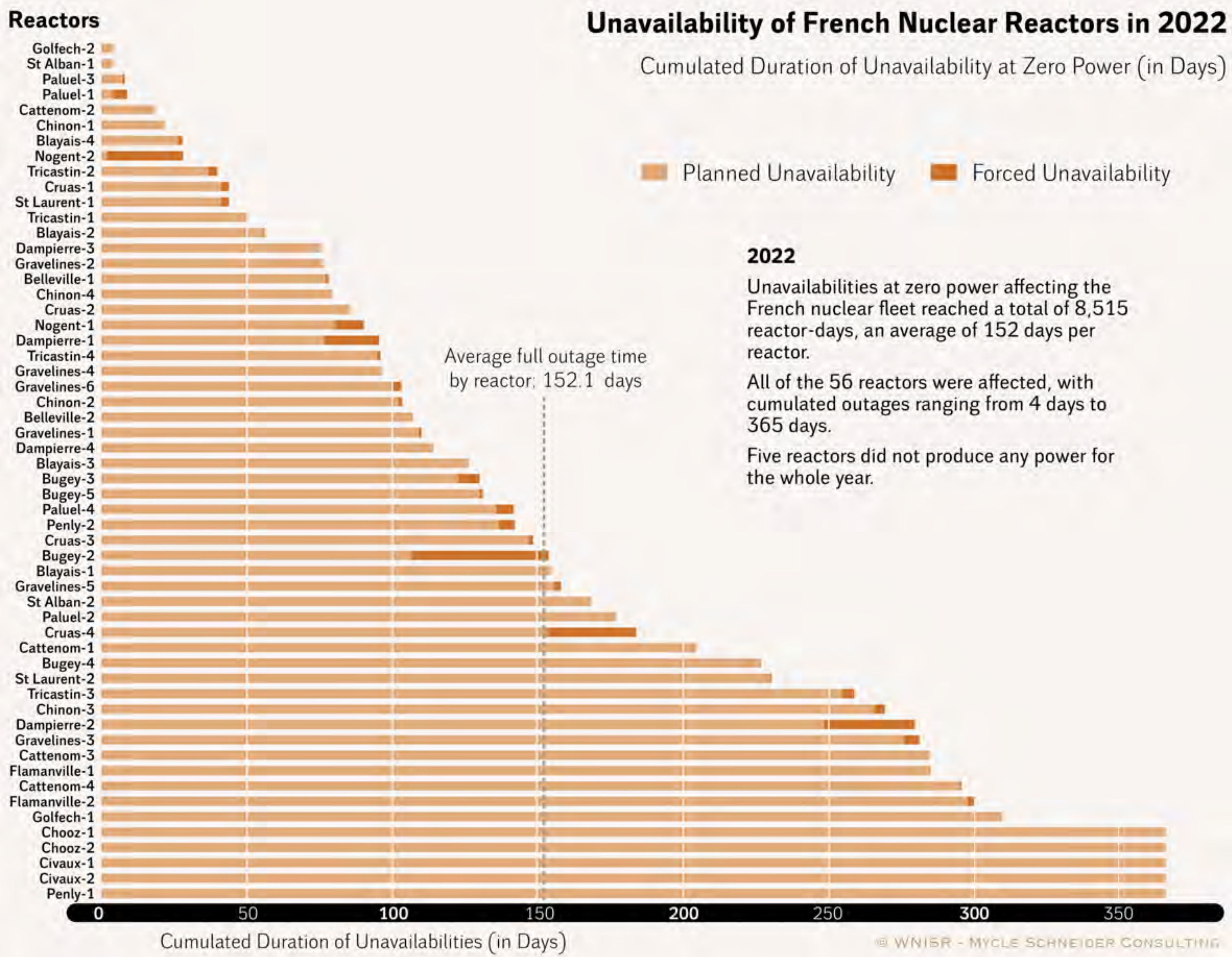
Sources: AGEB, 2023

FRANCE FOCUS – Nuclear Production / Share 1990–2022



Sources: RTE, 2000–2023, EDF 2023

FRANCE FOCUS – Unavailabilities in 2022



Sources: WNISR with RTE and EDF, 2023

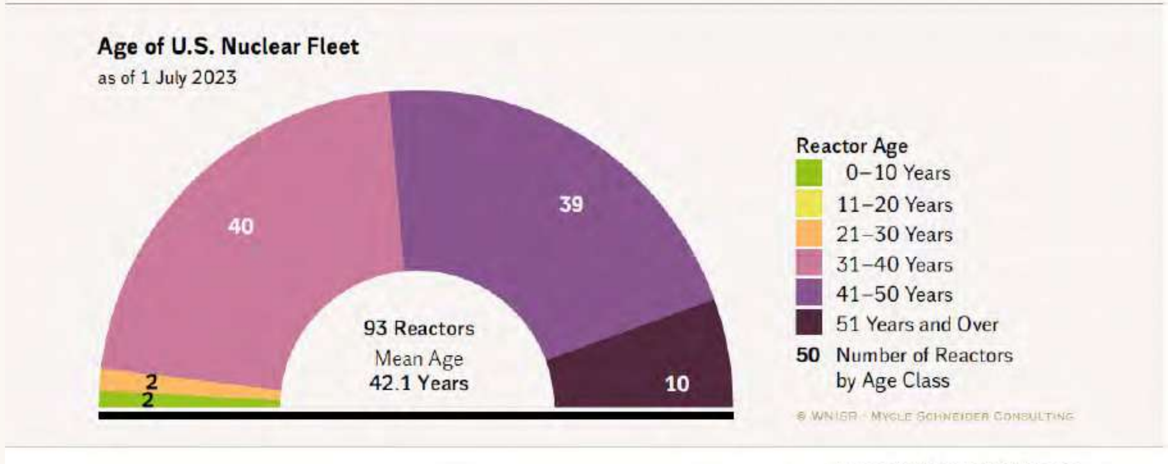
Timothy Judson, Syracuse, NY, United States – judson.tim@gmail.com

Timothy Judson provides industrial and policy analysis, with over twenty years of experience in the United States. He has published several reports on the nuclear industry and energy and climate policy, including "Nuclear Power and Climate Change: An Assessment for the Future" and "Too Big to Bail Out: The Cost of a National Nuclear Energy Subsidy." Since 2014, he has served as the Executive Director of Nuclear Information and Resource Service, a non-profit environmental organization based in the United States. He lives in Syracuse, New York, on unceded lands of the Onondaga Nation.

USA FOCUS - Overview

Nuclear Decline in U.S. Continued in 2022

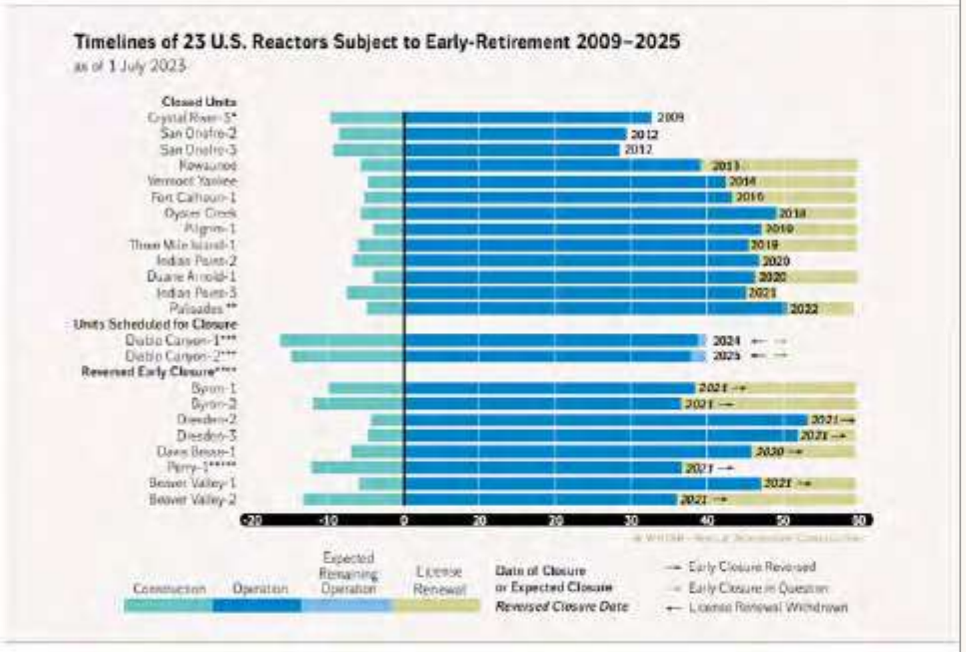
- Generation down 0.9% (to 771.5 TWh)
- Share of total electricity lowest since 1990s
  - 18.2% of utility scale generation
  - 17.9% if including off-grid solar
- 10 reactors over 51 years operational age
  - Oldest licenses expire in 2029



Sources: WNISR, with IAEA-PRIS, 2023

Retirements Outpace Additions 5:1 (2009–2023)

- 12 retirements
- 2 startups: Watts Bar-2, Vogtle-3
- 1 pending startup: Vogtle-4
- 1 proposed restart: Palisades-1
- 2 pending closures: Diablo Canyon-1 and -2



Sources: Various, compiled by WNISR, 2023

Proposed SMRs/Non-LWRs Uncertain

- NuScale SMR project cancelled (no fully certified design)
- 2 demonstration projects total 665 MW (no certified design)
- 2 microreactor demonstrations (no certified design)

USA FOCUS – Vogtle-3 & -4 Project Status

Vogtle-3 Startup

- Grid Connection: 1 April 2023
- Full Power: 29 May 2023
- Commercial Operation: 31 July 2023
- Equipment problems during startup
  - Main coolant pumps (3 outages, 34 days)
  - Turbine coolant leak (36-day outage)

Vogtle-4 Startup Delayed to 2024

- Fuel loading and startup approved 28 July 2023
- Main coolant pump motor failure

Cost Escalation Continues

- May 2023: co-owners' cost >US$31 billion
  Westinghouse settlement of US$3.7 billion
- Georgia Georgia Public Service Commission (PSC) staff testified that Vogtle-3 & -4 costs now exceed benefits

> "The cost increases and schedule delays have completely eliminated any benefit on a lifecycle cost basis."
>
> – Georgia PSC Staff

USA FOCUS – Proposed Reactor Design Status

SMRs and Non-LWRs – All Federally Sponsored

- U.S. DOE: Advanced Reactor Demonstration Program
  - NuScale CFPP – US$1.355 billion + land at Idaho National Lab (INL)
  - Terrapower and X-Energy – US$2.5 billion
  - Oklo Aurora and Terrapower MCFR demonstrators – land at INL
  - Kairos Hermes 2 – land at ORNL
- U.S. DOD: microreactor procurements
  - Project Pele and Eielson Air Force Base
- Tennessee Valley Authority
  - GE-Hitachi BWRX-300 SMR

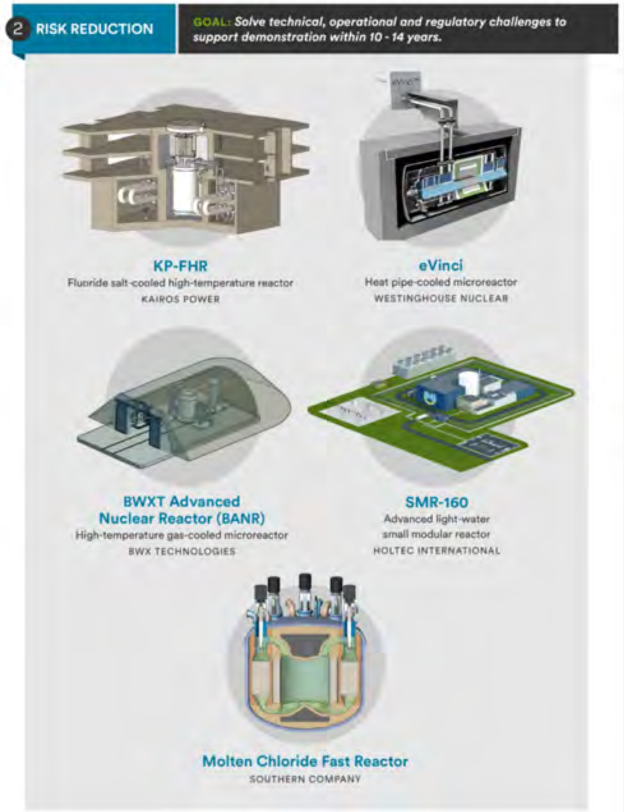
Construction and Licensing Status

- No construction starts
- No license applications submitted

Nuclear Startup Financing Risks

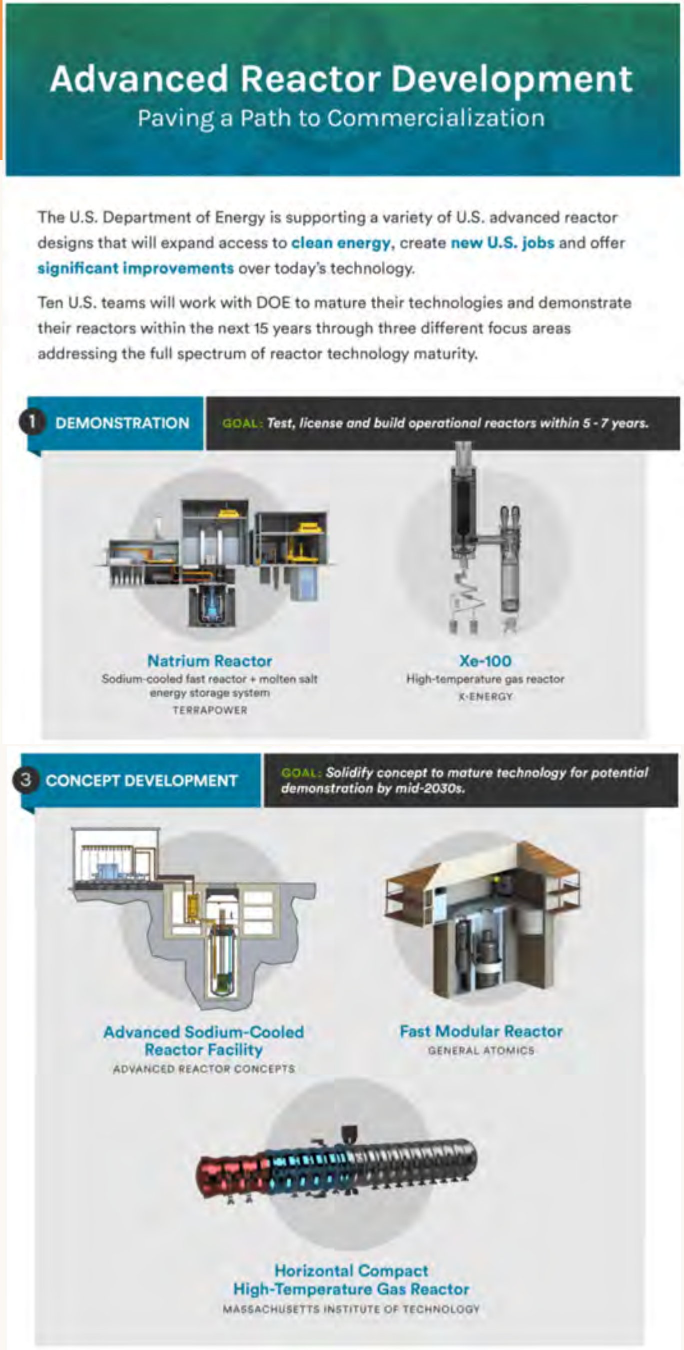
- Venture capital + DOE cost-sharing grants
- Startups “go public” via SPAC reverse mergers

  X-Energy SPAC deal canceled 31 October 2023



•Source: US DOE - Advanced Reactor Demonstration Program infographic, 2020

•https://www.energy.gov/ne/articles/infographic-advanced-reactor-development



USA FOCUS – New Business Trends

Spinoffs and Consolidation

- Constellation spun off from Exelon (2022)
  - 2023: acquired 44% of South Texas-1 and -2 (US$1.75 billion)
  - Fleet → 25 reactors
- Energy Harbor spun off from FirstEnergy (2019)
  - 2023: Vistra merger-acquisition (US$3.43 billion) = 6 reactors
- Dominion acquired SCANA in bankruptcy

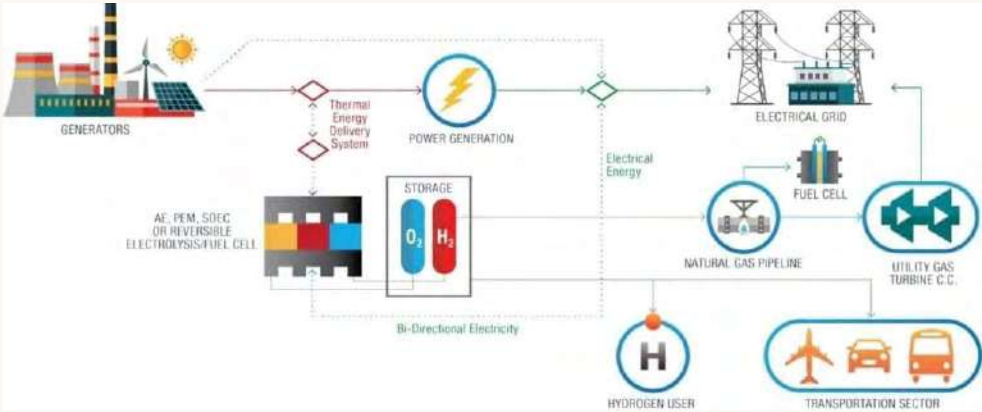
Hydrogen Production Projects

- Nuclear-Hydrogen Demonstration Projects
- Regional Hydrogen Hub Demonstration Projects
- Hydrogen Prod. Tax Credit (PTC): US$3/kg → US$57–US$72/MWh
  - H2 + Nuclear PTC → US$72–US$87/MWh

Data Center/Crypto Contracts

- Co-Located Data Centers at NPPs
  - Power off-take contracts at 6 sites (700 MW to 2.5 GW)
- Virtual Hourly Power Purchase Agreement (PPA)
  - Constellation-Microsoft contract for Virginia data center

Nuclear-Hydrogen Infrastructure



Source: USDOE, INL, April 2022

Susquehanna NPP Crypto Facility

Source: Talen Energy, 2021

USA FOCUS – Fraud and Corruption Cases

Corruption Cases

- Exelon
  - Four executives and lobbyists convicted May 2023
  - Illinois ex-House Speaker Madigan trial date set (1 April 2024)
- FirstEnergy
  - Ohio ex-House Speaker Householder sentenced to 20 years
  - Ohio ex-Republican Chairman Borges sentenced to 5 years
  - State PUC investigations uncover widespread dark money spending

Summer-2 & -3 Fraud

- Two SCANA executives convicted
  - COO Stephen Byrne: 15 months + US$1 million restitution +US$200,000 fine
- Two Westinghouse executives indicted
  - Vice President Jeffrey Benjamin's case thrown out due to biased grand jury pool
  - Re-indicted in November 2023

NuScale Investor Suits

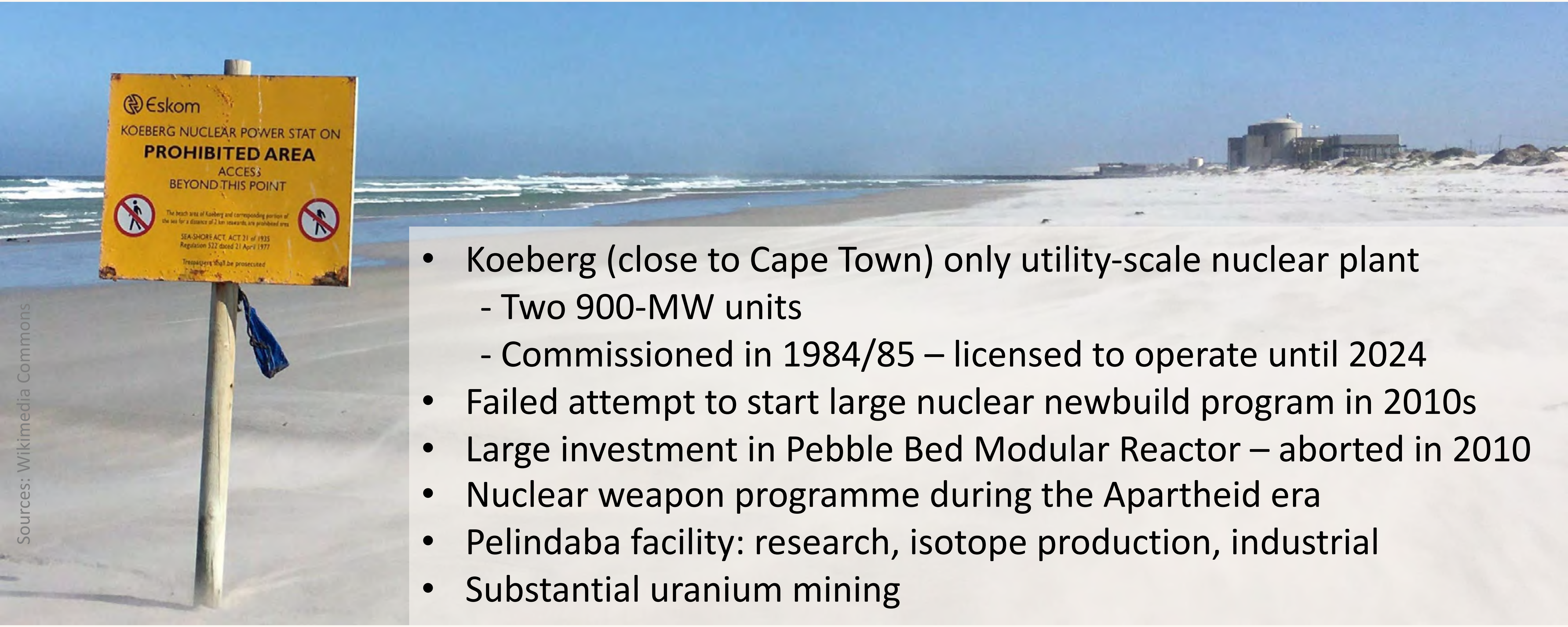
- Filed on 15 November 2023
- Claims false/misleading statements, "adverse facts" concealed from investors

Hartmut Winkler, Johannesburg, South Africa – hwinkler@uj.ac.za

Hartmut Winkler is a Professor in the Department of Physics of the University of Johannesburg in South Africa. After completing his PhD in Astronomy at the University of Cape Town, he joined the Soweto Campus of the former Vista University, where he started engaging in air quality research, which led to an interest in solar irradiance studies, solar energy potential and later energy studies in the broader sense. After a stint in University administration as Dean of Science, he returned to scientific work after joining the new University of Johannesburg.

In recent years he has been one of South Africa's most visible television and radio commentators on the country's electricity crisis.

SOUTH AFRICA FOCUS – History of Nuclear Industry



Sources: Wikimedia Commons

- Koeberg (close to Cape Town) only utility-scale nuclear plant
  - Two 900-MW units
  - Commissioned in 1984/85 – licensed to operate until 2024
- Failed attempt to start large nuclear newbuild program in 2010s
- Large investment in Pebble Bed Modular Reactor – aborted in 2010
- Nuclear weapon programme during the Apartheid era
- Pelindaba facility: research, isotope production, industrial
- Substantial uranium mining

SOUTH AFRICA FOCUS – Current Power Mix – Solar/Wind Potential

South Africa's electricity mix

- South Africa is heavily dependent on electricity from coal (>80%)
- Koeberg NPP should nominally produce 5% of South Africa's electricity
- Despite exceptional potential, solar and wind have only grown slowly

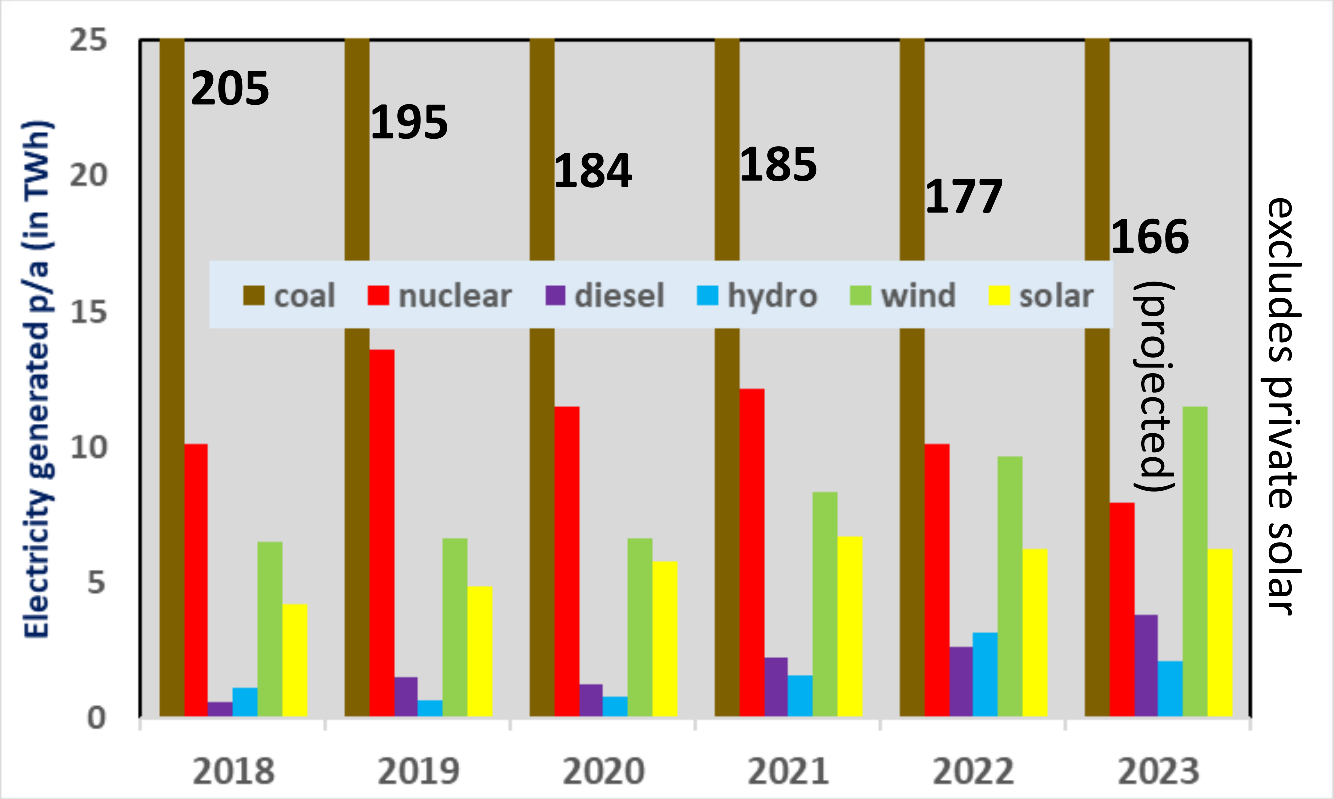
Solar irradiance

~2000 kWh/m^2 p.a.

(Spain ~1600; Belgium ~1100)

Wind speed

~8 m/s over large parts (average @100 m a.g.l.); comparable to good European onshore site

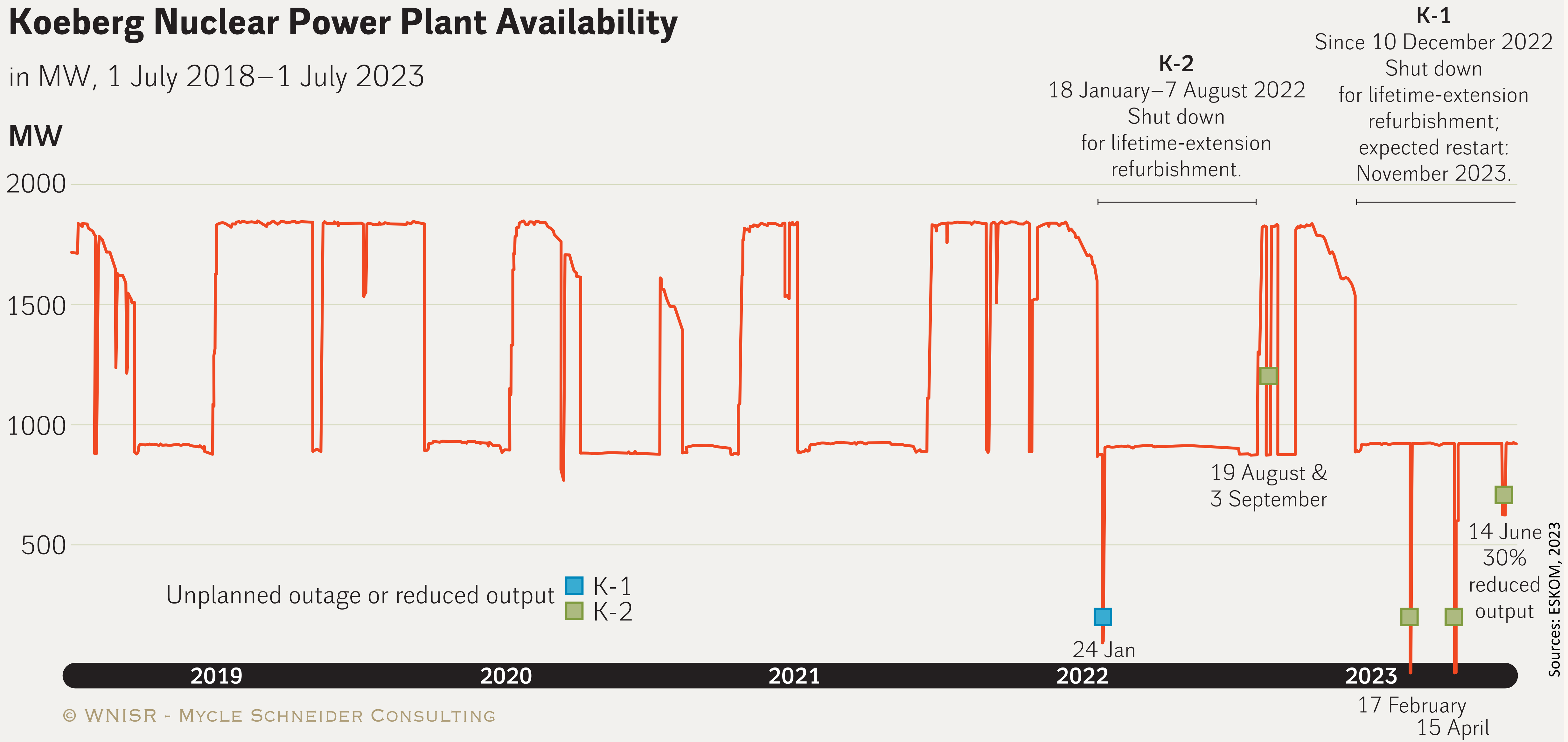


Sources: Eskom

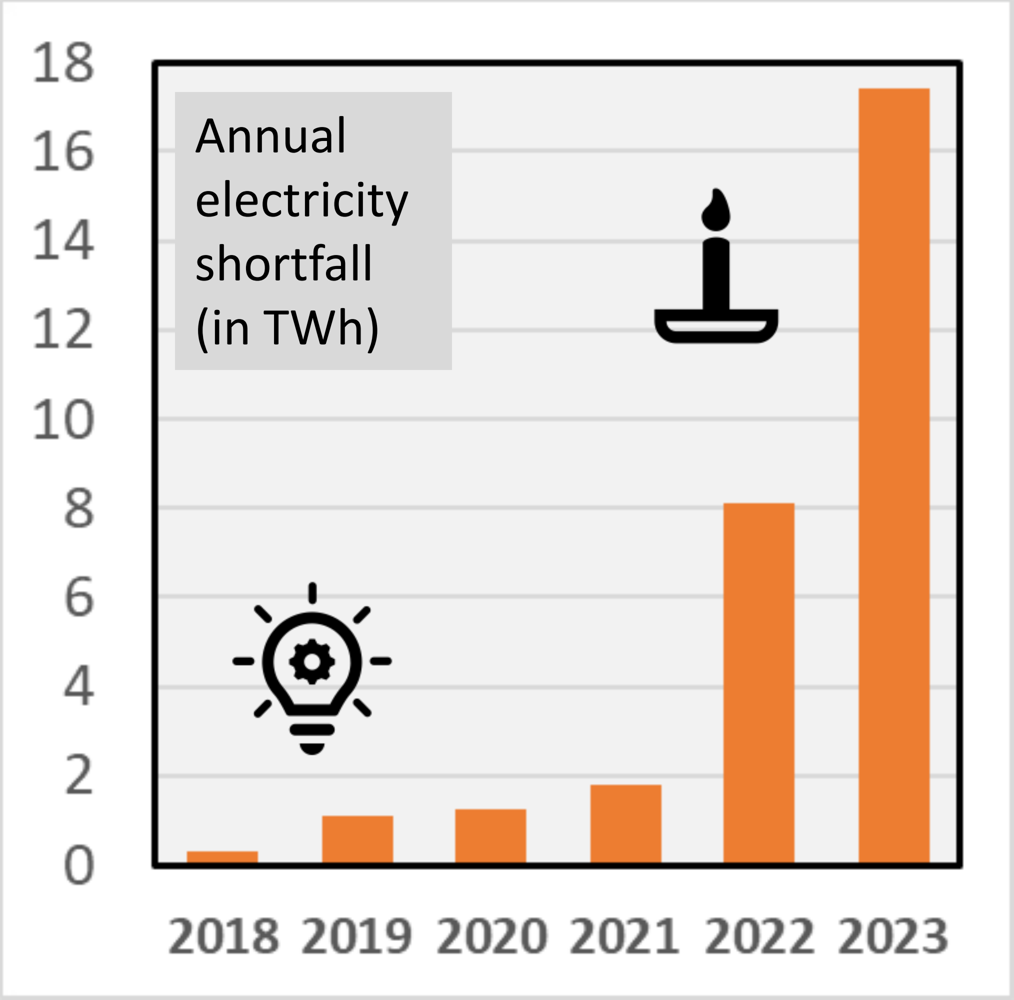
SOUTH AFRICA FOCUS – Koeberg Performance and Lifetime-extension

Koeberg Nuclear Power Plant Availability

in MW, 1 July 2018–1 July 2023



South Africa's Current Power Crisis



Source: Eskom

Consequences

- Setback for the economy
- Boom in rooftop solar
- "Just transition" vs. fixing the coal plants and delaying decommissioning
- Increase in nuclear lobbying for:
  - 2.5 GW new nuclear build
  - Small Modular Reactors (SMRs)
- Political ramifications? (general election in 2024)

Doug Koplow, Cambridge, MA, United States – dkoplow@earthtrack.net

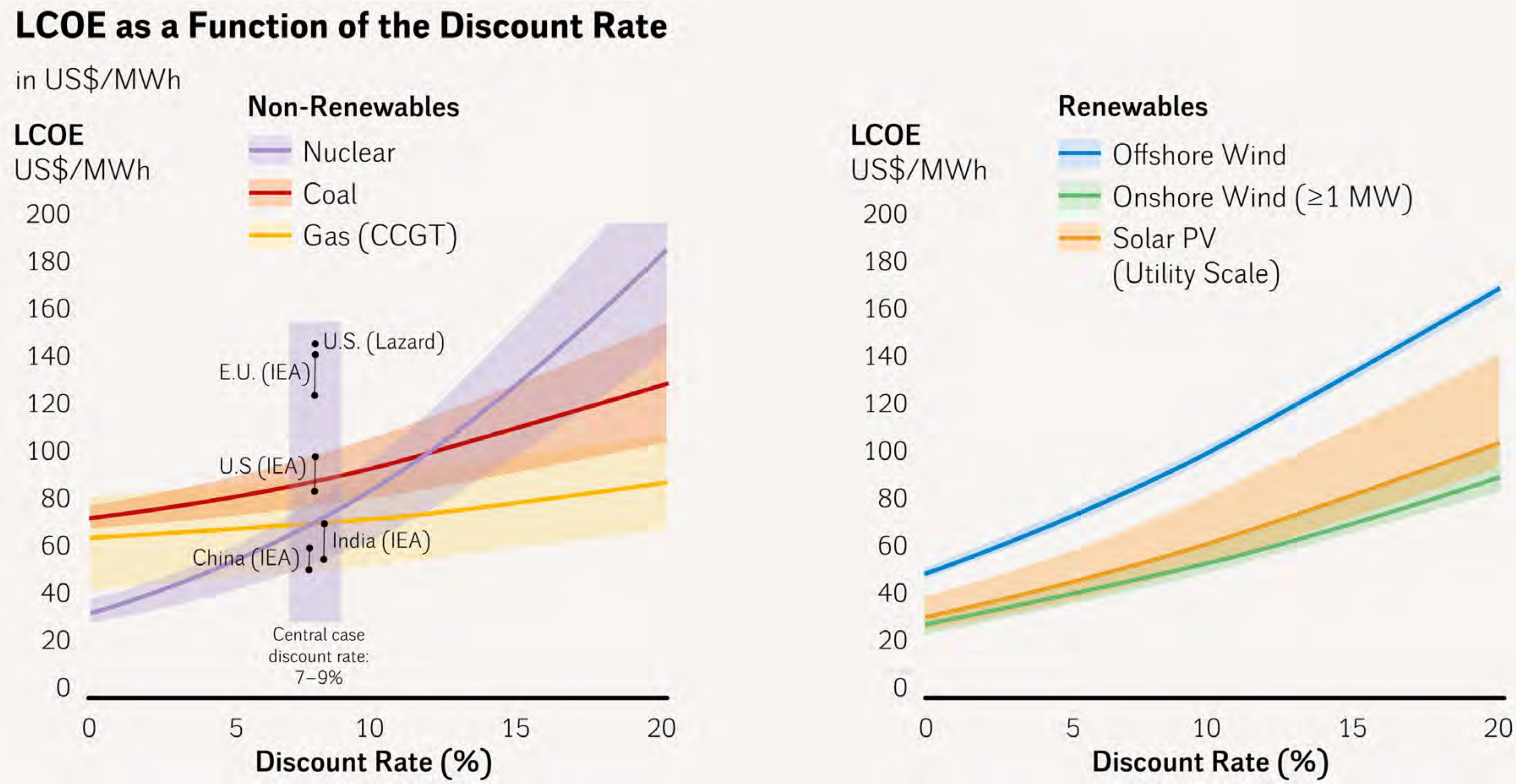
Doug Koplow is the founding director of Earth Track in Cambridge, MA.

For more than three decades, he has worked with environmental groups and international agencies to identify and measure environmentally harmful subsidies to natural resource extraction, and to document their pervasive reach and enormous scale.

His work has included detailed reviews of government support to the nuclear fuel chain, highlighting the many ways governments support the industry and shift business risks onto taxpayers. He holds an MBA from Harvard Business School and a BA in economics from Wesleyan University.

- **Traditional Assumption**—Expensive to build, inexpensive to run—**in Question**
  - Competition is putting even operating reactors under pressure
    - Inexpensive natural gas (e.g. U.S.)
    - Increasing success of variable renewables + firming; some commercial agreements around operating costs of reactors / most less expensive than newbuild
  - Aging plants often with higher outages (e.g. France) driving up operating costs
  - Load shifting to manage demand as well as supply

- **Growing Public Subsidies for Existing Reactors**
  - Belgium: pending contract-for-difference (price floor) for lifetime extension, cap on waste liability for operator Engie
  - France: renationalization of EDF; looking for E.U. support schemes
  - Japan: State support on massive post-Fukushima costs; considering subsidies to accelerate reactor restarts
  - U.S.: production tax credits at state-level to 19 reactors; estimated US$15 billion by 2030
  - U.S.: Federal tax credits, plus possible additive support if other uses (e.g. to hydrogen; additional US$6 billion to support reactors at risk of closure)



Sources: IEA and OECD/NEA, 2020, IEA, 2021–2023, Lazard, 2023

NUCLEAR ECONOMICS AND FINANCE – Nuclear LCOEs May Be Too Optimistic

- **Discount Rate**

  - Scale of investment, delivery delays, cost overruns on nuclear power plants suggest rate should be higher for nuclear than for other resources

- **Assumptions on Learning Curves**

  - Generally too optimistic, e.g. IEA's estimates assume Nth-of-a-kind (NOAK) costs for newbuild - Not supported by empirical evidence and cost escalation remains challenge for recent reactor construction projects

  - Reactor builds to achieve NOAK are speculative, with estimates ranging from five to many hundreds for newer SMRs.

  - Projected and actual performance are far apart (e.g. meta analysis of 88 projects)

    - Construction period: 5–9 years projected, 10–17 years actual.
    - Median construction costs: $5,122/kW projected, $9,250/kW actual (+80%)

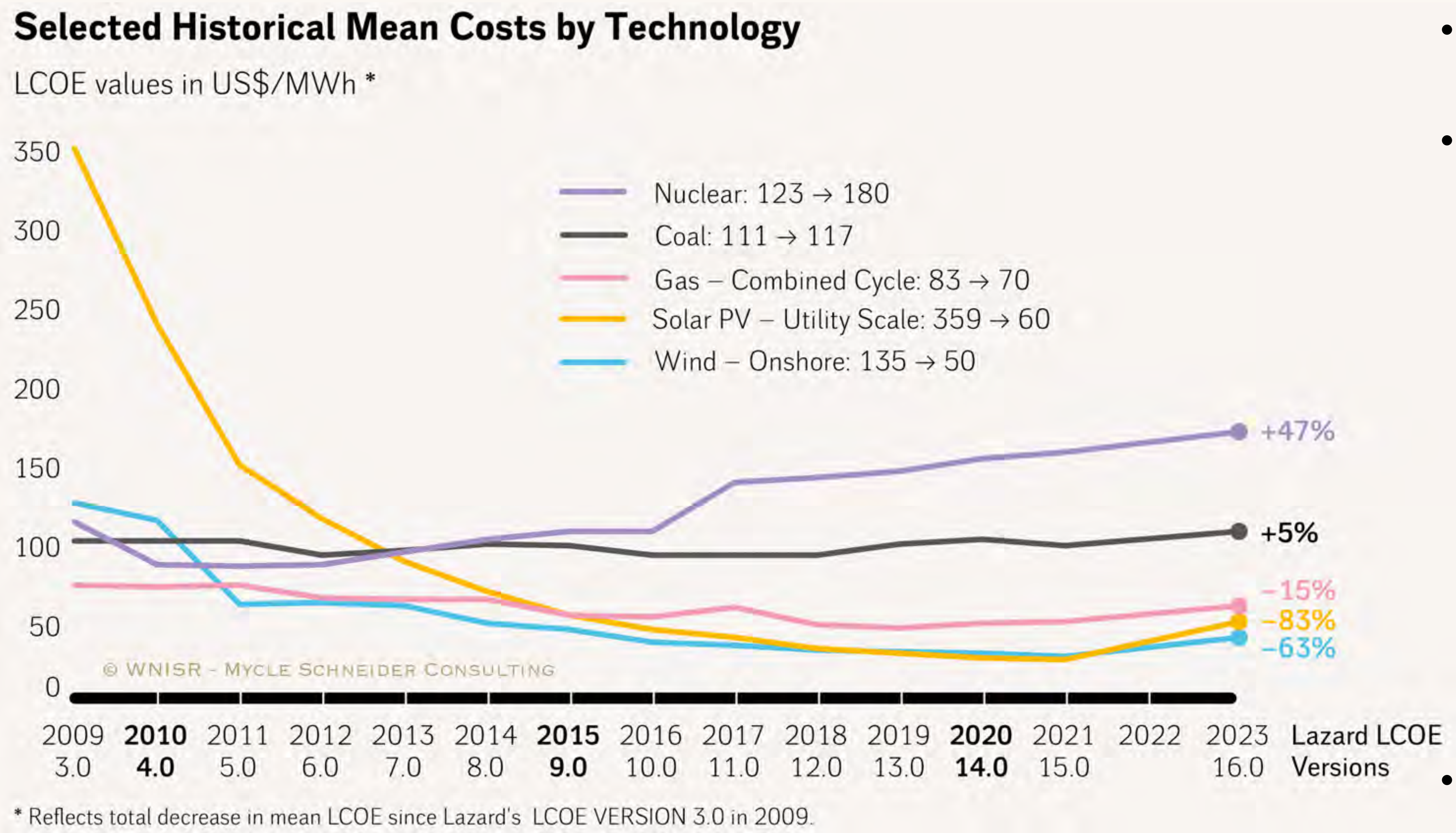
- **Public Subsidies**

  - Substantial portions of the nuclear chain are state-supported or fully socialized; even subsidy-free scenarios capture only part of these mechanisms

NUCLEAR ECONOMICS AND FINANCE – Large/Growing State Role in System

Production Step	State Involvement
Reactor Origin	*Reactor count / nameplate – 2018–2022* ▪ China: >40% / >40% ▪ Russia: 50% / 46%
Construction Starts, Host Country	*Reactor count, nameplate – 2018–2022* ▪ China: 53% / 55% ▪ Russia: 14% / 7%
Plant Financing - Domestic	*Reduced cost:* direct state ownership, sovereign guarantees, tax credits *Price floor:* contract-for-difference *Customer finance:* Construction Work in Progress (CWIP), Regulated Asset Base (RAB)
Plant Financing - Export	Dominated by China (US$19–22 billion) and Russia (large range; ~US$75 billion midpoint) Push for much higher support from OECD countries for SMRs, and via MDBs
Uranium Mining and Conversion	*Mining:* >50% state-owned; *Conversion:* 38% owned by Russia alone.
Uranium Enrichment	88% state-owned (46% Russia)
Reactor Decommissioning	>40% of countries have full or partial state funding; all backstop shortfalls
Nuclear Waste Repositories	State-owned in most countries, and usually at least partly state-funded as well
Nuclear Accident Liability	Mandated coverage very low; largest pool globally U.S. about US$13.6 billion; other countries much lower; Official cost of Fukushima so far US$233 billion, 16x higher. Most liability (including in U.S.) backstopped by the state, often for free.

NUCLEAR ECONOMICS AND FINANCE – Competitors Outperform Nuclear



Source: Lazard Estimates, 2023

- Large cost improvements in renewables vs. nuclear
- Scale of new investment confirms trend:
  - Nuclear: 58 reactors under construction worldwide (10-15/y?)
  - Wind: tens of thousands/year.
  - PV modules: hundreds of millions/year.
  - Utility scale batteries: more capacity to grid in 2022 than nuclear.
- Variable plus firming increasingly competitive.

Need for Continuous Power Puts Potential New Uses in Competition with Grid

Use Case	Use Needs 24/7 Operation to be Economic?	Process Equipment Damage from Intermittent Operation?	Use Requires Co-location with NPP?
Hydrogen Electrolysis	Yes	Some likely	Yes to use waste heat; No for electricity-only May need co-location to prove "clean hydrogen" under U.S. statute
Desalination	Yes	Some likely	Yes, to use waste heat as well; No if just powering with electricity
Industrial Process Heat	Yes, though heat can be co-produced	Yes, for high temperature process use	Yes; also lower temperature heat from existing reactors limits co-gen applications
Dedicated Loads			
Crypto	Probably not	No	No
Data Centers	Yes	Yes	No
All uses need cost-competitive power; newbuild too expensive.			

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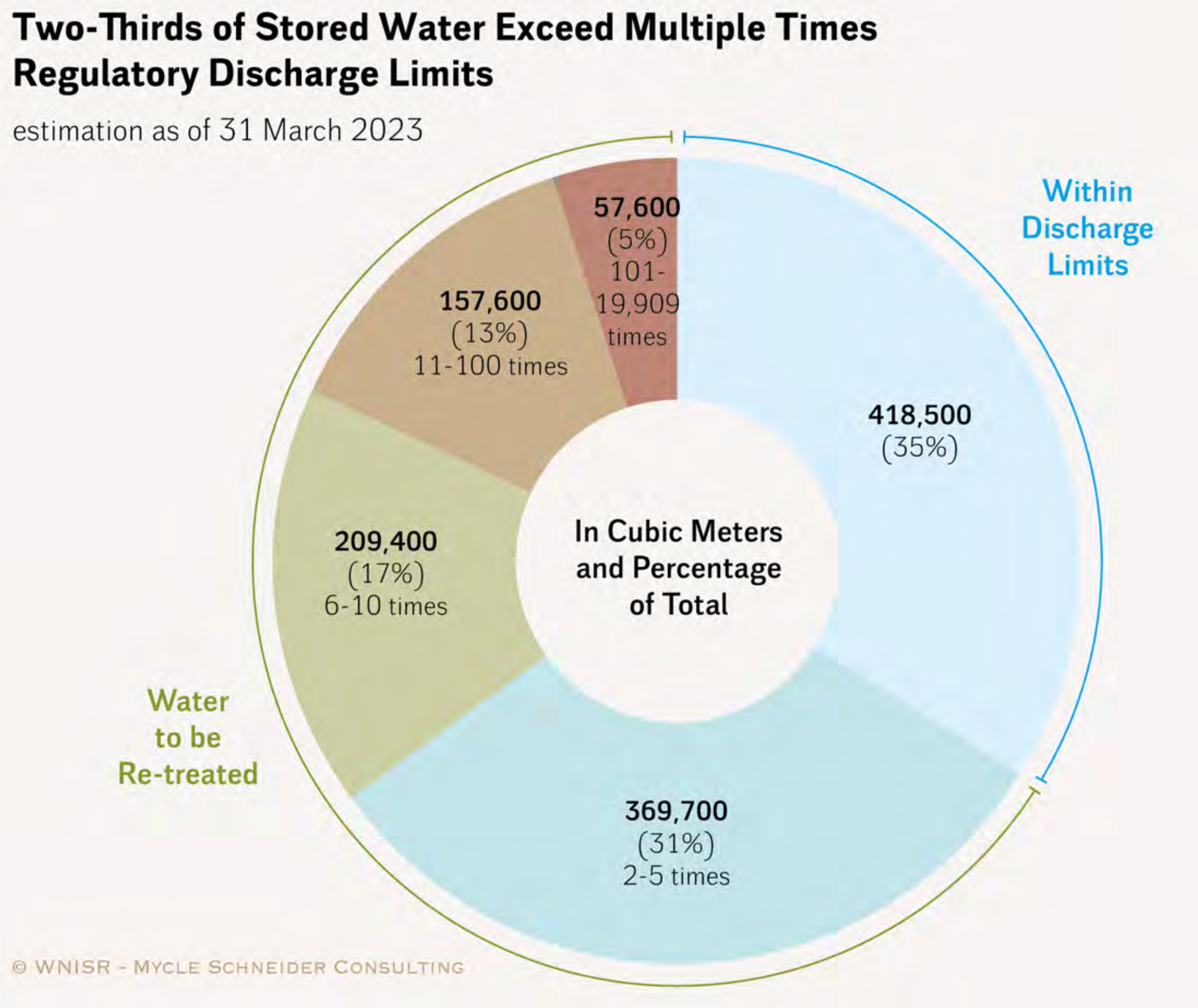
He is a member of the Advisory Board of Parliament's Special Committee on Nuclear Energy since June 2017. He is also a Council Member of Pugwash Conferences on Science and World Affairs (2007-09 and from 2014~). Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).

FUKUSHIMA STATUS REPORT – (1) Onsite Challenges

- **SPENT FUEL REMOVAL**
  - Unit 3 completed in February 2021
  - Preparatory work Units 1 and 2, removal delayed, to begin in FY 2027–2028, to be completed by the end of 2031, >20 years after the disaster began
- **CORE COOLING**
  - Water levels dropped in all three reactor pressure vessels after 7.4 magnitude earthquake on 16 March 2022; water injection rates increased but have stabelized at about 2.4m^3/h for Unit 1 and 1.5 m^3/h for Unit 3.
- **FUEL DEBRIS REMOVAL**
  - postponed several times
  - concern about potential collapse of pressure vessel support of Unit 1

- **CONTAMINATED WATER MANAGEMENT**
  - Reduction of water influx from 540 m^3/day to about 90 m^3/day
  - Equivalent amount of water partially decontaminated and stored
  - New 1,000-m^3 tank needed almost every 10 days
  - About 1.3 million m^3 of treated water were stored in 1,046 tanks
  - Water diluted by a factor of 100 (or more) prior to release
  - First batch release started on 24 August 2023
  - Operation will take at least three decades
  - Strategy remains widely contested, including overseas

FUKUSHIMA STATUS REPORT – (3) Onsite Challenges



Source: TEPCO Contaminated Water Portal Site, July 2023

FUKUSHIMA STATUS REPORT – Offsite Challenge

- **EVACUEES**

  - About 27,000 residents of Fukushima Prefecture still evacuees

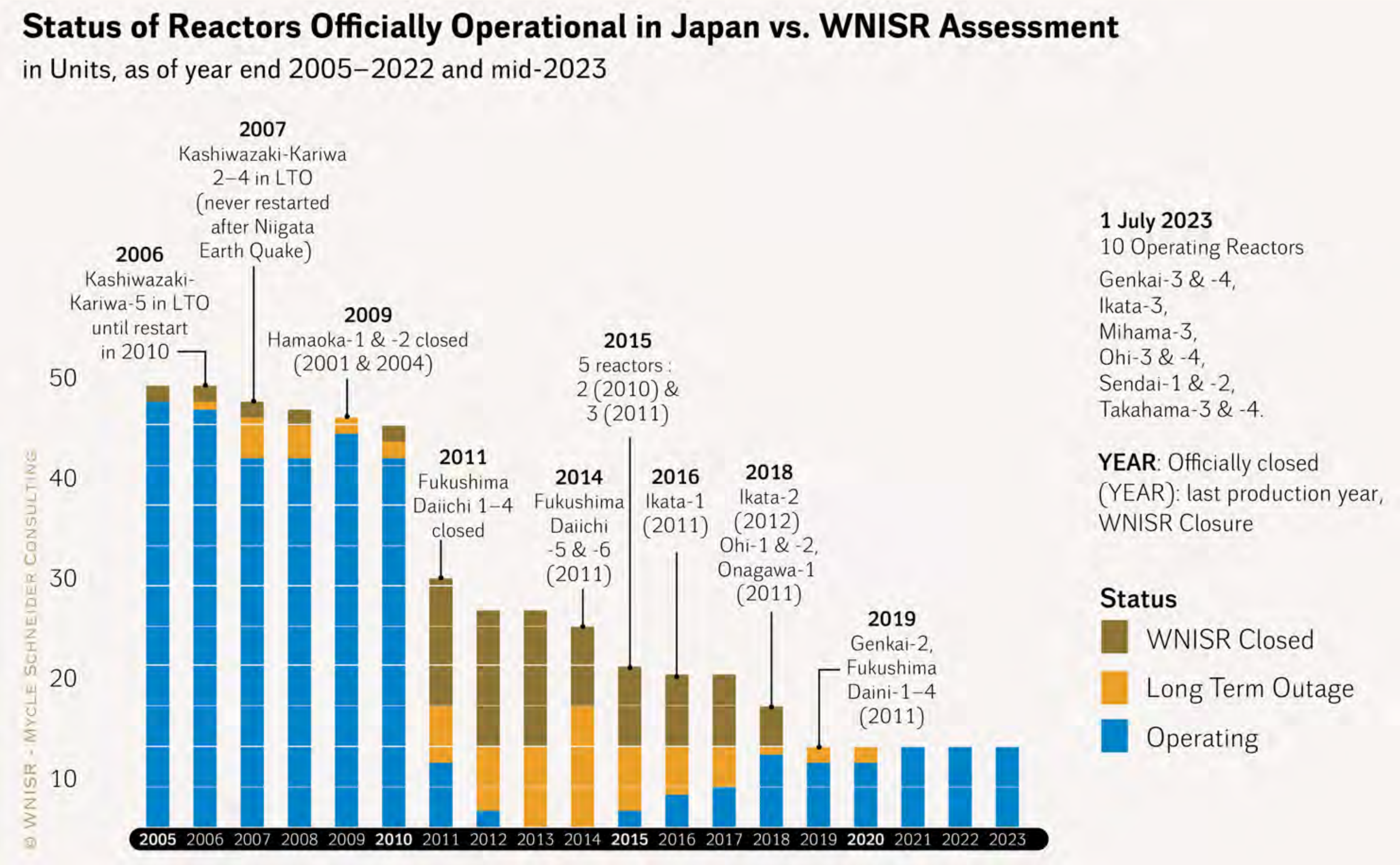
- **FOOD CONTAMINATION**

  - Officially, 36,309 samples were analyzed in FY2022
  - Only 135 from 10 prefectures exceeded legal contamination limits; but in Fukushima, increase from 42 to 51 (0.85%) of ~6,000 samples
  - 12 countries and regions (down from 54 countries) still have import restrictions for Japanese food items

- **DECONTAMINATION AND CONTAMINATED SOIL MANAGEMENT**

  - Four out of a total of ten storage facilities filled to capacity
  - About 88% of storage capacity filled without any final disposal plan yet

JAPAN FOCUS – Operational Status of Reactor Fleet



Sources: Various, Compiled by WNISR, 2023

FOCUS JAPAN – In the News…

- **Fraud Cases at Japan Steel Works**

  - Hundreds of falsification cases at key manufacturer of large forgings for nuclear power plants around the world (e.g. for EPRs in Europe).

- **New Nuclear Energy Policy**

  - GX Transformation laws major shift as they allow for the construction of new reactors in Japan for the first time since the Fukushima disaster.

  - Amends nuclear regulation to allow for lifetime extensions beyond 60 years.

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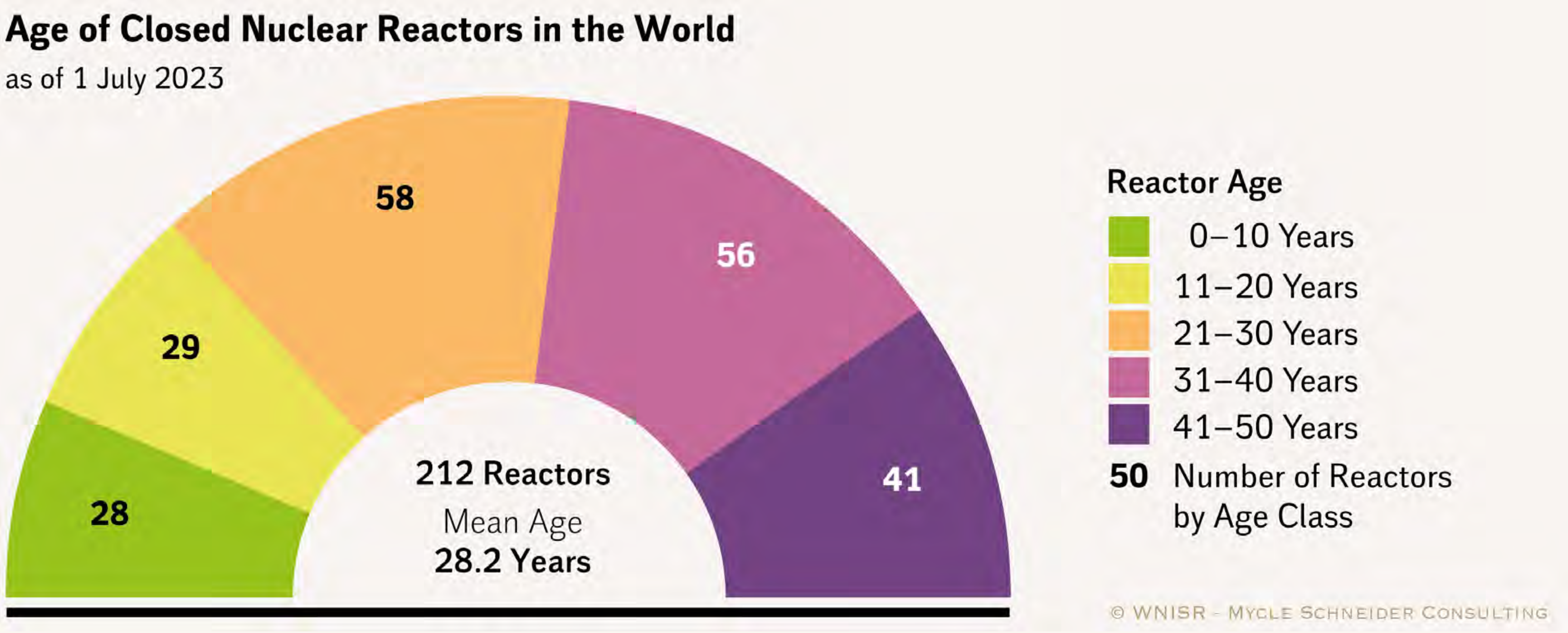
Alexander James Wimmers is a research associate of the AT-OM research group at the Workgroup for Economic and Infrastructure Policy (WIP) at the Berlin University of Technology (TU Berlin), Germany.

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.

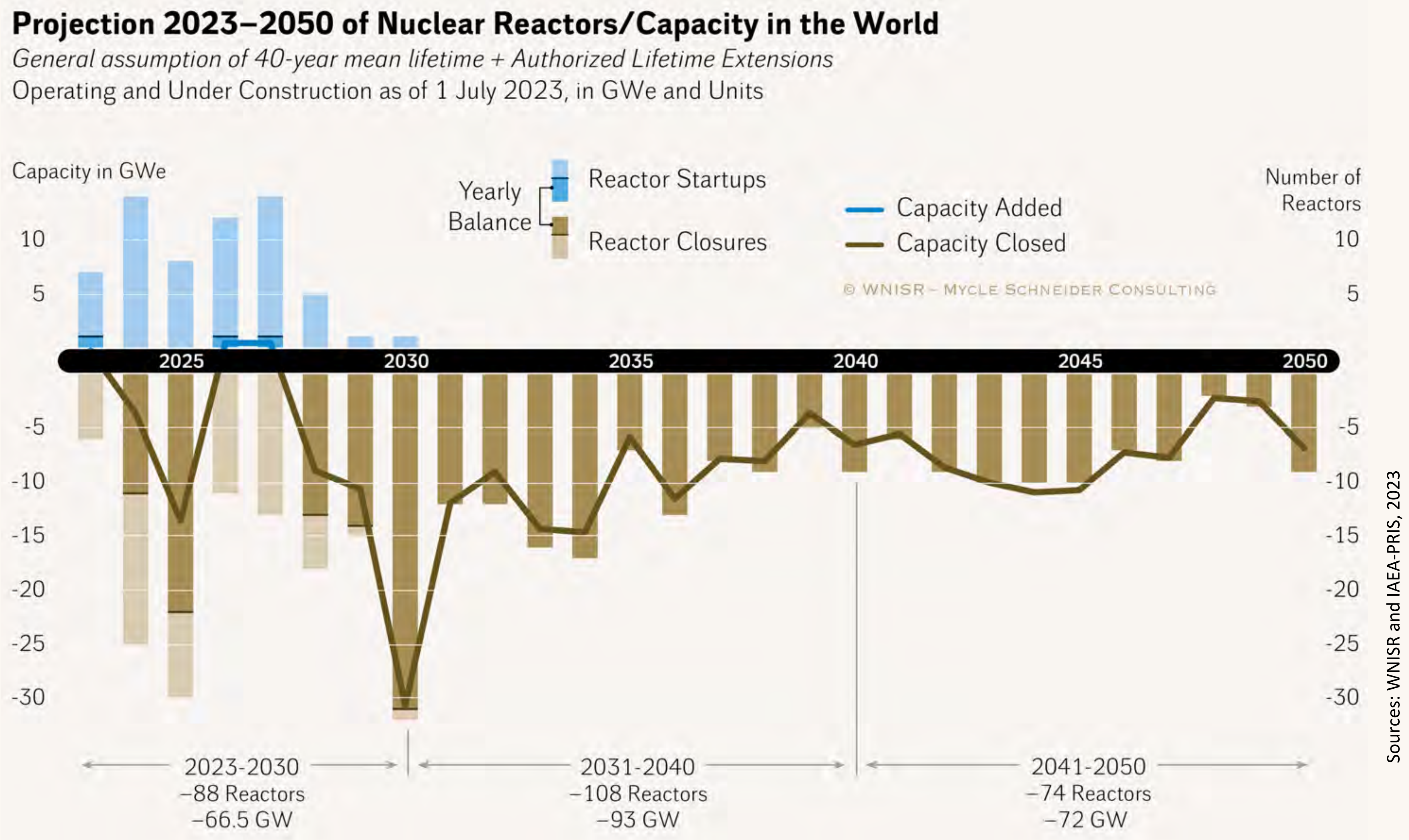
His current research focuses on the political economy of nuclear power, from new build, operation and decommissioning to nuclear waste management. He is a member of a long-term research project on nuclear decommissioning in cooperation with the University of Basel.

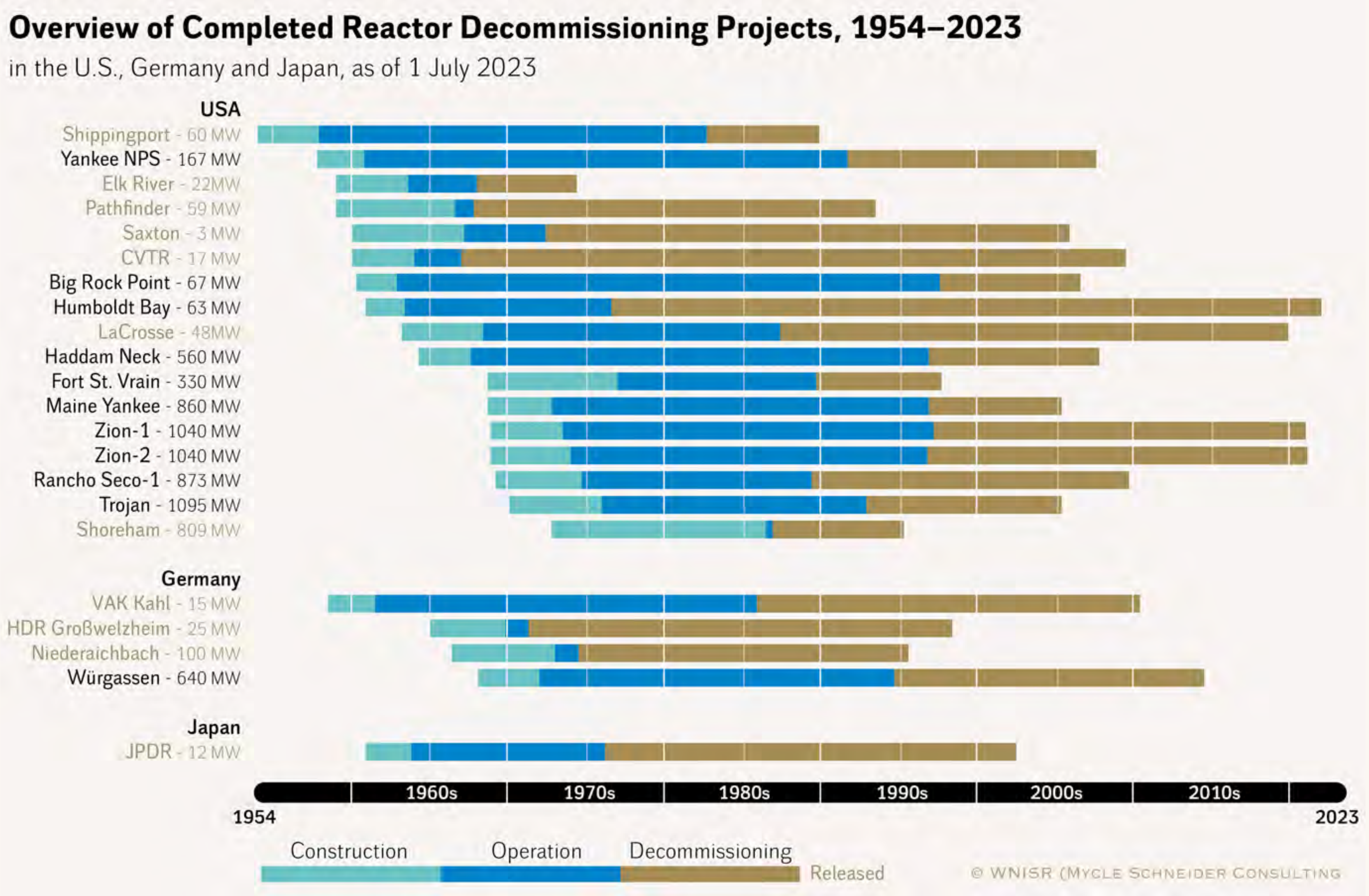
GLOBAL OVERVIEW – Age at Closure



Sources: WNISR, with IAEA-PRIS, 2023

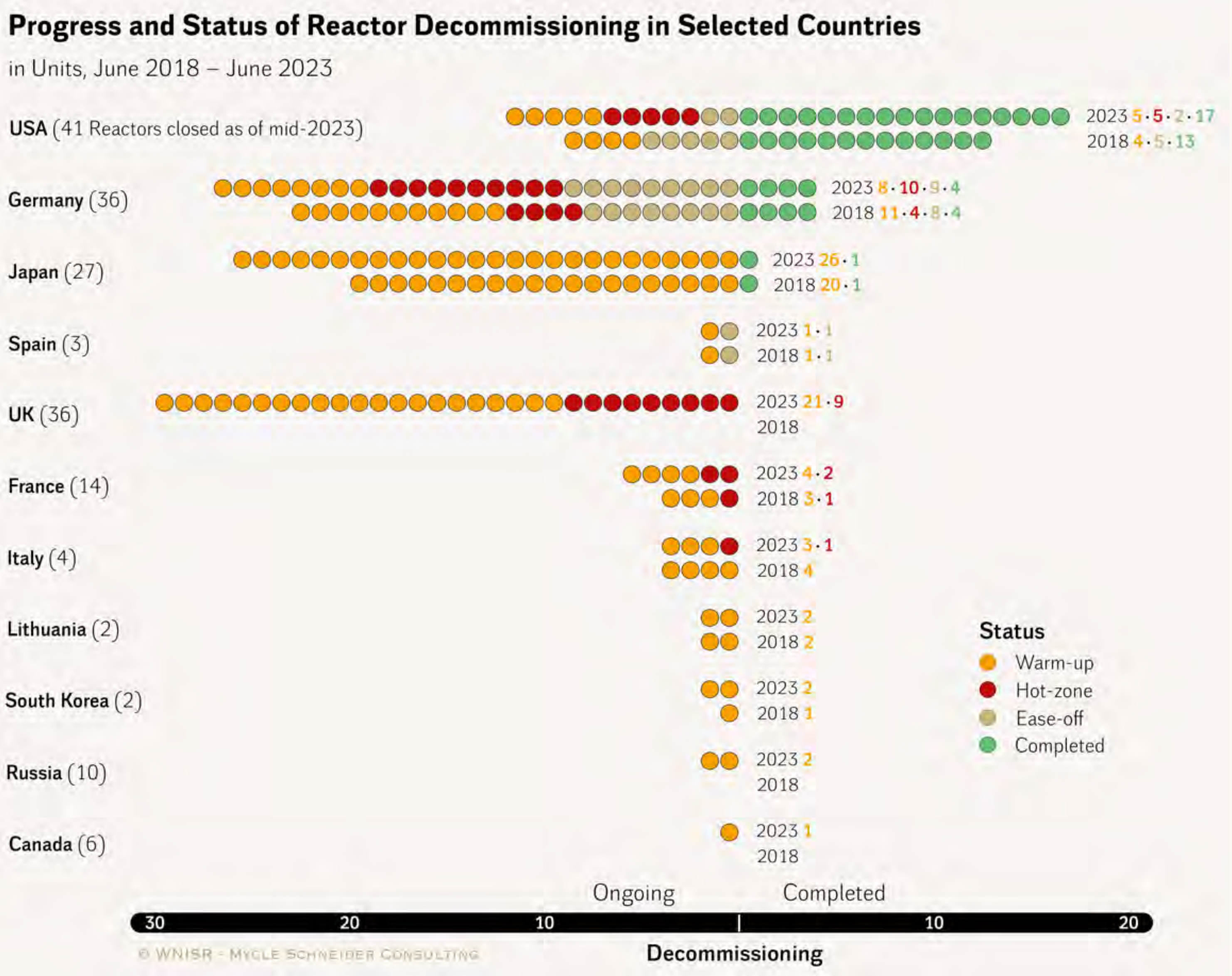
PROJECTIONS – The PLEX Projection





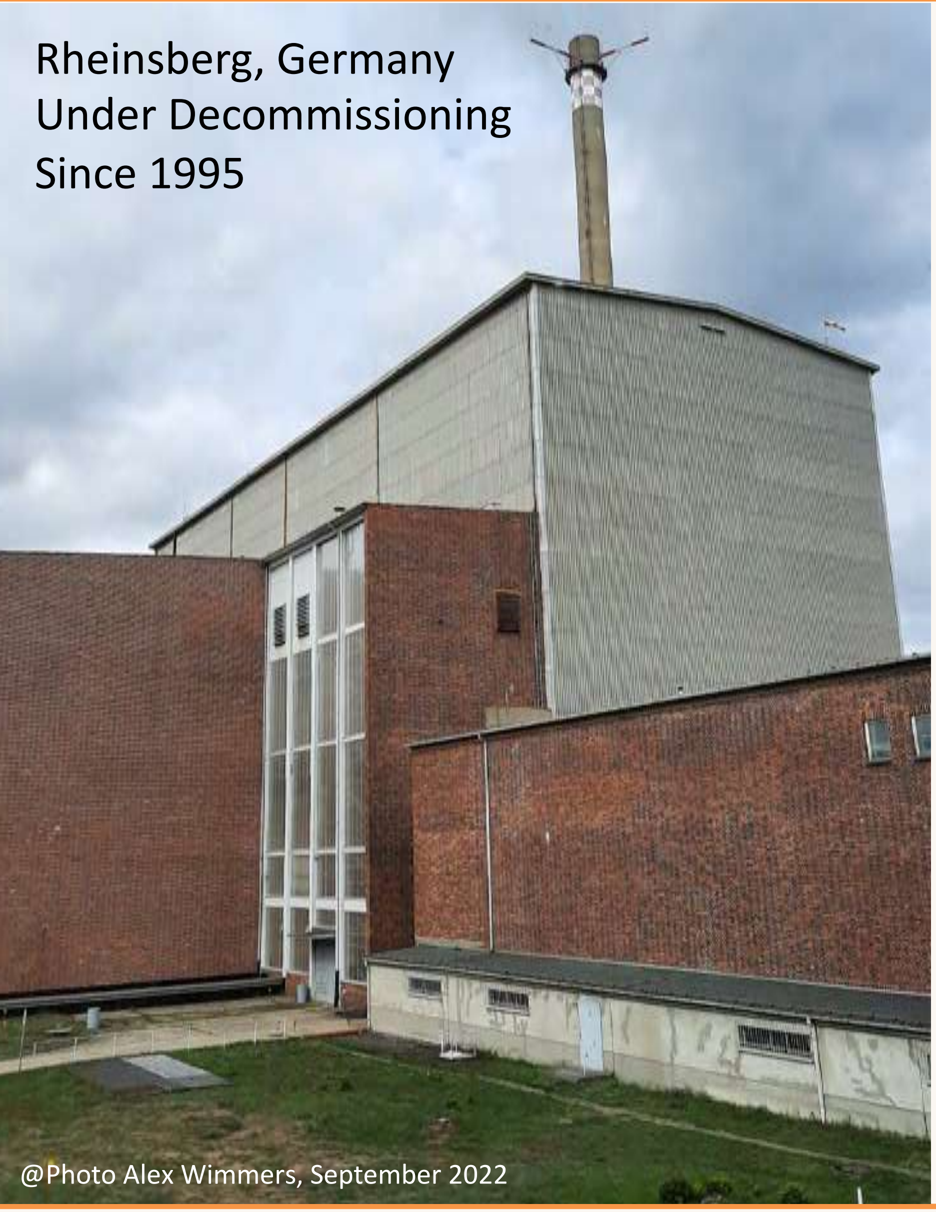
Sources: Various, compiled by WNISR, 2023

DECOMMISSIONING STATUS REPORT – Progress Slow, Some Developments



Sources: Various, compiled by WNISR, 2023

DECOMMISSIONING STATUS REPORT – Conclusions



- Historically often underestimated and underrepresented challenge in the nuclear system
- Decommissioning projects often experience delays resulting from uncertainties, e.g., contamination, high degree of asset specificity
- Final cost for decommissioning and liability in parts unresolved – in addition to the question of whether accumulated funds (provisions or external) will suffice
- Calculations based on cost estimations and provisions for Germany, Italy, and Lithuania place decommissioning costs in the range of 5 to 12 USD per MWh

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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 "Nuclear is not the Solution: The Folly of Atomic Power in the Age of Climate Change" (forthcoming from Verso).

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.

SMALL MODULAR REACTORS (SMRs) – Claims vs. Reality

- **IAEA (2022)**

  "more than eighty (80) SMR designs under development and deployment at different stages"

  → Many designs are early (PowerPoint) stage; some are dormant or abandoned

- **NEA (2023)**

  "substantial progress towards SMR deployment and commercialization… with much of this progress taking place during the past two years"

  → Only 2 x 2 SMRs deployed in the world:

  - twin HTGR units in China (construction in 109 months, instead of expected 50 months)

  - KLT-40S started in 2020 (13-year construction period instead of <3 years)

SMALL MODULAR REACTORS (SMRs) – Government Funding

France

€500 million (US$544 million) for NUWARD development

Canada

CAD970 million (US$708 million) from the Federal Infrastructure Bank to Ontario Power Generation for Darlington Project

South Korea

KRW399 billion (US$303 million) to establish the "Innovative [SMR] Technology Development Project"

Perspective

According to its third-quarter 2023 Earnings Call, NuScale has "invested more than US$1.8 billion" so far

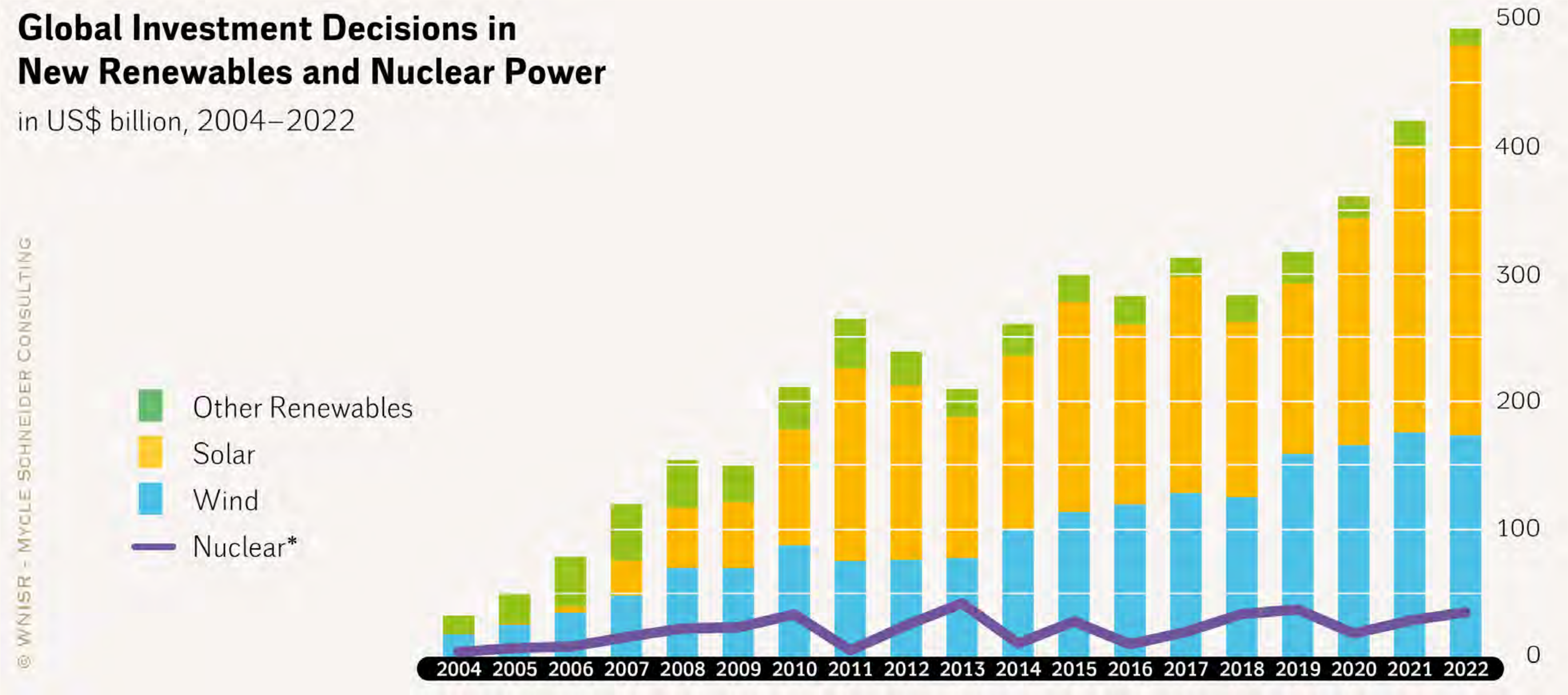
SMALL MODULAR REACTORS (SMRs) – The UAMPS Story

- **NuScale Power**
  - Company incorporated in 2007
  - Offered a 40 MW design, projected to cost US$160 million/unit
  - January 2008: "could be producing electricity by 2015-16"
- **Utah Associated Municipal Power Systems (UAMPS)**
  - Agreement in 2013 to "study the deployment of NuScale's 45-MW small modular reactor design by 2024"
  - By 2018, cost of 12 x 60-MW (720 MW) project = US$4.3 billion
  - By 2020, cost of 720 MW project = US$6.1 billion
  - Withdrawal of many municipalities from project
  - January 2023: cost of 6 x 77-MW (462 MW) project = US$9.3 billion
  - 8 November 2023: project terminated due to poor subscription

SMALL MODULAR REACTORS (SMRs) – NuScale Lost 80% of Share Value

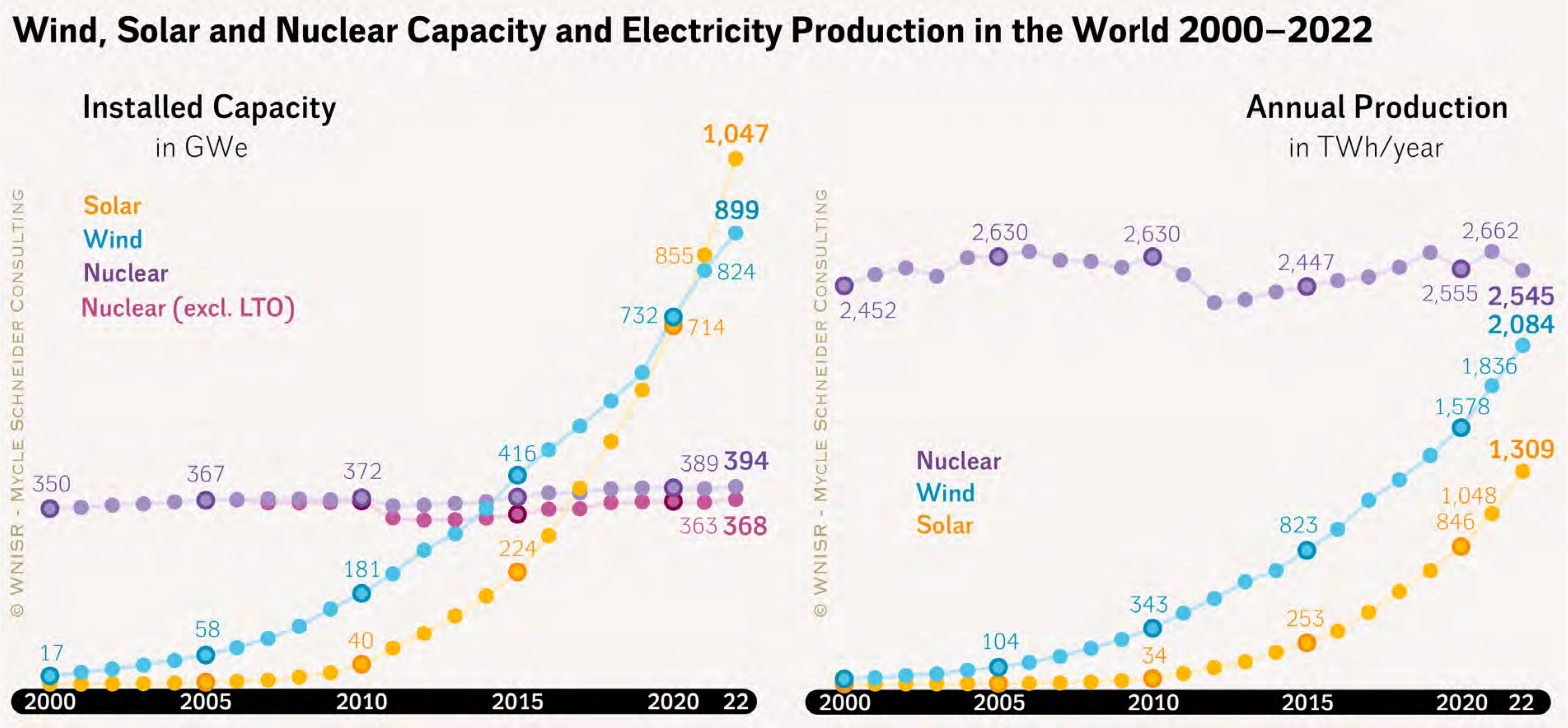
Source: Yahoo Finance, November 2023

NUCLEAR POWER VS. RENEWABLES – Investment Decisions



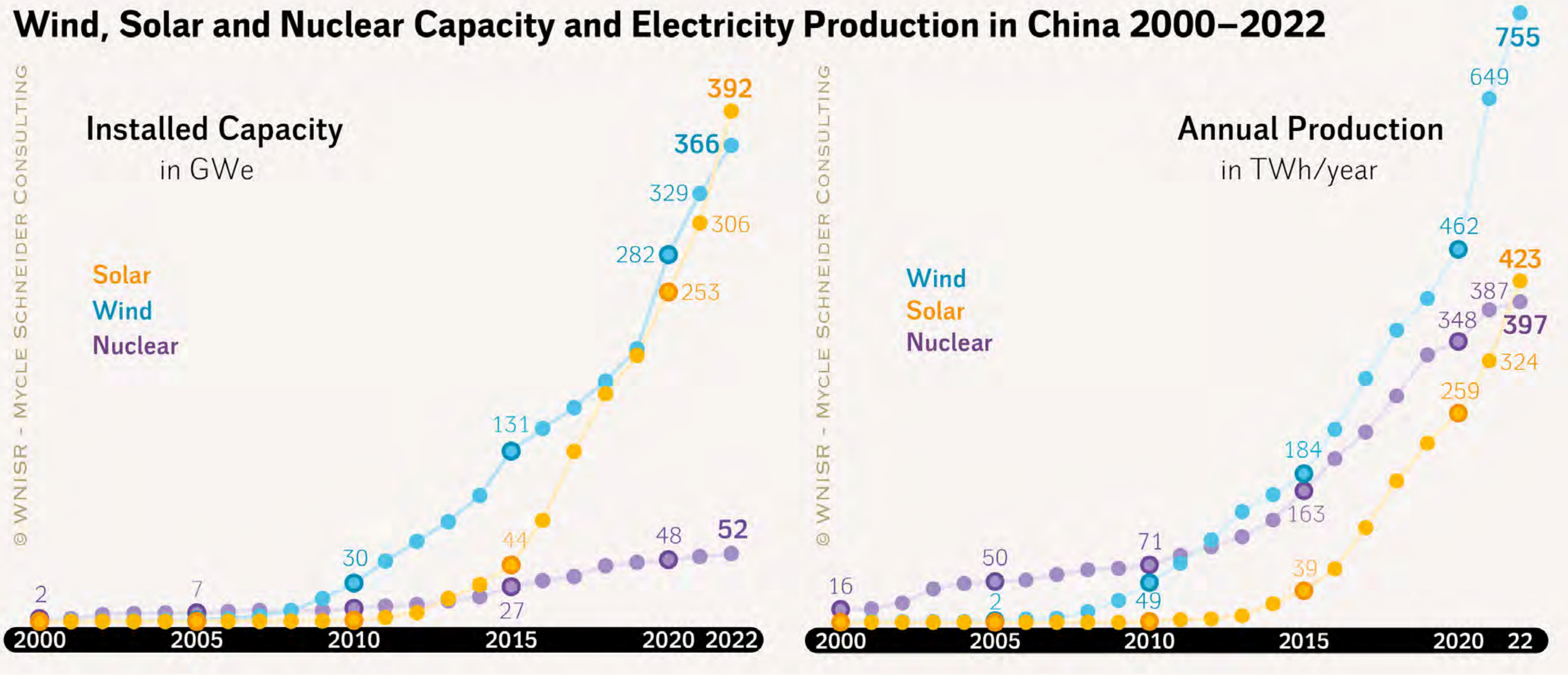
Sources: BNEF and WNISR Original Research, 2023

NUCLEAR POWER VS. RENEWABLES – Capacity and Production



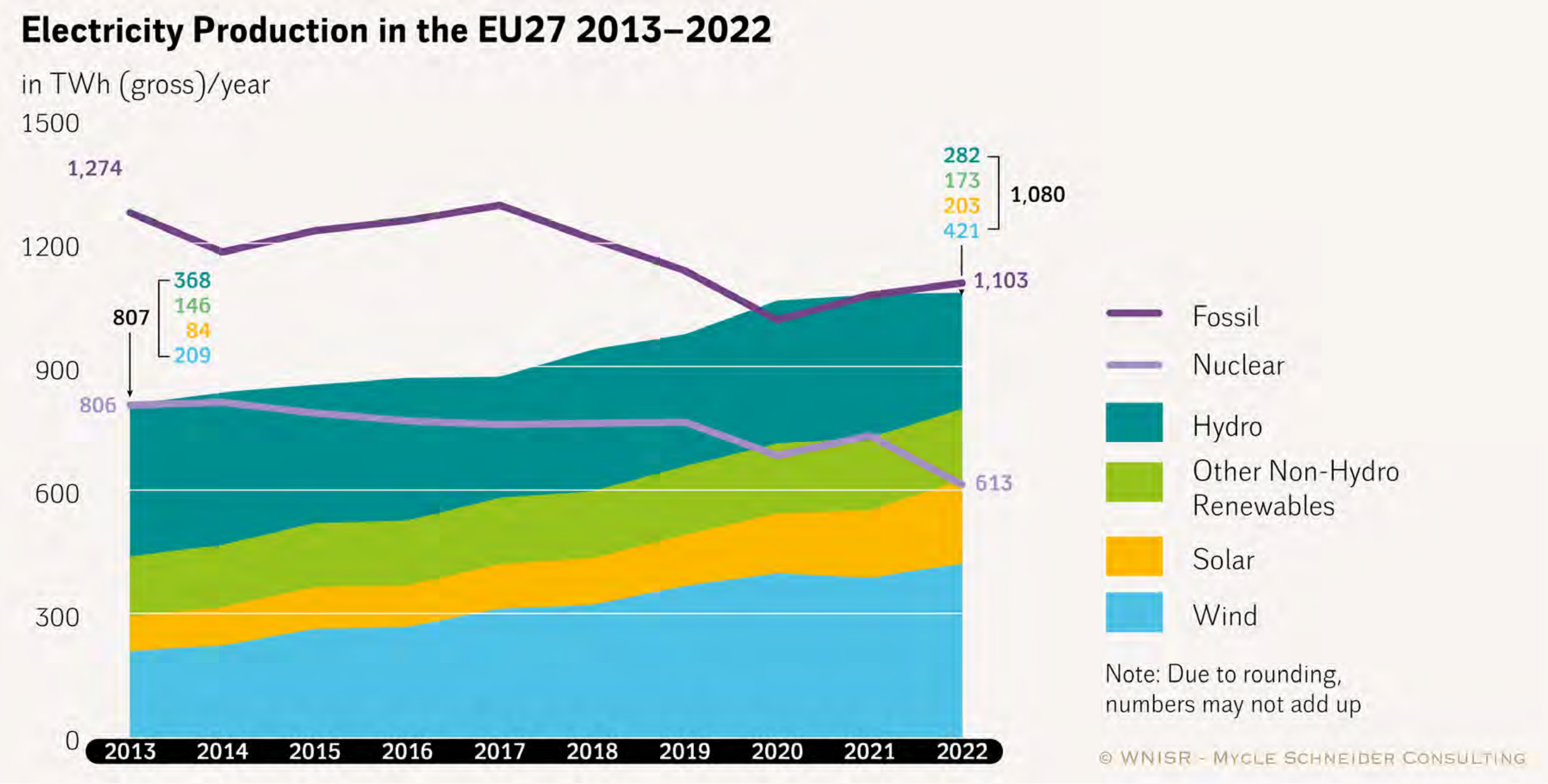
Sources: WNISR with IRENA, and Energy Institute, 2023

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – China



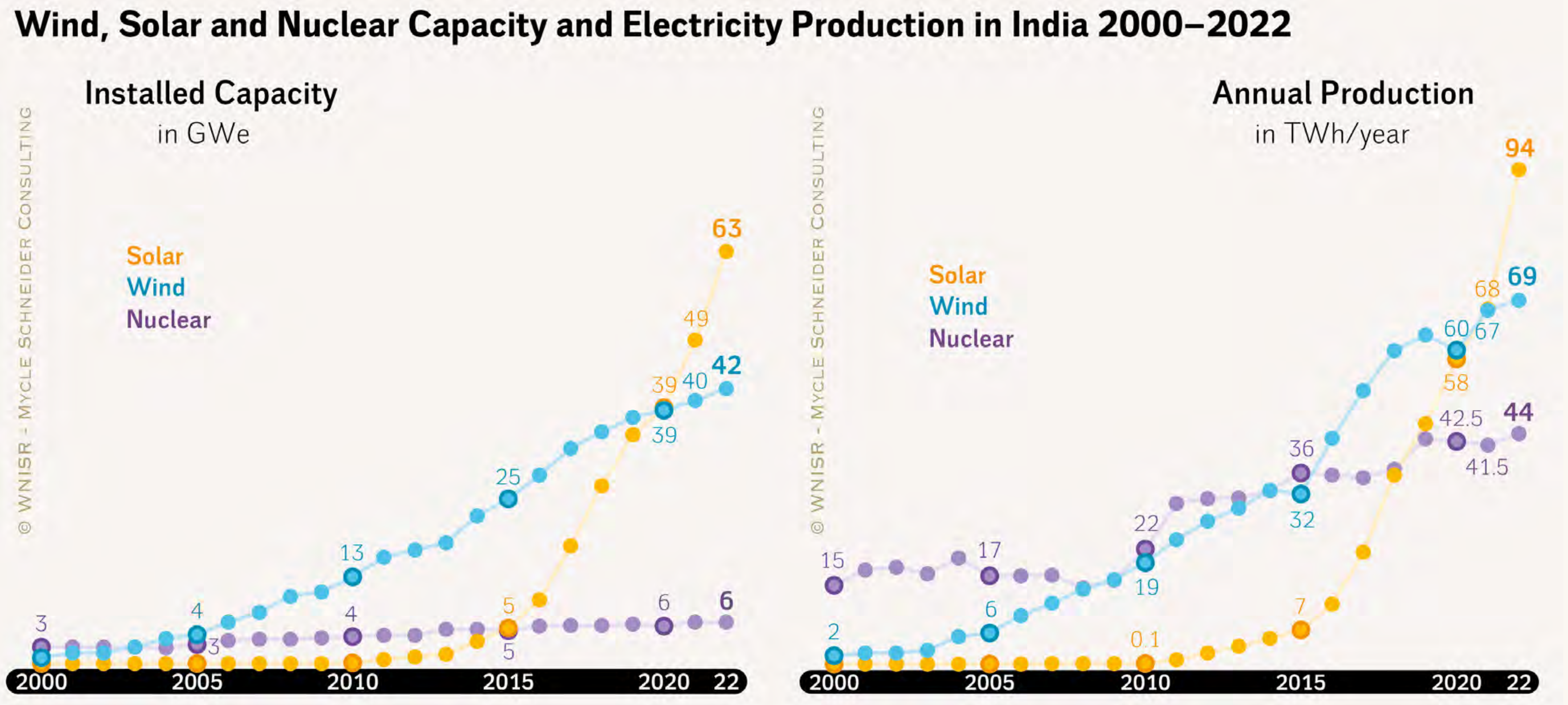
Sources: WNISR with IRENA and Energy Institute, 2023

EU27: Nuclear Output Lowest Since 1986, Exceeded by Solar + Wind



Source: EMBER, Yearly Electricity Data, June 2023

NUCLEAR POWER VS. RENEWABLES DEPLOYMENT – India



Sources: WNISR with IRENA and Energy Institute, 2023

CONCLUSIONS

- The global nuclear industry has been on a downward trend for a long time. The current building rate is insufficient to make up for closures and thus to guarantee its survival. Countless announcements but on the ground, there are no signs of any change.
- All 28 reactor construction starts between January 2020 and mid-2023 were either in China (18) or implemented by Russia (11) in various countries.
- The casted miracle solution to decline is disappointing: SMR projects fail to keep promises. They are difficult—thus long—to build, extremely expensive, and the few (four modules) that were completed in China and Russia underperform on the grid.
- NuScale, the most advanced SMR development in the west, is years behind schedule (whatever point of beginning), and
    - the cost estimate is now at US$9.3 billion for a 6-module plant, US$20,000/kW, at least 2 x cost of European EPRs;
    - the only commercial project (UAMPS) in the U.S. has been terminated;
    - investors loose confidence as NuScale shares lost 80% of their value in 14 months.
- Most SMR designs under development are at best in pre-licensing talks with regulators. Compared to the EPR timeline, that corresponds to the status in the mid-1990s with the first unit coming online in the E.U. in 2022.
- The main nuclear builders in the west have a long history of delays and cost-overruns. There is no evidence that this would be any different in the future. The financial state of EDF/Framatome and KEPCO/KHNP is of concern and inadequate for major additional nuclear projects. Human and financial resources are already stretched with operating fleets and ongoing projects.
- The increasingly widening gap between perception by the public and decision-makers and the industrial reality of the nuclear sector remains worrying, since, as a result, focus, human and financial resources are diverted from essential, available options.