Major Themes Driving New Nuclear – 2023

Andrew D. Paterson, EBI

TOKYO: Where to put solar and wind?

Despite: Cost Overruns, Fukushima, Chernobyl…

Nuclear Energy Enables Clean <u>Urban</u> Living

-- most of the Driving Factors are outside USA

- **Energy Security has leaped up to be #1 driver for new nuclear [NATO, Asia]**
  - Gas price roller coaster in 2022, plus cut off of Russian supply. <u>Nations seek autonomy.</u>
- **The track record on wind and solar <u>for URBAN energy</u>** has failed.
- **Large scale shift to Electric vehicles in OECD cities** demands Nuclear
  -- wind, solar, hydro cannot effectively charge millions of new EVs, nor rail.
- **Urban mass transit** will demand new nuclear; Renewables not reliable 24/7
- **Major shifts coming in Industrial sectors** from N.Gas to Hydrogen by nuclear
- **Nuclear is the only "always-on, emission-free, small footprint" solution**
  -- CCS can play a supporting role on reliability, but sites are limited in OECD.

EBI – on Strategic Intelligence & Finance for Environmental Markets

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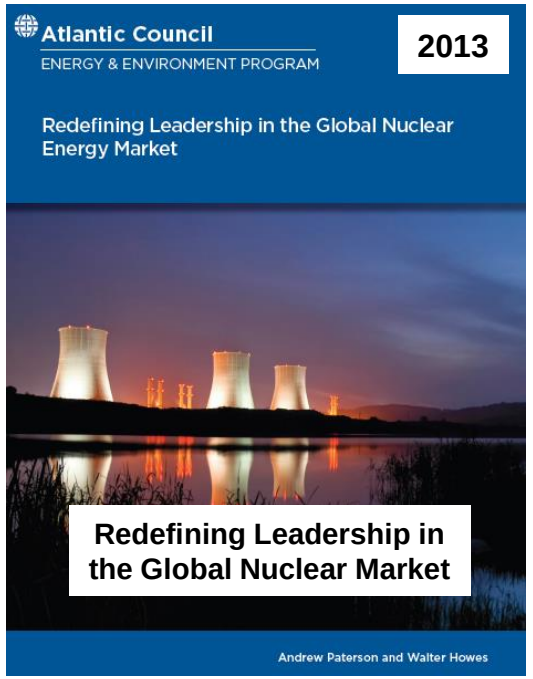
Advising U.S. Nuclear Infrastructure Council

United States NIC Nuclear Infrastructure Council

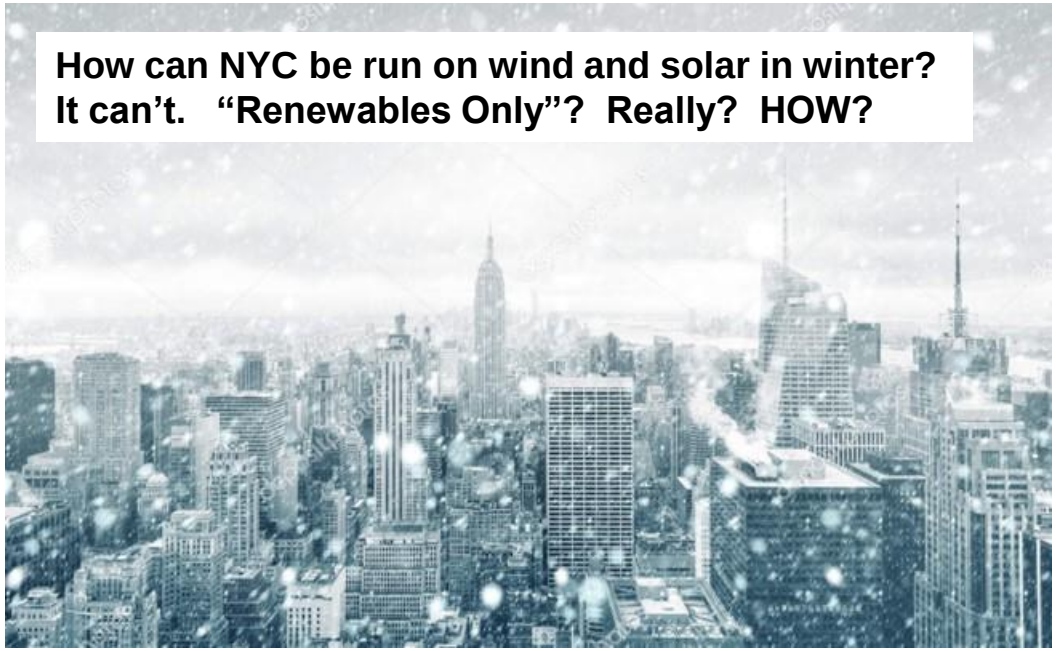
Policy and Market Factors Shaping National Nuclear Strategies
"Nuclear Energy Remains Vital to Urban Energy Reliability, amid "Pivot to Asia" (2015)
Expanding populations in Asia, high levels of economic growth, and increasing urbanization are combining to create demand for large amounts of reliable and affordable base-load electricity. Governments in Asia and some in the Middle East have recognized this need and have made nuclear power a major part of the energy mix. China alone is expected to have eight mega-cities and more than 200 cities with over one million residents by 2030. Affordable baseload electricity is crucial for these countries to sustain the high level of economic growth they have experienced during the last decade. Government enterprises are responsible for the building and operating nuclear power plants. IAEA sees total world capacity touching 600 GWe by 2030, from 370 GWe today, but capacity in Europe (160 GWe today) will decline by then.



www.climatechangebusiness.com/Policy_Market_Factors_Shaping_National_Nuclear_Strategies

SEOUL, SK: Where to put all the wind turbines?

How can any Urban Bus Fleet be charged by Solar at night? "Renewables Only" is not feasible.

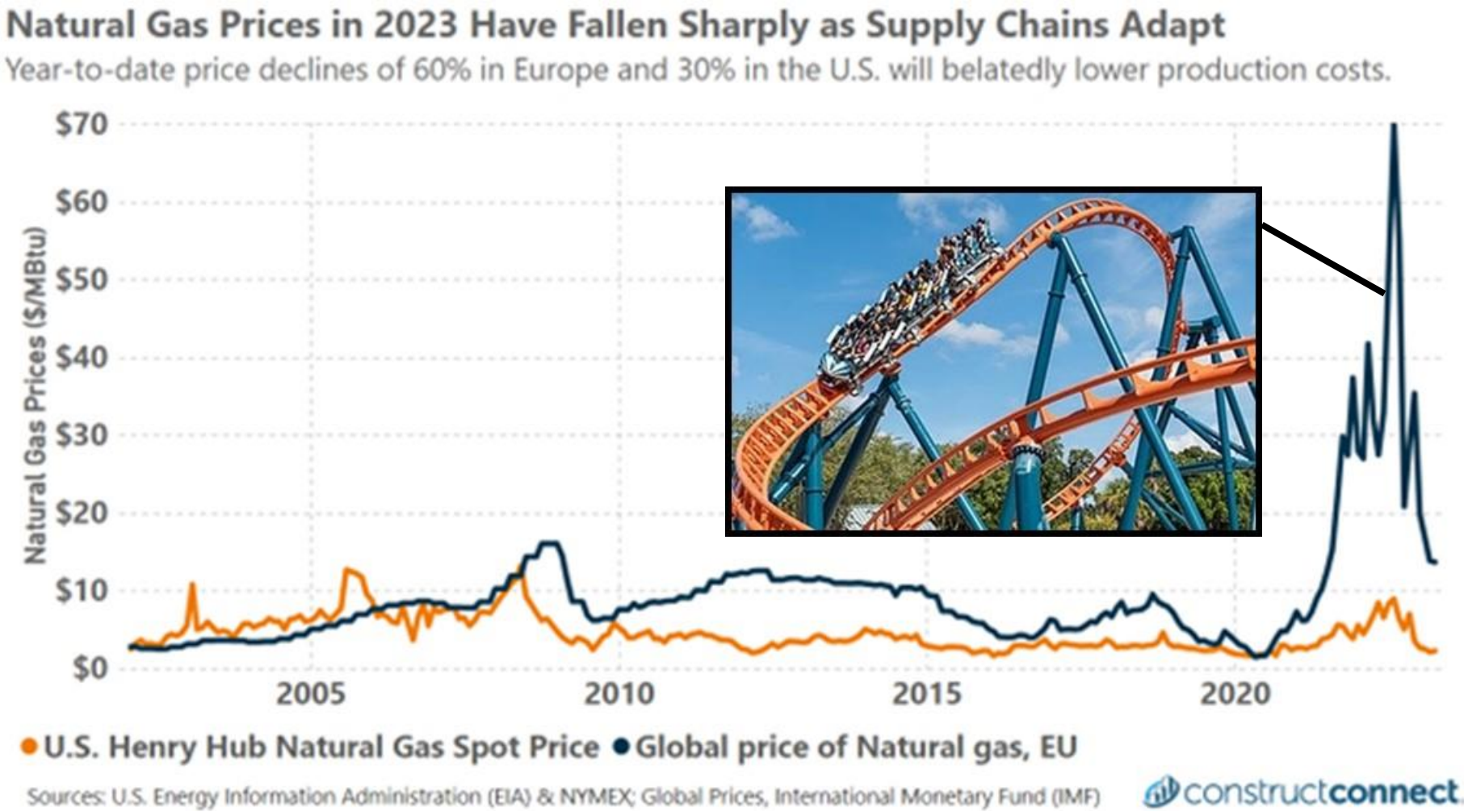


Aluminum smelting by wind and solar? NO

Retreat to the Future

"Renewables-ONLY" is Quaint… Medieval

BIG DISRUPTION IN ENERGY SECURITY for Europe / UK, 2022

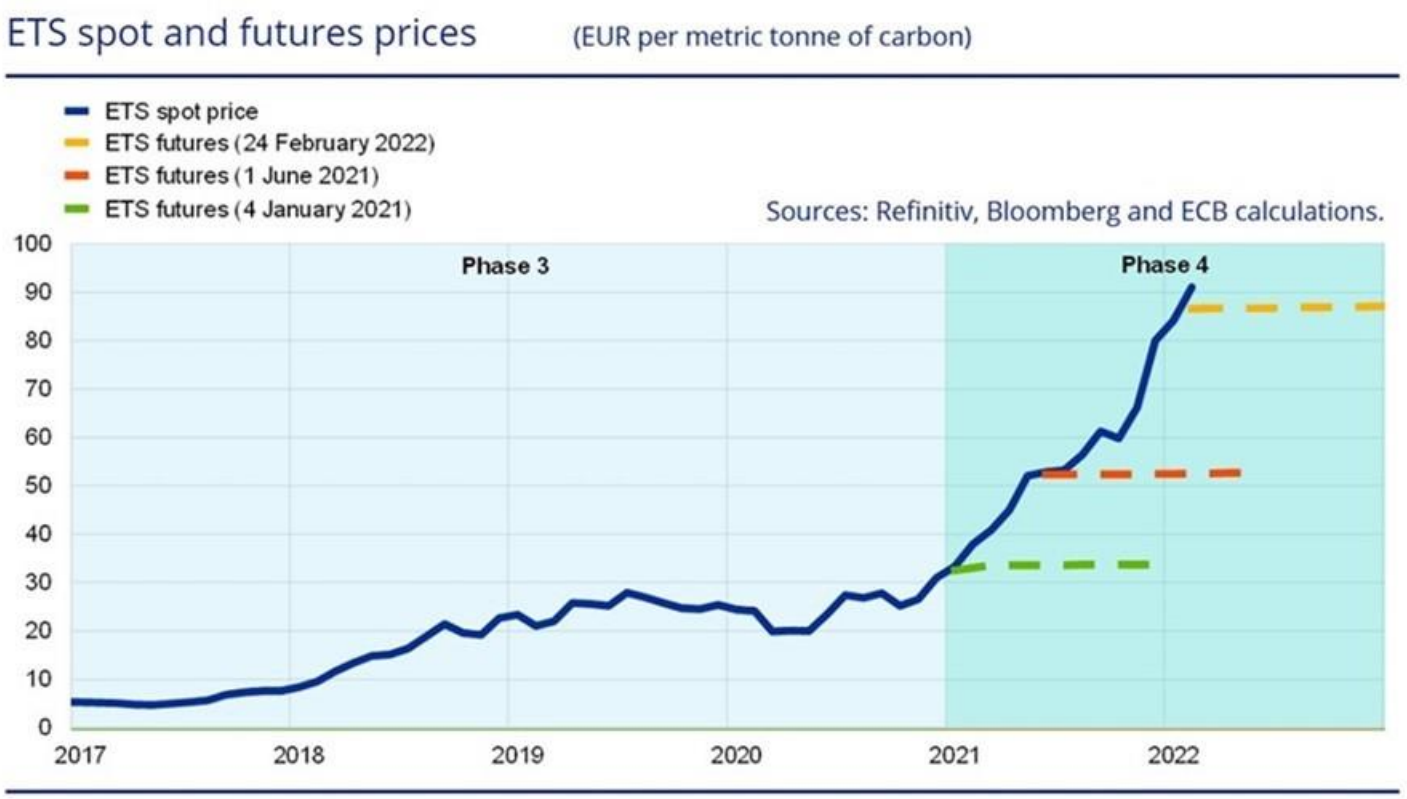


Nordstream Sabotage, Sept. 2022

EU – ETS adds more volatility to energy use prices

Adding Carbon Trading to variable Electricity market bidding, on top of gas fuel price fluctuations creates ***TRIPLE-LAYERED VOLATILITY… !***

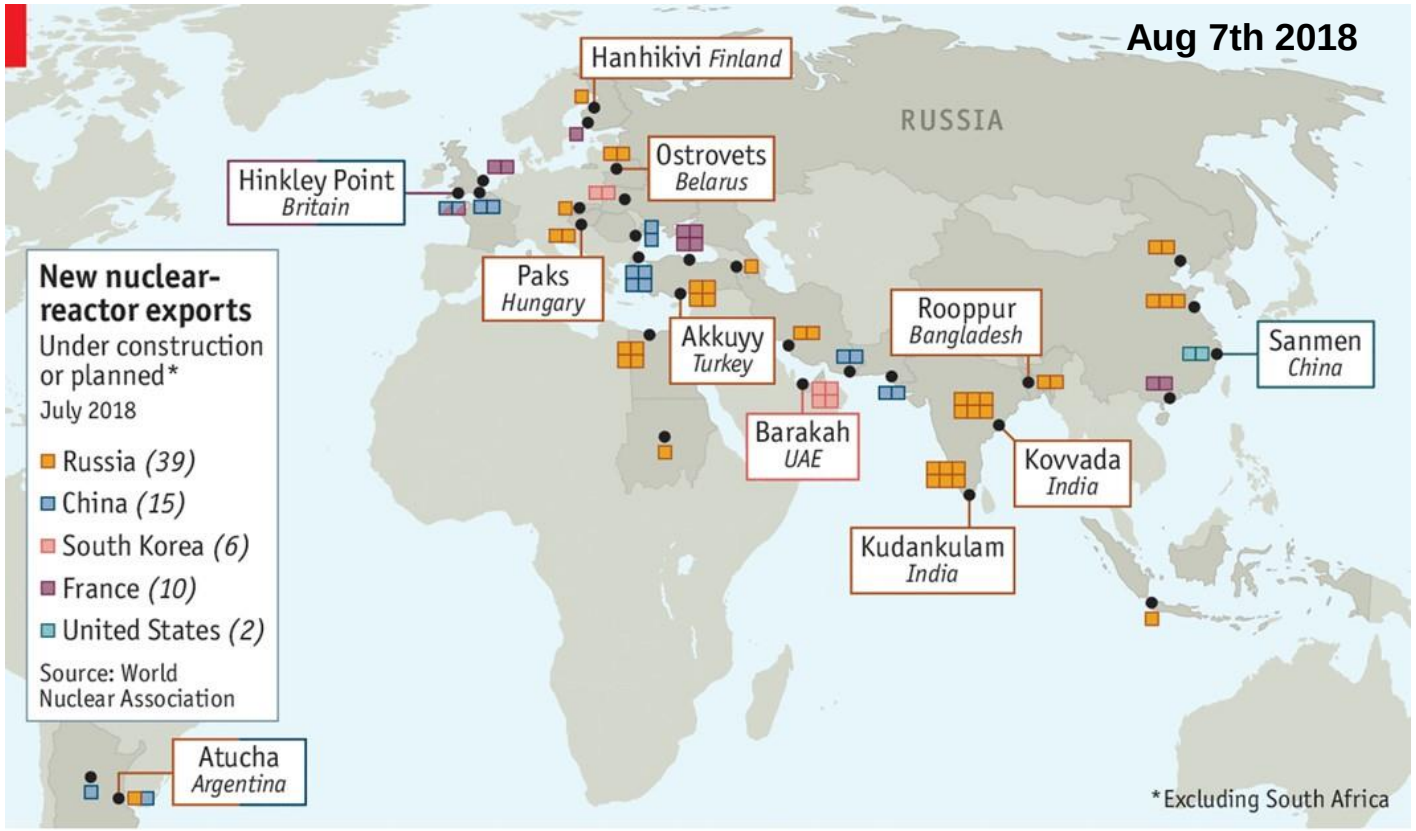
Why do States seek that?!!



The EU ETS has undergone numerous changes over the years. Introduced in 2005, the system was designed in trading periods and is now in its fourth trading phase. The latest observation is for February 2022 (ETS spot prices, monthly data).

Economist: Russia leads world in Reactor Projects…

“China is its only real competitor”... Or as some believe – They are working as a TANDEM.

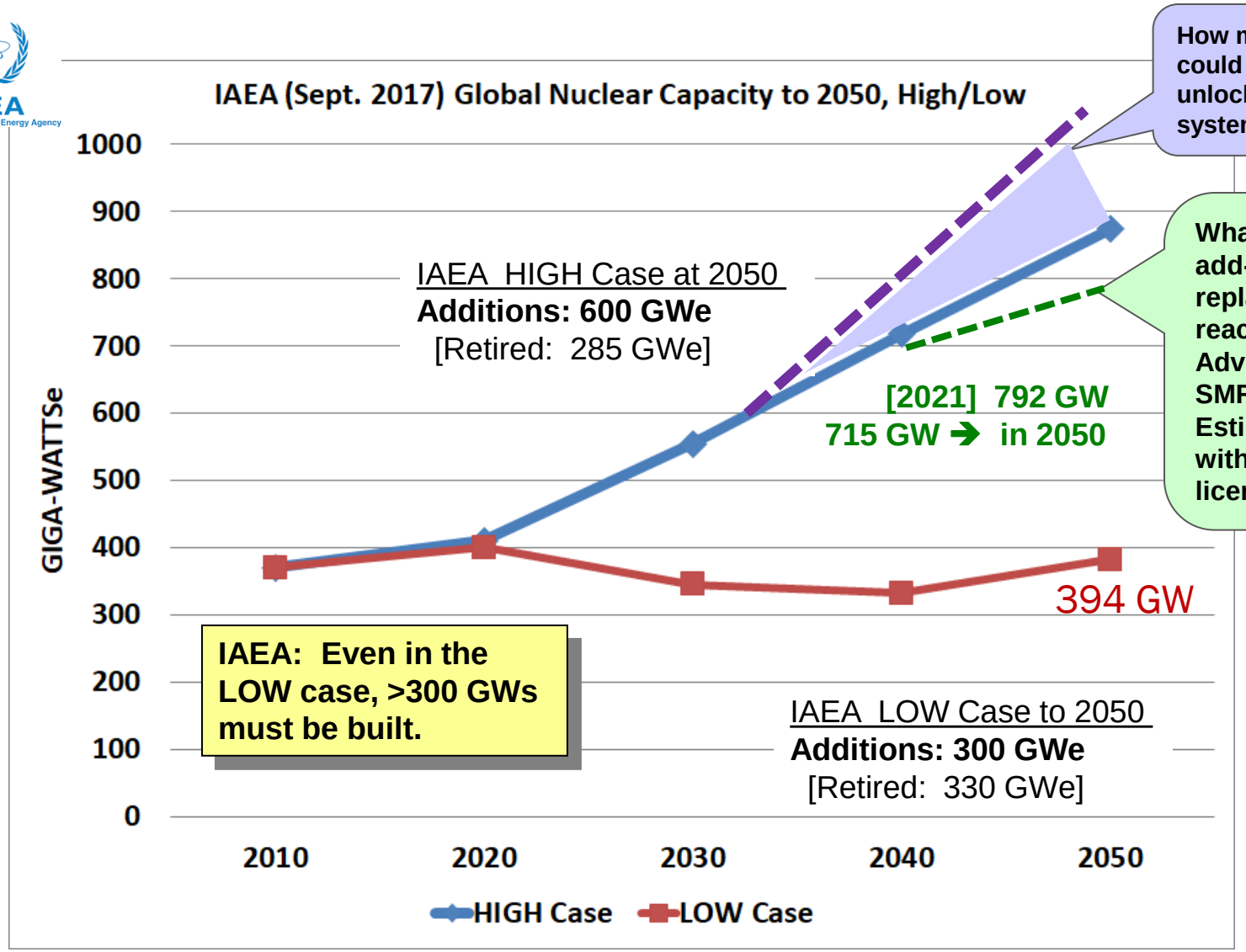


https://www.economist.com/graphic-detail/2018/08/07/russia-leads-the-world-at-nuclear-reactor-exports

Russia leads the world in Reactor Projects (2018)
“China is its only real competitor…
Russia’s nuclear programme has endured for two main reasons. Its designs are cheap, and Rosatom enjoys the backing of the state, which helps it absorb hard-to-insure risks like nuclear meltdowns. Its competitors trail hopelessly: France’s Areva (now Orano) has started building only two plants in the past ten years, in Finland and China; both are delayed and over budget. KEPCO, South Korea’s energy company, is facing a domestic backlash against nuclear power, while Westinghouse, in America, is only now emerging from bankruptcy.

Russia’s only real competitor is China, another country where government and business are tightly entwined. Until recently China has focused on meeting soaring demand for electricity at home. But importing raw materials and exporting technology is a better long-term bet, and so it has started to look abroad. A Chinese state-backed firm is partly funding Hinkley Point in Britain, and others are involved in plants in Argentina and Turkey. Yet although China will surely catch up, for now Russia has no serious rivals in the export of nuclear technology.
In a world that needs to generate much more electricity from nuclear power if it is to take de-carbonisation seriously, that is a sobering thought.

IAEA (Sept 2019) – High & Low World Estimates of Projected Nuclear Capacity PLANNED in 2030, 2040, 2050



How much market could SMRs, AMRs unlock for hybrid systems? >300 GW

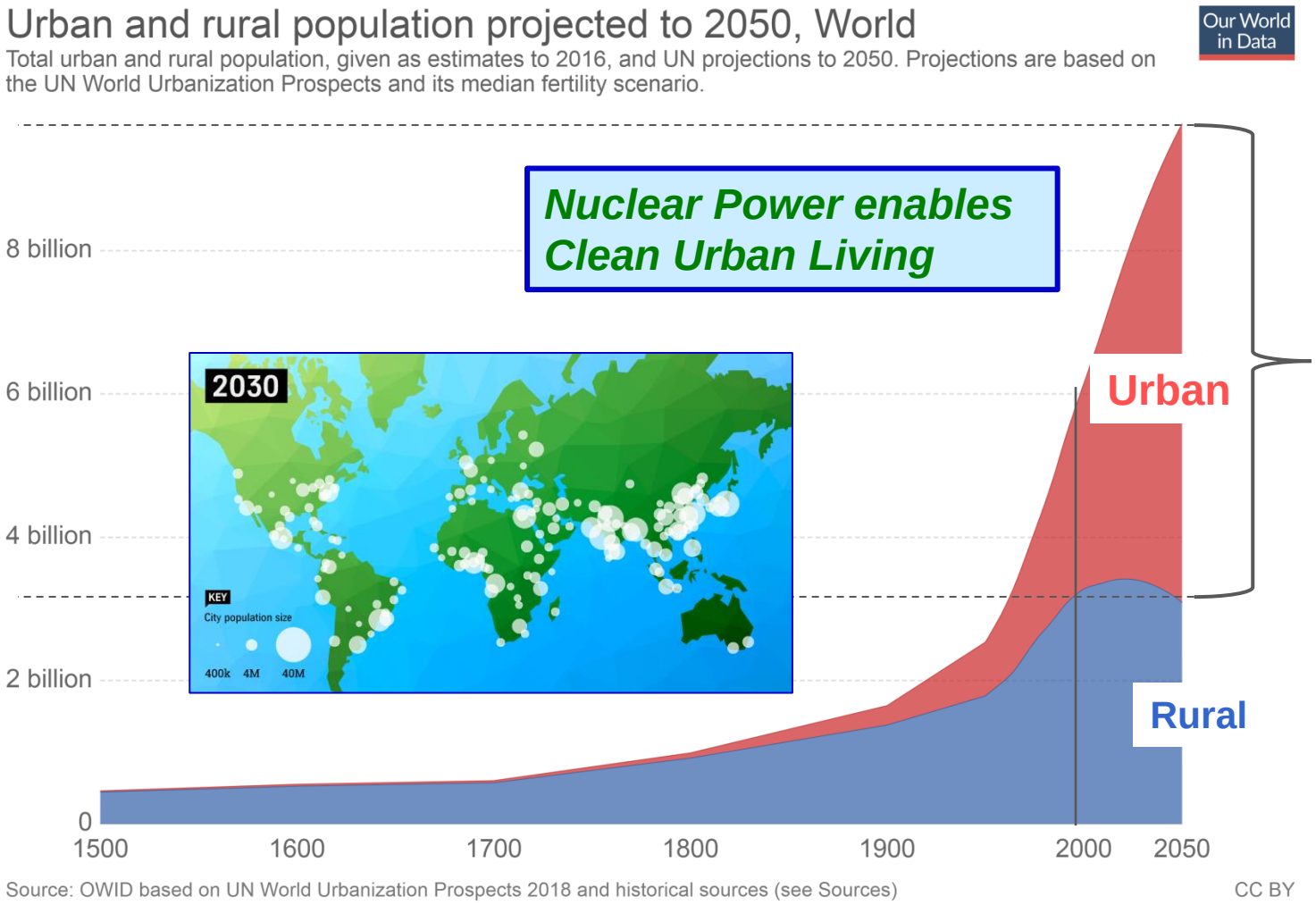
What portion of add-on and replacement reactors could be Adv Reactors, SMRs? Estimates vary with timing of license approvals.

SMR Plant requires less than half a square mile for 100 – 300 MWs.

www-pub.iaea.org/MTCD/publications/PDF/17-28911_RDS-1%202017_web.pdf Based on Country Plans submitted to IAEA

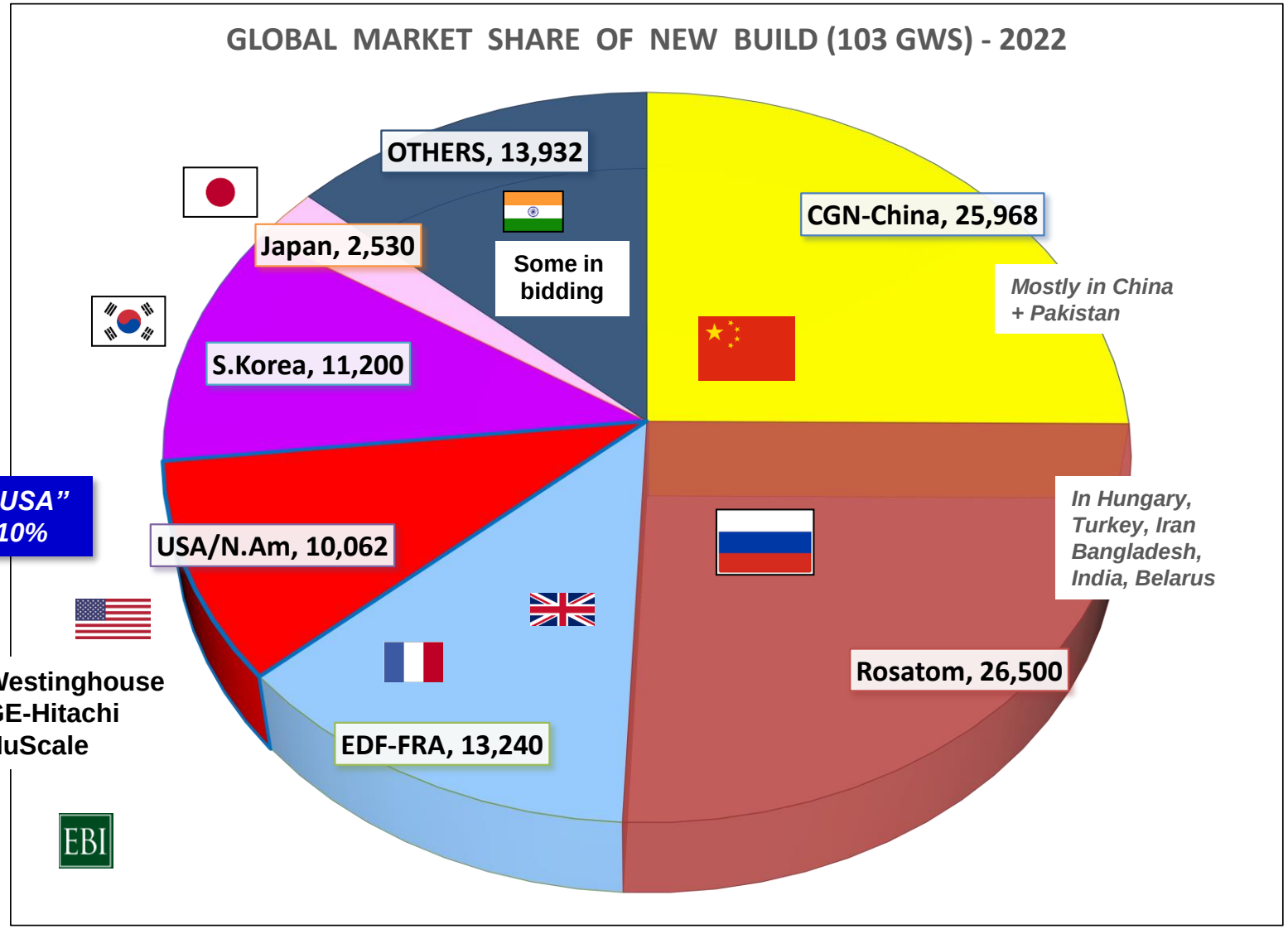
"Urban Security" – EXPONENTIAL CHANGE…

Massive Urbanization to 2050: +3b since 2010



https://ourworldindata.org/urbanization

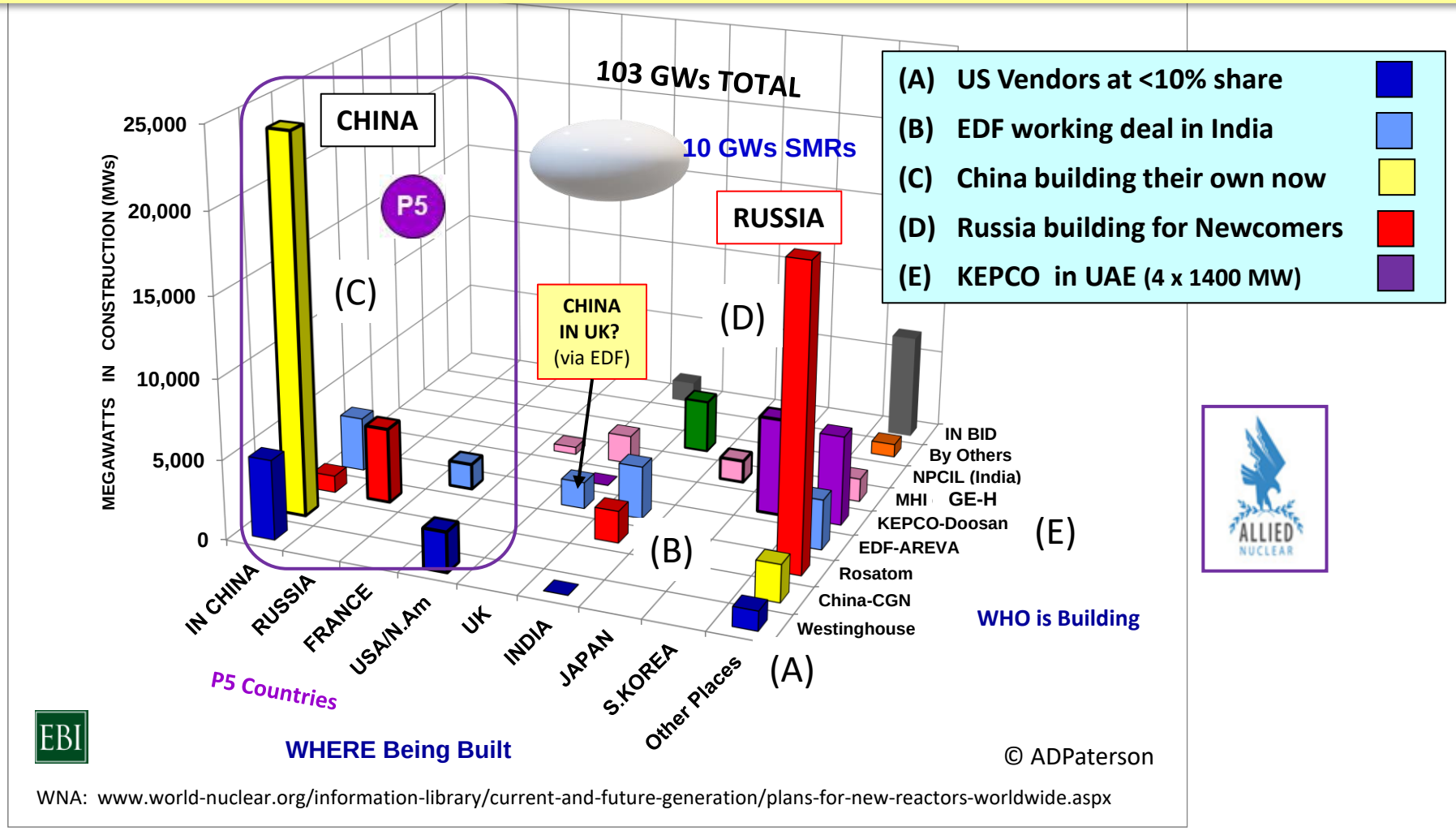
National Vendors dominate New Build: China & Russia



Sales units in MWs

China & Russia most active in Nuclear Project ARENA

From WNA listing of projects (2018-2028), augmented with trade press reports on projects very close to financing agreement. 30 GWs of 100+ GWs being built captively (no foreign contractors). **SMRs emerging.**



WNA: www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx

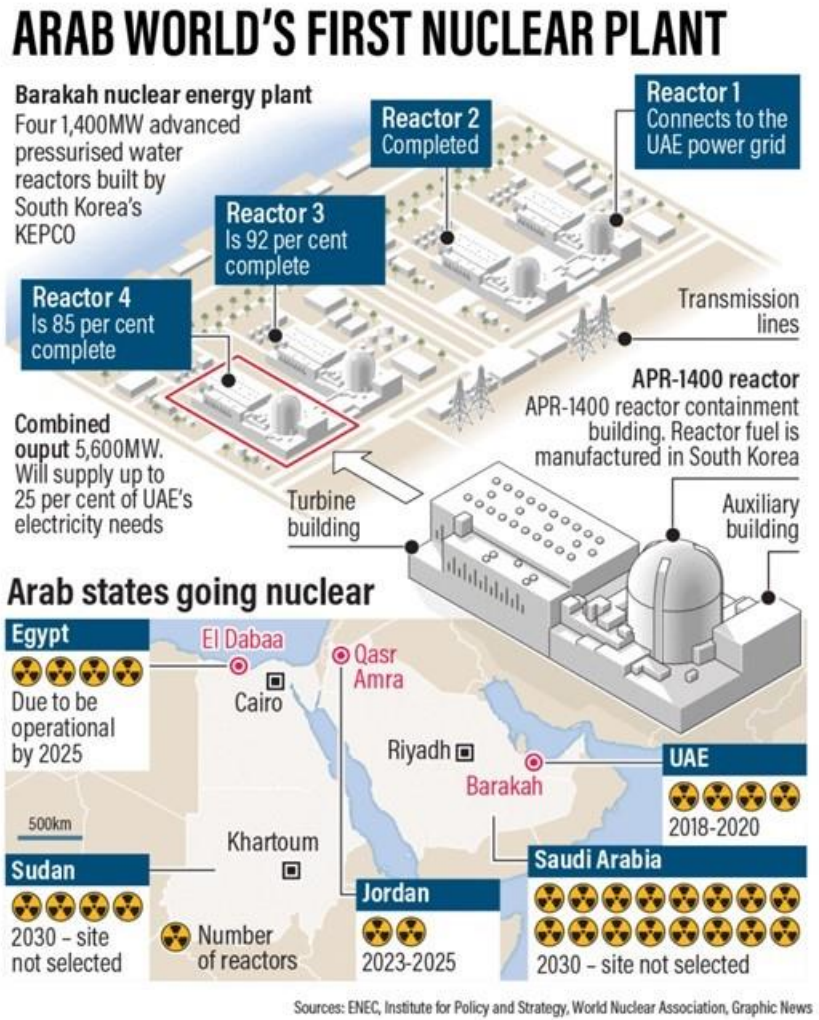
EVEN IN UAE… Emirates making major move on Chem Fabrication, 2022

UAE BARAKAH TURNS OPERATIONAL: 5600 Gwe, APR-1400s


President Yoon of SK visits UAE, Jan 2023


RUWAIS Chemical Refining Complex in UAE
$Billions

<u>PARTNERS</u>
Japan's Mitsui
SK GS Energy
India: Reliance



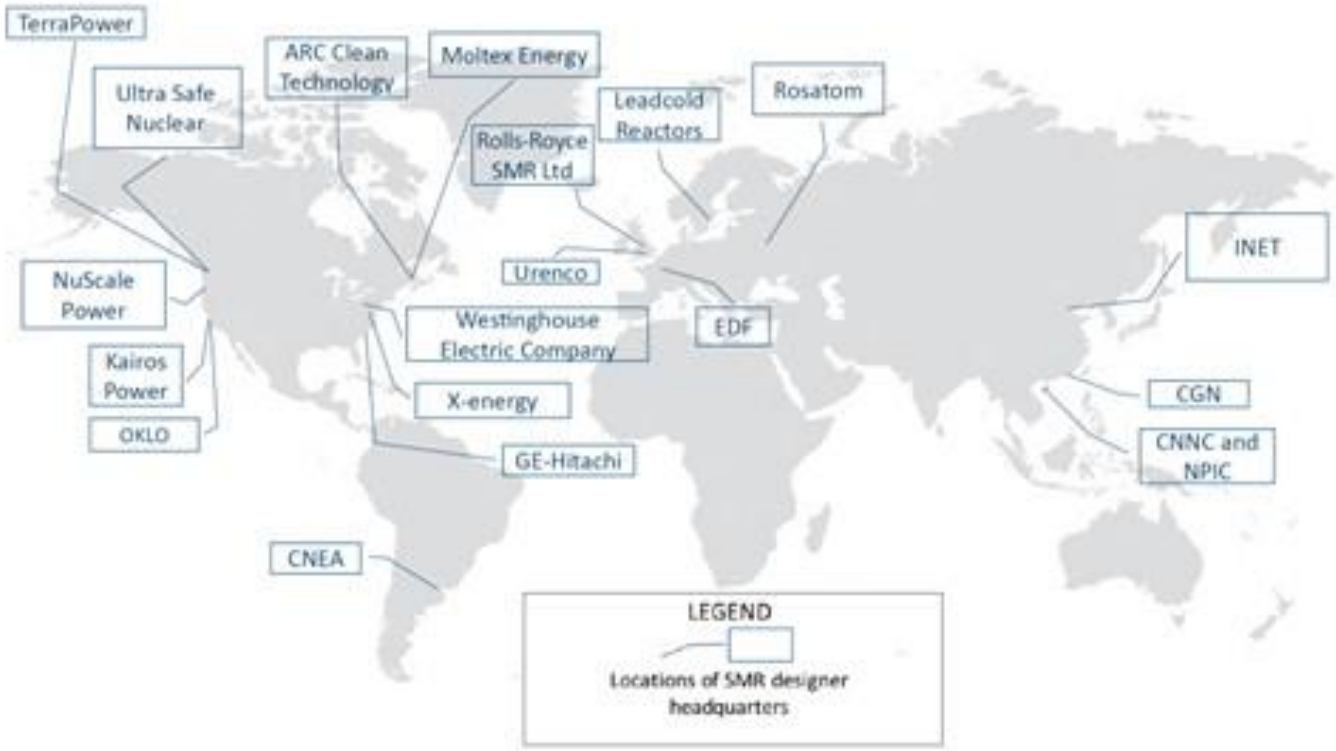
Interest is climbing on SMRs, worldwide

There is growing momentum for SMRs around the world

Countries are supporting SMR development through different approaches by facilitating the creation of a domestic programme and/or construction of demonstration and/or first-of-a-kind (FOAK) units. For these projects, progress extends beyond technological readiness to include other important factors for the commercialisation of SMRs.

https://www.oecd-nea.org/upload/docs/application/pdf/2023-02/7650_smr_dashboard.pdf

Figure 5. **Locations of SMR designer headquarters of a selection of SMRs**



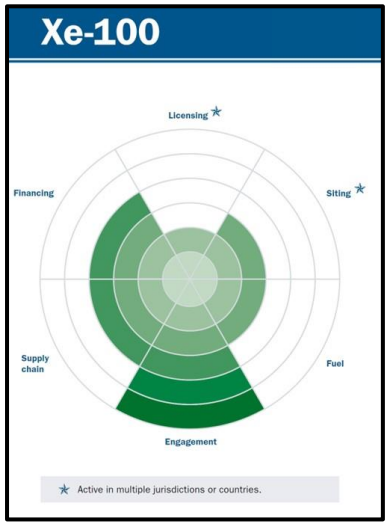
GE BWXR = 300 MWs

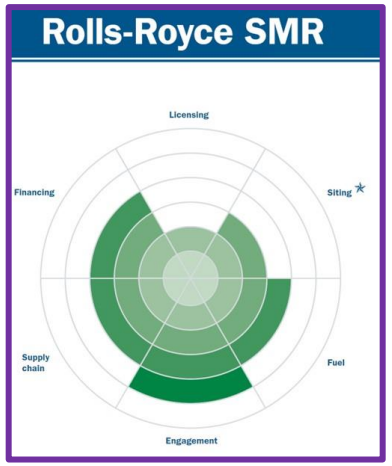
6 x 77 MWs = 462 MWs

NEA SMR Dashboard, Feb. 2023… Licensed by 2027-2030

Table 1. **The NEA SMR Dashboard progress criteria definitions**

Licensing	No information	Pre-licensing	Licence/construction/design certification application submitted	Design approved	Licence to construct approved	Licence to operate approved
	* Bonus for multiple jurisdictions					
Siting	No information	Non-binding agreements/MOUs/ non-binding announcements	Site owner has shortlisted the technology	Site owner has selected the technology	Received permit(s) and or licence(s) for construction on the site	Construction has started on the site
	* Bonus for multiple sites					
Financing[1]	No information	At least one announcement	Five or more announcements or USD 100 million	Ten or more announcements or USD 500 million	FOAK is fully financed	FOAK financed + progress for NOAK finance
Supply chain[2]	No information	Supplier days/ events/workshops/ trade shows/ non-binding agreements/MOUs/ non-binding announcements	Binding contracts for services & materials	Partnerships/joint ventures/consortia - all with EPCs	FOAK construction ongoing/ complete	NOAK construction ongoing
Engagement[3, 4]	No information	One or more engagements	Three or more engagements	Five or more engagements	Seven or more engagements	Ten or more engagements
Fuel	No information	Non-binding agreements & studies with national labs for RDD/Lab-scale production of fuel	Contracts/agreements with fuel supply chain (uranium/conversion/enrichment/ fabrication)	Operating fabrication facility producing fuel, or uses same fuel as existing/generation-III commercial reactors	Contracts for fuel for FOAK	Fuel loading has begun



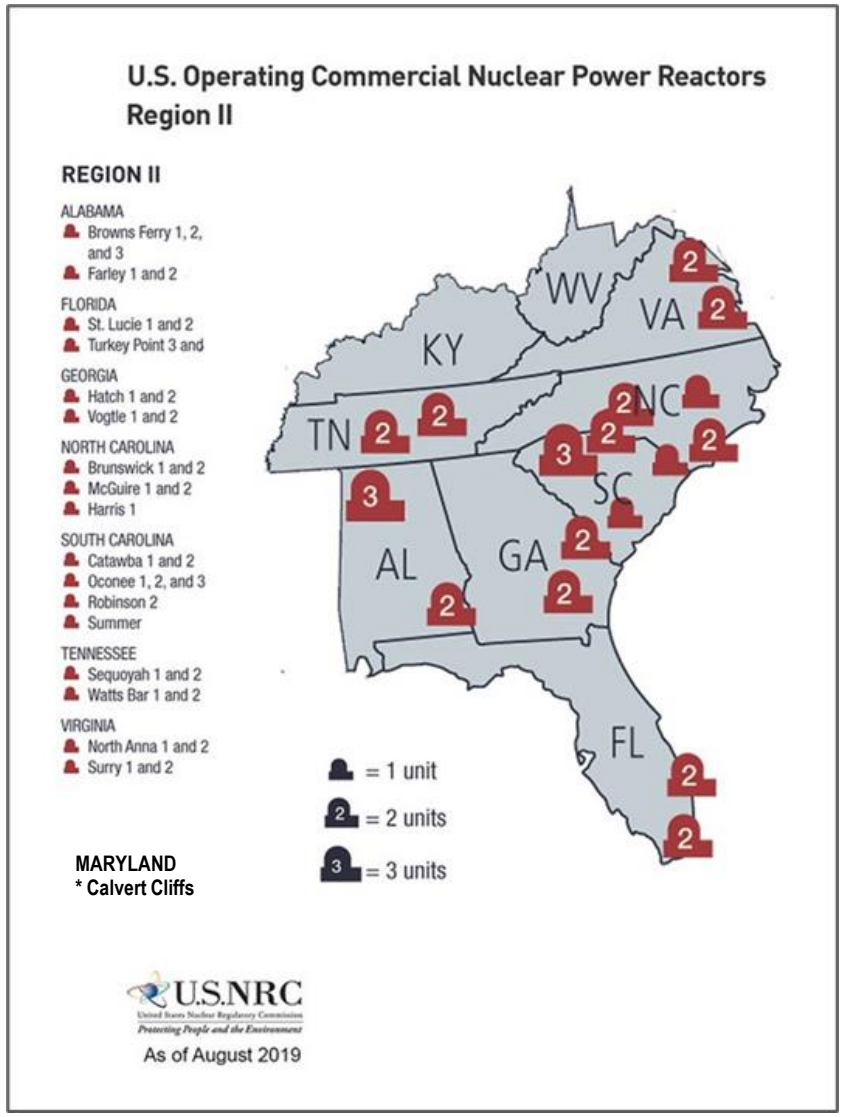


https://www.oecd-nea.org/upload/docs/application/pdf/2023-02/7650_smr_dashboard.pdf

GLOBAL DRIVERS ➔ SouthEast REGIONAL STRENGTH FOR EXECUTION

Bottom Line Up Front

- **Energy Security Drivers rising**
- **SouthEast** already benefits from a **critical mass of capabilities**, including plant operations and educational resources + **Exports**
- SSEB Region is **strongest** in USA for nuclear systems – the Southeast: NC, SC, GA home to 16 operating plants (+TN, AL, FL)
- **Military bases offer siting** options for SMRs with little "NIMBY" and skilled workforce on "First Deployments"
- **Public-Private partnerships** offer a path to financing first of a kind systems for a FLEET of nuclear SMRs.



NUCLEAR SMRs:

- **Charging urban fleets**
- **Look outside Power sector to Industrial sub-sectors**
- **Think Global, not local; Markets for Exports (Chem, fuels, ammonia)**
- **Manufacturing competitiveness, not just LCOE**
- **Higher Reliability, not just cost**

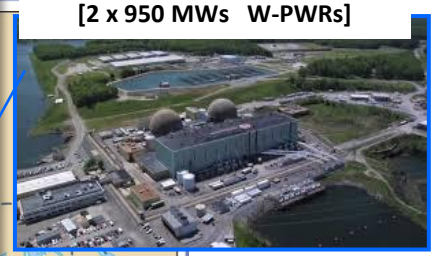
One Example: Virginia Nuclear Assets: Reactors, Fuel, Shipyards, Universities

Every State in SouthEast Region can set this profile.

Virginia Offers Distinguished Leadership in Nuclear Technology

- **Strong Research & Engineering capability [Univ's; DARPA, JLab]**
- **Unique Nuclear Fuel Fabrication capacity [BWXT, Framatome]**
- **More than 3,000 MWs of Nuclear Power Operations [DOM]**
- **Crown Jewel of Nuclear Navy at Norfolk Naval Station + Pentagon**
- **Superior ship-building and component manufacturing**

NORTH ANNA NUCLEAR PLANT
[2 x 950 MWs W-PWRs]



SURRY NUCLEAR PLANT
[2 x 840 MWs W-PWRs]

New Engineering Research Bldg [$80M]

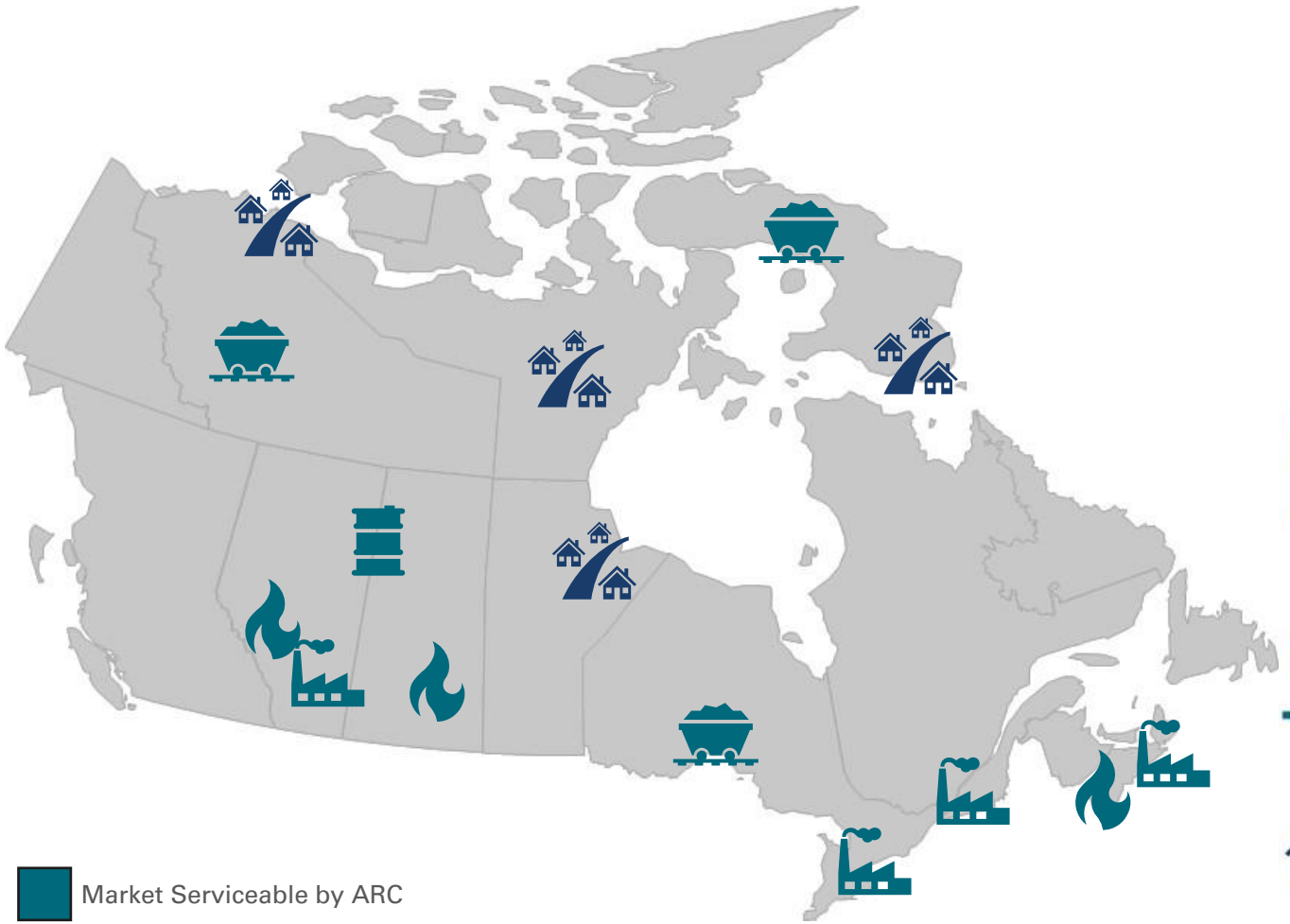
UNIVERSITIES

PENTAGON

Jefferson Lab

ODU Applied Research Ctr, [Newport News]

CANADA Nuclear Roadmap found Significant Market Potential for SMRs



Market Serviceable by ARC

Market Likely Serviced by Micro-SMRs

- ✓ **Steam for SAGD (steam-assisted gravity drainage) and electricity for upgrading at 96 facilities**
- ✓ Estimated 5% replacement by SMRs between 2030 - 2040

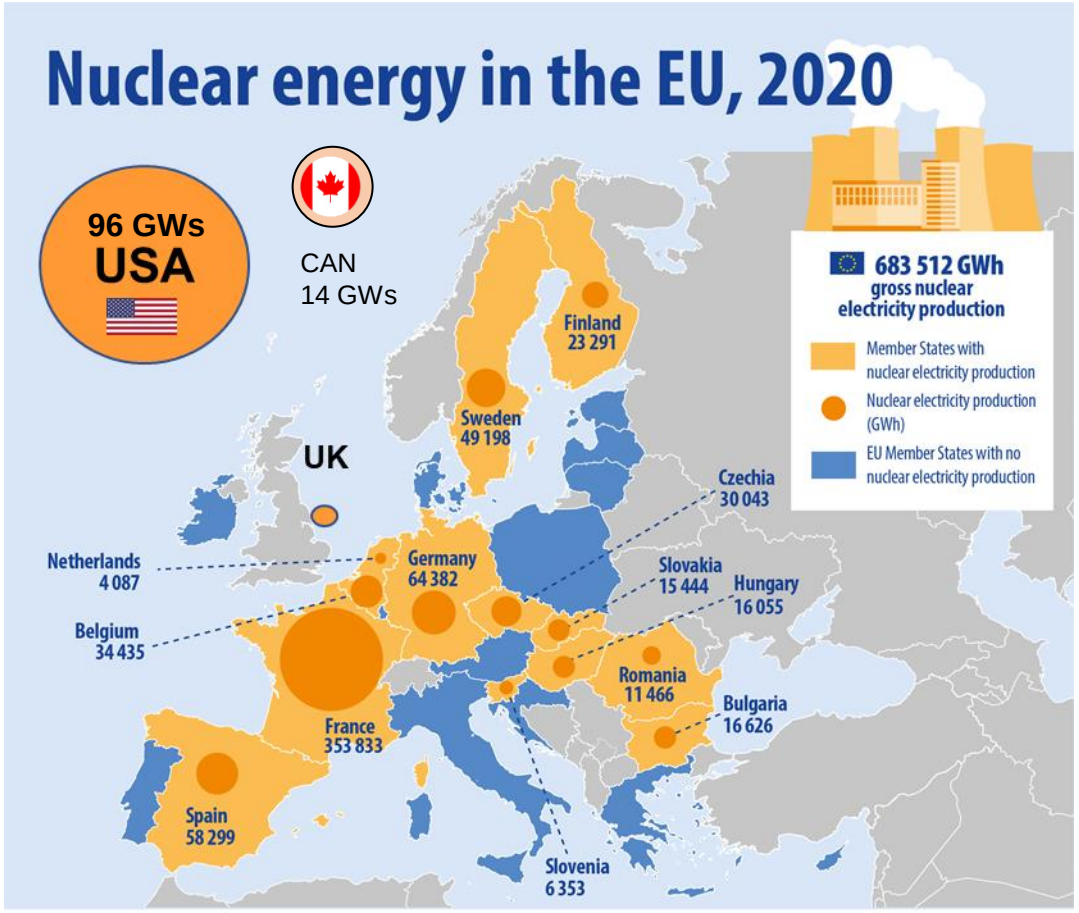
- ✓ **29 coal-fired units in Canada at 17 facilities that can be replaced by SMRs**
- ✓ Estimated 10% replacement by SMRs between 2030 - 2040

- ✓ **85 heavy industry locations (chemicals, refining, etc.)**
- ✓ Estimated 5% replacement by SMRs between 2030 - 2040

- ✓ SMRs could facility and enable new mining developments
- ✓ **24 current and potential off-grid mines**

- ✓ 79 remote communities in Canada with energy needs >1 Mwe
- ✓ Likely serviced by micro-SMRs that can replace costly diesel & heating oil

OVERVIEW: Europe suffering Energy Crisis after cutoff by Russia



In Europe

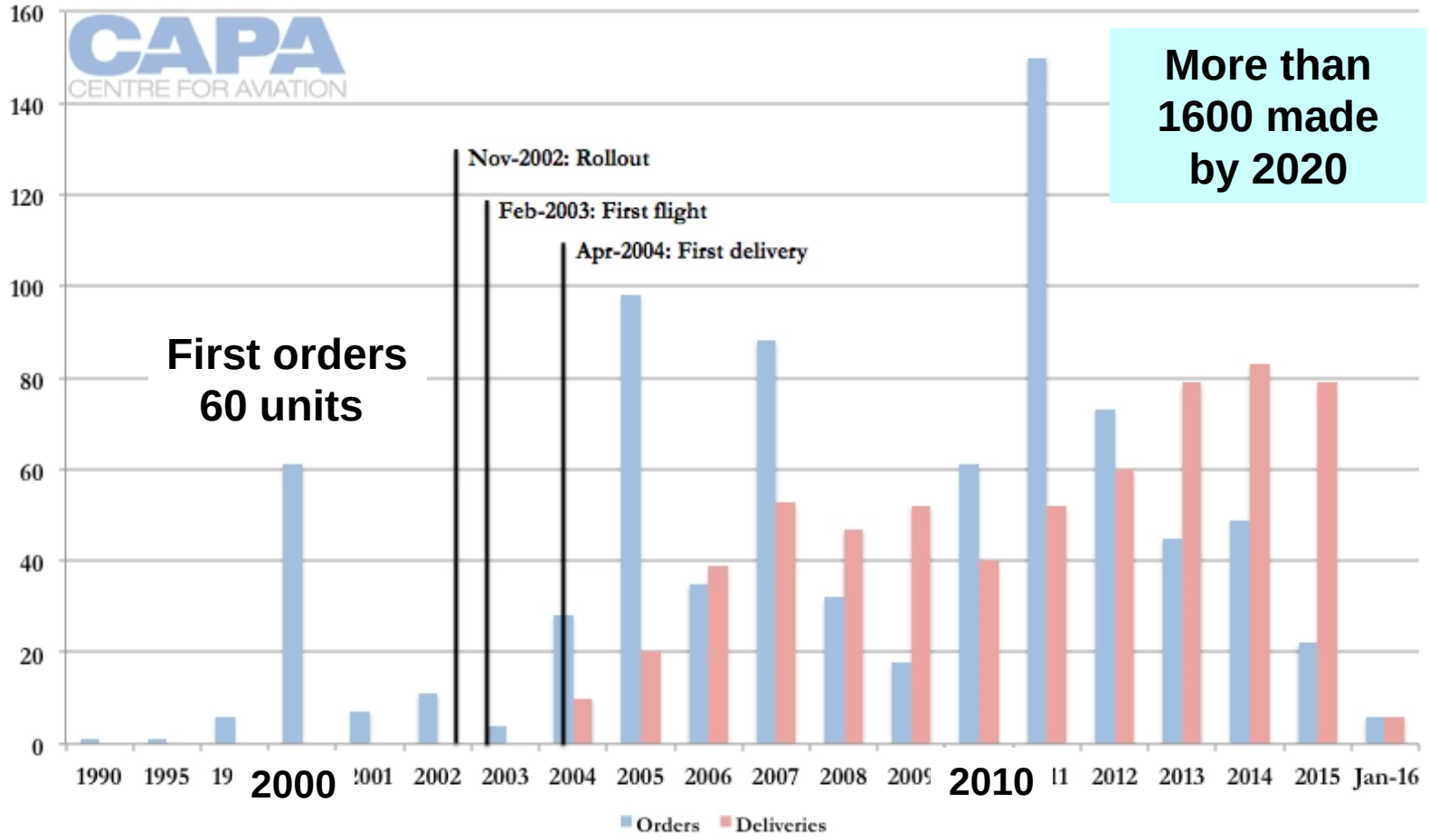
- **N/Gas price spike in 2022, price volatility, Heavy Geo-politics threaten supply**
- **Many fertilizer plants are closed (NatGas prices too high). Other industry strained.**
- **EU Facing €70 per ton of CO2 tax – which will hit industry hardest**
- **Closing most coal plants (reliable supply)**
- **Some nuclear plants closing in EU; Not many being extended *(vs USA, 80 GWs extending)***

In USA…

These factors run OPPOSITE

Comparison for SMRs: Ramp up of Boeing 777

With fleet purchasing each Boeing 777 runs about $400 million +/- 10%
The Value Proposition for SMRs is MANUFACTURING vs construction.

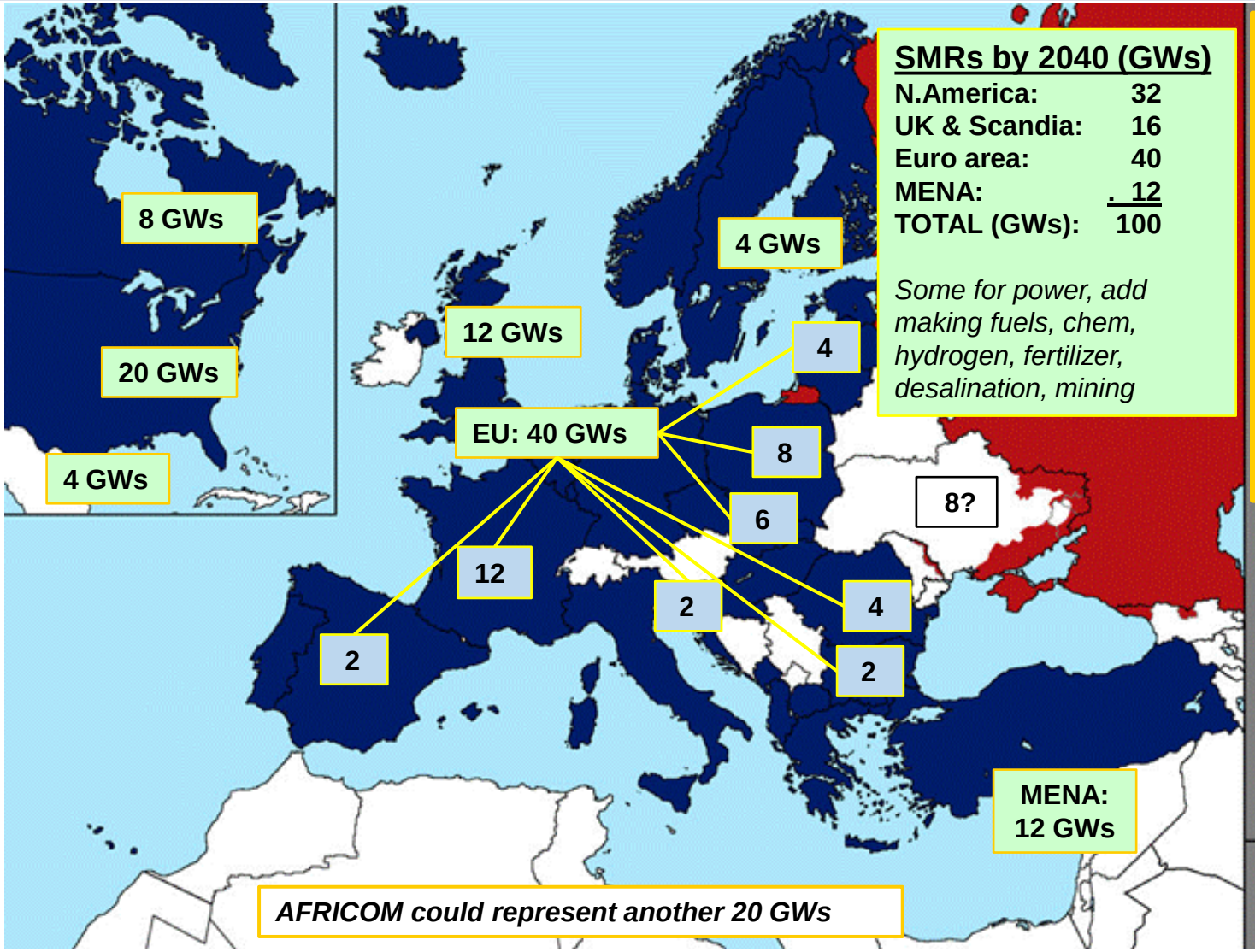


AN ALLIED MODEL: SMRs by 2040 in GWs

NATO Region
Possible SMRs by 2040: >100 GWs
(some at military bases)

Since the invasion of Ukraine in Feb. 2022, and the onset of a severe Energy Crisis in EU, the urgent drivers for SMRs:

* **Improved Mission Readiness**
* **Reduced Base Vulnerability**
* **Alternative energy supply – What if fuel is constrained? Aviation fuel, Diesel… ?**
* **Making liquid fuels and hydrogen from EU sources**
* **Higher reliability for Power**
* **Electric Urban transport**
* **District heating in cities**



SMRs by 2040 (GWs)

N.America:	32
UK & Scandia:	16
Euro area:	40
MENA:	12
TOTAL (GWs):	100

Some for power, add making fuels, chem, hydrogen, fertilizer, desalination, mining

NATO Territory is a Region to review for SMR installations, using manufactured SMRs or Micro-reactors (3MW-30MWs).

Based on open sources and plans announced by NATO member countries, this represents an EBI estimate of potential capacity by ANP to be deployed by 2040.
[Not a NATO estimate]

Military Member of NATO
Member of NATO
Member territory

CHINA in 2022 (WNA data):
52 GWs Operating,
24 GWs under construction.
44 GWs sited, planned.

August 2022

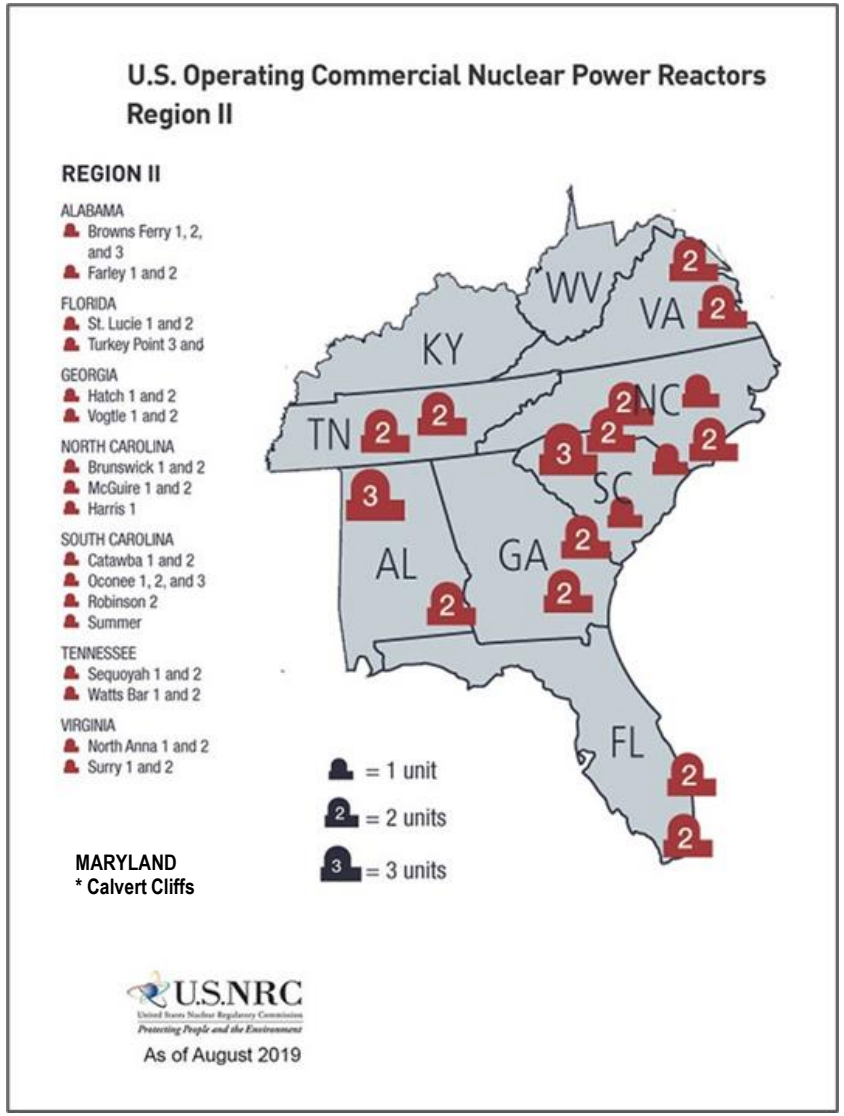
https://www.deviantart.com/nutshellcountries/art/Nato-2022-925202802

QUESTIONS & DISCUSSION WITH SSEB…

QUESTIONS ?

APPENDIX

BACKGROUND DATA ON PROJECTS



SWOT ANALYSIS OF ALLIES relative to Nuclear

STRENGTHS of EU / UK / USA – CAN

- ✓ Strong consumer markets for Energy
- ✓ Advanced manufacturing
- ✓ Superior Nuclear Ops Experience
- ✓ USA + CAN have energy resources
- ✓ Capital Markets are large ($Trillions)

WEAKNESSES of EU / UK / USA – CAN

- ➢ Stagnant GROWTH in demand for electricity in EU, N.Am
- ➢ Supply chain hollowed out by neglect, then pandemic
- ➢ Labour shortages in key skill areas
- ➢ Cost overruns in Large Nuclear Buildout -- Vogtle, HPC in UK, Flamanville, TVO
- ➢ EU must import a lot of energy

OPPORTUNITIES

- ✓ Replace 200 GWs of nuclear in USA, UK, EU+
- ✓ Accelerate Industrial De-carbonization
- ✓ How can EU include nuclear in GHG Policy?
- ✓ Rebuilding after war in Ukraine
- ✓ Many US manufacturers active in Europe

THREATS

- ✓ China will underbid any Allied nuclear bid
- ✓ Russia will still pursue some bids: HUN, TKY despite sanctions after invasion
- ✓ Rosatom and China are more active in Africa, and Developing World generally
- ✓ Russian has deployed small SMRs
- ✓ China completed ACR-100 (TRISO fuel)

EXPONENTIAL RESOURCE SHIFTS Dominate to 2050

Financing needs are rising geometrically worldwide as the pressures from massive urbanization, water stress, and advent of electric transportation (and mass transit) plus grid upgrades.

- **URBANIZATION: By 2050, Over 3b more people in cities, a DOUBLING**
- **WATER STRESS: Faced by <u>more than HALF global population</u>**
  - ✓ Drinking water delivery intensifies as a crisis
  - ✓ Potable water is needed for Agriculture (70% of water use)
  - ✓ Flooding also poses a threat to water treatment works
  - ✓ Without better sanitation, disease spreads rapidly in cities
- **SHIFT TO ELECTRIC TRANSPORT: Also driven by city growth**
  - ✓ Sales of electric vehicles and power demand will grow >400%
  - ✓ Electricity for charging vehicles rises 4x from 2030 to 2040
- **ENERGY & WATER INFRASTRUCTURE: $ TRILLIONS NEEDED**
  - ✓ Massive investment needed globally to upgrade cities' grid & water
- **RECOVERY & RESILIENCE CAN ONLY BE MET BY NUCLEAR POWER:**
  - ✓ Wind & solar are weather dependent – suffer reliability problems
  - ✓ Nuclear is not lowest cost but competitive, emission-free, and runs 24/7 – i.e., BEST FIT

Sectors for Cooperation

AMRs enable reach into Multiple Industrial Sectors

S.Korea is a global leader in every sector.

Fleet Approach to SMRs

ADVANCED SMALL MODULAR REACTORS
30 MWs to 300 MWs

- ✓ System Design
- ✓ Training
- ✓ Security
- ✓ Export
- ✓ Finance

Chemicals & Fuels

Green Hydrogen Production

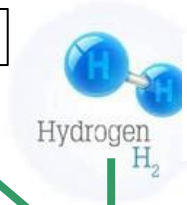
Ammonia Production & Fertilizer

Desalination

Aluminum & Metals Fab

Urban Transportation

FUEL CELLS (HVAC)
30 KWs to 30 MWs



Agriculture & Food Processing

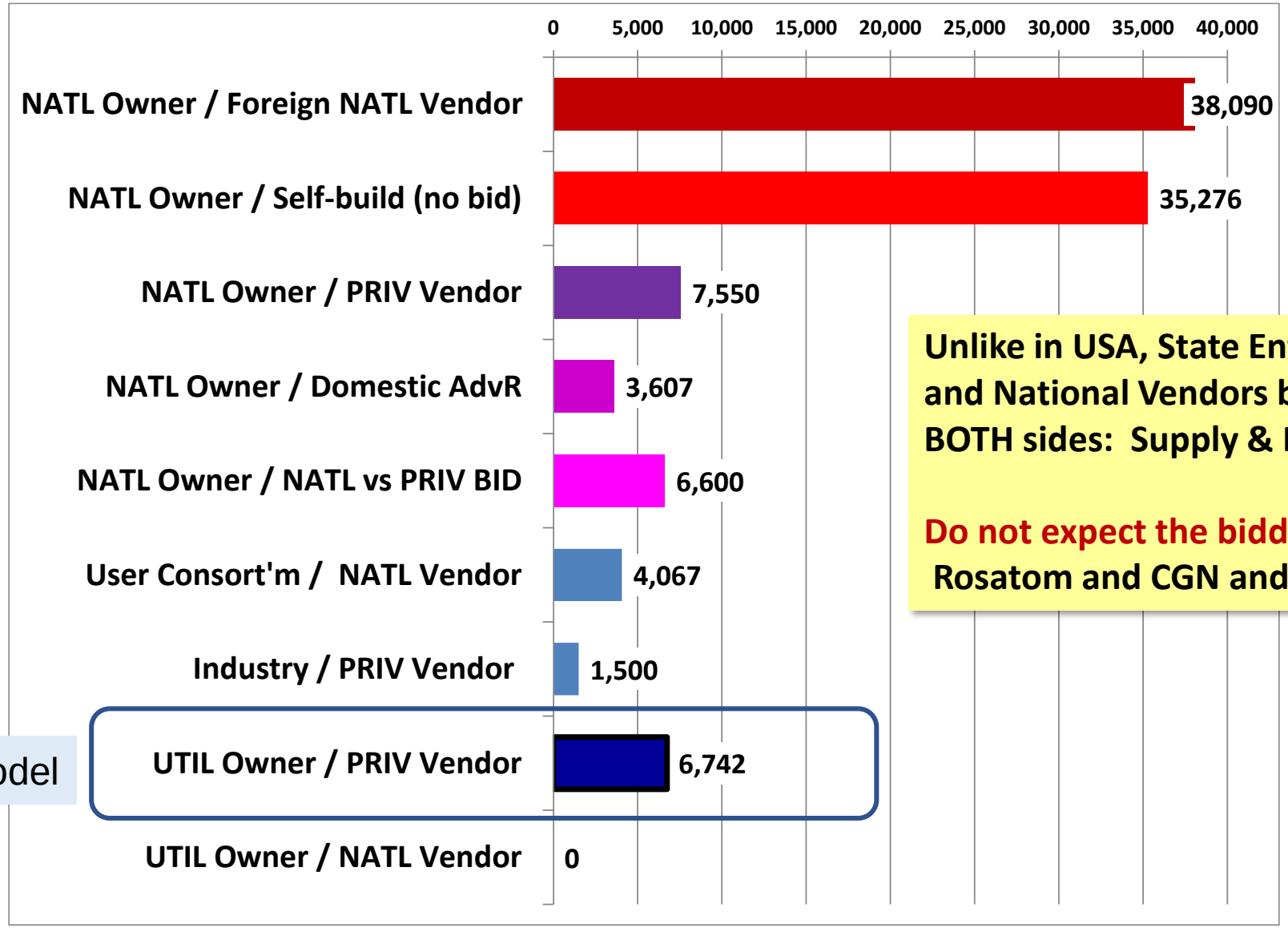
Chemical Plant Co-generation
[Wilton Industrial Park, Northeast UK]

First Responder Bases
Hospitals, Police, Govt

Farming, Food, Biomass

SHIP-BUILDING
-- Enabling platform for SMRs off-shore
-- Marine Transport

State Owners & National Vendors Dominate



US model

Unlike in USA, State Enterprises own Nuclear Plants, and National Vendors bid on the new construction. BOTH sides: Supply & Demand.

Do not expect the bidding to be "fair"…
Rosatom and CGN and EDF subsidize their vendors.

Global SMR Projects now nearing $65 Billion in total value

China or Russia	Stage of Development
Fuel load / Ops	5
Under Constr	4
Financing signed	3
Siting approved	2
JV Formed	1

	Standard LWR
	Advanced unit

								To be verified	
								Estimated	
				Operating by	MWs	[Reactors]	Total	$Billions	$Millions
		Projects		Average	Average	Units	MWs	Total Cost	Cost per MW
		20		2028	190	44	7,044	**$65.00 B**	$9.2 M
Locale	**Expected SMR Project**	**SMR Site**	**Reactor**	**Operating Date**	**Size (MWs)**	**Number (Reactors)**	**Total MWs**	**Project Cost ($Billion)**	**Cost per MW ($Mil)**
USA, Utah	UAMPS	INL, ID	NuScale LWR	2030	77	6	462	**$9.00 B**	$19.5 M
CAN, Ontario	OPG	Darlington, ON	GE LWR	2028	300	1	300	$1.80 B	$6.0 M
UK Site	RR SMR	Wales, UK TBD	Rolls Royce	2030	470	3	1410	$7.80 B	$5.5 M
UK Site	RR SMR	Moreside, UK	Rolls Royce	2032	470	2	940	$5.00 B	$5.3 M
CAN, NB	NB SMR	Pt. LePreau, NB	Moltex AMR	2029	300	1	300	$2.50 B	$8.3 M
CAN, Ontario	CNL	Chalk River, ON	USNC Micro	2027	5	1	5	$0.40 B	$80.0 M
USA, Alaska	US Air Force SMR	Eielson base, AK	AMR Micro	2027	5	1	5	$0.50 B	$100.0 M
USA DOE ARDP	TerraPower	Kemmerer, WY	Natrium AMR	2032	345	1	345	$3.50 B	$10.1 M
USA DOE ARDP	X-energy	Hanford, WA	X-e 100	2032	80	2	160	$2.40 B	$15.0 M
Poland	ZEPAK / Solorz	Patnow, PL	LWR SMR	2030	80	4	320	$9.60 B	$30.0 M
Poland	SYNTHOS	Oświęcim, PL	LWR SMR	2030	300	1	300	$1.80 B	$6.0 M
Bulgaria	Industrial AMR	Maritsa Iztok, BG	AMR	2028	80	6	480	$4.00 B	$8.3 M
Slovenia	Krško-2	Krško site, SLO	LWR SMR	2030	300	2	600	$3.00 B	$5.0 M
Romania	Cernavoda SMR	Cernavoda, ROM	NuScale LWR	2028	77	6	462	$6.00 B	$13.0 M
CH, Shanghai	**China NNC AMR**	Shandong AMR	HTR-PM	**2024**	210	1	210	$1.40 B	$6.7 M
RU, Siberia	Seversk Chemical + Rosatom MOX	Seversk, RU	TVEL BREST Lead-cooled	2027	300	1	300	$2.00 B	$6.7 M
RU, Arctic Circle	**Arctic Port**	Pevek, RU	2 x KLT-40C	**2020**	35	2	70	$0.50 B	$7.1 M
CH, Hainan	CNNC	Changjiang	ACP100 PWR	2026	125	1	125	$1.60 B	$12.8 M
CH, Floating	CNNC	Floating SMR	ACP100 PWR	2028	125	1	125	$1.20 B	$9.6 M
CH, Jiangxi	CNNC	Ningdu	ACP100 PWR	2028	125	1	125	$1.00 B	$8.0 M

SMR Projects in the Global "Arena" reach $65 billion in estimated project value (20+ projects)

At various stages of development, SMR projects announced by vendors, engineering partners and governments (either for siting or investment) have reached at least $65 billion in projected capital investment – about 20 projects including at least 40 reactors for a combined total near 7 GWs. Most of that capital investment lies in the future, as projects are still at various stages of development: from 1) an announced plan and JV by a Government; 2) affirmed siting with permits; 3) financing signed -- the biggest hurdle it seems; 4) under construction; 5) entered fuel loading and operation in a few cases. Each of these five stages represent a significant milestone with multiple stakeholders and a clear decision point. Cost estimates are still moving around due to the earlier stage of projects; some estimates are high and some are low, so the combined list should be near an expected value.

The table notes the Stage of Development of a project and highlights China & Russia versus allied actors. Also, whether the reactor design is a conventional LWR (either a BWR or PWR, Gen III) vs a more advanced "AMR" reactor and fuel design is shown.

Micro-reactors (sub-20 MWs) are for specialty applications and remote facilities (e.g., Arctic ports and stations). ADPaterson