An Electricity Strategy for Long War in Ukraine

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Note: readers should consider these slides a "beta version" assessment of a rapidly evolving situation and set of challenges. If I have information that looks dated, inaccurate, or otherwise suggests I need to update my thinking, please contact me and I will be happy to speak with you and alter the deck as may be warranted.

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Note: Industry experts with more detailed domain knowledge are likely to offer feedback. As they do, estimates and assessments will be revised and refined.

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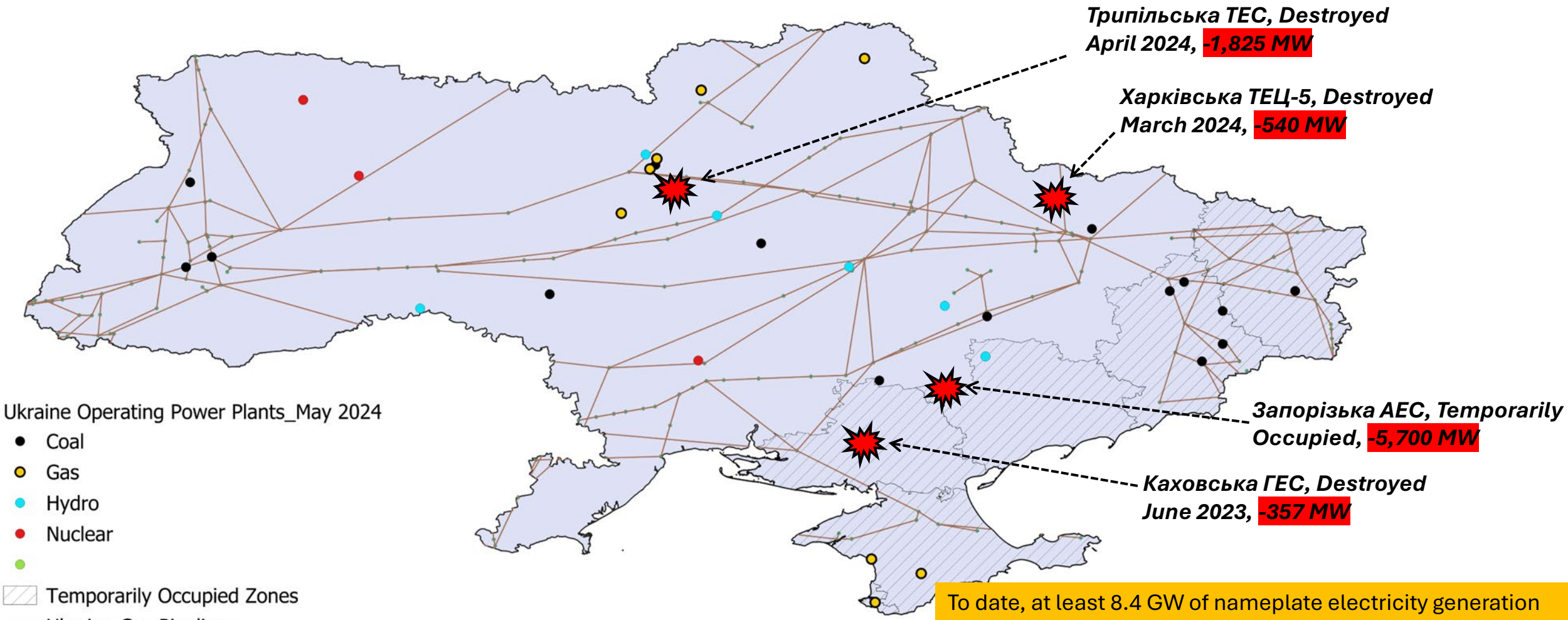
Executive Summary

- **Ukraine cannot win a long war without basic, resilient electricity supplies. People cannot live and industrial activity cannot resume without electrons. Both are mutually reinforcing and necessary for victory.**
- Current power system offers an irresistible and high “return per shot” for a Russian long-range strike complex capable of ranging all of Ukraine with cruise missiles and drones and a substantial portion with ballistic missiles, especially if able to launch from Belarus.
- Just like Ukraine cannot wait for 155mm artillery shells, so too it cannot wait for electrons. No time for “ideal” solutions. “Good enough” is name of the game.
- Ukraine’s military survived Russia’s early onslaught and successfully resisted in part because commanders dispersed forces before Russian strikes at war’s outset. Now, dispersion logic is also needed for the power sector.
- Gas turbine gensets whose replacement cost is partially ensured by the US Government are core to the solution.
- They can be fueled from a world-class existing gas pipeline system, widely spread out, and emplaced in affordable, hardened revetments to maximize Russian munitions requirements and put Russian strike operations “on the wrong side of economics and physics.”

Over-Centralization Creates Extreme Vulnerability

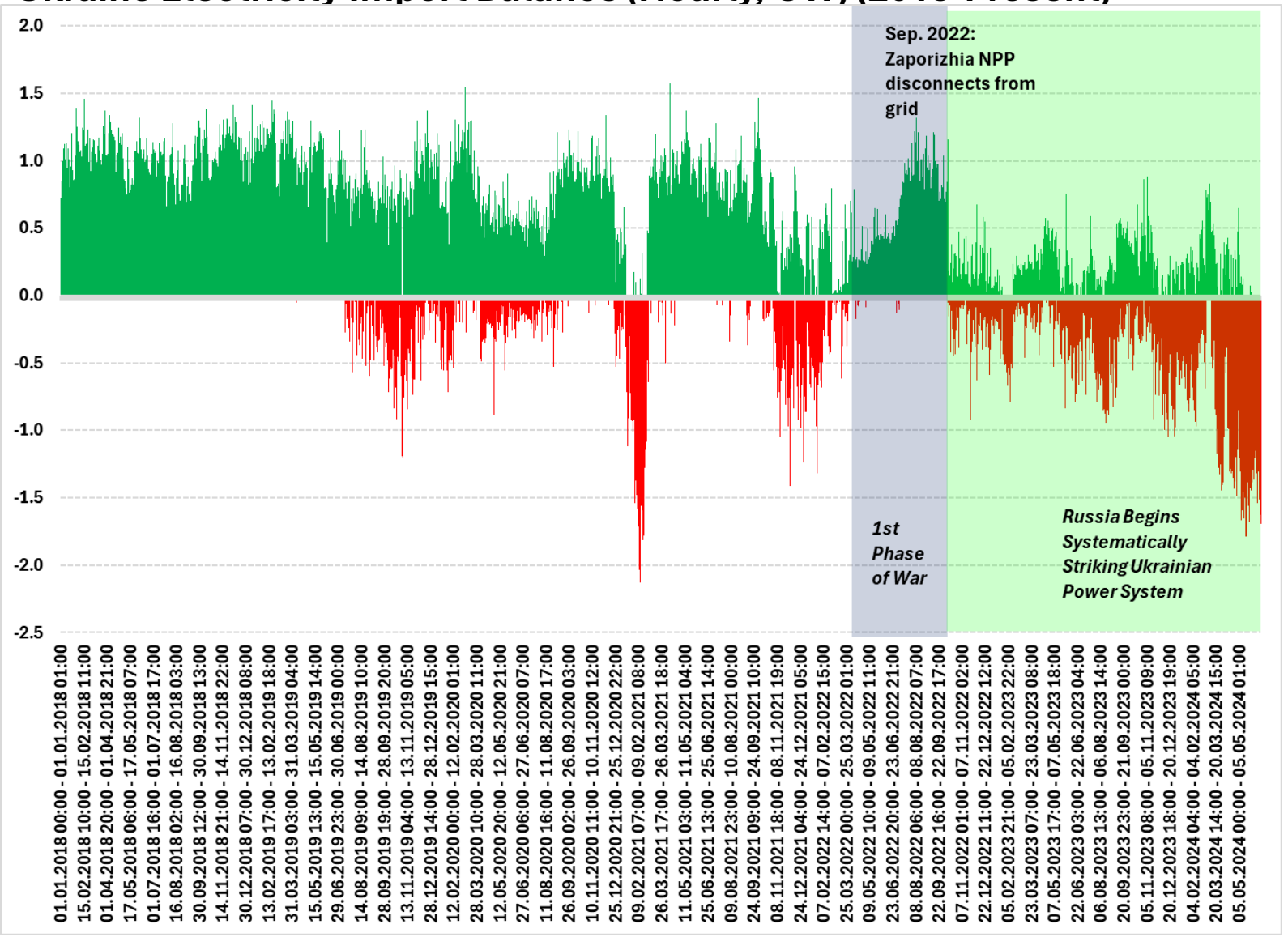
- **Current Ukraine dispatchable power base provides concentrated, high-payoff aimpoints for Russian munitions**
- **$25-$30 million of munitions can destroy a power plant that provides 5% of Ukraine's power and would cost billions to replace one-for-one**



To date, at least 8.4 GW of nameplate electricity generation capacity destroyed/rendered inaccessible by Russian kinetic actions

Rising Ukraine Electricity Imports Reflect Impact of Russian Strikes

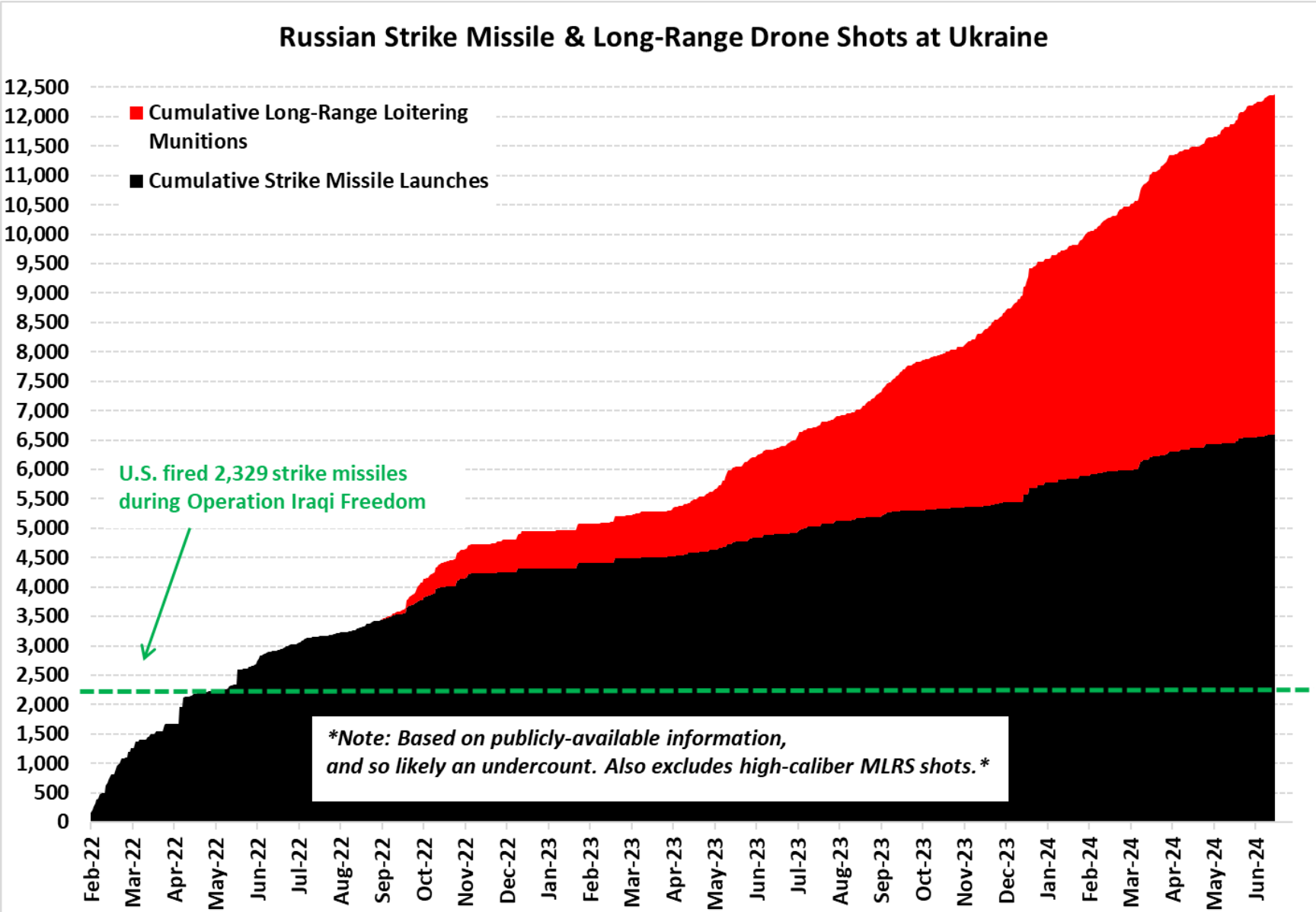
Ukraine Electricity Import Balance (Hourly, GW) (2018-Present)



Source: ENTSO-E, Author's Analysis

- From the end of 2014 through late 2021, Ukraine's daily electricity load typically peaked each winter at 20-22 GW.
- Russia's 2022 invasion cut the number roughly in half.
- There are not public load data since then, making it difficult to assess what recovery, if any, has occurred.
- The bottom line is that Russian strikes have severely impacted the Ukrainian electricity system.
- Absent rapid and decisive action, this winter threatens a major humanitarian crisis in Ukraine. This is likely a core Russian objective as Moscow seeks to destroy Ukraine's social cohesion and support in neighboring countries that Ukrainian refugees might flee to.

Russian Strikes Could Continue For Years



Source: CSIS and US DoD (first 6 weeks of war), Telegram (Ukraine Air Force acct.), Local Media

- Ukraine's power grid does not just face threats from Russia alone.
- **<u>Russia is the "shooter", but its military is accessing at least four military industrial bases: China's (many types of materials), Iran's (drones), North Korea's (munitions including ballistic missiles), and Russia's own.</u>**
- Speaking bluntly, the threat of drone and missile strikes on electricity system infrastructure will be persistent and large-scale.
- Air defense alone will not be sufficient.
- Physical system restructuring through dispersion and hardening will be critical to Ukraine's economic and national survival.

Possible Solution: Distributed Power Leveraging Ukraine’s Massive Gas Pipeline Network

Distributed Power Footprint Facilitates Industrial Revival and Protects People

- Increases Russia's targeting burden by an order of magnitude
- More affordable replacement of inevitable attrition of power generation assets
- Allows Ukraine to allocate more of its air defense systems to population centers and the front lines of fighting
- Longer term, creates connection points where natural gas units can be replaced with small modular nuclear reactors.
- Save lives first while restoring economic activity, set stage for "drop in" emissions reduction activities later.

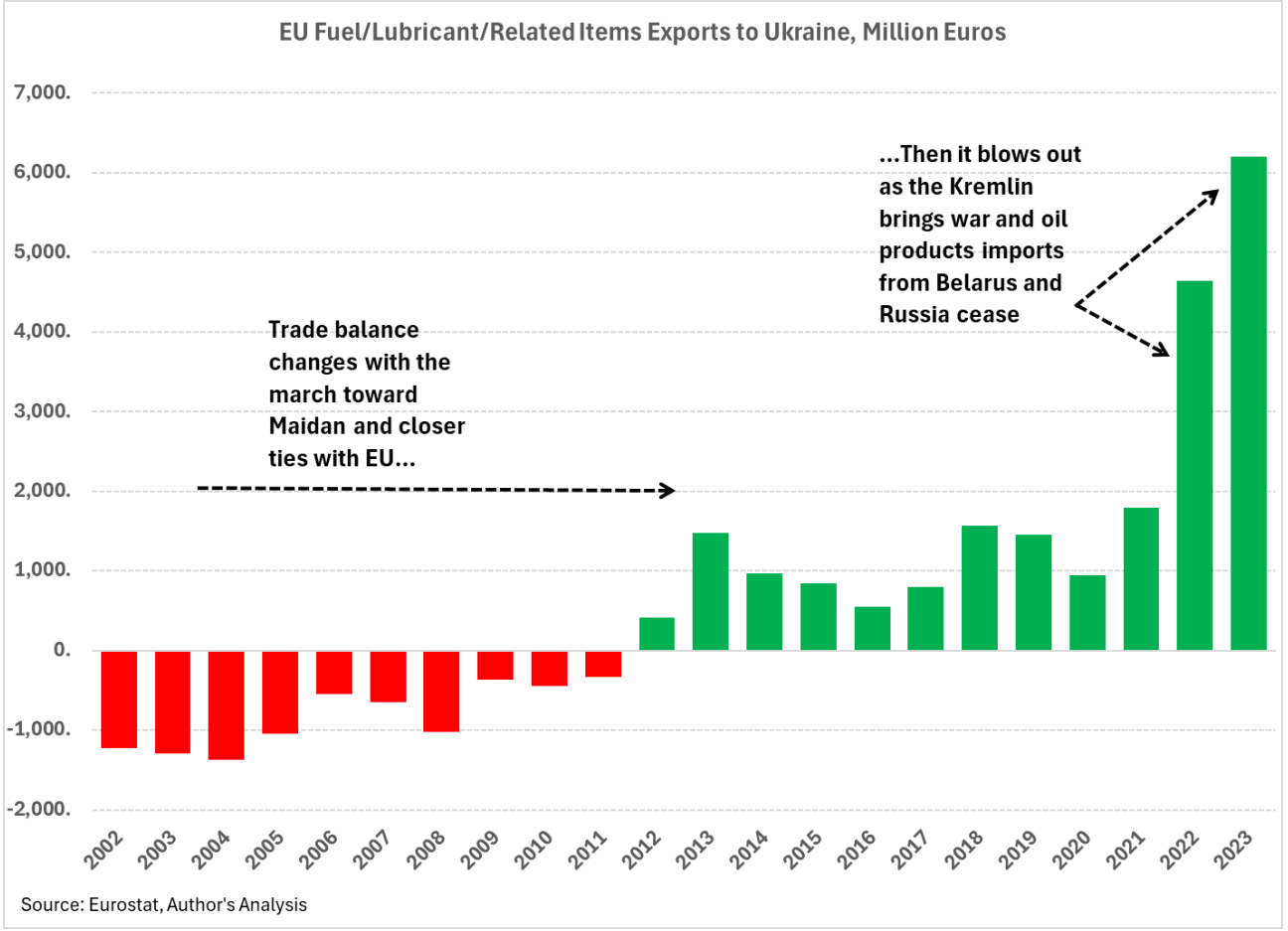
Key Tenet One: Leverage Gas Piston-Engine and Turbine Gensets

- Affordable
- 1-10MW systems are too small for key industrial applications. 25-50MW unit size offers better optionality for supplying civilian and industrial applications.
- Wide-second hand availability, far more diverse supplier array than is the case for Soviet-era power plant equipment
- Can design system for turbine genset fungibility—i.e. if the GE turbine gets blown up, can drop in a Rolls Royce unit
- Can access a global supply chain and reservoir of operational expertise for gas turbine power generation.
- **Turbines and piston-engine gensets are roughly "right-sized" to use plentiful gas supply spur lines that are already connected to industrial facilities in Ukraine**.

Why is Natural Gas Foundational to Ukraine's Electricity Security?

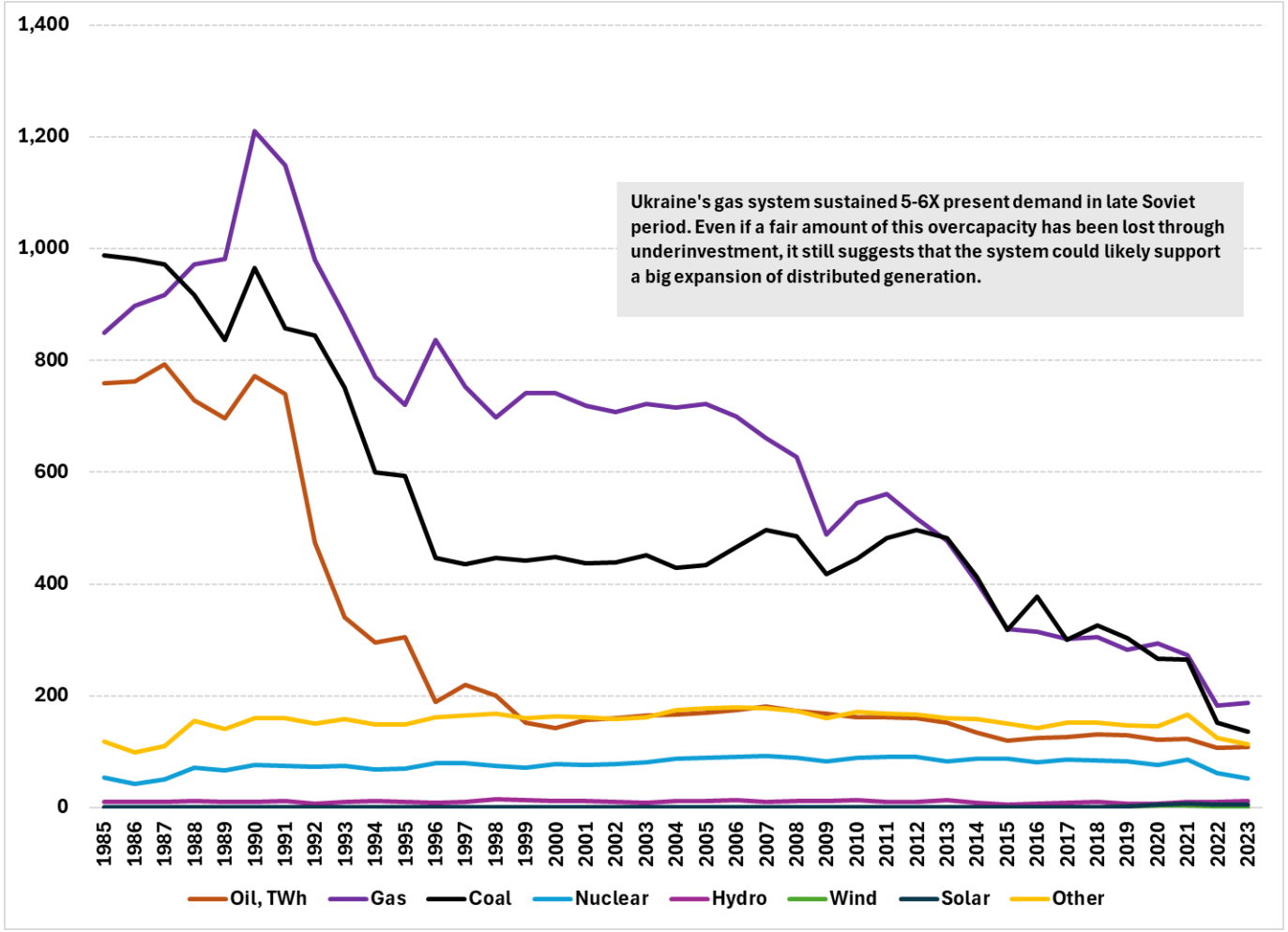
- 1 Gigawatt of generation capacity running for a 24-hour day generates 24 GWh of electricity.
- In raw heat terms, 1 GWh = 102,359 M^3 of natural gas. (https://unit-converter.gasunie.nl/)
- Adjusting for 20% simple cycle turbine thermal efficiency means 511,795 M^3 of gas used per GWh generated.
- 1 M^3 of gas = 9.77 kWh or 9.77 kWh * 3412 BTU/kWh = 33,335 BTU. Diesel fuel contains approximately 137,000 BTU/gallon, meaning that a gallon of diesel is the energy equivalent of 4.1 M^3 of gas. Thus, 511,795 M^3 of gas/4.1 M^3 gas per gal of diesel = 125,000 gal of diesel or about 3,000 bbl of diesel.
- **Thus 24 GWh * 3,000 bbl of diesel = approx. 72,000 barrels of diesel per day per GW.**
- **With over 8 GW of generation capacity offline, the volumes of diesel to even partially compensate are probably logistically impossible to supply.**
- **Diesel also likely costs 3-4X as much per unit of fuel energy as natural gas does.**
- **This means natural gas is extremely important for any plan to provide Ukraine with dispersed, dispatchable electricity generation in the near-term.**

Major expansion of diesel-based generation would blow out Ukraine's import bills…



Ukraine's Gas System Overbuild Relative to Current Demand Suggests Latent Potential to Support Distributed Generation

Ukraine Primary Energy Use, TWh (1985-2023)

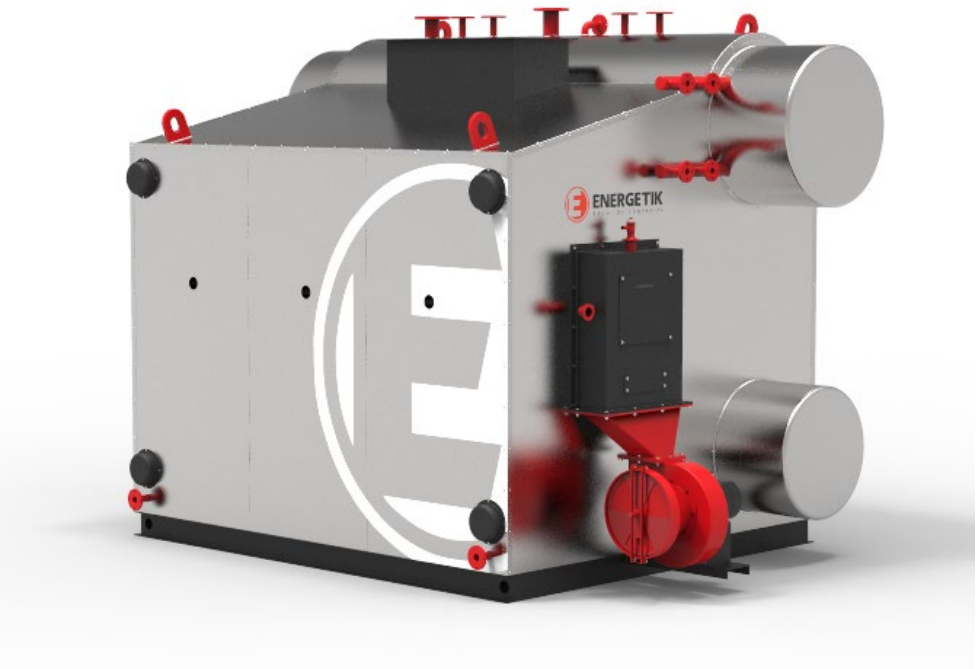


Source: Energy Institute Statistical Yearbook 2024, Author's Analysis

- I do not presently know how much of the gas distribution & transport capacity runs to cities versus industrial facilities and power plants.
- But I suspect there is sufficient geospatial correlation that underused/unused pipe capacity would offer ready distributed generation opportunities.
- Latent potential of system overcapacity also suggests that so long as there are sufficient compressor station spare parts, it will be reasonably resilient against Russian strikes.

Key Tenet Two: Leverage Existing Gas Transport Network and Offtake Connections

- UkrTransGaz claims operation of nearly 40,000 km of gas pipelines and 1,455 gas distribution stations.
- Past research has also suggested that Ukraine has 100,000 boilers deployed around the country, with at least half of boilers using gas as a fuel.
- This in turn suggests widespread availability of industrial gas connections.
- Data from a major Ukrainian boiler manufacturer shows that the hourly gas consumption of an industrial boiler making 2.5 tonnes of steam per hour is about the same as what's needed to run a 1 MW piston-engine genset.



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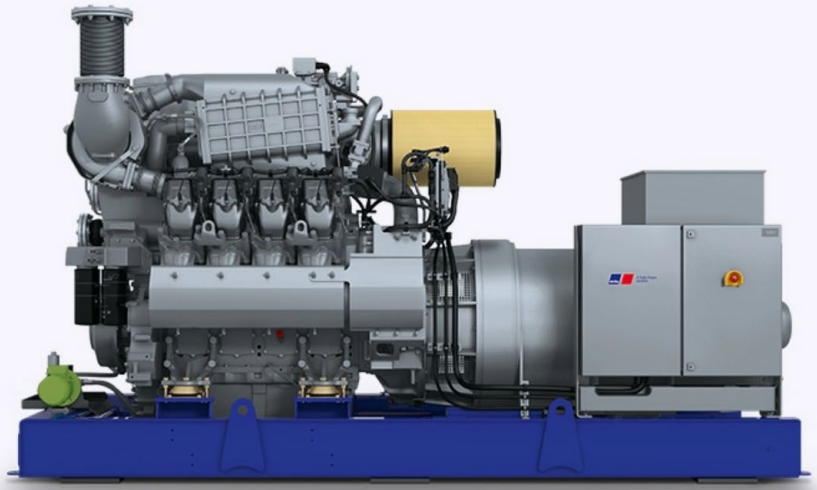
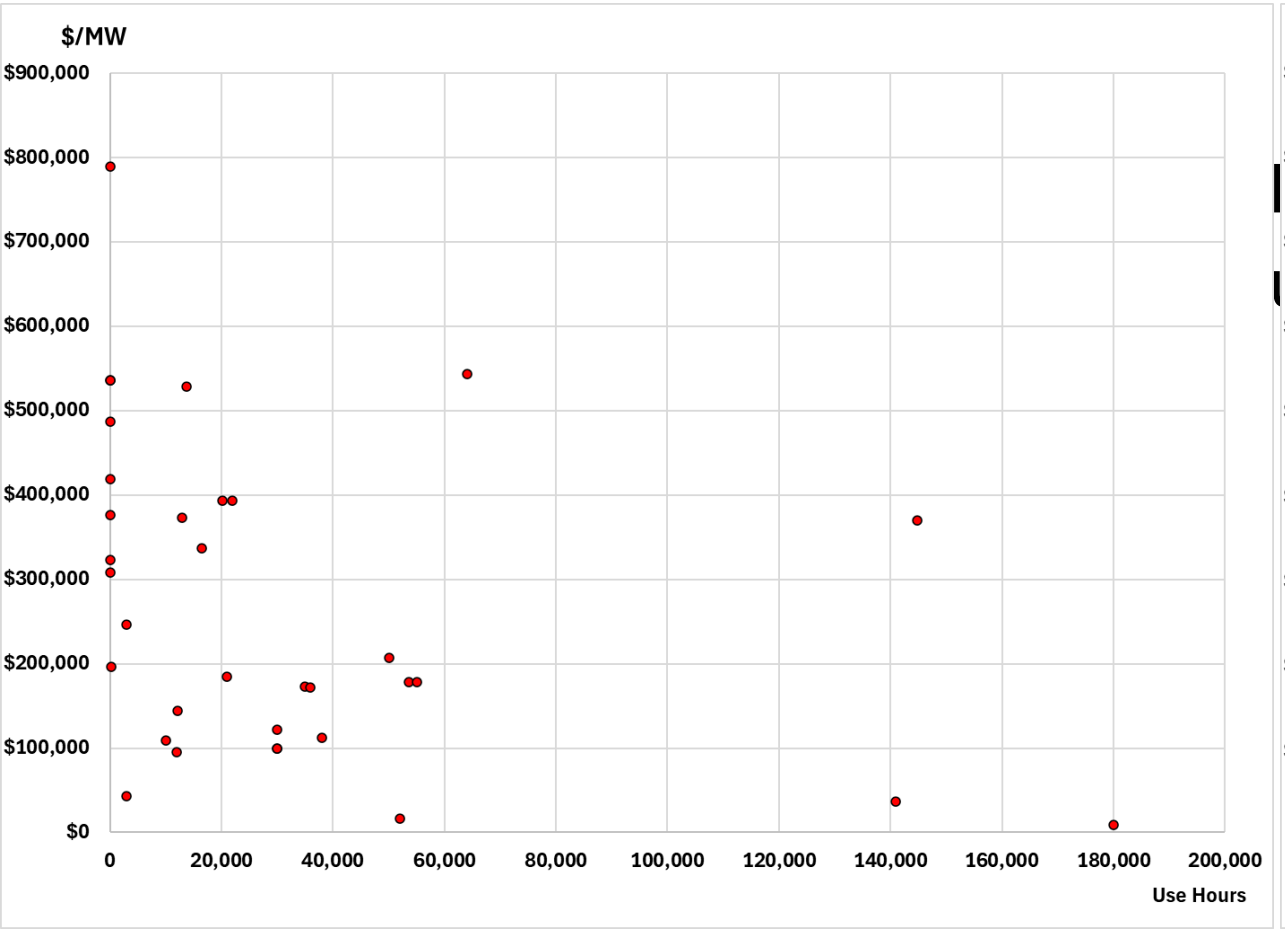


Distributed Generation Options' Est. Natural Gas Use

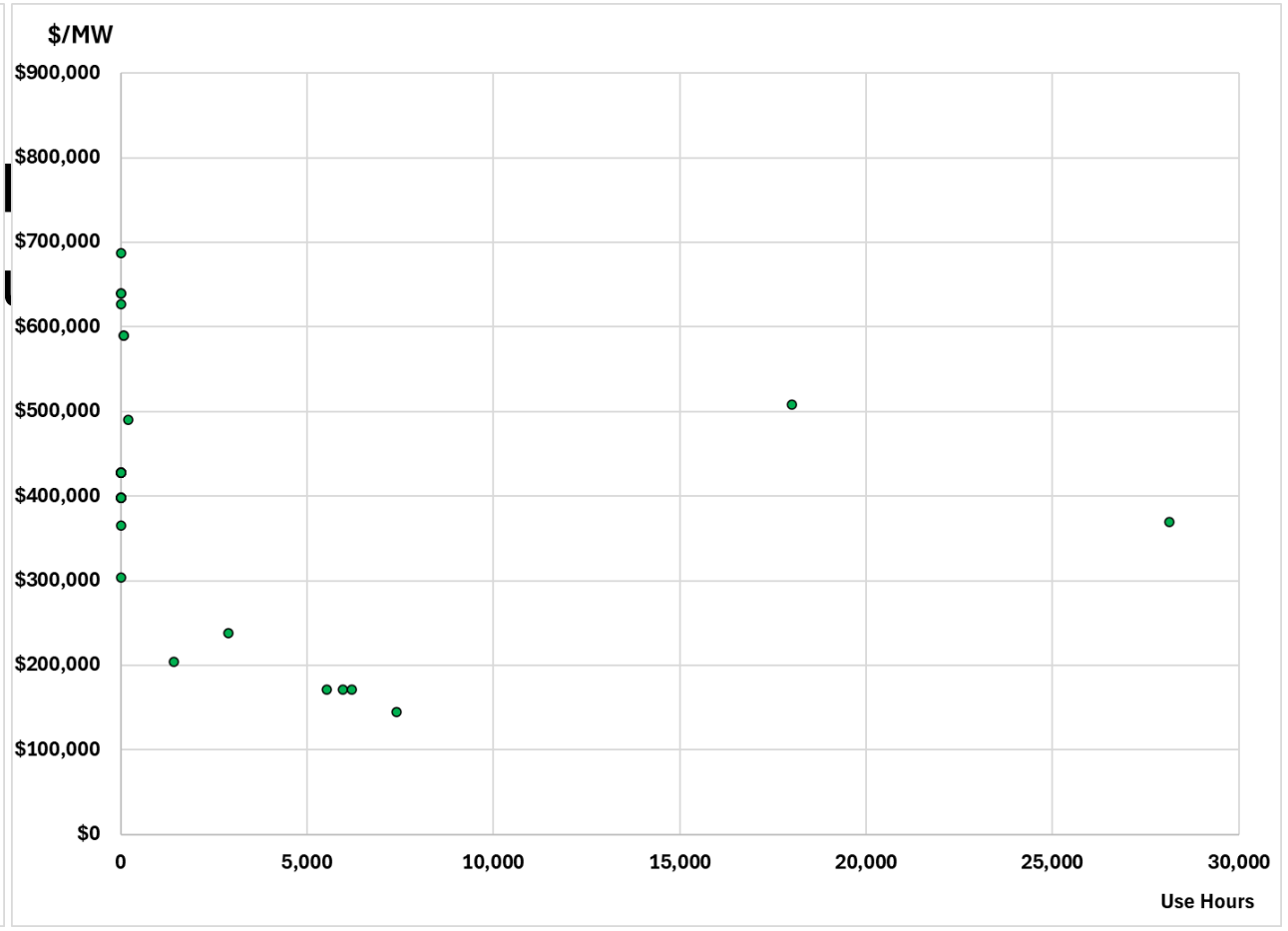
Manufacturer	Unit	Type	Output_MW	Frequency (Hz)	BTU/kWh @ 100% Load	BTU/MWh @ 100% Load	MMBTU of gas/hr	CF/gas/hr	M^3 gas/hr	Source
Cat	GE3412	Piston	0.5	60	10,595	10,595,000	5	5,298	154	https://s7d2.scene7.com/is/content/Caterpillar/CM20220105-e8e3b-4362f
Rolls-Royce	MTU 8V4000	Piston	1	50/60		7,803,244	8	7,803	227	https://www.mtu-solutions.com/eu/en/applications/power-generation/power-generation-products/gas-generator-sets/natural-gas-generator-sets/gas-powered-series-4000.html
Capstone	C1000S	Turbine	1	50/60	-	-	11	11,400	332	https://www.capstoneengineered.com/wp-content/uploads/2023/04/C1000S-High-Pressure-Natural-Gas.pdf
GE	LM2500 DLE (Simple-Cycle)	Turbine	22.7		9,501	9,501,000	216	215,673	6,283	https://www.gevernova.com/content/dam/gepower/global/en_US/documents/gas/gas-turbines/aero-products-specs/lm2500-60hz-fact-sheet-product-specifications.pdf

Distributed Genset Basic Capital Cost Per MW

Gas Turbine Gensets



Natgas Piston-Engine Gensets



Source: Machinio, Other Equipment Vendors, Author's Analysis

Capital Cost for Utility-Scale Generation Options: 4 X 54 MW aeroderivative simple cycle ($1.6 million per MW), 1 X 735 MW ultra-supercritical coal ($4.1 million per MW), 6 X 80 MW SMR Nuclear ($8.9 million per MW)

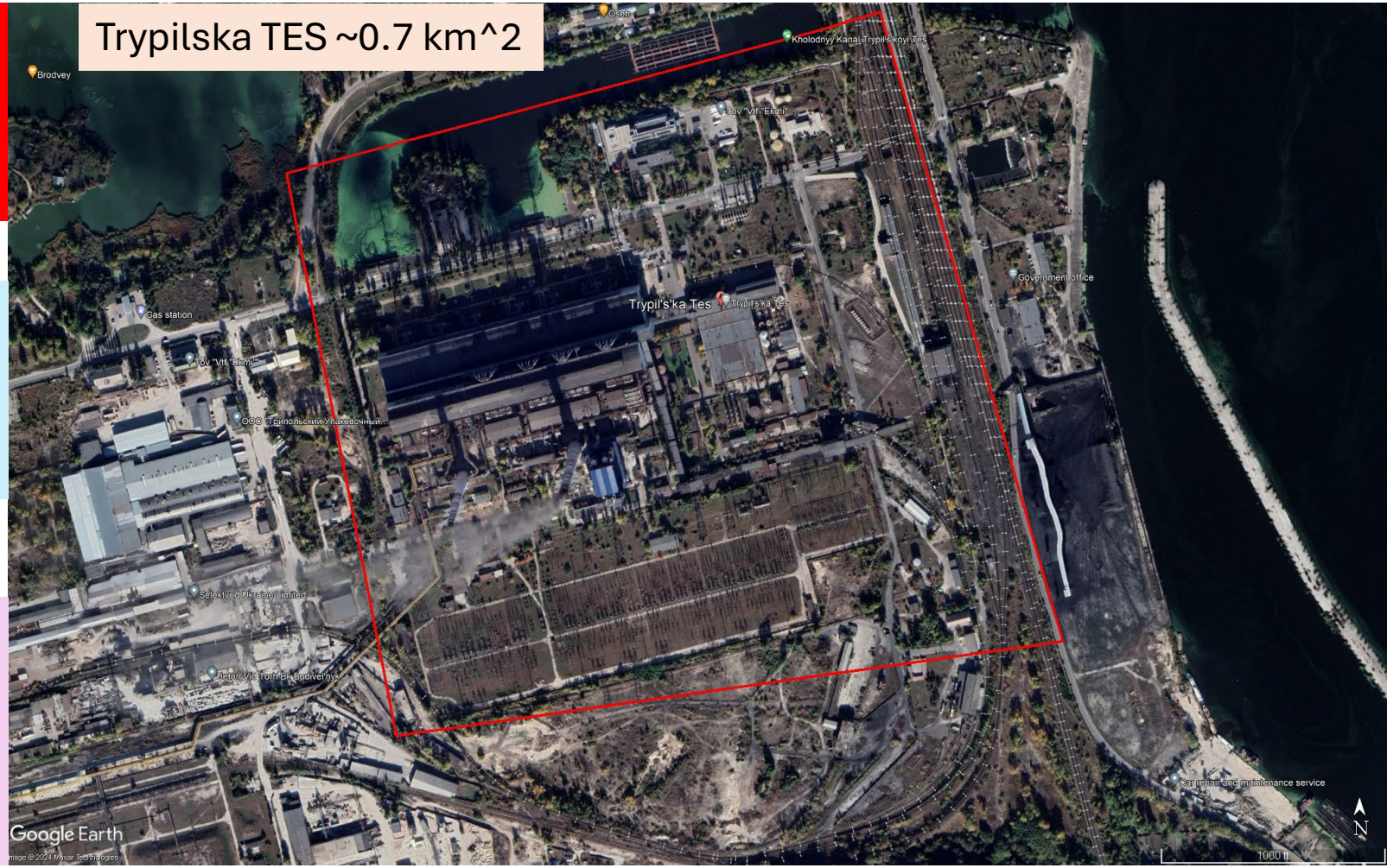
Source: https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2025.pdf

Distributed Power Footprint Also Strains Russian Strike Economics

11 missiles ($25-30 million' worth) destroyed 1,825 MW of centralized generation capacity worth billions of USD. ~$16,500 per MW destroyed

Imagine instead Russian targeters having to find and destroy 50-100 gas turbine gensets(20-40 MW apiece) scattered around Ukraine.

Munitions requirements rise by 50-fold or more, if 1-2 munitions tasked per asset. This means using the same types of missiles could now cost $100,000 or more per MW of generation capacity destroyed.



And of critical importance, the world has substantial supplies of piston engine and turbine gas-fired generators as well as hot manufacturing lines. This breaks Ukraine's dependence on trying to scrounge old Soviet power plant parts to repair Russian strike damage.

Distributed Facilities Can Also Be Protected More Easily

Why do these pictures of concrete revetments and hardened aircraft shelters show F-16s? Hint—it's not because Ukraine's Air Force will receive some this year. Rather, it's because an LM2500 gas turbine genset pack and an F-16 have broadly similar dimensions. (both fit within 16m long X 10m wide X 5 m tall)

Concrete shielding would require Russian forces to expend even more munitions while also facilitating decoy campaign

By US Air Force from USA - 130815-F-MF529-068, Public Domain, https://commons.wikimedia.org/w/index.php?curid=50925653

https://media.defense.gov/2010/Feb/09/2000396191/-1/-1/0/100201-F-0168M-279.JPG

Decoys Can Further Challenge the Russian Recon-Strike Complex and Munitions Stocks

- **$1,000 decoys can attract $1 million+ missiles**
- If Ukrainian firms can make decoys of HIMARS rocket launchers, artillery, MIG-29s, etc, they can certainly make decoy generator sets
- Source: https://amp.cnn.com/cnn/2023/09/11/world/ukraine-russia-decoy-weapons-intl/index.html, https://www.usni.org/magazines/proceedings/2024/april/decoy-warfare-lessons-and-implication-war-ukraine

Dispersed Targets Will Likely Increase Russian Reliance on Drones

- Ukraine has gotten good at countering long-range Shahed kamikaze drones with innovative ISR approaches (like listening systems) coupled with gun-based mobile fire teams.
- For the price of a single NASAMS or PATRIOT missile interceptor, Ukraine can likely create somewhere between 15 and 50 mobile fire gun trucks with thermal sights and heavy machine guns.
- Missile interceptors are expensive and Ukraine will be competing for supplies with US forces themselves, Israel, Taiwan, and other customers.
- Gun ammunition on the other hand is plentiful. A single plant can produce 24 million rounds per year of 12.7 X 99 mm NATO machine gun cartridges (https://ammoinc.com/2022/10/12/ammo-inc-new-plant-manufacturing-50-bmg-m33-high-accuracy-ammunition/)
- And unlike single use missiles, the trucks can engage targets over and over.

https://en.defence-ua.com/news/russia_changes_tactics_of_strikes_on_ukraine_reducing_use_of_shahed_drones-10388.html

These trucks cost about as much as 2 NASAMS missiles

Source: https://mil.in.ua/en/news/mobile-aa-fire-teams-received-pickup-trucks-from-the-come-back-alive-foundation-and-ukrnafta/

How to Incentivize Partners' Investment in Ukraine Distributed Gas-Fired Generation

Hint: Assurances Needed

Key Facilitator: US Government Economic Guarantees

- Hypothesis: Private parties will be willing to work in Ukraine on this effort is (1) they can find acceptable offtake counterparties and (2) if the USG underwrites 40-45% of equipment replacement value if assets installed under the project are damaged by Russian action (kinetic strikes, cyberattack, or sabotage)
- How many turbines can be replaced for the cost of a Patriot air defense missile battery (i.e. $1 billion)?
  - **At USD 1 million per MW, USG can underwrite more than 2 Gigawatts of generation capacity (assuming 45% replacement value underwrite).**
  - **This means 10% of the recent Ukraine aid package (a/k/a $6 billion) could potentially underwrite installation of 12 GW of generation capacity.**
  - **In simplest terms, this strongly suggests the US could de-risk private power investment in Ukraine for years to come.**
  - **Over time, as the system becomes more distributed, the underwrite risk decreases because Russia's rate of return from strikes on power plants diminishes.**

“Back of Envelope” Asset-Level Economics

http://insupplyco.com/products-tm2500.php#tab-1

11 days	33-36 MW	Up to 37%	5 min.	300+
Installation and Commissioning Time	Net Output	Efficiency	Start Time	Units Installed Worldwide

TM2500 Gas turbine genset (Used, 4,000 hrs):
35MW, $15 million purchase price, 7% interest rate, 10-year payback
Run 350 days/yr, 20 hrs/day = 245,000 MWh/yr.
Capital Cost = $2,089,944/yr or $8.53/MWh

9,688 M^3/gas/hr X 7,000 hrs/yr = 67,816,000 M^3 total gas use/yr

@27.3 M^3 per MMBTU and TTF gas at $21.3/MMBTU trailing 24-mo average = $52.9 million/year in fuel cost
$52.9 million/245,000 MWh generated plus 15% misc costs
Operating Cost = $248.36/MWh

Capital Cost ($8.53/MWh) + Operating Cost ($248.36/MWh) + 10% Profit Margin = **$282.57/MWh or $0.28/kWh**

Key Questions

- What will power costs to consumers look like? Will Ukraine govt/foreign partners need to potentially subsidize? How much will this cost?
- Can these new generating assets be rolled into existing power supply agreements? If not, how hard is it to restructure contracts?
- How do Ukrainian electricity providers think about a situation where more large industrial consumers build “behind the meter” generation and potentially sell surplus electricity back onto the grid?
- What does the “operational expertise tipping point” look like? Right now, US firms, especially in the oilfield services space, have deep expertise in operating distributed power assets under austere, near-war conditions in places like Afghanistan, Iraq, and Nigeria. Ukrainian personnel will need upfront training but it makes sense to indigenize operations as quickly as possible.
- As time evolves, Ukrainian firms can also likely produce the types of turbines needed.

Ukrainian Self-Production of Gas Turbines: A Long and Successful History







IN THE MARINE, POWER AND GAS INDUSTRY

The State Enterprise "ZORYA"-"MASHPROEKT" Gas Turbine Research & Production Complex has a 60-years experience in designing & production gas turbines for Navies, commercial and passenger vessels, power plants and gas piping units and drivers for production equipments. Since 1953 over 4500 marine & industrial gas turbines have been produced and supplied.

Ships of 20 countries worldwide, over 60 power plants, more than 150 gas pipelines compressor stations in Ukraine, China, Kazakhstan, Belarus, Czechia, Canada, Azerbaijan, Iran, Russia, USA, Ghana and other countries are equipped with "ZORYA"-"MASHPROEKT" gas turbines. The total power of the turbines exceeds 500 million kW and total firing time over 110 million hours.

According to gas companies statistics, the gas pumping units (GPU) driven by our gas turbines have been acknowledged most reliable comparing to driven by another companies. They have highest mean value of technical utilization coefficient, maximum time between failure and the highest availability factor.

Owing to the constant work on support and upgrade of the technical level, many turbines exceeded 80000 firing hours without factory repair. UGT16000 second generation leading turbines have accumulated over 100000 hours. UGT15000 third generation leading turbines have accumulated over 85000 hours, UGT25000 fourth generation turbine - over 60000 hours, UGT10000 fourth generation turbine has been put in to trial-commercial operation at Kirovogradskaya compressor station (Ukraine) in 2002 and already have accumulated 35000 working hours.

"ZORYA"-"MASHPROEKT" gas turbines were created for naval applications; they are also adjusted for working off-shore, on floating & stationary oil & gas platforms.

The specialist of "Mashproekt" (Scientific Research & Experimental-Design Works Center) is constantly working at creating new & upgrading early-developed gas turbines widely using modern sophisticated CAD\CAM systems.

"ZORYA"-"MASHPROEKT" facilities & laboratories have been equipped with up-to-date tools, equipment & technologies, the personnel there is well trained. High-temperature steel & alloy precision casting, precise isothermal & impulse extrusion, electro-beam welding, electro-beam & plasma coatings, laser cutting, electric methods of metal treatment-these make an incomplete list of advanced technologies applied at the enterprise.

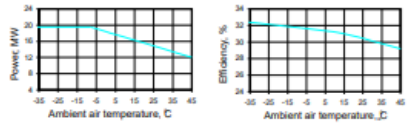
The specialist of the complex perform contract supervision, adjustment & alignment, guaranteed maintenance of prototype & stock-produced items on-site of the customer, and also after-sale maintenance through the whole service life.

Thousands of units built

And knowledge & experience building hundreds of units like the ones needed for distributed generation

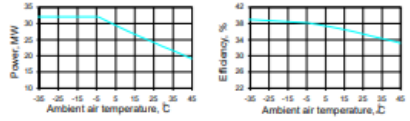
Perhaps build first Zorya Mashproekt international plant in Poland or Romania to supply Ukraine market during war?

UGT 16000
(DJ59)

Power, kW	16300	Exhaust gas temperature, C	354
Efficiency, %	31,0	Dimensions (LxWxH), m	5,9x2,1x2,4
Fuel gas consumption, nm³/kW-h	0,324	Weight, ton	13,5
Exhaust gas mass flow, kg/sec	98,5	Produced	144 units

UGT 25000
(DI80, DN80, DU80)

Power, kW	26700	Exhaust gas temperature, C	484
Efficiency, %	36,5	Dimensions (LxWxH), m	6,4x2,5x2,7
Fuel gas consumption, nm³/kW-h	0,275	Weight, ton	16,0
Exhaust gas mass flow, kg/sec	89,0	Produced	232 units

Additional Facility Hardening Options

- Go Underground

- 800 MW gas-fired plant built underground in Seoul
- Constructed underneath an older, now decommissioned plant built on the surface.
- The new plant is built 25 meters underground.
- That depth is likely beyond the reach of virtually all Russian standoff strike munitions aside from the relatively scarce Iskander SRBM and Kinzhal ALBM.

https://www.powermag.com/korean-utility-plans-first-underground-combined-cycle-power-plant/

Thank You!