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# The Deployment Plan

*How to Scale American Solar — Five Moves, One Product, and the Constraint Nobody Legislates.*

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Every quantitative reference traces to a filed SEC document, publicly-reported transaction disclosure, or industry-standard practitioner benchmark.

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> *"Do what you can, with what you have, where you are."* — *Theodore Roosevelt*

*The philosophy behind every move in this paper is that America has already legislated, litigated, standardized, prototyped, and demonstrated its way to the answer — one piece at a time, over fifty years — and has never assembled the pieces. Each of the five moves below is a version of the same idea: use what already exists.*

*This is an Institute Working Paper — some ideas, offered as a considered read of the evidence, from the seat a working practitioner sits in. Take it or leave it. Do with it what you want.*

## Disclosure

**The author holds a position in Cleveland-Cliffs Inc. (NYSE: CLF) as of 12 July 2026, discussed in Move 4 and in the appendix on strategic investment.**

The findings here admit opposing readings. Nothing in this paper is a recommendation to buy or sell any security, and nothing is a recommendation to file, litigate, appropriate, or legislate anything. The paper is analysis. The reader is entitled to weigh the disclosure accordingly and do with the argument whatever they choose.

## Terms and abbreviations

*This paper is written for readers who work in finance, not in electricity. The industry speaks almost entirely in initials. A full glossary of every acronym, agency, and technical term used in this paper — alphabetized with each set of letters spelled out and briefly defined — is at the back of the paper. Practitioners familiar with electricity terminology can proceed straight into Why Bother With More Solar. Readers who want to build their vocabulary as they read should keep a bookmark at the glossary.*

## Why Bother With More Solar

For thirty years American electricity demand ran flat. Utility planners forecast at zero to one percent annual growth. That is over. Beginning in 2023 and accelerating through 2024 and 2025, load forecasts across every U.S. grid operator rewrote themselves. PJM raised its fifteen-year peak forecast from roughly 150 gigawatts to 210. ERCOT projects roughly 40 gigawatts of new load by 2030 — larger than California's entire peak demand. NERC's 2024 Long-Term Reliability Assessment warned that summer reserve margins across half the country will fall below reliability thresholds by 2029.

Four forces converge. Data centers and artificial intelligence — a single hyperscale AI campus draws 300 to 500 megawatts continuously, and the Department of Energy's 2024 data-center report projects U.S. data-center electricity demand roughly triples by 2028. Electrification of transportation. Electrification of heat and industry. Manufacturing reshoring — semiconductor plants, battery gigafactories, chemical plants, and steel mills built under the CHIPS Act, the Inflation Reduction Act, and the Defense Production Act, each a gigawatt-scale customer of firm, reliable power.

The country needs more electricity from every credible source for the first time in a generation. Natural gas turbines will be built. Nuclear plants slated for retirement will be extended, and new small modular reactors will be built where regulators and finance allow. Wind, storage, geothermal, and hydro all have roles. Every credible integrated resource plan is a mix, and this paper does not argue otherwise.

But the paper is about solar. That deserves an argument.

Solar is the fastest new megawatt. A utility-scale solar plant can be built in twelve to twenty-four months. A combined-cycle gas plant takes three to five years. A conventional nuclear reactor takes ten to fifteen. When demand is doubling in half a decade, the plant that opens in 2027 is a different asset than the plant that opens in 2035.

Solar is the cheapest new megawatt. Utility-scale solar's levelized cost of energy in 2025 came in below new combined-cycle gas across most of the U.S. interconnection queue, and below new nuclear by a factor of two to four. The reasons are more industrial than technological — global manufacturing at scale, marginal cost of an installed panel measured in cents per watt — but the price is real, and it holds even after every tariff and interconnection charge that a U.S. project actually pays.

Solar is the most modular. Nuclear comes in thousand-megawatt blocks. Combined-cycle gas comes in one hundred to five hundred megawatt blocks. Solar comes in whatever size the load pocket asks for — five megawatts, fifty, five hundred. In a grid where the specific location of the new load is a data-center campus or a chip fab, granular deployment matters.

Solar's supply chain is running today. Global panel manufacturing has excess capacity. Modular racking and inverters are on twelve-week lead times, not twelve-month lead times. The bottleneck in a new nuclear reactor is a physical constraint of the reactor. The bottleneck in a new solar plant is not.

And solar's daytime output is matched to two large components of the new load. Data centers run twenty-four hours, but their compute-intensive training workloads have daylight-hour peaks. Air-conditioning load — the largest driver of summer demand — is a daylight-hour peak by definition. Solar is imperfect firm generation but it is well-matched to a share of the load curve nothing else covers as cheaply.

None of that says solar can do it alone. Solar's capacity factor is roughly twenty-five percent. Storage is required for evening load, and at scale storage is expensive. Land use at 1.2 acres per megawatt matters when the deployment is measured in tens of gigawatts. Every serious analysis is a mix, and this paper does not argue otherwise.

But it does argue this. Of the roughly 300 to 500 gigawatts of new generation the country needs to build over the next decade, solar can carry between a quarter and a third — perhaps 100 to 150 gigawatts — if it can be built and connected at the pace its cost and construction time would allow. That is not a small role. It is roughly the difference between meeting the demand curve and rolling brownouts.

And the country cannot do it under current conditions. In PJM the queue takes eight years. In every ISO, the wait exceeds the useful life of a utility interconnection agreement. Transformer lead times run eighteen to twenty-four months. A commercial rooftop that has a $0.41-per-watt physical floor sells for $1.71.

None of those bottlenecks is the panel. All of them are things the United States already legislated, litigated, standardized, prototyped, or demonstrated its way to the answer for — one piece at a time, over fifty years — and never assembled.

The rest of this paper is about assembling them.

## Executive Summary

Ask how to deploy solar at scale in the United States and you will be handed a plan to build solar. That plan is unnecessary. The panel is not the problem, and it has not been the problem for a decade.

Four findings converge.

Land is not the constraint. The Bureau of Land Management opened over 31 million acres and expects roughly 700,000 — two percent — to be developed by 2045. Its own rule admits why: parcels must lie within fifteen miles of high-voltage transmission. The agency screened for wire, not sun.

Hardware is not the constraint. A kilowatt of commercial rooftop solar, built up from glass, silicon, aluminum, copper and two person-hours, has a physical floor near $0.41 per watt against a market price of $1.71. Seventy-six percent of the price is organization.

Capital is not the constraint. GE Vernova paid $5.275 billion for the half of a transformer manufacturer it did not own.

Eminent domain is not the constraint. Twenty-one years after Congress created federal backstop siting authority for transmission, zero permits have issued. On one day in May 2024, FERC approved federal condemnation procedures unanimously and cost-allocation rules 2–1. *The rule nobody uses commanded every vote. The rule about who pays produced a dissent.*

What is scarce is a connection, a transformer, and a firm that can sell a roof cheaply.

Five moves follow. Three require no new legislation. None requires a tax credit. None requires an acre of new federal land.

| | MOVE | UNLOCKS | AUTHORITY |
|---|---|---|---|
| 1 | Connect and manage — energy-only interconnection, curtailment risk on the generator | The largest block of stalled capacity in America | FERC and the grid operators. None new |
| 2 | Use the interconnection you already have — surplus service at operating and retiring thermal plants | Immediate. Zero queue, zero right-of-way | None new |
| 3 | Reconductor — better wire on existing towers | Roughly double the capacity of existing corridors | State rate cases. None new |

| | MOVE | UNLOCKS | AUTHORITY |
|---|---|---|---|
| 4 | Fix the transformer bottleneck — which is not steel | The only physical constraint in the system | An appropriation |
| 5 | Standardize the product — a factory-built, type-certified solar block | The $1.30 per watt that is not physics | State and federal statute |

Move 5 is the longest section of this paper because it is the least examined — not because it is the most important. Moves 1 and 2 matter more, because Move 5 is bounded by field-installation economics that even a vertically-integrated manufacturer has failed to industrialize (see the Tesla natural experiment inside Move 5). The United States already knows how to make a factory-built structure cheap: it did it to the house in 1976, by inspecting it in the plant, affixing a federal label, and forbidding the county to re-inspect it. Manufactured homes cost roughly $55 to $65 per square foot against about $168 for site-built. No equivalent regime exists for solar, and the folding, pre-wired, drop-in-place array that would benefit from one was invented in 2017, works, and has deployed thirty-two megawatts.

And a corollary running through all five: put the solar at the load. BLM screened for wire; load centers are where the wire already is.

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### One more thing, and it is the point of the paper

Almost nothing in this paper needs to be invented.

Every move below already exists — as a working system inside the United States, as a right already written into every federal interconnection tariff, as a rule FERC has already issued, as a prototype the federal government already built, or as a body of law Congress already passed for a different object.

| MOVE | IT ALREADY EXISTS AS | STATUS |
|---|---|---|
| 1. Connect and manage | ERCOT, for a decade. And Order 845’s provisional interconnection service and service below nameplate capacity — rights in every tariff since 2018 | A checkbox nobody ticks |

| MOVE | IT ALREADY EXISTS AS | STATUS |
|---|---|---|
| 2. Use the interconnection you have | Surplus Interconnection Service, mandatory in every FERC-jurisdictional tariff since 2018; expanded by Order 2023 and by PJM in 2025 | A right nobody exercises |
| 3. Reconductor | Order 881 made ambient-adjusted ratings mandatory in July 2025. Order 1920 requires providers to *consider* advanced conductors | “Consider” is not “choose” |
| 4. Fix the transformer | RecX — a standardized rapid-deployment transformer, built by DHS and EPRI, completed 2014. Plus STEP, Grid Assurance, RESTORE | Keyed to terrorism, not to the queue |
| 5. Standardize the product | The 5B Maverick, invented 2017. And the HUD Code, which made a factory-built house cheap in 1976 | 32 megawatts deployed. Never applied to solar |

The United States has already legislated, litigated, standardized, prototyped and demonstrated its way to the answer, one piece at a time, over fifty years — and has never assembled the pieces. That is a far more hopeful finding than the alternative, and it is the reason this paper asks Congress for almost nothing.

## Move 1 — Connect and Manage

The largest lever in American energy policy. It costs nothing. It has run inside the United States for a decade.

Outside Texas, grid operators use what the Brattle Group calls “invest and connect.” A generator seeking Network Resource Interconnection Service must be shown deliverable to load under stressed conditions. Studies identify network upgrades. The generator pays for them, and they are built *before* it connects.

The consequences are measurable.

- In PJM, the timeline from application to commercial operation rose from under two years in 2008 to over eight years in 2025 — a figure reflecting the queue as it stood at the start of 2026, into which Order 2023’s reforms (cluster studies, readiness deposits, withdrawal penalties, timely-completion obligations) have begun to feed but not yet flowed through.

- Average interconnection costs for PJM queue projects rose eightfold, from $29/kW to $240/kW.
- FERC's target for executing an interconnection agreement is 8 to 11 months. The national average is 25 months; PJM averages 40. Projects in data center load-growth zones wait three to four years.
- For requests submitted 2018–2020, completion rates in ISO-NE, NYISO, PJM and SPP fell below ten percent.

ERCOT instead runs connect and manage: initial studies confirm adequate interconnection, congestion is resolved in real-time dispatch rather than in advance studies, and the generator accepts curtailment risk.

- ERCOT brought 14.2 GW online in 2021–22. PJM, more than twice its size, brought on 5.6 GW.
- ERCOT's average time to an interconnection agreement is 20 months against PJM's 40.

Same country, same panels, same capital. Roughly four times the throughput per unit of grid.

### Why this suits solar particularly

Connect and manage trades certainty of delivery for speed of entry, and puts curtailment risk on the developer. For solar, that is a cheap trade. Curtailment risk is diurnal, predictable, and generally bounded — cleanly so in duck-curve systems like California; less cleanly in ISOs where curtailment is driven primarily by transmission congestion or minimum-generation constraints rather than by daily oversupply. The shape of the risk is manageable in every case. A curtailed sunny hour costs its owner revenue. A four-to-eight-year delay costs the country a power plant.

### The honest objection

PJM's independent market monitor is right that connect-and-manage does not abolish network upgrade costs — it socializes them through the transmission cost-allocation charge, and it induces load to locate where consumers have already paid for transmission. ERCOT under-plans; its curtailment is high, and congestion recently forced the Texas commission to approve new lines anyway.

So do not import ERCOT's process alone. Import it alongside proactive regional planning, which pays for itself: MISO identified a $10 billion transmission portfolio supporting 53 GW of renewables against $37–68 billion of offsetting savings; PJM found $3.2 billion of upgrades supporting 75 GW of offshore wind — about $40/kW, against $6.4 billion previously identified for a fifth as much.

### What already exists

Everything.

ERCOT has run connect-and-manage for a decade, inside the United States, under FERC's nose, at four times PJM's throughput per unit of grid.

And the federal rules already grant most of what this Move asks for. FERC Order No. 845, issued April 19, 2018, amended the standard interconnection agreement that binds every jurisdictional transmission provider in the country. It requires them to:

- Allow provisional interconnection service — limited operation of a generating facility *before the full interconnection process is complete*. The right nominally exists, but the operating tariff qualifies it with *reasonable expectation* language that leaves the discretion with the transmission provider. The reform ask is a rebuttable presumption in favor of the generator: the provisional right becomes the default unless the transmission provider can specifically show why not;
- Allow a customer to request interconnection service below its generating facility's capacity, installing control devices to cap injection — which is precisely the clamped-export design proposed in Move 5;
- Allow the customer to build the transmission provider's interconnection facilities and standalone network upgrades;
- Create a surplus interconnection service process at existing points of interconnection.

Order No. 2023, in July 2023, went further — FERC's first overhaul of interconnection procedures since 2003. It imposed firm study deadlines and penalties, eliminated the "reasonable efforts" standard, and required transmission providers to allow more than one generating facility to co-locate behind a single point of interconnection and share a single interconnection request.

And MISO's "net zero" option dates to 2012, six years before FERC made it national.

So the fast track is not missing. It is unused.

Virginia's chief energy officer puts the mechanism precisely: developers examine PJM's Energy Resource Interconnection Service option, find that the contingency analysis makes it nearly as burdensome as full study, and go back to the queue. The right exists; the procedure defeats it.

Note the distinction. ERIS is a *queue product* — a less exhaustive study path that accepts higher curtailment as the cost of a shorter path in. Connect-and-manage is an *operating philosophy* — the ERCOT approach where generators connect first and are actively curtailed in real time. They converge in effect but differ in mechanism, and importing one does not automatically import the other. The reform in this Move is to make ERIS behave the way ERCOT's connect-and-manage behaves: a genuine fast track, not a longer path in a different lane.

And the live vehicle exists too. In October 2025 the Department of Energy exercised its rarely used authority under § 403 of the DOE Organization Act to direct FERC to act on large-load interconnection. FERC opened Docket No. RM26-4-000, which would establish the first federal standards for loads above 20 MW and for hybrid facilities combining load and generation at a single point of interconnection. That docket is the natural home for everything in this Move.

The ask is therefore small. Strip the contingency analysis out of ERIS. Cap the study scope. Require every grid operator to explain why its study takes longer than the software takes. Nobody has to pass a law.

### Who pays for connect-and-manage

This paper will not pretend the cost disappears. It moves.

Under invest-and-connect, the generator pays for the network upgrades its project triggers, before it connects. Average interconnection costs for projects in PJM's queue rose eightfold, from $29/kW to $240/kW. That is a real number and somebody pays it.

Under connect-and-manage, most of it is not avoided. It is socialized — recovered through the transmission cost-allocation charge, from load. PJM's independent market monitor makes exactly this objection, and he is right. In ERCOT, most interconnection costs are borne by energy users. Worse, the regime induces new load to locate where consumers have already financed transmission.

And this paper has already told you who is paying. Researchers at Lawrence Berkeley National Laboratory examining retail prices from 2019 through 2025 found that the main driver of increases was utility investment in grid infrastructure — aging equipment and resilience needs — not data centers.

So: the recommendation moves grid-infrastructure cost onto ratepayers who are already absorbing rising grid-infrastructure cost. That must be argued, not buried.

Here is the argument.

First, the cost is not new; the payer is. Network upgrades under invest-and-connect are ultimately recovered from consumers too, through the price of the power the generator sells. The difference is *when*, *how visibly*, and *whether the project happens at all.* Eighty percent of queued projects withdraw, frequently because upgrade costs exceed ten percent of project capital expenditure. An upgrade avoided by a project that never gets built is not a saving. It is a shortage.

Second, a megawatt-hour four years earlier is worth more to a ratepayer than an upgrade avoided. PJM's queue-to-operation timeline has grown from under two years to over eight. Capacity prices have risen accordingly. The ratepayer is already paying for scarcity, in the capacity auction, today.

Third — and this is the condition, not a footnote — socialized cost is only defensible if the network is planned proactively rather than project-by-project. MISO identified a $10 billion portfolio of transmission supporting 53 GW of renewables against $37–68 billion of offsetting savings. PJM found $3.2 billion of upgrades supporting 75 GW of offshore wind, roughly $40/kW, against a previously identified $6.4 billion for a fifth as much.

Connect-and-manage without proactive regional planning is a cost shift. With it, it is a cost reduction. ERCOT does the first and only partly the second, which is why its curtailment is high and why the Texas commission has had to approve new lines anyway.

Import both halves, or neither.

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### What to do

1. Make ERIS a genuine fast track. Virginia's chief energy officer notes that developers examine PJM's existing ERIS option and conclude it is nearly as burdensome as full study. Strip the contingency analysis. Cap the study scope. Let a developer elect curtailment risk in exchange for a queue position measured in months.
2. Automate the studies. They are computation, not construction. Third-party software has automated MISO's process to roughly ten days. Require every RTO to explain why its studies take longer than the software does.
3. Publish curtailment forecasts so developers can price the risk they are being asked to bear.

### The reliability objection, met

A reliability coordinator reading this Move will ask a fair question: connect-and-manage moves reliability decisions closer to real time, and NERC's transient-stability standards were written on the assumption that steady-state contingency analyses are done in advance. How does the Move reconcile with those standards?

The answer is that curtailment absorbs the delta. In a connect-and-manage regime, a generator that would have failed a transient-stability contingency in advance study is curtailed in real time when the contingency approaches. The reliability requirement is not relaxed; it is met at a different point in the operational cycle. ERCOT has operated inside NERC's transient-stability regime for the decade this Move draws on, using curtailment as the reliability instrument. The paper is not asking NERC to change a standard. It is asking transmission providers to accept curtailment as the mechanism that clears the standard.

### Where this Move lives — and where it does not

Connect-and-manage is a transmission-scale reform. It changes how large generators — utility-scale solar, wind, thermal replacement — obtain and hold interconnection service at FERC-jurisdictional voltages. It does not, on its own, unlock commercial rooftop or residential-scale solar, which interconnect at distribution voltages under state-jurisdictional tariffs. Those distribution-level unlocks — hosting-capacity maps, automated inverter-based interconnection, community-solar standards — are a separate reform path travelled inside state commissions and public-utility commissions. This Move is about the transmission bottleneck. The distribution-scale story is real and belongs in a companion paper on state-jurisdictional distribution reform.

### Where the moves live — voltage and jurisdiction

| MOVE | VOLTAGE LEVEL | JURISDICTION | VEHICLE |
|---|---|---|---|
| 1. Connect and manage | Transmission (typically 115–500 kV) | FERC | Order 845 / Order 2023 / RM26-4-000 |
| 2. Surplus interconnection | Transmission (at the retiring plant's switchyard) | FERC | Order 845's SIS process |
| 3. Reconductoring — transmission | Transmission | FERC | Order 1920 rulemaking |

| MOVE | VOLTAGE LEVEL | JURISDICTION | VEHICLE |
|---|---|---|---|
| 3. Reconductoring — distribution | Distribution (typically 4–34.5 kV) | State | State rate cases |
| 4. Transformers | Transmission and distribution | Federal industrial policy | Congressional appropriation |
| 5. Standardized product | Distribution (behind-the-meter and commercial) | State building codes + federal standard | State factory-built path first; federal standard later |

## Move 2 — Use the Interconnection You Already Have

The fastest interconnection is the one that exists. And there are hundreds of them, sitting at the end of transmission lines, attached to power plants that are shrinking.

Every large thermal plant terminates in a switchyard: a high-voltage equipment yard containing the generator step-up transformer, breakers, protective relays, and the connection to transmission. It represents a decade of permitting and a queue position that no longer has to be earned. It is the most valuable asset on the site and it does not appear on any map of solar potential.

### The wrinkle nobody mentions

Coal retirements are being delayed, not accelerated.

- Operators planned to retire 8.5 GW of coal in 2025. They retired 2.6 GW — the least since 2010. 4.8 GW slipped to a future year, and two plants totaling 1.1 GW cancelled retirement entirely.
- DOE emergency orders postponed several large closures. Another 1.2 GW planned for 2027 cancelled. A plant slated for 2026 pushed to 2029.
- Total U.S. coal capacity is scheduled to fall from 172 GW in May 2025 to 145 GW by end-2028 — but the schedule keeps moving. 58 percent of planned retirements are in the Midwest and Mid-Atlantic.

A strategy that waits for these plants to die will wait a long time.

### Which is why the right instrument is surplus interconnection — used correctly

And it must be used correctly, because the mechanism is more constrained than it first appears.

It is tempting to say that a coal unit with a 1,000 MW interconnection running at a forty percent capacity factor leaves 600 MW idle in an average hour. That sentence confuses energy with capacity, and an interconnection lawyer will reject it in a week.

Interconnection service is a firm right to inject at a point. It is not an energy-weighted average of what was actually injected. The incumbent generator holds a 1,000 MW right and may exercise it in any hour. FERC's definition, from Order No. 845, is exact: surplus interconnection service is any unneeded portion of the interconnection service established in a Large Generator Interconnection Agreement, such that if the surplus is utilized, the total amount of interconnection service at the point of interconnection would remain the same.

Three constraints follow, and every developer should know them before writing a term sheet:

| CONSTRAINT | CONSEQUENCE |
|---|---|
| Total injection at the point of interconnection must not increase | A running unit has not made its headroom "unneeded." It has merely not used it this hour |
| The incumbent controls the surplus. FERC directed providers to create a process for transfer of service the existing customer or an affiliate does not intend to use | A third party cannot help itself to another company's interconnection rights. It must be given them |
| No new network upgrades. On rehearing, FERC limited surplus service to the level accommodated without constructing new upgrades | The headroom is real but bounded |

**Studies still occur** — reactive power, short-circuit and fault duty, stability. They are far shorter than a cluster study. They are not zero.

### So where does it actually work?

Three site types, and the distinction is worth money.

1. Plants that are genuinely retiring. The interconnection right is being surrendered. This is the clean case, and roughly 25 to 30 gigawatts of coal interconnection is scheduled to be surrendered through 2028 — the fleet is planned to fall from 172 GW in May 2025 to 145 GW by the end of 2028 — plus gas and steam retirements on top.
2. Low-capacity-factor peakers. A unit that runs two hundred hours a year holds a firm right it almost never exercises. Its owner has every incentive to monetize the surplus, and no operational reason to withhold it.
3. Operating baseload units — with the incumbent's consent and a control scheme. Here the surplus is created rather than found. Co-located storage, or an operating protocol between the two resources, guarantees that combined injection at the point of interconnection never exceeds the LGIA limit. The coal unit backs down; the battery absorbs the overlap; the meter at the point of interconnection never notices.

The corrected proposition, and it is stronger than the one it replaces:

> *You do not need the plant to retire. You need the incumbent's consent and a control scheme.*

That is a harder sentence to say and an easier one to act on. It also identifies the counterparty precisely: the plant owner is not a seller of land. He is a seller of optionality on a right he paid for, and he will want to be paid for it. A joint venture, not an acquisition.

### What already exists

The instrument is federal law, it is mandatory, and it was expanded last year.

Surplus Interconnection Service was created by FERC Order No. 845 in 2018. FERC defined it as any unneeded portion of the interconnection service established in a Large Generator Interconnection Agreement, such that if the surplus is used, the total amount of interconnection service at the point of interconnection remains the same. Every jurisdictional transmission provider was required to build a process for it. It is separate from the full interconnection queue, and it lets a project come online sooner so long as no new network upgrades are required.

Order No. 2023 then required providers to open surplus service to new customers as soon as the original customer has executed its interconnection agreement.

And PJM expanded it in 2025. In a December 2024 filing accepted by FERC, PJM removed its own restrictions on surplus service, permitted storage resources to use it, and allowed requests to be processed on an expedited basis during the agreement implementation phase. PJM's stated reason was generator retirements, load growth, and near-term reliability risk. The grid operator with the eight-year queue has already told FERC that surplus interconnection is part of the answer.

MISO's equivalent — the "net zero" option — has existed since 2012.

So the coal plant does not need to retire, and the developer does not need to enter the queue. A thermal unit running at a forty percent capacity factor is leaving most of its interconnection idle in most hours, and the law has provided a mechanism to use it for seven years.

The gap is not legal. It is that almost nobody has asked.

### Where to look — a sample, not a list

There are hundreds of candidate sites. These are illustrative, drawn from EIA's reported retirement schedule, and every one comes with the caveat above: dates move.

| PLANT | STATE | CAPACITY | STATUS PER EIA |
|---|---|---|---|
| J.H. Campbell | Michigan | 1,331 MW | Slipped from 2025; delayed repeatedly by DOE order |
| Cumberland Unit 2 | Tennessee | 1,231 MW | Largest 2026 retirement |
| R.M. Schahfer 17 & 18 | Indiana | 722 MW | Postponed from 2025 to 2026 |
| South Oak Creek 7 & 8 | Wisconsin | 616 MW | Delayed from 2025 |
| Brandon Shores | Maryland | — | Retirement deferred to 2029 for reliability |
| Kingston 7, 8, 9 | Tennessee | — | Three units 2026, six in 2027 |
| Craig 1 | Colorado | — | Isolated; replacement weighted to wind and solar |
| Comanche | Colorado | — | Delayed from 2025 |

| PLANT | STATE | CAPACITY | STATUS PER EIA |
|---|---|---|---|
| F.B. Culley 2 | Indiana | 90 MW | Postponed to 2026 |
| Centralia Unit 2 | Washington | — | Converting to gas rather than retiring, 2028 |

In 2026 the sector plans to retire 6.4 GW of coal and 4.6 GW of gas and steam turbines — roughly 11 GW of utility-scale capacity, and roughly 11 GW of interconnection.

Note Centralia. The operator chose to convert rather than retire. That is the single most instructive line in the table: the interconnection is worth more than the boiler.

### Also available, and requiring nothing

Behind the meter at large load. A generator serving load behind a customer's meter never enters the queue. The market has already worked this out — 46 data center projects totaling 56 GW planned their own behind-the-meter generation, ninety percent announced in 2025 alone.

Distribution-level solar. Commercial rooftops, carports and parking structures interconnect at distribution voltage, subject to hosting-capacity limits rather than transmission queues.

### The corollary about siting

BLM screened its 31 million acres for proximity to transmission. The places with transmission are the places with load. Therefore:

> *The efficient place for American solar is on and beside the buildings, substations, and power plants already connected to the grid.*

Not because the desert is forbidden. Because the desert requires a wire, and the wire is the thing we cannot build.

## The Conversion Project Plan

*What it actually takes to put solar and storage on one retiring — or operating — thermal site. Durations are typical, not guaranteed, and overlap heavily.*

| # | WORKSTREAM | TYPICAL DURATION | NOTES AND DEPENDENCIES |
|---|---|---|---|
| 1 | Site control — purchase, lease or joint venture with the plant owner | 3–9 mo | The owner may prefer a JV; the interconnection is their asset, not yours |
| 2 | Interconnection rights — Surplus Interconnection Service request, or assignment of the existing LGIA | 6–12 mo | The whole thesis. Avoids a 40-month queue. Confirm the LGIA's MW limit and whether the point of interconnection is shared |
| 3 | Interconnection study — SIS or ERIS conversion | 6–12 mo | Runs concurrently with #2. Far shorter than a new NRIS cluster study |
| 4 | Environmental diligence — Phase I and II site assessment, asbestos, PCBs | 6–12 mo | Brownfield status is a feature: it narrows the questions |
| 5 | Coal ash (CCR) closure | 12–36 mo | Often the true long pole on a *coal* site. Avoidable by siting the array on adjacent land rather than on the ash pond |
| 6 | Demolition and decommissioning | 12–24 mo | Frequently unnecessary. Do not demolish the boiler to build a solar farm; use adjacent acreage and leave the switchyard alone |
| 7 | Local permitting, stormwater, grading | 6–12 mo | Brownfield redevelopment is politically easy. The county wants the tax base back |
| 8 | Offtake — PPA, utility contract, or co-located data center | 6–18 mo | Determines financeability. A co-located load is worth more than a PPA because it avoids the grid entirely |
| 9 | Equipment procurement | See below | The critical path |
| 10 | Financing | 6–12 mo | Post-§48E, the tax equity market for new solar is closing. Assume cash, debt, or safe-harbored equipment |

| # | WORKSTREAM | TYPICAL DURATION | NOTES AND DEPENDENCIES |
|---|---|---|---|
| 11 | EPC and construction | 12–18 mo | Solar is fast. This is not where the time goes |
| 12 | Commissioning, testing, COD | 3–6 mo | |

### The critical path is procurement, and inside procurement it is one item

| EQUIPMENT | LEAD TIME |
|---|---|
| Solar modules | 3–6 mo |
| Racking and trackers | 3–6 mo |
| Inverters | 6–9 mo |
| Battery storage | 9–15 mo |
| Medium-voltage transformers | 12–18 mo |
| High-voltage breakers | 12–18 mo |
| Generator step-up (GSU) transformer | 18–24 mo, and rising |

**Total, site control to commercial operation: roughly 36 to 48 months** — of which the interconnection queue, ordinarily the largest single block, has been reduced from forty months to under twelve.

And the long pole is a transformer. Which is Move 4.

## Move 3 — Reconductoring, Explained

Start with what it is, because the word conceals the idea.

A transmission line is a wire strung between towers. It cannot carry unlimited current because current heats the wire, heat makes the metal expand, expansion makes the wire sag, and a sagging wire eventually touches a tree. The limit on the line is not the tower. It is the wire’s tolerance for heat.

Conventional wire is aluminum wrapped around a steel core. An advanced conductor replaces the steel core with a composite core — carbon fiber, ceramic, or aluminum-alloy. The family includes ACCC (aluminum conductor composite core), ACCR (aluminum conductor composite reinforced), and ACSS (annealed aluminum steel-supported) among others. The composite barely expands when hot. So the wire can run at 200–220°C instead of roughly 90°C without sagging — and because the core is thinner and stronger, about thirty percent more aluminum fits in the same diameter at the same weight.

Result: on thermally-limited corridors, the same towers, on the same land, can carry roughly twice the power. (On long lines above roughly one hundred fifty miles the constraint is often stability rather than heat, and reconductoring does less. The two-thirds-of-the-time figure below reflects this in aggregate.)

> *This is not a new road. It is the same road with twice the lanes.*
>
> *Or, if you prefer: the same engine bay, the same chassis, the same footprint — and twice the horsepower. Nothing moves. Nothing is condemned. No one is asked for permission. The corridor simply does more.*

### The numbers

- Advanced conductors deliver capacity gains of fifty to one hundred fifty percent on existing towers.
- Most U.S. transmission lines are short — under fifty miles — and therefore limited by heat rather than by stability. In those cases, reconductoring plus marginal substation additions can up to double the power transfer capacity within an existing right-of-way.
- The wire costs two to four times more per foot than steel-core cable. But because reconductoring eliminates land acquisition, permitting and new towers, the total cost per foot runs about half that of a new line.
- Modeling published in *PNAS* found reconductoring the better choice on cost alone roughly two-thirds of the time, and — accounting for the slow timelines of new-build — enabling nearly four times as much new interzonal transmission capacity by 2035 at only slightly higher total investment. It could supply about eighty percent of the transmission capacity increase needed for 90 percent clean generation by 2035.

The doubling claim carries qualifications. Roughly-doubles is the shape of the answer on thermally-limited corridors where the associated substations and neighboring lines can accept the added flow. Two qualifications routinely apply. First, substation upgrades — protection resets, breaker and relay work, sometimes line-terminal work — are commonly required alongside the reconductor and are not free. Second, on a system where the neighboring lines are already congested, additional capacity on the reconductored corridor increases loop flows to those lines and the marginal capacity gain is smaller than the model predicts. Neither qualification changes the shape of the finding. Both belong in the sentence that presents it, because a transmission planner reading a plain-language *roughly doubles* has already thought of them.

Dynamic line rating is the cheaper cousin. Rather than assuming the worst-case still, hot day, sensors measure actual conditions; wind cools a wire and lets it carry more. PPL Electric achieved a fifteen percent rating increase and reported $64 million in congestion savings, deploying across 31 miles of 230 kV line for about $1 million.

## What already exists

FERC has already mandated the cheap half and asked politely about the expensive half.

Order No. 881, *Managing Transmission Line Ratings*, requires every U.S. transmission provider — inside organized markets and out — to use ambient-adjusted ratings as the basis for evaluating near-term transmission service. AAR replaces a static, worst-case seasonal rating with one recalculated at least hourly against forecast air temperature. The compliance deadline was July 12, 2025. It is in force today.

Order 881 stops short of mandating full dynamic line rating. But it requires the grid operators to build the systems and procedures so that any transmission owner who wishes to use DLR may do so. FERC removed the procedural friction and left the choice.

Order No. 1920 goes to the heart of this Move. It requires transmission providers to consider four alternative transmission technologies in long-term regional planning — dynamic line ratings, advanced power flow control devices, advanced conductors, and transmission switching — and to explain publicly how they will do so.

Consider.

That is the whole gap, and it is one word wide. A provider that considers advanced conductors and builds new towers anyway has complied. The reform is not a new rule. It is a change of verb.

## Why This Has Not Already Happened

The paper marvels — or the literature does — that Berkeley researchers found U.S. transmission operators unaware advanced conductors existed. That reading is not quite right. They were not unaware. They were uninterested.

A regulated utility earns a rate of return on capital prudently deployed. A new transmission line is a large capital addition earning that return for forty years. Reconductoring delivers the same capacity for roughly half the capital. Ask a rate-base-maximizing monopoly to spend half as much for the same result and it will study the question thoroughly, at length, and choose the towers.

No amount of engineering literature fixes that. It is not an information problem. It is an incentive problem.

The regulatory literature contains a well-developed answer: shared-savings and performance-based mechanisms that let a utility earn on the capacity it adds rather than on the capital it spends. Hawaii's PBR framework, New York's REV proceedings, and Rhode Island's PowerSector Transformation Initiative are the practical templates. The general observation — every recommendation in this paper asks somebody to earn less — is the reason none of the recommendations have already happened, and it is the first thing an investor, a commissioner, or a curious reader will want to know.

The paper returns to this in the Who Loses section. But it belongs here, in Move 3, because Move 3 is where the incentive misalignment is sharpest and cleanest, and where a reader who does not see it explained here will not understand why a manifestly cheaper answer has been sitting on the shelf for a decade.

A finer point on the ratebase argument. The incentive to defer reconductoring depends on remaining book value. Where the existing tower and wire are near the end of their depreciation schedule, the utility has already earned most of the return; retiring and replacing is a small write-off and a small addition, and the incentive to defer is thin. Where the depreciation schedule is long, the write-off is material and the incentive to defer is strong. The reform ask is line-by-line, not a general property of the technology.

Two operational objections a commissioner will hear from utility engineers.

*The reliability veto.* A utility engineer will argue that reconductoring compromises the redundancy of the original design — that a corridor rated at twice its capacity is more consequential to lose. That is sometimes true and always the utility's fallback. The answer is that redundancy can be preserved by staging: reconductor plus a stability-support device (advanced power flow control, a reactive-compensation asset, sometimes a battery) restores the N-1 posture the original design carried. The redundancy objection is real, and it has an engineered answer that is cheaper than the alternative.

*The dispatch problem.* Even where reconductoring doubles the physical capacity of a corridor, the surrounding system — substations, generation dispatch, load — must be able to use it. If the capacity ends up increasing loop flows to neighboring lines that are already congested, the marginal reconductor produces less than the model predicts. This is a system-planning objection, not a physics objection. It argues for pairing the reconductoring reform with proactive regional planning — which is the same coupling Move 1 requires and for the same reason.

### The jurisdictional split, and where the ask lives

Reconductoring on transmission lines is FERC-jurisdictional and shows up in the Order 1920 rulemaking, in regional planning processes, and in the *justify not choosing* verb change. That is the ask directed at the Commission.

Reconductoring on distribution lines is state-jurisdictional and shows up in state rate cases before the public utility commission. The same verb change applies, at the state level, with the same performance-based mechanism attached. The Hawaii, New York, and Rhode Island frameworks named above are all state instruments, and they are the reader-staffer's shortest path to a live docket.

The Move is asking two different rooms to do the same thing. A FERC reader-staffer is being asked to strengthen an existing federal order. A state-commission reader-staffer is being asked to open a rate case or docket that imports the same verb change under state authority. Both belong in this Move, and confusing the two produces a policy proposal that neither audience can execute.

And the federal money has arrived. On March 12, 2026 the Department of Energy announced a $1.9 billion funding opportunity for accelerated reconductoring and advanced transmission technology upgrades.

What the change of verb would look like. If state commissions and FERC required transmission providers to *justify not choosing* reconductoring — rather than merely to consider it — the same rule would carry a different burden of proof. That is the whole reform in one sentence. Whether anyone makes it happen is not the paper's decision to make.

Two constraints this paper will not pretend away.

Reconductoring an energized line requires an outage. On a congested corridor an outage is scheduled years ahead and costs the market real money. This is a scheduling problem, not a physics problem, but it is not nothing.

And Move 3 depends on Move 4. The Berkeley analysis is explicit that reconductoring works *in combination with marginal substation additions* — reactive compensation, relay and breaker upgrades, and transformer replacements. Transformers run fifteen to twenty-four months.

You cannot reconductor your way around a transformer shortage using transformers. The two moves must be sequenced together, and the appropriation in Move 4 is the enabling condition for the docket comment in Move 3.

### Why this is the elegant move

Federal transmission siting failed for two reasons: eminent domain requires taking land, and interstate lines founder on cost allocation — Ohio will not pay for a line that lowers prices in Virginia.

Reconductoring needs neither. It happens inside an existing right-of-way, so no land is taken and no siting board is consulted. It is a capital upgrade to an asset already inside one utility's rate base, so there is no interstate cost-allocation question to litigate.

It is the only way to expand the wire that does not require answering the question America has refused to answer for ninety years. The Department of Energy has finally noticed, committing $1.9 billion through a program called SPARK — *Speed to Power through Accelerated Reconductoring and other Key advanced transmission technology upgrades.*

And the binding constraint here is not cost. It is awareness. The Berkeley researchers who published the PNAS analysis spoke to U.S. operators who did not know advanced conductors existed.

### What to do

State commissions should require, in every transmission rate case, that the utility demonstrate why reconductoring was not selected in preference to new-build. Make advanced conductors the default and new towers the exception requiring justification. It is a docket question in fifty states, it costs the federal government nothing, and it is worth more than any siting statute Congress will pass this decade.

## Move 4 — The Transformer Bottleneck Is Not Steel

Almost everyone who examines this problem concludes that the constraint is grain-oriented electrical steel. It is not, and the evidence comes from the sole domestic producer's own disclosures.

Here is what is true. Transformers are scarce: order backlogs grew more than thirty percent in 2024 after two years of double-digit growth, and lead times run fifteen to twenty-four months. A generator step-up transformer is the long pole in the project plan above, and in most projects in America.

Here is what does not follow. Cleveland-Cliffs, the sole domestic producer of grain-oriented electrical steel, is not running at capacity. (Sole domestic — not only global source. GOES is imported into the United States from Japan (JFE, Nippon Steel), Korea (POSCO), and Europe (thyssenkrupp) as well.)

- Cliffs told investors the Weirton project would use under-utilized capacity to produce 30 to 40 percent more tonnage of grain-oriented electrical steel.
- Its fiscal 2025 shipments of stainless and electrical steel fell three percent — to 552 thousand net tons from 567 — while its total steel shipments rose four percent.
- It told the Secretary of Commerce in September 2025 that its electrical steel market is soft, its largest segment stagnant with excess inventory and declining sales.

That is not a company at a capacity ceiling. That is a company with idle capacity and insufficient demand. It would add capacity if the return warranted it. The return does not.

The grade-and-gauge complication. GOES is not one product. It is a family, and the family divides by magnetic-flux-density grade and by strip thickness. High-permeability GOES at thinner gauges — the material most in demand for the largest generator step-up and grid transformers — trades on a different price and lead time than the more general-purpose grades that constitute Cliffs' larger production run. Surplus in one grade and scarcity in another can coexist inside the same annual report. That is the reading a careful Commerce staff reviewing the Section 232 record would arrive at, and it is the reading the Institute's companion working paper on the transformer bottleneck develops in full. The one-sentence summary belongs here so that a policymaker reading only the Deployment Plan is not left with the impression that the industry disaggregates the way the balance sheet does.

### What already exists

The United States built the standardized transformer twelve years ago and filed it under counterterrorism.

**RecX** — the Recovery Transformer — was a Department of Homeland Security program, executed with the Electric Power Research Institute, that developed a rapidly deployable prototype transformer designed to replace the most common high-voltage units. It was completed in 2014.

Be precise about what that means. RecX was a *demonstration*. A tested prototype is not a qualified, warrantied, utility-accepted product with a supply chain, a service network, and type tests behind it. The distance from prototype to production is several years and several hundred million dollars.

Which is exactly what makes it the right target. The concept is proven and the industrialization is not funded. That is the definition of the thing a Defense Production Act Title III appropriation exists to buy — and it is a far more specific ask than "money for transformers."

The SKU has been designed. It has never been manufactured.

The sharing architecture exists too, and it is similarly misfiled:

| PROGRAM | WHAT IT IS | WHY IT DOES NOT HELP THE QUEUE |
|---|---|---|
| STEP (Edison Electric Institute, 2006) | 56 participating utilities contractually obliged to sell spare transformers to a stricken peer | Triggered only by an act of terrorism plus a presidential emergency declaration. Never triggered |
| Grid Assurance (2016) | A standalone company, founded by AEP, Berkshire Hathaway Energy, Duke, Edison, Eversource and others. Maintains an inventory of long-lead spares, warehoused in strategic locations, with pre-planned logistics | Subscription-based emergency restoration |
| RESTORE (North American Transmission Forum) | 18 companies, 40 utilities, spare exchanges across seven voltage classes | Emergency exchange |
| SpareConnect (EEI) | A networking portal for utilities seeking spares | No central database |

Read the second column. America has a standardized emergency transformer, a pooled national inventory, warehousing, transportation plans, and a legal architecture binding fifty-six utilities to share.

All of it is keyed to a terrorist attack. None of it is keyed to a two-year lead time.

The threat that has actually materialized is not a bomb at a substation. It is an order book. The country built the fire brigade and is now watching the building fill with water.

Two things follow.

Standardize and stockpile. Take RecX off the shelf. Define a small number of standard SKUs at the most common voltage and MVA classes. Build them on a line. Hold inventory against ordinary interconnection demand, not against catastrophe. The existing warehousing and logistics of Grid Assurance are the distribution channel.

Retarget the sharing programs. A spare transformer that can only move after a presidential declaration is not a spare. It is a museum piece with a guard.

### So what actually broke?

Intellectual property. Cleveland-Cliffs announced a $150 million transformer plant at Weirton in July 2024 and cancelled it on May 7, 2025, citing changes in scope from the project partner that no longer met its investment requirements. Its chief executive was blunter on the call: he could not proceed alone, because he has neither the licensing nor the intellectual property to build transformers.

The sole supplier of the steel could not make the transformer. Not because it lacked steel. Because it lacked know-how — and no one would sell it.

That is the real bottleneck, and it explains what the steel theory cannot:

| WHY | BECAUSE |
| --- | --- |
| Private capital is building transformer plants | GE Vernova, Eaton, Siemens Energy, Hitachi — they have the IP |
| GE Vernova paid $5.275 billion for the rest of Prolec GE | It was buying know-how and installed capacity, not steel |
| Cliffs' electrical steel volumes fell during a transformer shortage | The value-added winding and core-cutting steps happen abroad, and the cores are imported |
| Cliffs petitioned to tariff imported cores and laminations — and won | That is a demand-creation strategy, not a capacity strategy |
| A new entrant cannot simply build a transformer plant | Barriers are IP, skilled winders, and high-voltage test bays — not steel |

The Prolec multiple carries the argument on its own. GE Vernova's $5.275 billion price for the half of Prolec it did not already own implies roughly fifteen to sixteen times last-twelve-months EBITDA at plausible mid-cycle margins. That is a strategic-scarcity multiple, not an industrial-average one. The price is the argument. A buyer paying fifteen times for a transformer manufacturer is telling the market that installed transformer capacity — physical bays, skilled winders, qualified designs, utility relationships — is the constrained asset. Steel is not.

### The test-bay bottleneck

A transformer above roughly 345 kV cannot be shipped without high-voltage impulse and induced-voltage testing at a bay that few plants possess. The number of independent U.S. high-voltage test facilities of the required scale is small — measured in single digits. Weirton would have required either a new test bay of its own or a firm partnership with an existing facility, and neither existed at the point the venture cancelled. This is a physical bottleneck with a countable number of assets, and it is the piece of the industrial-policy ask that the private capital market will not build alone. A federal appropriation directed at test-bay capacity — one or two additional independent bays sited to serve the coming plants — is the single instrument most likely to shorten transformer lead times in the medium term. It does not require a tariff, a subsidy, or a licensing dispute. It requires a laboratory.

### The manufacturers' opposition, met

The Transformer Manufacturers Association of America opposes the expansion of derivative tariff coverage to finished transformers. Its strongest version of the case is not procedural. It is that a tariff on finished transformers would compound a cost pass-through onto the utility customer base that is already absorbing multi-year lead times and rising rates — the same ratepayers this paper's Move 1 discussion is trying to protect. That is a real objection and belongs in the record.

The answer is that the paper's Section 232 view is not a call for a tariff on finished transformers. It is a call for Commerce to disaggregate the record by grade and gauge before making any such decision, and to distinguish demand-creation instruments (tariffs) from capacity-creation instruments (Title III appropriation, IP licensing, test-bay construction). A tariff without the disaggregation risks compounding the pass-through the association warns about. A tariff after the disaggregation, if any, would be calibrated to actual gaps rather than to the wrong ones.

### The national-security counter-argument

A steelmaker will argue that Section 232 is a national-security instrument, and that even soft demand today does not obviate the security case tomorrow — that under-utilized capacity in peacetime is precisely what industrial-base statutes exist to preserve. The Institute's answer is not that the security frame is illegitimate. It is that a security case built on top of an idle-capacity finding must justify appropriation rather than tariff. A tariff transfers revenue from consumers to a producer that has already told its investors the market is soft. An appropriation buys the strategic assets — IP, test bays, standardized SKU tooling — that the producer's disclosures identify as the actual gaps. The security case is met more directly by the second than by the first.

### Therefore

Do not appropriate money for electrical steel tonnage. The tonnage is idle.

Do not appropriate money for transformer assembly generally. GE Vernova has committed roughly $11 billion in capex and R&D through 2028; Hitachi Energy is inside a $4.5 billion global build-out; Eaton is spending $340 million; Siemens Energy $150 million. Every one of those facilities opens in 2027 or later, and that lag is physical. Federal money buys nothing there.

Appropriate money for the three things that are actually scarce:

1. Demand certainty, so a domestic producer will invest ahead of the market. See the appendix.
2. Intellectual property and licensing for high-voltage transformer design — acquired, licensed, or developed under DPA Title III. This is the specific thing that killed Weirton.
3. Skilled labor and high-voltage test bays. A transformer must be tested before it ships, at voltages few facilities can generate. Test capacity is a physical bottleneck nobody discusses.

And note the framing that most proposals get backwards: appropriating money to *buy* scarce transformers bids up the price of scarce transformers. Appropriating money to *build the production line* ends the scarcity. Title III exists to do the second thing.

## Move 5 — Standardize the Product, Not the Subsidy

The §48E credit's begin-construction deadline for solar passed on July 4, 2026. The industry is mourning. The arithmetic says it should not.

| | PER WATT |
|---|---|
| Physical and labor floor, commercial rooftop | $0.41 |
| Benchmark market price | $1.71 |
| Gap — not physics | $1.30 |
| §48E credit at 30% of $1.71 | $0.51 |

A necessary correction to that floor. The $0.41 figure prices glass, silicon, aluminum and copper at world commodity rates. American solar has not been built in that market for years. Section 232 duties on imported steel run fifty percent; foreign-entity-of-concern content rules bite on projects beginning construction after December 31, 2025; and Commerce has extended derivative coverage to electrical steel laminations and cores. Racking steel, module frames, and cells all land here dearer than they clear abroad.

So state the floor twice.

| | PER WATT |
|---|---|
| World-price floor — materials and labor at global commodity rates | $0.41 |
| Tariff and domestic-content premium *(author's estimate; range)* | +$0.08 – $0.14 |
| Landed United States floor | ≈ $0.49 – $0.55 |
| Benchmark market price | $1.71 |

The gap between $0.41 and $1.71 is the argument. The gap between $0.41 and $0.55 is the honesty. Both are stated here so that the reader need not discover the second from a hostile source.

The floor is a commercial-rooftop figure. State it by segment so the reader can place the argument in his own market.

| SEGMENT | PHYSICAL + LABOR FLOOR $/W | BENCHMARK INSTALLED $/W | GAP THE ARGUMENT ATTACKS |
|---|---|---|---|
| Residential rooftop | $0.55 – $0.65 | $2.90 – $3.30 | ~$2.30 |
| Commercial & industrial rooftop | $0.41 – $0.50 | $1.65 – $1.80 | ~$1.30 |

| SEGMENT | PHYSICAL + LABOR FLOOR $/W | BENCHMARK INSTALLED $/W | GAP THE ARGUMENT ATTACKS |
|---|---|---|---|
| Utility-scale ground-mount, tracker | $0.30 – $0.36 | $1.05 – $1.20 | ~$0.75 |

*(Ranges are 2026 practitioner order-of-magnitude figures; edit with your own bids.)*

The pattern is uniform across segments — the physical floor is a small fraction of the installed price — but the gap is largest in the residential segment, where the site visit dominates and the tax credit was most consequential. The commercial rooftop segment is the paper's headline example because the $1.30 gap is the sharpest and the segment is the largest addressable market for the certified block. Utility-scale figures move for a different reason: field labor is efficient, land is cheap, and the tracker delivers superior kilowatt-hours per kilowatt.

The subsidy was two and a half times smaller than the inefficiency it concealed. Removing it does not make commercial solar uneconomic. A four-megawatt array at a 25 percent capacity factor generates 8,760 MWh a year, worth $876,000 at ten cents of avoided retail cost: a 7.8-year unsubsidized payback on a thirty-year asset.

And now pay for Move 1. Connect-and-manage puts curtailment risk on the generator. That is not free, and the payback above assumes none.

| CURTAILMENT | ANNUAL REVENUE | SIMPLE PAYBACK |
|---|---|---|
| 0% | $876,000 | 7.8 years |
| 10% | $788,000 | 8.7 years |
| 20% | $701,000 | 9.8 years |

The practitioner correction. The 7.8-year figure omits ongoing O&M and mid-life inverter replacement, both of which a developer will fold in before signing. Adding O&M at roughly $0.015 to $0.020 per watt per year and a mid-life inverter replacement at roughly $0.10 per watt around year 12 moves the zero-curtailment payback to about 8.5 to 9.0 years on a thirty-year asset. The argument survives; the number is honest. A hostile reader will do this math. So the paper does it first.

Read the trade. Twenty percent curtailment costs two years of payback. Eight years in PJM's queue costs eight years. For solar specifically — whose curtailment is generally diurnal, predictable and bounded, with exceptions in ISOs where curtailment is driven by transmission congestion or minimum-generation constraints — that trade is not close. But it is a trade, and this paper will show it rather than assert it.

The $1.30 is customer acquisition, plan review, inspection scheduling, financing, insurance, and margin stacked across four contracting layers in an industry of thousands of firms selling one roof at a time.

None of that is silicon. All of it is organization. So the question is what kind of organization removes it — and there is a natural experiment.

### The natural experiment: what vertical integration proved

*What follows applies the method a vertically integrated manufacturer would use — reason from physical constraints, integrate where the supply chain binds, buy the bottleneck rather than lobby it. Nothing here is attributed to any individual, and no statement is a quotation.*

The method's first move is to observe that Tesla has already run this experiment, and the result is not what enthusiasts expect.

Tesla acquired a solar installer in 2016 and pursued vertically integrated residential solar for a decade. It did not work. U.S. solar installations overall are forecast to fall from roughly 40 GW in 2025 to about 30 GW annually from 2028 to 2030. Tesla's solar business is now a rounding line inside a segment named for something else.

Meanwhile Tesla's energy storage business set a record of 46.7 GWh deployed in 2025, generating $12.8 billion of revenue, up 26.6 percent, at roughly thirty percent gross margin, with record margins for five consecutive quarters.

Same company. Same capital. Same founder. Same decade.

The difference is the shape of the product. A Megapack is manufactured in a factory, on a line, to a standard specification, and delivered on a truck. A rooftop solar system is assembled by a crew, on a building, to a bespoke design, after a site visit and a permit.

Vertical integration wins on the factory product and loses on the field product. That is not an opinion about Tesla. It is the $1.30 per watt, restated. The cost is in the site visit, not in the silicon.

### WHAT THE METHOD THEREFORE RECOMMENDS

1. Turn the bespoke object into a manufactured product. Large power transformers are custom-engineered to each utility's specification, which is precisely why they take eighteen to twenty-four months and why nobody can stockpile them. Standardize a small number of SKUs at the most common voltage and MVA classes, build them on a line, and hold inventory. This is the single highest-value unaddressed idea in American grid equipment, and it requires no legislation — only a buyer willing to accept a standard product instead of a bespoke one. That buyer could be the federal government.
2. Buy the bottleneck; do not tariff it. A tariff raises the price of a scarce input and produces none of it. An acquisition or a strategic investment produces capacity. See the Appendix.
3. Route around the queue rather than reforming it. Behind-the-meter generation, co-located load, and storage that lets a project connect at a lower firm capacity than its nameplate. Storage is a queue-avoidance device before it is an energy device.
4. Attack the machine that builds the machine. The constraint on transformers is IP, skilled winders, and high-voltage test bays. The constraint on solar cost is the site visit. Automate the site visit — prefabricated racking-and-module assemblies, factory-wired, craned into place — or accept $1.30 per watt forever.

### THE HONEST VERDICT

No, this would not be easy, and the evidence is that the most vertically integrated manufacturer in America tried the solar half of it and retreated.

Tesla's storage business is itself lumpy: deployments fell from 14.2 GWh in Q4 2025 to 8.8 GWh in Q1 2026, down 38 percent sequentially and 15 percent year over year, with energy revenue down 12 percent — and management warns of margin compression from low-cost competition, policy uncertainty and tariffs.

The lesson is not that a great company can solve this. It is that the field-installed, permit-dependent, site-specific product resists industrialization even in the hands of a company organized entirely around industrializing things.

Which is exactly why Moves 1, 2 and 3 matter more than Move 5. You cannot manufacture your way out of an eight-year queue.

But the field-installed product can be made less field-installed. That is the remainder of this Move.

### THE DEVELOPER'S ANSWER, MET

A commercial-solar developer reading this Move will observe that the industry has been trying to industrialize the site visit for a decade. Prefabricated racking, factory-wired module strings, roll-on canopies, integrated ballast trays — every architecture short of the certification preemption this paper proposes has been attempted, by well-capitalized companies, and none has scaled. The 5B Maverick literature reports roughly a 30 percent labor reduction on the site visit where the product is used. That saving is real, and it has not been enough to displace conventional installation across the industry.

The specific failure modes are three. Freight density — a folded array ships at roughly half the kilowatts-per-trailer of loose modules, so the freight penalty consumes much of the labor saving. Customer acquisition — a prefabricated product still requires the same door-to-door sales, financing conversation, and site-suitability review as any other array, so the $0.20-to-$0.30-per-watt customer-acquisition line is unaffected. The four-margin problem — even where the product itself is cheaper, the developer, EPC, subcontractor, and installer chain persists because each layer holds a distinct piece of the transaction, and prefabrication does not consolidate them.

The paper's answer is that none of the three failure modes is defeated by prefabrication alone. Freight density is a physics problem the design must solve. Customer acquisition falls to portfolio aggregation — one purchaser signing for many roofs — rather than to product design. And the four-margin stack falls only to vertical integration or type certification that lets a single firm carry the roof from design to interconnection. The certification preemption is the coordination instrument the prior attempts lacked, not a replacement for what they solved. Each of them contributed a piece of the answer. None of them was allowed to assemble the pieces.

As to the 5B deployment number. The public figure of thirty-two megawatts across 52 projects reflects the company's earlier disclosures; the paper cites it because it is the most-referenced, most-verifiable data point in the discussion. Any reader building on this paper should update the number against the company's current disclosures before publication of related work. The argument does not turn on the specific megawatt total. It turns on the fact that the SKU exists, has been deployed at production scale, and has demonstrated the labor saving the paper describes.

## Where the Megapack analogy holds, and where it breaks

It holds on process and it breaks on physics.

| | MEGAPACK | SOLAR ARRAY |
|---|---|---|
| What is scarce | Energy density | Area |
| Physical form | 3.9 MWh in a container-sized enclosure | ~1 MW per 1.2 acres of glass |
| Can it be shipped complete? | Yes | Never |
| Field labor | Crane it onto a pad; land AC cables | Mount, torque, wire, ground, test — thousands of times |
| Permitting | Listed equipment on a pad | A structure on a building, reviewed by a county |
| Utility's view of it | A known object with a known fault signature | A study |

The first row is the whole difference. A battery stores energy in chemistry, and chemistry is compact. A photovoltaic array converts a flux — about one kilowatt per square meter at noon — and a flux must be *intercepted*, which requires area.

Therefore the honest form of the LEGO idea is not *"the power plant in a box."* It is:

> *The block you can build is not the power plant. It is the acre, folded.*

Everything else in this paper follows from that sentence.

### AND A DISCIPLINE ABOUT THE LEGO METAPHOR

LEGO's virtue is many small interchangeable pieces. That is exactly the wrong instinct here.

Every connector between blocks is a labor unit, a failure point, a torque specification, an inspection item, and a place for water to enter. The design goal is therefore fewer, larger blocks — as large as a legal trailer and a telehandler permit. Not a bin of bricks. A pallet of walls.

## What already exists, and why it hasn't won

The 5B Maverick, launched in 2017, is the reference implementation.

What it is. Up to ninety modules mounted on nine hinged racks between composite steel-concrete beams, pre-assembled and pre-wired in the factory, packed vertically so that four blocks fit a 40-foot container or flatbed under a six-tonne payload. On site it is unloaded, unfolded to a ten-degree east-west pitch, and fastened. Shallow ground penetration. No cable trenching within the array. It folds back up and relocates.

What the company reports. Roughly 70 percent of field labor removed; about 30 percent of the on-site labor of a single-axis tracker; three people and a telehandler deploying on the order of a megawatt a week; 1.1 MW in a day with ten workers in Chile; wind resistance to 166 mph; and, because the east-west layout packs modules densely rather than tilting them optimally, substantially more energy per acre than trackers or fixed-tilt — while conceding lower yield per module.

*These are the manufacturer's figures and should be read as such. The engineering is not in dispute; the economics are.*

What happened. Fifty-two projects, thirty-two megawatts. A 1,392-unit order for Puerto Rico. Australian government funding to automate the assembly line and develop GPS-guided robotic deployment.

A real product, a real customer base, and about one-thousandth of one year of American installations.

### FIVE REASONS IT DID NOT TAKE OVER

1. It optimizes the wrong denominator. East-west packing maximizes kilowatt-hours per acre and sacrifices kilowatt-hours per kilowatt. Project finance models the second. A developer with cheap land in West Texas will take the tracker every time. Density is only valuable where land is scarce or the roof is fixed.
2. Freight. Four blocks per trailer at ~50 kW each is about 200 kW per truckload. Loose modules ship at roughly 350 to 440 kW in the same container. Prefabrication roughly halves shipping density, and a megawatt therefore takes about twice the trucks. On a long haul that erases a meaningful share of the labor saving.
3. The labor it saves is not where the money is. Field labor is on the order of $0.11 per watt in the physical build-up, and perhaps $0.20 to $0.30 in practice. Seventy percent of that is real money — and it is fifteen to twenty percent of a $1.30 gap.
4. It changes nothing about the four largest cost layers. Customer acquisition. Permitting and inspection. Interconnection. Margin stacked across developer, EPC, subcontractor and installer. A folded array arrives at the site having solved none of them.

5. The factory needs volume, and volume needs demand certainty. This is the same trap that killed the Weirton transformer plant and that the MP Materials structure was designed to escape. No one builds the line without an offtake.

### The product, in three SKUs

A standardized solar deployment system is not one object. It is three, plus an interface.

#### SKU A — THE ARRAY BLOCK

The acre, folded.

| ATTRIBUTE | SPECIFICATION |
| --- | --- |
| Capacity | 50–250 kW per block |
| Form | Accordion-folded, hinged racks; deploys with a telehandler and two to three people |
| Contents | Modules, rails, wiring harness, string connectors, grounding, rapid shutdown, monitoring |
| Factory work | Assembled, wired, torqued, tested and labeled before shipment |
| Field work | Unload, unfold, fasten, land one DC feeder |
| Transport | Legal width (102 in.) on a standard trailer. No permit loads |
| Foundation variants | (i) driven or screw pile, (ii) ballast tray for roofs and landfills, (iii) ground-screw for brownfield |
| Certification | Type-certified as a product, with a factory label. See Part V |

Design rules that matter more than they sound:

- No field trenching. Trenching is where schedule and injury live.
- No penetrations by default. Ballast for roofs, landfills, and capped ash ponds — which is precisely the retiring-coal-plant use case.
- One DC feeder per block. Every additional termination is a person-hour and a warranty claim.
- Redeployable. A block that can be unbolted and moved is collateral a lender can repossess. This is a financing feature, not an engineering one.

### SKU B — THE POWER BLOCK

Inverter, medium-voltage transformer, switchgear, protective relaying, metering, and controls, on a single skid, factory-wired and pre-commissioned.

**This already exists at utility scale** — the industry calls it a power skid or an e-house — and it does not exist as a standard product at commercial scale, which is where the $1.30 lives. Standardize two or three MVA classes and stop.

### SKU C — THE STORAGE BLOCK

A Megapack-class battery. Its function here is not energy. It is paperwork.

By clamping the plant's maximum AC export below its DC nameplate, storage converts a variable, uncertain injection into a fixed, known, dispatchable one. Which brings us to the idea worth more than all the folding.

### THE INTERFACE — AND THE REAL INVENTION

Standardize the interconnection application, not just the hardware.

Part of why a Megapack sells is that the utility already knows what it is: a known fault-current signature, a known protection scheme, a known ride-through behavior, a tested UL listing. It is not studied. It is looked up.

Do the same for solar. Define a small number of configurations — $n$ Array Blocks, one Power Block, one Storage Block, fixed maximum export — and pre-approve each one:

- a fixed maximum AC export, below nameplate, guaranteed by the storage block's controls;
- a published fault-current contribution and protection scheme;
- a certified anti-islanding and ride-through profile;
- a standard single-line diagram the utility has already reviewed.

The interconnection study then becomes a lookup. A developer who elects a standard configuration receives a standard answer in weeks.

This is worth more than every hour of field labor prefabrication can save, because interconnection is a forty-month line item in PJM and field labor is a fifteen-percent one.

## The nearer path — factory-built nonresidential structures under existing state programs

Before invoking a federal statute, look at what most states already do.

Most U.S. states operate factory-built nonresidential structure (FBNS) certification programs — a state agency inspects the assembly at the plant, affixes a state insignia, and the certified assembly may be installed in the field without local structural re-review of the certified portions. The regime is the state analog of the HUD Code, applied to nonresidential rather than residential factory-built products. It does not require a federal statute. It requires the certified solar block to qualify as a factory-built nonresidential structure under a small number of state programs — a project of months rather than years.

That is the near-term path. Pilot the certified solar block in three or four states with mature FBNS programs, prove the labor and permit-cost savings on live projects, and use the state-level track record as the record on which a federal standard is eventually built. The federal HUD-Code analogy remains the deeper template — it is the model for what a federally preempted solar-block regime would look like — but the near-term work is state-by-state, and it is executable this year.

The distinction that matters. The HUD Code preempts state and local building codes *by federal statute*. State FBNS programs achieve a functionally similar result *by state certification insignia*: the state, exercising its own authority, has already certified the assembly, and the locality accepts the certification rather than duplicating it. These are two different legal instruments producing similar practical effects. The paper endorses the FBNS route as the near-term path and the HUD-Code preemption as the eventual federal standard.

### The regulatory unlock: a HUD Code for solar

This is the least examined idea in this paper, and it is not an engineering idea.

A rooftop solar array is today treated as a structure, designed for a site, reviewed by a county. Every array is a bespoke submittal to one of thousands of authorities having jurisdiction, each with its own code cycle, plan reviewer, inspector, fee schedule, and interpretation of the same national electrical code.

American law already knows how to solve this, and has for fifty years.

The National Manufactured Housing Construction and Safety Standards Act of 1974 created the HUD Code, effective June 15, 1976. Its architecture:

- Federal construction and safety standards, uniform nationwide.
- Inspection in the factory by HUD-approved primary inspection agencies, enforced through state administrative agencies in 49 states.
- A red certification label affixed at the plant to every transportable section.
- Preemption of conflicting state and local building codes.

The preemption is not theoretical. Denver's building code states that the certificate of occupancy for a HUD home must carry the notice that the structure has not been inspected in its entirety by the City and County of Denver.

The economic result: manufactured homes run roughly $55 to $65 per square foot against about $168 for site-built. Harvard and Michigan researchers have found the quality and lifespan differences between the HUD Code and local site-built codes to be minimal.

### THE PROPOSAL

An Industrialized Solar Construction Standard, on the same architecture:

1. A federal construction and safety standard for factory-assembled photovoltaic array blocks — structural, electrical, fire, wind and seismic — coordinated with the existing standards the industry already meets: UL 61730 (photovoltaic module safety), UL 3703 (mounting systems for PV panels), NEC Article 690 (photovoltaic electrical), the applicable sections of the International Building Code and International Fire Code, and FM Global 4478 for roof-mounted arrays. The proposal is not to displace those standards but to consolidate them into a single certification the block carries with it.
2. Factory inspection and labeling by approved third-party agencies. The label travels on the block.
3. Preemption of local structural and electrical re-review of the certified assembly.
4. The AHJ retains what it should retain: the site. Attachment and ballast, setbacks, fire access pathways, roof structural capacity, the service connection, and the electrical point of common coupling.

The county stops reviewing the array and starts reviewing the roof. That is the correct division of labor, and it is exactly what the HUD Code did to the house.

### THE WARNING THAT COMES WITH THE MODEL — AND IT IS SEVERE

The HUD Code is a cautionary tale as much as a template, and any paper that cites the first half owes the reader the second.

Factory-built housing did get cheap. It also got zoned out. Production reached roughly 580,000 units in 1973 — about half the volume of the nation's site-built single-family construction. It is a small fraction of that today.

Three causes are consistently identified: restrictive zoning that limits where the homes may be placed; financing difficulty, because a unit on a non-permanent foundation is titled as personal property rather than real estate; and, in some markets, weaker appreciation. HUD's own 2011 analysis found that local regulations suppress placements and raise setup costs by ten to twenty percent in restrictive areas.

> *The HUD Code preempted the building code. It did not preempt zoning. The result was the cheapest housing in America, and nowhere to put it.*

That is precisely the failure mode a certified solar block would inherit. A federally labeled array whose structural review is preempted, arriving at a county that may still impose setbacks, screening, aesthetic review, and conditional-use hearings, is a cheap product with a siting problem.

Certification alone is therefore not the answer. It is half of it. The other half is the approval clock.

A certified solar block would hit precisely the same wall, in the form of local siting rules, aesthetic review, and setback requirements. Certification must therefore be paired with the two instruments recommended below:

- a commercial automated permitting standard — the residential version already exists, is federally authored, and is free; there is no commercial equivalent at all; and
- a shot clock with a deemed-granted remedy, on the telecommunications model, which forbids local *prohibition* rather than commandeering local *approval*.

Standardize the product. Automate the approval. Put a clock on the locality. Any one of the three alone accomplishes a fraction of what the three accomplish together.

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### What standardization actually saves

*An honest bridge from $1.71 to something better. The floor of $0.41 is a physical and labor minimum; the intermediate figures are the author's estimates, offered so the reader may substitute his own.*

| COST LAYER | ~$/W TODAY | WHAT ATTACKS IT | PLAUSIBLE AFTER |
|---|---|---|---|
| Modules, inverter, racking, wire | 0.24 | Nothing. Already commodity | 0.24 |
| Field labor and rework | 0.20–0.30 | Prefabrication. ~70% removed | 0.06–0.09 |
| Freight | 0.03 | Prefabrication makes this worse | 0.05–0.06 |

| COST LAYER | ~$/W TODAY | WHAT ATTACKS IT | PLAUSIBLE AFTER |
|---|---|---|---|
| Engineering and design | 0.10 | Standard SKU. One design, amortized | 0.02 |
| Permitting, plan review, inspection | 0.15–0.25 | Type certification + automated permitting | 0.03–0.05 |
| Interconnection study and delay cost | 0.10–0.30 | Pre-approved configuration | 0.02–0.05 |
| Customer acquisition | 0.20–0.30 | Portfolio aggregation. Not prefab | 0.05–0.10 |
| Financing and insurance | 0.10 | Standard product → standard underwriting | 0.05 |
| Stacked margin (4 layers) | 0.25–0.35 | Vertical integration. Not prefab | 0.10–0.15 |
| Total | ~1.71 | | ~0.62–0.81 |

Read the table honestly.

Prefabrication alone gets you from $1.71 to perhaps $1.45. It is worth doing and it is not the story.

**Prefabrication plus type certification plus a pre-approved interconnection package plus portfolio aggregation plausibly reaches $0.62 to $0.81** — a fifty to sixty percent reduction, achieved mostly by paperwork.

And none of it reaches $0.41, because someone still has to acquire the customer, finance the asset, and earn a return.

The single largest line prefabrication improves is one it does not touch: interconnection. The Storage Block and the pre-approved configuration do that.

### Where the block wins, and where it loses

A standard product is not a universal product. The block's economics are a function of two variables: the price of land and the price of a site visit.

### IT WINS WHERE LAND IS EXPENSIVE AND SITE VISITS ARE COSTLY

| APPLICATION | WHY |
|---|---|
| Commercial and institutional rooftops | Small crews, permit-heavy, ballasted, no trenching. The $1.30 lives here |
| Parking carports | Repeatable geometry; the structure is the product |
| Landfills, capped ash ponds, brownfields | No penetration permitted. Ballast is mandatory, and the block is ballasted by design |
| Retiring and operating power plant sites | Existing interconnection, existing switchyard. See Move 2 |
| Behind-the-meter at large load | No queue, no export, standard configuration |
| Islands, remote sites, disaster recovery | Labor is the binding constraint. Puerto Rico is the proof |
| Temporary and bridging power | Redeployability is worth a premium |

### IT LOSES WHERE LAND IS CHEAP AND LABOR IS CHEAP

Utility-scale desert installations with single-axis trackers. There, land costs almost nothing, crews are large and efficient, and the tracker's superior kilowatt-hours per kilowatt beats the block's superior kilowatt-hours per acre. The freight penalty then dominates.

Note where that leaves us. The block wins at the load and loses in the desert.

Which is precisely where Move 2 already pointed. The Bureau of Land Management screened its thirty-one million acres for proximity to transmission and expects two percent to be developed. The wire binds, not the acre. Solar belongs at the load.

The factory-built block is the right technology for the deployment strategy the first four moves already selected. That convergence is the strongest argument in its favor.

### What it would take

Five things, in order, and only one of them is engineering.

1. The standard. An industrialized solar construction standard, written once. Structural, electrical, fire, wind, seismic. This is a consensus-committee exercise of the kind the country runs constantly and well.
2. The certification regime and the preemption. Federal or a fifty-state model act. Factory inspection, third-party agency, a label on the block, and preemption of local re-review of the certified assembly. Statute required. This is the HUD Code, applied to a different object.
3. The pre-approved interconnection package. A small number of standard configurations with published protection schemes and fixed maximum export. FERC and the state commissions. No new law required — this is a tariff filing.
4. Demand certainty for the factory. The line does not get built on speculation, and this is where every prior attempt has died. The instrument exists and is documented. In July 2025 the Department of Defense gave MP Materials a ten-year price floor, a ten-year offtake of 100 percent of a new facility's output, $400 million of convertible preferred and a warrant. A federal anchor tenant contracting for a defined quantity of certified standard blocks — for federal buildings, installations, and brownfield sites — would do for the solar block what the offtake did for the magnet.
5. The engineering. Freight density is the unsolved problem. A block that ships at 200 kW per trailer against 400 kW for loose modules gives back much of what it saves. The design target is not a better hinge. It is kilowatts per cubic meter in transit. Whoever solves that solves the product.

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### The two instruments that must travel with it

Portfolio aggregation. One counterparty, one design, one interconnection, across many buildings. Fragmentation is what makes American rooftop solar expensive. Any entity that can contract for a hundred roofs at once — a real estate trust, a retailer, a hospital system, a state — captures most of the available savings with no policy change at all. A standard SKU makes portfolio contracting possible; without it, every roof is a negotiation.

C-PACE. In leased commercial real estate the tenant pays the electricity bill and the landlord owns the roof. Neither can capture the return; neither acts. This split incentive has killed more commercial rooftop projects than every zoning board in America combined. C-PACE attaches the obligation to the property, runs with the land on sale, and passes through under most triple-net leases to the tenant receiving the savings.

A certified block, sold into a portfolio, financed by C-PACE, on a pre-approved interconnection, permitted by an automated review. That is the whole of Move 5, and no element of it is worth much alone.

## Appendix — Should the United States Take a Strategic Position?

*The author holds CLF as of 12 July 2026 and this section is written about a policy instrument, not a security. It recommends no trade.*

The question was posed: if domestic electrical steel is strategic, why does the government not simply invest in the producer, as it has elsewhere?

It already has a template, and the template is precise. In July 2025 the Department of Defense entered a partnership with MP Materials, the only large-scale U.S. rare earth producer:

| INSTRUMENT | TERMS |
|---|---|
| Equity | $400M of convertible preferred, plus a warrant — approximately 15 percent as-converted. DoD positioned as largest shareholder |
| Debt | $150M loan for heavy rare earth separation |
| Price floor | Ten years. DoD pays the quarterly shortfall between the market price and $110/kg for NdPr — and receives 30 percent of the upside above the floor |
| Offtake | Ten years. DoD ensures 100 percent of the new facility's magnet output is purchased; the facility is structured to generate at least $140 million of annual EBITDA, inflation-adjusted |

That is the instrument that makes a company add capacity when the return does not yet warrant it. It is not a subsidy and not a tariff. It is a floor, an offtake, and an equity stake that lets the taxpayer share the upside it created.

Apply the structure, not the company. The transformer supply chain needs exactly what MP Materials needed: a price floor and a guaranteed offtake, so that a producer will build ahead of demand, plus federal equity so the public captures the value of the certainty it provides. The natural objects are Hi-B electrical steel capacity, standardized transformer SKUs, and high-voltage test capacity.

### On the specific suggestion that Cleveland-Cliffs is cheap

As a factual matter, its enterprise value is small relative to its strategic position. As of early July 2026 CLF's market capitalization was roughly $5.6 billion against an enterprise value near $13.3 billion, reflecting about $8 billion of debt. For comparison, GE Vernova paid $5.275 billion for half of a transformer joint venture.

And the reason it is inexpensive is not a secret. CLF reported roughly $18.9 billion of trailing revenue against a net loss of about $1.2 billion, negative free cash flow, and elevated leverage. Electrical steel is a small share of its business — stainless and electrical together were three percent of 2025 steel shipment volume. An acquirer buying CLF for its Butler mill would be buying a large, leveraged, loss-making integrated steelmaker in order to obtain it.

Which is the argument for the MP Materials structure rather than an acquisition. A price floor and an offtake on grain-oriented electrical steel would achieve the strategic objective — domestic capacity, built ahead of demand — without the government or a strategic acquirer taking on an automotive steel business it does not want.

And it addresses the actual cause of failure. Cleveland-Cliffs did not abandon Weirton for lack of steel or lack of capital. It abandoned it because a partner holding the intellectual property withdrew. A price floor does not solve that. Licensing does. Any federal instrument here should procure or underwrite the transformer design IP alongside the steel, or it will fund a mill that still cannot make the product.

The vendor-neutrality problem. A Title III instrument targeted at licensing transformer IP effectively routes federal money to whichever incumbent — Hitachi, Siemens Energy, GE Vernova, or Eaton — licenses to the domestic buyer. That is a politically freighted choice, and executive-branch buyers will understandably prefer not to make it. The paper's view is that Congress, not the executive branch, should authorize the specific instrument, and that the authorization should include an explicit vendor-neutrality mechanism — competitive licensing, best-value award, or transparent auction — that keeps the appropriation from becoming a designation. Buying the bottleneck is the right move. Naming the winner is not the government's job to do quietly.

*Nothing in this appendix is investment advice, a valuation, or a recommendation regarding any security. Financial figures are drawn from public market data as of early July 2026 and from the company's filings, and change daily.*

## What Not To Do

Do not restore the tax credit. It was smaller than the waste. Restoring it re-anesthetizes an industry that has just been given a reason to confront its own cost structure.

Do not open more federal land. Thirty-one million acres are open. Two percent will be used.

Do not legislate transmission siting as though it were the constraint. Twenty-one years, two acts of Congress, one unanimous rulemaking, zero permits.

Do not tariff your way to capacity. A duty on imported transformer cores raises the cost of the seventy-five percent of electrical steel America imports, and produces no domestic tons. It is paid by an industry employing roughly forty thousand people to protect one employing about fifteen hundred.

Do not build a single hundred-mile square. One transmission corridor, one weather system, one target.

## Magnitudes

*The single fairest criticism of an earlier draft was that it diagnosed without sizing. Below is the sizing, with the honesty that ranges this wide demand.*

| MOVE | ORDER OF MAGNITUDE | BASIS | CONFIDENCE |
|---|---|---|---|
| 1. Connect and manage | 2× to 4× the national rate of interconnection | ERCOT brought 14.2 GW online in 2021–22 against PJM's 5.6 GW at more than twice ERCOT's size | Author's inference from published throughput. Not modeled |

| MOVE | ORDER OF MAGNITUDE | BASIS | CONFIDENCE |
|---|---|---|---|
| 2. Surplus interconnection | ~25–30 GW of firm coal interconnection surrendered through 2028, plus gas, steam and peaker headroom | EIA: coal fleet planned to fall 172 GW (May 2025) → 145 GW (end 2028) | Sourced. Retirement dates slip |
| 3. Reconductoring | ~4× the interzonal transmission capacity addition by 2035 versus new-build only; ~80% of what a 90%-clean grid requires | Chojkiewicz et al., *PNAS* (2024) | Peer-reviewed |
| 4. Transformers | The appropriation required is small against one manufacturer's capex. GE Vernova alone has committed roughly $11 billion through 2028 | Company investor update | The *quantum* of a Title III ask is not estimated here |
| 5. Standardize the product | $1.71 → ~$0.62–0.81/W. Technical potential on medium and large buildings is 386 GW / 506 TWh | NREL rooftop assessment; author's cost bridge | The economically viable share at $0.81 is not modeled. It is larger. By how much, this paper does not say |

What the table concedes. Two of the five rows are the author's inference and are labeled as such. A reader who needs a number to two significant figures should not take it from this document. A reader who needs to know whether the prize is measured in gigawatts or in hundreds of gigawatts has it here.

## Who Loses

Every move in this paper takes something from someone. A document that names no opponent has not been read by its opponents, and this one intends to be.

| MOVE | WHO LOSES, AND HOW HARD THEY WILL FIGHT |
|---|---|
| 1. Connect and manage | Transmission owners lose network upgrade capital expenditure that earns a regulated return. Incumbent generators lose scarcity rents in the capacity market. Ratepayers absorb socialized upgrade cost — see *Who pays*, above |
| 2. Surplus interconnection | The incumbent plant owner surrenders optionality on a right he paid for and may prefer to monetize himself. He is the counterparty, not the obstacle. Pay him |
| 3. Reconductoring | Utilities lose rate base. This is the whole story, and it is below |
| 4. Standardized transformers | Manufacturers lose the margin on bespoke engineering. The shortage is currently profitable. A commodity SKU is not |
| 5. The Solar Block | Four stacked margins are four firms' payrolls — developer, EPC, subcontractor, installer. Every one belongs to a trade association that will comment on the standard |

### The one that explains everything

Return to reconductoring. This paper marvels that Berkeley researchers spoke to U.S. transmission operators who were unaware advanced conductors existed.

They were not unaware. They were uninterested.

A regulated utility earns a rate of return on capital prudently deployed. A new transmission line is a large capital addition earning that return for forty years. Reconductoring delivers the same capacity for roughly half the capital. Ask a rate-base-maximizing monopoly to spend half as much for the same result and it will study the question thoroughly, at length, and choose the towers.

No amount of engineering literature fixes that. It is not an information problem. It is an incentive problem.

Which names the remedy. The regulatory literature contains a well-developed answer: shared-savings and performance-based mechanisms that let a utility earn on the capacity it adds rather than on the capital it spends. Hawaii's PBR framework, New York's REV proceedings, and Rhode Island's PowerSector Transformation Initiative are the practical templates. It is the necessary companion to the verb change in Move 3, and without it, *justify not choosing* will produce excellent justifications.

The general rule. Every recommendation in this document asks somebody to earn less. That is not a defect of the recommendations. It is why they have not already happened, and it is the first thing an investor, a commissioner, or a congressional staffer will want to know.

## Sequencing

| MOVE | OWNER | FIRST MEGAWATT | REQUIRES |
|---|---|---|---|
| Behind-the-meter at load; surplus interconnection | Developers, today | Now | Nothing |
| Reconductoring default in rate cases | 50 state commissions | 12–24 months | A docket |
| Pre-approved interconnection configurations | FERC, state commissions | 12–24 months | A tariff filing |
| Connect-and-manage / ERIS fast track | FERC, grid operators | 18–36 months | A rulemaking |
| Transformer IP, test bays, price floor and offtake | Congress, DoD, DOE | 36 months to steel | An appropriation |
| Industrialized solar construction standard | Consensus committee, then Congress | 24–48 months | Statute |
| Federal anchor offtake for certified blocks | GSA, DoD | 24 months | An appropriation |
| Commercial automated permitting + C-PACE | Congress, states, DOE | 24–48 months | Statute |

The first row requires no policy at all. It requires a developer to stop asking permission to connect to a grid, and to serve a customer standing on the site.

And note which rows are cheap. A tariff filing, a docket, and a consensus standard. The three most valuable interventions in this table cost the federal government almost nothing, and none of them is a subsidy.

## Glossary of Terms and Abbreviations

*This paper is written for readers who work in finance, not in electricity. The industry speaks almost entirely in initials. Here they are, alphabetically, with the letters spelled out.*

**AC / DC** — Alternating Current and Direct Current. Solar panels produce DC; the grid runs on AC; an inverter converts one to the other.

**ACCC** — Aluminum Conductor Composite Core. A power line whose steel core is replaced with carbon fiber. See *reconductoring*.

**AAR** — Ambient-Adjusted Rating. A transmission line rating recalculated at least hourly against forecast air temperature, rather than a fixed worst-case assumption. Mandatory since July 12, 2025.

**Behind the meter (BTM)** — Generation serving a customer's own load without crossing the utility's meter. It never enters the interconnection queue.

**AHJ** — Authority Having Jurisdiction. The county, city or state official who reviews a permit application and inspects the work. There are thousands of them, each with its own interpretation of the same code.

**BLM** — Bureau of Land Management. The Interior Department agency administering roughly 245 million acres of federal land.

**CAISO** — California Independent System Operator. Runs California's grid.

**Capacity factor** — Actual output divided by theoretical maximum. Solar runs about 25 percent; nuclear about 90 percent.

**CCR** — Coal Combustion Residuals. Coal ash. Closing an ash pond is a federal obligation and a long pole in redeveloping a coal site.

**COD** — Commercial Operation Date. When a plant begins selling power.

**C-PACE** — Commercial Property Assessed Clean Energy. Financing in which the obligation attaches to the building rather than the owner and travels with the property on sale.

**Curtailment** — Being ordered to stop generating because the grid cannot absorb the output. It costs the generator revenue, not equipment.

**DLR** — Dynamic Line Rating. Sensors that measure real conditions on a power line so it can safely carry more current when the weather is cool or windy.

**DoD / DOE** — Department of Defense; Department of Energy. Different agencies, one letter apart, both appear here.

**DPA Title III** — Defense Production Act, Title III. Existing federal authority to fund domestic industrial capacity for defense-critical goods. Needs an appropriation, not a new law.

**EIA** — U.S. Energy Information Administration. The federal statistical agency for energy. Source of the retirement data in Move 2.

**EPC** — Engineering, Procurement and Construction. The contractor who builds the thing.

**ERCOT** — Electric Reliability Council of Texas. Runs the grid for most of Texas, largely islanded from the rest of the country.

**ERIS** — Energy Resource Interconnection Service. *Connect me, and curtail me when the grid is constrained.* Fast.

**NRIS** — Network Resource Interconnection Service. *Guarantee I can deliver at all hours*, which requires network upgrades the generator must pay for before connecting. NRIS is why the queue is eight years long.

**FERC** — Federal Energy Regulatory Commission. The federal agency governing interstate electricity and gas transmission.

**e-house / power skid** — A factory-built enclosure containing inverter, transformer, switchgear and protection, delivered pre-wired on a skid. Standard at utility scale; nonexistent at commercial scale.

**GOES** — Grain-Oriented Electrical Steel. The specialty steel from which transformer cores are wound. Roughly a quarter of a transformer's cost.

**GSU transformer** — Generator Step-Up transformer. Raises a power plant's output to transmission voltage. Lead time eighteen to twenty-four months. The long pole in almost every project in America.

**Hi-B** — High-permeability grain-oriented electrical steel. A more efficient grade than conventional. Made in the United States at exactly one mill.

**HTLS** — High-Temperature, Low-Sag. The class of advanced conductors that makes reconductoring work.

**HUD Code** — The Manufactured Home Construction and Safety Standards, effective 1976. Federal construction standards for factory-built homes, inspected in the plant and preempting local building codes.

**Interconnection queue** — The line of proposed power plants awaiting permission and engineering to connect. Currently about 2,600 gigawatts nationally — larger than the entire installed U.S. grid.

**ISO / RTO** — Independent System Operator / Regional Transmission Organization. Non-profit entities that dispatch regional grids and run wholesale electricity markets. They do not own the wires. The seven are listed here by name.

**ISO-NE** — ISO New England. The six New England states.

**ITC / §48E** — The federal Investment Tax Credit for clean energy. For solar, the begin-construction deadline passed on July 4, 2026.

**kV / MVA** — Kilovolt, a measure of voltage. Megavolt-ampere, a measure of a transformer's rated throughput. Together they specify what a transformer is.

**LGIA** — Large Generator Interconnection Agreement. The contract giving a power plant the right to inject power at a named point, up to a stated megawatt limit.

**MISO** — Midcontinent Independent System Operator. Fifteen states from Minnesota to Louisiana.

**MW / GW / MWh / GWh / TWh** — Megawatt and gigawatt measure power, the rate of flow. Megawatt-hour, gigawatt-hour and terawatt-hour measure energy, the quantity delivered. A 100 MW plant running one hour delivers 100 MWh. The United States consumes roughly 4,200 TWh a year.

**NdPr** — Neodymium-praseodymium. The rare earth alloy at issue in the MP Materials transaction described in the Appendix.

**NREL** — National Renewable Energy Laboratory. The federal lab that publishes the solar cost benchmarks used here.

**NYISO** — New York Independent System Operator. New York State.

**PJM** — Pennsylvania–New Jersey–Maryland Interconnection. Founded in 1927 by utilities in those three states, it now dispatches the grid across thirteen states and the District of Columbia — from Illinois to Virginia — and is the largest wholesale electricity market in the world. The name is a fossil; the territory long ago outgrew it. When this paper compares PJM with ERCOT, it is comparing the biggest grid in America with the fastest one.

**Power block / array block / storage block** — The three standardized components proposed in Move 5.

**Order 845 (2018)** — FERC's reform of the standard interconnection agreement. Created surplus interconnection service, provisional interconnection service, the right to request service below nameplate capacity, and the customer's option to build.

**Order 881 (2021)** — *Managing Transmission Line Ratings.* Requires ambient-adjusted ratings on all transmission lines; compliance deadline July 12, 2025.

**Order 1920 (2024)** — Long-term regional transmission planning and cost allocation. Requires providers to consider dynamic line ratings, advanced power flow control, advanced conductors, and transmission switching.

**Order 2023 (2023)** — FERC's first overhaul of interconnection procedures since 2003. Cluster studies, firm deadlines, penalties, and co-location of multiple generators behind a single point of interconnection.

**Provisional interconnection service** — A right, since 2018, to operate a generator at limited output before the full interconnection study process is complete.

**PPA** — Power Purchase Agreement. A long-term contract to buy a plant's output. It is what makes a project financeable.

**STEP / Grid Assurance / RESTORE** — Industry programs that pool and share spare transformers. See Move 4.

**Single-line diagram** — The one-page electrical schematic a utility reviews to approve an interconnection.

**SKU** — Stock Keeping Unit. A standard product configuration, ordered by number rather than designed.

**RecX** — A rapidly deployable, standardized prototype high-voltage transformer developed by the Department of Homeland Security with EPRI, completed in 2014.

**Reconductoring** — Replacing the wire on an existing transmission tower with a better wire, roughly doubling how much power the line can carry. Same towers, same land, same right-of-way.

**Right-of-way (ROW)** — The legal corridor of land a transmission line occupies.

**SIS** — Surplus Interconnection Service. Lets a new generator use an existing generator's unused interconnection capacity without taking a new place in the queue.

**SolarAPP+** — A free federal software tool that reviews residential solar permit applications for code compliance automatically and issues the permit instantly.

**SPP** — Southwest Power Pool. The central plains, Oklahoma to the Dakotas.

  

**Telehandler** — A forklift with a boom. The only heavy equipment a prefabricated array requires.

**Switchyard / substation** — The high-voltage equipment yard where a power plant meets the transmission system. Contains the GSU transformer, breakers and protective relays. It is the most valuable and least visible asset at any retiring power plant.

## Closing — The Baratelli View

The United States does not have an energy problem. It has an institutional problem that presents as an energy problem.

Twenty-six hundred gigawatts of generation sit in interconnection queues. Nearly eighty percent will withdraw.

Do not read that first number as a project pipeline. It is an option book — the same site filed in three places, speculative applications, and free optionality on a queue position that once cost almost nothing to hold. Order No. 2023's study deposits, readiness requirements and withdrawal penalties exist precisely to price that option, and they are the right response.

But discount it by half and the argument is unchanged. Thirteen hundred gigawatts of serious projects is still comparable to half the installed American grid, waiting on permission. In PJM the wait has grown from two years to eight while the country argues about which electrons to generate.

The panel is cheap. The land is empty. The capital is chasing. The steel is idle. What is missing is a connection, a transformer design, and a firm that can sell a roof for what a roof costs.

Three of the five moves require no new law, and not one of them requires a new idea.

Connect-and-manage has run in Texas for a decade. Provisional interconnection and the right to request service below nameplate have been in every federal tariff since 2018. Surplus interconnection service is mandatory, was expanded by PJM last year, and is barely used. Ambient-adjusted ratings became compulsory in July 2025. Advanced conductors must already be *considered* in every long-term transmission plan. The Department of Homeland Security built a standardized rapid-deployment transformer in 2014 and filed it under counterterrorism. The folding, factory-wired array was invented in 2017. And in 1976 the United States decided that a house built in a factory need not be re-inspected by a county, and cut the price per square foot roughly in half.

Every piece is on the shelf. Nobody has assembled them.

That is a hopeful finding, not a damning one. A country that must invent its way out of a crisis is in trouble. **A country that must merely *use* what it has already built is one signature away.**

The four largest costs in an American solar installation are a sales call, a plan review, an interconnection study, and four stacked margins. A hinge does not touch any of them. What touches them is a label affixed in a factory, a pre-approved single-line diagram, a portfolio contract, and a firm willing to own the whole chain.

Deploy the conditions. The solar deploys itself.

Build the block — and understand that the block is the easy part. The expensive part of American solar has never been in the field. It has always been in the file.

*— Philip A. Baratelli, CPA The Baratelli Institute 12 July 2026*

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*The cost floor, the cost bridge in Move 5, and parcel-yield figures are the author's calculation on assumptions stated in text, presented in components so that readers may substitute their own.*

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