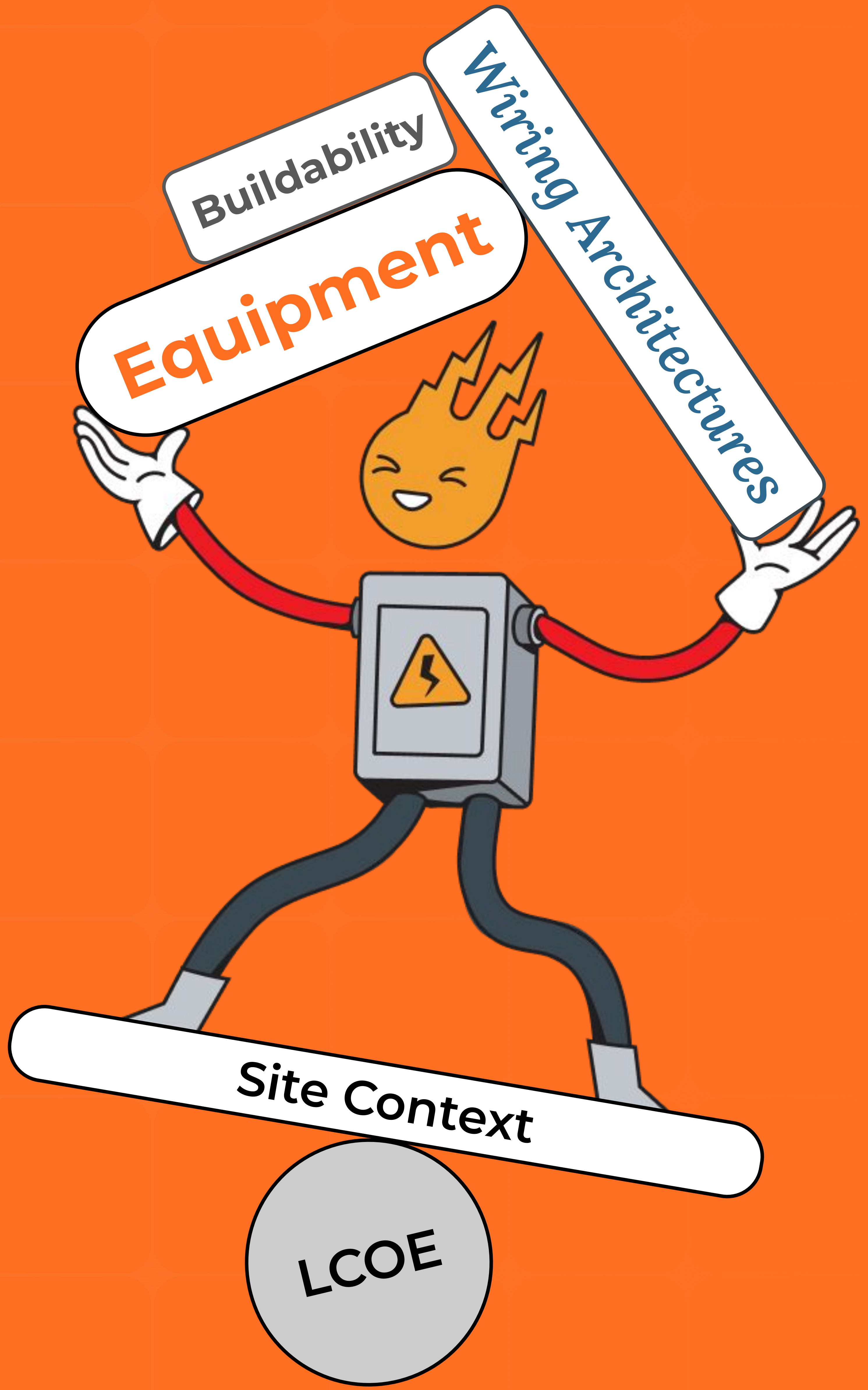
PVFARM

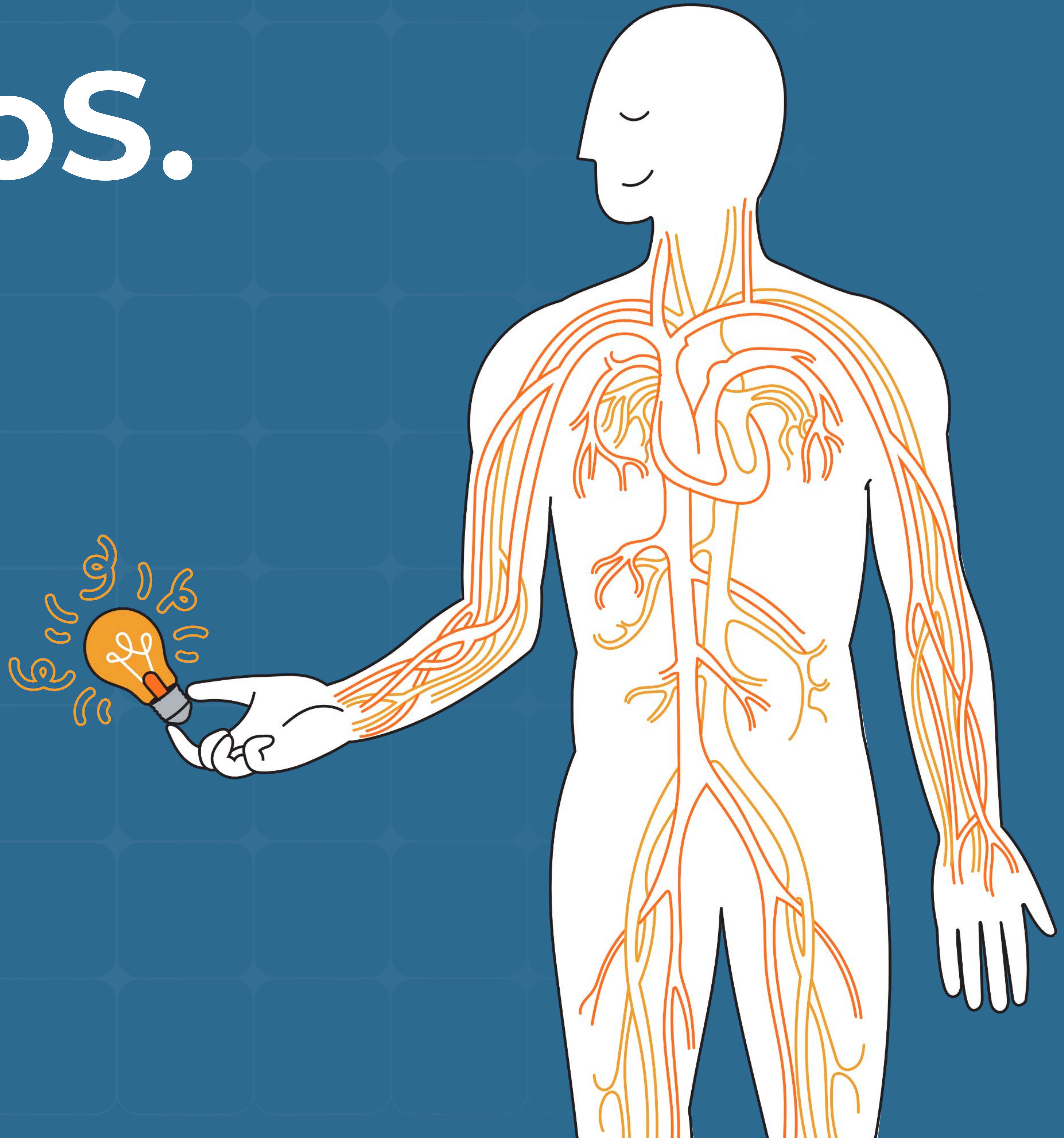
Needle Movers First: *Making High-Impact Decisions Early in Design*

Balancing Act
Context



Electrical BoS. Features

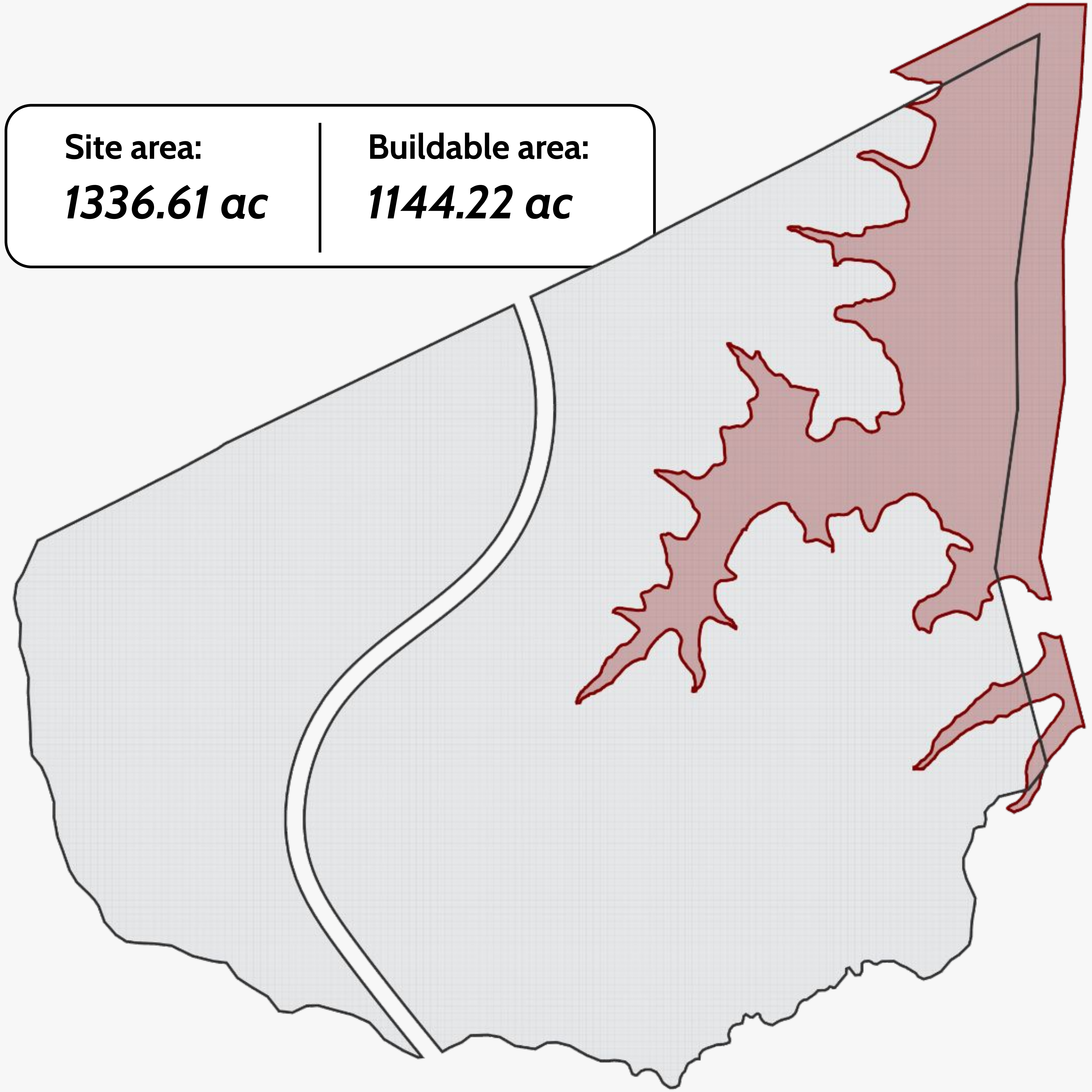
Moving electricity from the solar panels to the grid is where the purpose meets power



Time Value Trade-Off

Site area:
1336.61 ac

Buildable area:
1144.22 ac



Tracker 84 mods

PV Module 540W

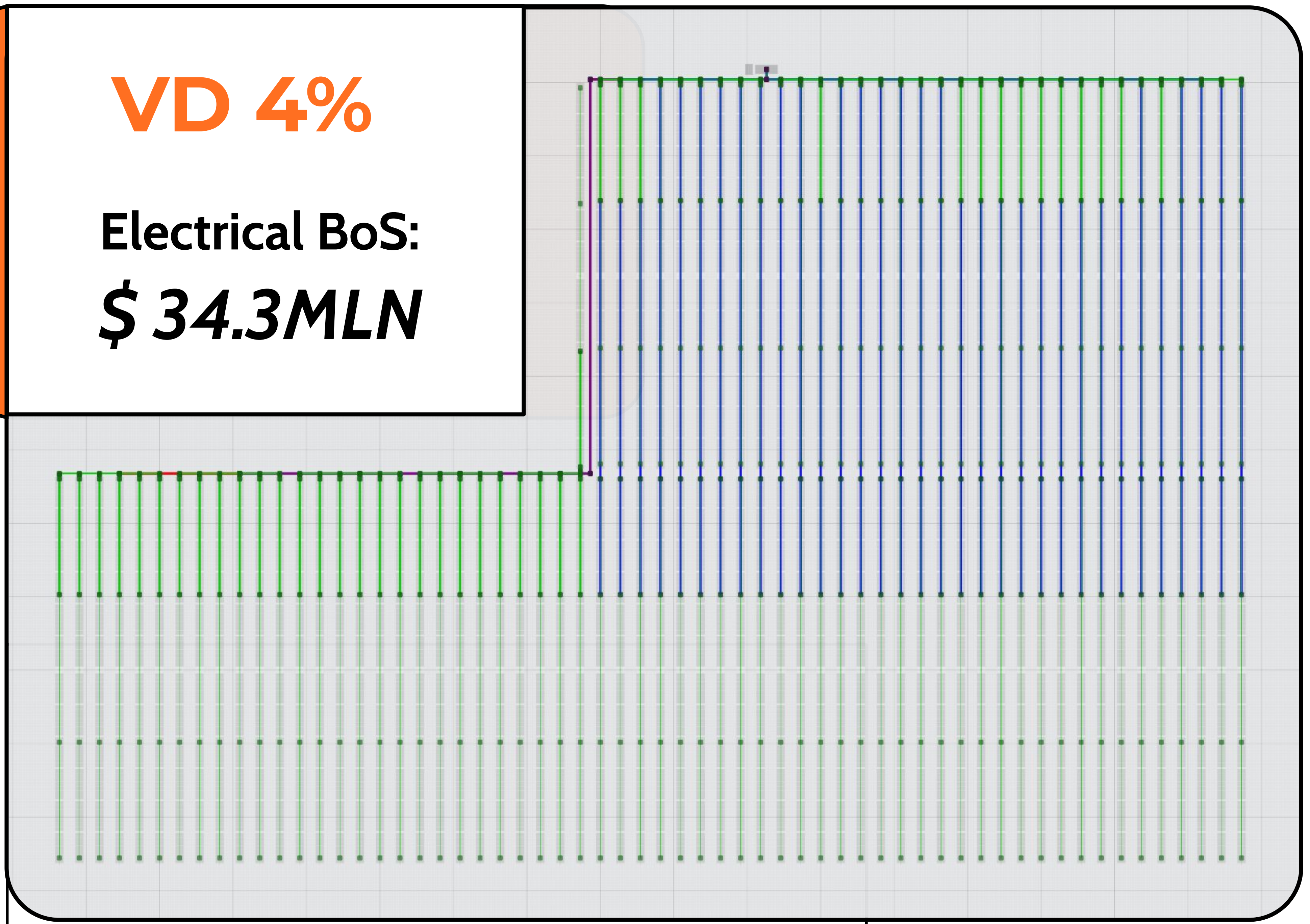
CBX 400A

Inverter
3600kVA

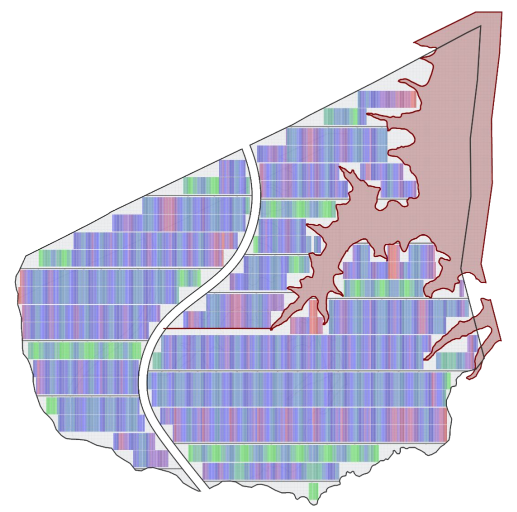
VD 4%

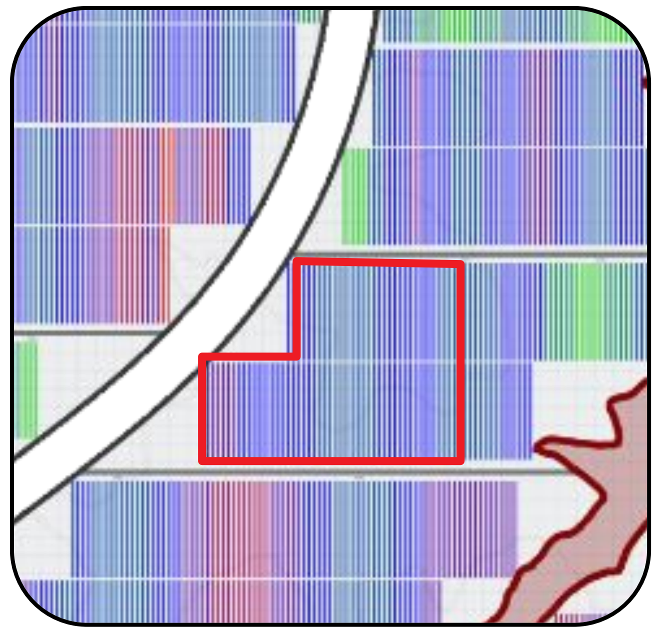
Electrical BoS:

$ 34.3MLN



VS

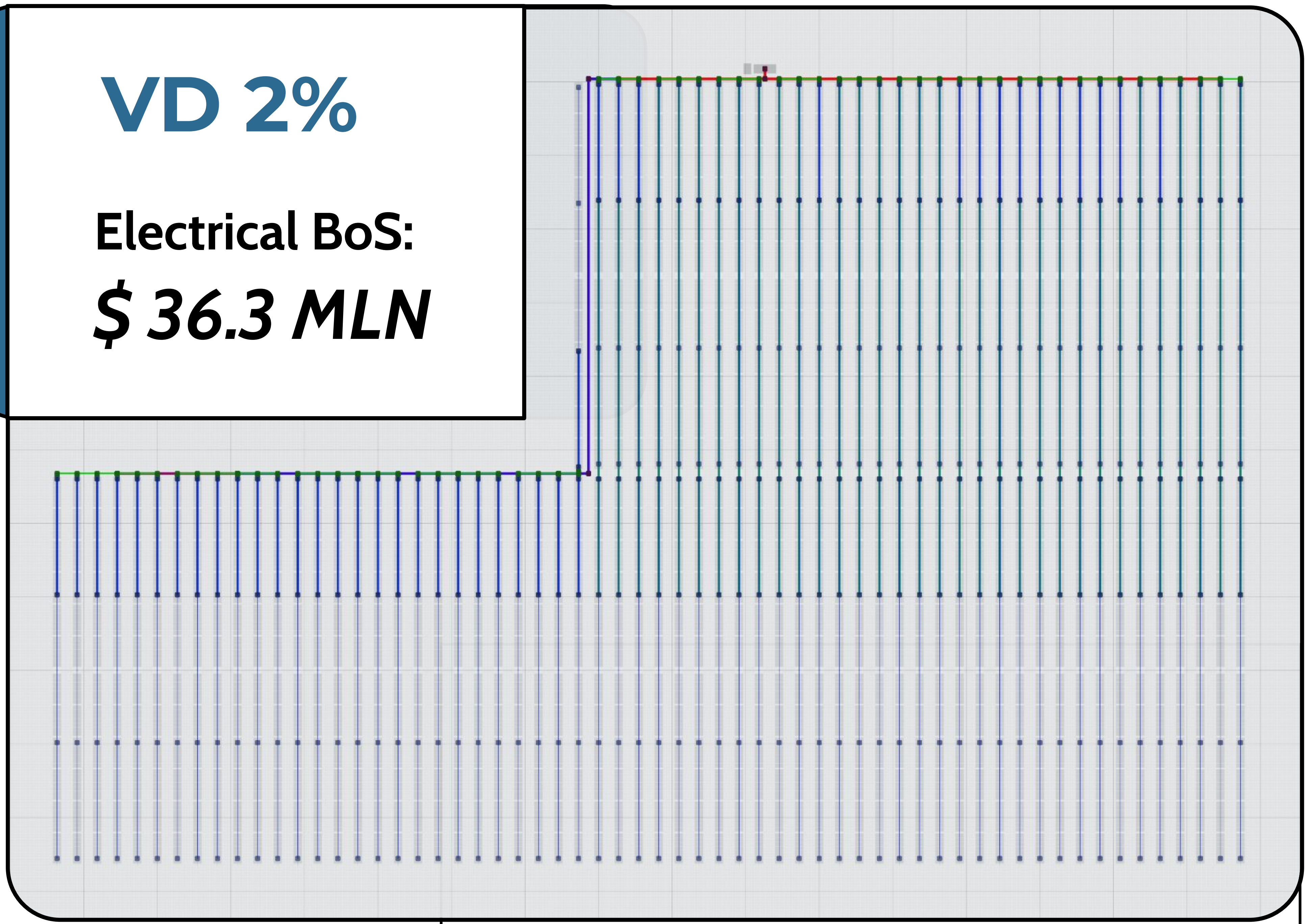


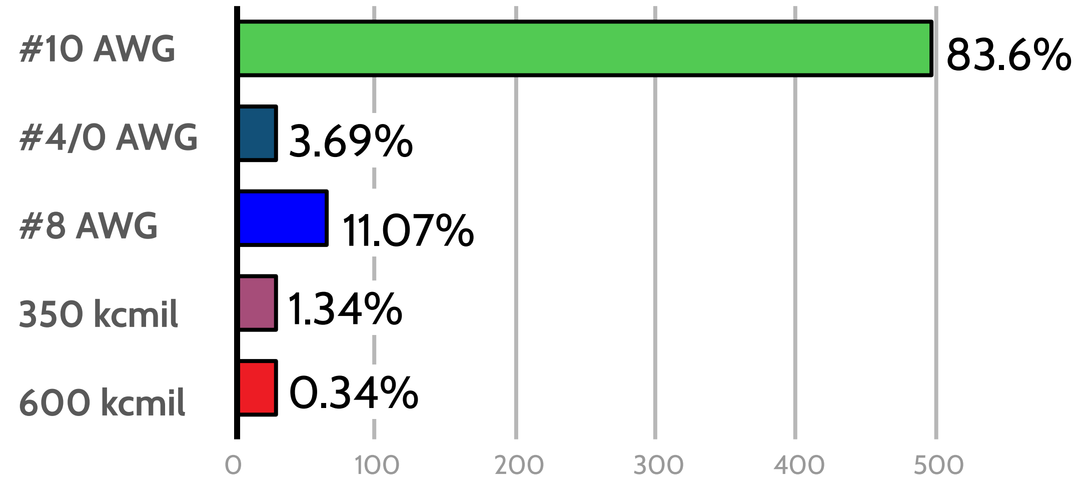


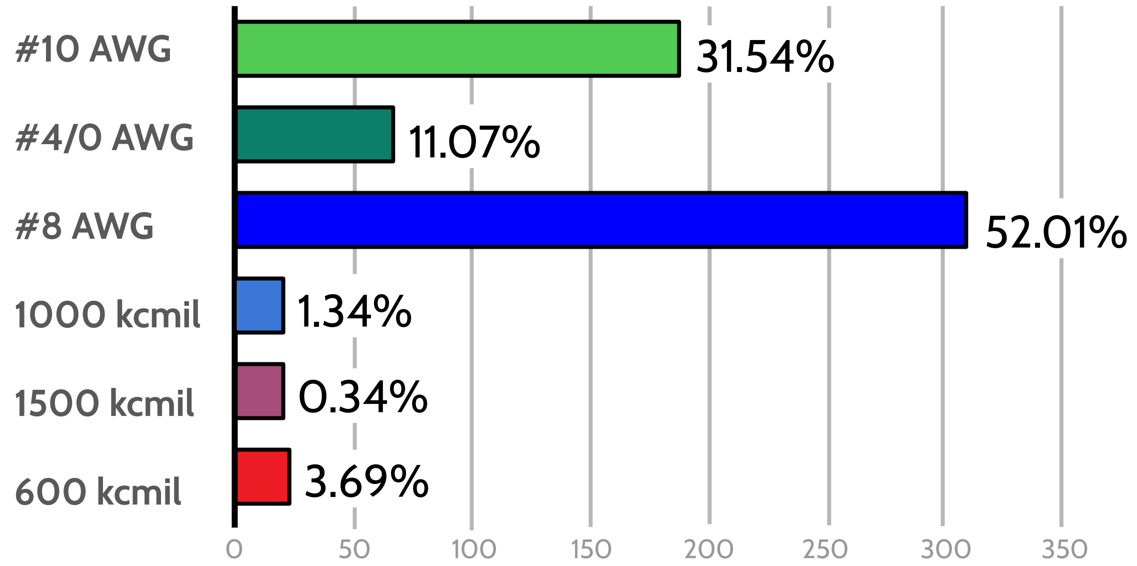
VD 2%

Electrical BoS:

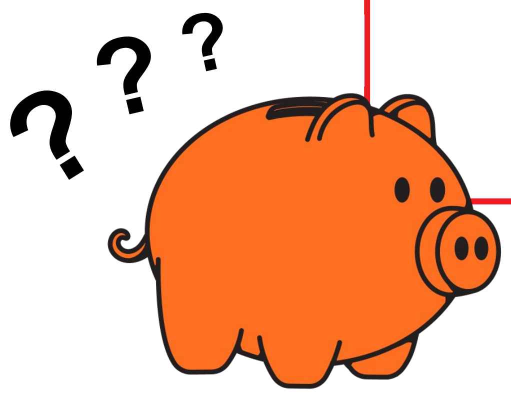
$ 36.3 MLN

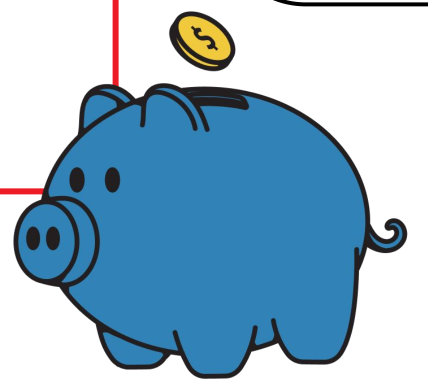






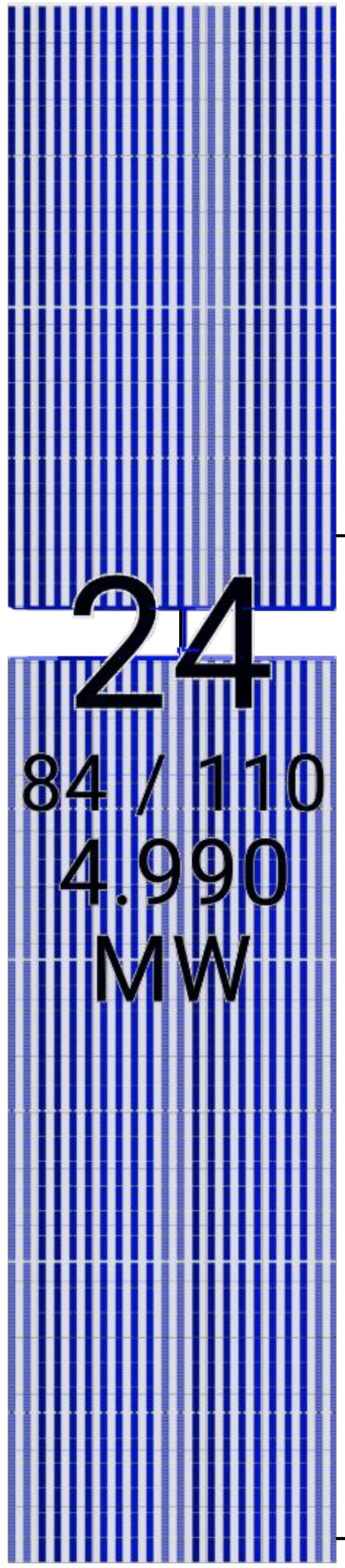
A 4% voltage drop saves $2M in construction — but costs $40M in lost energy over 30 years





The gap that costs millions

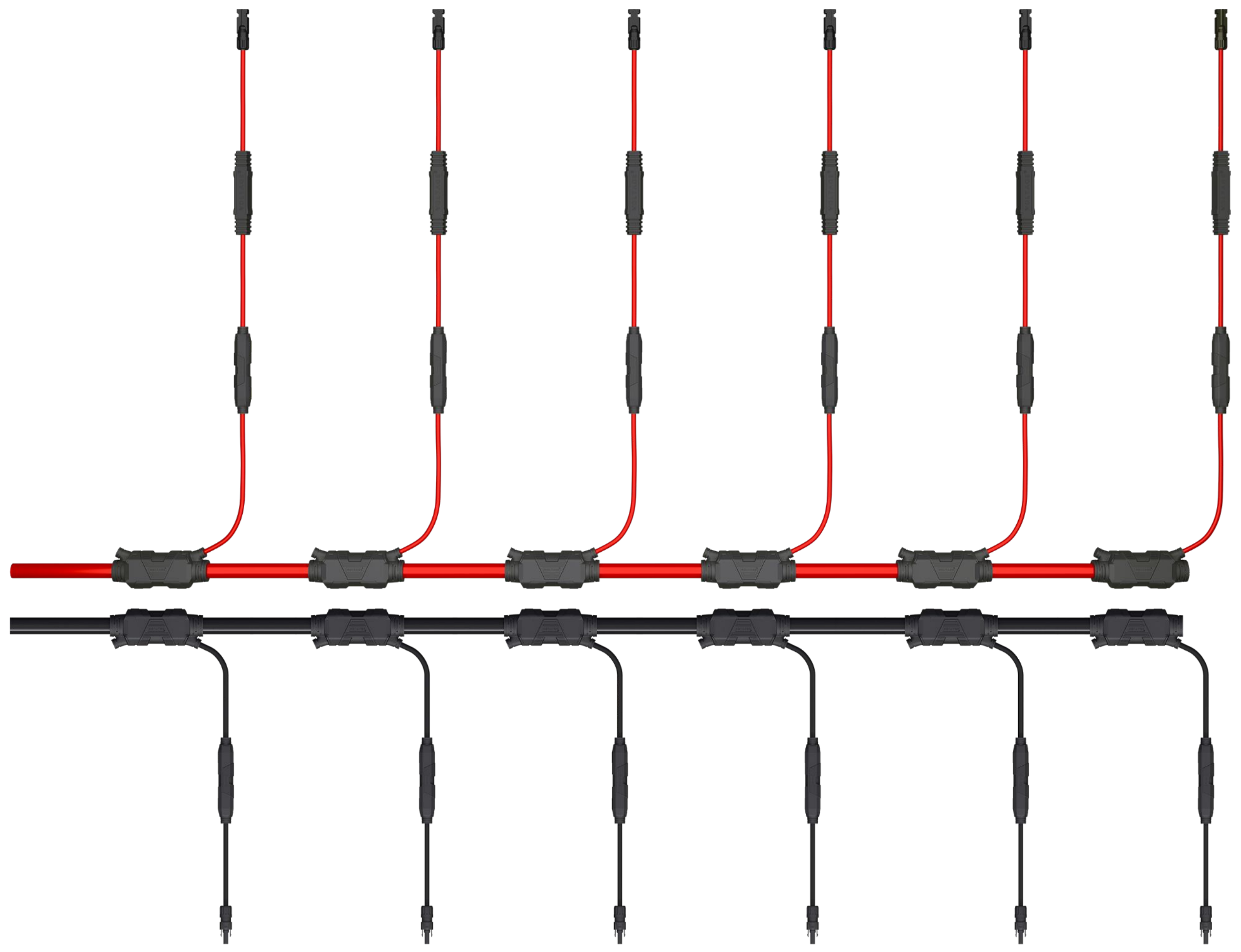
$1.3M EBOS Cost Swing per Block

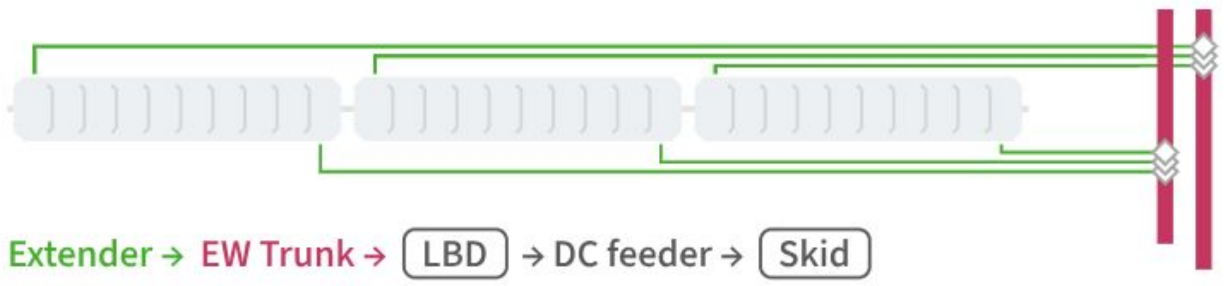


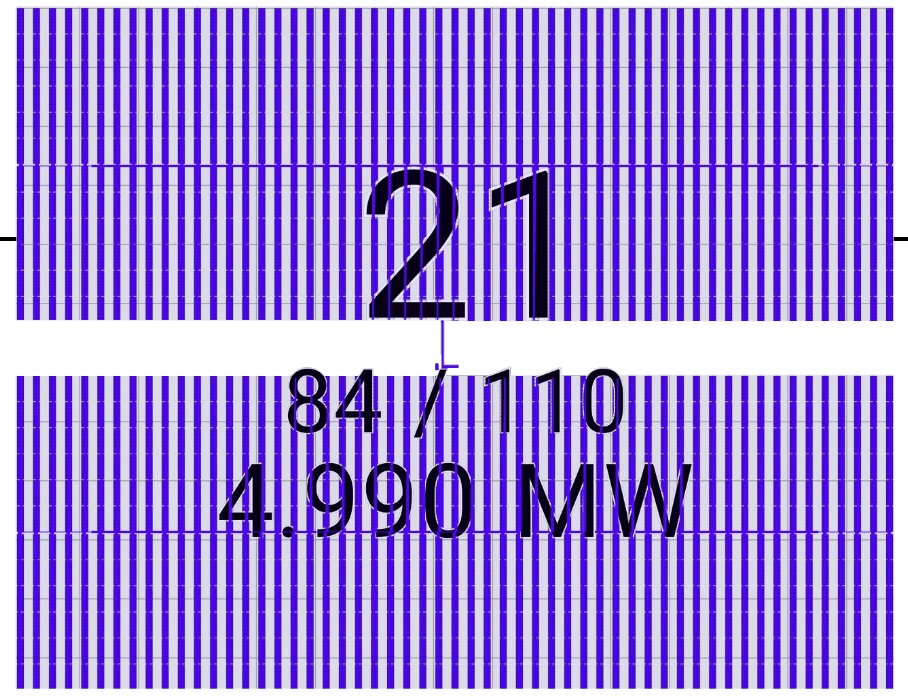
Electrical CAPEX:
0.3802 $/W

LCOE, $/MWh:
58.43 $/MWh

Distributed		Clustered
Partial		Full
Middle of row		End of row
Single array		Multi array



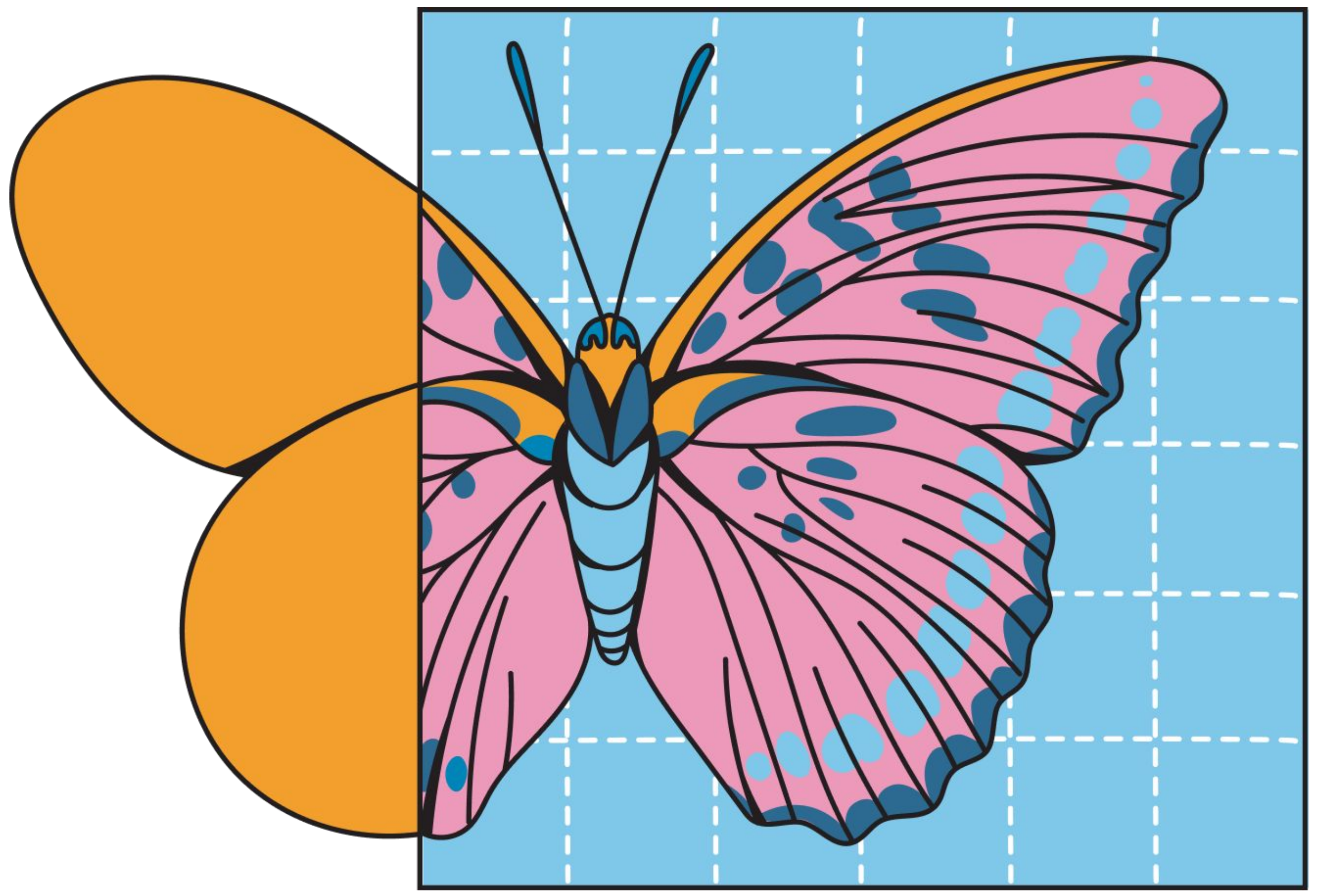




Electrical CAPEX:
0.1195 $/W

LCOE, $/MWh:
49.23 $/MWh

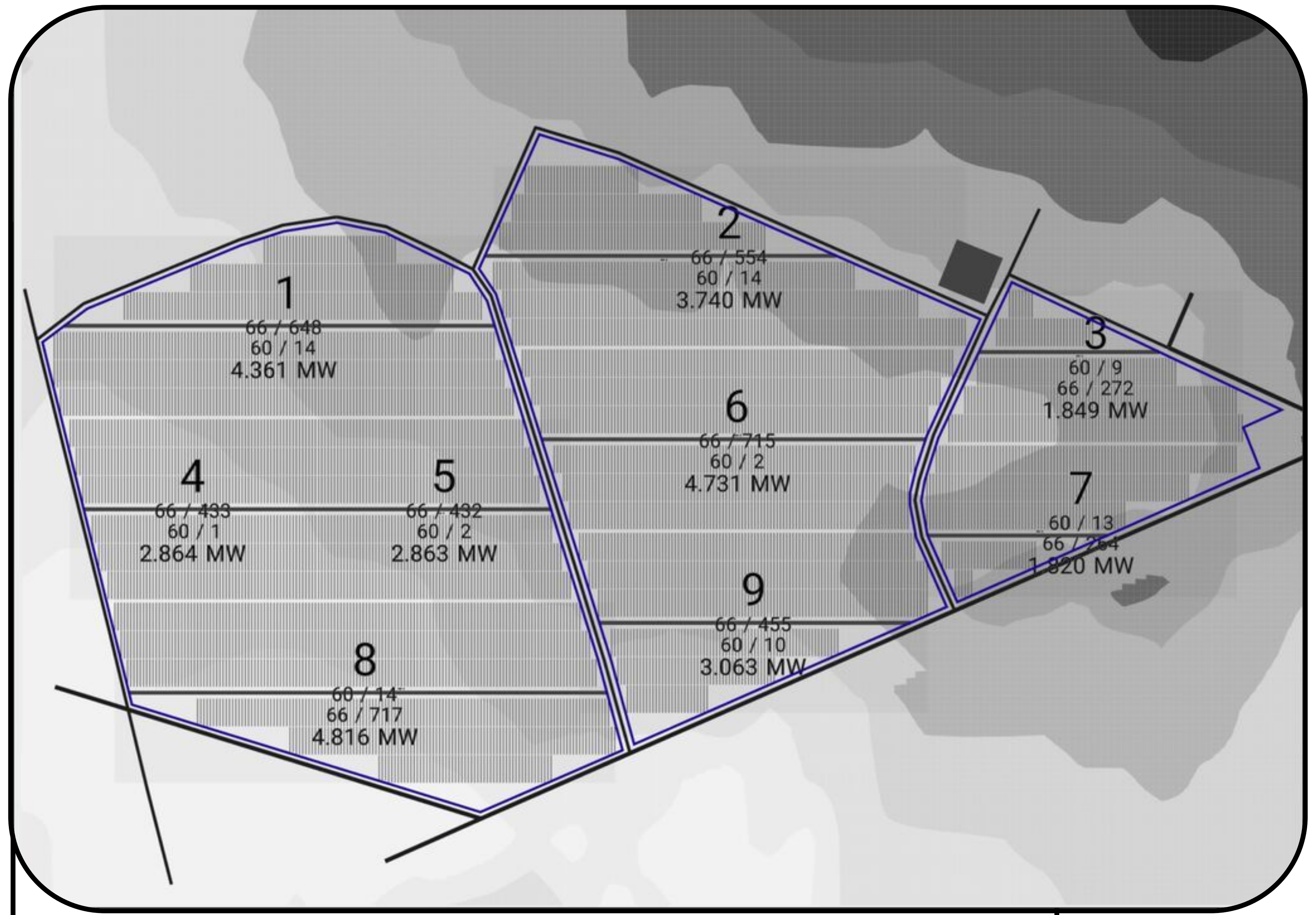
Distributed		Clustered
Partial		Full
Middle of row		End of row
Single array		Multi array

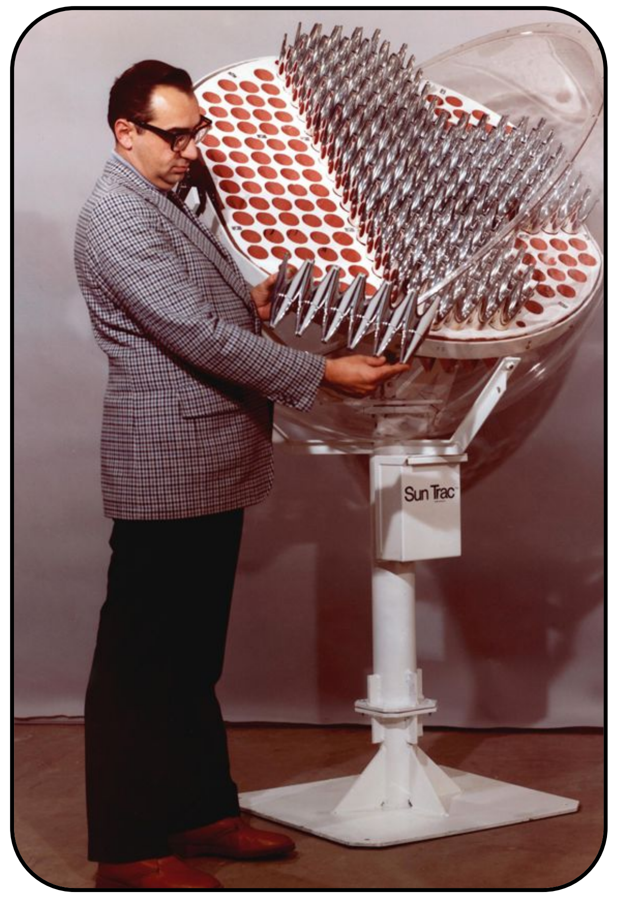


Fast Evolving

10 Years Ago vs Now

10 Years Ago



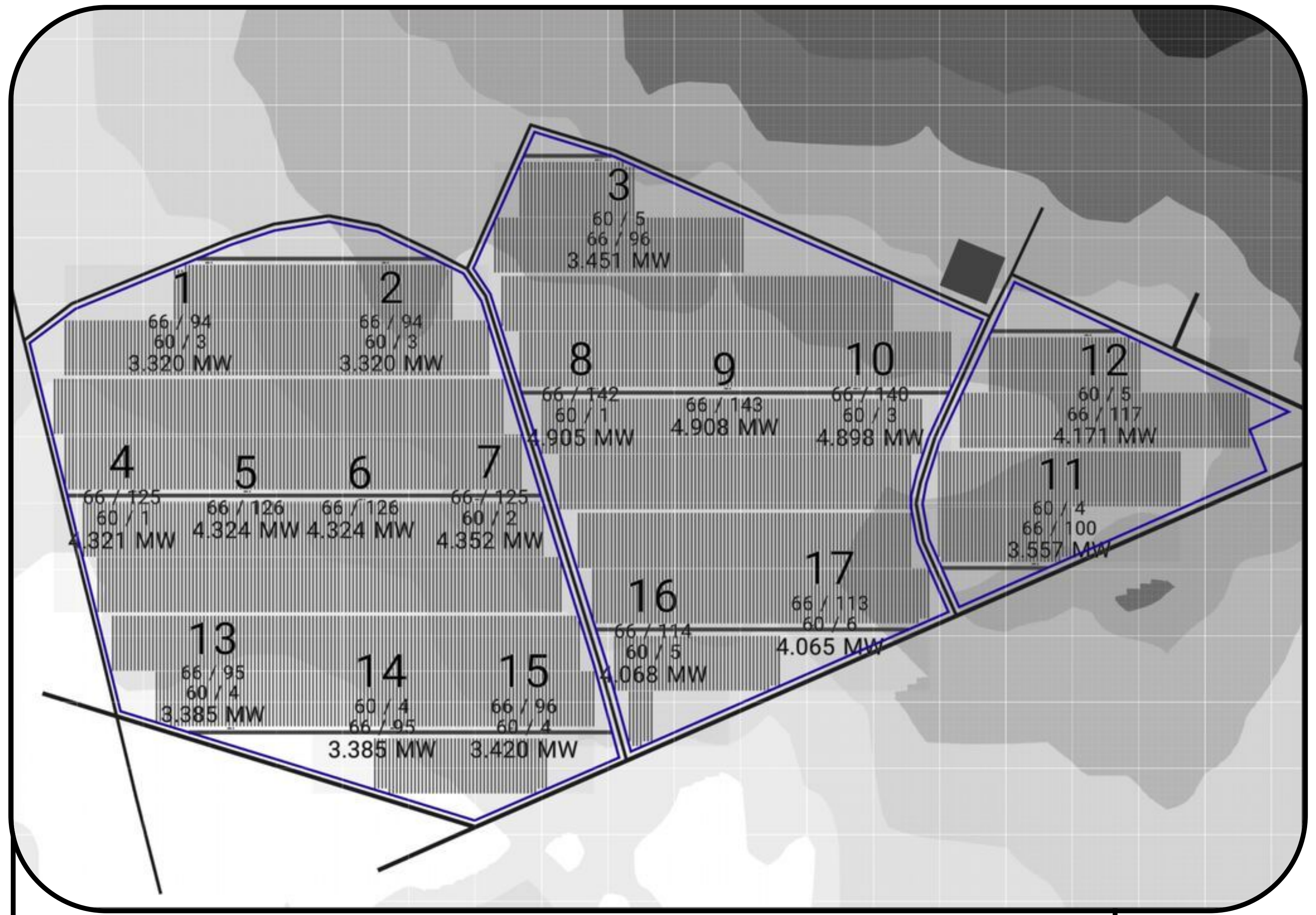


Capacity: *30.1 MW*

Energy: *26,816 MWh*

Modules: *301,080*

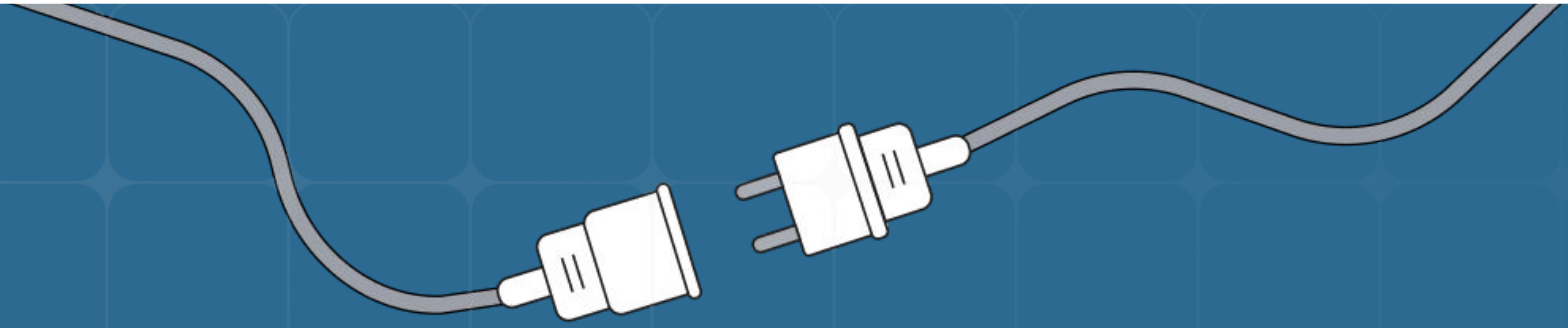
Today



Capacity: *68.2 MW*

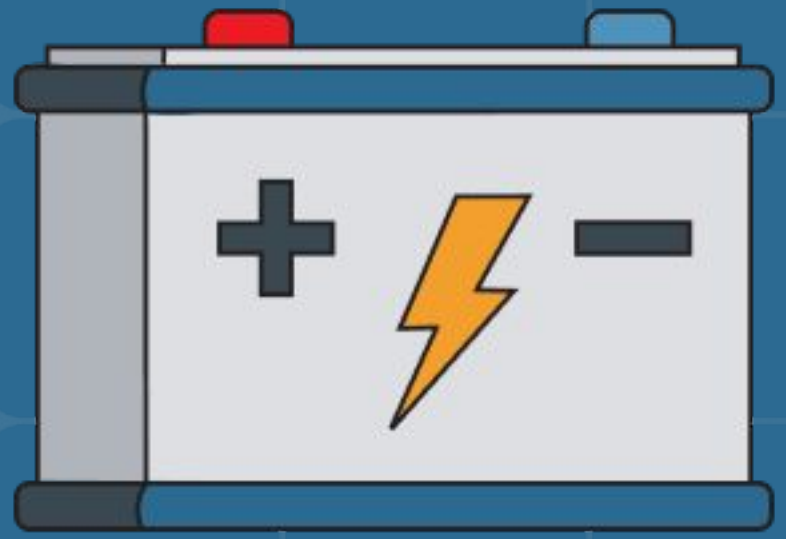
Energy: *75,857 MWh*

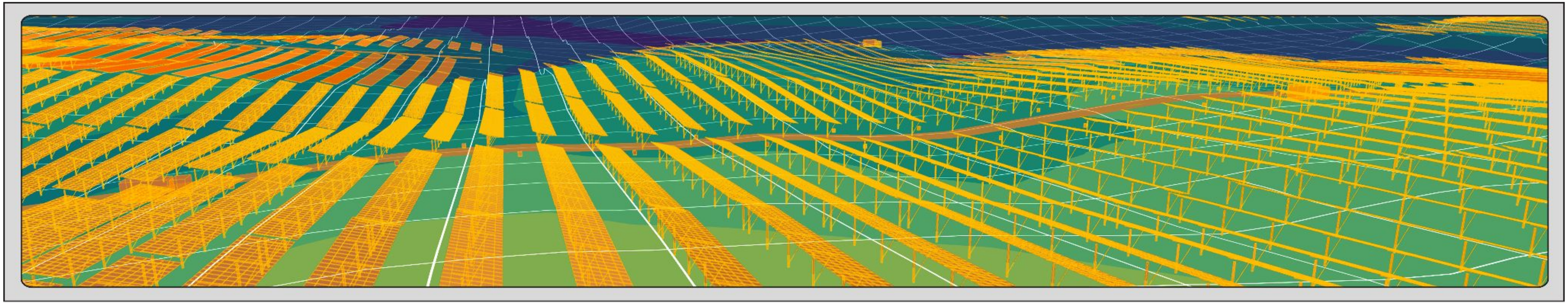
Modules: *131,106*

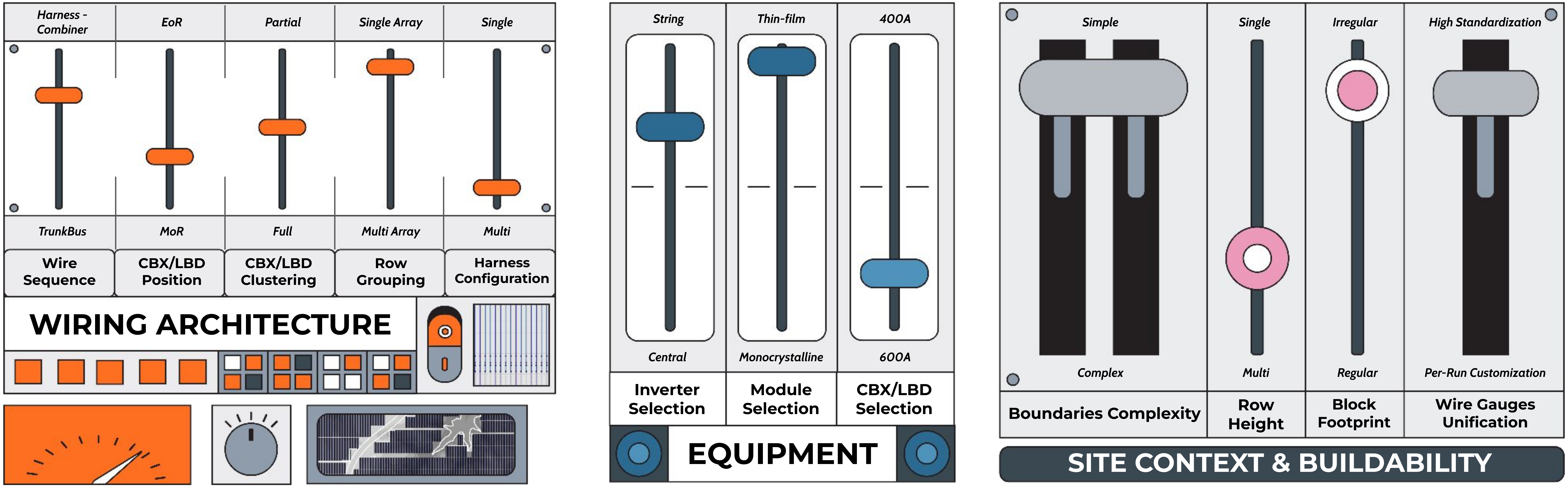


Electrical Parameters

Knobs you turn to shape outcomes - guiding energy, cost, and complexity with every choice





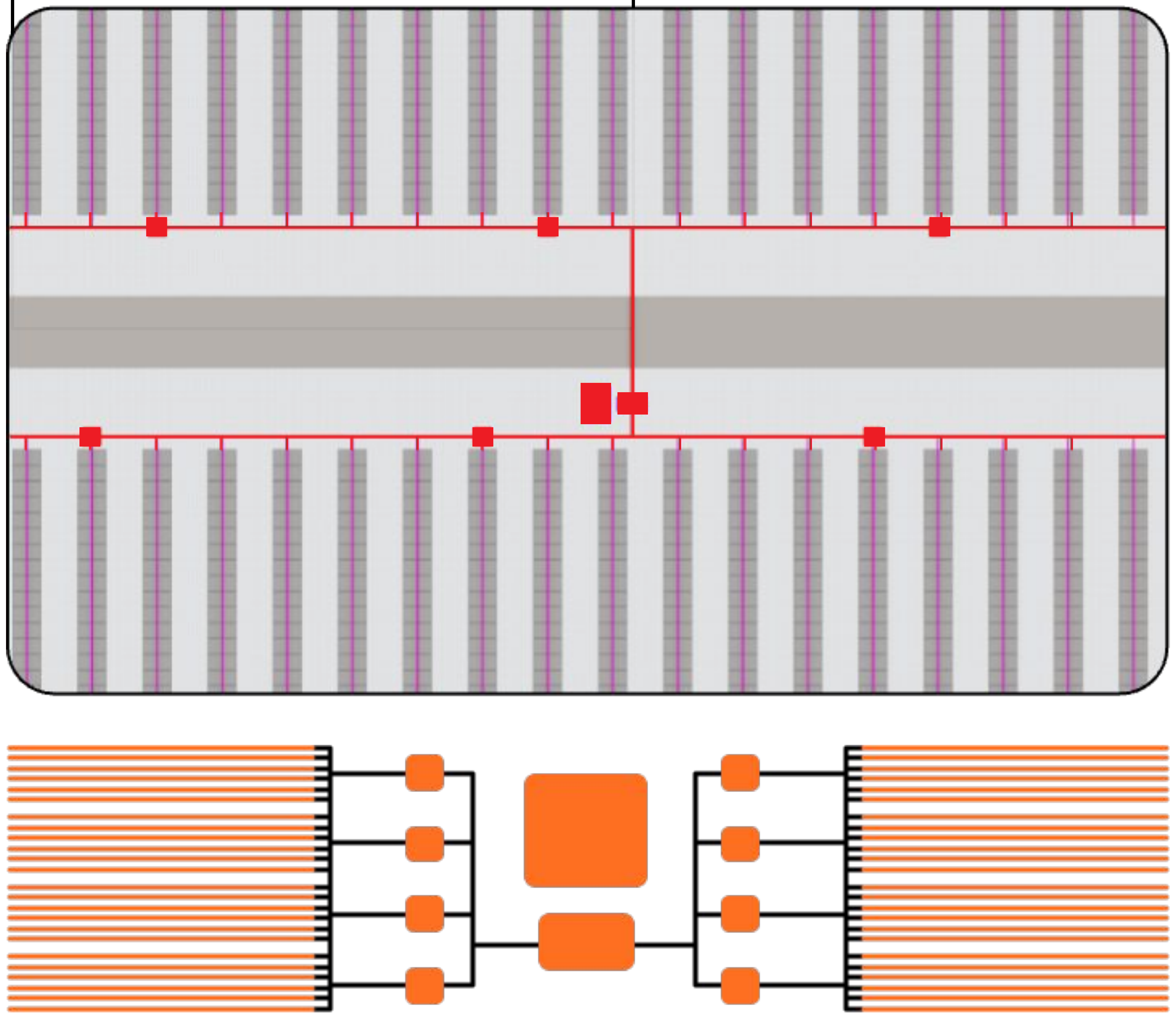

Harness - Combiner
EoR
Partial
Single Array
Single
TrunkBus
MoR
Full
Multi Array
Multi
Wire Sequence
CBX/LBD Position
CBX/LBD Clustering
Row Grouping
Harness Configuration
WIRING ARCHITECTURE
String
Thin-film
400A
Central
Monocrystalline
600A
Inverter Selection
Module Selection
CBX/LBD Selection
EQUIPMENT
Simple
Single
Irregular
High Standardization
Complex
Multi
Regular
Per-Run Customization
Boundaries Complexity
Row Height
Block Footprint
Wire Gauges Unification
SITE CONTEXT & BUILDABILITY

1 Inverter Selection

Inverter power, Inverter type

Central Inverter

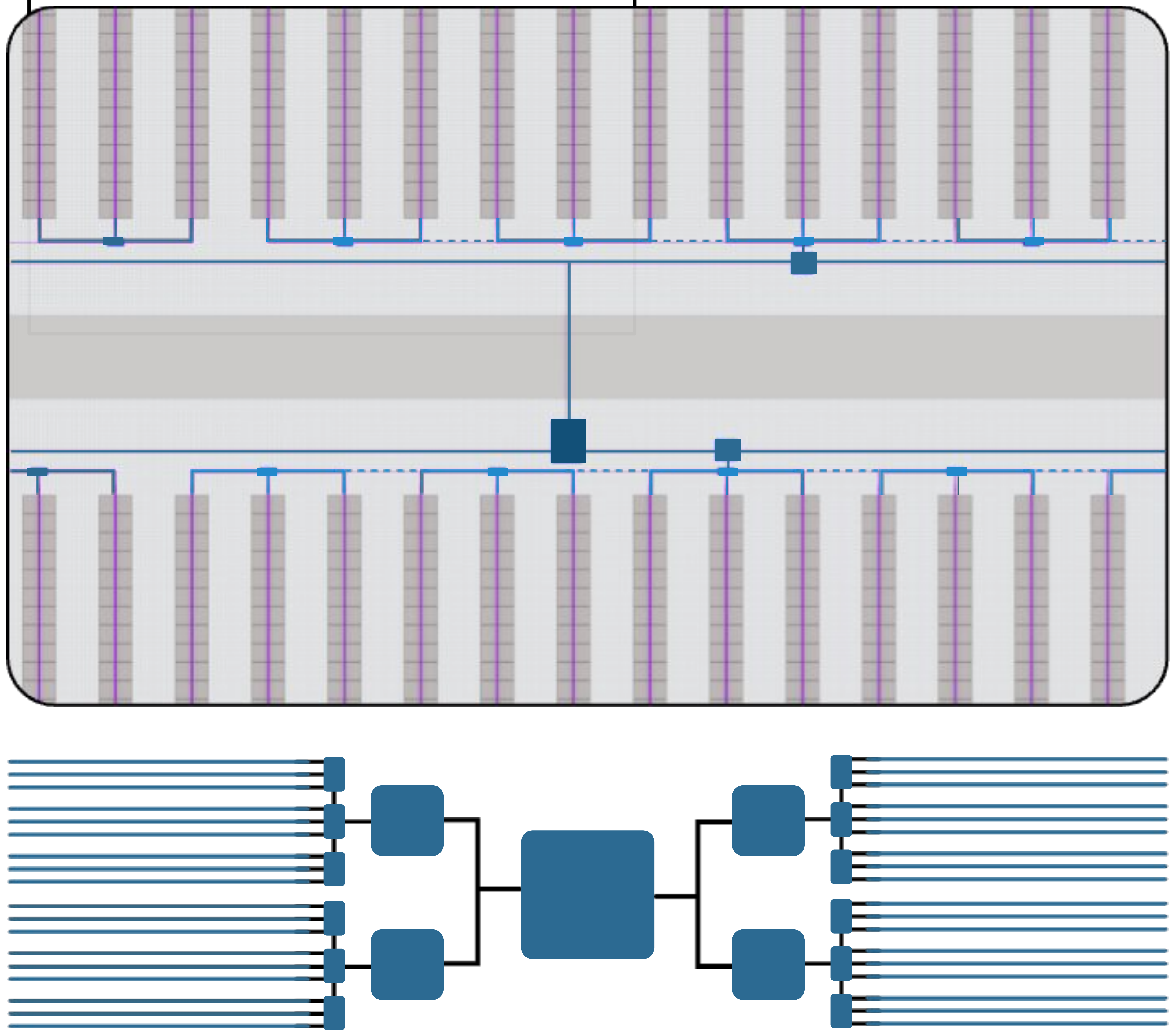
Transformer → Inverter → Combiner-box → Tracker



VS

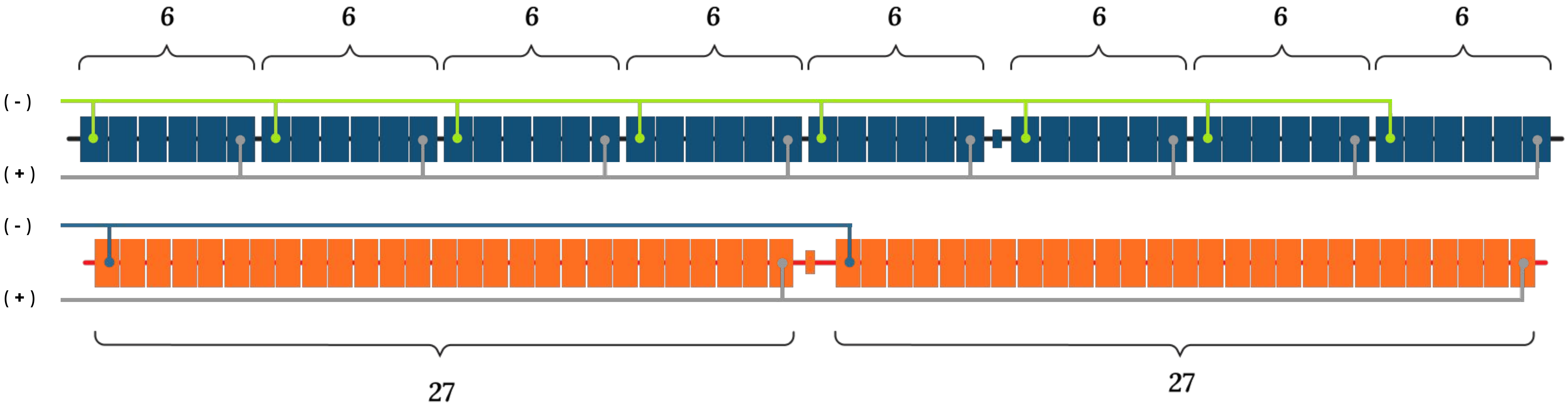
String Inverter

Transformer → Combiner-box → Inverter → Tracker



2 Module Selection

Module Power, Module type



Thin-film

First Solar
String size: *6 mods*
Total: *54 mods*
23.2kW tracker power

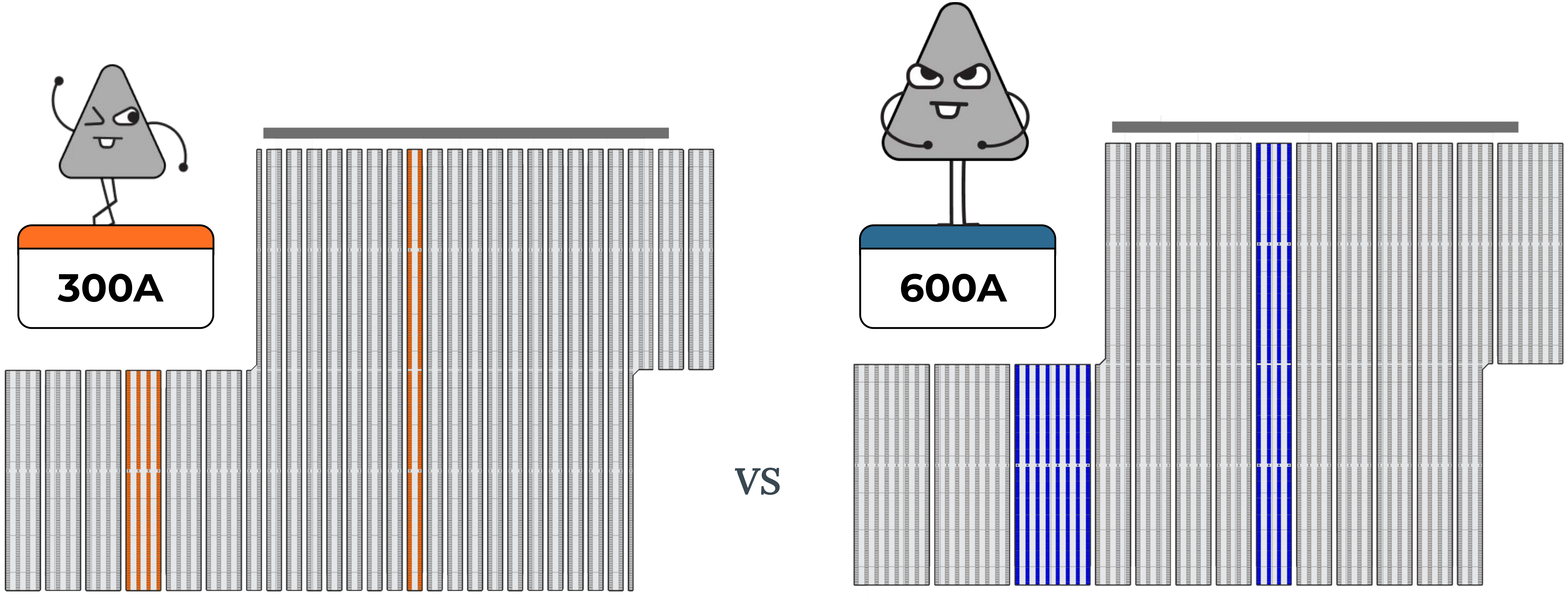
Monocrystalline

Canadian Solar
String size: *27 mods*
Total: *54 mods*
21.9kW tracker power

In the Harness scheme, electrical costs are higher with thin-film modules due to the greater labor intensity of installing the Harness (more strings need to be connected). In the Trunk Bus scheme, electrical costs are higher with thin-film modules due to the greater number of Extenders.

3 CBX/LBD Selection

Ampacity



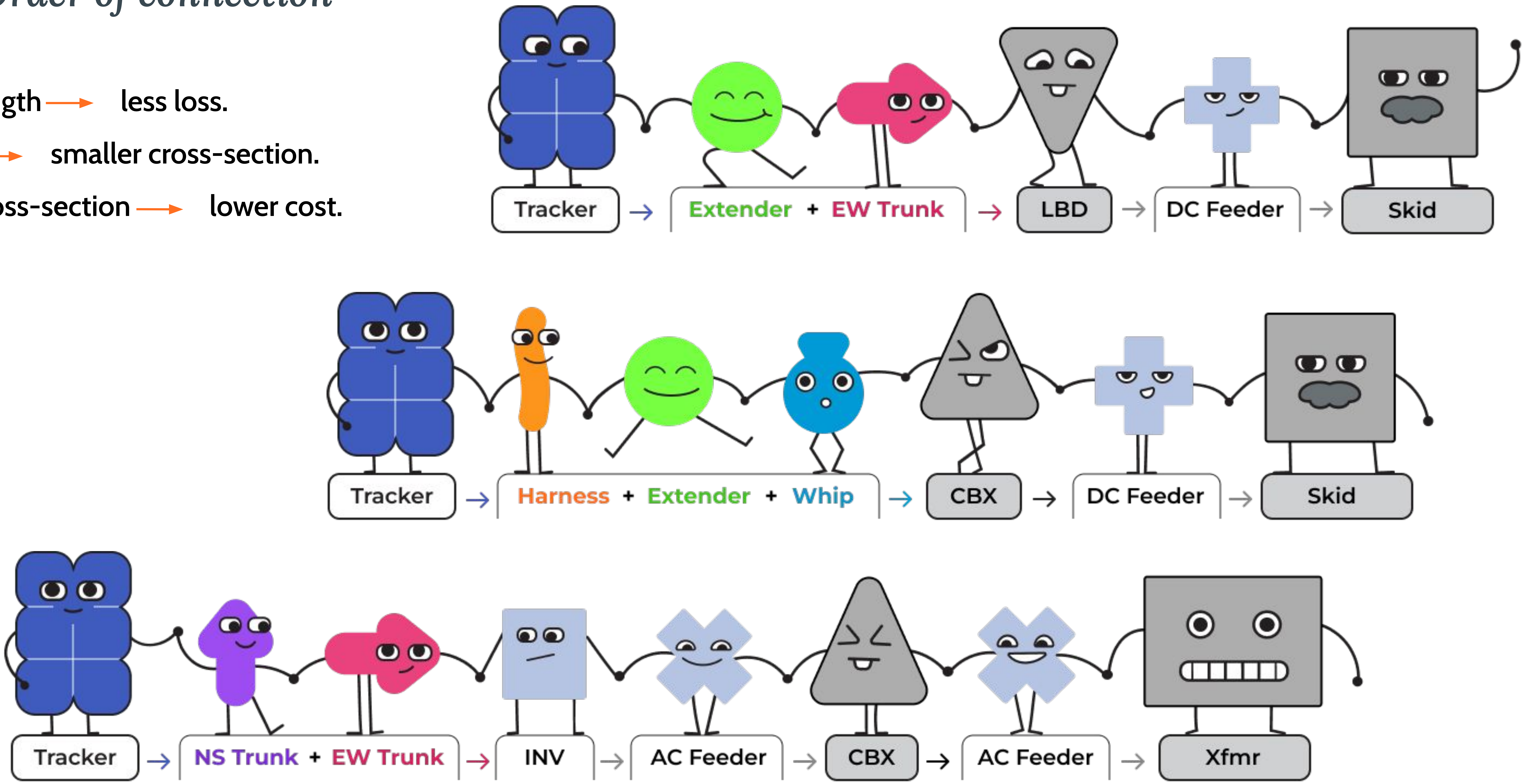
4 Wire Sequence

Order of connection

Shorter length → less loss.

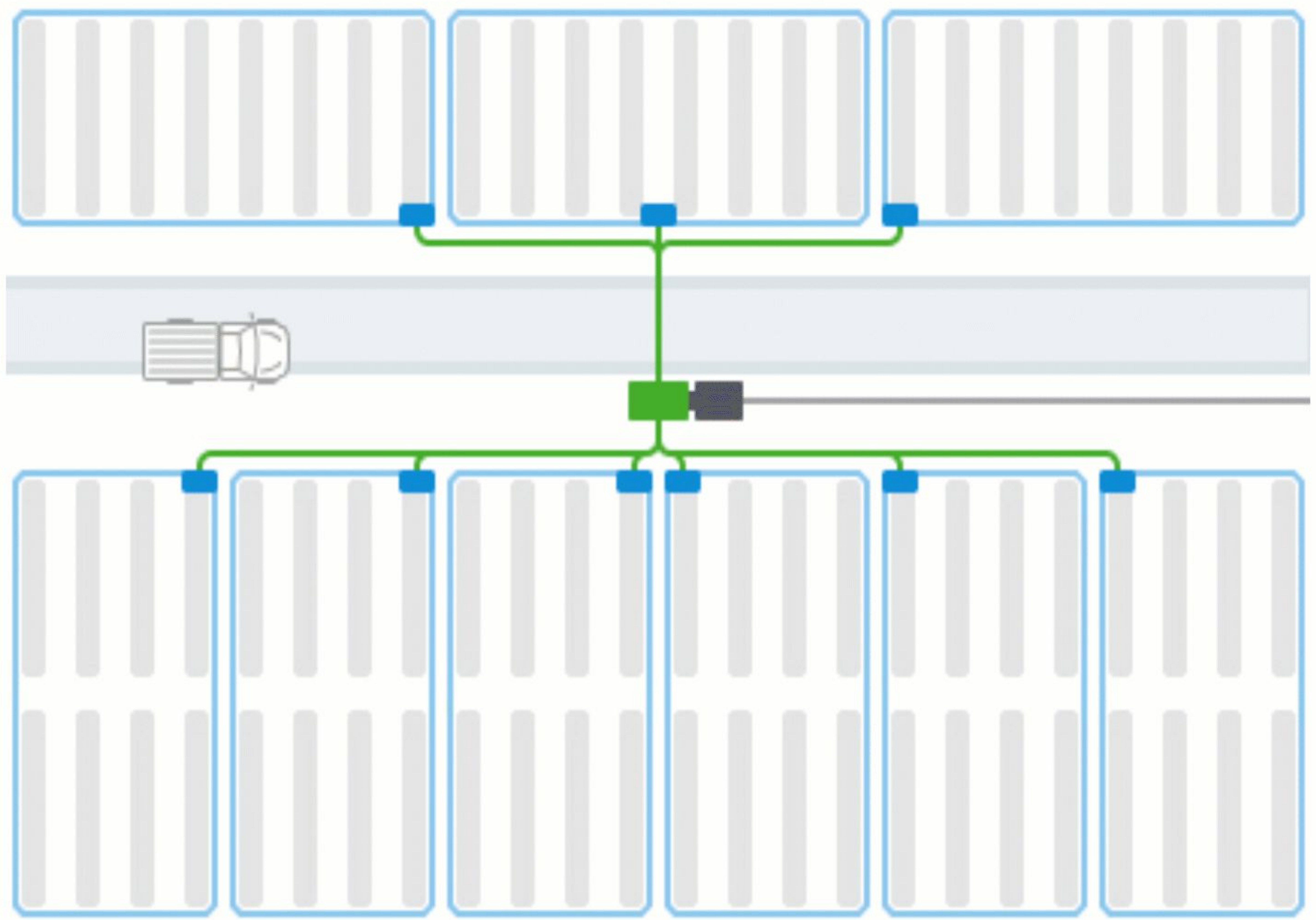
Less loss → smaller cross-section.

Smaller cross-section → lower cost.



CBX/LBD Features

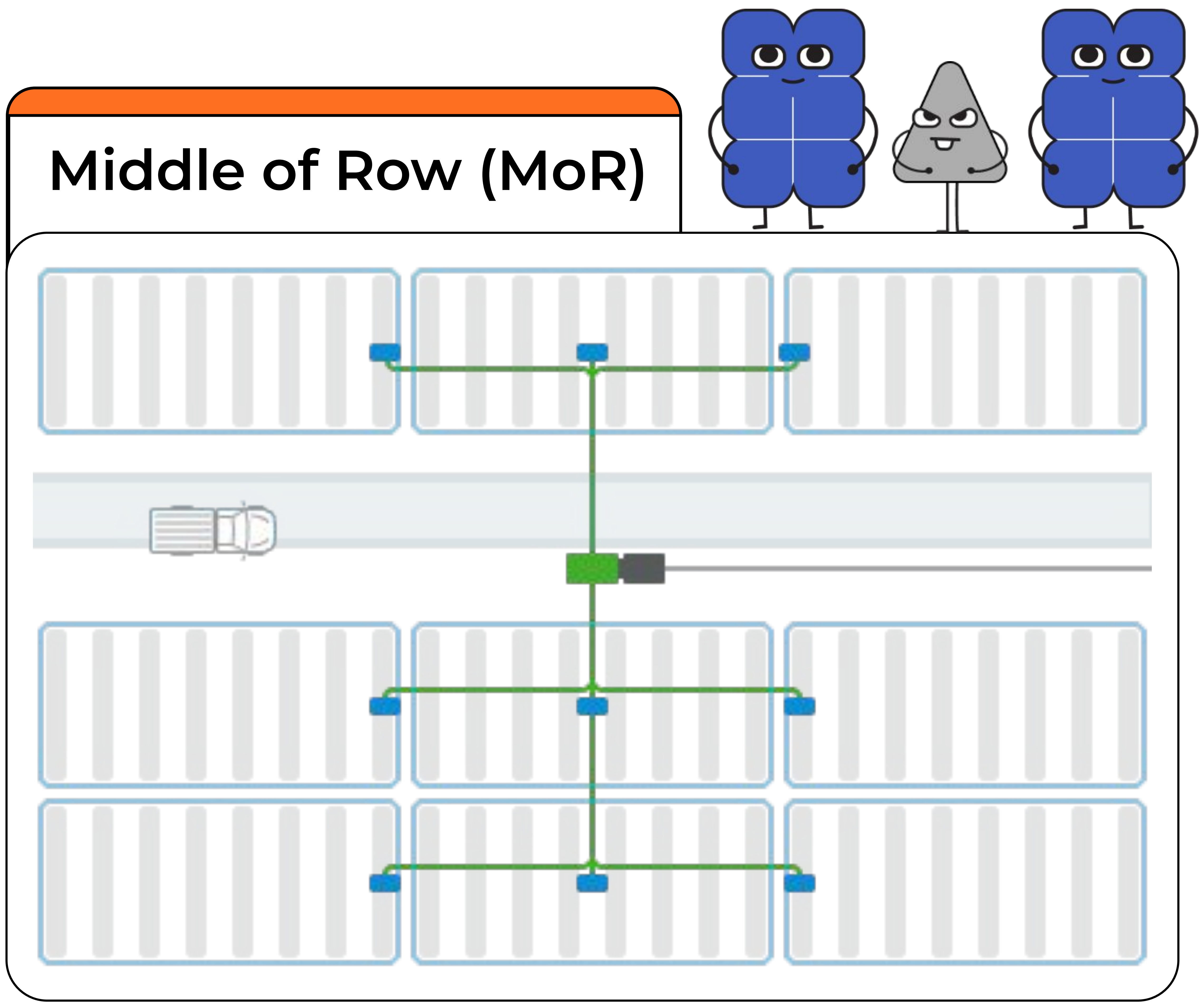
Distributed	Clustered
Partial	Full
Middle of row	End of row
Single array	Multi array



5 CBX/LBD Position

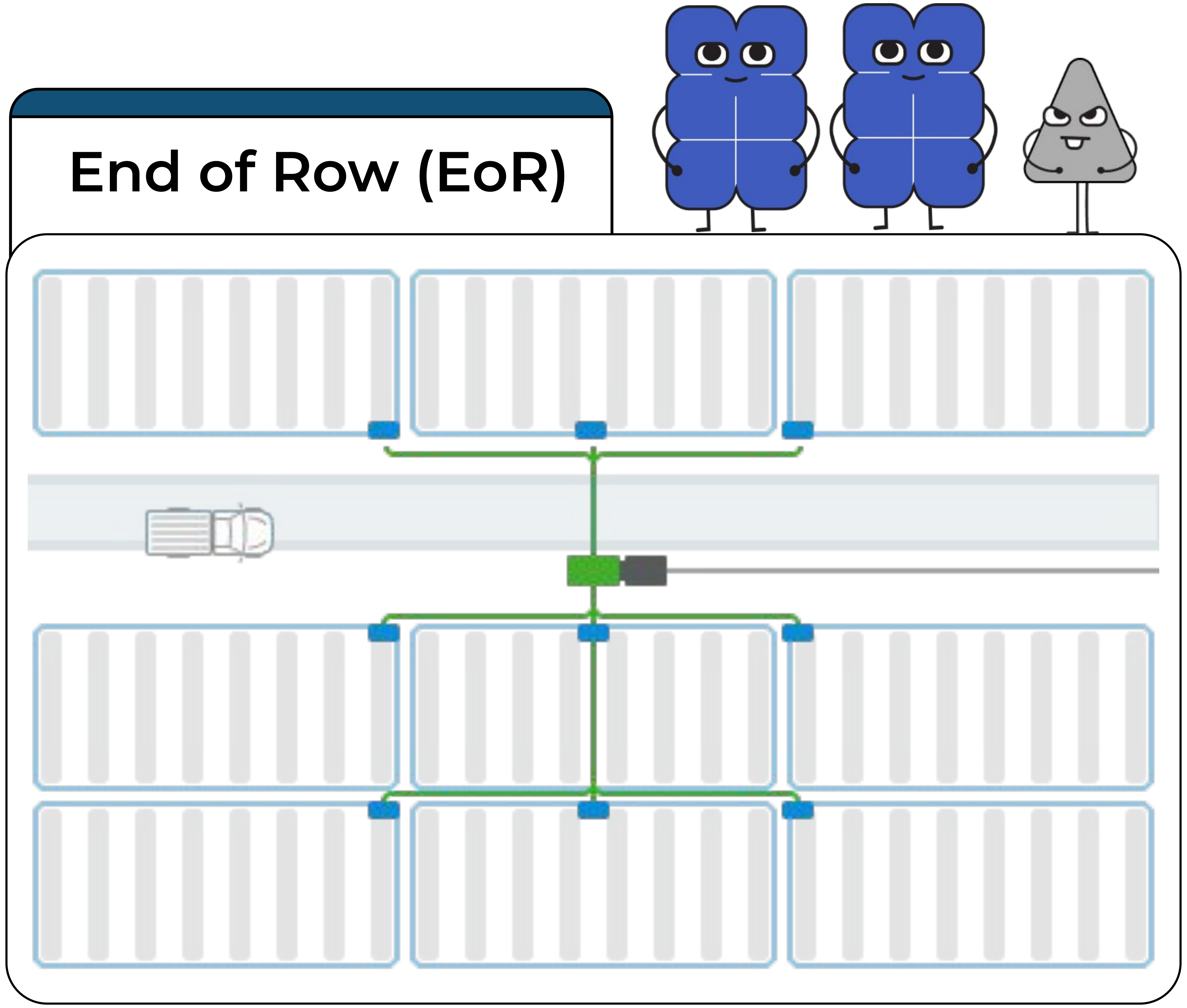
Affects trench lengths, voltage drop, and block connectivity

Middle of Row (MoR)



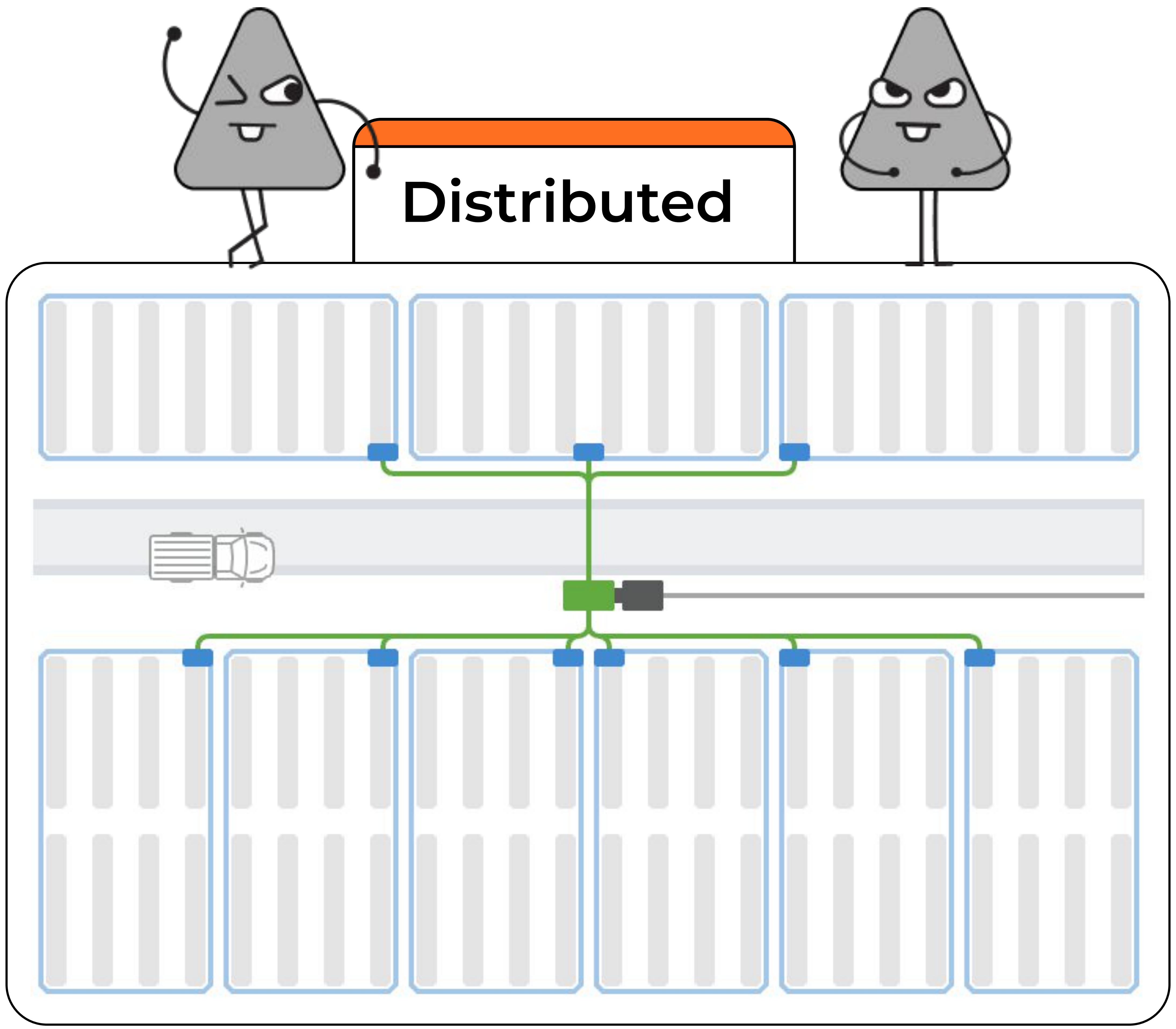
VS

End of Row (EoR)

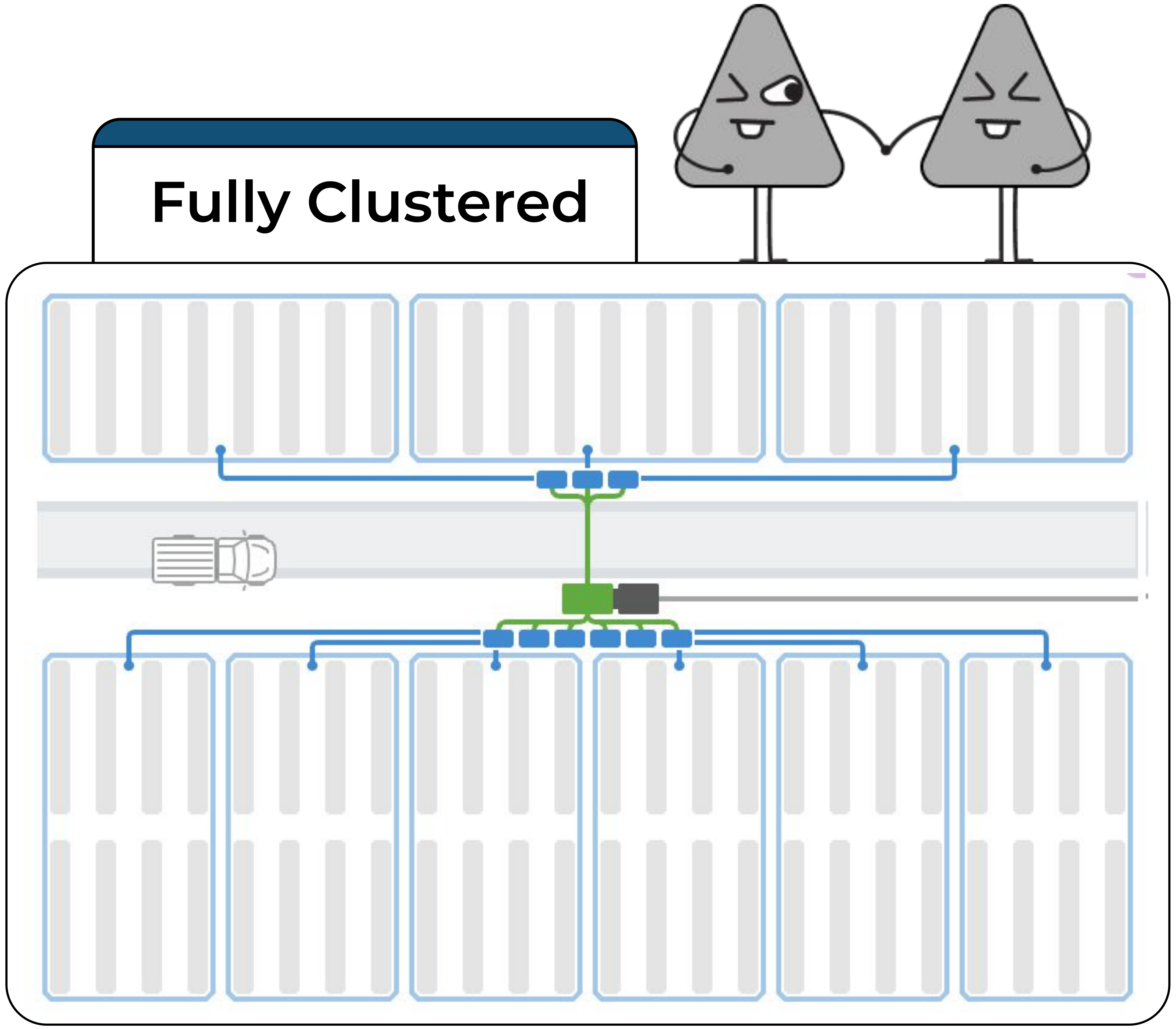


6 CBX/LBD Clustering

Drives concentration of terminations and trench convergence points

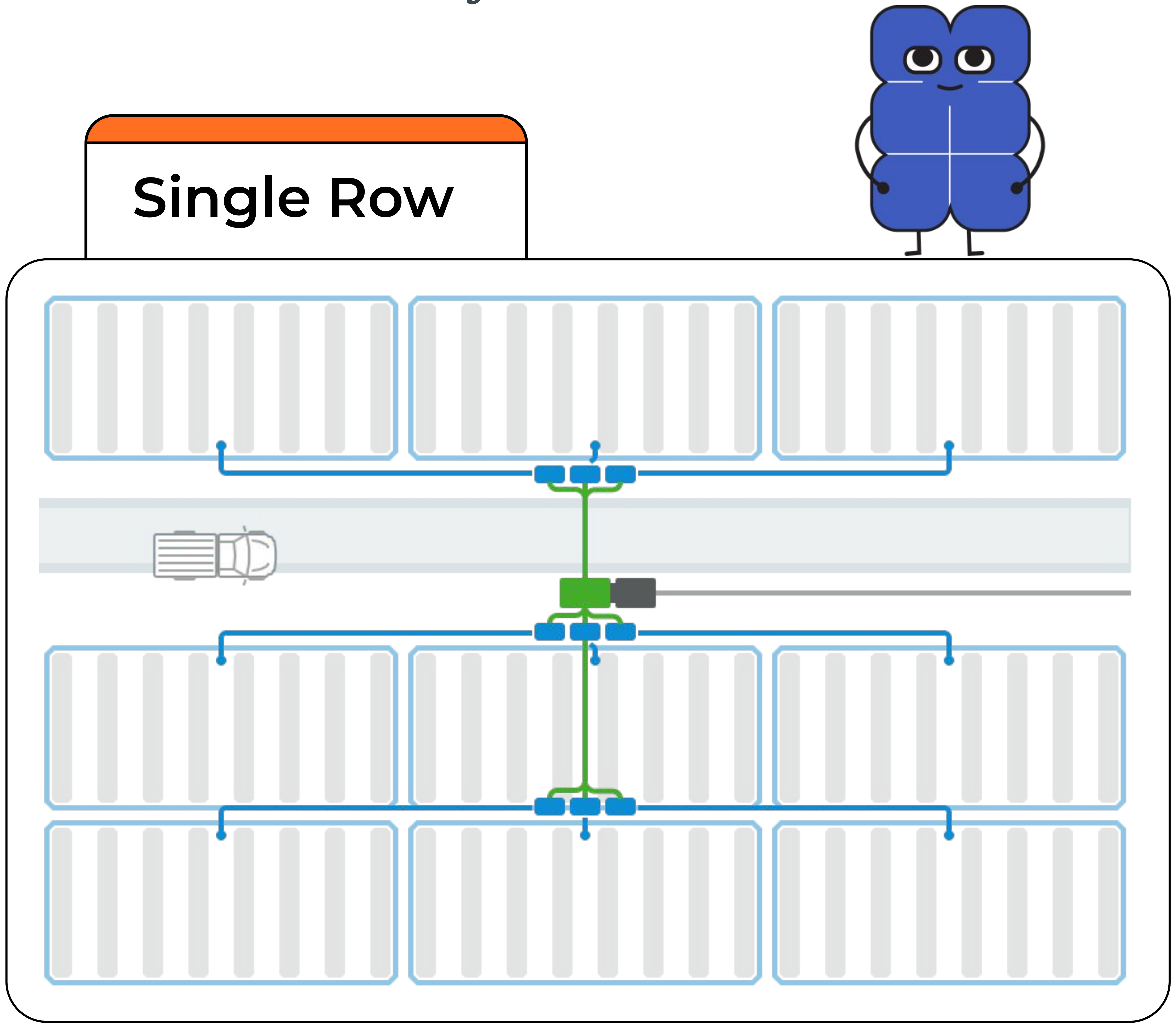


VS

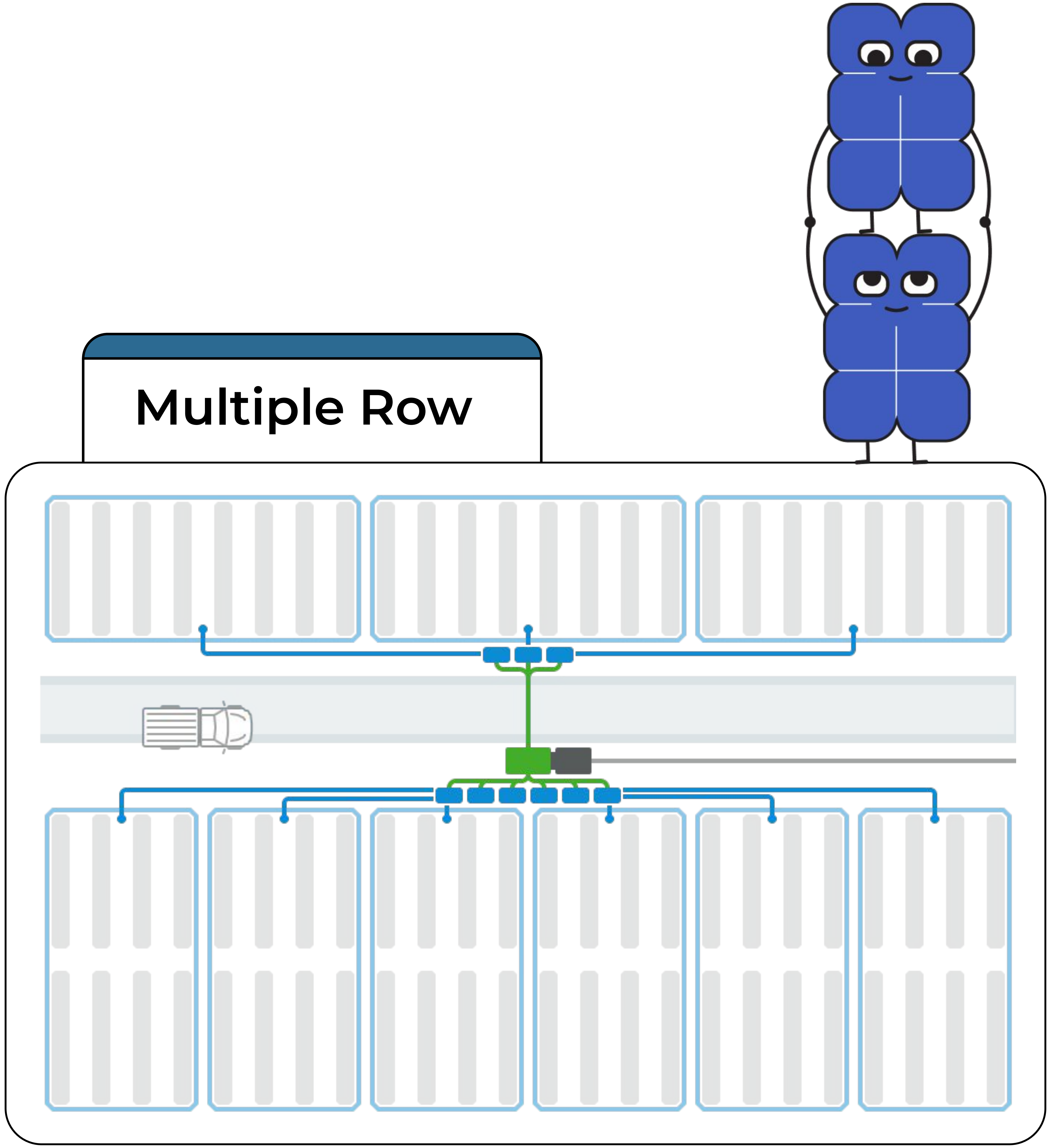


7 Row Grouping

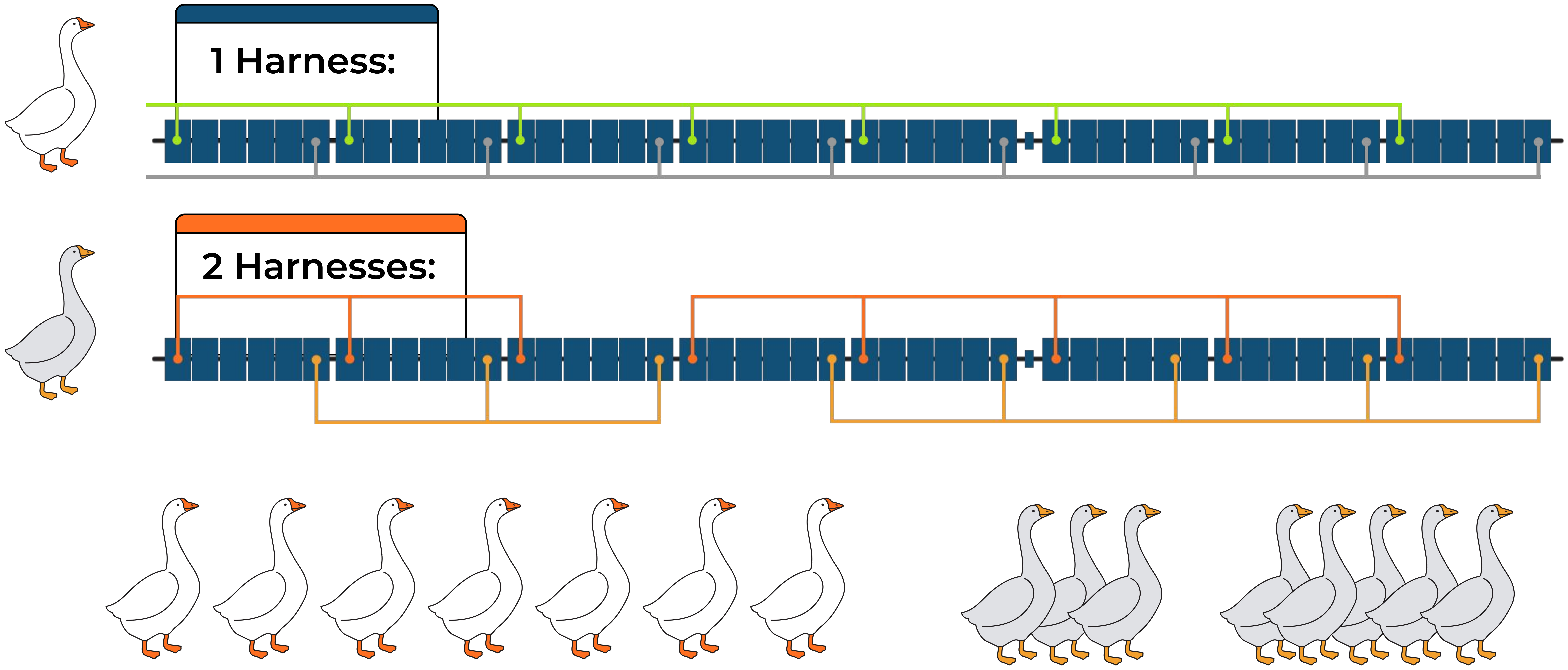
Determines wiring symmetry and layout predictability across the field



VS



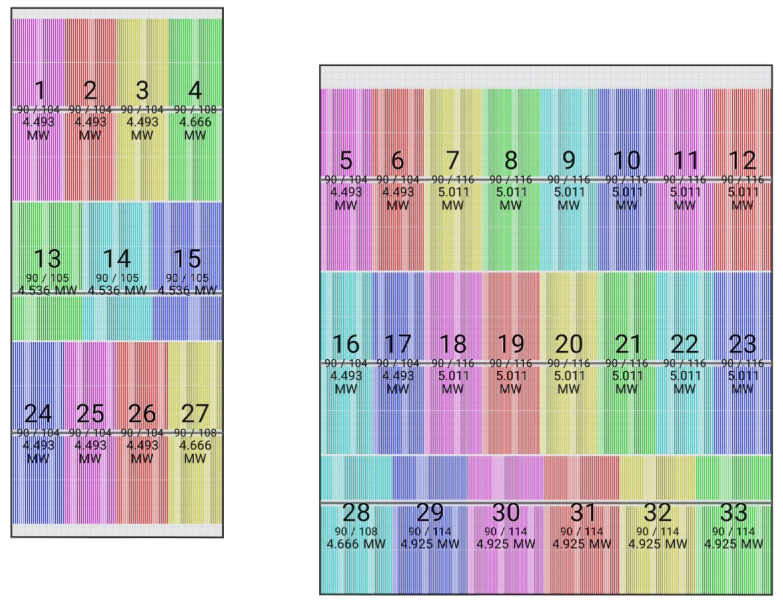
8 Harness Configuration



9 Boundaries Complexity

Complex boundaries reduce block uniformity

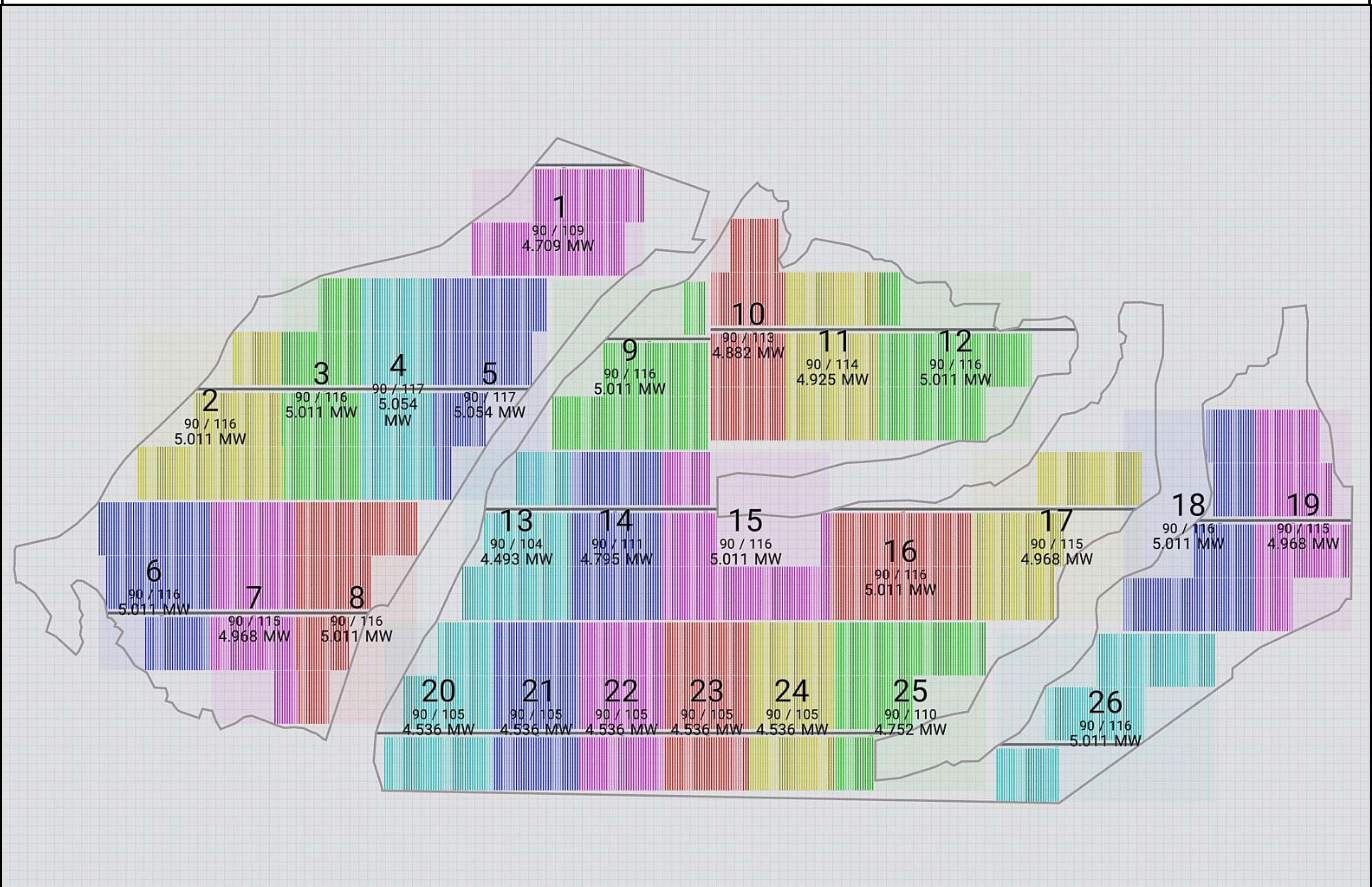
Simple Boundary



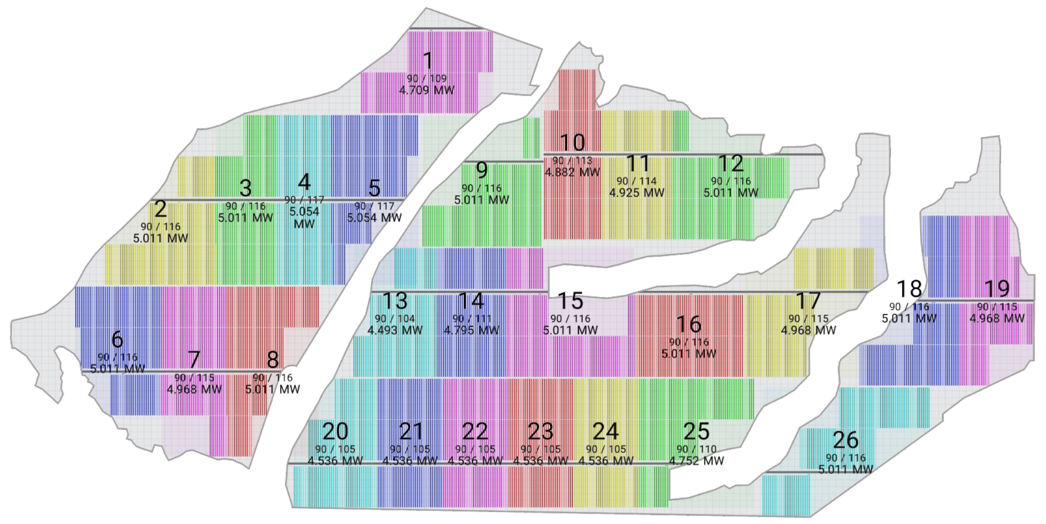
654 Acres

157.3MWDC

33 blocks



Complex Boundary



654 Acres

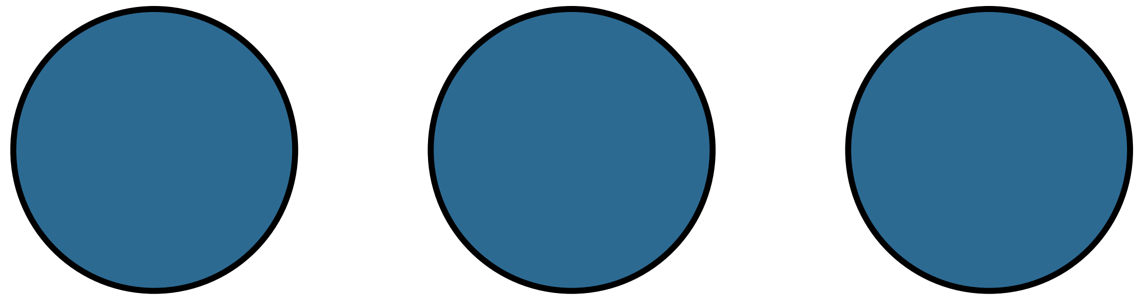
126.4MWDC

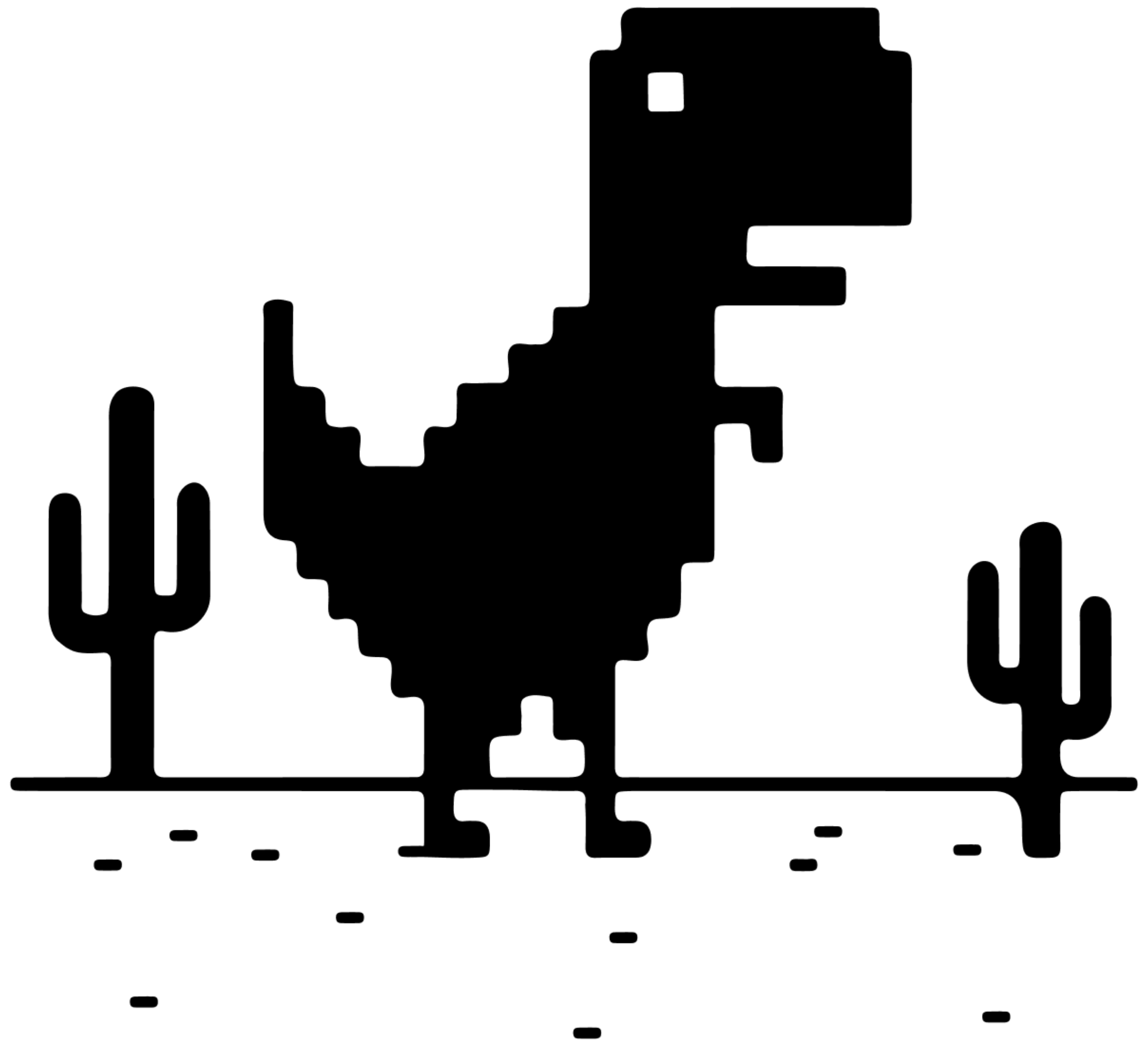
26 blocks

10 Wire Gauges Unification

Sometimes, simplicity is the most valuable optimization

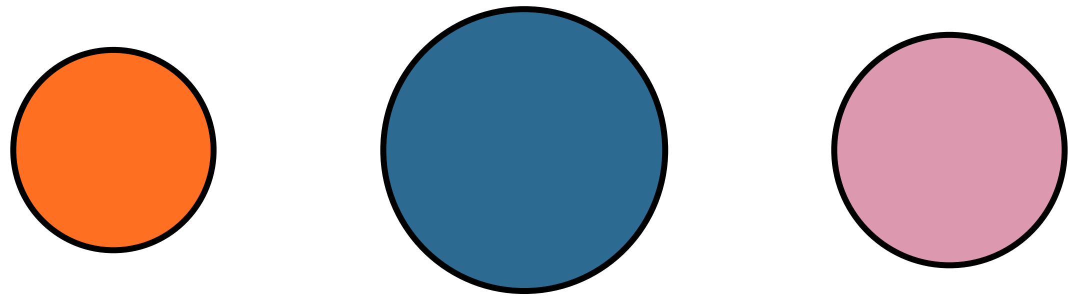
Optimized for construction





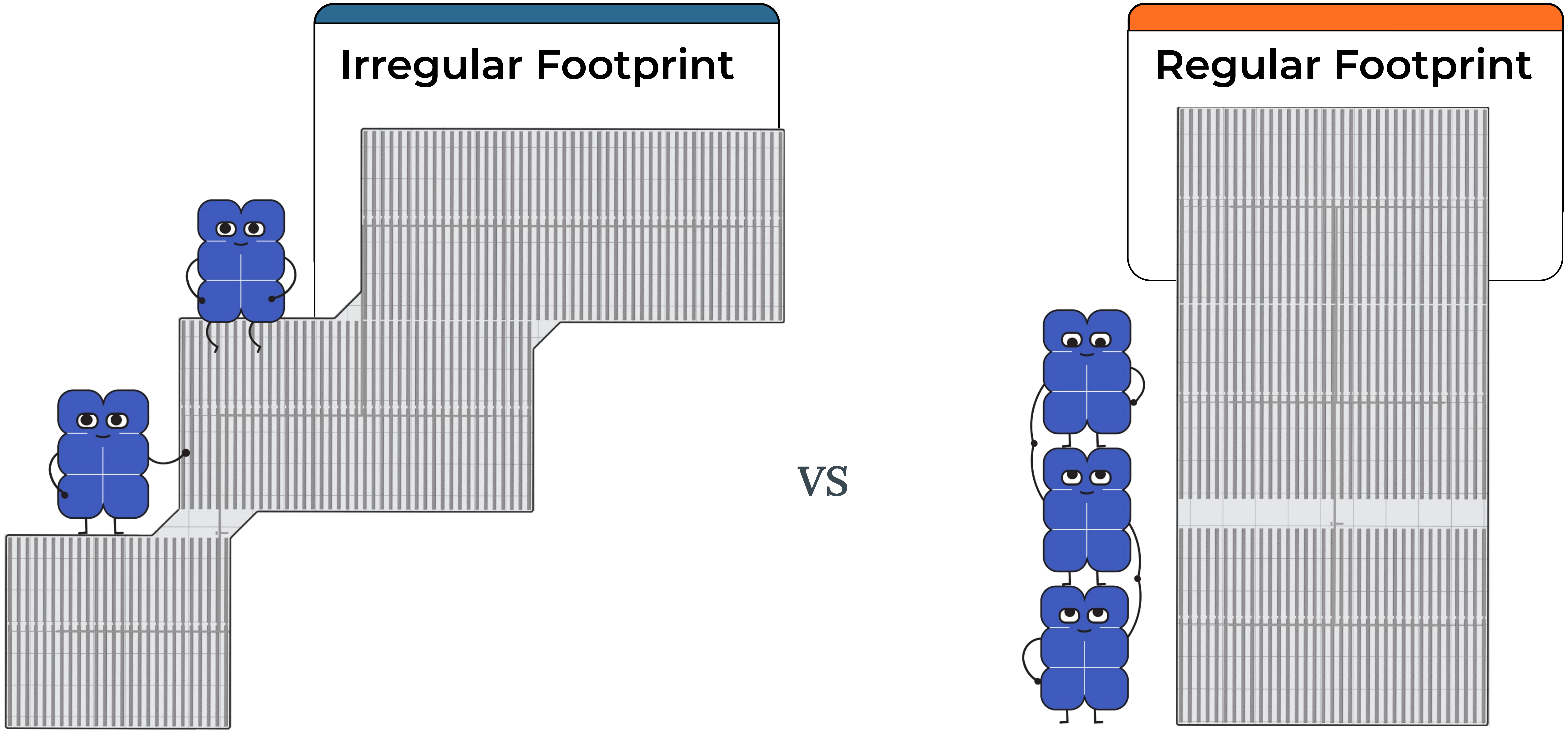
VS

Optimized for materials



11 Block Footprint

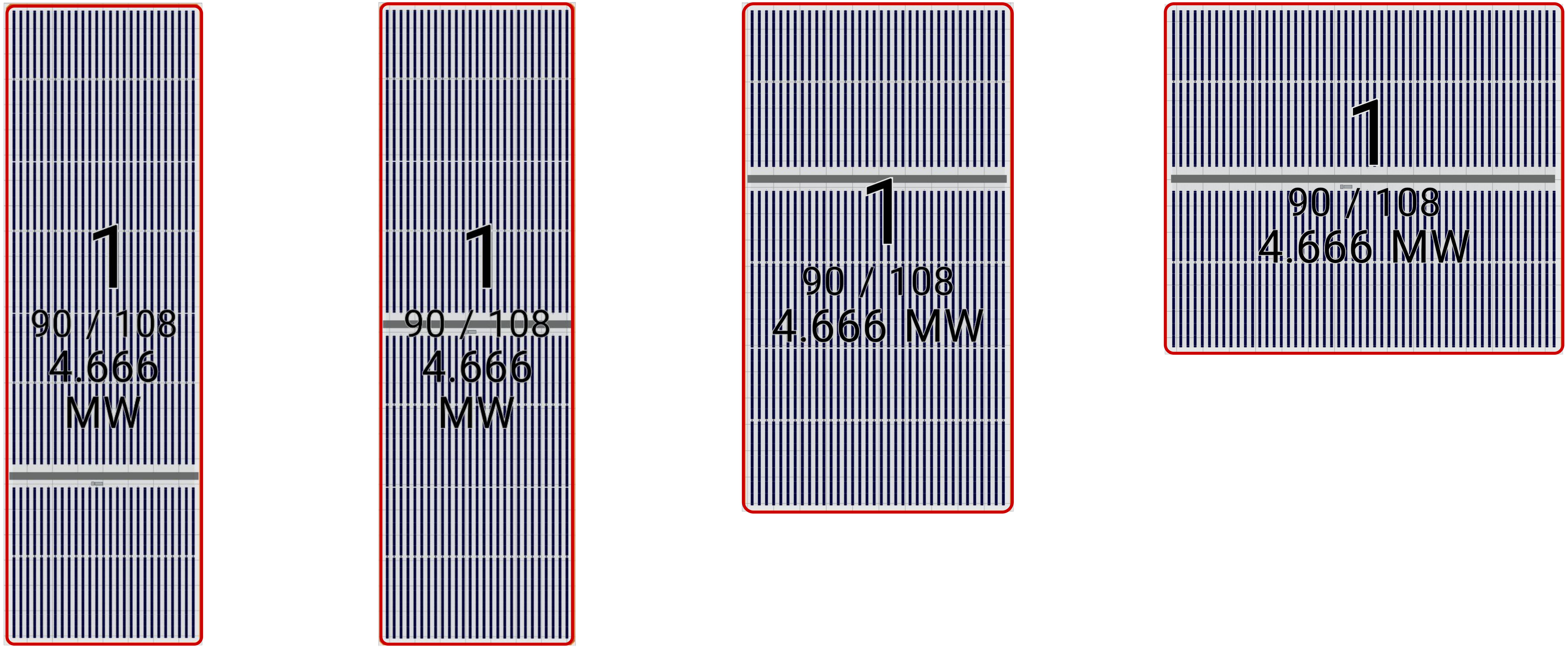
The fancier the block footprint, the more variation in wire lengths, gauges, and routing



12 Row Height

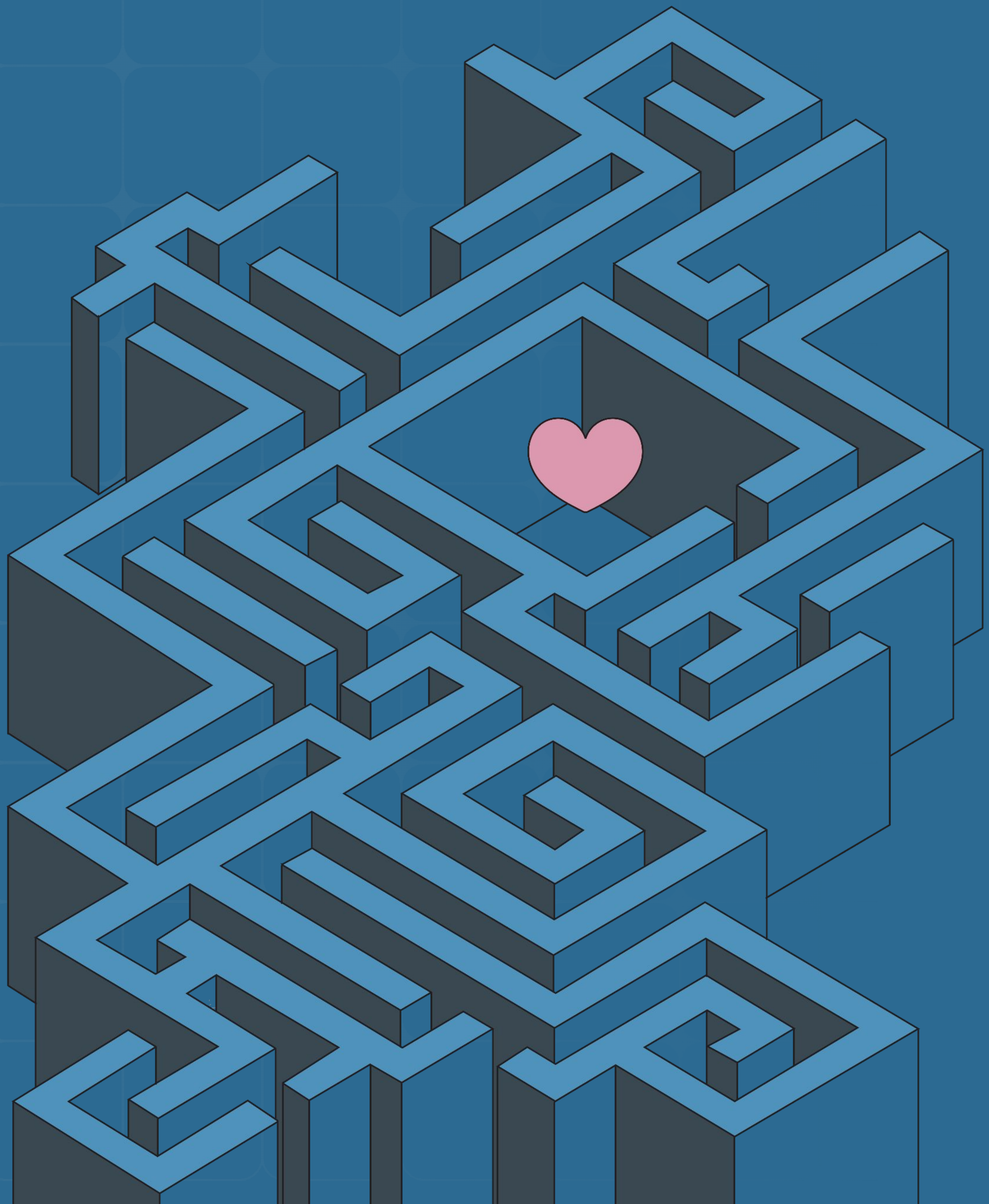
As a proxy for low voltage drop

Max RH = 3 | Max RH = 2 | Max RH = 2 | Max RH = 1



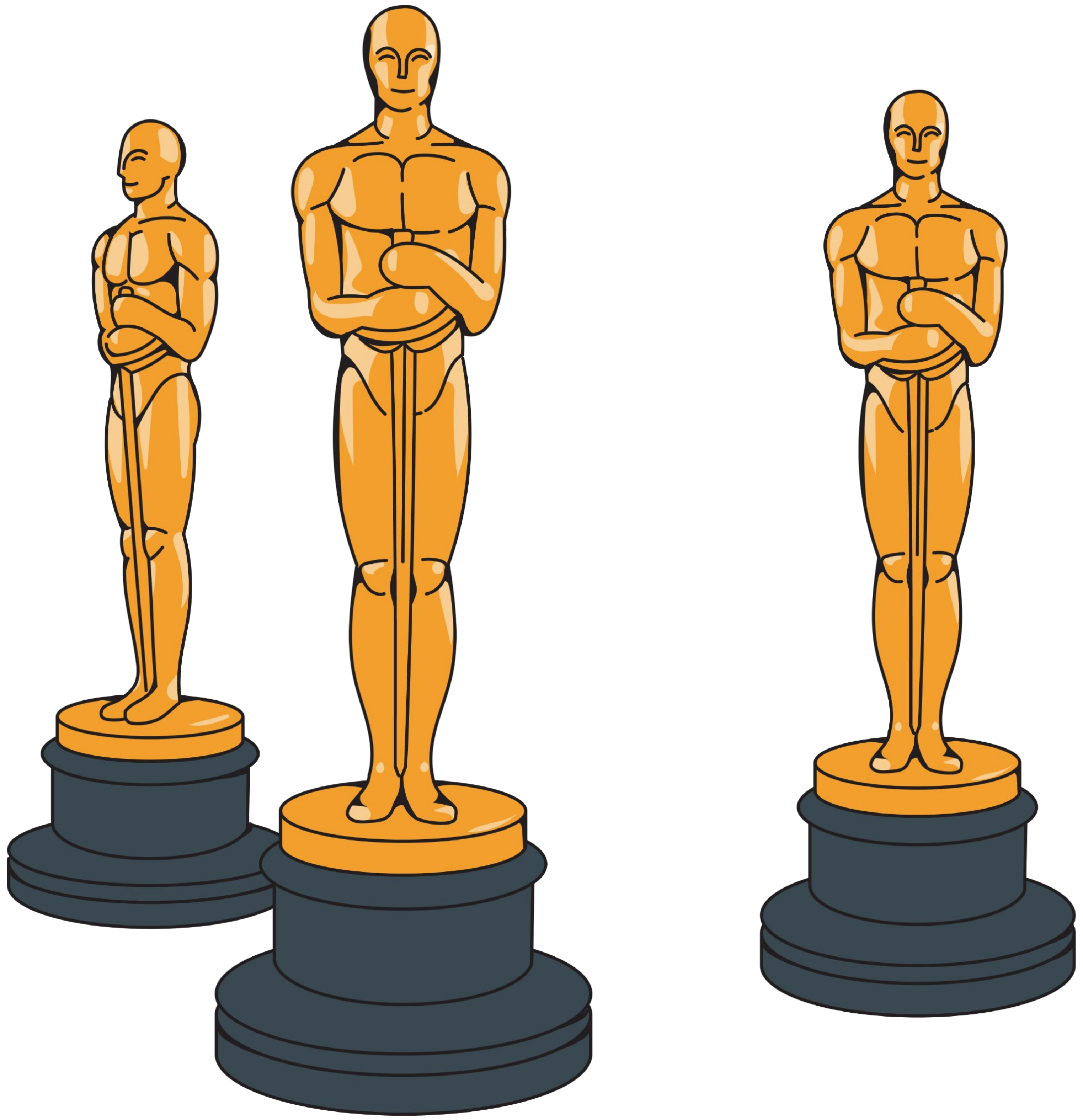
Prioritising Parameters

The essence of strategy is choosing what **NOT TO DO** ***at the early design phase***



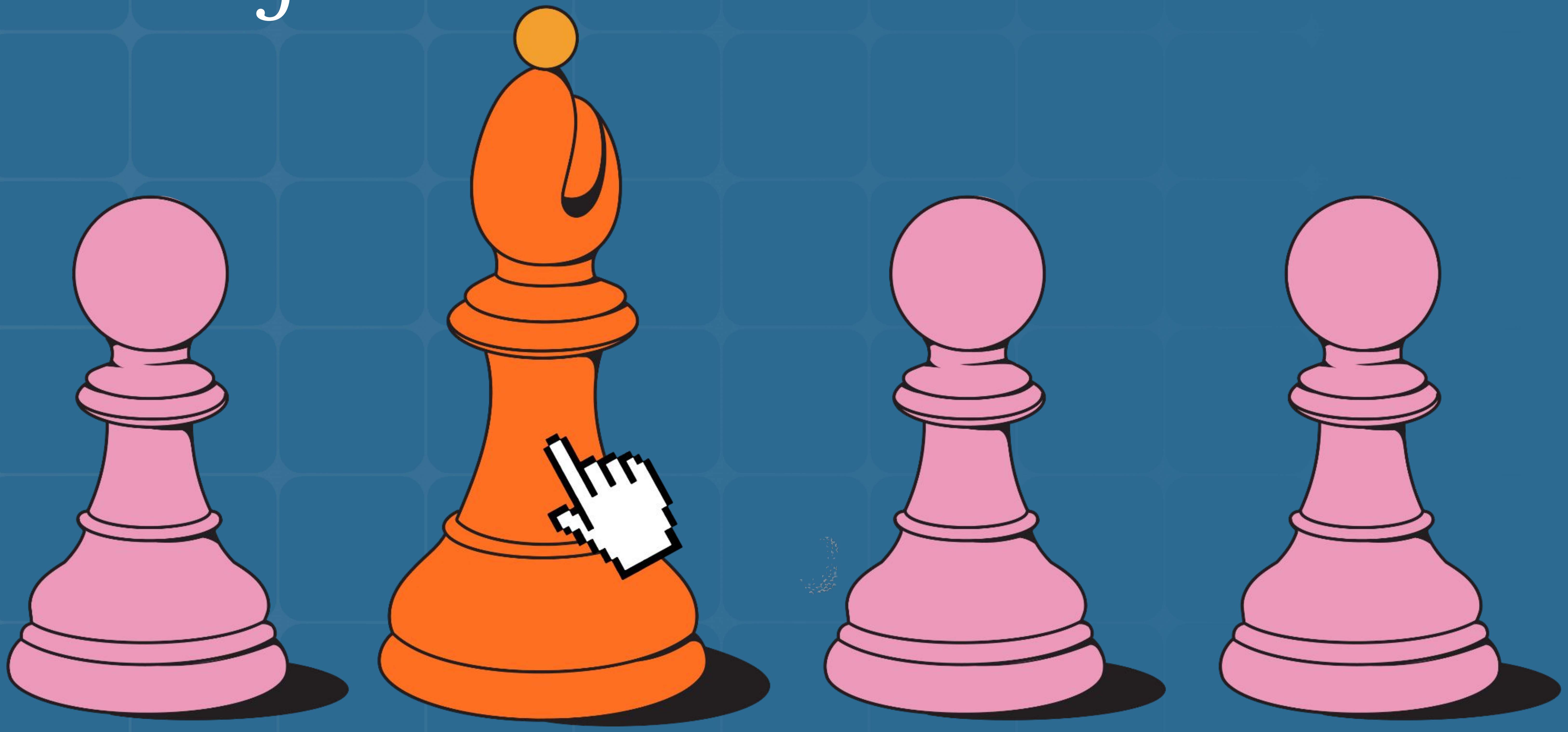
Grand Prix Evaluation Rules

Dimension	*Definition*
Cost Impact	How much this parameter influences total electrical system cost
Design Lock-In Risk	How hard it is to change this decision later in the design/construction
System Interaction	How many other design elements this parameter affects or constrains



Defining Cost Impact

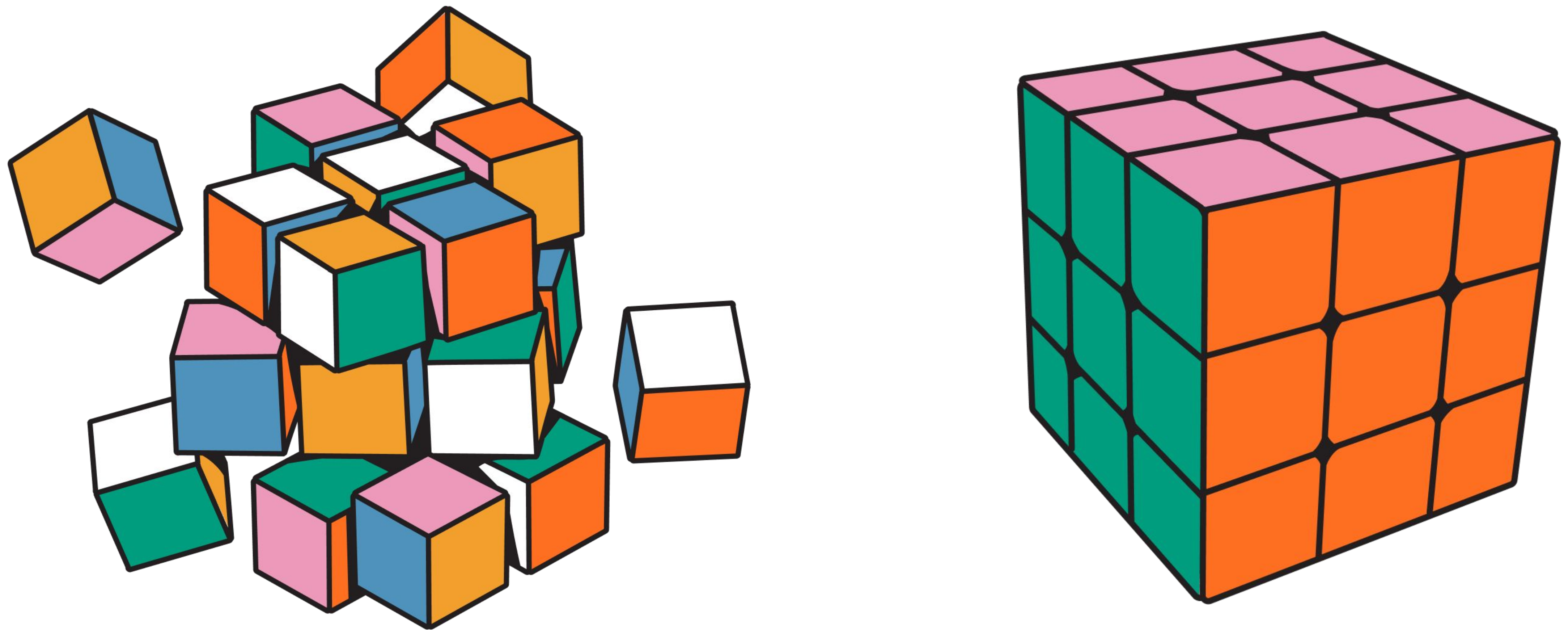
Two tests walk into a lab...
only the variable changed!

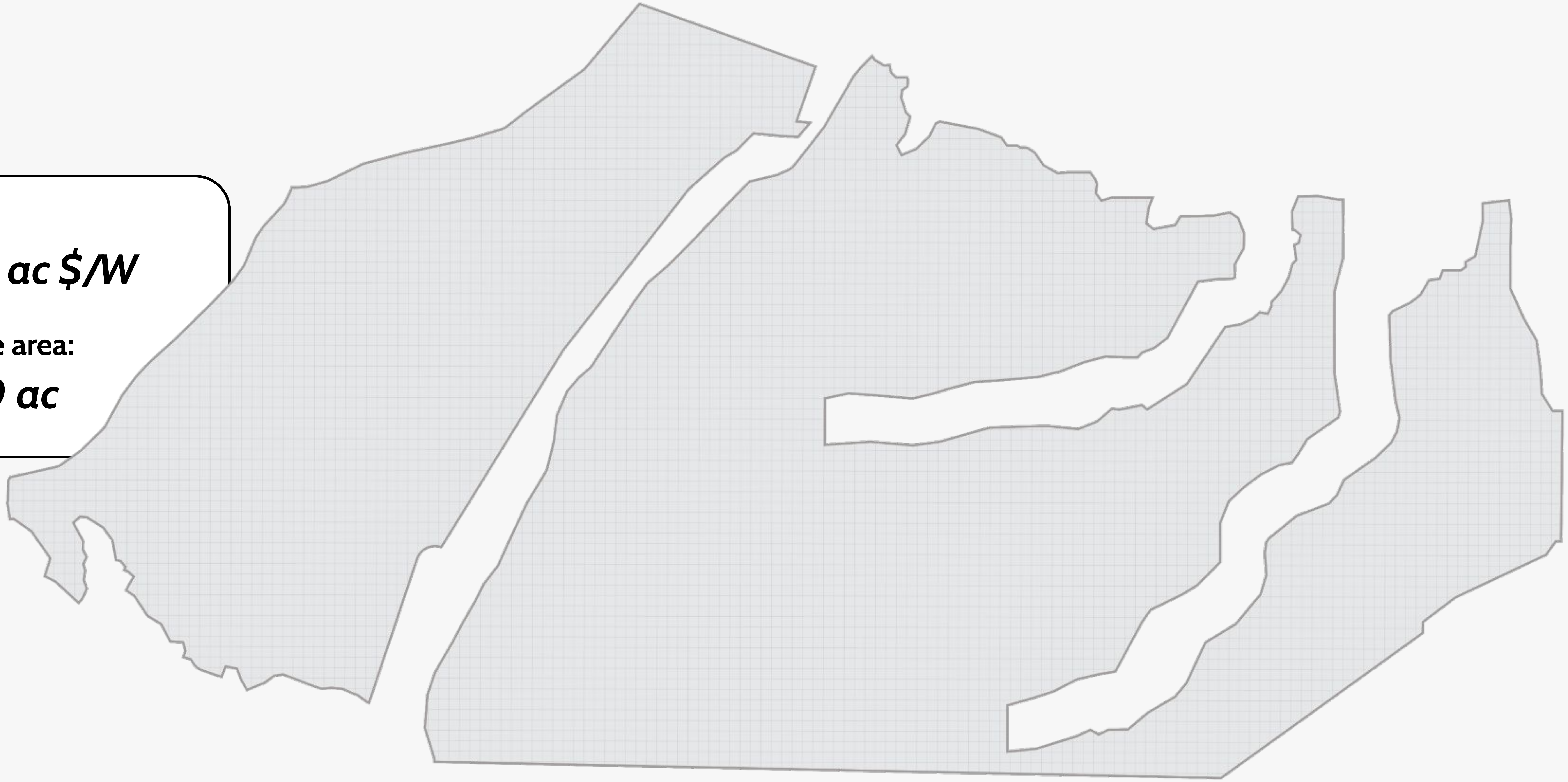


Controlled Comparison Method

Strengthens decision-making by avoiding misleading correlations

1. Lock all other variables and run best vs worst (or A vs B) scenarios for that parameter
2. Normalize the result to $/W or $ impact per MW
3. Measure impact





Site area:
657.57 ac $/W

Buildable area:
653.50 ac

Tracker 84 mods

PV Module 540W

CBX 300A

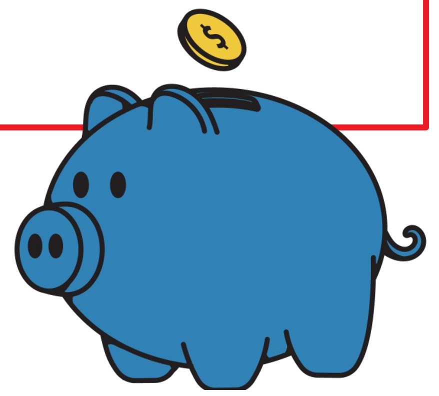
CBX 600A

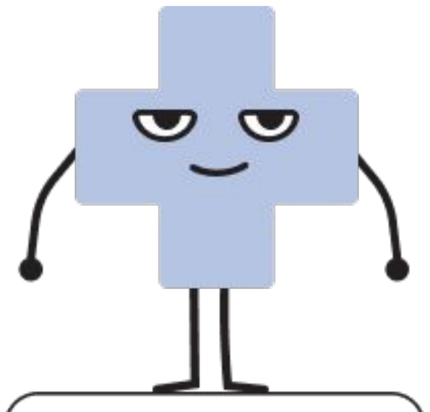
Inverter
840; 4200

Inverter Type

Central vs String

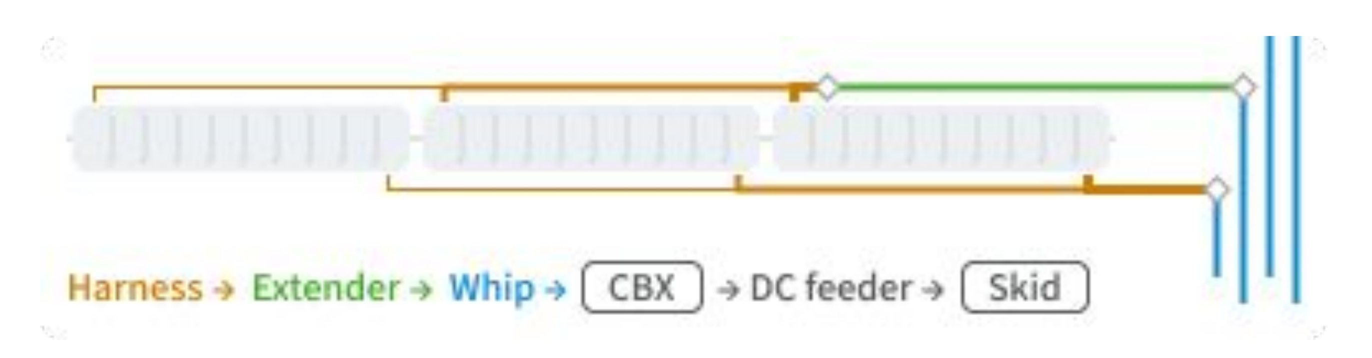
Using String Inverter lowers EBOS by **1.25%**
$0.2M saved





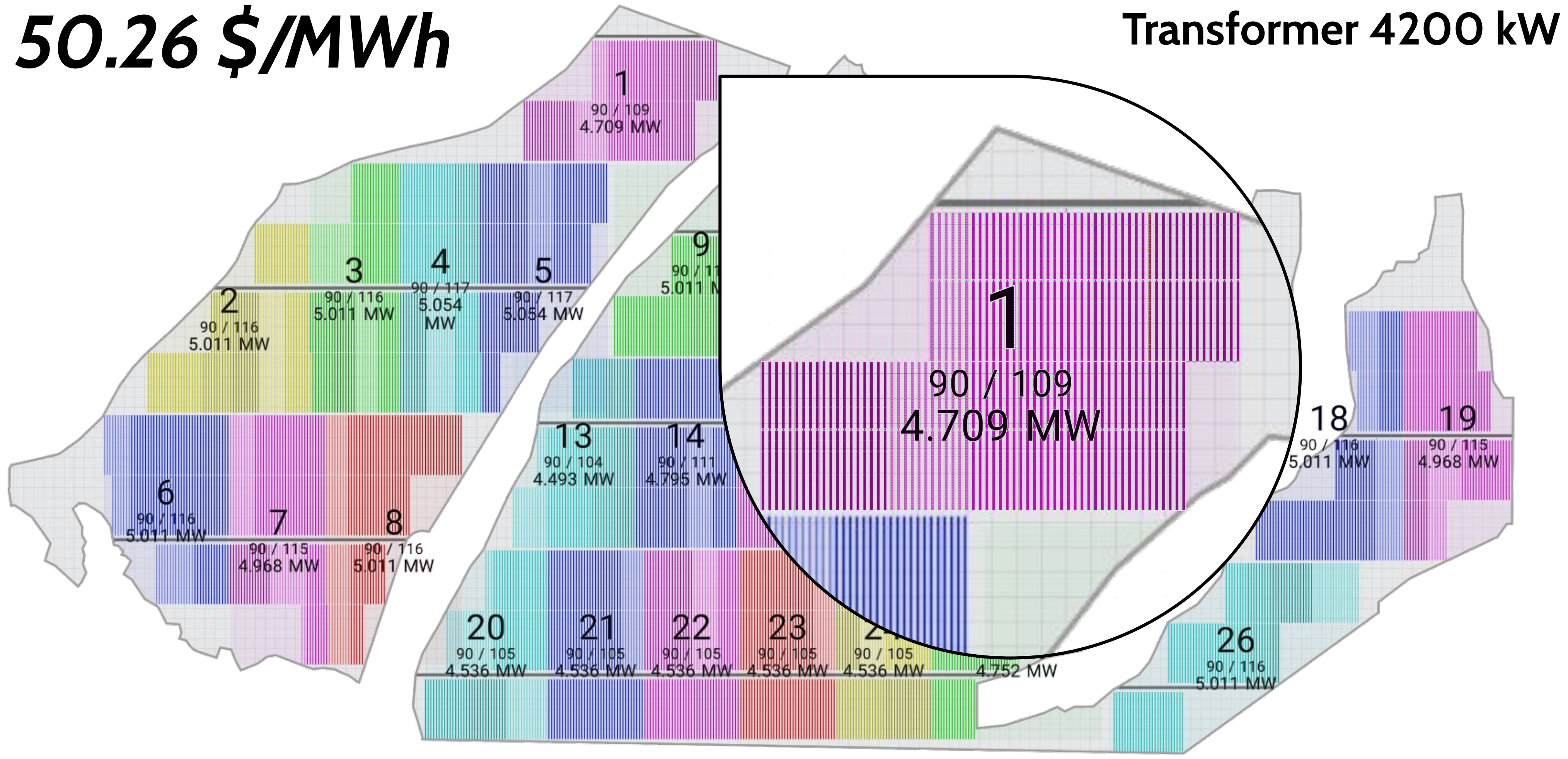
Central Inverter

Electrical CAPEX:
0.1288 $/W

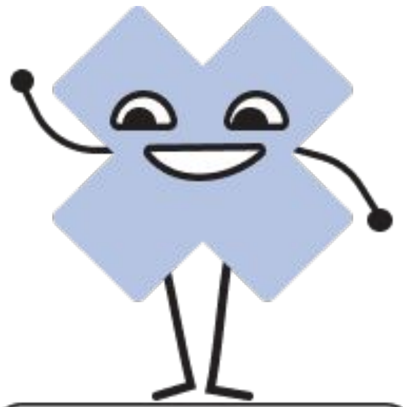


LCOE, $/MWh:
50.26 $/MWh

Inverter 4200kVA
Transformer 4200 kW

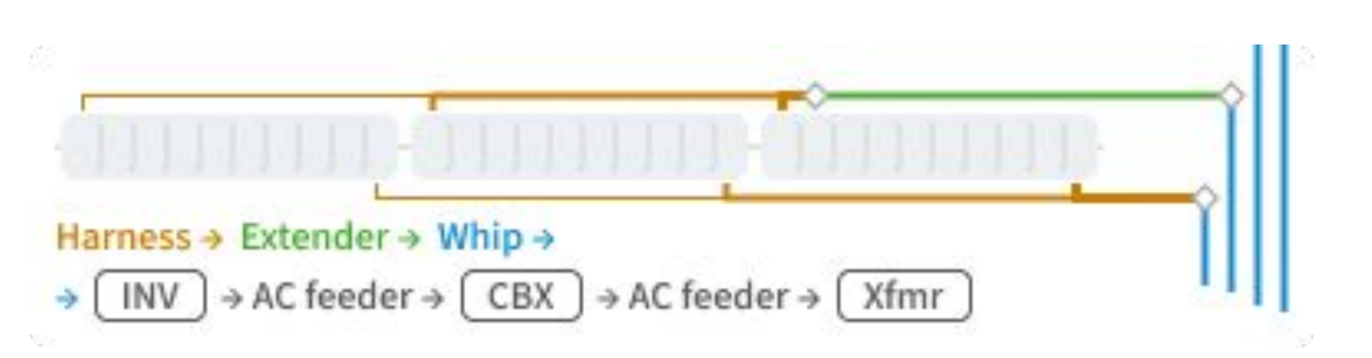


VS



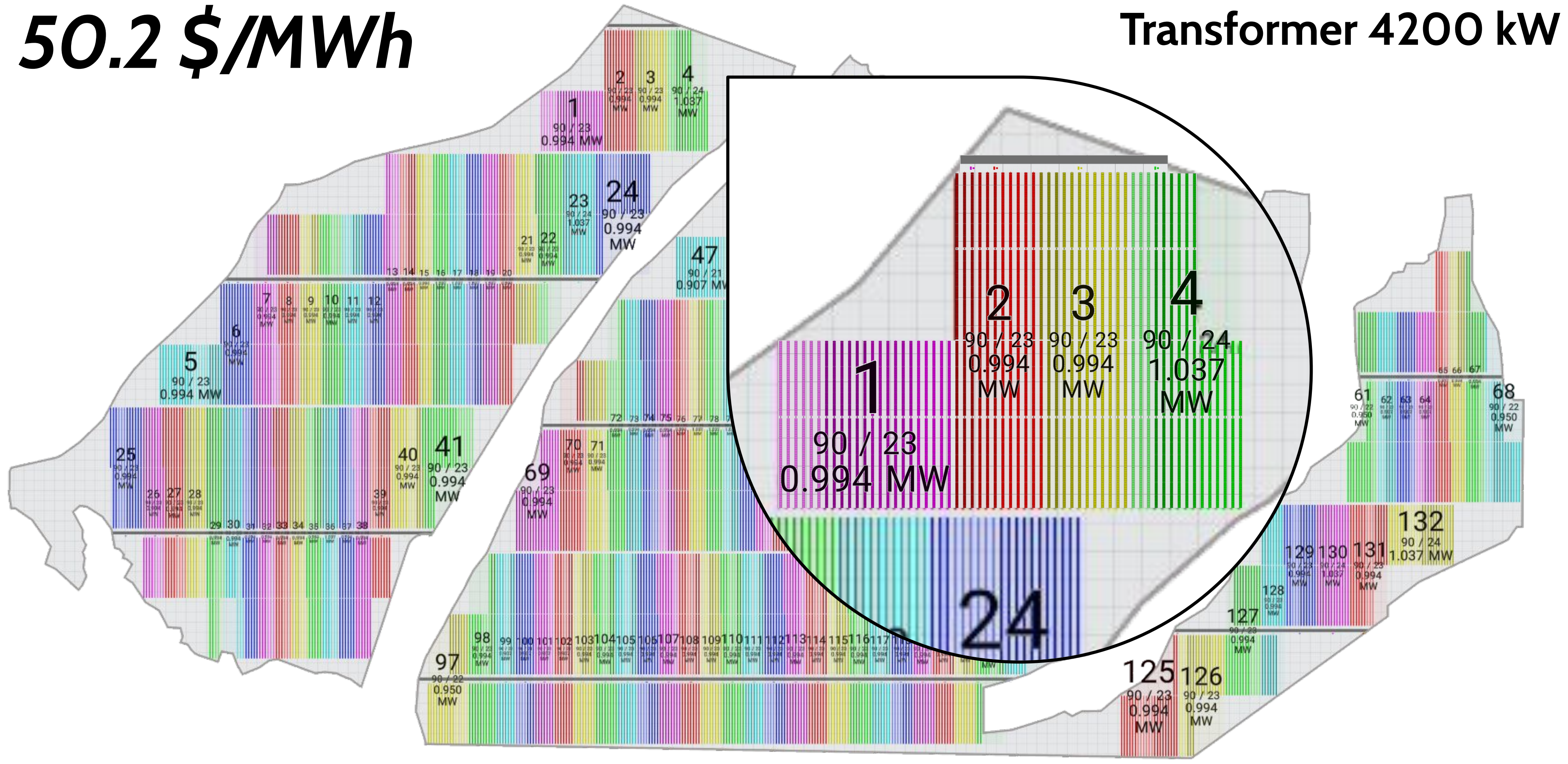
String Inverter

Electrical CAPEX:
0.1272 $/W



LCOE, $/MWh:
50.2 $/MWh

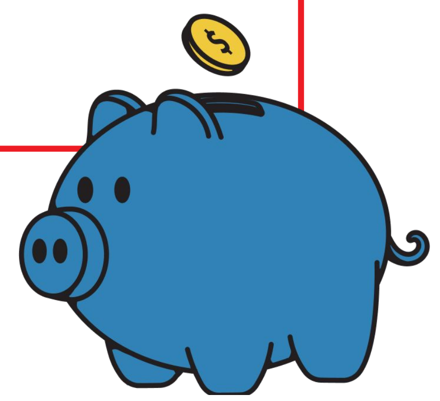
Inverter 840kVA
Transformer 4200 kW



Inverter Power

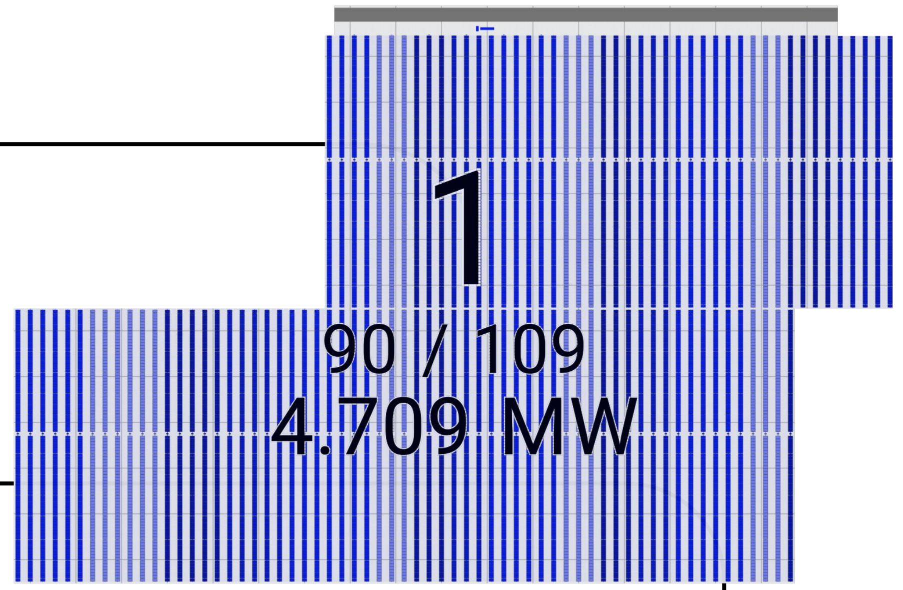
With a lower inverter power rating, electrical costs are reduced because the total length of DC feeders is shorter. In large blocks, some combiner boxes are located far from the central inverter, which requires long DC feeder runs. At the same time, the lengths of the Harness, Extender, and Whip do not depend on the inverter capacity, since the combiner group size is the same in both cases.

Using Inverter 840 lowers EBOS by **3.2%**
$0.54M saved

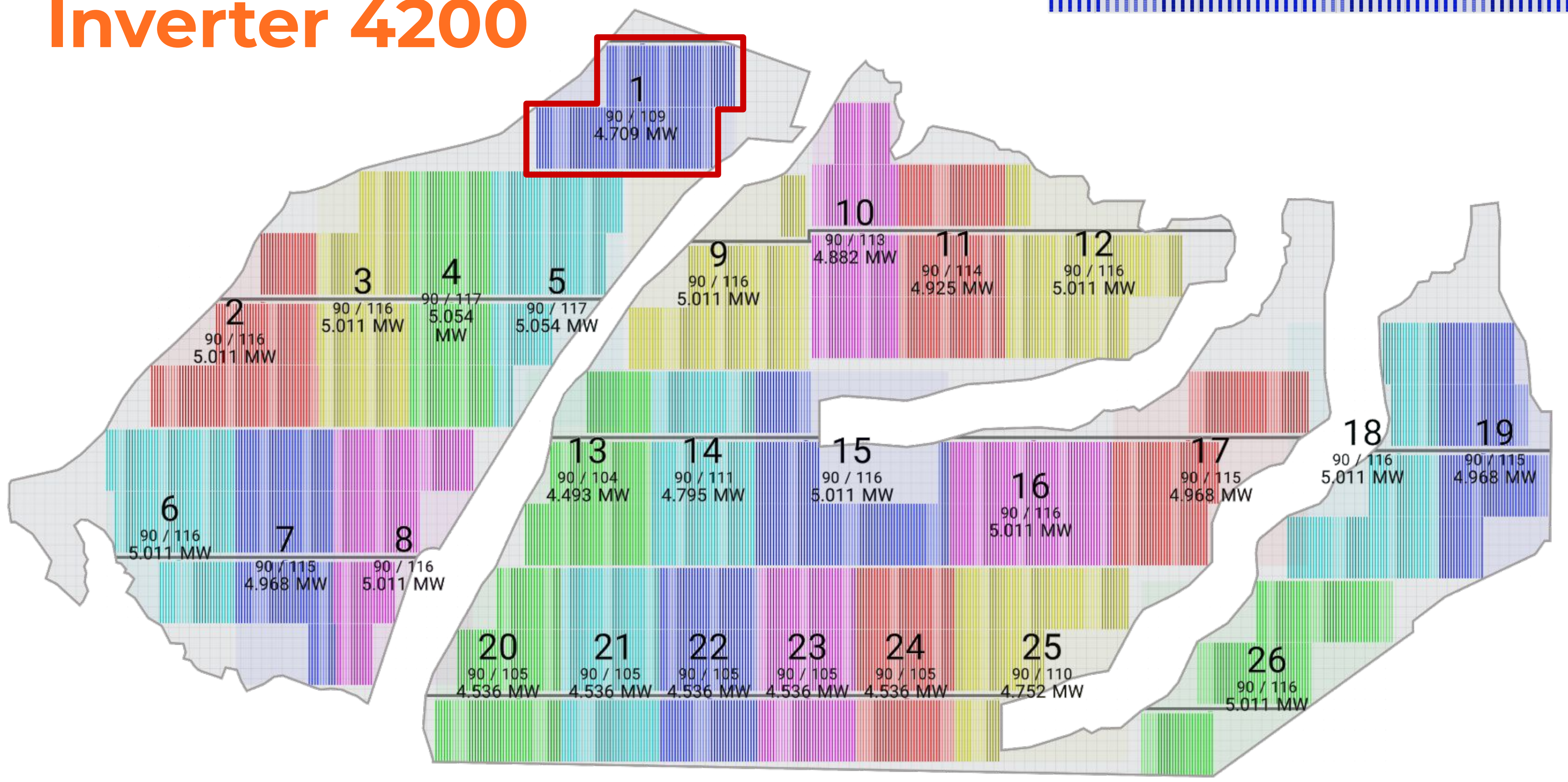


Electrical CAPEX: ***0.1331 $/W***

LCOE, $/MWh: ***52.08 $/MWh***



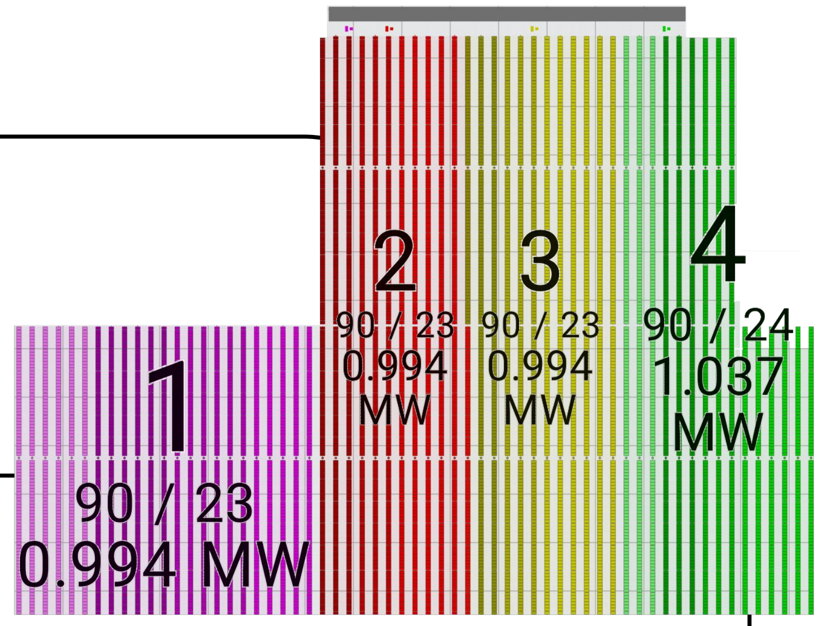
Inverter 4200



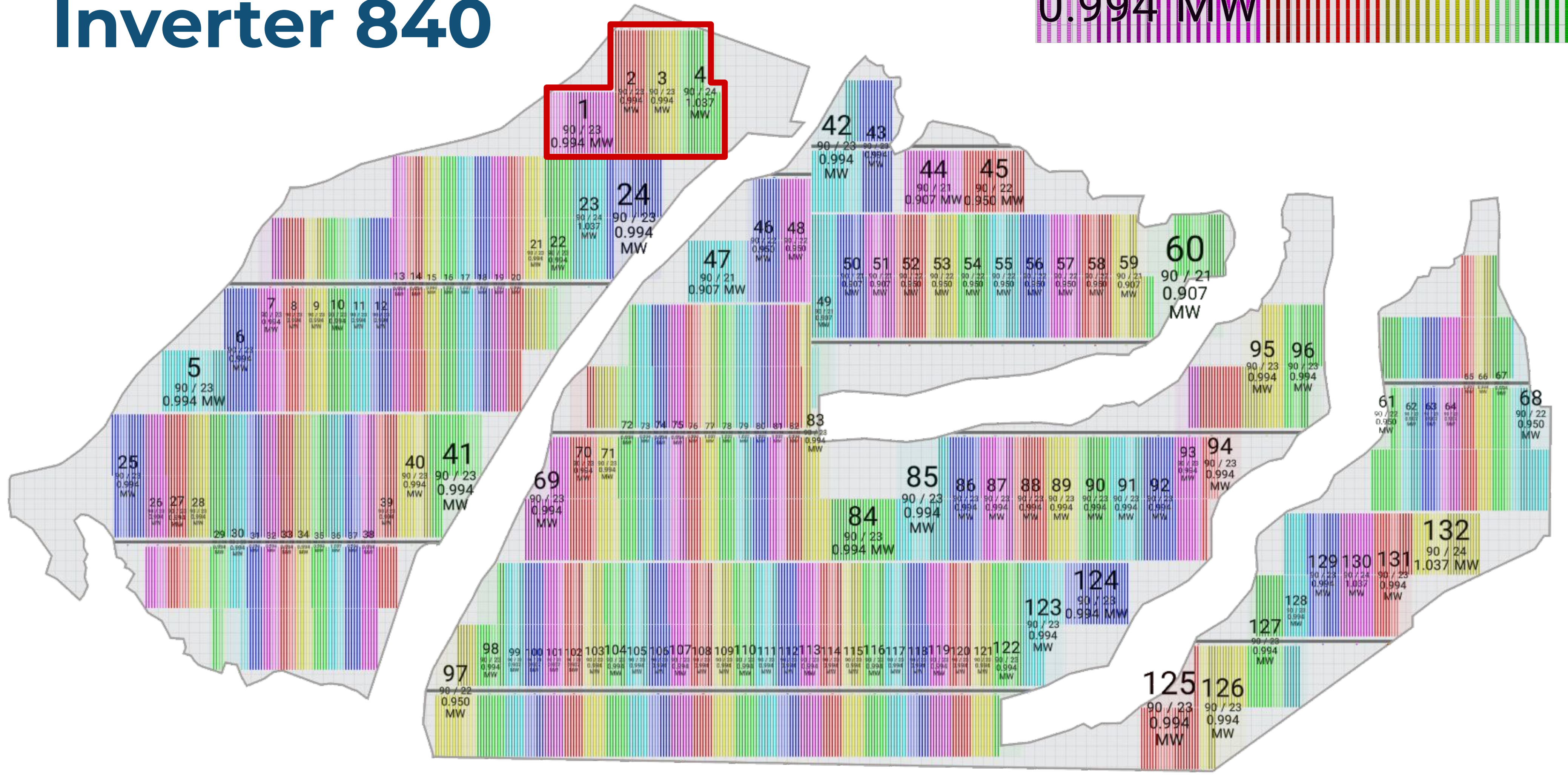
VS

Electrical CAPEX: ***0.1288 $/W***

LCOE, $/MWh: ***50.26 $/MWh***

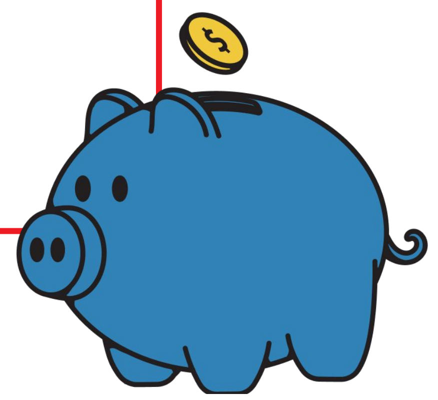


Inverter 840



PV Module Type

Using Monocrystalline lowers EBOS by **28.4%**
$6.08M saved



Monocrystalline

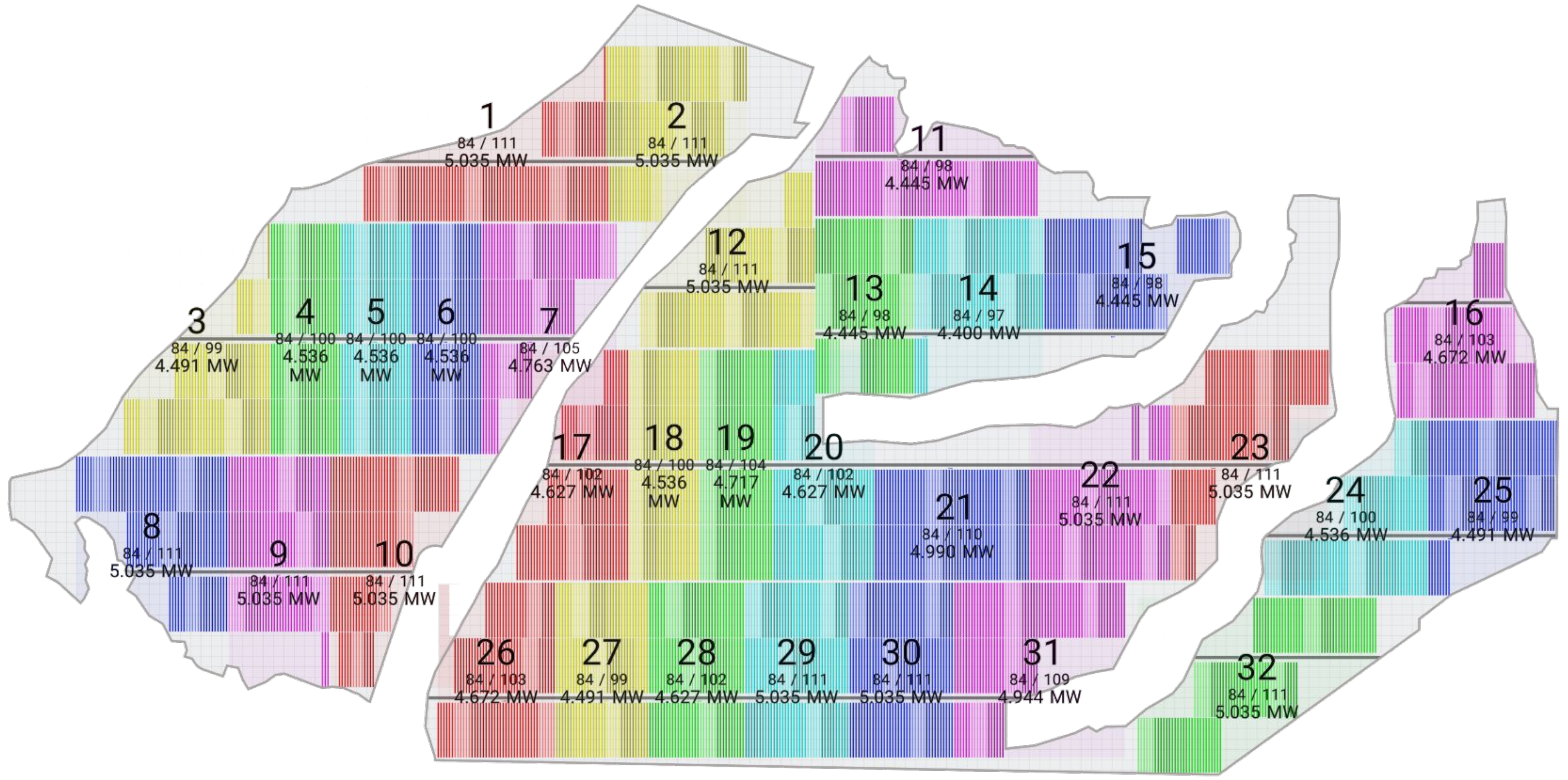
Canadian Solar
String size: *27 mods*
Total: *54 mods*
21.9kW tracker power

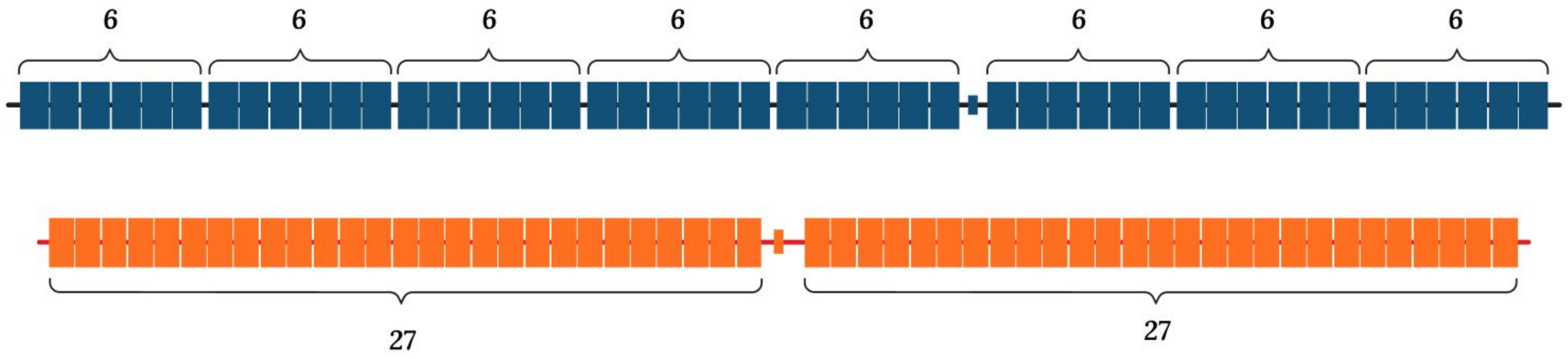
Electrical CAPEX:
0.1213 $/W
LCOE, $/MWh:
48.52 $/MWh

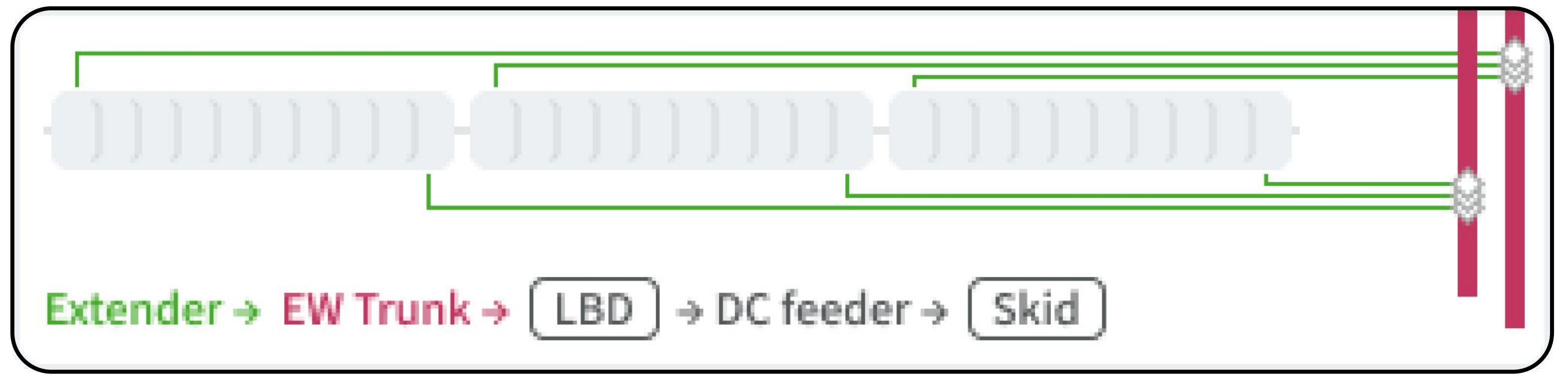
Thin-Film

First Solar
String size: *6 mods*
Total: *54 mods*
23.2kW tracker power

Electrical CAPEX:
0.1694 $/W
LCOE, $/MWh:
50.74 $/MWh

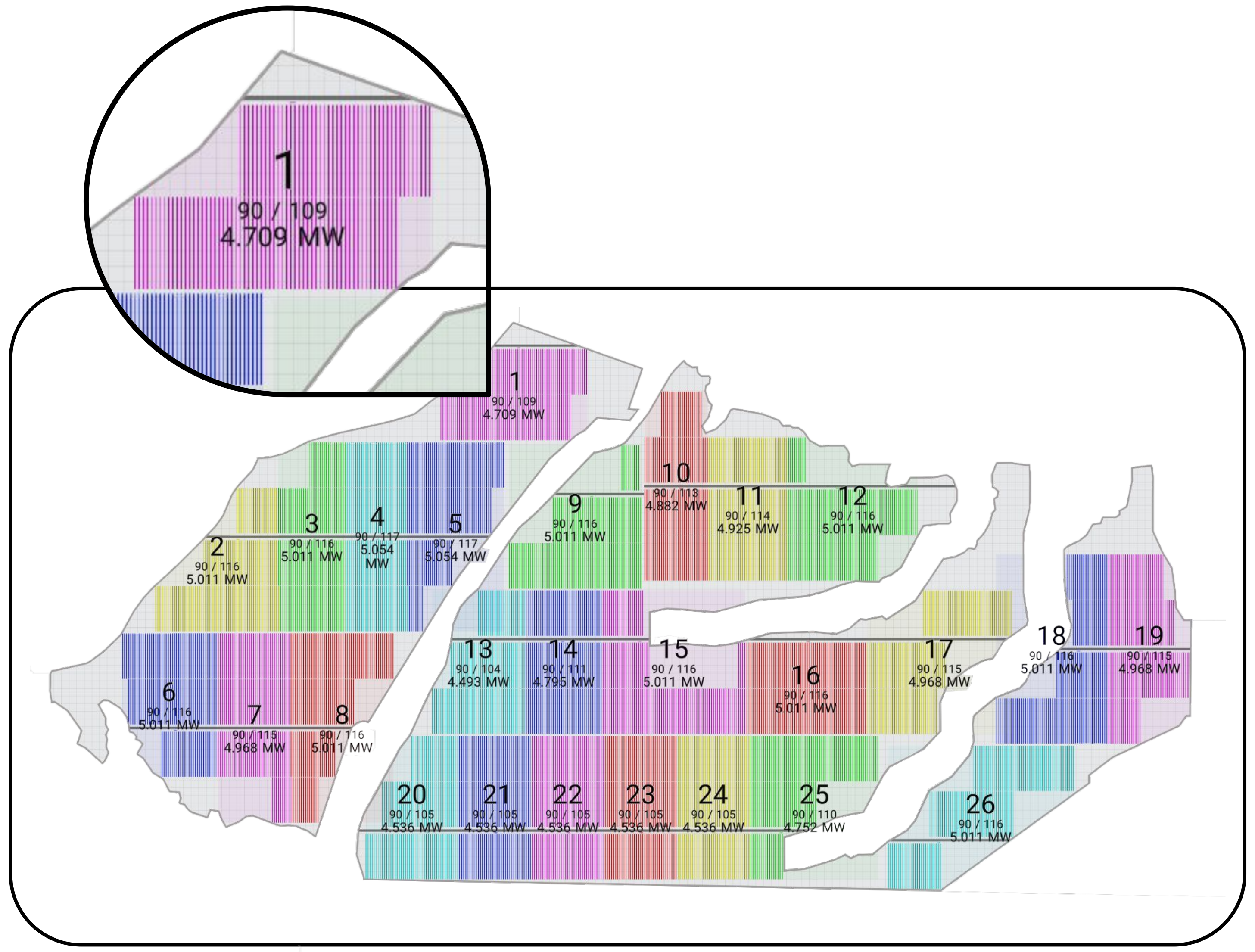




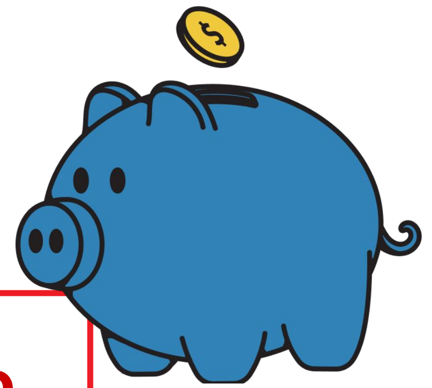


CBX/LBD Ampacity

Affects conductor type/size, termination complexity, and layout adaptability



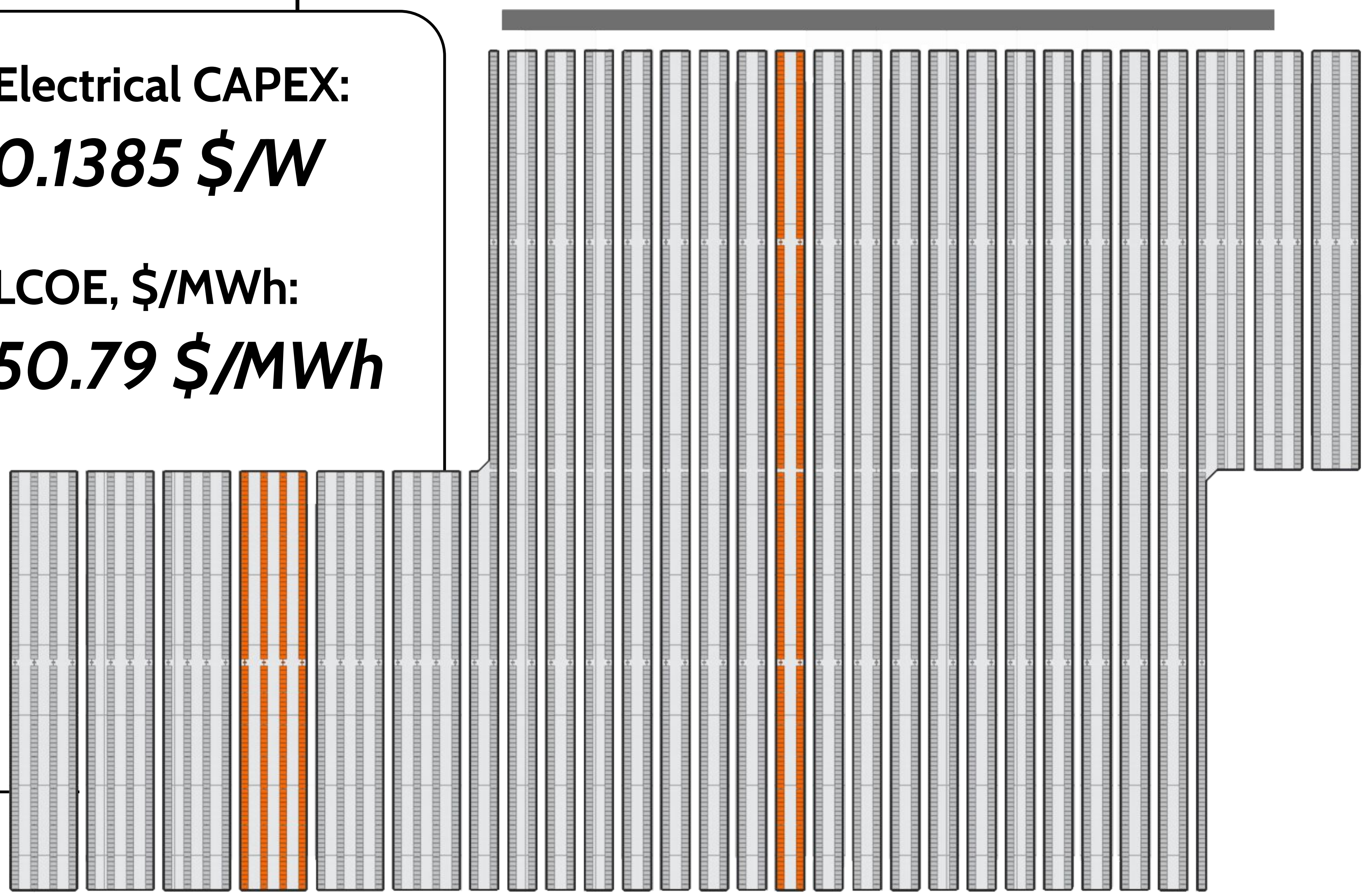
Using 600A lowers EBOS by **5.6%**
$0.98M saved



300A

Electrical CAPEX:
0.1385 $/W

LCOE, $/MWh:
50.79 $/MWh

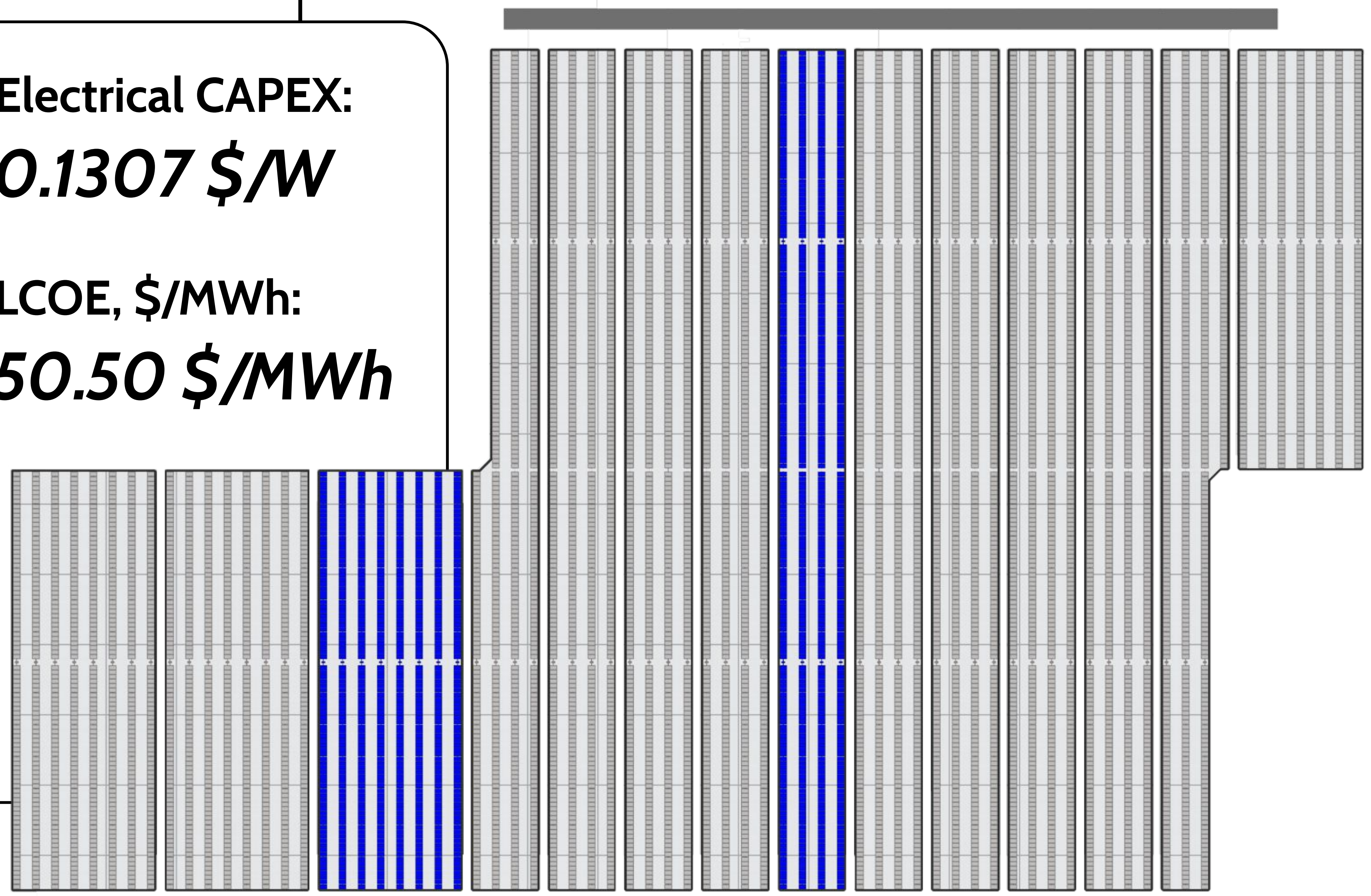


VS

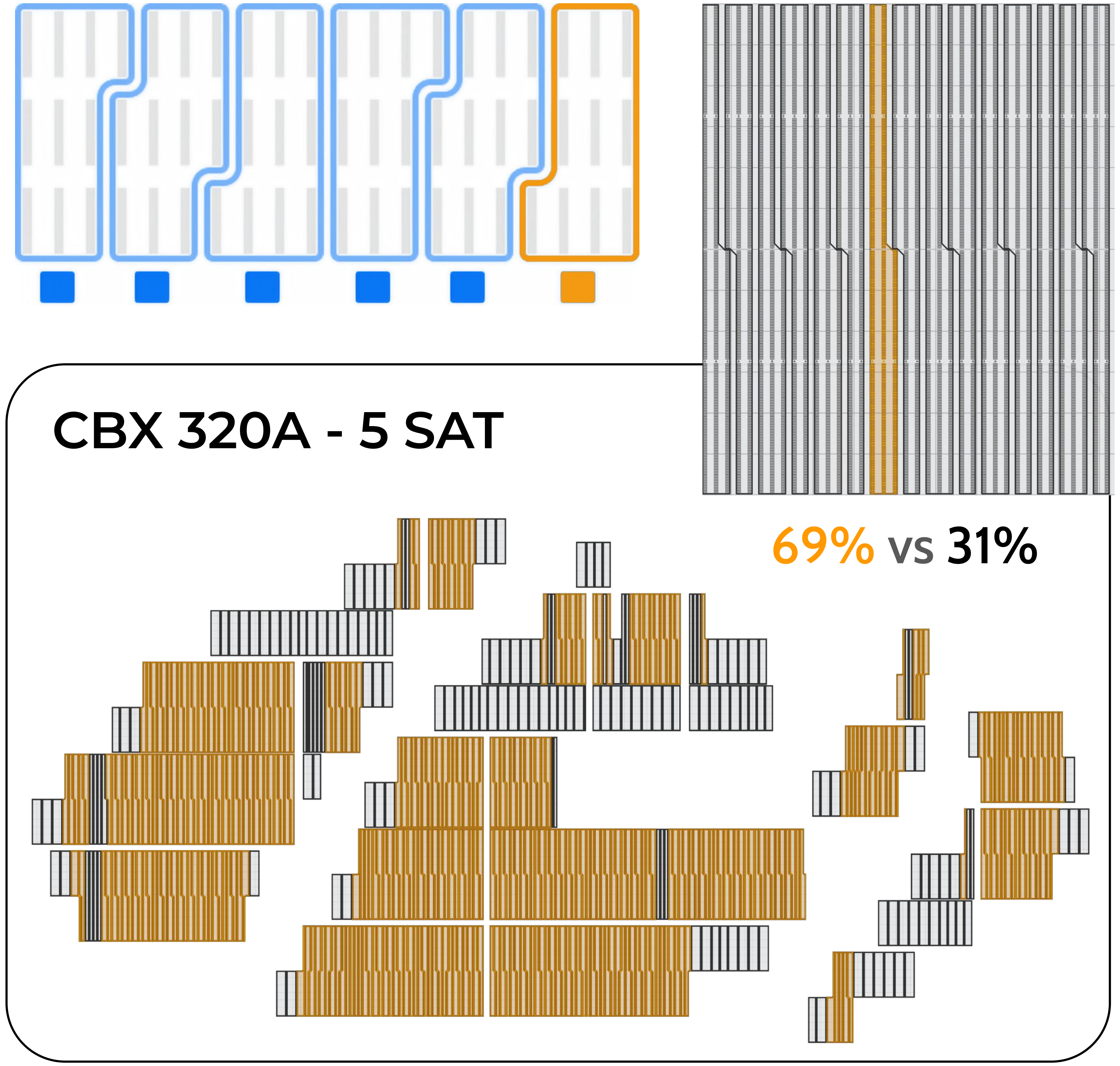
600A

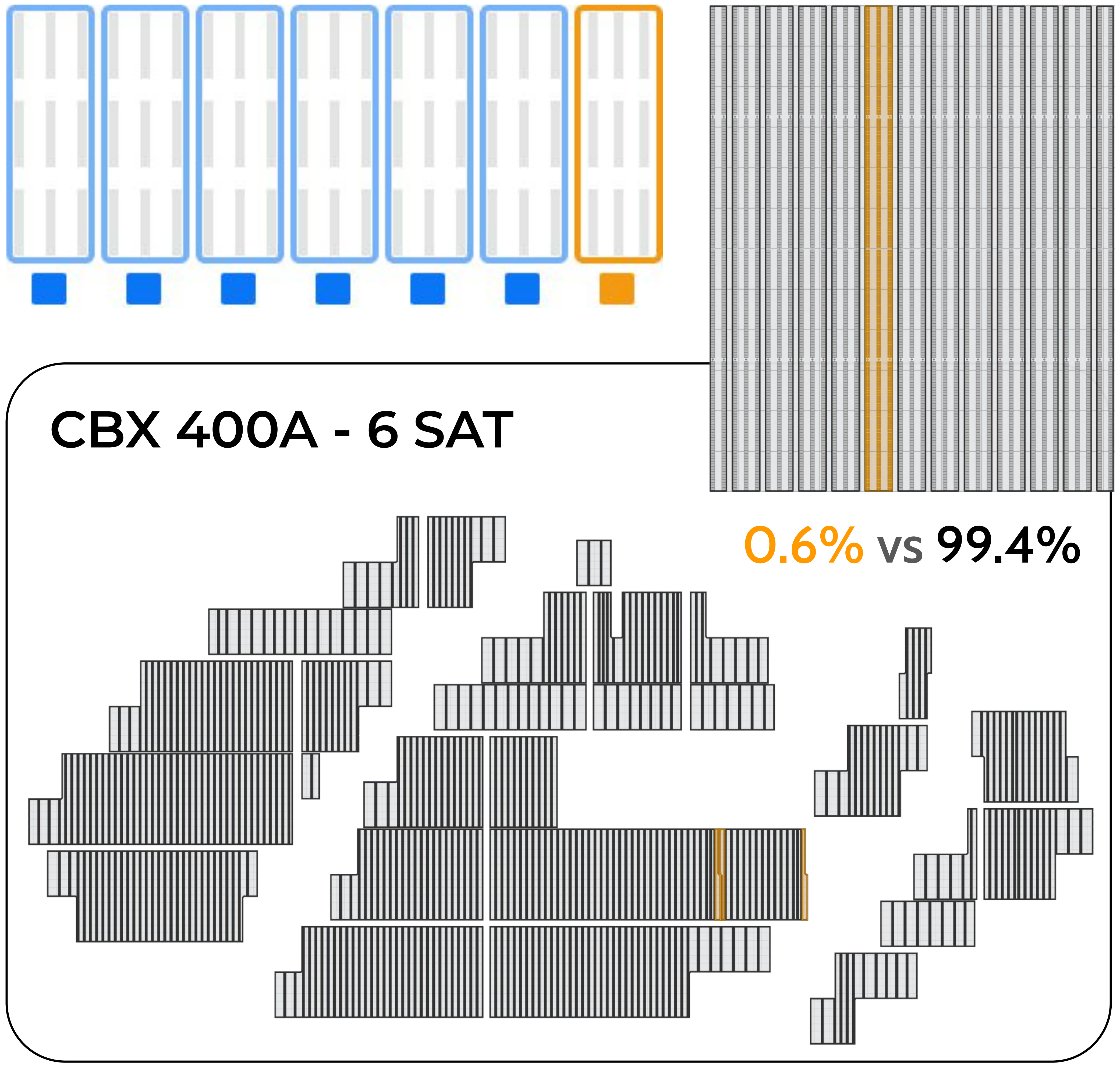
Electrical CAPEX:
0.1307 $/W

LCOE, $/MWh:
50.50 $/MWh

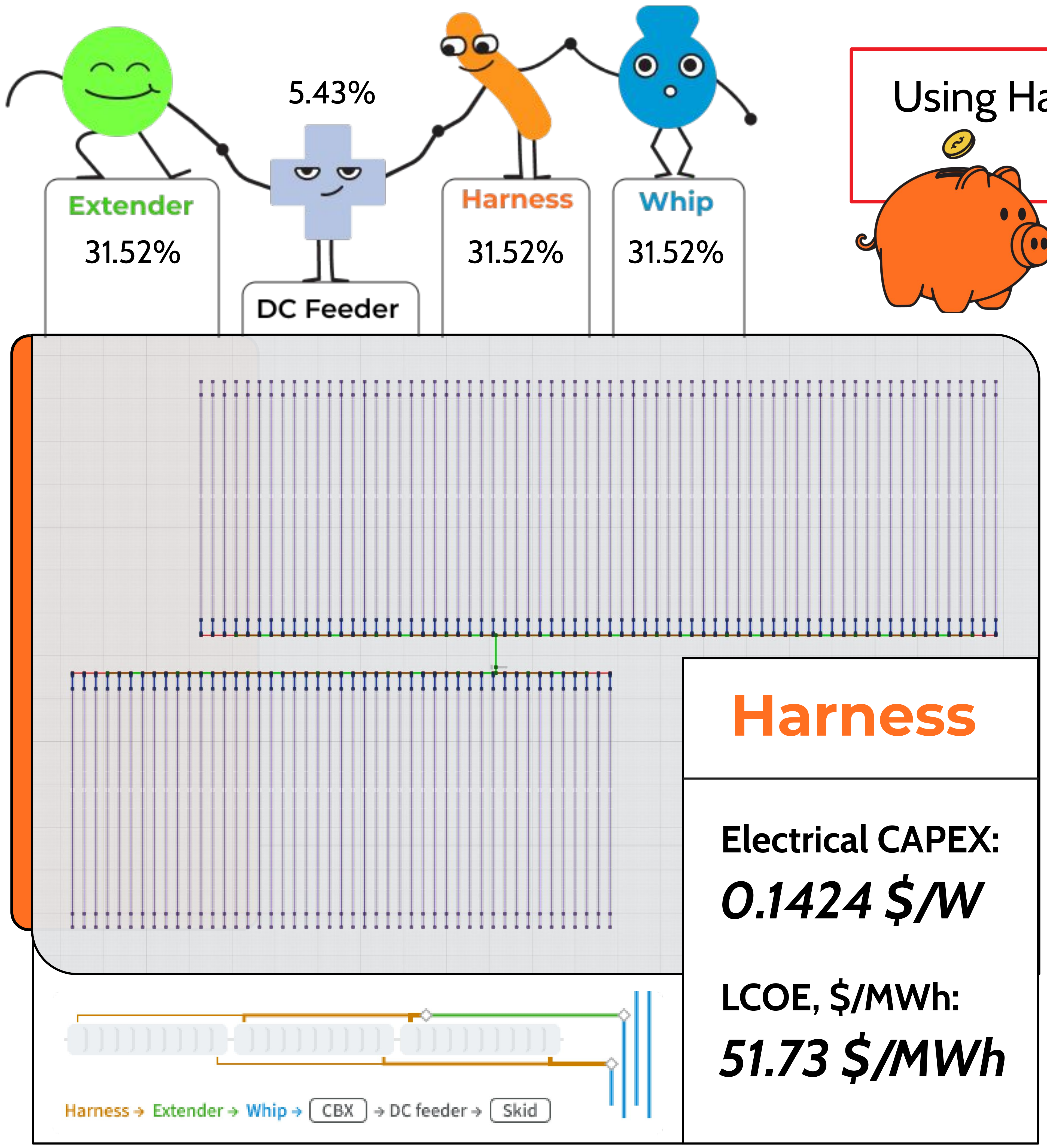


Optimised for Load vs Buildability



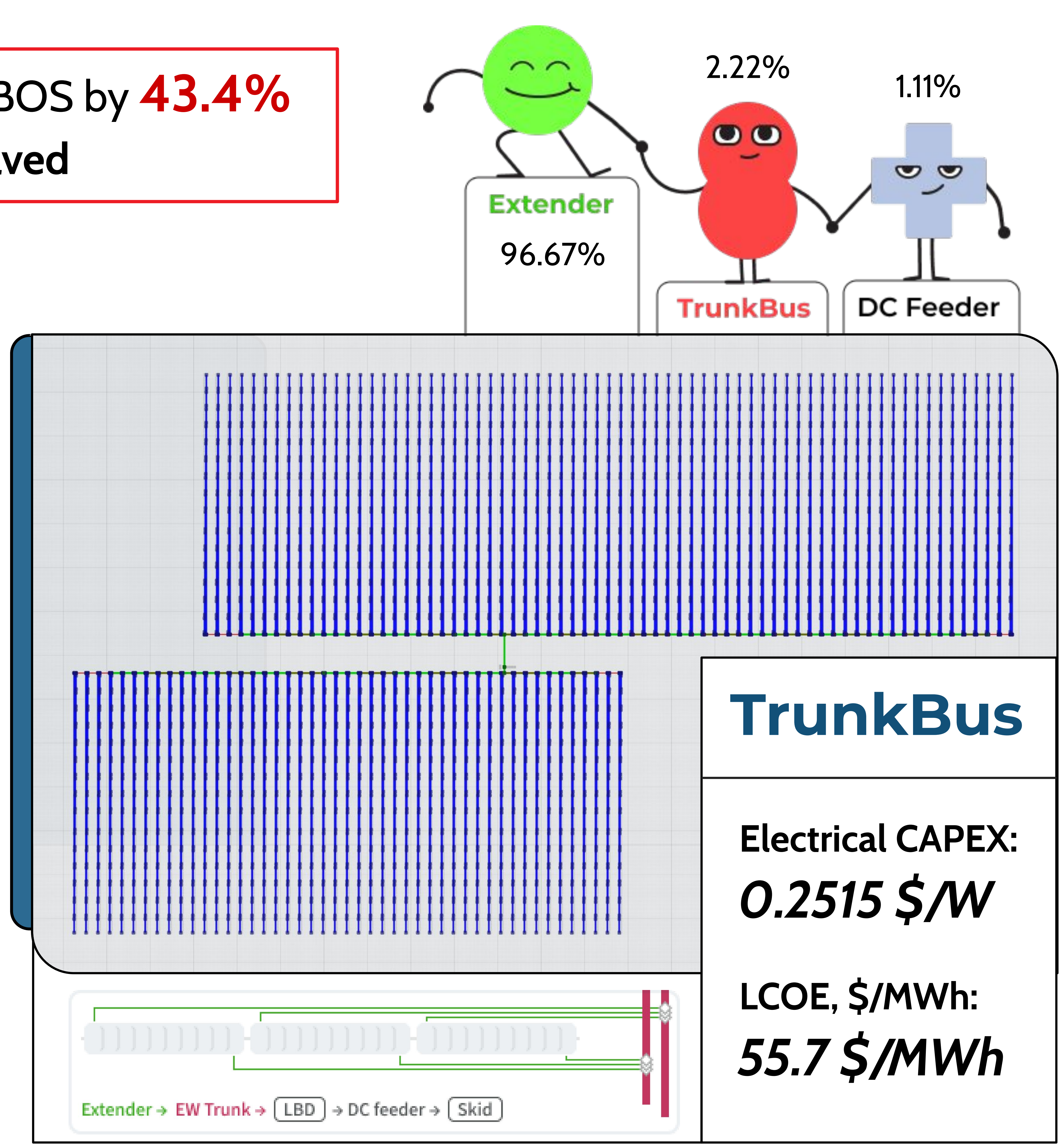


Wire Sequence



Using Harness lowers EBOS by **43.4%**
$13.8M saved

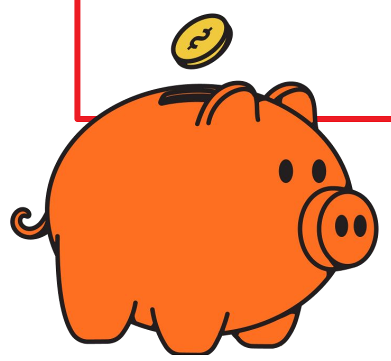
VS



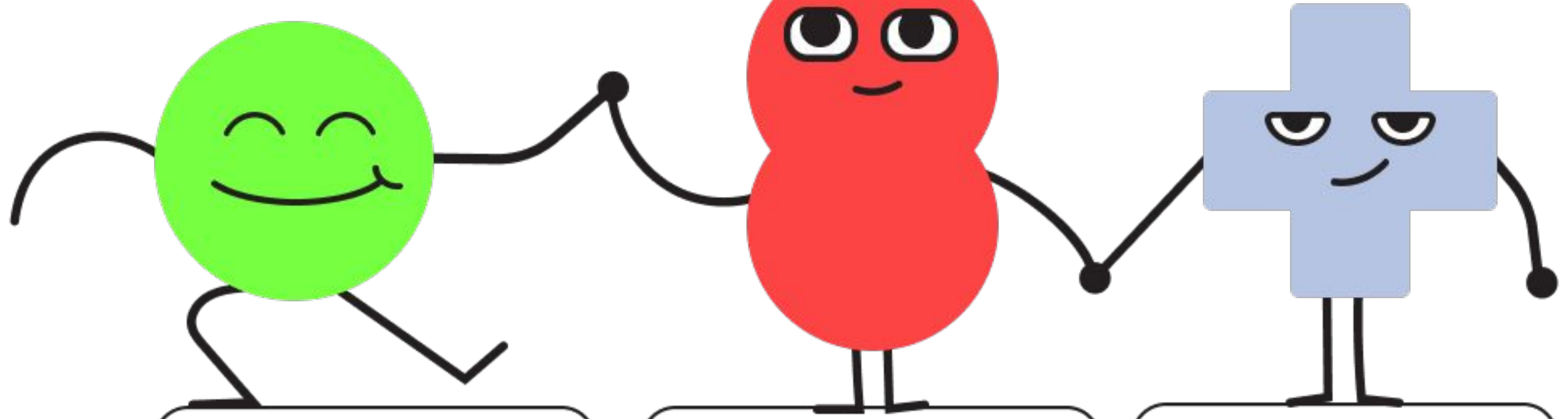
CBX/LBD Position

Middle of Row (MoR)
vs End of row (EoR)

Using MoR lowers EBOS by **28.1%**
$9.18M saved



750 kcmil | 350 kcmil | #10 AWG

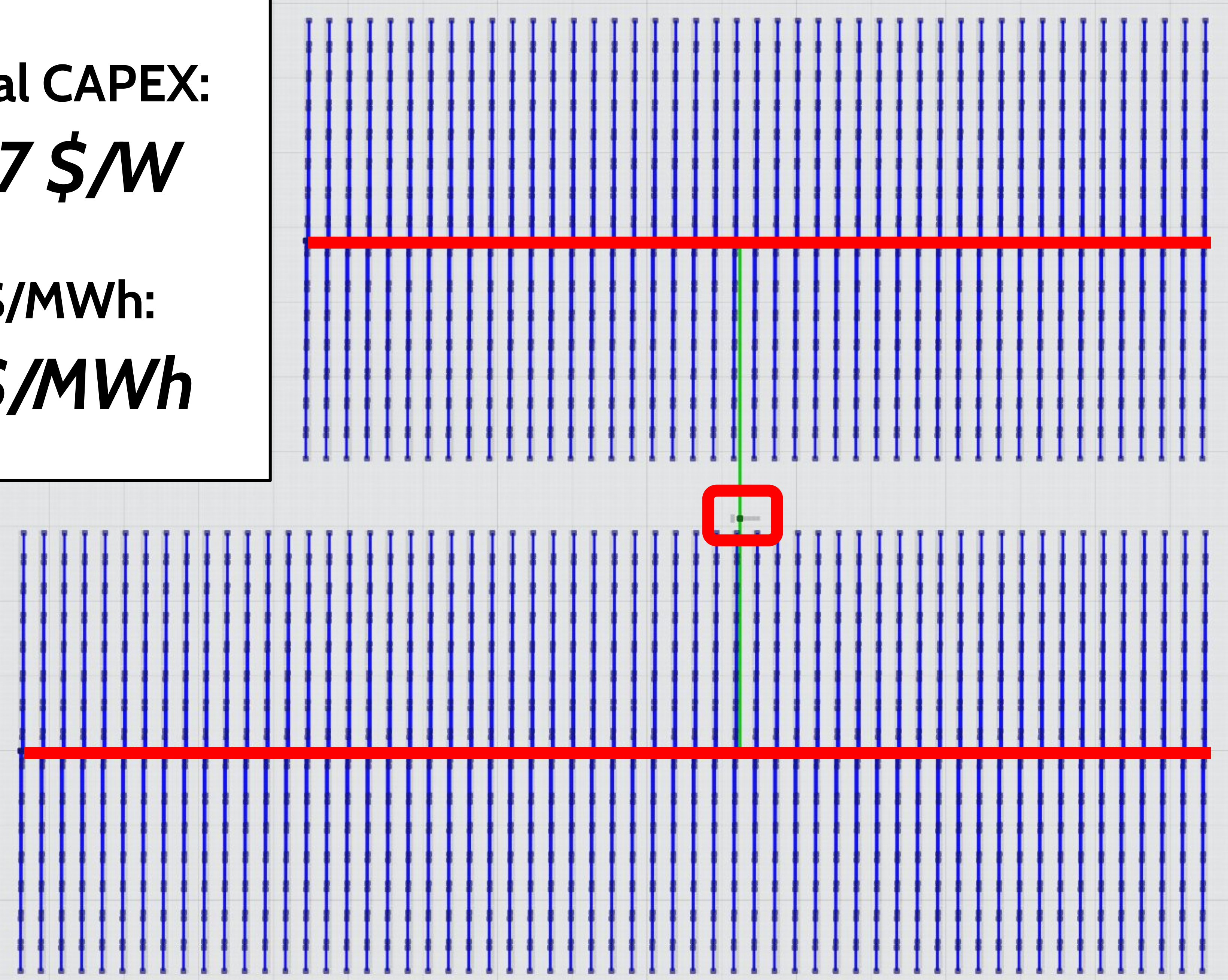


Extender | TrunkBus | DC Feeder

MoR

Electrical CAPEX:
0.1857 $/W

LCOE, $/MWh:
53.3 $/MWh

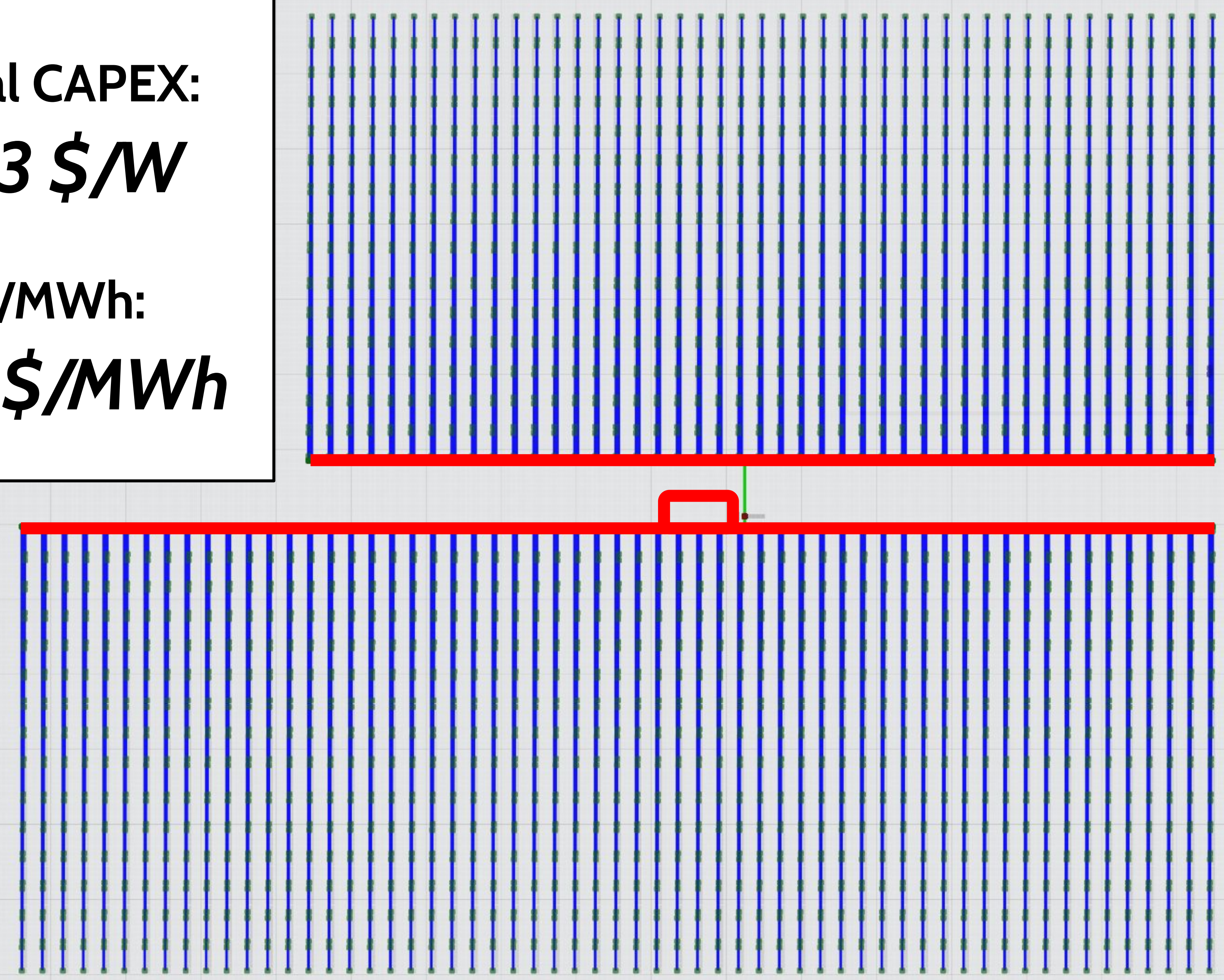


VS

EoR

Electrical CAPEX:
0.2583 $/W

LCOE, $/MWh:
55.94 $/MWh



CBX/LBD Clustering

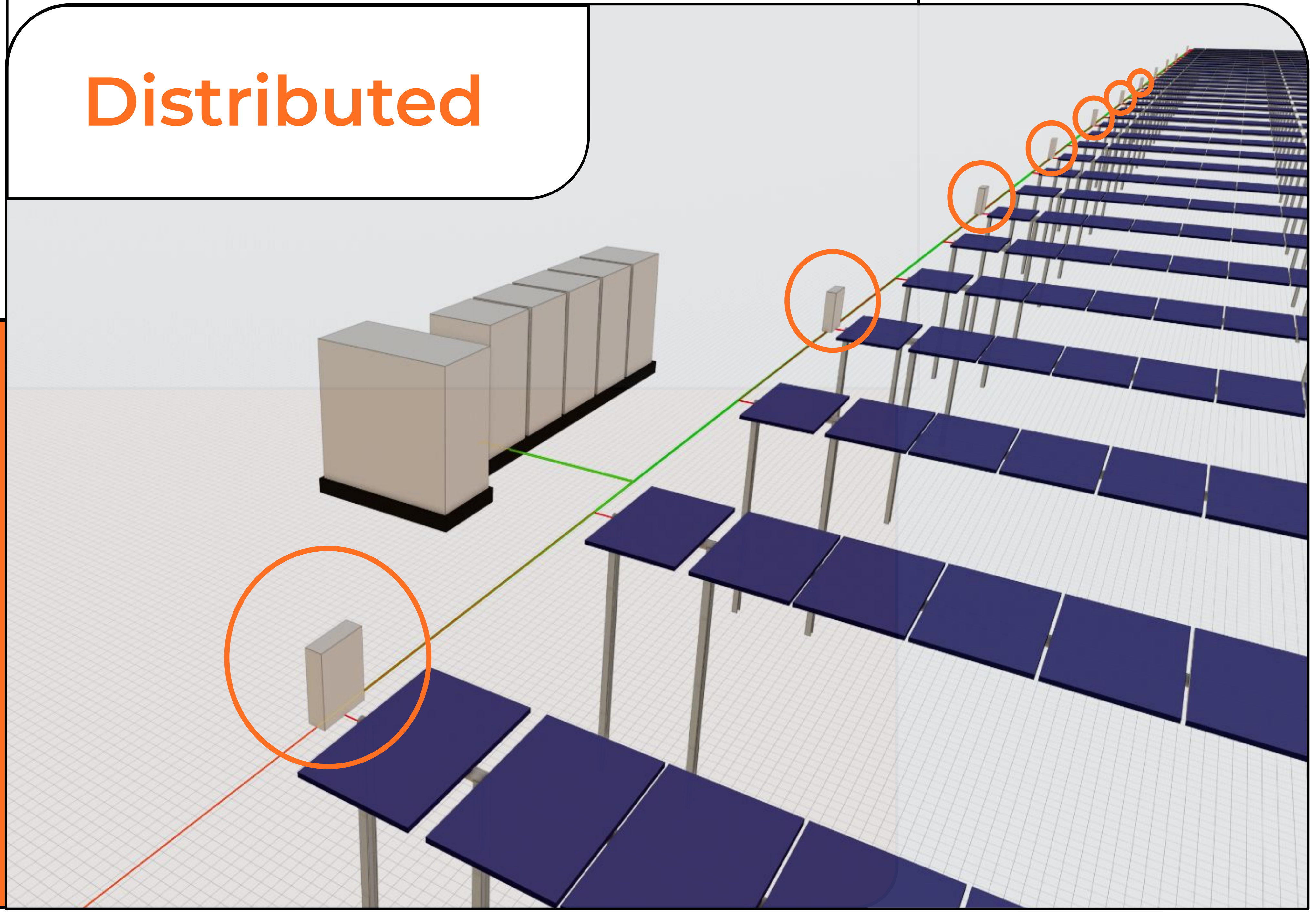
Distributed vs Clustered

Using Distributed lowers EBOS by **6.9%**
$1.24M saved

Electrical CAPEX: *0.1331 $/W*

LCOE, $/MWh: *50.59 $/MWh*

Distributed

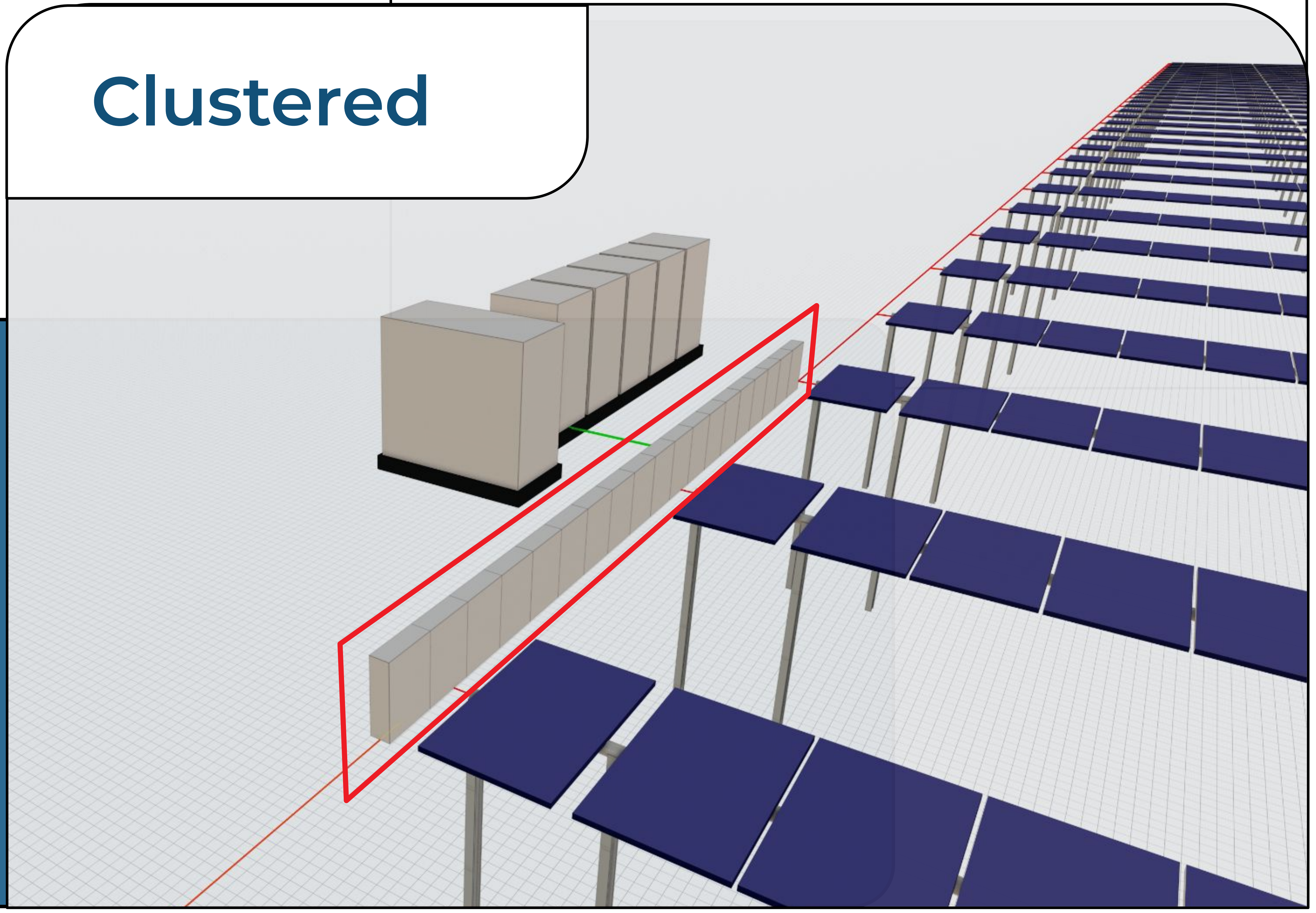


VS

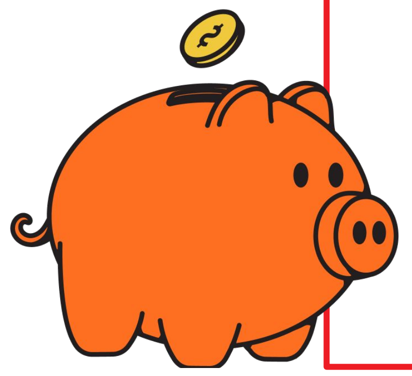
Electrical CAPEX: *0.1429 $/W*

LCOE, $/MWh: *50.95 $/MWh*

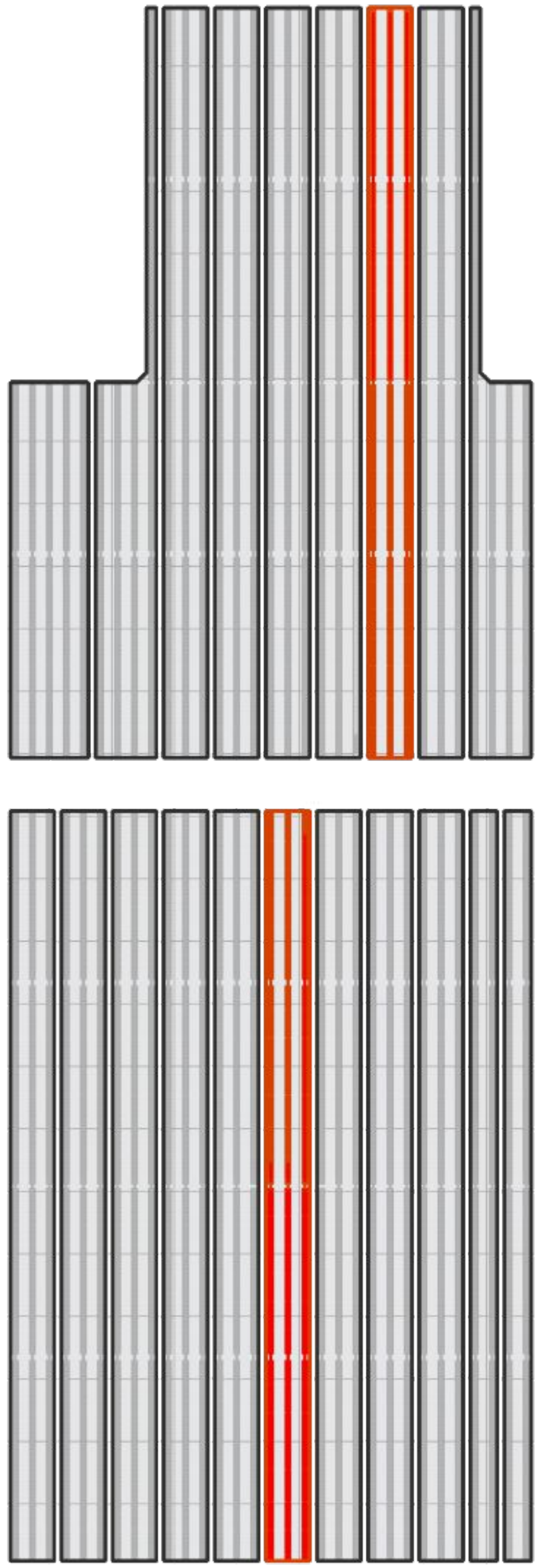
Clustered



Row Grouping



Using Multiple row grouping lowers EBOS by **24.22%**
$7.6M saved

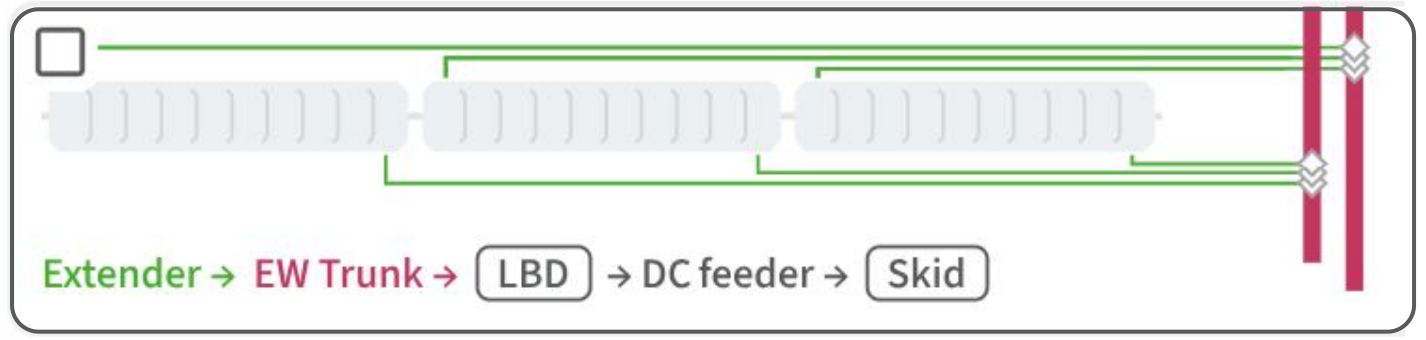


Multiple

Electrical CAPEX:
0.2488 $/W

LCOE, $/MWh:
53.88 $/MWh

Distributed		Clustered
Partial		Full
Middle of row		End of row
Single array		Multi array

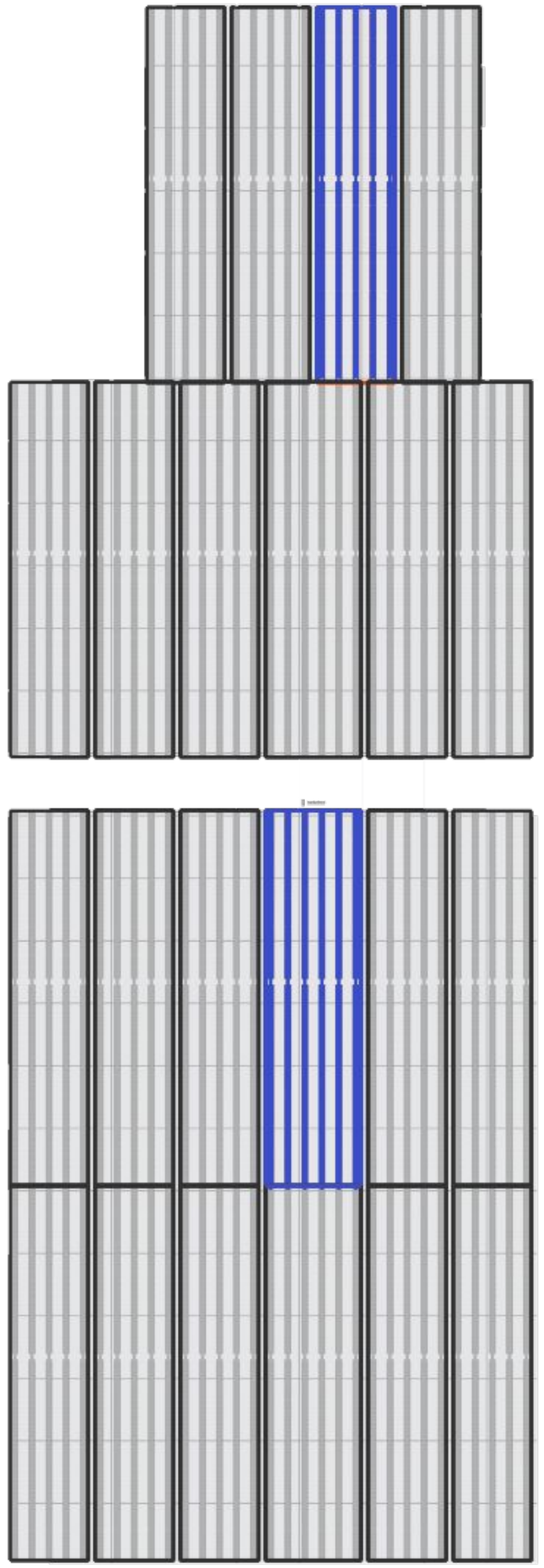


Single

Electrical CAPEX:
0.1886 $/W

LCOE, $/MWh:
54.13 $/MWh

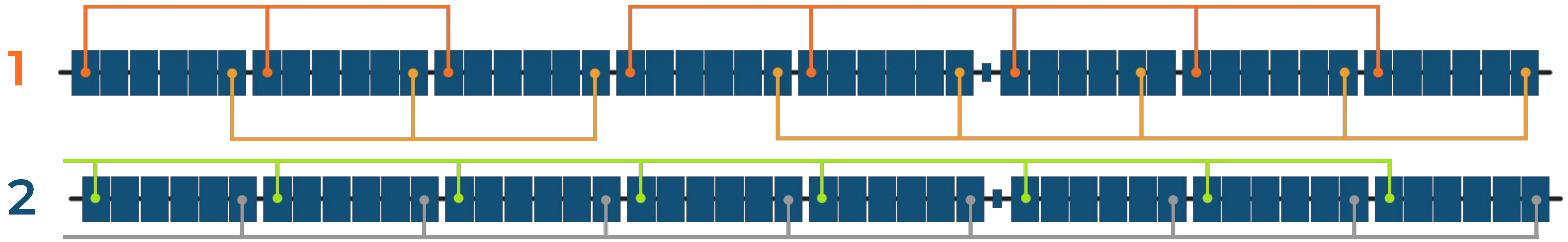
Distributed		Clustered
Partial		Full
Middle of row		End of row
Single array		Multi array



Harness Configuration

With two harnesses, the cost increased, but the voltage drop was reduced by half - from 3% to 1.5%

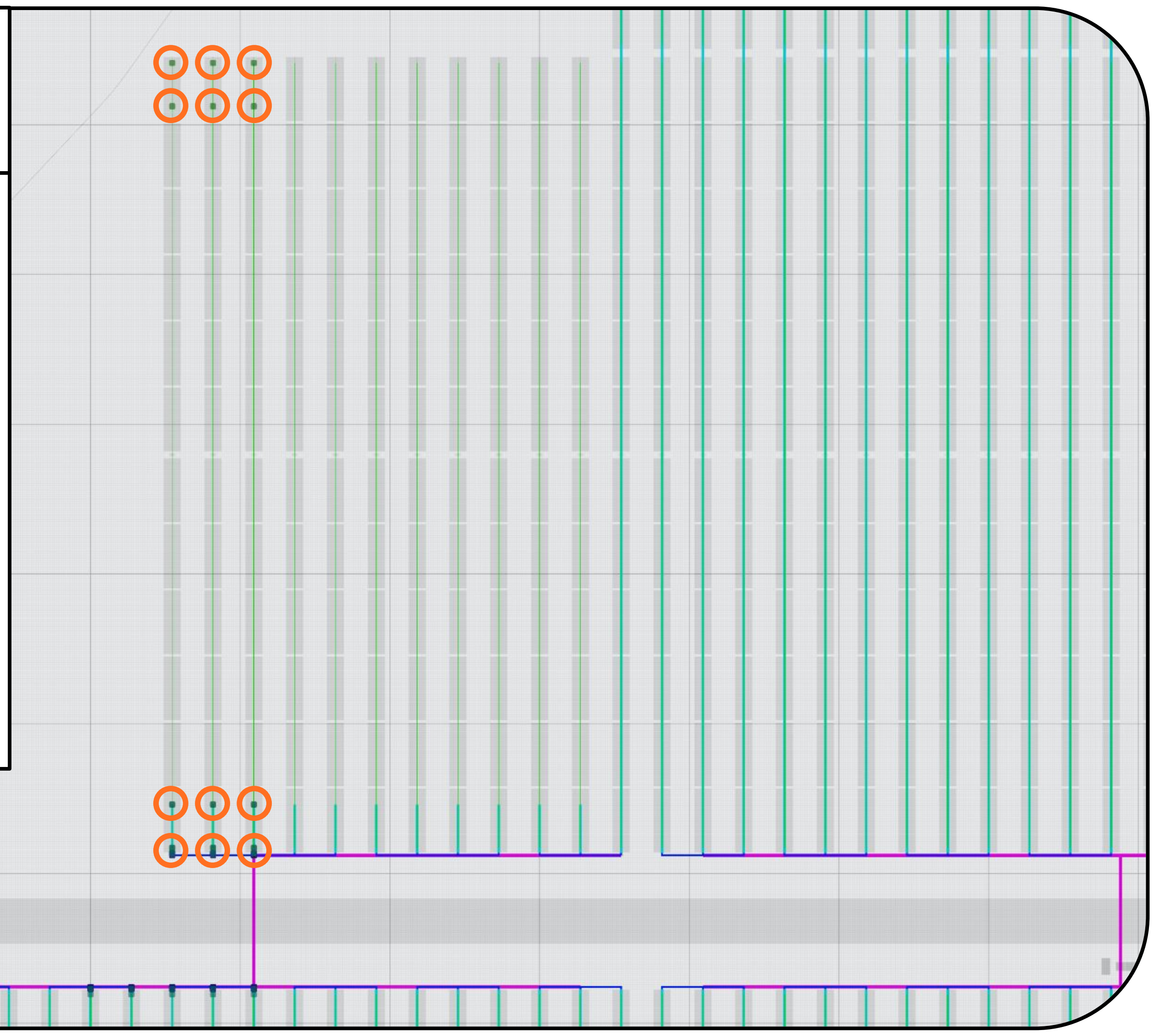
Using 1 Harness lowers EBOS by **11.3%**
$2.1 M saved



1 Harness

Electrical CAPEX:
0.1296 $/W

LCOE, $/MWh:
49.27 $/MWh

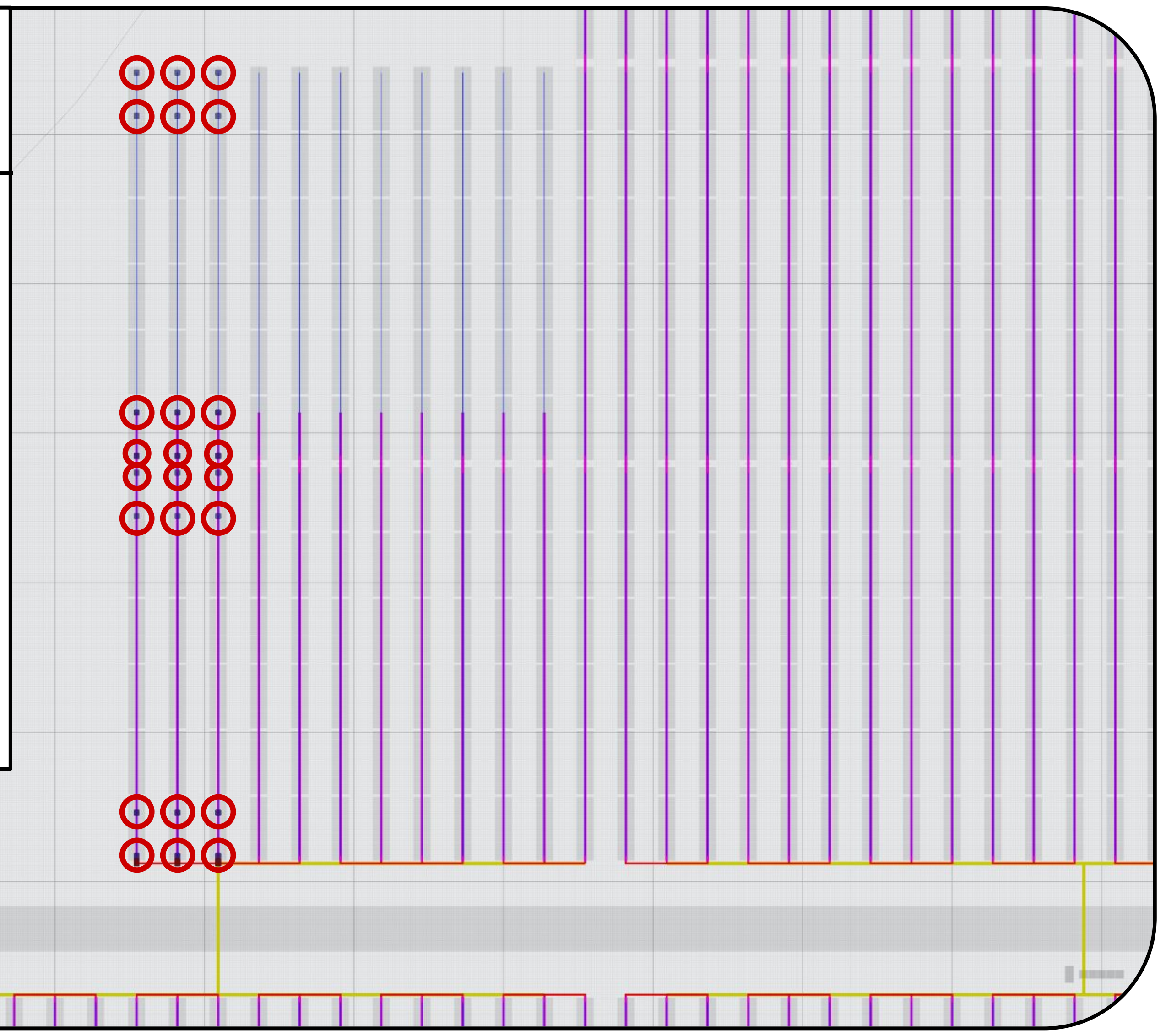


VS

2 Harnesses

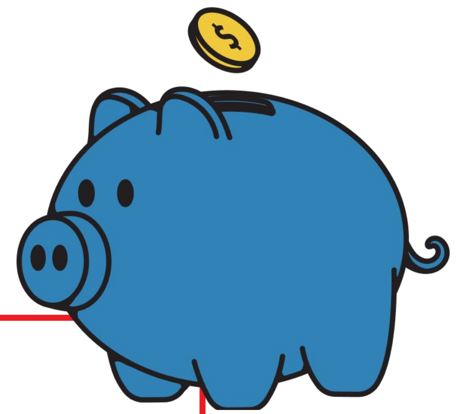
Electrical CAPEX:
0.1461 $/W

LCOE, $/MWh:
49.87 $/MWh



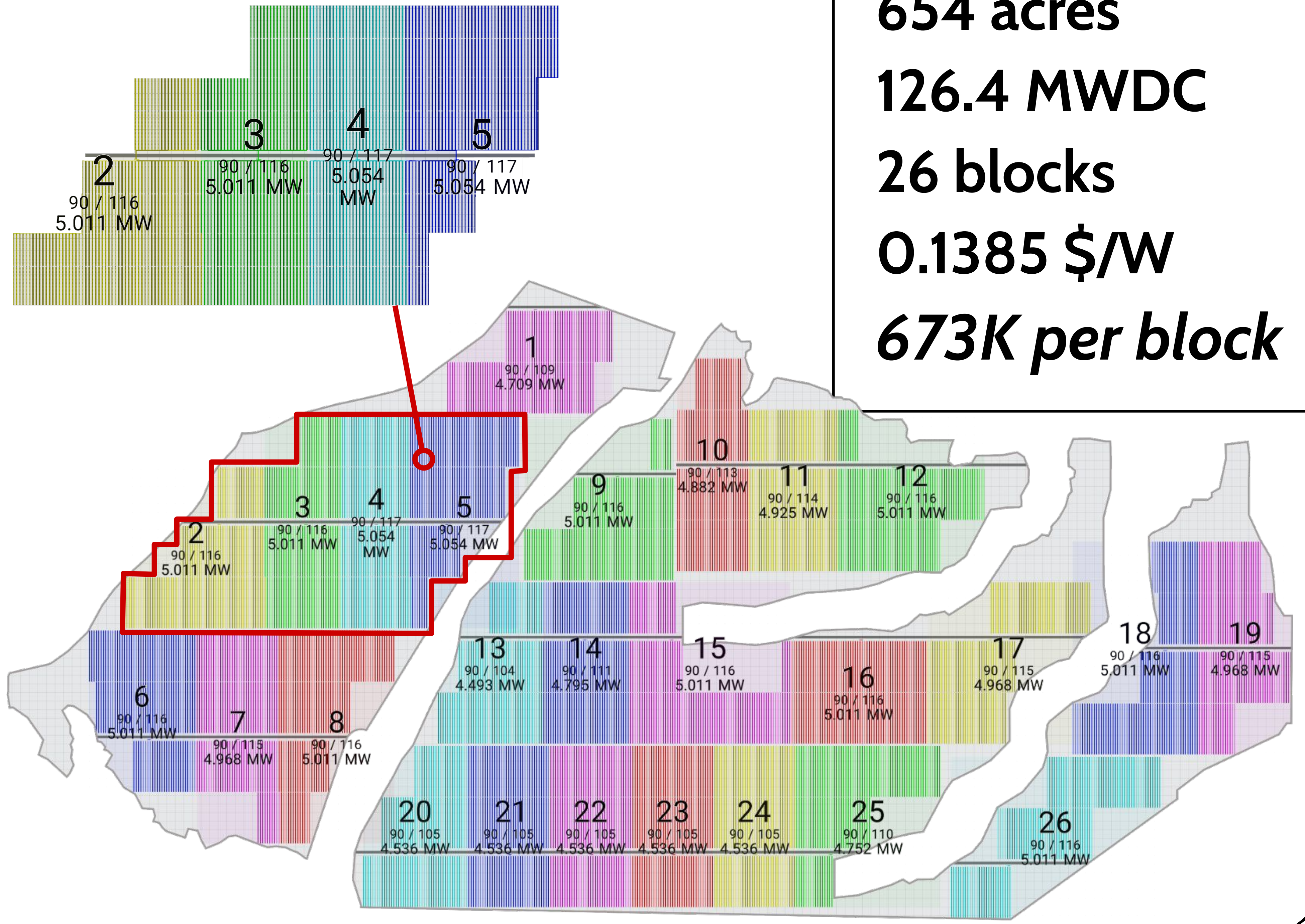
Boundaries Complexity

Same buildable area and DC/AC ratio, max DC optimisation



Using Simple Boundaries lowers EBOS by **2.6%**
$30K saved per block

Complex Boundaries

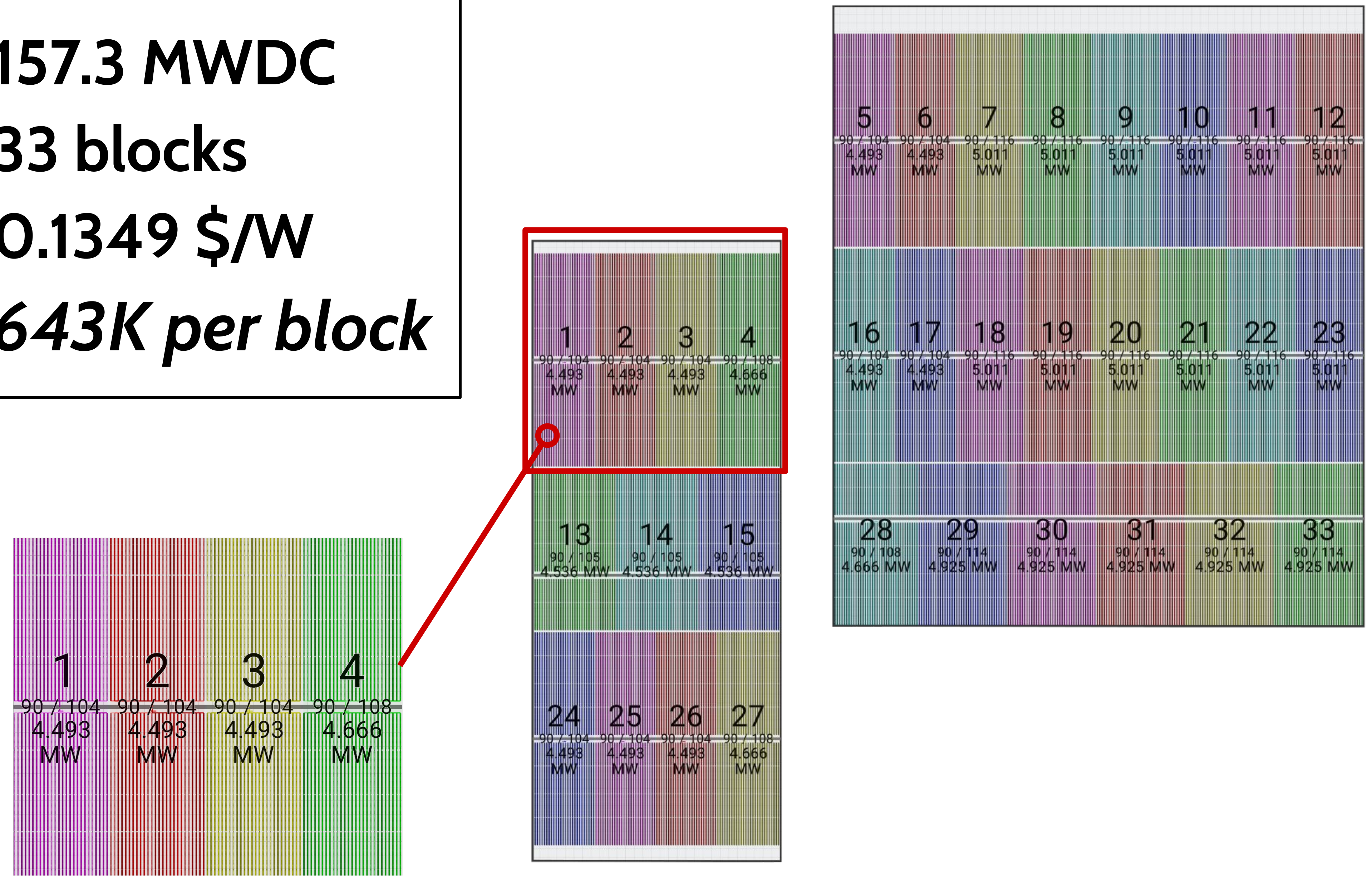


654 acres
126.4 MWDC
26 blocks
0.1385 $/W
673K per block

VS

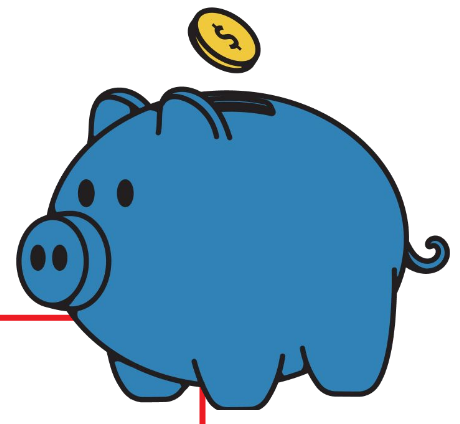
Simple Boundaries

654 acres
157.3 MWDC
33 blocks
0.1349 $/W
643K per block



Boundaries Complexity

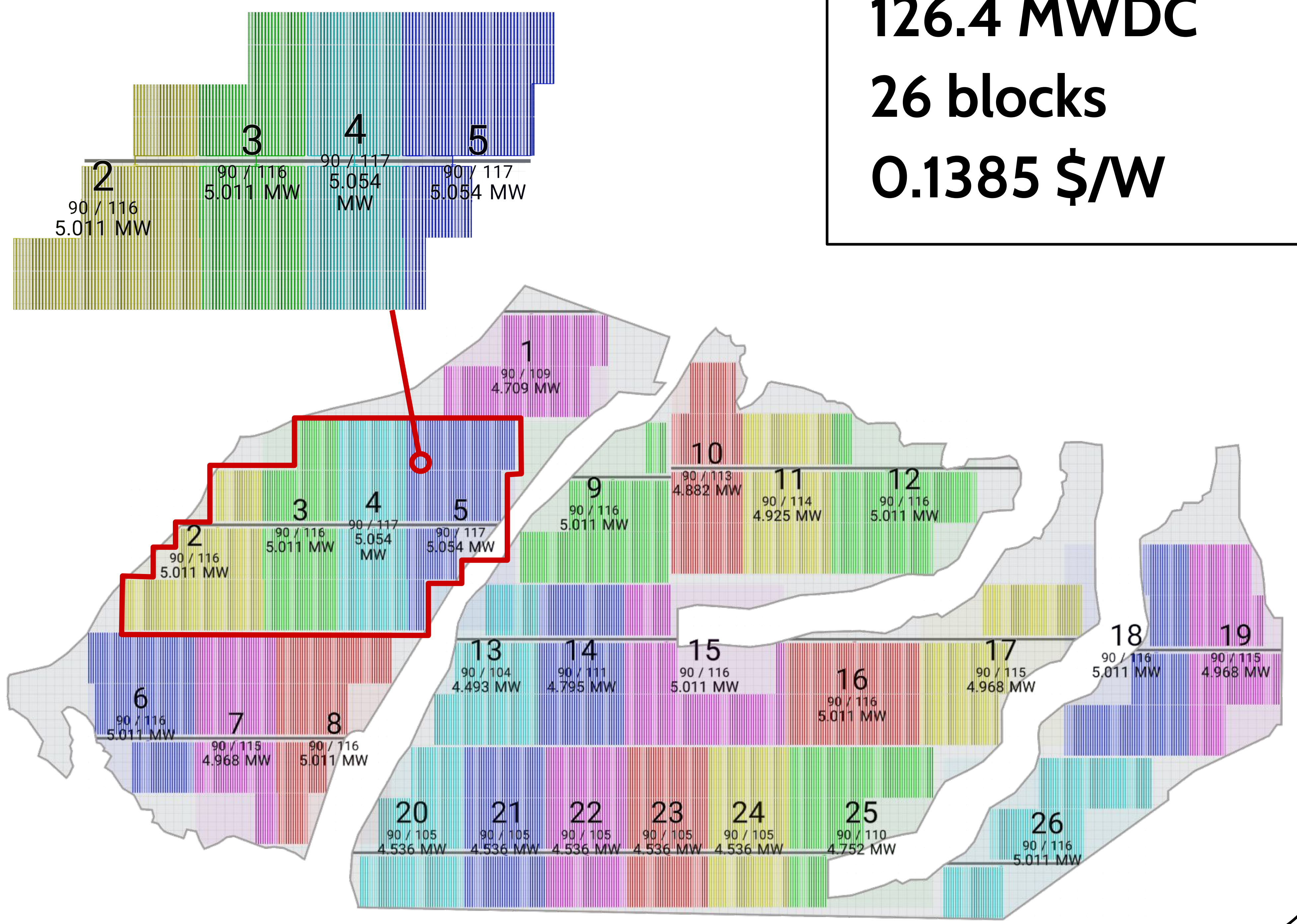
Same buildable area, same DC/AC ratio, same number of blocks



Using Simple Boundaries lowers EBOS by **3.0%**
$0.52M saved

Complex Boundaries

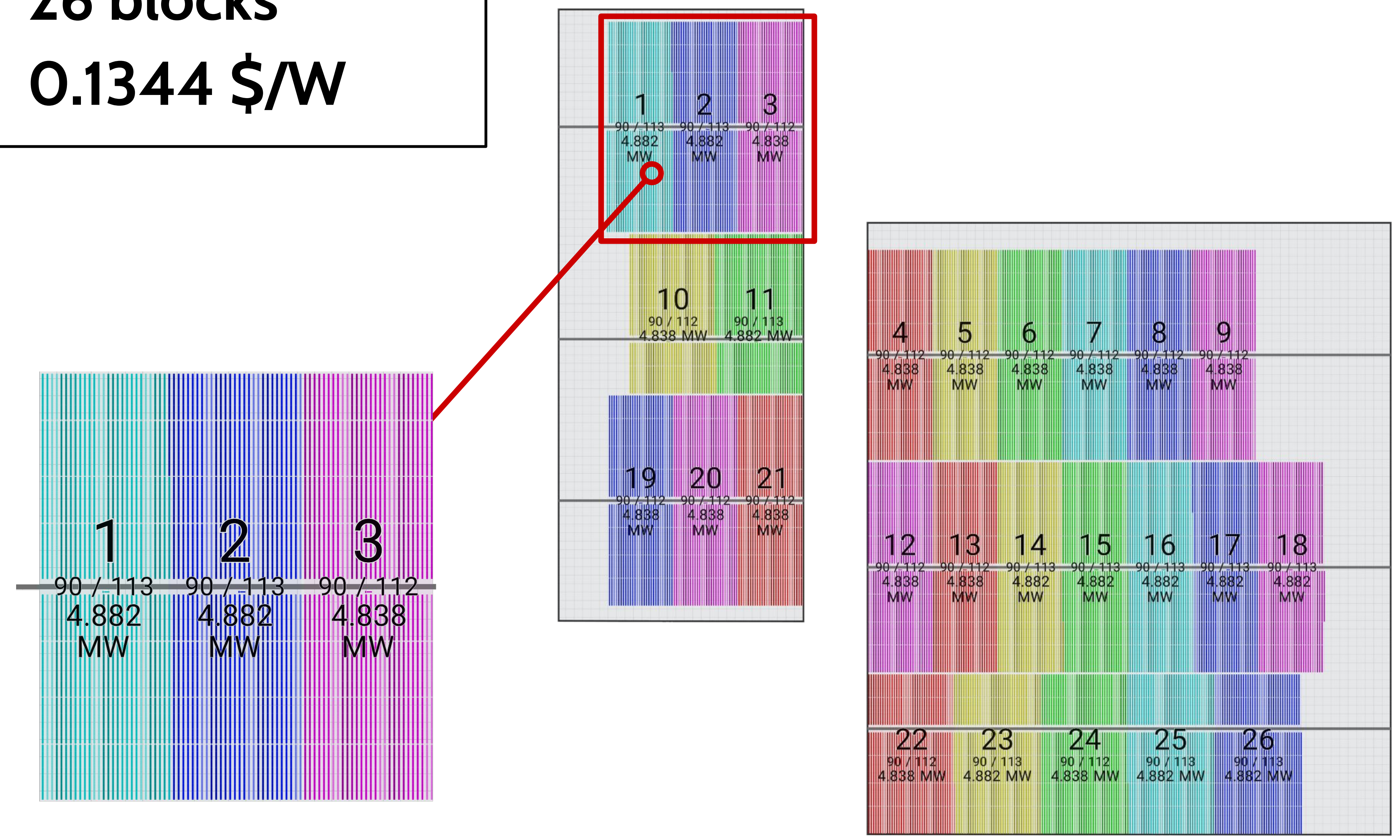
126.4 MWDC
26 blocks
0.1385 $/W



VS

Simple Boundaries

126.4 MWDC
26 blocks
0.1344 $/W

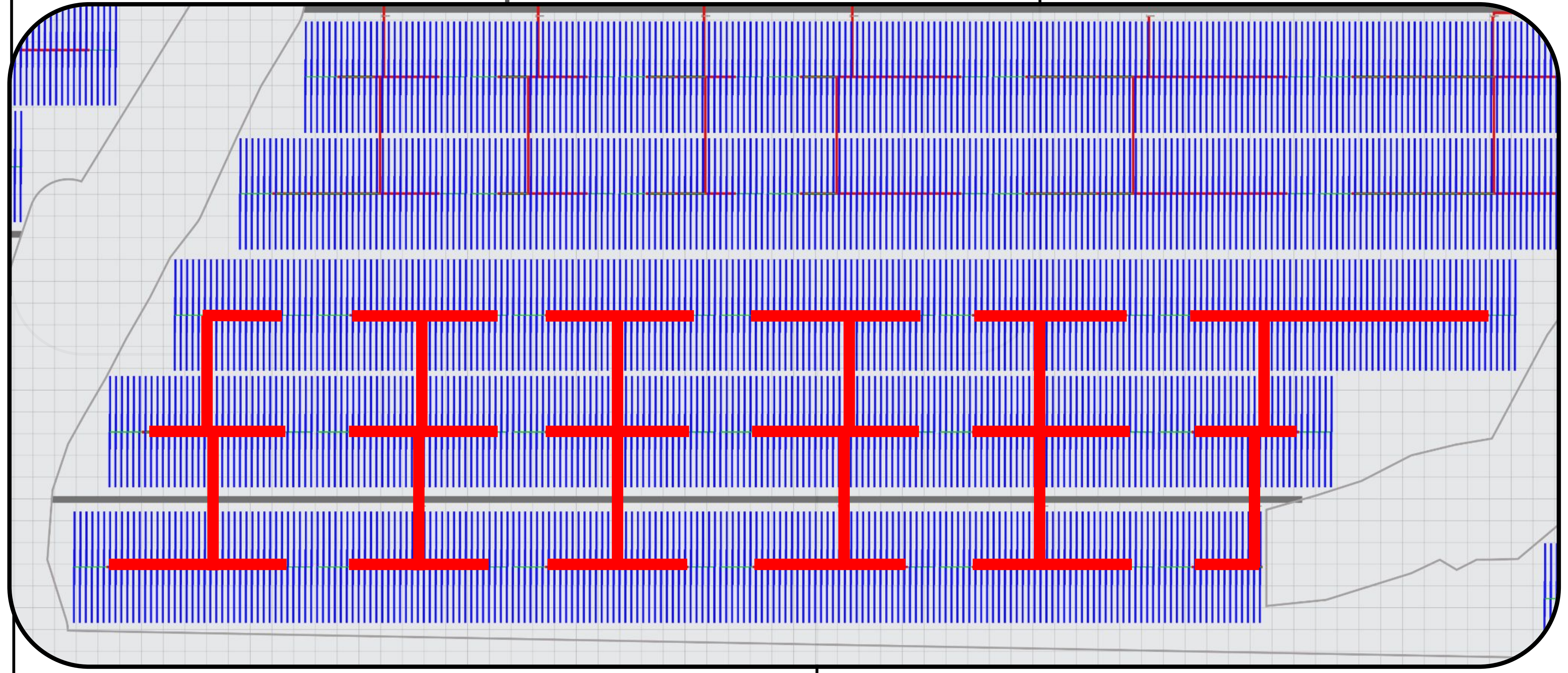


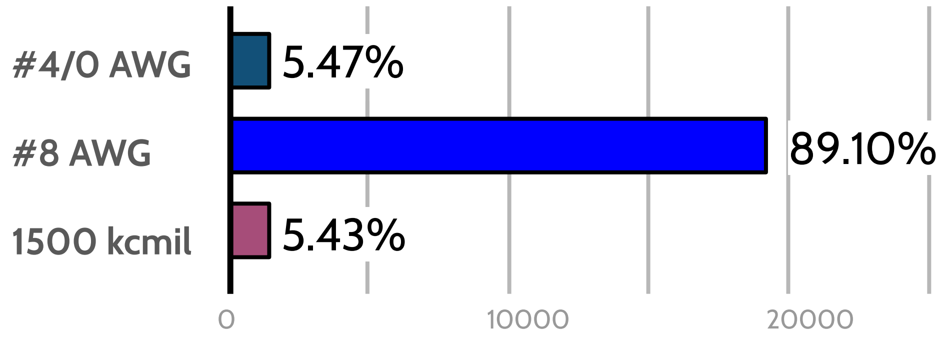
Wire Gauges Unification

Affects procurement logistics, labor complexity, and splicing strategies

Electrical CAPEX:	LCOE, $/MWh:
0.1248 $/W	*48.65 $/MWh*

2 Wire Gauges

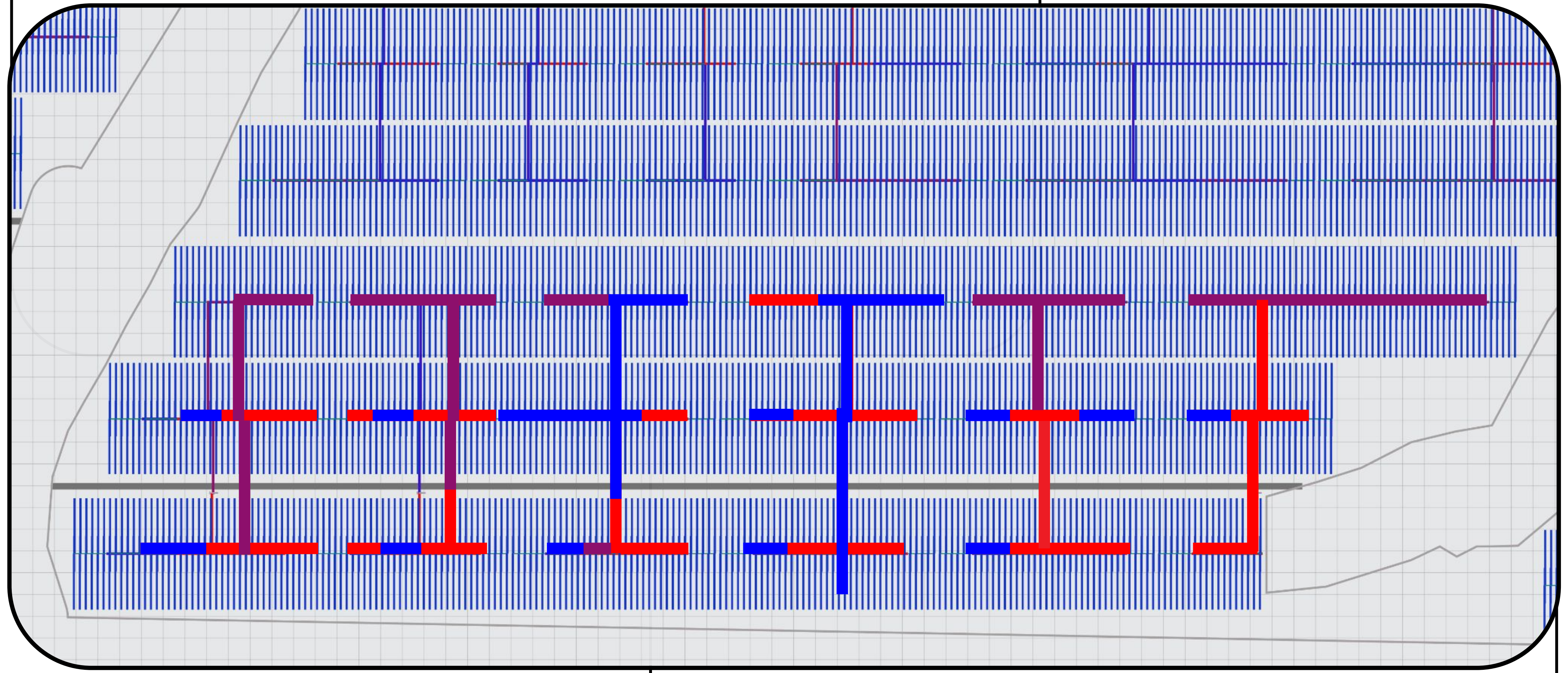


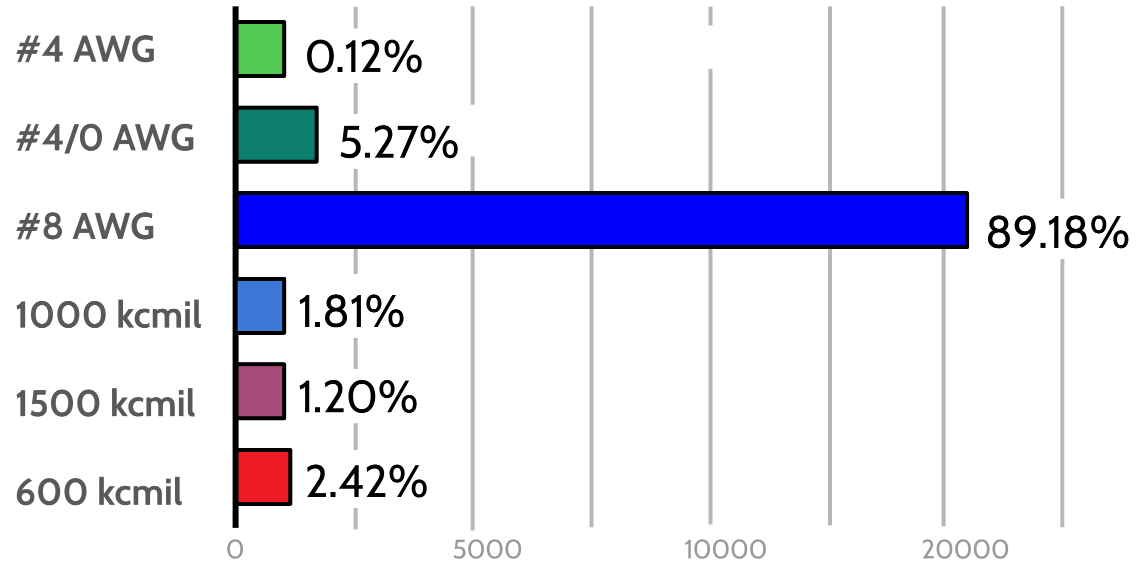


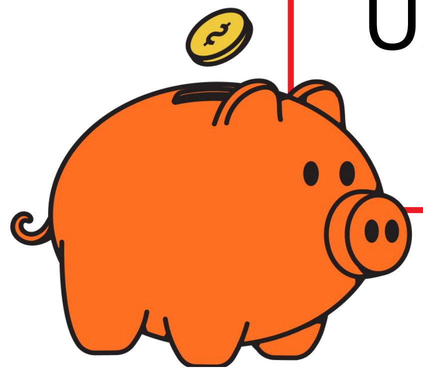
VS

Electrical CAPEX:	LCOE, $/MWh:
0.1234 $/W	*48.60 $/MWh*

6 Wire Gauges



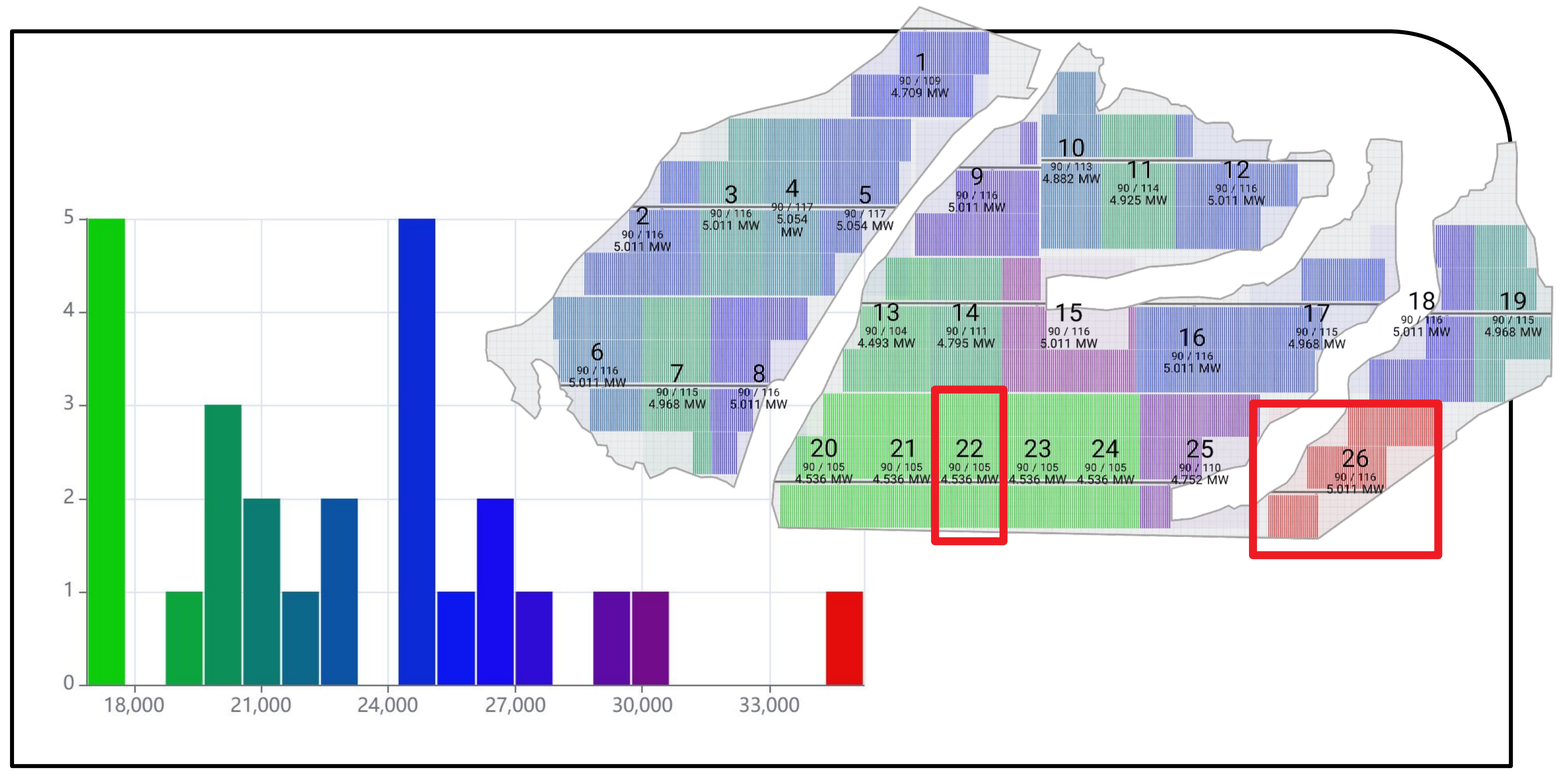




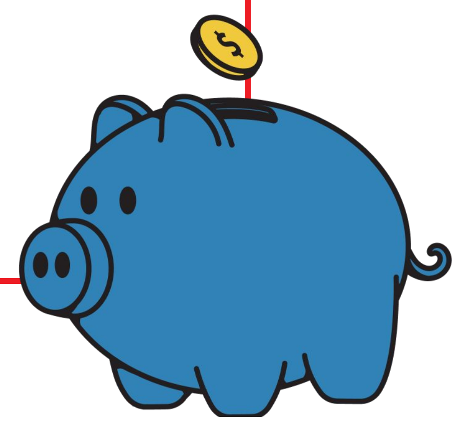
Using 6 wire gauges lowers EBOS by **1.1%**
$0.18M saved

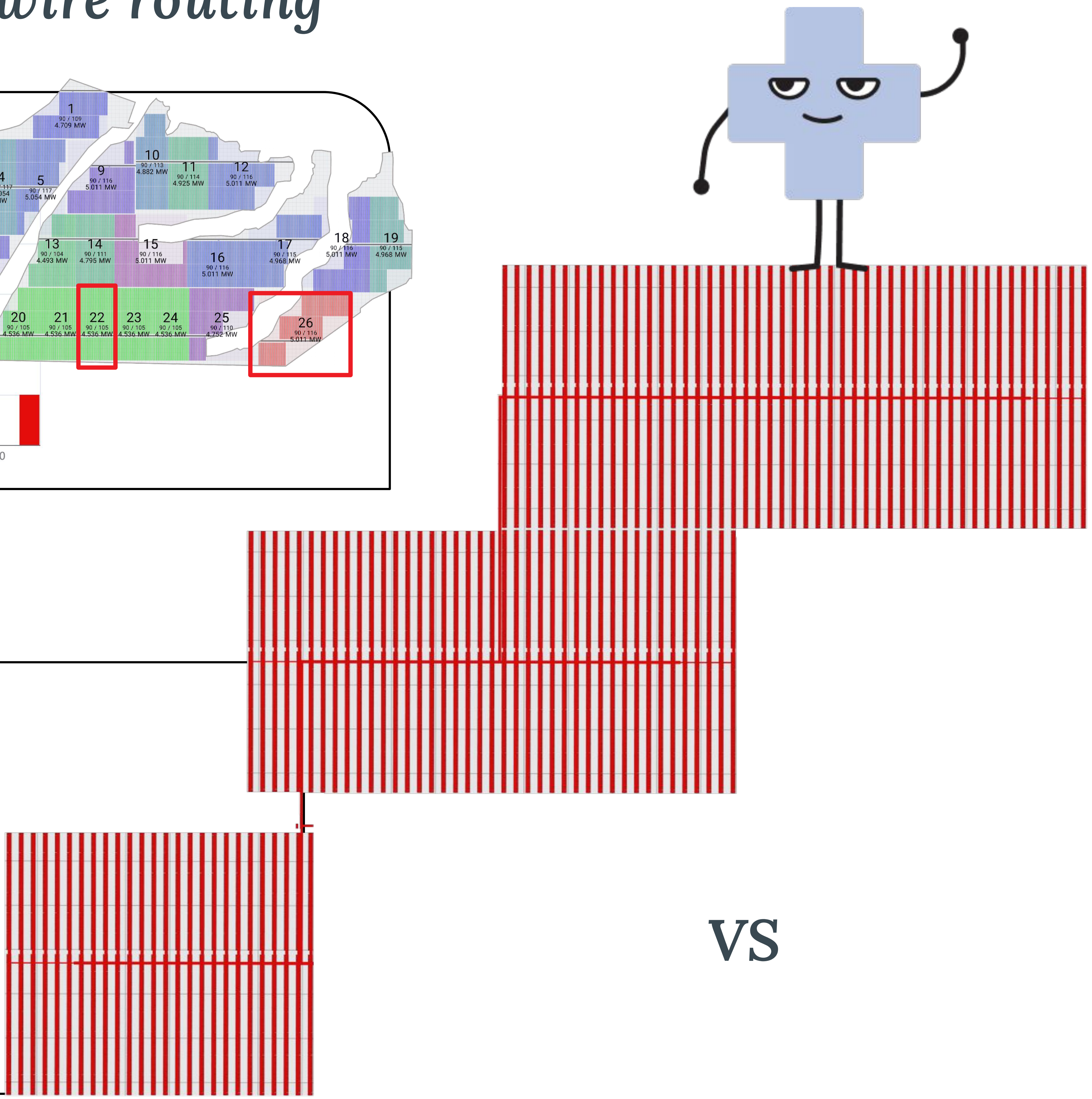
Block Footprint

Affects procurement logistics, labor complexity and wire routing



Designing regular shaped blocks lowers EBOS by **9.4%**
$1.7M saved





$ 716,138

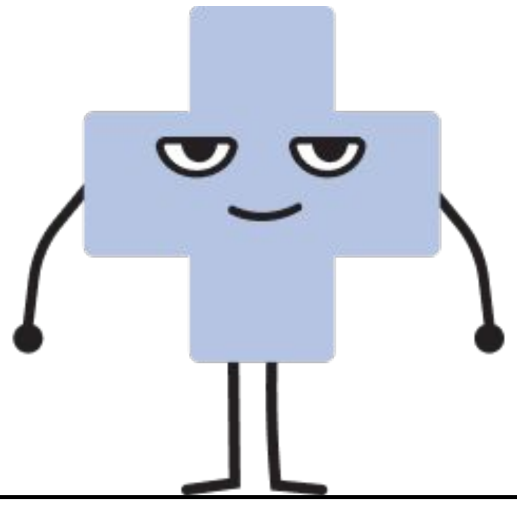
Electrical CAPEX:

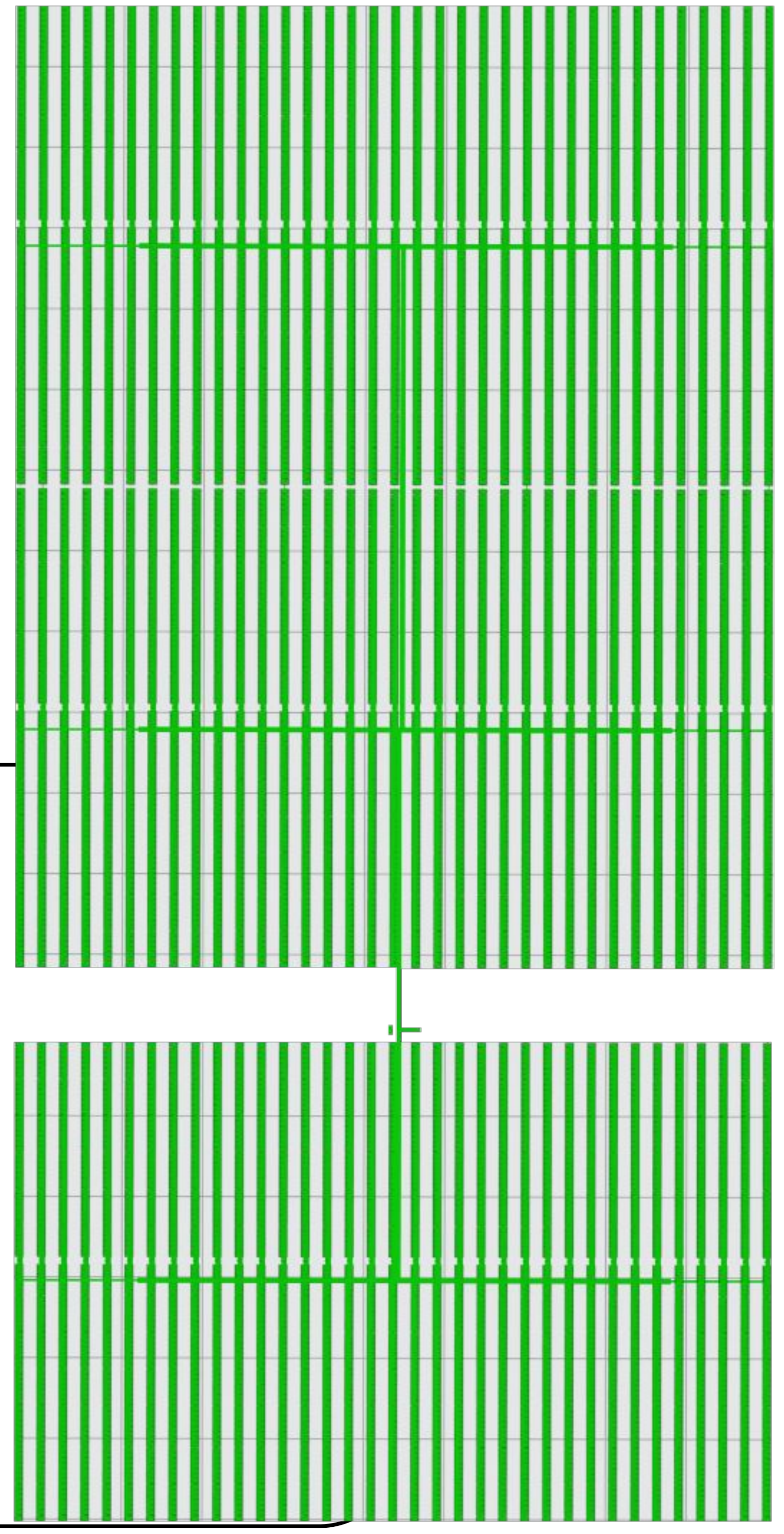
0.1429 $/W

DC Feeder Length:

35,000 ft

VS





$ 587,087

Electrical CAPEX:

0.1294 $/W

DC Feeder Length:

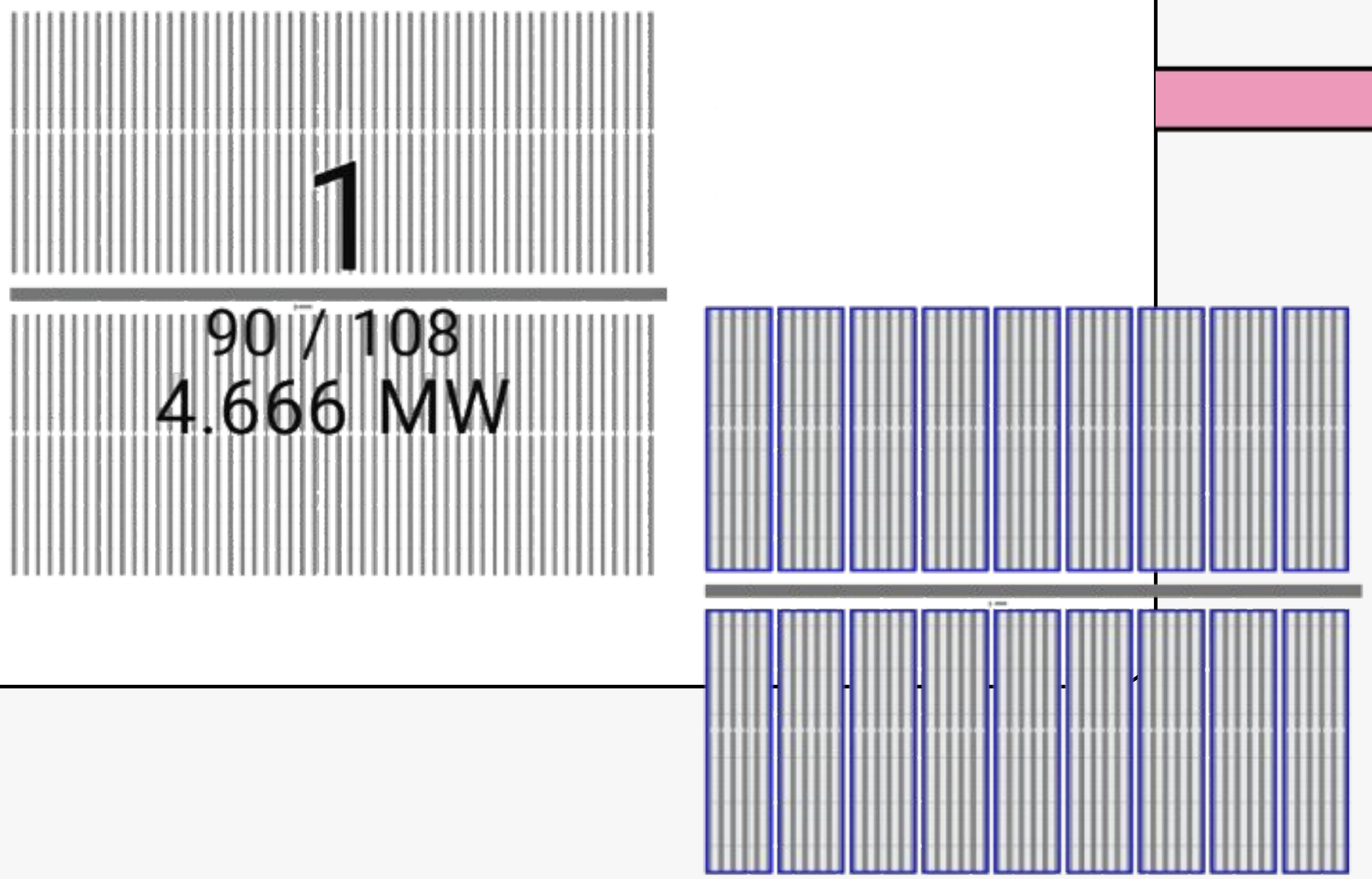
17,000 ft

Designed Standard Blocks vs Reality

Designed Standard Blocks

$/W (Ideal):

$ 0.1186



Designed Layout

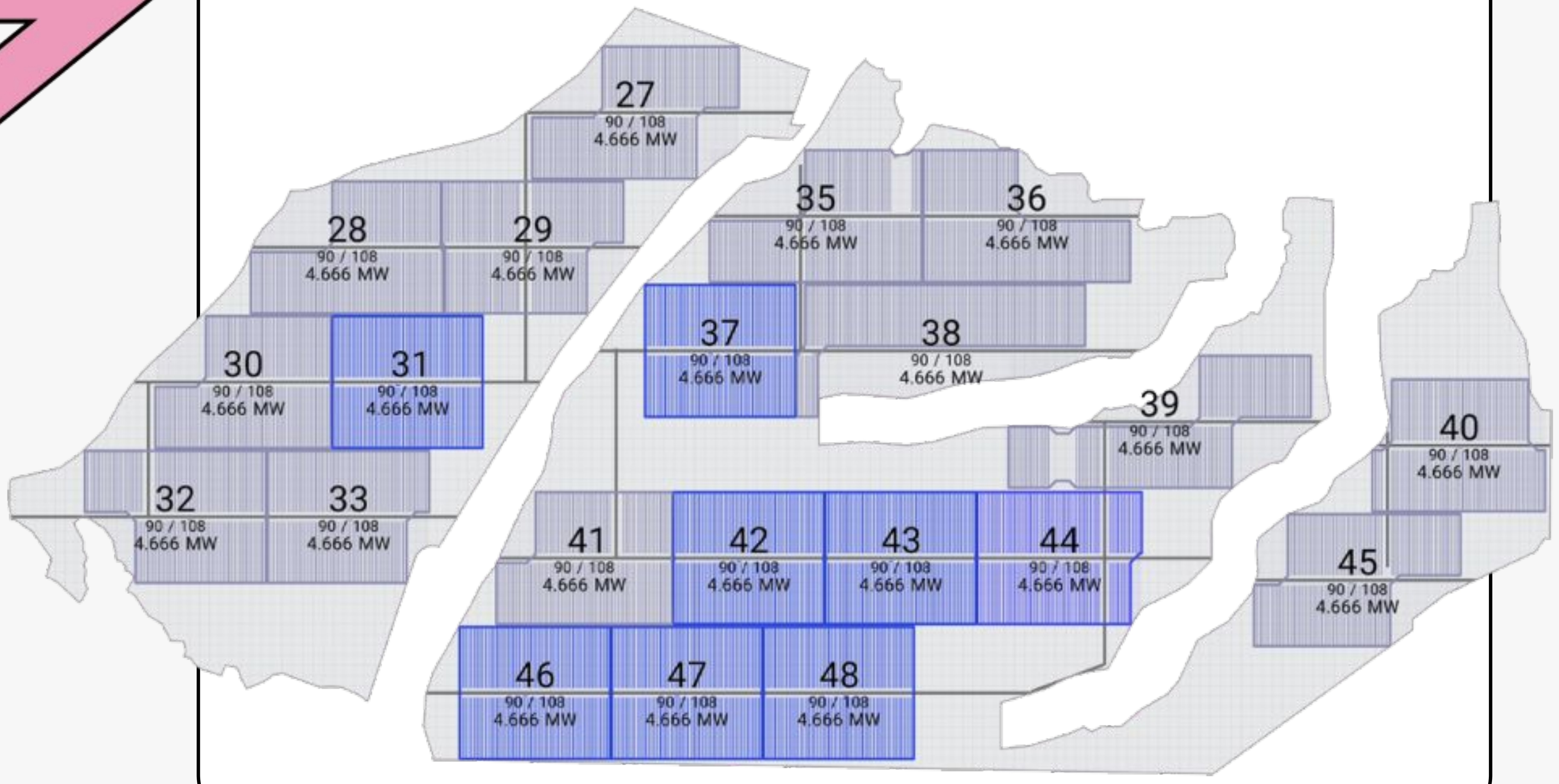
$/W (Actual):

$ 0.1215

Total Blocks: *21*

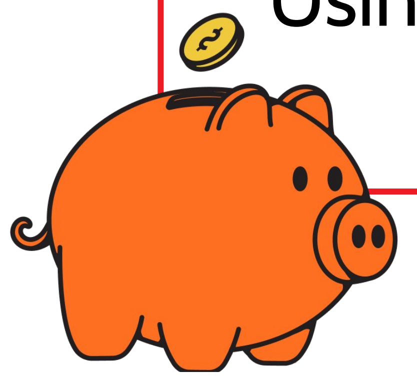
Standard Blocks: *8*

Standard Block Coverage: *38% (8/21)*



Row Height

Complex boundaries

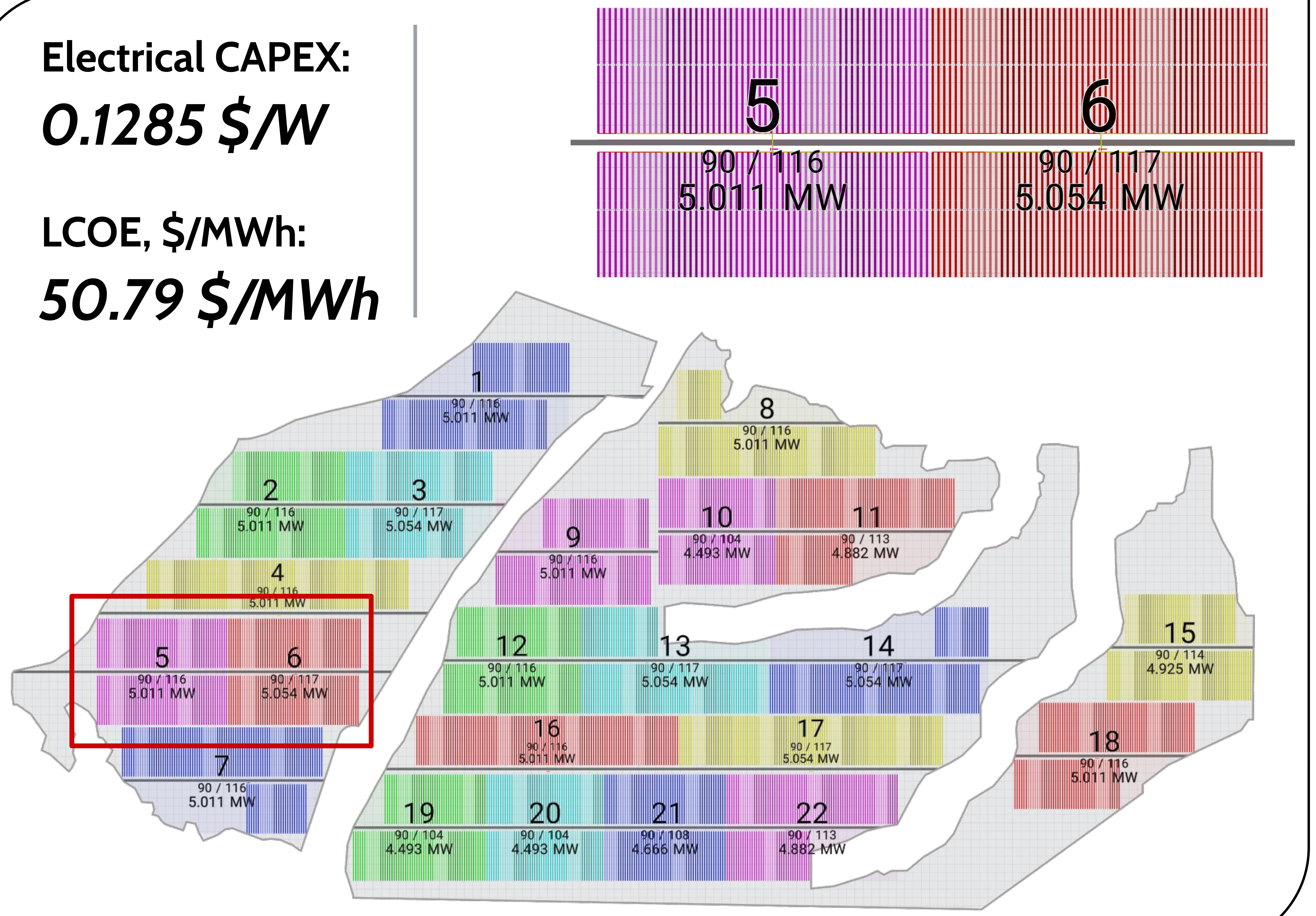


Using Single RH lowers EBOS by **9.8%**
$1.8M saved

Single row height (1)

Electrical CAPEX:
0.1285 $/W

LCOE, $/MWh:
50.79 $/MWh

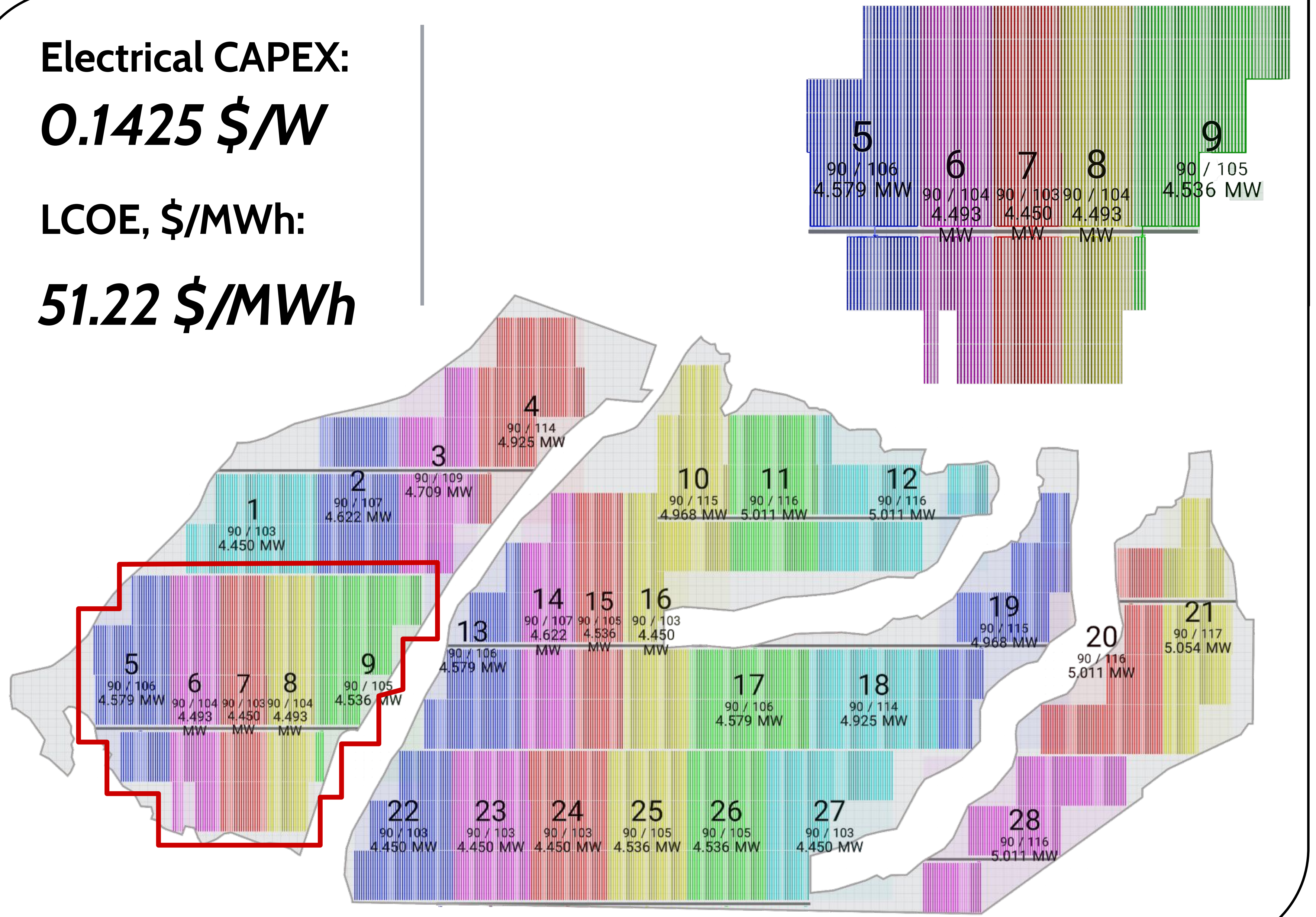


VS

Multiple row height (3)

Electrical CAPEX:
0.1425 $/W

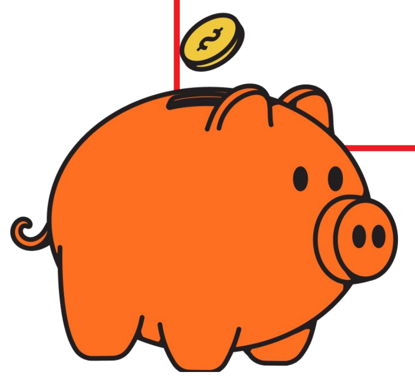
LCOE, $/MWh:
51.22 $/MWh



Row Height

Simple boundaries

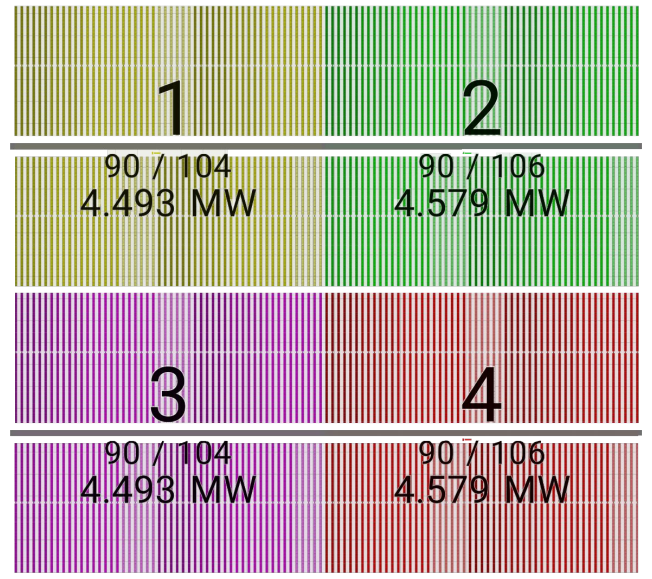
Using Single RH lowers EBOS by **9.7%**
$2.2M saved

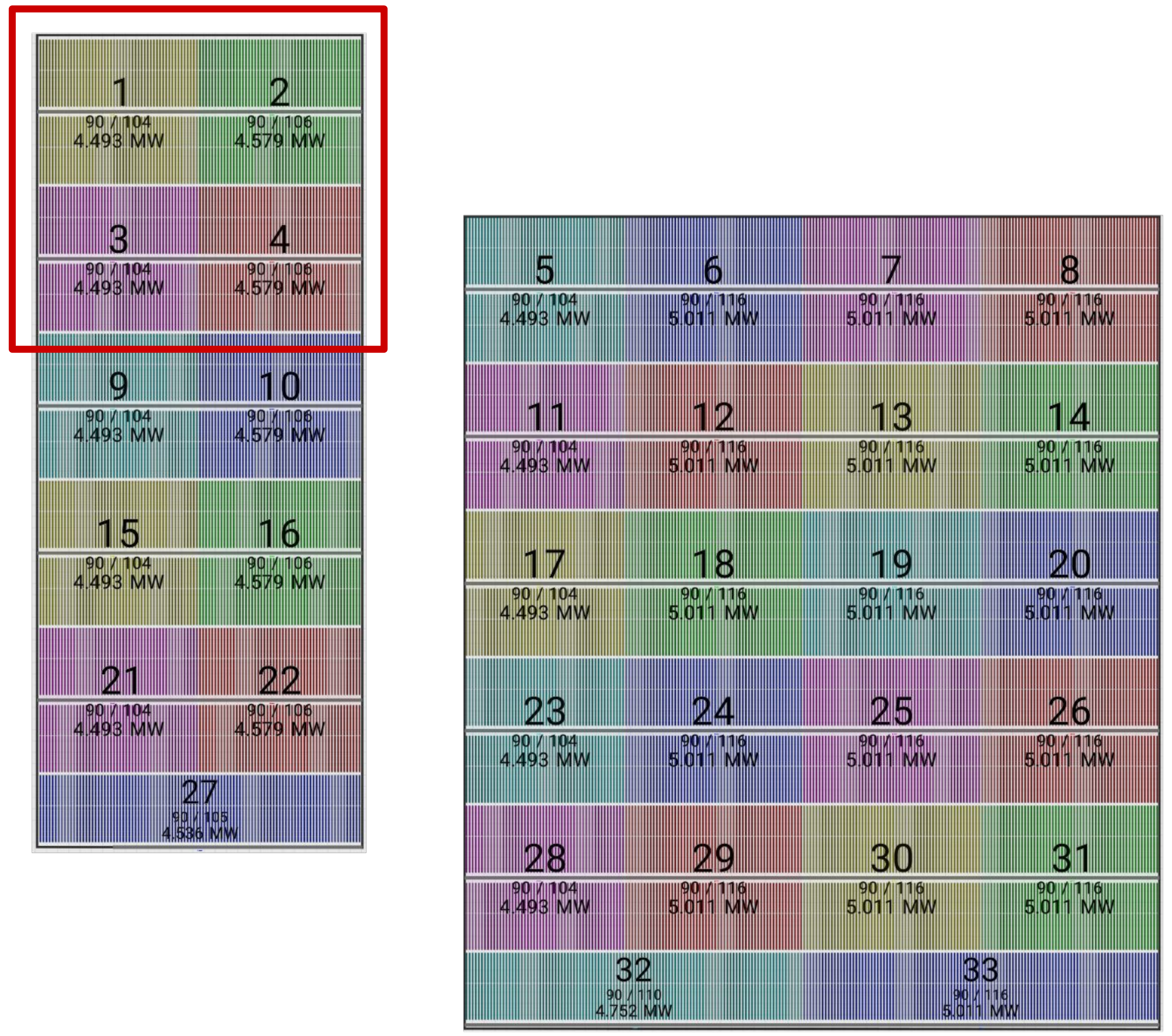


Single row height (1)

Electrical CAPEX:
0.1323 $/W

LCOE, $/MWh:
49.81 $/MWh



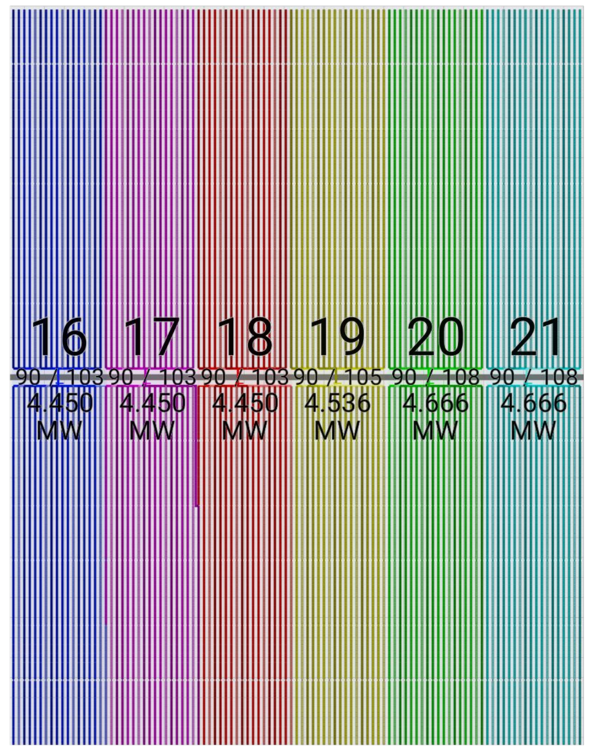


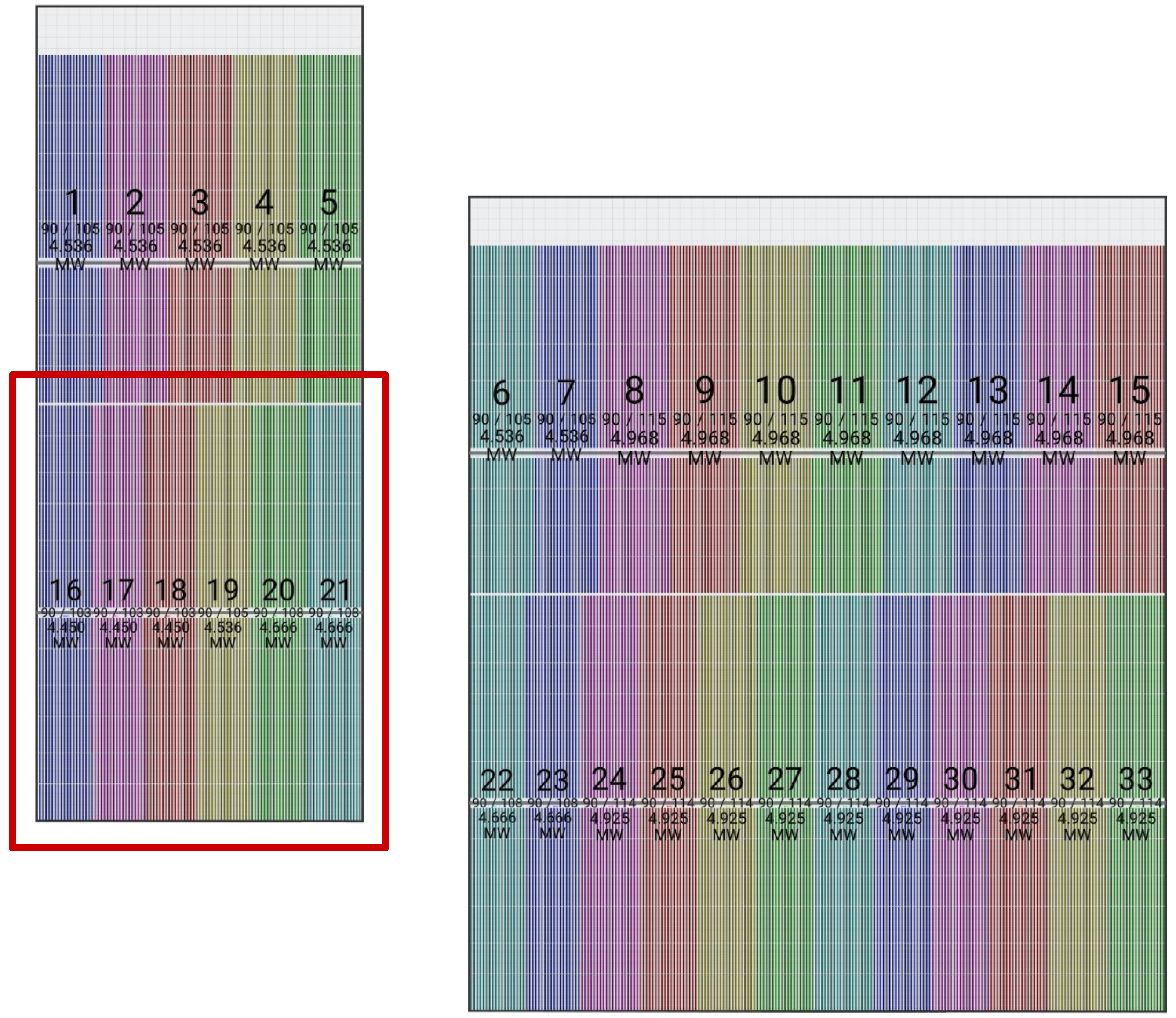
VS

Multiple row height (3)

Electrical CAPEX:
0.1465 $/W

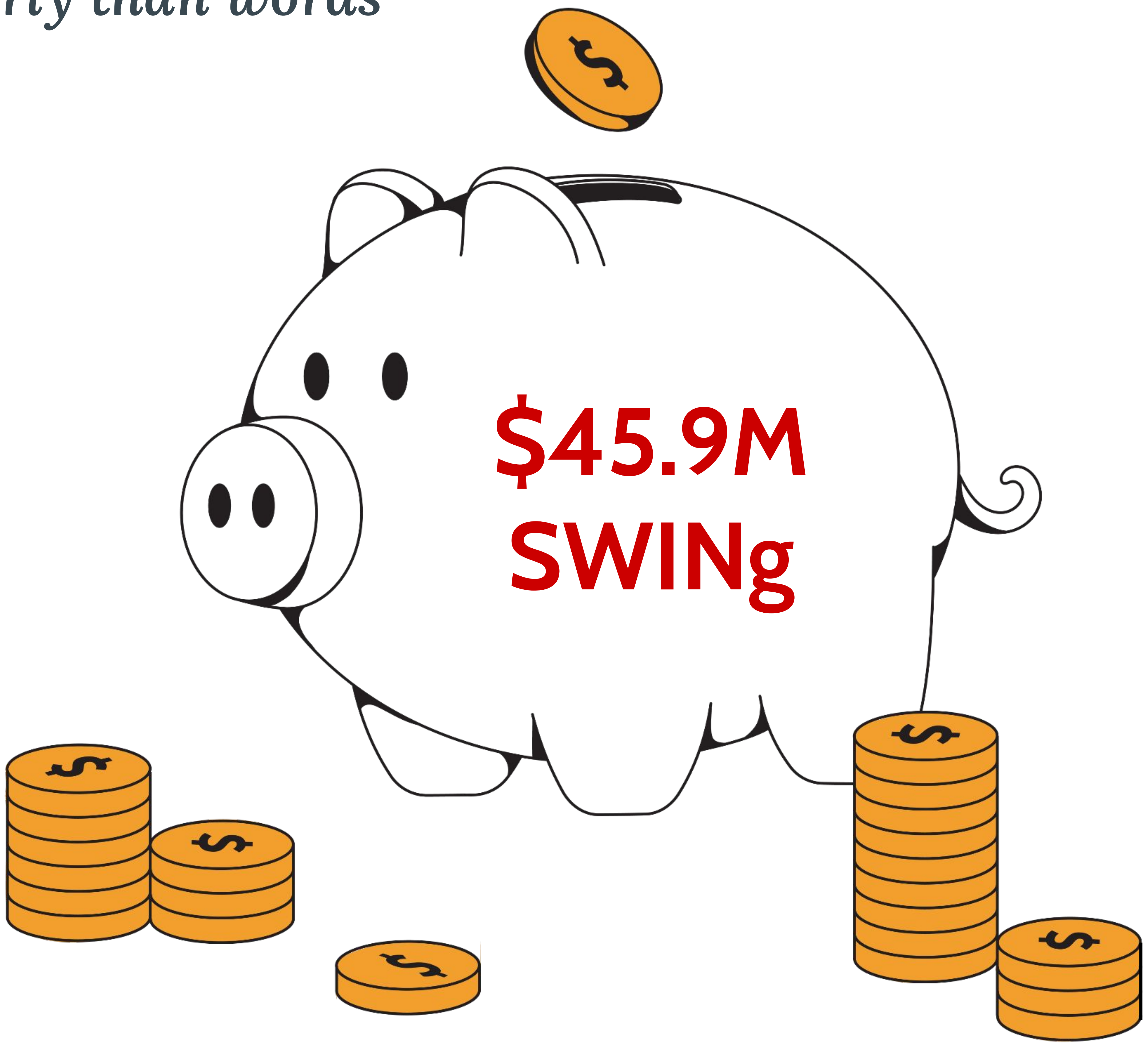
LCOE, $/MWh:
50.05 $/MWh



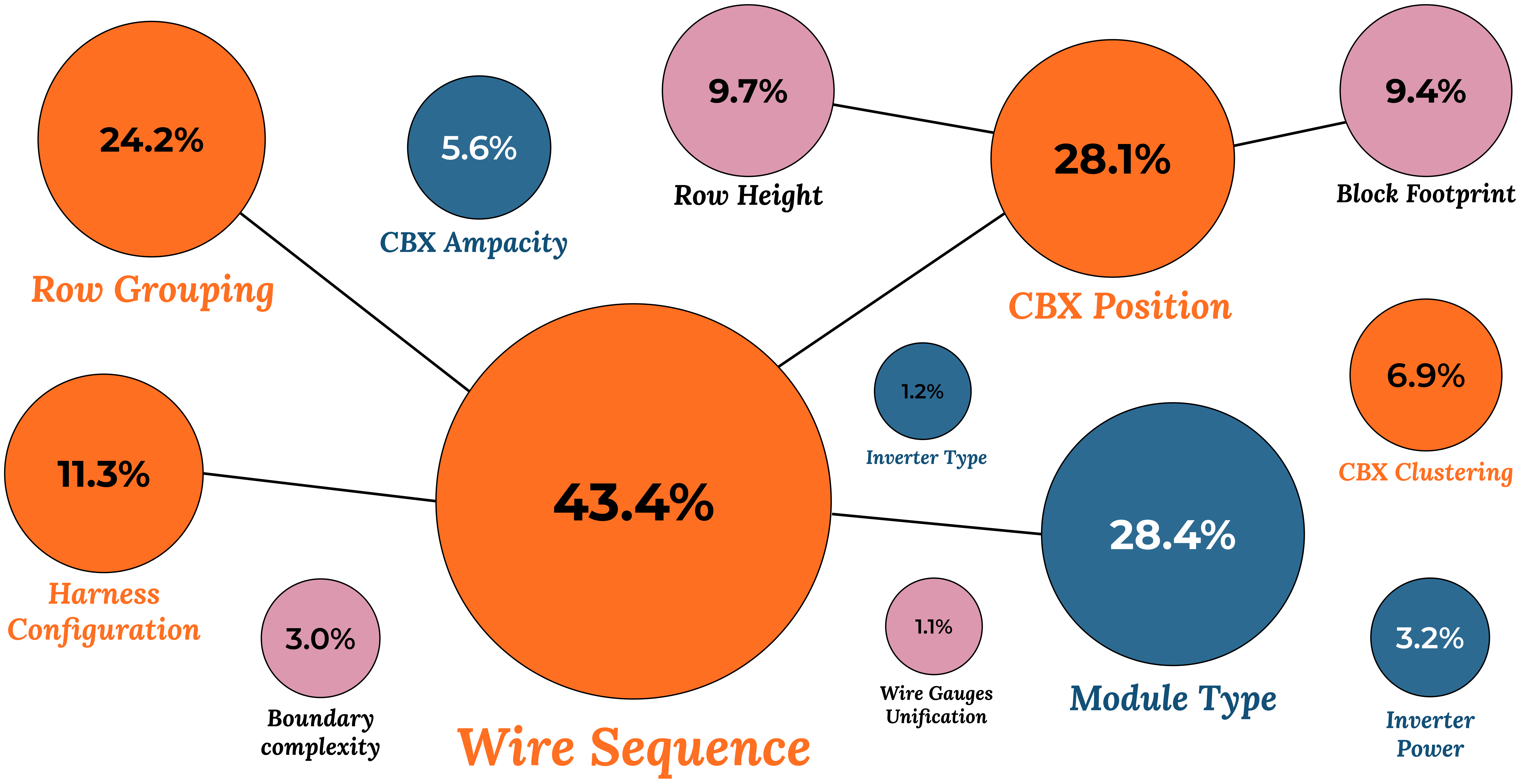


Total Cost Gap

Sometimes numbers speak more clearly than words

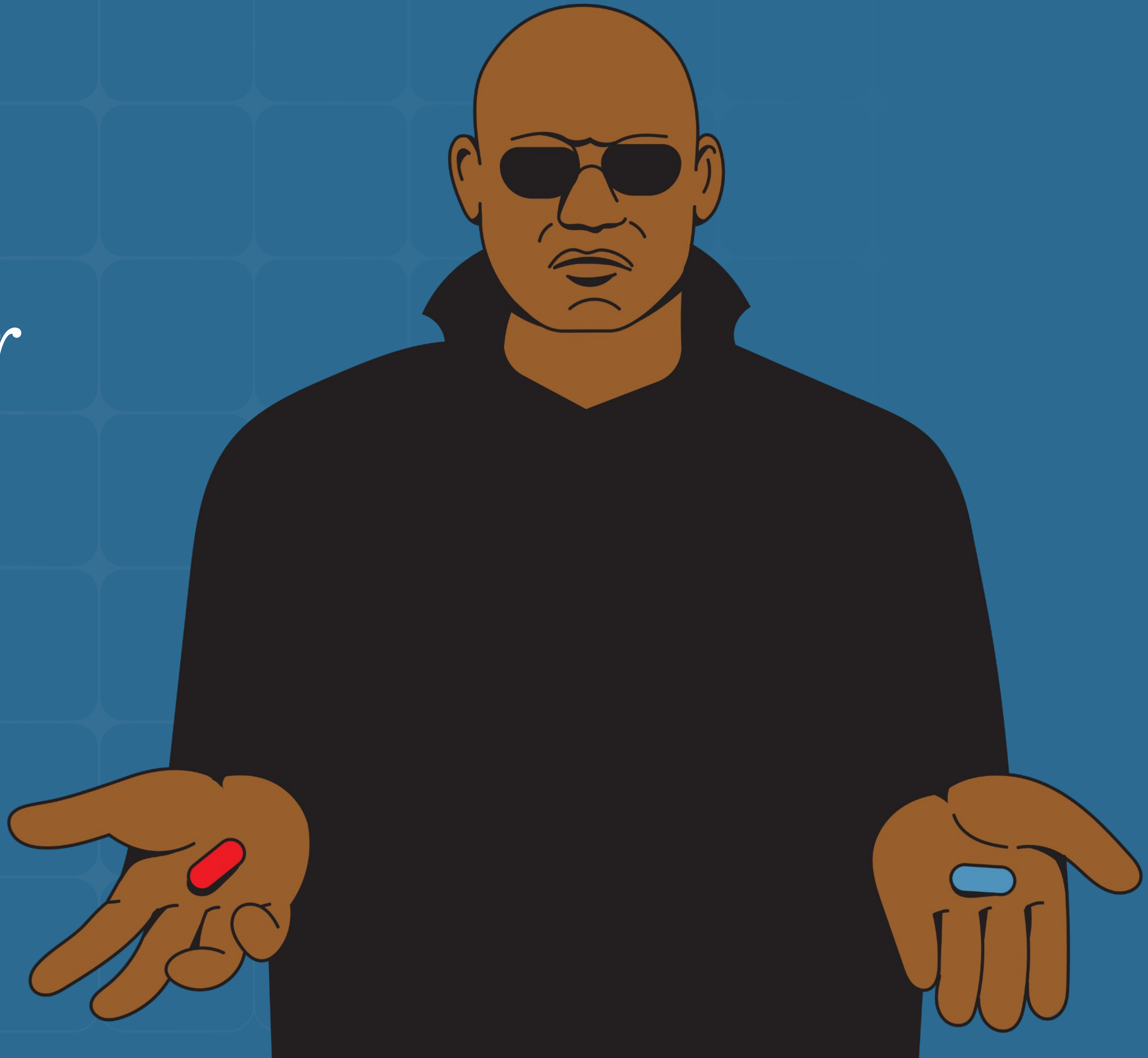


Parameter	DIFF, % EBOS CAPEX	$, MLN Saved
Inverter Type	1.2	0.2
Inverter Power	3.2	0.5
Module Type	**28.4**	**6.1**
CBX Ampacity	5.6	1.0
Wire Sequence	**43.4**	**13.8**
CBX Position	**28.1**	**9.2**
CBX Clustering	6.9	1.2
Row Grouping	**24.2**	**7.6**
Harness Configuration	11.3	2.1
Boundaries Complexity	3.0	0.5
Wire Gauges Unification	1.1	0.2
Block Footprint	9.4	1.7
Row Height	9.7	1.8


24.2%
Row Grouping
5.6%
CBX Ampacity
9.7%
Row Height
28.1%
CBX Position
9.4%
Block Footprint
6.9%
CBX Clustering
1.2%
Inverter Type
11.3%
Harness Configuration
43.4%
Wire Sequence
28.4%
Module Type
3.0%
Boundary complexity
1.1%
Wire Gauges Unification
3.2%
Inverter Power

Defining Design Lock-In Risk

Emphasizes the early anchor decisions vs. late-flex items



	Electrical parameters	Feasibility	Conceptual design 10%	Preliminary design 30%	Detailed design 60%	IFC 90%	Value
Equipment	Inverter Type	0	1	0	0	0	4
	Inverter Power	0	0	1	0	0	3
	Module Selection	1	0	0	0	0	5
	CBX/LBD Selection	0	0	1	0	0	3
Wiring Architecture	Wire Sequence	0	0	0	1	0	2
	CBX/LBD Position	0	0	1	0	0	3
	CBX/LBD Clustering	0	0	1	0	0	3
	Row Grouping	0	0	1	0	0	3
	Harness Configuration	0	0	0	1	0	2
Site Context & Buildability	Boundaries Complexity	1	0	0	0	0	5
	Wire Gauges Unification	0	0	0	0	1	1
	Block Footprint	0	0	1	0	0	3
	Row Height	0	1	0	0	0	4

Defining System Interaction

It's not over engineering if the systems are best friends!

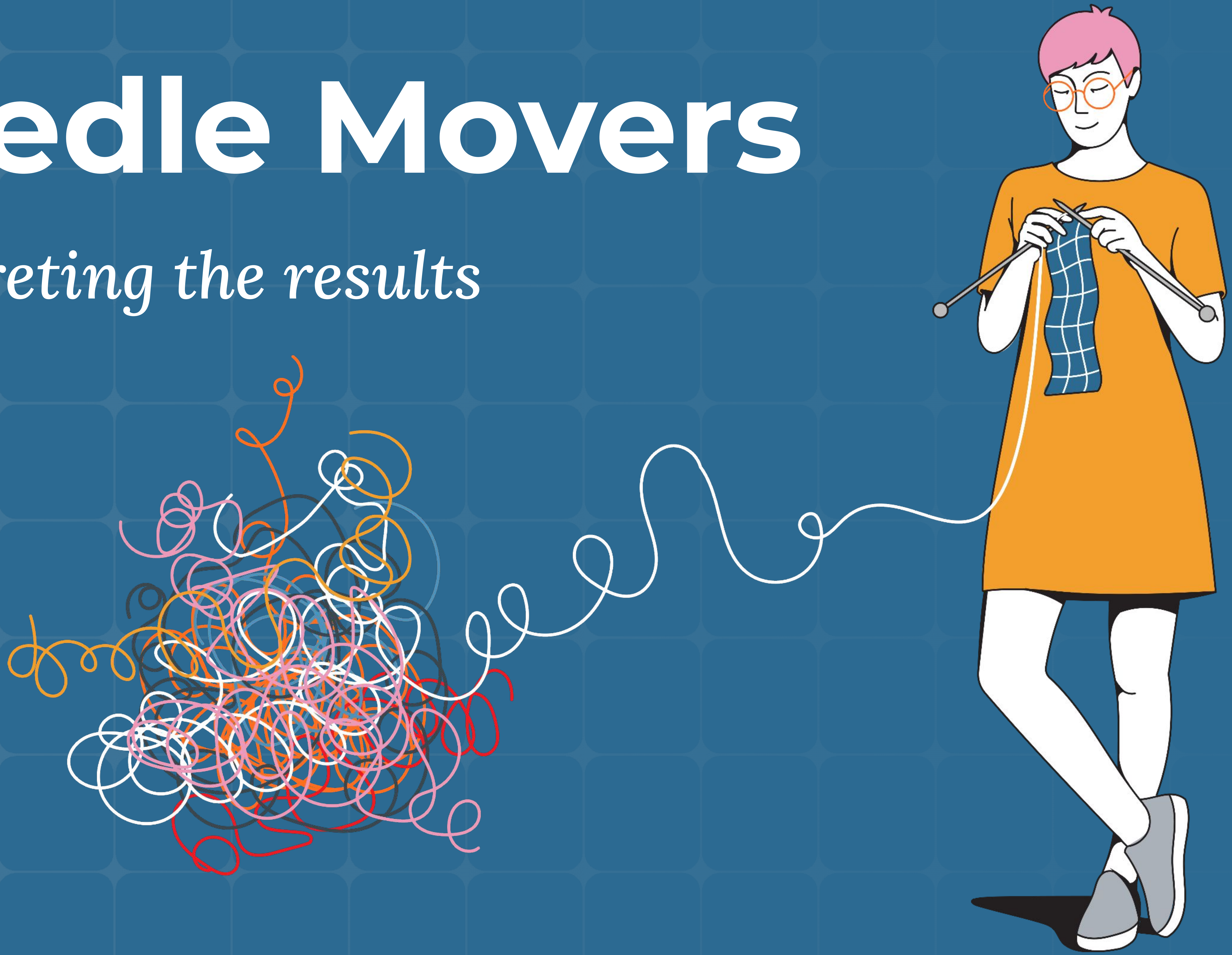
Cross-System Interaction Heatmap

How many downstream design decisions, systems, or disciplines are affected when this parameter changes?

	Energy	Layout	Blocking	Electrical Engineering	Procurement	Value
Inverter Type	1	1	1	1	1	**5**
Inverter Power	1	1	1	1	1	**5**
Module Selection	1	1	1	1	1	**5**
CBX/LBD Selection	0	0	0	1	1	**2**
Wire Sequence	0	0	0	1	1	**2**
CBX/LBD Position	0	0	0	1	0	**1**
CBX/LBD Clustering	0	0	0	1	0	**1**
Row Grouping	0	0	0	1	1	**2**
Harness Configuration	0	0	0	1	1	**2**
Boundaries Complexity	0	1	1	0	0	**2**
Wire Gauges Unification	1	0	0	1	1	**3**
Block Footprint	0	1	1	0	0	**2**
Row Height	0	1	1	0	0	**2**

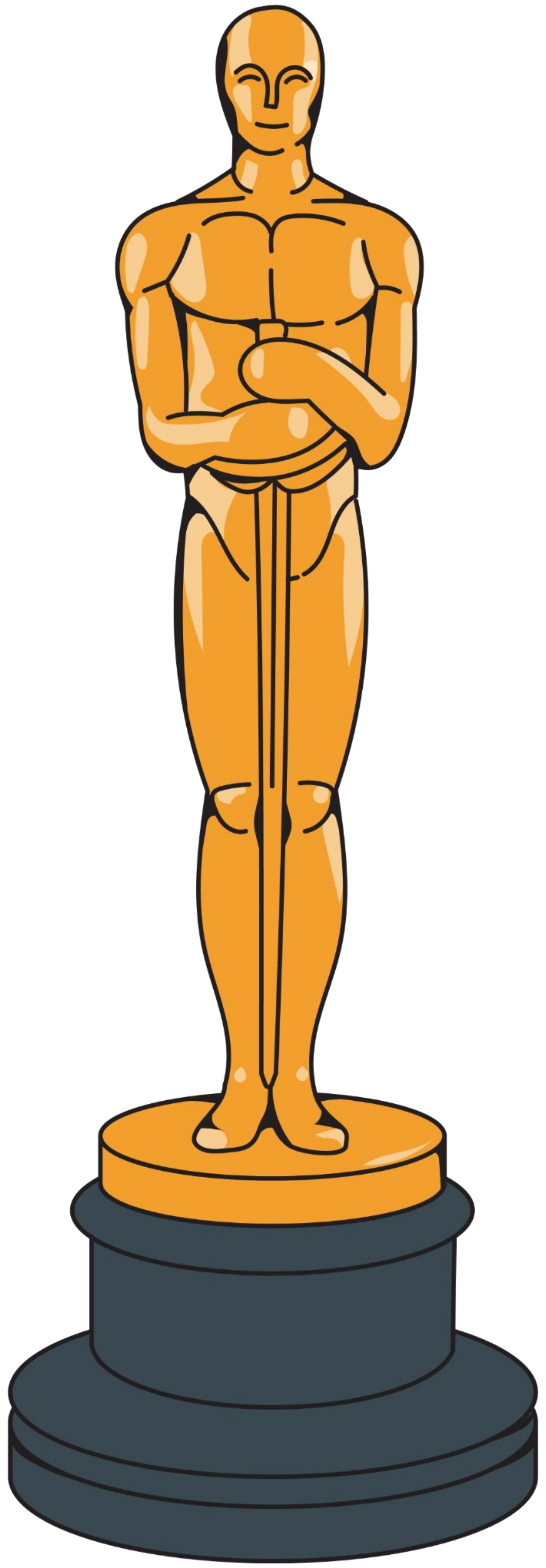
Needle Movers

Interpreting the results

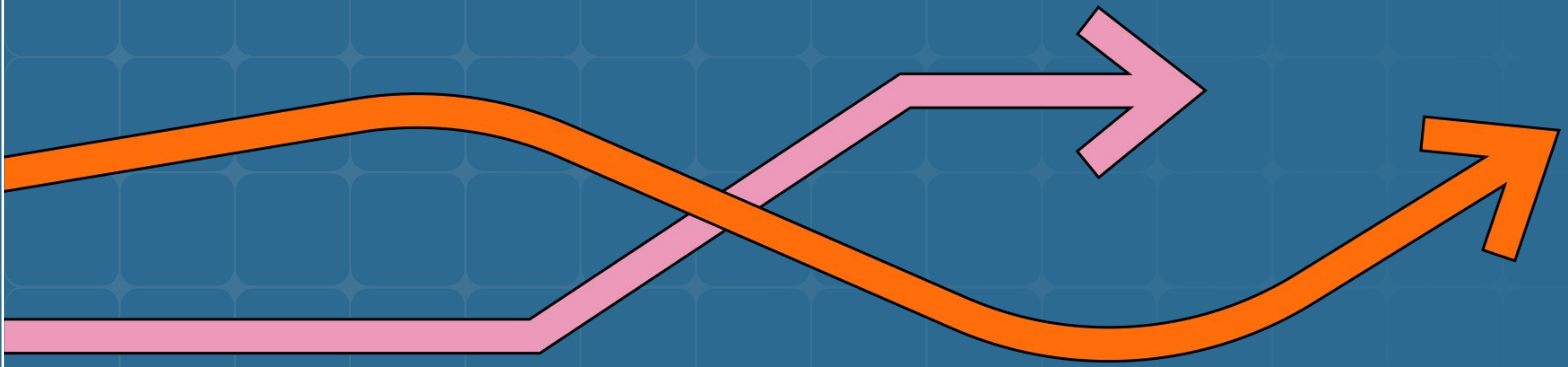


Scored Parameter List

Electrical Parameters	*Cost Impact*	*Lock-In-Risk*	*System Interaction*	*Total Score*
Module Selection	3	5	5	13
Inverter Type	1	4	5	10
Wire Sequence	5	2	2	9
Boundaries Complexity	2	5	2	9
Inverter Power	1	3	5	9
CBX/LBD Position	4	3	1	8
Row Grouping	3	3	2	8
Row Height	1	4	2	7
CBX/LBD Selection	1	3	2	6
Block Footprint	1	3	2	6
CBX/LBD Clustering	1	3	1	5
Harness Configuration	1	2	2	5
Wire Gauges Unification	1	1	3	5



PVFARM	Module Selection: **thin-film**	Module Selection: **crystalline**	Inverter Type: **String**	Inverter Type: **Central**	Wire Sequence: **H→W→F**	Wire Sequence: **H→EWT→F**	Wire Sequence: **E→EWT→F**	Wire Sequence: **NST→F**	Boundaries Complexity	Inverter Power	CBX/LBD Position: **End of Row**	CBX/LBD Position: **Middle of Row**	Row Grouping: **Single Array**	Row Grouping: **Multi Array**	Row Height: **One SAT**
Module Selection: **thin-film**					❤️	❤️	💀	❤️			❤️	💀			
Module Selection: **crystalline**															
Inverter Type: **String**					❤️	💀	💀	💀							
Inverter Type: **Central**															
Wire Sequence: **H→W→F**	❤️		❤️								❤️	💀			
Wire Sequence: **H→EWT→F**	❤️		💀								❤️	💀			
Wire Sequence: **E→EWT→F**	💀		💀										❤️	💀	❤️
Wire Sequence: **NST→F**	❤️		💀								❤️	💀			
Boundaries Complexity															
Inverter Power															
CBX/LBD Position: **End of Row**	❤️				❤️	❤️		❤️							
CBX/LBD Position: **Middle of Row**	💀				💀	💀		💀							
Row Grouping: **Single Array**							❤️								
Row Grouping: **Multi Array**							💀								
Row Height: **One SAT**							❤️								



Ways to Design EBOS

There's more than one way to do it right – it all depends on the context, including inputs, goals, and constraints

Thank you!

Any questions?

PVFARM