# Energy Storage Optimization for Solar Power Plant Applications

Andrew Oliver, PhD. Chief Technology Officer

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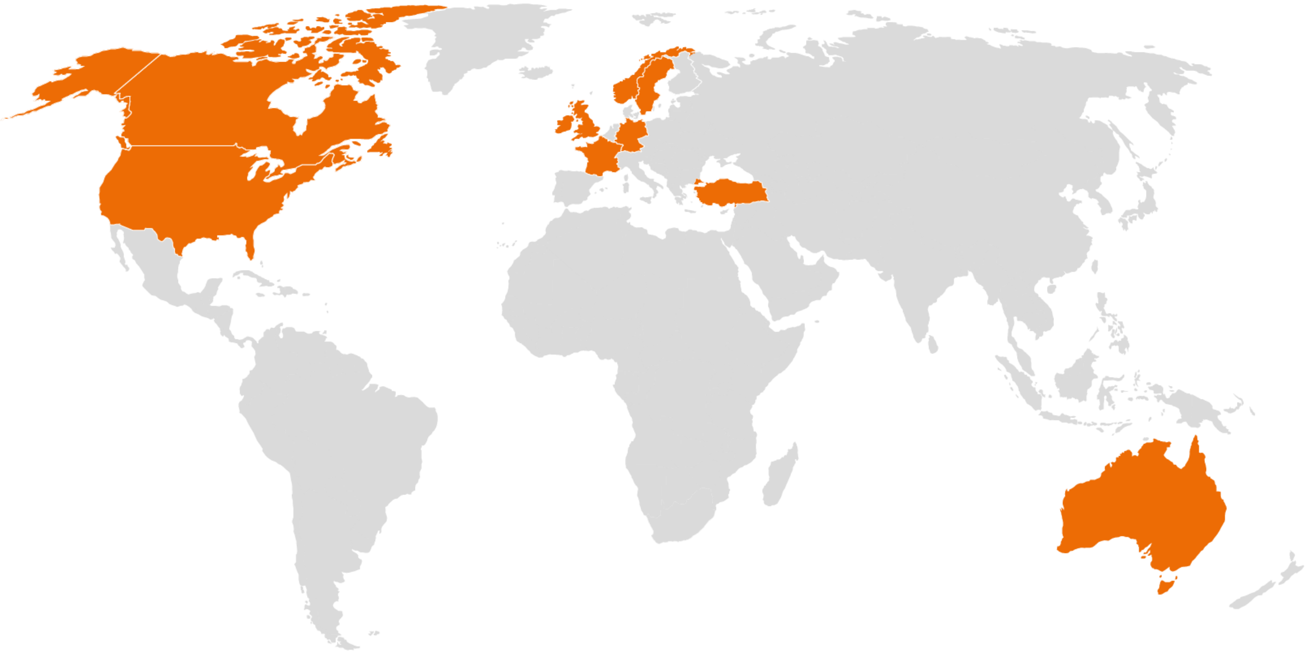
# RES Overview

**16,000** MW
CONSTRUCTED / DEVELOPED

**37**
YEARS OF EXPERIENCE

**5,000** MW
OF OPERATIONAL ASSETS SUPPORTED

**2,000**
EMPLOYEES



## ACTIVITIES

- DEVELOP
- CONSTRUCT
- OPERATE

## TECHNOLOGIES

- WIND
- SOLAR
- STORAGE
- T&D

# Background - Why solar plus storage?

SOLAR

- ✓ Fastest growing renewable & cost reductions expected to continue to outstrip wind
- ✓ Capture prices expected to be at or above LCOE in all markets (except CAISO) by 2023

STORAGE

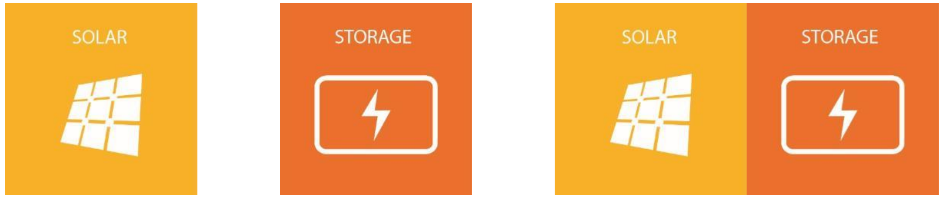
- ✓ 2 hour 'peaker' storage now pricing at < $700/kW
- ✓ The grid's "multi-tool" (ancillary services, black start, etc)
- ✓ Sub 200ms from 'rail to rail' time easily achieved

SOLAR + STORAGE

- ✓ Capacity provision with zero fuel cost by using 'clipped energy' (see 'DC coupled')
- ✓ Zero Cost interconnection for the storage
- ✓ Solar arbitrage: becoming more important as
  - Renewable penetration increases (hedges price cannibalization)
  - Price volatility increases & market settlement windows reduce
- ✓ Ramp mitigation when the sun is going down, or on partially cloudy days

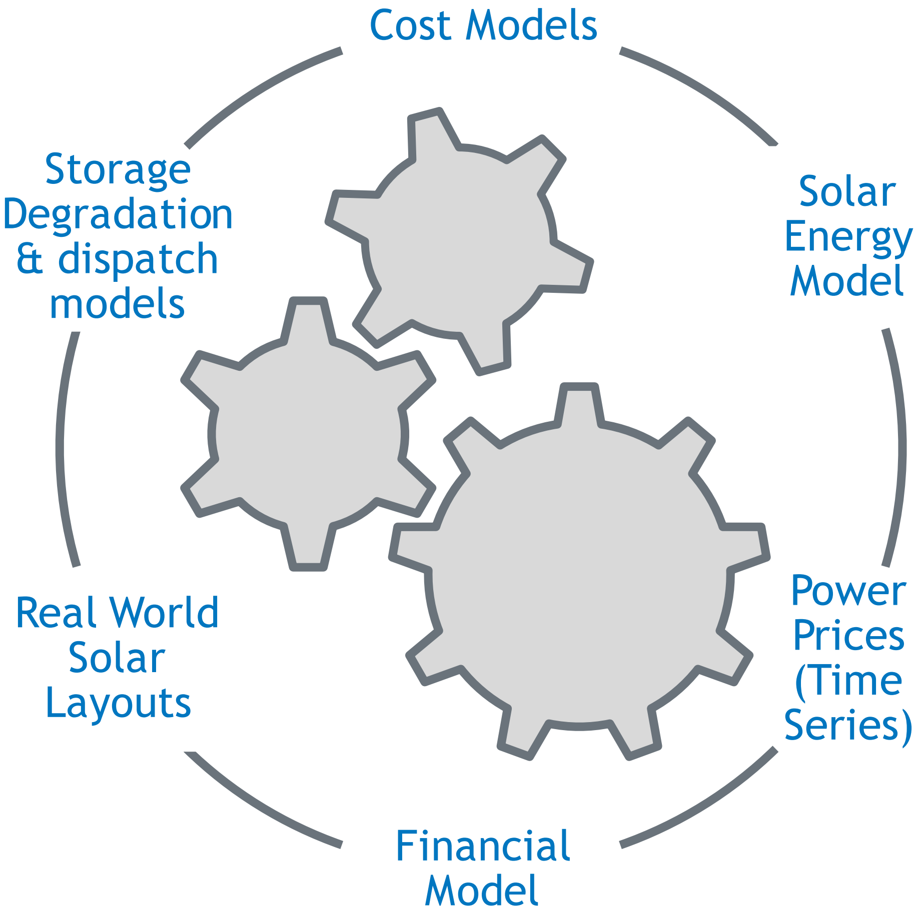
# Background - Purpose (Our Business need)

For the following technologies




And for a given business case, optimize for either

1) Lowest Cost of Energy
   - Use case: Development team bid for a PPA
2) Maximum Revenue to a Corporate CfD provider
   - Use case: Development team bid for a PPA
3) Lowest CapEx
   - Use case: Construction team bid to owner who has already selected panels, trackers, etc.




By integrating these components

CfD = Contract for Difference (virtual PPA)

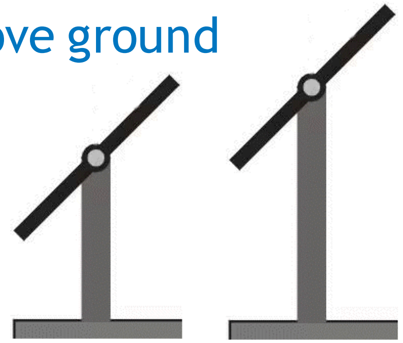
# Solar Design Levers & Considerations

# Solar Design Levers

Solar design is complex to optimize: below are some of the parameters that can be changed

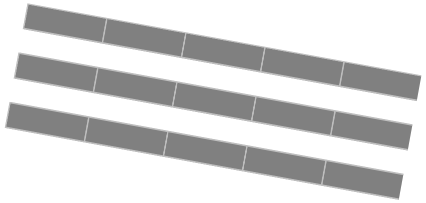
- Each parameter affects Energy production and CapEx. Some affect OpEx, such as land area (i.e. land rent)
- The Optimal Design will change dependent on latitude and other site characteristics

## Height above ground



Important for Bi-facial panels

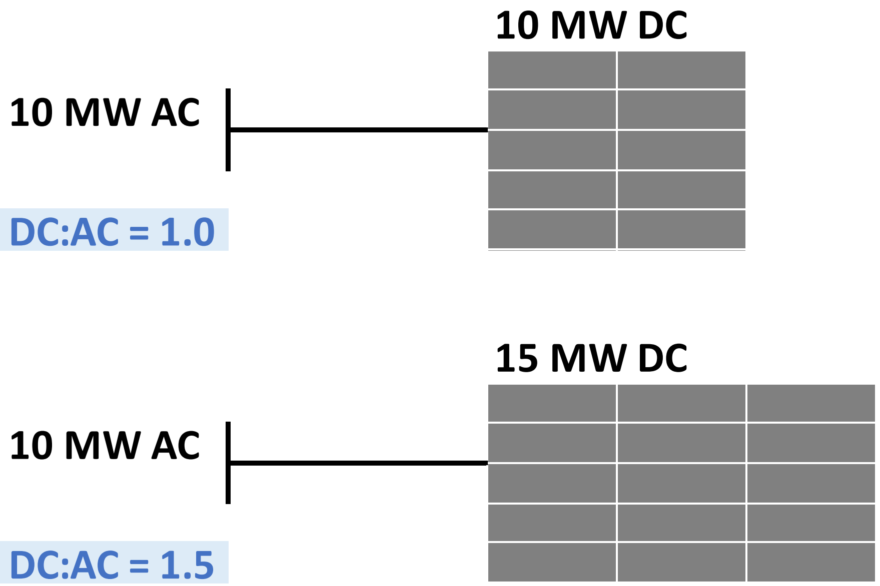
## Azimuth



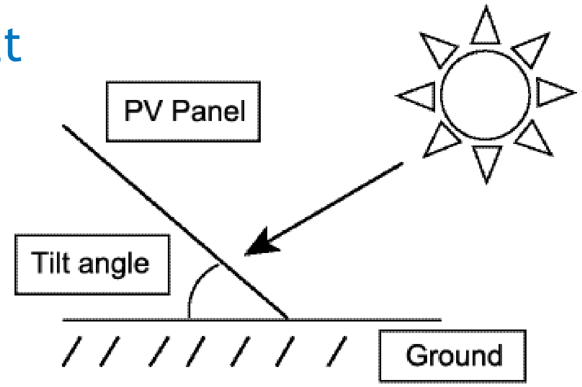
## DC/AC ratio

AC GRIDCONNECTION

DC ARRAY SIZE

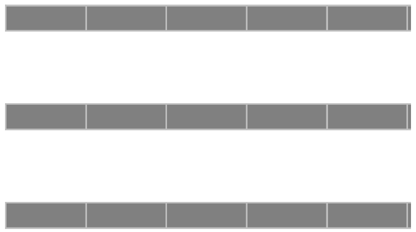



## Tilt




Fixed tilt systems only

## Ground Cover Ratio

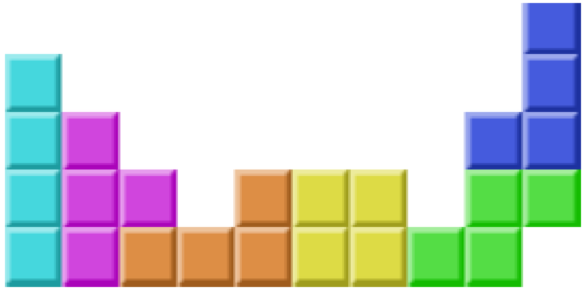


# Real World Solar Layout Design ("Block Tetris")

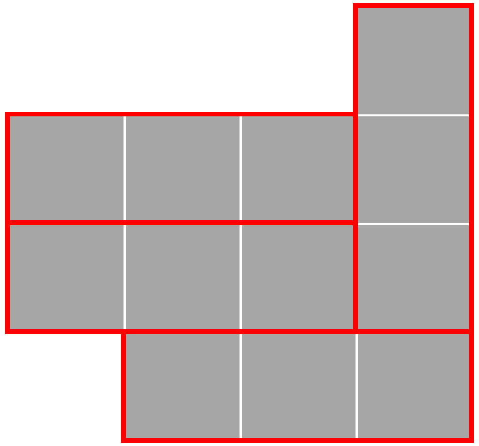
- Real sites aren't ideal
  - Fields usually aren't rectangular in shape
  - There are often many areas where arrays can't be built

- How do we fit our standard 'electrical block' into a given land boundary while minimizing the number of bespoke electrical blocks?
  - To ensure that every block has a fully utilized inverter
  - That blocks are contiguous to the extent possible
  - While minimizing electrical losses

- RES uses the term "Block Tetris" to describe this problem



Tetris



"Block Tetris"

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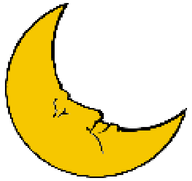
# Storage Design Levers & Considerations

# The Arbitrage Fallacy

Energy Storage is not just about “Buy low, sell high” a.k.a. ‘Arbitrage’, so modeling needs to stack values



2MWh @ $10/MWh
TOTAL = $20


2MWh @ $60/MWh
TOTAL = $120

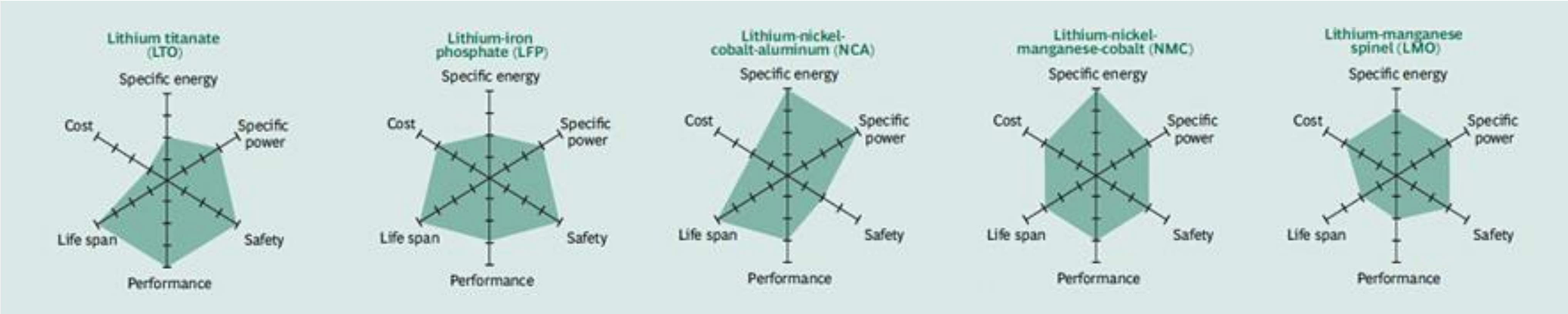

**$ 36,500 / MW / yr**

- A 2 hour battery costs a bit shy of $400k for the modules & racks alone!!
- Most grid nodes have Simple Payback of 15+ years, though some high value nodes can beat this if prices persist
- Storing curtailed wind or solar energy is simply an arbitrage case where the buy-price is zero

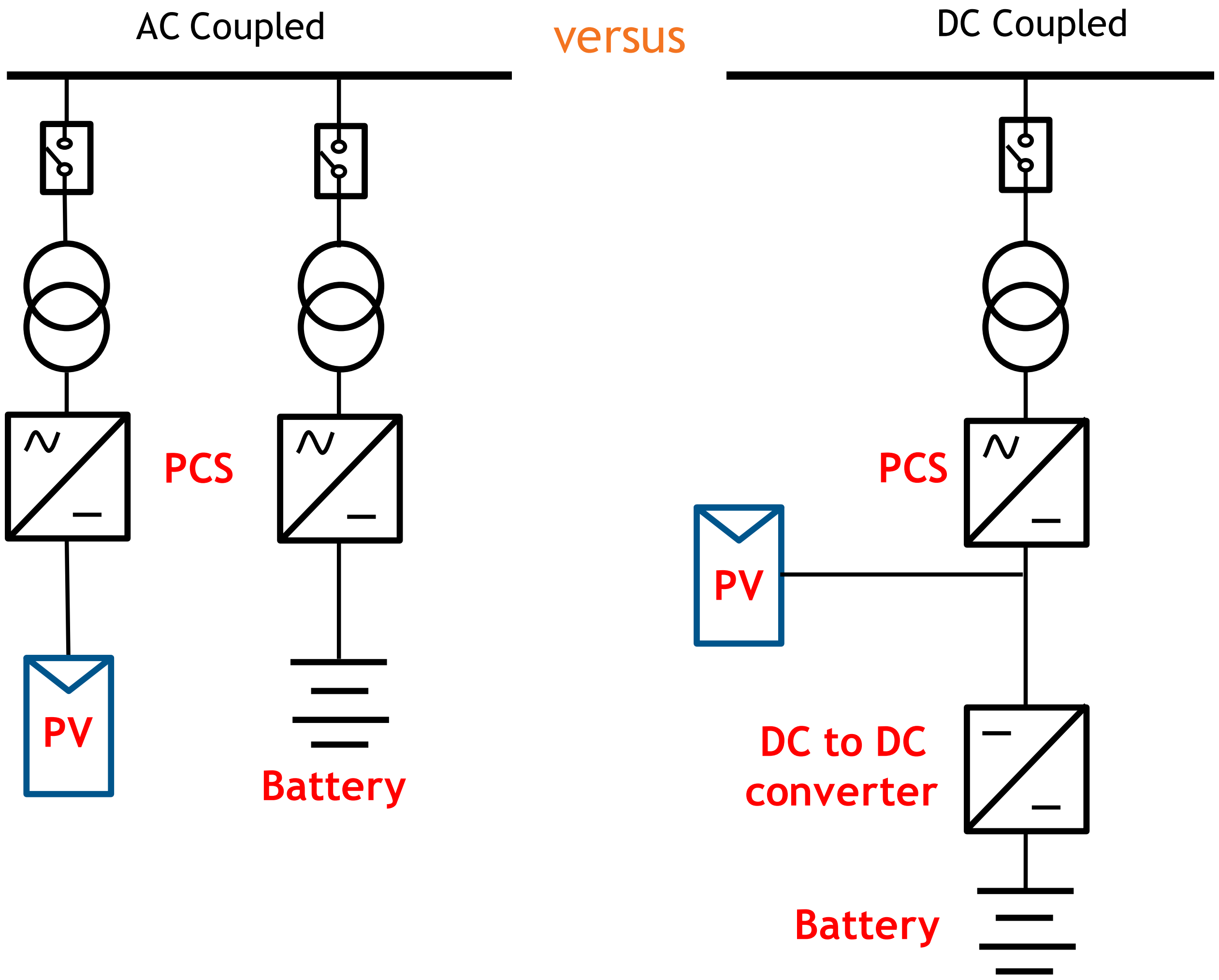
# Lithium Batteries come in many ‘flavors’

- Safety (Some chemistries are inherently safer than others)
- Current rate limitation (How quickly can I charge and discharge my battery?)
  - Faster charging batteries generally cost more
- Round trip efficiency (If I put 100 units of energy into the battery how many will I get out?)
- Usable ‘state of charge range’ (If I buy 100 units of storage can I use it all?)
- Commodity Cost (Some have more expensive metals in them)
- Cycle life (Some chemistries are capable of more cycling)
- Energy Density (Some require more volume to store the same amount of energy >> BOS cost)
- Use case details
  - E.g. Holding afternoon solar over night for morning dispatch requires a larger battery
  - E.g. Definitions: Guaranteeing that 90% of 365 days will have a 2 hour post-sundown dispatch is very different from saying that I will fill deliver a total of 657 hours (90% of 730 hours) in the same window

“Here’s your beer, but you can’t drink it all!”

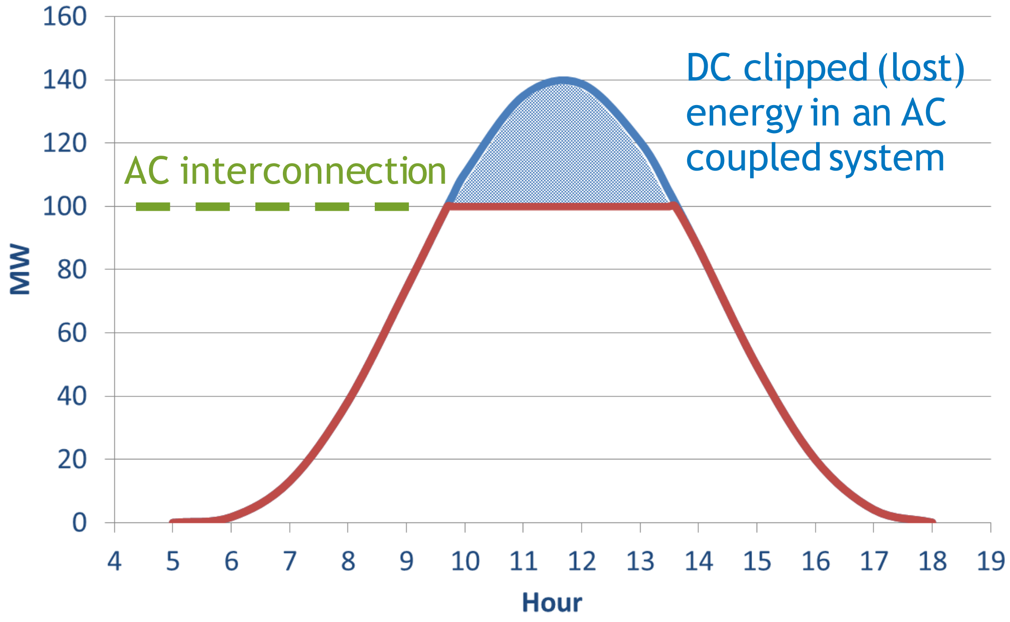


# DC versus AC coupled system topology




## Some advantages of DC coupled

- Half as many switchgear and pad transformers
- Up to 2% lower losses for solar energy that goes through the battery
- Capture of clipped Solar Energy



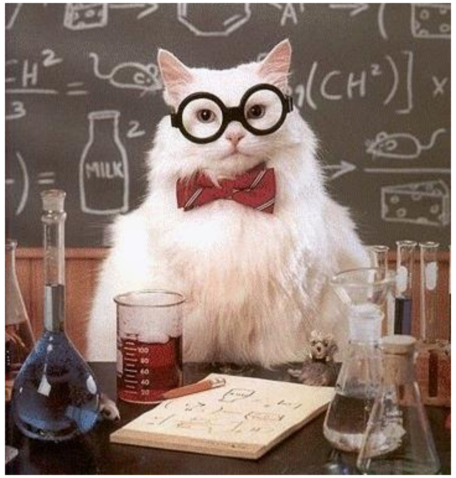
# Solar + Storage: A design challenge

# Perspectives & key takeaways

1. Adding energy storage always increases the delivered cost of solar energy on a $/MWh basis (a battery storage does not create energy!), so we need to solve a simple value equation (otherwise just build solar)

Market Value (Solar+Storage) – LCOE (Solar+Storage) > Market Value (Solar Only) – LCOE (Solar Only)

2. To maximize value, we cannot standardize the ratio of storage MW to solar MW, the duration of energy storage or the solar-pv DC/AC ratio: these are all highly dependent on the use case



**As you can probably tell by now, "It's Comp-li-cat-ed"**

- Literally millions of solar + storage designs are possible

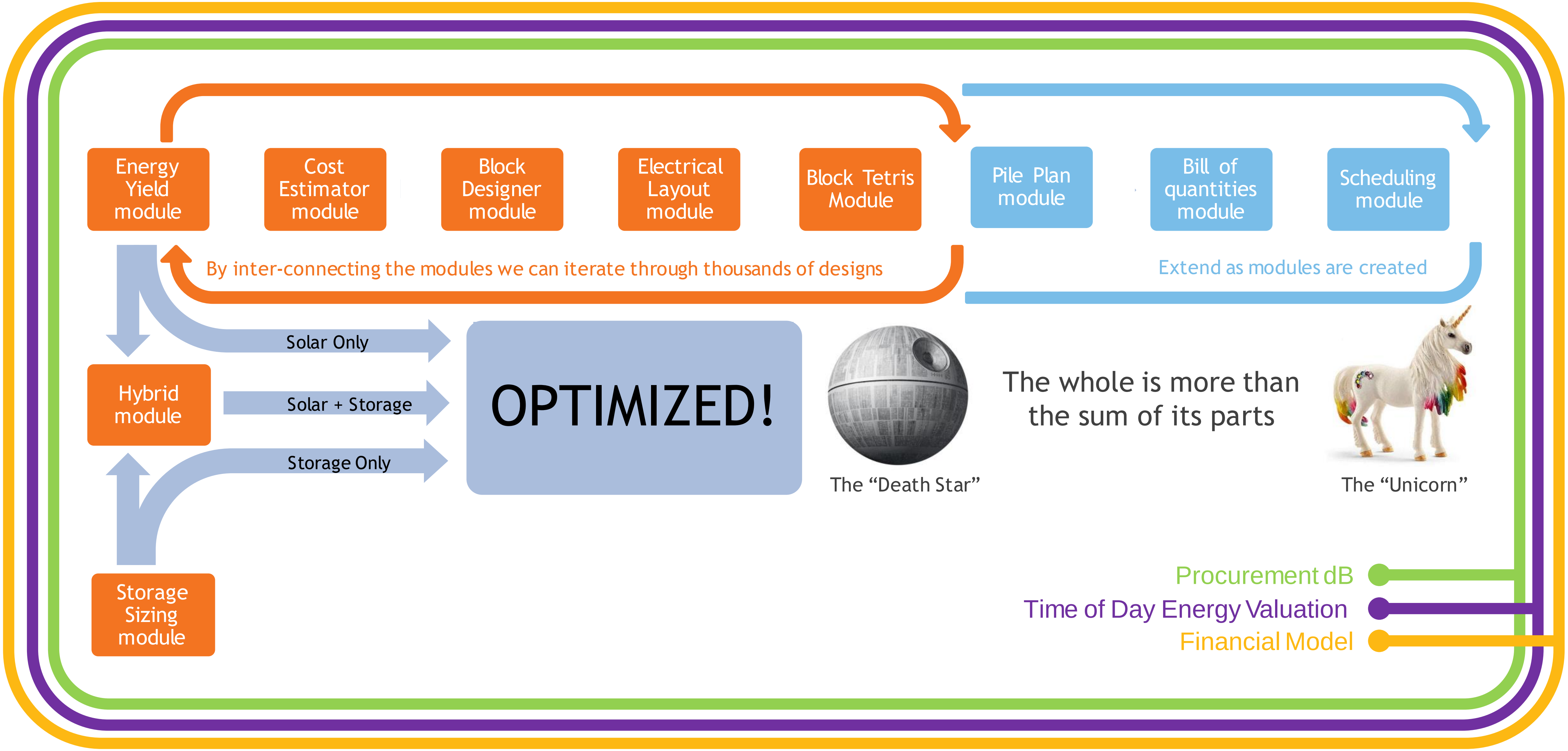
  Q: How do we find the best one?

  A: Not without computational firepower & fully integrated models

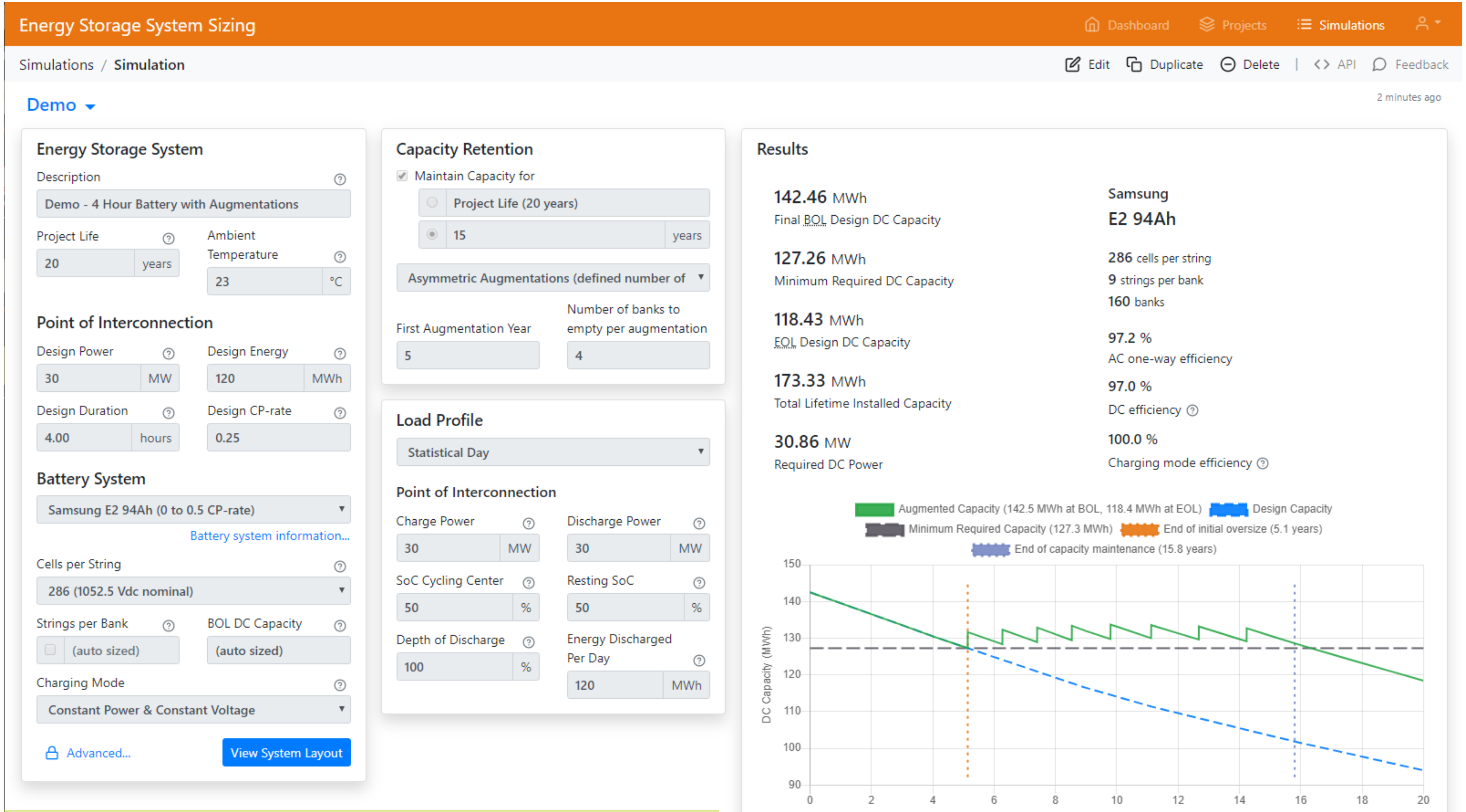
Key takeaways: Unless you have fully integrated models, you will leave money on the table and / or waste a lot of time exploring options. You will also need to be highly prescriptive about how you will operate the plant upfront as there only so many configurations that can be explored by hand

# A Vision

- Optimizing the outcome for a subsystem will not, in general, optimize the outcome for the system as a whole ("The Prisoner's dilemma")



# RES Storage degradation & replenishment tool



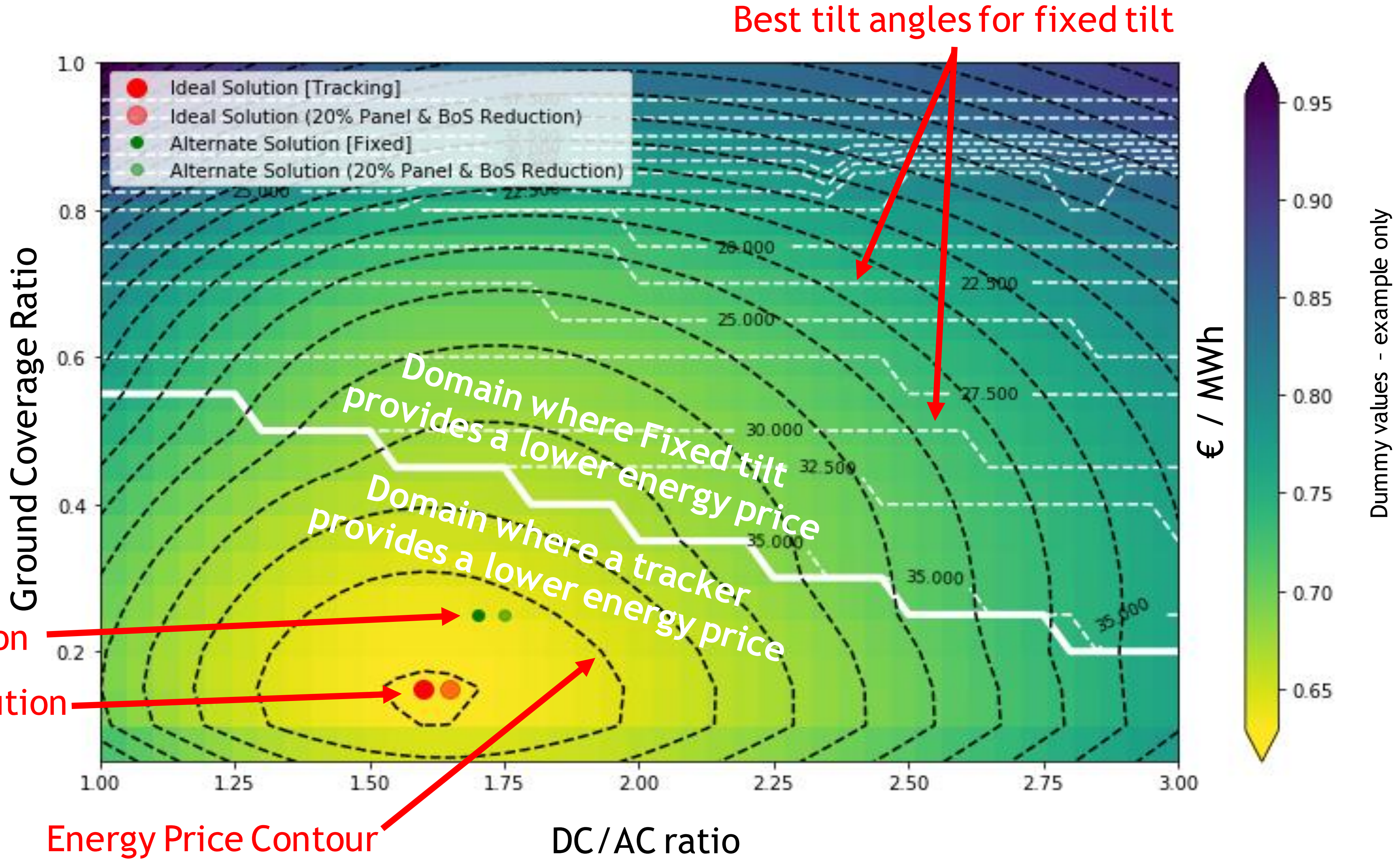

RES already had a battery degradation & replenishment calculator. Our challenge was to integrate this with our solar tools

# Case Studies

# Example Result (Solve for lowest LCOE: Solar Only)

Inputs


- AC MW
- Land available
- Land Cost
- Equipment choices



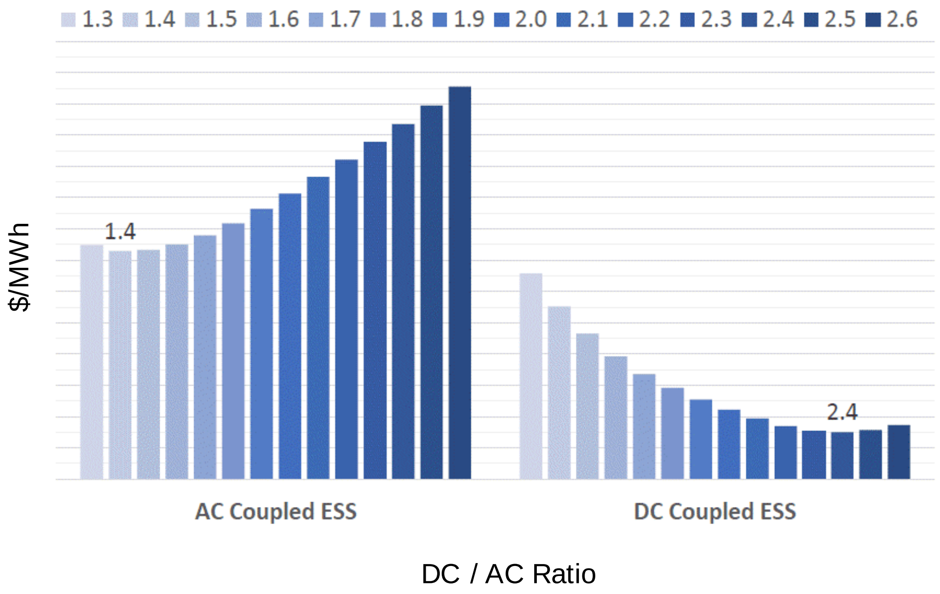
# Example Result (Solve for lowest LCOE: Solar + Different Storage Durations)

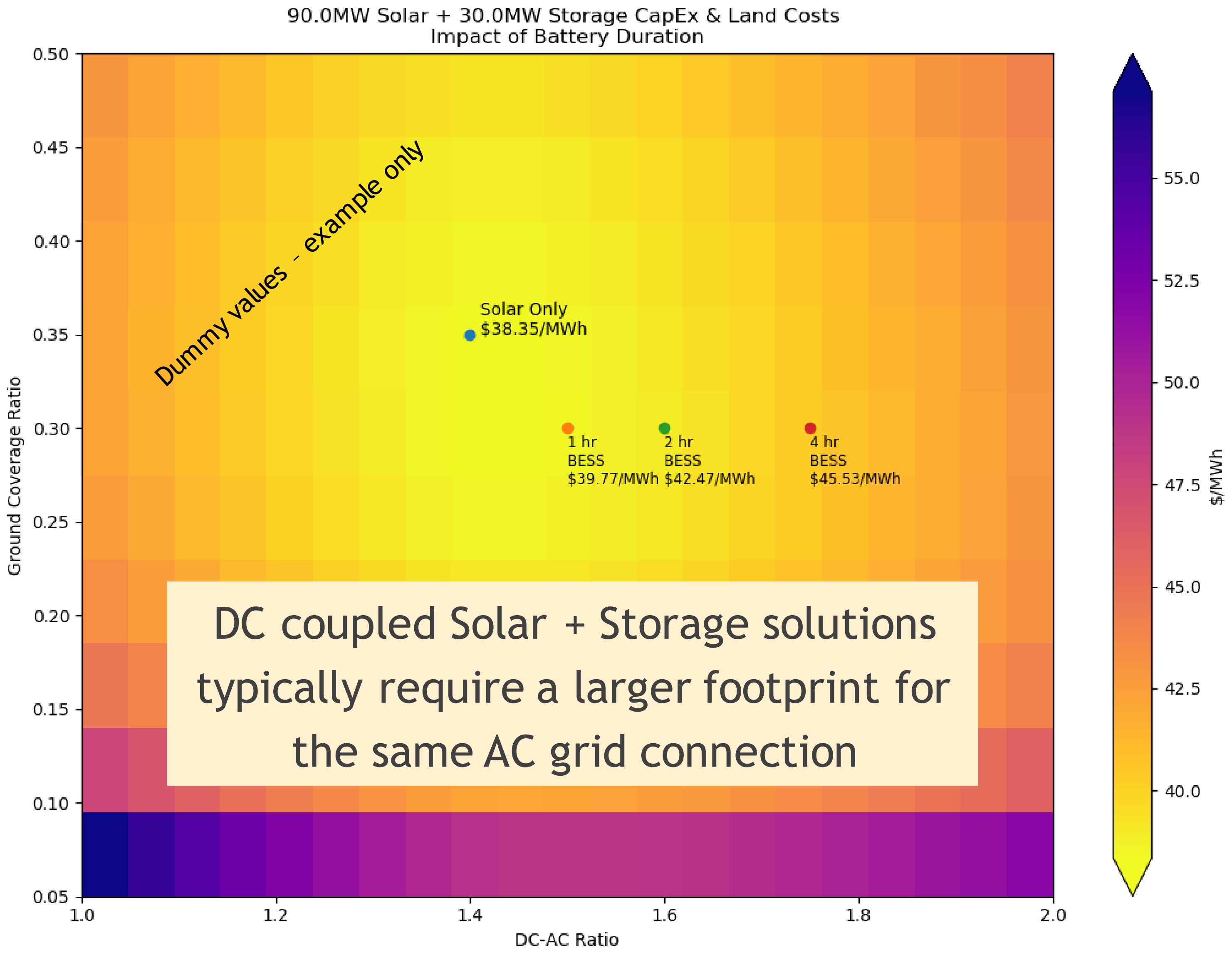
## Simple Use case

Put all the clipped solar energy in the battery and discharge it just after the sun goes down

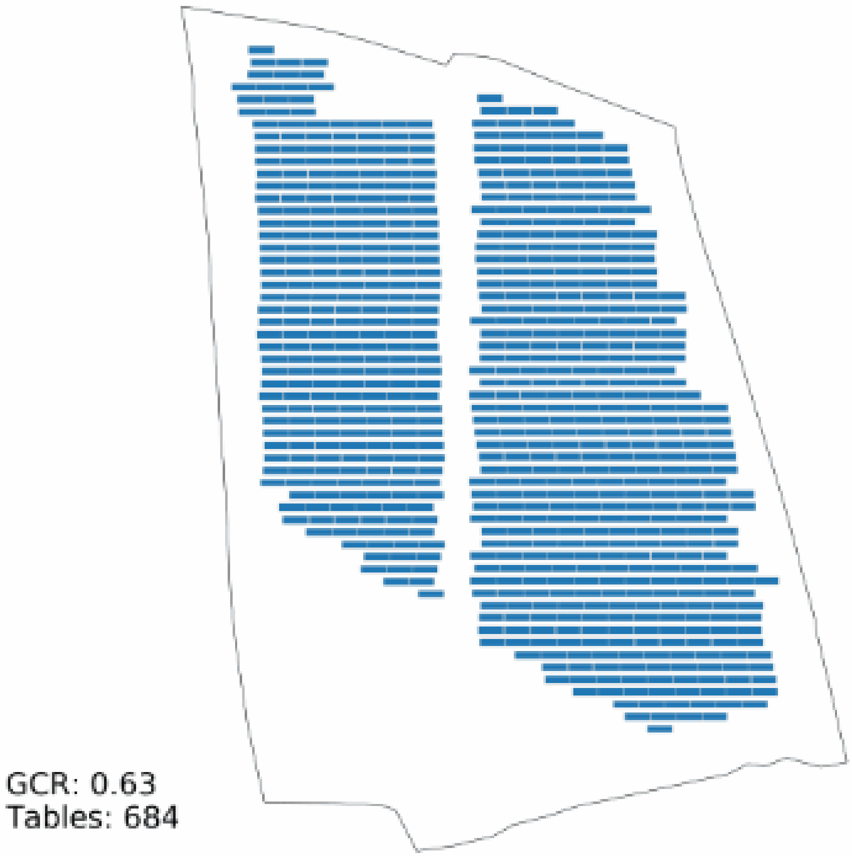
## DC coupled vs AC coupled

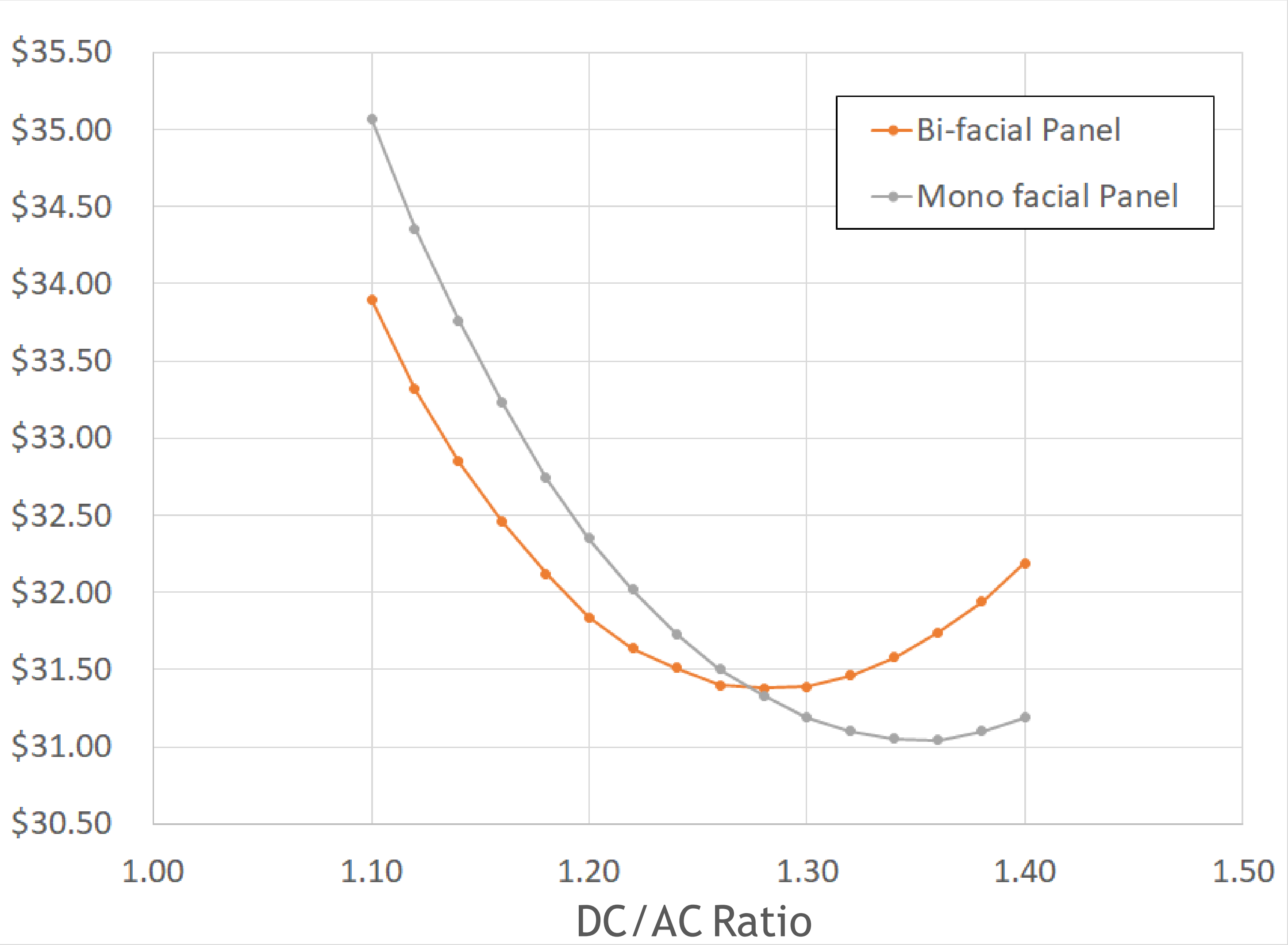
DC coupled solutions can sometimes provide much better economics



# Integrate “Block Tetris” (Work in Progress)



# Capacity "Blocks"

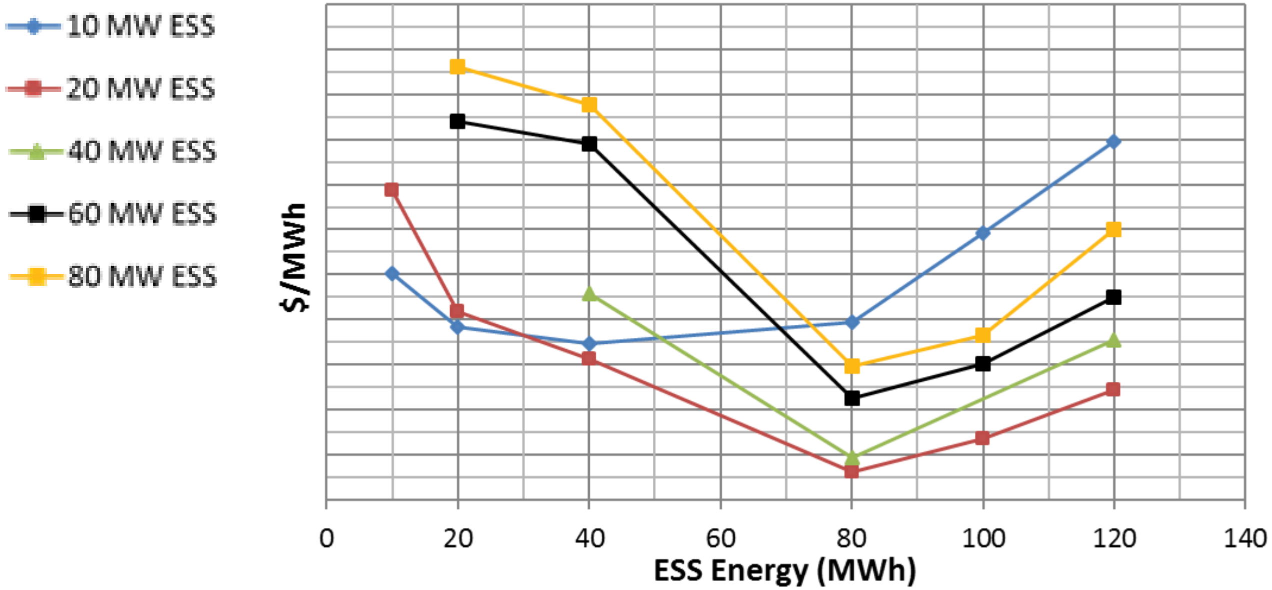
Capacity payments typically worth $20,000 to $100,000 / MW / year (dependent on market)

An example analysis might ask, "What amount of storage is required to deliver capacity blocks of N hours with a certain confidence for 300 days / year?"

Month of Year

| Hour of Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 3 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 4 | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| 5 | 0% | 0% | 0% | 2% | 13% | 21% | 15% | 4% | 0% | 0% | 0% | 0% |
| 6 | 0% | 0% | 3% | 25% | 45% | 53% | 54% | 36% | 12% | 2% | 0% | 0% |
| 7 | 0% | 4% | 24% | 53% | 56% | 62% | 67% | 66% | 49% | 24% | 4% | 0% |
| 8 | 11% | 28% | 46% | 60% | 62% | 69% | 72% | 73% | 60% | 50% | 27% | 11% |
| 9 | 34% | 44% | 52% | 65% | 68% | 74% | 77% | 76% | 64% | 55% | 38% | 31% |
| 10 | 38% | 48% | 59% | 70% | 72% | 78% | 79% | 79% | 68% | 58% | 40% | 33% |
| 11 | 40% | 55% | 67% | 74% | 74% | 78% | 81% | 80% | 71% | 60% | 43% | 36% |
| 12 | 40% | 54% | 67% | 74% | 74% | 78% | 79% | 80% | 71% | 59% | 43% | 36% |
| 13 | 38% | 53% | 65% | 72% | 72% | 76% | 78% | 79% | 69% | 57% | 40% | 33% |
| 14 | 36% | 47% | 57% | 66% | 67% | 72% | 76% | 74% | 64% | 54% | 39% | 31% |
| 15 | 30% | 42% | 50% | 58% | 60% | 66% | 68% | 67% | 59% | 49% | 27% | 19% |
| 16 | 7% | 26% | 42% | 51% | 52% | 59% | 61% | 60% | 50% | 24% | 4% | 1% |
| 17 | 0% | 4% | 18% | 39% | 43% | 52% | 54% | 48% | 22% | 2% | 0% | 0% |
| 18 | 0% | 0% | 1% | 8% | 20% | 33% | 33% | 16% | 2% | 0% | 0% | 0% |
| 19 | 0% | 0% | 0% | 0% | 2% | 6% | 6% | 1% | 0% | 0% | 0% | 0% |
| 20 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 21 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 22 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | | | | | | | | | 0% | 0% | 0% | 0% |

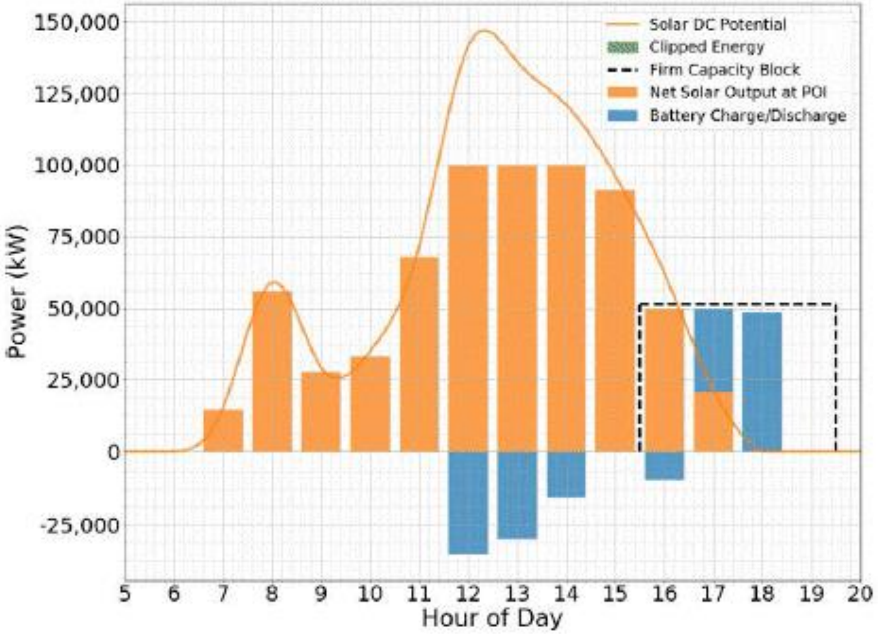
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 3 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 4 | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| 5 | 0% | 0% | 0% | 1% | 5% | 11% | 8% | 2% | 0% | 0% | 0% | 0% |
| 6 | 0% | 0% | 0% | 8% | 23% | 34% | 31% | 17% | 1% | 0% | 0% | 0% |
| 7 | 0% | 0% | 0% | 25% | 35% | 46% | 48% | 39% | 16% | 0% | 0% | 0% |
| 8 | 0% | 0% | 0% | 35% | 47% | 58% | 64% | 55% | 31% | 3% | 0% | 0% |
| 9 | 0% | 0% | 3% | 50% | 57% | 65% | 72% | 68% | 44% | 16% | 0% | 0% |
| 10 | 0% | 2% | 23% | 56% | 62% | 72% | 77% | 75% | 55% | 31% | 1% | 0% |
| 11 | 1% | 19% | 39% | 62% | 66% | 76% | 79% | 78% | 61% | 40% | 8% | 0% |
| 12 | 9% | 28% | 47% | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 18% | 2% |
| 13 | 18% | 35% | 55% | 99% | 99% | 100% | 100% | 100% | 96% | 89% | 24% | 12% |
| 14 | 25% | 39% | 53% | 96% | 96% | 99% | 99% | 99% | 91% | 79% | 29% | 18% |
| 15 | 23% | 38% | 49% | 87% | 86% | 94% | 95% | 95% | 79% | 69% | 21% | 11% |
| 16 | 6% | 24% | 41% | 74% | 77% | 86% | 89% | 88% | 72% | 52% | 3% | 1% |
| 17 | 0% | 3% | 17% | 0% | 1% | 1% | 2% | 1% | 0% | 0% | 0% | 0% |
| 18 | 99% | 100% | 100% | 2% | 8% | 17% | 19% | 7% | 0% | 0% | 99% | 98% |
| 19 | 73% | 92% | 99% | 0% | 1% | 3% | 3% | 1% | 0% | 0% | 79% | 67% |
| 20 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 21 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 22 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 23 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |



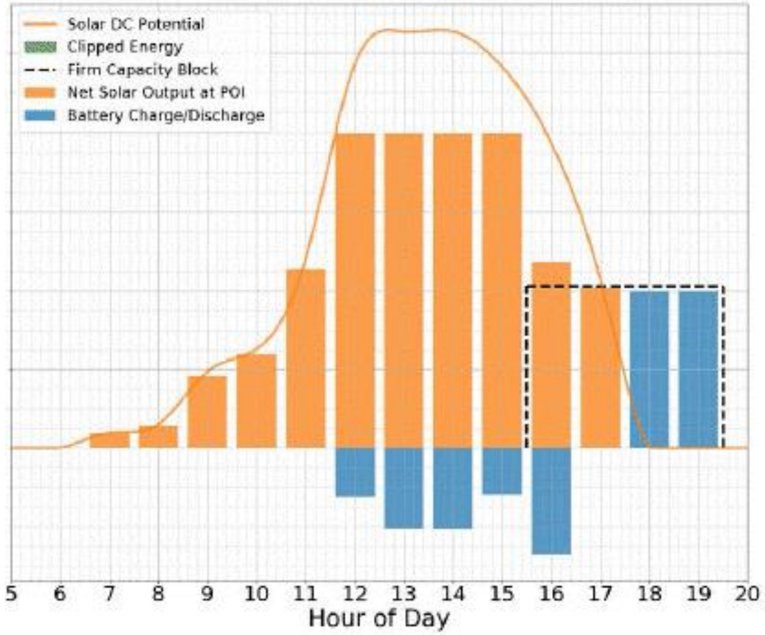

… The answer would not be obvious or tractable without computational firepower

# Evening sunshine?

In this example we are creating 4 hour blocks of power in the evening with a 2h battery and comparing two different solar fixed-tilt configurations of different azimuths (180° & 225°)




| Array Azimuth | 180° (South facing) |
|---|---|
| Firm Power Perf. | 75% |
| Generation | 286 GWh / Year |




| Array Azimuth | 225° (South-west facing) |
|---|---|
| Firm Power Perf. | 100% |
| Generation | 263 GWh / Year |

- The south-facing solar array generates 8.7% more energy
- However, it only fills up the firm capacity blocks 75% of the time compared to the s.w. facing array
- Should we add more batteries (south facing array), or accept that we'll generate less energy (s.w. array)?

This trade-off of more energy versus fewer batteries is easy to evaluate, provided that your software tools are fully integrated

# Key Takeaways

- Unless you have fully integrated models, you will leave money on the table and / or waste a lot of time exploring options

- You will then also need to be highly prescriptive about how you will operate the plant upfront as there only so many configurations that can be explored by hand

- Models to integrate include:
  - Cost Models (Solar & Storage)
  - Energy Models (Solar)
  - Power Prices (Time Series)
  - Financial Model
  - Real World Solar Layout Design
  - Storage Degradation & Dispatch models

Can solar + storage defeat
the dastardly duck curve?

# Thank You

Andrew Oliver, PhD.
Chief Technology Officer
andrew.oliver@res-group.com