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Transforming ENERGY

Toward Integrated Transmission-Distribution Planning: Approaches and Perspectives

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Outline

1 Why capture T&D together?

2 T&D Simulation vs T&D Planning

3 Deep Dive: Experiences from LA100

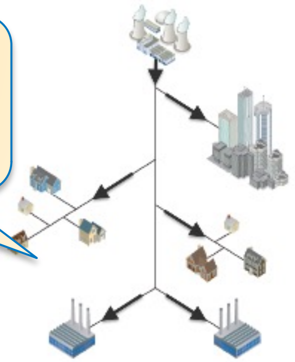
4 Future Directions

Evolution of the Grid → Evolution of Distributed Energy Resource (DER) behavior

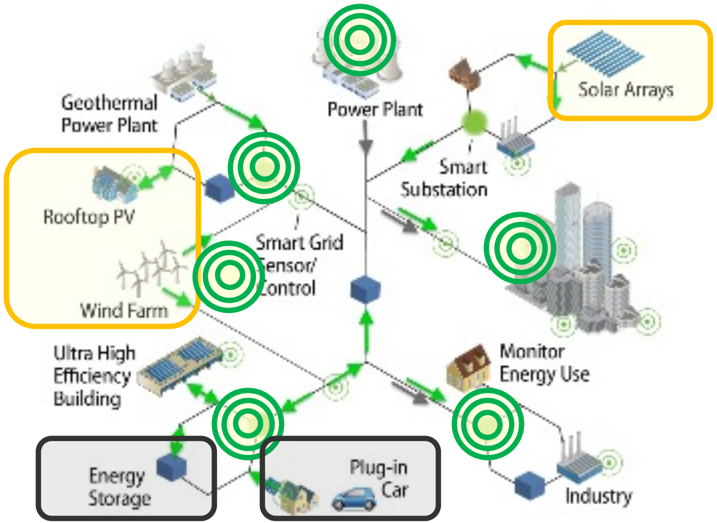
Figures adapted from Dr. Ben Kroposki, NREL

Current Power System

- Large Generation
- Central Control
- Highly Regulated



Emerging Power System

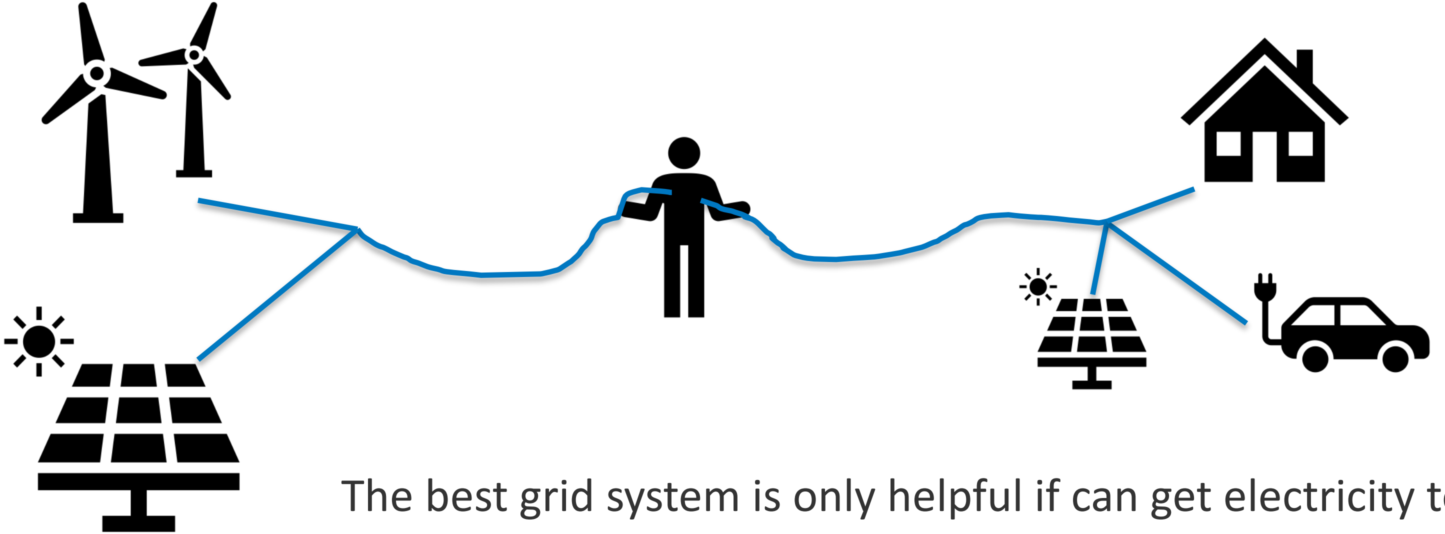


DRIVERS
- Increased variable generation
- More bi-directional flow at distribution level
- Increased number of smart/active devices
- Evolving institutional environment

Our Evolving Power System Context

- Explosion of DER resources: Solar, Storage
  - Up to ~5+MW likely distribution connected
- Electrification of transportation
- New communications and controls (e.g. Smart Grids)
- Updated standards – e.g. IEEE 1547-2018
- TSO-DSO (e.g. NY-REV, Europe, etc.)
- FERC 2222: Let the DERs participate

Why Include Distribution?



The best grid system is only helpful if can get electricity to the customer...

And increasingly customers/others want to share their solar/storage production

Transmission & Distribution Together

Application	Needs
DER Energy Impacts (Net Load)	Data Exchange
Low Penetration price-responsive DERs	Data Exchange
Higher-Pen price-responsive DERs (Price Maker)	Technical potential: lumped DERs D-limits: T&D Co-simulation
Bulk Services from DER and DR	Technical potential: lumped DERs D-limits: T&D Co-simulation
TSO-DSO/Aggregator Market Design	Co-Simulation
Distribution-Sited System Resources	Iterative hand-offs?
Non-wires Alternatives	Scenario Comparisons
Truly Co-designed T&D	Work in progress

Project funding: GMLC 1.4.15

Co-simulation -- e.g. HELICS™:

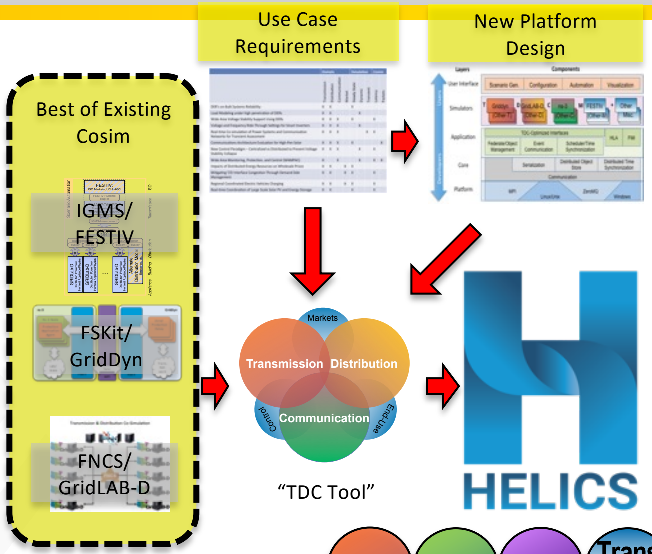
Hierarchical Engine for Large-scale Infrastructure Co-Simulation

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

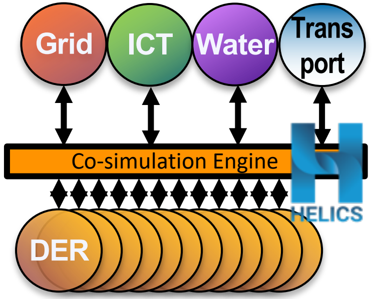
High-performance co-simulation to combine best-in-class tools for breakthrough ESI analysis

Capabilities:

- **Scalable:** 2-100,000+ Federates
- **Cross-platform:** HPC (Linux), Cloud, Workstations, Laptops (Windows/OSX)
- **Modular:** mix and match tools
- **Minimally invasive:** easy to use lab/commercial/open tools
- **Open Source:** BSD-style.
- **Many Simulation Types:**
  - Discrete Event
  - QSTS
  - Dynamics
- **Co-iteration enabled:** "tight coupling"



v2.0 available now at https://www.github.com/GMLC-TDC/HELICS-src

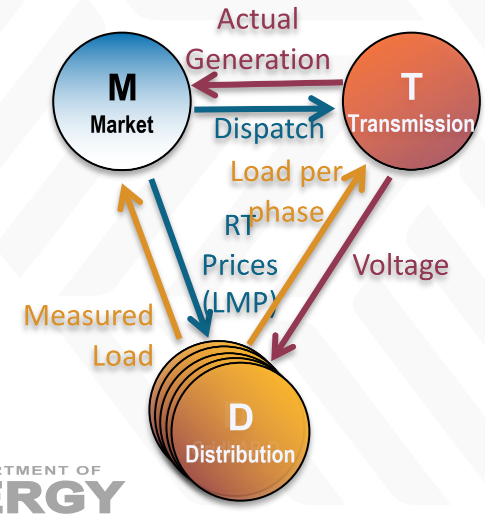


B. Palmintier, et al., "Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework," Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Pittsburgh, PA, 2017.

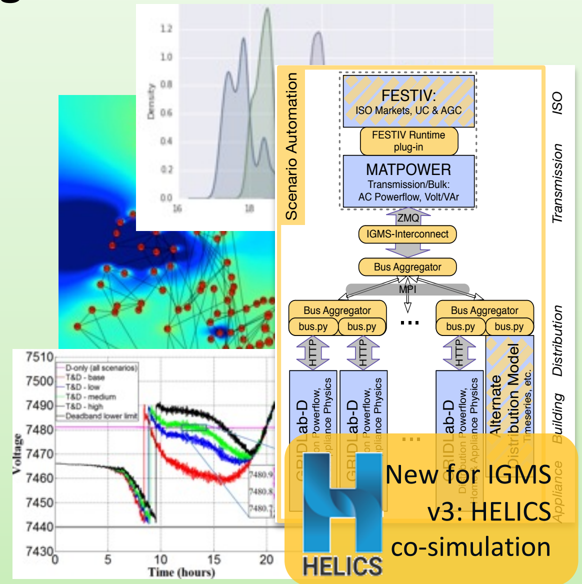
Pacific Northwest National Laboratory · Lawrence Livermore National Laboratory · NREL · Argonne National Laboratory · Oak Ridge National Laboratory · Sandia National Laboratories · INL Idaho National Laboratory

Co-Simulation: Powerflow + Market Operations

- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs



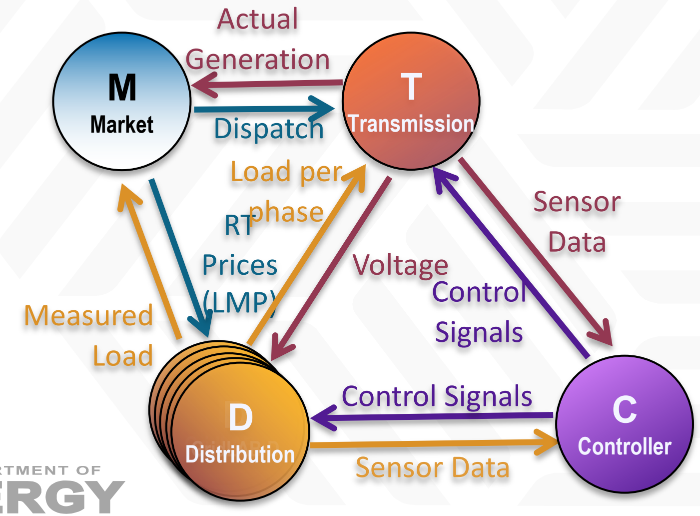
Large-scale DER-Market Interactions



NREL's Integrated Grid Modeling System (IGMS) provides a full-scale co-simulation with transmission-level markets, 1000s of distribution feeders, and 1Ms of DERs

Adding Controllers…
e.g. Control Architecture Scaling & Performance

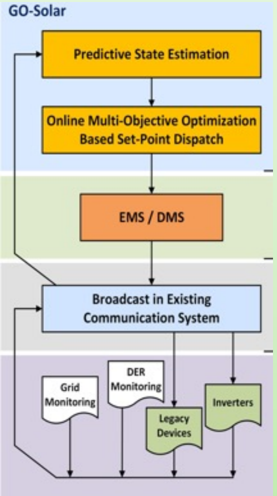
- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs
- Controller Data (Messages)
  - Sensor Readings, Control Signals



Novel T&D Control Architecture

__Design:__ Predictive State Estimation & Machine Learning Control

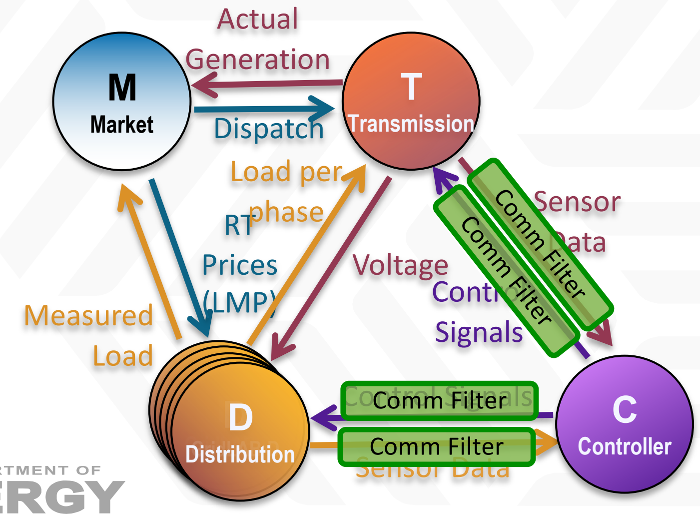
__Grid Sim:__ Entire Island of Oahu, HI with >1M electric nodes.



Ex: GO-Solar (ENERGISE)

… and Simple Communication
e.g. Design-stage Cybersecurity Evaluation

- Built in "Filters" for
  - Delays
  - Random drops
  - Other message effects (e.g. packetization)
  - And more
- No changes to domain models



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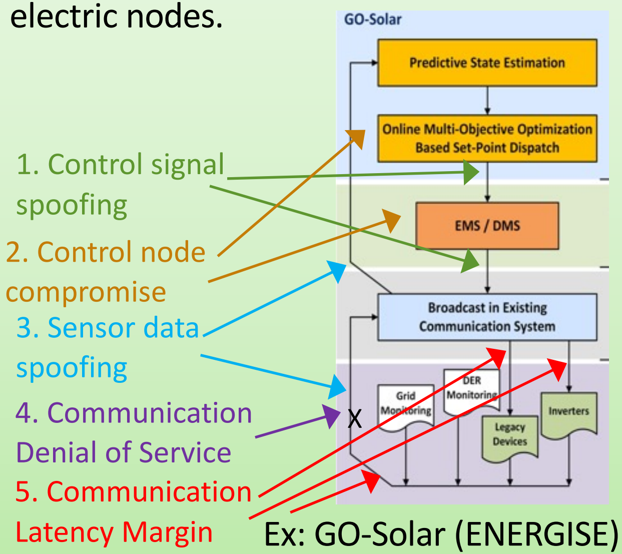
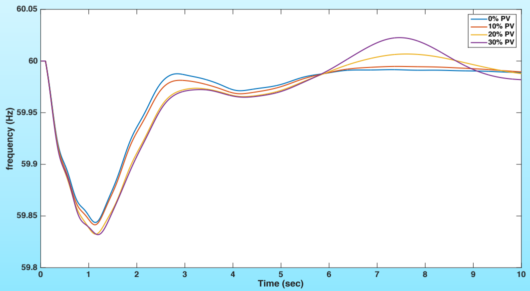


Ex: GO-Solar (ENERGISE)

Some Other Use Cases



T&D frequency stability with high DER

ADMS Testbed and other PHIL with larger grid models

Large-scale DER-Market Interactions

- 35k feeders
- WECC-240 trans.
- 25M homes
- Simplified CAISO-style Market

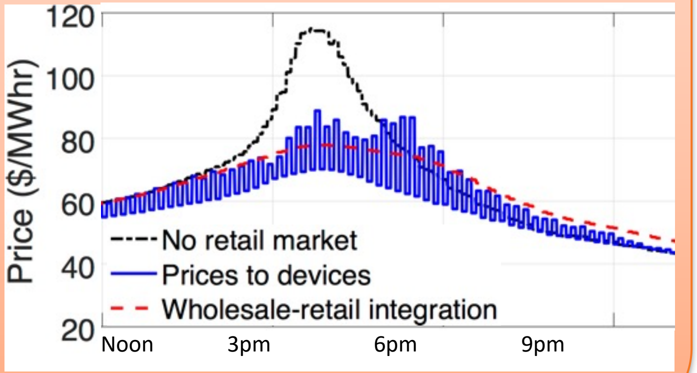
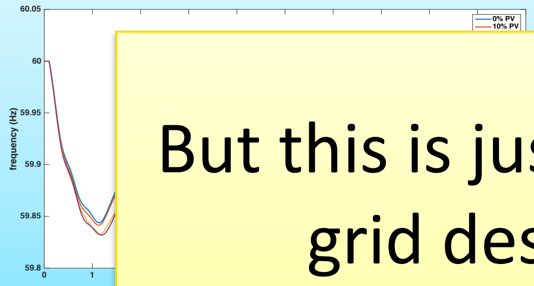


Figure from Trevor Hardy, PNNL

Some Other Use Cases



T&D f

Large-scale DER-Market Interactions

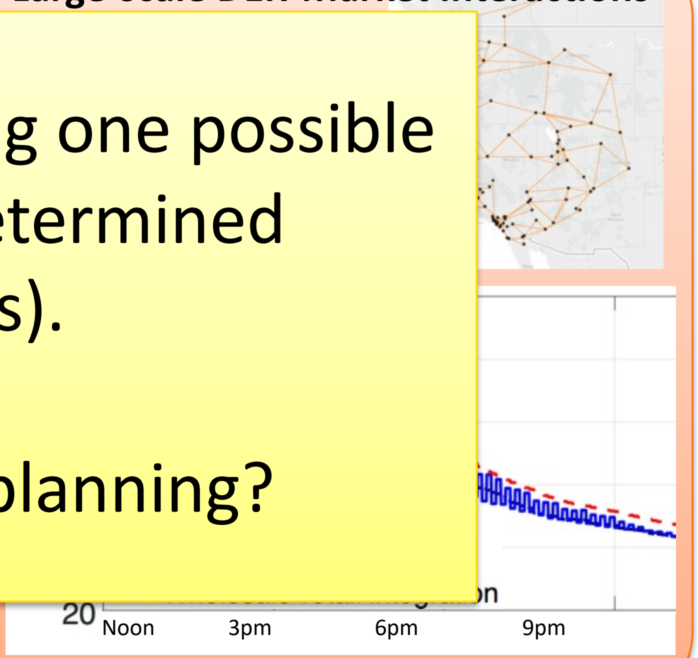


Figure from Trevor Hardy, PNNL

But this is just simulating one possible grid design (pre-determined investments).

What about joint planning?

ADMS Testbed and other PHIL with larger grid models

LA100

The Los Angeles 100% Renewable Energy Study

- What are the **pathways and costs to achieve a 100% renewable electricity supply** while electrifying key end uses and maintaining the current high degree of reliability?
- What are the potential benefits to **the environment** and **health**?
- How might **local jobs** and the **economy** change?
- How can communities shape these changes to prioritize environmental justice?

Website: https://maps.nrel.gov/la100
Report: https://maps.nrel.gov/la100/report

Components of LLA100

The Customer

CHAPTER 3
Electricity Demand Projections

CHAPTER 4
Customer-Adopted Rooftop Solar & Storage

The Power System

CHAPTER 5
Utility Options for Local Solar & Storage

CHAPTER 6
Renewable Energy Investments & Operations

CHAPTER 7
Distribution System Analysis

The Community

CHAPTER 8
Greenhouse Gas Emissions

CHAPTER 9
Air Quality & Health

CHAPTER 10
Environmental Justice

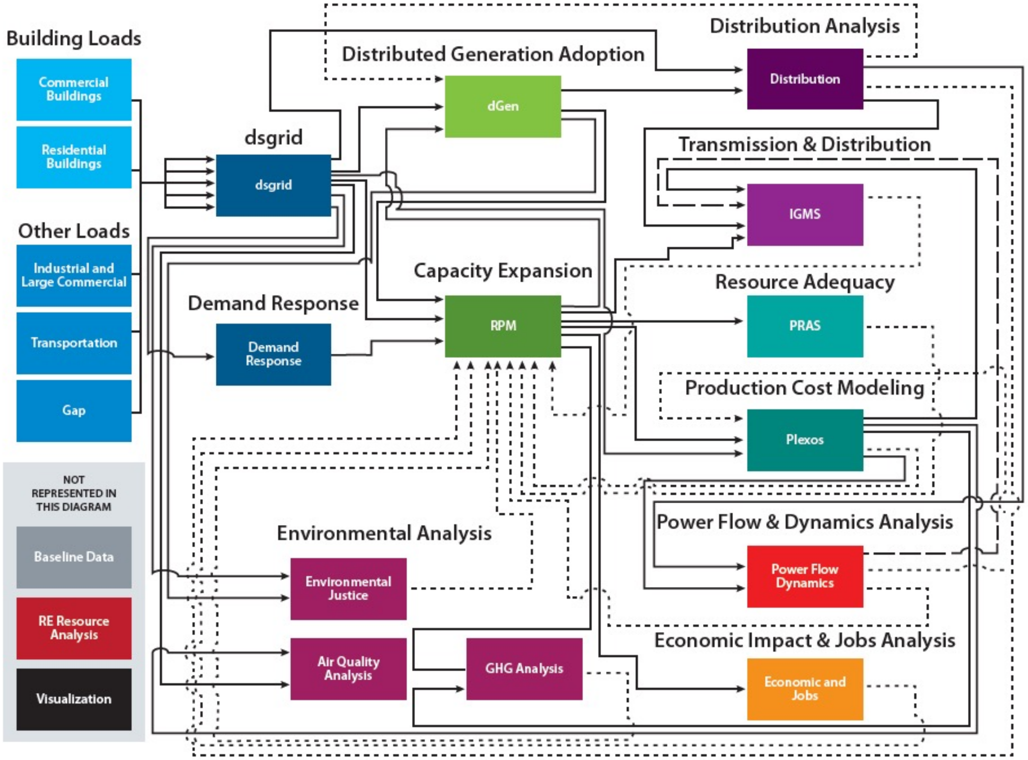
CHAPTER 11
Economic Impacts & Jobs

Unprecedented Model Resolution and Integration

dGen
Modeled every property in LA (**625,291** agents), totaling **>65M** simulations

Buildings
Modeled **>7M** buildings using **3.6M** processor hours, which would take **>60 years** to finish on a laptop

dsgrid
Allocated **5** modeling teams' loads to **625,291** geographic locations, generating **>3.5M** combinations and producing **50 TB** of data; if stored in CDs, this would be taller than a **16-story building**



Distribution
Modeled every electric wire in LA (over **1,600** circuits) for thousands of scenarios each—totaling **>25M** detailed engineering simulations

RPM
Simulated >**8,000 years** of dispatch , which would require **2 decades** worth of computing on a laptop

Plexos
Ran **>7.6** node-years on Eagle, which is like conducting a simulation **24/7 for 7.6 years straight** on a laptop

= Over 100 million simulations

Scenarios Based on LA Advisory Group Priorities

SB100

Evaluated under Moderate, High, and Stress Load Electrification

- 100% clean energy by **2045**
- Only scenario with a target based on retail sales, not generation
- Only scenario that allows up to 10% natural gas, offset by renewable electricity credits
- Allows existing nuclear and upgrades to transmission

Early & No Biofuels

Evaluated under Moderate and High Load Electrification

- 100% clean energy by **2035**, 10 years sooner than other scenarios
- No natural gas generation or biofuels
- Allows existing nuclear and upgrades to transmission

Limited New Transmission

Evaluated under Moderate and High Load Electrification

- 100% clean energy by **2045**
- Only scenario that does not allow upgrades to transmission beyond currently planned projects
- No natural gas or nuclear generation

Transmission Focus

Evaluated under Moderate and High Load Electrification

- 100% clean energy by **2045**
- Only scenario that builds new transmission corridors
- No natural gas or nuclear generation

Each Scenario Evaluated Under Different Customer Demand Projections (different levels of energy efficiency, electrification, and demand response)

Moderate

High

Stress

Quick Summary: Across All Scenarios

Efficiency
Electrification
Flexible Load

Customer Rooftop Solar

Renewable Energy

Solar: + >5,700 MW
Wind: + >4,300 MW

Storage (including coupled with solar)

+ >2,700 MW

Distribution, Transmission

Renewably Fueled Combustion Turbines

+>2,600 MW
(in basin)

Much More

New

Natural gas → Biofuel/ hydrogen

Today:
Daily

Future:
Infrequently

Components of LA100

Loads include end-use electrification, climate change (more AC), and EVs including Fast Chargers.

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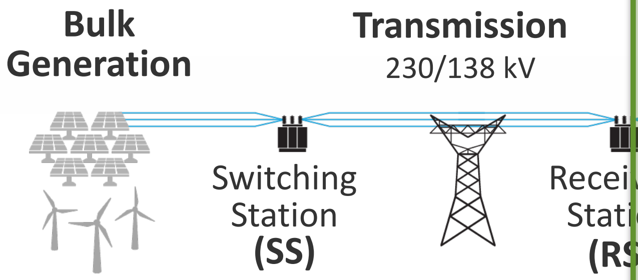
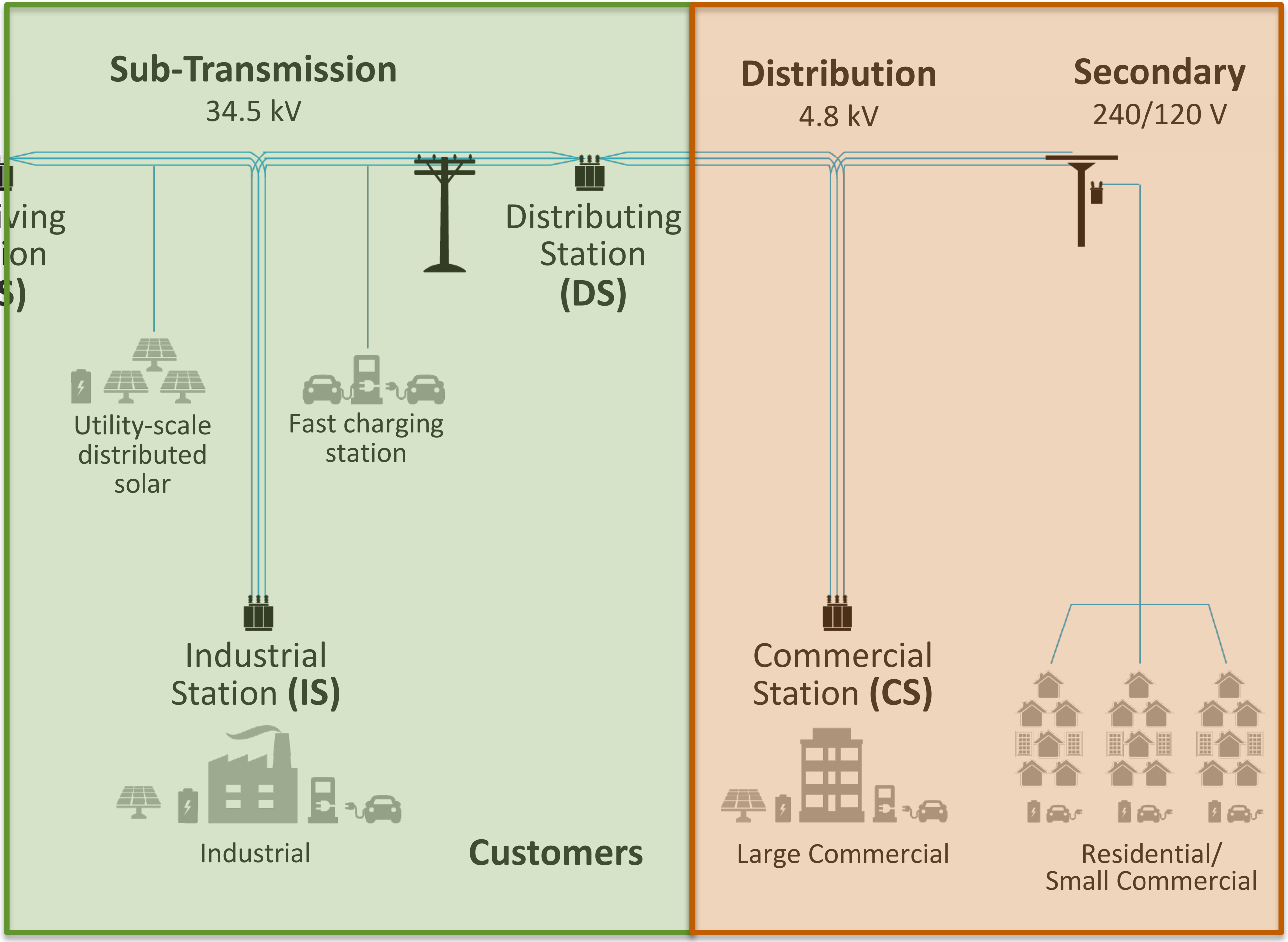




In LA100, when we say "distribution," we mean both 34.5kV sub-transmission and 4.8kV local distribution.

Note: many U.S. utilities use 12.47/13.2/13.8kV for all but the largest loads. (which conect at 69kV or 138kV)

Changes in 100% Systems: Distribution Analysis

Traditional and Low RE Systems

Size based on single peak load planning time point

Regulation to manage voltage drop

100% RE Systems

Multiple design points: Load, EVs, Load vs solar, etc.

Regulation to manage voltage drop (load) and rise (generation)

Non-traditional sources of voltage control (advanced inverters)

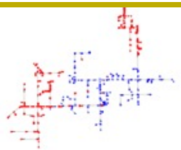
LA100 Methods for Distribution Cost Analysis

(1) Build Electric Models (>1400 feeders, >80% of system)

Input data for these electrical models comes from LADWP (GIS/PGES) and reflects the best knowledge of their current system

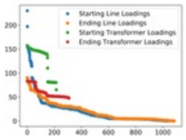
(2) Allocate (LA100) loads and attach local solar and storage

Our best guess, but loads are a complex allocation problem with some known errors, and DER patterns only capture a few possible patterns



(3) Power flow modeling to identify overloads or voltage problems

Models of the future, based on the real physics of the system. A dozen timepoints to capture multiple critical conditions



(4) Identify upgrades to solve these problems (Using NREL algorithms)

***Upsize** to larger transformer or lines,*
***Change settings** on voltage regulators or capacitors,*
***Install New** voltage regulators or capacitors*

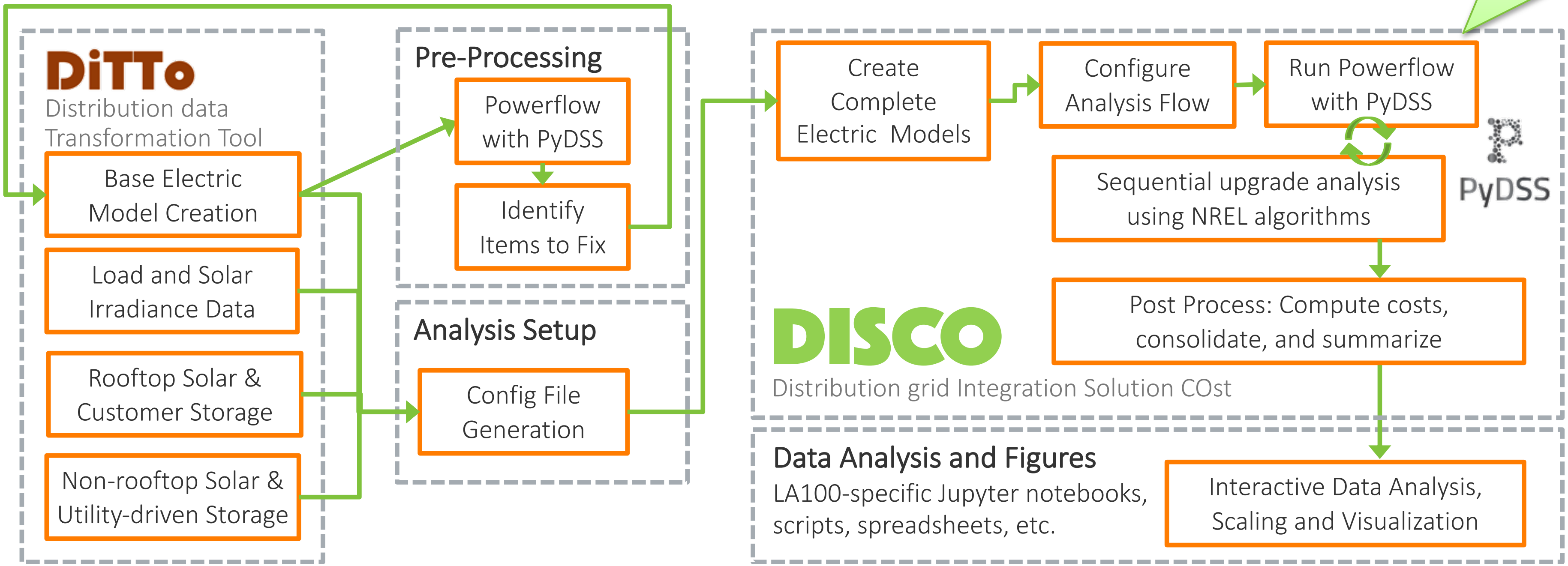
$

(5) Estimate the corresponding costs

Unit cost data from LADWP based on their actual costs

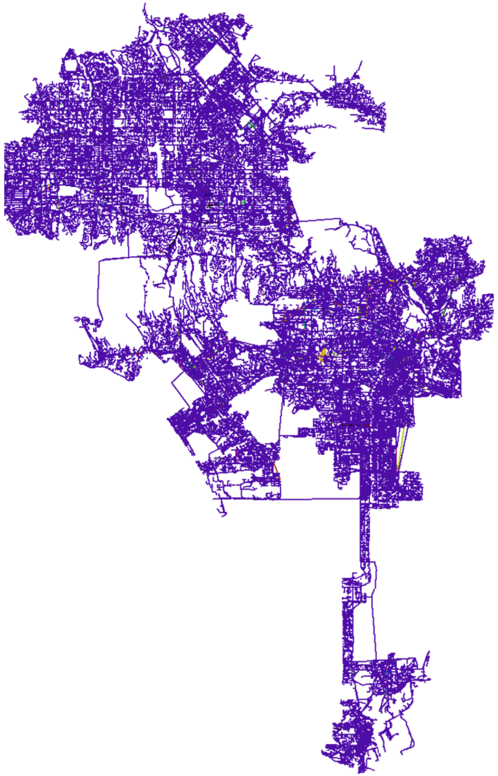
Doing this at scale —
A peak under the hood

>25 million
Power flows



Key T&D Interface Question

Where could **non-rooftop solar** be deployed within LA with the **lowest distribution system costs** in 2045?



Flow of Distribution Analysis to Look at the Additional Costs to Add Non-Rooftop Solar

Some circuits have known overloading or voltage challenges today (data from LADWP). Data and model issues also exist.

1 Today

2A 2045 Load, Customer Adopted Solar and Storage

2B 2045 with possible non-rooftop solar

Get curves of the costs to integrate local solar up to the technical potential

Categories of In-Basin Renewable Resources

Utility-scale resources built to meet overall system needs

Based on bulk capacity expansion modeling

Resources located at existing generating sites

Transmission tied

100 MW to 1.5 GW/site

“Non-rooftop” Solar and Storage

Connected to 34.5kV.

Located based on GIS analysis.

up to 84 MW/site potential
up to 16 MW/site built

Distribution Connected

Rooftop Solar and Customer-adopted storage

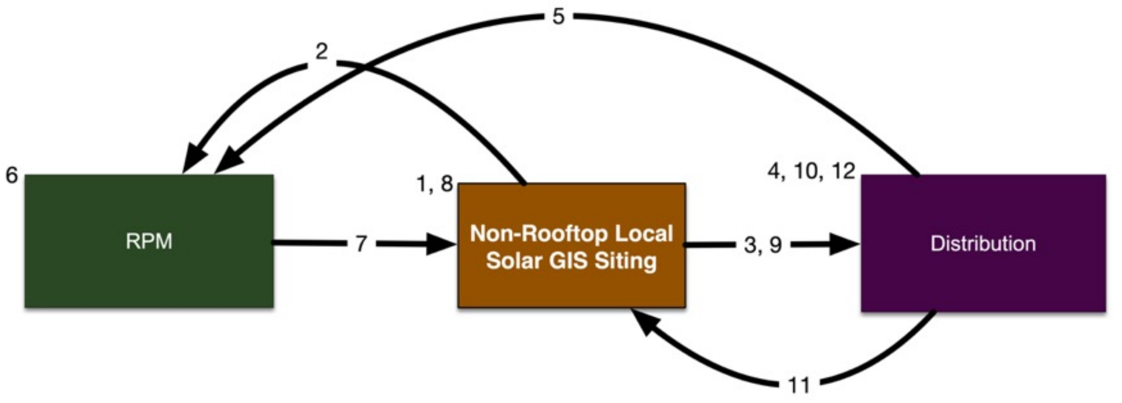
Both 4.8kV and 34.5kV

Based on customer adoption models

1 kW to 10s MW/premise

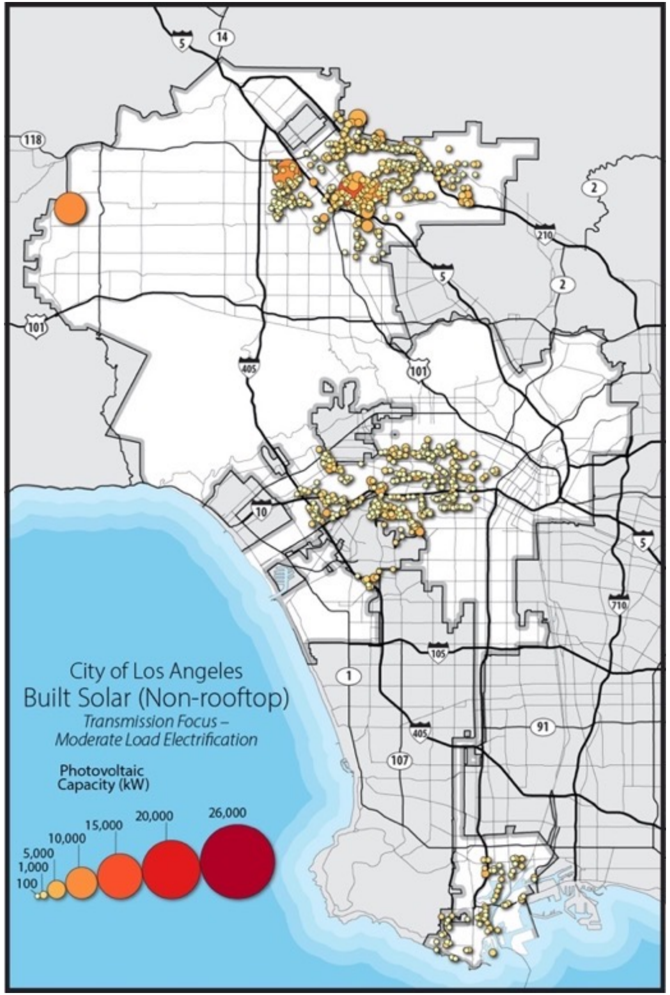
T&D Feedback

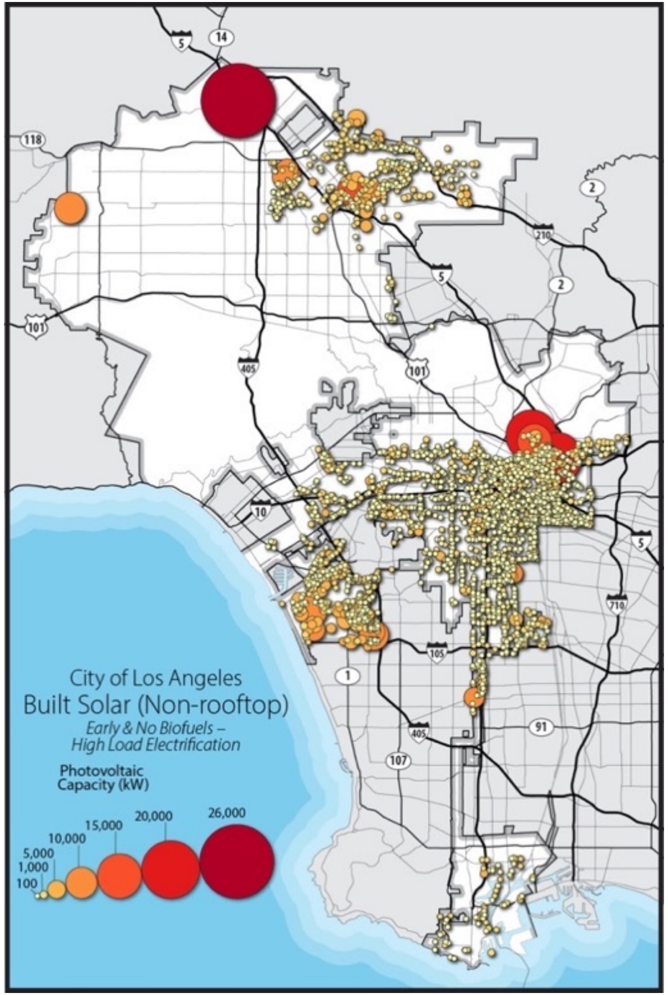
- Iterate:
  - System Capacity Planning (RPM)
  - Siting
  - Cost Curves



1. Non-Rooftop Local Solar creates GIS siting evaluation and techno-economic ranking (Ch. 5).
2. Non-Rooftop Local Solar passes nodal capacity limits to RPM (Ch. 5).
3. Non-Rooftop Local Solar passes ranked sites to distribution.
4. Distribution creates cost curves (Ch. 5).
5. Distribution passes curves to RPM (Ch. 5).
6. RPM determines mix of generation investments required to reach 100% RE (Ch. 6).
7. RPM passes nodal local solar deployments for GIS siting (Ch. 7).
8. Non-Rooftop Local Solar sites RPM nodal solar deployments at optimal locations using GIS techno-economic ranking (Ch. 7).
9. Non-Rooftop Local Solar passes information on new non-rooftop solar and storage capacity to Distribution (Ch. 5).
10. Non-Rooftop Local Solar passes information on new non-rooftop solar and storage capacity to Distribution (Ch. 5).
11. f needed, iterate between GIS analysis and Distribution cost curves to adjust sites to reduce upgrade costs (Ch. 5).
12. Compute actual distribution integration costs (Ch. 7).

Capacities of non-rooftop solar (2045)

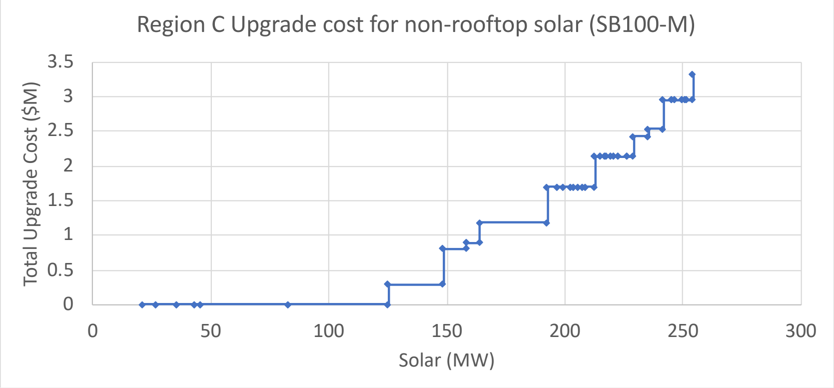


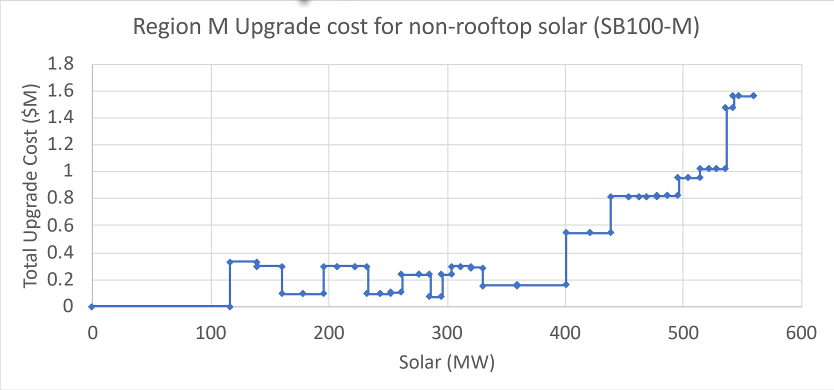


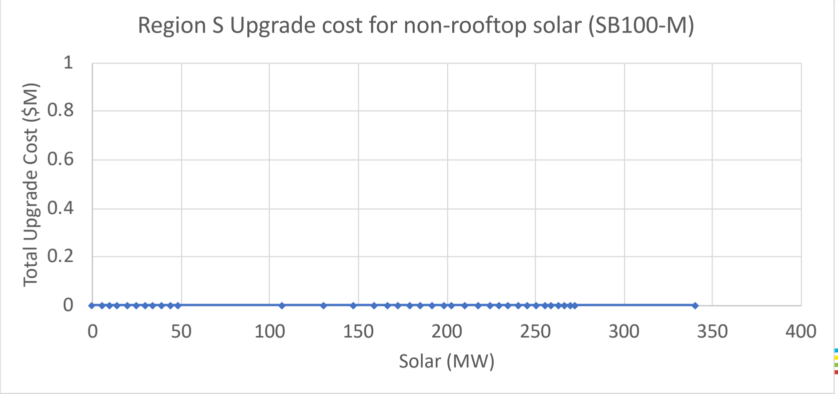
How do grid integration costs change with capacity?
(See Chapter 5)

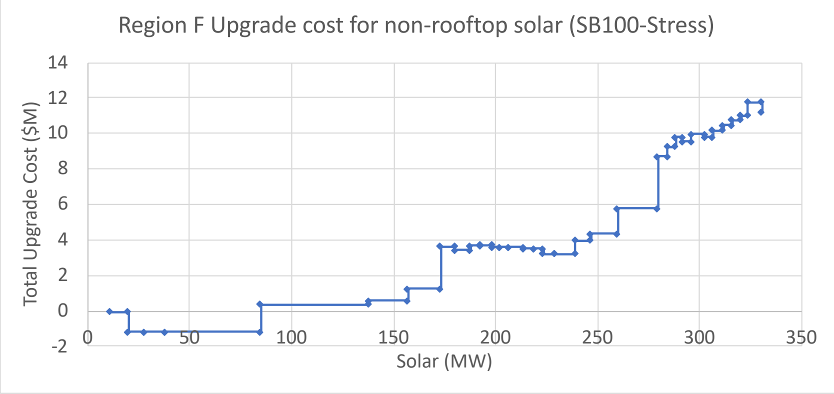
Reminder: costs relative to load and rooftop solar

- It depends...







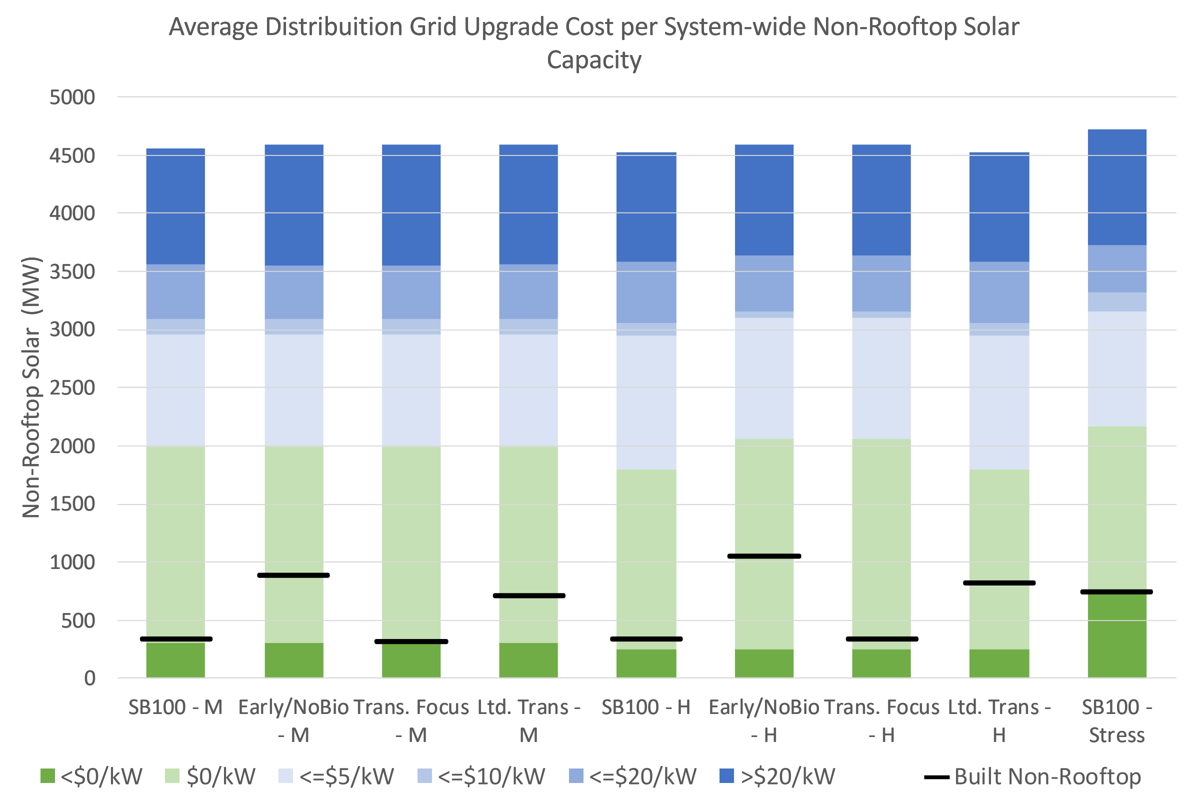


How do grid integration costs change with capacity?
(See Chapter 5)

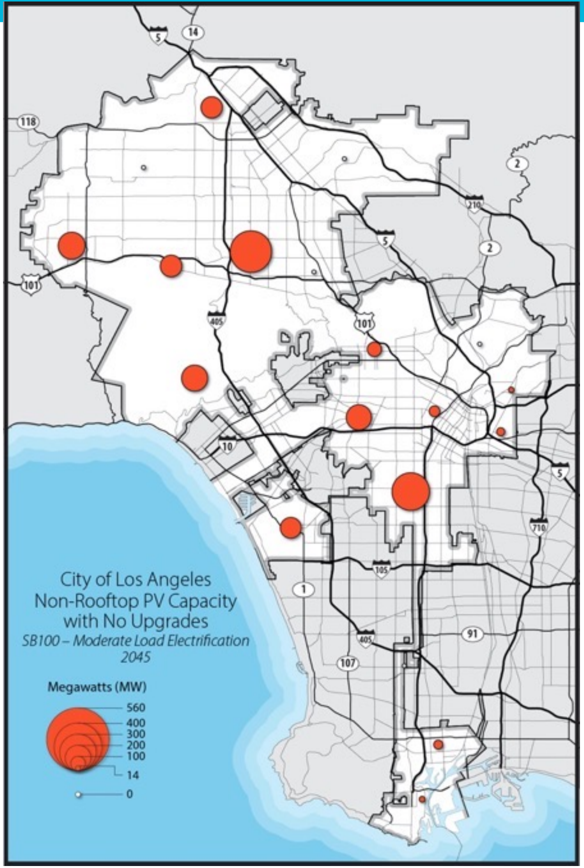
- Built capacities are generally in the low range of system-wide upgrade costs.

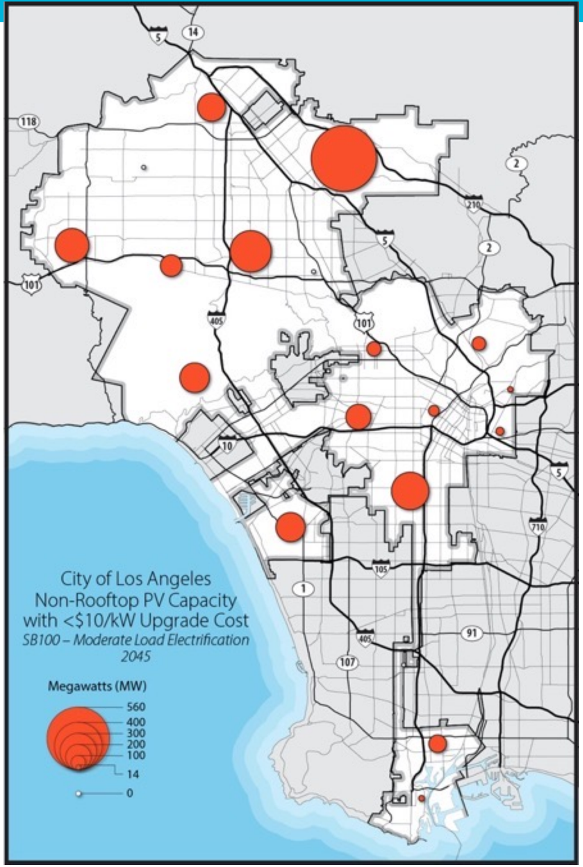
Note these capacities are system wide, meaning:

- *Regions with locally high penetration may have non-zero integration costs*
- *The total capacity for each bar corresponds to non-rooftop solar siting based on grid costs*



Spatial Breakdown for No upgrades and <$10/kW

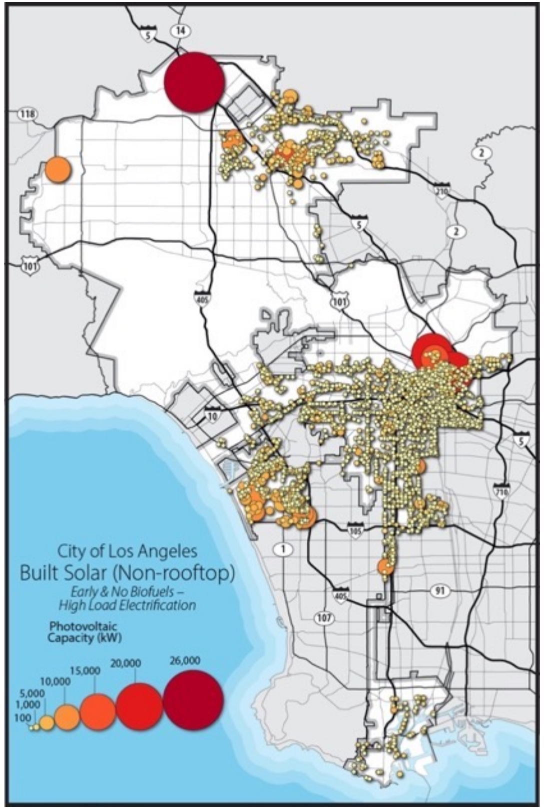




Key Findings: Non-rooftop solar integration

Distribution integration does not add much to cost of utility-scale solar

- Non-customer local solar capacity that gets built is a small fraction of technical potential
- Regions can accommodate a lot of solar with no 34.5kV upgrades
- Integration costs for our scenarios are low compared to cost of the generation (the solar panels and storage)



Limitations

- Dispatch Managed for bulk needs not distribution
  - Result: RS-region (local) peak net loads have no support from storage.
  - Future: Distribution-aware dispatch (co-simulation?)
- Customer-driven adoption exogenous

Future Directions for Co-optimized T&D Planning

- More room with state of the art:
  - Iterations/siting beyond local non-rooftop solar
  - Joint operations/production cost
- Additional Feedbacks:
  - Rate structures for adoption models
  - Customer response to incentives and market signals
- Future:
  - Truly endogenous simulation driven optimization of T&D together.

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Thank you

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