



Methods to Model a 100% Renewable Electric Power System

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Modeling and Analysis Lead

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

- Illustrate the methods that are needed to meet the City Council's motion

  "to determine what investments should be made to achieve a 100 percent renewable energy portfolio"

- This 100% renewable energy portfolio needs to be technically feasible and reliable

- This project relies on a suite of modeling and simulation tools to determine what investments could be made to achieve a reliable 100% renewable energy portfolio

Framing The Problem

- What are some plausible scenarios of renewable resources that might achieve meeting 100% of LADWP's demand?

- Would these scenarios achieve the same level of reliability that LADWP currently achieves?

- How much would these scenarios cost?

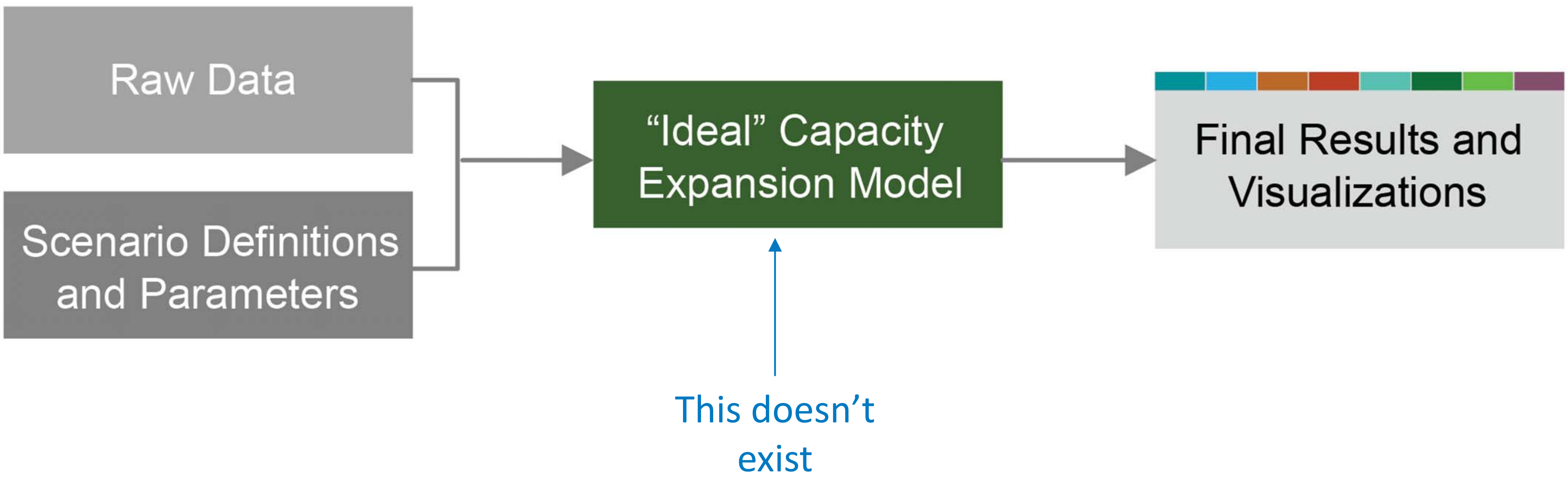
Modeling 100% Renewable Energy

- The LA100 study is similar to integrated resource plans (IRPs) and other planning exercises, but is exploring a "space" that has never been explored

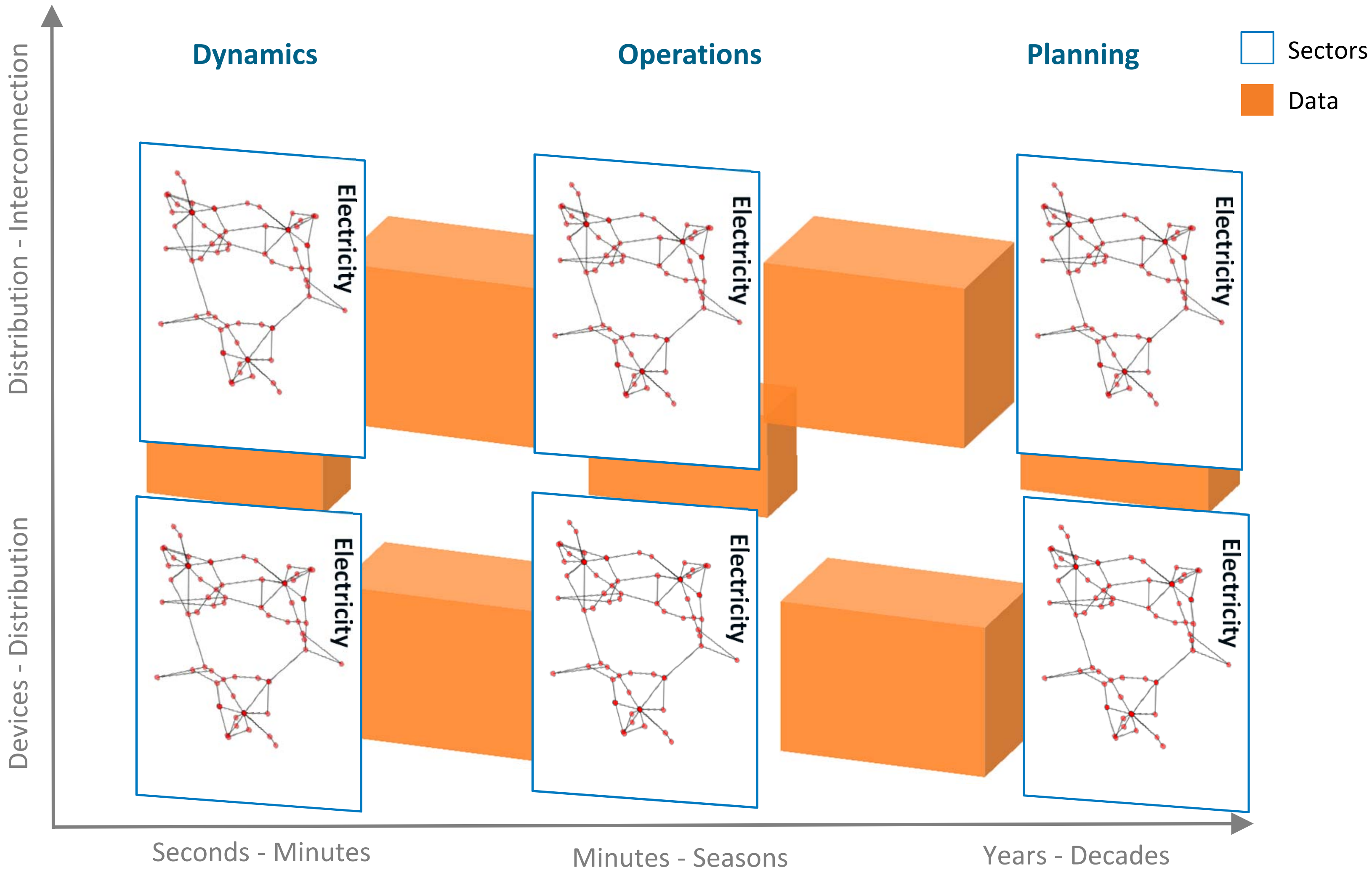
- We will follow proven methods and use state-of-the-art tools
  - Where commercial tools are best in class, we will use them
  - Where we think commercial tools are insufficient, we will use NREL tools

- A study with this level of detail has never been done before, and we are excited to bring NREL's modeling tools and capabilities to bear on this interesting and important study

The Ideal Study



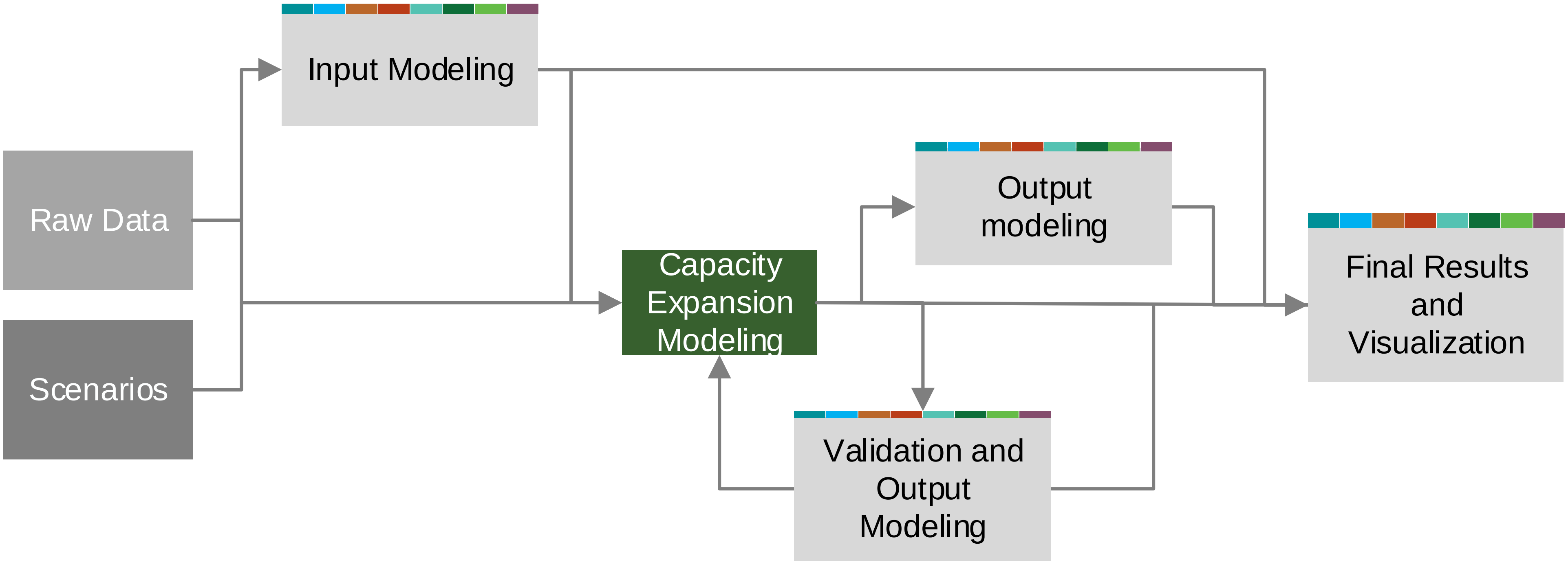
No Single Model Covers All of This



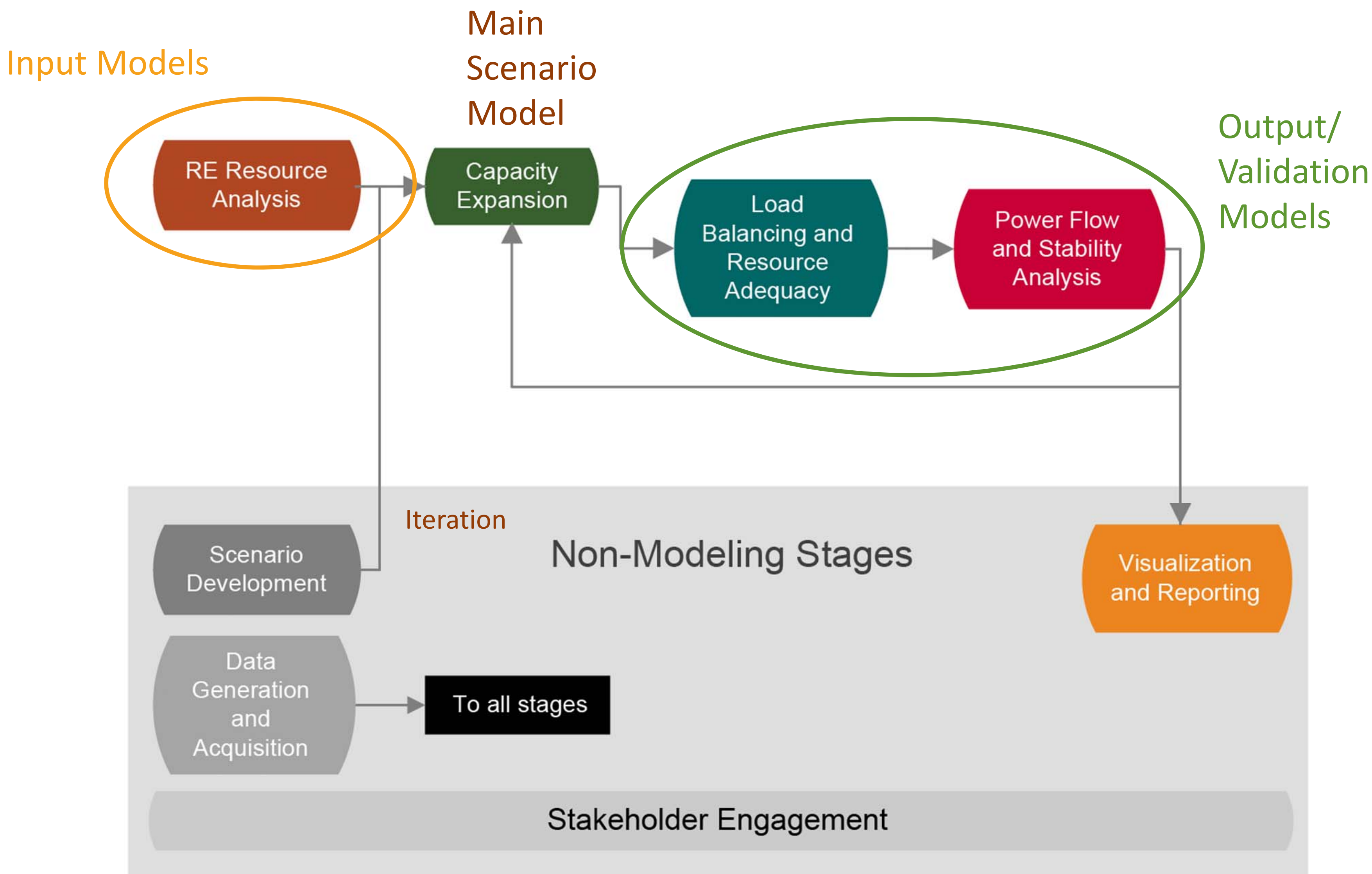
Modeling 100%

- No single model can evaluate the geographic and temporal aspects of power system operations
- Even “traditional” integrated resource plans require the use of multiple models

Classes of Models



Traditional (Detailed) Integrated Resource Plan Process

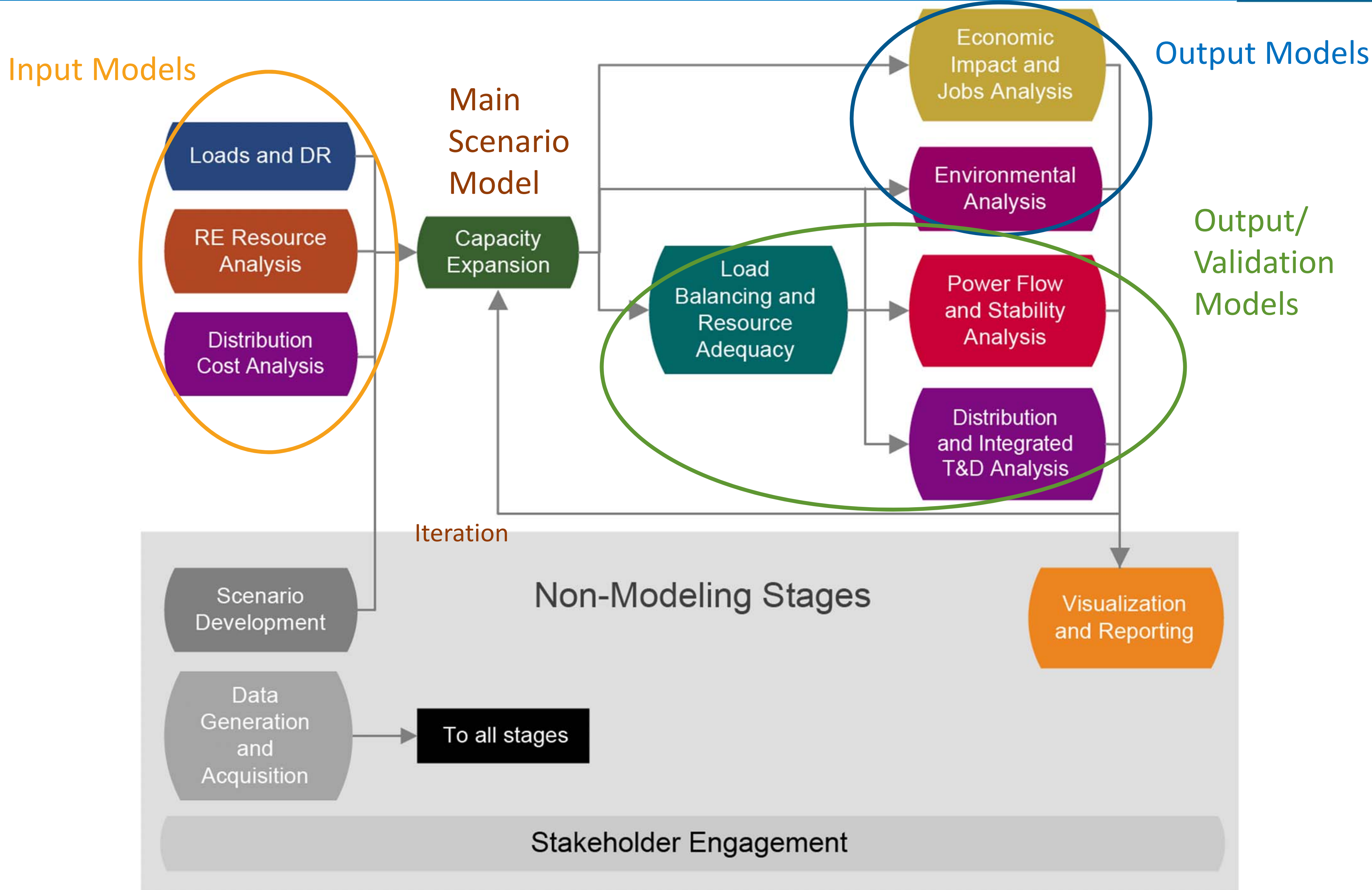


Modeling 100%

LADWP

- We are adding additional
  - *Geographic* considerations including loads and distribution system
  - *Scope* (economic and environmental analysis)

Steps of the LA 100% Renewable Energy Study



Step 1 (Non-Modeling)

1. Data collection and scenario development

Steps 2-4 (Input Modeling)

1. Data collection, scenario development
2. Estimate load growth and demand profiles
3. Determine renewable resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs

Step 5 (Main Scenario Modeling)

1. Data collection, scenario development
2. Estimate load growth and demand profiles
3. Determine renewable resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs
5. Develop optimal expansion plan and distributed resource adoption scenario

Steps 6-8 (Validation Modeling)

1. Data collection, scenario development
2. Estimate load growth and demand profiles
3. Determine renewable resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs
5. Develop optimal expansion plan and distributed resource adoption scenario
6. Simulate grid operations and performance including load balancing, operating reserves, and resource adequacy
7. Evaluate transmission system reliability
8. Validate operation of integrated transmission and distribution system

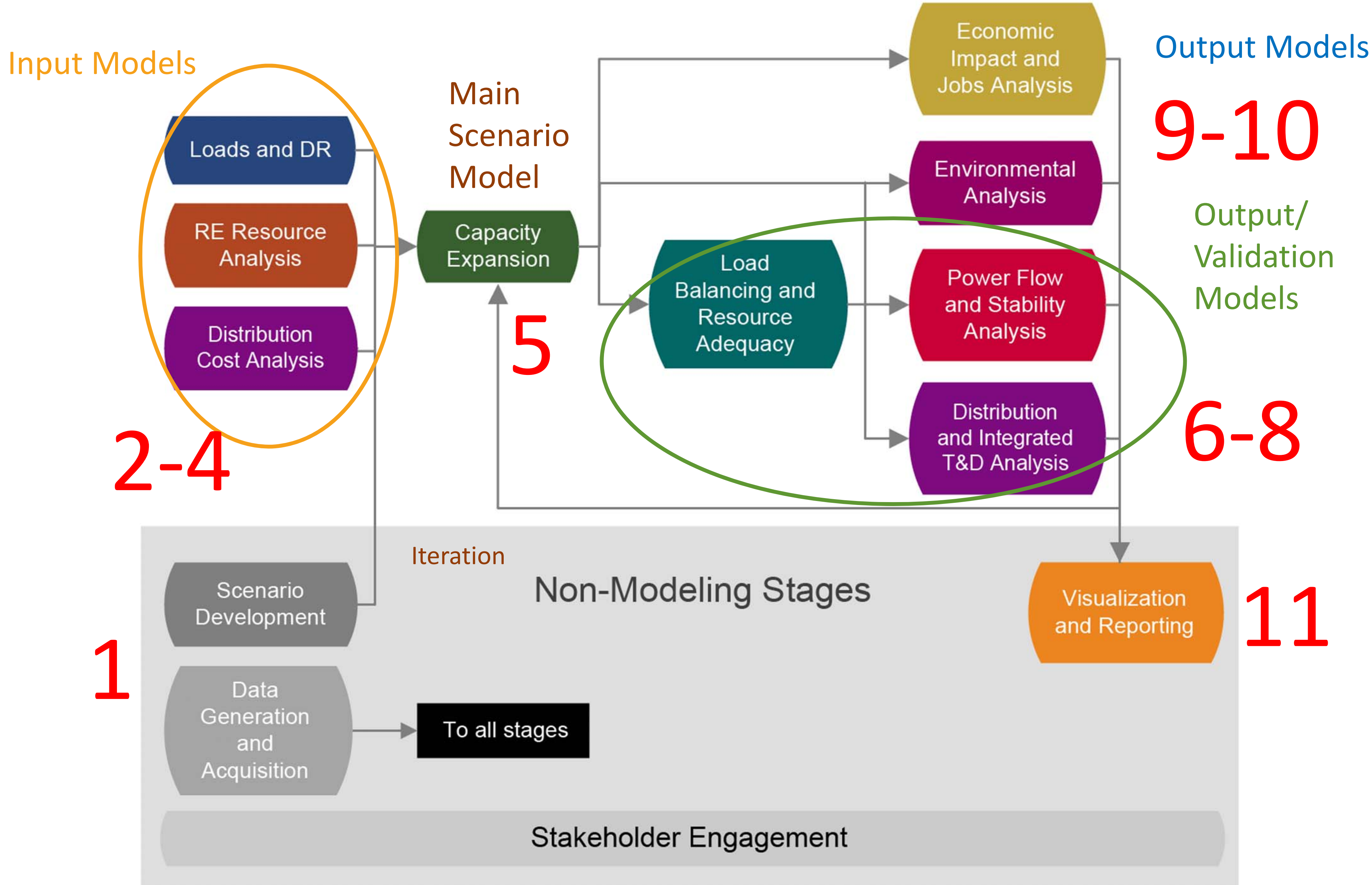
Steps 9-10 (Output Modeling)

1. Data collection, scenario development
2. Estimate load growth and demand profiles
3. Determine RE resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs
5. Develop optimal expansion plan and distributed resource adoption scenario
6. Simulate grid operations and performance including load balancing, operating reserves, and resource adequacy
7. Evaluate transmission system reliability
8. Validate distribution system operation and integrated T&D system performance
9. Evaluate environmental benefits and impacts
10. Evaluate local job and economic development impacts

Step 11 (Visualization and Communication)

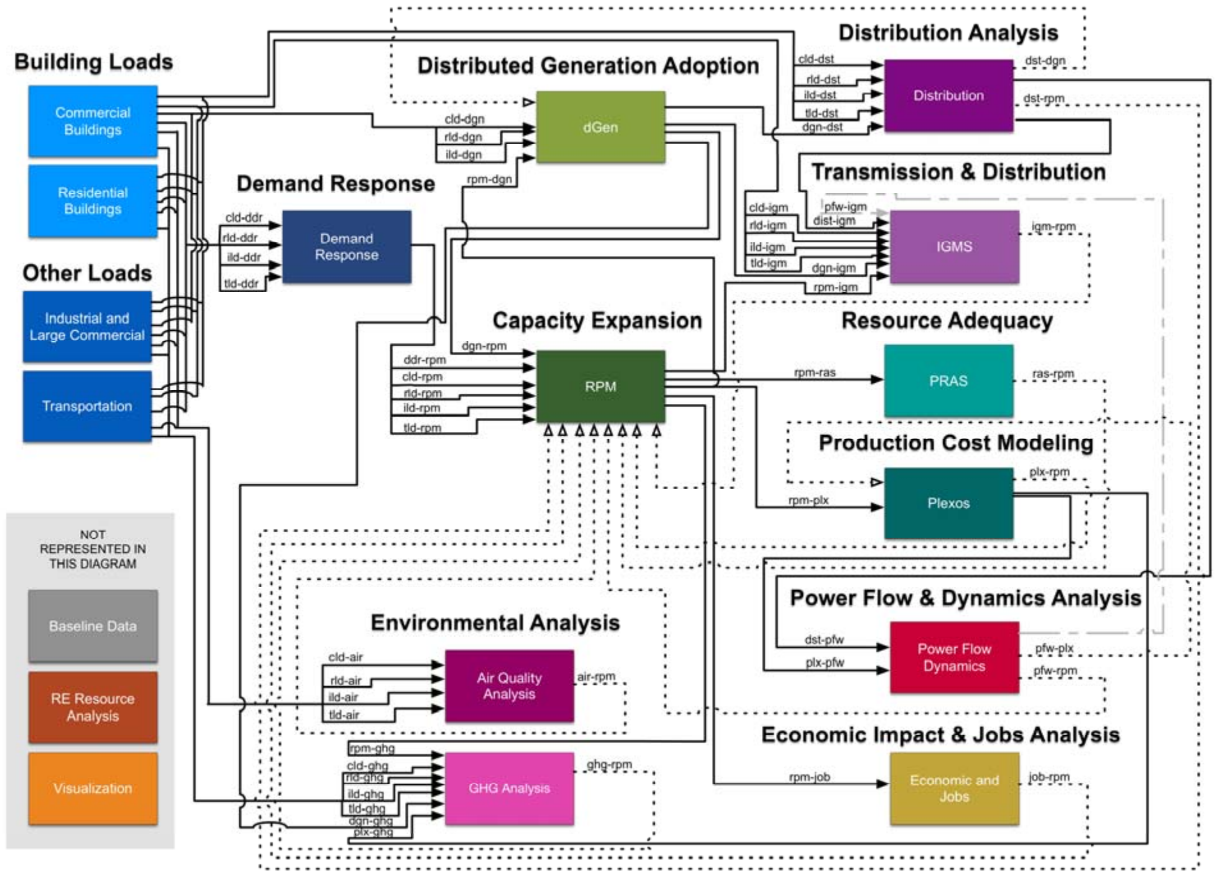
1. Data collection, scenario development
2. Estimate load growth and demand profiles
3. Determine RE resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs
5. Develop optimal expansion plan and distributed resource adoption scenario
6. Simulate grid operations and performance including load balancing, operating reserves, and resource adequacy
7. Evaluate transmission system reliability
8. Validate distribution system operation and integrated T&D system performance
9. Evaluate environmental benefits and impacts
10. Evaluate local job and economic development impacts
11. **Visualization and communication**

Steps of the LA 100% Renewable Energy Study



Step 1 – Data Collection and Scenario Development

- Data collection needed for each step
- Also need processes for data in different formats
- Dedicated project data traffic cop



Meghan Mooney

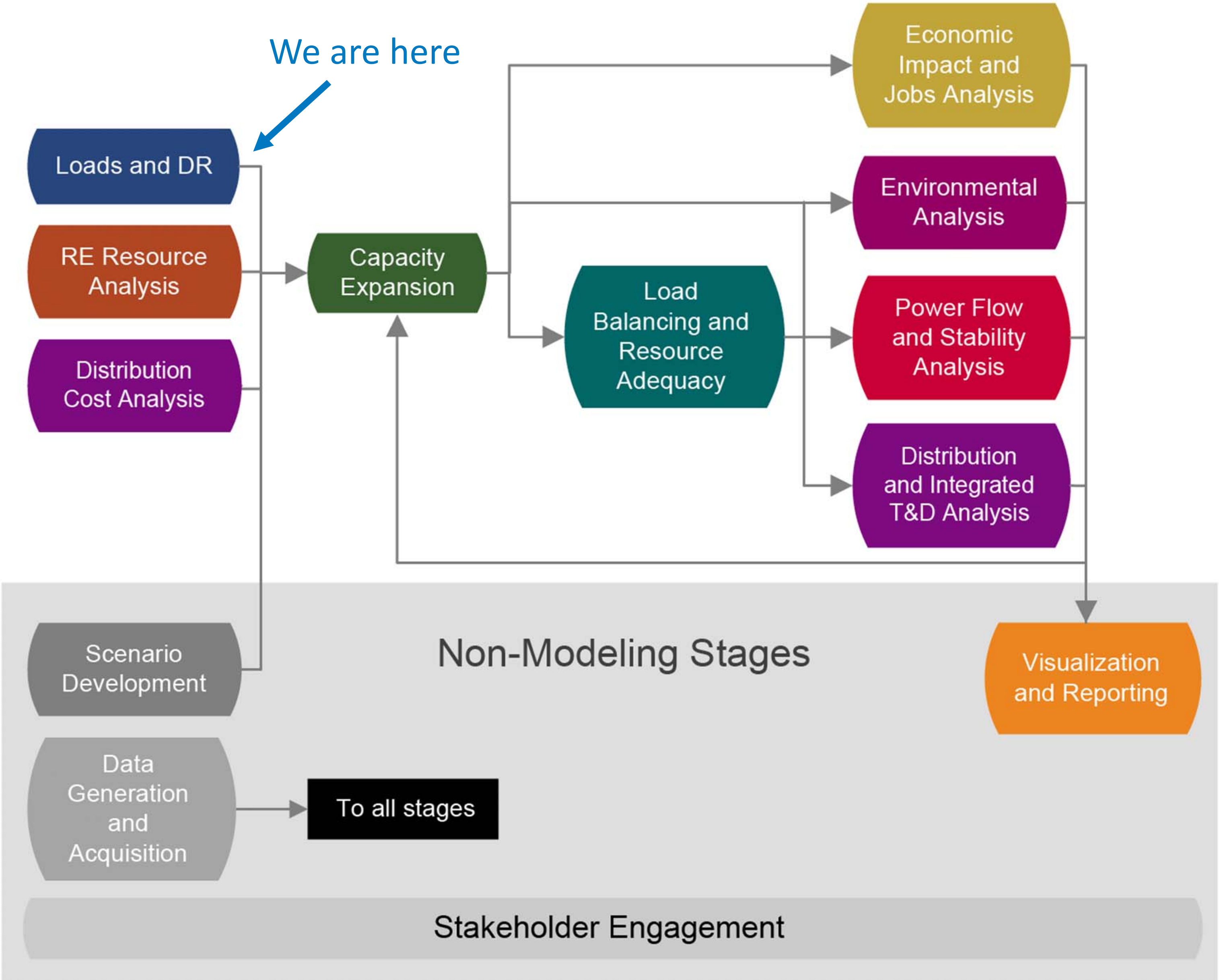
Step 1 – Data Collection and Scenario Development

		LADWP 2017 IRP *Recommended Case*	100% RE Reference	LA-Leads	Transmission Renaissance	Limited Transmission	Emissions Free	Net 100%	Load Modern-ization	Western Initiatives
	Compliance Year:	--	2045	2035/2040	2045	2045	2045	2045	2045	2045
Technol-ogies Eligible in the Compliance Year	Biomass	Matches 2017 IRP Technology Mix	Y	Y	Y	Y	N	Y	Y	Y
	Biogas		Y	Y	Y	Y	N	Y	Y	Y
	Electricity to Fuel (e.g. H2)		Y	Y	Y	Y	Y	Y	Y	Y
	Fuel Cells		Y	Y	Y	Y	Y	Y	Y	Y
	Hydro - Existing		Y	Y	Y	Y	Y	Y	Y	Y
	Hydro - New		N	N	N	N	N	N	N	N
	Hydro - Upgrades		Y	Y	Y	Y	Y	Y	Y	Y
	Natural Gas		N	N	N	N	N	Y	N	N
	Nuclear - Existing		N	Y	N	N	Y	Y	N	N
	Nuclear - New		N	N	N	N	N	N	N	N
	Wind, Solar, Geo		Y	Y	Y	Y	Y	Y	Y	Y
	Storage		Y	Y	Y	Y	Y	Y	Y	Y
DG	Distributed Adoption	Reference	Balanced	High	Low	High	Balanced	Balanced	Balanced	Balanced
RECS	Financial Mechanisms (RECS/Allowances)	-	N	N	N	N	N	Yes	N	N
Load	Energy Efficiency	Reference	Moderate	High	Moderate	High	Moderate	Moderate	High	Moderate
	Demand Response	Reference	Moderate	High	Moderate	High	Moderate	Moderate	High	Moderate
	Electrification	Reference	Moderate	High	Moderate	High	Moderate	Moderate	High	Moderate
Trans-mission	New or Upgraded Transmission Allowed?	Matches 2017 IRP	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors	New Corridors Allowed	No New Transmission	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors
WECC	WECC VRE Penetration	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	High

Dan Steinberg

Recap - Scenarios

Step 2 – Loads and Demand Response



Step 2 – Goals

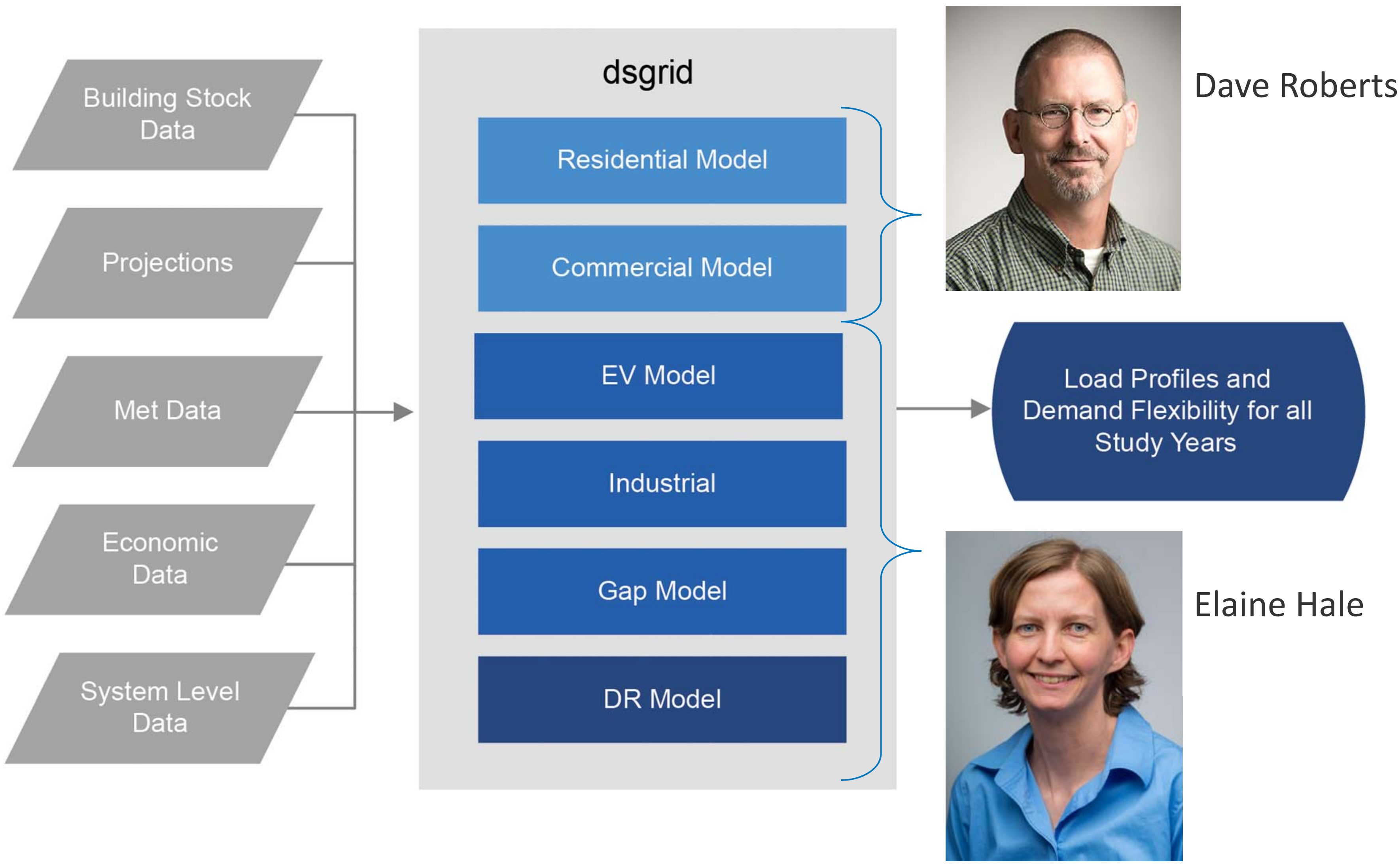
- Generate a dataset that represents the load that LADWP will need to serve in the coming decades
- Helps us understand interesting "standalone questions," such as:
  - How will demand grow (or not)?
    - How much electric vehicle (EV) charging will LADWP need to serve?
    - What about electrification of loads served by natural gas?
  - How flexible will loads get?

Step 2 – Load Profiles

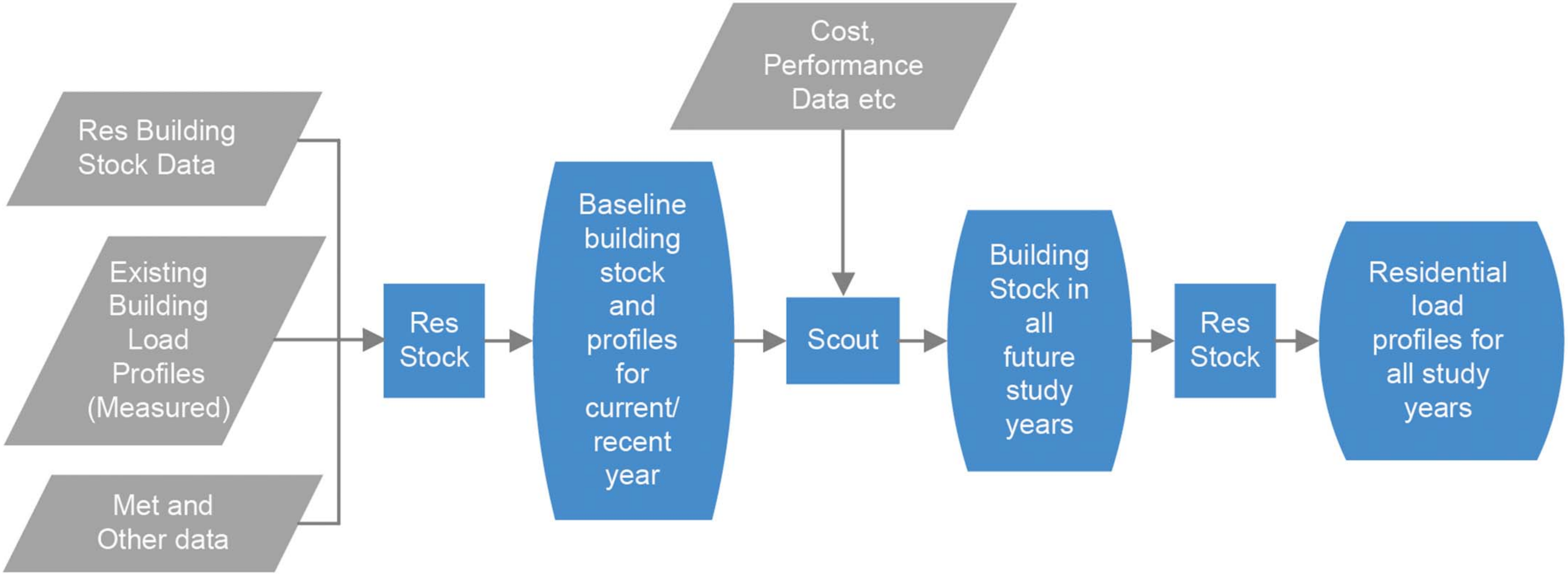
Five types of loads modeled:

1. Residential Buildings
2. Commercial Buildings
3. Industrial Loads
4. Electric Vehicles
5. Leftovers

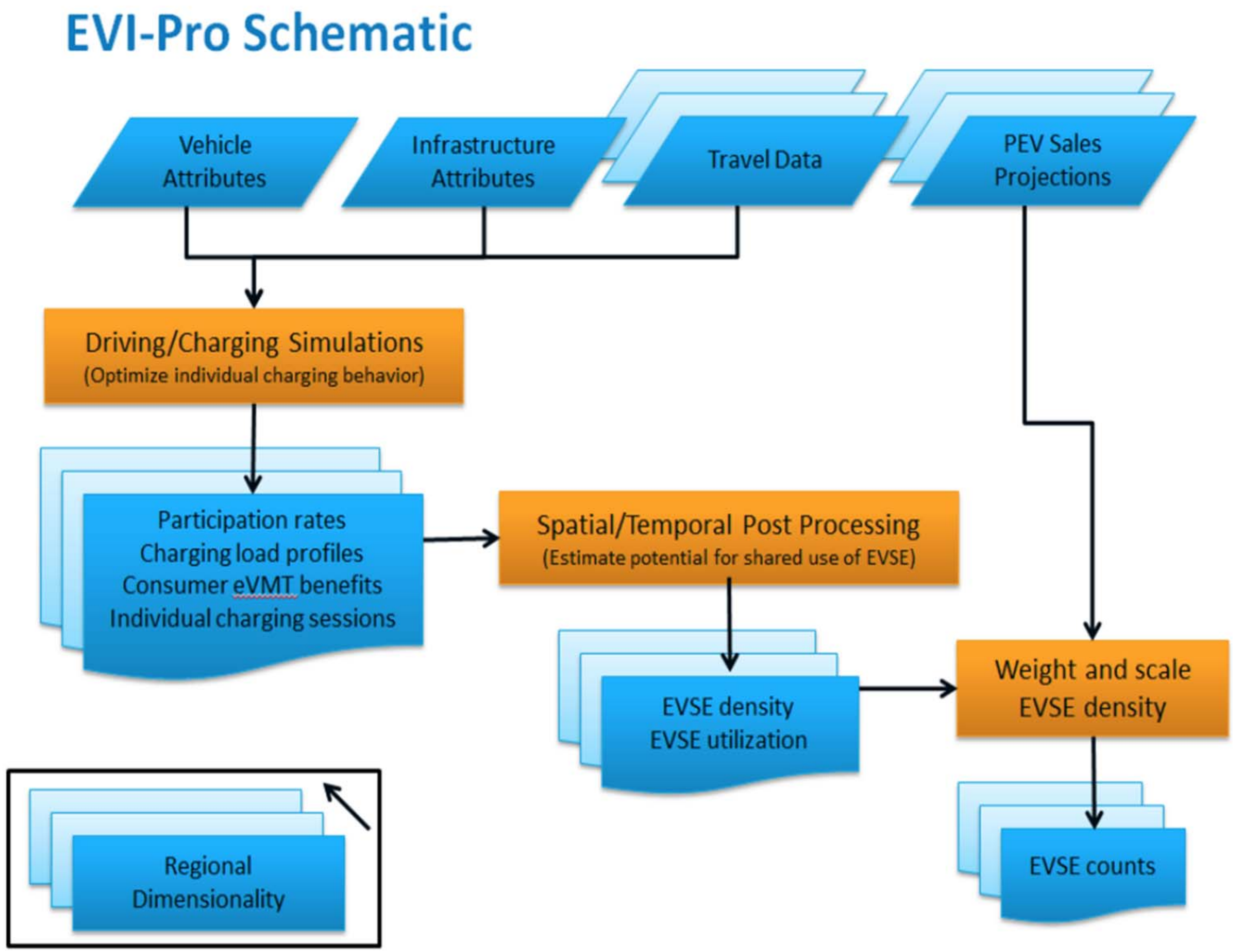
Loads Evaluated with NREL's dsgrid Model



Example – Residential Building Loads



Electric Vehicles

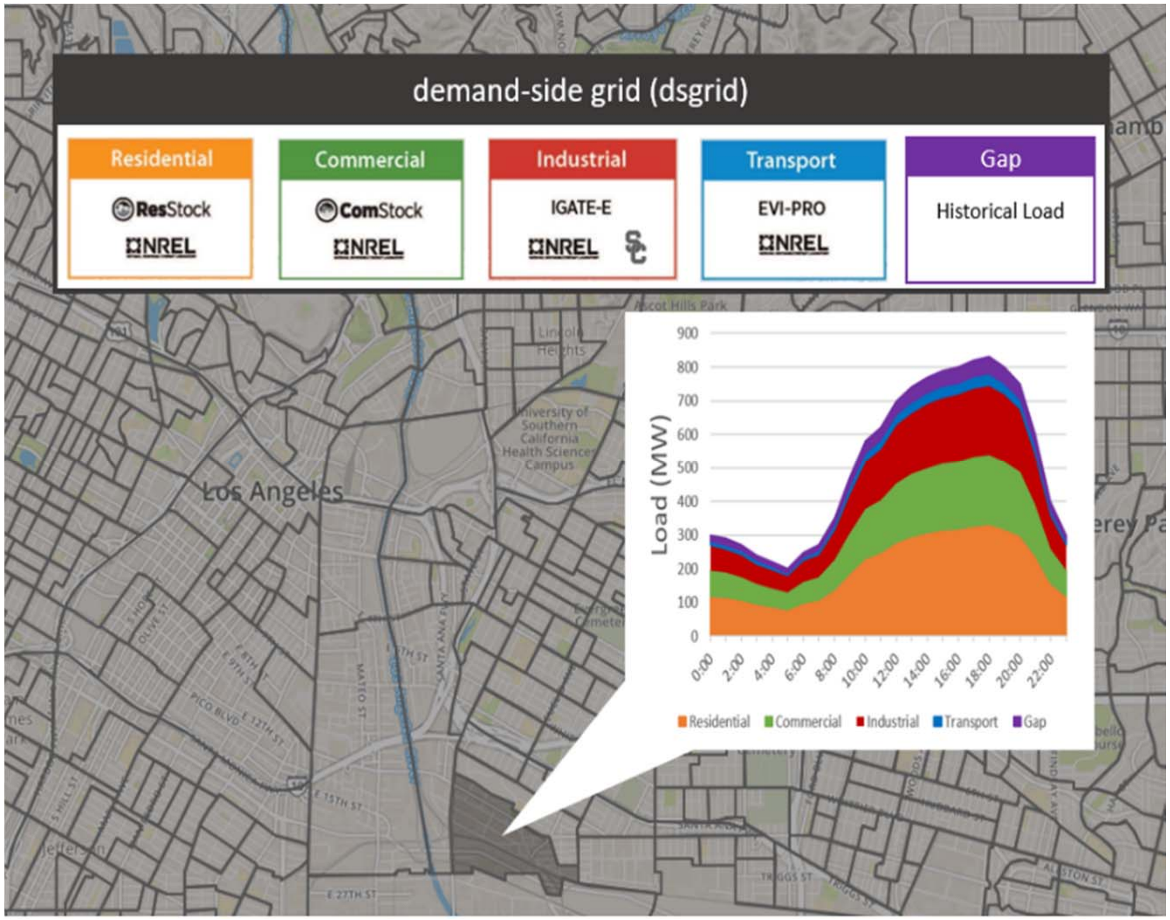


Industrial Demand

Not a single model—combines:

- Individual analysis for certain large loads (airport, port, large industries) derived from existing data and regional projections
  - Use data from advanced metering infrastructure (AMI)
- Analysis by University of Southern California for electricity associated with water infrastructure
- IGATE-E for other industrial loads without AMI data?

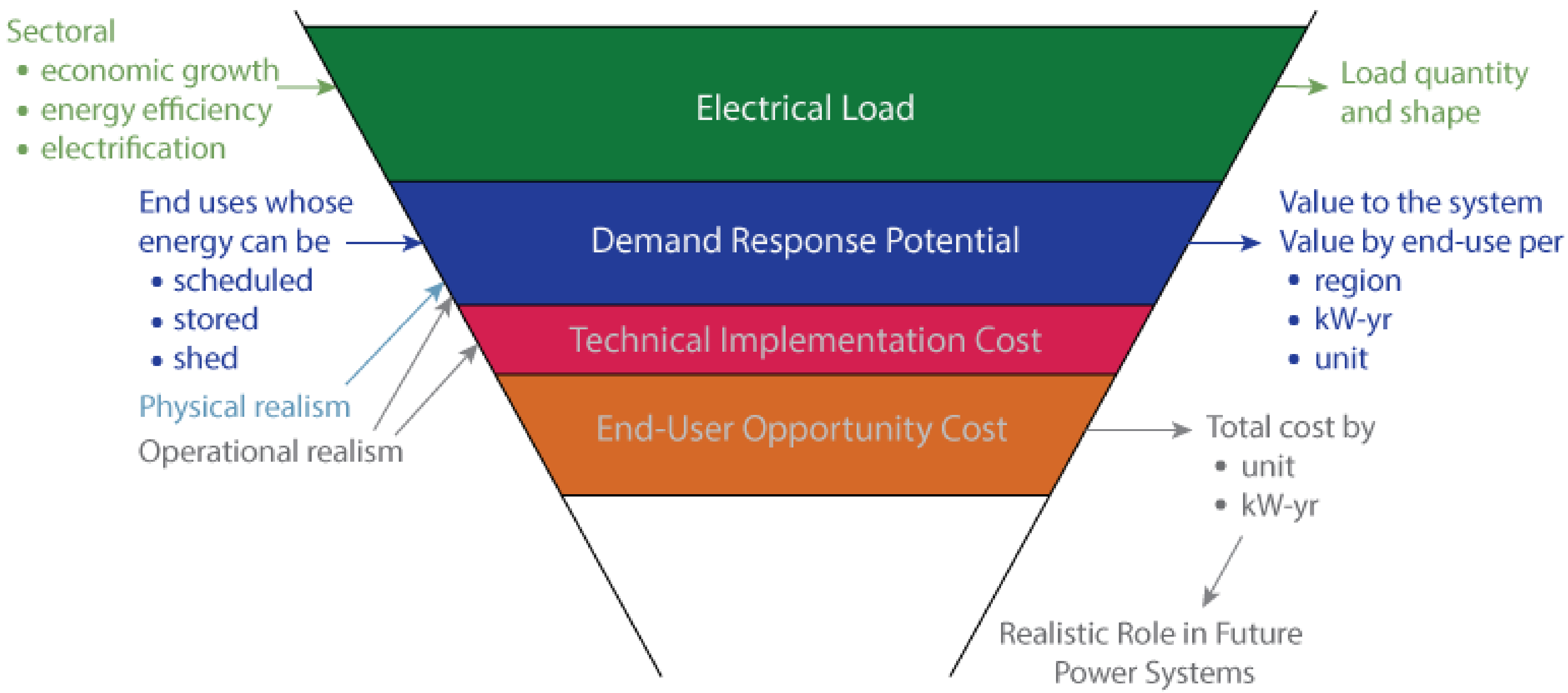
Gap Model



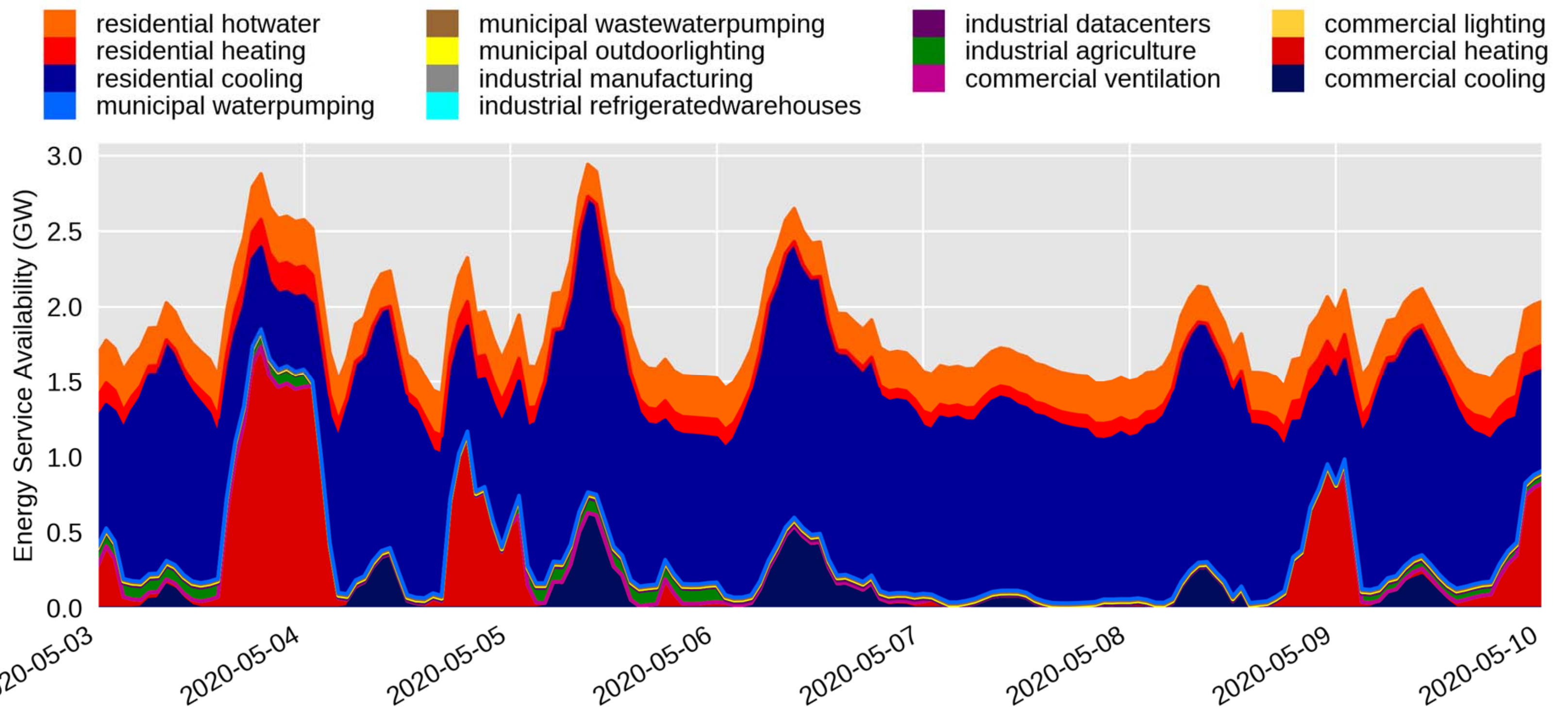
Outdoor lighting, other non-modeled loads.
This should be small if we do our job correctly.

Demand Response and Flexibility

- Traditional load modeling can capture efficiency, but not price-responsiveness—particularly for electric vehicles and smaller commercial and residential loads
- Separate modeling effort applied to demand response and load flexibility:

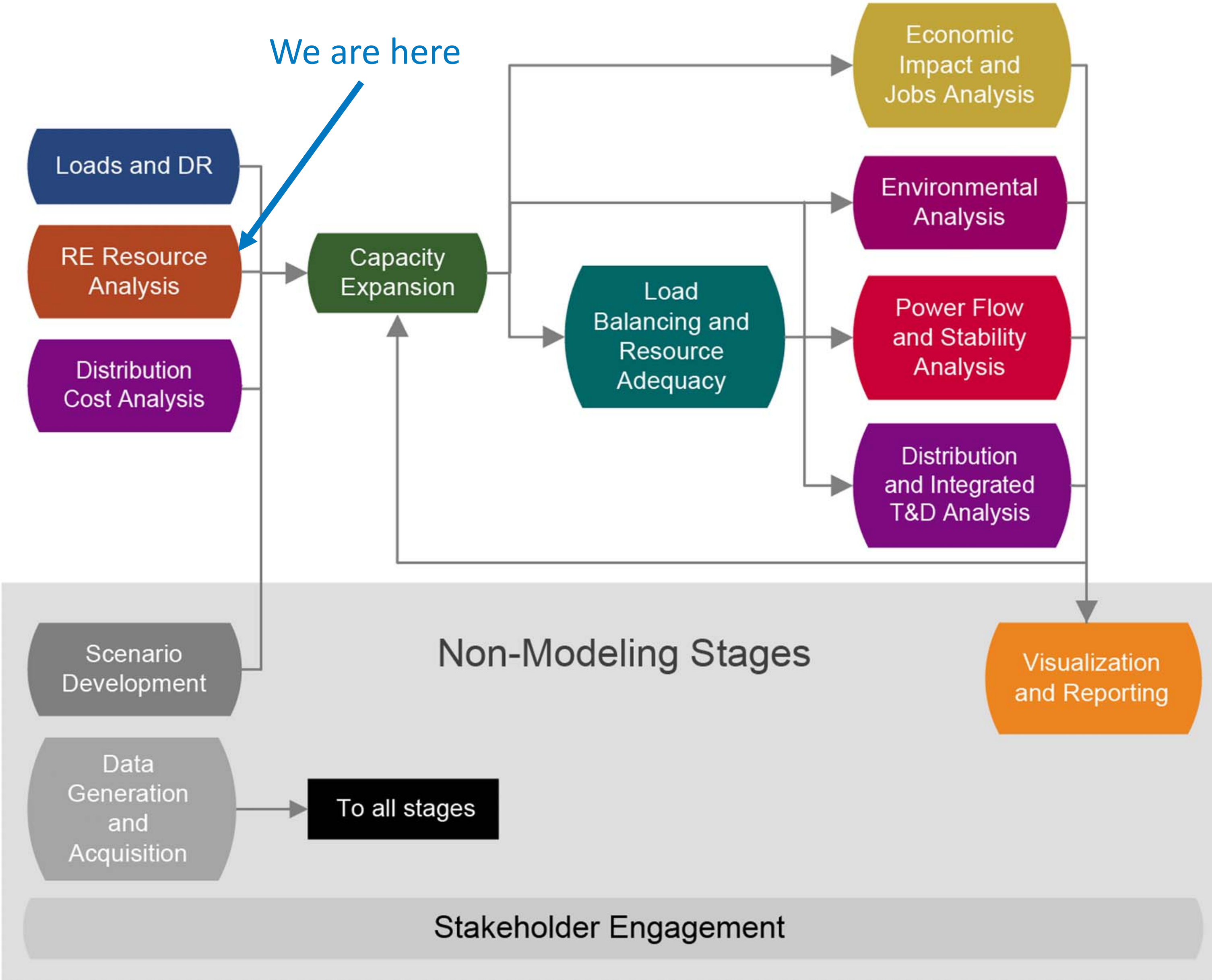


Demand Response and Flexibility



Example outputs: Demand available for load shifting in the Western U.S. during one week

Step 3 – Renewable Resource Analysis

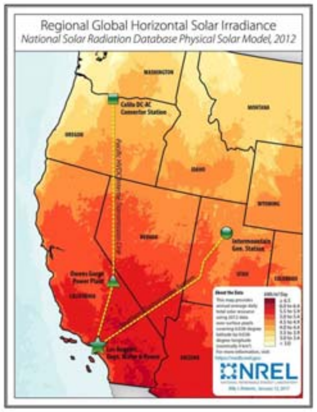


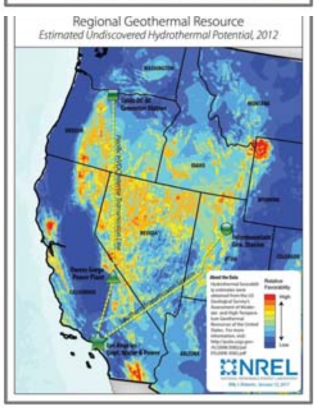
Step 3 – Goals

- Generate a dataset that represents the renewable resources available to LADWP
- Helps us understand interesting "standalone questions," such as:
  - How many MW of wind are available in Southern California or other locations?
  - How much solar is available in-basin?
  - How much land area might be required to meet the 100% goal?

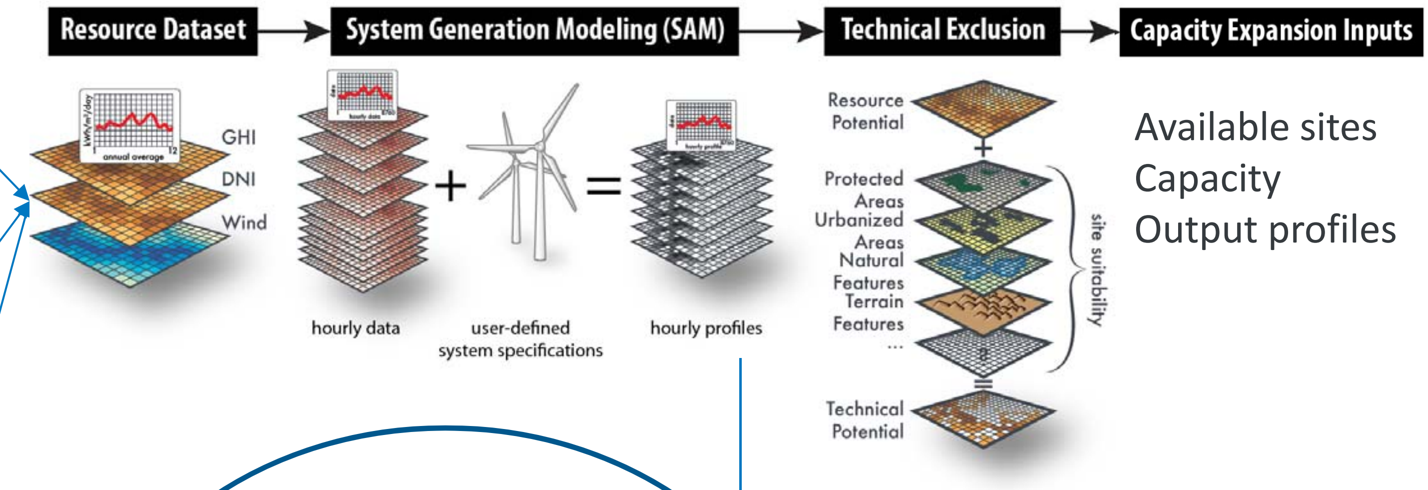
Step 3: Renewable Resource Analysis

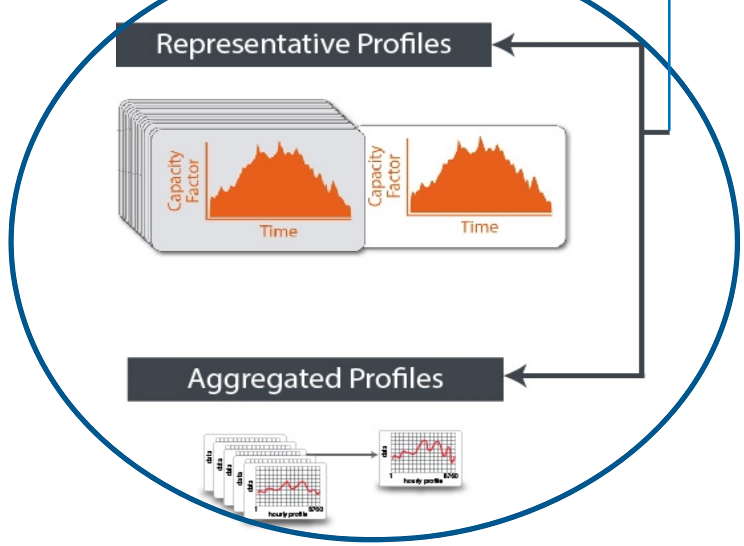
LA DWP





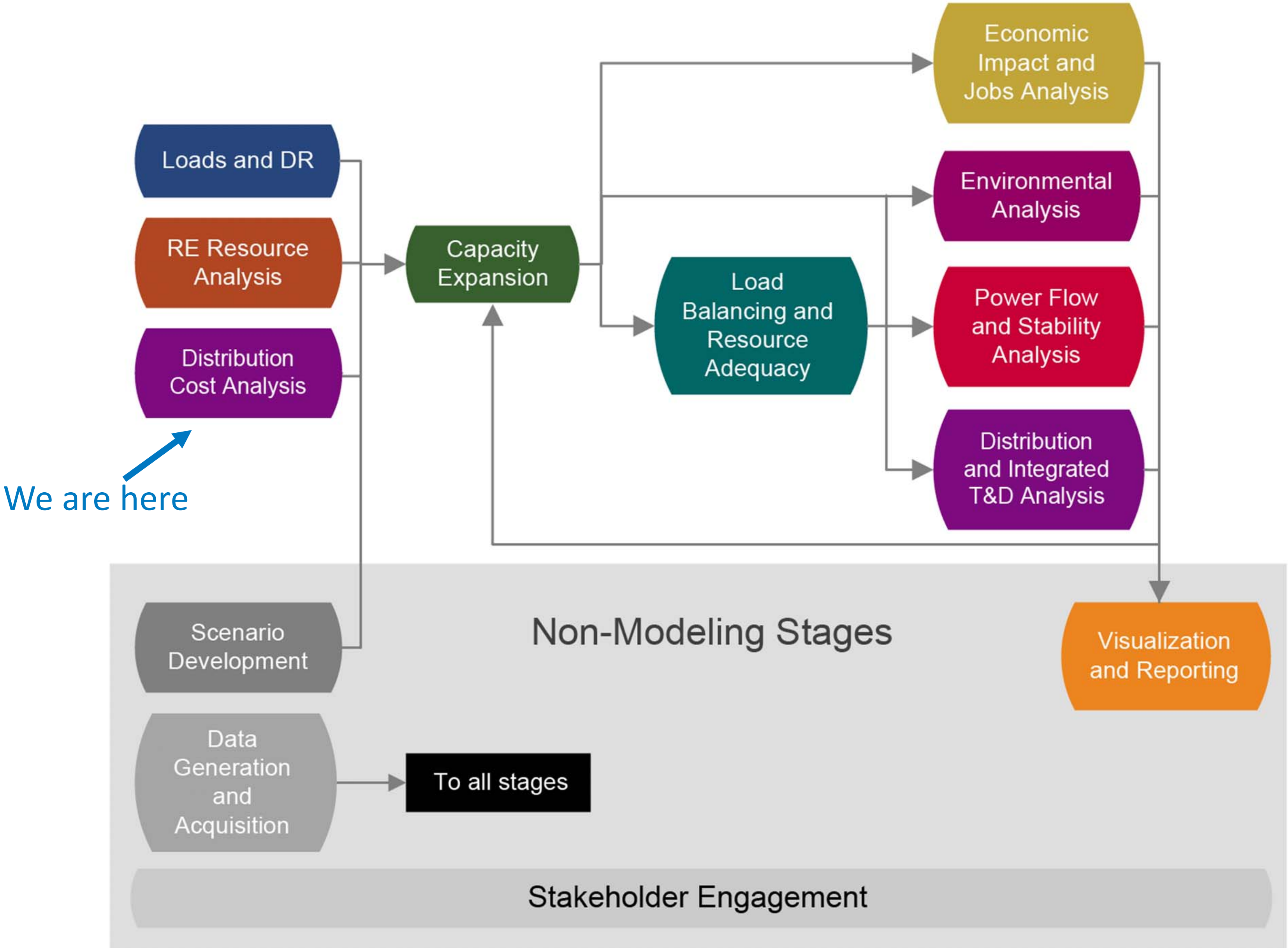
NREL's Renewable Energy Potential (reV) Model





Nick Grue

Step 4 – Distribution System Cost Analysis



Step 4 – Goals

- Generate a dataset that represents the ability of LADWP's distribution network to accommodate DGPV
- Helps us understand interesting "standalone questions," such as:
  - How many distributed PV can be accommodated in the city of Los Angeles?
  - How much will it cost to upgrade the distribution network to add more PV?

Step 4 – Distribution System Cost Analysis

Two not-so-simple questions:

1. Will all the rooftop PV we (may) install break LADWP's distribution network?
2. If so, what are the costs of distribution system upgrades needed for large DGPV deployment?

Distribution Cost Analysis

LA DWP

Hosting Capacity – Point at which you can't add any more PV without additional upgrades

Cost Analysis – How much $ per unit of PV to add additional hosting capacity

Step 1. Select the power factor set point to use for all DPV inverters

Step 2. DGPV hosting capacity analysis

Step 3. Map violations identified at the hosting capacity limit to a set of upgrades that can be used to mitigate them

Step 4. Obtain a range of unit costs associated with each of the selected upgrades

Step 5. Calculate the total costs associated with all upgrades required to increase penetration

Step 6. Deploy mitigation solutions in OpenDSS

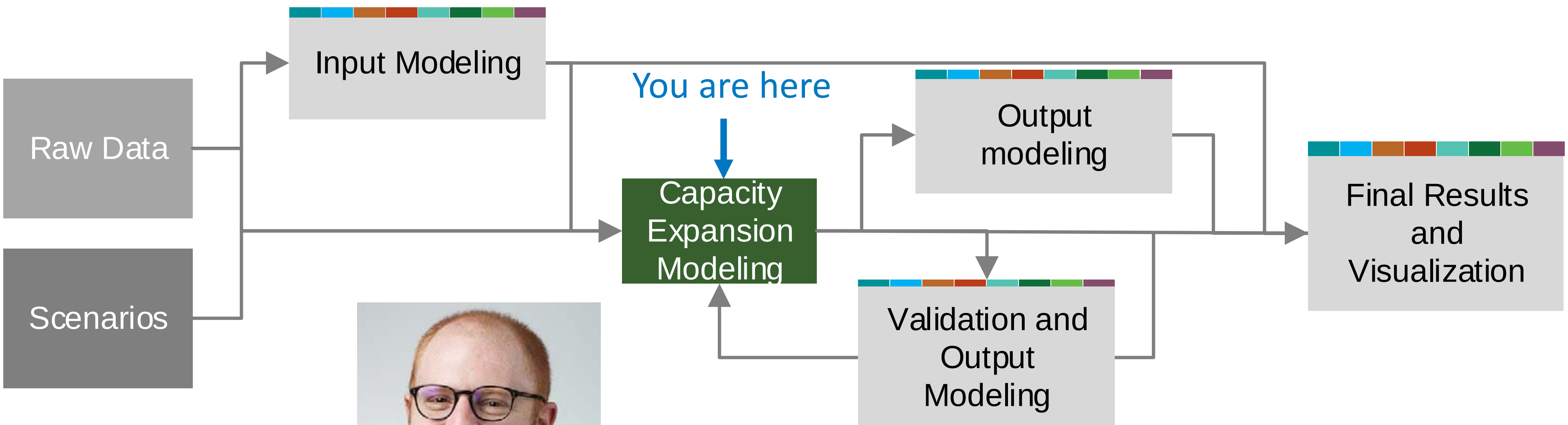
Repeat

Bryan Palmintier

Kelsey Horowitz

Step 5 – Capacity Expansion

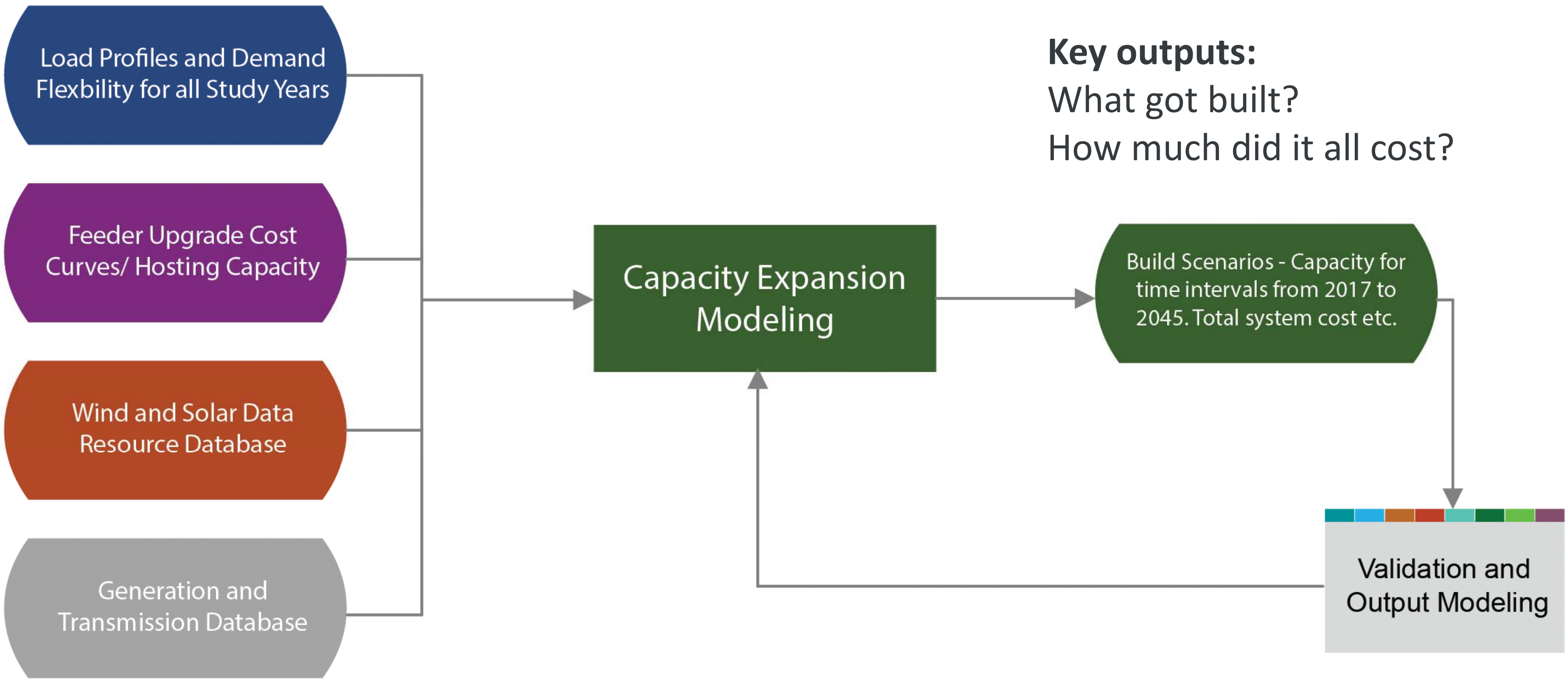
- Determines the generation mix for each scenario
- Considers utility-scale generator development and customer adoption of DERs
- The "core" model of the LA100 study



Dan Steinberg

General Flow of Capacity Expansion Modeling

Key outputs:
What got built?
How much did it all cost?



NREL's Capacity Expansion Modeling System

Ben Sigrin

This stage uses RPM as the main model, supplemented by dGen

Input Data

Capacity Expansion Modeling

DGPV adoption (Dgen)

Convergence Runs

G&T (Bulk Power) CEM (RPM)

Build Scenarios – Capacity for time intervals from 2017 to 2045. Total system cost etc

Validation and Output Modeling

Brady Stoll

Resource Planning Model (RPM)

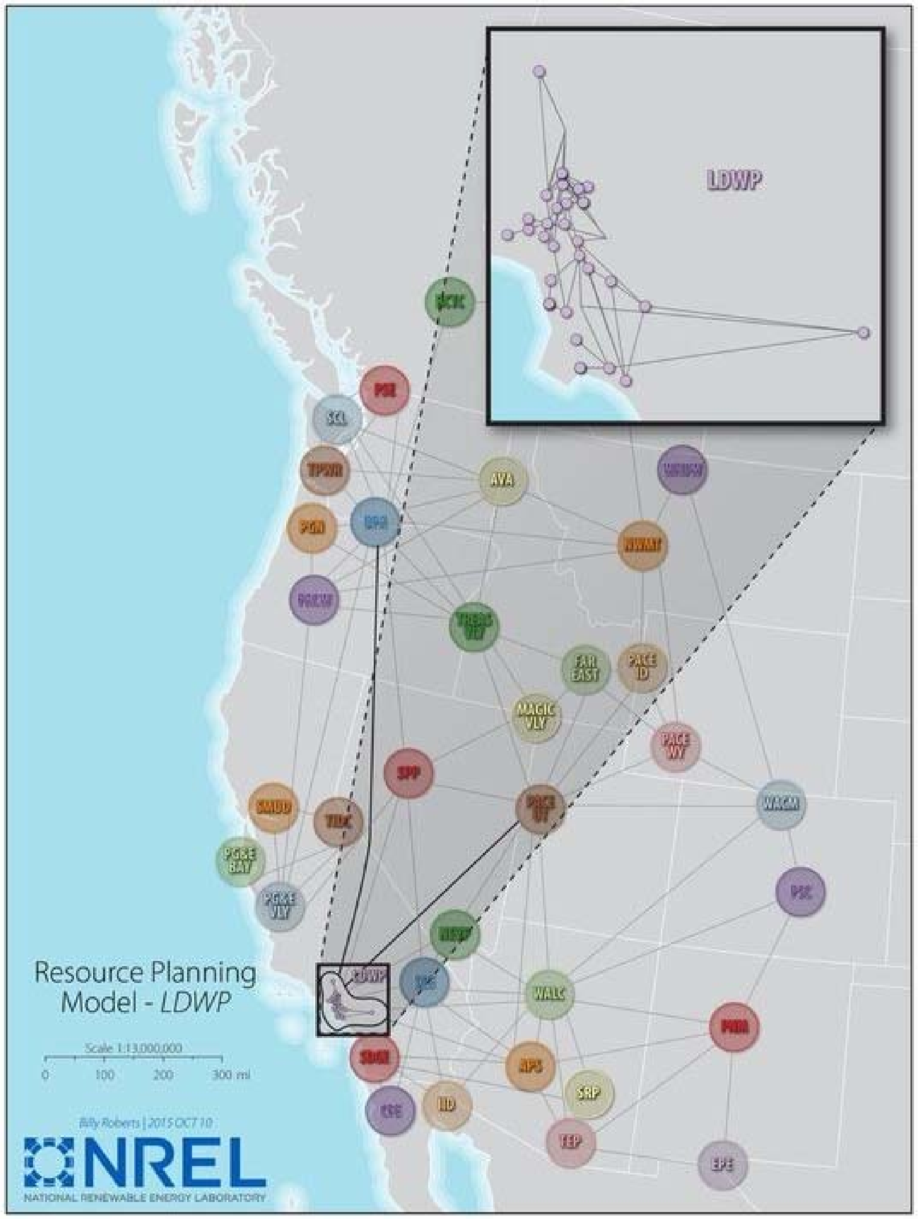
Capacity expansion model for a *regional* electric system

Key features:

- Individual generation unit and transmission line representation
- Hourly chronological dispatch and detailed system operation representation
- High spatial resolution informs generator siting options, particularly for renewable resources
- Flexible data structure to develop models for customized regions
- Models the cost and value of storage and other enabling technologies

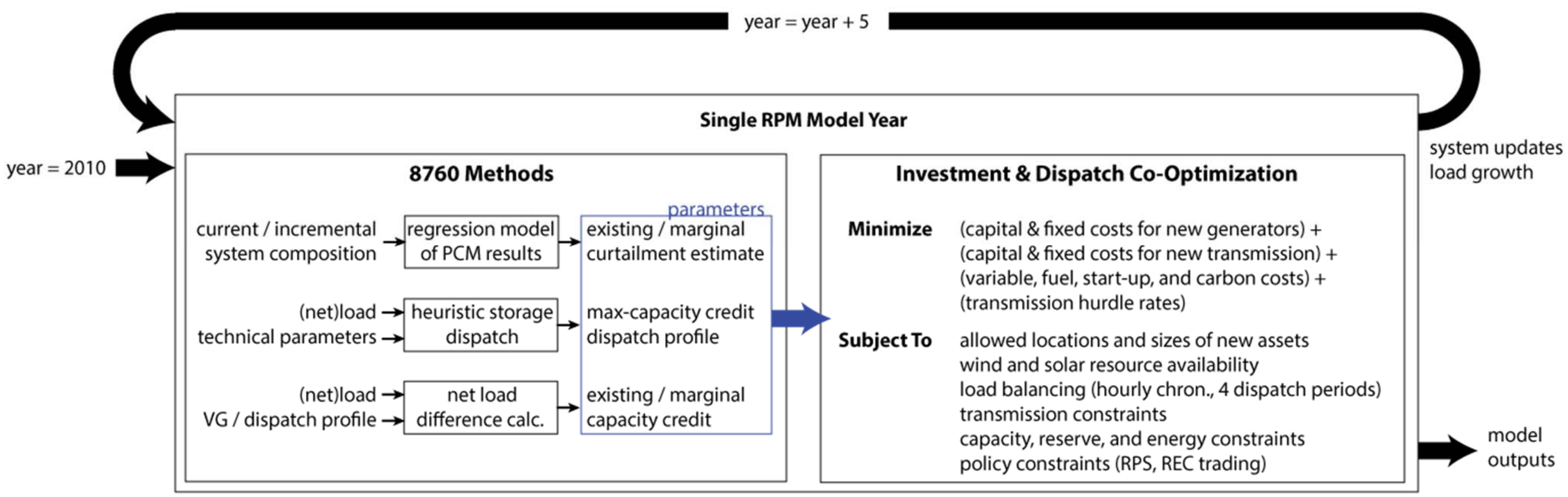
http://www.nrel.gov/analysis/models_rpm.html

Geographical Scope



RPM is a mixed nodal/zonal model

RPM Application of Hourly Data for Key VG Analysis



System Requirements Simulated

LA DWP

- **Firm Capacity.** Capacity on the system that is ready to be scheduled and dispatched to meet load. Of particular interest here is having sufficient capacity to meet peak or near-peak load, the magnitude and timing of which is uncertain.
- **Energy.** Basic provision of real power that is transmitted to utility customers. RPM also captures the ability of certain resources to shift generation from low price to high price times.
- **Spinning Reserves.** Capacity that can quickly ramp up to make up for unexpected large generator or transmission line outages.
- **Regulation Reserves.** Load following capacity that continuously (e.g., every 4 to 6 seconds) balances out net-load forecast errors.
- **Flexibility Reserves.** These reserves are similar to regulation, but are used to balance out longer-term (1-4 hour) uncertainty in variable generation.

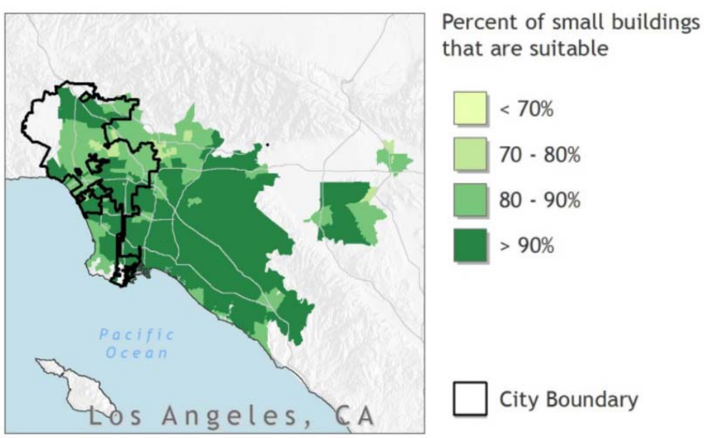
Services Provided by Generator Class

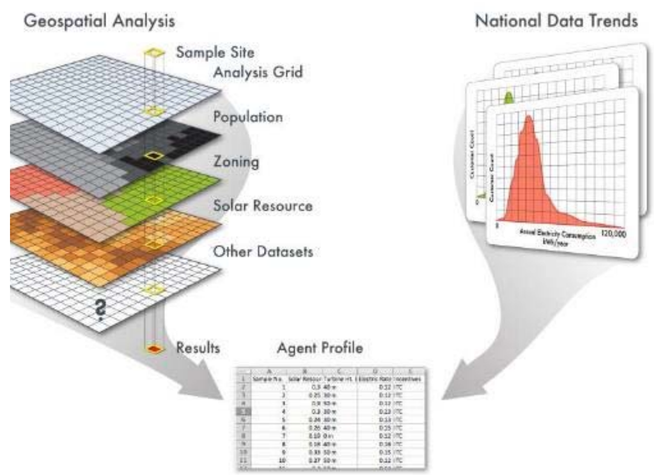
	Dispatchable Generator	Variable Generators	CSP with TES	Battery Storage
Firm Capacity	Full CV	Partial CV	Partial CV	Partial CV
Energy	Yes	Yes, as energy is available	Yes, from array or if energy in storage	Yes, if energy is in storage
Spinning Reserves	Yes	No	Yes	Yes, if long enough storage
Regulation Reserves	Yes, ramp rate constrained	No	Yes, if energy in storage	Yes, if energy in storage
Flexibility Reserves	Yes	No	Yes, if long enough storage	Yes, if long enough storage

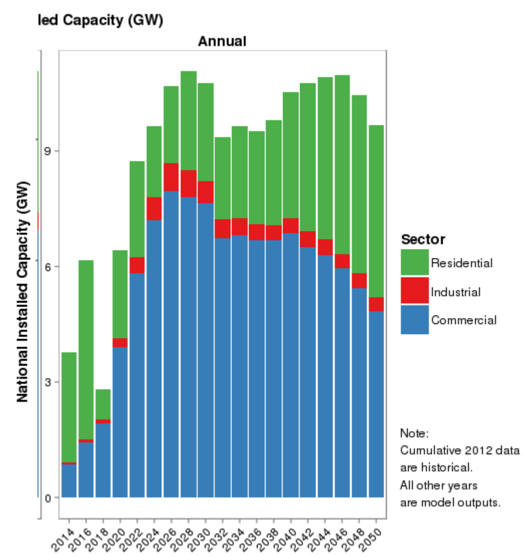
Distributed Technology Diffusion (dGen)

RPM does not estimate DG adoption.
A separate model (dGen) is used.

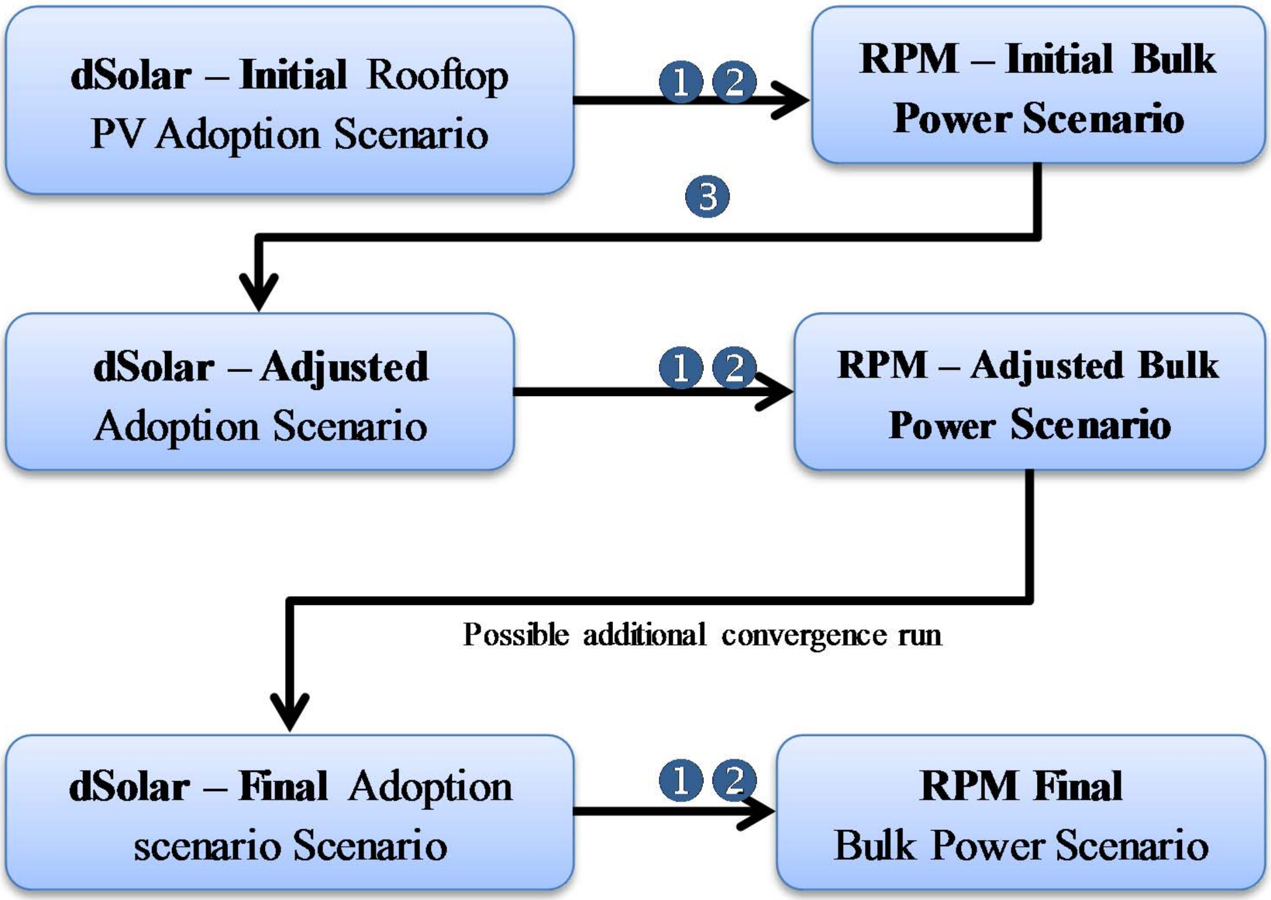
- Forecasts customer adoption of distributed generation technologies (solar, storage, wind, geothermal) for residential, commercial, and industrial entities, given assumptions about future electricity costs, technology cost and performance, policy and regulation, and customer behavior
- High geographic resolution enables state, utility, or city-specific analysis with overlay of multiple spatial layers





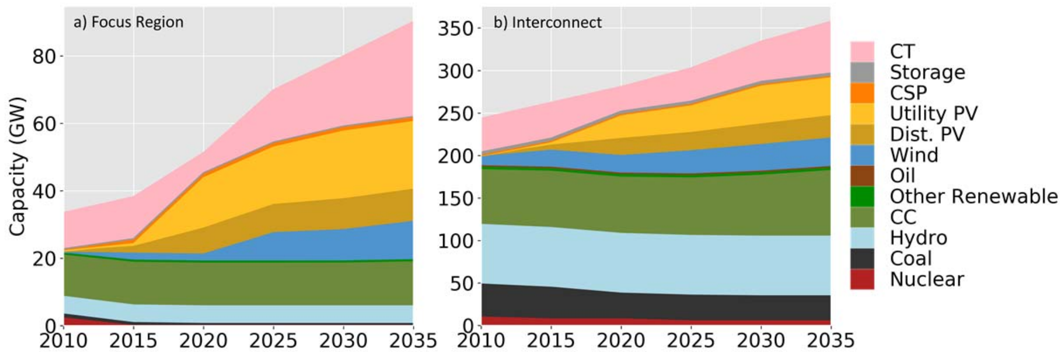


RPM/dGen Linkage

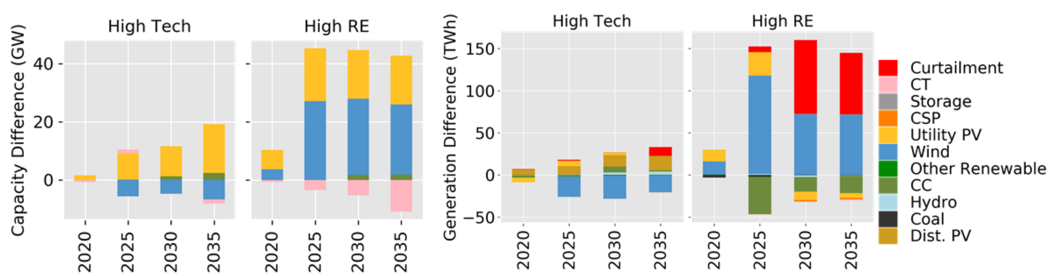


1. Rooftop PV capacity by region
2. Rooftop PV generation
3. Impact on rooftop PV curtailment rate and value

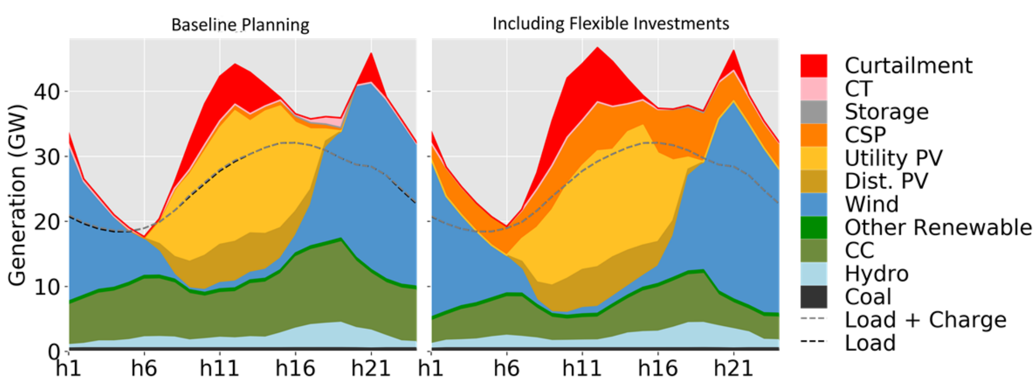
Example Results



Growth in capacity



Comparisons across scenarios



System dispatch (for *preliminary* validation and analysis)

At This Point…

- We have now generated a plan to meet 100% RE using what we believe is the most advanced capacity expansion tool in existence and best-in-class renewable resource data
- We have calculated system costs and estimated emissions reductions

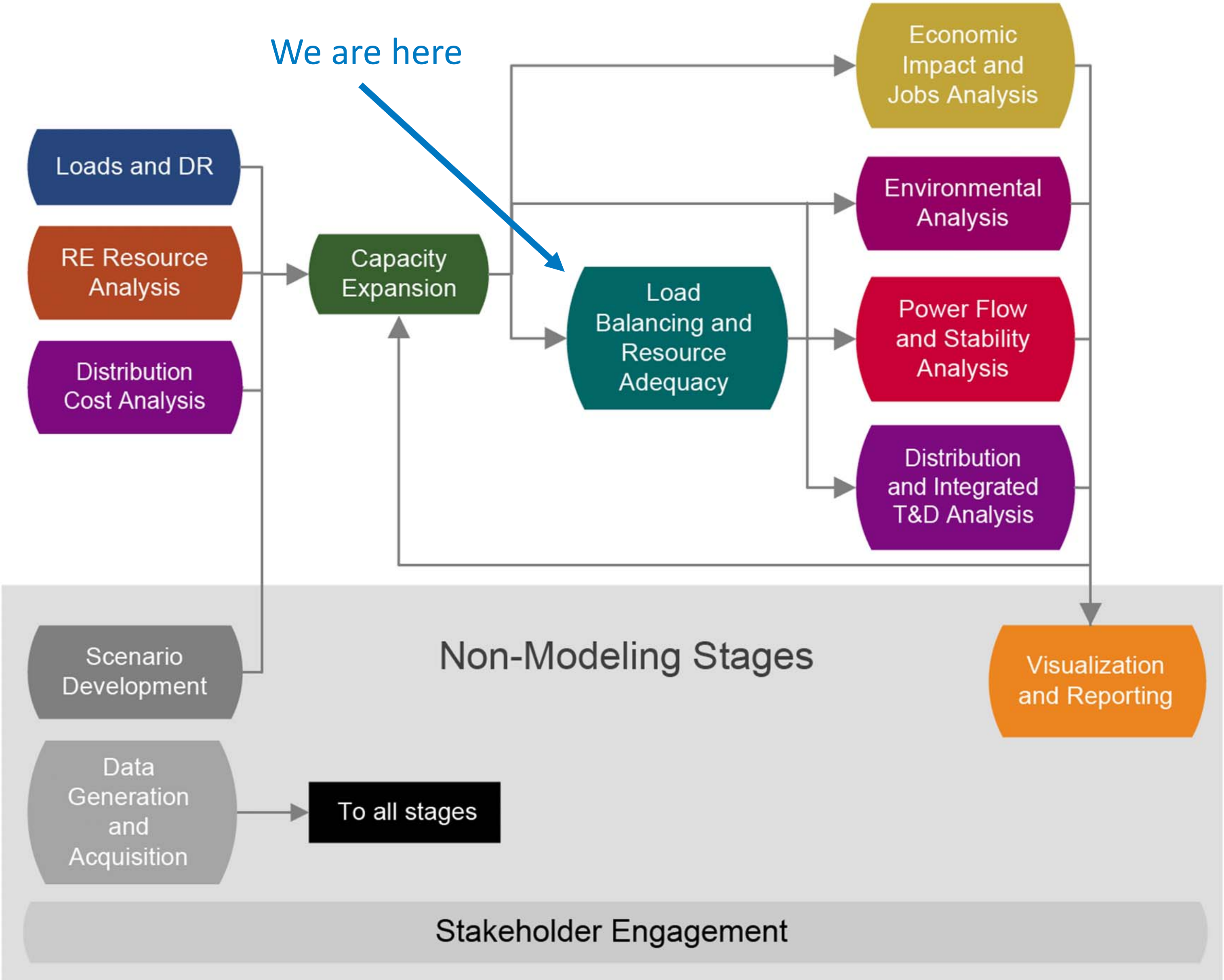
But we are not done yet.

We need to validate all of this and make sure this plan really works.

Why We Are Not Done at This Point of The Study

- We have not yet validated:
  - Resource adequacy
  - Hourly and subhourly ramping requirements for all time intervals
  - Operating reserve requirements for frequency stability including frequency response obligation
  - Ability to meet contingency events
  - Transmission system reliability
  - Distribution system reliability
- In addition to these other key metrics:
  - Air quality and public health benefits
  - Economic and job impacts

Step 6 – Load Balancing and Resource Adequacy

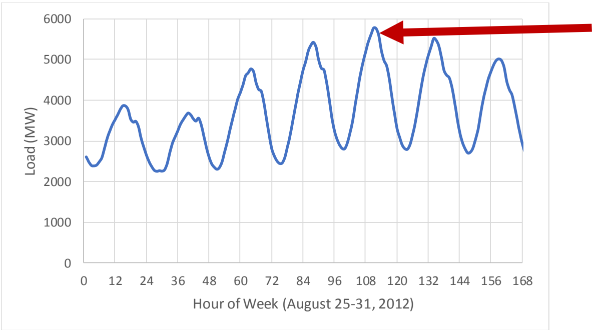


Step 6 – Load Balancing and Resource Adequacy

Goals - Answer two main questions:

1. Can the bulk power system actually balance load in each time period?
   - Production Cost (Dispatch) Modeling

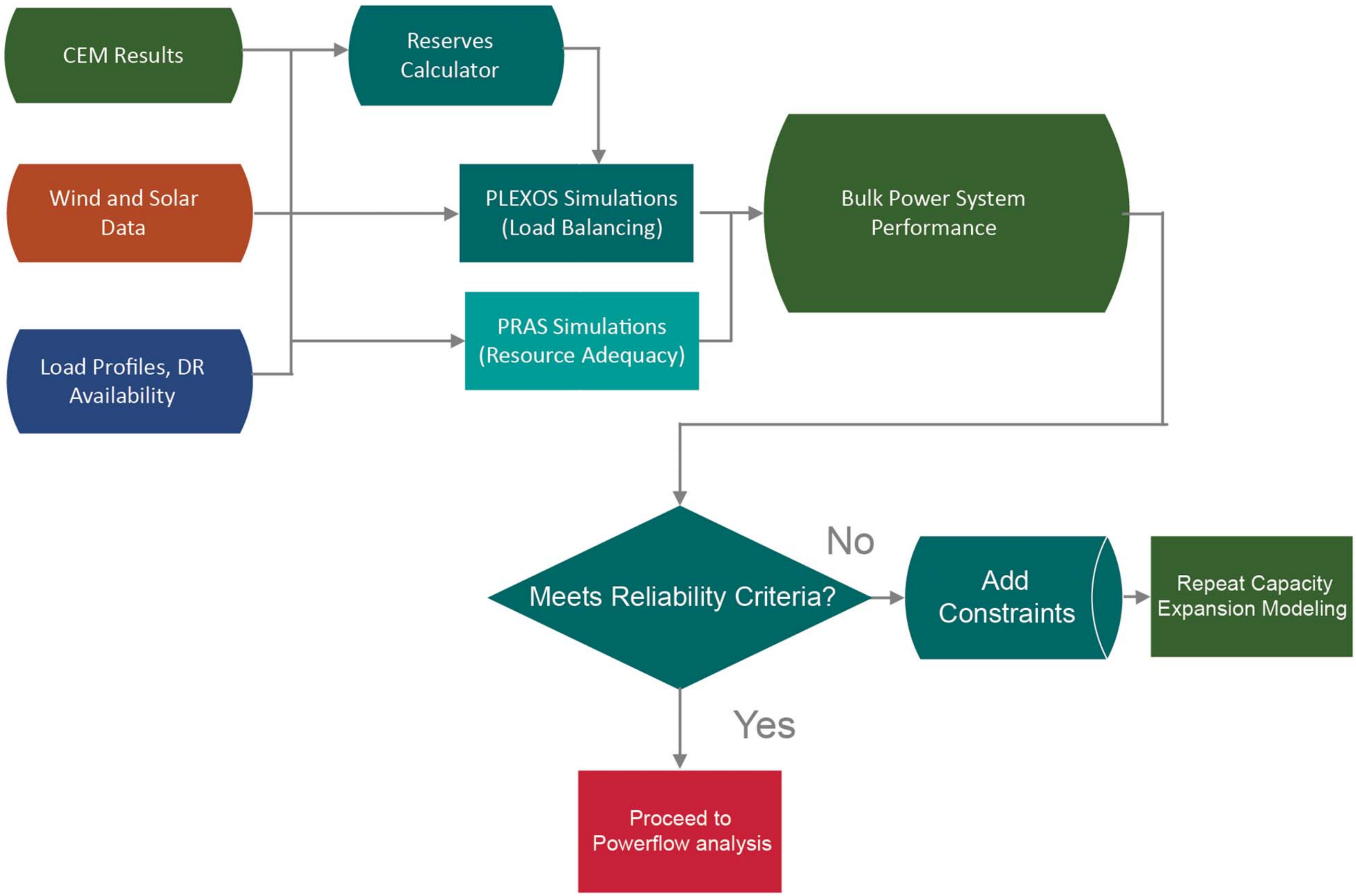
2. Does the system have enough generation resources to meet the demand on a really hot summer day?
   - Resource Adequacy Modeling



What is the probability that LADWP will have enough generation capacity here?

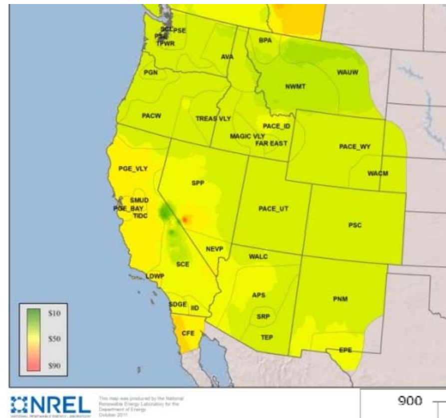
Jennie Jorgenson

Flow of Load Balancing and Resource Adequacy



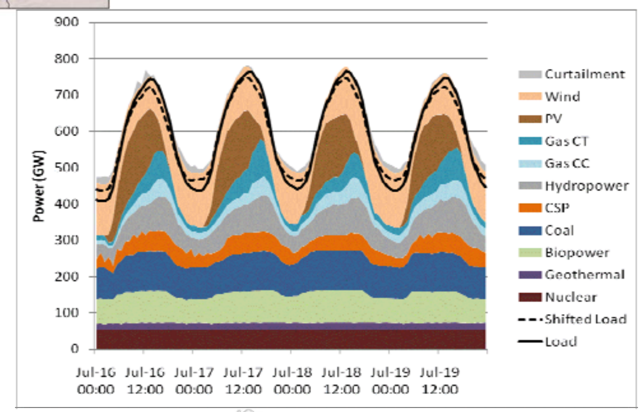
PLEXOS Production Cost Model

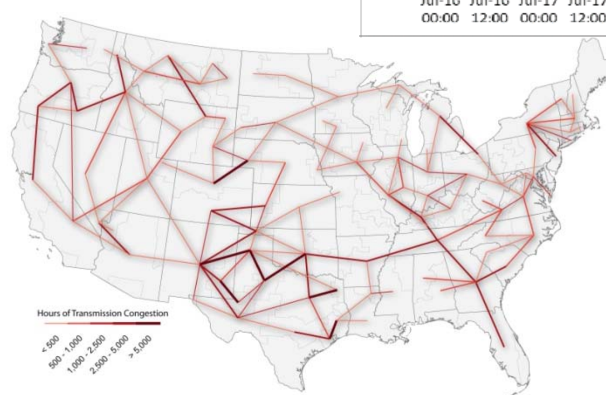
- Hourly or subhourly chronological
- Commits and dispatches generating units based on:
  - Electricity demand
  - Operating parameters of generators
  - Transmission grid parameters
- Used for system generation and transmission planning
  - Increasingly used for real-time operation



Locational prices, production cost

Dispatch information, fuel usage



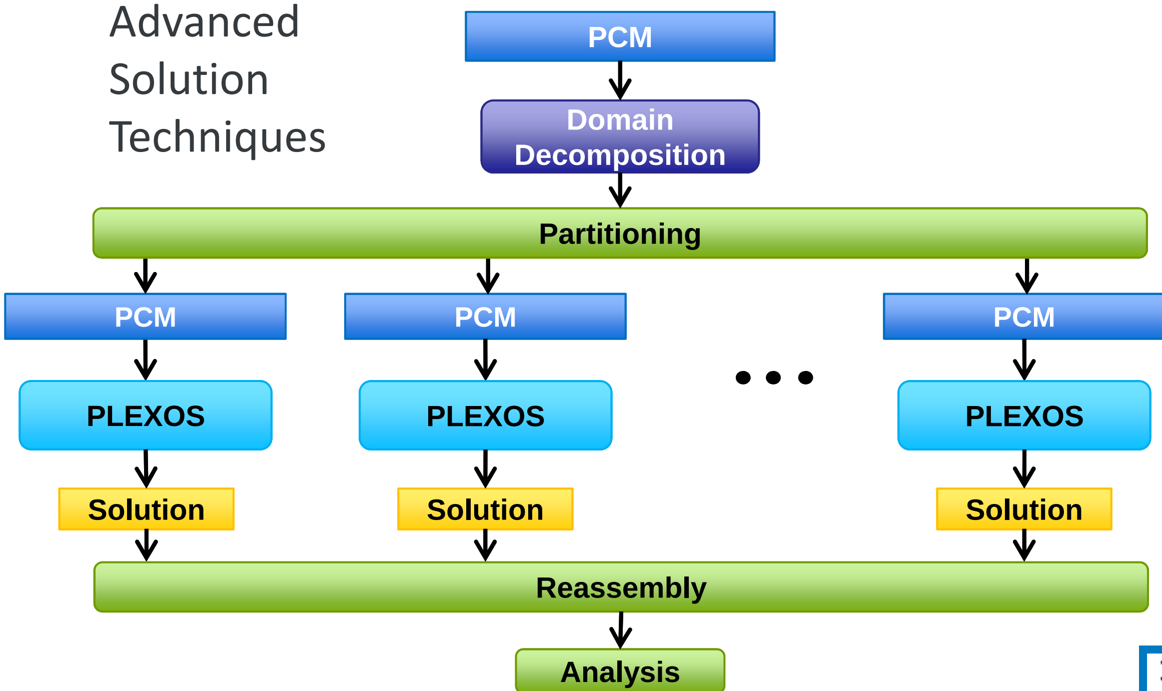


Transmission congestion

NREL's Value Add

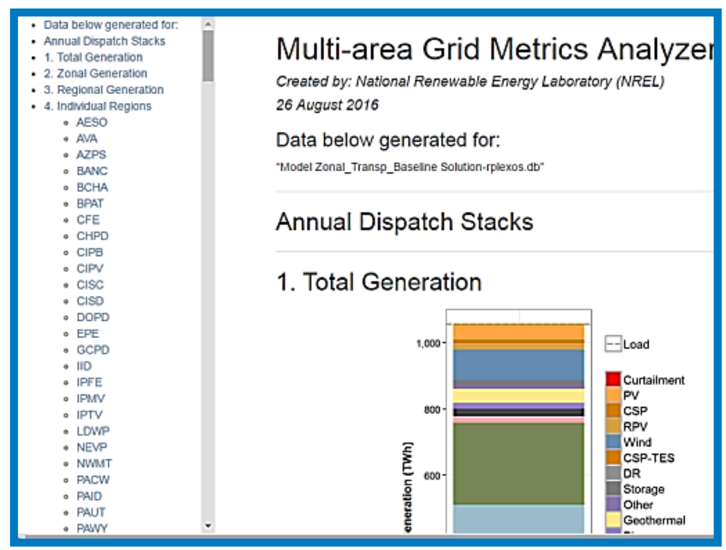
LA DWP

Advanced Solution Techniques

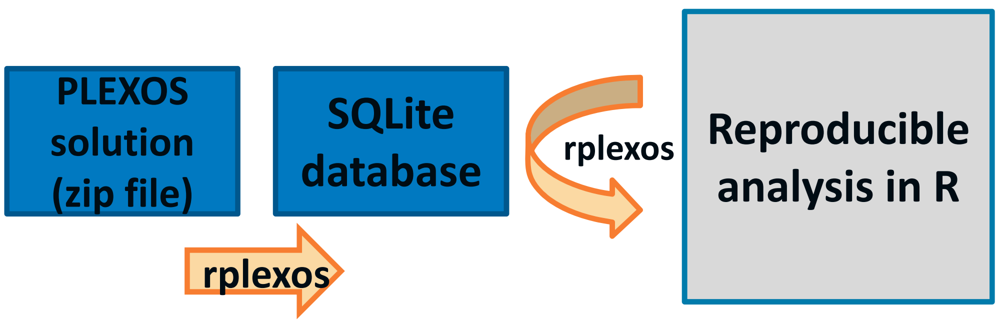


NREL Peregrine HPC

Automated Solution Processing

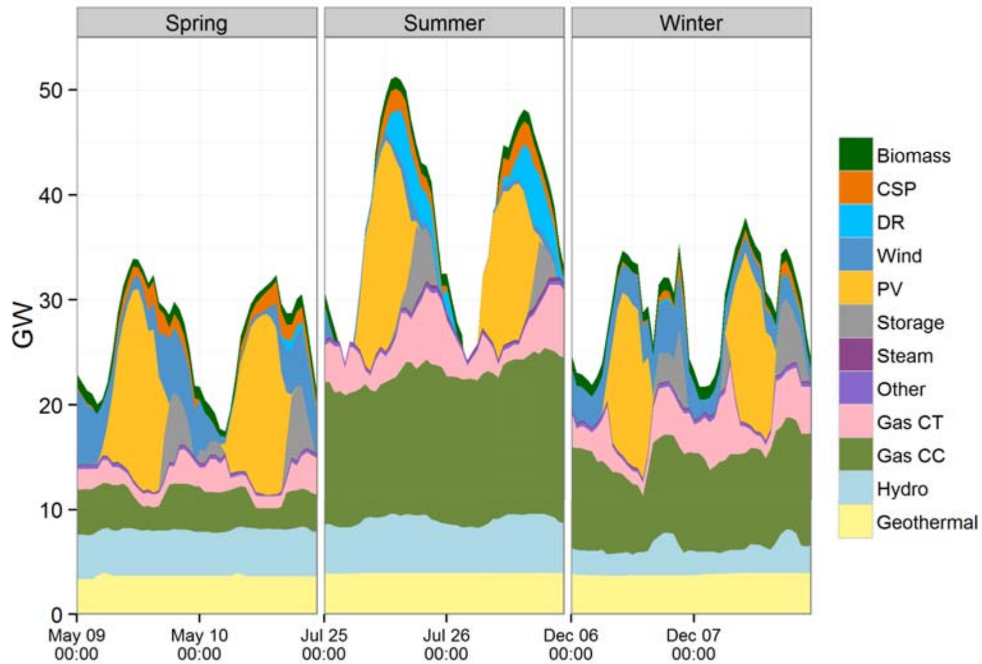


Automated Data Processing

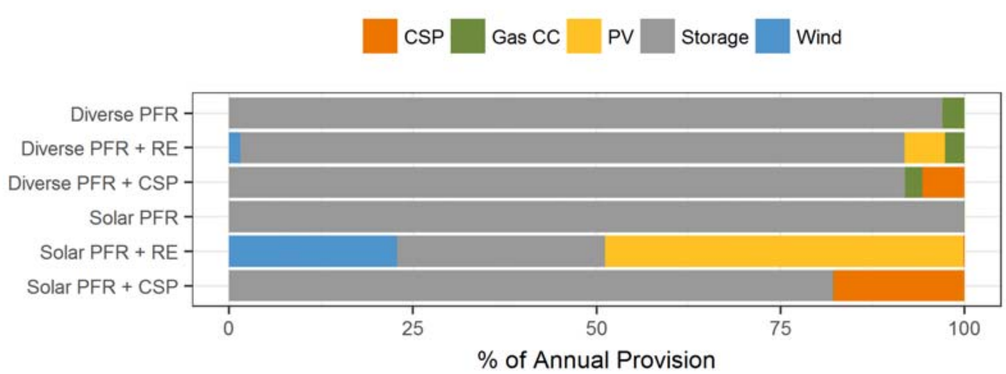


Example Results

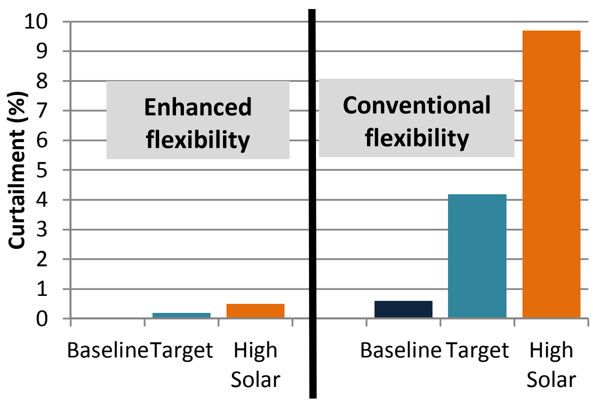
System Dispatch



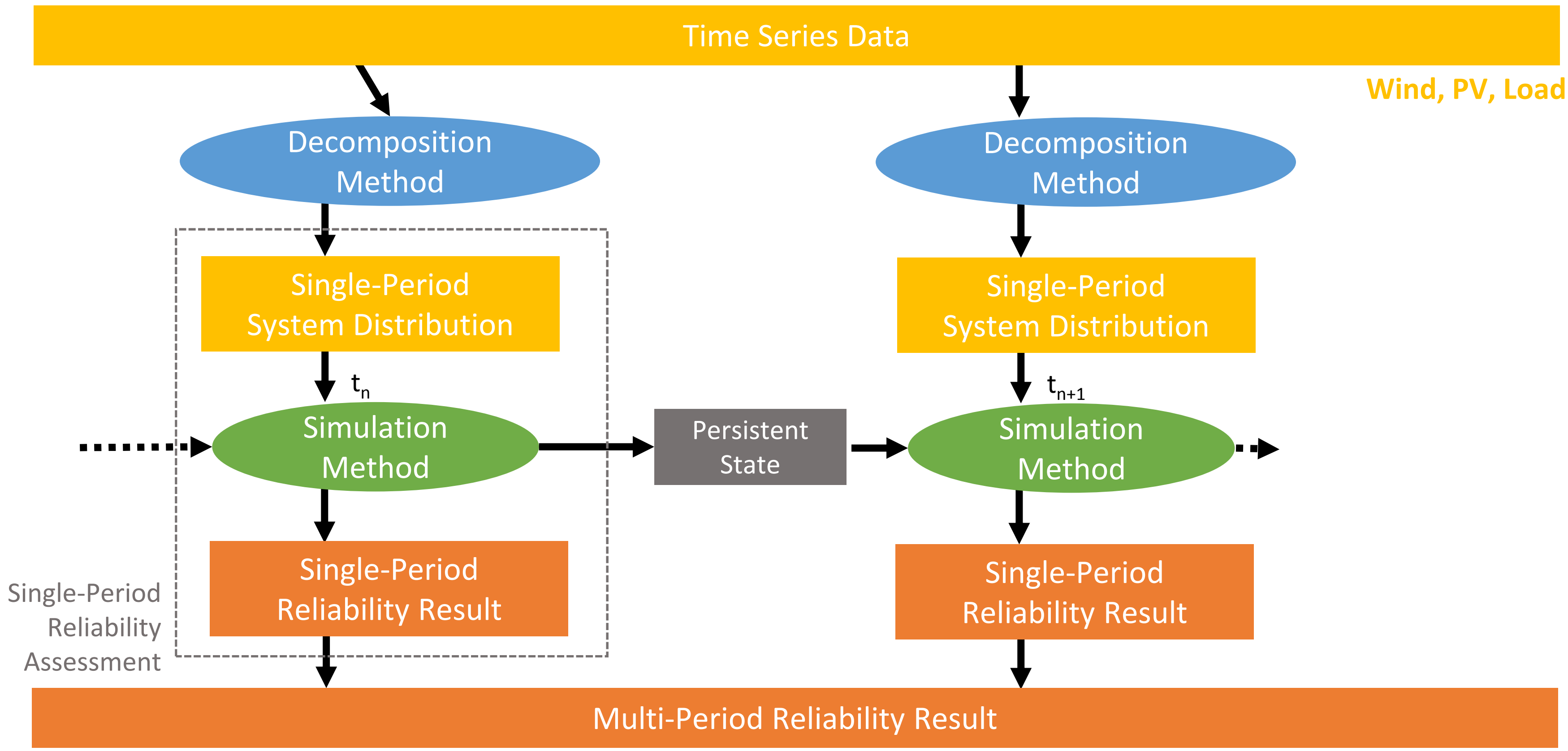
Operating Reserves Provision



Curtailment



NREL's Probabilistic Resource Adequacy Suite (PRAS)

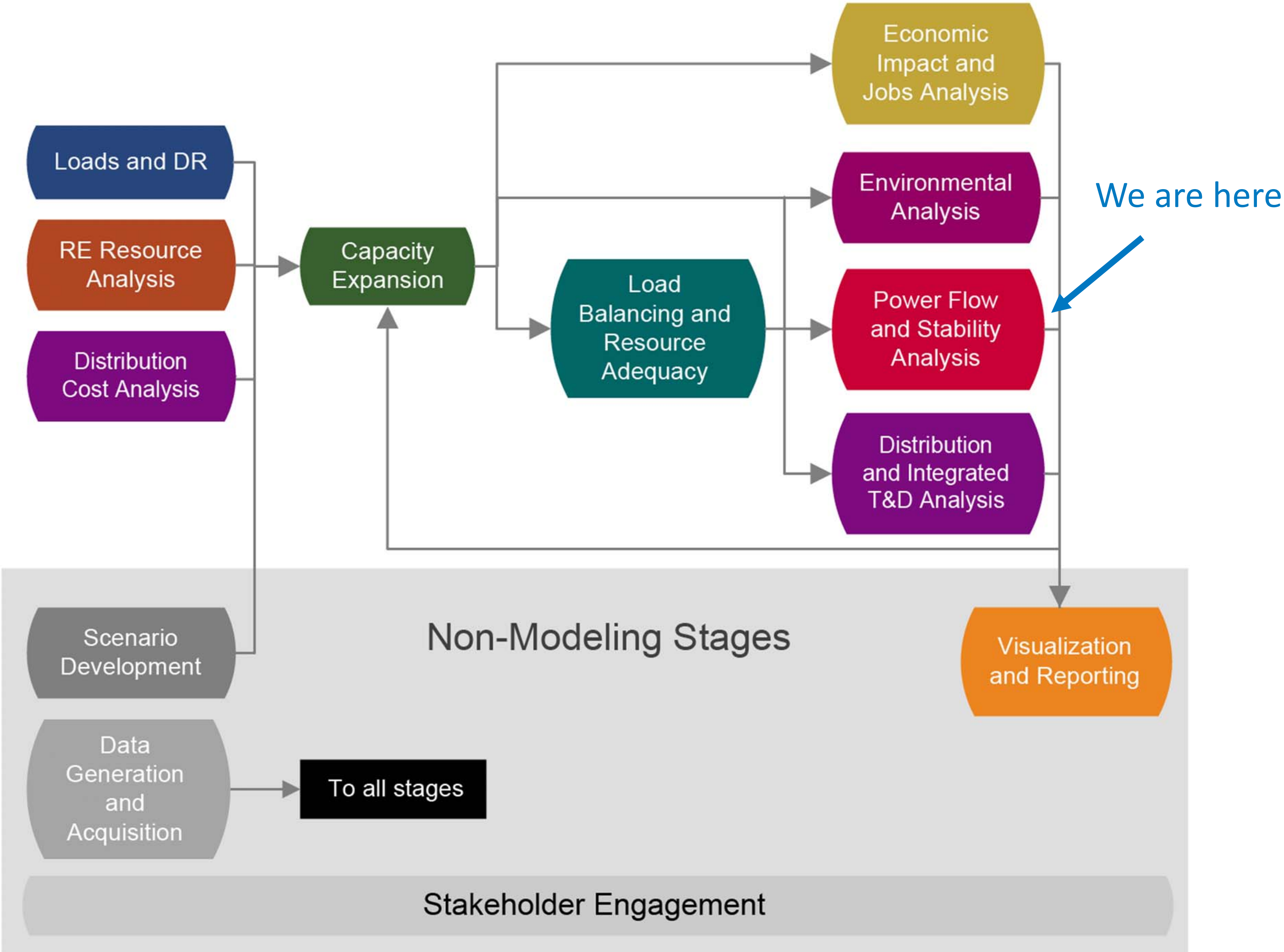


Performs a statistical analysis of the likelihood that LADWP will not have enough generation to meet load during every hour of the year

Resource Adequacy Metrics:

- Loss-of Load Probability (LOLP)
- Loss-of-Load Expectation (LOLE)
- Expected Unserved Energy (EUE)

Step 7 – Transmission and Stability Analysis

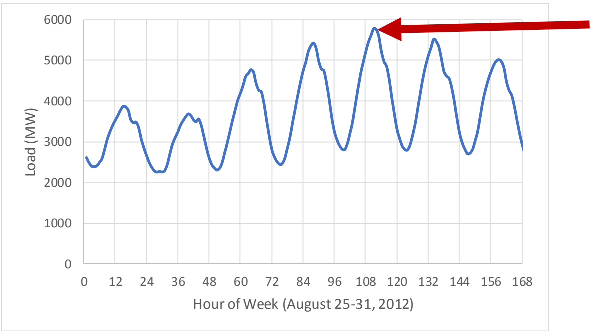


Step 7 –Transmission and Stability Analysis

Goals - Answer two main questions:

1. Will the transmission system work reliably?
   - AC Power Flow Analysis

2. Will the system continue to work if there is a failure of any single component
   - Contingency/Stability Analysis

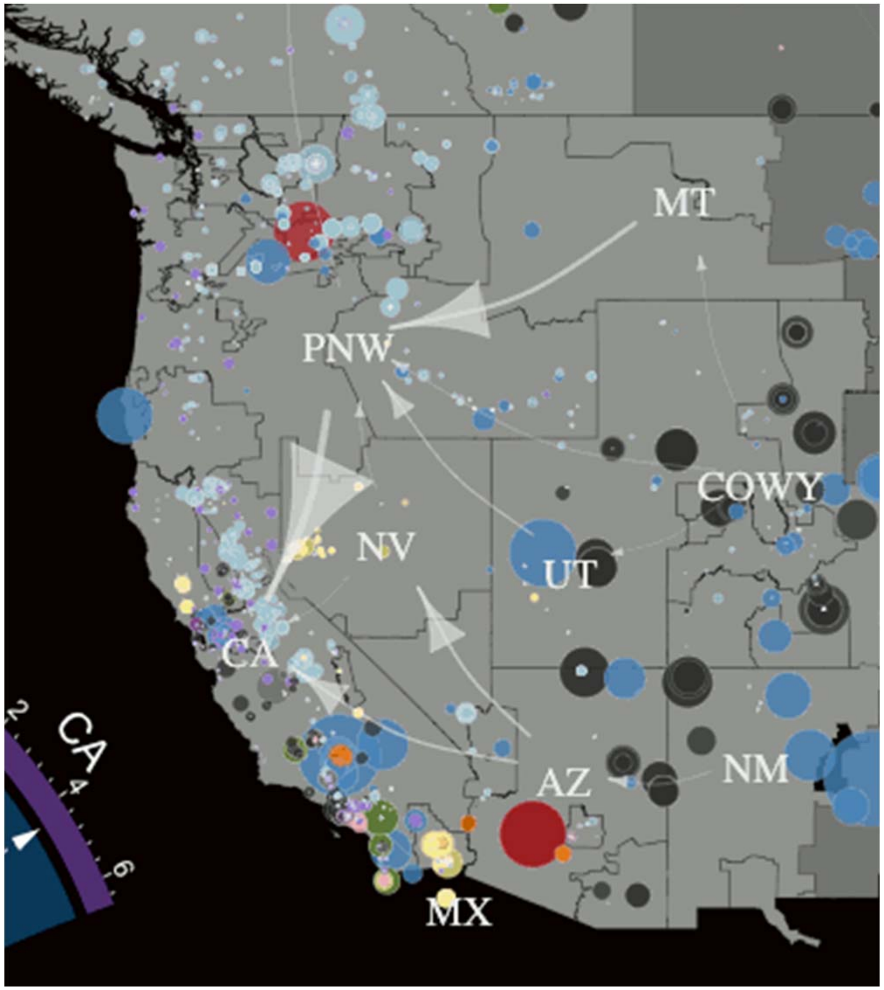


What happens if a power line fails here?

Himanshu Jain

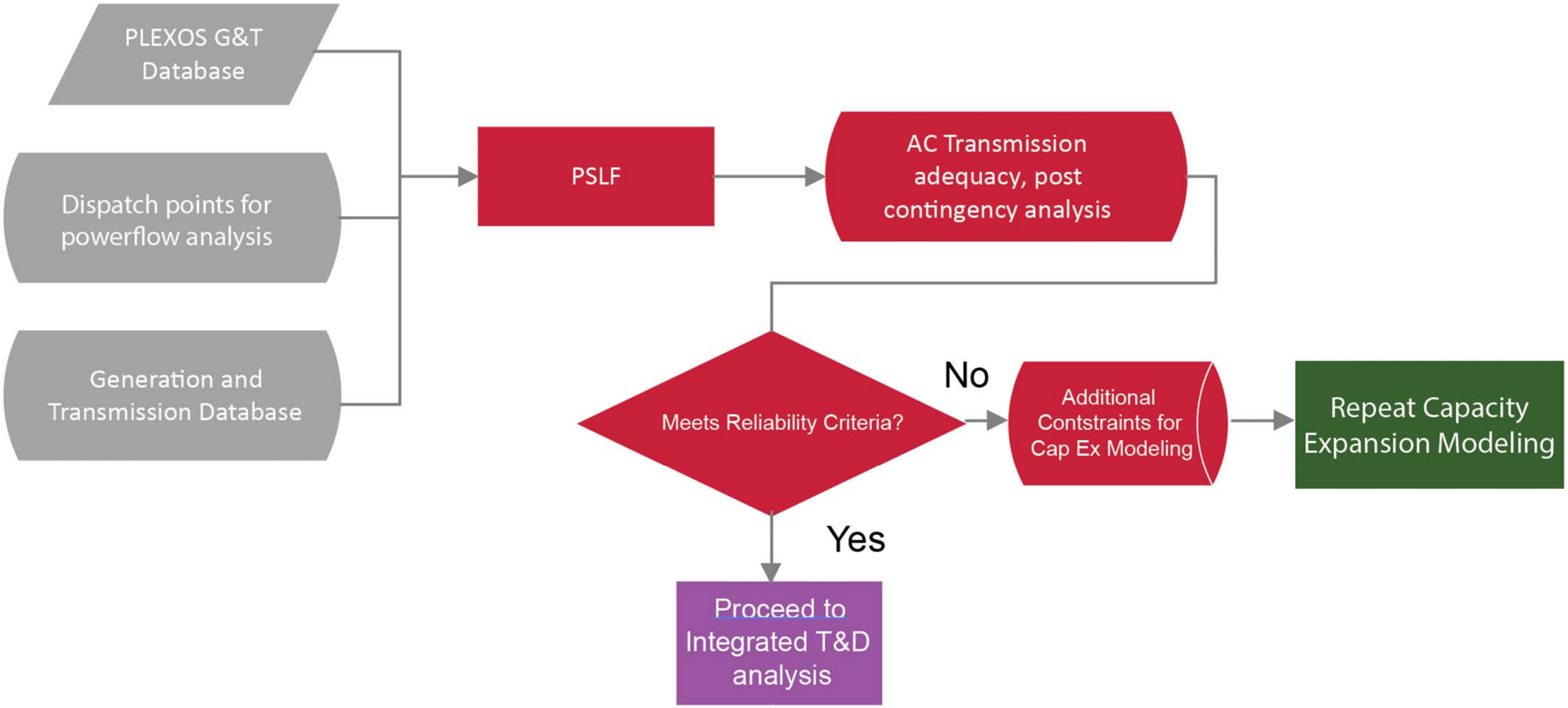
Yingchen (YC) Zhang

Step 7 – Transmission and Stability Analysis



- Performs a deep dive on transmission system adequacy using detailed physics-based models of the entire interconnection; ensures the system is stable
- Looks for conditions where the transmission system will break, typically by exceeding the capacity of individual lines or other components
- Simulates a few very short snapshots (typically less than 30 seconds) of system operation

Power Flow and Stability



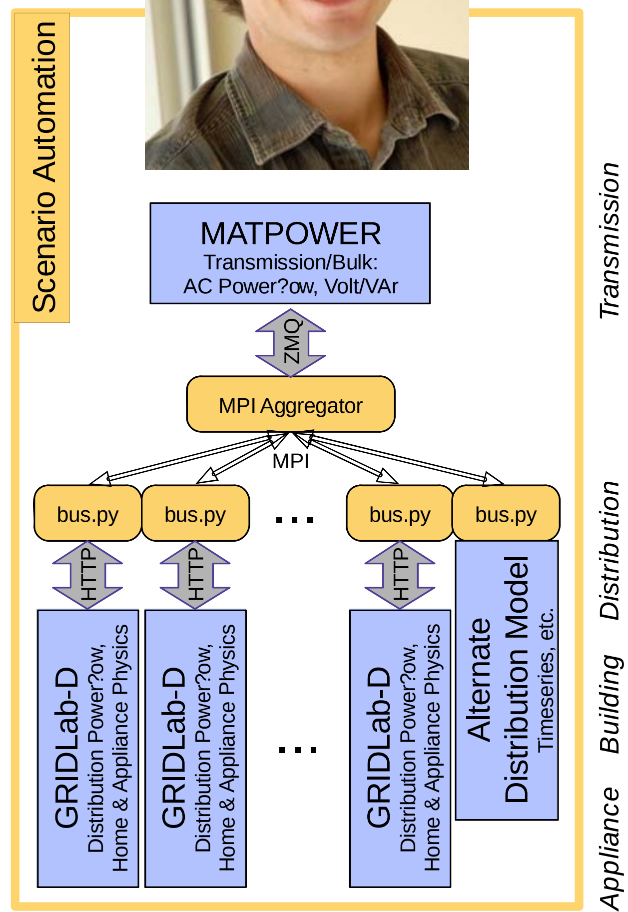
We use General Electric's industry-standard transmission simulation tool, "Positive Sequence Load Flow" (PSLF)—the same tool used by LADWP and many other organizations.

Step 8 – Integrated T&D Modeling

LA DWP

- We need to double-check that all that distributed PV still hasn't broken the distribution network
- We also need to examine the impacts of distributed PV feeding back onto the transmission network
- We will use the NREL Integrated Grid Modeling System (IGMS)

Bryan Palmintier

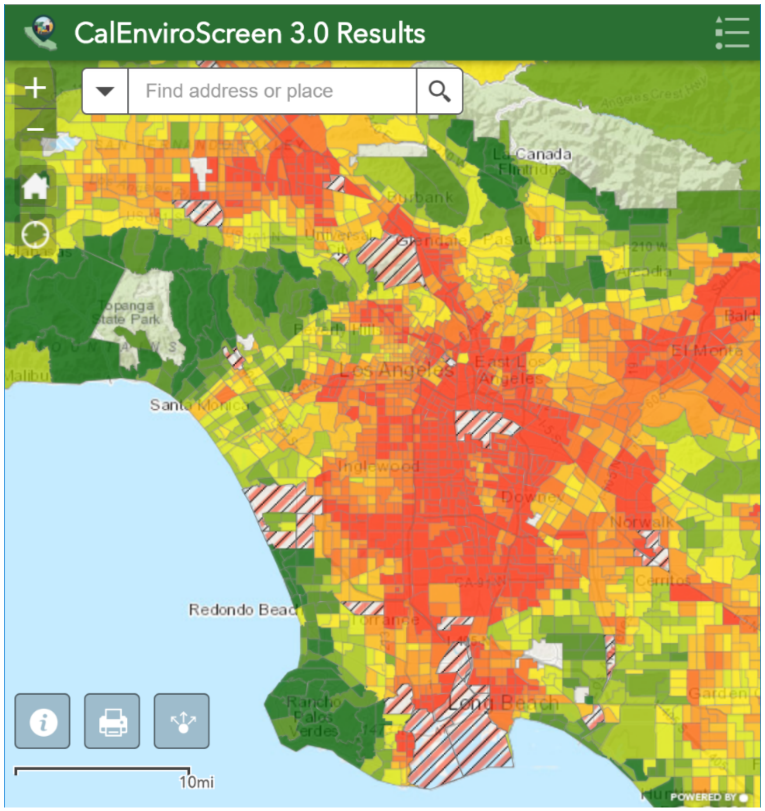


Analyze the Interaction of the Distribution and Transmission Networks:

- AC power flow with MATPOWER
- Detailed distribution feeders modeled with GridLAB-D (three-phase, unbalanced AC power flow)
- Co-simulation with ZeroMQ and MPI
- Semi-automated scenario construction
- Semi-automated results processing
- 100s of transmission nodes, ~1,000 distribution feeders run on HPC resources

Steps 9-10 – Environmental, Economic, and Jobs Analysis

Methods discussed in separate presentations



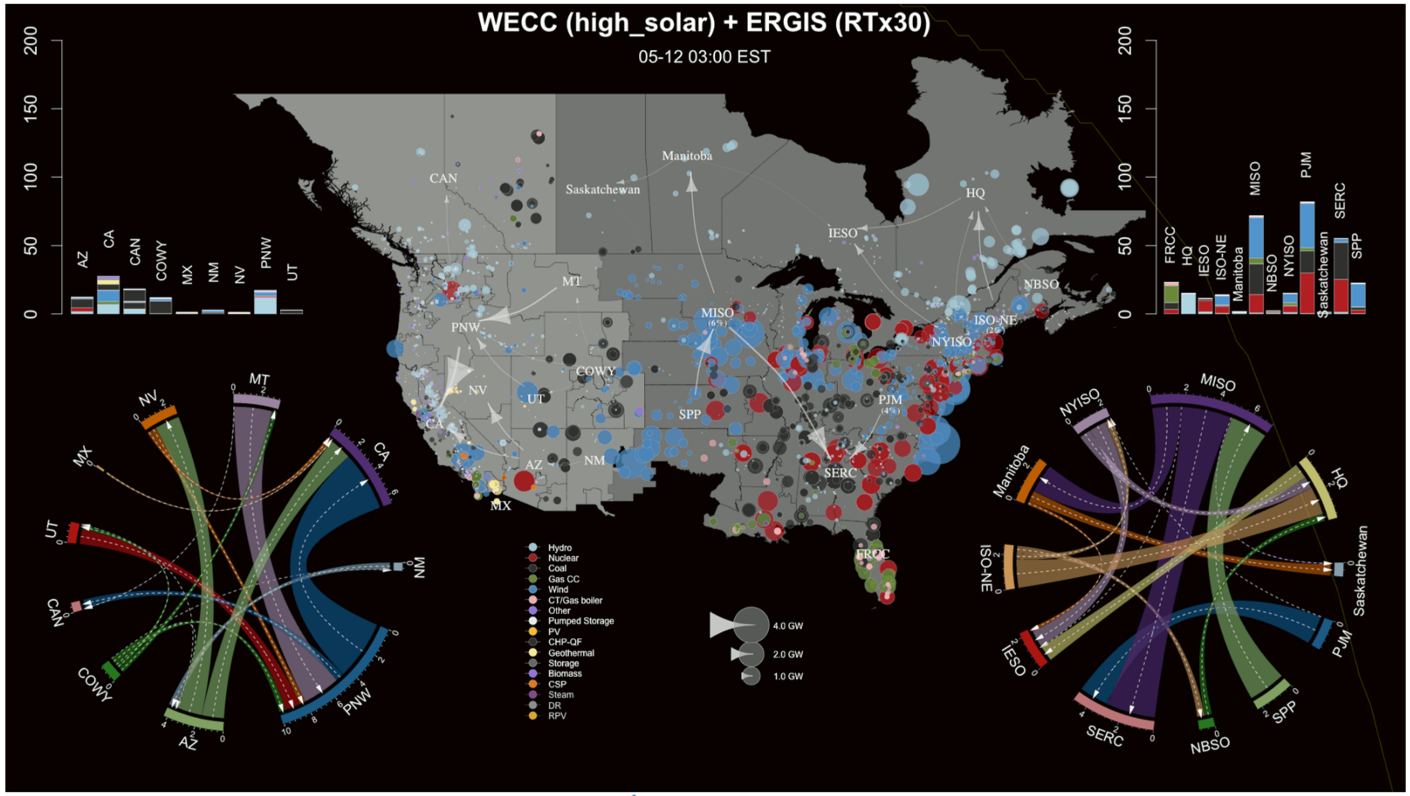
Up next

Garvin Heath

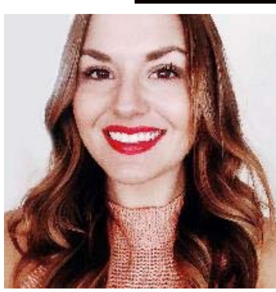
David Keyser

Step 11 – Visualization and Communication

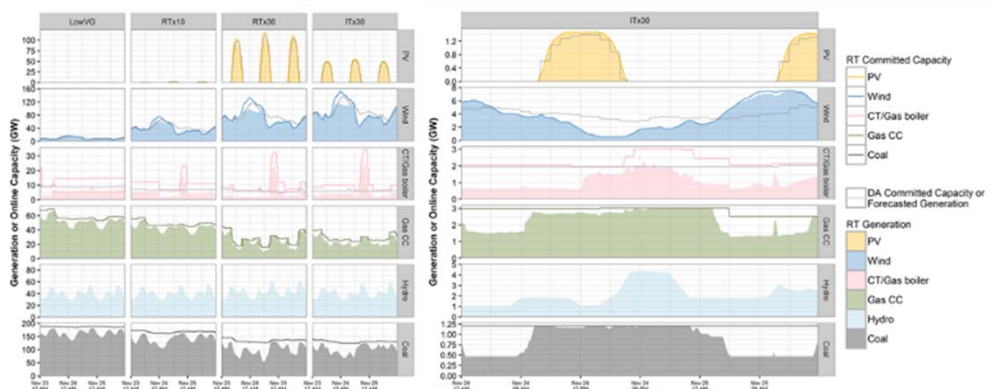
Aaron Bloom



Kenny
Gruchalla



Devonie
McCamey



Summary

- Ensuring a reliable 100% renewable system requires simulation across large geographic and temporal scales
  - Individual circuits to the Western Interconnection
  - Seconds to years
- Multiple models are routinely used for traditional grid plans to explore this range of issues
- Moving to 100% RE will require even more detailed simulations to understand new elements of the evolving power system

Summary – What the Models Will Do

- Generate plausible scenarios
- Test them thoroughly at all time scales
- Generate key performance metrics:
  - Cost
  - Reliability
  - Emissions and environmental impact

Thank you!

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Los Angeles Department of Water & Power