Load Forecasting Overview:

A journey from legacy best practices to modern day challenges

2023 NARUC Electrification and Load Forecast Training

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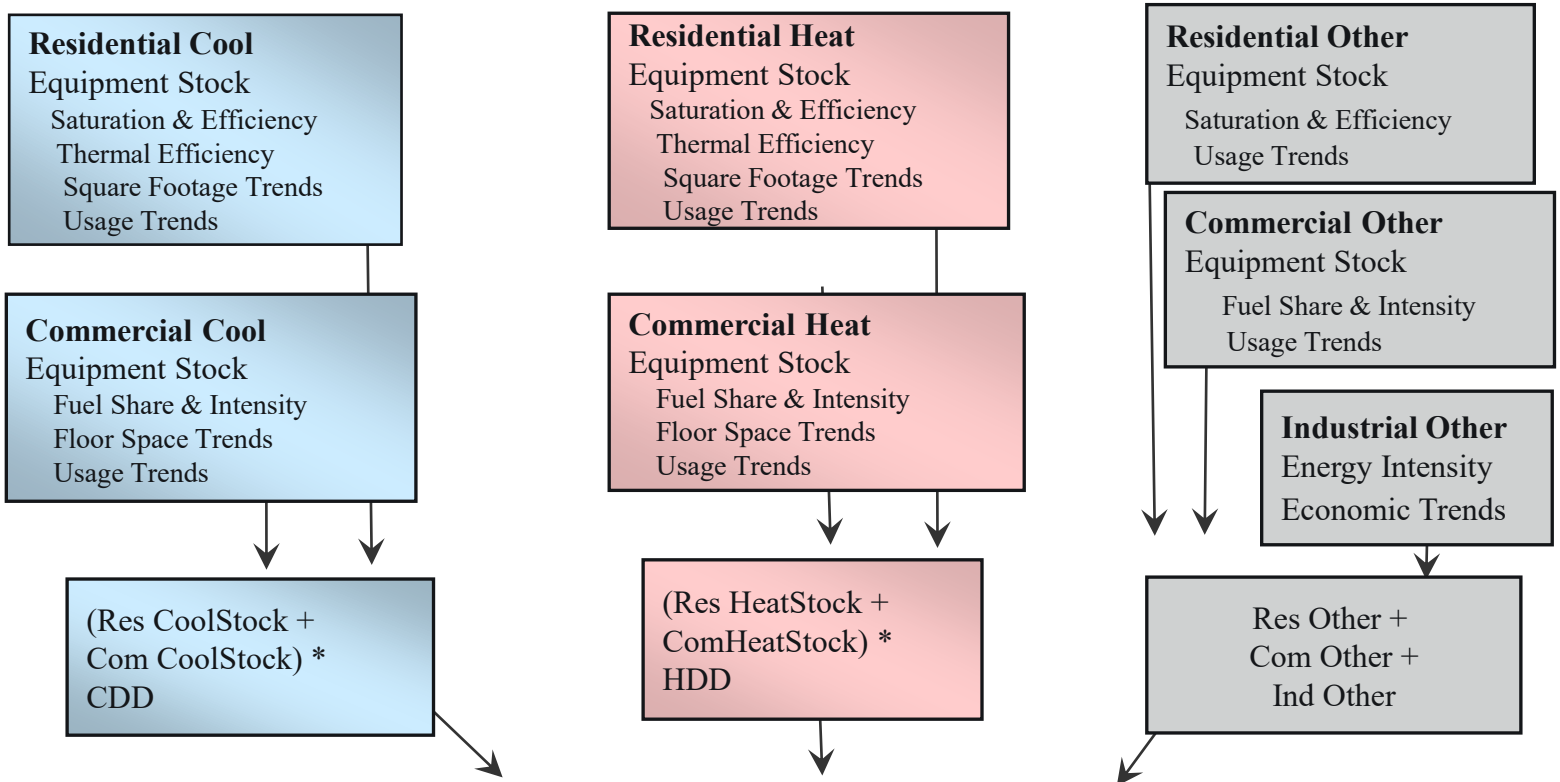
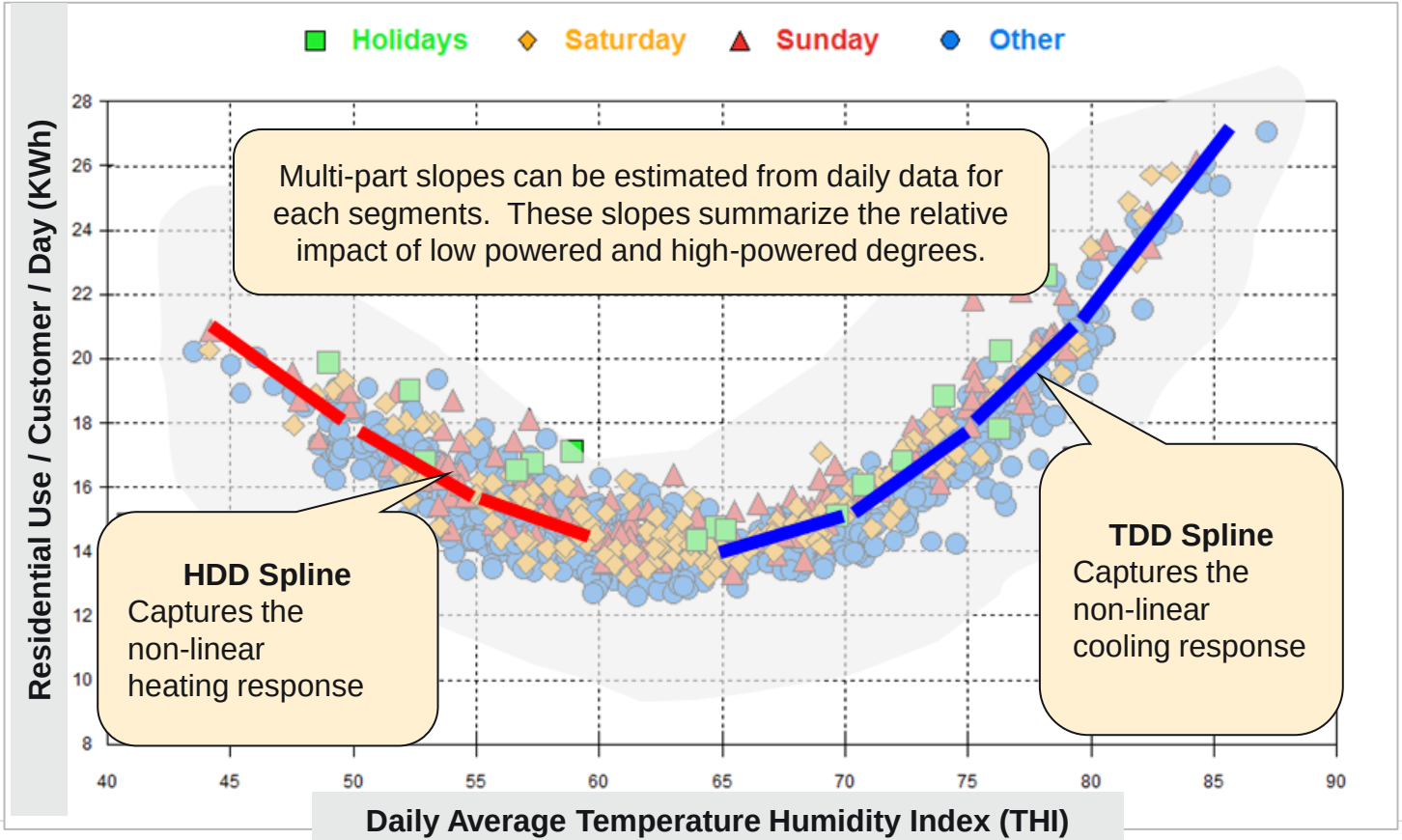
Legacy Forecasting Best Practice: Statistically Adjusted End Use (SAE) Modeling

- A hybrid modeling framework that incorporates the strongest characteristics of econometric and end-use modeling approaches, including:
  - **Structural Changes:** Saturation and efficiency trends, square footage, and thermal shell integrity improvements.
  - **Economic impacts:** Households, Employment, Real Personal Income, Real Gross Market Product (GMP).
  - **Price impacts:**
  - **Weather:** Heating Degree Days (HDD) and Cooling Degree Days (CDD)
- Appropriate interaction of these variables.
- A statistical step to calibrate the inputs.
- The framework is highly flexible and can be customized to meet specific load forecasting requirements.

Legacy SAE Modeling Framework



Weather Response Functions



Residential SAE Customization

- **Building Type**
  - Single Family
  - Multi Family
  - Mobile Home
- **End-Uses**
  - Heating
    - resistance, furnace fans, heat-pump
  - Cooling
    - central, room, heat-pump
  - Water Heating
  - Cooking
  - Refrigeration
  - Dishwasher
  - Clothes washer/dryer
  - TV
  - Lighting
  - Miscellaneous
    - Dehumidifiers, pool pumps, misc. plug loads, etc.

- **Stock of Units/Saturations**
  - Regional EIA estimates
  - NREL ResStock state and county level 2018
  - Appliance saturation surveys
- **Efficiency**
  - Regional EIA estimates, average stock efficiency
  - Regional EIA estimates, existing and new efficiency
  - DSM potential studies

Commercial SAE Customization

- **Commercial Building Types**
  - Assembly
  - Education
  - Food Sales
  - Food Services
  - Health Care
  - Lodging
  - Large Office
  - Small Office
  - Retail
  - Warehouse
  - Other
- **End-Uses**
  - Heating
  - Cooling
  - Ventilation
  - Water Heating
  - Cooking
  - Refrigeration
  - Lighting
  - Office
  - Miscellaneous

- **Starting Mix of Building Sq Ft**
  - Regional EIA estimates
  - NREL ComStock state and county level 2018
- **Employment Projections**
  - State or county level employment projections by sector
    - Map sectors to building types

Industrial SAE Customization

Industrial Sectors			
Agriculture	●	Glass	○
Mining	●	Aluminum	○
Construction	●	Iron and Steel	○
Food	○	Fabricated Metals	○
Wood	○	Machinery	○
Paper	○	Computers and Electronics	○
Bulk Chemical	○	Electrical, Appliances, & Components	○
Plastics & Rubber	○	Transportation	○
Cement & Lime	○	Balance of Manufacturing	○

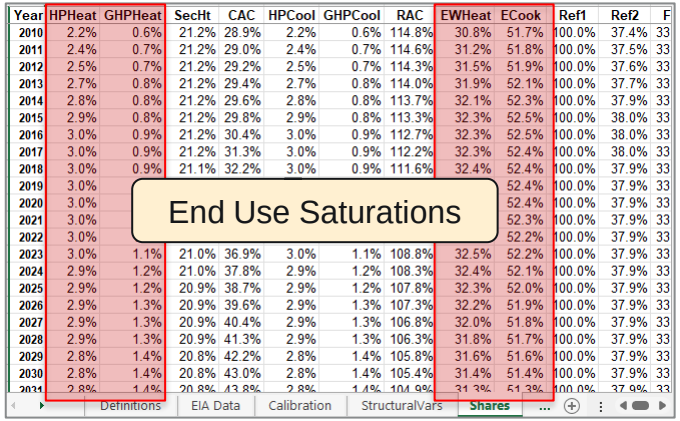
■ Non-Manufacturing

■ Manufacturing

Forecast intensities by sector.

Building Electrification:

- Building Electrification will be managed by changing the Saturation on heating, water heating, and cooking end uses.
- Building Performance Standards can be addressed by customizing the Thermal Efficiency trend.



Year	HPHeat	GHPHeat	SecHt	CAC	HPCool	GHPCool	RAC	EWHeat	ECook	Ref1	Ref2	F
2010	2.2%	0.6%	21.2%	28.9%	2.2%	0.6%	114.8%	30.8%	51.7%	100.0%	37.4%	33
2011	2.4%	0.7%	21.2%	29.0%	2.4%	0.7%	114.6%	31.2%	51.8%	100.0%	37.5%	33
2012	2.5%	0.7%	21.2%	29.2%	2.5%	0.7%	114.3%	31.5%	51.9%	100.0%	37.6%	33
2013	2.7%	0.8%	21.2%	29.4%	2.7%	0.8%	114.0%	31.9%	52.1%	100.0%	37.7%	33
2014	2.8%	0.8%	21.2%	29.6%	2.8%	0.8%	113.7%	32.1%	52.3%	100.0%	37.9%	33
2015	2.9%	0.8%	21.2%	29.8%	2.9%	0.8%	113.3%	32.3%	52.5%	100.0%	38.0%	33
2016	3.0%	0.9%	21.2%	30.4%	3.0%	0.9%	112.7%	32.3%	52.5%	100.0%	38.0%	33
2017	3.0%	0.9%	21.2%	31.3%	3.0%	0.9%	112.2%	32.3%	52.4%	100.0%	38.0%	33
2018	3.0%	0.9%	21.1%	32.2%	3.0%	0.9%	111.6%	32.4%	52.4%	100.0%	37.9%	33
2019	3.0%								52.4%	100.0%	37.9%	33
2020	3.0%								52.4%	100.0%	37.9%	33
2021	3.0%								52.3%	100.0%	37.9%	33
2022	3.0%								52.2%	100.0%	37.9%	33
2023	3.0%	1.1%	21.0%	36.9%	3.0%	1.1%	108.8%	32.5%	52.2%	100.0%	37.9%	33
2024	2.9%	1.2%	21.0%	37.8%	2.9%	1.2%	108.3%	32.4%	52.1%	100.0%	37.9%	33
2025	2.9%	1.2%	20.9%	38.7%	2.9%	1.2%	107.8%	32.3%	52.0%	100.0%	37.9%	33
2026	2.9%	1.3%	20.9%	39.6%	2.9%	1.3%	107.3%	32.2%	51.9%	100.0%	37.9%	33
2027	2.9%	1.3%	20.9%	40.4%	2.9%	1.3%	106.8%	32.0%	51.8%	100.0%	37.9%	33
2028	2.9%	1.3%	20.9%	41.3%	2.9%	1.3%	106.3%	31.8%	51.7%	100.0%	37.9%	33
2029	2.8%	1.4%	20.8%	42.2%	2.8%	1.4%	105.8%	31.6%	51.6%	100.0%	37.9%	33
2030	2.8%	1.4%	20.8%	43.0%	2.8%	1.4%	105.4%	31.4%	51.4%	100.0%	37.9%	33
2031	2.8%	1.4%	20.8%	43.8%	2.8%	1.4%	104.9%	31.3%	51.3%	100.0%	37.9%	33

Definitions | EIA Data | Calibration | StructuralVars | Shares

End Use Saturations

ref2022.d011222a	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Building Shell Efficiency Index 3/										
Space Heating										
Pre-2015 Homes	0.952	0.945	0.939	0.934	0.927	0.921	0.914	0.907	0.900	0.892
New Construction	0.891	0.880	0.878	0.876	0.876	0.876	0.877	0.876	0.876	0.875
All Homes	0.945	0.938	0.932	0.926	0.920	0.914	0.908	0.902	0.895	0.889
Space Cooling										
Pre-2015 Homes					0.974	0.972	0.970	0.967	0.965	0.962
New Construction	0.999	0.995	0.994	0.993	0.994	0.994	0.994	0.994	0.994	0.994
All Homes	0.984	0.982	0.980	0.978	0.976	0.974	0.972	0.970	0.968	0.966

Building Shell Indices

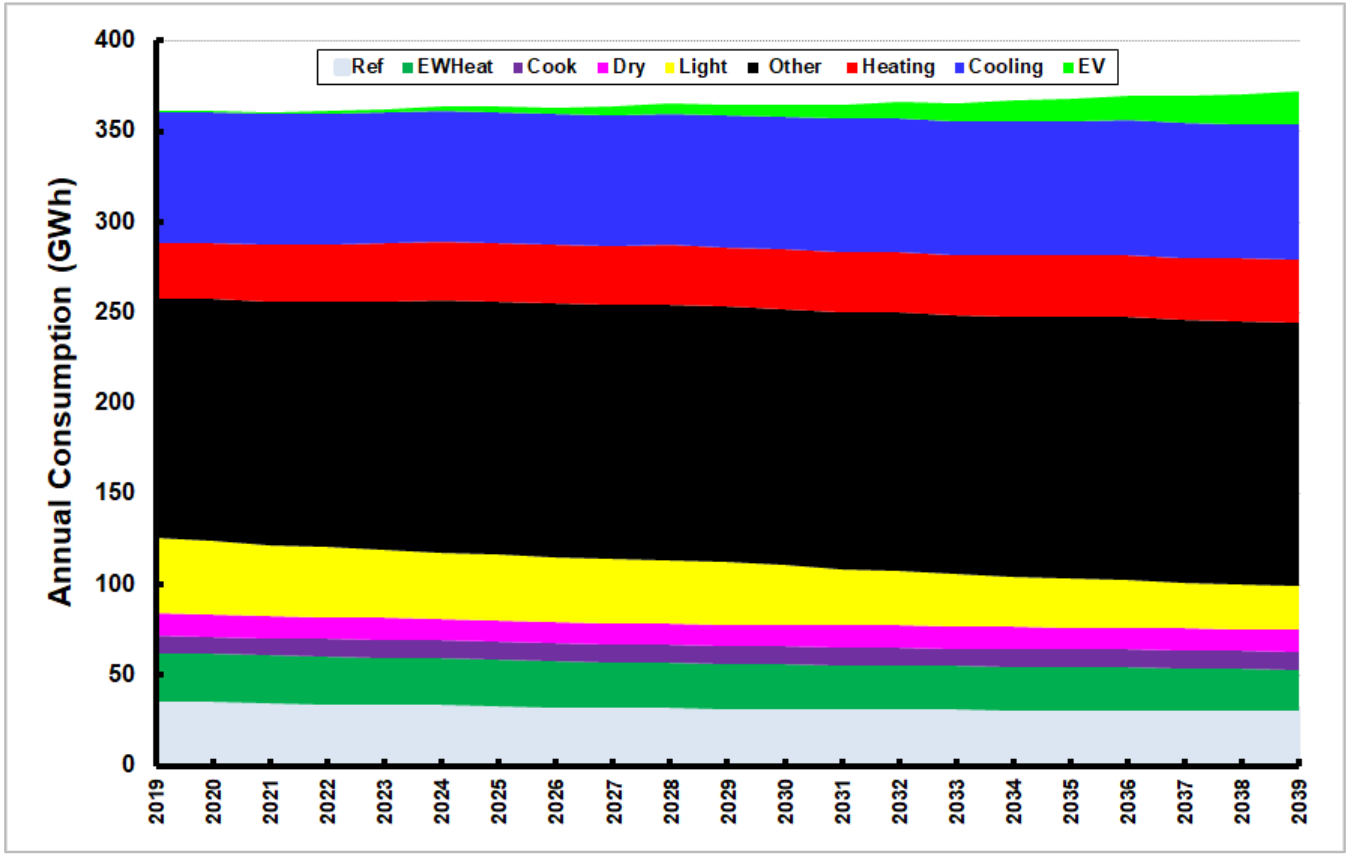
Integration of Energy Efficiency programs

- SAE Modeling approach integrates Energy Efficiency Savings from all sources:
  - *Codes & Standards*
  - *Naturally Occurring Market Adoption*
  - *Energy Efficiency Programs*

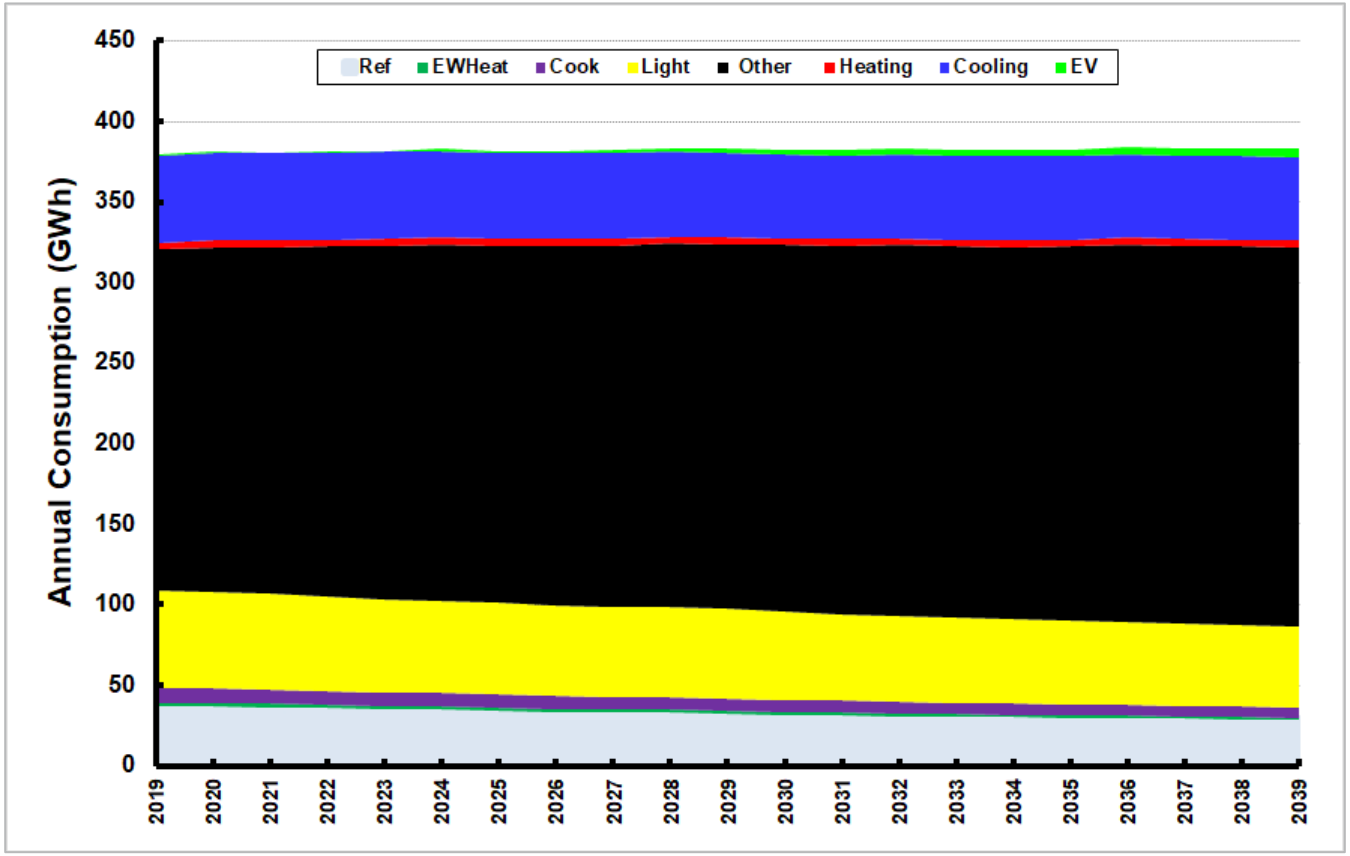
- There are a variety of approaches to explicitly integrate utility energy efficiency programs:
  - *Add Back*
  - *Wedge Approach*
  - *Adjusted Intensity Approach*
  - *DSM Variable*

- The appropriate method is driven by data availability and forecast requirements

Residential End Use Forecast



Commercial End Use Forecast

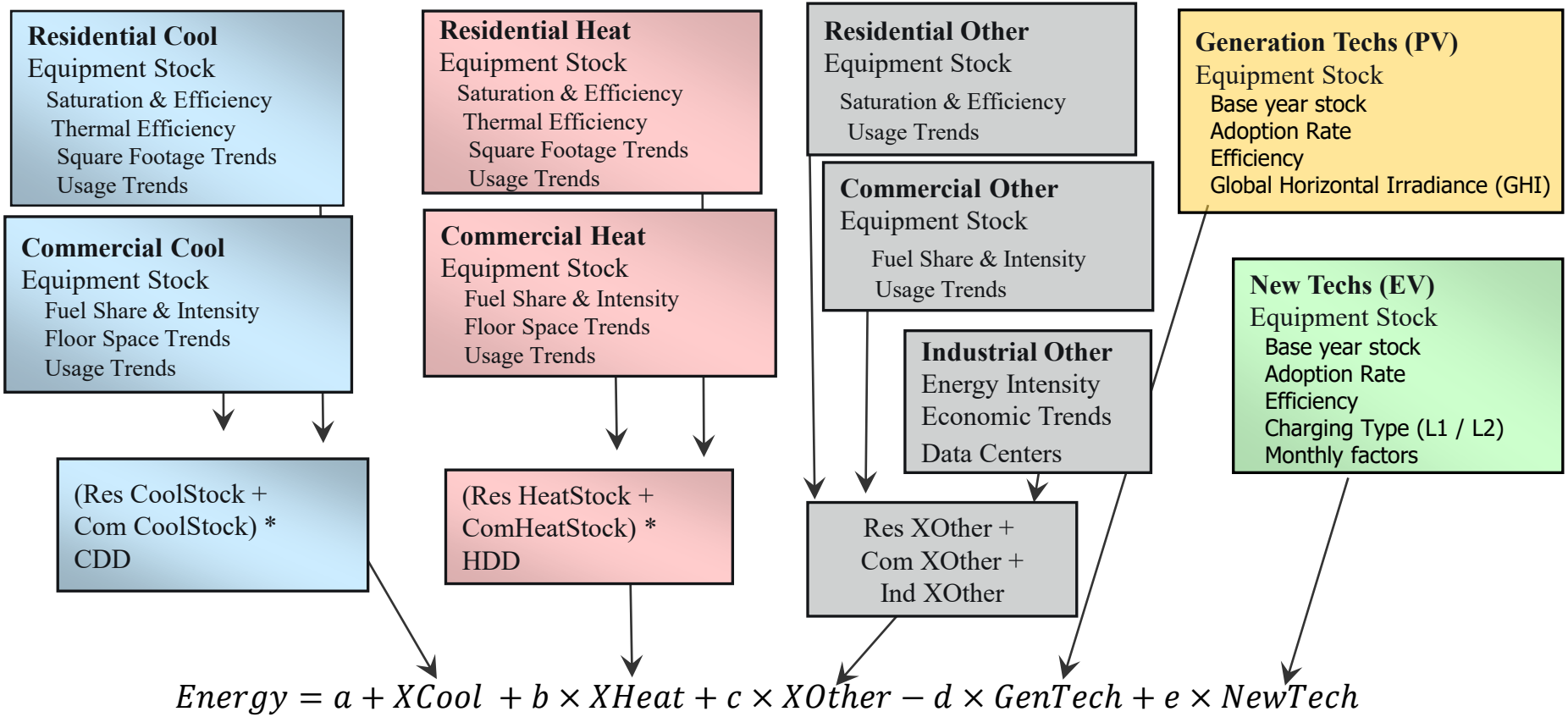


Utility Forecasting Landscape

Modern Day:
Statistically Adjusted End Use (SAE) Modeling

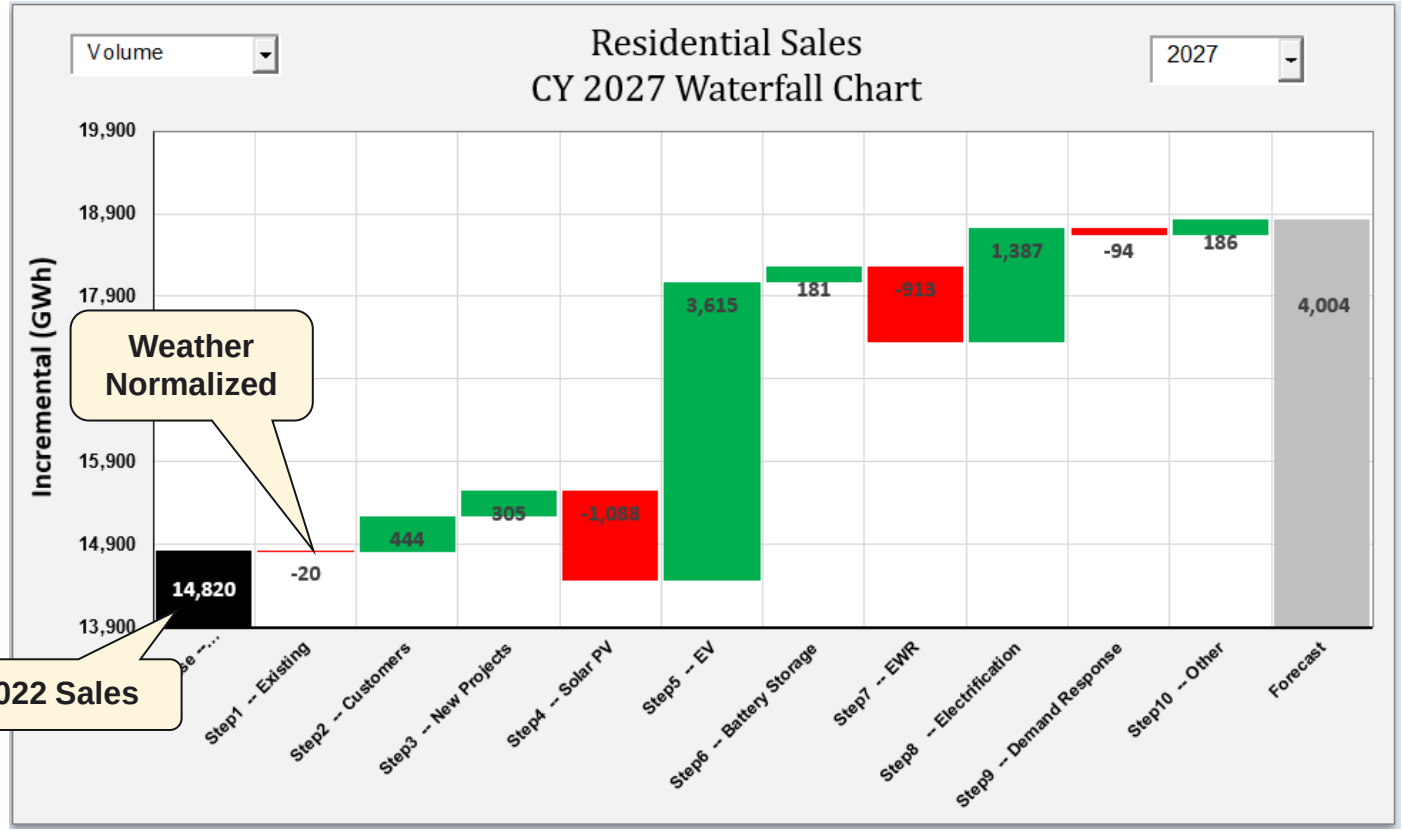
- A hybrid modeling framework that incorporates the strongest characteristics of econometric and end-use modeling approaches, including:
  - **Structural Changes:** Saturation and efficiency trends, square footage, and thermal shell integrity improvements.
  - **Economic impacts:** Households, Employment, Real Personal Income, Real Gross Market Product (GMP).
  - **Locational trends:** Google Mobility data (Res, Workplace, Retail)
  - **Price impacts:**
  - **Weather:** Cooling Degree Days (CDD), Heating Degree Days (HDD)
  - **Additional Weather:** Global Horizontal Irradiance (GHI), Climate Change Trends
  - **New Technologies:** Solar PV, Electric Vehicles, Battery Storage.
- Appropriate interaction of these variables.
- A statistical step to calibrate the inputs.
- The framework is highly flexible and can be customized to meet specific load forecasting requirements.

Modern Day SAE Modeling Framework

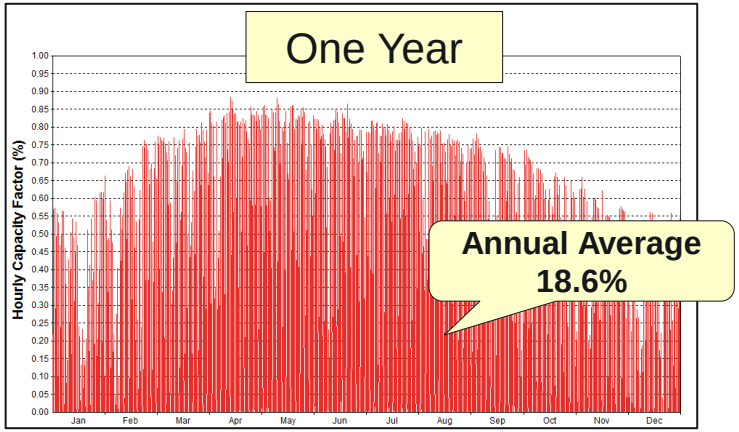


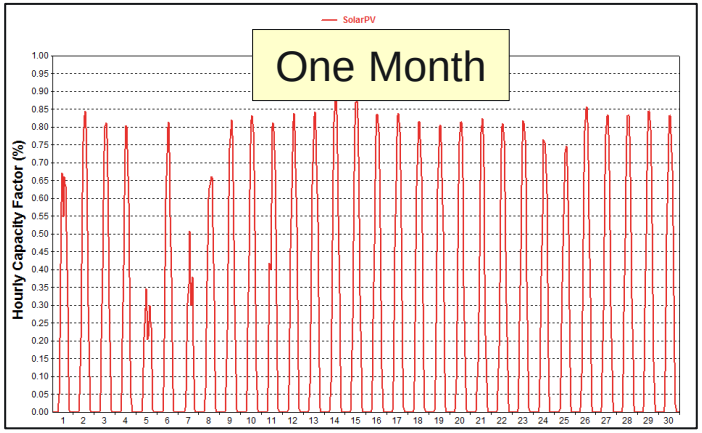
$$Energy = a + XCool + b \times XHeat + c \times XOther - d \times GenTech + e \times NewTech$$

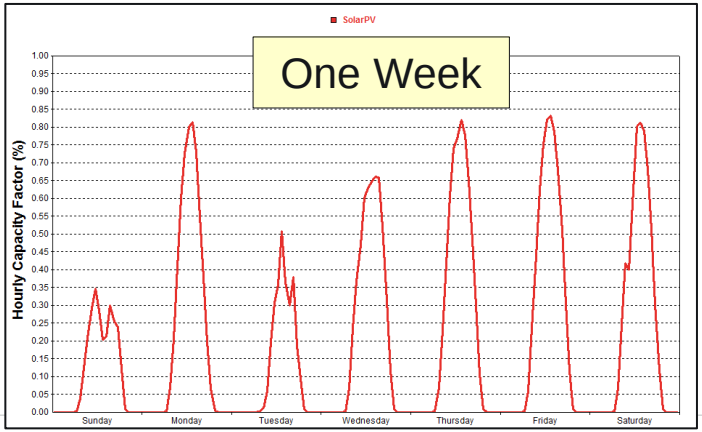
Load Forecast Waterfall

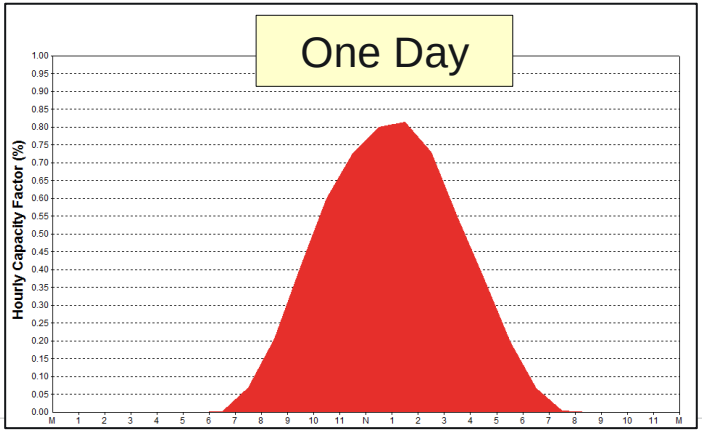


BTM Solar PV Shapes









EV Charging Forecasting Scope

Passenger Vehicle Charging	
Charging Type	Stock Units
Res Level 1	# of Ports
Res Level 2	# of Ports
Workplace Level 2	# of Ports
Public Charging Level 2	# of Ports
Public Charging Direct Current Fast Charger	MW or MVA

Fleet Vehicle Charging	
Charging Type	Stock Units
Light-Duty Sedan	Vehicle Miles Traveled
Medium-Duty Truck	Vehicle Miles Traveled
Agriculture Truck	Vehicle Miles Traveled
Construction Truck	Vehicle Miles Traveled
Utility Truck	Vehicle Miles Traveled
Tractor-Trailer	Vehicle Miles Traveled
Drayage Truck	Vehicle Miles Traveled
Refuse Truck	Vehicle Miles Traveled
Bus	Vehicle Miles Traveled

Each passenger vehicle charging category requires forecasts of the following:

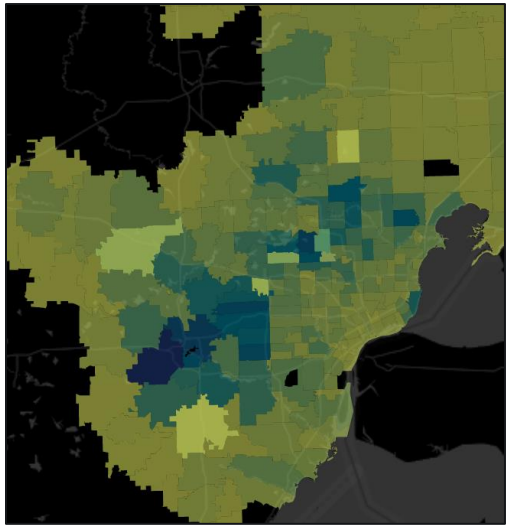
- # of Ports
- Annual KWh / Port
- Hourly Load Shape

Each fleet vehicle charging category requires forecasts of the following:

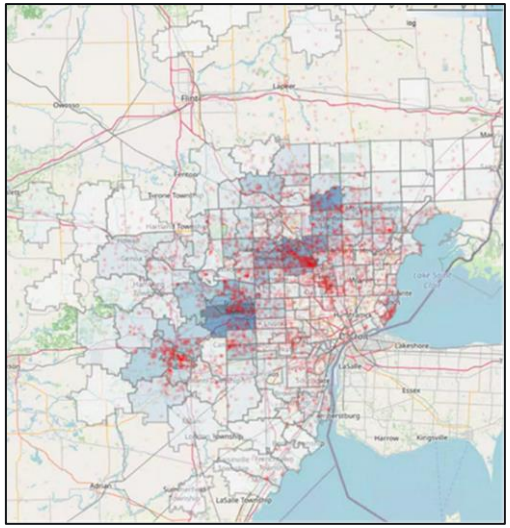
- # of Vehicles
- Vehicles Miles Traveled
- KWh / Mile
- Hourly Load Shape

DER adoption is concentrated in small pockets on the grid.

Heatmap of EV Level 2 Residential Charging

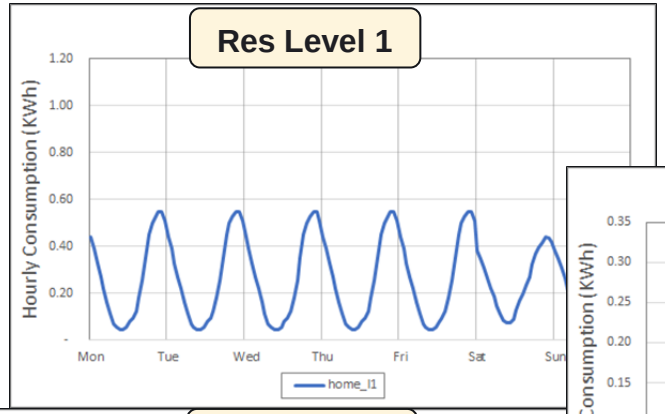


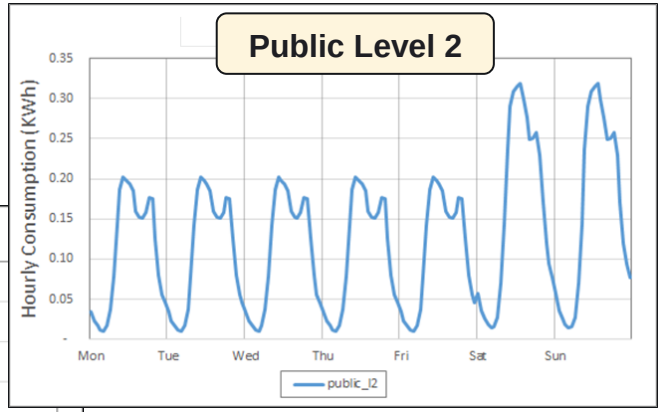
Residential EV propensity to adopt models

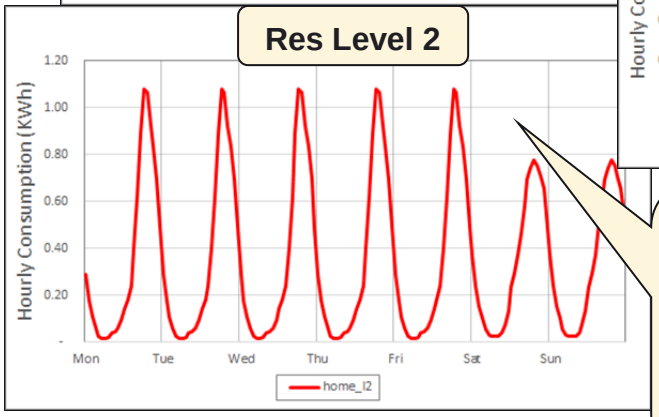


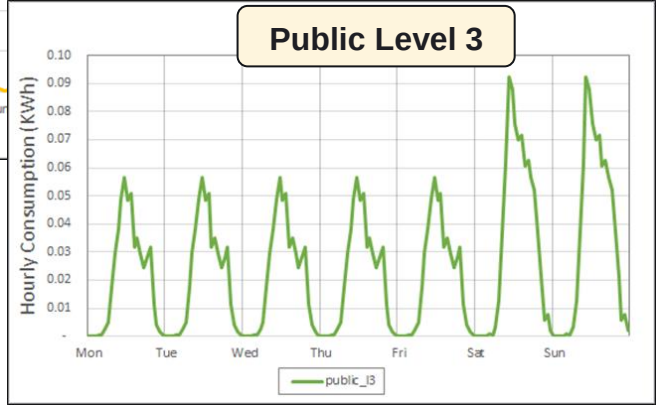
- Political Affiliation
- Income
- Maximum Education
- Car Sharing Status
- Residence Type
- Home Ownership
- # of Vehicles owned
- Public Charging Stations / Capita
- Distance to City Center

EV Load Shapes







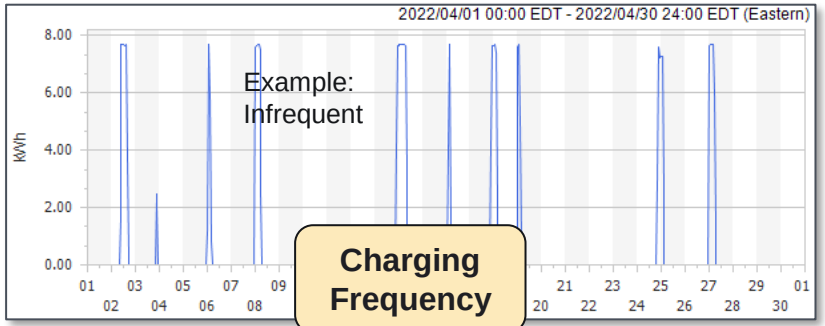


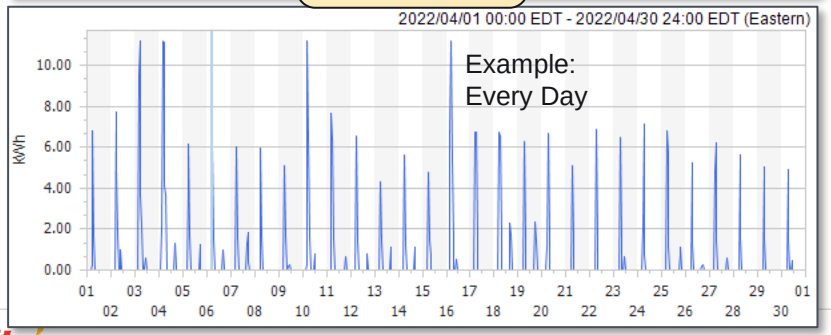
Charging Strategies

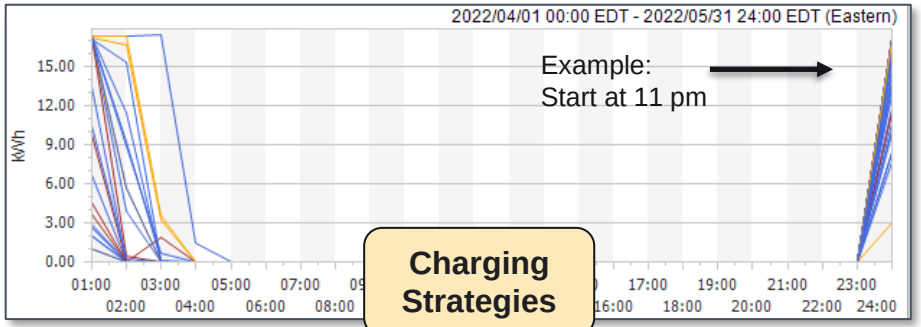
1. Plug in after work
2. Plug in at 11 PM
3. Charge By Morning
4. Slow Charge
5. Random

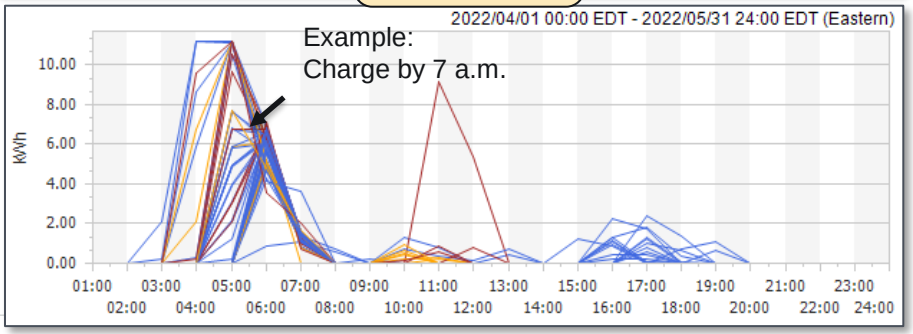
Res Level 2 Charging – EV Data

- Utility sample of 1,200 customers on their EV Rate
  - Dedicated meter for EV charging
  - 11 pm - 9 am is off peak
  - On/Off price ratio: ~ 2 to 1



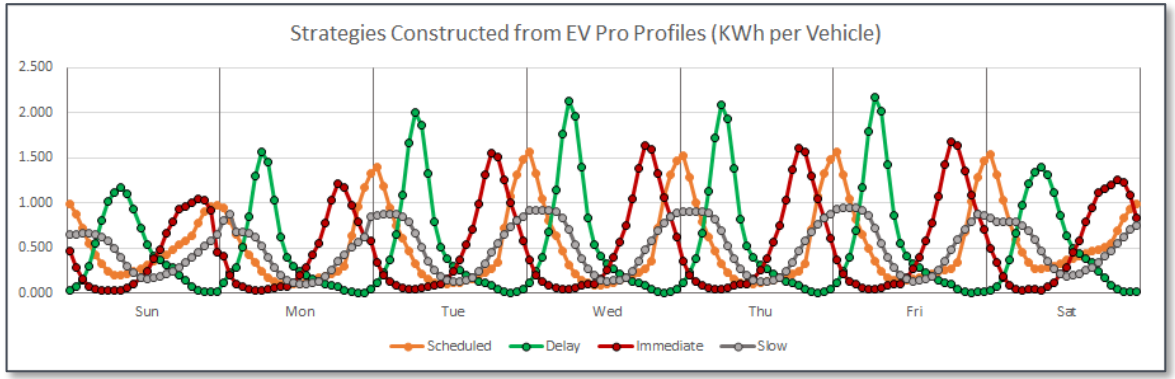




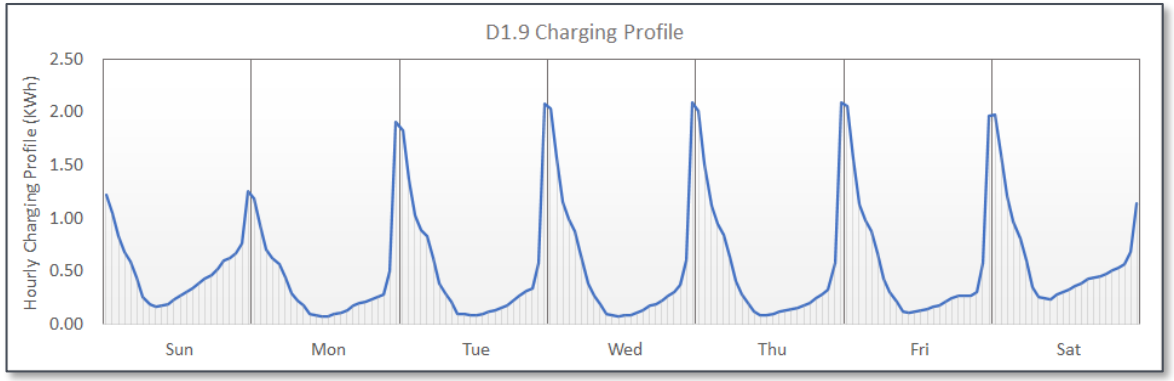


Residential Level 2: Weighting Charging Strategies

» Charging Strategies
- Scheduled: charge at 11PM
- Delay: – charge by 05,06,07,08
- Immediate: – charge after work
- Slow: – flatter version of immediate

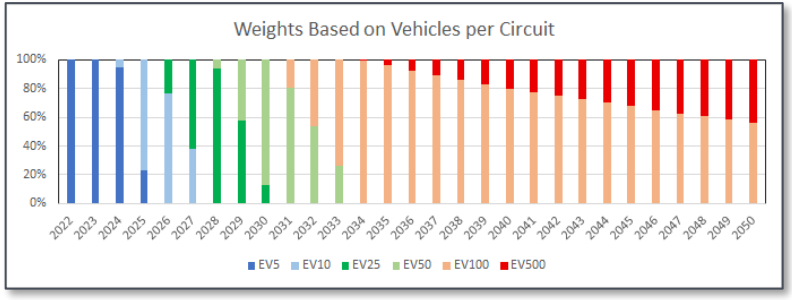


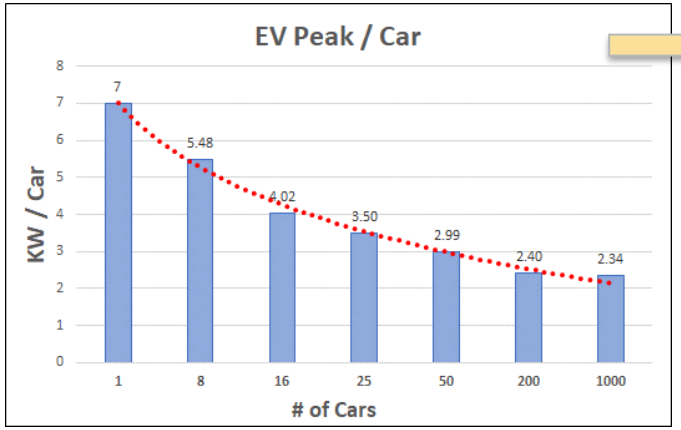
» Final Level 2 profile is a weighted average of the strategy profiles, where the weights vary over time.

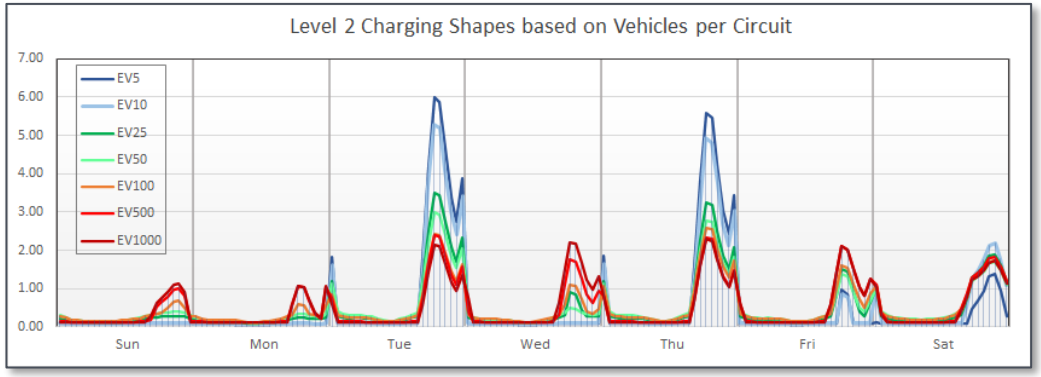


EV Diversity by Sample Size

- Diversity Analysis
  - Based on number of vehicles
  - Max KWH falls as number of vehicles grows
- Steps to create less diverse shapes
  - Modify shape with day of week multipliers
  - Calibrate to Target Max kWh
  - Weight shapes over time based on vehicles per circuit

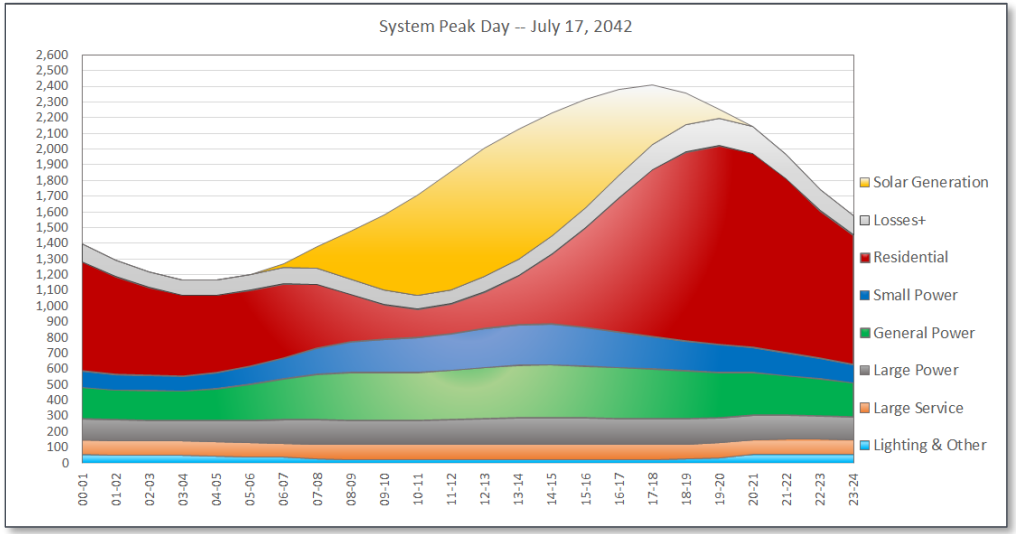




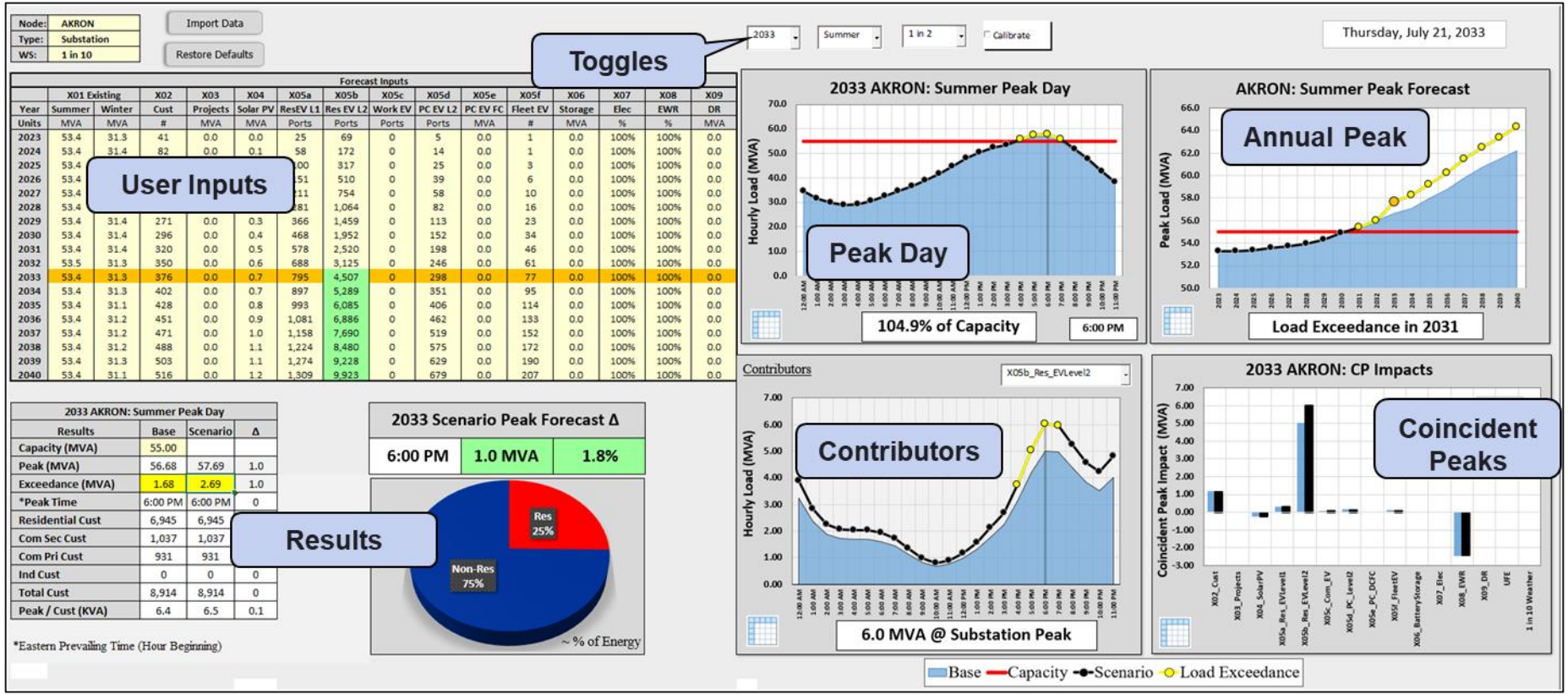


Future System Peak Day

- Rapid adoption of new technologies has significant leverage to influence future load shapes.
- Combining strong end use forecasts with their respective hourly load shapes is essential for facility planning.



Interactive Forecast Dashboard



Forecast Inputs															
	X01 Existing		X02	X03	X04	X05a	X05b	X05c	X05d	X05e	X05f	X06	X07	X08	X09
Year	Summer	Winter	Cust	Projects	Solar PV	ResEV L1	Res EV L2	Work EV	PC EV L2	PC EV FC	Fleet EV	Storage	Elec	EWR	DR
Units	MVA	MVA	#	MVA	MVA	Ports	Ports	Ports	Ports	MVA	#	MVA	%	%	MVA
2023	53.4	31.3	41	0.0	0.0	25	69	0	5	0.0	1	0.0	100%	100%	0.0
2024	53.4	31.4	82	0.0	0.1	58	172	0	14	0.0	1	0.0	100%	100%	0.0
2025	53.4					100	317	0	25	0.0	3	0.0	100%	100%	0.0
2026	53.4					151	510	0	39	0.0	6	0.0	100%	100%	0.0
2027	53.4					211	754	0	58	0.0	10	0.0	100%	100%	0.0
2028	53.4					281	1,064	0	82	0.0	16	0.0	100%	100%	0.0
2029	53.4	31.4	271	0.0	0.3	366	1,459	0	113	0.0	23	0.0	100%	100%	0.0
2030	53.4	31.4	296	0.0	0.4	468	1,952	0	152	0.0	34	0.0	100%	100%	0.0
2031	53.4	31.4	320	0.0	0.5	578	2,520	0	198	0.0	46	0.0	100%	100%	0.0
2032	53.5	31.3	350	0.0	0.6	688	3,125	0	246	0.0	61	0.0	100%	100%	0.0
2033	53.4	31.3	376	0.0	0.7	795	4,507	0	298	0.0	77	0.0	100%	100%	0.0
2034	53.4	31.3	402	0.0	0.7	897	5,289	0	351	0.0	95	0.0	100%	100%	0.0
2035	53.4	31.1	428	0.0	0.8	993	6,085	0	406	0.0	114	0.0	100%	100%	0.0
2036	53.4	31.2	451	0.0	0.9	1,081	6,886	0	462	0.0	133	0.0	100%	100%	0.0
2037	53.4	31.2	471	0.0	1.0	1,158	7,690	0	519	0.0	152	0.0	100%	100%	0.0
2038	53.4	31.2	488	0.0	1.1	1,224	8,480	0	575	0.0	172	0.0	100%	100%	0.0
2039	53.4	31.3	503	0.0	1.1	1,274	9,228	0	629	0.0	190	0.0	100%	100%	0.0
2040	53.4	31.1	516	0.0	1.2	1,309	9,923	0	679	0.0	207	0.0	100%	100%	0.0

2033 AKRON: Summer Peak Day			
Results	Base	Scenario	Δ
Capacity (MVA)	55.00		
Peak (MVA)	56.68	57.69	1.0
Exceedance (MVA)	1.68	2.69	1.0
*Peak Time	6:00 PM	6:00 PM	0
Residential Cust	6,945	6,945	
Com Sec Cust	1,037	1,037	
Com Pri Cust	931	931	
Ind Cust	0	0	0
Total Cust	8,914	8,914	0
Peak / Cust (KVA)	6.4	6.5	0.1

SAE Framework Flexibility

- The SAE Framework has significant flexibility and can be customized to meet specific load forecasting requirements.

- Output Requirements
  - Monthly Energy & Peak
  - Hourly Loads

- Forecast Segmentation
  - System level
  - By Sector (Res, Com, Ind)
  - By Building Type (Res Single Family, Res Multi Family, Com Office, Com Warehouse, Com Lodging, etc.)
  - By Distribution Node (Substation, Feeder, Transformer)

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