GHG Emission Benefits and Air Quality Impacts of California Renewable Energy Integration and Electrification

ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

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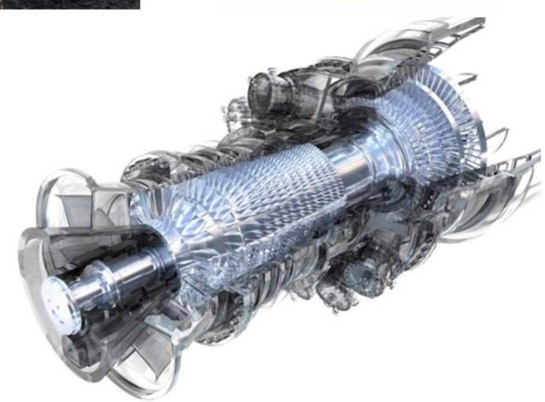
April 15, 2015

Outline

- Motivation and Background
- Dynamic Dispatch and Air Quality
- Can “Electrification” Help?
- What Else Could Help?
- Summary

Motivation – Clean, Efficient & Sustainable

- All societies and economies depend upon energy conversion
  - Economic prosperity
  - Health
  - Mobility
  - Freedom, Quality of Life, …
- Everything that companies and people do has some dependence upon & relationship to energy conversion
- <u>Fortunately</u> humans have discovered and advanced energy conversion technology
  - Fire
  - High density energy carriers (e.g., HC fuels)
  - Engines
  - Environmental Improvements
    - Higher efficiency
    - Lower emissions



Motivation – Clean, Efficient & Sustainable

Unfortunately energy conversion technologies are the largest contributors to significant environmental and geopolitical problems

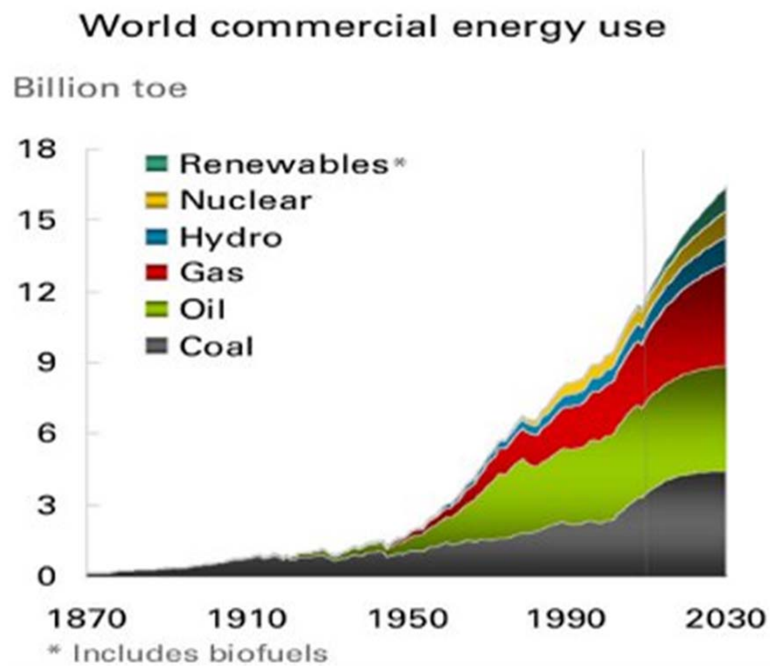
- Criteria Pollutant Emissions
  - Acid Rain
  - Particulate Matter
  - Volatile Organic Compounds
  - Nitrogen and Sulfur Oxides
  - Carbon Monoxide
  - …

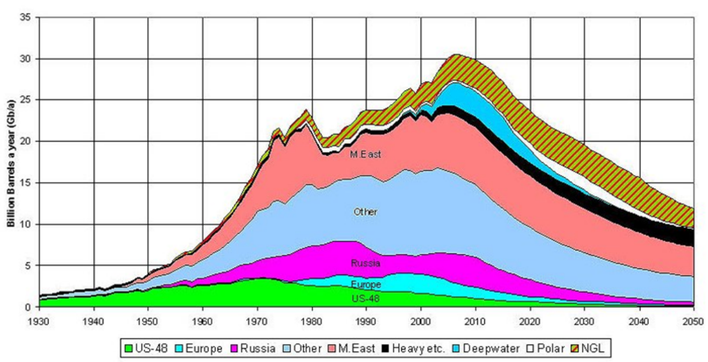
  } Serious Health and Air Quality Consequences

- Greenhouse Gas Emissions
  - Carbon dioxide, methane, nitrous oxide, …
- Resource recovery damage (e.g., mines)
- Regional resource depletion – energy geopolitical dependencies
- Overall primary energy resource depletion – not sustainable

Motivation – Clean, Efficient & Sustainable

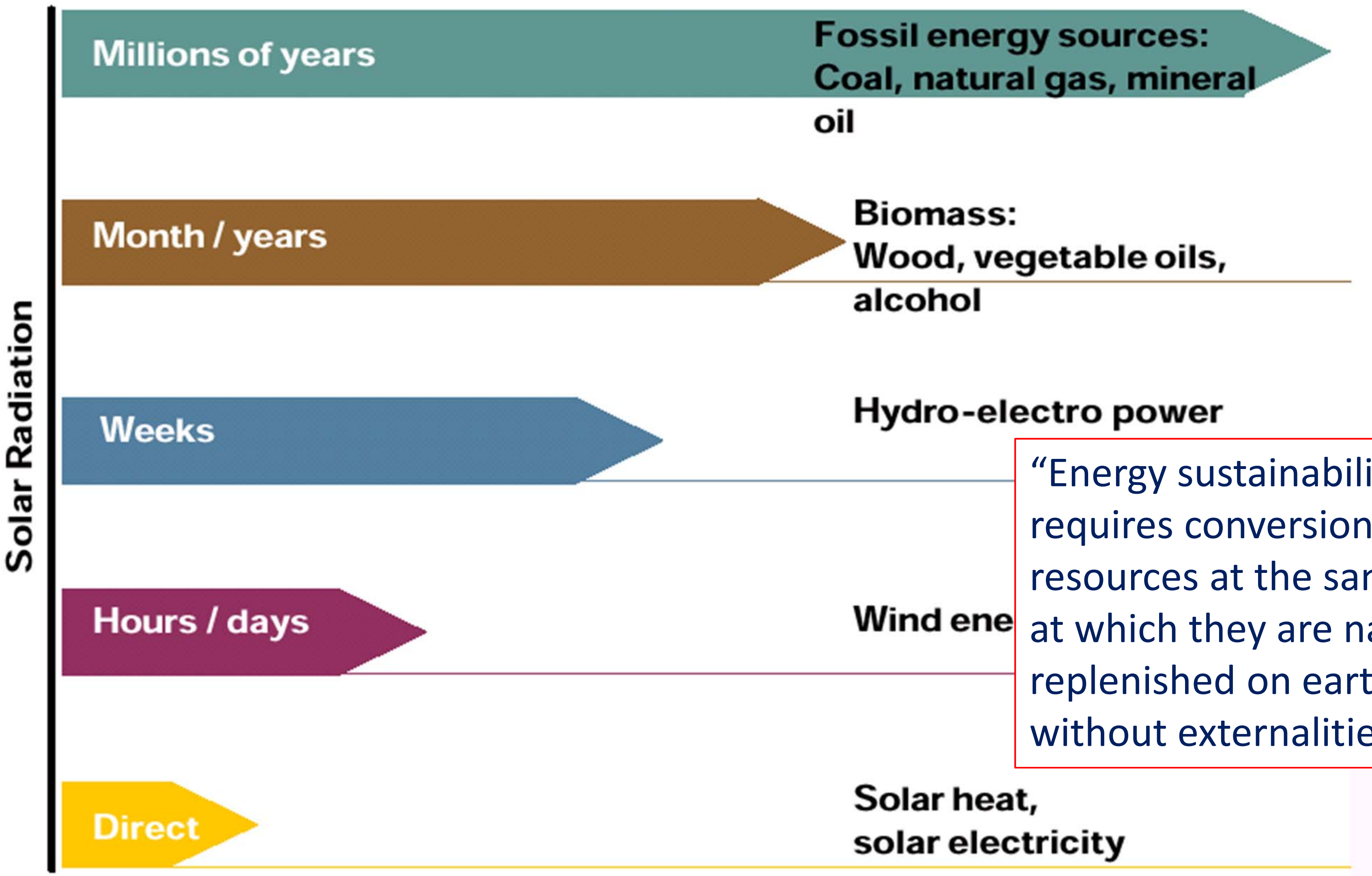
- Most projections (EIA, IEA) suggest “more of the same”
- So our current path for energy conversion will lead to:
  – Air quality problems
    (not clean, not sustainable)
  – Greenhouse gas emissions
    (not efficient, not sustainable)
  – Resource depletion
    (not clean, not efficient, not sustainable)





What Should We Do?

Primary Energy: All Comes from the Sun



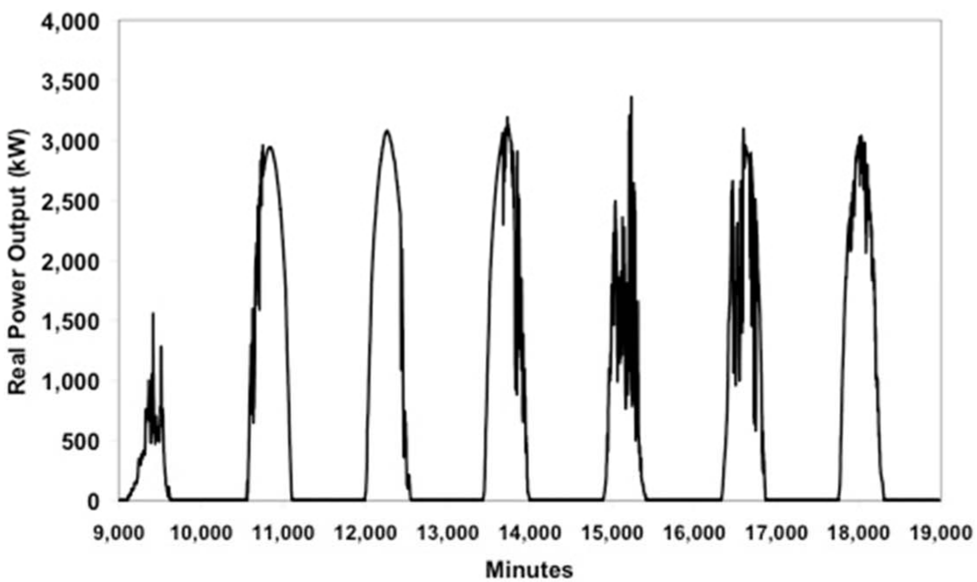
"Energy sustainability requires conversion of resources at the same rate at which they are naturally replenished on earth without externalities"

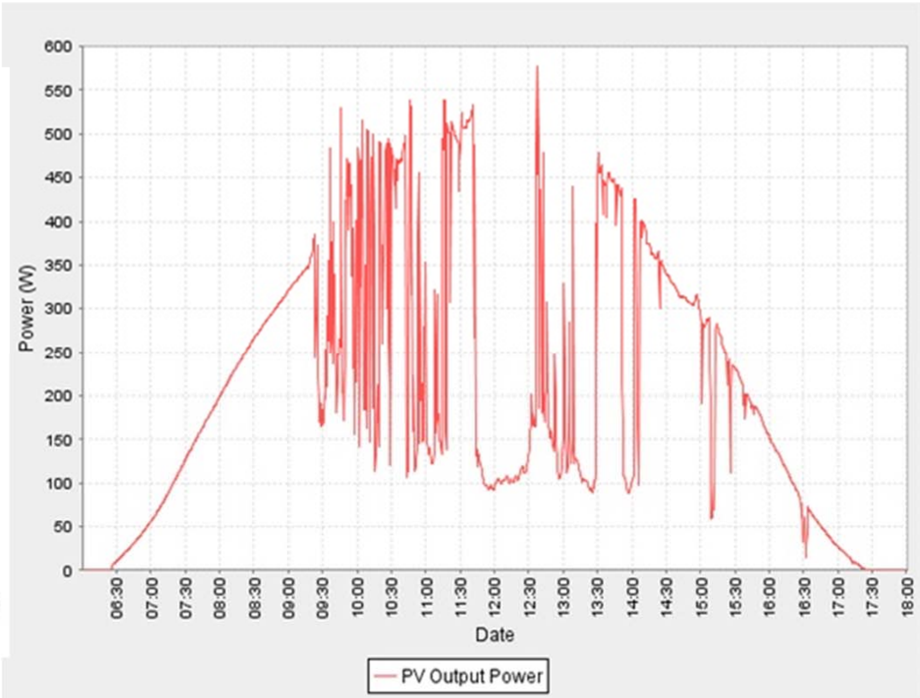
Courtesy: BMW Group, 2000

Motivation & Future Grid Challenges

Use MORE Solar Power

- Challenges: 20-30% capacity factor, intermittent, diffuse, expensive to recover





Motivation & Future Grid Challenges

Wind Power – Challenges: Intermittency, non-coincidence

Example of Intermittency & Non-Coincidence with Peak Demand

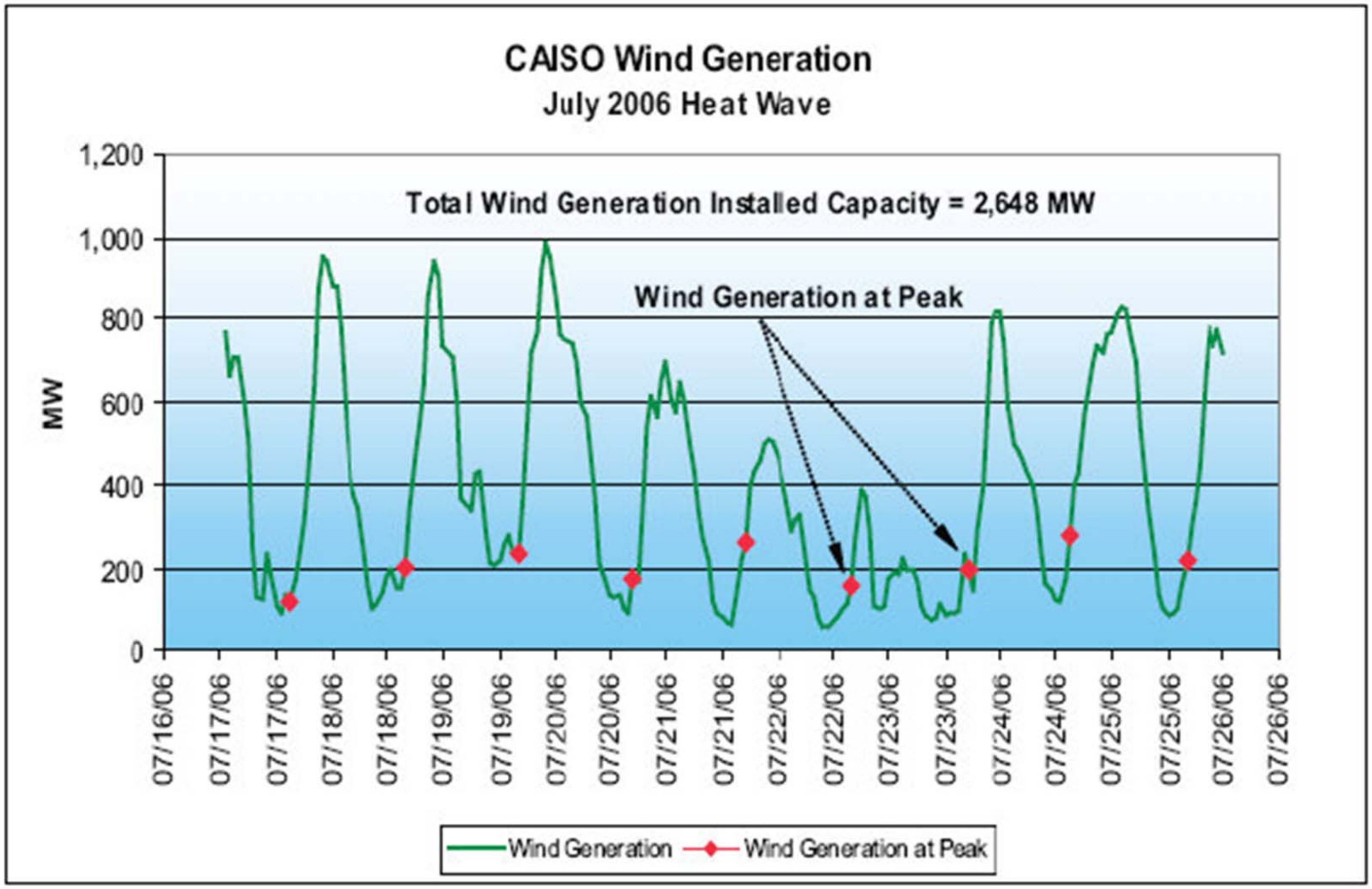
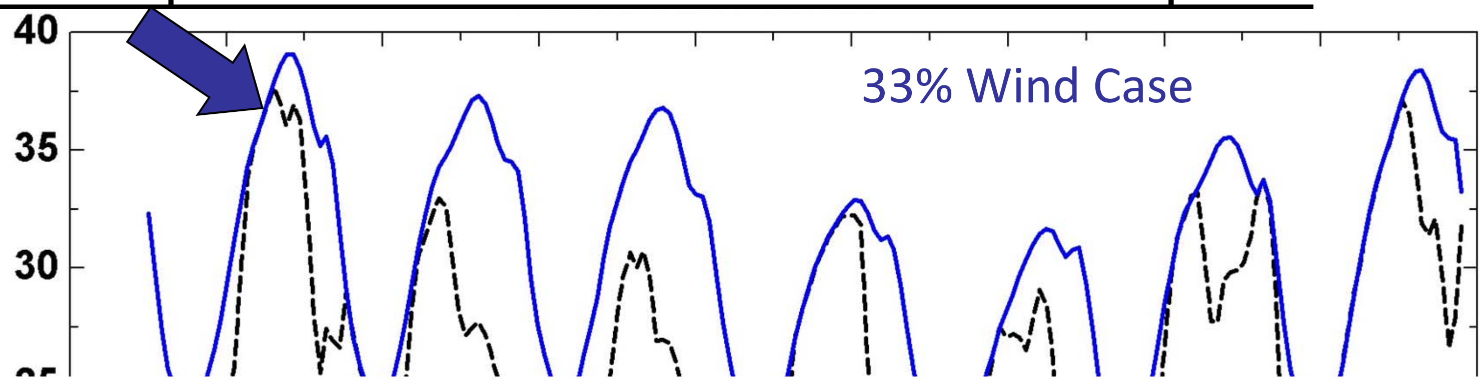


Figure 5-2: California ISO Wind Generation during the 2006 Heat Wave

CAISO, 2007

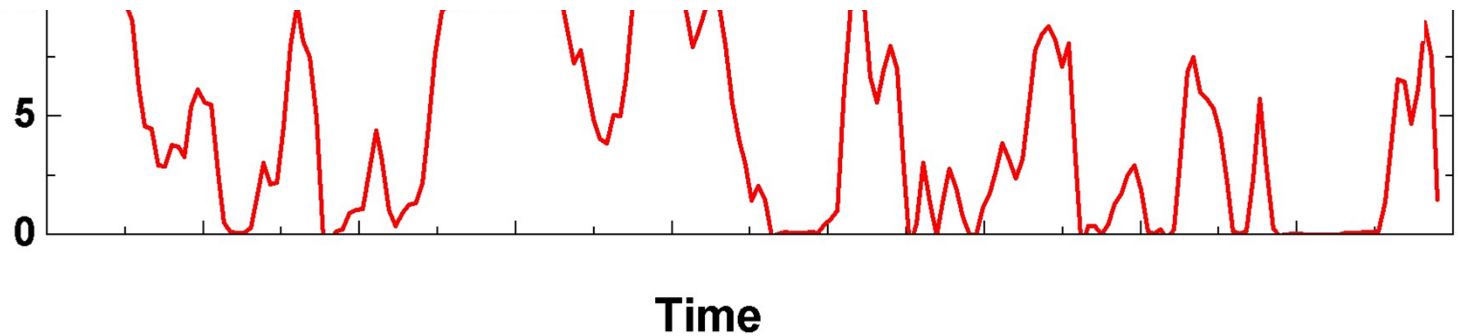
Motivation & Future Grid Challenges

Dynamic Dispatch of Balance Power Generators required



Real Grid Disturbance Example:

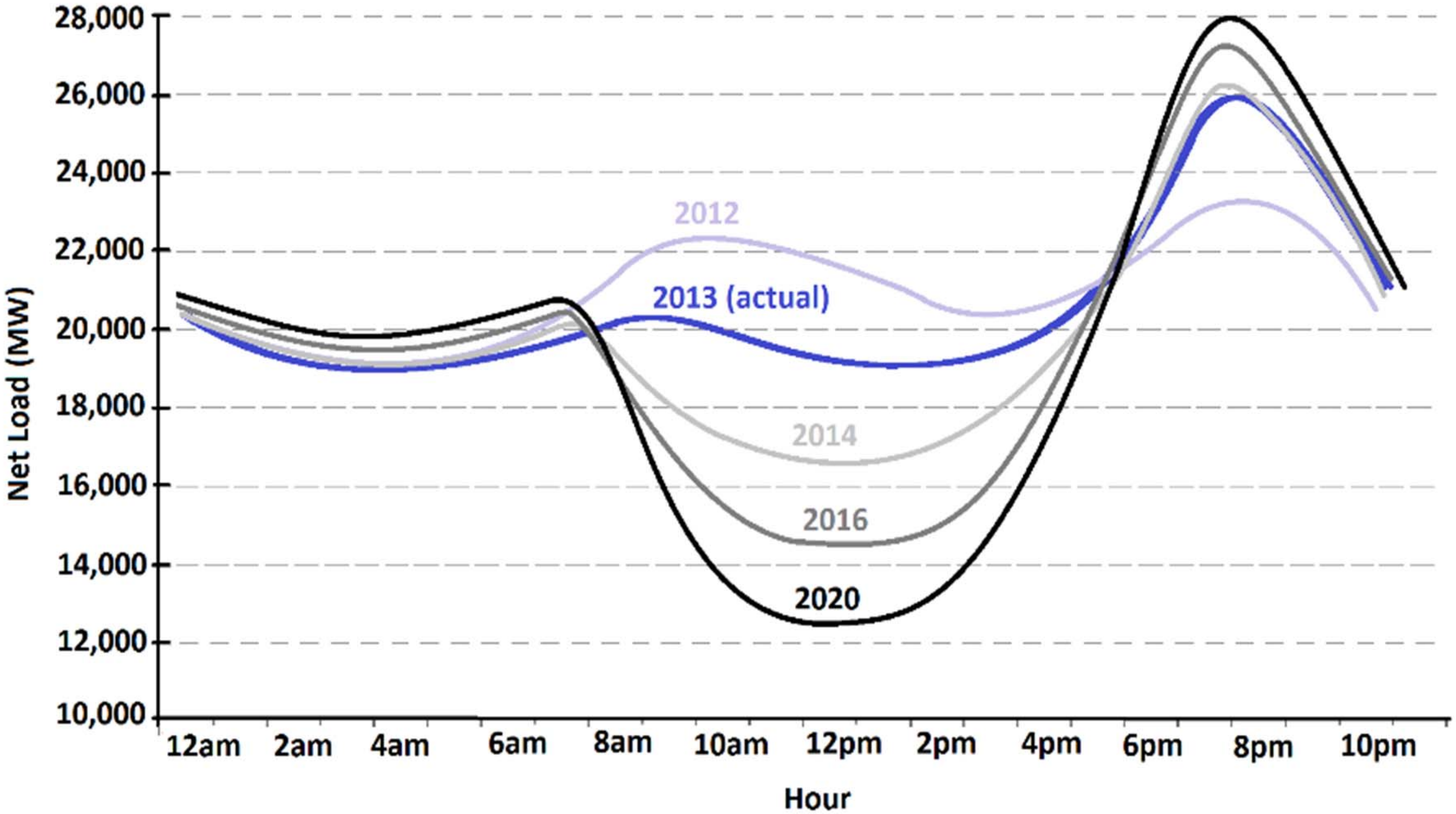
- In Texas on Feb. 26, 2008 wind power dropped 1200MW in 10 minutes
- The disturbance was registered throughout the U.S. and as far as Manitoba!
- Blackouts were avoided by massive load shedding by industrial customers
- Similar disturbances have been registered in Germany, Northern Europe



Motivation & Future Grid Challenges

Ramifications – Increased Renewables

- Net CA load profile on a Spring Day ("Duck Curve")



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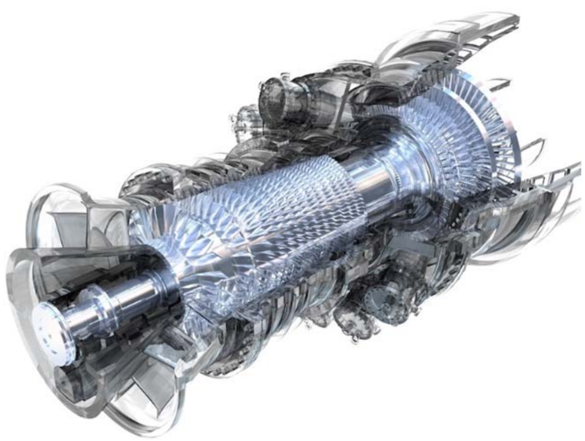
Dynamic Dispatch and Air Quality

<u>Dynamic Dispatch of Balance Power Generators – Air Quality</u>

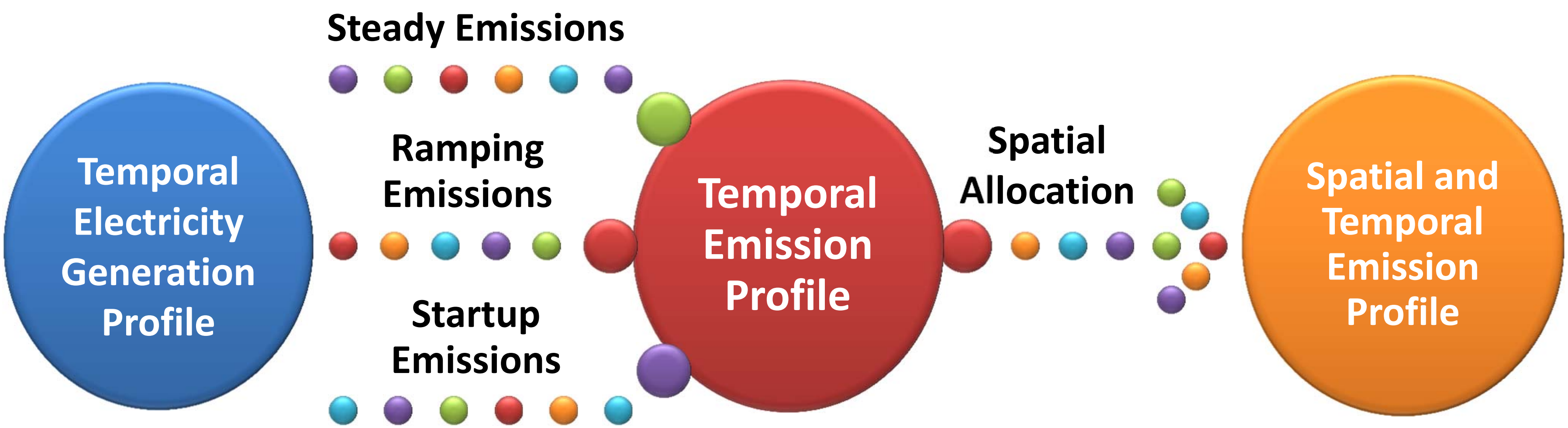
- Assume 33% renewables (wind & solar) – reduced emissions
- Assume all balance power provided by gas turbines
  - Current peaker (dynamic) and load-following plants
  - Start-up, shut-down, and ramping emissions considered
- Produce spatially & temporally resolved emissions fields for use in atmospheric chemistry & transport model



Dynamic Dispatch and Air Quality

Approach and Methodology

- Method for finding temporal and spatial criteria pollutant emission profiles

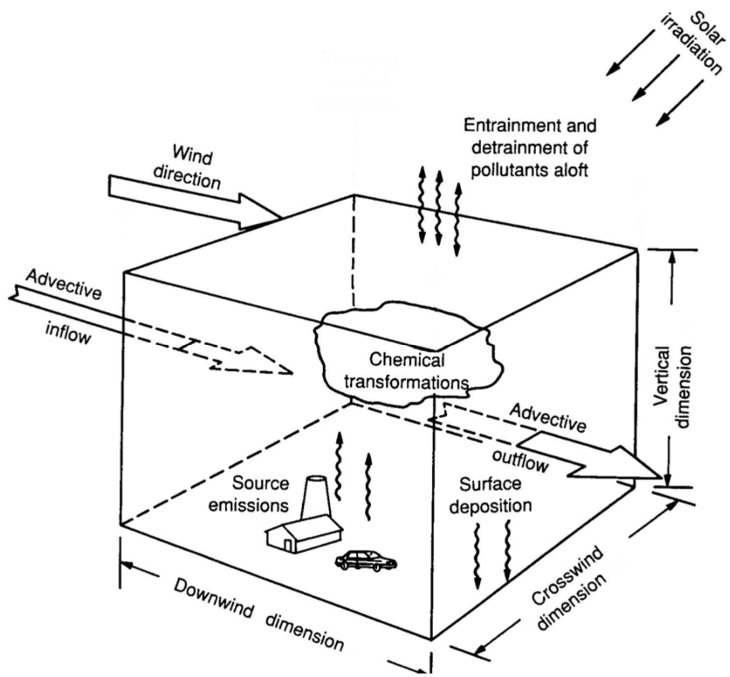


Dynamic Dispatch and Air Quality

Emissions Processing, Atmospheric Chemistry and transport

- UCI-CIT Model (SoCAB)
- CMAQ and CAMx models (for entire state)

$$\frac{\partial Q_m^k}{\partial t} + \nabla \cdot \left(u Q_m^k\right) = \nabla \cdot \left(K \nabla Q_m^k\right) + \left(\frac{\partial Q_m^k}{\partial t}\right)_{sources/sinks} + \left(\frac{\partial Q_m^k}{\partial t}\right)_{aerosol} + \left(\frac{\partial Q_m^k}{\partial t}\right)_{chemistry}$$

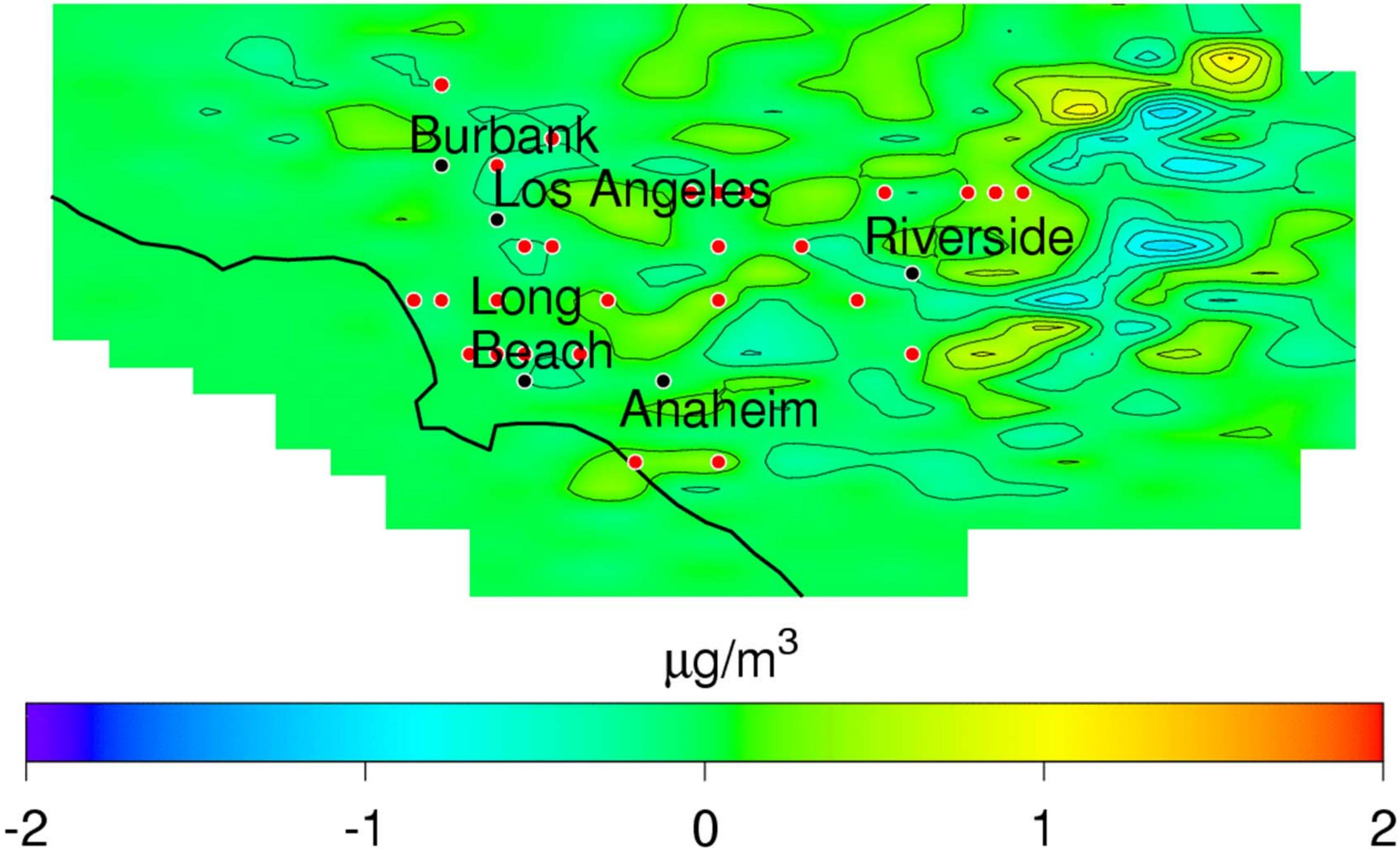


Dynamic Dispatch and Air Quality

<u>Dynamic Dispatch of Balance Power Generators</u>

- 24-hour average particulate matter ($PM_{2.5}$) difference plot

(Dispatch Case – Baseline case)

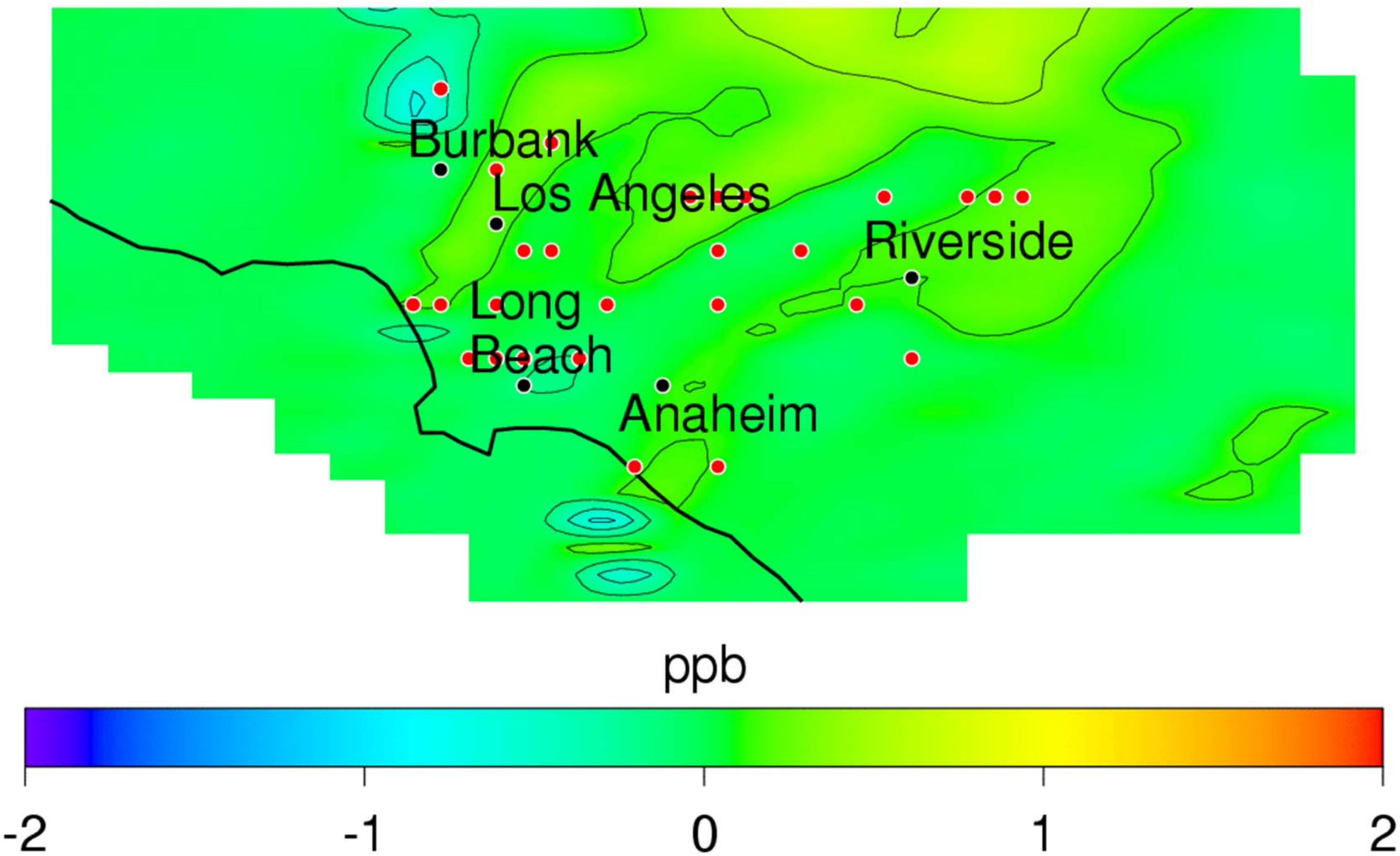


Dynamic Dispatch and Air Quality

Dynamic Dispatch of Balance Power Generators

- 8-hour average ozone (O_3) difference plot

(Dispatch Case – Baseline case)



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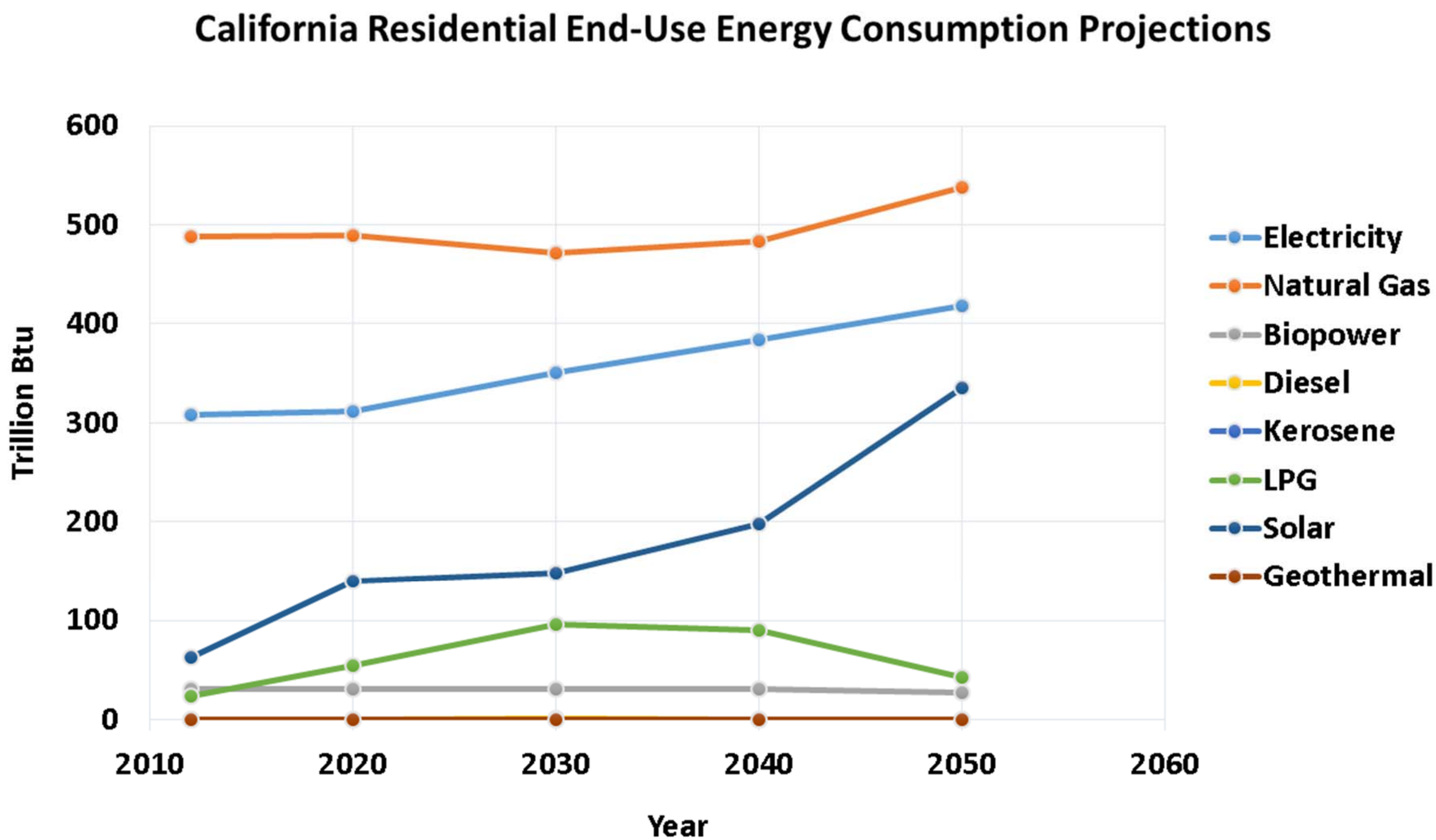
Can "Electrification" Help?

- Projected distribution of end-use energy sources (MARKAL)



Can "Electrification" Help?

- Method used for adjusting projected statewide electricity demand profile after implementing electrification

Total Electrification Load

- **Find BAU electric penetration from fuel consumption projections**
- **Determine total amount of non-electric fuel removed**
- **Compute total electricity load added by accounting for efficiency ratios**

Electrification Temporal Load Profile

- **Find temporal electrification load profile using hourly Load Shapes for each EPA SCC code (residential, commercial, industrial)**
- **Adjust electrification load Profile for scenarios including transportation using ZEV-NET EV charging data**

Adjusted statewide demand profile

- **Add temporal electrification load profile to state original demand profile**

Can "Electrification" Help?

- Tools used to determine the temporal generation profile

MATLAB

- **Finding the electrification load profile and adjusting statewide original demand profile**

Adjusted State Temporal Electricity Demand Profile

↓

HiGRID

- **Determining Renewables Temporal Electricity Generation Profile**
- **Determining Complementary Technologies Temporal Load Profile**

Dispatchable Load = Adjusted Demand – Renewable Generation – Complementary Tech Load

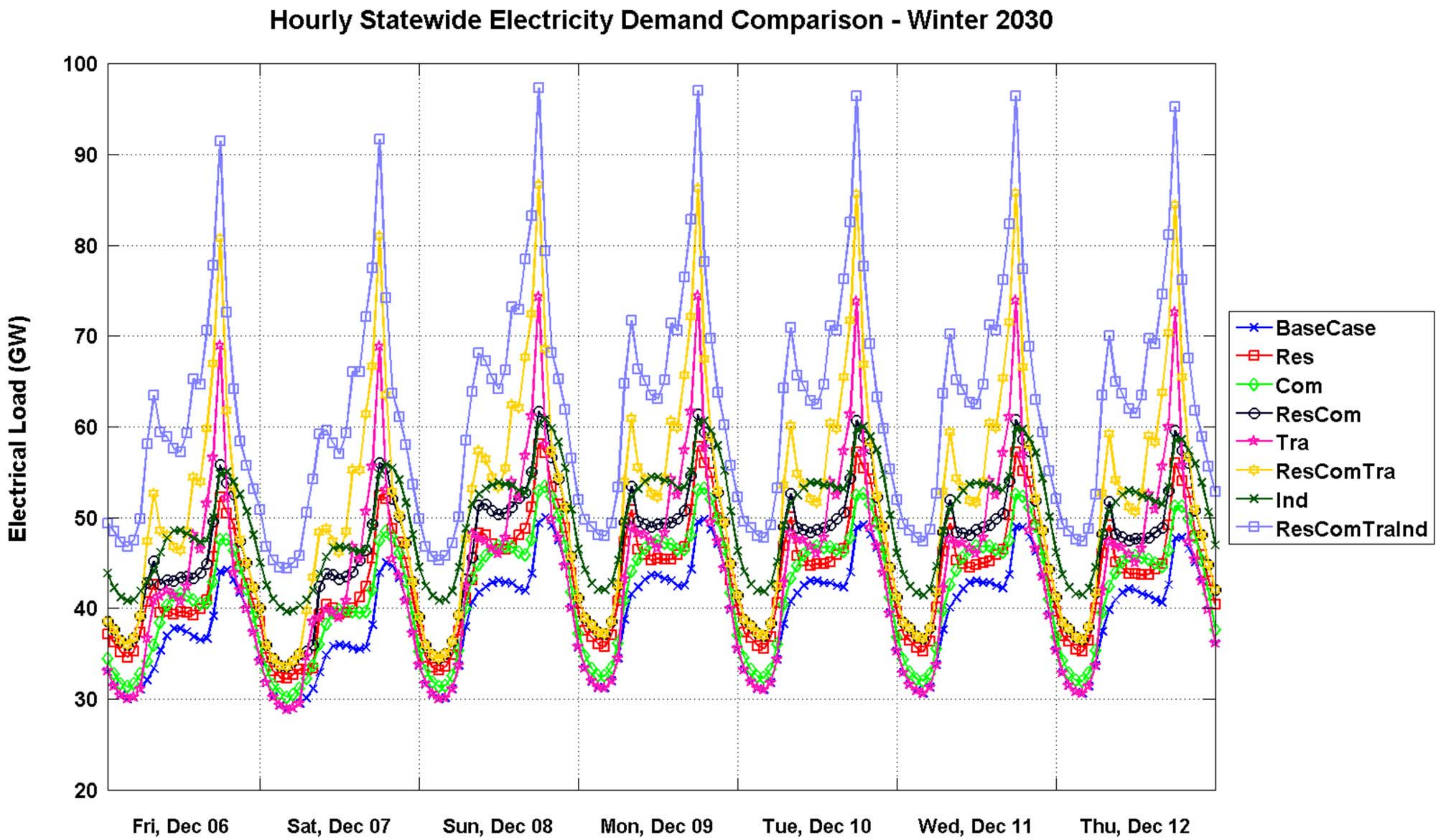
↓

PLEXOS

- **Dispatching Utility Generators and Determining their Temporal Generation Profile**

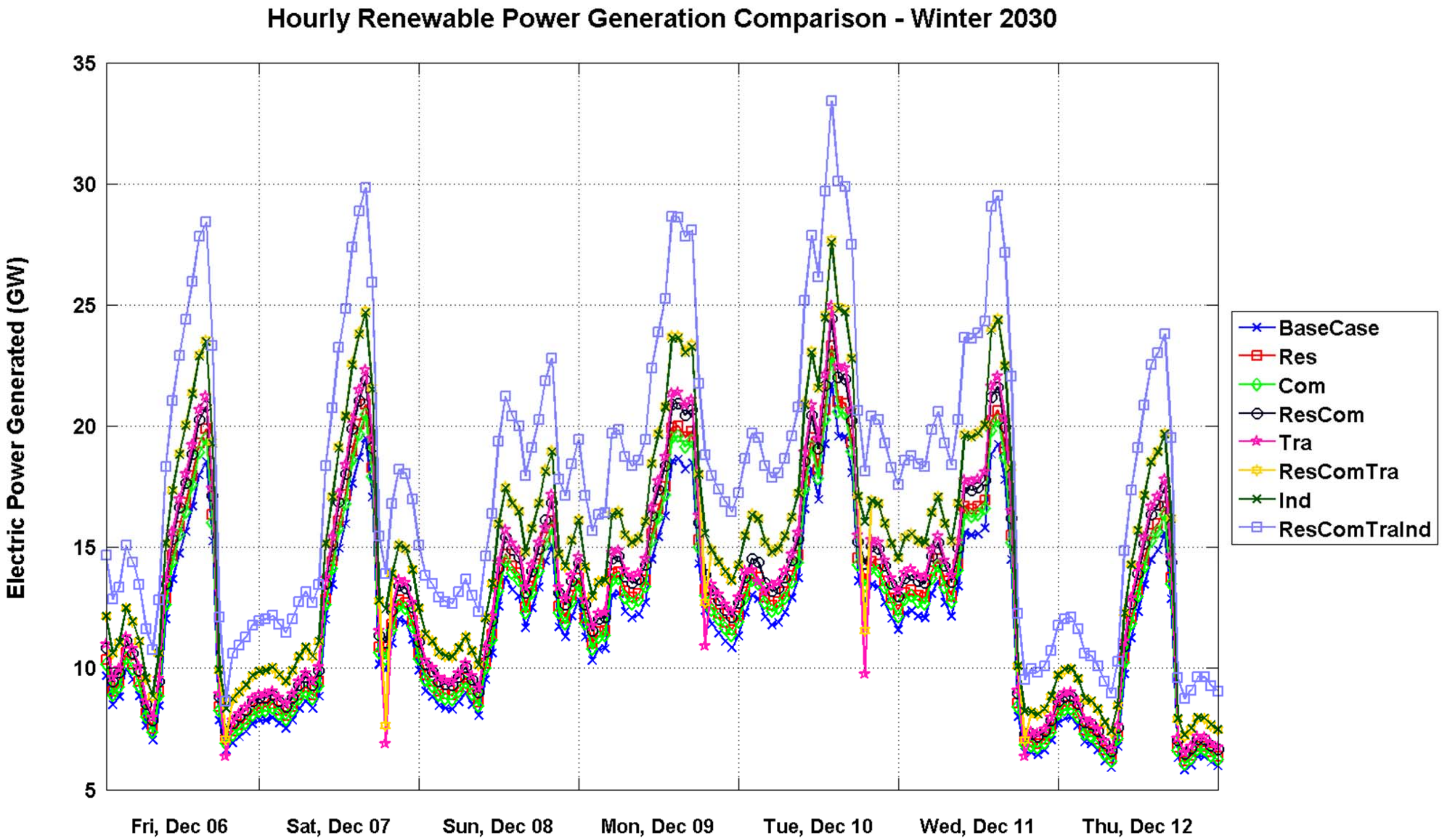
Initial Electrification Results

- 2030 Scenarios Comparison: Statewide Demand Profile



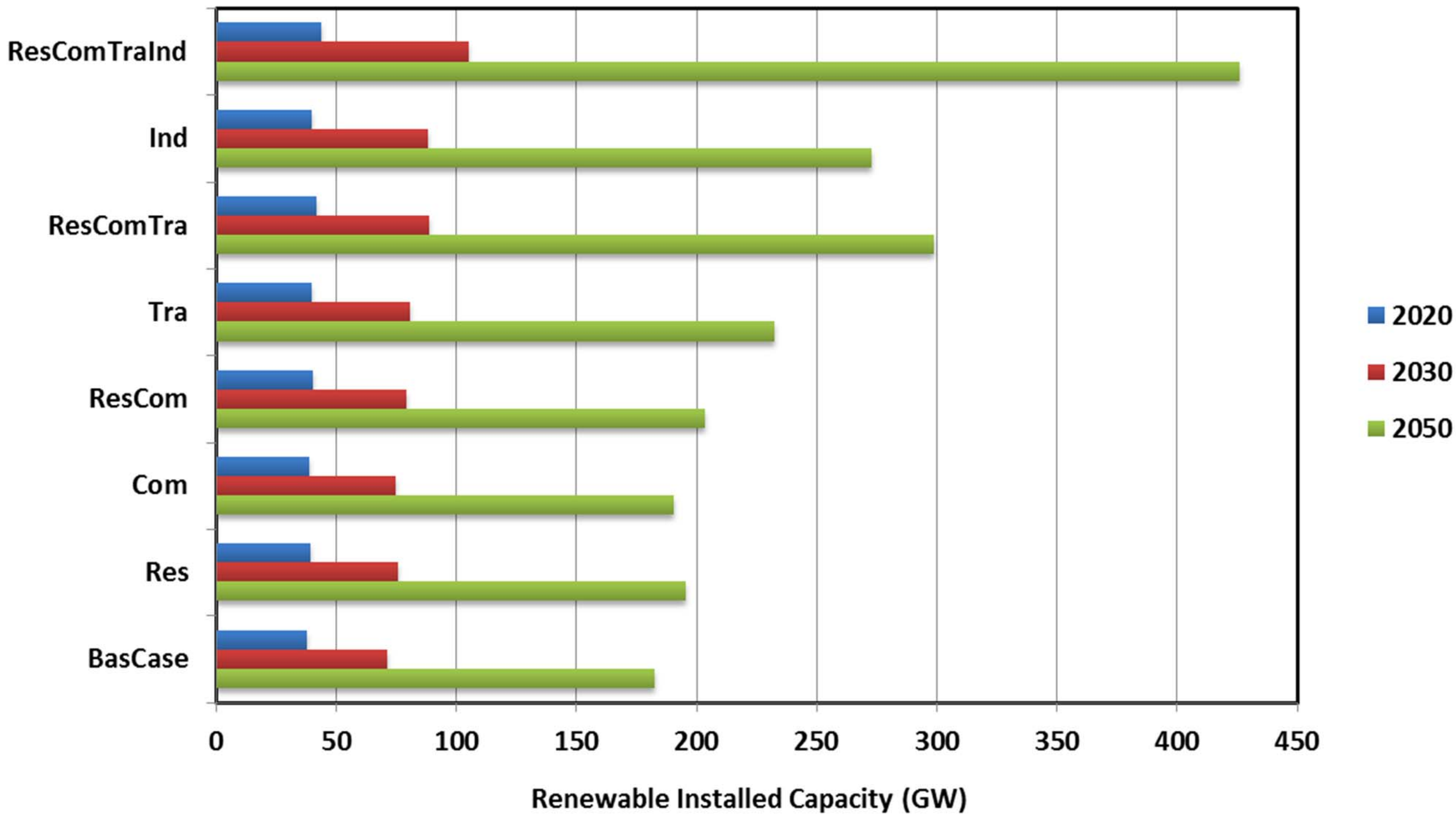
Initial Electrification Results

- 2030 Scenarios Comparison: Renewable Load Profile



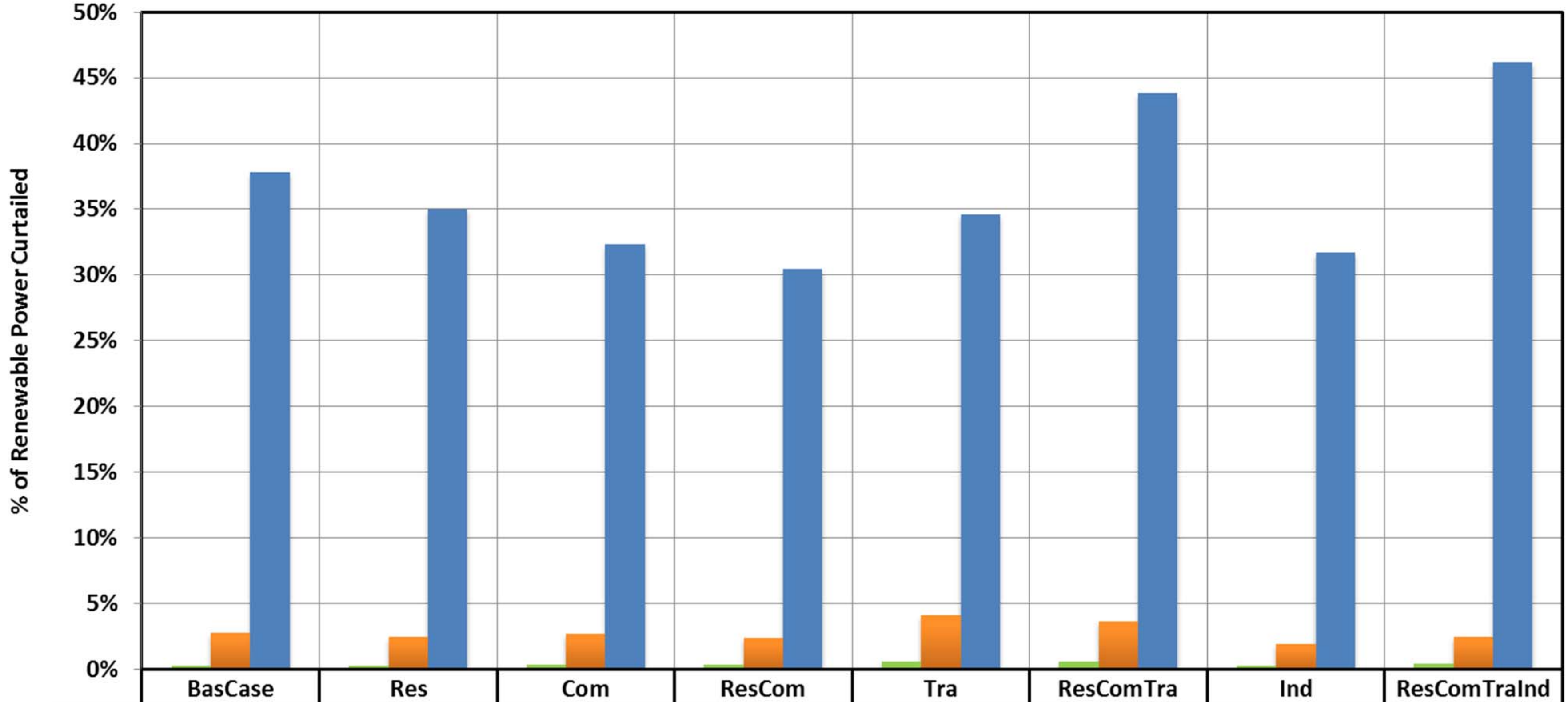
Initial Electrification Results

- Required Renewable Capacity Comparison



Initial Electrification Results

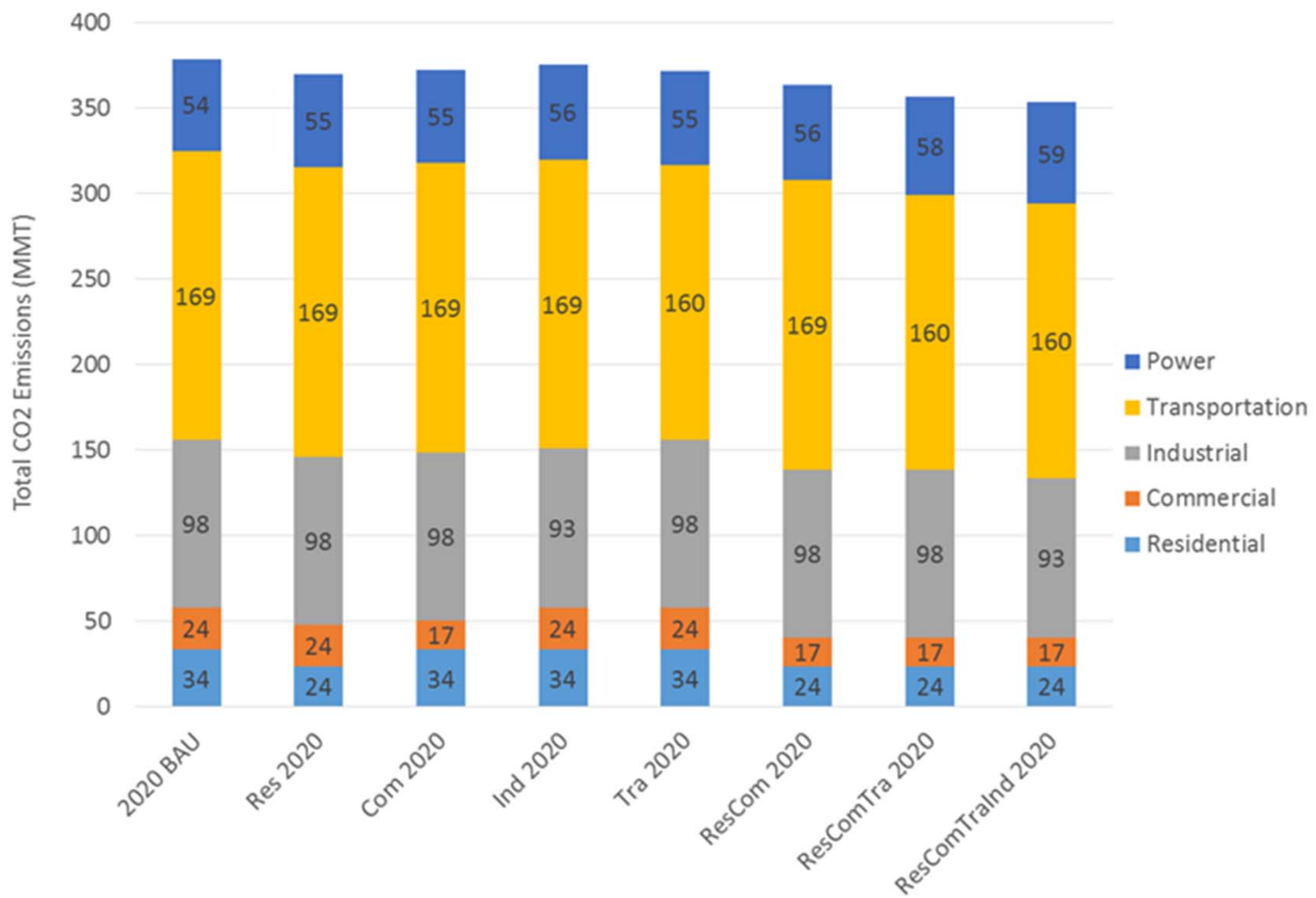
- Curtailed Renewable Power Comparison



	BasCase	Res	Com	ResCom	Tra	ResComTra	Ind	ResComTraInd
2020	0.27%	0.24%	0.33%	0.31%	0.58%	0.53%	0.23%	0.39%
2030	2.78%	2.43%	2.69%	2.34%	4.07%	3.64%	1.89%	2.47%
2050	37.78%	35.01%	32.33%	30.46%	34.59%	43.81%	31.69%	46.19%

Initial Electrification Results

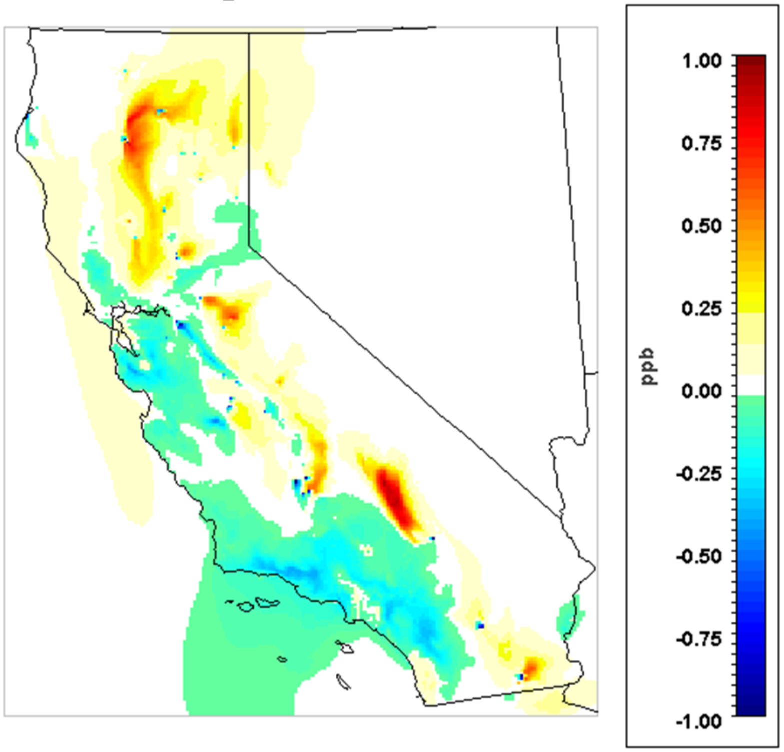
- GHG Emissions Comparison



Initial Electrification Results

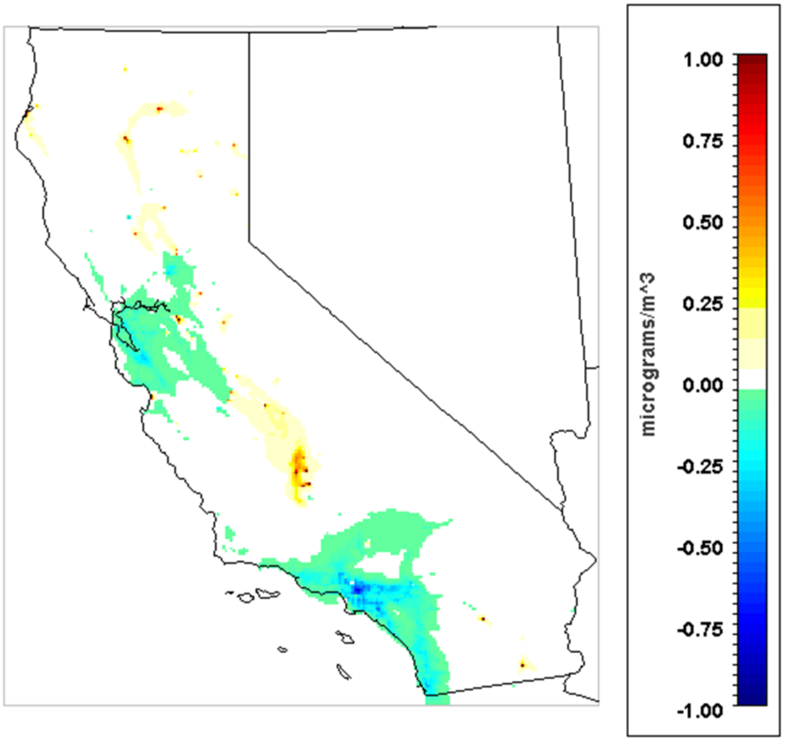
- 2030 Summer Transportation Case: Air Quality Impacts

Δ [O_3] Relative to Base



-2.41 to +0.92 ppb

Δ[$PM_{2.5}$] Relative to Base

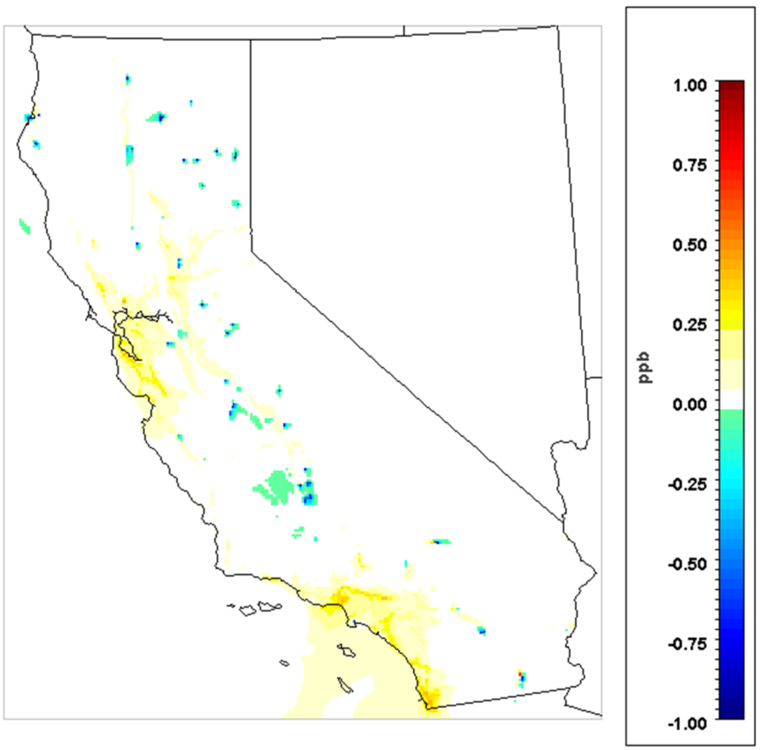


-0.76 to +2.04 µg/m^3

Initial Electrification Results

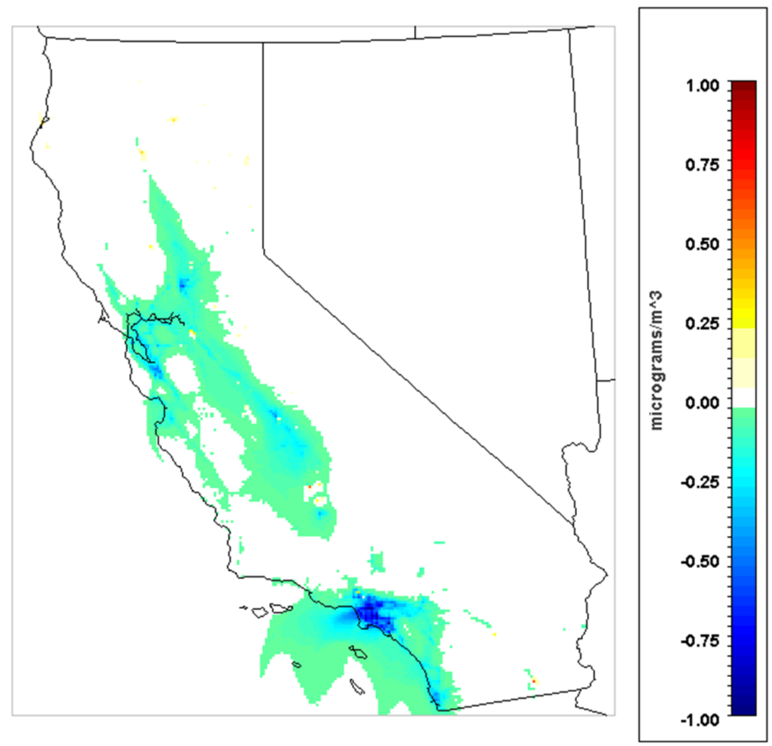
- 2030 Winter Transportation Case: Air Quality Impacts

Δ $[O_3]$ Relative to Base



-1.63 to +0.67 ppb

Δ$[PM_{2.5}]$ Relative to Base



-01.08 to +0.60 μg/m³

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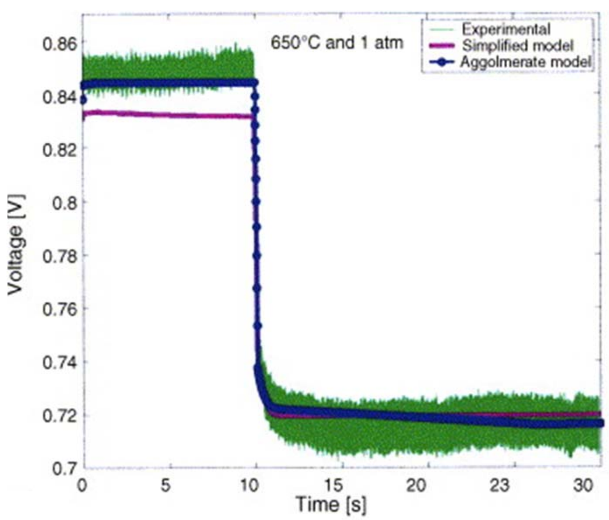
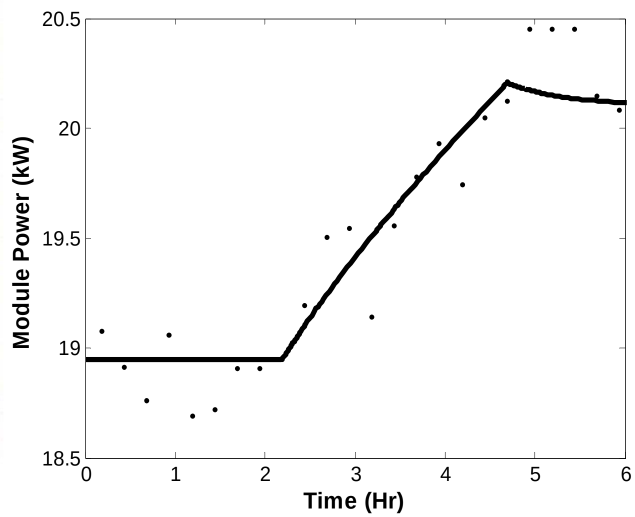
Cleaner Dynamic Dispatch Generators (Fuel Cells)

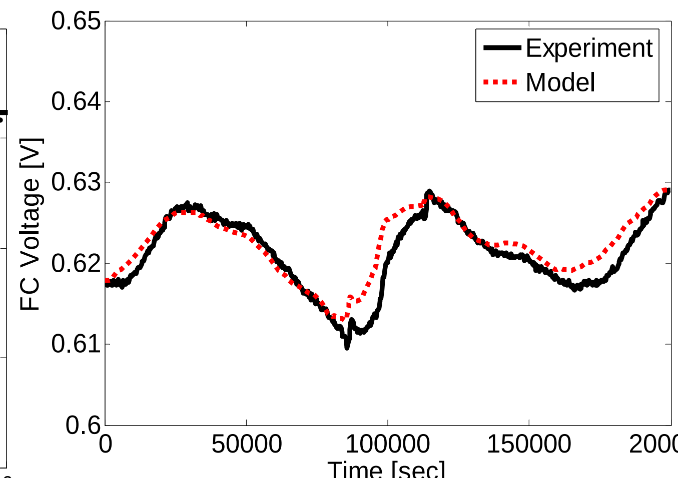
Single Cell MCFC Test Stand

Siemens Integrated SOFC System

Siemens/SCE 220 kW SOFC/GT Hybrid





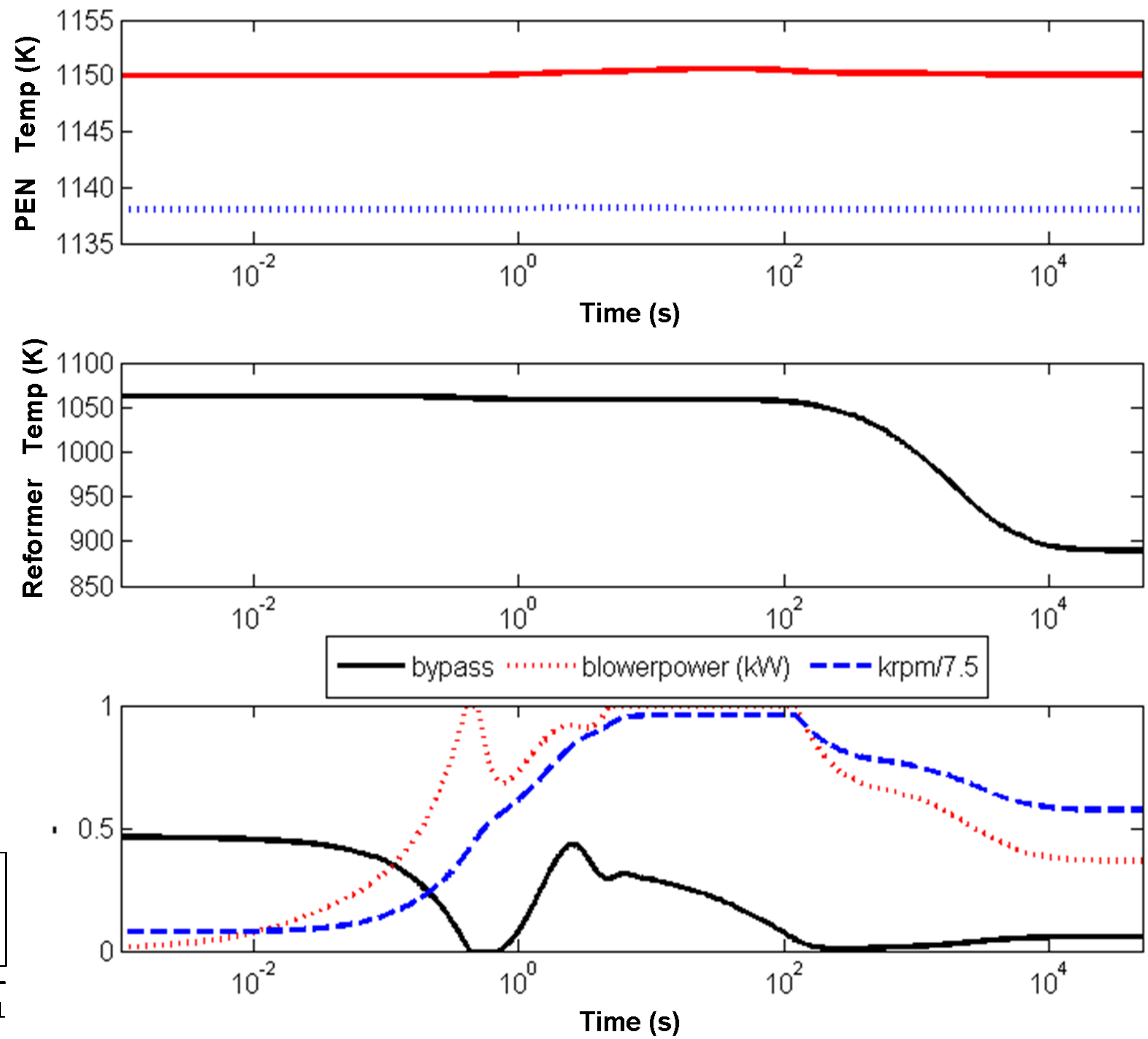


Cleaner Dynamic Dispatch Generators (Fuel Cells)

Integrated SOFC system

25 to 70 amp current increase perturbation

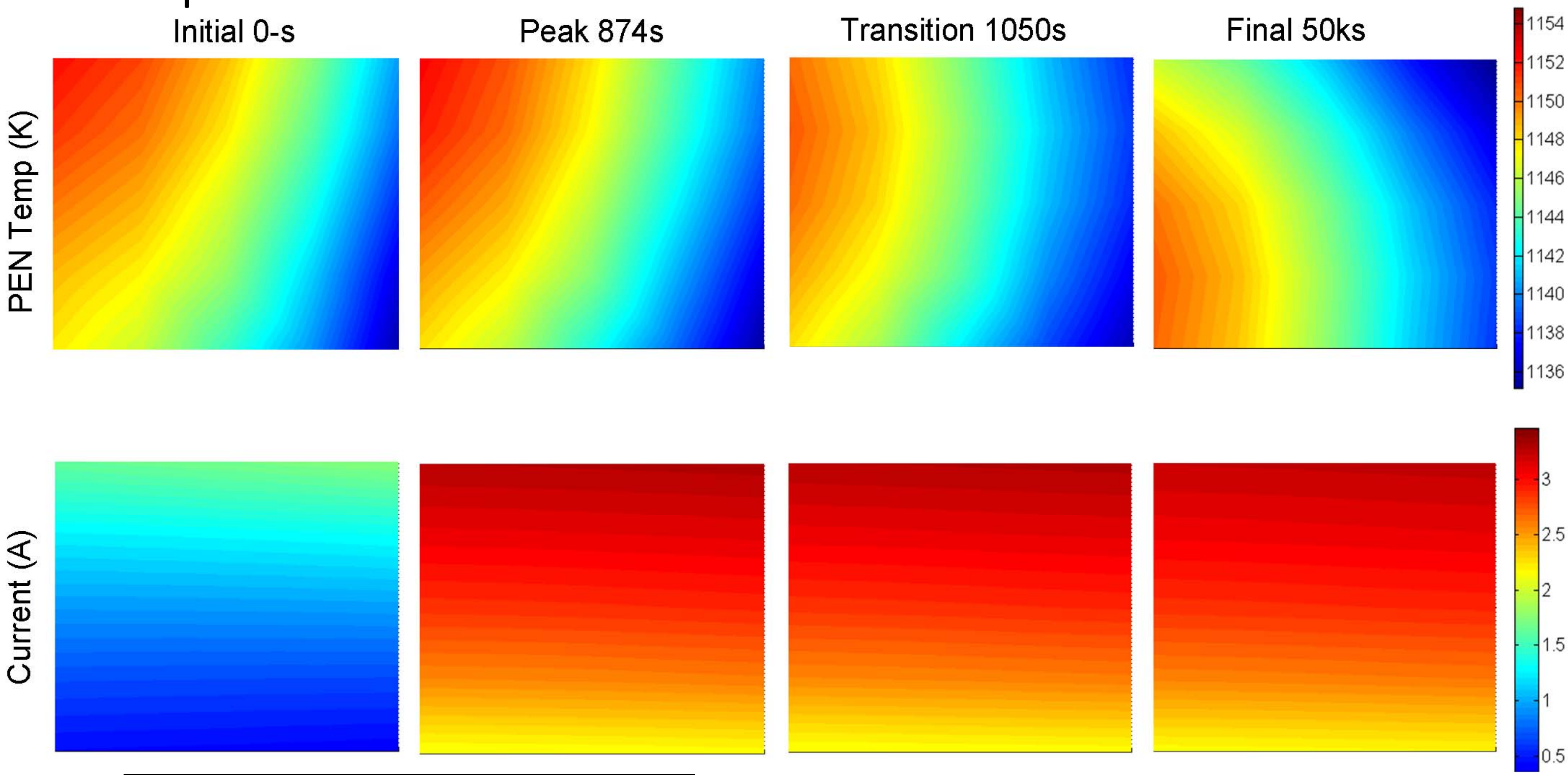
Control actions:



Mueller, F., Jabbari, F., Brouwer, J., Journal of Power Sources, Vol. 187, Iss. 2, pp. 452-460, 2009

Cleaner Dynamic Dispatch Generators (Fuel Cells)

Integrated SOFC system - 25 to 70 amp current increase with PEN temperature feedback

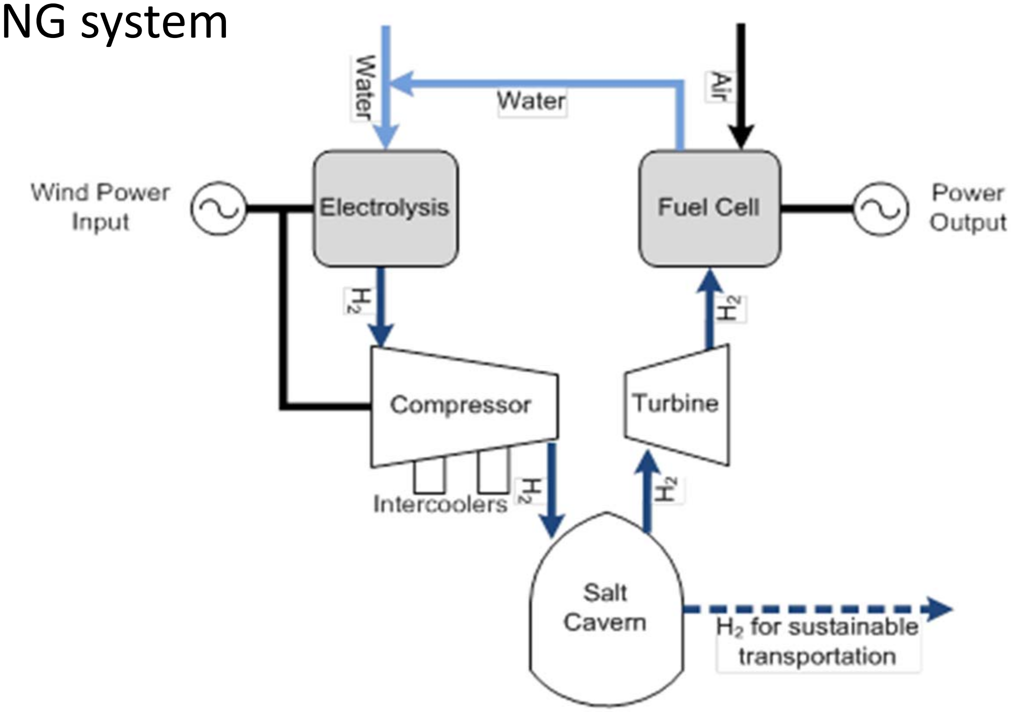


Mueller, F., Jabbari, F., Brouwer, J., Journal of Power Sources, Vol. 187, Iss. 2, pp. 452-460, 2009

Massive Energy Storage

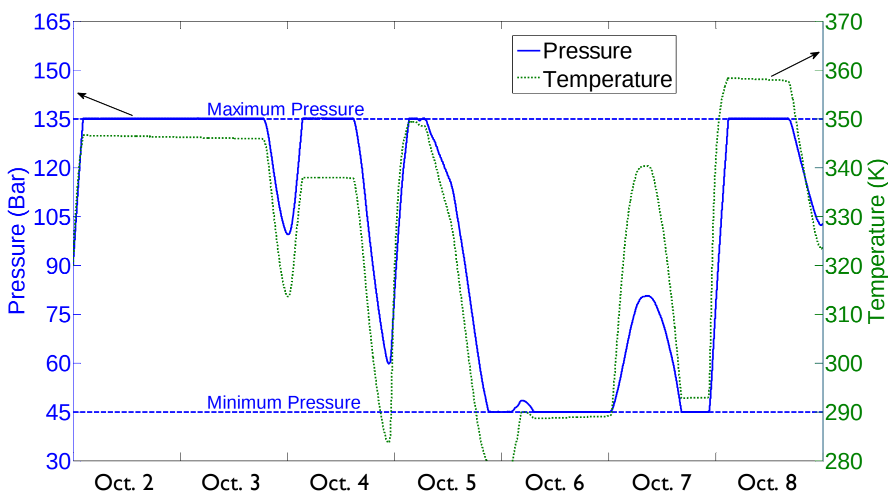
Need for Massive Energy Storage

- Fundamental feature needed: separated energy & power design
  - Pumped Hydro – best locations/resources taken; water/environ. implications
  - Compressed Air – emerging; resources scarce
  - Flow Batteries – emerging; currently expensive; materials
  - Hydrogen – emerging; more energy dense than compressed air; transportation fuel; NG system

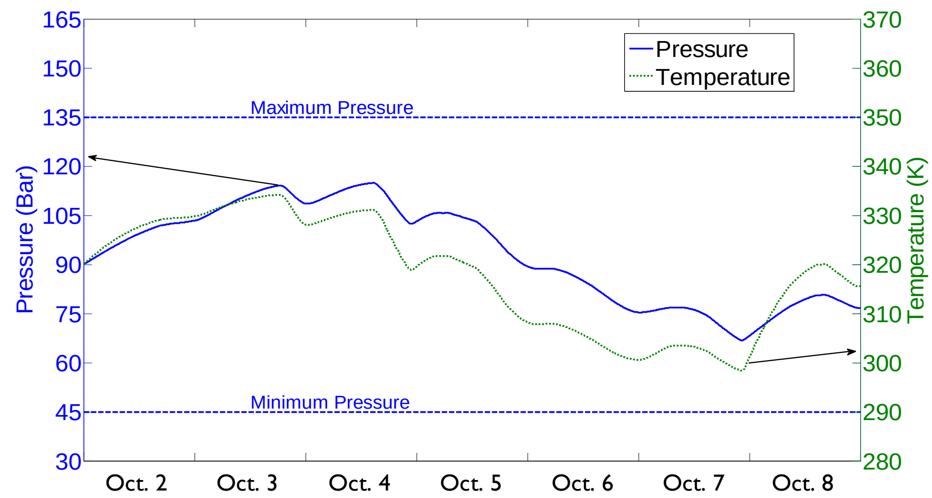


Massive Energy Storage

- Compressed Air Energy Storage



- Hydrogen Energy Storage

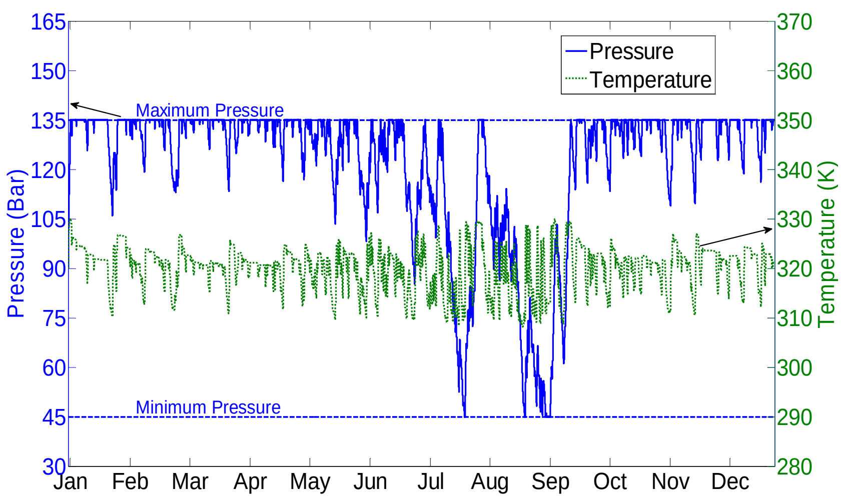


- CAES is limited by its low volumetric energy density
  - Maximum cavern pressure leads to curtailed wind energy
  - Minimum cavern pressure requires other power plants to come online to meet grid demand
- Hydrogen energy storage captures all wind energy and meets grid demand at all times

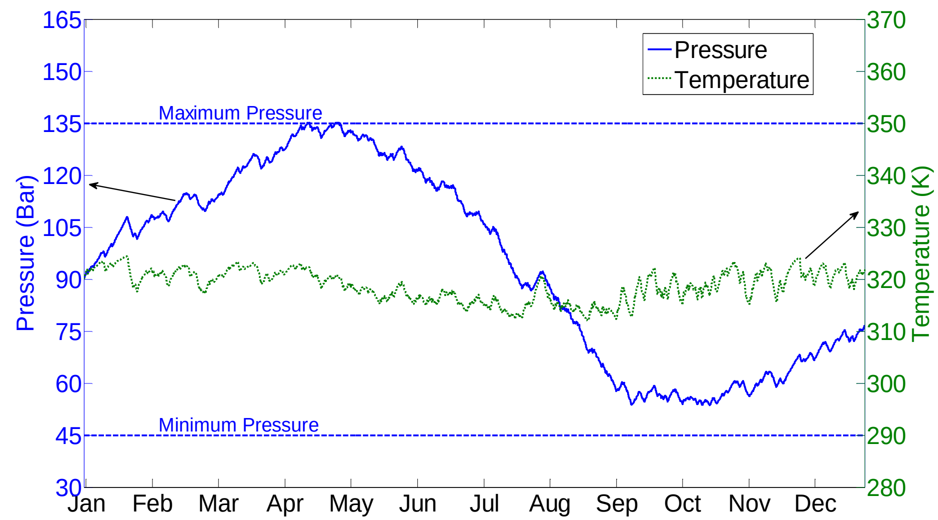
Maton, J.P., Zhao, L., Brouwer, J., Int'l Journal of Hydrogen Energy, Vol. 38, pp. 7867-7880, 2013

Massive Energy Storage

- Compressed Air Energy Storage



- Hydrogen Energy Storage



- CAES cavern is completely depleted during the summer demand peak
- Hydrogen energy storage successfully shifts seasonal wind power
  - Wind energy stored in winter is used to provide for the large summer demand
- Hydrogen available for transportation

Maton, J.P., Zhao, L., Brouwer, J., Int'l Journal of Hydrogen Energy, Vol. 38, pp. 7867-7880, 2013

Massive Energy Storage

- Where can we store the gas?
  - Why not use the natural gas infrastructure?

Table 5: List of underground natural gas storage facilities in California [42]

STORAGE FACILITY	WORKING GAS CAPACITY (m³)
Pacific Gas and Electric Company (PG&E)	
McDonald Island	2,321,994,000
Pleasant Creek	63,713,250
Los Medanos	508,176,882
Southern California Gas Company (SoCal)	
Aliso Canyon	2,435,262,000
Honor Rancho	685,271,400
La Goleta	608,815,500
Playa del Rey	67,960,800
Independent Storage Providers	
Wild Goose	1,415,850,000
Kirby Hills	424,755,000
Lodi	481,389,000
Gill Ranch	566,340,000
Central Valley	311,487,000
TOTAL	**9,891,014,832**

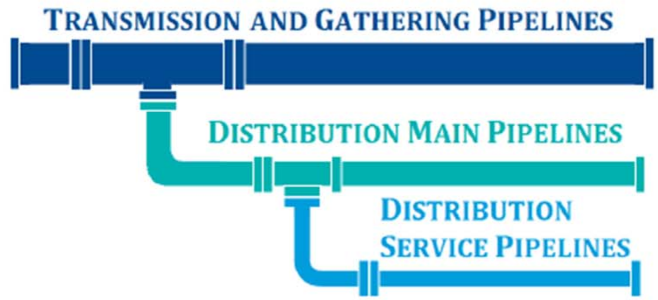


Table 4: Volume of the natural gas transmission pipeline network

PIPELINE TYPE	VOLUME (m³)
Transmission Lines	5,629,180
Gathering Lines	9,409
Distribution Mains	>350,735*
Distribution Service Lines	>159,389*
TOTAL	6,148,713

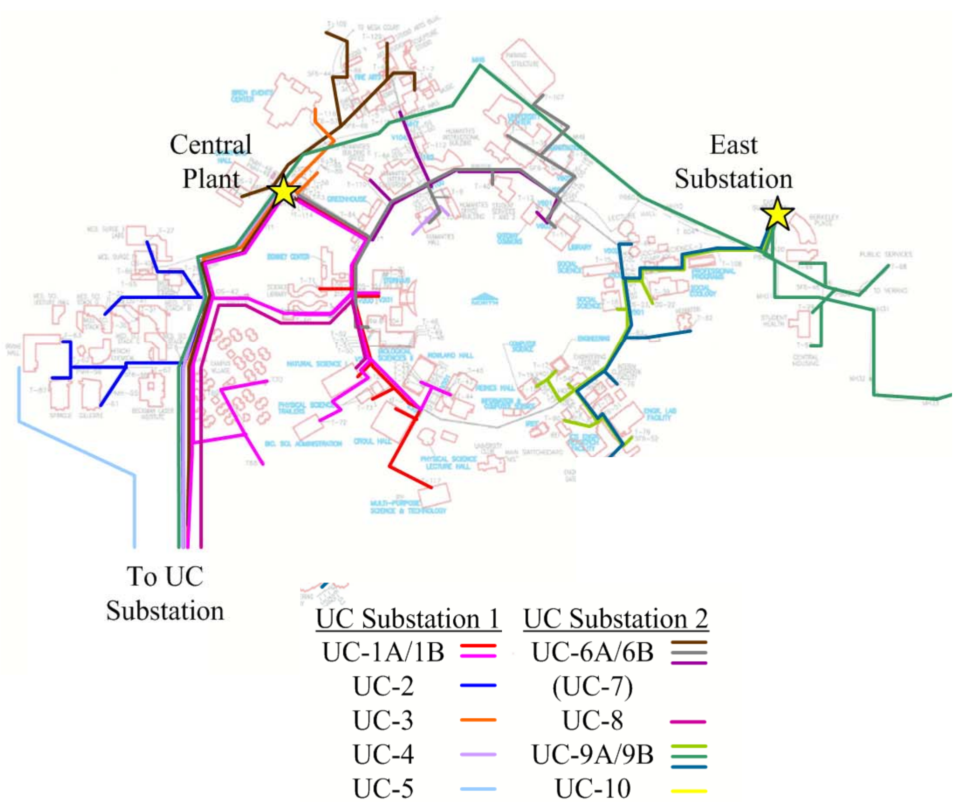
* Diameter for distribution lines is given in ranges. The estimated volume has been obtained using the lower value of each range

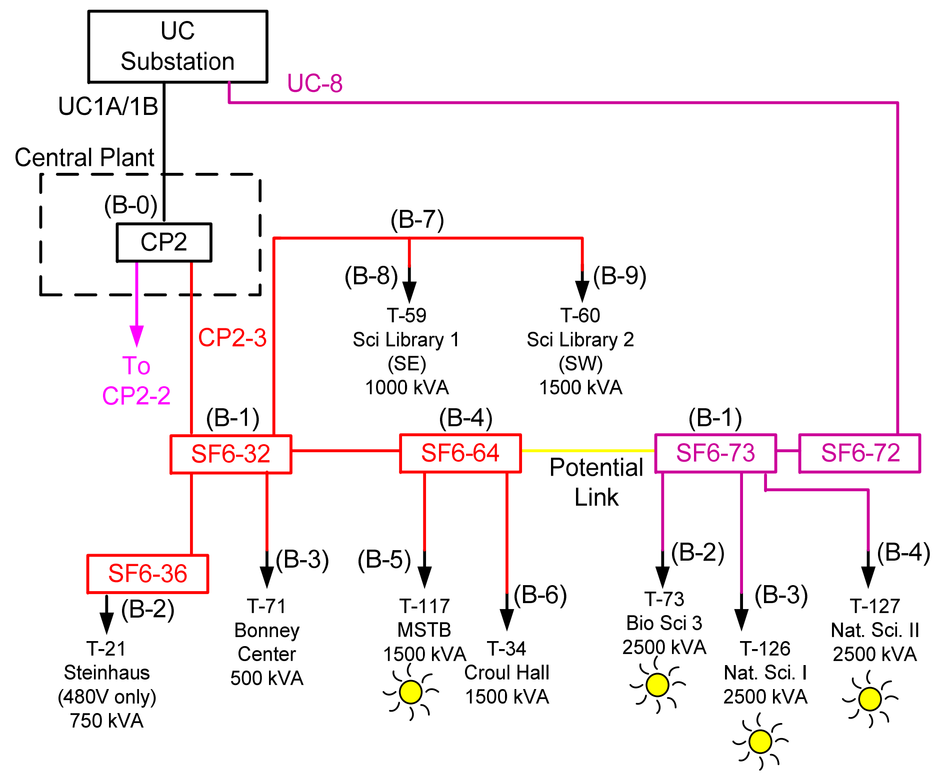
Adria Carmona, M.S. Thesis, UC Irvine, Jack Brouwer, advisor, August, 2014

UCI Microgrid & Irvine Smart Grid Demonstration (ISGD)

UCI Microgrid

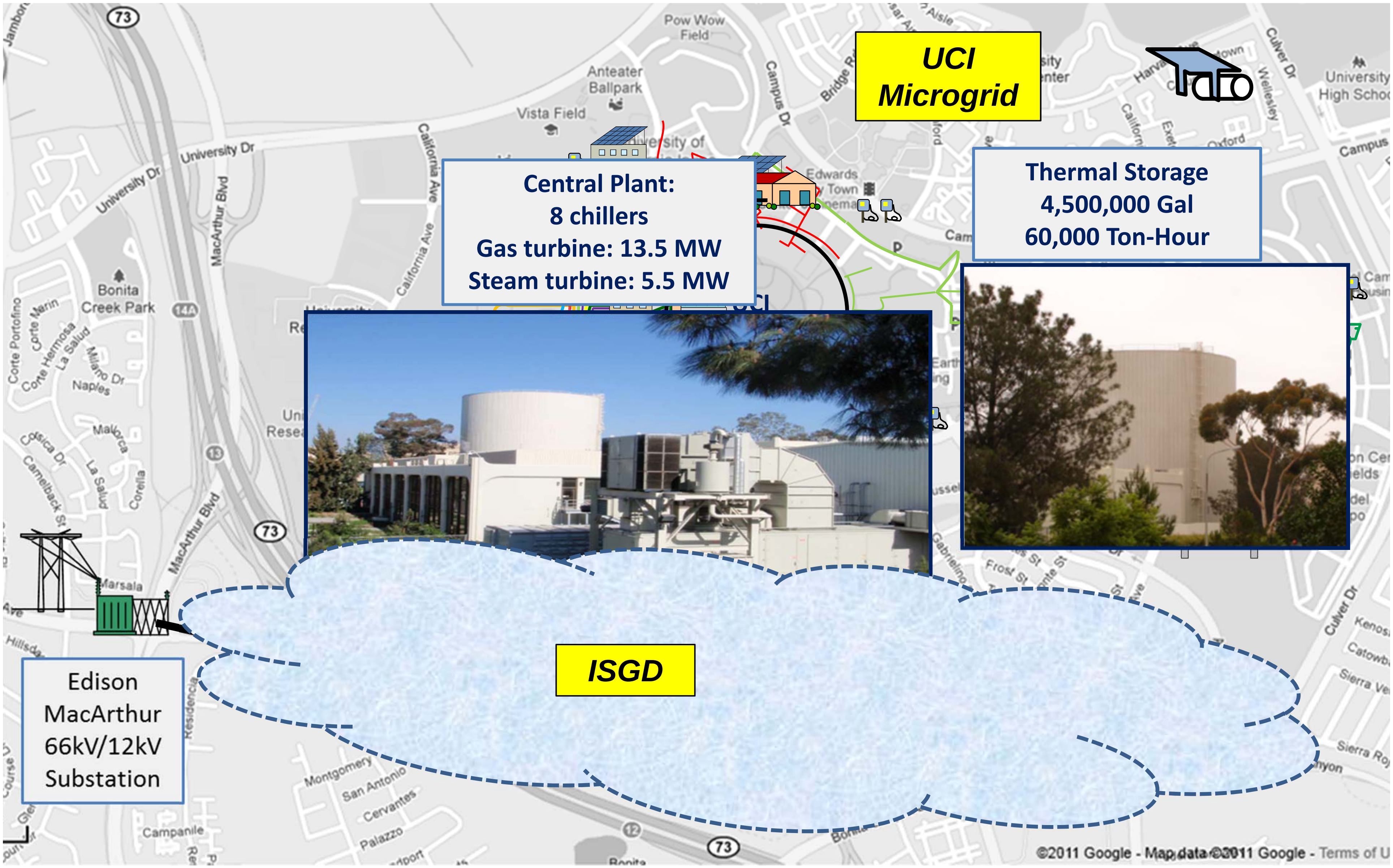
Can UCI electric infrastructure support the Smart-Grid vision?



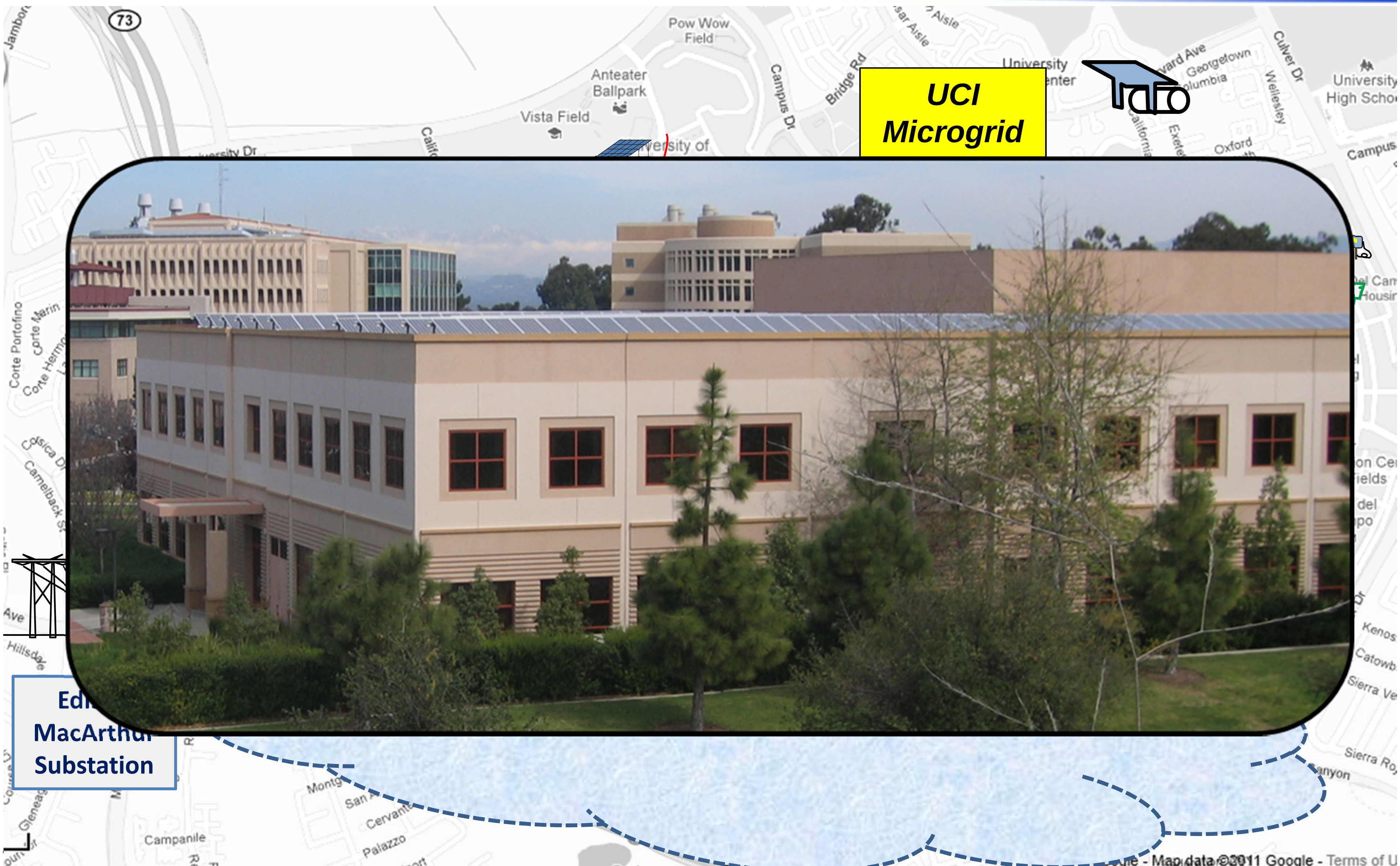


What electrical infrastructure upgrades are beneficial?

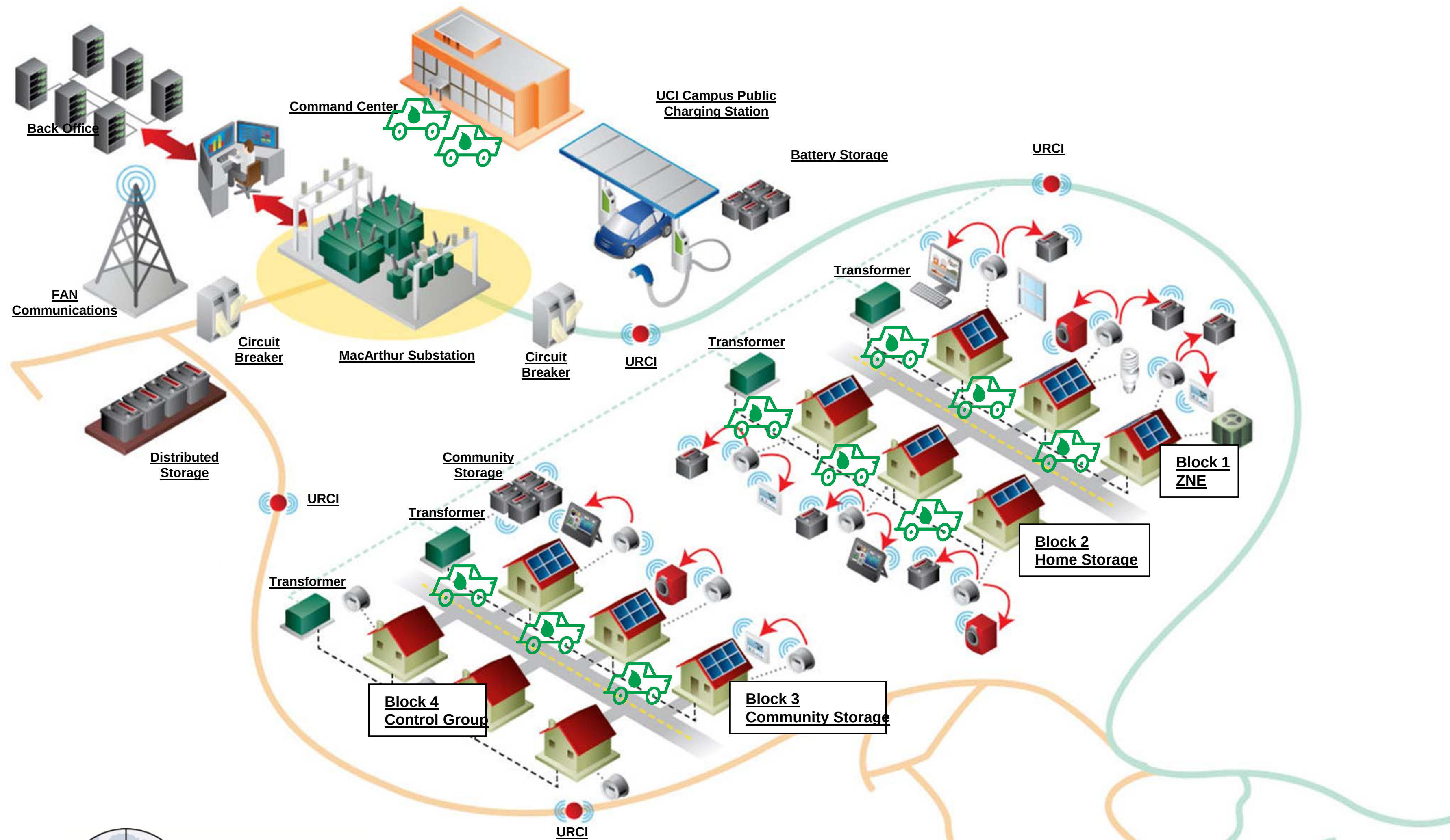
UCI Microgrid



UCI Microgrid



Irvine Smart Grid Demonstration (ISGD)



Irvine Smart Grid Demonstration (ISGD)

Irvine Smart Grid Demonstration (ISGD)

Irvine Smart Grid Demonstration (ISGD)

- Solar Car Shade with Battery Energy Storage System

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Summary

- We should and we will use more and MORE renewable power
- Renewable power must be complemented by clean, efficient, sustainable energy conversion that is dynamically dispatched
- Without clean dispatchable power air quality could worsen with increased use of renewable power
- Electrification enables increased renewable use, changes demand profile, reduces GHG, but, may not improve air quality
- Fuel cells can be designed and controlled to produce clean, efficient and dispatchable power
- Massive energy storage is required – only certain technologies are applicable at this scale due to energy/power features
- Smart Grid technologies are required to help manage the integrated suite of technologies

Acknowledgements

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  - Li Zhao, Scott Samuelsen, Faryar Jabbari, Richard Hack, Brendan Shaffer, Allie Auld, Fabian Mueller
  - Other APEP/NFCRC Students and Staff
- Funding & Collaboration
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