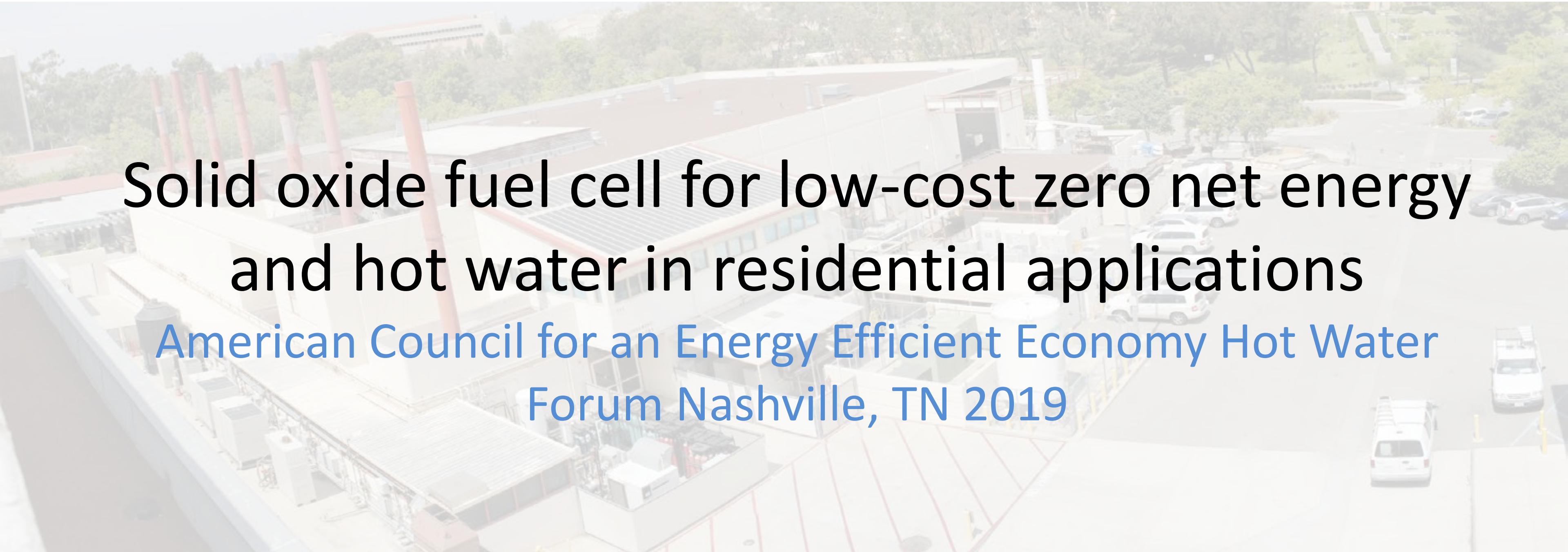

Solid oxide fuel cell for low-cost zero net energy and hot water in residential applications

American Council for an Energy Efficient Economy Hot Water Forum Nashville, TN 2019

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY of CALIFORNIA · IRVINE

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March 12, 2019

Background

- California has aggressive energy goals:
  - SB 100 in California
    - 60% electrical energy must be generated from renewables by 2030
    - **100% *Carbon free* by 2045**
  - California's Title 24 building codes
    - New homes and businesses must achieve ZNE building standards by 2020 and 2030
    - Introduces new metric to calculate ZNE

http://www.50states.com/flag/caflag.htm

Background

- A ZNE Building is "one where the net amount of energy produced by **on-site renewable energy resources** is equal to the value of the **energy consumed annually by the building**"

ENSIA

AirMECH

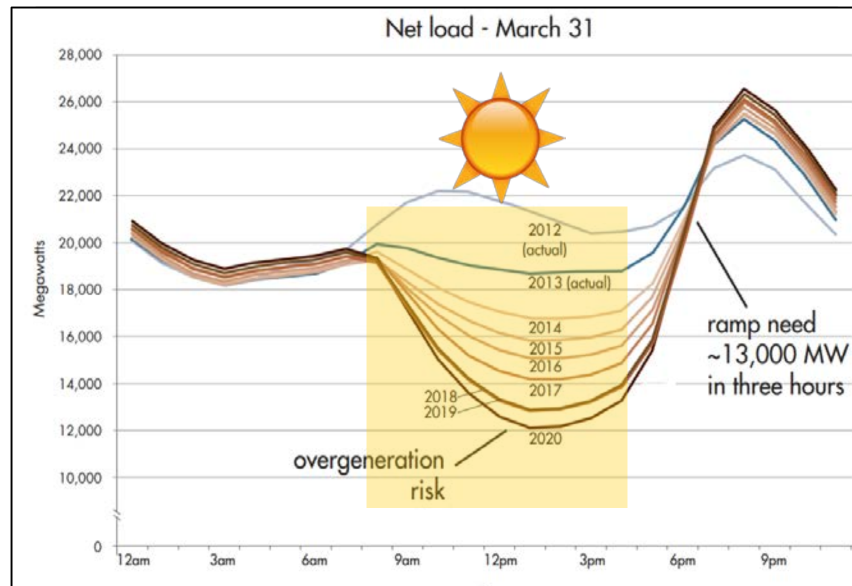
ACS

Solar and Wind Energy Generation Systems are Necessary for ZNE

Challenges with integrating more Renewables:

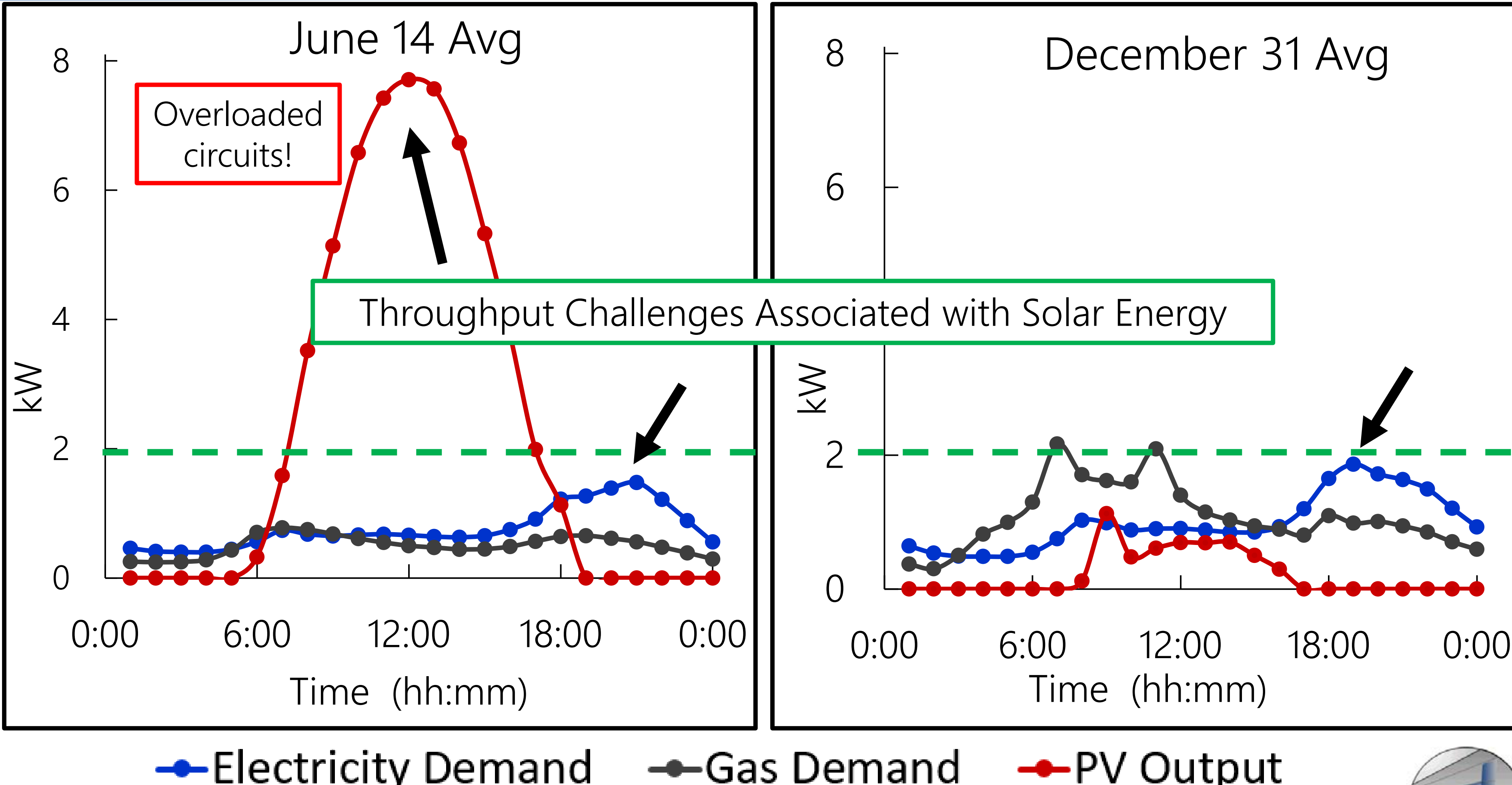
- Renewables are <u>intermittent</u>, <u>variable</u>, and <u>unpredictable</u>
- Grid lacks flexibility to handle dynamics of renewables
- Curtailment may result in negative prices


ENSIA



Source: CAISO, 2013

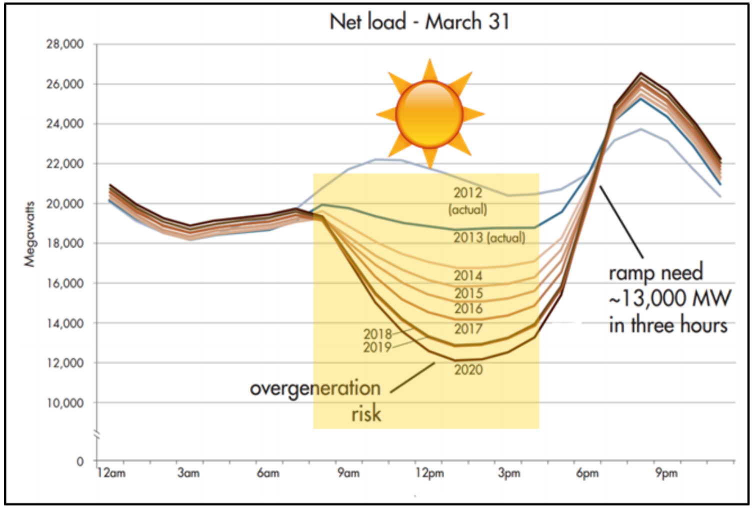
High Demands not Coincident with Solar Energy



Problem Statement

Our proposed solution:

Use the existing NG system as an **energy storage** and **transport medium** to support the integration of RE systems with our current electrical grid.



Source: CAISO, 2013

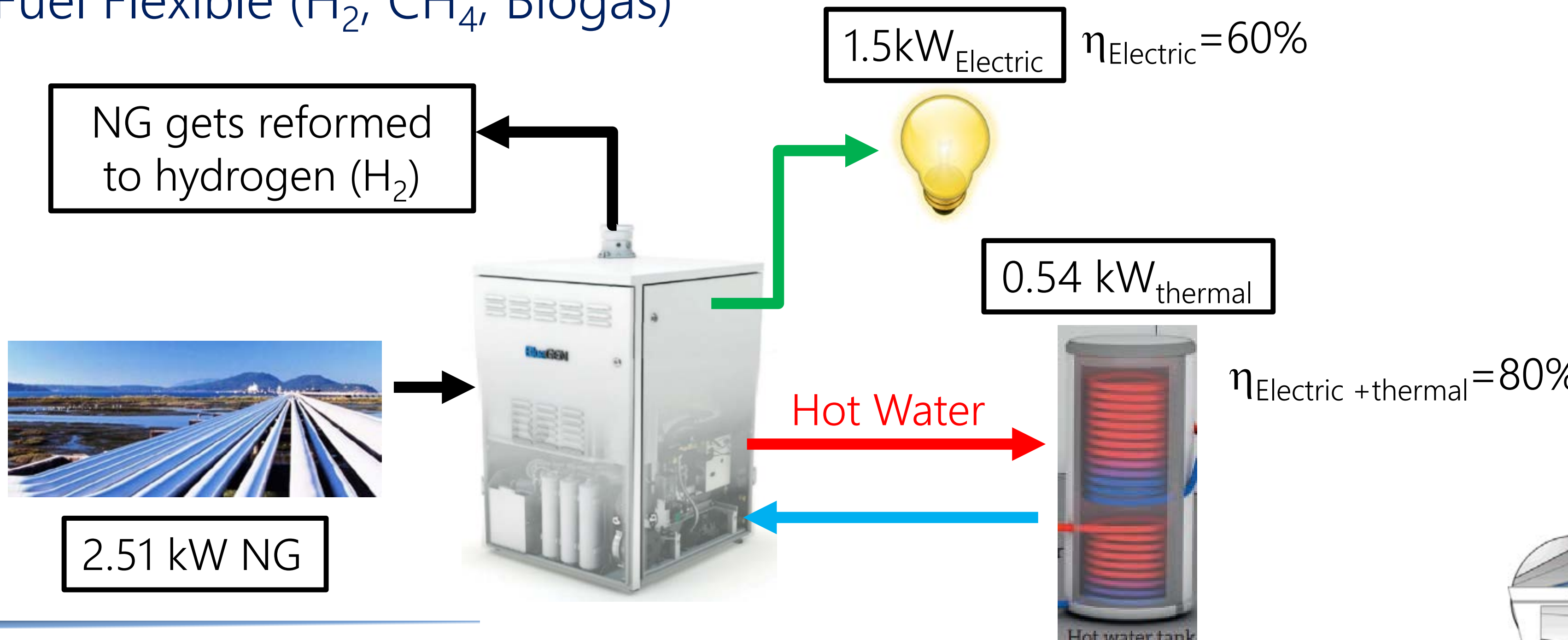
Problem Statement

In this study we use a fuel cell with micro combined heat and power to theoretically and experimentally :

1. Evaluate how this system can achieve ZNE efficiently in a residence compared to completely electrifying the residence
2. Evaluate how this system can support future climate goals

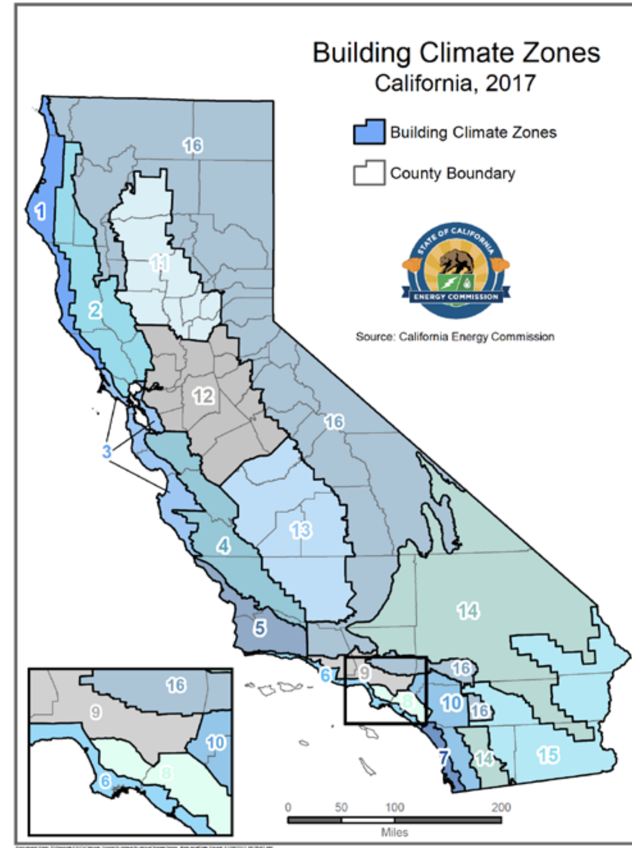
Advantages of High Temperature Fuel Cells

- Electrochemically generates electricity at high efficiencies
- Due to high operating temperatures, simultaneously provide electricity and quality heat
- Internally exchange heat with the hot exhaust gas
- Fuel Flexible (H_2, CH_4, Biogas)



Calculation of Zero Net Energy for Various Residences

- Average, hourly electrical and gas residential demand data for every day of the year of residences in various climate zones
  - Developed by NREL based upon climate and geography
- Developed a model to estimate the hourly solar irradiance on PV panels for each residence
  - TMY3 data sets from NREL that contain 1 year of typical hourly data for various climate zones
- Excess electricity is exported to grid through net metering

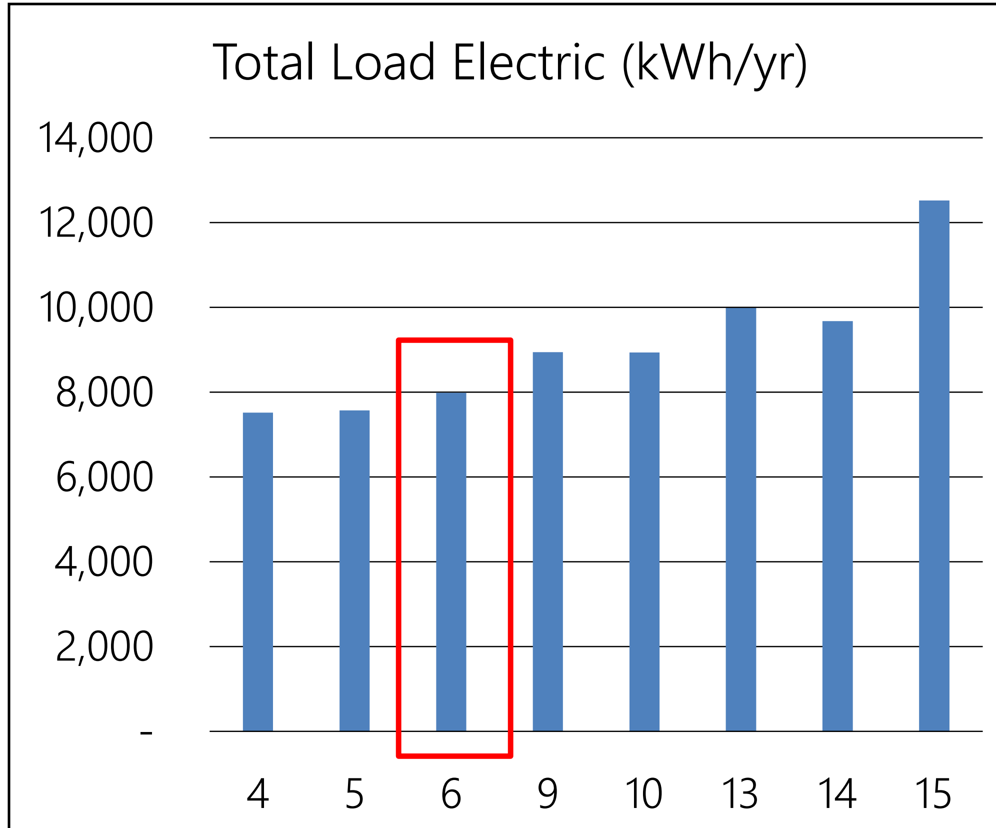


Calculation of Zero Net Energy for Various Residences

- Time Dependent Valuation (TDV) Factor
  - California Energy Commission developed regional, hourly, TDV values for various climate zones in California
  - Accounts for cost to consumer, utility, and society to provide energy based on **time of use**, **climate**, **geography**, **fuel type**
- Four Cases:
  1. Electric Residence with PV
  2. Electric Residence with PV + SOFC 
  3. Mixed fuel (gas and electric) Residence with PV
  4. Mixed fuel (gas and electric) Residence with PV + SOFC 

Average Yearly Electrical Load

Climate Zone	Location
4	San Jose- Reid
5	Santa Maria
6	Santa Monica
9	Burbank-Glendale
10	Riverside
13	Fresno
15	Palm Springs

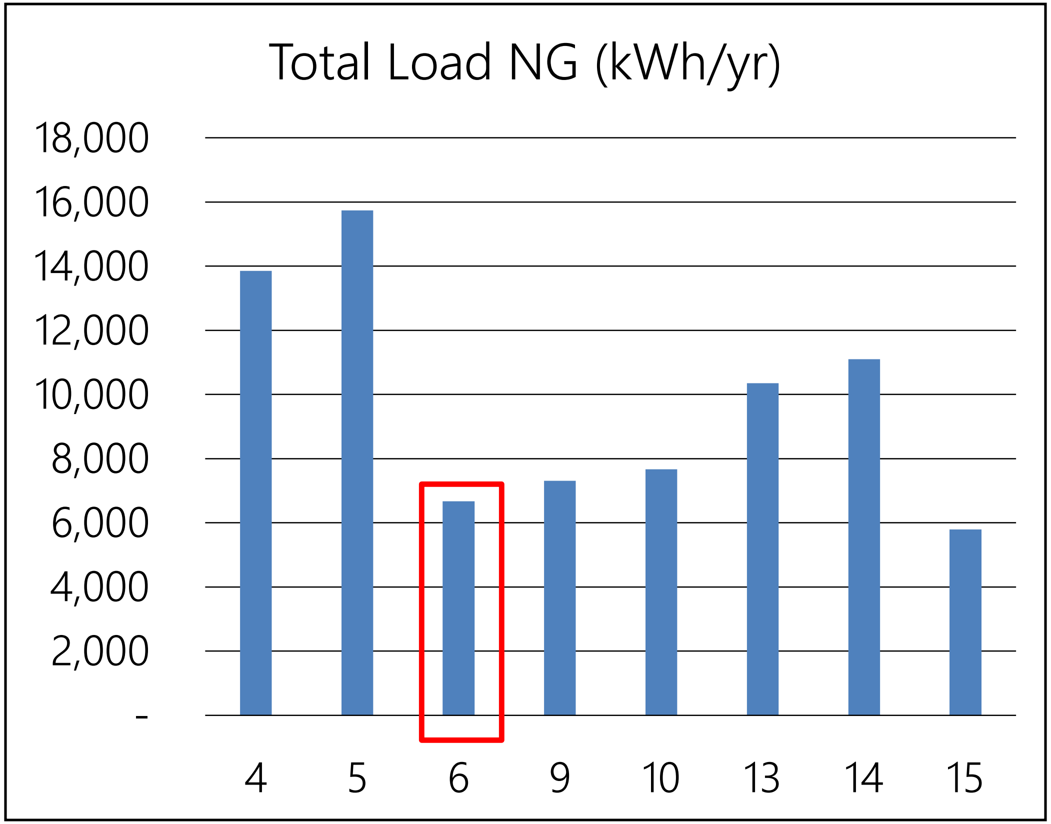


American Planning Association

Average Yearly Heating Load

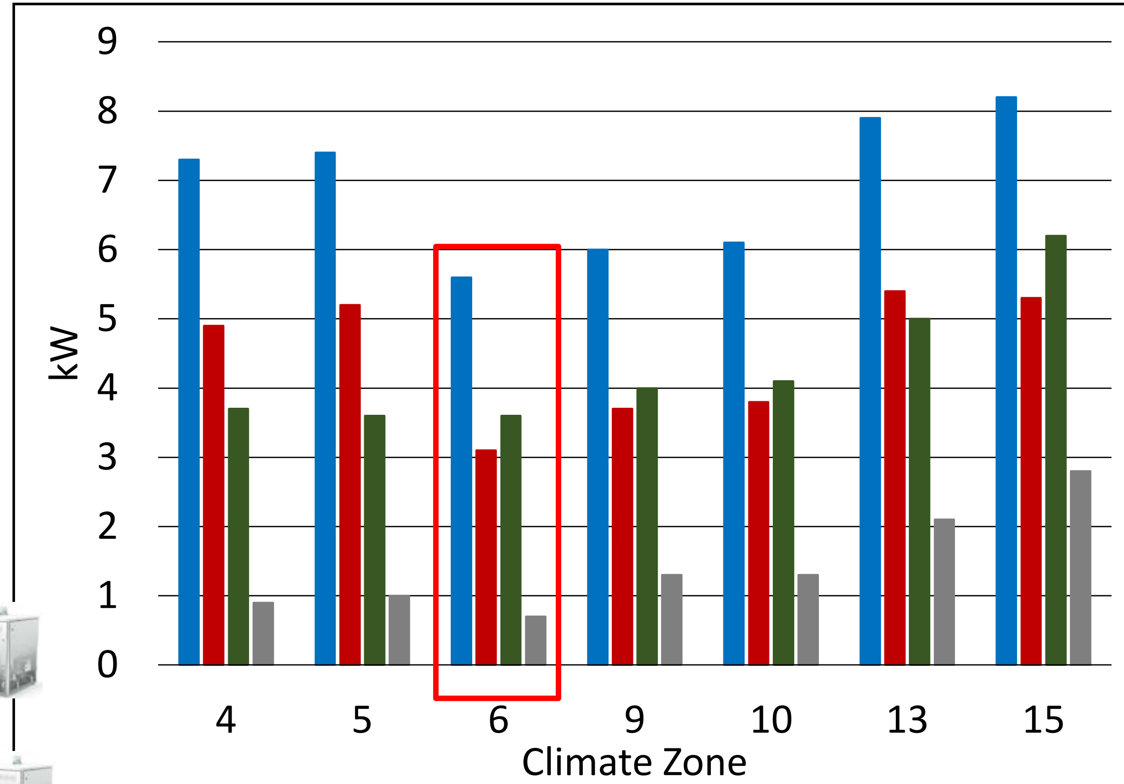
Climate Zone	Location
4	San Jose- Reid
5	Santa Maria
6	Santa Monica
9	Burbank-Glendale
10	Riverside
13	Fresno
15	Palm Springs

American Planning Association



Necessary PV Sizes to Achieve ZNE

Climate Zone	Location
4	San Jose- Reid
5	Santa Maria
6	Santa Monica
9	Burbank-Glendale
10	Riverside
13	Fresno
15	Palm Springs



- All Electric Residence with PV
- All Electric Residence with PV + SOFC
- Mixed-Fuel Residence with PV
- Mixed-Fuel Residence with PV + SOFC

Problem Statement

SB 100 in California: **100% *Carbon free* by 2045**

In this study we use a fuel cell with micro combined heat and power to theoretically and experimentally:

2. **Evaluate how this system can support future climate goals**

<u>Natural Gas Grid</u>

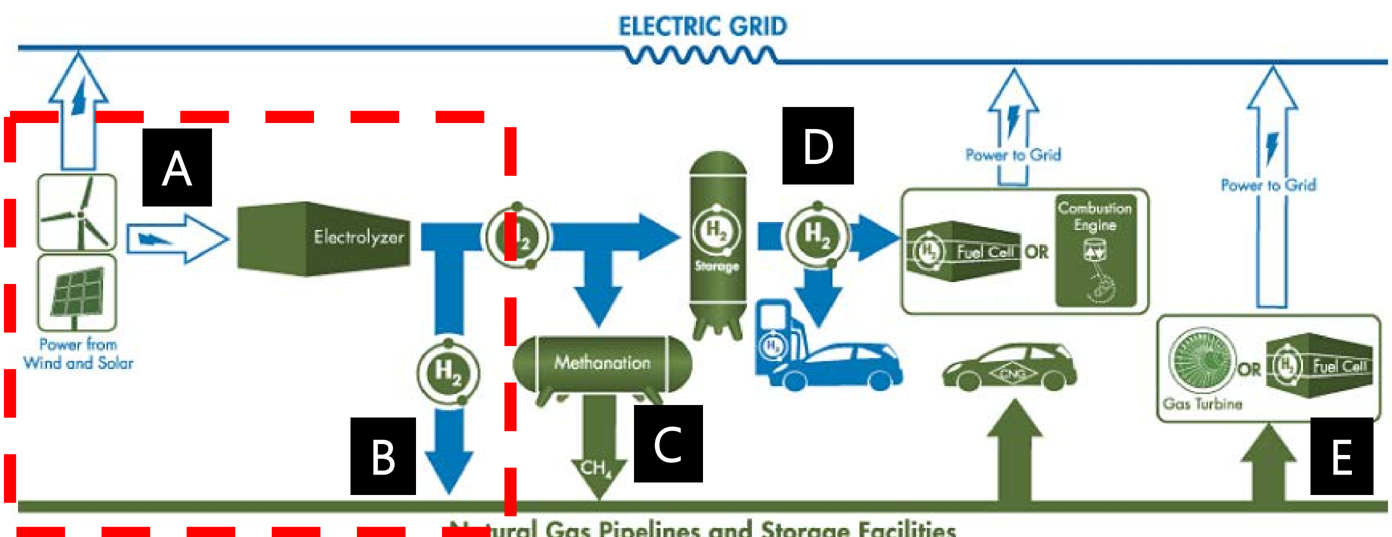
- Ubiquitous presence and T&D resource
- Dispatch ability to handle the dynamics of intermittent renewables
- **Massive seasonal energy storage**

Power-to-Gas

Natural Gas Grid **(massive seasonal energy storage buffer)**

A. Use excess renewable energy to produce H_2
B. Direct injection of H_2 at limited quantities
~~C. Conversion of H_2 to CH_4 (main component of NG)~~
D. Use for zero emission transportation (FC vehicles)
E. Use for electricity generation

SB 100 in California: **100%** ***Carbon free*** **by 2045**



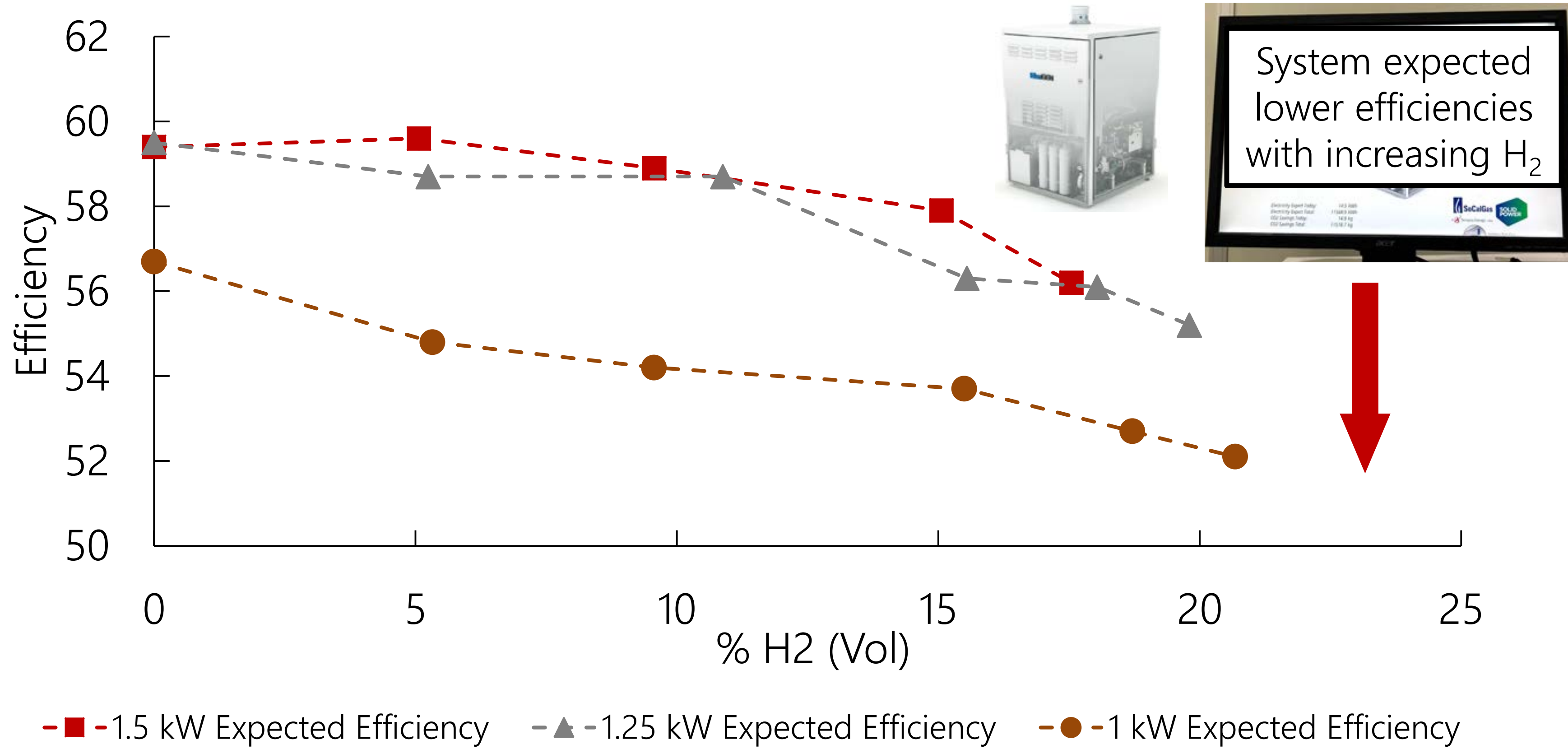
Potential Impact of H_2 on a NG Appliance

- Heating value
  - H_2: 13 MJ/m^3
  - NG: 41 MJ/m^3
- Designed a Mixing Chamber
- Maximum 20% (vol) H_2

→ flow more H_2 to deliver the same amount of energy

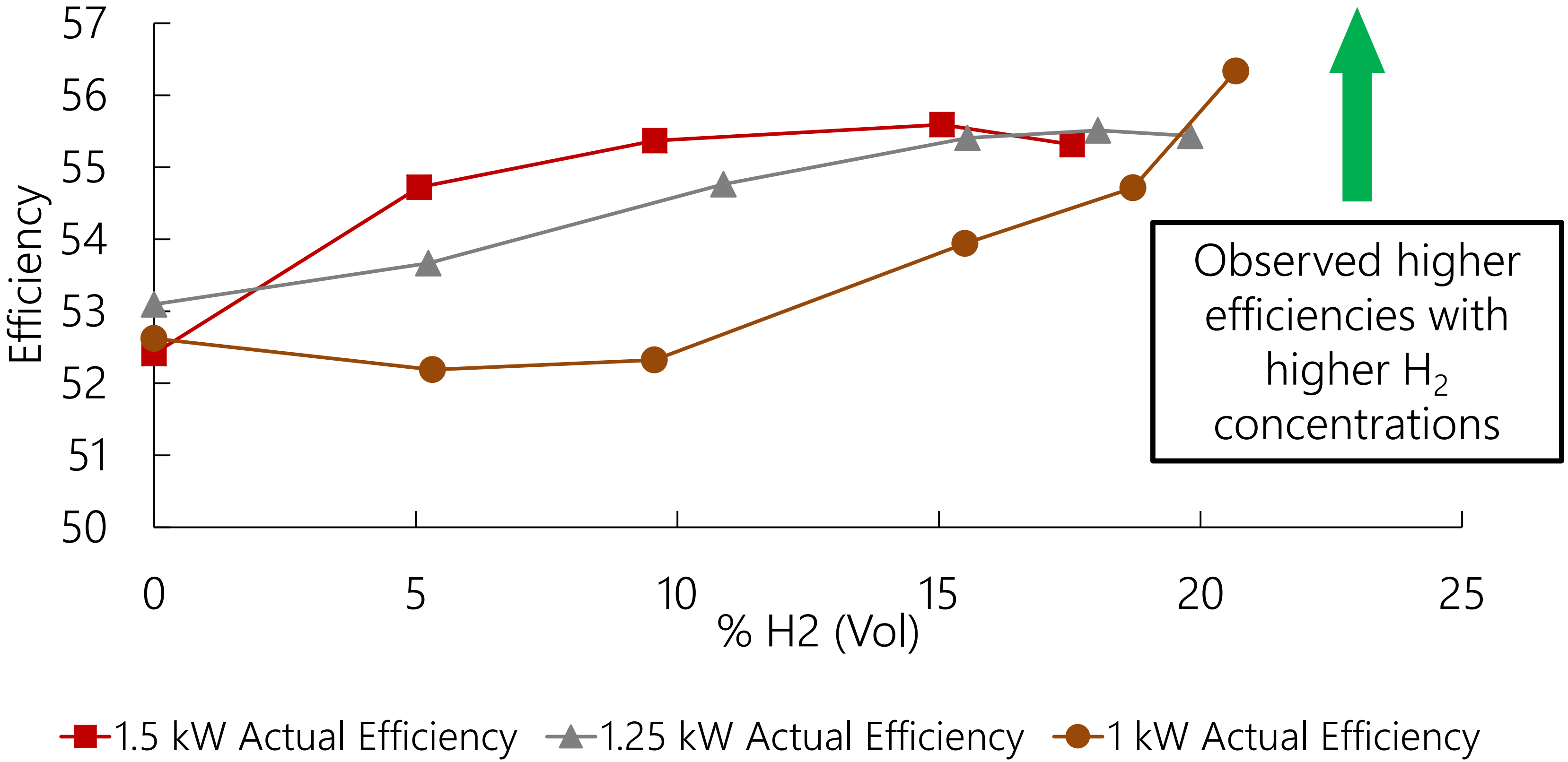
Mixing Chamber

Apparent Reduction of Efficiency Due to Unknown Gas Composition

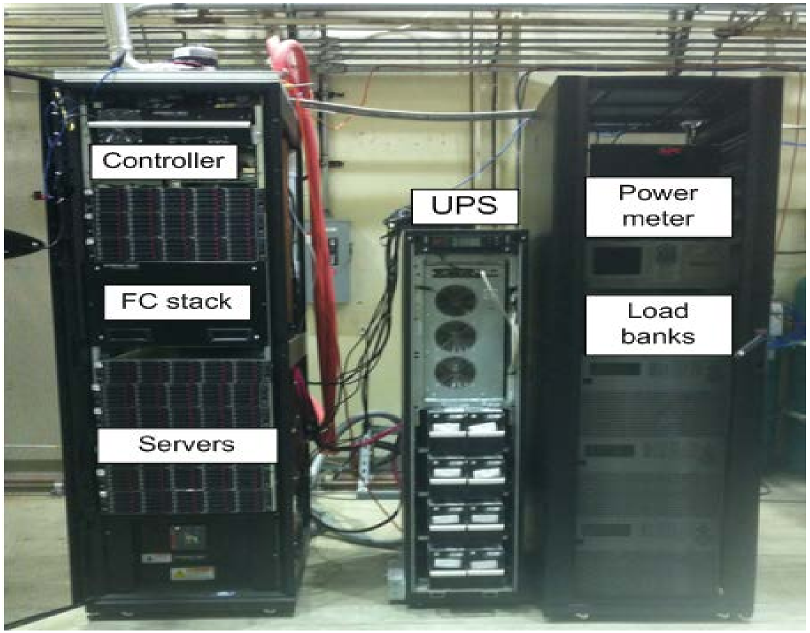


To deliver the same amount of energy:
Flowrate increases as H_2 concentration increases

Actual Efficiencies



Existing Fuel Cells that Operate on 100% H_2



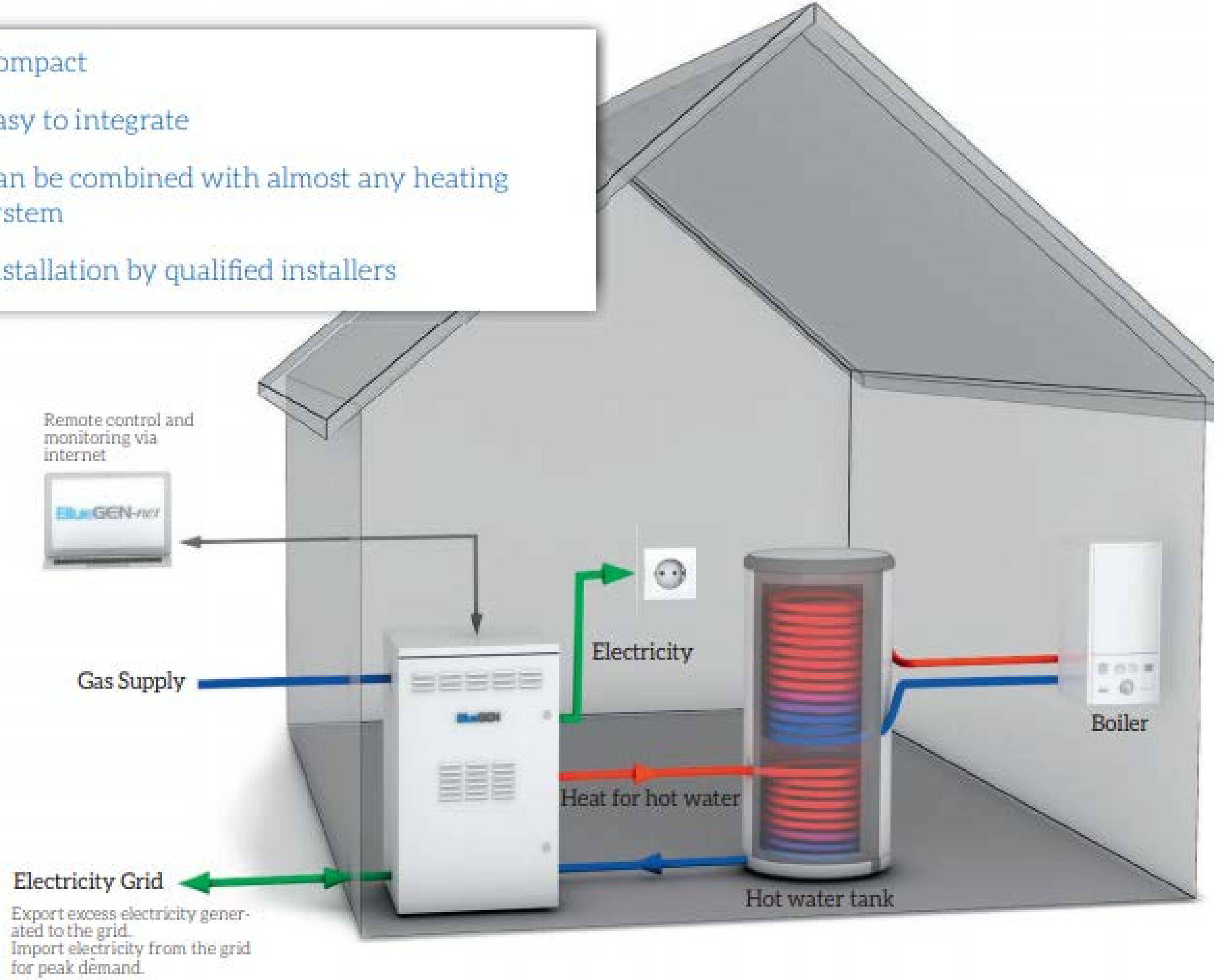
Irvine, California
Server rack

Busan, South Korea
31 MW

Conclusions

- Low Cost $1000/kW (1.5kW ~$2500)
- Challenge is making gas renewable (biogas, H_2)
- NG system will be essential to achieve ZNE and to be **carbon free by 2045**

- Compact
- Easy to integrate
- Can be combined with almost any heating system
- Installation by qualified installers



SOFC Experimental System Performance

- Ultra-low emissions and criteria pollutants