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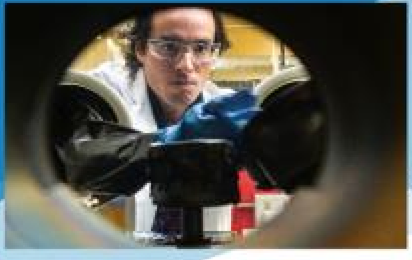
NATIONAL RENEWABLE ENERGY LABORATORY


Renewable Hydrogen for a Carbon-Free Data Center

J. Kurtz,[1] Z. Ma,[1] S. Hammond,[1] T. Cader,[2] and K. Wipke[1] (presenter)

Fuel Cell Seminar & Energy Exposition
Long Beach, California

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1. National Renewable Energy Laboratory
2. Hewlett Packard Enterprise

NREL/PR-5400-70479

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- Research
  - Modeling
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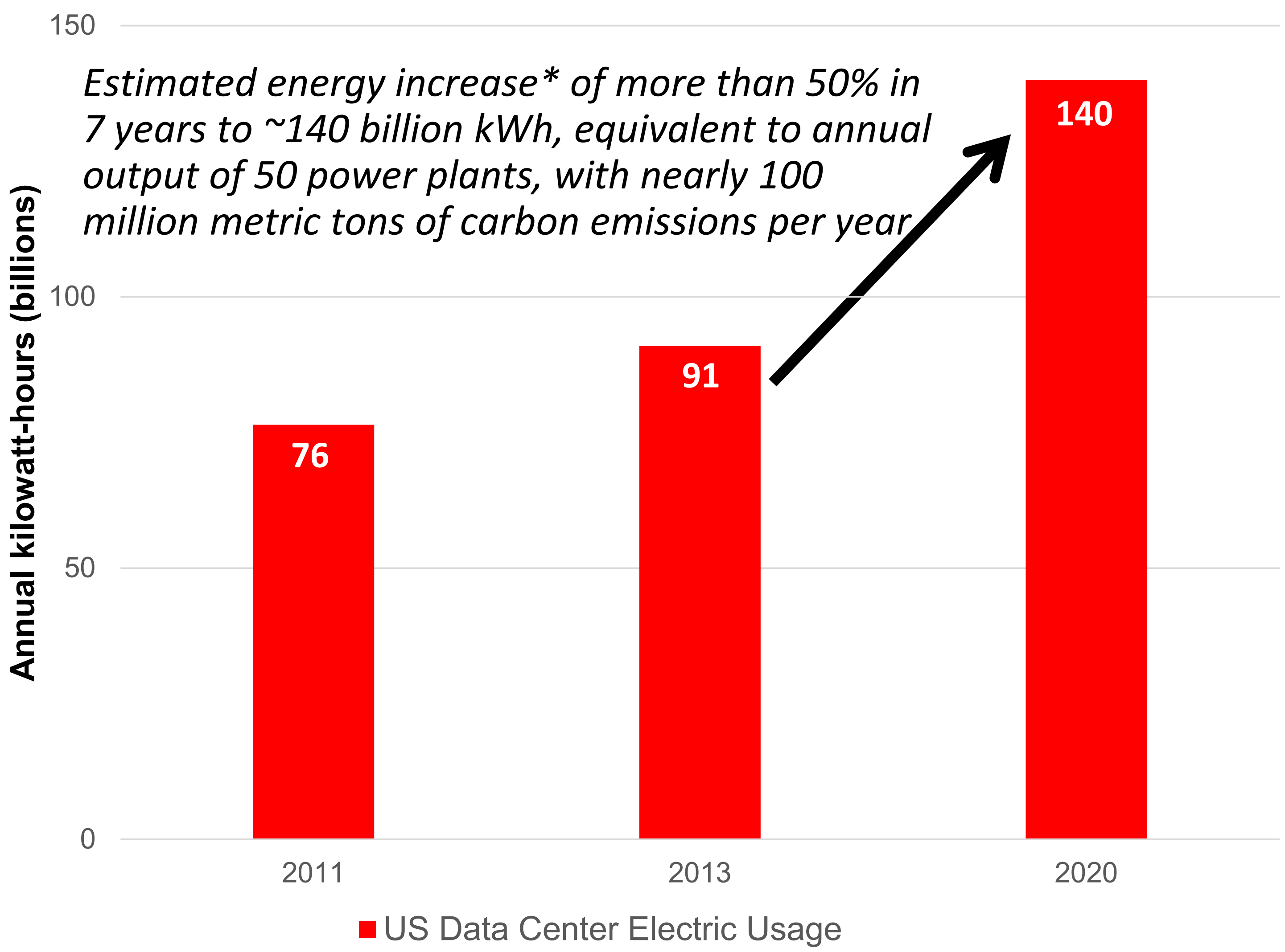
- Partners

Data Center Grand Challenge



* http://www.nrdc.org/energy/data-center-efficiency-assessment.asp

Carbon-Free Data Center Vision

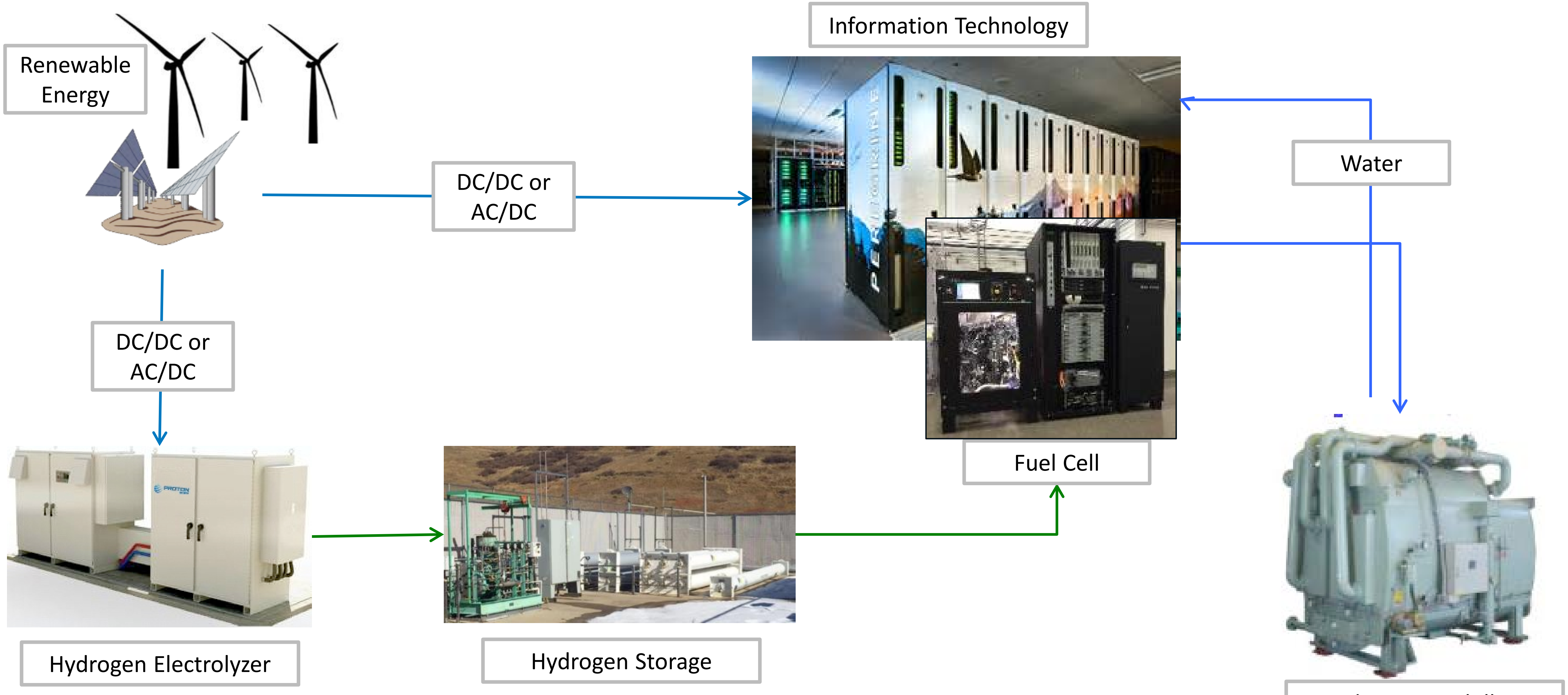
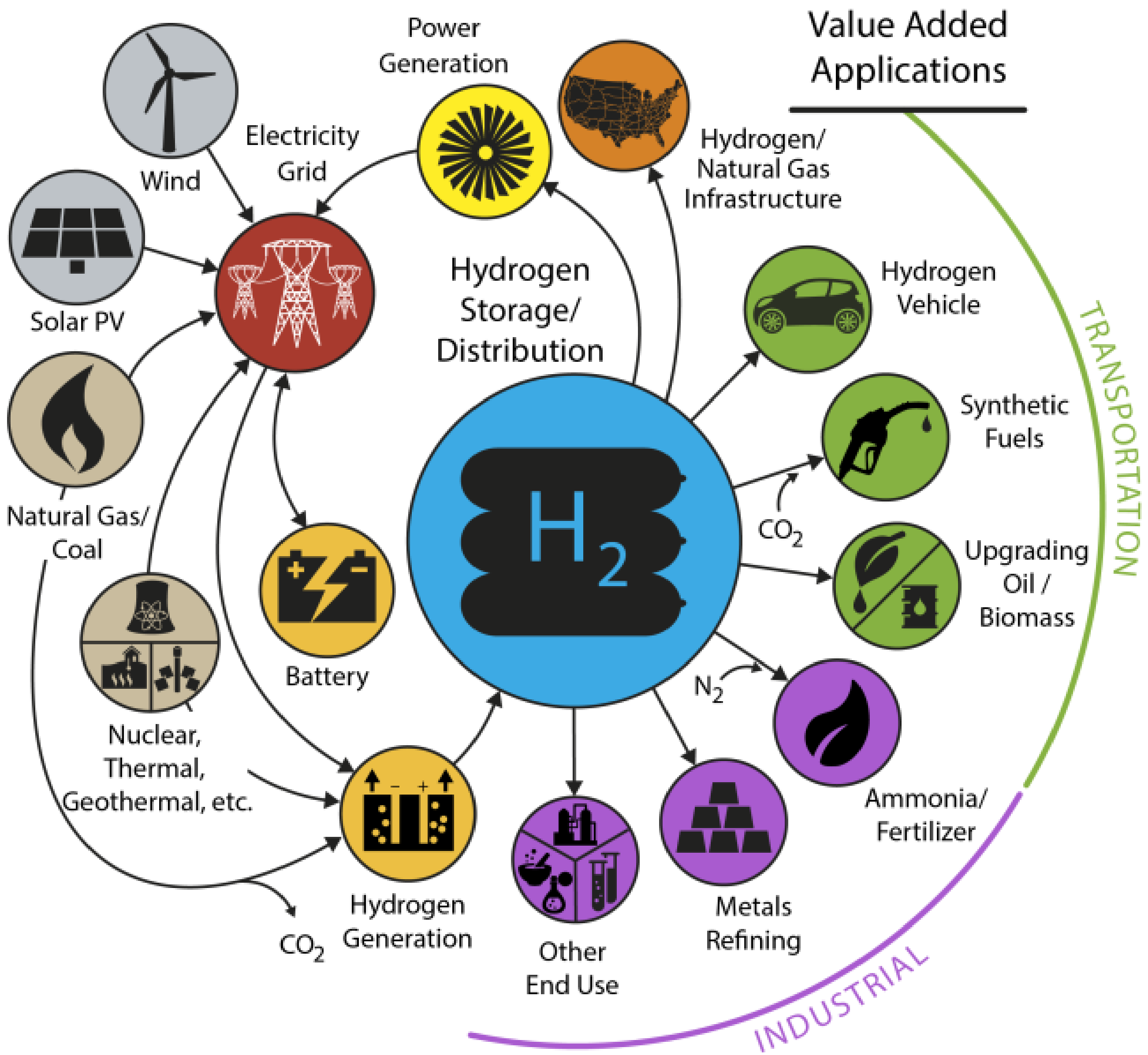


Photo credits (L to R): Proton Onsite; NREL; Power Innovations; NREL; HPE

Schematic illustrative of possible system

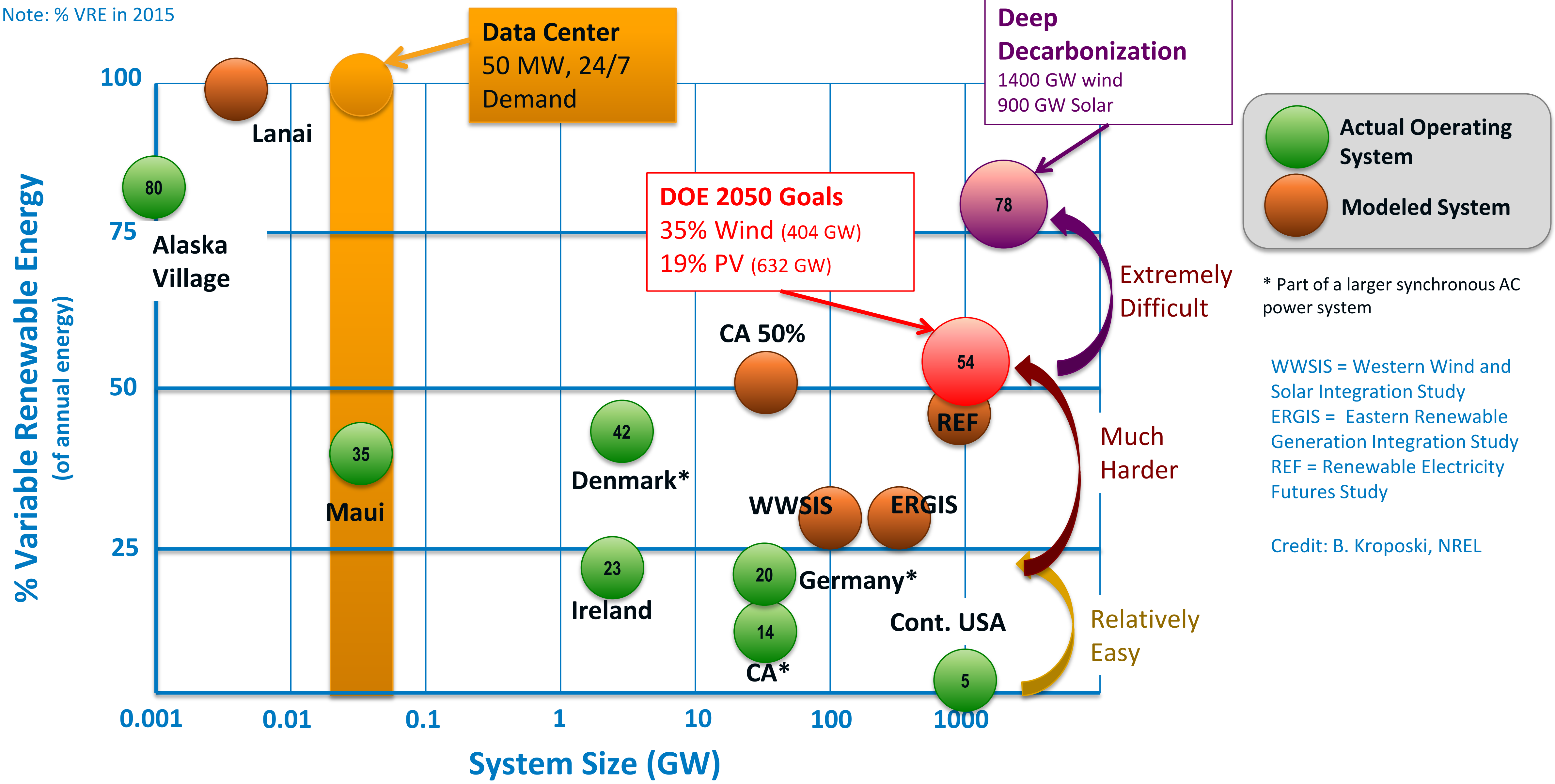
Carbon-Free Data Center and H2@Scale



- The Carbon-Free Data Center connects power demand with renewables via hydrogen
- Decreasing price and increasing capacity of renewables supports identification of new applications to utilize hydrogen
- A single data center demand can be 50 MW 24/7
- H2@Scale vision includes economic, security, and environmental benefits

Carbon-Free Data Center Scale Comparison

Note: % VRE in 2015



* Part of a larger synchronous AC power system

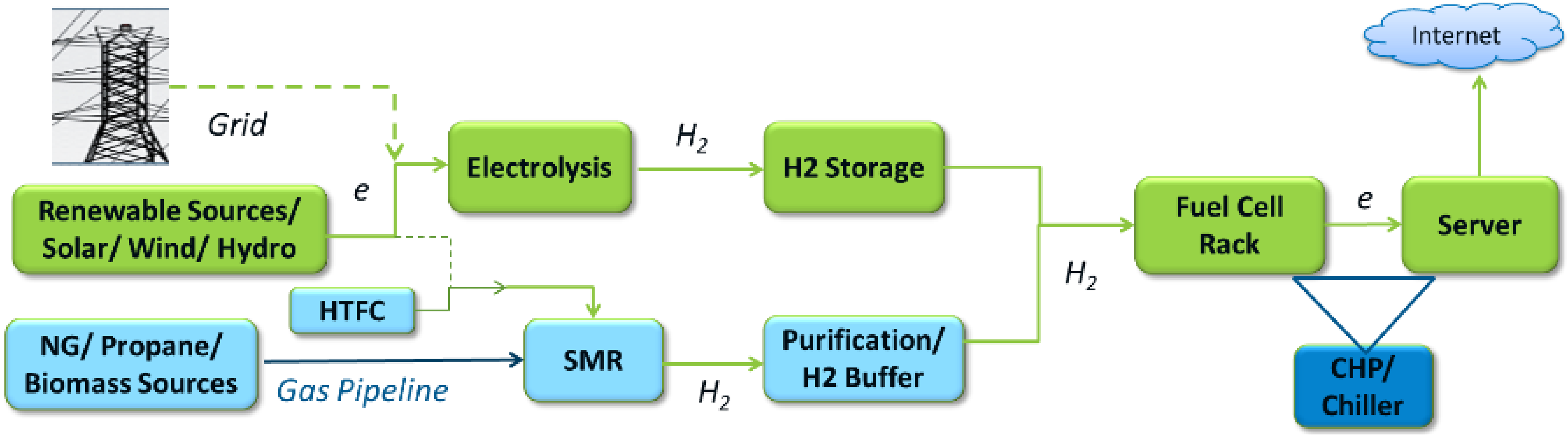
WWSIS = Western Wind and Solar Integration Study
ERGIS = Eastern Renewable Generation Integration Study
REF = Renewable Electricity Futures Study

Credit: B. Kroposki, NREL

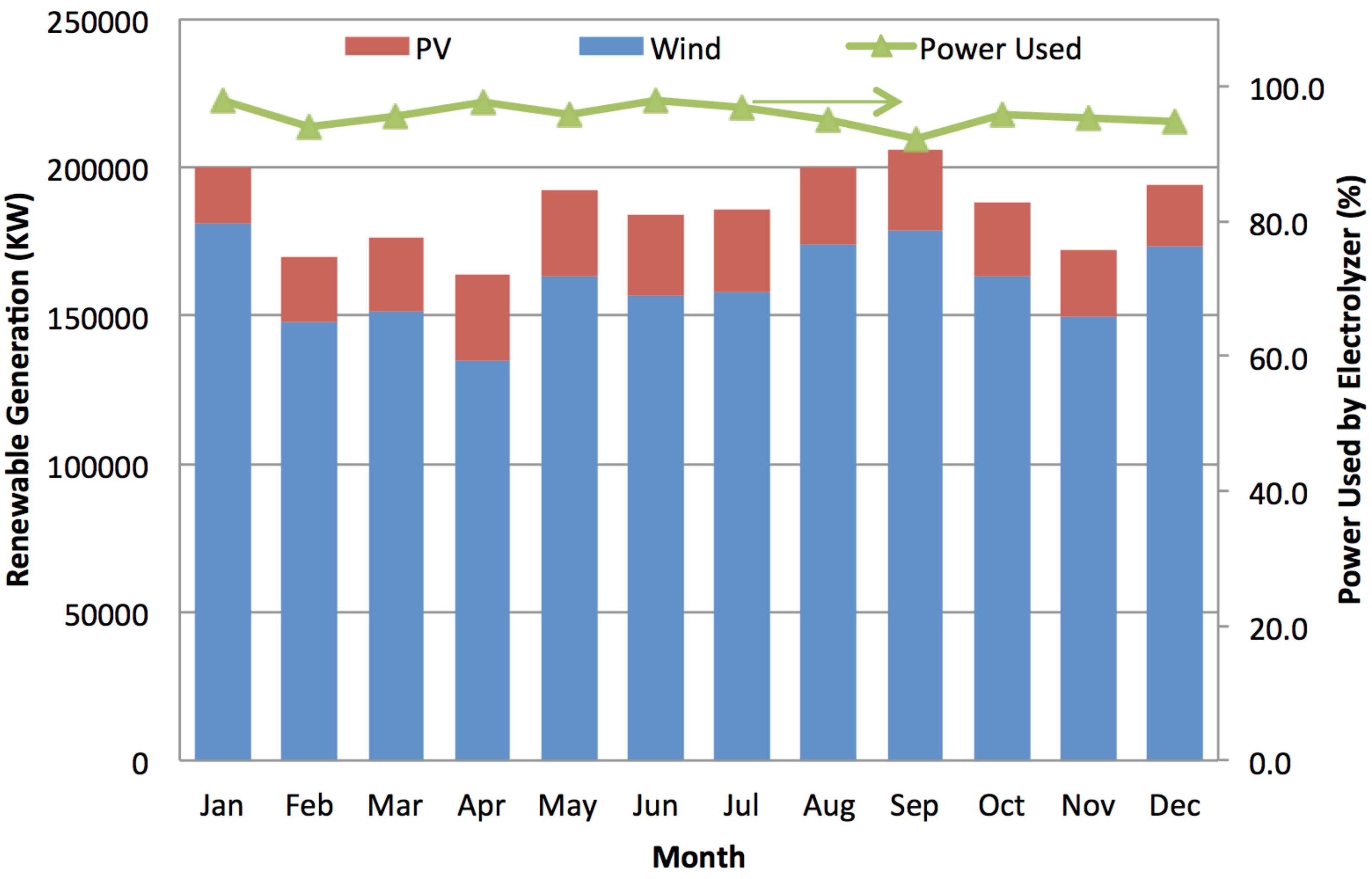
System Modeling (in progress)

Scenarios	Sizing	Economics

• Locations
  • Quincy, WA
  • San Antonio, TX
• Energy Sources
  • 100% renewable (PV and wind)
  • Natural gas to hydrogen
  • Grid independent and grid dependent
	• Renewable generation name plate
	• Renewable generation output estimate
	• Electrolysis name plate
	• Hydrogen production estimate
	• Hydrogen storage
	• Equipment footprint
	• 50 MW 24/7 demand
		• Renewable generation and hydrogen infrastructure
		• Data center total cost of ownership
		• Capital costs
		• Operation and maintenance costs
		• Cost estimates include current and projected

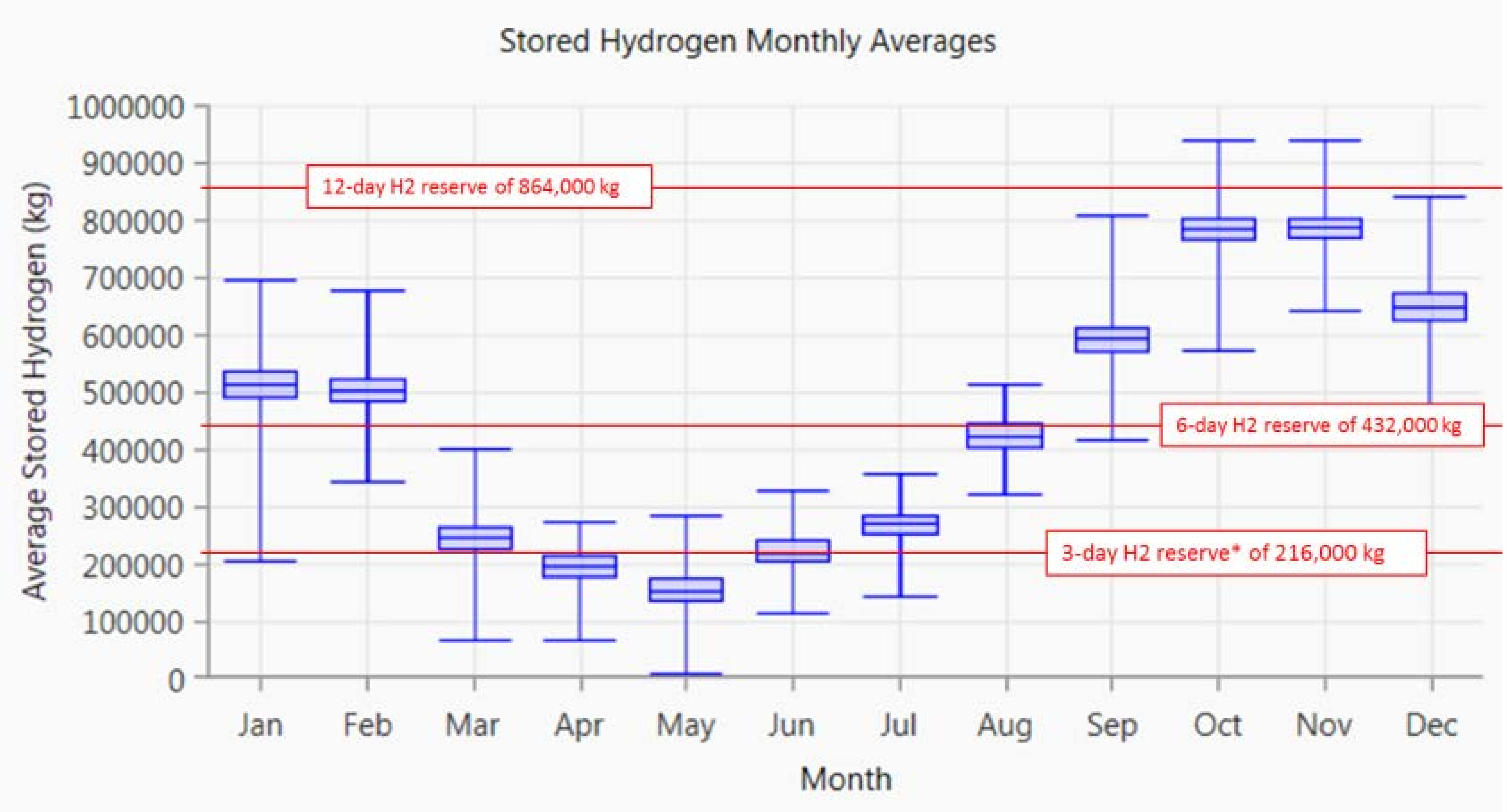


Renewable Hydrogen Production Modeling



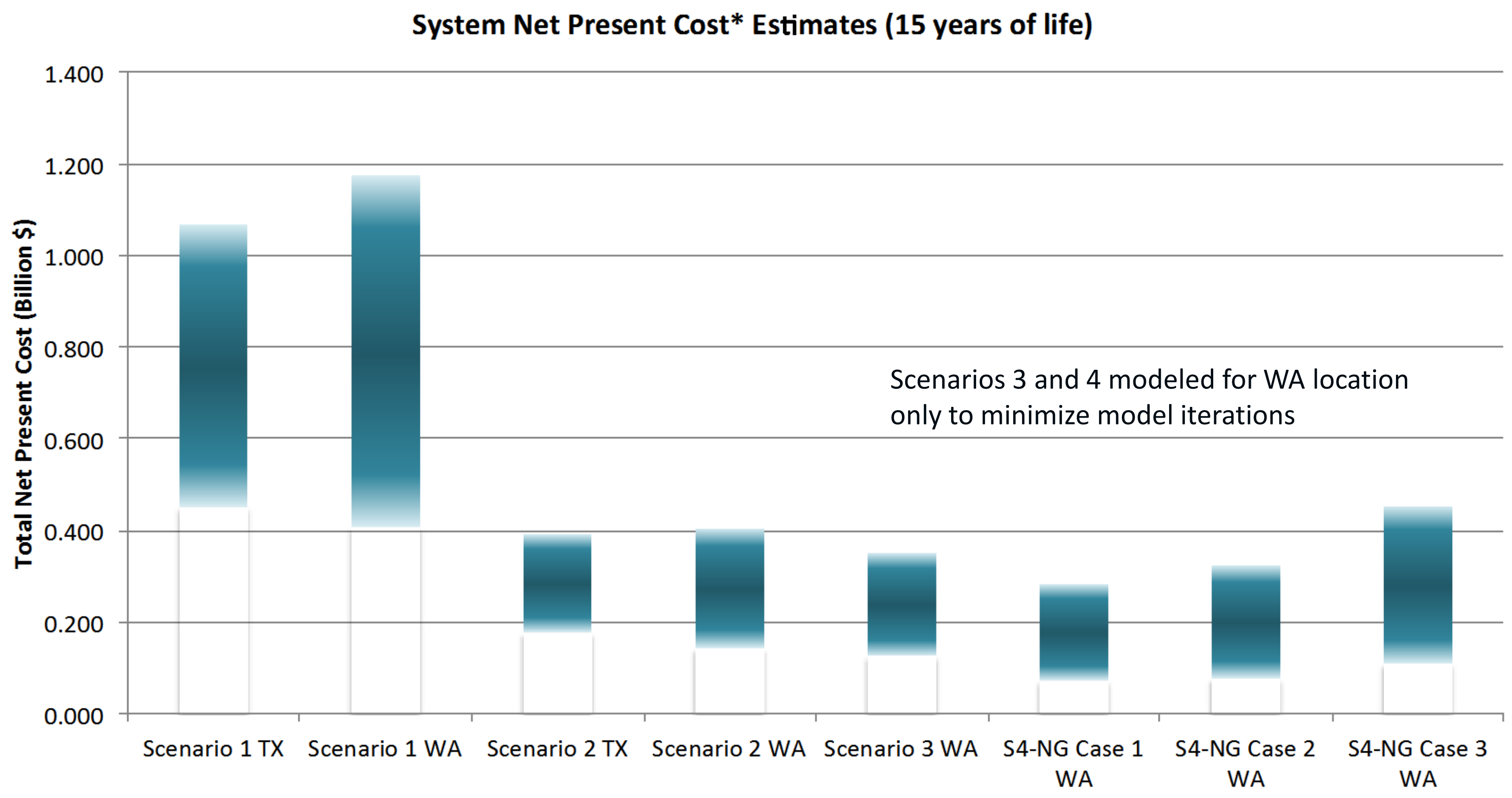
- ~33% renewable generation capacity factor (location specific)
- Electrolyzer follows variable renewable generation
- Nameplate size to ensure sufficient storage during low or no renewable generation
- Example – 100% renewable, WA location has 635 MW generation (525 MW is wind) and 250 MW of electrolysis
- Smaller systems for other intermediate scenarios

Renewable Hydrogen Storage Modeling



- Hydrogen storage for minimum 3 day reserve (216,000 kg)
- 50 MW, 24/7 demand = 72,000 kg H_2/day (~50% efficient fuel cell)
- Some months hydrogen production is less than demand (e.g., February to April in WA)
- System footprint and hydrogen storage is largest for 100% renewable scenarios (e.g., ~650 acres in WA)

System Economic Estimates (excludes data center costs)



- *High estimates based on current costs and low estimates based on projected costs
- Lower capital cost does not necessarily result in lower total cost of ownership

Modeled scenarios

Scenario 1: Grid-independent, renewable generation to hydrogen directly to fuel cell power in server racks.

Scenario 2: Grid-independent, renewable generation to hydrogen production to fuel cell power and to supply power to servers in rack.

Scenario 3: Grid-tied, renewable and fuel cell power supply.

Scenario 4: Three cases: Reforming natural gas hybrid with grid and renewable to produce hydrogen to supply fuel cells to power server racks.

Data Center Total Cost of Ownership

Integrated Fuel Cell Data Center	Comparison to Baseline, Air Cooled Data Center (traditional)
Hydrogen distribution inside data center	+ Lower cost than electrical distribution inside data center + Simplified mechanical system + Estimated lower operation and maintenance costs - High capital costs
Fewer IT racks for data center load	+ Liquid cooled ~1.8x higher rack density than air cooled + Decreased data center footprint and decreased building shell cost
Resiliency	+ Individual racks can continue operation while maintaining other racks + External diesel generator backup and uninterruptible power supplies are not needed

	Standard Data Center	Fuel Cell Data Center
Critical IT load (MW)	50	50
Rack power (kW)	12	60
# of IT racks	4,167	833
IT cooling methodology	Air	Liquid
Fuel Cell Racks (130 kW per rack)	0	424
% IT rack load to air	100	30
% IT rack load to water	0	70
Central UPS?	Yes	No
Diesel generators?	Yes	No
Chiller types	Absorption	Adsorption
Chiller capacity (tons of refrigeration)	1,200	200
Cooling towers?	Yes	Yes

Hardware Proof-of-Concept

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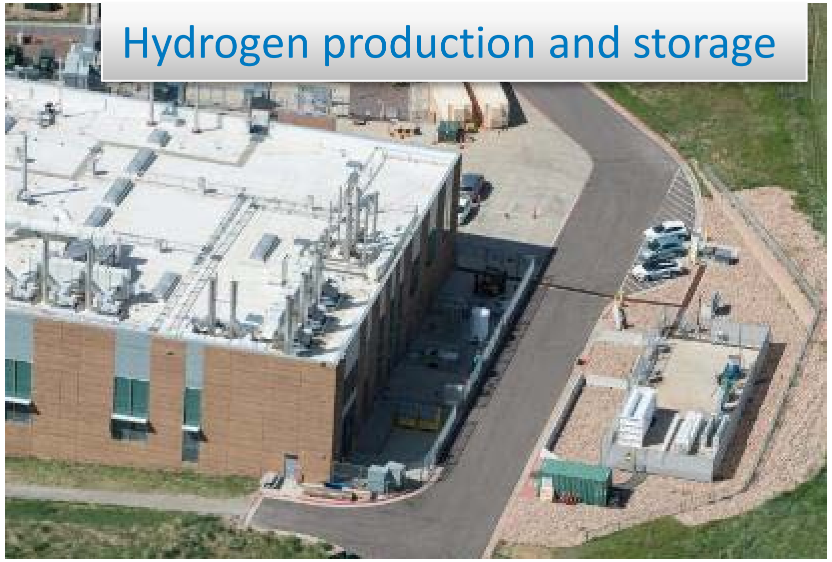
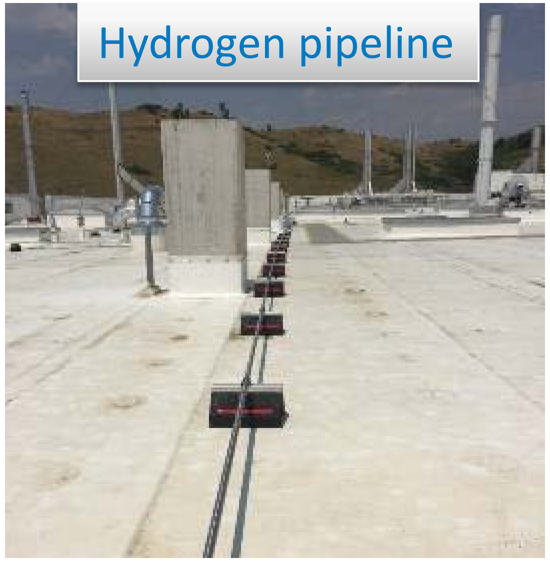


Hydrogen production and storage



Hydrogen pipeline

Planned location for FC IT rack in data center

Proof-of-concept experiment of the integrated system for verification of safe operation in data center

- Status: 11/6 integrated FC IT rack at NREL's Energy Systems Integration Lab; completing safe operation verification
- SC17 High Performance Computing Conference visits
- Operation in data center planned end of November

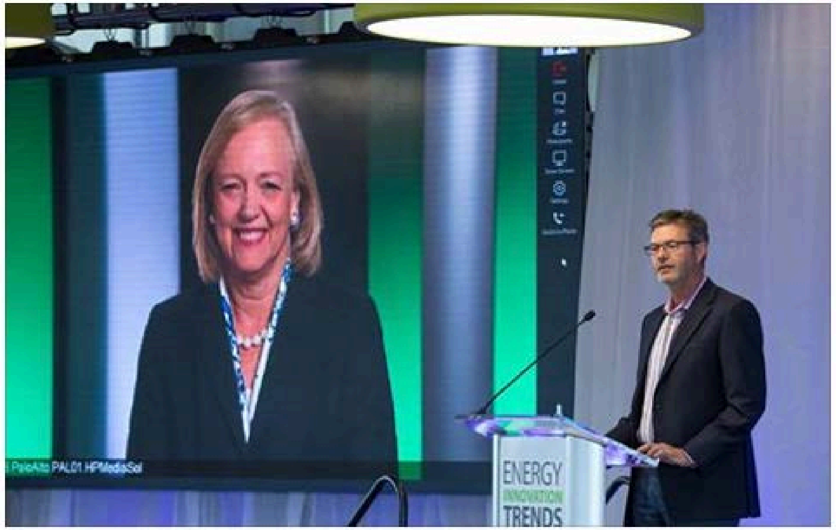
Photos from NREL (top row) and Power Innovations (bottom)

Partners

HPE	Daimler	Power Innovations	NREL

Meg Whitman
15 hrs ·

I'm honored to have been a guest at National Renewable Energy Laboratory Partner Week, speaking with other organizations about the role and importance of innovation. As the demands placed on data centers increases, putting strain on the availability of power and its cost, there is a growing need for more sustainable solutions. Thanks to our continued partnership, Hewlett Packard Enterprise and National Renewable Energy Laboratory are pioneering the use of hydrogen fuel cells to create carbon free data centers with better power delivery, availability, and resiliency.



Meg Whitman and Steve Hammond NREL Partnership Event

The integrated fuel cell and IT racks at NREL for initial shakedown this week.

Summary

Holistic System Vision

- Conceptual models for size, performance, and economic estimates
- Economically viable near-term option includes natural gas
- Lowest up-front costs may not be lowest total cost of ownership options

Product Acceleration

- Verify proof-of-concept in a functional data center
- Identify codes and standards for hydrogen fuel cells in data centers
- Automotive fuel cell in a new application => increase quantity and decrease cost
- Partners include product developers and end users

What's Next

- Identify systematic solutions for challenges
- Refine and define system
- Improve estimates
- Validate system and install at scale

With the sustained drop of the cost for renewable power, long-term renewable hydrogen to supply fuel cells for powering a data center can realize both decarbonization and economic returns.

Backup

Scenarios Modeled

		Facility power to racks?	24/7/365 operation of FCs?
Scenario 1	Wind/PV to H2 to powering IT	No	Yes
Scenario 2	Wind/PV to H2 to powering IT Wind/PV to directly powering IT	Yes	No
Scenario 3	Wind/PV to H2 to powering IT Wind/PV to directly powering IT Grid power	Yes	No
Scenario 4, Case 1	Natural gas with SMR to H2 Grid power	No	Yes
Scenario 4, Case 2	Natural gas with SMR to H2 High temp FC for power	No	Yes
Scenario 4, Case 3	Natural gas with SMR to H2 High temp FC for power Wind/PV to H2 to powering IT	No	Yes

Modeling Objectives and Considerations

Carbon free computing – Utilize hydrogen as energy storage to integrate renewable solar and wind resources for a data center

- Model Scope: The hydrogen generation , storage, and consumption equipment will be defined in a conceptual block diagram. These components and subsystems will be included in a **conceptual** model to:
  - create equipment sizing (quantity and footprint)
  - annual renewable generation profile (based on Quincy, WA and San Antonio, TX locations)
  - annual renewable hydrogen generation profile
  - annual hydrogen demand profile
  - equipment cost estimates (based on current technology status, which are undersized for this full scale rollout)
- Model Setup
  - Two locations: San Antonio, TX and Quincy ,WA
  - Two cost inputs: current and projected values.
  - Three scenarios were considered:
    1. Grid-independent, renewable generation to hydrogen production to fuel cell power for data center (long-term vision)
    2. Grid-independent, renewable generation to hydrogen production to fuel cell power and renewable generation for data center
    3. Grid-dependent, renewable and fuel cell supply (basis for near-term vision)
    4. Natural gas reforming to hydrogen storage to fuel cell power for data center
  - No thermal load was considered yet.
- Model Results
  - Verified required capacity, load, and hydrogen storage.
  - Generated electricity and hydrogen generation profile.
  - Sized equipment.
  - Estimated electric and capital cost.

Annual Renewable Generation, Fuel Cell, Electrolyzer and Excess Power Estimate Scenario 1 Quincy WA

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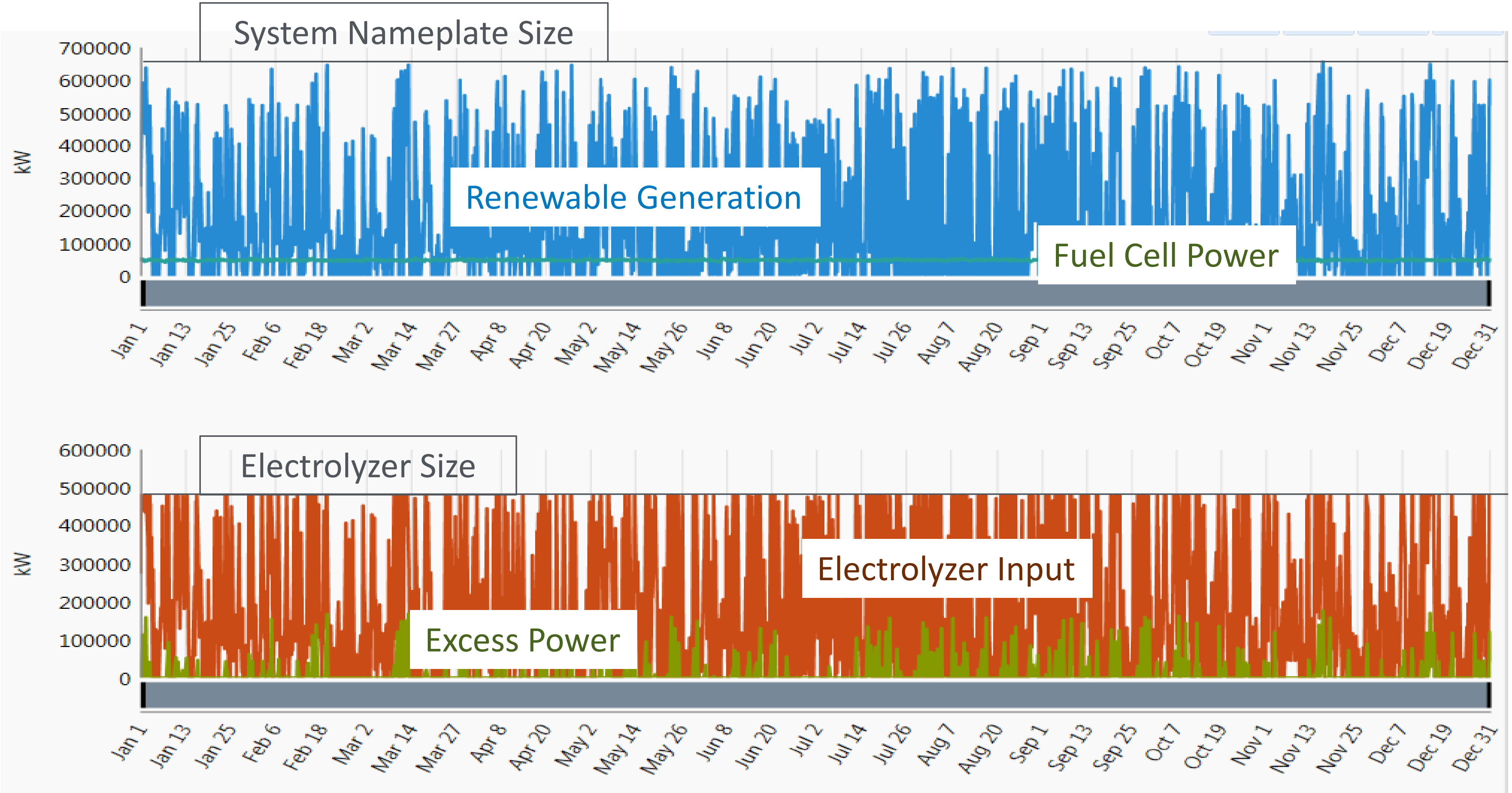

- Generation does peak at nameplate capacity
- FC Power constant for Data Center demand
- Electrolyzer size limited to 480 MW, which results in small amounts of excess renewable generation (< #%)

Jan-Mar Renewable Generation, Fuel Cell, Electrolyzer and Excess Power Estimate Scenario 1 Quincy WA

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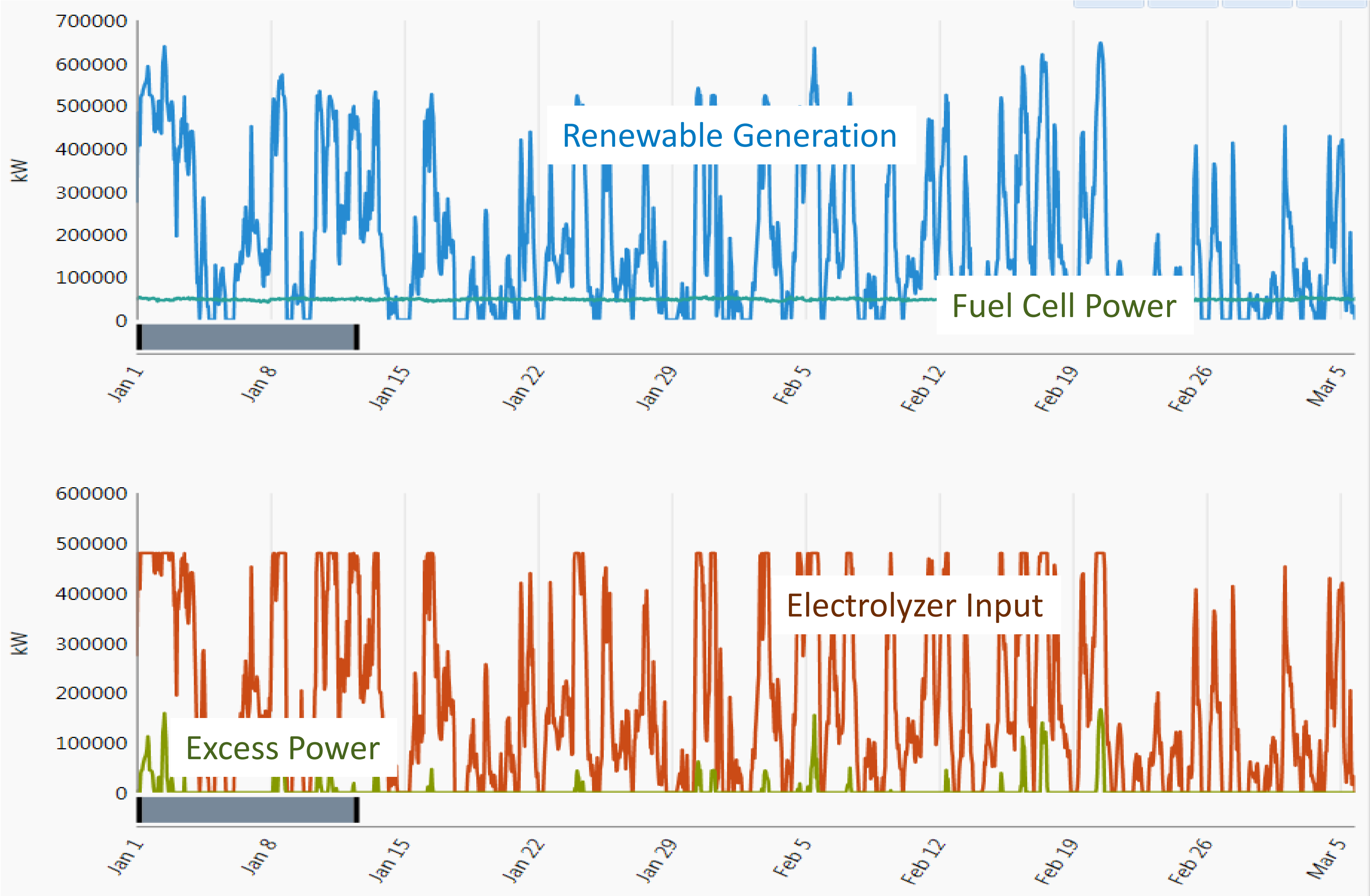

- Zoomed in to show highly variable operation
- Electrolyzer operation follows renewable generation profile
- Gaps in electrolyzer power indicate low renewable resources and depleting hydrogen storage
- Storage sizing dependent on renewable generation profile

Summary of Options Considered

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Scenarios	1. Wind/PV -> H2 -> IT	2. Wind/PV -> H2 -> IT & Wind/PV -> IT	3. Add grid to 2	4. Add NG to 3
Description	All data center power comes from renewable produced hydrogen Includes San Antiono, TX & Quincy, WA locations	Data power is shared with direct renewables (highest efficiency, most intermittent) & renewably produced hydrogen Includes San Antiono, TX & Quincy, WA locations	Scenario 2 and Includes grid power purchase and sell cost Includes Quincy, WA location	Scenario 3 and Includes natural gas and steam methane reforming Includes Quincy, WA location
Pros	Zero emissions (excluding component manufacturing) Electrolyzer handles renewable intermittenancy and variability FC deliver constant, high quality power	Best renewable round trip efficiency. Lower capital cost reduced renewable and hydrogen storage capacity.	Possible option for near-term	Possible option for near-term
Cons	~35% round trip efficency requires large renewable size High runtime onFC and electrolyzer increases maintenance costs	Requires both electrical and hydrogen infrastructure in the data center. Need controlling coordination of renewable power supply and fuel cell ramping	Not zero emissions Requires grid connection	Not zero emissions Requires grid connection

Component Cost Estimates

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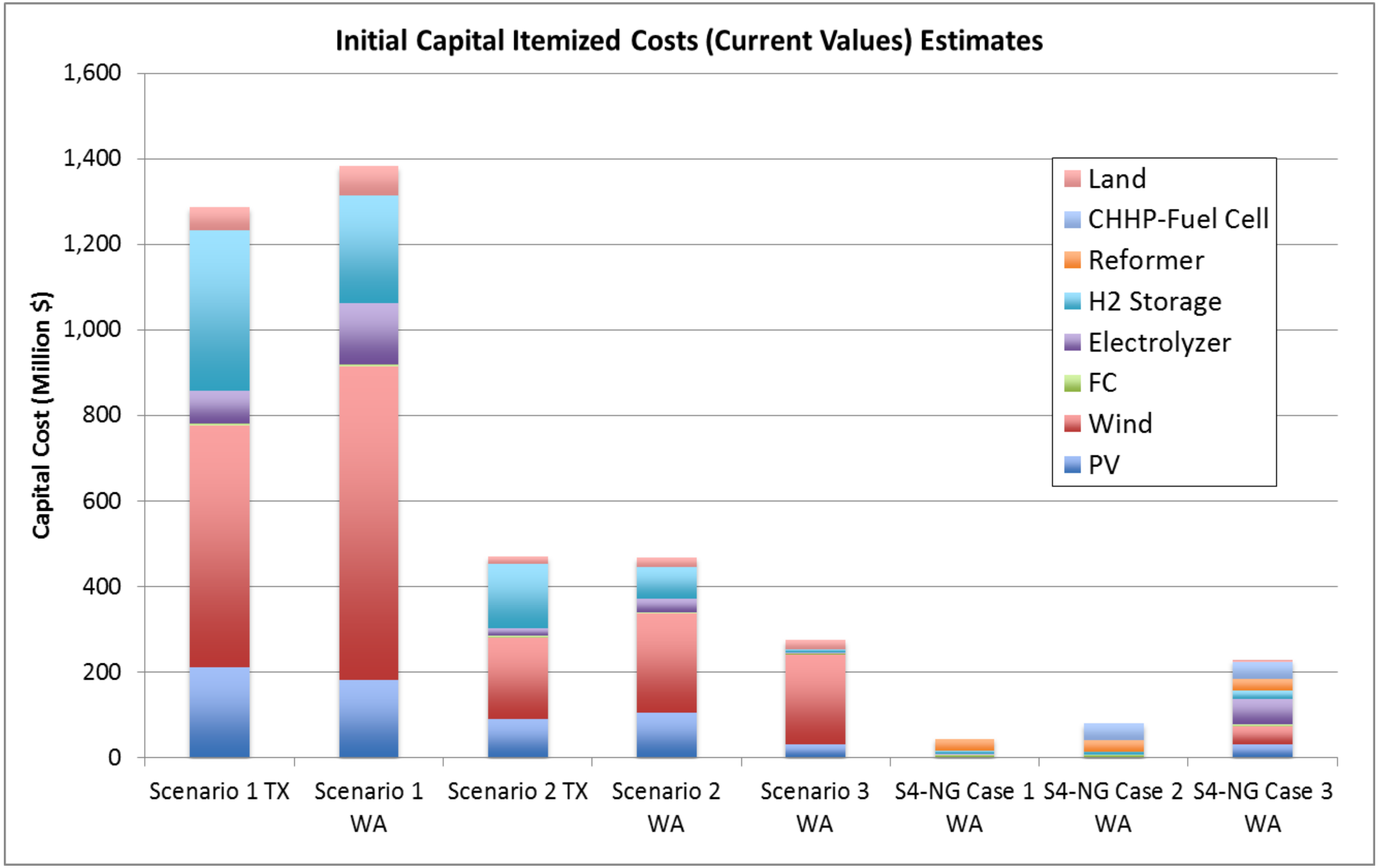
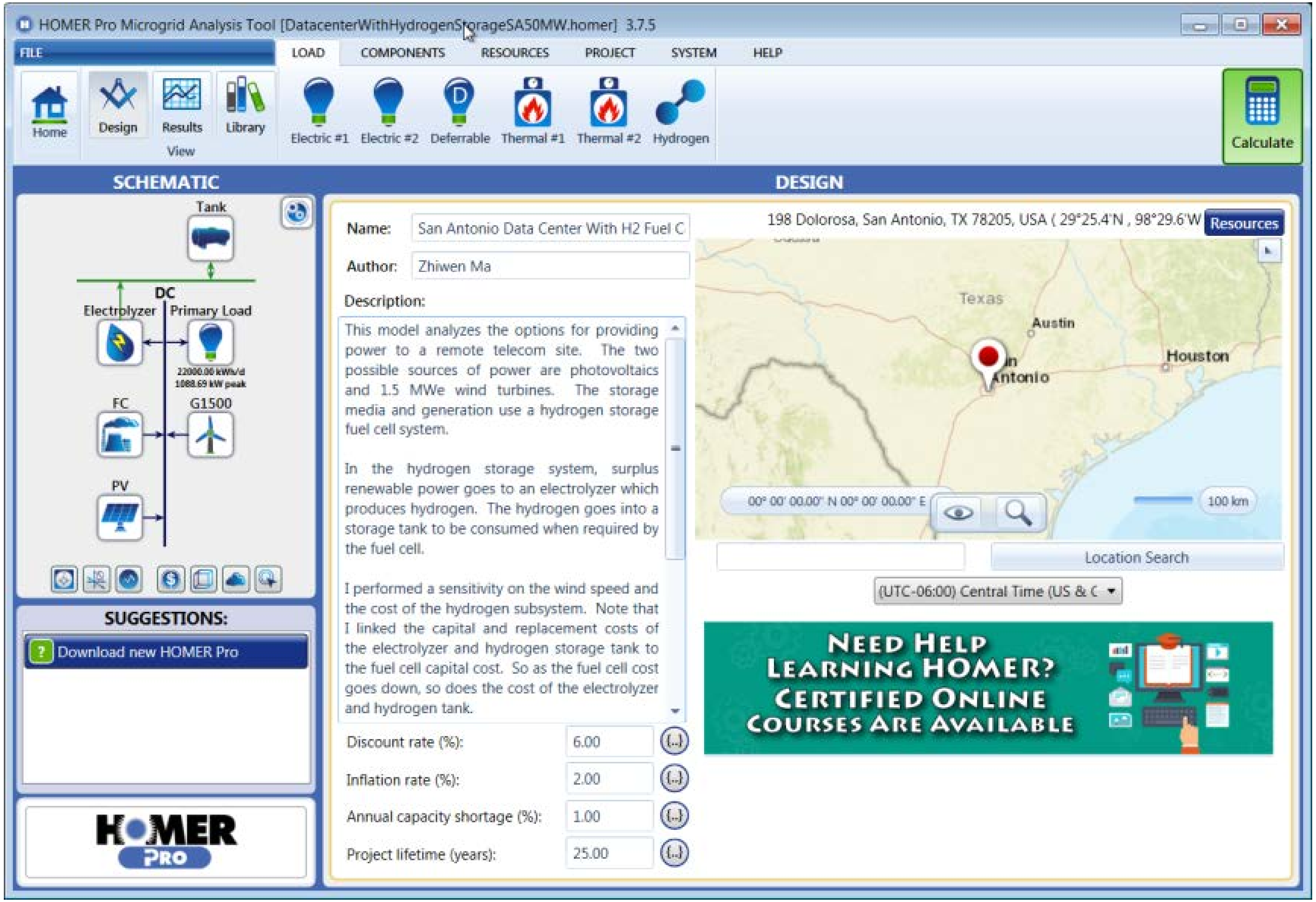
Installed Components	Current Cost (2016)	Projected Cost (2030?)	Reference Source
Wind ($/kW)	1,397	1,200	NREL report TP53045
Solar ($/kW)	1,500	1,000	GTM Research and DOE SunShot
Fuel cell ($/kW)	300 (eff. 50%)	50 (eff. 50%)	Industry and DOE Goal
Electrolyzer ($/kW)	1200 (eff. 65%, 25 yrs continuous)	800 (eff. 75%, 25 yrs)	NREL report TP53045 and internal discussion
Storage ($/kg)	500 (10 yrs)	7 (20 yrs) Cavern	Refer to DOE MYRDD and TP53045

Note: No land cost were considered in COE numbers next.

Modeling – Economic Results Summary



HOMER Model Configuration



Scenario Results Summary

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	Scenarios	1. Wind/PV -> H2 -> IT		2. Wind/PV -> H2 -> IT & Wind/PV -> IT		3. Add grid to 2	
		TX Site	WA Site	TX Site2	WA Site3	TX Site4	WA Site5
PV	Size (MW)	140	120	60	70	Not Run	20
	Annual Generation (kWh/yr)	242,453,051	210,345,034	103,908,450	131,465,646	Not Run	35,037,505
	Footprint m^2 (acres)	903,000 (223)	774,000 (191)	387,000 (96)	594,000 (147)	Not Run	129,000 (32)
	COE ($/kWh)	0.063	0.06	0.063	0.06	Not Run	0.06
	Capacity Factor	20%	20%	20%	20%	Not Run	20%
Wind	Size (MW)	405	525	135	165	Not Run	150
	Annual Generation (kWh/yr)	1,418,475,413	1,412,478,713	597,630,030	692,633,836	Not Run	403,565,346
	Footprint m^2 (acres)	1,458,000 (360)	1,890,000 (467)	486,000 (120)	451,500 (112)	Not Run	540,000 (133)
	COE ($/kWh)	0.02	0.04	0.02	0.02	Not Run	0.04
	Capacity Factor	40%	31%	50%	48%	Not Run	31%
FC	Size (MW)	60	60	60	60	Not Run	50
	Annual Generation (kWh/yr)	419,750,000	419,750,000	102,908,450	215,187,945	Not Run	20,141,200
	Footprint m^2 (acres)	In Data Center	In Data Center	In Data Center	In Data Center	Not Run	In Data Center
	Efficiency	50%	50%	50%	50%	Not Run	50%
	Capacity Factory			23%	21%	Not Run	80%
Electrolyzer	Size (MW)	250	480	60	100	Not Run	10
	Power Consumption (kWh/yr)					Not Run	
	Water Consumption					Not Run	
	Annual H2 production (kg/yr)	25,820,120	25,740,828	4,400,394	6,711,857	Not Run	1,204,779
	Efficiency	65%	65%	65%	65%	Not Run	65%
	Capacity Factory	51%	37%	51%	47%	Not Run	37%
	Footprint m^2 (acres)					Not Run	
H2	Storage Amount (kg)	3,000,000	2,000,000	1,200,000	600,000	Not Run	60,000
	Storage Footprint	305,400 (75)	203,600 (50)	122,160 (30)	61,080 (15)	Not Run	6,108 (2)

Scenario Results Summary – Costs

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Scenarios	1. Wind/PV -> H2 -> IT		2. Wind/PV -> H2 -> IT & Wind/PV -> IT		3. Add grid to 2	
	TX Site	**WA Site**	**TX Site2**	**WA Site3**	**TX Site4**	**WA Site5**
Estimated Capital Cost (Billion $) Current Costs	1.365	1.365	0.688	0.511	Not Run	0.611
Estimated Capital Cost (Billion $) Projected Costs (~2030)	0.775	0.964	0.270	0.330		0.547
Total Footprint (acres)	360	467	126	147	Not Run	133
Conclusions	Need to add	Need to add	Need to add	Need to add	Need to add	Need to add