“Valuation of Hydrogen on the Electric Grid” Project kickoff meeting

H2@Scale CRADA project

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Agenda

Time	Topic
1:00	Introductions and Project overview
1:15	Background - Relevant previous work - Grid modeling tools
1:30	Analysis scenarios for this project
1:45	Open discussion
2:00	Conclude

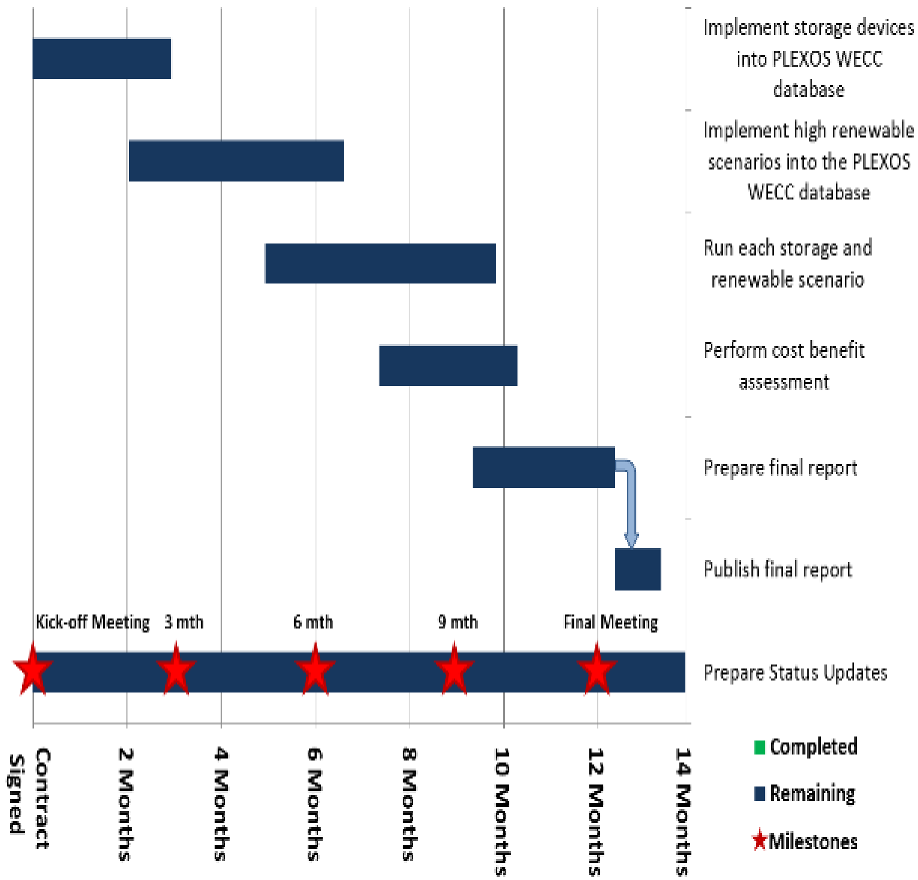
Administration: Roles and Deliverables

Project participants and roles

Participants	Role
EPRI (Matt Pellow)	• Project management • Technical review • Prime contracting partner to DOE for H2@Scale co-funding • Ensure deliverables to Supplemental funder
NREL (Josh Eichman)	• Execute grid modeling analysis • Provide interim and final results
Supplemental funders • Pacific Gas & Electric • Xcel Energy • Nebraska Public Power District • Southern Company • San Diego Gas & Electric	• Provide input on scenario selection • Ask questions! • Co-funding the work – *Thank you!*

Project deliverables

Task	Deliverable Description	Due Date
1.1	Project kickoff meeting	2/1/2018
2.1	Scenario set discussion draft	2/1/2018
2.3	Finalized technology scenario set, fully specified, incorporating stakeholder input, in consultation with EPRI PM.	3/1/2018
1.2	1st-quarter project meeting and update	4/1/2018
5.1	Table of key non-generating assets by scenario	7/1/2018
5.2	Table of capital costs of non-generating assets, in consultation with EPRI SMEs	7/1/2018
1.2	2nd-quarter project meeting and update	7/1/2018
1.2	3nd-quarter project meeting and update	10/1/2018
5.3	Full table detailing, for each scenario: - Individual costs and total cost - Individual value streams and sum of these - Variance from baseline scenario	12/1/2018
6.1	Draft 2018 year-end full interim progress report	11/15/2018
1.2	4th-quarter project meeting and update	12/15/2018
6.3	Draft final project report	3/15/2019
6.5	Final project summary (slide presentation)	4/1/2019
1.4, 1.5	Final comprehensive presentation to industry participants	4/1/2019



Proposed quarterly project meetings (2018)

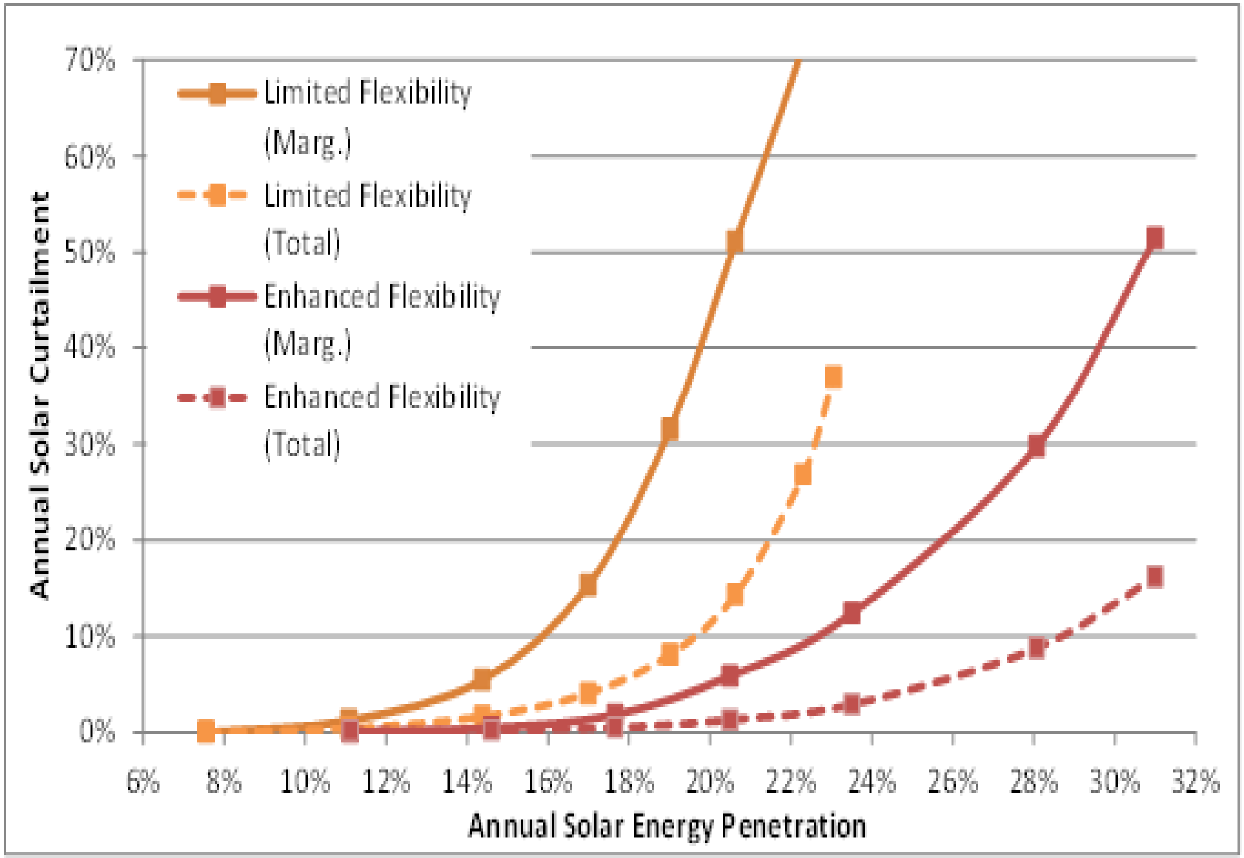
- March 28, 2018
- June 27, 2018
- September 26, 2018
- December 12, 2018

Wednesdays at 1pm Pacific time

Background: Previous research

Projected curtailment rates for high-renewables scenarios

- Curtailment increases as more renewables are installed
- Consequently, the value of renewables also decreases



Source: www.nrel.gov/docs/fy16osti/65023.pdf

Projected decreasing marginal value of storage

- The marginal value of storage falls with each additional MW
- Example for California in 2024
  - Full = 1325MW
  - Half = 663MW
  - Quarter = 331MW

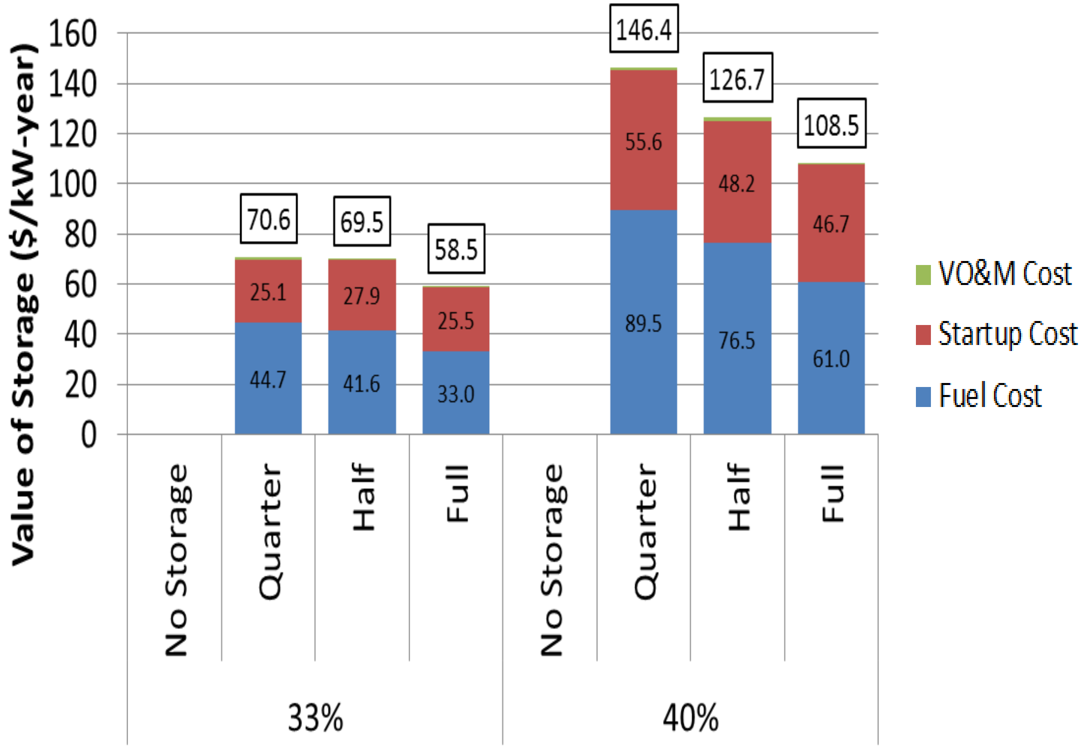
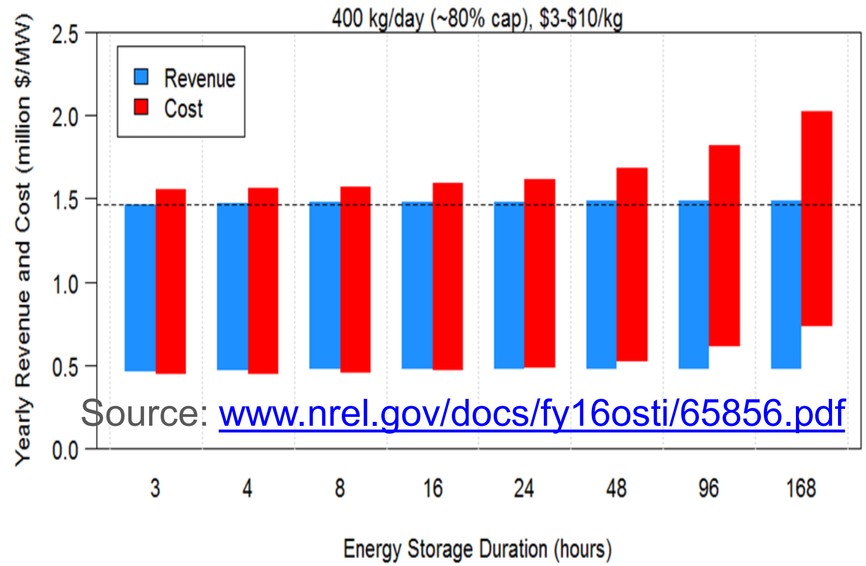


Figure 1: Value of storage providing both energy and reserves per unit of capacity for three levels of installed capacity

Source: www.nrel.gov/docs/fy16osti/65061.pdf

Market value for long-duration storage

- Previous work has shown that there is limited <u>market value</u> for multi-day storage
- Are new markets necessary to incentivize long-duration storage capacity?



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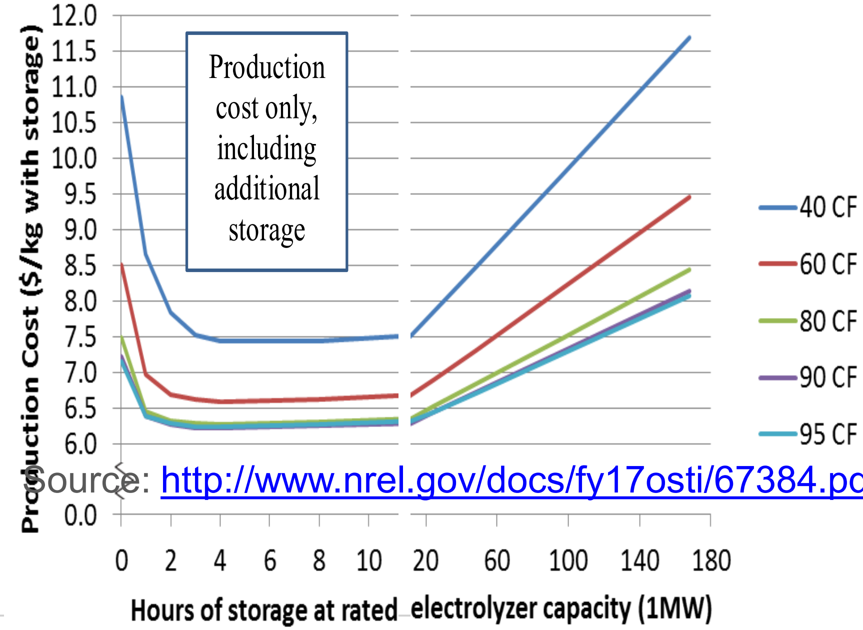
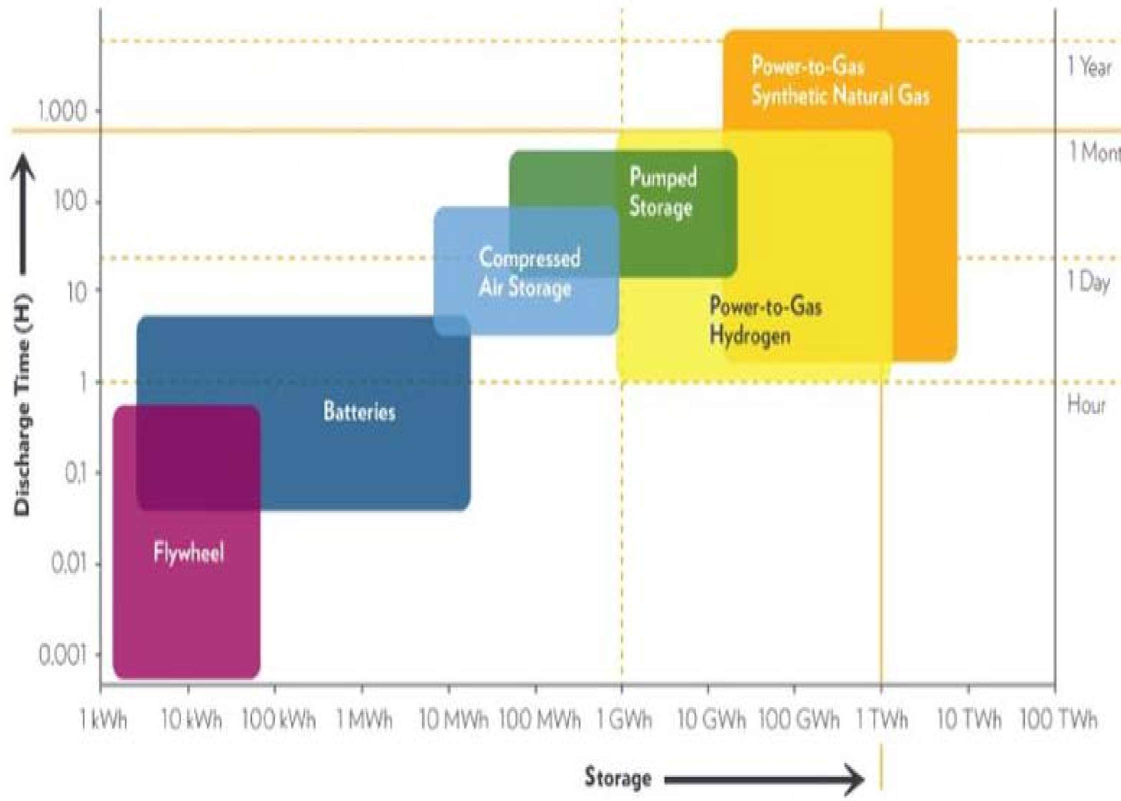


Source: http://www.nrel.gov/docs/fy17osti/67384.pdf

Example technology types (focus on underlined items)

- Mechanical
  - Flywheel
  - <u>CAES</u>
  - <u>Pumped hydro</u>
- Thermal
  - Hot storage: molten glass, molten salts, underground heat storage
  - Cold storage: paraffin, ice, water, ground source heat pump
- Electrochemical
  - <u>Battery</u>
  - <u>Flow battery</u>
  - <u>Hydrogen (Electrolysis)</u>
- Electrical
  - Capacitors
  - Superconducting magnets
- Nuclear fuel
- Chemical
  - Fossil fuels (including <u>Methane)</u>
  - <u>Hydrogen</u>
  - <u>Liquid fuels</u>



Source: ITM power

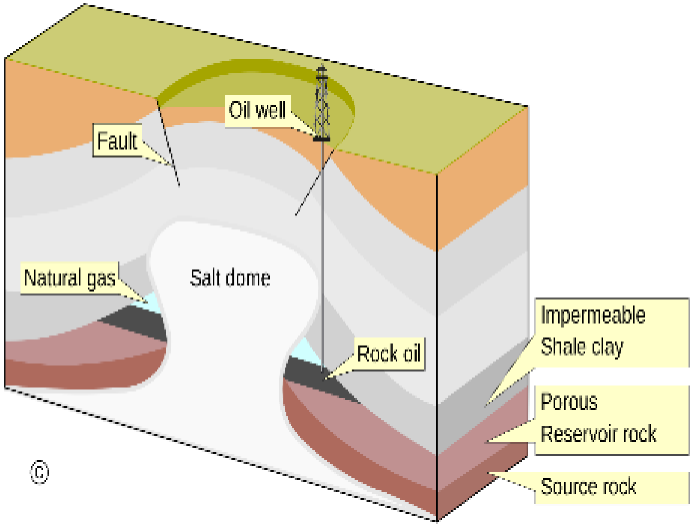
Hydrogen storage options

- Tank/tube storage
  - Steel tube or tank
  - Carbon fiber tank
  - Metal hydride

Source: Kwik Trip Inc., NREL 33250

Source: Keith Wipke, NREL 15

- Storage as by-product
  - Ammonia, liquid fuel, etc.
- Underground geologic storag
  - As hydrogen, methane, etc.

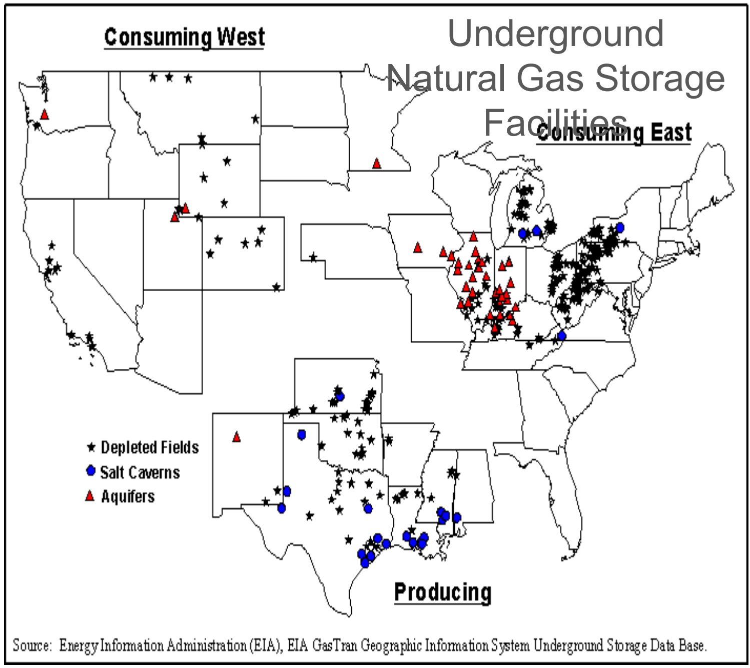


Source: By MagentaGreen (Own work) [CC BY-SA 3.0, via Wikimedia Commons]

Underground storage opportunities for Power-to-gas

- Natural Gas System
  - 305,000 miles of transmission pipelines
  - 400 underground natural gas storage facilities
  - 3.9 Bcf underground storage working gas capacity

Source: www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/index.html

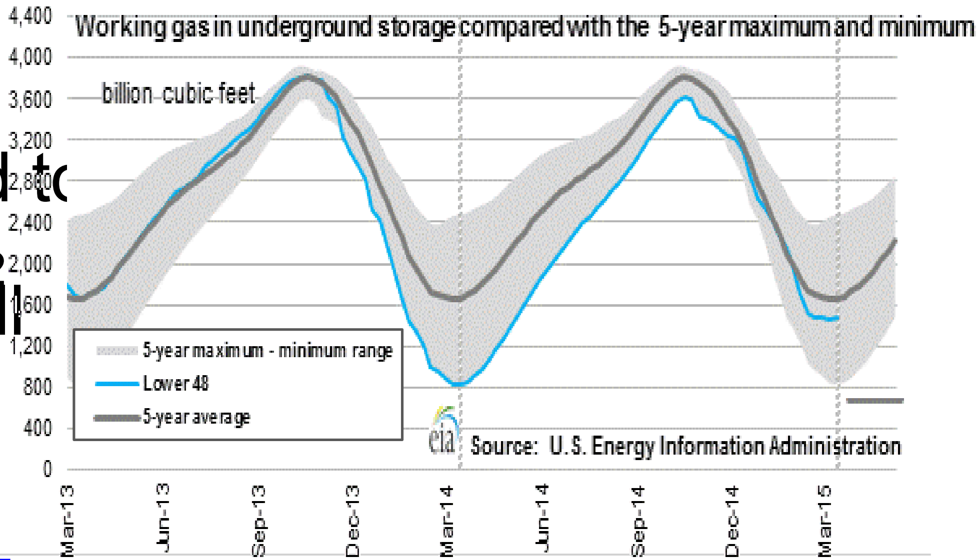


- Storage equates to…
  - 38 billion kg of H_2 used to produce CH_4 from CO_2 methanation for one fill

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

(Sabatier process)

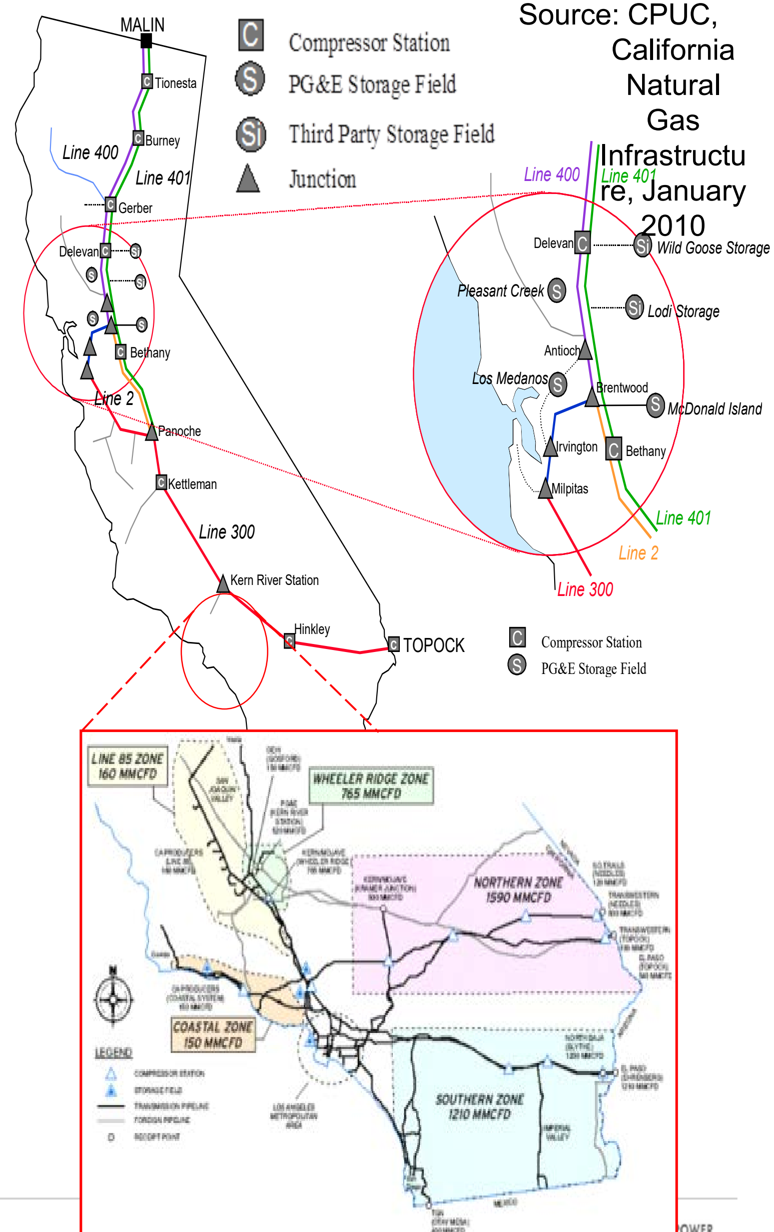
Source: https://www.hydrogen.energy.gov/pdfs/htac_apr15_07_eichman.pdf



Underground storage opportunities for Power-to-gas

- PG&E and SoCalGas/SDG&E gas infrastructure
- Working gas capacity
  - SoCalGas: 131Bcf
  - PG&E: 42Bcf
  - Independent: 63Bcf

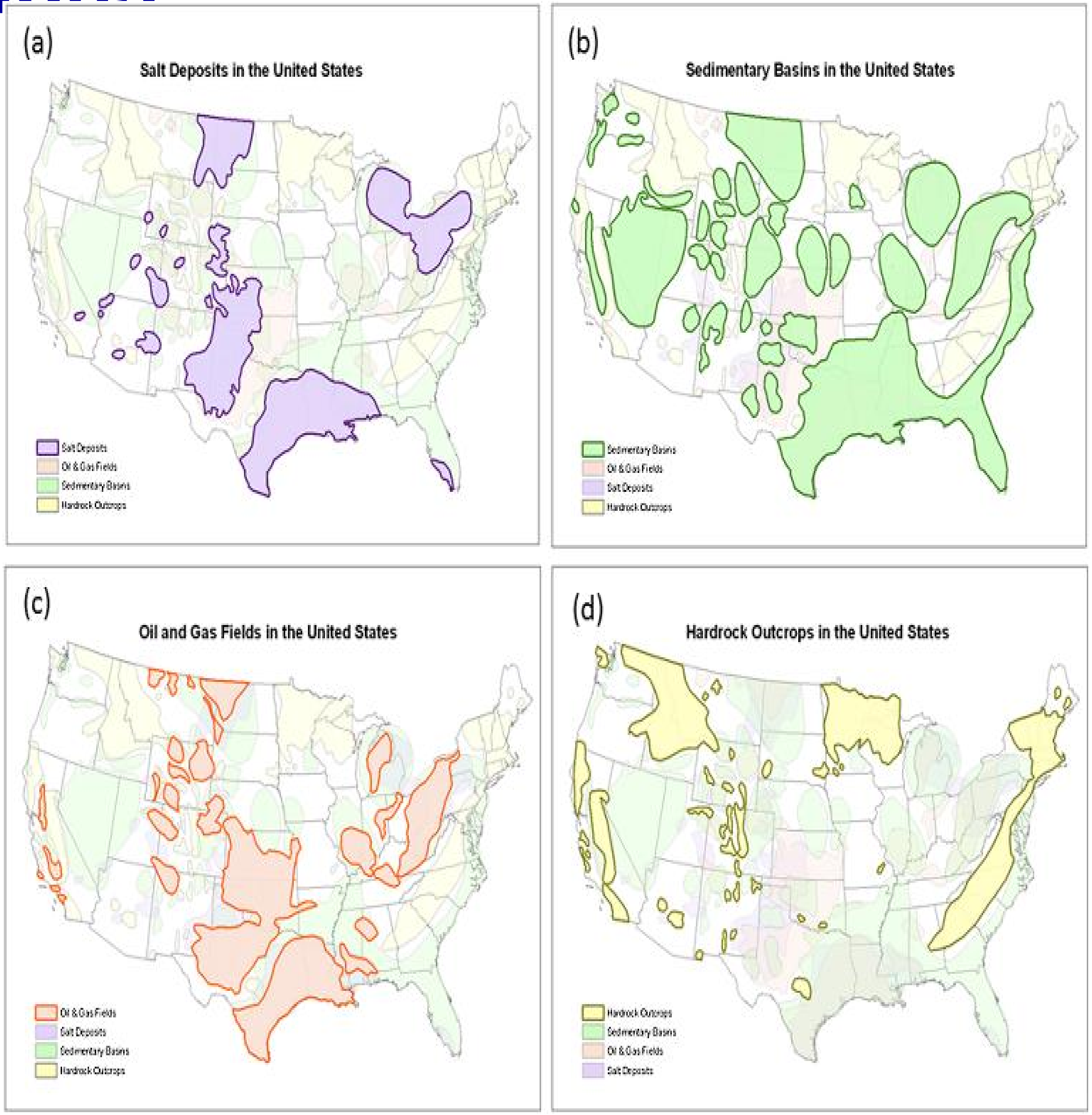
- Provides weeks to months of buffering capacity



Source: CPUC, California Natural Gas Infrastructure, January 2010

Geologic Formations

- A variety of geologic formations are available in the U.S.
- Each type of formation has positives and negatives for storage.
  - Capital cost
  - Volume
  - Cushion gas
  - Injection/withdrawal rate



Source: Lord 2014, https://doi.org/10.1016/j.ijhydene.2014.07.121

Analysis scenarios for this project

Scenarios

- Main Considerations
  - Resource types (see table)
  - Renewables (50%, 70%, & 90% CA-RPS incl. large hydro)
- Sensitivities
  - Power capacity
  - Storage efficiency

Type of resource	Duration of storage	Li-ion battery	Compressed air energy storage	Redox flow battery	Pumped hydro	P2G2P	P2G with sale of product
Short-term storage	2-6 hours	X					
Long-duration storage	8-20 hours		X	X	X	X	
Seasonal storage	3 mont hs		X	X	X	X	
Power-to fuels/chemi	3 mont						X

We are targeting maximum of 20-25 scenario runs – so we must establish priority for each sensitivity item

Compare benefits to costs

- After running PLEXOS scenarios to determine the benefit, we will compare to the cost to determine competitiveness
- Production cost differences vs. Annualized equipment cost. Costs include:
  - Equipment and balance of plant capital
  - Fixed operation and maintenance costs
  - Potential product revenue streams (i.e., sale of hydrogen)

One approach

		Near-term battery deployments	Long-duration energy storage				Seasonal energy storage					Power-to-fuels/chemicals	
Scenario #	RES pen.	Li-ion batteries (4h)	CAES (20h)	Li-ion batteries (20h)	Redox flow battery (20h)	P2G2P (20h)	CAES (3 month)	Li-ion batteries (3month)	Redox flow battery (3month)	P2G2P (3 month)	P2G to MeOH (3 month)	P2G with H2 sale	P2G to MeOH with sale
1	50%	x											
2	50%	x	x										
3	50%	x		x									
4	50%	x			x								
5	50%	x				x							
6	50%	x					x						
7	50%	x						x					
8	50%	x							x				
9	50%	x								x			
10	50%	x									x		
11	50%	x										x	
12	50%	x											x
13	80%	x											
14	80%	x	x										
15	80%	x		x									
16	80%	x			x								
17	80%	x				x							
18	80%	x					x						
19	80%	x						x					
20	80%	x							x				
21	80%	x								x			
22	80%	x									x		
23	80%	x										x	
24	80%	x											x

A 2nd approach

- ***What are the priority scenarios?***

- ***What is less important?***

		Near-term battery deployments	Long-duration energy storage				Seasonal energy storage					Power-to-fuels/chemicals	
Scenario #	RES pen.	Li-ion batteries (4h)	CAES (20h)	Li-ion batteries (20h)	Redox flow battery (20h)	P2G2P (20h)	CAES (3 month)	Li-ion batteries (3month)	Redox flow battery (3month)	P2G2P (3 month)	P2G to MeOH (3 month)	P2G with H2 sale	P2G to MeOH with sale
1	50%	x											
2	50%	x	x										
3	50%	x		x									
4	50%	x			x								
5	50%	x				x							
6	50%	x					x						
7	50%	x								x			
8	50%	x									x		
9	50%	x										x	
10	50%	x											x
11	70%	x											
12	70%	x	x										
13	70%	x		x									
14	70%	x			x								
15	70%	x				x							
16	70%	x					x						
17	70%	x								x			
18	70%	x									x		
19	70%	x										x	
20	70%	x											x
21	90%	x								x			
22	90%	x									x		
23	90%	x										x	
24	90%	x											x

Open discussion

Together…Shaping the Future of Electricity

Backup: Project task list

Tasks

1. Project stakeholder meetings
2. Establish fully specified set of analysis scenarios in consultation with industry participants
3. Implement high renewable scenarios into the PLEXOS WECC database
4. Simulate each scenario in PLEXOS
5. Perform cost/benefit assessment
6. Document findings

Tasks

1.0 Project stakeholder meetings

- 1.1 Kickoff meeting. EPRI will convene a project kickoff meeting including industry participants and NREL investigators, to be held before 2/1/2018.
- 1.2 Quarterly project meetings. EPRI will convene quarterly project meetings for industry participants to hear project updates and discuss project content.
- 1.3 Quarterly progress reports. NREL investigators will attend quarterly project meetings to provide updates to, and discuss questions with, industry participants.
- 1.4 Final project meeting. EPRI will convene a final project meeting upon the conclusion of work.
- 1.5 Final comprehensive presentation to industry participants. NREL investigators will present a comprehensive summary of findings to industry participants, discuss insights and implications, and discuss participant questions.

Tasks

2.0 Establish fully specified set of analysis scenarios in consultation with industry participants

- 2.1 Initial scenario set draft. NREL investigators will provide EPRI with discussion draft of technology deployment scenario set.
- 2.2 Review technology scenarios with industry participants. NREL investigators will participate in the project kickoff meeting and record input from industry participants concerning the technology scenarios.
- 2.3 Finalize the technology scenario set. EPRI will collaborate with NREL to produce a finalized set of technology scenarios that incorporates industry feedback.
- 2.4 Document the finalized scenario set. NREL investigators will document the finalized set of technology scenarios, incorporating industry participant input per consultation with EPRI, as a Word document and slide presentation.

Tasks

3.0 Implement high renewable scenarios into the PLEXOS WECC database

- 3.1 Tabulate initial model-output generation portfolio determined by ReEDS for high-renewables scenarios. NREL investigators will tabulate generation portfolios for WECC high-penetration scenarios determined by NREL's ReEDs model.
- 3.2 Present modeled generation portfolio to industry funders for comment. NREL investigators will present the ReEDs-output generation portfolios to industry participants at a quarterly project meeting, by 7/1/2018.
- 3.3 Revise generation portfolio mix as necessary, incorporating participant input. NREL investigators will record industry participant feedback on generation portfolio scenarios. EPRI will consult with NREL to finalize the generation portfolio scenarios, incorporating industry participant input.
- 3.4 Implement modeled generation portfolio in PLEXOS. NREL investigators will enter generation portfolio scenarios into PLEXOS.

Tasks

4.0 Simulate each scenario in PLEXOS

- 4.1 Execute each scenario in PLEXOS. NREL investigators will execute each scenario in PLEXOS.
- 4.2 Identify main outcomes in post-processing. NREL investigators will summarize main outcomes from model runs in writing to EPRI.
- 4.3 Check results for consistency and alignment with expectations. NREL and EPRI will together review model results and specify expected, unexpected, and/or noteworthy outcomes.

Tasks

5.0 Perform cost/benefit assessment

- 5.1 List key non-generating assets for each scenario. NREL investigators will tabulate key non-generating assets (e.g. electrolyzers, other storage units) included in each scenario.
- 5.2 Tabulate capital costs of key non-generating assets. NREL investigators and EPRI will collaborate to generate a table of capital cost assumptions for key non-generating assets for use in the cost/benefit assessment.
- 5.3 For each scenario, tabulate:
  - 5.3.1 Individual costs and total cost
  - 5.3.2 Individual value streams and sum of these
  - 5.3.3 Variance from baseline scenario
  - 5.3.4 NREL investigators will compile this table. EPRI will critically review.

Tasks

6.0 Document findings

6.1 Write 2018 year-end full interim progress report. NREL investigators will document project work to date (including methodology in use; results to date; any preliminary insights; and remaining project work to complete) and deliver to EPRI by 11/15/2018.

6.2 Review 2018 year-end full interim progress report. EPRI will review 2018 year-end interim progress report for completeness and quality and, upon approval, distribute to industry participants by 12/1/2018.

6.3 Write final project report. NREL investigators will prepare a comprehensive project report, detailing: motivation; background and prior work; full modeling methodology and input parameters (by reference at EPRI PM discretion); complete results; brief discussion of significance. NREL will deliver to EPRI by 3/15/2018.

6.4 Review final project report. EPRI will review 2018 year-end interim progress report for completeness and quality and, upon approval, distribute to industry participants by 4/1/2019.

6.5 Final project summary (slide presentation). NREL investigators will summarize analysis methodology, results, and insights/implications in slide presentation delivered to EPRI.