DOCKETED	
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Document Title:	Presentation - Zero Emissions Energy with Hydrogen
Description:	S2.201 Jack Brouwer, UC Irvine
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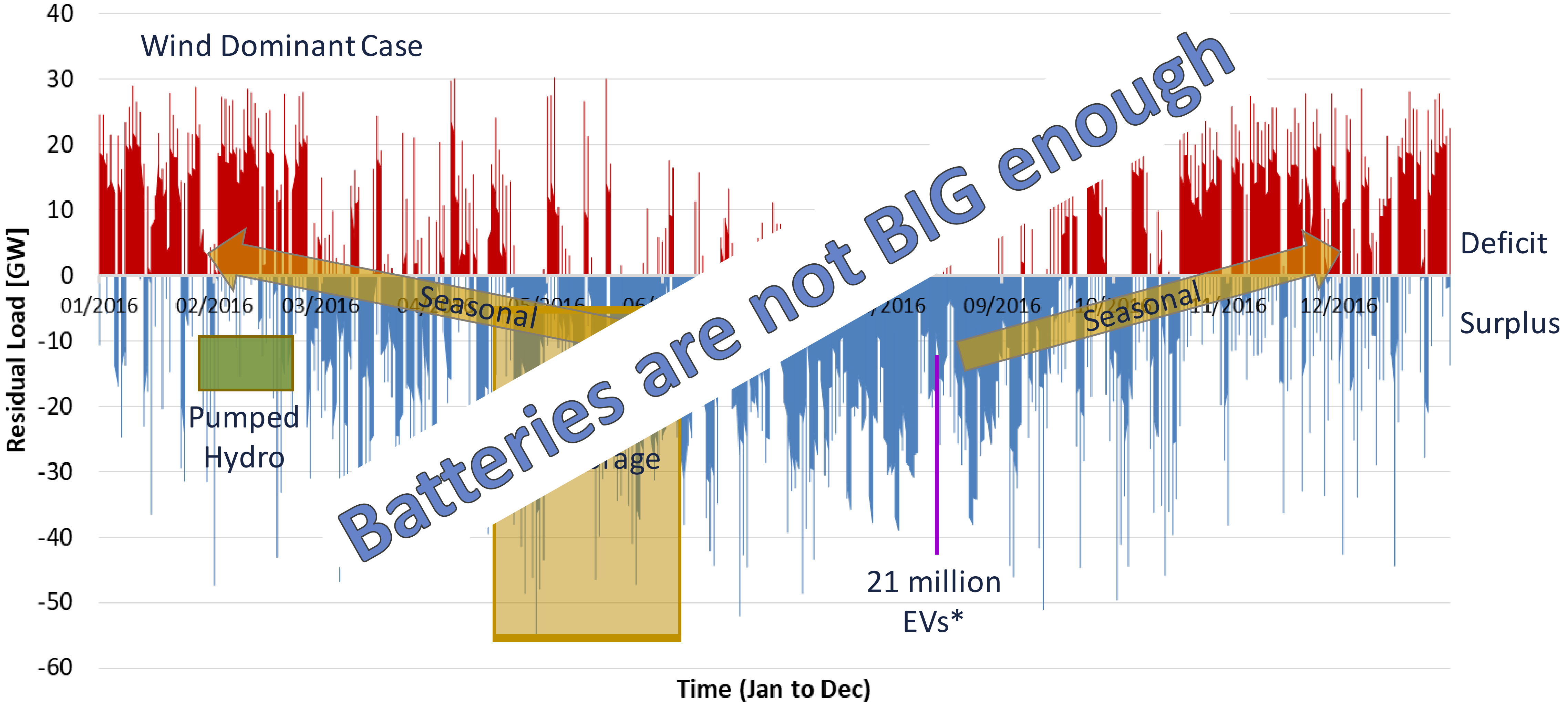
Zero Emissions Energy with Hydrogen

IEPR Commissioner Workshop on Hydrogen to Support CA Clean Energy Transition

Jack Brouwer

July 28, 2021

Amount of Storage Required for 100% Renewable – CA



* Nissan Leaf Equiv. – 62 kWh

Saeedmanesh, A. Mac Kinnon, M. Brouwer, J., Current Opinion in Electrochemistry, Vol. 12, pp. 166-181, 2018

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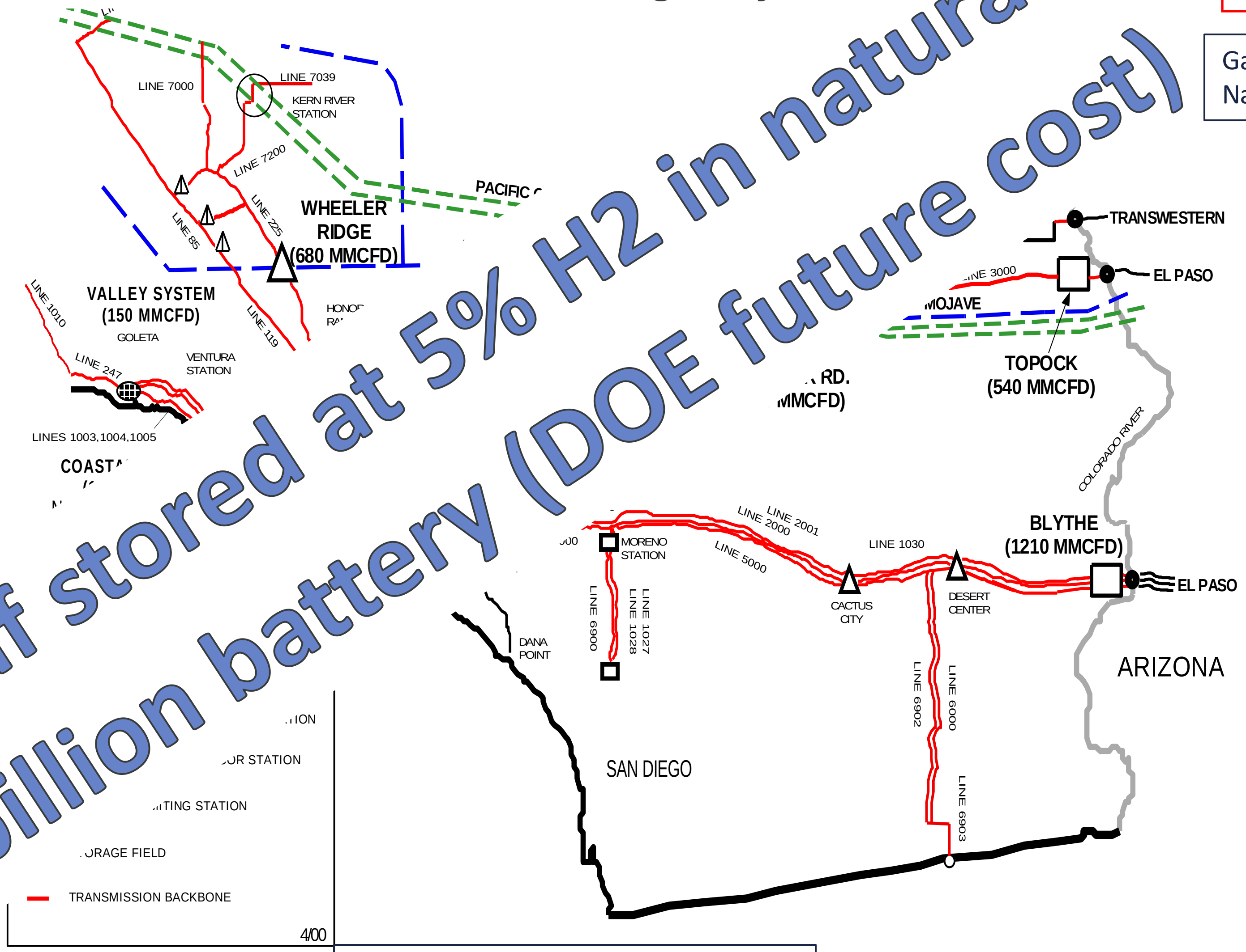
Resilient Storage & Transmission/Distrib… Resource

- Natural Gas Transmission, Distribution & Storage System

> 99.999% available

Gas Technology Institute, Assessment of Natural Gas … Service Reliability, 2018.



650 GWh if stored at 5% H2 in natural gas

$130 billion battery (DOE future cost)

Carmona, Adrian, M.S. Thesis Project, UC Irvine, J. Brouwer advisor, 2014.

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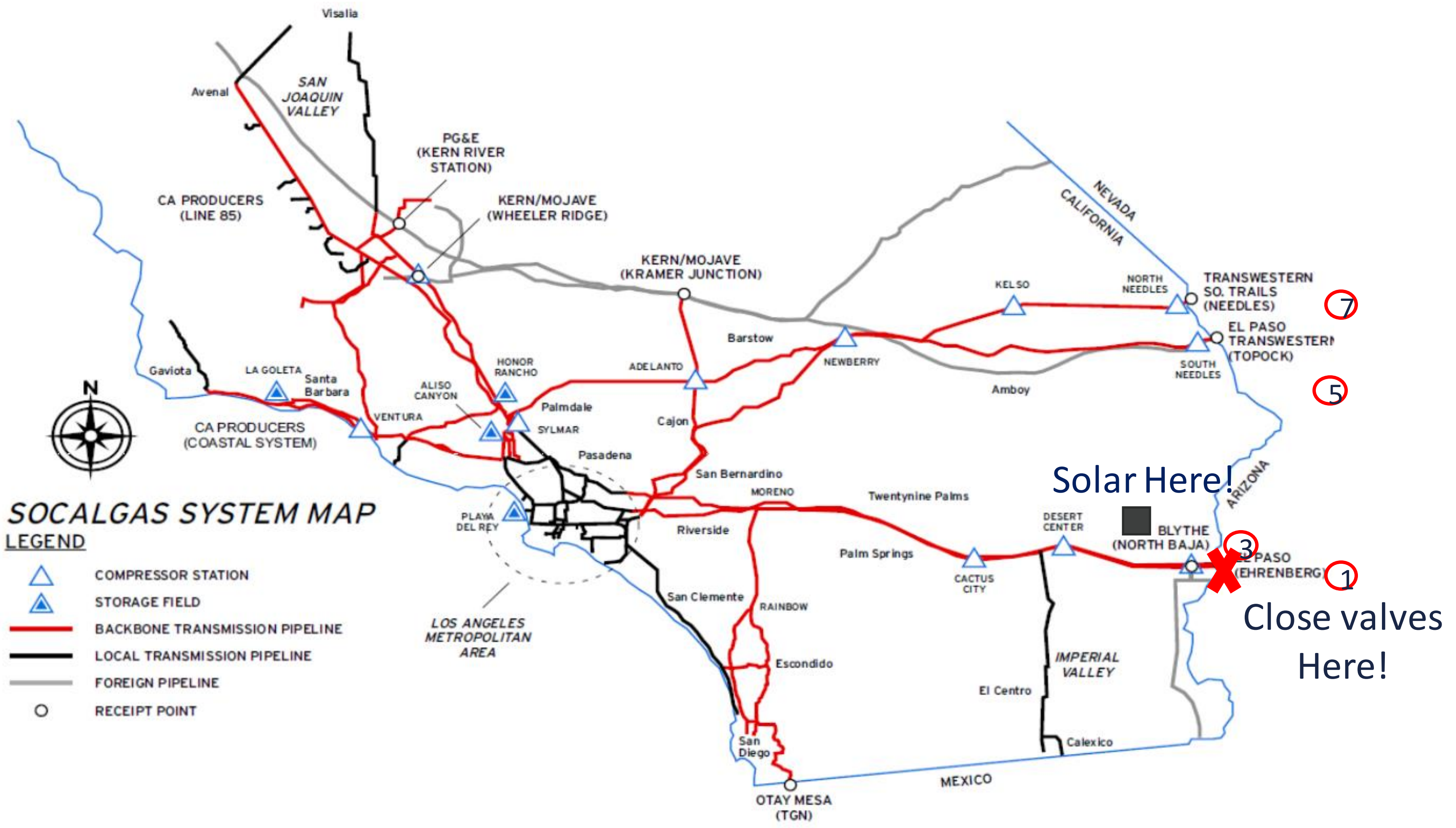
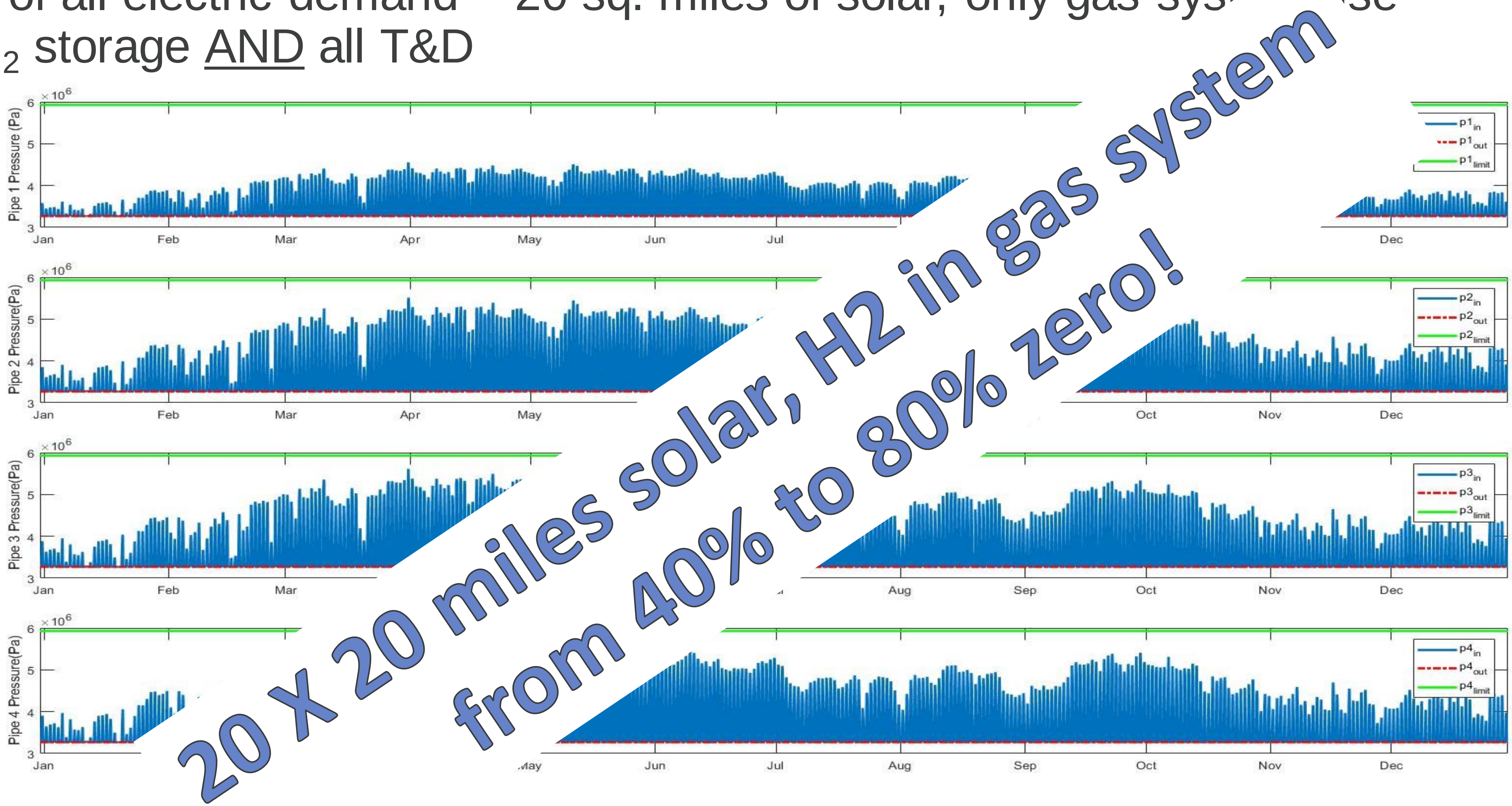
Gas System – MASSIVE Resource for Zero Emissions

- First mix up to X% – ADD grid renewables & transportation electrification
- Then piecewise conversion to pure hydrogen



Gas System – MASSIVE Resource for Zero Emissions

- 40% of all electric demand – 20 sq. miles of solar, only gas syst[…] use for H_2 storage <u>AND</u> all T&D

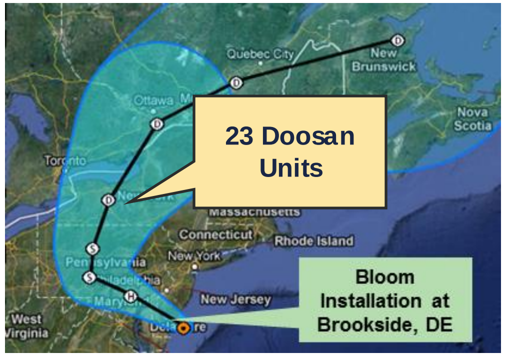


Demonstrated Resilience of Fuel Cells and Gas System

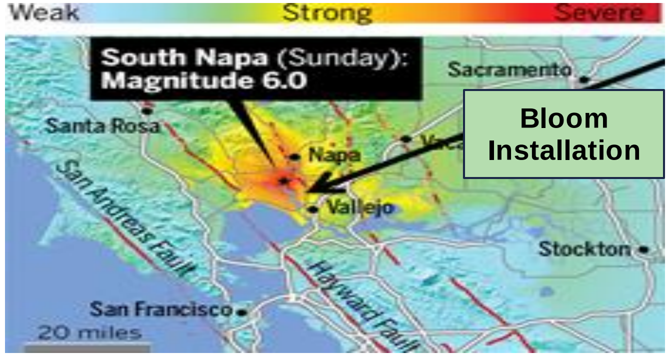
San Diego Blackout, 9/28/11

Winter Storm Alfred, 10/29/11

Hurricane Sandy, 10/29/12



CA Earthquake, 8/24/14

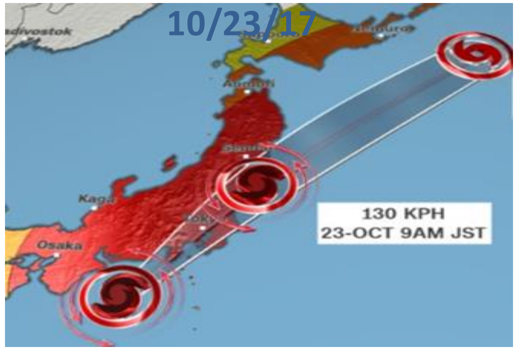


Data Center Utility Outage, 4/16/15

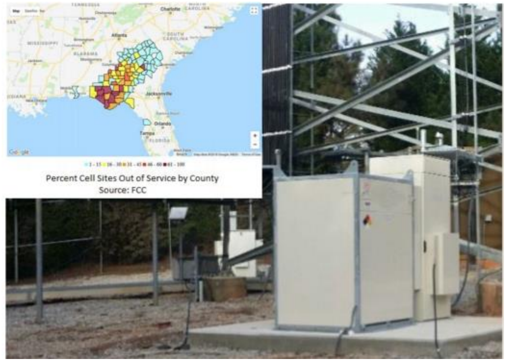
Hurricane Joaquin, 10/15/15

Napa Fire, 10/9/17

Japanese Super-Typhoon, 10/23/17

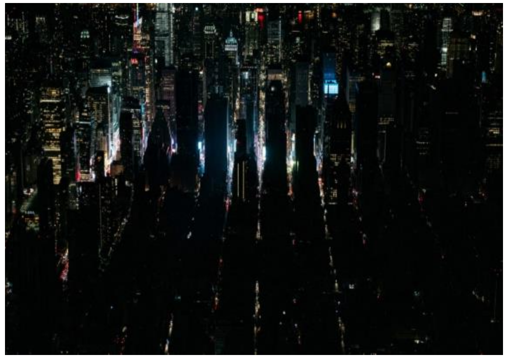


Hurricane Michael, 10/15/18

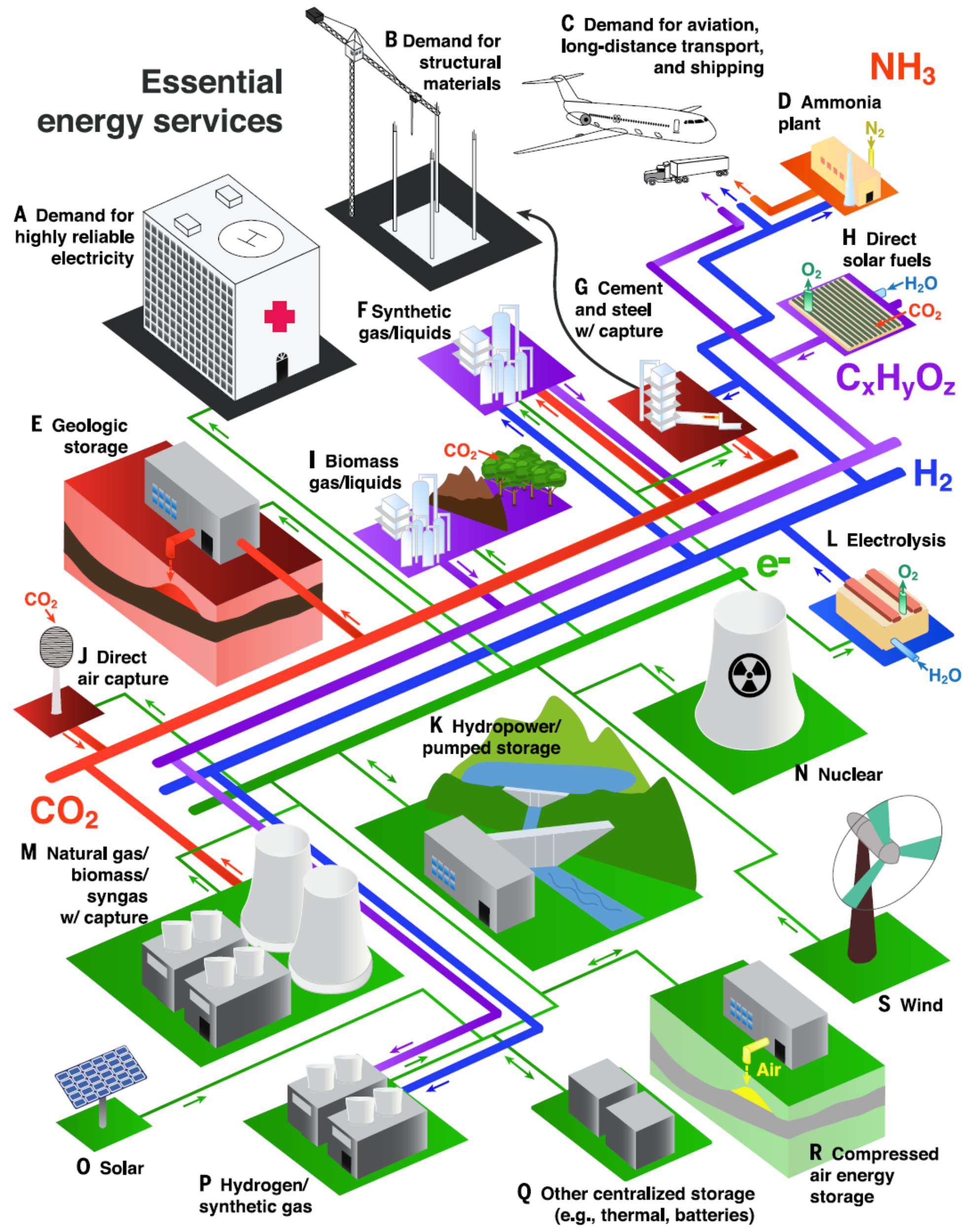


Ridgecrest Earthquakes, 7/4-5/19

Manhattan Blackout, 7/13/19



Why Hydrogen? Required for completely zero emissions



REVIEW SUMMARY

ENERGY

Net-zero emissions energy systems

Steven J. Davis*, Nathan S. Lewis*, Matthew Shaner, Sonia Aggarwal, Doug Arent, Inês L. Azevedo, Sally M. Benson, Thomas Bradley, Jack Brouwer, Yet-Ming Chiang, Christopher T. M. Clack, Armond Cohen, Stephen Doig, Jae Edmonds, Paul Fennell, Christopher B. Field, Bryan Hannegan, Bri-Mathias Hodge, Martin I. Hoffert, Eric Ingersoll, Paulina Jaramillo, Klaus S. Lackner, Katharine J. Mach, Michael Mastrandrea, Joan Ogden, Per F. Peterson, Daniel L. Sanchez, Daniel Sperling, Joseph Stagner, Jessika E. Trancik, Chi-Jen Yang, Ken Caldeira*

Davis *et al.*, *Science* **360**, 1419 (2018)   29 June 2018

Why Hydrogen? Zero Emission Fuels Required

- Provide zero emissions fuel to difficult end-uses

Anything that requires (1) rapid fueling, (2) long range, (3) large payload

Why Hydrogen? Industry Requirements for Heat, Feedstock,

- Many examples of applications that cannot be directly electrified

Steel Manufacturing & Processing

Cement Production

(Photo: ABB Cement)

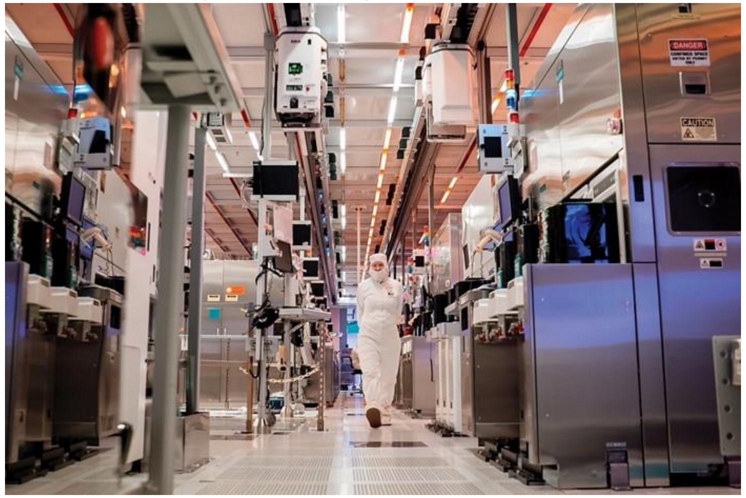
Plastics

(Photo: DowDuPont Inc.*)*

Ammonia & Fertilizer Production

(Photo: Galveston County Economic Development)

Computer Chip Fabrication



(Photo: American Chemical Society)

Pharmaceuticals

(Photo: Geosyntec Consultants)

Hydrogen is Essential for Sustainability

Hydrogen: 11 features required for 100% zero carbon & pollutant emissions

- Massive energy storage potential
- Rapid vehicle fueling
- Long vehicle range
- Heavy vehicle/ship/train payload
- Seasonal (long duration) storage potent
- Sufficient raw materials on earth
- Water naturally recycled in short time o
- Feedstock for industry heat
- Feedstock for industry chemicals (e.g.
- Pre-cursor for high energy density ren
- Re-use of existing infrastructure (lowe

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Current Opinion in Electrochemistry

Review Article

Hydrogen is essential for sustainability

Alireza Saeedmanesh, Michael A. Mac Kinnon and Jack Brouwer*

Sustainable energy conversion requires zero emissions of greenhouse gases and criteria pollutants using primary energy sources that the earth naturally replenishes quickly, like renewable resources. Solar and wind power conversion technologies have become cost effective recently, but challenges remain to manage electrical grid dynamics and to meet end-use requirements for energy dense fuels and chemicals. Renewable hydrogen provides the best opportunity for a zero emissions fuel and is the best feedstock for production of zero emission liquid fuels and some chemical and heat end-uses. Renewable hydrogen can be made at very high efficiency using electrolysis systems that are dynamically operated to complement renewable wind and solar power dynamics. Hydrogen can be stored within the existing natural gas system to provide low cost massive storage capacity that (1) could be sufficient to enable a 100% zero emissions grid; (2) has sufficient energy density for end-uses including heavy duty transport; (3) is a building block for zero emissions fertilizer and chemicals; and (4) enables sustainable primary energy in all sectors of the economy.

Address
National Fuel Cell Research Center, University of California, Irvine, 92697-3550, United States

electricity generation, and industrial applications, will increase substantially over this century [7–14].

Since the Industrial Revolution, the vast majority of energy converted in society has been obtained from fossil fuels – coal, natural gas, and petroleum – which require tremendously long times for earth and the power of the sun to produce. This trend is widely expected to continue in coming decades [15–18]. Although the available global quantity of these fuels is extremely large, they are nevertheless finite and so will inevitably 'run out' at some near future time as we consume them much faster than the earth produces them [19]. A primary reason for their continued use is economics – energy from fossil fuels has been more cost effective than most other sustainable forms of energy, including renewable resources.

In addition, the continued use of fossil fuels is associated with increased criteria pollutant and greenhouse gas emissions [20]. Emissions from fossil fuel combustion degrade air quality, pose human health risks, and drive global climate change. In 2017, global energy-related CO_2 emissions reached an historic high of 32.5 Gt as a result of

Saeemanesh, A., Mac Kinn
Hydrogen is Essential for Sustainability, Curre
Opinion in Electrochemistry, 2019.

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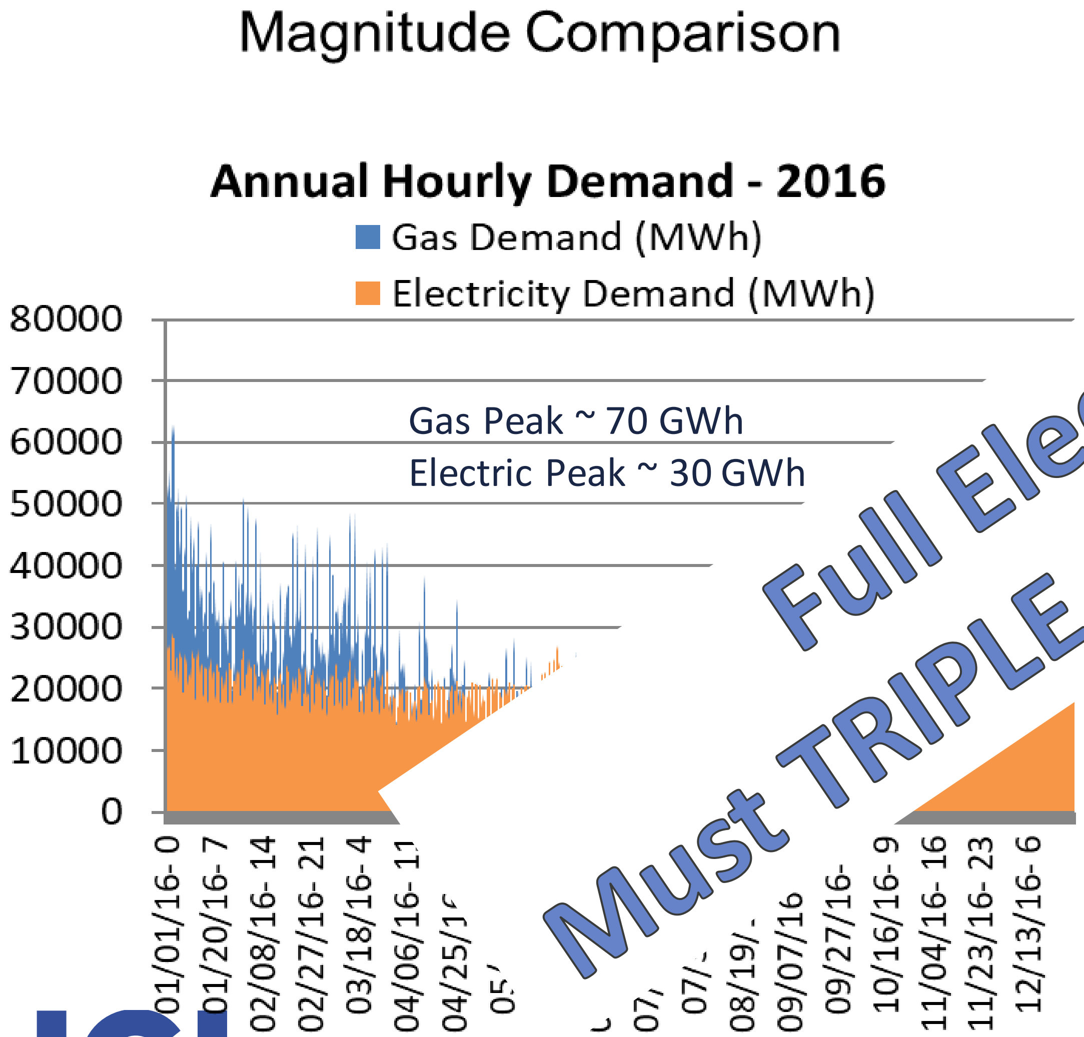
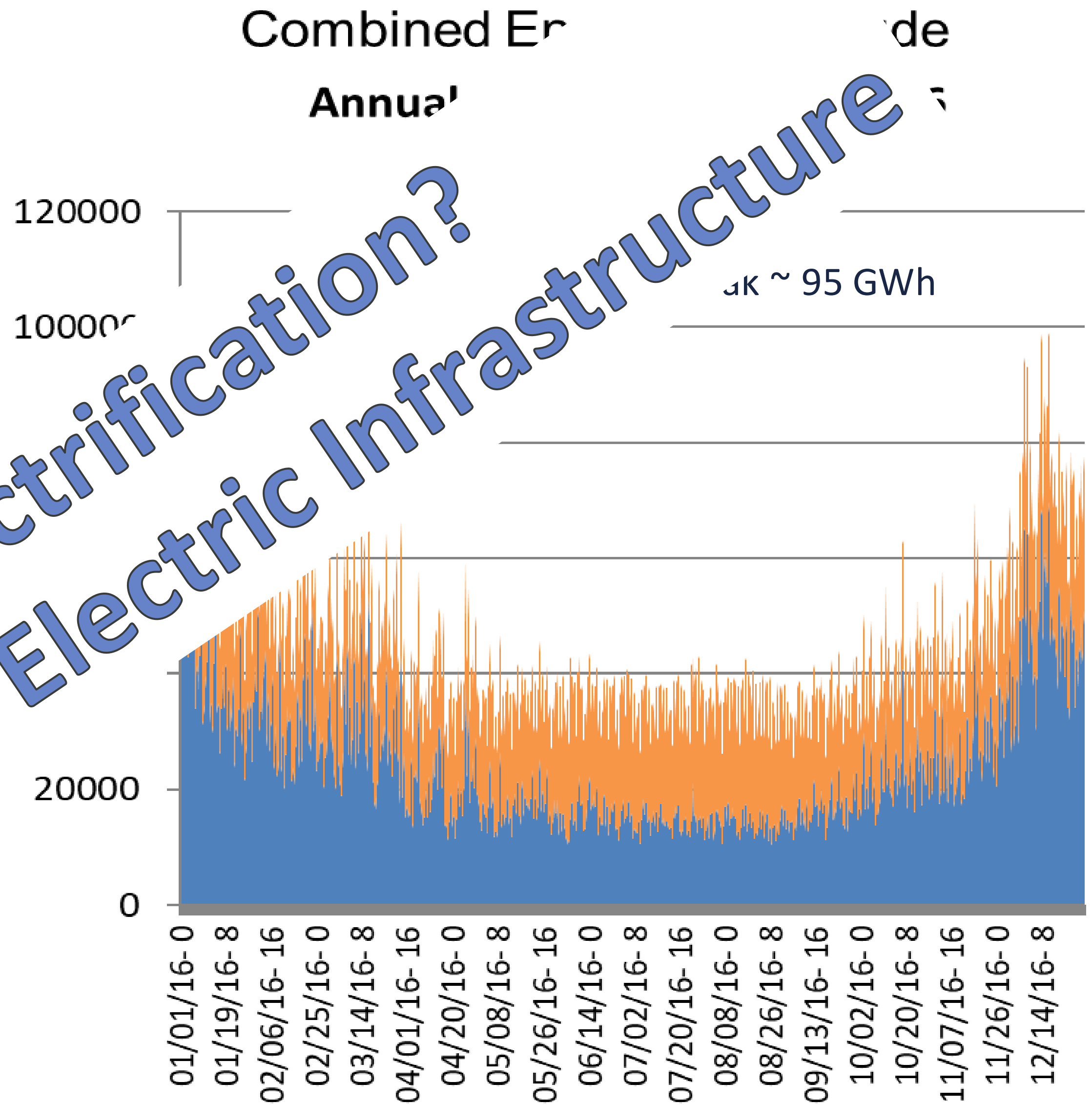
Backup Slides

RD&D Topic #1: System Dynamics of 100% Zero Em[...]ions Options

- Northwestern U.S. Energy Dynamics





Full Electrification?

Must TRIPLE Electric Infrastructure

RD&D Topic #2: Hydrogen Safety & Sensing

Tests for Hydrogen Safety

Fire

Excessive Tank Pressure (Blocking all safety valves)

Mechanical Damage

Courtesy: BMW Group, 2000
and Garrity, Murdoch Univ., 2002

Hydrogen Leak **Gasoline Leak**

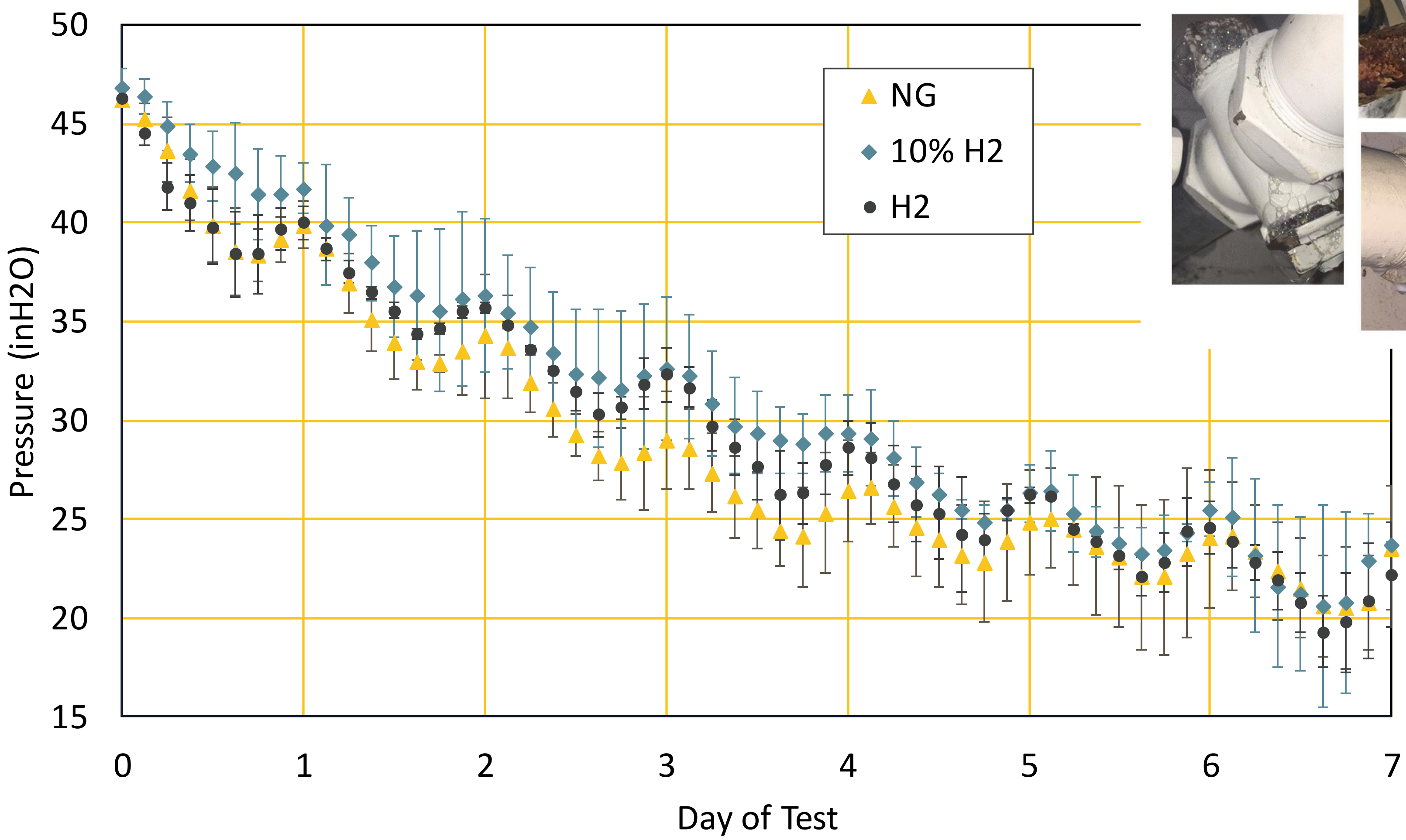
RD&D Topic #2: Hydrogen Safety & Sensing

- Hindenburg and the Hydrogen Bomb
  - No nuclear reactions
  - Hindenburg disaster caused by paint and skin
- H_2 characteristics
  - Broadest flammability limits
  - Low ignition energy (at stoichiometric)
  - Highest diffusivity
  - Lowest density
- Can be safer than gasoline & natural gas, but different!
  - In the event of an accident/leak – creation and ignition of a flammable mixture is less likely with hydrogen than with gasoline, perhaps more likely than with NG
- But, fire marshals, codes, standards, regulations, are not currently friendly
- Recently – disinformation

RD&D Topic #3: H_2 leakage from NG Infrastructure

H2 injection into existing natural gas infrastructure (low pressure)

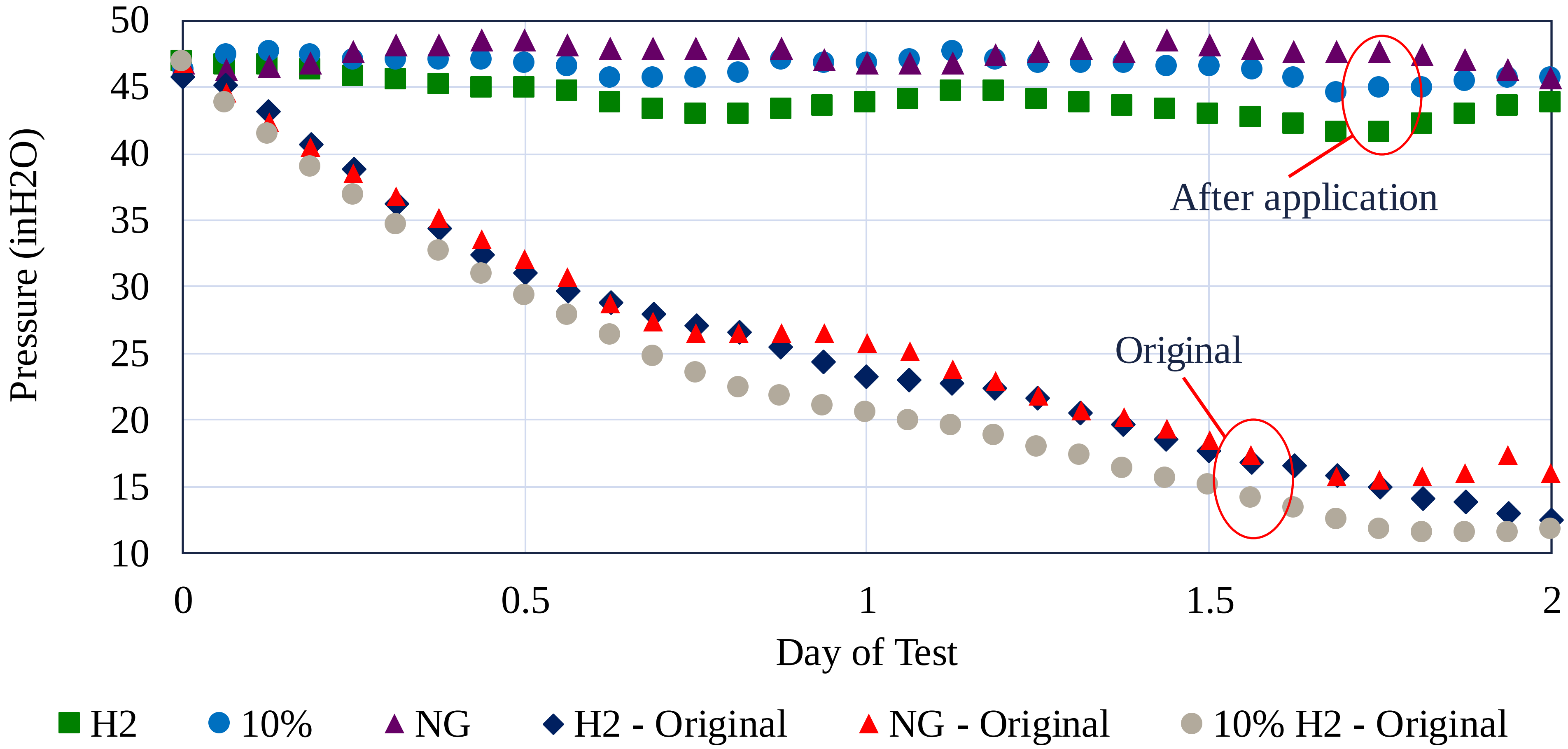
- NG, H_2/NG mixtures, H_2 leak at same rate



RD&D Topic #3: H_2 leakage from NG Infrastructure

H2 injection into existing natural gas infrastructure (low pressure)

- Copper epoxy applied (Ace Duraflow®) to mitigate H_2 leaks



RD&D Topic #3: H_2 leakage from NG Infrastructure

- Results from a previous study (1992) ...pport our recent findings!

Lea...	CH4
~~Diffusi...~~	
~~La...~~	
~~Tu...~~	

Entra...

Comm...

International Journal of Hydrogen Energy

ELSEVIER

Volume 45, Issue 15, 18 March 2020, Pages 8810-8826

Hydrogen leaks at the same rate as natural gas in typical low-pressure gas infrastructure

Alejandra Hormaza Mejia [a], Jacob Brouwer [a], Michael Mac Kinnon [b]

Show more

https://doi.org/10.1016/j.ijhydene.2019.12.159

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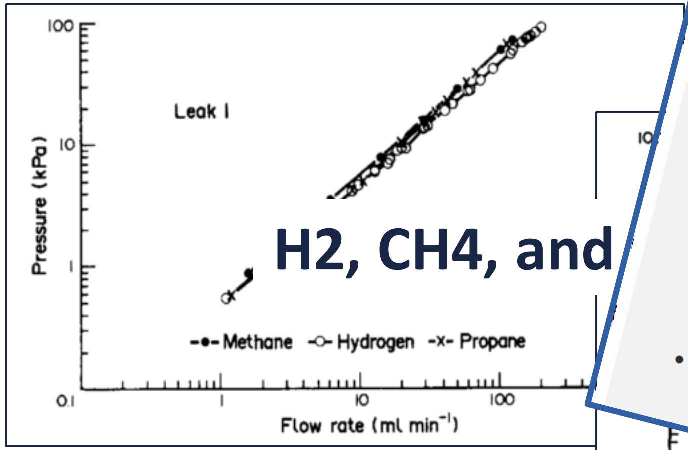
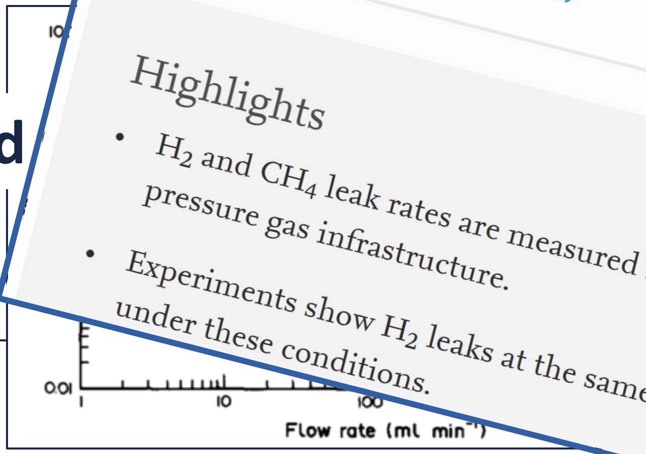
Highlights

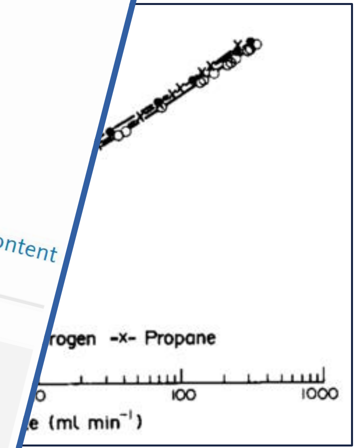
- H_2 and CH_4 leak rates are measured in unmodified low pressure gas infrastructure.
- Experiments show H_2 leaks at the same rate as CH_4 under these conditions.

- First publication on this topic: Swa... ...gy, Vol. 17, pp. 807-815, 1992.



H2, CH4, and





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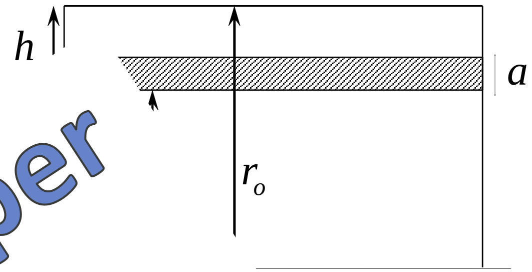
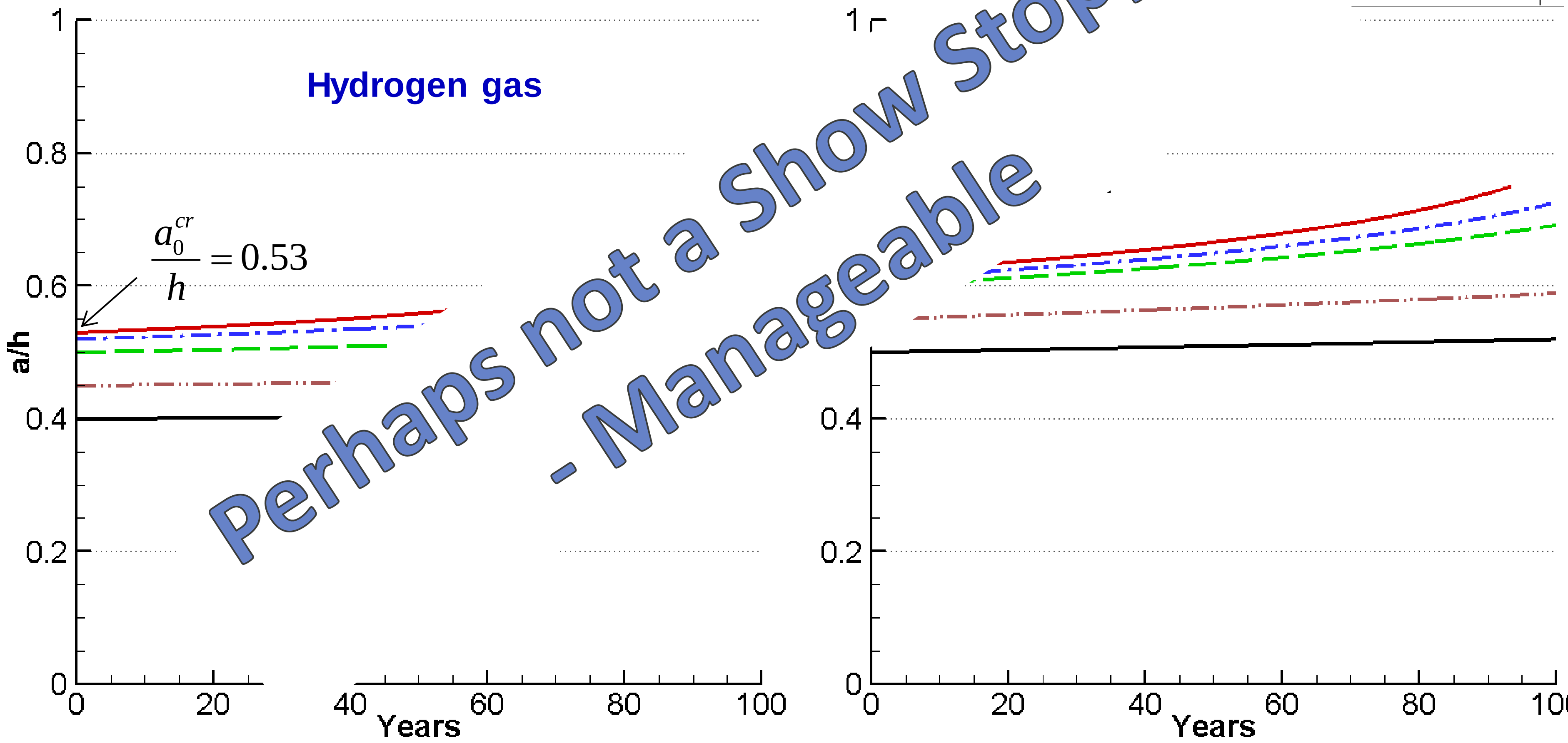
RD&D Topic #4: Existing Pipeline Embrittlement

Simulation of H2 embrittlement and fatigue crack growth with UIUC

- Fatigue crack growth in 6” SoCalGas pipeline

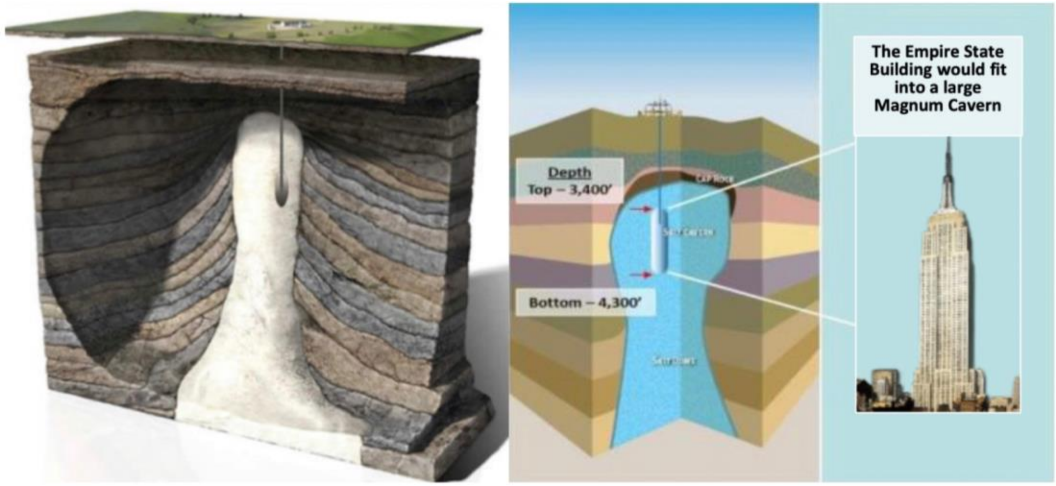


0.188” wall thickness: $(h = 0.188'' = 4.8\text{ mm})$



Perhaps not a Show Stopper - Manageable

RD&D Topic #5: Massive Storage Facility Transformation



Plan for storing hydrogen in Utah salt caverns

Images: Los Angeles Department of Water and Power

Salt Caverns already widely used and proven

- Air Liquide & Praxair operating H_2 salt cavern storage in Texas since 2016
  - Very low leakage rate
  - Massive energy storage
  - Safe & Low-cost storage
- Similar success in Europe
- Magnum working with LADWP to adopt similar

Current CA depleted oil and gas fields not yet used or proven for H_2 use

- Several research and development needs
  - H2 leakage
  - H2 reaction with petroleum remnants
  - H2 biological interactions
  - H2 storage capacity
  - H2 safety

NG utilities must participate

RD&D Topic #6: End-Use Impacts of H_2/NG mixtures & variability

Meter-sets
- Physical flow/measurement characteristics
- Heating value and Wobbe Index
- …

Consumer appliances
- Stove-top, oven, space heater, water heater, …
  - UCI investigations, European studies exist
  - Up to 20% H_2 in NG likely manageable

Power plants
- Already capable of significant H_2/NG blends (e.g., 30%)
- R&D for higher H_2/NG blends
- Locations where high H_2 (up to 100%) can be evaluated

Industry
- Ammonia, refining, glass, …

NG utilities must participate