Solar Hydrogen:

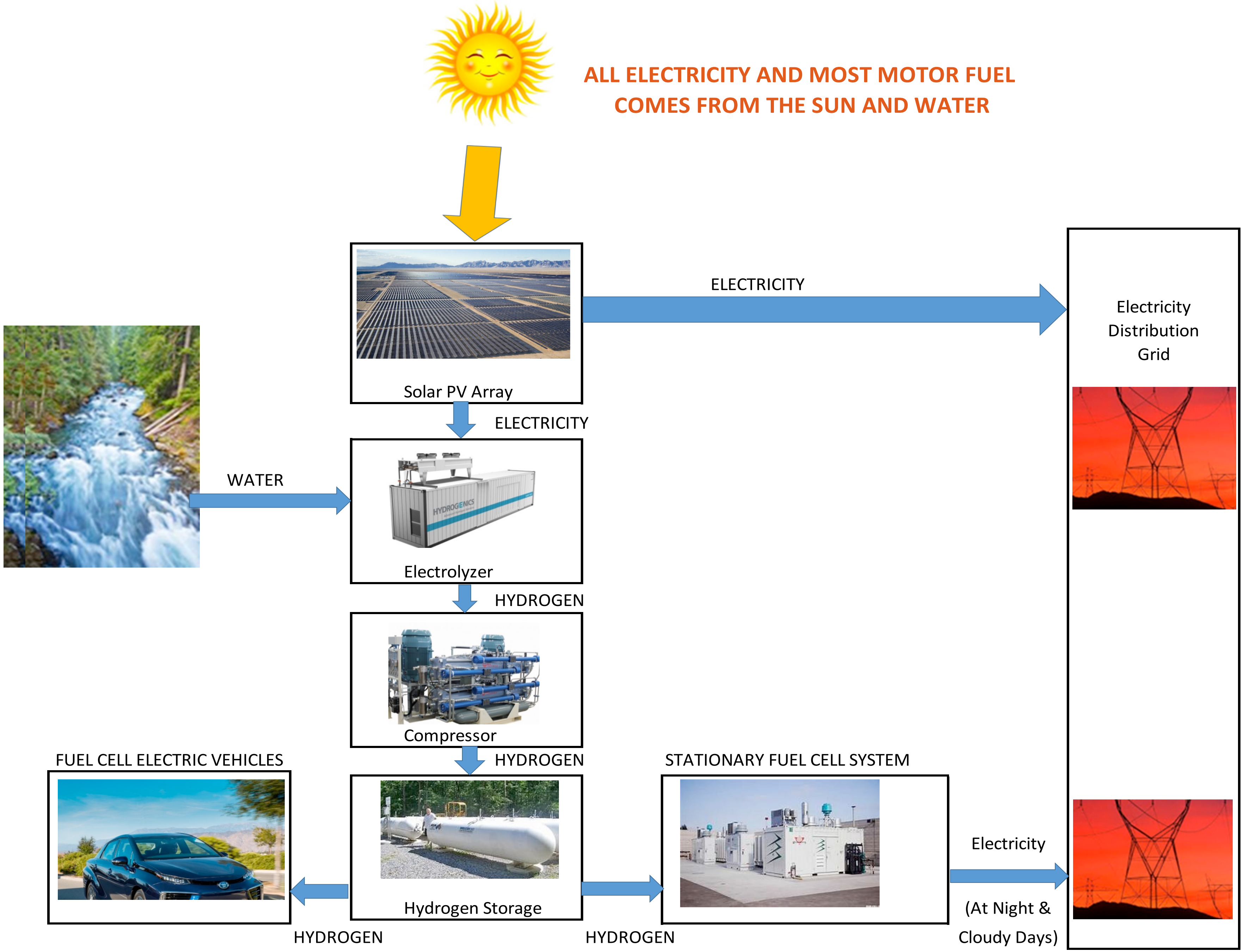
The Ultimate Solution to Prevent More Climate Change

By C. E. (Sandy) Thomas, Ph.D.

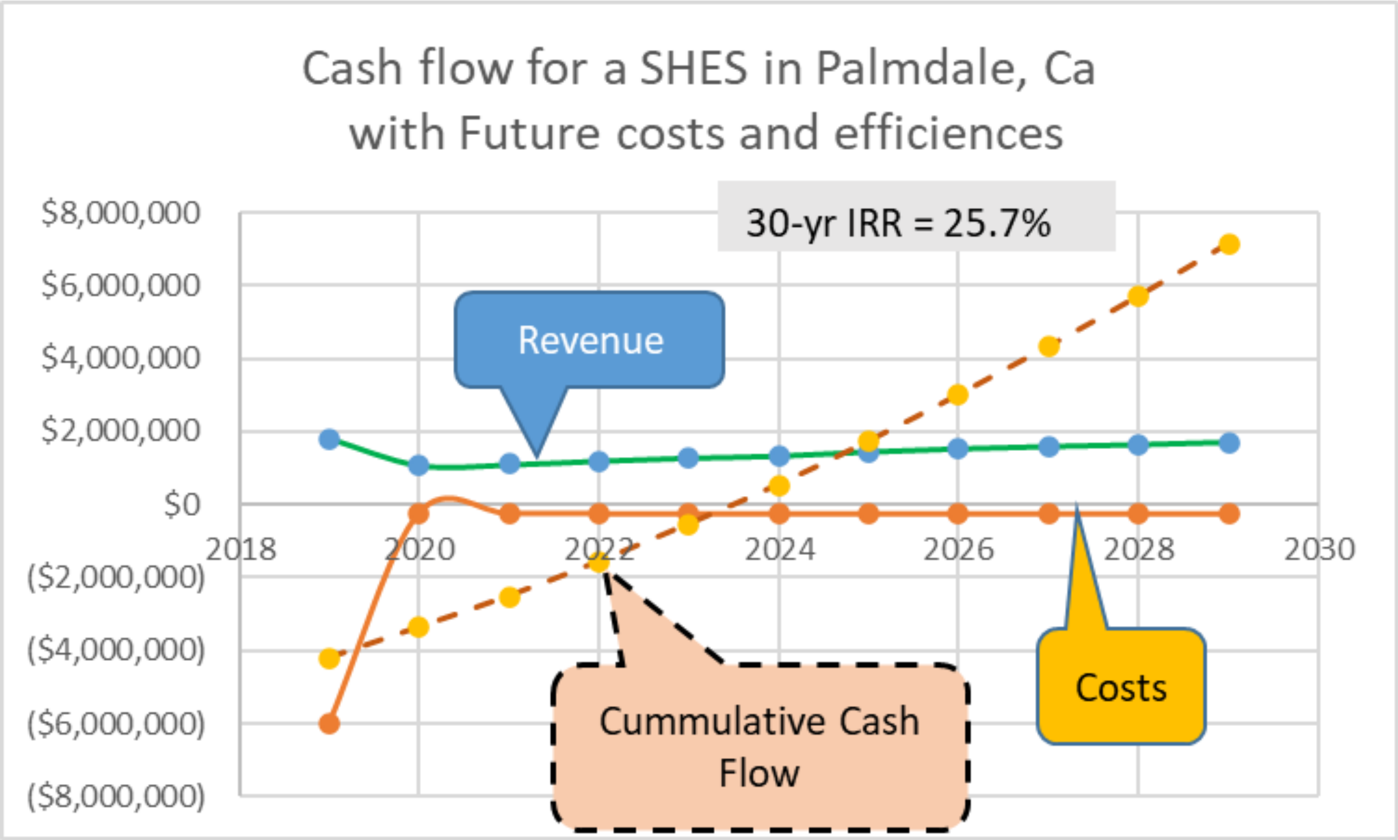
Former President (ret) H2Gen Innovations, Inc.

Alexandria, Virginia

www.solarhydrogen.net


ALL ELECTRICITY AND MOST MOTOR FUEL
COMES FROM THE SUN AND WATER
Solar PV Array
ELECTRICITY
Electricity
Distribution
Grid
ELECTRICITY
WATER
Electrolyzer
HYDROGEN
Compressor
HYDROGEN
FUEL CELL ELECTRIC VEHICLES
Hydrogen Storage
STATIONARY FUEL CELL SYSTEM
Electricity
(At Night &
Cloudy Days)
HYDROGEN
HYDROGEN

Solar Hydrogen Cash Flow Calculation



New York and Palmdale SHES Performance

	New York		Palmdale	
	Current	Future	Current	Future
PV Power (MW)	6.66	5.88	4.64	4.11
30-year IRR	8.8%	21.2%	12.3%	25.7%
Capex ($ Millions)	15.82	8.30	11.14	6.02

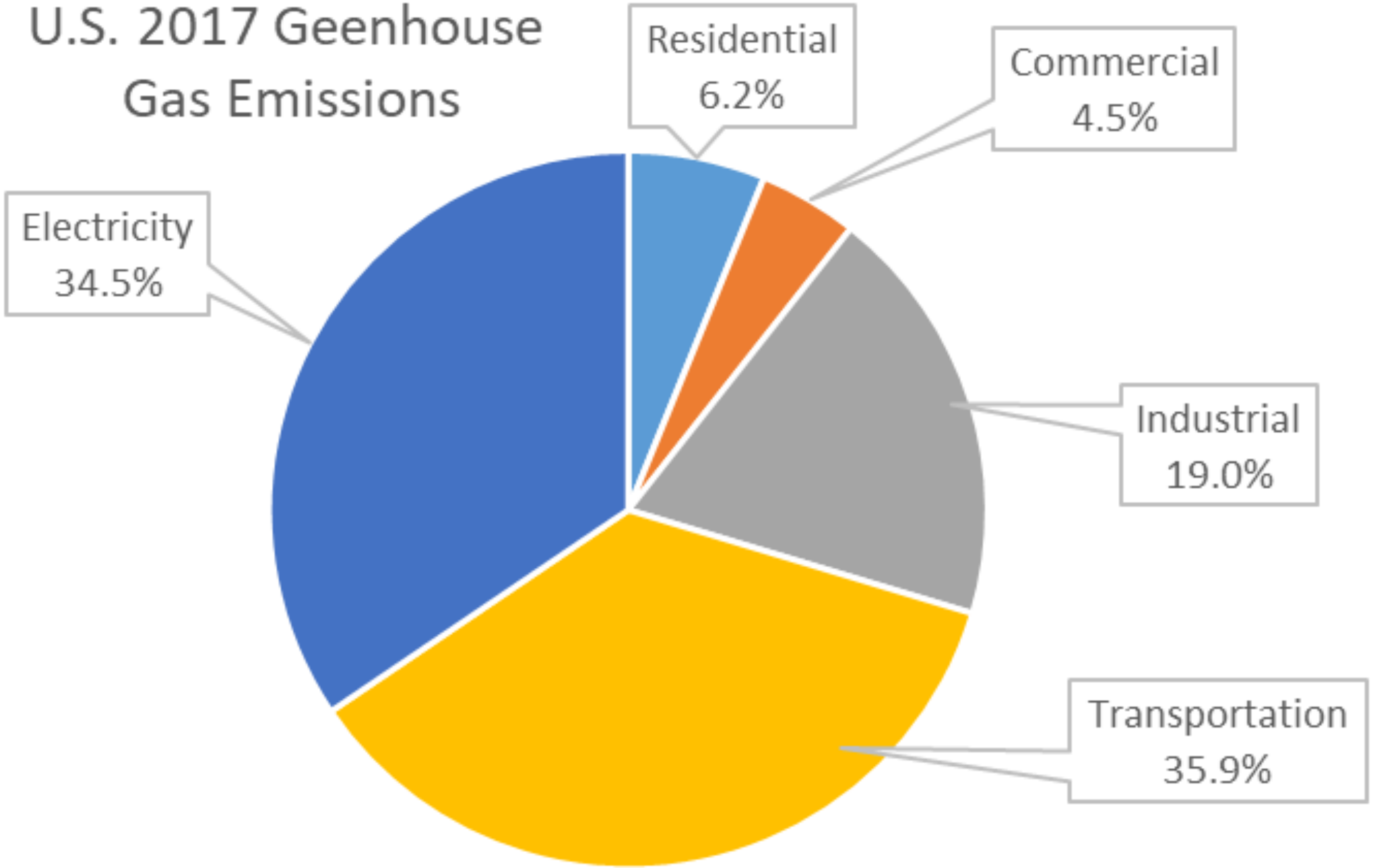
Distributed Power Generator to supply One MW peak and 720 kW average power 24/7

GOAL OF A SOLAR HYDROGEN ENERGY SYSTEM (SHES)

- To meet the 2050 Greenhouse Gas reduction goal

(80% below 1990 levels by 2050)

Sources of US Greenhouse Gas (GHG) Emissions



Current efforts to reduce GHGs are not sufficient

- Adding more renewable electricity to the grid
- Transportation:
  - Battery Electric Vehicles (BEVs)
  - Plug-In Hybrid Electric Vehicles (PHEVs)

Is adding renewable electricity sources enough? Suppose Utilities Install PV Solar Capacity to generate 100% of all electricity

- What fraction of electricity could be provided by solar?

100% Solar Electricity Peak *Capacity* is Not Enough!

Backup Power Required When the Sun is not shining Generates Considerable GHGs:

<u>Average Solar Capacity Factor* </u>Averaged over the top 11 Electricity producing Sates is 55.18%, so Backup Electricity generators must supply a least 44.8% of all U.S. electricity even with 100% solar electricity *Capacity at local noon*:

	Electricity		PV CF
	BkWh/yr	Cumulative %	
TX	454.0	11.9%	54.60%
FL	238.3	18.2%	55.83%
CA	215.1	23.9%	57.37%
PA	197.0	29.0%	52.83%
IL	187.3	34.0%	54.77%
AL	142.4	37.7%	55.72%
NY	133.4	48.2%	56.23%
GA	130.8	44.7%	56.10%
NC	134.4	41.2%	55.04%
OH	118.9	51.3%	55.49%
WA	114.1	54.3%	53.03%
Electricity-Weighted Average			55.18%

*Capacity factor = fraction of electricity load that can be provided by PV solar

PV Back-Up Power Options

- Nuclear (Fission & Fusion)
- Other Renewables
- Fossil Fuel Power Plants

Ratio of GHGs to GHG Goal* in 2050 with low-carbon NGCC backup Power

Non-Electricity GHGs by Sector	2050 GHGs
Residential	288
Commercial	269
Industrial	1650
Transportation	1322
Total non-electricity GHGs	3530
NGCC backup to solar	1108
Total GHG emissions	4638
2050 GHG goal	1279
Ratio GHGs/Goal	**3.63**

These are non-Electricity GHGs in MMT in 2050 according to AEO-2020

MMT = Million Metric Tonnes

*2050 GHG Reduction Goal: 80% below 1990 GHG level

Storage Required for Electricity

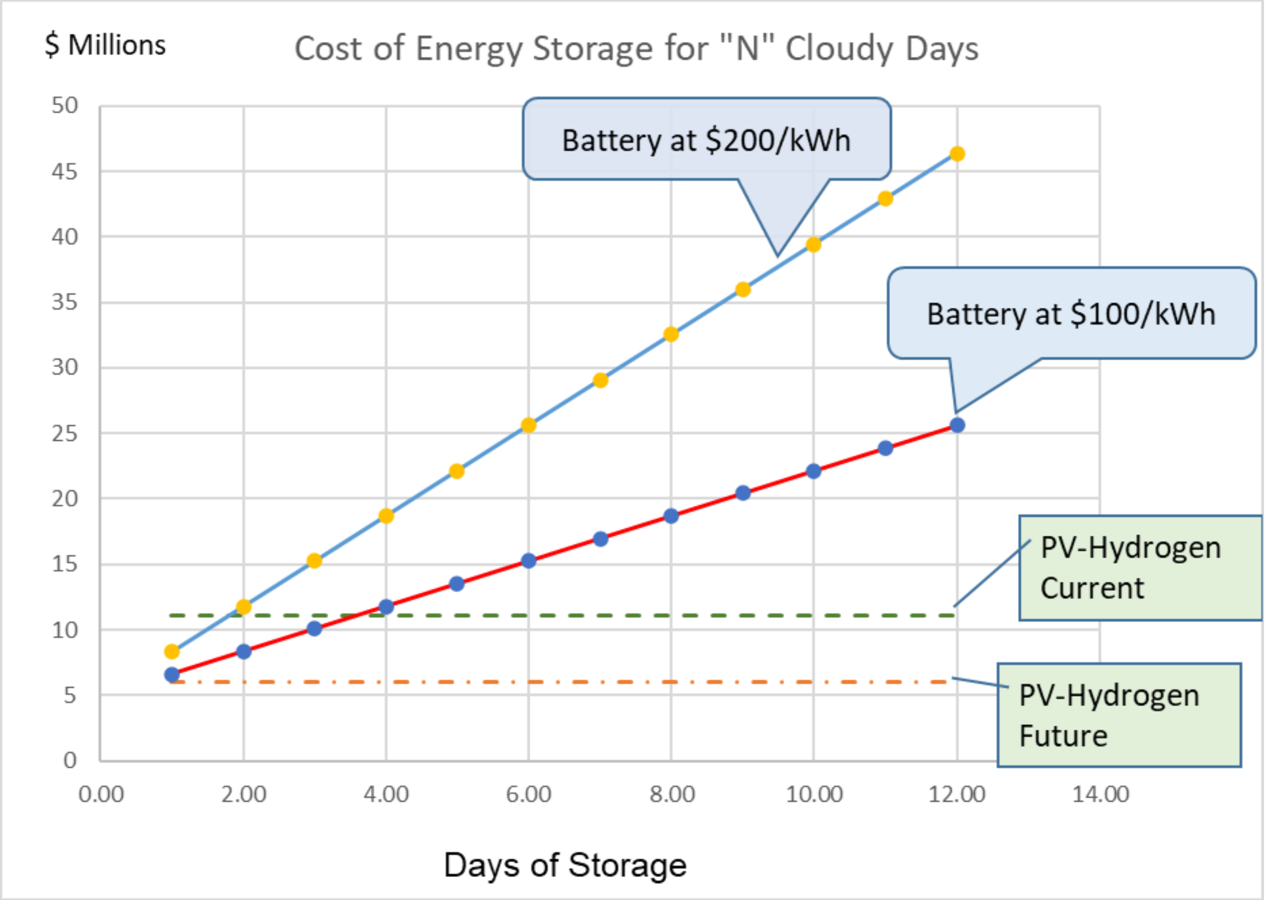
- Even 100% PV Solar will not be sufficient to meet Climate Change Goal (80% reduction below 1990 levels by 2050) due to backup required at night and on cloudy days:

PV Backup Source==>	NGCC	NGCC+CCS	Coal + CCS	
GHG rate	507.2	50.9	219.0	gr/kWh
Residential	288.1	288.1	288.1	MMT
Commercial	269.1	269.1	269.1	MMT
Transportation	1650.1	1650.1	1650.1	MMT
Industrial	1322.3	1322.3	1322.3	MMT
Total non-electricity GHGs	3529.6	3529.6	3529.6	MMT
NGCC PV Solar Backup	1108.4	111.2	478.6	MMT
Total GHGs	4638.0	3640.9	4008.2	MMT
2050 GHG goal	1279.4	1279.4	1279.4	MMT
Ratio of GHGs to goal	**3.63**	**2.85**	**3.13**	

Two Storage Options for Electrical Energy:

- Hydrogen
- Batteries

Short-Term Energy Storage Capital Costs: Hydrogen vs. Batteries



PV Hydrogen for one-MW peak and 720-kW average power 24/7

Seasonal Electricity Storage: Hydrogen vs. Batteries

	Current Data		Future Data	
	PV-H2	PV-Battery	PV-H2	PV-Battery
Battery Energy Cost		\$190/kWh		\$100/kWh
Battery Power Cost		\$400/kW		\$256/kW
Peak Storage (kWh)	1,409,351	1,028,149	1,210,022	1,028,149
PV Peak Power (kW)	4,636	2,474	4,110	2,474
PV Cost(\$/kW)	\$1,090/kW	\$1,090/kW	\$708/kW	\$708/kW
	Total costs (\$Millions)			
PV Cost	4.85	2.70	3.37	1.75
Electrolyzer Cost	4.22		1.14	
Storage & Compression	1.18		1.05	
Fuel Cell Cost	0.89		0.47	
Battery Power Cost		0.99		0.63
Battery Energy Cost		195.3		102.8
Total Capex	11.14	199.03	6.02	105.20
Ratio of PV-Battery to PV-H2 cost=>		**17.9**		**17.5**

All for 1 MW Peak Power and 720 kW average power plus storage for 100 vehicles (BEVs or FCEVs)

Transportation GHG reduction options

- Hybrid Electric Vehicles (HEVs)
- Plug-In Electric Vehicles (PHEVs)
- Battery Electric Vehicles (BEVs)
- Fuel Cell Electric Vehicles (FCEVs)

Electric Vehicles: Battery vs. Hydrogen?

- Battery Electric Vehicles (BEVs)
  - Cost More
  - Generate More GHGs (even if hydrogen is made from natural gas)
  - Take Longer to Refuel
  - Have Shorter Range
  - More Difficult to power heavy vehicles such as buses, trains, military vehicles, and planes
- Compared to Fuel Cell Electric Vehicles (FCEVs)

Conclusions

1. Current Greenhouse gas reductions efforts (renewable energy and energy efficiency) are not sufficient
2. [even with 100% Solar *capacity with natural combined cycle (the lowest carbon back-up),* utilities would still generate 3.6 times the Greenhouse gas reduction goal
3. We must have energy storage (batteries or hydrogen) to fully exploit renewables
4. **Battery storage costs 17 times more than hydrogen storage**
5. SHES Enables the GHG reduction goal (80% below 1990 levels by 2050)
6. No Government Mandates or Expenditures Required
7. Oil Imports Eliminated

THANK YOU

For details,

See www.solarhydrogen.net

Questions?

Back-Up Slides showing cash flows

Example of Five-Year Cash Flow: Palmdale with future efficiencies and costs

	2019	2020	2021	2022	2023
	Year 1	Year 2	Year 3	Year 4	Year 5
Gasoline cost ($/gallon)	3.33	3.89	4.22	4.43	4.62
Building electricity per year (kWh/yr)	6,348,742	6,348,742	6,348,742	6,348,742	6,348,742
Net energy delivered	6,348,742	6,348,742	6,348,742	6,348,742	6,348,742
T&I		$22,156	$22,156	$22,156	$22,156
O&M		$195,805	$195,805	$195,805	$195,805
Down Payment = 100%	$ 6,018,654				
Purchased electricity during PV-H2 downtime	kWh/yr	190,462	190,462	190,462	190,462
Downtime purchased electricity costs		$ 31,560	$ 31,502	$ 34,074	$ 35,959
PEM FC & electrolyzer replacment costs					
Total annual costs	$ 6,018,654	$249,521	$249,464	$252,035	$253,920
	Year 1	Year 2	Year 3	Year 4	Year 5
PV Investment tax credit = 30 %	$ 1,805,596				
solar buyback electricity price (c/kWh)	16.59	16.57	16.54	17.89	18.88
Com. electricity price (c/kWh)	16.59	16.57	16.54	17.89	18.88
Avoided Carbon tax on 703 kW electricity		$ 37,072	$ 50,691	$ 64,147	$ 78,883
Carbon tax ($/tonne)	$16.54	$27.56	$38.59	$49.61	$60.64
Avoided heating costs		$1,389	$1,532	$1,777	$1,968
Electricity sales		$1,051,987	$1,050,082	$1,135,790	$1,198,643
Total revenue	$1,805,596	$1,090,448	$1,102,304	$1,201,715	$1,279,494
cash flow	(4,213,057)	840,928	852,841	949,680	1,025,573
15-yr IRR	23.86%				
30-yr IRR	**25.68%**				

Example of Five-Year Cash Flow: New York with future efficiencies and costs

	2019	2020	2021	2022	2023
	Year 1	Year 2	Year 3	Year 4	Year 5
Net energy delivered	6,348,742	6,348,742	6,348,742	6,348,742	6,348,742
T&I		$30,556	$30,556	$30,556	$30,556
O&M		$278,180	$278,180	$278,180	$278,180
Down Payment = 100%	$ 8,300,478				
Purchased electricity during PV-H2 downtime	kWh/yr	190,462	190,462	190,462	190,462
Downtime purchased electricity costs		$ 37,368	$ 38,403	$ 39,944	$ 40,949
PEM FC & electrolyzer replacment costs					
Total annual costs	$ 8,300,478	$346,105	$347,139	$348,680	$349,685
	Year 1	Year 2	Year 3	Year 4	Year 5
PV Investment tax credit = 30 %	$ 2,490,143				
solar buyback electricity price (c/kWh)	17.70	19.62	20.16	20.97	21.50
Com. electricity price (c/kWh)	17.70	19.62	20.16	20.97	21.50
Avoided Carbon tax on 703 kW electricity		$ 38,014	$ 51,978	$ 65,776	$ 80,885
Carbon tax ($/tonne)	$16.54	$27.56	$38.59	$49.61	$60.64
Avoided heating costs		$1,389	$1,532	$1,777	$1,968
Electricity sales		$1,245,611	$1,280,086	$1,331,474	$1,364,952
Total revenue	$2,490,143	$1,285,014	$1,333,595	$1,399,027	$1,447,806
cash flow	(5,810,334)	938,909	986,456	1,050,347	1,098,121
15-yr IRR	18.59%				
30-yr IRR	**21.23%**				