Electrolysis Overview

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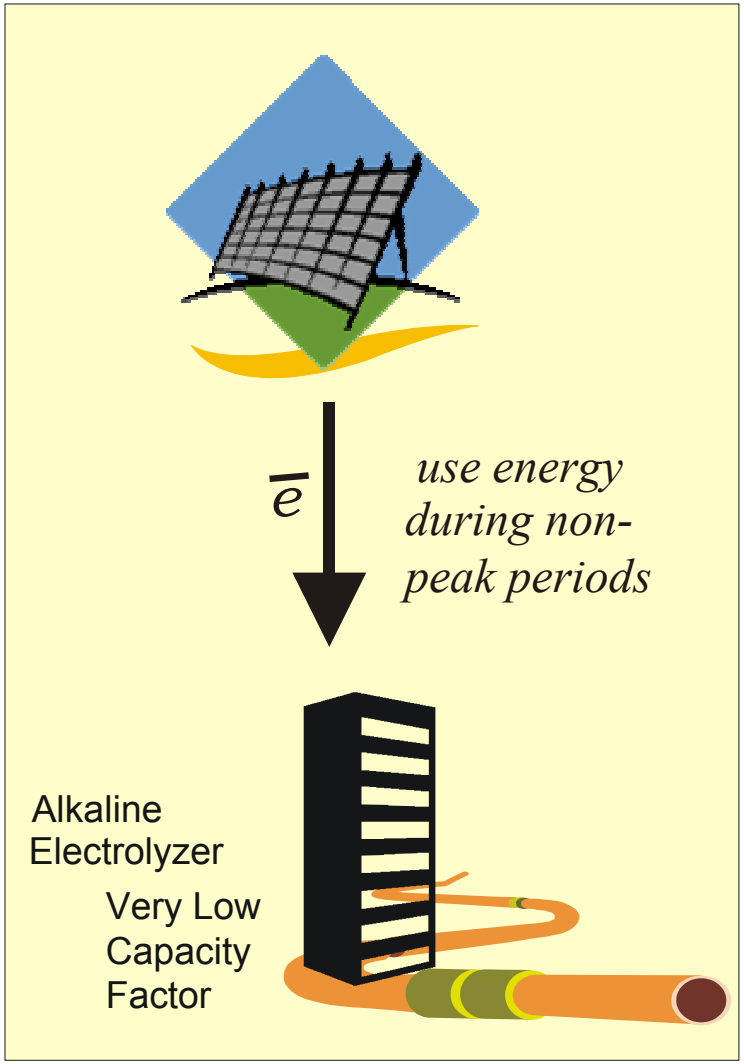
Topics of Interest

- **Initial analysis of solar electrolysis**
- *Resource availability*
- *Electricity costs for hydrogen fueling stations*
- *Power requirements of Electrolysis fueling stations*

Solar Electrolysis Analysis

- 1997-1998 study
- Based on deregulated electricity marketplace
  - Assumes retail time based energy pricing
    - On-peak ~650 (retail -14 cents/kWh)
    - Off-peak for ~5000 hours/year (6 cents/kWh)
    - Super off-peak ~3,100 hours/year (5 cents/kWh)
- 10 MW capacity electricity production
- Wheeling charges included
- No hydrogen storage
- Alkaline electrolyzer at $600/kW capital cost
- PV generation ~$3000/kW DC out

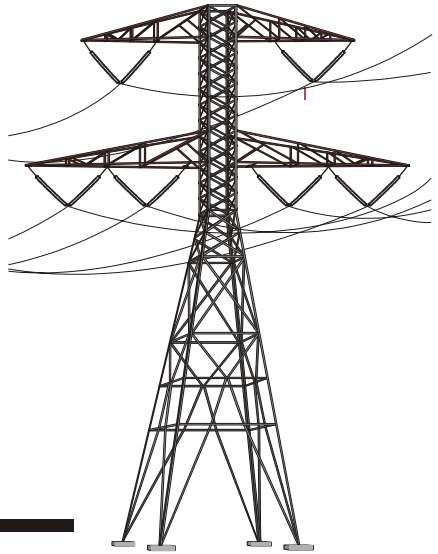
Scenario 1: electricity produced from solar used to make hydrogen



H_2 *produced when renewables operate*

Scenario 2a: hydrogen from solar + grid electricity to baseload electrolyzer

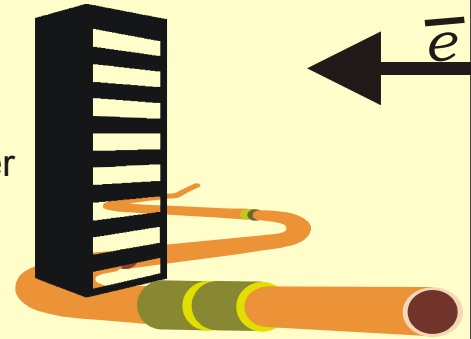
$\bar{e}$ *use all renewably-produced electricity*



$\bar{e}$

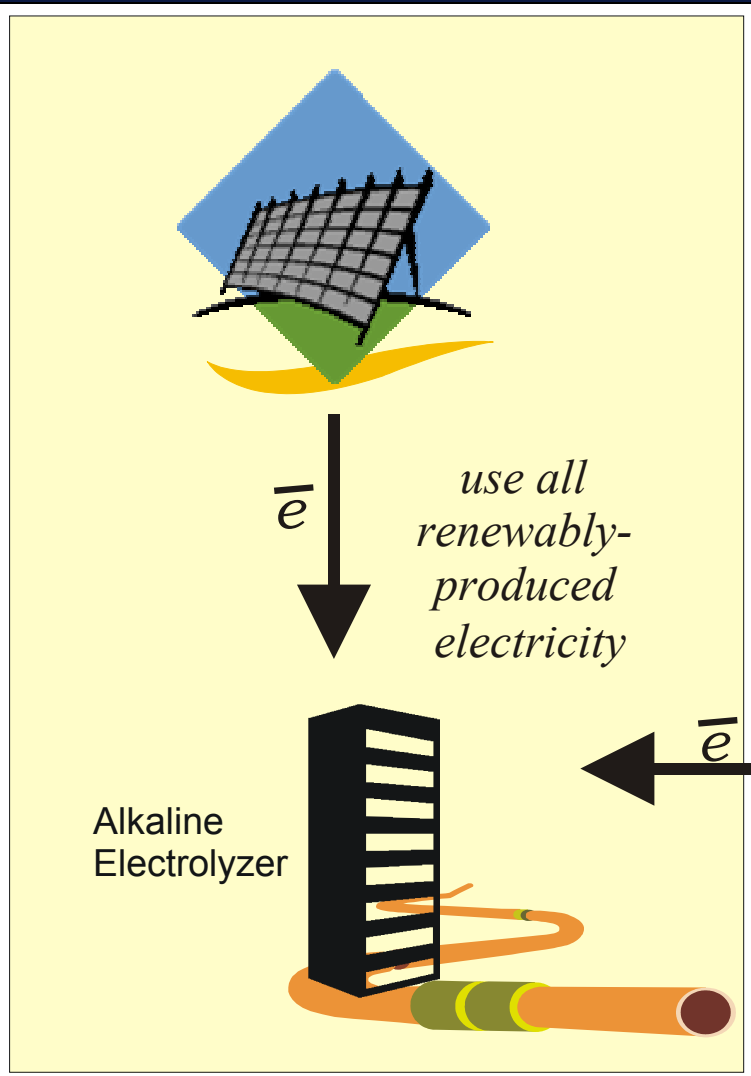
purchase enough energy to baseload electrolyzer

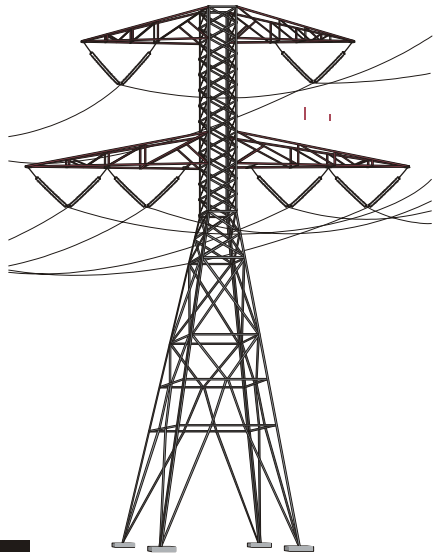
Alkaline Electrolyzer



H_2 *produced 95% of the year*

Scenario 2b: hydrogen produced from solar + non-peak grid electricity

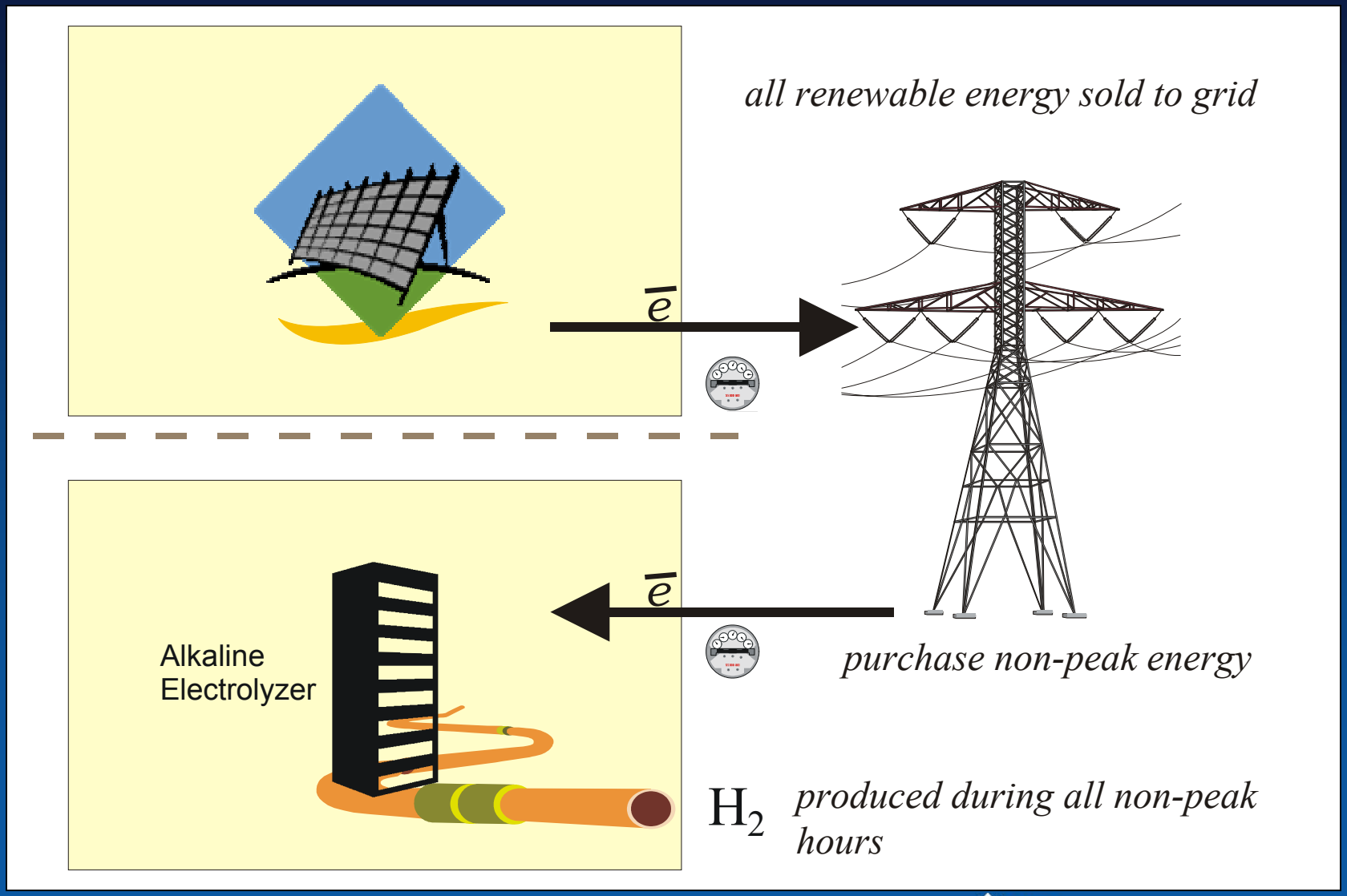




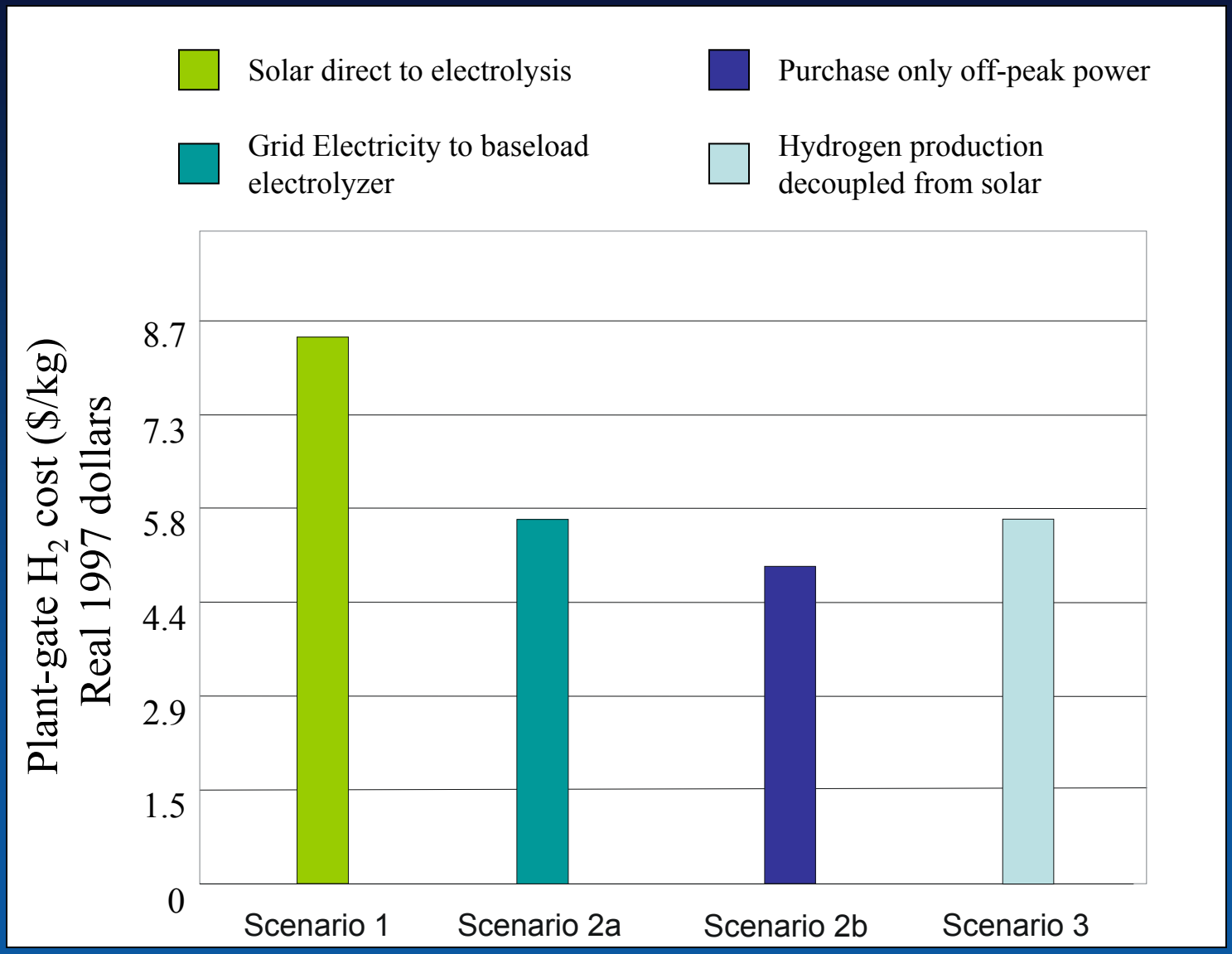
purchase non-peak energy when renewable isn't operating

H_2 produced during all non-peak hours and on-peak hours when renewables operate

Scenario 3: hydrogen production decoupled from renewables



The Potential Payoff



Initial Analysis Results

- Cost advantages exist when the capacity factor of the electrolyzer is increased over the capacity factor of the solar system
  - However baseloading is not required
  - Trade off between low cost electricity and electrolyzer capacity factor
  - Advantages to being able to use off peak electricity
- Further study is needed to determine the optimum balance of selling high and buying low grid electricity

Topics of Interest

- *Initial analysis of solar electrolysis*
- **Resource availability**
- *Electricity costs for hydrogen fueling stations*
- *Power requirements of Electrolysis fueling stations*

Renewable Resources for H_2

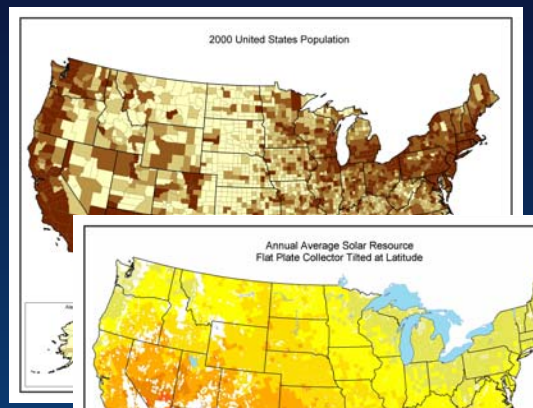
- Where are the solar resources for hydrogen generation?
- How much hydrogen can be generated from solar energy in the U.S.?
  - Today's electrolyzer: 62 kWh/kg (55% efficiency, LHV, 63% HHV)
  - Average yearly solar data, 100 km^2 grids
- How much hydrogen does this represent per person?
- What fraction of the U.S. motor gasoline consumption can be met with this hydrogen?

Solar Assumptions

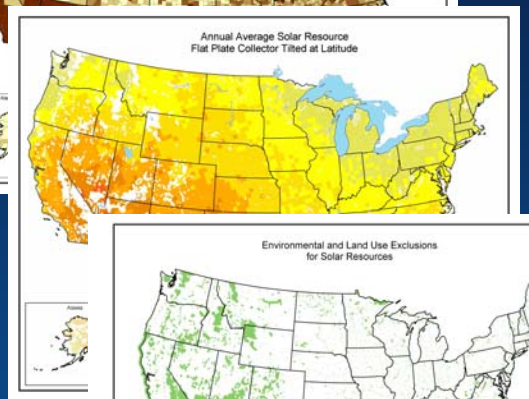
- Non-Tracking Flat Plate Collector Tilted at Latitude
- Any given cell will have no more than 10% of its land area dedicated to PV development
  - 30% of this area will actually be covered with solar panels (total of 3% land coverage)
- Solar energy can be converted to electricity at an average system efficiency of 10%
- Exclusions include: National Parks, Fish and Wildlife service lands, specially designated lands, water, wetlands and airports

Creation of Solar Resource Map

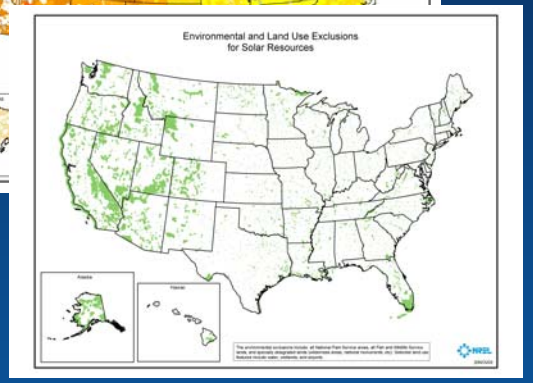
U.S. Population Distribution

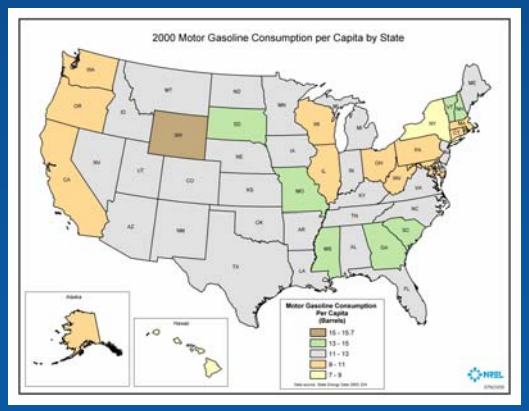


Solar Resources in the U.S.



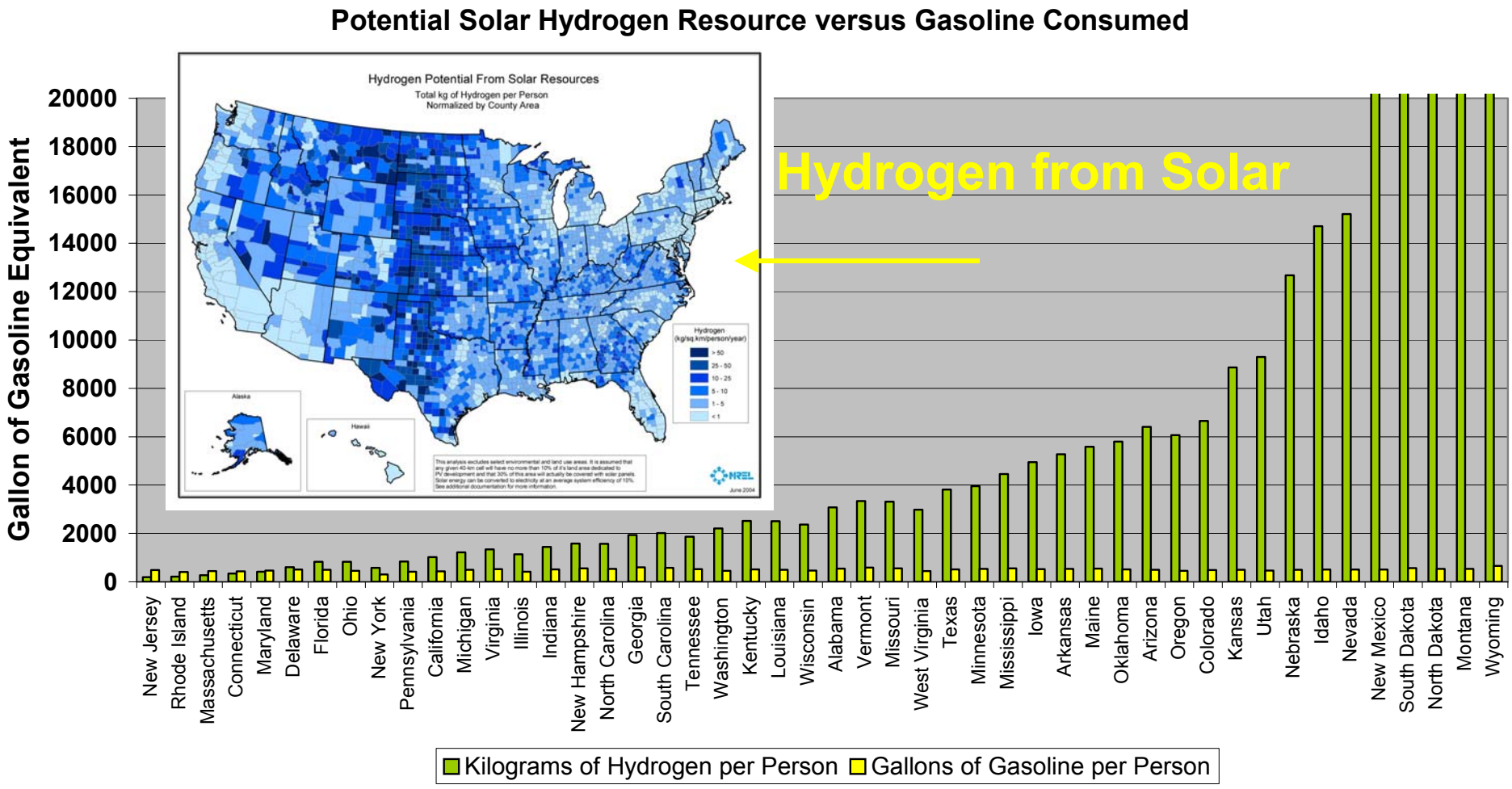
No Solar Allowed Here





Compare potential hydrogen production to year 2000 gasoline consumption by state

Solar Hydrogen Potential versus Gasoline Consumed by State



Summary of Results

- All but 5 states in the continental United States have enough solar resources to meet transportation needs at state level
  - New Jersey, Rhode Island, Massachusetts, Connecticut, Maryland are the exceptions
- Minimum: New Jersey, 194 kg H_2/person/year/state
  - 0.4 times the gasoline consumption
- Maximum: Wyoming 51,000 kg H_2/person/year/state
  - 78 times the gasoline consumption
- Study does not quantify how much hydrogen from solar will cost; need to employ other analysis methodologies

Topics of Interest

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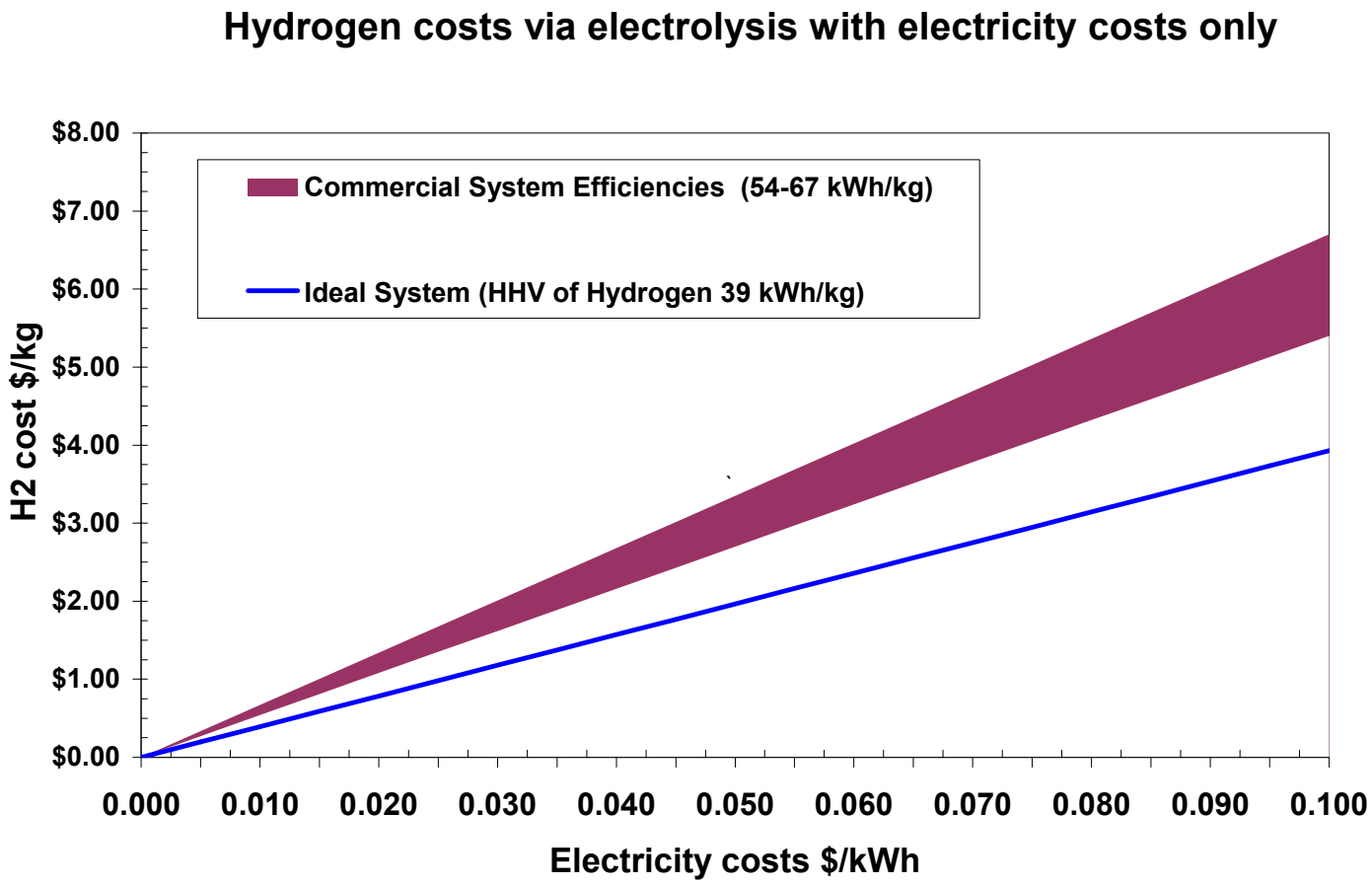
- *Power requirements of Electrolysis fueling stations*

Electrolysis - Electricity Costs are Key



Hydrogen < $3.00/kg

Today's systems electricity costs must be between 4 and 5.5¢/kWh.

For ideal systems, electricity prices must be less than 7.5¢/kWh

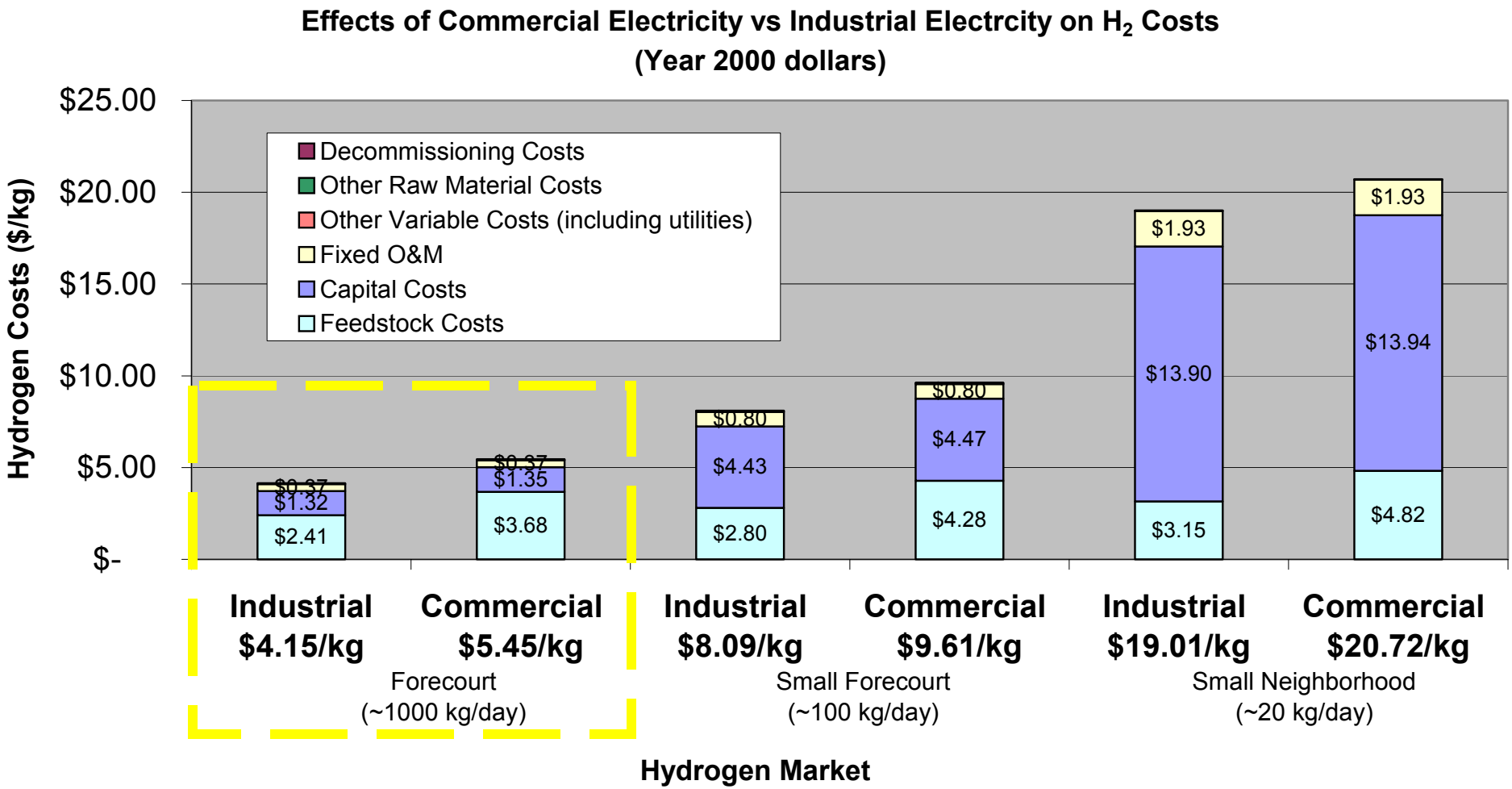
Definition of Hydrogen Production Scenarios

Scenario	Number of Cars Served	Hydrogen produced kg/year
Home	1-5	200-1000
Neighborhood	5-50	1000-10000
Small Neighborhood	50-150	10,000-30,000
Small Forecourt	150-500	30,000 – 100,000
Forecourt	**>500**	**> 100,000**

Details of Analysis

- Analysis of the current state of electrolysis
- Three systems analyzed, detailed economic information will remain confidential
  - Forecourt
  - Small Forecourt
  - Small Neighborhood
- Discounted cash flow analysis
  - 10% IRR
- Industrial and commercial electricity pricing
  - EIA projections

Hydrogen Costs - Industrial and Commercial Electricity



Driving cost of hydrogen (Industrial Electricity)

- Forecourt case
  - electricity represents 58% of the cost at $2.41/kg
  - capital costs 32%
- Small forecourt case
  - electricity represents 35% of the cost at $2.80/kg
  - capital costs 55%
- Small neighborhood case
  - electricity represents 17% of the cost at $3.15/kg
  - capital costs 73%

Improving efficiency will help, but electricity price is crucial

Increase in electricity costs → increase in hydrogen costs

- Forecourt case
  - Hydrogen price increase from $4.15/kg to $5.45/kg, an increase of 31%.
- Small forecourt
  - Hydrogen price increases from $8.09/kg to $9.61/kg, an increase of 19%.
- Small neighborhood case
  - Hydrogen price increases from $19.01/kg to $20.72/kg, an increase of 9%.
- As electrolysis technology improves capital costs will become less of a factor for smaller systems and the effect of higher electricity costs will be significant for all systems.

Where does Solar fit in?

- Solar can be a winner in niche markets with high solar availability and limited grid connections for hydrogen production, but can it work economically in other markets?
- Can solar be effectively combined with other green sources to provide a higher electrolyzer capacity factor?
- What is the cost of solar generated energy?
  - Can it be used to peak shave when electricity prices are high?
  - Can it be used to supplement wind-electrolysis systems?
- Direct DC can be fed to electrolyzer. What are the system cost savings/advantages?

Topics of Interest

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- **Power requirements of Electrolysis fueling stations**

Electrolyzer Energy Requirement

Size	Manufacturer Model	Number of Cars Served	Hydrogen Production Rate	Annual energy required for H2 production
			kg/hr	MWh/year
Home	Avalence Hydrofiller 15	1.5	0.04	18
Home	Proton HOGEN 20	2	0.04	26
Small Neighborhood	Stuart IMET 300	12	0.3	131
Neighborhood	Norsk HPE 24	94	2.2	1007
Neighborhood	Teledyne EC-500	110	2.5	1380
Small Forecourt	Teledyne EC-750	165	3.8	2060
Forecourt	Norsk Atmospheric Type No.5040 (5150 Amp DC)	1900	43.6	20,400

Can Solar meet these power requirements?

- If fueling stations were put next to grocery stores, discount stores, etc. how much power could be produced from rooftop arrays?
- If fueling stations were neighborhood stations, could the solar systems be co-located?
- Could home fueling be powered by rooftop PV panels?

Topics of Interest - Conclusions

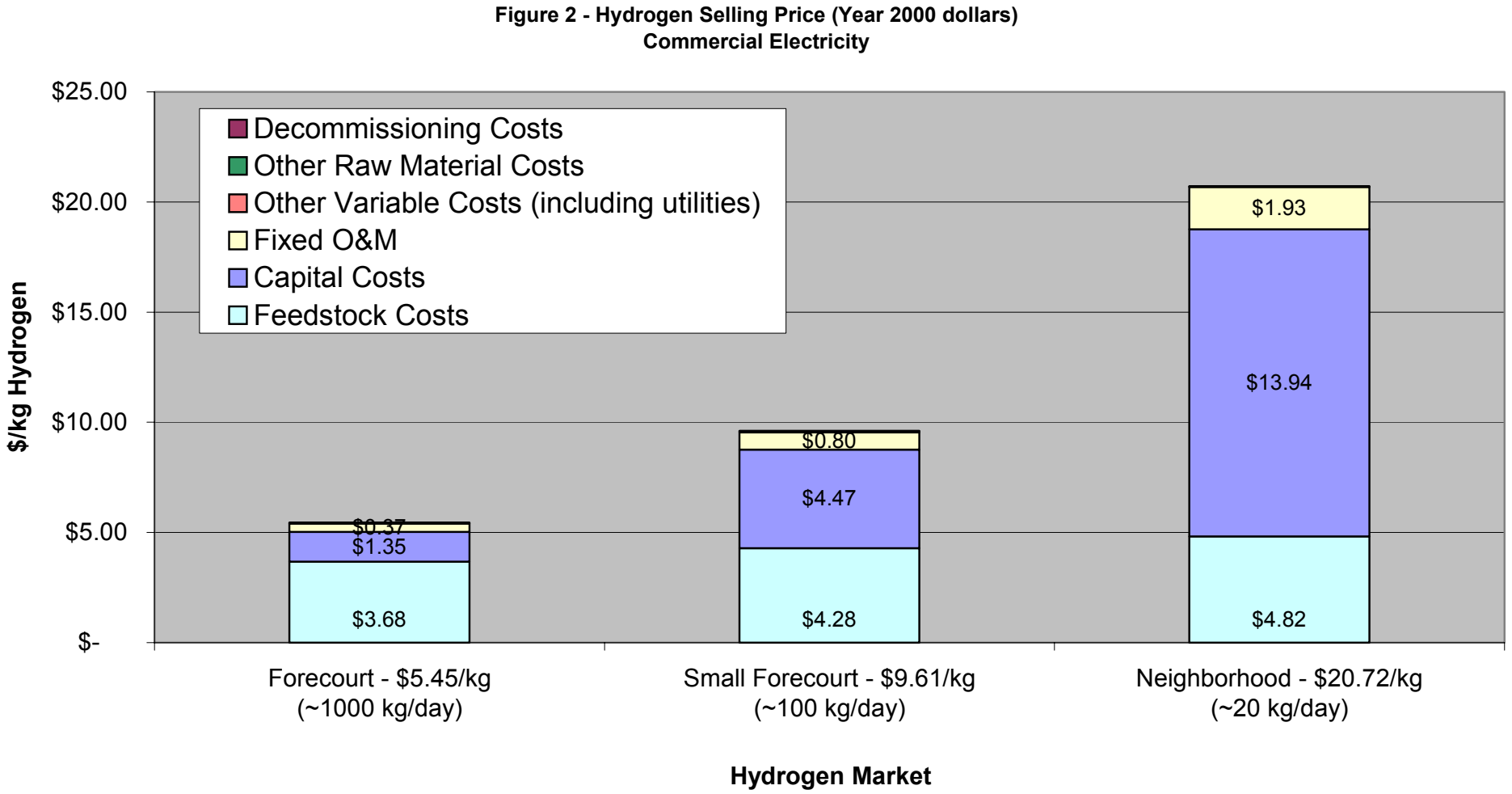
- **Initial analysis of solar electrolysis**
  - Advantages to increasing the capacity factor of the electrolyzer by supplementing solar hydrogen systems with off peak grid electricity
- **Resource availability**
  - Nationally there is enough solar energy resources to meet hydrogen needs, but some states fall short.
- **Electricity costs for hydrogen fueling stations**
  - Hydrogen costs are largely dependent on electricity costs.
- **Power requirements of Electrolysis fueling stations**
  - A large 2000 kg/day (3600 car) station would require at least 40 GWh/year

Next Steps

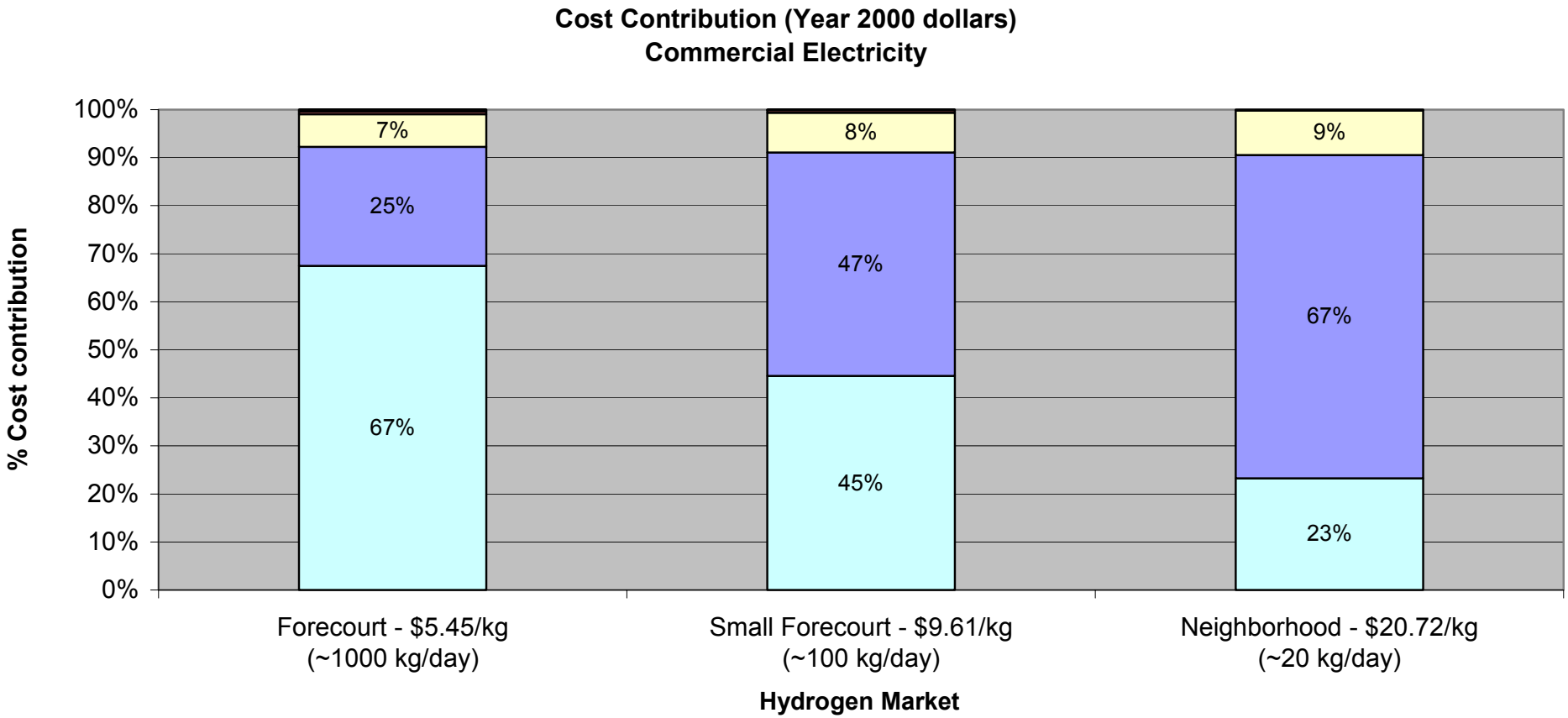
- Determine optimum configuration of solar/grid/electrolyzer system
- Investigate potential hardware advantages of solar/electrolysis systems
- Investiagate non-PV solar options
- Consider sizes of solar systems needed for different hydrogen production rates
- Establish costs for hydrogen production in various regions in the United States using solar energy

Thank You

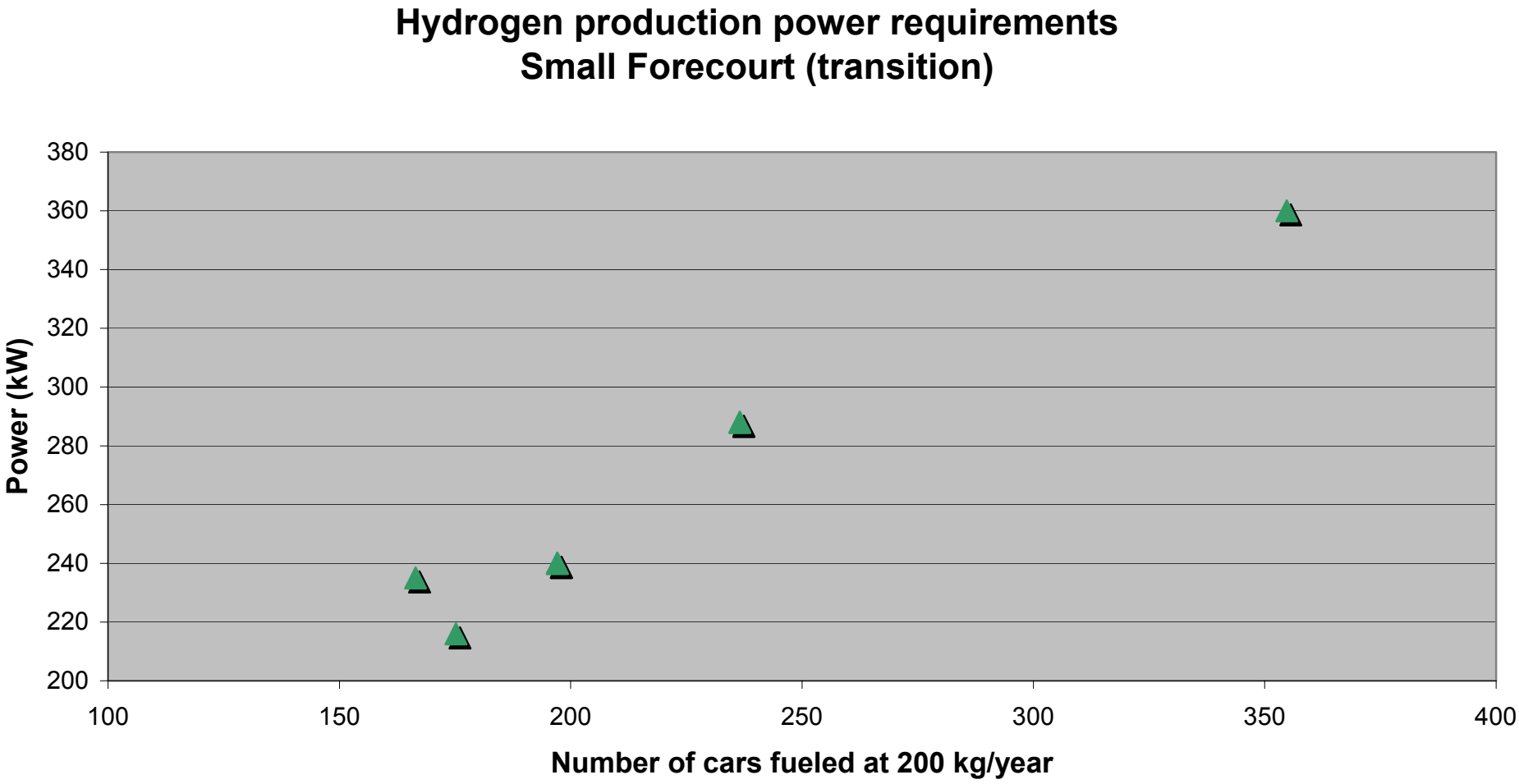
Hydrogen Costs with Commercial Electricity



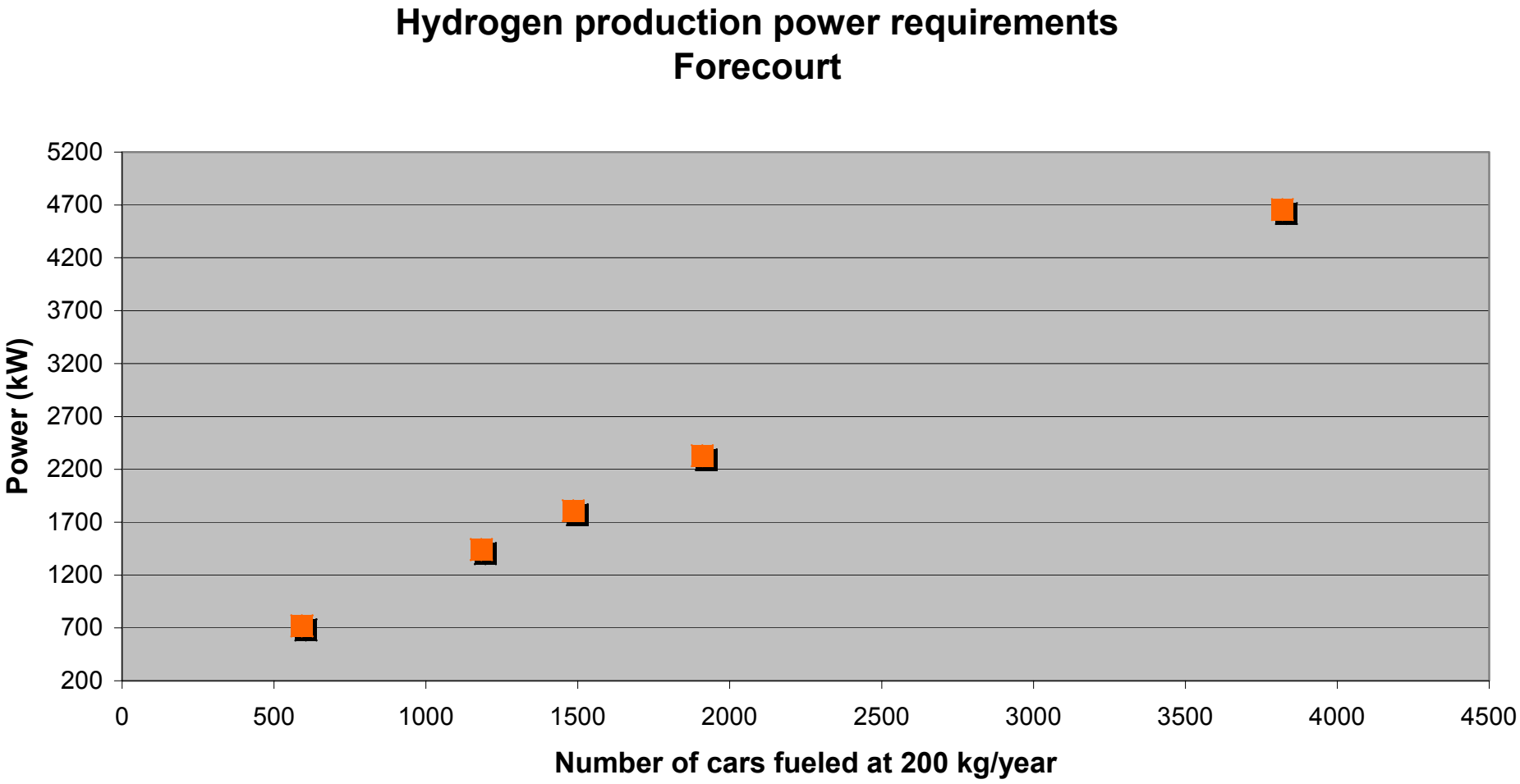
Hydrogen Costs with Commercial Electricity



Near Term Transition Station Sizes



Long Term Station Sizes



Energy and Power requirements by size

- A large 2000 kg/day (3600 car) station would require at least 40 GWh/year (4.6 MW)
- A small forecourt station with one pump would require at least 2.1 GWh/year (240 kW)
- A neighborhood station would require
  - 210 MWh/year (24 kW) to serve 20 cars
  - 1.4 GWh/year (157 kW) to serve 110 cars
- A home station would require 18-26 MWh/year (2-3 kW) per home

Hydrogen from Solar
(per km^2 per person)