A Hybrid Solar Concentrator for the Electrolytic Production of Hydrogen

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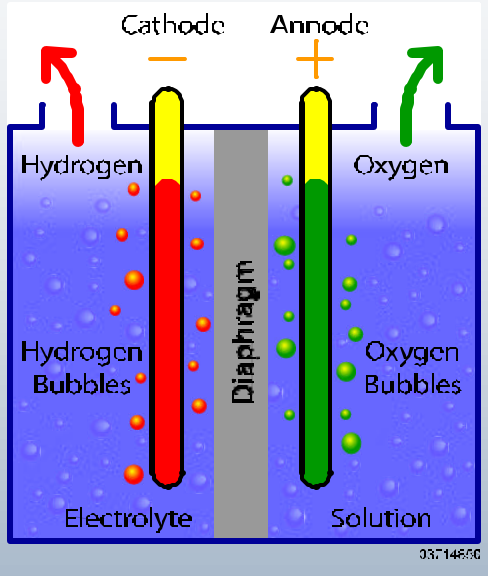
Reasons for Exploring Hydrogen Production through Concentrated Solar Energy and Electrolysis

- CO_2-free energy and feedstock
  - Needs only solar energy and water
- Potential for sharply reduced costs of hydrogen production from a renewable resource---hybrid technology uses both solar thermal energy and phovoltaic electricity.
  - One of 4 fundamental technological and economic challenges identified by NRC/NAE ("The Hydrogen Economy" 2004)
  - International cost studies predict $800/kW and less for concentrator photovoltaic systems at GW-production levels
- Potential for distributed hydrogen production
  - Recommendation ES-5 in NRC/NAE study states distributed hydrogen production systems deserve increased R&D support

Renewable Hydrogen Production via Electrolysis

Wind



Photovoltaics (PV)

Concentrated Solar Thermal (Stirling engine)

Concentrator Photovoltaic Systems

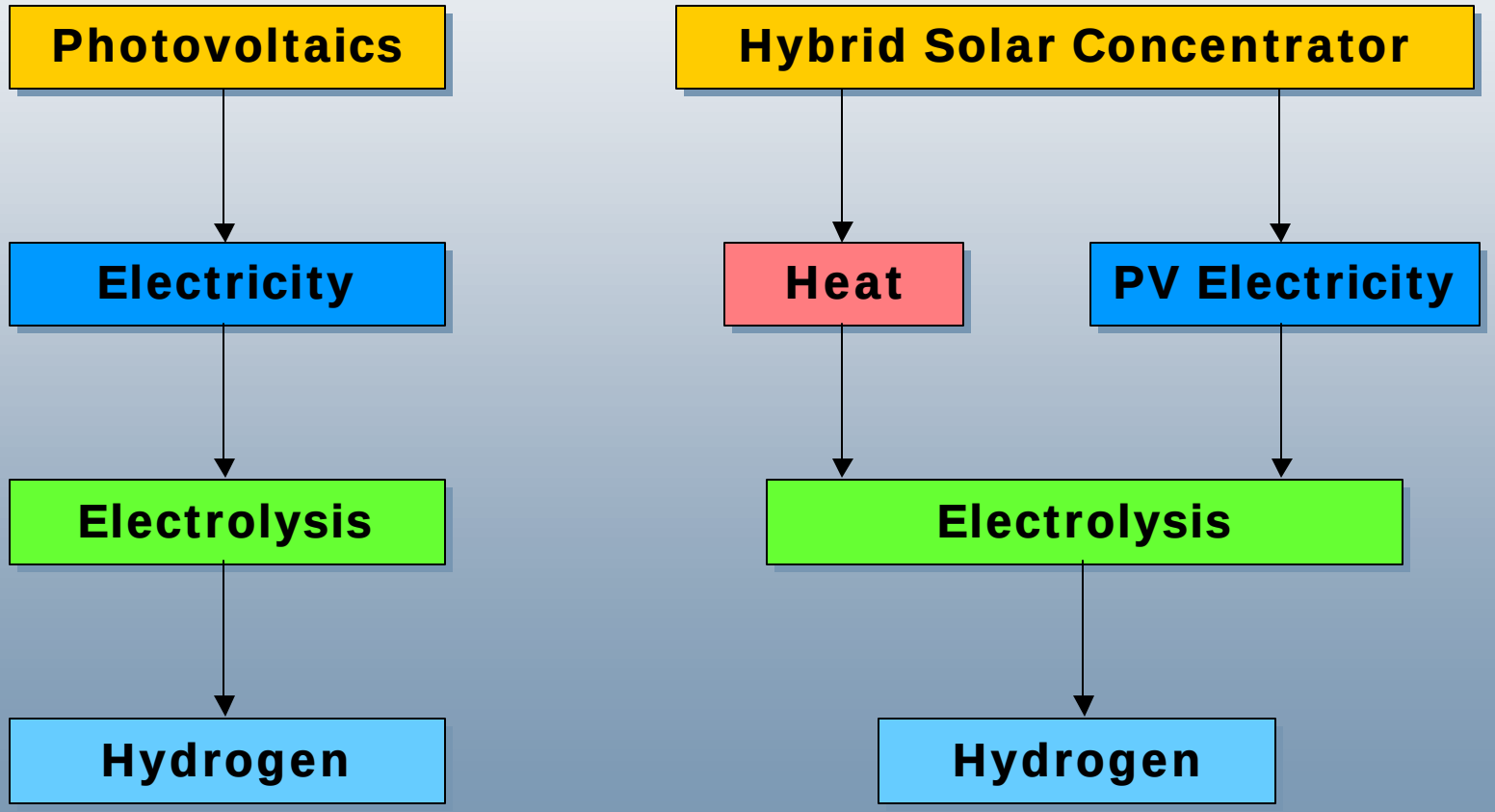
Linear Reflecting

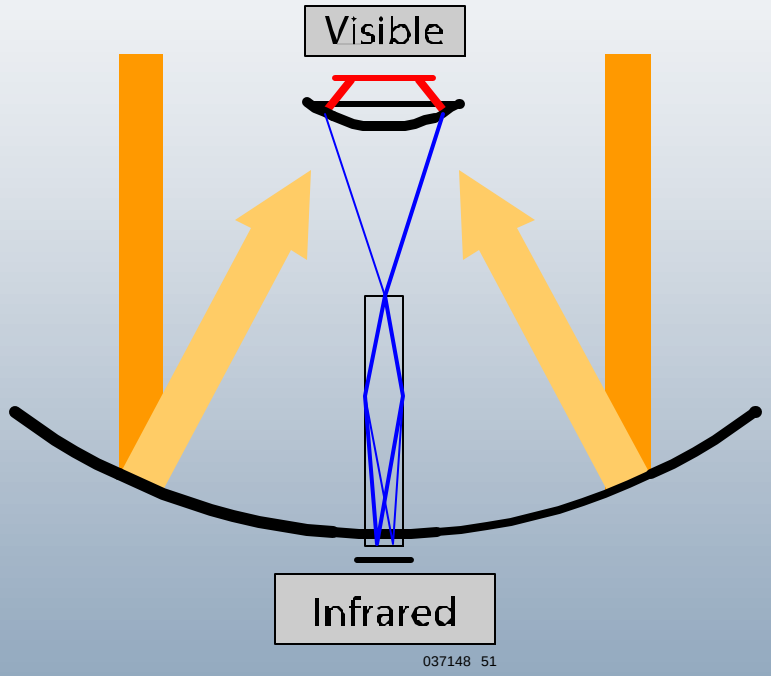
Point Focus Reflector and its 20kW Receiver

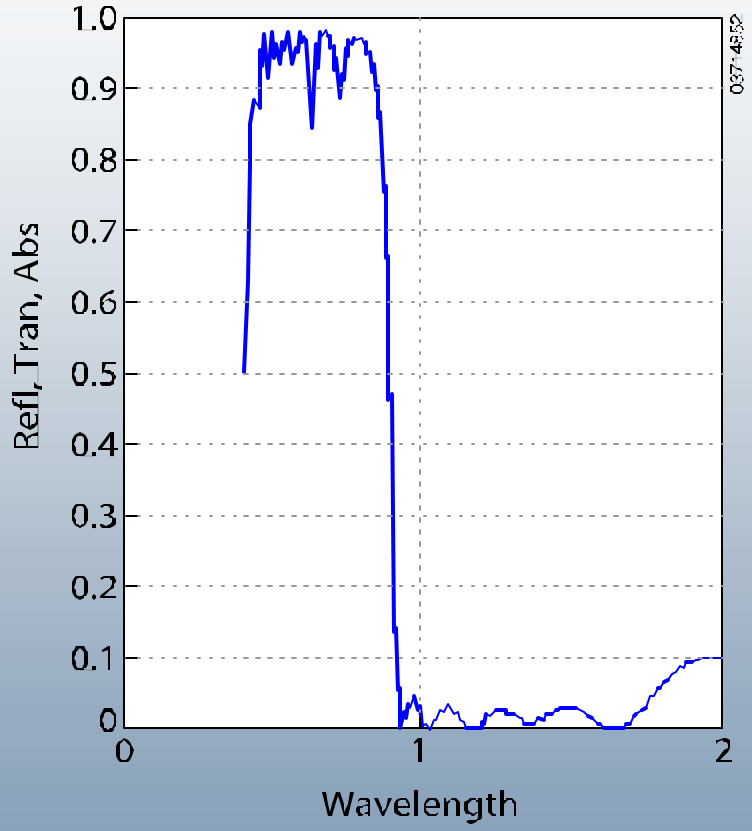
25 kW Point Focus Fresnel Lens

Linear Fresnel Lens

Two Photovoltaic Pathways for Producing Hydrogen by Electrolysis

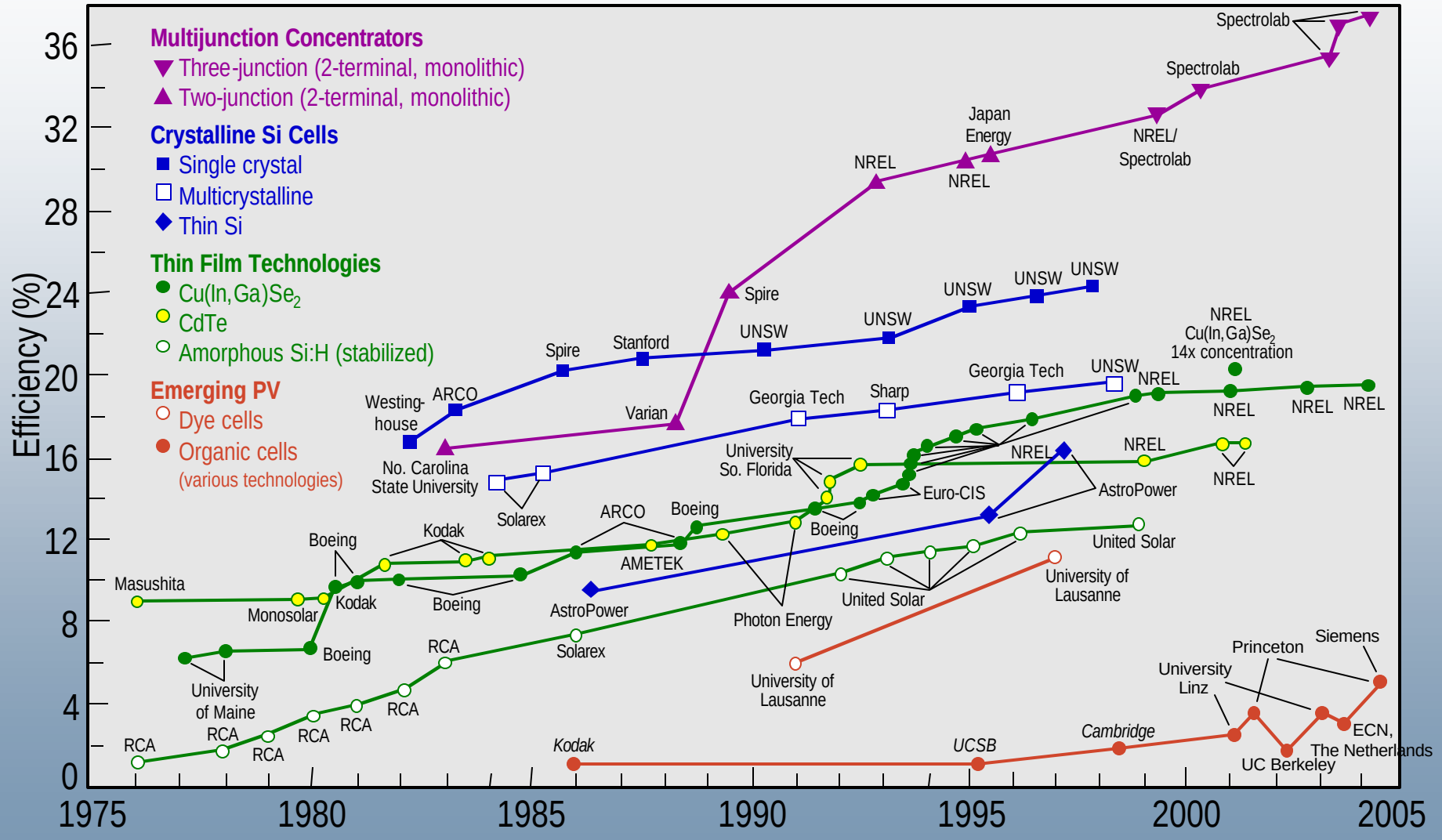


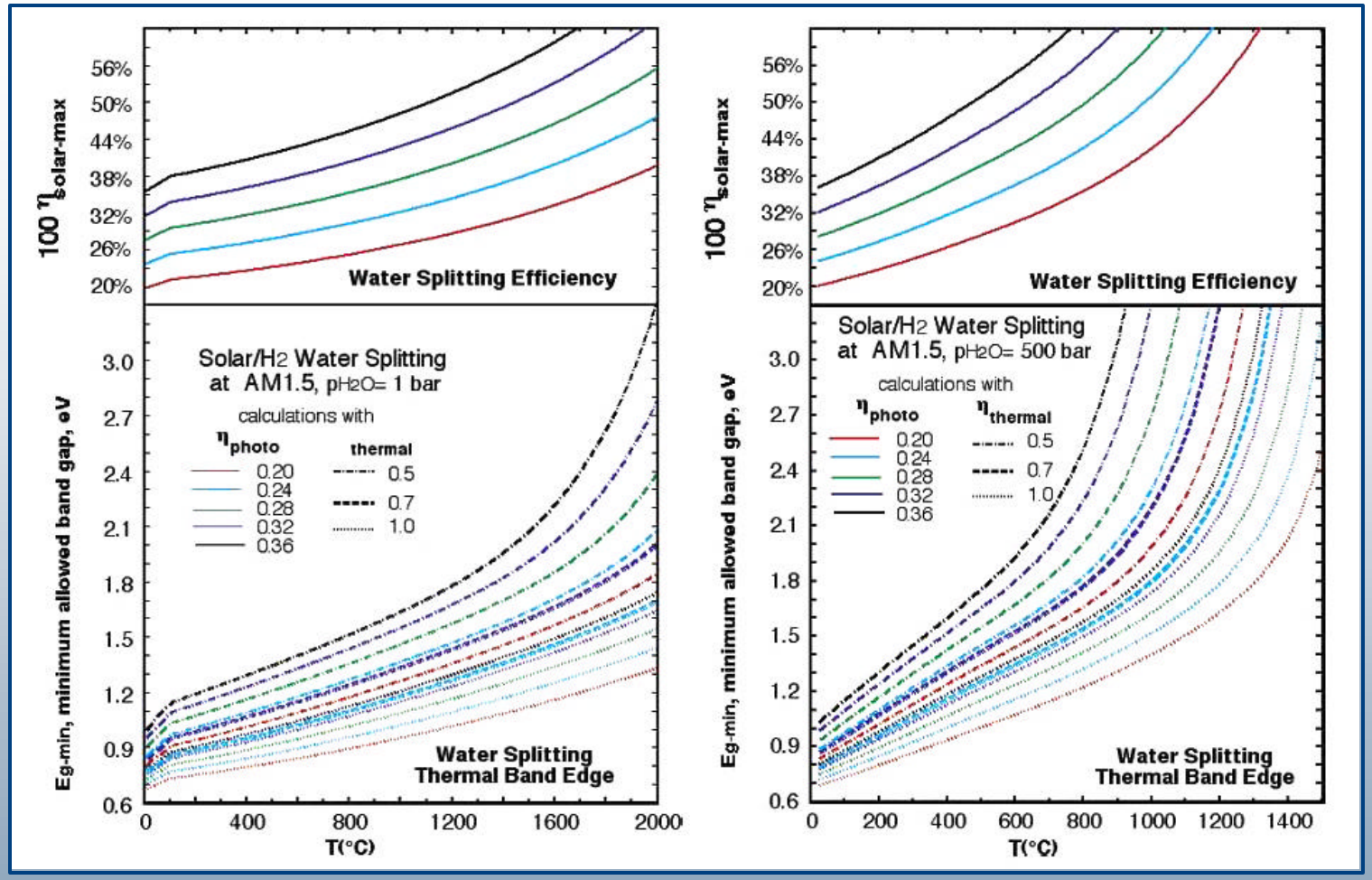




Solar concentrator splitting infrared radiation from visible to generate heat or additional electricity using a thermophotovoltaic cell.

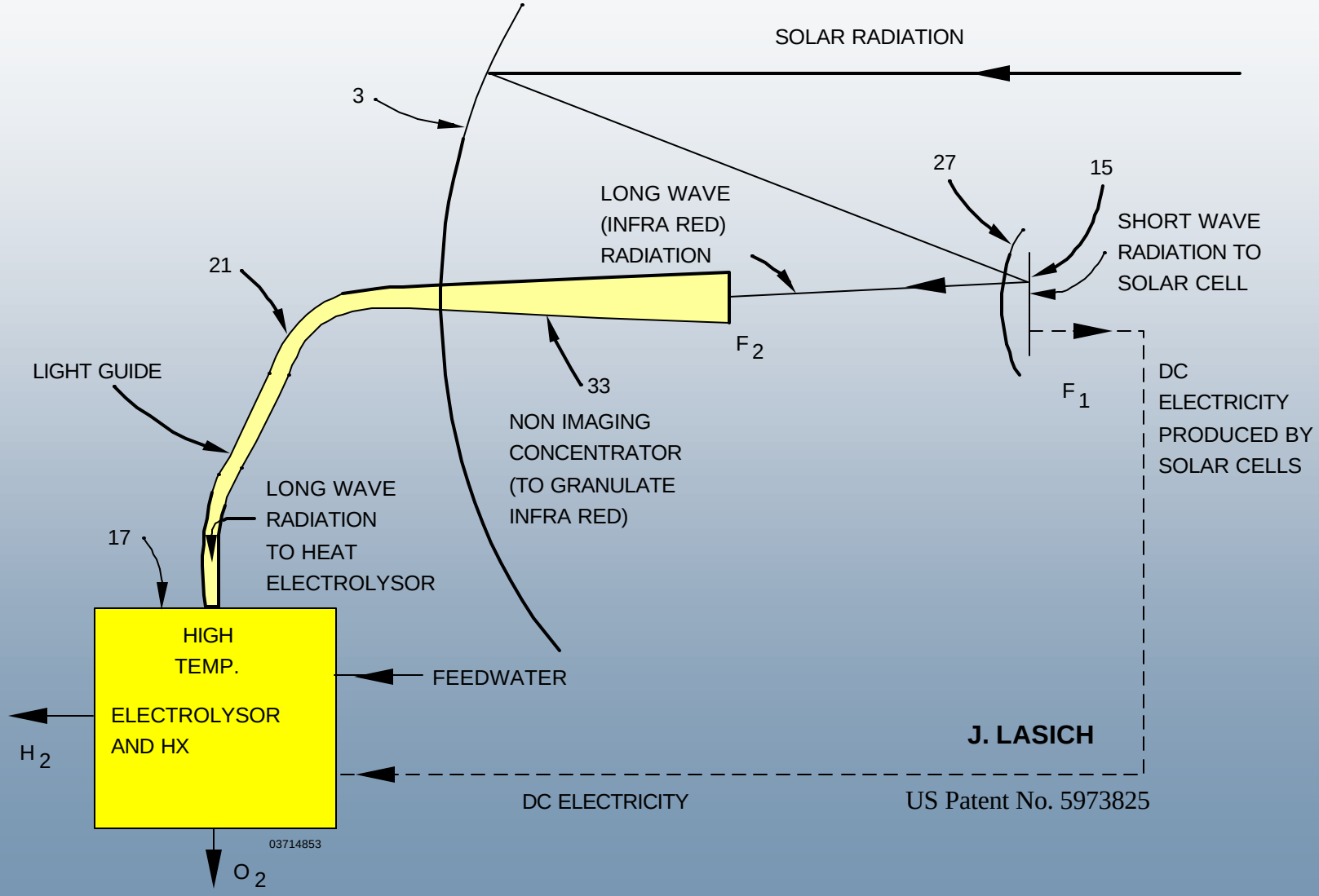
Best Research-Cell Efficiencies





Energy conversion efficiency of solar-driven water splitting to generate H_2 as a function of temperature at AM1.5 insolation, with the system minimum band gap determined at pH_2O = 1 bar and at 500 bar. (S. Licht, J. Phys. Chem. B, Vol. 107, No 18, 4253, 2003.

HSC System Layout

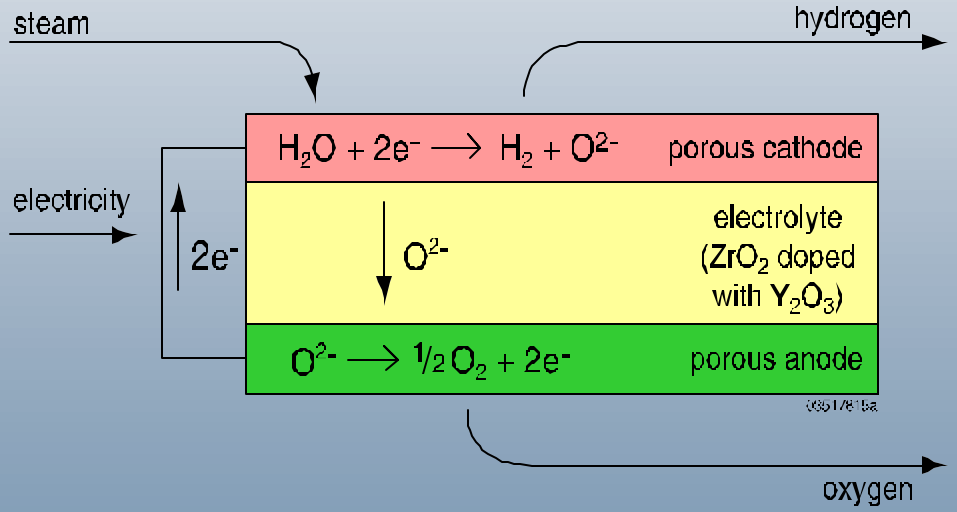


Hybrid (Heat plus Electricity) Solar Concentrator System for Hydrogen Production

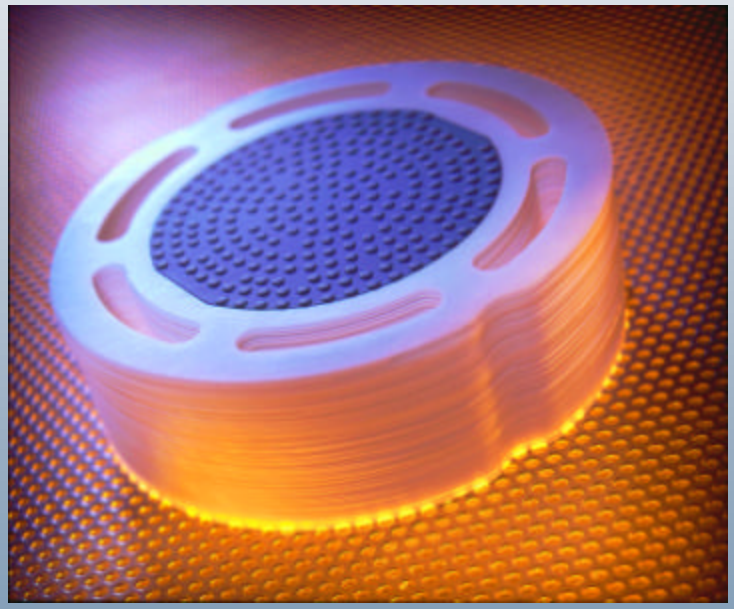
- Spectrum splitter for point focus reflecting concentrator from Australia's Solar Systems P/L sends reflected infrared solar radiation through fiber optics light pipe---held by J. Lasich.
- Experiments for their patents showed a 40% augmentation of hydrogen production above that from solar electricity alone---at T = 1000 ^{0}C.
- These experimental results indicate that a sunlight to hydrogen conversion efficiency of 40% can be achieved today using solar cells with efficiencies above 35% and optical efficiency of 85%.

Solid Oxide Electrolyser/Fuel Cell

High Temperature (1000°C) Solid Oxide Electrolysis



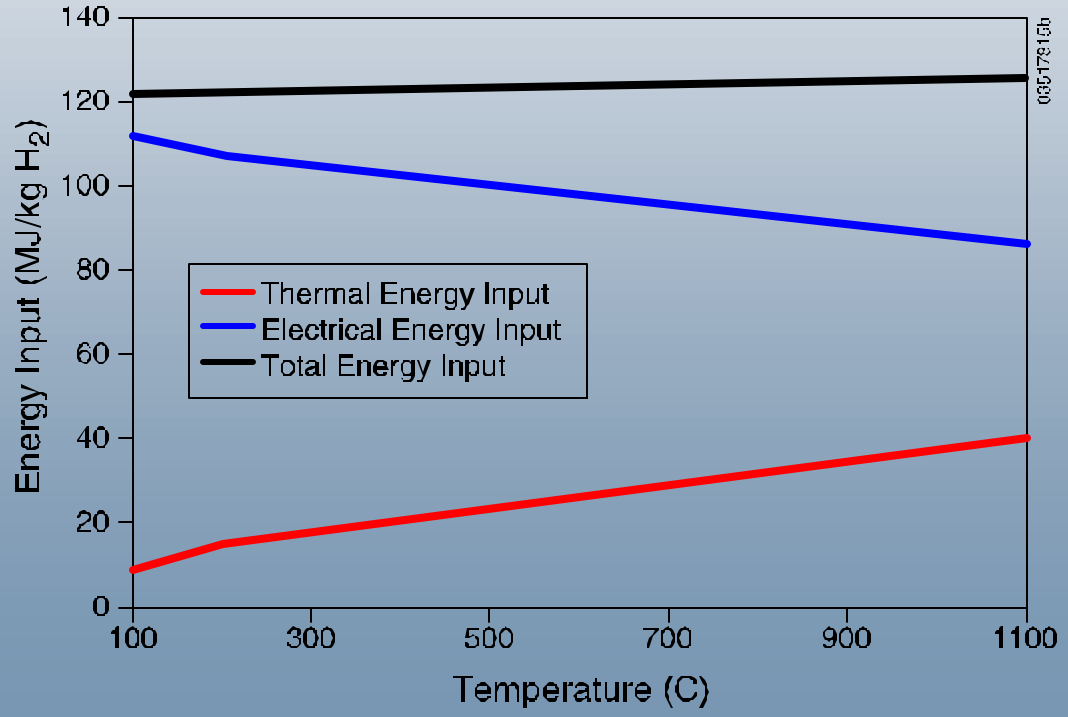
Electrolyser/Fuel Cell Stack



Solid Oxide Electrolyser/Fuel Cell

- Regenerative solid oxide electrolyser/fuel cell system uses both heat and electricity to produce hydrogen----and can produce electricity from hydrogen
- Excellent match with hybrid solar concentrator system

Energy Input to Electrolyser



HSC System Description

- Consists of 4 major components
  - Concentrator Photovoltaic (CPV)
  - Spectral Splitter
  - Light Pipe
  - Solid Oxide Electrolyzer Cells (SOEC)

Component & System Cost

Component Cost (per kW)	Current Cost for a 1 kW System	10 MW System Est. Cost per kW (Yr. 2020)
CPV*	$10,000	$800.00
Dichroic Filter	500	10.50
Light Pipe**	990	24.75
SOEC***	2,000	400.00
Unknown Cost	5,000	5.00
Total	$18,490	$1,240.00

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*Carlos Algora, Chapter 6 in "Next Generation in Photovoltaics — High Efficiency through Full Spectrum Utilization" edited by A. Marti & A. Luque, Institute of Physics Publishing, 2004

**Prices quoted by CeramOptec

***Manufacturing costs quoted by Ceramatec, Inc.

Hydrogen Cost

	10 MW System
System Cost	$1,240 / kW
Hydrogen Produced in 1 hour*	4,045 kg
Hydrogen Produced in 1 year**	14,766,075 kg
Hydrogen Cost (per kg)	$3.63 / kg +/- 25%

*Assumes each cell is capable of producing 75L/min.

**Assumes an average of 10 hrs. of daylight every day

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How Does CPV Electrolysis Compare to Other Methods

Process	Hydrogen Production Cost (per kg)
Gas Reformation*	$1.15
Wind Electrolysis*	3.10
CPV Electrolysis	**3.63 ± 25%**

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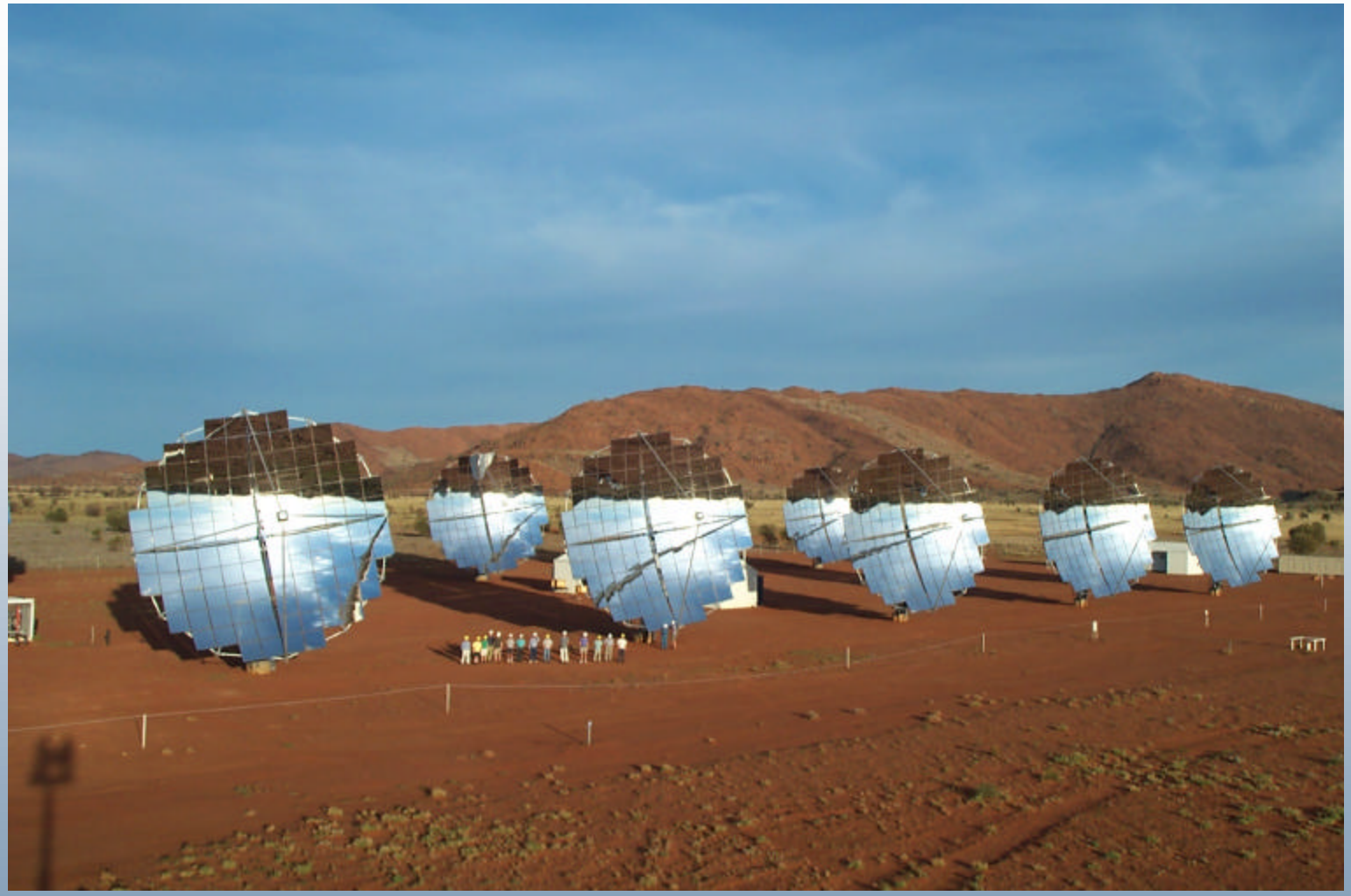
*D. Mears, M. Mann, J. Ivy, M. Rutkowski, "Overview of Central H2A Results," 2004 US Hydrogen Conference Proceedings, April 26 - 30, 2004.



Solar System's Solar Farm on aborigine lands near Alice Springs, Australia. Each dish is nominally 20 kW but can accommodate new high efficiency solar cells to achieve 30 kW. With heat booster each retrofitted dish can convert solar energy to hydrogen at 45% efficiency.

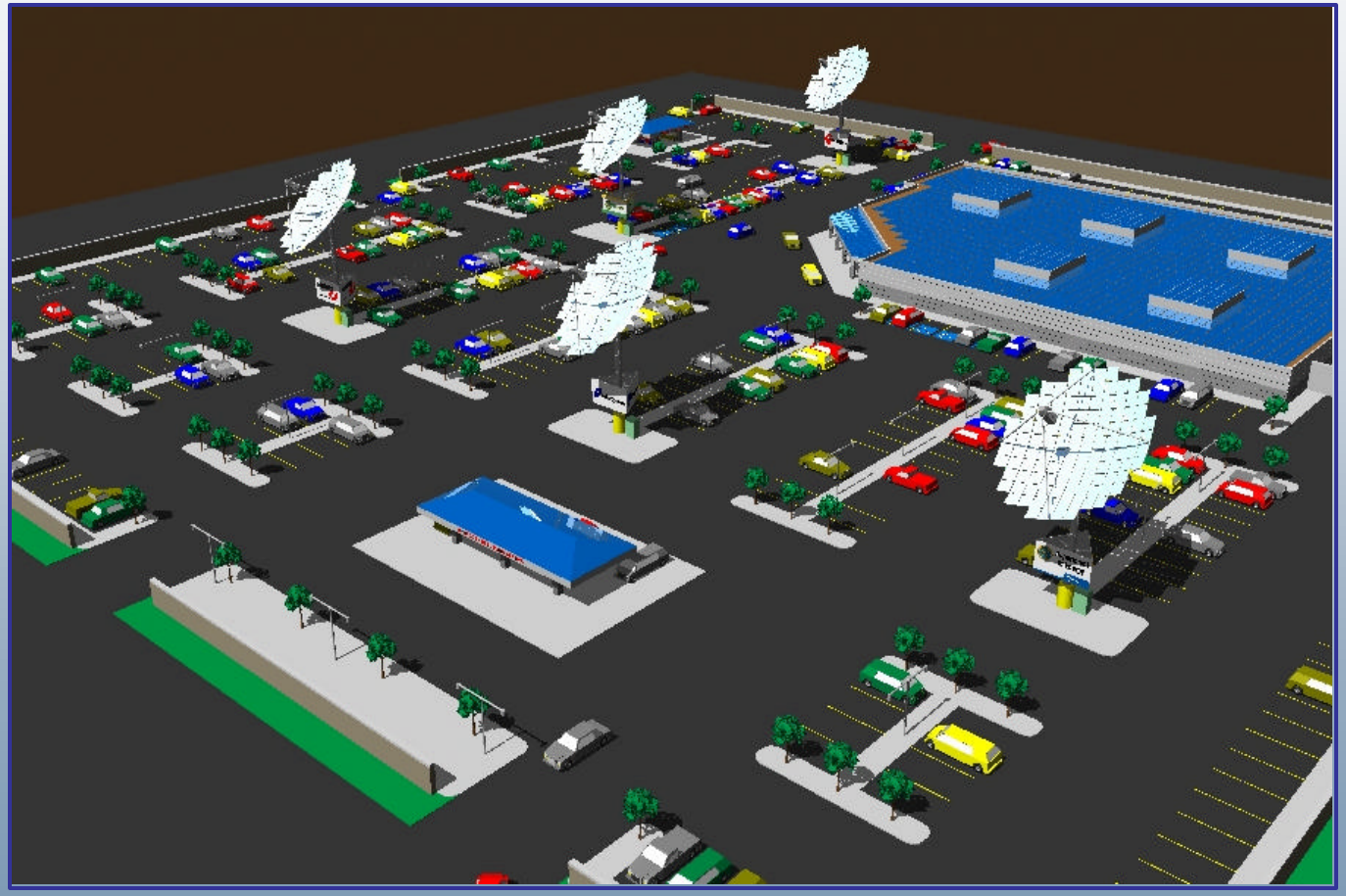
Discussion

- Economic analysis has considerable uncertainty due to technology innovation
  - Need to use agreed-upon economic framework to evaluate potential for this technology to compete with other hydrogen production technologies (H2A)
- Concentrator PV systems are just beginning to enter distributed power generation markets---1 MW/year worldwide.
  - Long-term cost potential of 3 cents/kWh with systems costs less than $800/kW
  - High efficiency solar cells already in large-scale production for satellites---equivalent to 500 MW annually for 500X concentrators
- Time-frame to demonstrate hydrogen production costs for concentrator PV systems is 5 years or less due to modularity (20 kW to 50 kW), short construction times, cheap materials and simple technologies (except for the solar cells.
- Stripping infrared thermal energy permits solar cells to operate at higher electrical efficiency
  - Contrary to generation of electricity from thermal sources
- Potential to minimize distribution costs due to on-site production (e.g. clean-energy malls with solar concentrators and hydrogen fueling stations)

The Hybrid Solar Concentrator (HSC) H_2 Potential

- HSC is a potential “leap frog” technology that could rapidly lower the cost of clean hydrogen because of technology advances in high efficiency PV cells and solar thermal boost
- **40% conversion of solar energy to hydrogen possible with today’s component technologies---with 50% on the horizon**
- HSC is a possible “pot of gold at the end of the rainbow” for clean hydrogen production

On-Site HSC
Hydrogen Production

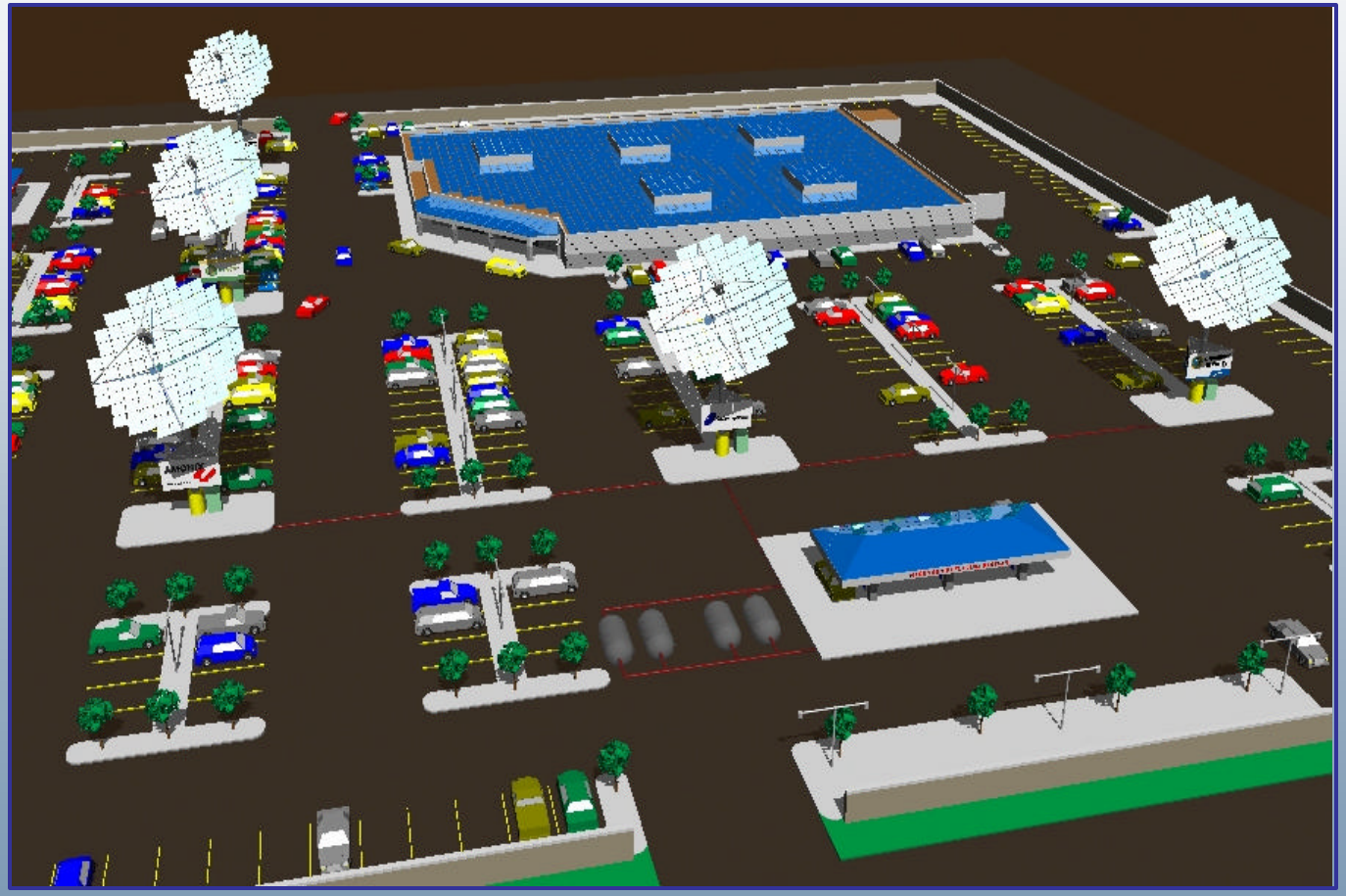


Clean Energy Shopping Mall

On-Site HSC
Hydrogen Production

Clean Energy Mall for Hydrogen Vehicles

On-Site HSC
Hydrogen Production



Hydrogen Underground Storage Tanks and Fueling Station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TIFF (Uncompressed) decompressor
are needed to see this picture.