Solar and Electric Power in Transportation

Ruth Douglas Miller
Kansas State University
ChE 650 January 2006

KS Deffeyes on Hubbert's Peak

- " Chevron's ads say that we are burning two barrels of oil for every new barrel we find. ExxonMobil is stating that, since the mid-1980s, we have been consuming more oil than we discover. Shell has announced that they will now focus on drilling for natural gas and not oil." http://www.princeton.edu/hubbert/current-events.html Nov 2005

Glenn Morton, Sr. BP Geologist:

- Reserves have no bearing on production rate; it is production rate which fuels the world. It does no good to have $1 billion in the bank if one can only withdraw $10 per day.
- Countries past their peak in oil production have not been observed to increase their production with higher prices.
- Hubbert predicted world production peak in 2000. All signs point to him being off by only five years on a 56-year-old prediction.
- ~ASA 2005 Annual Meeting Abstract, Aug 2005

KSU's Solar Cars: Solution, Apollo, CATalyst

I want one of those! When will I be able to buy one?

Solar Rayce Car Specifications

- 10-hour day, average at least 25 mph in mixed driving over 10 days
- Array: about 8 m^2; car must fit in “box”. Generates 1.2-2 kW power; 1.5 kW typical
- Battery weight restricted so capacity is less than 5 kWh.
- Driver weight fixed at 80 kg (176 lb) min.
- Rules specify driver eye height, range of vision
- Vehicle mass 170-250 kg (375-550 lb)

“Gemini”, Queens Univ. ASC 2003

How Far and How Fast?

- Winning cars in 2005 averaged 46 mph over 2950 miles, including in-town traffic
- Many cars travel 65 mph on highways
- “Free speed” (array alone) typically just under 40 mph; now may be upwards of 50 mph?
- Battery energy up to 200 miles at 35 mph
- Motor limitations probably set max speed to 80 mph

Stage start, Winnipeg, MB

Comparison

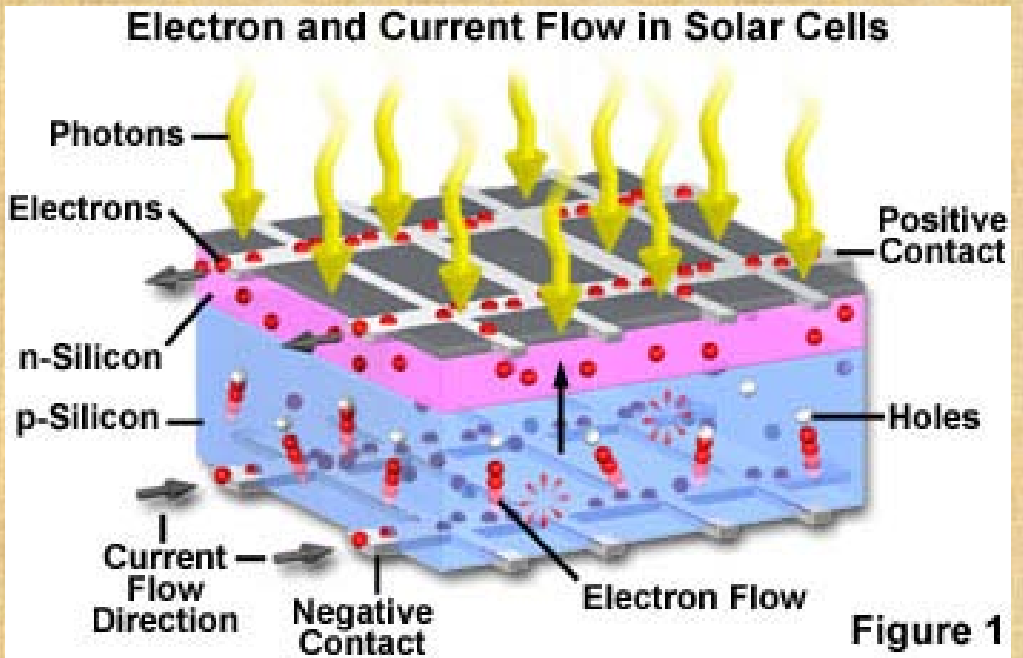
	ICE	Solar raycecar
Mass	1500 kg	200 kg
Available power	11-20 kW	1.2-2 kW
Range	300 miles/tank	200-400 miles in daylight <200 mi pack alone
Payload	5 people + 3 large suitcases	One person, no cargo
Cost	US $ 20,000	US $200,000 (mostly solar cells)

KSU Paragon, 2005

How do solar cells work?

- Diode junction has no free charges to conduct current
- Sunlight gives bound charges energy to conduct themselves out of junction

•Efficiency: how much of solar spectrum can cell convert to electricity?



Source: http://www.mic-d.com/java/solarcell/

Charging at Medicine Hat, 2005

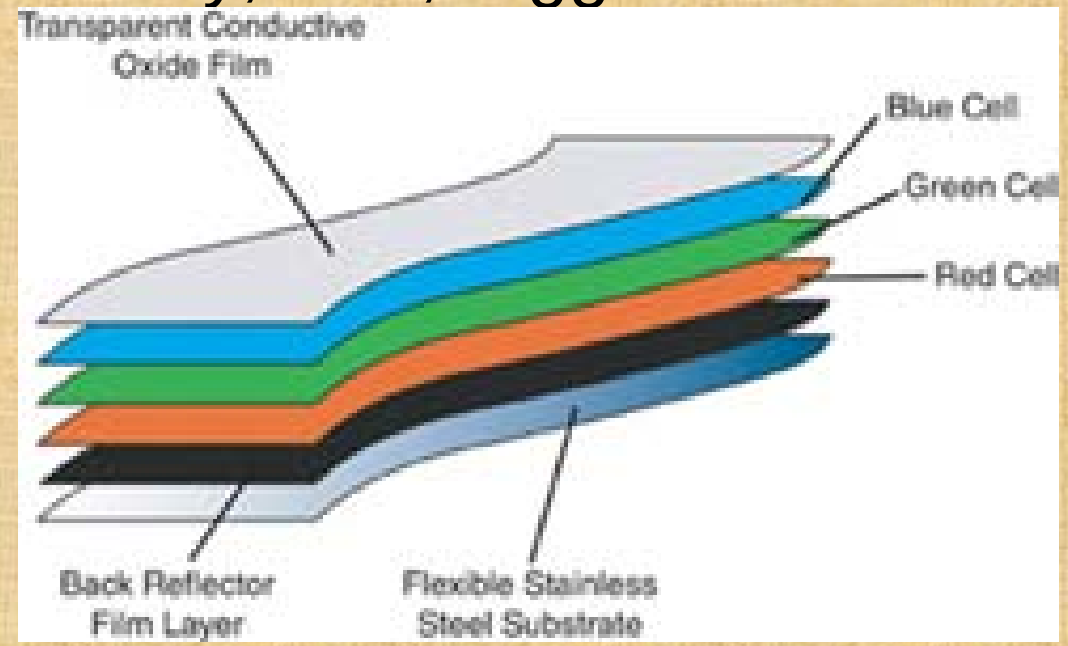
Solar Cell Availability

- Amorphous Silicon: 5-10% efficient, $7/W
- Silicon polycrystalline: 5-10% efficient, $7/W
- Silicon monocrystalline: 15-20% efficient, $7/kW
- Gallium-arsenide multi-junction: 20-30% efficient, $100/W and up

UniSolar shingles. Source: http://www.uni-solar.com/interior.asp?id=67

Physical Differences

- Multiple junctions absorb photons at multiple wavelengths: increase efficiency, increase cost
- Mono-crystalline structure conducts all excited electrons out with little loss: fragile as thin glass
- Amorphous materials lose on efficiency, gain on flexibility, cost, ruggedness



UniSolar a-Si cell structure. Source: http://www.uni-solar.com/interior.asp?id=67

Operating Cost

- ICE, 30 mpg, US $3/gal, 300 mi: $30/day
- Solar car: free as sunshine
  - Full battery pack: 5 kWh, $0.08/kWh: 40 cents for nearly 200 miles, even in rain
  - Battery pack charge time: 5 hrs in good sun with a 1.2kW array, 10 hrs from grid

Disadvantages

- Solar cells are expensive and very fragile
  - $7/W = $10K without assembly costs
- A lot of solar cells makes for a large, awkward vehicle
- Best batteries (Li-ion) are highly sensitive and produce toxic gas if mishandled
- Batteries cannot be charged very quickly

ETS (Quebec) Li-ion battery fire, FSGP ‘04

Alternatives

- Petrol-electric hybrid
  - Best choice at present
  - Potential for small on-car solar array
  - Or home solar charging station
- Hydrogen fuel cell
  - Hydrogen is a portable fuel, like petrol
  - Splitting water is very inefficient
  - More efficient to split petroleum—carbon emissions and scarcity

On-car Solar Array?

- Small car has 1-1.5 m^2 roof area for array
- Van has 2.5 m^2 area
- 20%-efficient silicon solar cells: 200-400 Watts
- Cost: $7/watt = $2,100 (plus assembly, electronics, and you need a hybrid!)
- In town, typically generate 100 W every 5 mins with regenerative braking
- “feel-good” solution, but with standard car, minimal practical benefit

On-home Solar Charging Station

- Plenty of roof area: cheaper, less efficient cells ok.
- Battery weight unimportant: use Pb-acid.
- OR: charge one car pack while driving with the other
- Need: good sun, hybrid car
- Stored energy to recharge car overnight, also other electric energy needs in home
- Reasonable solution for in-town driving

Hydrogen: Fuel Cell Car

- Fuel cells generating 10 kW are available; 7.5kW fuel cell system sells for $35,000.
- A 500-kg 2-passenger vehicle can run about 80 miles on one standard tank of H_2
- Perfectly clean: exhaust is water
- Safer than petrol: H_2 goes up and away, does not stick to humans/clothing
- Oxygen from air: no O_2 tank needed


273

Hydrogen Problems

- How to store a very light gas that can find its way through very small holes?
  - H_2 pipelines have been suggested (replacing methane) but H_2 will leak out of anything, especially under pressure
- Refueling with pressurized H_2 is tricky
- Must pressurize to get enough energy
- Fuel cells don't like heat (Texas, CA…)
- Generating H_2 from water takes more electricity than the fuel cell produces

Long-Term Solutions?

- Mass-transit: highly successful in Europe
- Ultralight vehicles: since when do we need a 1.5-tonne car to transport an 80-kg human plus 50 kg of groceries?
- Petrol-electric hybrid vehicles
- Safer battery packs, greater energy density
- Solar panels on homes with charging stations
- Hydrogen may make sense if generated with renewable energy (solar, hydro, wind) close to its use site.

So when can I own one of those?

- Buy a hybrid, put solar cells on your roof, and the answer could be: tomorrow!