Fuel Cells for Distributed Power

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Alaskan Electrical Energy Conference

- First held in Fairbanks, September 2002
  - 300 attendees, 100+ papers
  - Attended by
    - Alaskan Utilities
    - University and NL researchers
    - State and Federal policy makers
    - Equipment suppliers
    - Village Residents
- Second conference to be held in Talketna, April 27-29, 2004

Efficiency

- A measurement of how well a device converts the energy of a fuel into useful work.
- Higher efficiency means lower fuel costs
- Higher efficiency often comes at higher capital cost
- The highest efficiency device may often not be the most commonly available technology

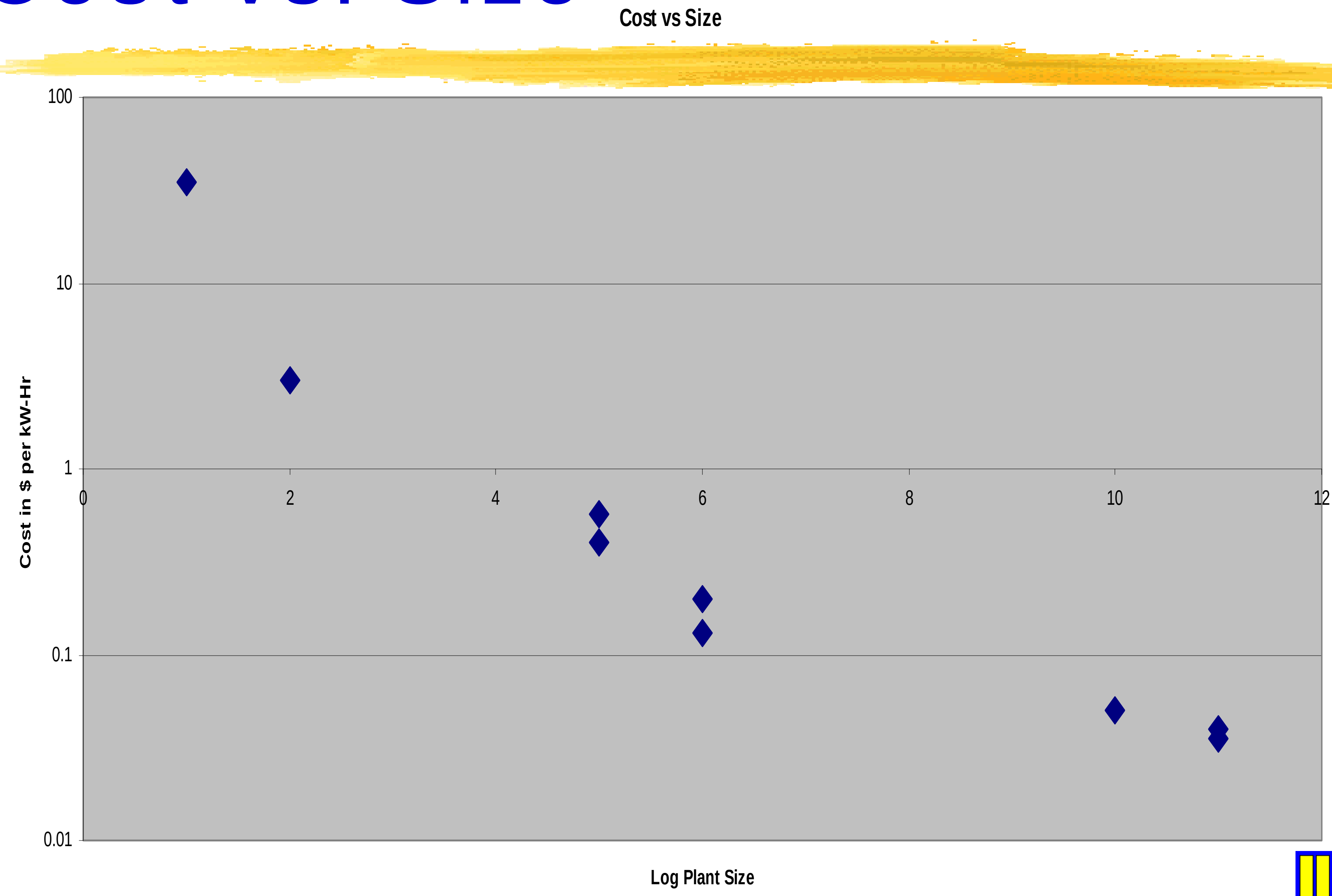
Fuel Costs in Alaska

Fuel Costs	Cents per kW hr
Gas	2.93
Coal	1.58
Diesel	8.20
Methanol	10.00
Hydrogen	500.00

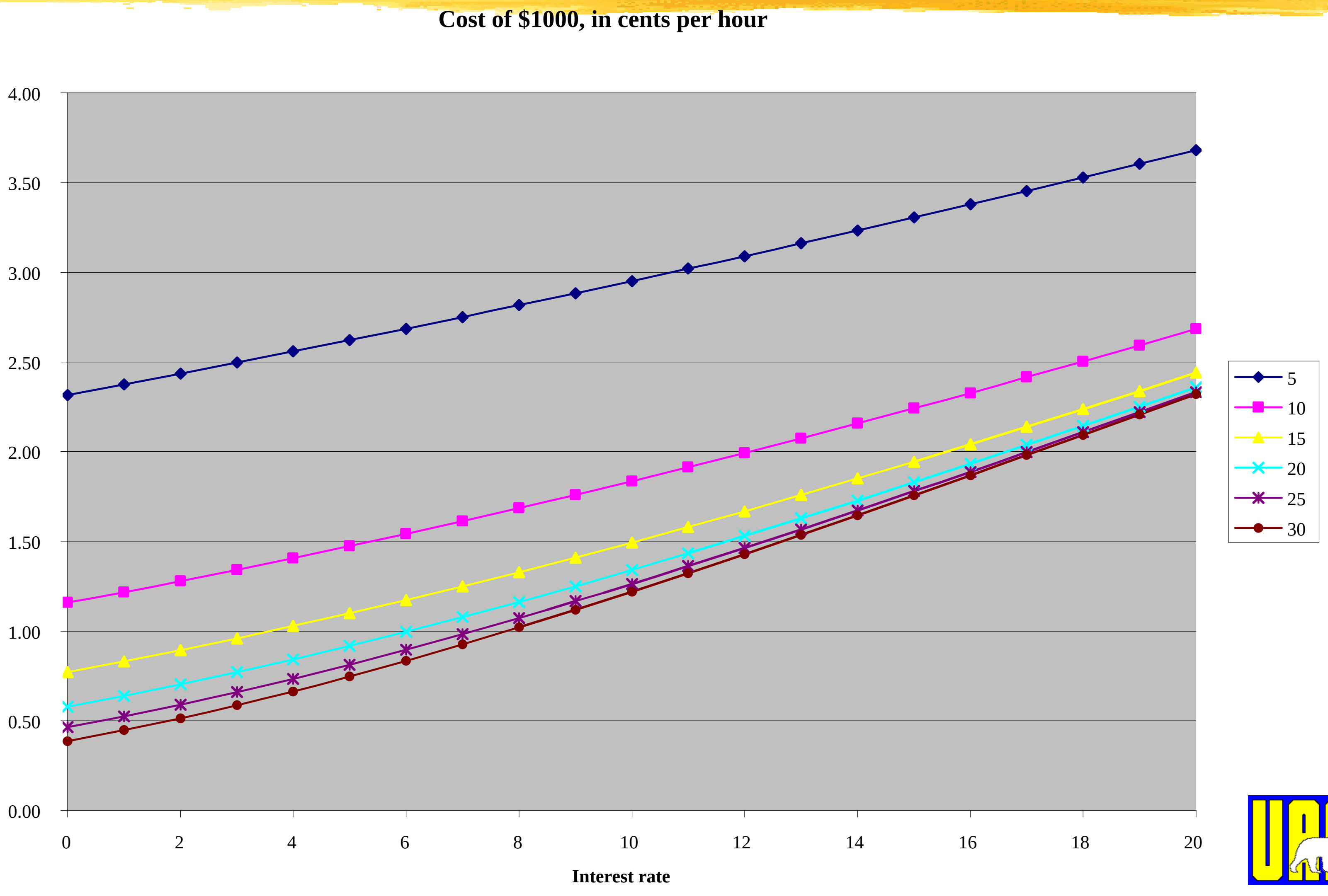
Size vs. Electricity cost

	Size	$ per kW-hr
Coal Plant	100 MW	0.04
Large Hydro	100MW	0.04
Natural Gas	10 MW	0.05
Wind	1 MW	0.13
Battery	1 MW	0.2
Diesel Generator	100KW	0.4
Solar Cell	100 KW	0.57
Small Hybrid	100 W	3
Dry Cell	10 W	35

Cost vs. Size


Cost vs Size
100
10
1
0.1
0.01
0
2
4
6
8
10
12
Cost in $ per kW-Hr
Log Plant Size

Cost of Capital



Calculation for solar cells

- $6 per watt installed (with batteries)
- Typical household uses 1kW (Alaska)
- Availability of Solar 1/3
- $18000 capital cost
- 25 year lifetime
- Gives 9 cents per kW-hr if cost of money is zero

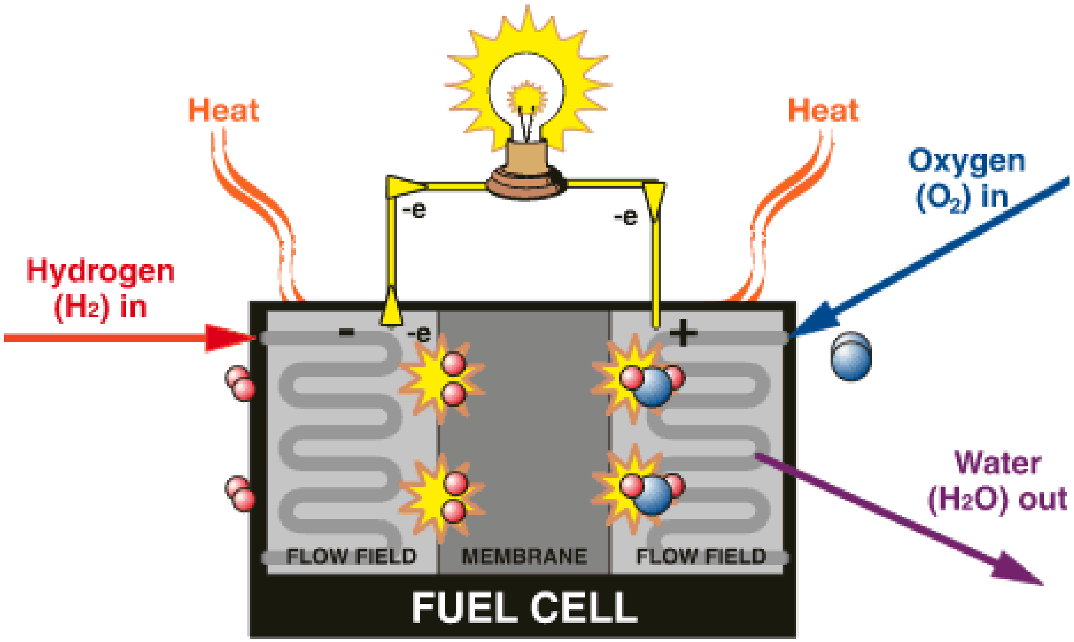
But..

- The cost of money is not zero, and at 6% the cost of power doubles
- And the batteries will not last 25 years, so they are on a higher cost curve, and increase the capital required…
- So Solar cells still don’t compete with grid connected power, except for peaking loads in warm climates

What is a fuel cell?

- A device that converts the chemical energy in a fuel directly to electrical energy.
- Requires fuel flow and oxygen flow, electrodes, and an electrolyte
- Half cell reactions
  - H_2--> $2H^+$ + $2e^-$
  - O_2 + 4^{e-} --> 2 O^{+2}

Fuel cell basics



Advertised Advantages

- Few moving parts (in the stack)
- Clean (when operating on hydrogen)
- Efficient (at low power)
- Cost effective (in mass production)
- Reliable (projected)

Possible disadvantages

- Susceptible to impurity contamination
  - Electrode poisoning
  - Conductor corrosion
- Air flow requires blower or compressor
  - There are moving parts to move air
- Hydrogen management
- Cost

Parts of a fuel cell system

- Fuel cell stack
- Air handling device
- Fuel handling device
- Fuel conversion device
- Heat management system
- DC to AC converter (inverter)
- Control system

Electrical issues

- Electricity needs to be generated and consumed simultaneously
- Electrical loads vary with time
- Electrical systems must load follow
- Fuel cells operating on hydrocarbon fuels must use batteries or be grid connected for maximum efficiency

Fuel conversion

- Fuel cells use hydrogen as fuel
- Pure hydrogen is not found in abundance in nature
  - Energy storage vs. fuel
  - Most hydrogen produced in US is from Natural Gas
- Total system efficiency must count conversion of water or hydrocarbon to hydrogen
- A hydrogen infrastructure does exist, but hydrogen is still significantly more expensive than other hydrocarbon fuels.

Reformers

- A device to convert a hydrocarbon fuel to a hydrogen rich gas stream
- Uses part of the energy of the fuel for the conversion process
- Operate at high temperature (800C)
- Produce CO_2 as byproduct
- Efficiency of 35 to 80%
- Do not load follow well

Fuel Cells

- Five types
  - Alkaline
  - Phosphoric Acid
  - Molten Carbonate
  - Solid Oxide
  - Polymer Exchange Membrane
    - Direct Methanol

Phosphoric Acid

- Largest installation in world at Anchorage Post Office (shut down after 3 years)
- Stack degradation within a few years
- Capital cost of $3000/kw, life of 5 years gives capital cost of 7.8 cents / kW-hr
- Net efficiency of about 35%
- Status: Commercial (maybe), in niche markets
  - Issue: Long term stack reliability, cost

Solid Oxide Fuel Cells

- Westinghouse Successfully demonstrated 200 kW units for 16,000 hours on Natural Gas
- Building factory, will deliver 200 kW units @$4500 per kW, starting in 2006 (???)
- Working on 5kW system with FCT
- Efficiency of 50% net electrical on NG at 200kW
- Status: Pre commercial
  - Issue: Cost of manufacturing


FUEL CELL
FNG
FIRE
EXTINGUISHER

Results to date with 5 kW FCT SOFC

- Unit delivered 10 months late
- Started on August 1, 2003
- Producing 4.2 kW DC power, >50%
- Operating continuously since startup, except for one scheduled outage (4000 hours)
- Best performance from small scale fuel cell in our program

Issues with FCT SOFC

- Needs N2-H2 mixed gas for startup
- Needs electrical power for start up
- Operates on Natural Gas
- Unit is physically large and heavy
- Still very expensive
- Units are still not commercially available

Molten Carbonate

- Technology in initial field demonstration phase (early 1990's)
- Projected to be more cost effective than other FC
  - Low Cost materials
- Still a few years away from commercialization
- Status: Pre commercial
  - Issue: Stack lifetime

State of the PEM

- Technology for transportation
  - Only fuel cell technology with high energy density
  - Very good load following on hydrogen
- Field demonstrations not succeeding
  - Membrane lifetime issues
  - Efficiency issues
  - Fuel reformer issues
  - Cost!!!
- Status: Prototype
  - Issues: Reliability, efficiency, cost

Fuel Cell System Efficiency (at UAF)

- Stack Efficiency
- Balance of Plant
- Reformer
- Inverter
- Batteries

PEM Efficiency

- Stack Efficiency 60%
- BOP Efficiency   85%
- Reformer Efficiency 35-65%
- Inverter Efficiency   90%
- Batteries   90%
- Overall efficiency <25%

- Conclusion: PEM fuel cells in distributed configuration is less efficient than grid!

SERC Methanol Fuel Cell

Results on SERC System

- Systems starts up independently
- Efficiency of 22.5% AC out
- Methanol readily available
- Stack lifetime still questionable
- Mechanical systems still suspect
- System still not Arctic hardened
  - Water vapor resulting in ice accumulation

Direct Methanol Fuel Cell

- Advantages
  - Directly converts methanol to electricity
- Disadvantages
  - Poor polarization performance
  - Short lifetime (10s-100s of hours)
  - Complicated balance of plant
- Contact with Direct Methanol fuel cell company last night for cold weather test.

Fuel Cell summary

- Fuel cells are real
  - Physics and chemistry are based on real science
- Despite decades of R&D, fuel cells are not yet ready for prime time
- Niche markets for fuel cells will likely develop before mass markets
  - Remote power may be perfect niche, but may not have enough users to develop market.

Economic analysis of 5 kW Hydrogen Renewable system

- Wind turbine (free, because you have it already)
- Electrolyzer for 5 kW $150K .7
- Compressor and backup $120K .85
- Storage tank $ 5K
- Fuel Cell $ 50K .5
- Inverter $ 1K .9
- Total $325K .3
- Cost of electricity about $2/kw-hr for 5 year lifetime (not bad, if it would last that long)

Fuel calculations for 1kW systems

- Diesel Engine produces 13 kW-hr of electricity per gallon of fuel (33% efficiency)
- For a 1 kW system fuel cell system at 40% efficiency, 1 kW load requires 1.54 gallons of diesel fuel per day, or 307 gallons of fuel, or 6 barrels.
- For bottled hydrogen, using a PEM fuel cell of 50% efficiency, 1 tank = 9kW hr, 1 day at 1 kW= 2.66 bottles/day = 532 bottles of H2= 112,200 ft3 of H2, or at 100 psig, a container of 25 feet on a side.
- For a methanol system at 25% efficiency, using a mixture of methanol and water = 22 ml/minute= 1.332 liters/hr= .35 gallons/hr= 8.4 gallons/day = 1680 gallons/season = 31 barrels/ 200 day season.