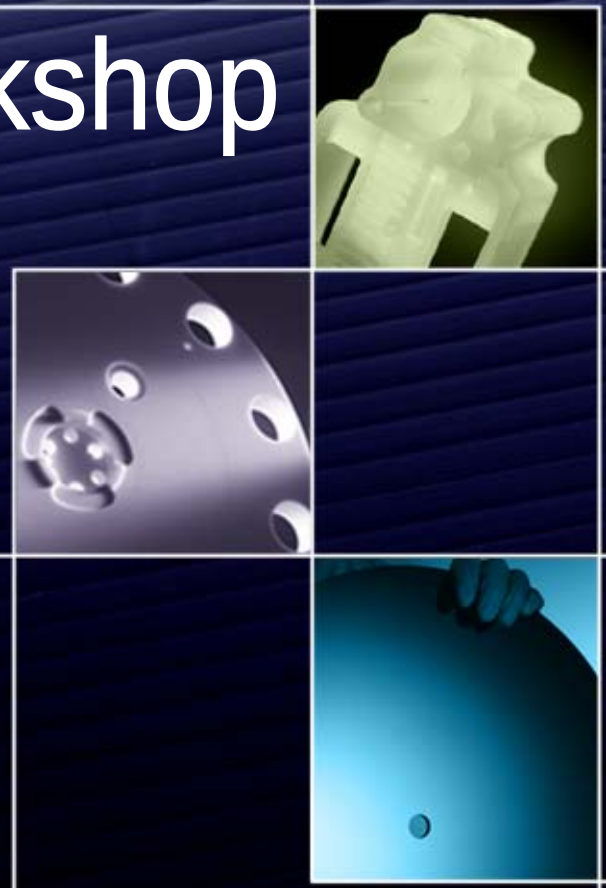
CoorsTek
Amazing Solutions.®

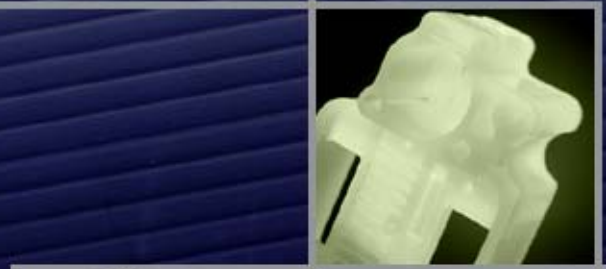
6th Annual SECA Workshop

April 18-21, 2005



CERAMIC FUEL CELL INDUSTRIAL BASE MOBILIZATION

W. Grover Coors
Chief Scientist
Fuel Cell R&D



CoorsTek
Amazing Solutions.

How big is the SOFC marketplace?

How big is the SOFC marketplace?

1 gigawatt?

How big is the SOFC marketplace?

1 gigawatt?

10 gigawatt?

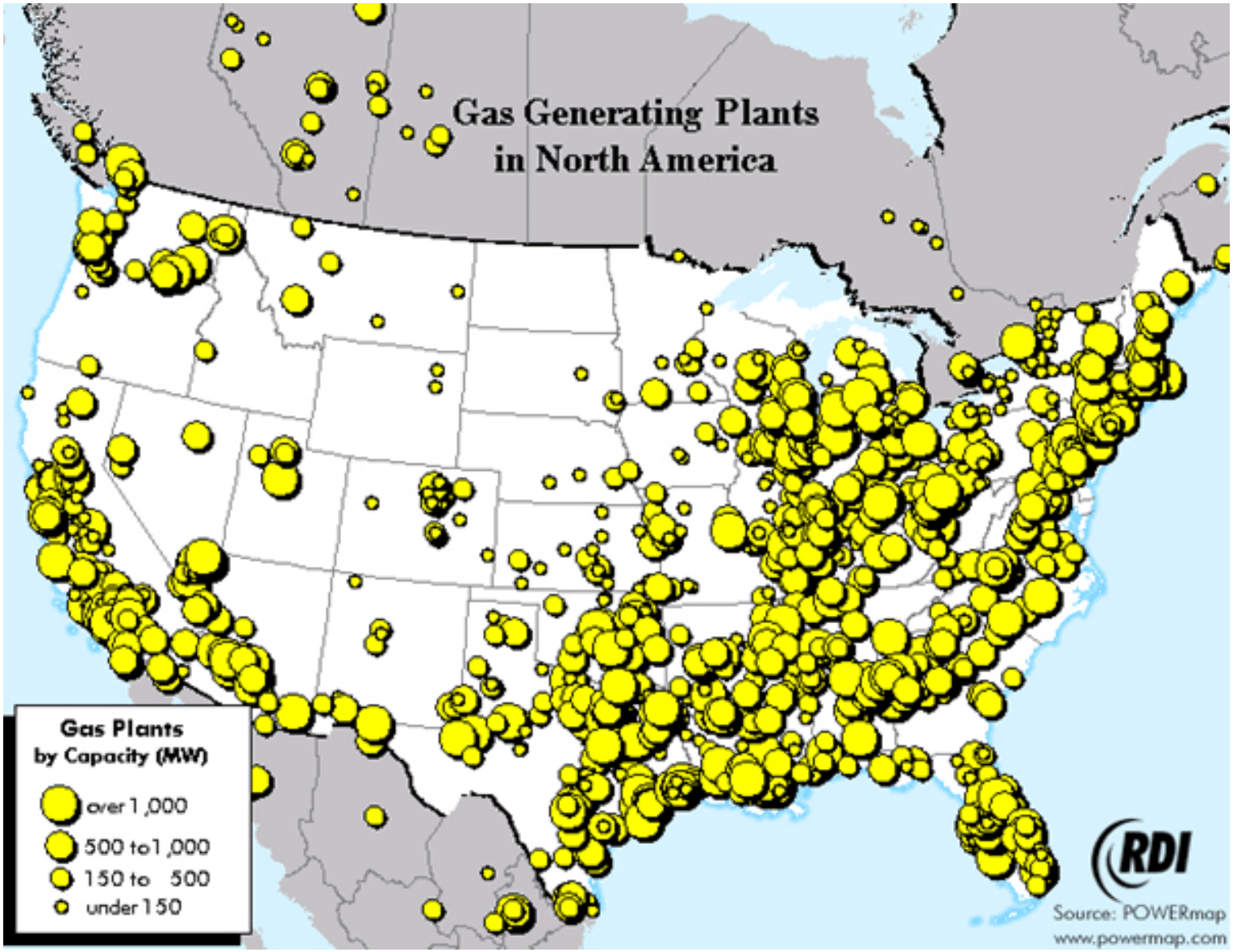
How big is the SOFC marketplace?

1 gigawatt?

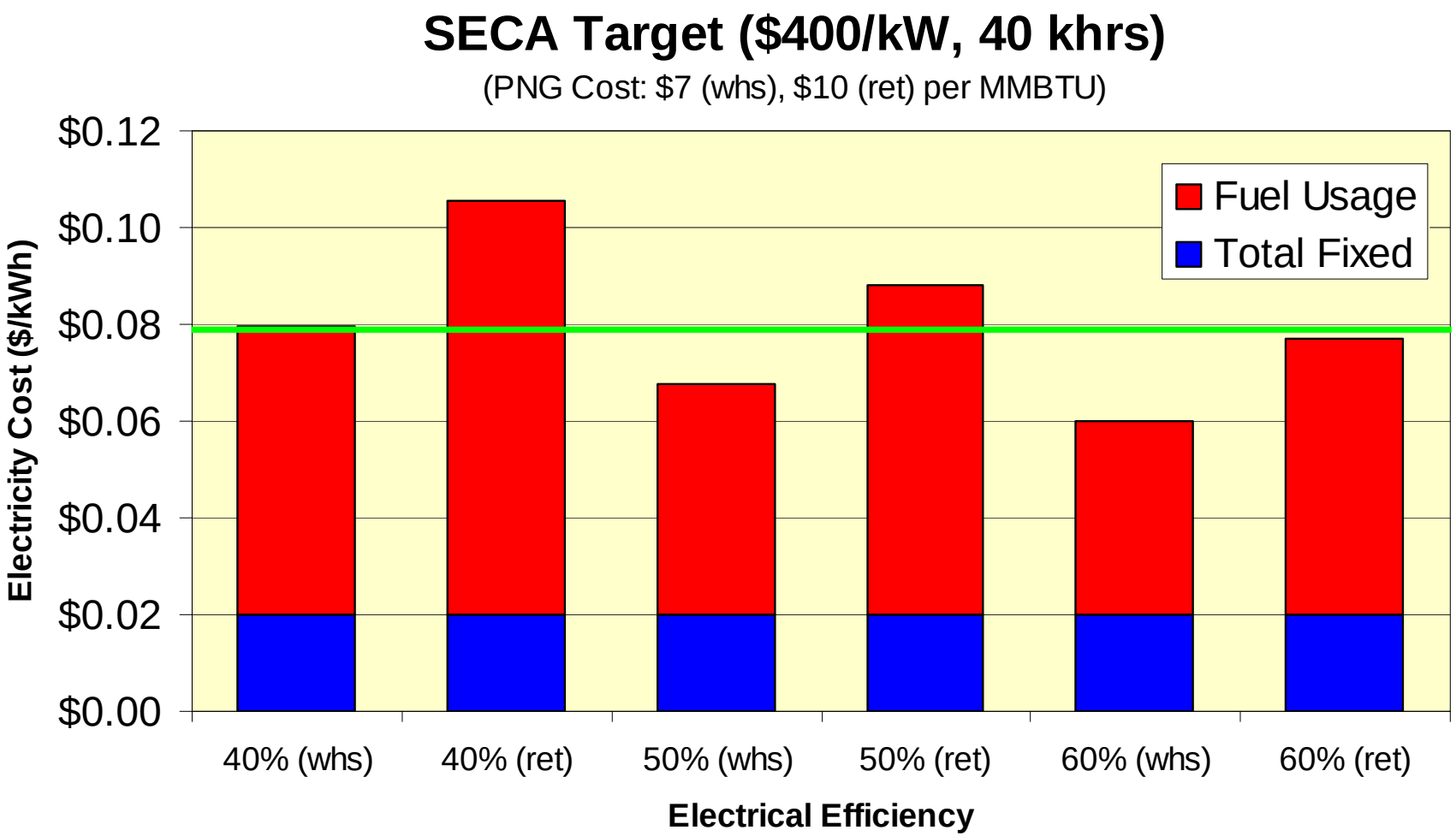
10 gigawatt?

100 gigawatt?

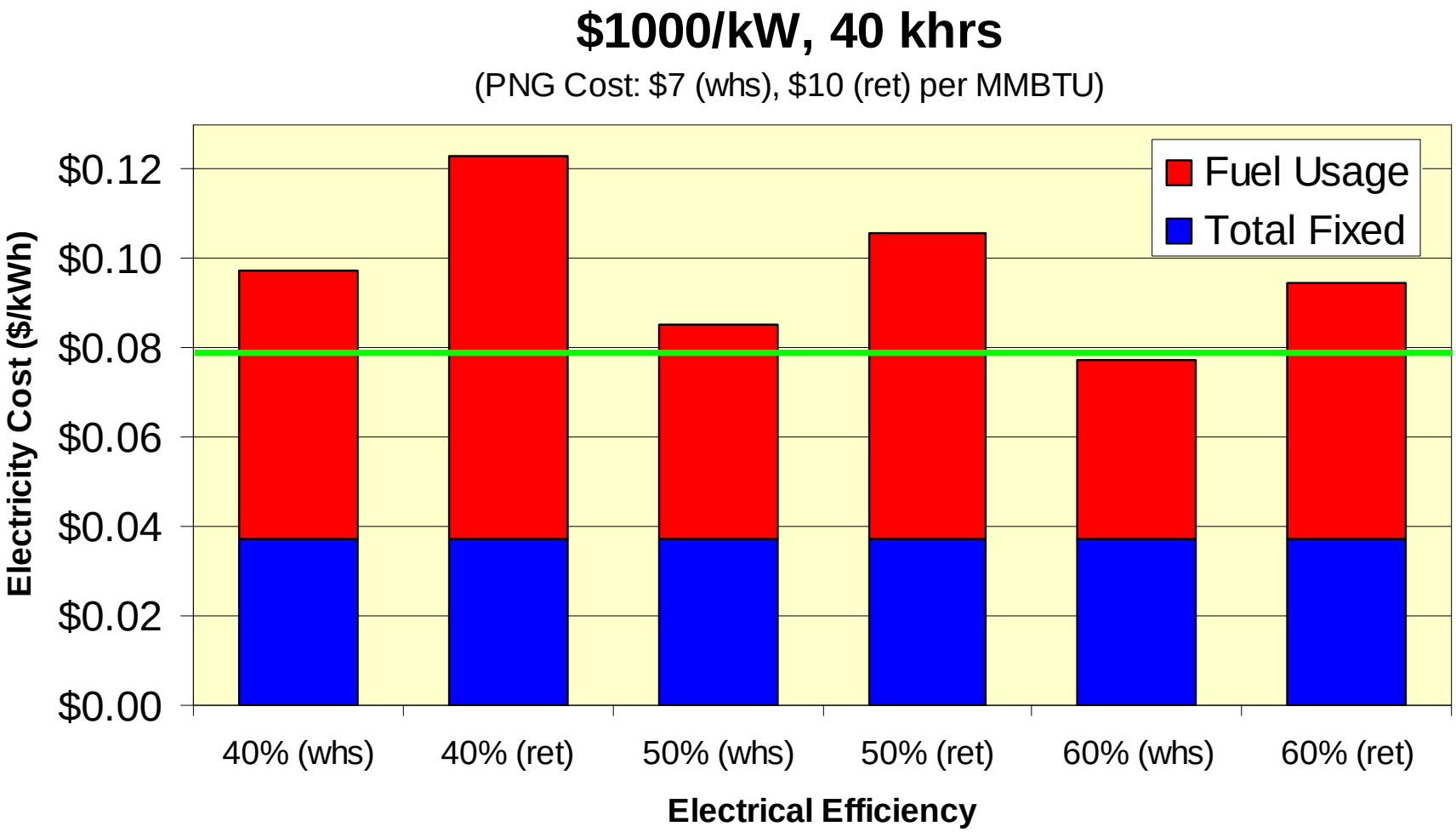
Natural Gas Power Generation



Cost of delivered electric power



Cost of delivered electric power

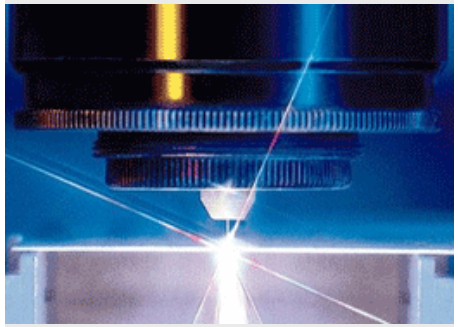


Market size depends on efficiency

40% → 1 GW

50% → 10 GW

60% → 100 GW



Commercial Success Depends On:

- Low cost/ high volume manufacturing
- High fuel cell efficiency

Pathway to Low Cost/ High Volume Manufacturing

CoorsTek Locations and Capacity

Serving our customers where they need us...

...from 18 facilities and over two million square feet worldwide!

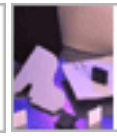
CoorsTek Products and Markets

Serving virtually every industry in the global economy…


Aerospace and Aviation


Air-Bearing Guideways


Analytical Labs

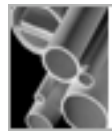

Armor Protection


Chemical Processing


Defense and Security


Electronics


Electron Tube Components


Fuel Cell Components

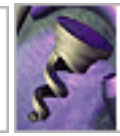

Food & Beverage


Industrial


Labware


Laser Equipment Components


Medical


Mining and Minerals


Oil & Gas


Optical


Power Generation


Precision Measurement


Pulp & Paper


Semiconductor


Telecom

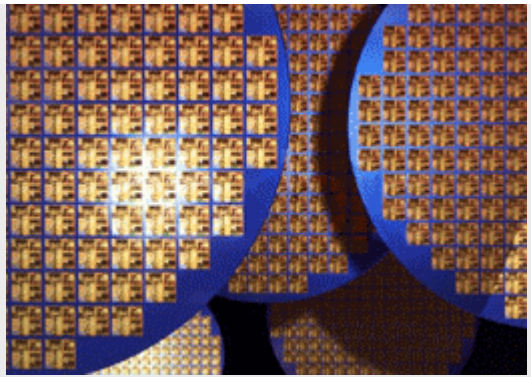

Thermal


Transportation


Tubes & Rods


Wire and Cabling

Mission

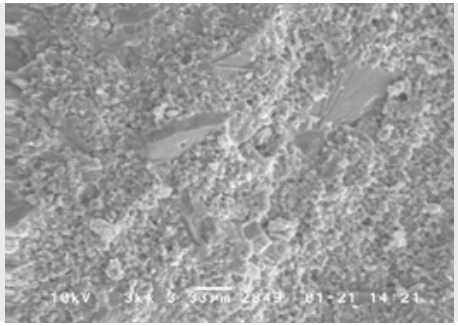




Our strategy is to provide value
in many diverse markets by
employing our Core Business Strengths in expanding or developing technology niches.

- Custom Engineering
- Materials Expertise
- Operational Excellence
- *Rapid Execution!*

Core Business Strengths – Materials Expertise

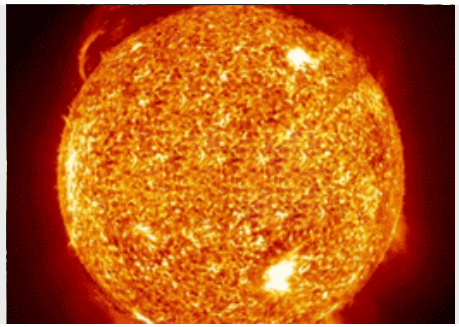
From materials design to the finished component, our vertically-integrated manufacturing ensures quality throughout the process…



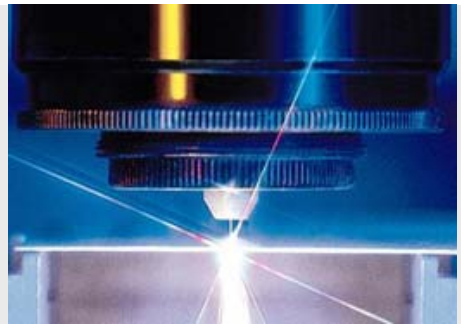
Materials Design →

Material Preparation →

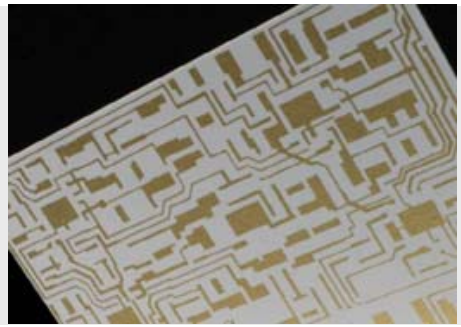
Forming



Sintering →



Machining →

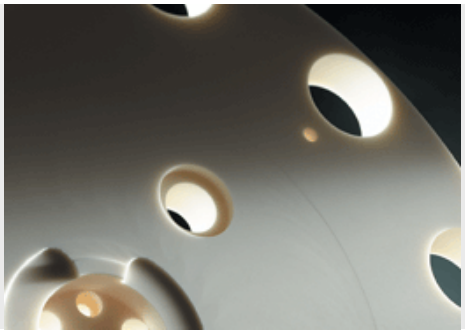


Finishing

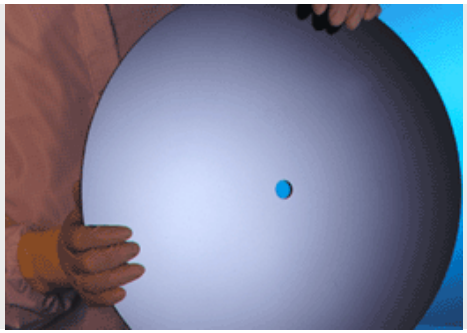
Core Business Strengths – Materials Expertise

CoorsTek solves customer challenges using a very large variety of materials...

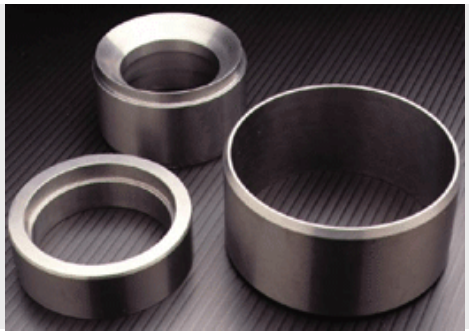
Technical Ceramics



High-Purity Aluminas



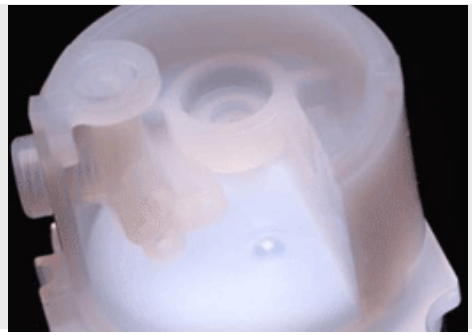
Silicon Carbides



Tungsten Carbides

Zirconias

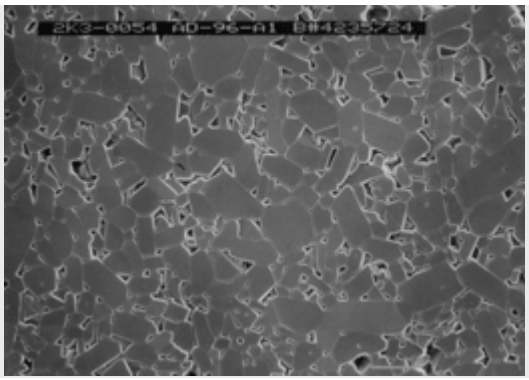
High-Performance Plastics

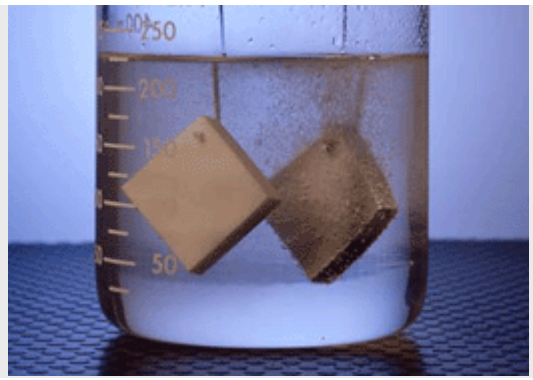


High-Temperature Fluoropolymers

Elastomers and Teflons

Analytical Lab





- Powder characterization
  - BET, sedigraph
- Physical
  - Density, mercury, porosimetry
  - Phase assemblage by XRD
- Chemical composition
  - ICP-OES, XRF, Laser
  - Ablation-MS
  - ICP-MS
- Mechanical
  - Flexural, compressive, tensile
  - Strength, modulus, hardness, wear
- Thermal
  - Expansion
  - DSC, DTA, TGA
- Electrical
  - Dielectric constant, loss tangent
  - Volume resistivity
- Microstructural analysis
  - Digital SEM
  - EDS
- Failure analysis

Core Business Strengths – Operational Excellence

OpX

OpX is a hybrid of several best-practice techniques including lean manufacturing, quality control systems, and six sigma/black belt continuous improvement.

ISO, QS, and TS-compliant manufacturing

State-of-the-art manufacturing facilities – over TWO MILLION square feet of manufacturing capacity worldwide!

Lean manufacturing techniques

Raw materials needed for 1MW

Metric: 1Kg powder/1kW electricity

1 metric ton of powder = **1MW**

So…….What Does a GW Look Like?

1000 metric tons ~ 1GW

Mill Raw Materials

1MW/load, 1-2charges/day

1/2 GW/year

Spray Dry: GW/year

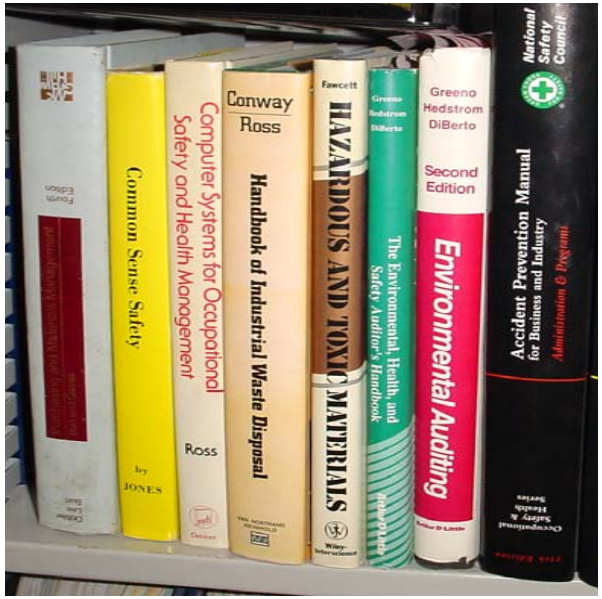
Spray Dry Milled Body

2MW/hour

6-7 GW/year

Waste Collection and Treatment

Regulations



Chemical Handling

Water Treatment

Waste Disposal

Extrusion: GW/yr

400,000 fired ft/year

40MW/year

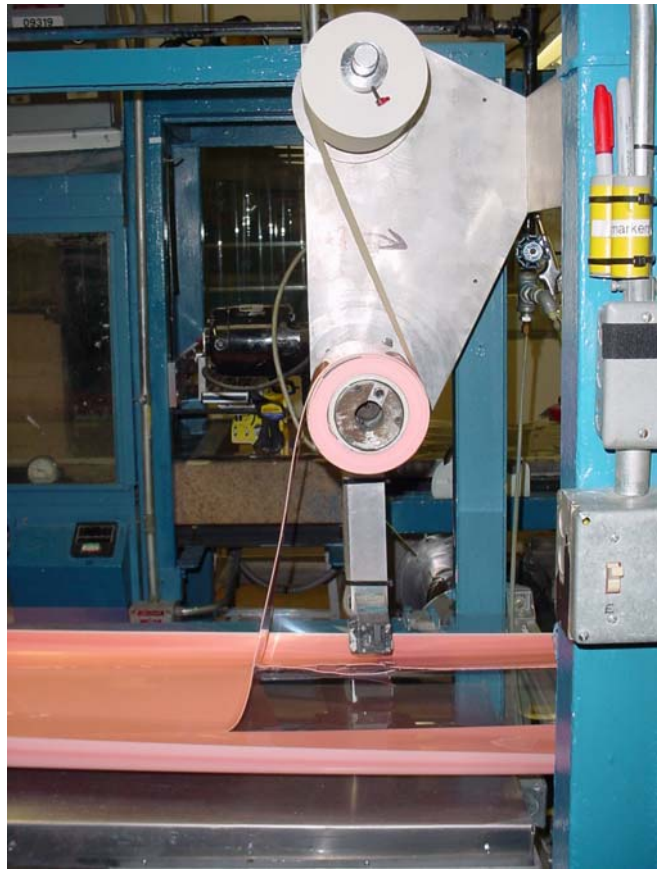
1/25 GW/year

Tape Cast: GW/year

1MW/2-3 days

1/10-1/5 GW/year

Tape Cast: GW/year



3-7 m/hour, 17cm wide

0.5-1.2m^2/hour

7-20MW/year

1/50 or less of a GW/year

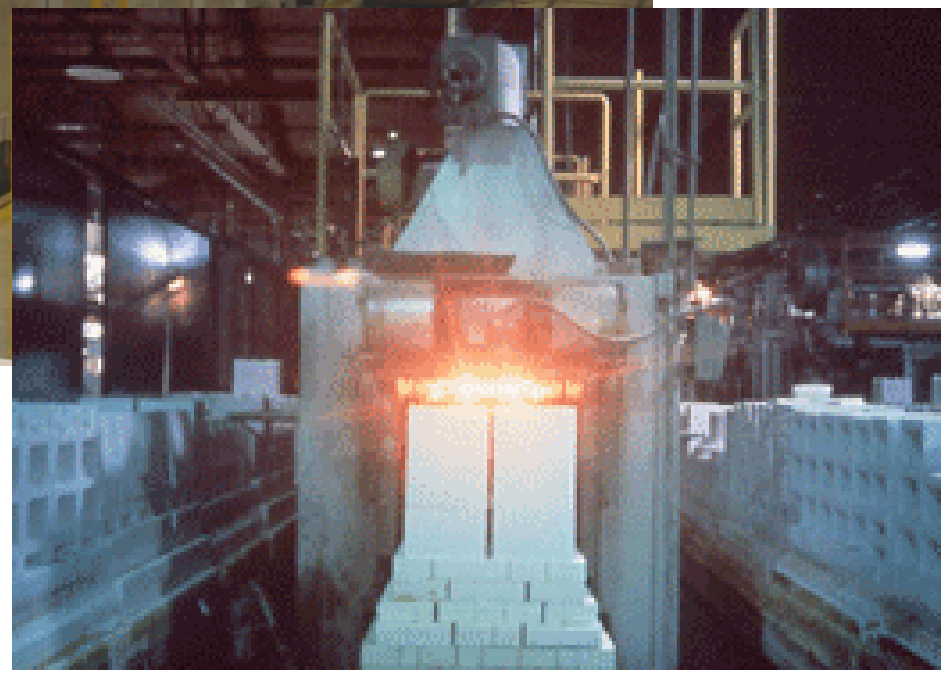
Roll Compaction: GW/year

300 ft/hour, 1ft wide

235 miles/year

>500 GW/year

Firing: GW/year



12cars/day

45ft^3/car

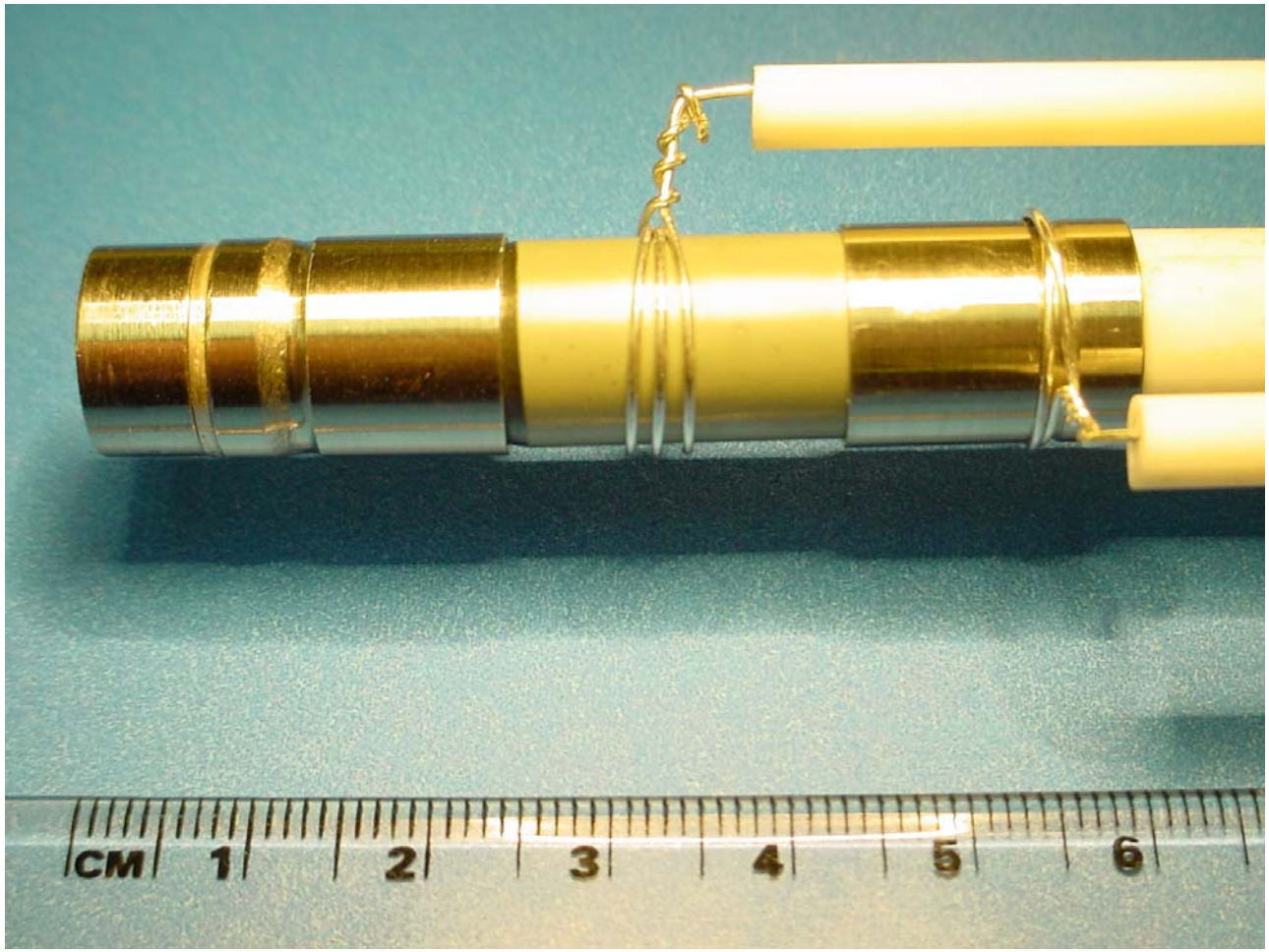
1GW/year

Necessary Steps

- Develop strategic raw material infrastructure
- Design with cost-effective mfg. processes early on
- 10 GW by 2010? –
  we better get busy

Pathway to High Efficiency

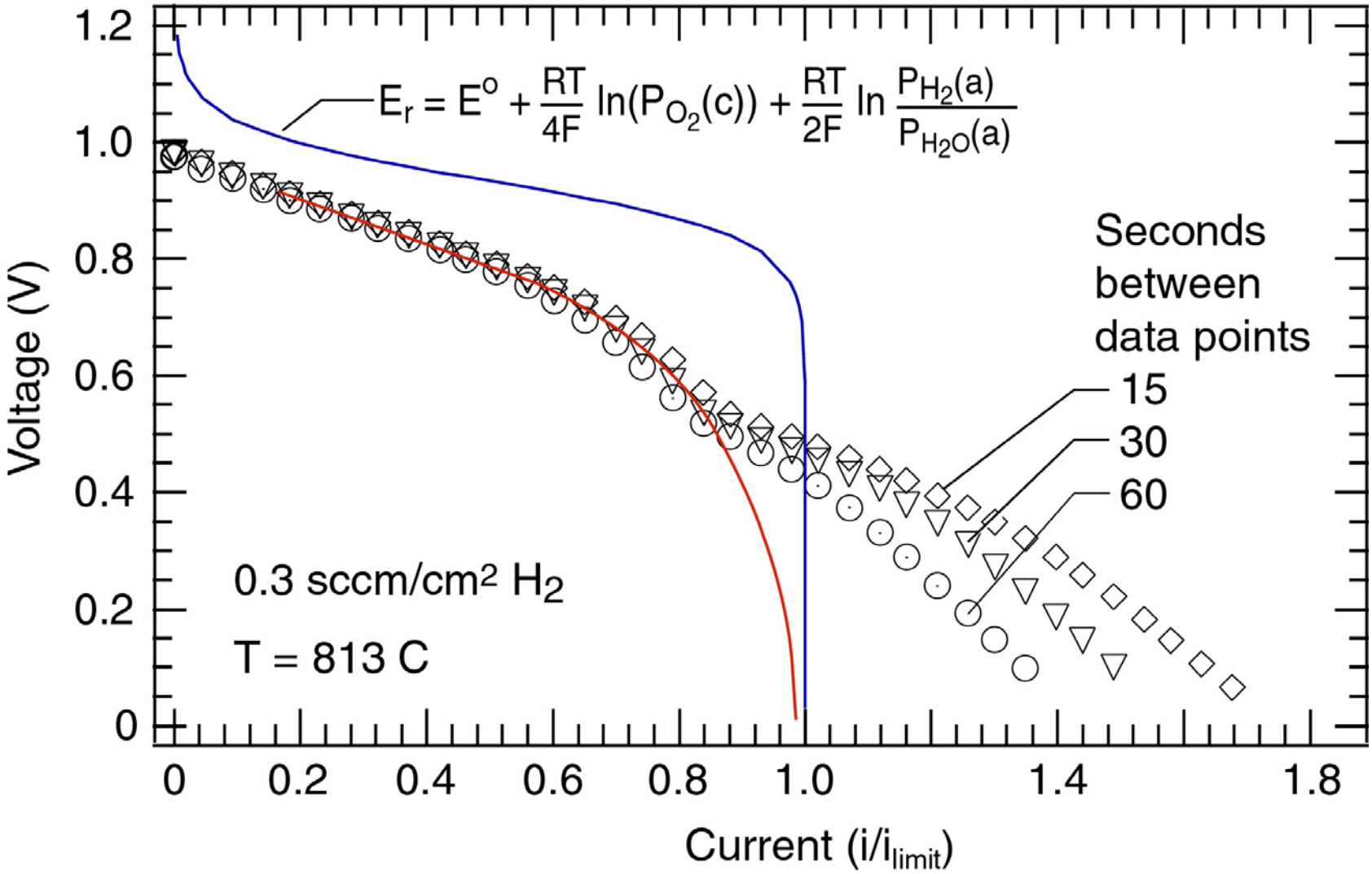
Tubular SOFC Test Fixture



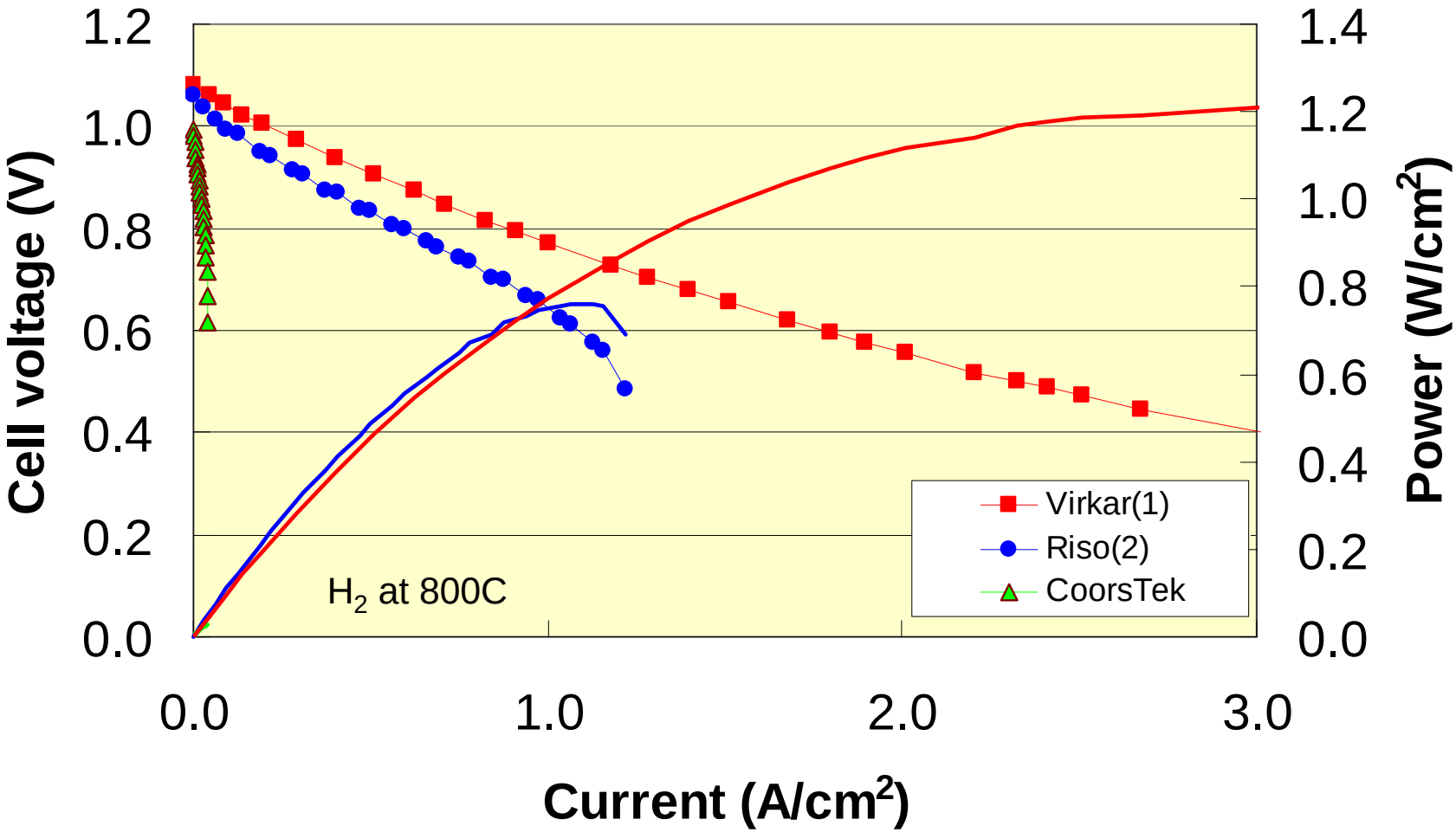
5 cm^2 active area, isobaric

Approximates a CSTR

Nickel Oxidation at High Uf

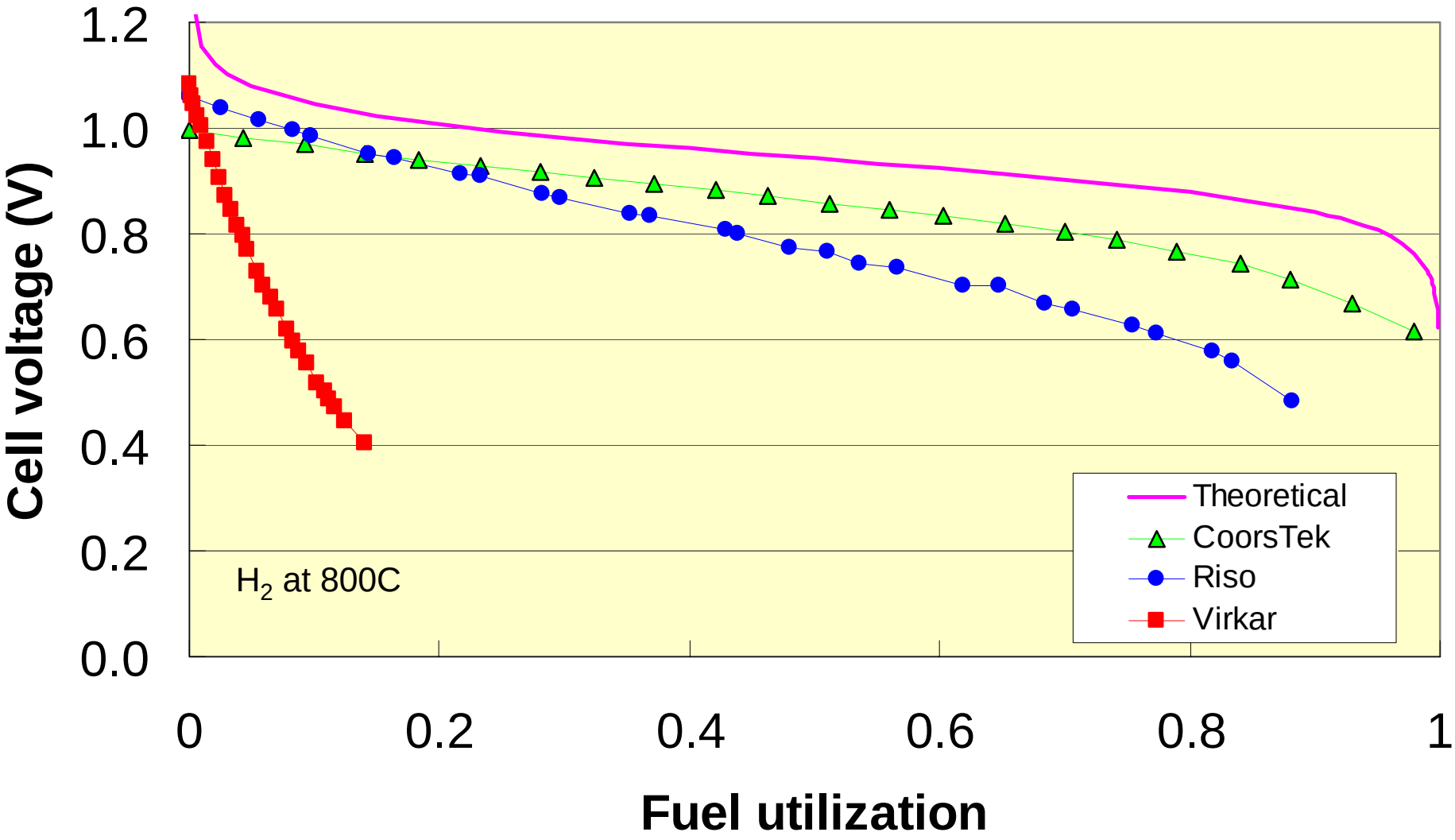


Traditional I-V Characterization

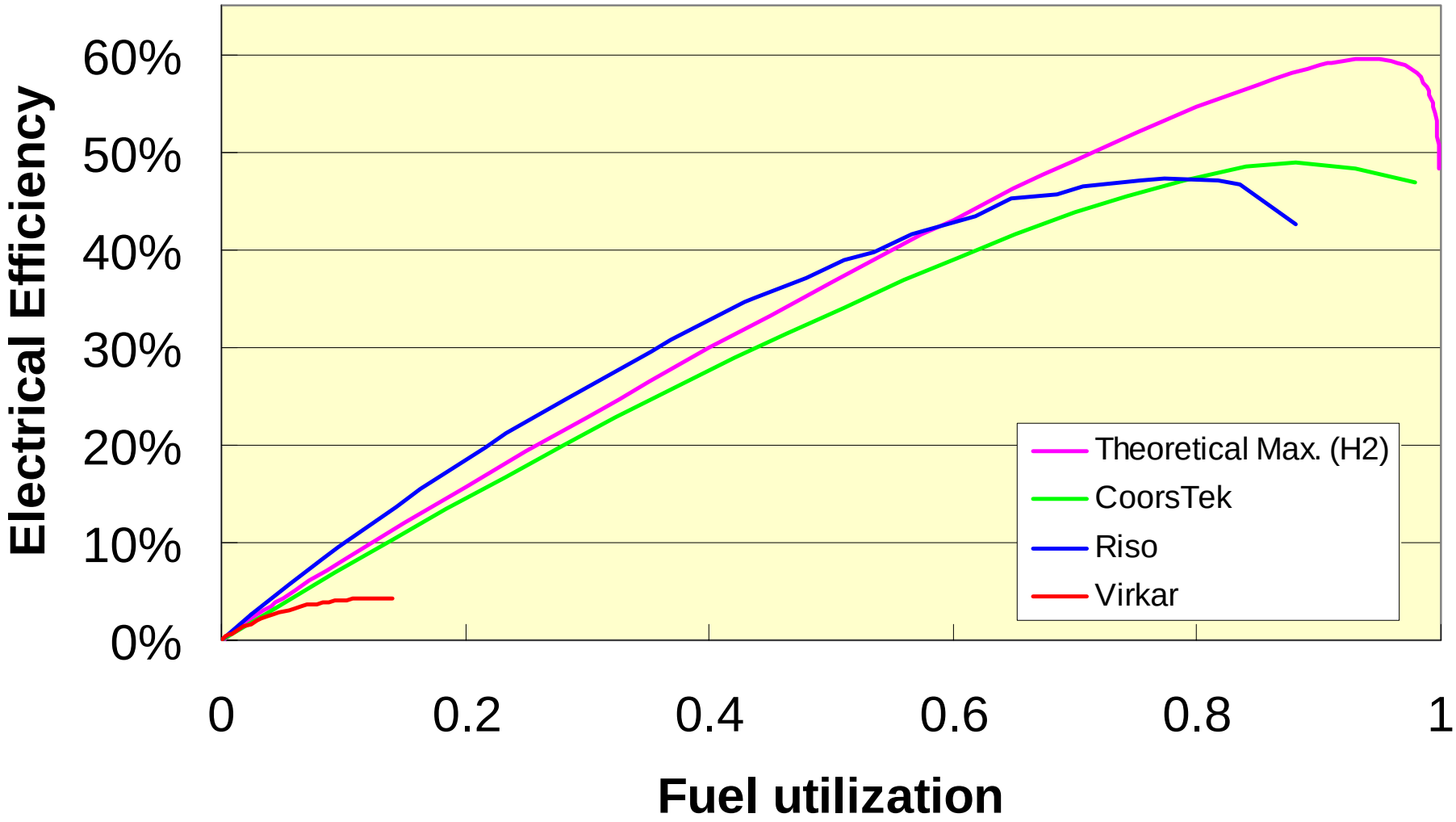


(1) F. Zhao and A.Virkar, J. Power Sources, 141 (2005) 79-95
(2) M. Mogensen and P. Hendricksen, Fig. 10.7, High Temperature Solid Oxide Fuel Cells, Singhal and Kendall, Ed. (2004)

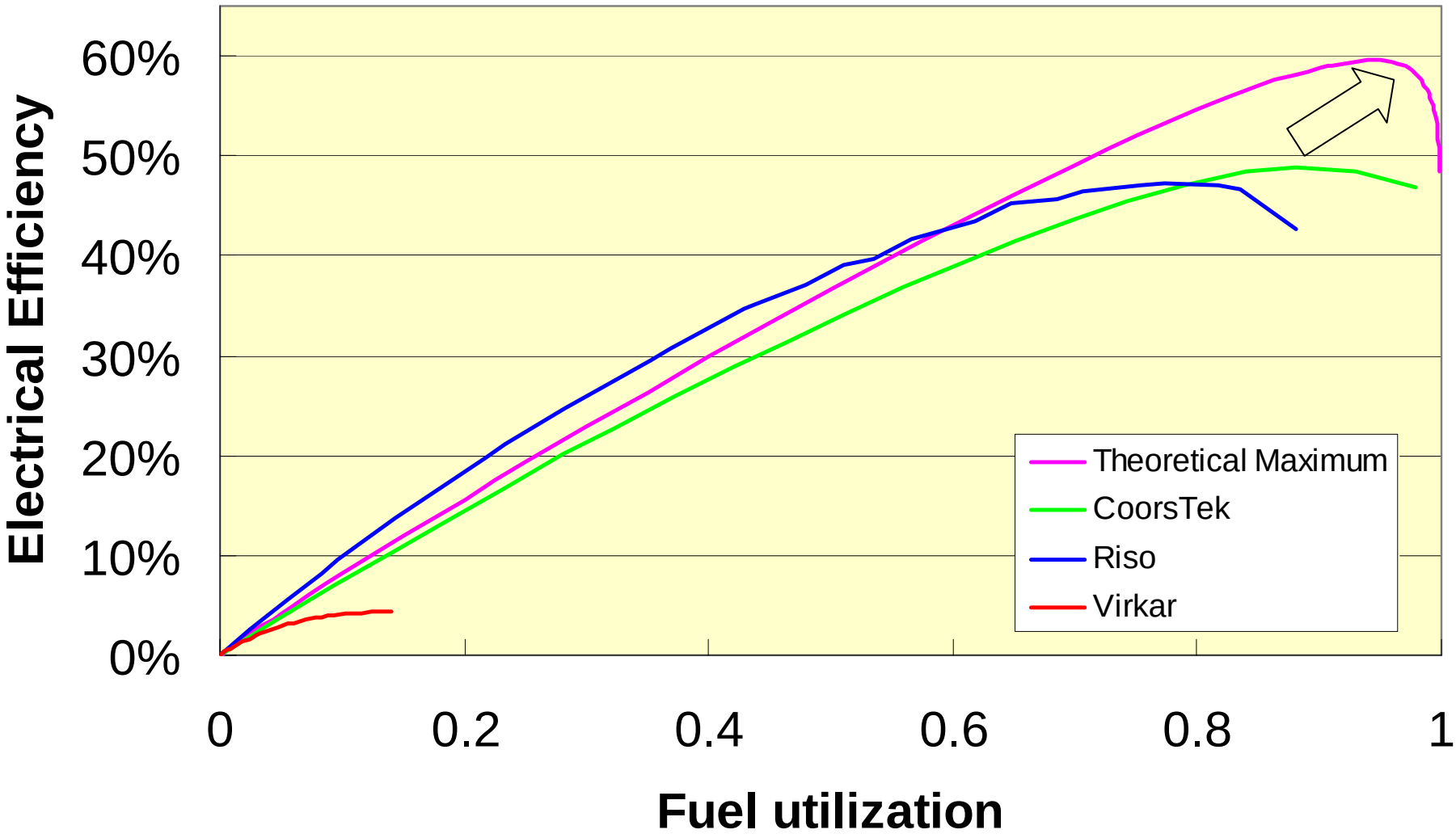
Vcell vs.Fuel Utilization



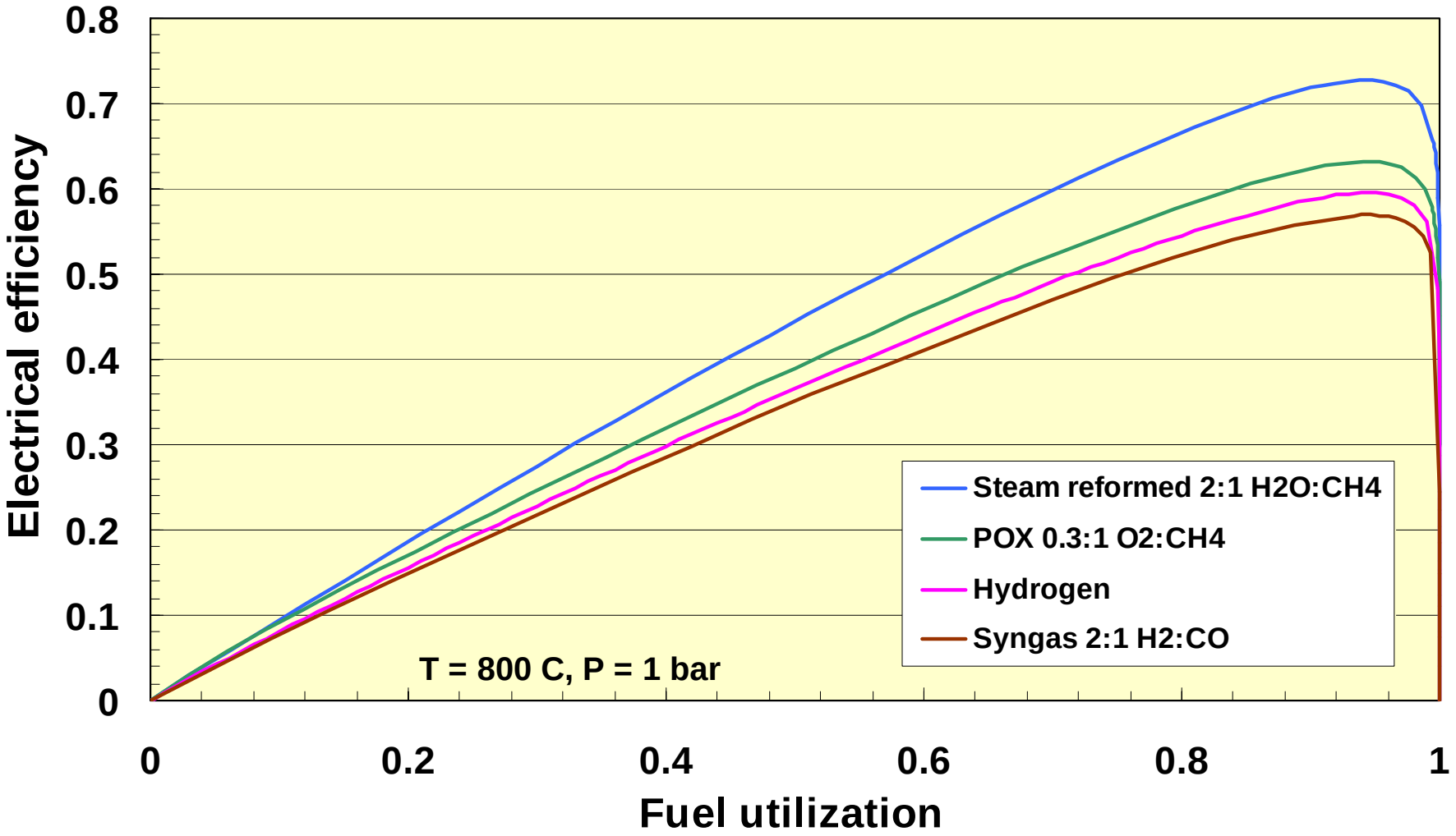
Electrical Efficiency vs. Fuel Utilization (Hydrogen)



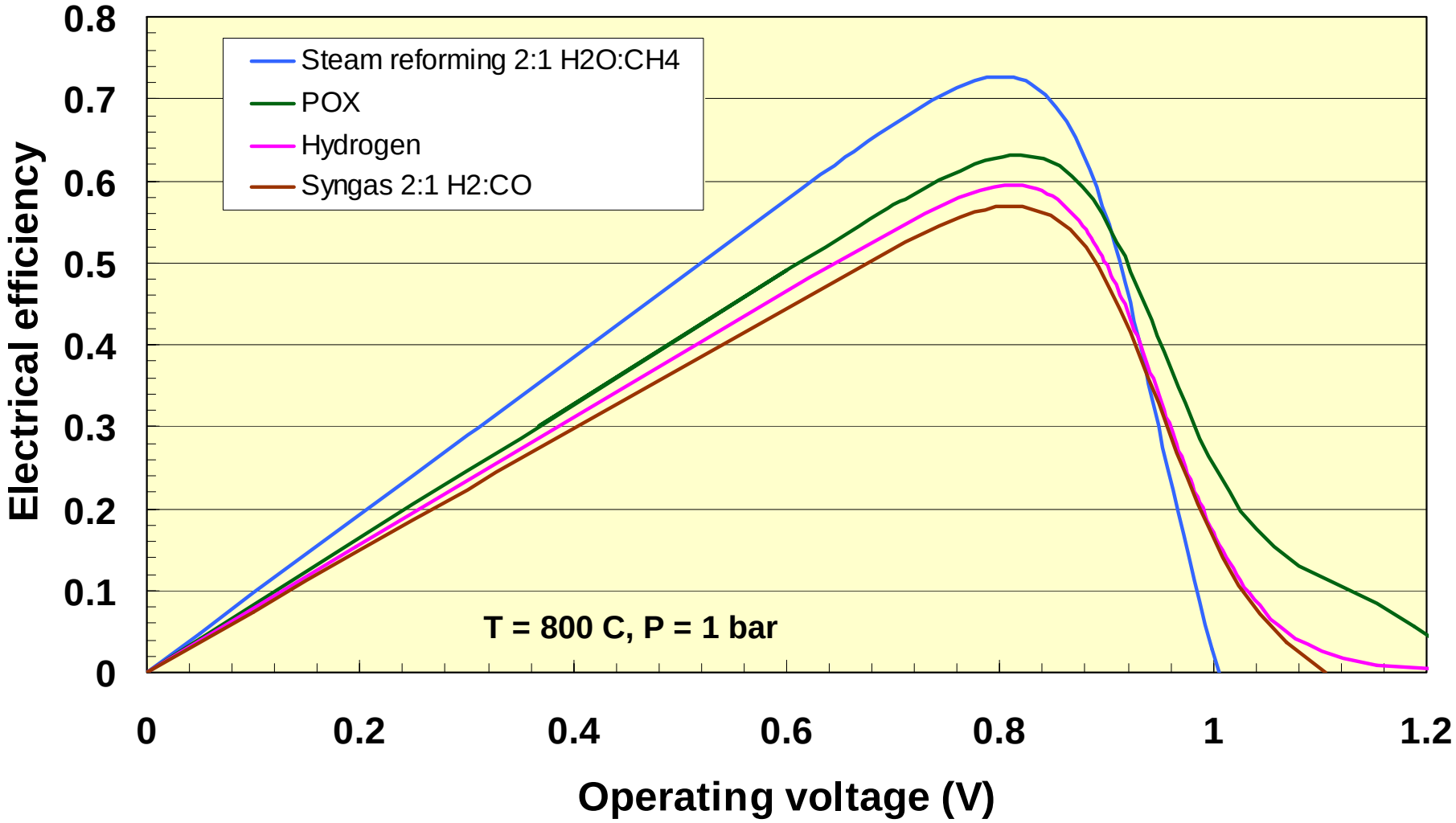
Electrical Efficiency vs. Fuel Utilization (Hydrogen)



Electrical Efficiency vs. Fuel Utilization (methane)



Electrical Efficiency vs. Vcell (methane)



Necessary Steps

- Cell and short stack testing near I_{lim}
- Assess impact of design variants on η_e (tubular vs. planar)
- Evaluate cost/performance of raw materials (eg. pre-calcined 8YSZ vs. “reaction sintered”)

Necessary Steps

- Test hydrocarbon fuels at high U_f
- Better understand anode oxidation
- Assess impact of gas impurities at high fuel utilization (eq. sulfur)
- Reallign power density expections
  (Can affordable systems be constructed at 100 mW/cm^2?)

Summary

- Cost and Efficiency must me addressed together
- SECA cost targets must be met at >50% η_e
- Begin developing The Ceramic Manufacturing Industrial Base **now**
  (need ~ 10,000 tonnes by 2010)