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?
Cost of delivered electric power

SECA Target ($400/kW, 40 khrs)
(PNG Cost: $7 (whs), $10 (ret) per MMBTU)

Electricity Cost ($/kWh)

40% (whs) 40% (ret) 50% (whs) 50% (ret) 60% (whs) 60% (ret)

Electrical Efficiency

Fuel Usage
Total Fixed
Cost of delivered electric power

$1000/kW, 40 khrs
(PNG Cost: $7 (whs), $10 (ret) per MMBTU)
Market size depends on efficiency

40% → 1 GW

50% → 10 GW

60% → 100 GW
Two Elements of Commercial Success

Commercial Success Depends On:

- Low cost/ high volume manufacturing
- High fuel cell efficiency
Pathway to Low Cost/High Volume Manufacturing
Serving our customers where they need us...

...from 18 facilities and over two million square feet worldwide!
Serving virtually every industry in the global economy...
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!*
From materials design to the finished component, our vertically-integrated manufacturing ensures quality throughout the process...
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 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, 1-2 charges/day

1/2 GW/year
Spray Dry Milled Body

2MW/hour

6-7 GW/year
Waste Collection and Treatment

Regulations

Chemical Handling
EHS Issues

Waste Disposal

Water Treatment
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
3-7 m/hour, 17cm wide
0.5-1.2m²/hour
7-20MW/year

1/50 or less of a GW/year
300 ft/hour, 1ft wide
235 miles/year

>500 GW/year
12 cars/day
45 ft$^3$/car
1 GW/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
5 cm² active area, isobaric
Approximates a CSTR
Nickel Oxidation at High Uf

\[ E_r = E^0 + \frac{RT}{4F} \ln(P_{O_2}(c)) + \frac{RT}{2F} \ln \frac{P_{H_2}(a)}{P_{H_2O}(a)} \]

Seconds between data points

- 15
- 30
- 60

0.3 sccm/cm² H₂

T = 813 °C
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

Cell voltage (V)

Fuel utilization

Theoretical
CoorsTek
Riso
Virkar

H₂ at 800°C
Electrical Efficiency vs. Fuel Utilization (Hydrogen)

- Theoretical Max. (H2)
- CoorsTek
- Riso
- Virkar

Fuel utilization

Electrical Efficiency

April 2005
Electrical Efficiency vs. Fuel Utilization (Hydrogen)

- Theoretical Maximum
- CoorsTek
- Riso
- Virkar

Graph showing the relationship between electrical efficiency and fuel utilization.
Electrical Efficiency vs. Fuel Utilization (methane)

- Steam reformed 2:1 H2O:CH4
- POX 0.3:1 O2:CH4
- Hydrogen
- Syngas 2:1 H2:CO

T = 800 C, P = 1 bar
Electrical Efficiency vs. Vcell (methane)

- Steam reforming 2:1 H2O:CH4
- POX
- Hydrogen
- Syngas 2:1 H2:CO

T = 800 C, P = 1 bar
• Cell and short stack testing near $I_{lim}$
• Assess impact of design variants on $\eta_e$ (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)
- Realign power density expectations
  (Can affordable systems be constructed at 100 mW/cm$^2$?)
• Cost and Efficiency must be addressed together
• SECA cost targets must be met at >50% $\eta_e$
• Begin developing The Ceramic Manufacturing Industrial Base **now**
  (need ~ 10,000 tonnes by 2010)