Status and Trends for Stationary Fuel Cell Power Systems

Dan Rastler

Technical Leader, Distributed Energy Resources Program

drastler@epri.com

650-855-2521

Discussion Topics

- Review Technical and R&D Status
- Markets and Applications
- R&D Needs
- Gaps and Critical Success Factors for Large Scale Commercialization
- CleanTech Accelerator for Silicon Valley

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Why the Interest in Fuel Cells?

- Very high fuel conversion efficiencies
- Direct conversion avoids combustion process – allows for very low emissions
- High reliability- fewer moving parts
- Modularity – scale-able to many sizes from 1 kW to 10’s MW – offering a wide range of applications
- Quite Operation - < 60 dBA
- High Power Quality – due to use of dc to ac power conditioning equipment
- Waste heat – which can be used in cogeneration applications enabling higher overall fuel efficiencies
- Fuel Cells are ideal distributed generators, enabling power to be sited at the ‘point of use’

Introduction: Fuel Cell Types

They can be Characterized by electrolyte type, materials of construction and operating temperature

Type	Temp F	Electrolyte	Materials
PEMFC Polymer-exchange membrane fuel cells	200	Fl, Sulfonic Carbon Acid Polymer	Carbon, Sainless Steel Pt. Catalyst
PAFC Phosphoric-acid Fuel cels	400	Phosphoric Acid	Carbon Pt. Catalyst
MCFC Molten-carbonate fuel cells	1200	Lithium, Potassium Carbonate Salts	Ni - catalyst Stainless Steel
SOFC Solid-oxide fuel cells	1500-1800	Yittra & Zirconium Oxides	Ceramic Nickel Alloys
AFC Alkaline fuel cell	250-480	KOH and NaOH	Ni, metal oxides Pt. Catalyst

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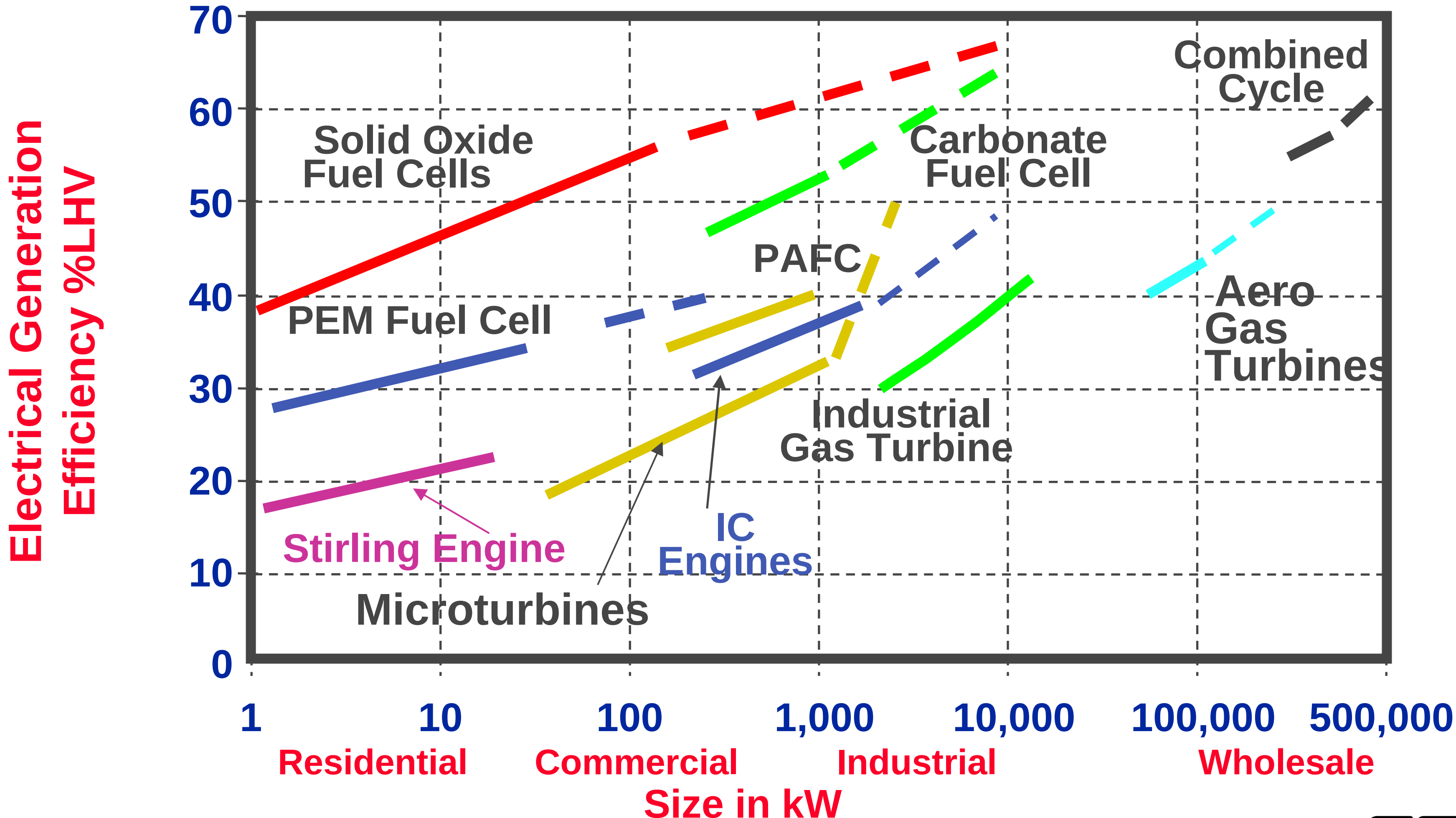
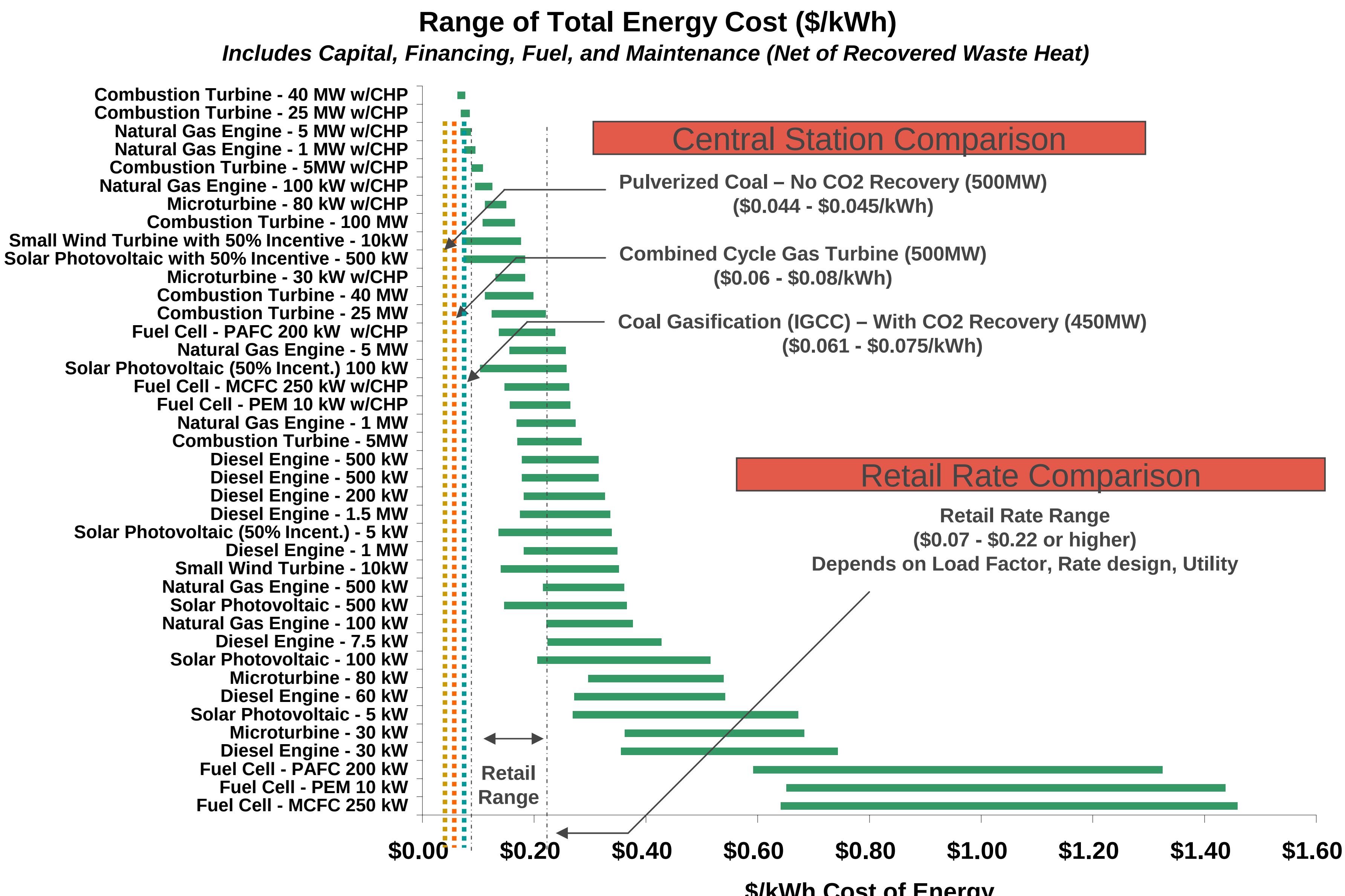
Fuel Cell Types and Comparisons

Fuel Cell Type and Scale in kW	Electrical Efficiency, LHV	Current and {Projected} Cost $/kW	Status
PAFC 200 – 1,000	40%	$ 4000 {3000}	Commercial
MCFC 250-1000	44-55%	$4000 {1200}	Pre-commercial
PEMFC 5 kW to 1,000	32-42%	$2000-$4000 {900}	Pre-production trials Under development
SOFC 5 kW – 1,000	40-55%	$20,000 {700-900}	Beta trials Under development

Fuel Cell System Trends Compared with other Distributed Generation Technologies

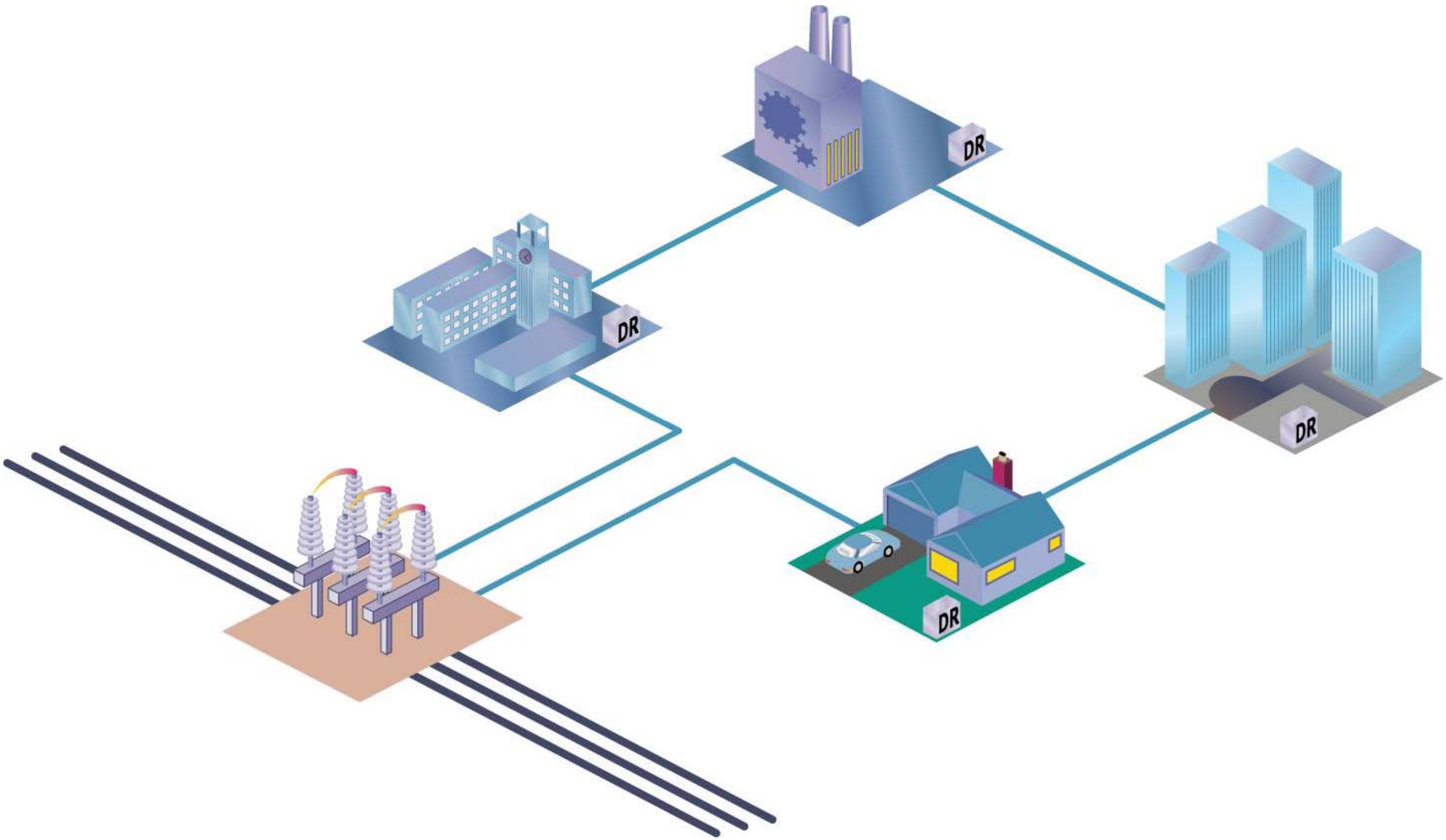


Benchmarking Fuel Cells



What Might the Future Look Like?

Grid integrated Distributed Power



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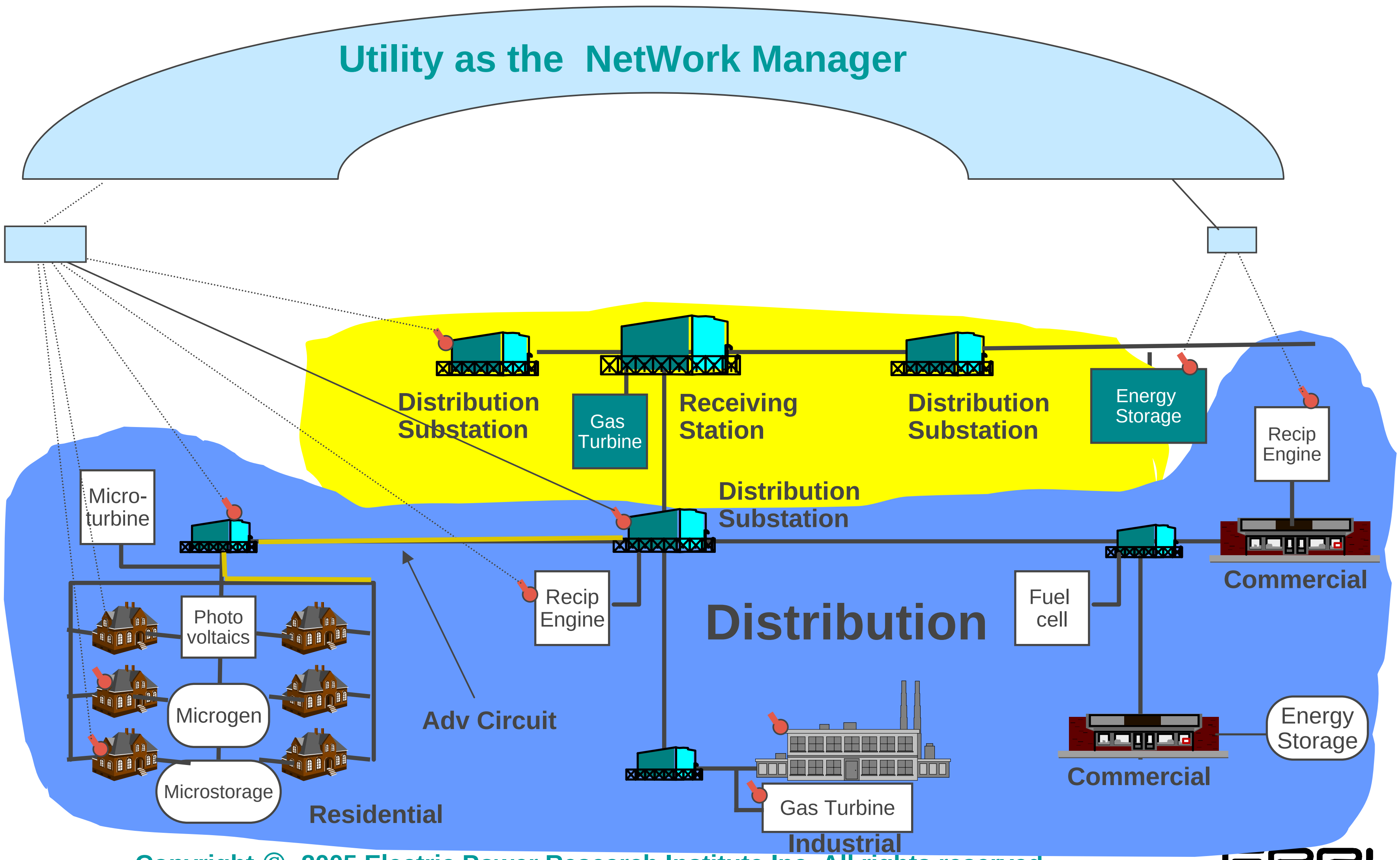
Vision: Distributed Energy Resources

Imbedded systems at End-user locations; Smart Grid; Dispatchable DER Assets; Utility as the Network Manager



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Overview
Status of Stationary Fuel Cell Power Systems

Polymer Electrolyte Membrane (PEMFC)

- 1-10 kW
- 25-40 % efficiency LHV
- $ 5,000 /kW

Phosphoric Acid Fuel Cells (PAFC)

- 200-1000 kW
- 40 % efficiency LHV
- $ 3,500 / kW

Molten Carbonate Fuel Cells (MCFC)

- 250- 1,000 kW
- 45 % efficiency
- $ 3,000-4,000 / kW

Solid Oxide Fuel Cells (SOFC)

- 1-250 kW
- 45-48 % efficiency
- $10,000 - 20,000/kW

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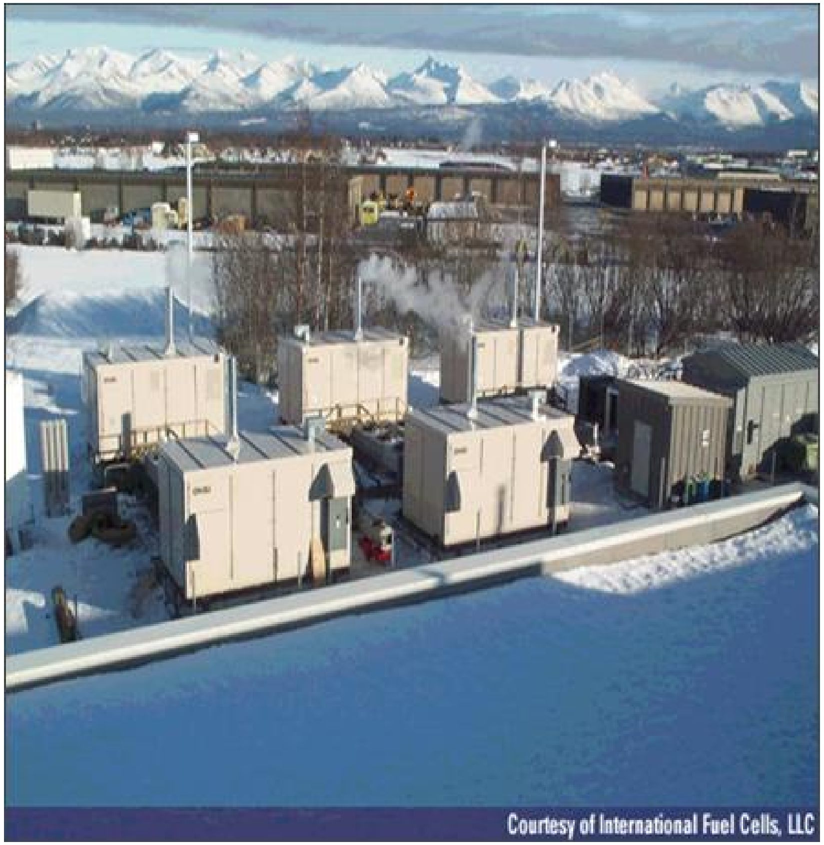
Phosphoric Acid Fuel Cells

Have been fully demonstrated in the field; show good availability and reliability; but have not secured market penetration do to high capital costs



Carbonate Fuel Cell Systems

Several pre-commercial systems and field trials under way

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Status: Solid Oxide Fuel Cell Systems

Several field trials have occurred; Advanced technology still in R&D Lab phase

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Small SOFC systems are under laboratory evaluation

Mitsubishi Materials Corporation

Fuel Cell Technology

Ceramic Fuel Cells Limited

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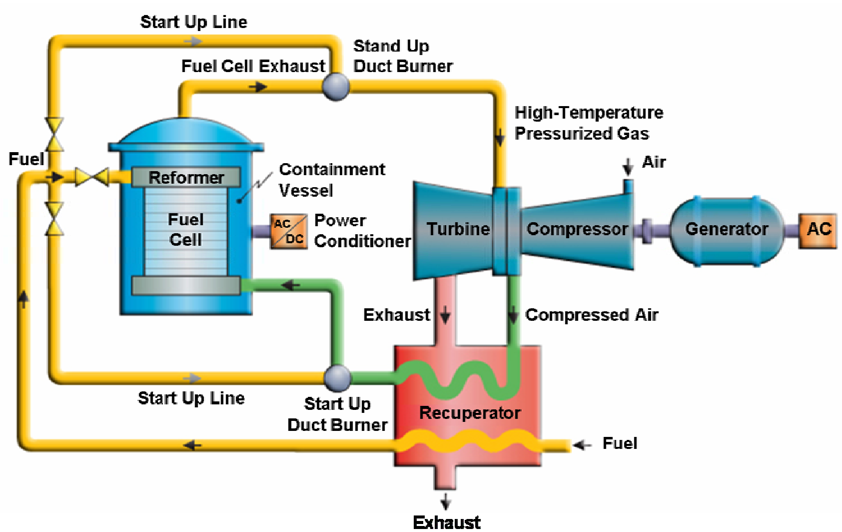
Status: PEMFC Systems

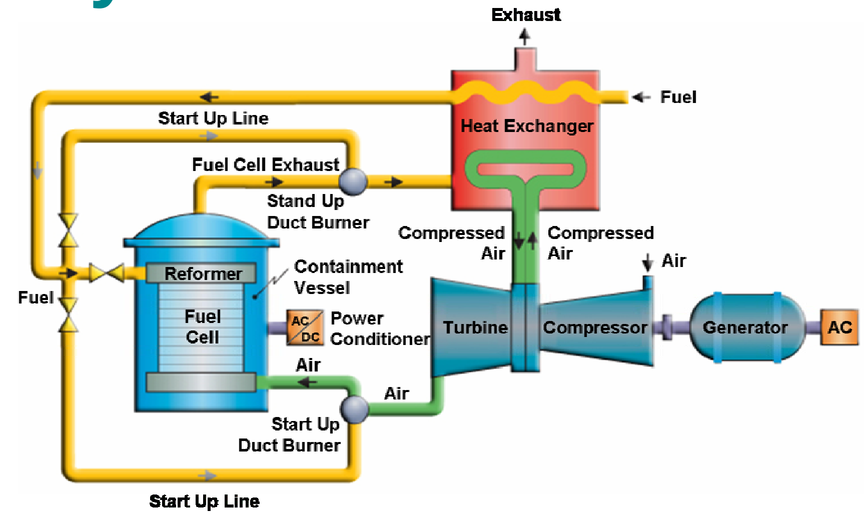
Most vendors developing systems for telecom and battery replacement markets

I-1000™ 1kW PEM Fuel Cell

GM Demo at Dow

Fuel Cell Turbine Hybrid Cycles





Direct Cycle	Characteristic	Indirect Cycle
Pressurized	Fuel Cell Pressure	Non-Pressurized
Higher	Efficiency	High
More Difficult to Match	Flow & Pressure/ratio	Easier to Match
Limited	Operational Flexibility	Some

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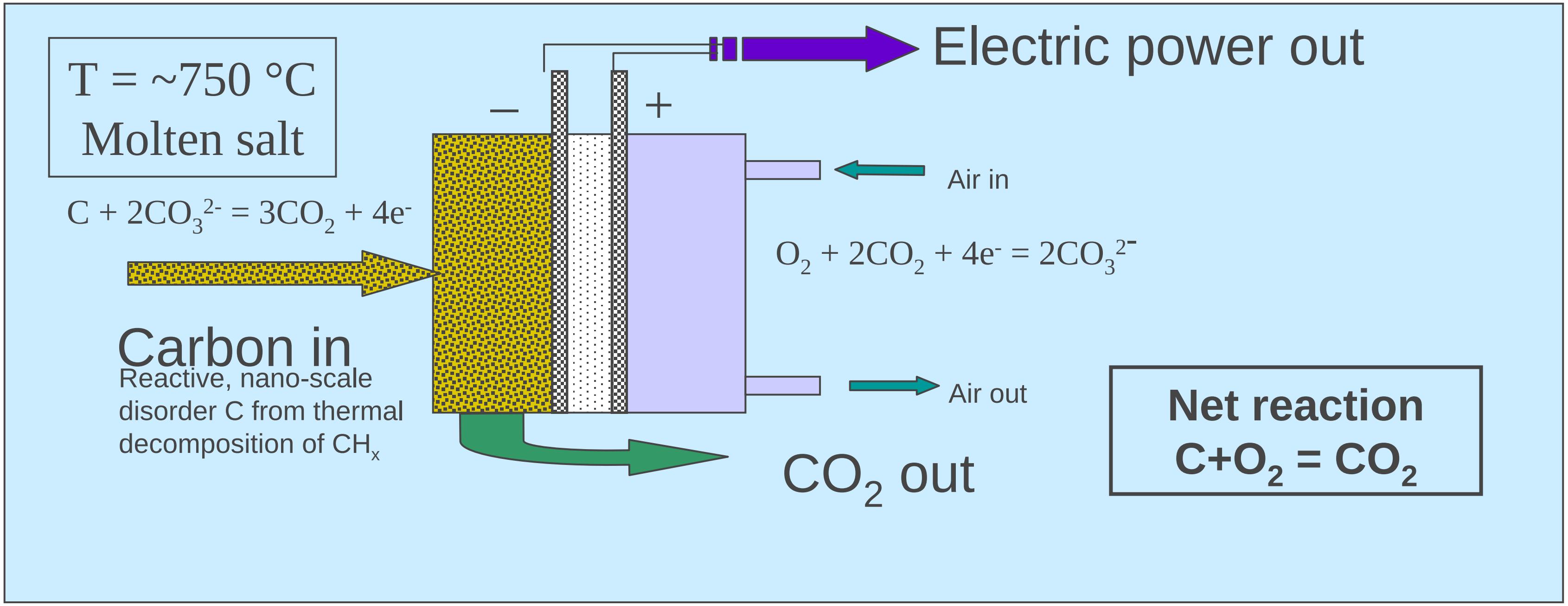
Direct Carbon Fuel Cell (DCFC)

Emerging Technology in Lab Stage
R&D at LLNL, SRI, SARA and CellTech



- The <u>net</u> reaction is the same as combustion
- Electric power and CO_2 are the products
- 80 % of heat of combustion is convertible into power
  - HHV= (32.8 MJ/kg-C; 14.1 MBTU/lb-C)

PEMFC R&D Needs for Stationary Power

Key Areas of R&D:

- Durable electrolyte
- High temperature electrolyte
- Lower Pt. Loadings
- Low System Efficiency
- Complex Fuel Processing

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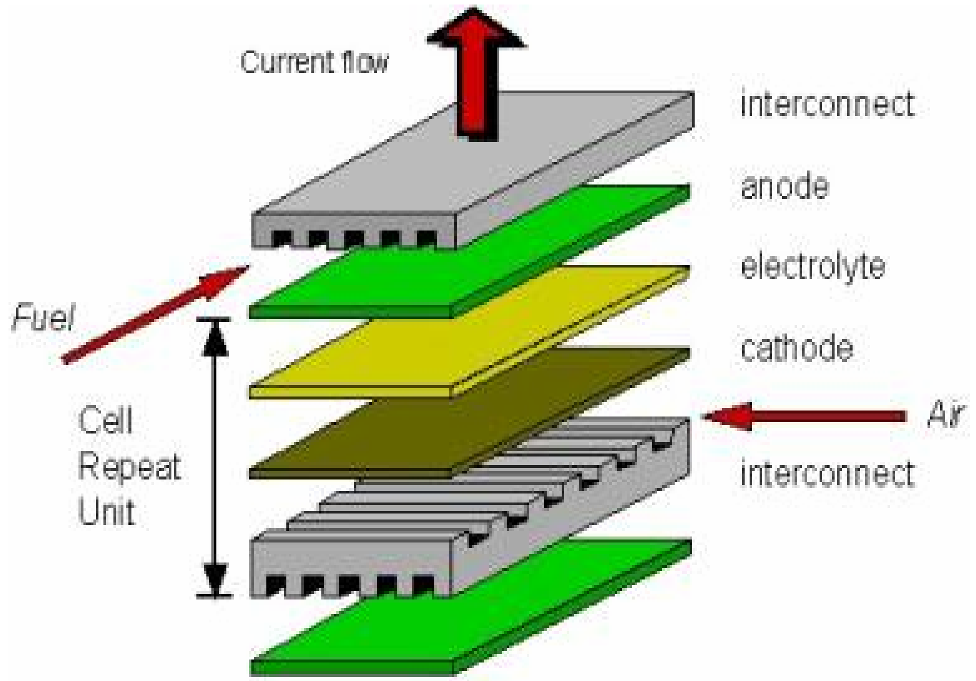
SOFC R&D and Materials Research Needs

Key Areas of R&D:

- Stable Interconnect under anode and cathode environments
- Advanced Electrodes
- Seals
- Low cost fabrication methods
- High power density
- Durability



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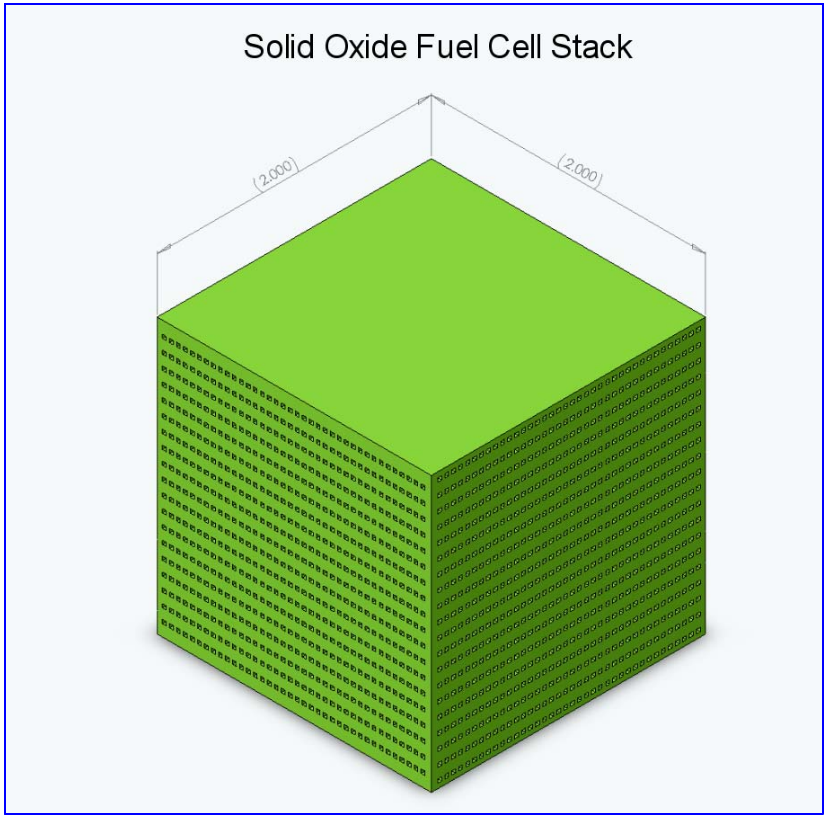
Advanced SOFC Concepts Under Development



Siemens-Westinghouse **CeramPhysics, Inc.**

Innovation and R&D Required for Large Markets

Efficiency, LHV

35-45

2005-2008

Early Markets
- Schools & Universities
- Government Buildings
- CHP; Free Fuel
- National Parks
- Military Bases
- State RPS Programs

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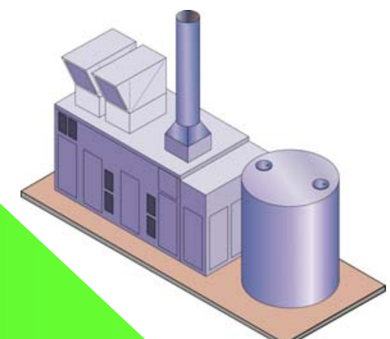

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2008-2010

- 5 kW – 75 kW PEMFC
- 250 – 1 MW MCFC, and SOFC
- 5- 40 kW SOFC
- $ 1,500-$2,000 / kW

2010-2020

- 75 kW – 250 kW PEMFC
- 250 – 3 MW MCFC, SOFC
- 2 – 50 kW SOFC
- 1MW + SOFC-CT
- <<$ 800 /kW

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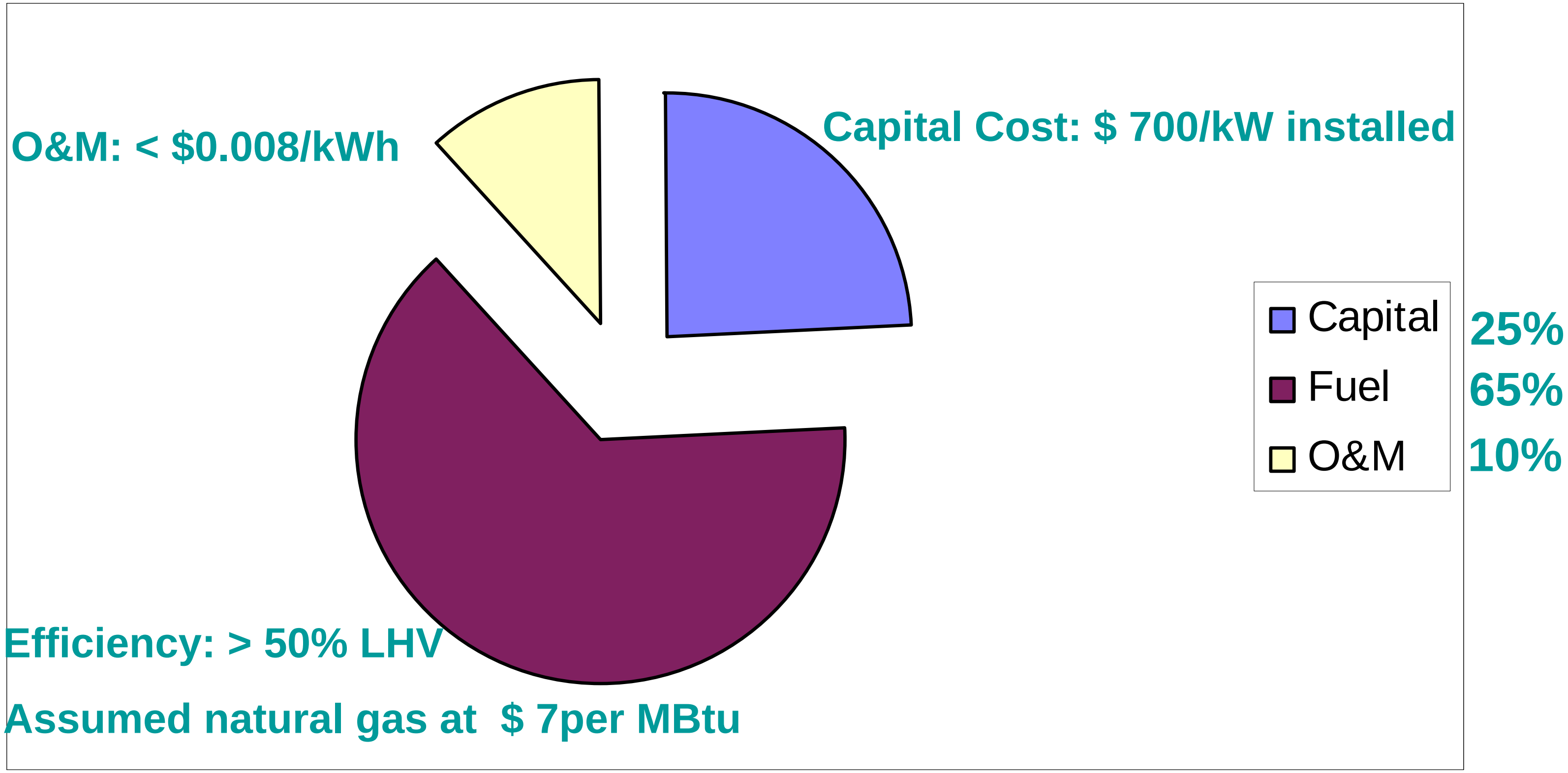
R&D Targets Needed to achieve 8 cents/kWh
Distributed Fuel Cell Power System Requirements
All Electric Case – non-cogeneration /cooling scenario



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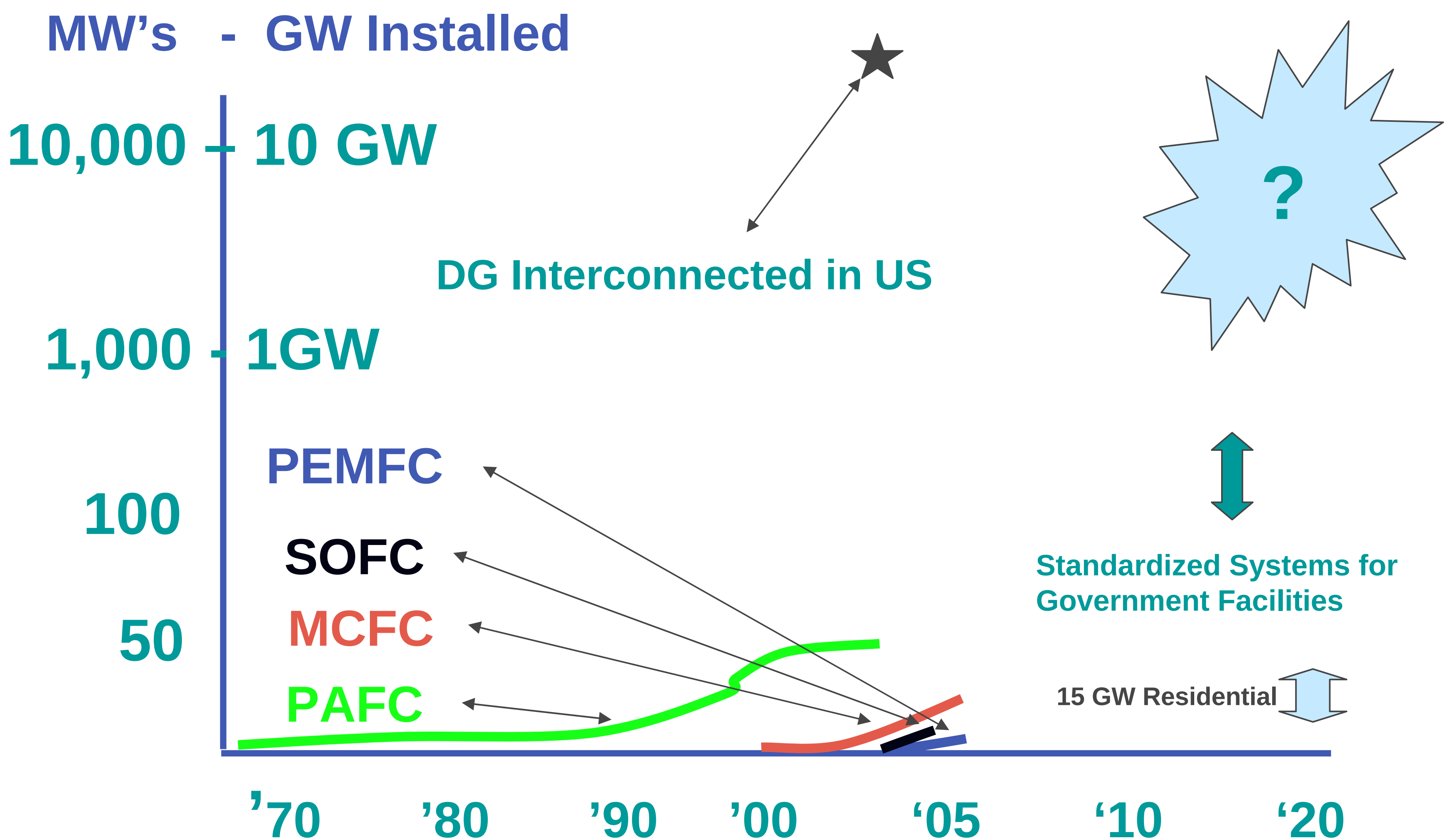
Gaps and Barriers to Large Market Applications

- **Breakthroughs are needed -** current systems offer limited market applications
- **High Capital Cost** – systems < $ 700 per kW installed
- **Long Durability and Life** – fuel cell stack life ~8-10 years
- **Low Cost of Electricity** – vs. other DG options and retail delivered power (< 8 cents per kWh)
- **Technology risk –** competitive markets will not adopt until fuel cells are proven
- **High Installation Costs** – including permitting, and interconnection & project development
- **Regulatory Framework -** Competitive market structure limits adoption of emerging options

Stationary Fuel Cells – Trends What does the Future Hold?



CleanTech Accelerator for Silicon Valley
" A Working Concept "

Goals:

- Establish and Grow the "EcoSystem" for CleanTech R&D in California – starting with Si Valley Companies, Talent, Skills, & Resources

- Facilitate Networking, Deal Flow, Early-Stage Investments in CleanTech Areas:
  - Energy: Alternative Energy Systems; Grid; Fuel
  - Materials
  - Water
  - Environment
- Accelerate market application of CleanTech products and services

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Thank You!

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