F. Solid Oxide Fuel Cells and Stationary Applications

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Solid Oxide Fuel Cells and Stationary Applications

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SECA 2000 Market Segments Requirements

Several distinct markets exist for stationary SOFC generators, each with distinct characteristics and requirements.

Residential	• Highly variable power requirements • High competing price of power (¢/kWh basis) • Highest requirements for reliability and ease-of-installation • CHP is difficult
Commercial	• Peaky power requirements • Baseload or peak-shaving applications are possible, depending upon rate structures. • CHP potential exists in some applications. • “Premium” power credit can increase the value of on-site generators.
Industrial	• Increased likelihood of dedicated loads • High demand charges in some applications will favor peak-shaving systems. • CHP potential exists in many applications. • “Premium” power credit can increase the value of on-site generators.
Grid-support	• Can be installed to offset T&D and new generation capacity investments • Implies that system is dispatchable by the local utility or ISO • Most attractive for high efficiency systems, where the marginal cost of power is competitive with wholesale rates (1 - 4 ¢/kWh).

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SECA 2000 Market Segment Requirements

Performance and cost requirements for distributed generators vary by market segment.

	Stationary					Transportation	
	Buildings		Industrial	Utility		Automotive	Heavy Duty
	Residential	Commercial		Distributed	Central		
1. Capacity (kW)	1 - 5	20 - 500	200 - 2000	500 - 5000	> 100,000	30 - 90	60 - 2000
2. Efficiency %[1]	> 35	> 35	> 40	> 40	> 55	> 40	> 40
3. Life (years)	> 10	> 10	> 15	20	20	0.5 [3]	2 - 10 [3]
4. O&M (hours)	> 4000	> 1000	ongoing	ongoing	ongoing	> 200	> 200
5. Heat Recovery • Temperature Level	Important 80 - 220° F	Important 80 - 250° F	Important a. 120 - 300° F b. 80 - 220° F	Not Important N.A.	Not Important N.A.	Not Important N.A.	Not Important N.A.
6. Cyclability	Important	Important	Not Important	Important	Not Important	Very Important	Important
7. Emissions[2] NOx (ppm)	< 20	< 20	~ 150	~ 50	~ 150	~ 50	~ 50
8. Startup Time	Important[4]	Important[4]	Important[4]	Not Important	Not Important	Very Important	Very Important

[1] Electric generation only; in cogeneration applications combined electric-thermal efficiencies approach 85%.
[2] Varies by application and region; estimates reflect trends toward increasingly stringent regulations.
[3] Actual operating time of the power system (not vehicle life).
[4] Importance depends upon operation strategy. Peak-shaving units will require rapid startup, but base-loaded systems will not.

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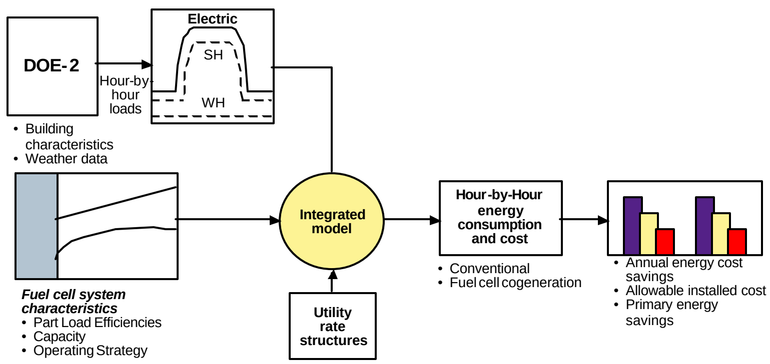
SECA 2000 Market Segment Requirements

We have used a detailed economic model to estimate the allowable cost of distributed power technologies in a variety of applications.



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SECA 2000 Market Segment Requirements

These analyses have shown that distributed generation technologies could generate economic value at installed costs of $2,500 and below.

	Market Segment	Typical Capacity	Allowable Installed Cost[1] ($/kW)	
			Entry[2]	Sustained[2]
On-site	Commercial Cogeneration	50 kW - 2 MW	$1,500 - 2,000	$800 - 1,300
On-site	Industrial Cogeneration	5 - 200 MW	$1,000 - 1,200	$800 - 1,000
On-site	Residential Power	0.5 - 10 kW	$1,000 - 2,500	$800 - 1,000
Utility	Distributed Power	5 - 20 MW	$1,300 - 1,500	$800 - 1,300
Utility	Central Station	100 - 500 MW	$900 - 1,100	$700 - 900

[1] Total installed system costs, including all owners costs. Targets apply widely to industrialized country markets. Costs have been calculated based on a range of electricity and gas rate structures. Allowable costs for hydrogen fueled systems would be considerably lower as merchant hydrogen prices are typically 2-3 times as high as natural gas.
[2] "Entry" costs are based on early high value markets. "Sustained" costs must be realized to achieve significant market penetration.

Note that these costs do not include "premium" power benefits, which might increase the allowable costs by 25% or more above the values shown here (in selected applications).

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SECA 2000 Market Segment Requirements

Residential applications have potential “mass markets”, but pose unique technical and cost challenges.

- Electric load profiles are highly variable:
  - Peaks are ~ 10 kW in many homes
  - Baseload is often 0.1 kW or less
  - Average loads can be quite small, ~ 0.5 - 1.5 kW
  - ⇒ *The most cost-effective on-site generators will be small, baseloaded architectures, provided that they can operate in parallel with the utility grid.*
- From the home owners perspective, the generator must “look” like a typical appliance.
  - Minimal installation requirements
  - Minimal service requirements (once per year maximum)
  - Long operating life
- Little coincidence between thermal and electric loads in many US markets, making CHP difficult.
- Unresolved (but certainly challenging) codes and standards issues relating to onsite generators and onsite hydrogen flows, even as dilute H_2.

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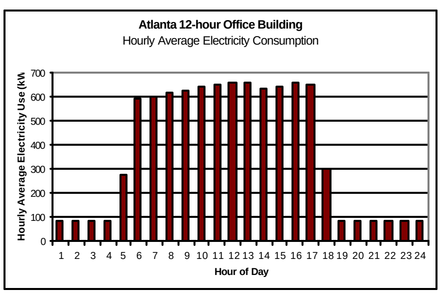
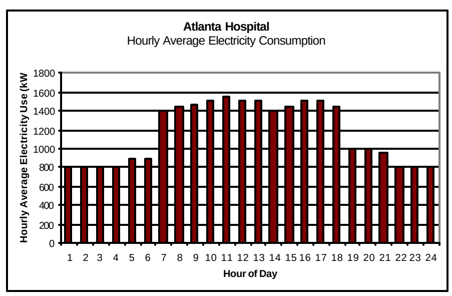
SECA 2000 Market Segment Requirements

Commercial building load curves present unique challenges and opportunities for distributed generators.





- Variation in peak and baseload power demand impact multiple generator specifications, including:
  - Capacity factor of load-following systems
  - Opportunities for demand charge reduction
  - Optimal product sizing strategy
  - Turndown requirements

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SECA 2000 Market Segment Requirements

Significant markets exist for generators with rated capacities greater than 10 kW (e.g., non-residential units).

Building Type	Baseload Power Requirements (kW)*	% of US Commercial Electricity Use (kWh)
• Large High-Rise Office • Largest Hospitals • Largest Hotels • Large Shopping Mall	1,000+	20%
• Hospitals (200 - 300 beds) • Large Hotels (750 rooms) • Office (200,000 sq. ft.) • School (125,000 sq. ft.) • Large Retail	200 - 1,000	35%
• Office (50,000 sq. ft.) • Average Hotel (75,000 sq. ft., 125 rm) Multi-family (100 units)	50 - 200	35%
• Fast Food Restaurant (4,000 sq. ft.) • Small Office Building (10,000 sq. ft.) • Multi-family (<25 units)	10 - 50	10%

*Peak loads can be 2-3 times higher.

However, large numbers of potential kWh sales do not necessarily imply large numbers of unit sales!

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SECA 2000 Market Drivers

As the energy industry deregulates, market drivers for stationary power generation are rapidly changing.

Energy Costs Matter!

- Technologies that can successfully compete with the grid on a ¢/kWh basis can bring value to the end user.
- However, prevailing costs may not be the best indicator of economics:
  - Utilities may adjust their rate strucutres in light of competition from on-site generators
  - Electricity rates are falling in the wake of deregulation.
- Even if the marginal cost of power generation is high, on-site generators may still be able to bring about value through demand charge ($/kW) reduction.

- **Energy cost savings can be a powerful (but complex!) driver for on-site power generation.**

Some power is "premium"

- Growing distribution of electronic devices is increasing users' sensitivity to minor variations in power quality and/or reliability.
- For many users, the cost of a power outage is substantially larger than the cost of power
  - Credit-card processing centers
  - Internet servers
  - Brokerage houses
  - etc.
- Deregulation does not necessarily provide for grid-reliability, thus raising uncertainties in the future.

- **There is an increasing focus on "point-of-use" solutions to power quality issues.**

Who will own the generator?

- Electricity users could own the generator
  - This allows for the full realization of energy cost savings.
  - However, it is beyond the "core business" of many end users.
- Gas/electric utilities could own the generator
  - This allows for the full realization of infrastructure cost savings (avoided T&D costs, etc.)
- Third parties are starting to play a role in DG
  - ESCOs
  - etc.

- **Ownership structures will affect the economic and operating requirements of all distributed generators.**

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SECA 2000 Special Issues for SOFC Applications

SOFC has attractive characteristics for many (not necessarily all) stationary power applications.

- Heat recovery potential:
  - Can interface with most industrial and commercial thermal needs
  - Allows for operation of multi-effect absorption cooling technology.
- Electric Conversion Efficiency:
  - Allows for higher "allowable costs" than lower efficiency options
  - Higher efficiency can decouple the economics from the need for heat recovery.
- Fuel processing simplicity:
  - Reduces risk and cost of technology.

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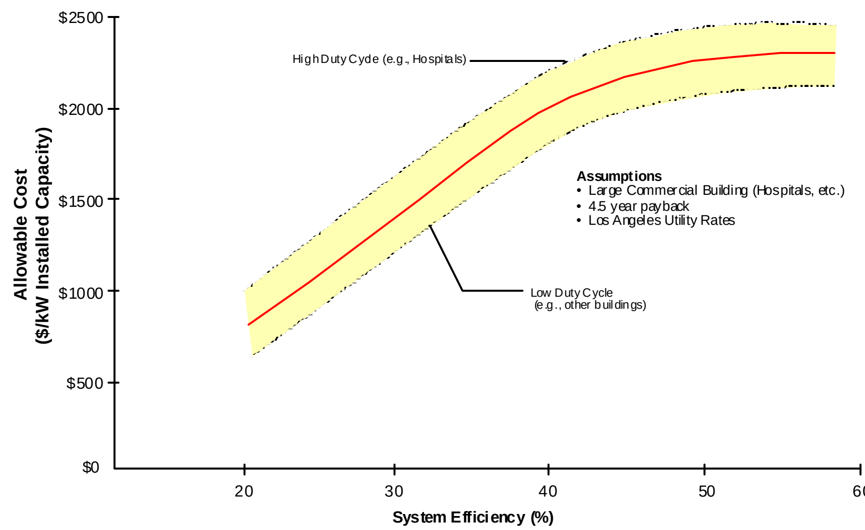
SECA 2000 Special Issues for SOFC Applications

SOFC's high electrical efficiency leads to higher allowable costs than lower efficiency options.



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SECA 2000 Special Issues for SOFC Applications

There are several issues which require quantification to better understand the application range of SOFCs.

- Thermal losses:
  - At what combination of operating characteristics (capacity factor) and rated capacity do thermal losses become unacceptable? (see next slide)
- Cyclic operation:
  - Can the system be shut off (for example, during periods of low or zero loads)?
  - How many cold start cycles are acceptable? How can the system be designed to minimize fatigue factors relating from thermal expansion/contraction?
  - What are the losses during "idle" periods, and how can they be minimized?
- Start-up time:
  - How fast can the system be started?
  - How should it be maintained (e.g. at what temperature) when idle?

The above issues become increasingly important in lower capacity ranges associated with residential and light commercial service.

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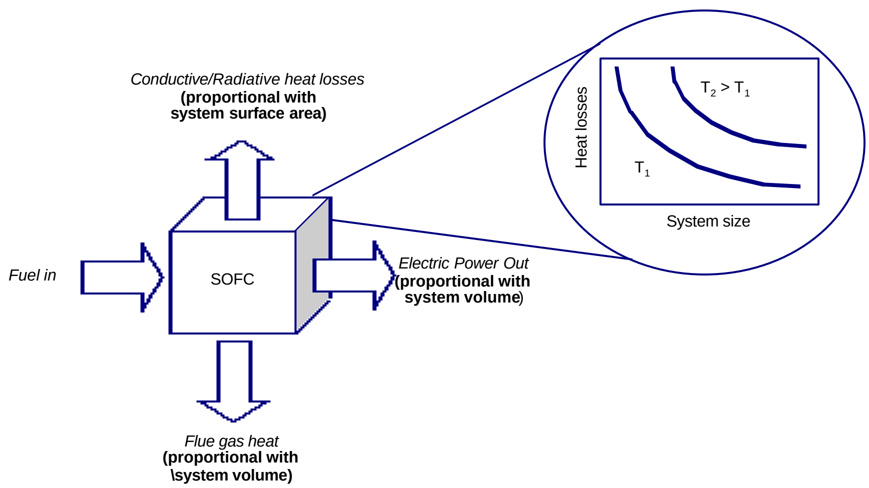
SECA 2000 Special Issues for SOFC Applications

Thermal losses for SOFCs become particularly important in lower capacity ranges associated with residential and light commercial service.



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