Market Assessment of Hybrid Power Systems for DOE's Industry of the Future

prepared by

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Discussion Points

1. Background
2. Overview: Industrial Applications
3. Major Drivers
4. Technology Assumptions
5. Economic/Market Analyses Approach
6. Example Results
7. Hybrid Fuel Cell/System Issues

In 1999, Arthur D. Little undertook as study for the DOE to assess the opportunities for distributed power technologies in the Industrial Sector:

- Internal combustion engines
- Gas turbines
- Fuel cells (simple cycles)
- Fuel cells (hybrid cycles)

Questions Addressed:

- Potential market (which technologies and industries)
- Technology improvements to increase market potential
- Potential public benefits (fuel savings, impact on emissions, etc)
- Role of DOE to accelerate market

The presentation reviews some of the important conclusions of this study and how it might provide guidance for fuel cell hybrid power technology developments.

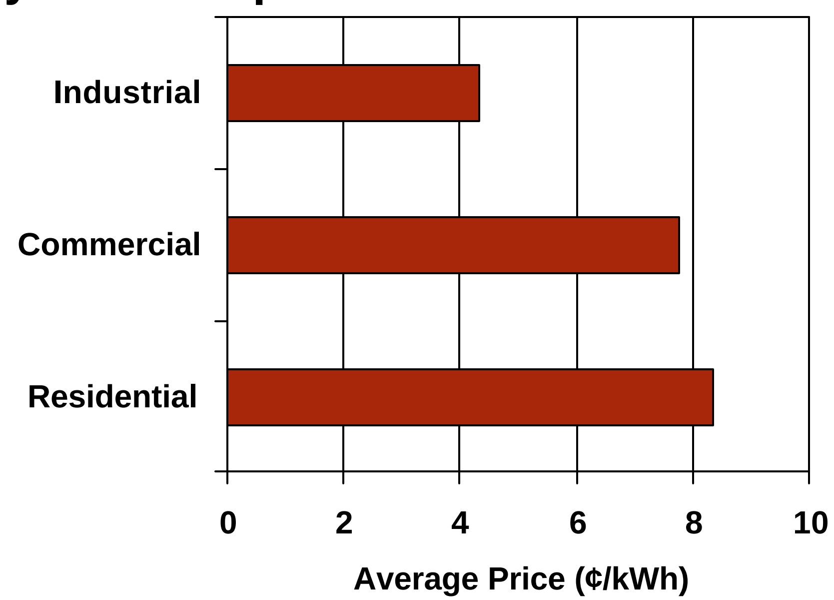
There are both pros and cons associated with industrial applications of distributed power.

Pros:

- **High duty cycles for both electricity and thermal loads**
- **Relatively large scale (economics of scale in equipment)**
- **On-site O&M capability**

Cons:

- **Largest single issue is that industrial users usually have access to relatively low-cost power!**



There are several categories of on-site power for industrial facilities:

Simple Generation	The dedicated, continuous provision of electric power
Traditional Cogeneration	The continuous provision of electric power and heat, as steam or hot water to match industrial thermal needs
Tightly-coupled Cogeneration	The continuous provision of electric power and heat, as hot exhaust gases from the generation equipment
Backup Power	The provision of power for standby needs only, to be called upon only when the primary power source fails
Remote Power	The continuous provision of electric power in locations that are not served by the electric grid
Premium Power	The continuous provision of high-quality and/or uninterruptible electric power at a quality and/or reliability to justify a higher value for the power
Wastes and Biofuels	The conversion of process wastes into electric power and heat, as steam or hot water

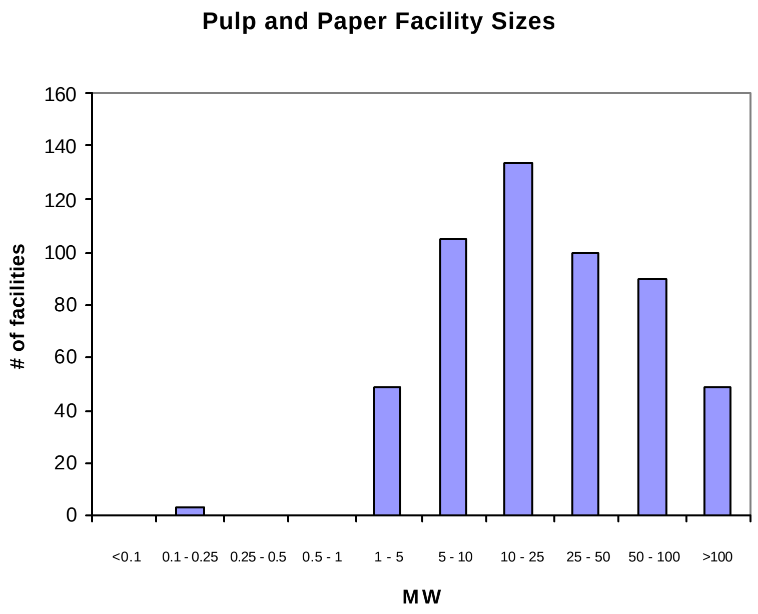
Each application category places different value in the efficiency, operating temperatures, reliability, and cost of the power generation technology options.

Each industry sector has different types of opportunities for distributed generation/cogeneration.

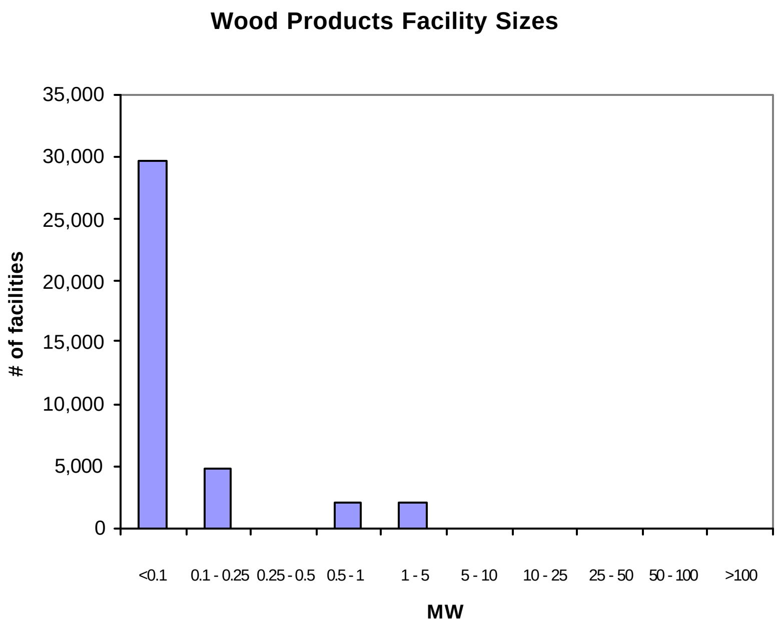
	Simple Generation	Traditional Cogen.	Tightly-coupled Cogen.	Backup power	Remote power	Premium Power	Generation Using Wastes & Biofuels	
Petroleum refining	○	○		●			○	Industry of the Future
Other petroleum	○	○		○			○	Industry of the Future
Chemicals	○	○	○	●			○	Industry of the Future
Steel	○	○	○	●			○	Industry of the Future
Metal Casting	○			●				Industry of the Future
Pulp & Paper	○	○	○	●	○	●	●	Industry of the Future
Wood Products	○	○	○	○	●		●	Industry of the Future
Mining	○		○	●	●		○	Industry of the Future
Agriculture (Food Proc)	○	○	○	○			○	Industry of the Future
Primary Aluminum	○			●				Industry of the Future
Aluminum Products	○	○		●				Industry of the Future
Glass	○		○	●				Industry of the Future
Printing	○	○	○	○			○	Manuf.
Textiles	○	○	○	○		●		Manuf.
Misc. manufacturing	○	○	○	○				Manuf.
Electronics	○			○		●		Other
Oil and Gas E/P	○			●	●			Other
Agriculture (Prod'n)	○		○	○	○		○	Other

○ *Will employ if economical* ● *Critical need, integral to normal operation*

There is a wide variation on the power requirements between and within each industrial sector.



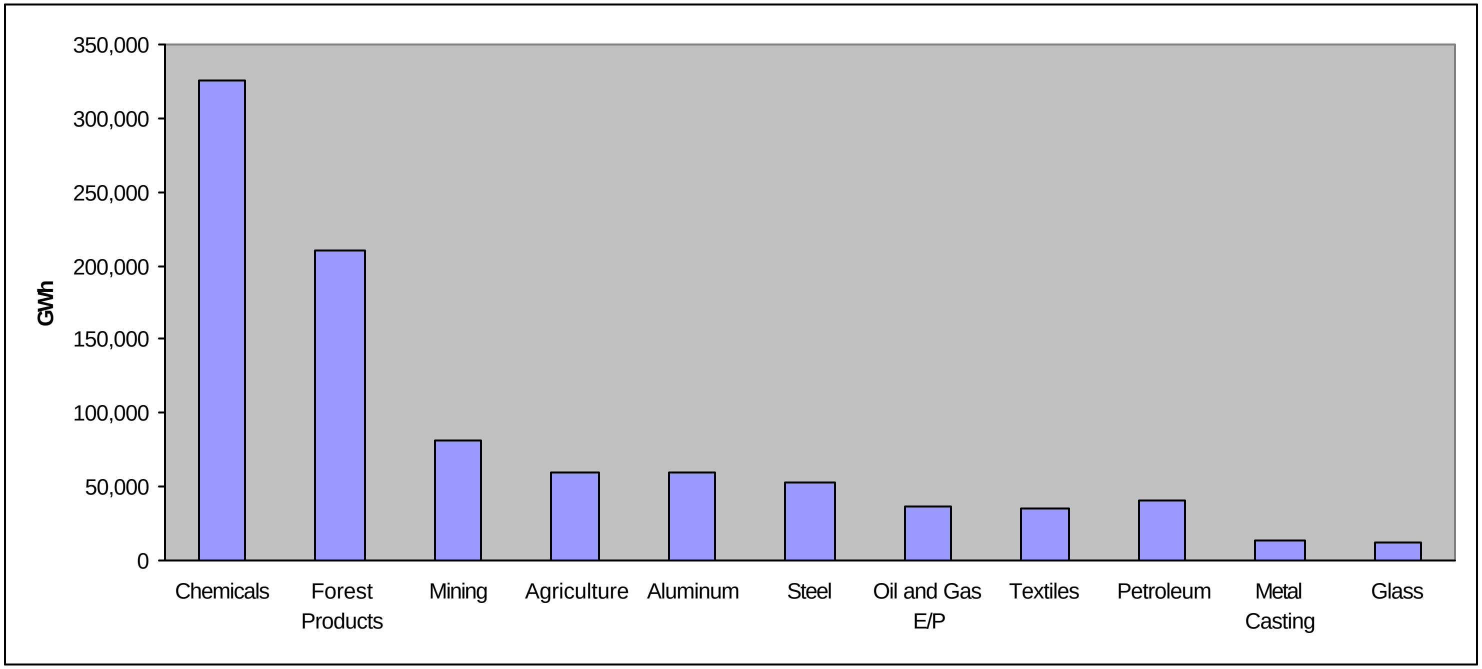
Average load factor = 98%



Average load factor = 83%

Many of these loads are in the under 10 MW power range of primary interest in DG.

The overall electricity consumption in industry is roughly 30% of the total with chemicals being dominant.



The penetration of co-generation in the US lags significantly behind the global leaders, ...

	Total GW	Cogen GW	%	Total GWh	Cogen GWh	%
US	754,584	45,924	6	3,373,173	303,585	9
Netherlands	20,395	7,400	36	85,325	36,410	43
Japan	219	15	7			
Austria	54,840	13,539	25	17,521	3,471	20
Belgium	76,149	3,001	4	14,851	691	5
Denmark	11,160	7,967	71	53,561	30,166	56
Finland	14,570	4,543	31	69,372	22,535	32
France	109,699	3,170	3	512,899	9,864	2
Germany	114,896	22,543	20	555,002	37,814	7
Italy	244,073	34,670	14	68,180	7,673	11
UK	73,238	3,525	5	347,369	18,908	5
Sweden	141,639	10,240	7	33,758	2,923	9

… indicating that significant increases in industrial co-generation are likely to be possible in the US.

The 1999 view of technology characteristics requires some updating with respect to both timing and probable cost/performance characteristics.

		Installed Cost ($/kW)		Non-fuel O&M (¢/kWh)		Elec Efficiency (LHV)	
		High	Low	High	Low	Low	High
Fuel Cell Hybrids	2005	2,000	1,500	1.9	0.9	65%	70%
	2010	1,500	1,000	1.4	0.4	70%	75%
High T Fuel Cells	2005	2,000	1,500	2.0	1.0	45%	55%
	2010	1,500	1,200	1.5	0.5	50%	60%
Low T Fuel Cells	2005	2,000	1,000	1.75	1.0	32%	42%
	2010	1,000	750	1.5	0.5	35%	45%
Recuperated Microturbines	2005	700	500	0.5	0.3	33%	36%
	2010	600	400	0.2	0.1	38%	42%
Unrecuperated Microturbines	2005	560	400	0.5	0.3	20%	23%
	2010	480	320	0.2	0.1	23%	30%
Large Reciprocating Engines	2005	550	375	1.3	0.6	29%	41%
	2010	500	350	1.0	0.5	30%	47%
Small Reciprocating Engines	2005	700	450	1.7	1.3	26%	35%
	2010	650	400	1.3	1.0	26%	37%

A particularly important performance parameter for industrial applications will be O&M costs (often quiet uncertain in new technologies).

The “technical potential” in industry is over 200,000 MW over the next 20 years.

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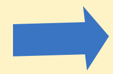
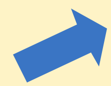
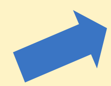
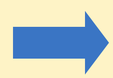
	Simple Generation	Traditional Cogen	Tightly-Coupled Cogen	Backup Power	Remote Power	Premium Power	Wastes & Biofuels
Agriculture	11,100	6,400	11,100	600	0	0	4,100
Primary Aluminum	8,500	<100	<100	2,500	0	<100	0
Aluminum Products	1,000	100	100	<100	0	<100	0
Large Chemicals	22,700	20,000	22,700	6,800	0	200	12,000
Small Chemicals	34,000	26,000	34,000	10,200	0	300	0
Glass	1,700	200	1,700	200	0	<100	0
Metal Casting	2,200	<100	<100	100	0	0	<100
Mining	17,900	0	0	1,800	3,600	200	0
Oil and Gas E/P	9,700	0	0	3,200	8,700	100	0
Petroleum Refining	4,800	4,500	4,800	1,400	0	<100	4,800
Other Petroleum	800	100	0	<100	0	0	0
Pulp and Paper	19,800	19,500	19,800	6,000	1,000	1,000	19,800
Wood Products	6,900	900	6,900	300	1,400	0	1,900
Steel Mills	5,700	2,700	2,700	600	0	300	5,200
Steel Products	1,500	0	<100	<100	0	<100	0
Textiles	6,300	4,700	6,300	300	0	<100	400
Total	154,600	85,000	110,300	34,100	14,600	2,400	48,300

Note: Numbers are not additive since use in one application may preclude use in another.

There has been a shift in the market drivers for on-site power (and cogeneration) over the last four years.

Market Driver	Change in Importance
Energy Cost Savings	
Power Reliability	
Energy Cost/Availability Hedging	
Grid Support	
Environmental	

In general, the role of power reliability (as a component of premium power) as a driver for on-site power has increased placing ever more importance on technology reliability characteristics.

Applications which place high value on efficiency are target opportunities for fuel cell hybrids — example, simple generation:

	Net Impacts by 2020 (annual unless otherwise stated)					
	Cumulative Market Penetration *(MW)*	Primary Energy Displaced *(Trillion Btu)*	Energy Cost Savings *($Million)*	CO_2 Displaced *(kTons)*	SO_2 Displaced *(kTons)*	NOx Displaced *(kTons)*
Recuperated Microturbines	18,600	160	$1,080	52,800	314	250
Unrecuperated Microturbines	<100	<10	<$10	<100	<1	<1
Small Reciprocating Engines	<100	<10	<$10	<100	<1	<1
Large Reciprocating Engines	10,800	170	$590	34,800	185	150
High Temperature Fuel Cells	<100	<10	<$10	<100	<1	<1
Low Temperature Fuel Cells	<100	<10	<$10	<100	<1	<1
Fuel Cell Hybrids	13,400	500	$810	59,200	266	195
Total	***42, 800***	***830***	***$2,480***	***146,800***	***766***	***595***

Due to their very high efficiency, the primary value of fuel cell hybrids is the electric power generated — even in cogeneration applications

	Fuel Cell Hybrid @ 65%	Recuperated Microturbine @ 30%
Annual Value of Electricity Generated (per kW of capacity)	$350	$350
Annual Value of Gas Displaced (in cogeneration)	$46	$200

Assumptions:	Electricity Cost = $0.05/kWh Gas Cost = $4.00/MMBTu Duty Cycle = 80%

The economic application of fuel cell hybrids is not as directly linked to cogeneration applications as are lower efficiency technologies.

There are a number of important technical issues which must be addressed in order to assess industrial opportunities for fuel cell hybrid systems.

- What will be the efficiency of SOFC-based fuel cell hybrids when stacks are operated at significantly lower temperatures such as SECA goals of below 700°C?
- What will be the temperature of waste heat streams (available for cogeneration) for the different architectures?
- How will the reliability and O&M cost of hybrid architectures compare with simple cycle systems?
- Are there tradeoffs between efficiency, reliability, cost, and reject heat temperatures which significantly impact optimum system design? (particularly given an increasing focus on power reliability as being a driver).
- At what capacities are the increased complexities of hybrid architectures justified by increases in generation efficiencies?