DISTRIBUTED POWER GENERATION THE LOGICAL RESPONSE TO RESTRUCTURING AND CONVERGENCE

by
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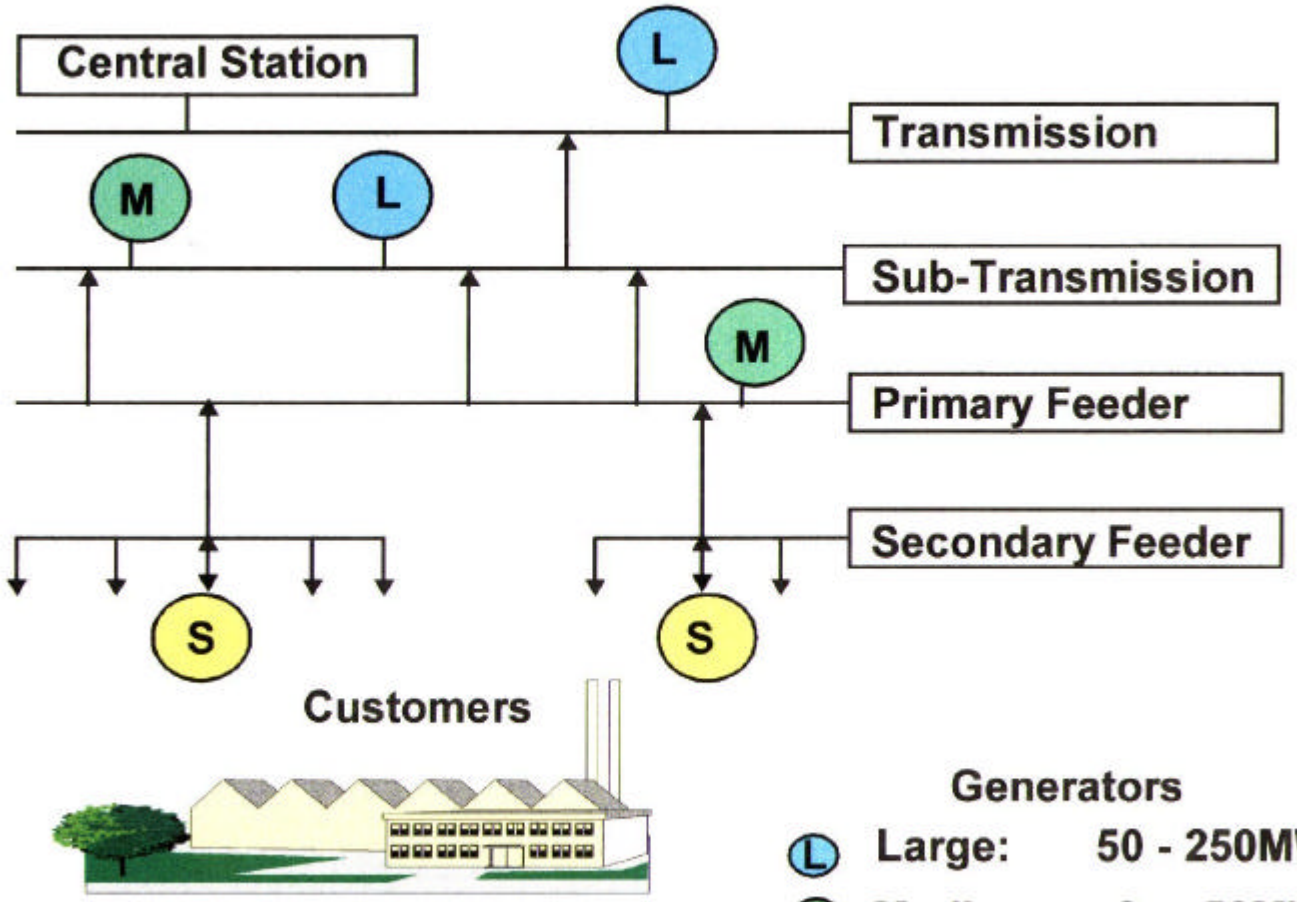
What is Distributed Generation"?

- **Small-scale power generation (usually less than 50 megawatt capacity) near the load that provides more economic, and/or less polluting power supply and management options for energy customers and utilities than conventional central generation.**
- **Generally all on-site generation, including cogeneration, and premium, backup and standby power.**
- **Usually grid-connected, but also small-scale generation for remote power.**
- **Mainly gas-fired or high-tech renewable energy technologies.**

Distributed and Modular Generation Levels



Generators

- L Large: 50 - 250MW
- M Medium: 2 - 50MW
- S Small: 10 - 2000kW

After: Touchton & Cohn, 1995

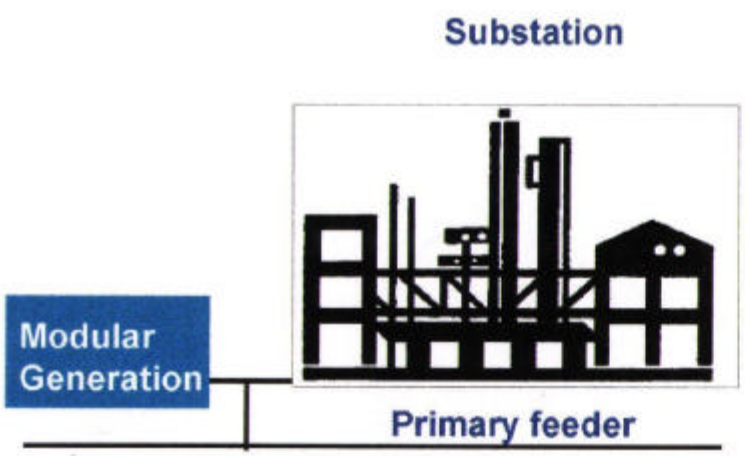
- **However, the definition of distributed generation is now being broadened to include modular generation usually high-efficiency, gas-fired turbine systems with capacities up to 250 MW that are either utility-owned, or IPP, EWG and merchant plant projects.**

Technologies for Distributed Generation

- Diesel Engines (50 kW-6 MW)
- IC Engines (5kW-2MW)
- Combustion Turbines (1-50MW)
- Microturbines (25-5OO kW)
- Fuel Cells, Commercial PhosAcid (200 kW-2MW)
- Fuel Cells, Molten Carbonate (250kW=2MW)
- Fuel Cells, Proton Exchange Membrane (1=250kW)
- Fuel Cells, Solid Oxide (250 kW-5MW)
- Battery Storage (500-50OOkWh)
- Photovoltaic Arrays (<1 kW-1 MW)
- Wind Turbines (10kW-1MW)

Distributed Power Benefits

Grid Support



- T/D System Asset Management
- Reliability and Power Quality Support
- Bulk Power Risk Management

Value Added Services

- Energy Services / Cogeneration
- Backup and Standby Power
- Premium and Remote Power

Adapted from: Michael J. Gluckman, TriStar Ventures Corp., Subsidiary of Columbia Gas System, August 1996

Technologies for Modular Generation

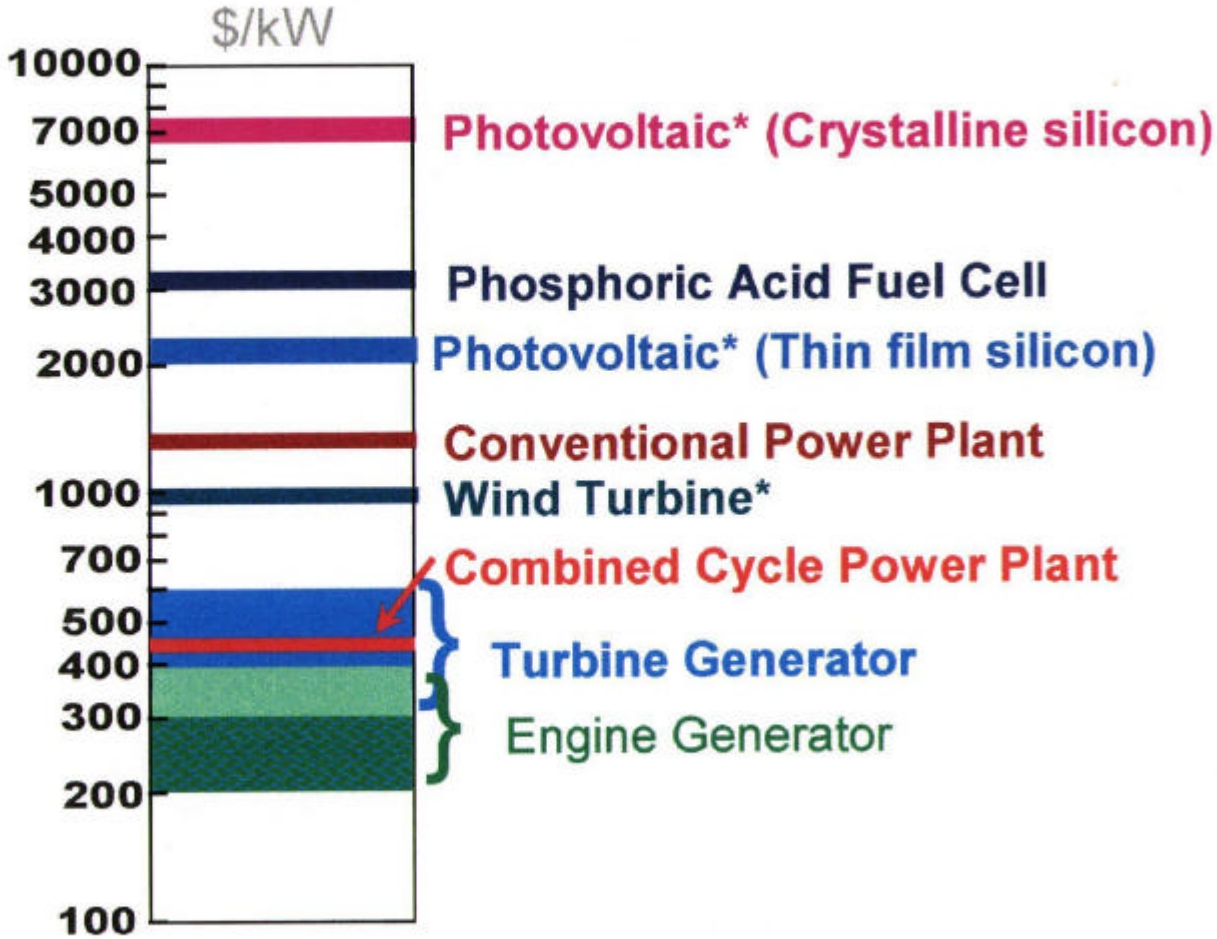
- **Combustion Turbines (50-25OMW)**
- **Combined Cycle Turbine Plants (150-25OMW/module)**

- **First, let us concentrate on the key techno-economic, resource-economic, and structural drivers for success of distributed and modular power.**

On the positive side these drivers are:

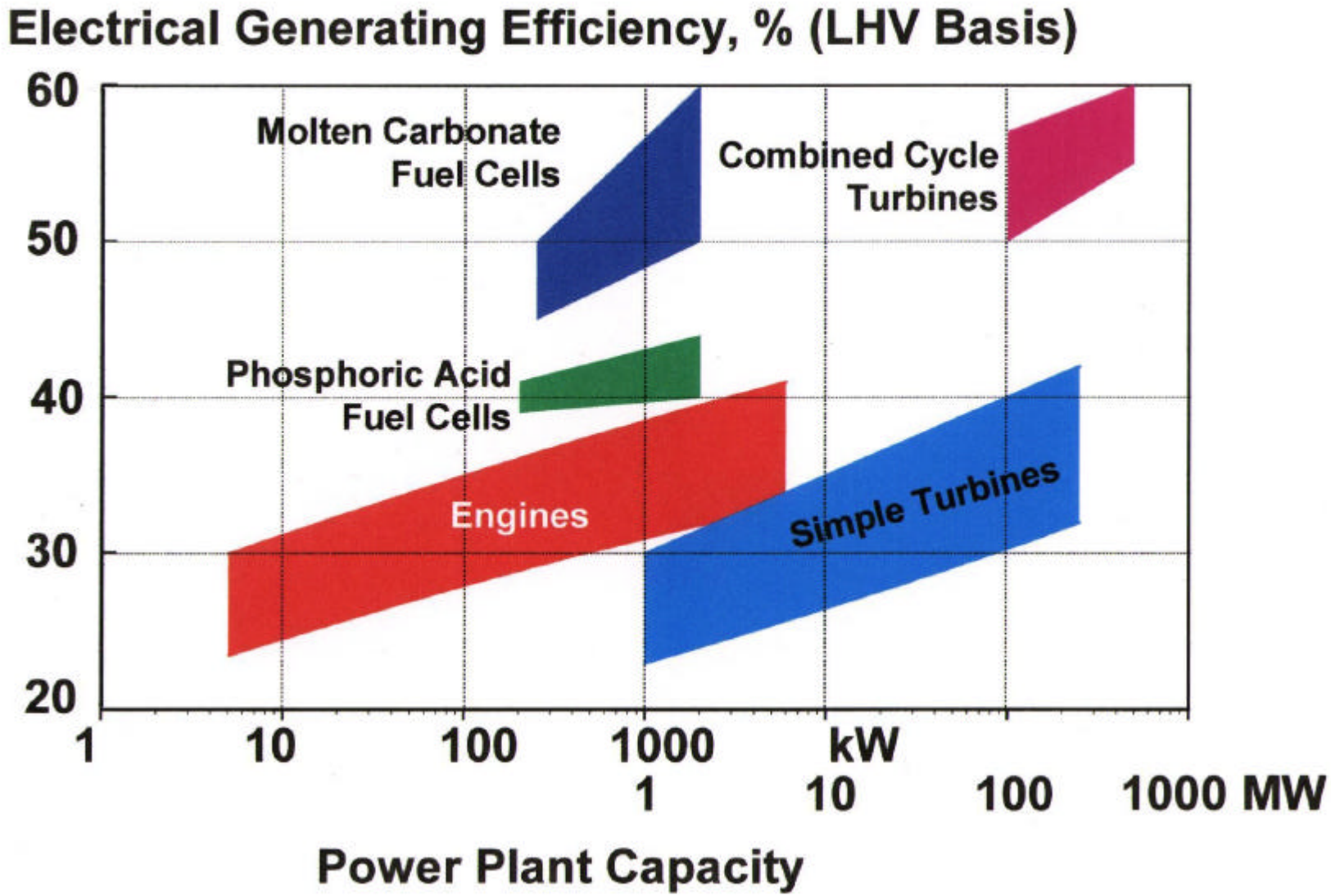
- **Continuing improvements in the performance, and reduction in the cost of simple gas turbines, combine-cycle systems', microturbines and fuel cells.**

Capital Costs for Distributed and Modular Generation Technologies



*Not Dispatchable

Performance Comparison



Positive Drivers

- **Rapid advances in wind, photovoltaic and solar-thermal power technologies, and associated reductions. min the cost of these renewable power sources.**

Positive Drivers

- **Adequate long-term supplies of natural gas at competitive prices thanks to:**
  - **Continuing rapid advances in E&P technologies**
  - **Continuing increases in the economically recoverable North American resource base and in deliverability**
  - **High levels of drilling and reserve replacement**

U.S. Gas Supply -- Price and Technology Elasticity (in 1990 dollars)

Lower-48 Resource Base (1 /1 /91) -- 1295 Tcf

1990 Technology:
Recoverable at $2.50 $/MMBtu 400 Tcf
Recoverable at $3.50 $/MMBtu 600 Tcf

2010 Technology:
Recoverable at $2.50 $/MMBtu 600 Tcf
Recoverable at $3.50 $/MMBtu 825 Tcf

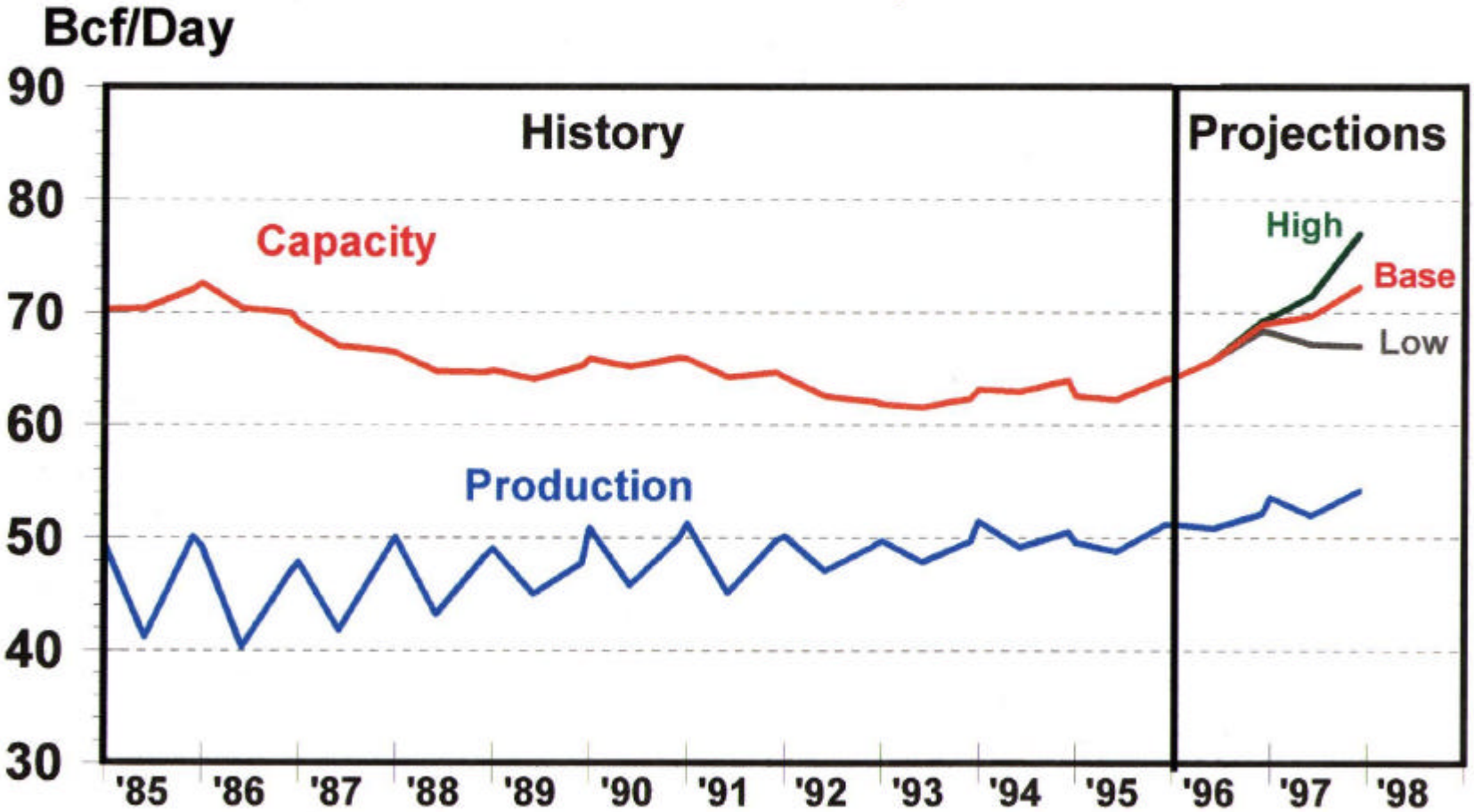
1992 National Petroleum Council Study

Gas Resource Base
(Tcf)

	Lower-48		Canada	
	1995 Tech	2015 Tech	1995 Tech	2015 Tech
Cumulative Production	750	750	94	94
Reserves	160	160	71	71
Reserve Appreciation	454	498	36	36
New Fields	782	880	463	510
Shale	98	134	----	----
Coal Seams	87	110	78	125
Tight Gas	156	240	53	87
Low Btu Gas	15	15	----	----
Total "Ultimate"	2,502	2,787	796	924

GRI Baseline Projection (1997 Edition)

Dry Gas Daily Production Rate and Wellhead Productive Capacity in Lower 48 States, 1985-1997



Source: Energy Information Administration, December 1996

Natural Gas Exploration, Development, Production and Reserve Replacement

	1990	1991	1992	1993	1994	1995	1996
Active Rig Count	464	351	331	364	427	385	464
Gas Well Completions	10705	9452	8091	9864	9057	8692	9648
Gas Wells/Rig	23.1	26.9	24.4	27.1	21.2	22.6	20.8
Total Discoveries, Tcf	12.4	7.5	7.0	8.9	12.3	11.0	12.3
Net Revisions and Adjustments, Tcf	7.1	7.4	8.3	6.31	7.4	8.3	7.9
Total Additions, Tcf	19.5	14.9	15.3	15.2	19.7	19.3	20.2
Additions/Well, Bcf	1.8	1.6	1.9	1.5	2.2	2.6	2.2
Dry Gas Production, Tcf	17.2	17.2	17.4	17.8	18.3	18	18.9
Reserve Replacement, %	113	87	88	85	108	107	107

Source: Energy Information Administration

CAPACITY OF PROPOSED PIPELINE & GATHERING PROJECTS
(MMCF/D)

• Canada	8615
Sable to Northeast	930
Alberta to East	7685
Rocky Mountain	755
Gulf	7191
LA, MS, AL	2146
Texas	4415
To West	630
Total	16561

Source: P.D. Holtberg, The Energy Daily Conference, Washington, DC, July 17-18,1997

Positive Drivers

- **Growing economic and environmental advantages of gas-fired distributed generation over all forms of central generation.**

Positive Drivers

- **The synergy between modular merchant plants, wholesale competition, and the establishment of regional independent systems operators. Growing convergence of industrial and aeroderivative turbine technologies.**

Convergence of Industrial and Aeroderivative Turbine Technologies

- **Pressure ratios and combustor temperatures have increased thanks to design and materials advances.**
- **As a result, simple combustion turbine efficiencies have increased substantially, to well above those for conventional steam-electric plants (about 40% lower heating value basis).**

Convergence of Industrial and Aeroderivative Turbine Technologies

- **Correspondingly, heatrates of simple combustion turbines expressed in terms of the amount of natural gas required to produce 1 kWh of electricity, have dropped from 13 cu.ft./kWh to as little as 9 cu.ft./kWh.**

Convergence of Industrial and Aeroderivative Turbine Technologies

- **At the same time, the cost of simple turbine plants of 150-250 MW capacity has dropped to less than $200/kW, and that of combined-cycle plants to about $300/kW. Corresponding all-in construction costs have dropped to $300/kW and $450/kW, respectively.**

Convergence of Industrial and Aeroderivative Turbine Technologies

Turbine Class	Pressure Ratio	Combustor Temp	Exhaust Temp, F	Effi-ciency, %*	Heatrate, Btu/kWh*
Industrial					
Simple Cycle	6:1-15:1	<2300	1000	28-32	13,500-11,800
Combined Cycle				50-55	7,500-6,900
Aeroderivative					
Simple Cycle	Up to 35:1	2300-2600	700-900	32-42	11,800-9,000
Advanced					
Simple Cycle	Up to 30:1	2600	1100	37-40	10,200-9,500
Combined Cycle				57-60	6,700-6,300
Prospective Combined Cycle (2005)		2800-3000		68	5600

*Efficiency based on lower heating value and heat rate on higher heating value of natural gas. Lower heating value equals about 90% of higher heating value.

Source: Paul Bautista, Gas Research Institute, Oil & Gas Journal, Vol. 94, No. 33, August 12,1996, pp. 43-46, 48.

Decline in Cost of Advanced Turbine Systems (Excluding Site, Site Preparation, Interest During Construction)

Turbine Class	Capacity, MW	Cost, $/kW
Industrial (GE, Westinghouse, ABB, Siemens, Solar)	**1-230 Simple Cycle** **250-750 Combined Cycle**	**500-200** **500-350**
Aeroderivative (GE, Westinghouse, UTC, Rolls Royce, Allison)	**14-51**	**470-300**
Advanced (Siemens, Westinghouse, GE, ABB)	**150-250 Simple Cycle** **250-750 Combined Cycle**	**200-175** **350-280**

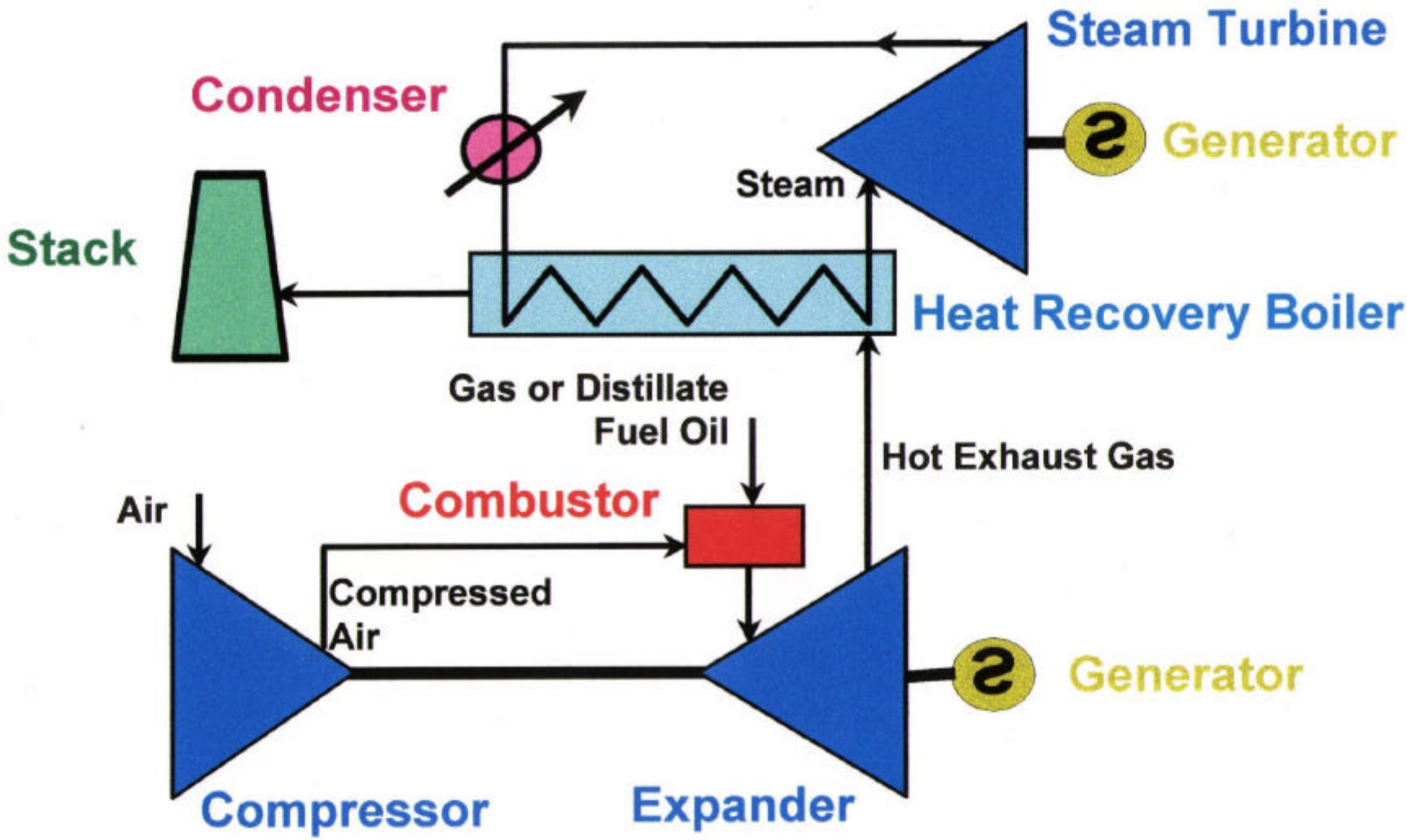
Source: Roland Isernhagen, Black & Veatch, October 5, 1995

New Economics of Simple Combustion Turbines
Intermediate and Base Load 0peration: 150 MW

Installed Cost, $/kW		200	
All-In Investment Cost, $/kW		300	
O&M Costs, cents/kWh*		0.3	
Capital Recovery Factor, %/year		15	
Efficiency (lower heating value), %		39	
Heatrate (higher heating value), Btu/kWh		9,700	
Delivered Natural Gas Price, $/million Btu		2.50	
Annual Operating Factor, %	85		40
Power Cost, cents/kWh	3.3		4.0

*Non-fuel

Combined Cycle Power Generation



Convergence of Industrial and Aeroderivative Turbine Technologies

- **When using the 1000°F waste heat from a combustion turbine and raising steam in a heat recovery boiler to power a steam turbine (combined-cycle operation), efficiencies have risen to 57-60% and gas requirements have dropped to about 6.5 cu. ft./kWh.**

Convergence of Industrial and Aeroderivative Turbine Technologies

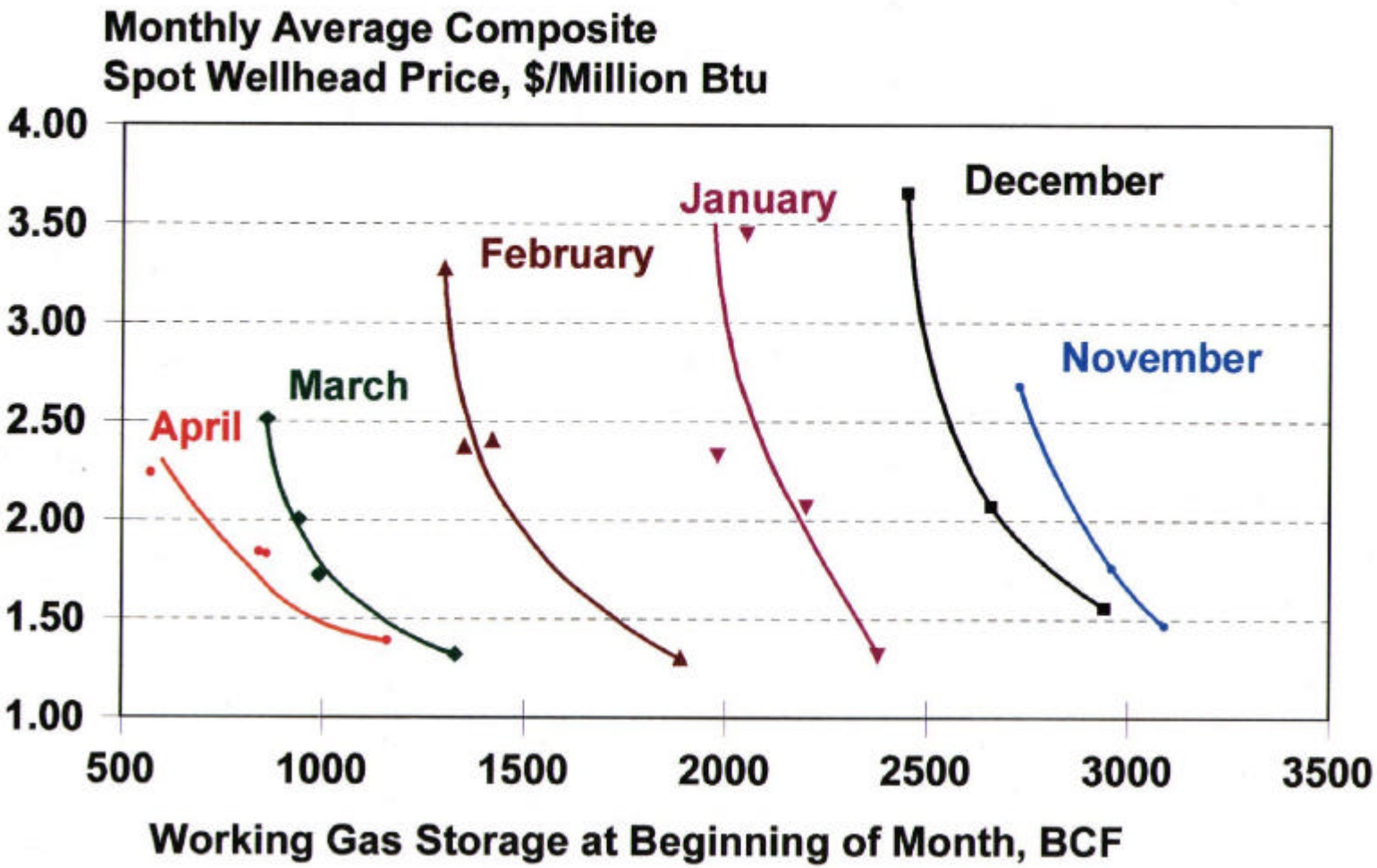
- **At a cost of $450/kW and at delivered natural gas prices of $2.50/million Btu, a new combined-cycle unit can produce power for 3 cents/kWh or less with full recovery of capital costs and at a variable cost of 2.0 cents/kWh or less. This compares favorably with a marginal cost for new clean coal plants of at least 5 cents and a variable cost of existing coal capacity. of about 2 cents.**

New Economics of Combined-Cycle Baseload Power Generation

Installed Cost of 250 MW Plant	$350/kW
All-in Investment Cost	$450/kW
Annual Operating Factor	85%
O&M Costs (non-fuel)	0.5 cents/kWh (or less)
Capital Recovery Factor	15%/year
Capital Charges	0.9 cents/kWh
Efficiency (lower heating value)	57%
Heatrate (higher heating value)	6,600 Btu/kWh
Delivered Natural Gas Price	$2.50/million Btu
Power Cost	3.0 cents/kWh

Spot Wellhead Price Volatility as a Function of Storage Volumes

Withdrawal Seasons: 1993/94 - 1996/97



There are a few potentially negative factors:

- **High natural gas price volatility,**
- **Large excess of coal and nuclear capacity at variable costs of $20-30/MWH, or less.**
- **<u>Engineering</u> reserve margins considerable higher than <u>economic</u> reserve margins**
- **Therefore, probable persistence of the "electron bubble" to 2005 and beyond.**

Total 1995 U.S. Generating Capacity
(Including Non-Utility Capacity)

	Generating Capacity, GW	Capacity Factor, %	Generation, Billion kWh	Ideal Capacity Factor, %
Coal Steam	327.3	63.5	1821	80-85
Other Fossil Steam	168.6	24.6	364	40-70
Combined Cycle	22.5	50.0	99	60-85
Comb. Turbine/ Diesel	62.1	10.1	55	65-80
Nuclear Power	99.2	77.5	673	80-90
Other	118.4	38.1	392	40-50
Total	798.1	48.7	3404	70.4

Source: Paul D. Holtberg, Gas Research institute, July 1997

- **Is distributed generation the logical endpoint of the convergence of the electric and gas industries?**
- **What are the customer and shareholder benefits of this convergence?**
- **Is the non-affillated energy service company the most cost-effective interface between the customer and the energy provider?**

WHAT IS AN ENERGY SERVICES COMPANY?

It is fuel neutral, bundles supply- and demand-side services, and seeks national or global residential/commercial/industrial markets

It offers:

- **Commodity management Facilities management**
- **End-use equipment specifying/ financing/leasing/servicing**
- **Energy management/billing services General financial services**

It supplements core competencies with alliances/partnerships/joint ventures/specialized contracts/competencies of preferred suppliers

- **If gas-fired distributed generation proves to be the most cost-effective option for endusers of electrons (and cogenerated Btu's) and for energy service providers, where is the economic null-point between the pipe and the wire as a function of conversion technology, gas cost and customer class?**

- **What are the structural implications of the following examples of emerging and commercial technologies which indicate that the economic null-point is increasingly on the customer's premises?**

AlliedSignal Turbo Generator ™

75 kW, $375/kW Installed Cost
3' x 5'x 6', 1000 lbs.
One Moving Part: No Lubrication (Air Bearings); Multi-Fuel Capable; Heat Rate with Natural Gas 12,500 Btu (HHV)/kWh
Electric Efficiency (LHV) 30%, Cogeneration Capable
Noise Level 65 Decibels @ 10 meters
NOX Emissions with Natural Gas <25 ppm; Ultra-Low Emission Model <11 ppm
Marketed through Energy Service Cos. (Unicom, Sonat Power Systems, Mercury Electric, New Energy Ventures, Energis Resources)
Authorized Service Provider - Honeywell
10,000 Hours between Maintenance

Fuel Cost @ $3.50/million Btu	4.4 cents/kWh
Non-Fuel O&M	0.5 cents/kWh
Capital Charges @ 80% Op. Factor & 15%/yr Capital Recovery	0.8 cents/kWh
Total	5.7 cents/kWh

Economics of International Fuel Cells Corporation/ONSI 200 kW Natural Gas Fired PC-25 Phosphoric Fuel Cell System in High Load-Factor (Hospital) Applications

Basis:

Installed Cost Less $1000/kW DOE Credit - $3000/kW
Capital Recovery Factor - 12%
Annual Load Factor - 95% (8322 hrs of operation)
Electric Efficiency (higher heating value 36%
Heatrate - 9480 Btu/kWh
Waste Heat Recovery as Hot Water - 700,000 Btu/hr (equivalent to 875,000 Btu/hr of fuel input at 80% efficiency)
Implicit Overall Thermal Efficiency - 82%
Natural Gas Cost - $3.50/Million Btu

Cents/kWh	
Capital Charges	4.3
Fuel	3.3
O&M	2.0*
Subtotal	9.6
Hot Water Credit	-1.5
Net Power Cost	8.1

***Includes $600/kW overhaul costs every 6 years**

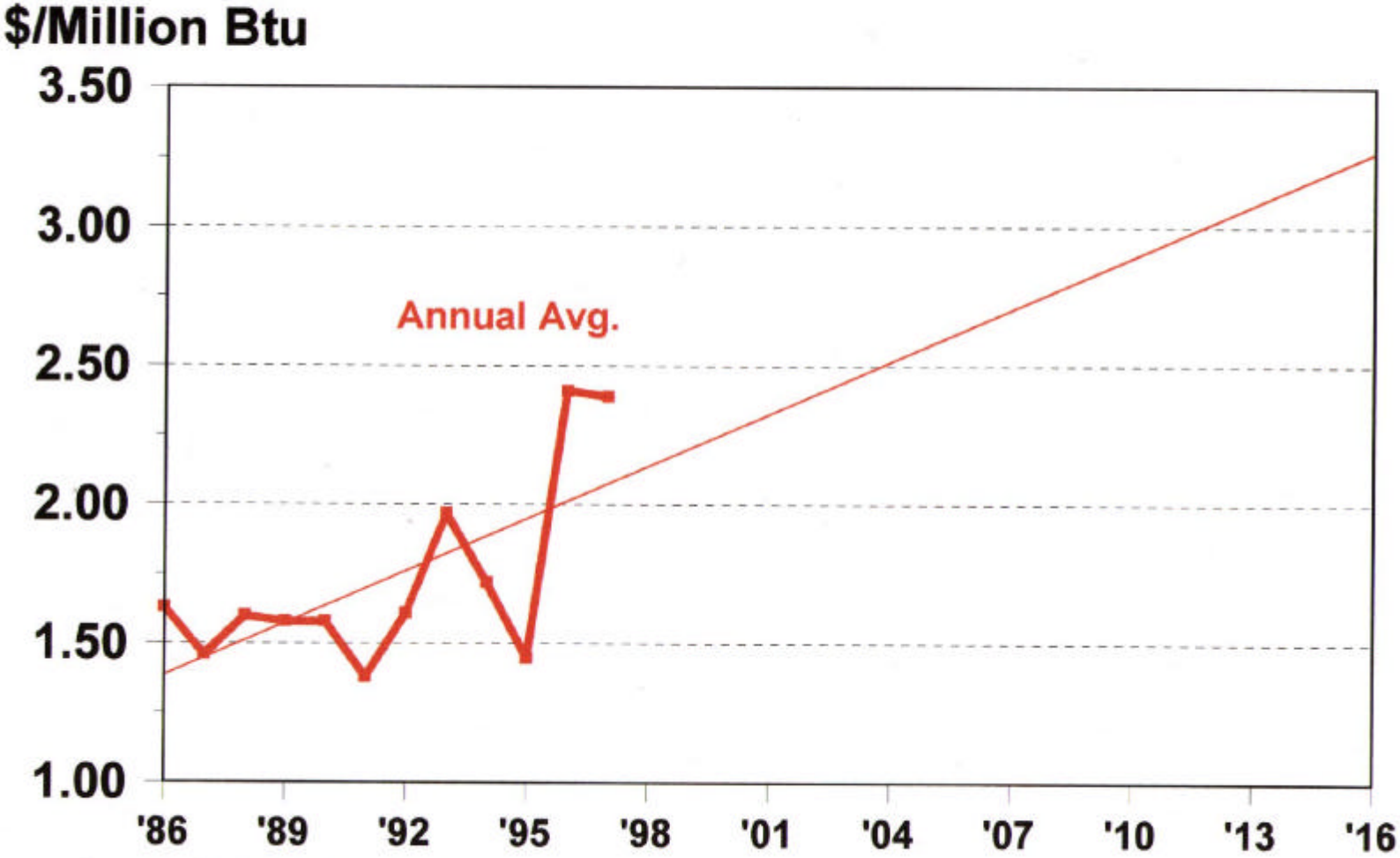
Distributed Generation with Simple Combustion Turbines

25 MW with Heat Recovery

Installed Cost, $/kW	400
All-In Investment Cost, $/kW	500
Annual Operating Factor, %	90
Non-Fuel O&M Costs, cents/kWh	0.5
Capital Recovery Factor, %/Year	15
Efficiency (lower heating value), %	34
Heatrate (higher heating value), Btu/kWh	11,100
Delivered Natural Gas Price, $/million Btu	3.00
Power Cost, cents/kWh	4.8
Waste Heat Credit @ $3.00/million Btu	2.3
Net Power Cost, cents/kWh	2.5

- **On the presumption that Lower-48 natural gas supply plus Canadian imports will be adequate to meet currently projected demand at stable or only moderately higher prices in constant dollars, what share of future U.S. gas consumption will be used for central and distributed power generation vs. for direct enduse?**

Composite, Volume-Weighted Spot Wellhead Prices -- Trends



Source: Natural Gas Week

Composite Spot Wellhead Prices, $/Million Btu

Year	Monthly Avg High	Annual Avg	Monthly Avg Low
1986	2.06	1.63	1.42
1987	1.74	1.46	1.37
1988	1.89	1.60	1.34
1989	2.06	1.58	1.40
1990	2.23	1.58	1.32
1991	1.71	1.38	1.07
1992	2.23	1.61	1.07
1993	2.18	1.97	1.66
1994	2.40	1.72	1.34
1995	2.07	1.45	1.25
1996	3.66	2.41	1.66
1997	3.46	2.39	1.72
1986-97 Average	2.31	1.73	1.39

Source: Natural Gas Week

Projections of Lower-48 Composite Wellhead Prices

	1996	2000	2005	2010	2015
Least Squares Fit (1986-1997 data)					
Current $/Million Btu	2.01	2.27	2.58	2.89	3.21
This Study, Option I -- 02/98 ($1.73 in 1996, 2%/year real escalation, 3%/year inflation)					
1996 $/Million Btu	1.73	1.87	2.07	2.28	2.52
Current $/Million Btu	1.73	2.10	2.68	3.43	4.37
This Study, Option 2 -- 02198 ($2.01 in 1996, no real escalation, 3%/year inflation)					
1996 $/Million Btu	2.01	2.01	2.01	2.01	2.01
Current $/Million Btu	2.01	2.26	2.62	3.04	3.52
GRI -- 08/97					
1996 $/Million Btu	2.14	1.94	1.85	1.90	1.94
Current $/Million Btu	2.14	2.10	2.27	2.59	3.24
EIA -- 11/97*					
1996 $/Million Btu	2.18	2.05	2.09	2.25	2.32

*EIA Projection for 2020: $2.47/Million Btu (1996 $)

Projected U.S. Gas Consumption, Tcf/Year

	Actual 1995	2000	2005	2010	2015
Residential	4.9	5.2	5.4	6.5	5.8
Commercial (Incl Cogen)	3.0	3.3	3.5	3.7	4.0
Industrial (Incl Cogen and Lease and Plant Fuel)	9.6	10.4	11.3	12.0	12.7
Central Power Gen (Incl IPPs & EWGs)	3.3	3.6	4.6	5.4	6.8
Natural Gas Vehicles			0.1	0.4	0.6
Pipeline Fuel	0.7	0.8	0.9	1.0	1.1
Total	21.6	23.3	25.6	28.0	31.0
Total Gas Use for Central Power and Cogeneration	5.5	5.9	7.1	8.1	9.5

Sources: 1998 Edition of Gas Research Institute Baseline Projection, August 1997.

Projected Gas Consumption for Power Generation, Tcf/Year

	Actual 1995	2000	2005	2010	2015
Utilities & Divested Utility Capacity	3.1	2.9	3.7	4.1	5.1
IPPs, EWGs, etc.	0.2	0.6	0.8	1.4	1.7
Industrial Cogen	2.1	2.2	2.4	2.5	2.6
Commercial Cogen	0.1	0.2	0.2	0.2	0.2
Total	5.5	5.9	7.1	8.1	9.5

Source: 1998 Edition of Gas Research Institute Baseline Projection, August 1997

- **Will straight gas LDCs be able to retain residential and commercial customers without advanced technologies that keep direct gas use competitive or allow LDCs to provide complete on-site gas-fueled energy services in competition with electricity?**

- **Can a 5-10 Tcf/yr increase in gas consumption for various forms of power generation over the consensus 30-31 Tcf Year 2015 projection be accommodated without a substantial increase in gas prices?**

Divergence in Projected Increases in Annual Gas Consumption for Power Generation Excl. Coqenerators) 1995-2015

	Net Capacity Change, 1995-2015, GW**	Assumptions*	Change in Gas Consumption, Quads
Combustion Turbine/Diesel	+154.7	70% Gas-Fueled 30% Op. Factor 10,000 Btu/kWh	+2.8
Combined-Cycle	+140.2	100% Gas-Fueled 70% Op. Factor 6,500 Btu/kWh	+5.6
Non-Coal Steam-Electric Gen.	-42.2	40% Gas-Fueled 50% Op. Factor	-0.8
Implicit Increase in Net Gas Consumption*		11,000 Btu/kWh	+7.6
EIA Projection**			+5.3
GRI Projection***			+3.6

*Independent assessment by H.R. Linden, 2/16/98. **Energy Information Administration, Early Release of the Annual **Energy Outlook 1998, November 1997.
***Gas Research institute, Baseline Projection of U.S. Energy Supply and Demand, August 1997.

- **Who will capture the $40 billion value added at the burner tip over the wellhead cost of gas?**
- **Will there be an erosion of the value of gas in the residential and commercial markets with ongoing electrification?**
- **Will gas merely become the preferred fuel for distributed and central power generation?**

Natural Gas Value Chain 1996

Value Added over Cost of Gas, $billion

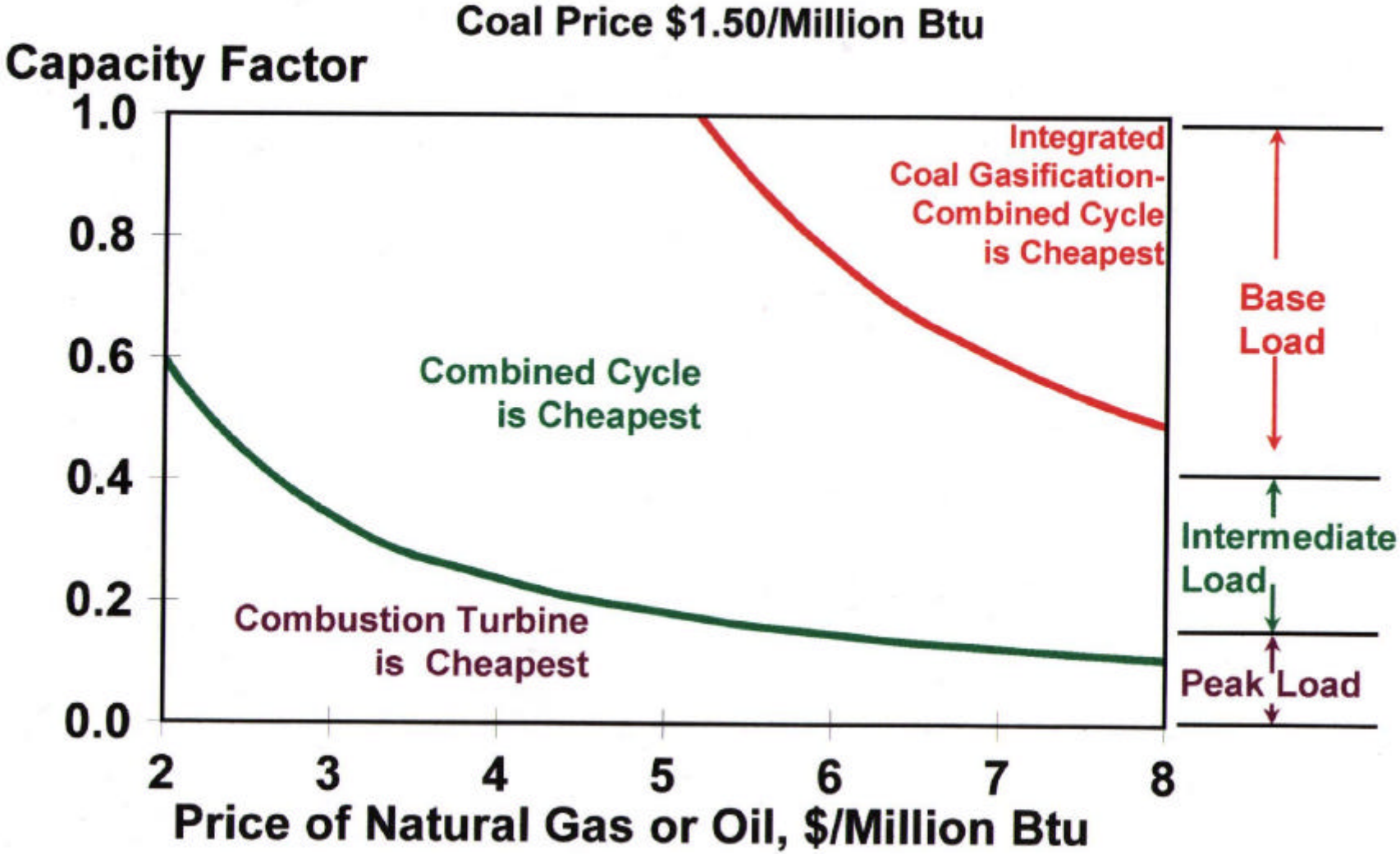
• Transport to City Gate	11.5
• Residential Market	15.6
• Commercial Market	6.7
• Industrial Market	5.8
• Electric Utilities	0.5
• Total	40.1

Source: Energy Information Administration, Monthly Energy Review, January 1998

- **Can we dismiss clean coal technologies as an economically and environmentally competitive source of baseload power?**

- **What are the break-even prices for delivered natural gas that can compete with clean coal-fired baseload power in combined-cycle turbine systems?**

Power Generation Break-Even Fuel Prices for Turbine Cycles



Current Clean Coal Technology Baseload Power Generation Economics

Basis:	**Coal**	**$1.50/million Btu**
	Annual Operating Factor	**85%**
	Non-Fuel O&M Costs	**1 cent/kWh**
	Capital Recovery Factor	**15%**

	Pulverized Coal With Flue Gas Desulfurization and Selective Catalytic Reduction	Atmospheric Fluidized Bed Boiler	Integrated Coal Gasification Combined Cycle	
			Present	Proiected
Investment:	**$1300/kW**	**$1300/kW**	**$2200/kW**	**$1500/kW**
Heatrate:	**$10,000 Btu/kWh**	**10,000 Btu/kWh**	**8,500 Btu/kWh**	**7,500 Btu/kWh**
Cost of Power	**5.1 cents/kWh**	**5.1 cents/kWh**	**6.7 cents/kWh**	**5.1 cents/kWh**

Conclusions

Growth of distributed and modular generation is a rational response to:

- **Electric restructuring**
- **Convergence of the power and gas businesses**
- **Advances in enabling technologies**
- **Increasing environmental compliance costs for existing fossil fuel-fired central generation**
- **Erosion of economic viability of nuclear capacity**

Conclusions

- **However, much of the future success and economic viability of distributed and modular generation depends on ample supplies of natural gas at prices well below the break-even level with new clean-coal baseload power, and on reductions in gas price volatility.**

Conclusions

- **If constraints on C02 emissions materialize, the power industry will be the first target and massive shifts to gas-fired combined-cycle generation will be necessary, especially if the projected 40 GW of nuclear capacity retirements by 2015 actually occur.**

Conclusions

- **Even without binding C02 emissions limits, an increase of 5-10 Tcf of 2015 gas demand above the 30-31 Tcf projected for 2015 is within the zone of reasonableness. The gas price response depends on further E&P technology advances since the resource base is adequate.**

Conclusions

- **Planned increases in U.S. and Canadian gas pipeline capacity seem adequate to handle any likely incremental demand for power generation, although growth in storage capacity and deliverability may pose a problem,**

Conclusions

- **Among renewable technologies, wind power and, in the near future, photovoltaic power have the best prospects for becoming competitive,**
  but their intermittent nature will require substantial fossil fuel and nuclear back-up.

Conclusions

- **The long-term trend of electrification of stationary energy enduse, and the improvements in distributed generation and cogeneration technologies and economics, pose threats to the viability of straight gas LDCs.**

Conclusions

- **Energy service companies, either dependent or affiliates of large restructured electrons and Btu providers, see destined to capture a large share of the current retail sales margins.**