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COLLABORATIVE ADVANCED GAS TURBINE (CAGT) PROGRAM STATUS

AN INTERNATIONAL INITIATIVE TO CATALYZE AN INTERCOOLED AERODERIVATIVE (ICAD) GAS TURBINE LAUNCH ORDER

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ABSTRACT

This paper describes the status of the Collaborative Advanced Gas Turbine (CAGT) Program's initiative to commercialize InterCooled AeroDerivative gas turbine (ICAD) technology. CAGT is a consortium of domestic and international electric companies, gas companies and research organizations. ICAD gas turbine technology was selected by CAGT member companies and potential suppliers in a competitive $5 million screening study of various advanced gas turbine options in the 1992-94 time frame. Efforts to commercialize ICAD began in 1994-95. The most attractive ICAD gas turbine options were based on high thrust engines produced by General Electric, Pratt & Whitney and Rolls Royce aircraft divisions. Simple cycle ICAD represents a new intermediate load gas turbine product class with costs and performance unlike any other product available today. Simple cycle efficiencies will approach those of many operating combined cycles, but with the low capital costs and rapid start times of a peaking gas turbine. ICAD simple cycle units would be in the 100-130 MW size range with efficiencies in the range of 45-48% + LHV and combined cycle efficiencies potentially as high as 60% + LHV. All efficiencies are presented in the paper in lower heating value (LHV). ICAD gas turbines will address a wide range of simple cycle, cogeneration, innovative repowering, combined cycle, distributed generation and renewable energy applications. CAGT members have several projects underway with the goal of the first ICAD unit to begin operation before the year 2000. Industry restructuring has reduced near-term demand for new generation in the United States with a corresponding drop in gas turbine prices. Given the large development cost for any new gas turbine product, potential ICAD suppliers have indicated the need for a launch order to proceed with development. CAGT is pursuing a number of project development and strategic alliance strategies globally to organize a launch order in the range of 10-15 projects. Efforts are also underway to examine options for demonstrating ICAD on a smaller scale (Small ICAD or SICAD) which would address the emerging market for distributed generation. CAGT members feel the low costs and flexibility offered by ICAD could be a significant source of competitive advantage in restructuring electric markets. CAGT members invite others to join the program.

I) BACKGROUND

The Collaborative Advanced Gas Turbine (CAGT) Program was initiated in 1991 by the California electric and gas utilities and targeted at replacing 20,000 MW of aging cycling steam units. Since markets for gas turbines are world-wide, the collaboration was expanded to include "buyer" perspectives from North American and Europe. CAGT is currently managed by the Electric Power Research Institute (EPRI) on behalf of the membership indicated in Figure #1. Sacramento Municipal Utility District (SMUD) in California and National Power of England are chairman and vice-chairman of the CAGT Steering Committee. A key CAGT premise was that high thrust aircraft engines represented an under-exploited electric industry opportunity. Aeroderivative gas turbines reflect technology innovations resulting from billions of dollars in R&D spent by the defense and aircraft industries on improved transportation gas turbines. For example, the high technology aircraft engines recently introduced on the BOEING 777 cost on the order of $1 billion each to develop and represent the cutting edge in commercial gas turbine technologies. The major aircraft engine suppliers (General Electric, Pratt & Whitney and Rolls Royce) each have production capacity in the range of 300 units per year for these engines. In comparison, conventional heavy frame gas turbines have development costs in the range of $100 million with much lower production volumes and lag aircraft engines by a number of years with respect to the most recent innovations in technology.

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The 40 MW and 39-40% LHV simple cycle efficiency GE LM6000, is the current state-of-the-art aeroderivative in operation for electric power production. The LM6000 has high component commonalty with the aircraft engine and was designed for minimal development costs in adaptation to electric applications. The LM6000 has been highly successful in cogeneration and Public Utilities Regulatory Policy Act (PURPA) markets of the 1980s and early 199s. With over 85 units sold, the LM6000 has an unmatched reliability in operation. However, in terms of total MW sold, most of the total future global market for gas turbines is forecasted in sizes larger than 50 MW. A major technical debate existed prior to the program as to whether advanced cycles applied to aeroderivative gas turbines could make them competitive and even superior on an efficiency and cost basis with larger heavy frame gas turbines in the mid-size range (50-200 MW). the "buyers" view was that increasing supplier and product options would be of larger benefit to the industry, given limited RD&D funds, than focusing on incremental innovations in large heavy frame turbines that would occur anyway as the result of market forces.

Approximately $5 million was spent in CAGT Phase I screening studies. A Technical Review Committee, composed of CAGT members, worked closely with the three aircraft engine supplier teams in the 1992-94 time frame to evaluate a range of advanced cycle options applied to aeroderivatives. The following advanced cycle options were investigated by each manufacturer relative to efficiency, capital costs, economics, commercial potential, and development costs:

- Evolutionary improvement of high thrust aeroderivatives
- Compressor intercooling for simple cycle and combined cycles
- Massive steam injection (STIG)
- Reheat combustors
- Chemical recuperation
- Humid air turbines (HAT)
- Kalina and other bottoming cycles
- Combination advanced cycles, e.g., chemically recuperated ISTIG (CRISTIG)

Intercooled aeroderivative (ICAD) gas turbines were selected as the preferred technology for commercialization. The focus of the CAGT Program shifted from an initial emphasis on high efficiency baseload to high value intermediate load applications emphasizing flexibility (Figure #2). This evolution reflected the broadening market perspectives in CAGT membership and the dramatic changes in electric markets in the 1992-94 time frame. ICAD's attractiveness was identified as:

- Low cost and high efficiency simple cycle ICAD turbine represents a new intermediate load option with major advantages over current peaking and combined cycle gas turbines;

- "Doable" development costs, low technical risks, and potential for near-term use;

- Market potential relative to a diversity of innovative repowering, mid-sized combined cycle and distributed generation applications, particularly feedwater preheating of large steam units, and

- Intercooling provides a "building block" towards many ultra-high efficiency advanced cycles.

II) HISTORICAL MARKET CONTEXT

As illustrated by Figure #3 from the December 1994 Public Fortnightly article by Charles Bayless, the CEO of Tucson Electric, gas turbines and natural gas delivery systems are displacing coal and nuclear steam technologies in markets for new generation. This has been a driving force in electric industry restructuring. The traditional electric utility market structure was vertically integrated and organized around large, capital intensive central station steam units that delivered electricity to customers through large regional transmission and local distribution systems. From the 1960s to the 1990s, power plants were built in increasing large sizes to take advantage of the higher efficiencies and the economies of scale inherent in large steam units. Regulated monopoly market structures and captive local distribution markets were required to make this strategy work. Since the 1960s, however, growth in steam plant efficiencies have been limited and significant diseconomies of scale have been realized as the result of the capital risks and inflexibility of steam units in the 500-1000 MW range. As natural gas prices dropped in the 1980's and low capital cost and high efficiency gas turbines emerged, natural gas delivery systems using gas turbines proved in many markets to have electricity costs significantly lower than the delivered cost of the electric utilities. These factors provided strong incentives for industrial customers in high cost areas to by-pass the utility, i.e. a driving force for deregulation.

One purpose of CAGT is to help members study gas turbine technology trends and changes in order to better anticipate major market dislocations, to avoid technological "dead-ends", and to make wiser decisions on strategic investments. The perspective presented in Figure #3 is that gas turbine systems have relative small economies of scale and those larger than 150 MW will potentially experience diseconomies of scale resulting from increased market risk, opportunity costs, and lower flexibility. Gas turbines and natural gas-based electric supply systems represent a fundamentally different system of technologies than those historically used by utilities. The economics of highly integrated gas turbines in a range of duty cycles, natural gas systems, and electric systems for rapidly changing electric markets are not yet fully understood. Gas turbine technology and application innovations also continue to evolve. Technology forecasts that simply extrapolate the past, but don't capture potential paradigm shifts, have proven to sometimes result in decisions that "bet the company" or miss investment opportunities.

Most utility aeroderivative gas turbine experiences in the 1960's and 1970's were based on peaking applications. The CAGT gas turbine technical investigations were an outgrowth of utility research in the 1980's on optimizing aeroderivative gas turbines for high capacity factor applications. This research included the small Allison steam-injected gas turbine (STIG), the GE LM5000 STIG and the proposed intercooled steam injected gas turbine (ISTIG). The CAGT Program also grew out of the California market, which is perceived by many as the "birth place" of the independent power industry in the 1980's. Aeroderivative gas turbines in the 5-50 MW size range emerged in the third party power PURPA markets of the 1980's for the first time on a significant scale in baseload cogeneration applications. Operating reliability in these PURPA units has been extremely high.

III) ICAD TECHNOLOGY

Figure #4 illustrates the technology of intercooling of the aeroderivative gas turbine between the low pressure and the high pressure stages of compression. The high compression ratios and the two compressors on separate shafts are features unique to aeroderivative gas turbines which are optimized for aircraft simple cycle operation. The intercooler removes heat from the air after it undergoes compression in the low pressure compressor. The net impact of intercooling is to increase the amount of power from a LM6000-class aeroderivative from the range of 40-50 MW up to 100-130 MW simple cycle. Compressor intercooling has a direct thermodynamic benefit and cooling of the cooling air to the high pressure turbine allows the turbine rotor inlet temperature to increase to over 2600 degrees Fahrenheit.

The ICAD simple cycle appears to represent a new intermediate load gas turbine product class with capital cost and performance unlike any other product available today. The efficiencies of ICAD gas turbine systems are compared in Figure #5 with those of current aeroderivatives, current and projected future heavy frame gas turbine systems and operating steam units. ICAD will increase aeroderivative simple cycle efficiencies from the current 39-42% range LHV up to 45-48% + range depending on the specific design and manufacturer. The most efficient heavy frame simple cycle gas turbines will be in the range of 38%, while low cost peaking turbines will have efficiencies in the range of 28-34%.

The dramatic increase in power can result in a significant drop in equipment prices, installation costs and operating costs for ICAD relative to current aeroderivatives. Some of the benefits of the lost cost and high efficiency simple cycle ICAD indicated by CAGT members and others are listed in Figure #6. The ICAD simple cycle will have efficiencies in the range of current operating combined cycles. The ICAD simple cycle will have lower capital costs than a new combined cycle while retaining the flexibility of a peaking gas turbines, i.e., rapid start times. Many large combined cycles in operation have average operating efficiencies below those of full load rated efficiencies due to load-following (i.e., part-load operation). Rather than running a large combined cycle at part load and limiting cold start times to the steam bottoming cycle, the modularity of ICAD units could take advantage of an "on-and-off" dispatch strategy allowing operating efficiencies close to those of full load.

ICAD combined cycle efficiencies will improve relative to current aeroderivatives from the low 50% range up to as high as 60% + in some instances. An ICAD combined cycle will have a bottoming cycle almost double the size of an LM6000 engine, allowing for significantly lower bottoming cycle costs and higher efficiencies. Figure #7 compares a current aeroderivative with an ICAD combined cycles and illustrates the significant potential cost savings (from around $700/kw to around $500/kw). Given the pricing and installation assumptions internalized in Figure #7, the information should be used with great caution for anything other than a relative comparison of LM6000 and ICAD combined cycles. (Price estimates for both the LM6000 and the ICAD have dropped since this analysis was initially developed.)

The high of power from the topping cycle (80-85%) in an ICAD combined cycle creates capital cost and operating advantages over similar sized heavy frame combined cycles which have a much lower amount of power from the topping cycle (66% range). Most economies of scale in gas turbine prices and installation costs are achieved at the 100 MW level with only small marginal improvements beyond that range. Steam bottoming cycles achieve a significant economy of scale in moving from the 10 MW range of the LM6000 combined cycle up to 100 MW of the largest heavy frame combined cycles. The relatively small efficiency and economic advantages of large heavy frame combined cycles, such as the Frame H class, over an ICAD combined cycle, will largely come from the scaling up of the steam bottoming unit. However, the steam bottoming cycle is still the most expensive portion of a combined-cycle, in the range of 2-3 times that of the gas turbine on a $/kw installed basis. The high ICAD simple cycle efficiency will allow the expensive bottoming cycle to be lessened or deferred in intermediate load applications, while still achieving high levels of economic dispatch.

IV) ICAD APPLICATION

The greatest commercial strength of ICAD gas turbines is the wide range of simple cycle, cogeneration, innovative repowering, mid-size combined cycles, distributed generation (large industrial, transmission system and municipal) and renewable energy applications (Figure #8).

A. Intermediate Load

CAGT members feel the low costs and flexibility offered by ICAD could be a significant source of competitive advantage in restructuring electric markets. An analysis in Figure #9 by San Diego Gas and Electric of simple cycle ICAD gas turbines in a distributed deployment scenario compared to a heavy frame repowering project and peaking applications. When the costs of the new transmission requirements of the repowering project are included, the ICAD was shown to have lower busbar energy costs for capacity factors in the 10-60% range. ICAD simple cycle will also offer many secondary planning, dynamic operating benefits and salvage value benefits over larger heavy frame combined cycles for intermediate load applications that are not included in this analysis. Since aeroderivative gas turbines are designed for cycling duty in aircraft applications, ICAD will have lower variable O&M costs relative to heavy frame gas turbines for intermediate load applications as shown in Figure #10. New advances in heavy frame technology, i.e., the H class engines, will narrow the range over which ICAD will have a busbar cost advantage. However, the busbar energy costs will be so close, that consideration must be given to the risk of investments in such large combined cycle projects in the several hundred million dollar range (H class combined cycles will be over 400 MW), when a much smaller and more flexible one will fit the need for about the same cost. Market risk for ICAD intermediate load projects will be substantially lower than conventional peaking or combined cycle systems because of the flexibility of ICAD to perform well as a baseload, intermediate load, or peaking unit under a broad range of scenarios of fuel costs, capacity value, and energy value.

ICAD will likely cost a little more than the cheapest peaking turbines, but the dramatically higher efficiency will significantly increase dispatch, resulting in "energy costs" that should be substantially lower than a peaking turbine (e.g., a peaking turbine that dispatches under 5% of the time will likely have costs over $0.25-30/kwh). As previously shown in Figure #5, ICAD simple cycle efficiencies will be substantially better than even the full load efficiencies of operating steam units. Thus, ICAD simple cycle could achieve almost a baseload dispatch in the near-term in places like Texas and California where natural gas steam units are usually at the margin. ICAD simple cycle will almost double the efficiencies of operating 1960's vintage aeroderivative peaking units. This has major strategic implications for the amount of power that could be obtained in gas-constrained areas from a gas pipeline "on-peak" operation. e.g., Northeastern US.

B. Municipal and Local Distribution Company Services

Gas turbine technology and application innovations such as ICAD will continue to shape electric market structure, while new market structures will increasingly reward advantages of gas turbine features not previously valued. Figure #11 illustrates the on-going vertical separation of the US electric industry and markets for new generation into bulk power commodity producers, regional power pools, and local distribution companies. Power pools will make electric markets for commodity power increasingly dynamic and "real time", placing a premium on the flexibility of gas turbine systems like ICAD's ability to respond "just in time" to rapidly changing market conditions. Supercritical cycle steam units that take 24 hours to turn-on will have many opportunity costs and efficiency penalties in such a market. Many large, inefficient, and inflexible aging steam units now used for intermediate load, peaking, and stand-by generation will likely be accelerated into retirement in such a scenario.

The Sacramento Municipal Utility District (SMUD) perspectives are representative of an emerging new major class of electricity buyers in electric power pools, i.e., the local distribution company. SMUD wants some generation to insure reliability and to provide a more effective "buffering" and negotiating position with a regional power pool. The regional power pool is dominated by a hydro system that undergoes drought cycles. If energy prices on the spot market are cheap in a wet hydro year, or if natural gas prices for generation are high, an ICAD will dispatch as a low capacity factor unit and the extra cost of the bottoming cycle is avoided. If prices on the spot market are high, ICAD will dispatch as a high capacity factor unit because of the high simple cycle efficiency advantage over peaking turbines. If circumstances warrant, the bottoming cycle can be added later to improve operating efficiencies. SMUD also indicates that the greater availability of "quick starting" ICAD capacity would allow increased use of low energy cost and wind energy.

This local distribution company "buyer" perspective for new generation choices is also illustrated by the Tucson Electric (a city sized utility) perspectives article by Charles Bayless. Similar feedback to CAGT was received from municipal utilities in the Pacific Northwest and other hydro-based electric systems with significant seasonal variation. As power flows more freely in future unregulated markets and power pool become more dynamic, this need for local firming and buffering power is likely to grow. Similarly, retail wheeling proposals could force residential and commercial utility customers to organize into municipal power "buying" groups to increase negotiating leverage in wholesale markets. ICAD could become a particularly attractive option for local integrating electric and gas wholesales services by the emerging merchant power industry targeted at such residential and commercial buying groups. This is depicted in Figure #12

One last consideration on ICAD simple cycle applications and changing electric markets is salvage value and life cycle asset utilization. Salvage value consideration may provide further advantages to ICAD simple cycle gas turbines. The salvage value of the steam units has proven to be minimal, creating high transition costs for utilities and PURPA steam unit operators seeking to exit generation markets. Many PURPA steam wood waste units under 10 years old can be purchased for only the small fraction of the original install cost. Factory packaged aeroderivative gas turbine simple cycle units will have much higher salvage value than steam plants or heavy frame simple or combined cycles and can be moved much more easily to new sites for a variety of uses.

C. Feedwater Preheating Repowering

The high simple cycle efficiency and low exhaust temperature of ICAD will be attractive for feedwater preheating of large steam units. SK Power in Denmark is planning a new 400 MW supercritical steam unit that could use two natural gas fired ICAD gas turbines for feedwater preheating and the intercooler heat for district heating. This innovative new coal-gas and steam-gas turbine hybrid will allow a higher efficiency gas fired cycling unit to operate in conjunction with a baseload coal unit. The gas use efficiency of ICAD in this application will be in the range of 59-60%. An LM6000 aeroderivative or a Frame 7F in this application would only achieve efficiencies in the 54-55% range.

Figure #13 illustrates the Danish feedwater preheating strategy in a repowering application of a large existing coal unit. Feedwater preheating could represent a major large steam plant repowering strategy and new gas market in the United States, particularly for coal-fired units. Most steam units installed in the 1960's and 1970's are now candidates for full repowering, given that the low simple cycle efficiency heavy frame gas turbines would almost triple the unit size. The associated large capital investment would be tied to an aging steam unit and subject to substantial market risks of stranded investment. ICAD feedwater preheating repowering would only increase capacity in the range of 10-30%, would achieve high efficiencies and would in some circumstances reduce coal use in the boiler, offering a potential environmental credit.

D. Cogeneration

ICAD will have advantages over heavy frame gas turbines in cogeneration and small steam plant repowering application. Because of the high electric/thermal ratio, for a fixed thermal load ICAD will generate substantially more power at higher efficiencies than a heavy frame simple cycle gas turbine. For example, a heavy frame gas turbine serving the same thermal load as an ICAD would likely be only in the range of 40 MW. Such a gas turbine would be significantly more costly than a 100-130 MW ICAD. A larger heavy frame combined cycle serving the same load as a simple cycle ICAD would have to pay the extra cost of the steam bottoming unit. The intercooler heat will also be of value in some low temperature cogeneration applications, potentially allowing cogeneration without a heat recovery steam generator.

E. PURPA Steam Unit Repowering

A large number of small 20-30 MW steam units were developed in the 1980's under PURPA. These steam units are technically and economically a good candidate for ICAD repowering if gas service and transmission capacity is available. As in cogeneration applications, the high electric to thermal ratio will allow a 100-130 MW ICAD to be used in such applications rather than the small and less economic 40-60 MW heavy frame. Since many of these PURPA units have low temperature and pressure steam condition, the high exhaust temperatures of heavy frame gas turbines would be a thermodynamic mismatch.

V. ICAD MARKETS

Global markets for gas turbines are forecasted to be over 20,000 MW per year in the 2000-2010 time frame. Gas turbines will be the dominant new generation option of choice in the United States. The market for new generation in the United States is likely to be dormant in the 1996-1999 time frame as the result of industry restructuring causing the deferral of decisions to replace aging steam units or add new capacity. ICAD is targeted for entering the market in the 1999-2002 time frame when the growing pent-up demand for new and replacement generation will likely be realized. A recent market study of ICAD simple and combined-cycle applications indicates that if priced within 10% of peaking gas turbines, the global market for ICAD could be in the range of 3,000-4,000 + MW per year after the year 2000. If ICAD were priced more aggressively and/or unconventional "niche" market applications developed, the total ICAD market could be still larger.

CAGT's European representation has help to clarify interest in Europe, with particularly strong interest in feedwater preheating, hot wind box, intermediate and cogeneration applications. Significant attention in 1994-95 was spent by CAGT on discussions with utilities and IPP's in the North American market. The perception which emerged was that the value of the higher efficiency and dispatch could command in the range of a 10% price premium over less efficient frame gas turbines in the same size range. A larger premium might be a possibility once the user value of the higher dispatch, flexibility, and innovative application were fully validated and understood by the market. However, even lower prices might be required for the first units because of the perceived technical risks of new product introduction. Based on current market conditions, an ICAD market entry price range target of $200-220/kw has been suggested by CAGT.

The following reflects some of the insights gained from the interactions between CAGT and potential future ICAD users in North America. Significant market interest in the United States and Canada has been stimulated in ICAD which would be catalyzed commercially if offered by a manufacturer at a competitive market price. The high simple cycle efficiency usually received a very favorable reaction, particularly from utilities operating large combined cycles for intermediate load. Wholesale wheeling also appears to be encouraging the location of new peaking and cycling units closer to load centers so as to avoid the need for new transmission system investments that might have low asset utilization, i.e., offering increased opportunities for off-peak wholesale wheeling. GRI conducted an assessment of repowering for the gas industry and concluded that partial repowering, including feedwater preheating and hot wind box, will likely increase in interest in the United States relative to traditional full repowering. This reflects the industry trend towards avoiding large capital investment risks given market uncertainties. EPRI's Repowering Program has received feedback on the growing interest in partial repowering. Feedback on application interest in ICAD varied significantly depending on the market circumstances, resource mix, relative fuel prices, and timing of need for new capacity.

1. Interest in the ICAD simple cycle gas turbine in the US appeared to be highest in areas where natural gas is cheap and aging steam plants were used for cycling, e.g., California and Texas. The perspective was that the high simple cycle efficiencies, low first costs, and flexibility could accelerate early retirement of the older steam units under some scenarios. Lower water requirements than a combined cycle were mentioned as a plus in Texas and the Pacific Northwest (PNW). Purchases of 100 MW sized gas turbines seemed particularly popular for peaking.

2. Interest in simple cycle ICAD also appeared to be high in areas where "cheap" regional electricity was variable on a seasonal or annual basis, i.e. utility systems with significant amounts of hydro power or smaller utilities buying power in power pools like California or the Pacific Northwest (PNW). Large numbers of combined-cycles are being installed in the PNW. The PNW Planning Council see the attractiveness of ICAD as a "discount" combined cycle to be used as baseload for 3-6 months in dry hydro years (1 year in 4 on average) and for peaking in wet years.

3. In the Southeastern US, where load is growing and coal is cheap, regulated utilities are installing "least cost" and inefficient central station peaking gas turbines units in the near-term. The value realized from the higher dispatch of ICAD simple cycle, distributed applications, and feedwater preheating repowering has not yet been determined.

4. In the Northeastern US, feedwater preheating repowering has gotten the attention of a number of utilities seeking to improve the performance and dispatch competitiveness of existing steam units. ICAD feedwater repowering could address heat rate improvement, O&M reduction, and NO_x reduction needs. In addition to lower total costs and risks than full repowering, excess capacity and market uncertainties favors feedwater repowering strategies that only add small increments of power.

5. The potential for the high simple cycle efficiency ICAD to be able to get more peaking power out of the fixed gas capacity in the Northeast has created some interest in replacement strategies for the old and inefficient peaking gas turbines now used.

6. Interest in ICAD seemed to exist in major oil-producing areas as a more economically effective cogeneration strategy for refineries and enhanced oil recovery, e.g., in Gulf region, Texas, and California.

7. IPP interest seemed strongest in the ICAD as a "discount" combined cycle for competitive advantage in bidding for new power contracts, low risk merchant plant strategy, and as a "value added" partial repowering strategy for existing large steam units that are being offered for sale by utilities as the result of deregulation.

8. Large electric utilities with surplus power in Canada, who are seeking to sell power in the US, viewed ICAD as complementary to their power transaction as a local firming capacity, particularly in transmission-constrained areas. Merchant electric and gas marketing companies appeared interested in the concept of simple cycle ICAD as an approach to local integration of regional bulk electric and gas

services. Gas pipeline companies appeared interested in ICAD feedwater preheating repowering as a potential new gas market in the Northeast and Central states.

9. Mid-sized and large municipal utilities appeared interested in ICAD to insure price and reliability stability by retaining the make-or-buy option for power, i.e., ICAD as local and dynamic firming capacity. The potential selling off of the Federal Power marketing agencies and associated "cheap" power has been one stimulus. The electric industry is also disaggregating into wholesale power pools and retail local distribution companies that usually correspond to urban centers. The feedback received from energy marketing companies was that ICAD could be a valuable complement with wholesale wheeling of electricity to mid-sized cities currently buying power from traditional utilities in areas with high residential and commercial retail rates.

10. Traditional utilities concerned about wholesale and retail wheeling are beginning to consider placing in new cycling and peaking units closer to load centers (i.e., distributed generation) to increase grid asset utilization, avoid investment in new transmission assets, and to prevent the creation of excess transmission capacity that could be used by others for wheeling purposes. Currently, ICAD is at the bigger end of the range for distributed generation and would tend to address large industrial customers or small to mid-sized cities' distributed applications.

11. Over 8000 MW of small 20-30 MW range steam units which were installed to burn wood waste or use other renewable fuels in the 1980's were identified as candidates for ICAD repowering and the potential for renewable-gas hybrids. Federal and State Renewable Energy Programs are highly interested in salvaging these plants, even if as renewable-gas hybrids. A number of utilities with environmental interests saw ICAD's quick start capability as complementary to planned intermittent wind farm and customer energy efficiency additions.

12. Major new products were announced by General Electric, Westinghouse and Siemens in 1994-95. Simple cycle efficiencies for frame gas turbines have reached 38% + for simple cycle and into the 58-60% range for combined-cycle. However, these improvements are all in conjunction with larger size units targeted at baseload operation. Many users questions whether such large machines would be a good match with most intermediate load applications in the US and, although the $/kw would be attractive, the large total costs were viewed as negative.

VI) CURRENT CAGT PROGRAM AND ICAD LAUNCH ORDER INITIATIVE

CAGT efforts to commercialize ICAD began in mid-1994. Three projects are under development including one in Europe and two in the United States, with the goal of having the first operational unit in place by 1999. The current CAGT Program includes the following scope:

1) ICAD Market Definition, Awareness and Development
- ICAD Application Analysis, Gas Turbine Trends Analysis and Market Awareness
- Clarification of ICAD Product Requirements and Focus Group for Standard Specification

2) ICAD Launch Order Development
- West Coast Joint Venture – PURPA Steam Unit Repowering
- SK Power Project – Feedwater Preheating of New Supercritical Pulverized Coal Unit
- Northeastern US Project – Feedwater Preheating of Large Gas/Oil Fired Steam Unit
- Cofunded Application Projects and Strategic Alliances

3) ICAD Product Evaluation and Testing
- Reliability, Availability and Maintainability (RAM) Design Analysis
- Planning Prototype Durability Surveillance Program
- Definition of Small ICAD and Advanced Cycle ICAD Programs

The feedback from the potential suppliers of ICAD in 1994-95 was that under ordinary market circumstances, the ICAD is an attractive enough commercial product to proceed with its development (without the need for a substantial RD&D subsidy or large launch order). However, industry restructuring in the United States has resulted in the deferral of demand for new generation with a corresponding decrease in gas turbine prices. Given the large development cost for any new gas turbine product, potential ICAD suppliers have indicated the need for a launch order and/or development funding support from external sources. CAGT is proceeding with numerous project development and strategic market alliance strategies globally to develop a launch order of at least 10-15 projects. However, the reduced near-term demand in the United States, softness in gas turbines prices, and general market uncertainty represents a major hurdle to the development of ICAD at present.

In response to this challenge, the CAGT Steering Committee on October 23, 1995 authorized two new directions for CAGT:

- A launch order development initiative with the goal of identifying and developing 10-15 ICAD projects globally that demonstrate the various applications of ICAD; and

- Definition of a small ICAD program (SICAD) that would demonstrate the ICAD in smaller sizes for distributed applications and would leverage national RD&D programs on small turbines.

CAGT plans to "seed" a number of projects and alliances through site and application specific feasibility studies. The intent is to use CAGT funds as a catalyst for other sources of funds from the host site, supplier, government organizations, and the other groups with similar objectives, e.g., gas marketing companies or environmental groups. The ICAD launch order strategy will also actively seek to develop joint market relationships for ICAD through strategic alliances with IPP's, gas marketing companies, and other organizations (e.g., regional National Laboratories), particularly for pursuing projects in Asia and Latin America. The site specific project studies would be conducted over the 1996-97 time frame and would target the following applications:

- Intermediate load
- Feedwater preheating, hot wind box, and generator repowering

- Distributed generation; municipal and cogeneration
- ICAD combined-cycle and phased construction
- ICAD PURPA steam unit repowering and renewable applications

The general selection criteria for CAGT-supported project studies would include:

- Potential for Real Project (e.g., target site, management commitment, new power need, etc.)
- Timing of Commercial Project (1999-2002)
- Host Cofunding and Internal Champion
- Support of Federal, State, and Other Organizations
- Target Applications (i.e., to ensure broad coverage of ICAD range of applications)
- Geographic Coverage (i.e., to ensure broad market exposure)
- Potential for Demonstration Projects (e.g., alliances in manufacturer's home state)
- Sharing of Information
- Priority for CAGT, EPRI, and GRI Members

CAGT will actively pursue with others the creation of a Department of Energy (DOE) Advanced Turbine Systems Program for mid-size turbines (20-150 MW) to address market needs for better intermediate load, distributed, and repowering gas turbine technologies. The Gas Turbine Association (GTA) of manufacturers is developing a proposal for such a program as a follow-on the DOE Advanced Turbine Systems small (<20 MW) and large (>400 MW) gas turbine programs. DOE, EPRI, and GRI will be conducting gas turbine RD&D needs workshops in 1996 that will examine a number of applications targeted by ICAD, including intermediate load, repowering, and renewable-gas hybrid retrofit applications.

VII) SUMMARY

CAGT members invite others to join the program and participate in the development of the launch order for ICAD. CAGT is a "buyers"-led initiative seeking to develop a launch order to encourage manufacturer development of ICAD gas turbine technology. ICAD simple cycle will have costs and performance for intermediate load applications unlike anything else on the market today. ICAD will also enable new repowering applications like feedwater preheating. Participation in CAGT will offer many insights and significant market intelligence on changing markets and future gas turbine technology and applications. Participating in ICAD commercialization offers users a potential source of competitive advantage in future project and a major new business opportunity. For more information on CAGT and ICAD contact George Hay at (510) 988-9792 (telephone), (510) 988-0402 (fax) or also by email at geohay3@aol.com.

U. S. Organizations

Electric Power Research Institute
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Sacramento Municipal Utility District
Southern California Gas
State of Connecticut (*)
Northeast Utilities (*)

(*) New Phase II Members

European and Canadian Organizations

Elkraft of Denmark
National Power of England
British Gas of England
Electricite de France
KEMA of The Netherlands
Canadian Electric Association
TransAlta of Canada
ENEL of Italy (*)

AERODERIVATIVE MANUFACTURERS

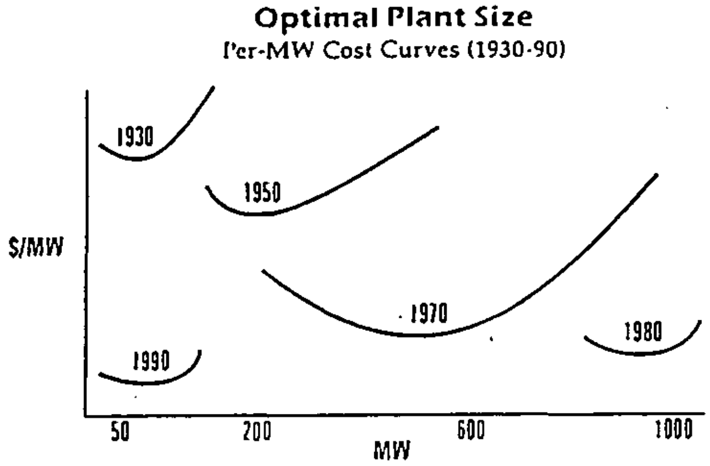
General Electric
Turbo Power and Marine
Rolls-Royce

CAGT Phase I Sponsors
Figure 1

Factors	1991 CAGT Focus	Current CAGT Focus
Primary Driver	Baseload Efficiency	Flexibility, Low First Costs and Application Diversity
Application International	PG&E Central Station Site Repowering Needs	Diverse Intermediate, Repowering & Distributed Mid-size Needs
Duty Cycle	Baseload for Commodity Power	Flexible Intermediate and Higher Value Power
Fuel	Natural Gas	Natural Gas & Fuel Hybrids
Unit Size Range		
Complex Cycle	50-200 MW	125-150 MW
Simple Cycle	Not Targeted	100-130 MW
Efficiency Goals for Mid-Size		
Combined Cycle	56-62% LHV	56-60% + LHV
Simple Cycle	Not Targeted	45-48% +
Cost	Beat Large Combined Cycle for Baseload	Beat Large Combined Cycle for Intermediate
Development Costs	Large Government Support Likely Needed	Government Support Secondary to Market Forces
Technical Risk	High in Demo	Low in First Unit
Time Frame		
– Demonstration	1996-98	First Commercial 1999+
– Commercial	2000-2005	Launch Order 1999-2002

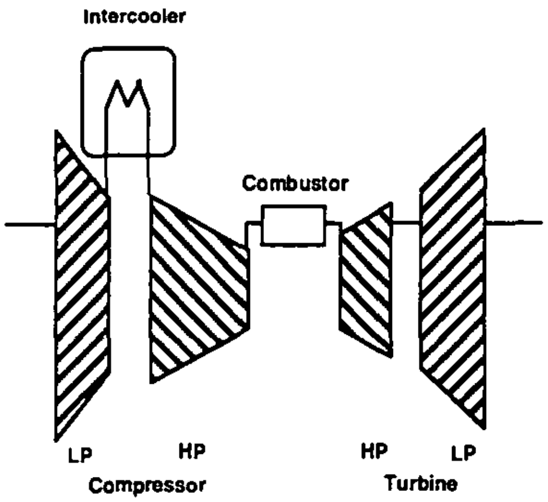
CAGT Program Evolution
Figure 2

- Natural gas fired gas turbines driving industry restructuring with different economics than coal/nuclear steam paradigm of 1930-1980
- Large 200+ MW gas turbine units likely to have many diseconomies of project scale
- Gas Turbines in 5-150 MW size range likely to be preferred by buyers in scenarios where capital risks, opportunity costs, operating flexibility, life cycle asset management, fleet, energy delivery infrastructure and customer service attributes are considered.

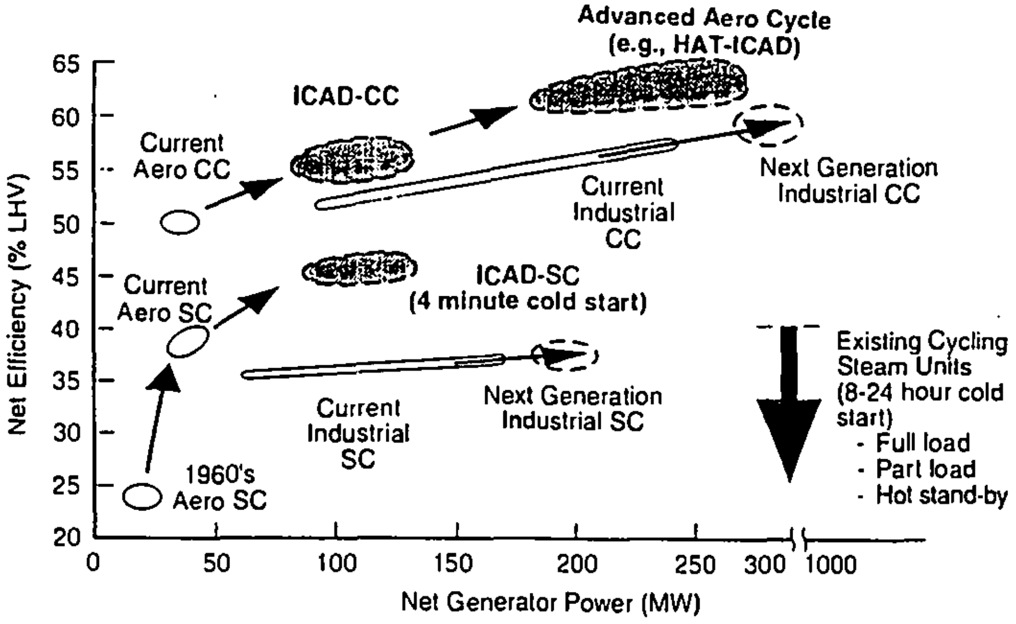


Electric Industry Economics of 1990's and Beyond
Figure 3
Source: Charles Bayless - Public Utilities Fortnightly (12/1/94)

- Reduces compression work
- Higher compression ratios and increased mass flow
- Colder cooling air allows higher turbine rotor inlet temperatures and higher efficiency



ICAD - The Benefits of Intercooling
Figure 4

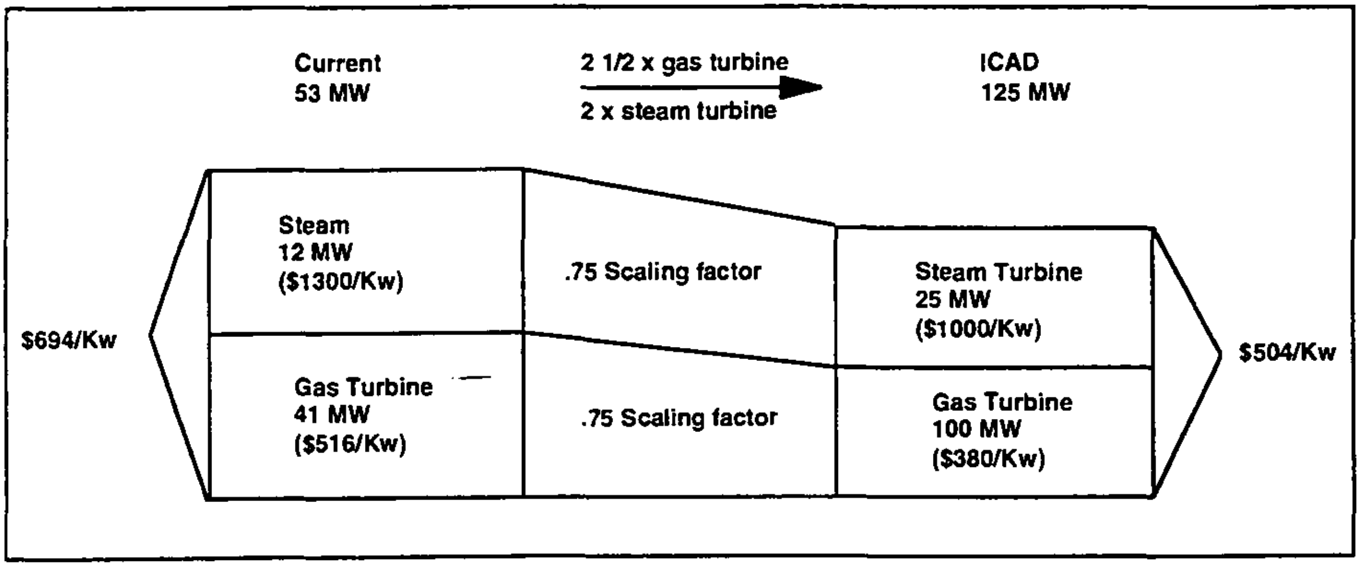


ICAD = Intercooled Aeroderivative
SC = Simple Cycle
CC = Combined Cycle
HAT = Humid Air Turbine

ICAD Gas Turbine Represents Flexibility New Intermediate Load Product Class
Figure 5

- High-efficiency
  - 45 to 48% LHV for Simple Cycle
  - 55 to 60% LHV for Combined-Cycle
- 20-125 MW size allows smaller capital investment (Reduced investment risk)
- Flexibility
  - A "winner" at intermediate capacity factors
  - Can run at higher or lower capacity factors without major penalties
- Minimum water use
- Low Emissions
- Smaller siting footprint; Shorter starting times
- Flexibility of Applications - Especially for Intermediate Load, Repowering, and Feedwater Preheating

Advantages of the Intercooled Aeroderivative (ICAD) Gas Turbine
Figure 6



Comparison of Current Aeroderivative and ICAD Combined Cycle Costs
Figure 7

Cycling Simple Cycle Strategies (Central Station
- Single Unit (100 + MW)
- Multiple Units

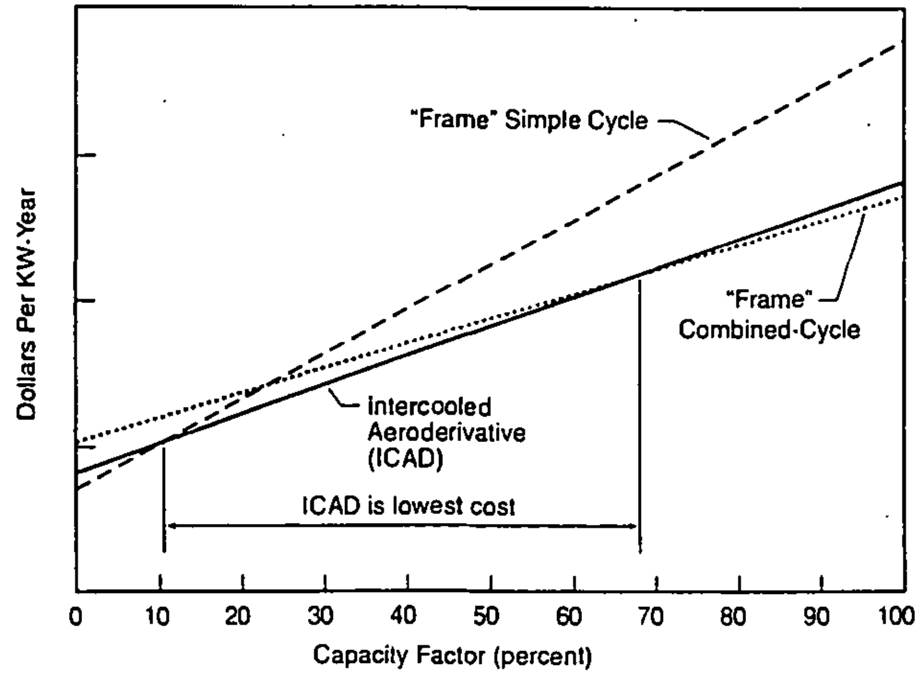
Combined Cycle Strategies (Central Station)
- Single Topping Cycle Unit (120 MW)
- Multiple Topping Cycle Units (240 MW)
- Phased Construction of Bottoming Cycle (1-4 ICAD Units)

Repowering Stragies for Existing Units and Sites
- Full Repowering (25-75 MW Steam Plants)
- Hot Windbox Partial Repowering (Coal or gas unit)
- Feedwater Preheater Partial Repowering (Coal or gas unit)
- 100 MW Simple Cycle Generator Repowering

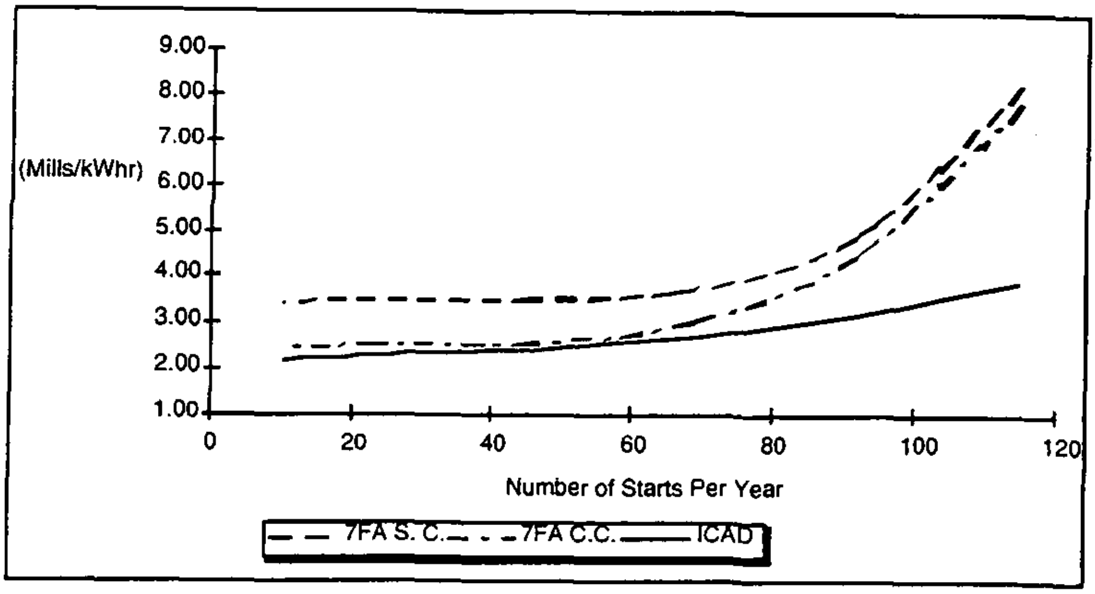
Distributed Application Strategies
- Transmission System Reinforcement (Simple Cycle)
- Transmission System Reinforcement (Combined Cycle)
- Customer Site (Electric Only)
- Customer Site (Cogeneration/Simple or Combined Cycle)
- Portable Simple Cycle Units

Alternative Fuels/Gasification/Hybrid Strategies
- Feedwater Preheating or Hot Wind Box Configurations in New Pulverized Coal Unit.
- Coal, Waste Fuel, Biomass and Heavy Oil Gasification
- Repowering of Existing PURPA Waste Energy Facilities
- Solar Thermal and Geothermal Repowering and Feedwater Preheating of ICAD Bottoming Cycle in New Units
- Wind Farm with Simple Cycle ICAD for Distributed Firming Capacity

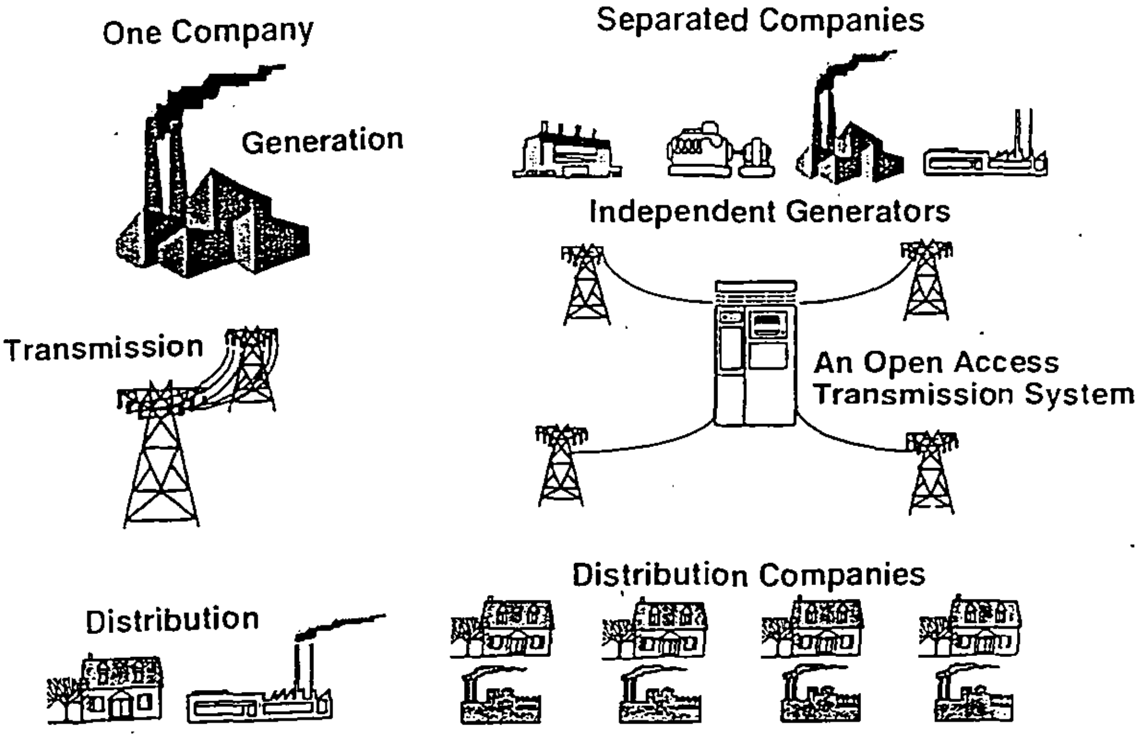
ICAD Gas Turbine Applications
Figure 8



Intercooled Aeroderivative (ICAD) Gas Turbine Attractive Over a Wide Range of Capacity Factory
Figure 9
Source - Tiff Nelson - San Diego Gas and Electric

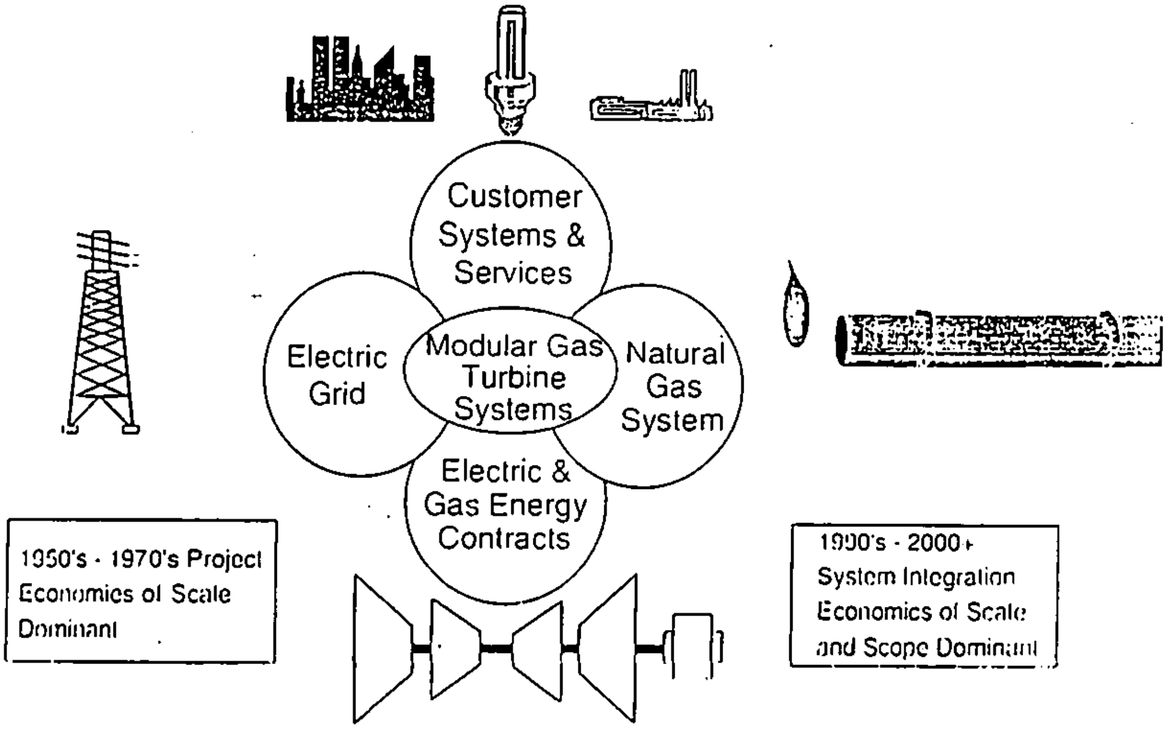


Variable O&M Costs Versus Number of Starts Per Year
Figure 10
Source: CAGT Sponsored Analysis by Fluor Daniel, Inc.

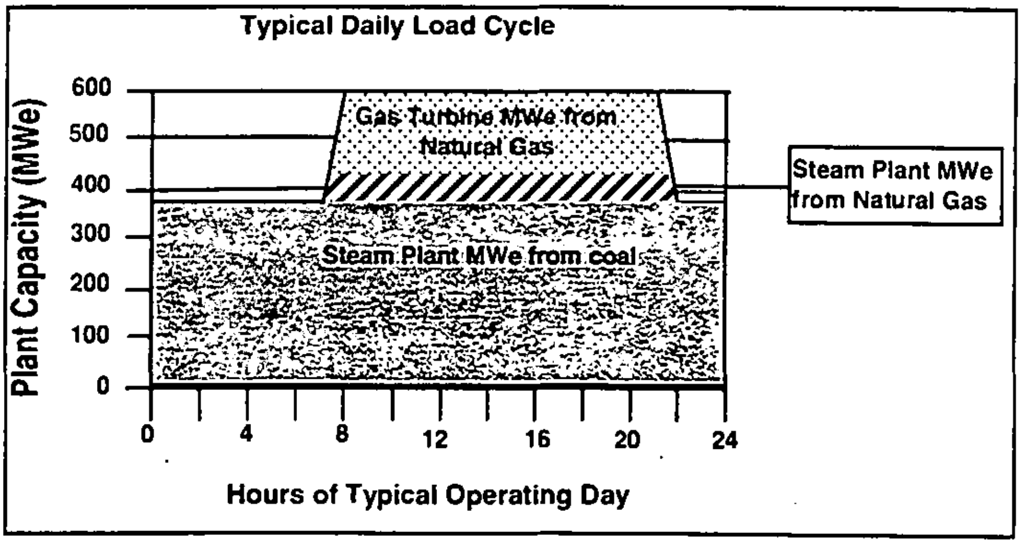


The Changing Utility Industry
Figure 11

WEINBERG ASSOCIATES



Gas Turbines System Paradigm for Integrating Merchant Services
Figure 12



Feedwater Preheating for Supercritical Coal-Fired Plant

Cycle Description	Net Efficiency Range (LHV)
Supercritical Coal	47-48%
Hybrid with feedwater heating	49-52%
Gas use efficiency (intercooled aeroderivative)	59-60%
Gas use efficiency (LM6000)	54-55%
Gas use efficiency (F-technology)	54-55%

Comparison of Hybrid Cycle Efficiencies
Figure 13