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LIST OF ACRONYMS

ANSI	American National Standards Institute
ARB	California Air Resources Board
ASME	American Society of Mechanical Engineers
ATS	Advanced Turbine System
BACT	Best Available Control Technology
CEC	California Energy Commission
CEM	Continuous Emission Monitoring
CO	Carbon monoxide
CO_2	Carbon dioxide
DLN	Dry Low NO_x
DOE	U.S. Department of Energy
EIA	Energy Information Agency
EERC	Environmental Engineering Research Corporation
EPA	U.S. Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
GDP	Gross Domestic Product
IC	Internal Combustion
ISO	International Organization for Standardization
LAER	Lowest Achievable Emission Rate
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitric oxide plus nitrogen dioxide
NH_3	Ammonia
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research
RAMD	Reliability, Availability, Maintainability, and Durability
RATA	Relative Accuracy Test Audit
SCAQMD	South Coast Air Quality Management District
SCR	Selective Catalytic Reduction
SETAC	Society of Environmental Toxicology and Chemistry
SO_2	Sulfur dioxide
TDL	Tunable Diode Laser
UCSD	University of California, San Diego
UVDOAS	Ultra Violet Dispersion Optical Adsorption Spectroscopy
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

A central issue facing the California Energy Commission (CEC) and other State agencies is how to provide an adequate supply of electric power to the citizens of California at a cost low enough to encourage economic growth and enhances human welfare and in a way that preserves the quality of the environment. To assist in addressing this issue, a Workshop on the Environmental Impacts of New Generation in California was conducted by the CEC and EPRI at the Hyatt Islandia Hotel, San Diego, California on October 28, 1999. Its purpose was to clarify the state of knowledge regarding the management of emissions from existing and future power generation options for California. The outcomes of this workshop are expected to stimulate the follow-on actions covered under Next Steps below. The discussions focussed on three topics: generation emission and control, emissions measurements and reliability, and life cycle assessment, as described below.

Generation: Emissions and Control

California's current situation and likely future trends with regard to electricity needs, generation mix and pollutant emissions were reviewed. Five main points relevant to air quality emerged:

- While within California electricity consumption increased 15% from 1985 to 1995, the fossil fuel burned for electricity generation within the state decreased 11%.
- Emissions from combined utility and co-generation sources in 1996, as a fraction of all stationary sources in California, accounted for 15% of the NO_x, 20% of the CO, 6.5% of the PM_{10}, and 7.3% of the sulfur dioxide. These are sufficiently large proportions to be of importance for impact analysis.
- By 2020, the population may increase 25% while economic activity may increase 35%.
- Much future new electricity generation is likely be installed in relatively small units at or near end users. Referred to as "distributed generation," this new energy supply pattern is likely to become increasingly important between 2002 and 2010 as competition increases for delivery of lowest cost electricity.
- Increased use of distributed generation will likely result in substantially higher emissions compared to more conventional central station generation.

The environmental performance of several power generation technologies was reviewed. NO_x emission levels typical of units installed in the late 80s and early 90s typically ranged from 2.5 to 4.5 gmNO_x/bhp-hr (~200 to 400 ppm NO_x @ 15%O_2) for reciprocating engines (using gas or oil) and 300 to 400 ppm (@ 15% O_2) for gas turbines. Three categories of technologies now available can achieve significant reductions from the above emission levels:

- New technologies with modified combustion can achieve the following levels of NO_x emissions when burning natural gas
  - Reciprocating engines: 0.7 to 1.5 gm NO_x/bhp-hr (~65 to 90 ppm NO_x @ 15% O_2)
  - Gas turbines: 25 ppm (with dry low NO_x or steam/water injection @ 15% O_2)

- Advanced burners (surface stabilized or catalytic combustion): 2 to 3 ppm @ 15% O_2
- Post-combustion clean-up (selection catalytic reduction or SCONOx): less than 1 to 2 ppm @ 15% O_2

Critical issues for which more information or research is needed include:

- Achieving cost reductions in the advanced NO_x reduction technologies
- Confidence in the reliability, availability, maintainability, and durability of the advanced technologies under actual long-term operating conditions
- Concepts for reducing environmental impacts for distributed generation units while maintaining the benefits of distributed generation
- Information exchange on current costs and performance of advanced electric generation technologies

Measurements and Reliability of Emissions

Reliability for routine measurements of the very low (<10 ppm NO_x) emissions levels obtainable by the advanced electric generation technologies was addressed. The following points summarize the current situation:

- The American Society of Mechanical Engineers (ASME) Codes and Standards Committee concluded that four instrument types (chemiluminescence, FTIR, UVDOAS, TDL) are "capable of accurate measurement of NO + NO_2 in the 1 to 5 ppm range".
- The EPRI/Utility Continuous Emissions Measurement Working Group reviewed the experience of five energy companies at operating power plants. The group concluded that the available field-capable instruments do not yet produce accurate nor reproducible measurements on operating equipment. Problems range from specifications for reference methods to specifications of monitoring under various operating conditions that could lead to emission violations during start-up.
- A coordinated national effort is required to accomplish the following:
  - Improve calibration and sampling procedures
  - Develop measurement protocols, reference methods, and continuous emission monitoring protocols that yield realistic information from a variety of combustion systems

Life Cycle Assessment

The implementation of a preferred generation mix that meets the electricity needs of the citizens of California should be based on an integrated life-cycle evaluation. Life cycle assessment is a systematic evaluation methodology of all the cradle to grave aspects, including efficiency, capital and operating cost, manufacturing, what to do with the hardware when its useful life is over, etc., and of alternative technologies and generation infrastructure. The question of how to conduct such assessments was addressed. The discussion illustrated the following main points:

- Life cycle assessment has been productively applied in the manufacturing and process industries.
- Rules of analysis have been developed by international standards organizations.

- Critical issues for which more information is needed include:
  - Ability to conduct life cycle design (as opposed to assessment) for electricity generation options
  - Inclusion of economic and non-economic considerations in the assessments

Next Steps

In the drive for excellence in environmental protection, regulatory philosophy at both the Federal and State level has been to require applicants and operators to control emissions to as low a level as can be reached. Criteria such as "best available control technology" (BACT) and "lowest achievable emission rates" (LAER) have been imposed with the concept "if it can be done, it must be done." This approach has raised issues and conflicts, which remain to be addressed on a continuing basis as part of the next steps.

The presentations and discussions gave a picture of what is known and what yet needs to be known with regard to the environmental impacts of new generation in California. Four follow-on steps were identified for the CEC to lead, initiate, or join a larger national effort.

Concerning workshop follow-on steps, the participants came to the following conclusions:

- A set of "Technology Assessment Guides" for generation/emission control technologies, measurement techniques and integrated evaluation methodologies should be made widely available to achieve consistency in reviewing technology performance. A Steering Committee with representatives from the research, industrial, energy companies, and regulatory communities should be convened to develop the contents of such guides.
- A "Syllabus" providing an up-to-date, comprehensive compilation of reliable information sources would be an invaluable contribution. A group should be charged with the responsibility for developing a structure for organizing the syllabus and populating the database with information currently in hand or available from the workshop participants.
- Information exchange forums should be developed and supported that include an authoritative web-site and annual workshops.
- A public research plan to address these (and other) information needs must be developed. Much work is already underway in many quarters. Steering groups should be established in each major area to identify critical gaps with particular relevance to California.

Conclusions

Most of the recommendations for further discussion and research and for follow-on activities for gathering, codifying and disseminating information are covered under specific topic headings in these notes. In addition, a number of comments were relevant to the formulation of policy and the setting and enforcement of rules. General consensus seemed to have been reached on several points.

- Standards designed to protect the environment should be thoroughly science-based.
- Output-based standards (emissions per unit of electricity produced) are preferable to concentration-based standards (ppm).

- Regulations should encourage, rather than discourage, the development of new, cost-effective approaches to emission control.
- Lack of consistency of approach (referred to as “disconnects”) among the several Federal and State agencies should be addressed.
- Sampling and measurement methods have to be improved to enable credible regulation.
- The value of “wringing out the last few ppm” should be carefully evaluated.

1
INTRODUCTION

A workshop on the Environmental Impacts of New Generation in California was conducted by the California Energy Commission (CEC) and EPRI at the Hyatt Islandia Hotel, San Diego, California on October 28, 1999.

The purpose of the workshop was to clarify the state of knowledge regarding the management of emissions from existing and future power generation options for California. The outcomes of the workshop were intended to provide the public, industry, and regulators with a sound basis for implementing the most environmentally and economically desirable generation mix that meets the electricity needs for the citizens of California. Specifically, the workshop focussed on air emissions, the ability to measure air emissions accurately, and to manage air emission effectively in coordination with the integration of all environmental impacts via life-cycle considerations in technology review and selection criteria.

The workshop was part of a continuing process of information gathering and analysis. It was intended to initiate a continuing discussion among research, governmental, regulatory, industrial and academic participants on the development and evolution of a preferred electricity generation mix for California. Four specific workshop follow-on activities were cited:

1. A contents outline for a technology assessment guide
2. A syllabus of the best available information on candidate technologies, their environmental characteristics and their place in the electricity supply spectrum
3. A technical and scientific exchange forum for continuing discussions of environmental impacts from a variety of generating technologies, emission measurement technologies, pollutant mitigation technologies and emerging research findings
4. A plan for public research and development to foster innovations in generation technology consistent with environmental protection and economic development

These notes record the main points raised by the attendees and will provide points of departure for follow-on steps. The Executive Summary focuses on objectives, outcomes and next steps. This Introduction reviews the background and objectives which motivated the workshop and summarizes the 4 sessions of the workshop. Each session is briefly summarized followed by key points from the presentation. Appendix 3 contains all the visuals used by the workshop participants.

The first session, “Generation: Emissions and Control,” dealt with trends related to new electricity generation technologies in California with particular emphasis on air emissions and their control. These notes also present data in four tables on energy use and electricity generation in California and compare the emissions from major categories of energy producing sources. All the data are compiled in similar units.

The second session, “Emission Measurement and Reliability,” addressed the problem of quantifying the emissions with emphasis on the performance of routine monitoring methods over a wide range of NOx concentrations under power plant operating conditions.

The third session, “Environmental Life Cycle Implications,” identified available methods to account for aspects such as the mobilization of materials, construction of machines and their ultimate disposal or recycling as well as the environmental impacts of energy generation itself.

During the fourth and last session of the workshop, “Gaps and Analysis,” Dr. David Rohy, Prof. Scott Samuelsen and Ms. Ellen Petrill facilitated feedback and discussion among all attendees. The notes describe the process, summarize an overview by Prof. Samuelsen, and list several consensus points that emerged. Appendix 3.15 and 3.16 reproduce the details of the points recorded during the session on overheads and flip charts.

These notes end with two sections. The Conclusions encapsulate several questions and points of view expressed during the presentations and discussions. The Recommendations for follow-on efforts address broadening of existing technology and assessment guides, and the preparation of a syllabus of current information, and the fostering of information exchange forums and the planning of research.

For the sake of completeness, Appendix 1 reproduces the agenda. Appendix 2 is a list of all attendees and their points of contact. Appendix 4 provides biographical sketches of the presenters and session chair persons.

2
GENERATION: EMISSIONS AND CONTROL

Central to understanding the air quality impacts of new generation in California is knowing the current and planned energy use and generation. Therefore, this session of the workshop provided information on energy consumption and generation, the expected emissions associated with current and emerging technologies, and the simulated consequences of various market driven distributed and centralized generation combinations.

Summary of Current Situation and Trends

Current energy and emissions data and likely future trends in power consumption, fuel use, emissions from power generation and California air quality are in Tables 1 and 2. Table 3 shows the relative contribution of electric power generation to overall state wide emission of nitrogen oxide (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO) and inhalable particulate matter (PM_{10}).

Table 1 is added to these notes to provide a perspective on the current scale and balance of electricity consumption and generation. As large, central station generating plants are supplemented or replaced by smaller, more widely distributed generating facilities, California's fuel consumption and electricity generation and use patterns will see significant changes.

Table 1
Energy and Electricity in California: Current Situation and Trends

Items	Quantities
Total energy use[1,2]	1.94 x 10^6 GWh ~ (6,600 x 10^{12} Btu)
Total installed generating capacity[1,2]	~54,000 MW
Total electricity consumption[1,2]	218 x 10^3 GWh ~ (740 x 10^{12} Btu)
Total in-state electricity generation[1,2] (consumption + losses – net imports)	202 x 10^3 GWh ~ (690 x 10^{12} Btu)
Net electricity imports[3]	51,200 GWh ~ (174 x 10^{12} Btu) (~25% of in-state generation)
Electricity consumption[3]	230 x 10^3 GWh~ (700 x 10^{12} Btu) in 1995 15% increase from 1985 to 1995
In-state fuel consumption to generate[3]	380 x 10^3 GWh ~ (1300 x 10^{12} Btu) in 1995 11% decrease from 1985 to 1995
Population[3]	+ 25% by 2020
Economic activity[3]	+ 35% by 2020

[1]1997 data except consumption is from 1996; [2]from CEC and EIA (U.S. Department of Energy) web-sites; [3]from workshop presentations App 3.1, 3.2.

Table 2
California Air Emissions, Statewide for 1996[1]

Source	**Emissions (tons/day)**			
	NO_x	**CO**	**PM_{10}**	**SO_x**
Electric Utilities	52	33	5	9
Co-generation	42	38	4	2
Total Power Generation	94	71	9	11
Total Fuel Combustion	520	270	42	61
Total Stationary Sources	630	350	140	150
Total Mobile Sources	2,600	15,000	110	97
Total Natural Sources	9	580	90	-
Total Statewide	3,300	19,000	2,400	250

[1]ARB Web page

Table 3
Relative Air Emissions from Electric Power Generation
(derived from Table 2)
[(Electric Utilities + Co-generation)/Totals] x 100%

Air emissions from elec. util and co-gen	As a fraction of total fuel combustion (%)	As a fraction of total stationary sources (%)	As a fraction of statewide totals (%)
NO_x	18	15	2.8
CO	26	20	0.4
PM_{10}	21	6.4	0.4
SO_x	18	7.3	4.4

During the workshop, ambient air quality conditions in California were summarized. The State is largely in attainment for NO_x and SO_2 ambient air quality standards with some districts in non-attainment for CO. The State is largely in non-attainment for PM_{10} and O_3.

In order to gauge the impact of new generation in California, one must know what the future generation mix will look like. The workshop did not address this issue but focussed instead on the role of new technologies, especially distributed generation. An analysis of the potential market sizes for distributed generation (DG) technologies as a source of electric power under deregulation was presented by Horgan (App 3.2). Her analysis showed:

- By 2002, the market potential of distributed generation for peak load applications could range from 300 MW for microturbines to 750 MW for diesel engines.
- For base load applications, the potential market of distributed generation is much less; the Advanced Turbine System (ATS, represented by the Solar Mark 350 turbine) may have the largest potential use at about 350 MW.
- By 2010 the market for DG is expected to grow significantly with several technologies having market potentials of 600 to 1000 MW for peaking; the base load market potential grows only modestly from 2002 to 2010.
- The implementation of distributed generation technologies is likely to result in higher NO_x emissions compared to alternatives. For example, the amount of NO_x added by 1000 MW in peaking capacity would be 3 times greater if 29% of this increase were generated with micro-turbines as compared to adding all of the peaking capacity with more conventional, centrally sighted generation. Analogously, increases in base load capacity via distributed generation with conventional turbines would substantially increase NO_x emissions over addition of central power stations.

The following questions are typical of those raised to be dealt with regarding future costs and regulatory policies:

- What will be the cost and, therefore, the effect on market penetration by distributed generation as NO_x emissions are forced below 10 ppm?

- What are the criteria for adopting performance data from a few units as overall emission limits for a technology?
- What is the influence on environmental quality when the increased use of distributed generation changes the location of pollutant discharges?
- What is the probability of increasing the shift of reciprocating engines from emergency generation to peak shaving?
- How will the market for distributed generation change as a function of the price of NO_x emission credits?
- When co-generation replaces both electricity from the grid and process heat from on-site boilers, what regulatory actions are needed to give credit for displaced boiler emissions as well as for displaced central power system emissions?

Summary of Technology Status

The achievable emissions levels of traditional and many advanced technologies are well known. These were discussed in three categories.

1. Traditional technologies: reciprocating (diesel and gas/dual fuel) engines; gas turbines (simple and combined cycle) incorporating combustion modifications (dry low NO_x (DLN); steam or water injection)
2. Advanced burner concepts: surface stabilized combustion or catalytic combustion suitable for application in turbines, power boilers, industrial furnaces, etc.
3. Post-combustion technologies (Selective Catalytic Reduction [SCR]; SCONOx) which can be added to essentially all combustion equipment

The achievable NO_x levels are shown in Table 4.

Table 4
NO_x Emissions from Current and Advanced Technologies

Gas and Dual-fuel Reciprocating Engines (App 3.5)		
	Traditional (1988-1992)	*Current*
Spark ignition engines	3.3g/kwh ~ (2.5 gm/bhp-hr)	0.9 g/kwh ~ (0.7 gm/bhp-hr) (65 to 70 ppm)
Dual-fuel engines	6 g/kwh ~ (4.5 gm/bhp-hr)	1.3 to 2 g/kwh (1 to 1.5 gm/bhp-hr) (85 – 90 ppm)
(with SCR)	--	0.13 g/kwh ~ (0.1 gm/bhp/hr) (~10 ppm)
Gas Turbines		
Gas turbines (with DLN)	300 to 400 ppm	25 ppm @ 15% O_2 (80 to 90% reduction)
Advanced Surface-stabilized and Catalytic Burners (App 3.7; 3.8)		
Surface stabilized combustion	--	9 ppm @ 3% O_2/ (< 2 ppm @ 15% O_2)
Catalytic combustion	--	< 2.5 ppm @ 15% O_2/ (some tests < 1.5 ppm)
Post-combustion Clean-up Technologies (App 3.3; 3.4; 3.9)		
Selective catalytic reduction (SCR) (no direct reports/ inferred from other sources)	--	1 to 5 ppm @ 15% O_2)
SCONOx	--	< 2 ppm @ 15% O_2 (< 0.8 ppm in 2 demos)

More information is needed about the following:

- Reliability, availability, maintainability, and durability (so-called RAMD) problems. Confidence needs to be developed in the performance of the advanced technologies under actual, long-term operating conditions. While this is being addressed in numerous demonstrations and extended operating periods (1000's of hours) with numerous (100's) of start-ups and shut-downs being recorded, additional independent demonstrations will be needed.

- Cost. One analysis was presented that evaluated the costs of post-combustion removal of NO_x. The analysis compared the cost of achieving 25 ppm from a gas turbine using dry low NO_x techniques with the cost of achieving 3 ppm with SCR or 2 ppm with SCONOx. The additional removal was achieved at a cost of over $19,000/ton NO_x for SCR and over $25,000/ton NO_x for SCONOx. An important open issue for future attention and discussion is how to achieve significant cost reductions for the currently favored advanced approaches, particularly the post-combustion technologies.
- Performance during transients. During plant start-up the emission control equipment must operate for certain lengths of time at temperatures below those necessary for pollutant capture or destruction. During these periods, excursions of emission levels beyond the permitted limits will occur. Because no technological means as yet exists for eliminating these excursions, the permit language must allow for these transient conditions.
- Applicability to smaller units for distributed generation. Little information was presented on this topic. Those technologies judged likely to achieve significant penetration are the established ones, such as diesel, reciprocating gas or dual-fuel engines, and gas turbines, both simple and combined cycle. The information presented at the workshop indicated low emission candidates for distributed generation, such as microturbines and fuel cells, are so costly that they are not likely to gain significant market share in the near term. Therefore, more information is required on the field performance of combustion modifications (such as DLN) of microturbines and on the relative (per kwh) cost of using post-combustion NO_x control with small units.

Presentations from Generation: Emissions and Control Session

Of the ten presentations given during this session, the first three provided background on the energy and environmental situation in California. The other seven reviewed important technologies.

- The present mix of electricity generation and the degree of attainment of air quality goals in California (Honton)
- The likely penetration of distributed generation into the California power generation market and the potential environmental effect of that penetration (Horgan)
- Some guidelines for power plant permitting process and for interpreting Best Available Control Technology (BACT) requirements (Tollstrup)
- An overview of the development status and potential applications issues of several low NO_x technologies (Angello)
- Two on the present status and development possibilities for existing technologies (Burnette, Witherspoon).
- Three on more recent technological developments for various advances in both combustion modification and post-combustion clean-up (Smith, Solt, Davis).
- One on the use of biomass and its potential effect on California air emissions (Tiangco)

The gist of the 10 presentations is given below.

"Environmental Challenges for New Generation"
(E. J. Honton, Resource Dynamics Corporation)

Historical data on the trends in electricity use in California show a 15% increase from 1985 to 1995 while the consumption of fuels burned within the State to produce it decreased by 11% over the same time period. This decreased fuel use stems from a combination of increased generation efficiency and increased imports of electricity.

At the same time, much of the State remains in non-attainment of ambient air quality standards with respect to fine particulate (PM_{10}) and ozone. As a result, the anticipated substantial growth in population and electricity needs, referred to by David Rohy in his introductory remarks, will require continuing reductions in emissions and an associated tightening of air pollution regulations.

Honton described the existing licensing and regulatory trends in control requirements for existing central plants from BACT to LAER. Against this background, the increased use of distributed generation units of smaller size poses serious technical and regulatory challenges. Regulation of small units falls to 35 separate air quality management districts; expected emission rates from smaller units are generally higher than for the larger, central plants (See Fig. 21, Appendix 3.1).

Cost projections for a range of alternative technologies including photovoltaics, wind, fuel cells, and micro-turbines suggest substantial reductions in the cost of some the more advanced options by 2010 (See Fig. 22, App 3.1.)

In conclusion, eight trends or evolving requirements will challenge policy makers, permitters, and technology developers. These are:

- A possible large shift in the use of reciprocating engines (high NO_x emitters) from emergency-only use to peak shaving
- The increased use of microturbines (high CO and NO_x) in urban areas
- Higher priced NO_x emission allowances
- Crediting the thermal side of co-generation for displaced boiler emissions
- The increased use of distributed generation
- A demand for simpler, standardized air quality regulations
- A shift from case-by-case assessment methods to
- \- presumptive BACT for power generation industry
- \- standardized siting requirements
- \- type testing and inspection for distributed generation
- A need for an authoritative Website for information exchange on generation, emission control, and measurement of emissions.

“The Potential Impacts of Distributed Generation of California Emissions”
(S. Horgan, Distributed Utility Associates)

In a study conducted for the California Air Resources Board (ARB), Distributed Utility Associates attempted to quantify the likely effect of distributed generation on air emissions in California. The first step was to estimate a market penetration for eight distributed generation technologies (microturbines, ATS, diesel, dual fuel, fuel cells, renewables, etc.) both for peak-shaving and for baseload by the years 2002 and 2010. These estimates were done from two viewpoints: utility economics (in which these technologies would be installed by the utility as an alternative to enhancing or expanding the delivery grid) and customer economics (where electricity users might choose to install on-site generation as a cheaper or more reliable alternative to grid power).

In all cases, (utility or customer economics; peak shaving or baseload; 2002 or 2010) some technologies have the potential for significant penetration. It should be noted that the technology costs, which formed an important basis for these estimates, were provided by technology vendors and were not displayed in this presentation. (See Figs. 5 and 6 in App 3.2). On the basis of emissions rates for individual technologies (also supplied by the equipment vendors and not specified in the paper) and for the average emissions of the California grid-connected generation units, it was possible to estimate the net (distributed generation emissions minus displaced central plant production) increase/decrease in state-wide emissions. In all cases, (See Fig. 7 in 3.2) the emissions increased.

In the case of customer owned and sited generation, a benefit to cost ratio was calculated and the optimum number of hours that each technology would be run were presented (some were run full-time; some only a small fraction). Again the net emissions increased.

The essential conclusion, when viewed against the background of the Honton paper, reinforces the notion that an increase in the amount of distributed generation in California will likely result in environmental consequences that will require careful attention by vendors, users, and policy and regulatory agencies.

“Guidance on Power Plant Permitting and BACT”
(M. Tollstrup, California Environmental Protection Agency)

The ARB is working to develop some uniform guidelines for use by the various permitting/licensing agencies in their consideration of large gas-turbine power plants. (Currently, the licensing responsibility lies with the California Energy Commission for plants of 50 MW or larger and with the 35 Air Quality Management Districts for smaller plants.) The intent is to develop some consistency of criteria and approach across the State in the interpretation of BACT and emission offsets.

At the present time, there are 42 proposed projects of simple and combined-cycle co-generation plants of between 100 to 1000 MW (an aggregate total of 25,000 MW). Of these, three have been licensed and ten more are in the review process.

While the ARB does not establish BACT, the ARB guidance document reviews the status of technology and suggests parameters for setting BACT limits. Definitions of BACT for two types of technology are based achievable emissions (Table 5):

Table 5
BACT for Gas Turbine Technologies

Technology	Achievable Emissions Levels (ppm @ 15% O_2)
Simple cycle gas turbine	NO_x: 5 ppmvd, 3 hr. rolling average CO: 6 ppmvd, 3 hr. rolling average VOC: 2 ppmvd, 3 hr. rolling average
Combined cycle/co-generation	NO_x: 2.5 ppmvd, 1 hr. rolling average, or 2.0 ppmvd, 3 hr. rolling average CO: 6 ppmvd, 3 hr. rolling average VOC: 2 ppmvd, 1 hr. rolling average

For guidance purposes, the NO_x output basis from well controlled plant are as follows (Table 6):

Table 6
Expected Output from Well-controlled Plants

Plant Type	Emissions (lb NO_x/MWh)
Coal plant (w. SCR)	0.85.
Gas-fired boiler	0.15
Gas turbine (combined cycle)	0.05

Table 7 shows typical ranges of NO_x and other emissions based on data from three gas-fired power plants ranging from 500 to 678 MW in capacity.

Table 7
Typical Range of Emissions

Substance	Emission (tons/year)
NO_x	150 to 200
CO	480 to 630
VOC	20 to 200
PM_{10}	90 to 120
SO_x	10 to 40

The other subject for guidance concerned emission offset trading, under the umbrella of a system called RECLAIM. The plants operating below their permit levels can sell emissions credits to plants exceeding certain limits. ARB suggests that the value of these credits, which can be quite high (a range of $11,000 to $28,000 per ton was postulated), can drive technology development as plants strive for the very low emissions to generate saleable credits.

The review concluded with questions relevant to permitters, vendors and operators:

- How to decide when a single unit's very low emissions performance constitutes a basis for imposing that limit on others?
- How should offset credits be allocated to combined cycle units which displace process heat as well as electricity?

"Gas Turbine Environmental Control Issues"
(L. Angello, Clean Air Technologies)

As a point of departure for more specific discussions of technology options, Angello presented a summary of environmental control issues and a survey and comparative description of several low NO_x technologies for the purpose of identifying cost-effective control alternatives and providing perspectives on new technologies for planning purposes.

The key environmental management issues related to NO_x included:

- health effects
- ammonia discharges
- low level NO_x measurement
- the need for an independent review of alternative control technologies

The technologies discussed included:

- catalytic combustion
- surface stabilized combustion
- selective catalytic reduction
- SCONOx

A brief description of each technology was given (see App 3.4). All have demonstrated the ability to achieve very low (1 to 5 ppm) NO_x levels under test conditions and in some field applications.

Concerns that were highlighted included:

- For catalytic combustion:
  - a need to establish confidence in materials performance and durability
  - the degree of system complexity
  - performance at low turndown
  - technology application dependent on engine-specific design features
- For surface stabilized combustion:
  - a need for independent demonstrations on operating gas turbines (planned at 75 kW to 1 MW)
- For SCR:
  - mixed operating experience (performance shortfalls; premature catalyst replacement) on oil-fired combined cycle applications and high temperature simple cycle applications (OK for low temperature, gas-fired, combined cycle turbines)
- For SCONOx:
  - mechanical and control system complexity
  - materials life
  - confidence in scaled-up designs
  - need for independent demonstration to establish thermal performance and reliability over normal operating conditions—turndown, start-ups/shutdowns.

This presentation stimulated considerable discussion and debate particularly by vendor representatives. Some felt that many of these issues had been satisfactorily resolved by more recent experience as discussed in subsequent presentations. (See Solt and Davis in App 3.8 and 3.9).

The next five presentations addressed specific technologies: reciprocating internal combustion (IC) engines, gas turbines, surface stabilized combustion, catalytic combustion and SCONOx.

“Applications and Control of Combustion Systems: Reciprocating Internal Combustion Engines” (J. Burnette, Fairbanks Morse Engine Division)

Considerable progress has been made in NO_x reduction in reciprocating gas and dual-fuel (gas-diesel) engines using technology from the late 80’s and early 90’s through the adjustment of air/fuel ratios, injection timing retard and reduction of air manifold temperature. NO_x reductions of about 40% were achieved but at the expense of 15 to 30% reductions in thermal efficiency.

More recent low emission technologies including:

- lean burn combustion
- micro-pilot ignition (for dual-fuel engines) and
- selective catalytic reduction

have achieved substantial NO_x reduction and improved thermal efficiency. Spark ignition engines have brake thermal efficiency up to 40% at NO_x levels of 0.7 gm/bhp-hr (compared to conventional BACT of 32 to 38% efficiency and 2.5 gm/bhp-hr) with similar advances in dual-fuel engines (See Figures 1 and 3 in 3.5). SCR is used only in critical non-attainment areas.

A brief discussion was introduced on the merits of output standards (gm NO_x per bhp-hr) vs. concentration standards (ppm), which might appear to encourage “dilution as a solution.”

Environmental signatures of Mid-range Gas Turbine systems (L. Witherspoon, Solar Turbines, Inc.)

For commercial gas turbines in the 1 to 20 MW size range, NO_x emissions typical of equipment manufactured in the 1980’s ranged from 125 to 250 ppm (@ 15% O_2). Much progress was made with improved combustion design achieving 80 to 90% reduction in the early 90’s to the 25 ppm level. This was done while maintaining an engineering emphasis on reliability, availability, maintainability and durability (RAMD) and adding fuel flexibility with dual-fuel options.

Development efforts are underway to investigate technologies that may have the potential to reduce manufacturer warranties below the 25 ppm NO_x level for small gas turbines. At a minimum the technologies should allow for a more robust combustion system at the 25 ppm NO_x warranty level.

More recently, development work via the Advanced Turbine Systems (ATS) program, lower NO_x emissions are expected along with further improvements in efficiency that are 15% higher than 1991 turbines, lower life cycle costs resulting in 10% lower cost power and continued RAMD improvements. The advances, embodied commercially for the first time in the Mercury 50 (the basis for the ATS system) referred to in the Horgan paper (App 3.2) were achieved as part of the collaborative industry-DOE effort. Combustion modifications, including advanced hot wall liner technology, variable geometry fuel injection and others hold promise of reaching single digit levels, although at somewhat higher cost. Some ATS technologies will not be retrofitable to older units; such technology is considered next generation gas turbine technology.

For the existing fleet of gas turbines and those commercially available today, the use of SCR and SCONOx for post-combustion clean-up results in very high incremental cost of NO_x removal.

The cost of going from DLN levels of 25 ppm to the 2 to 3 ppm levels are estimated at $15,000 to $20,000 for SCR and around $25,000 for SCONOx for the additional tons of NO_x removed.

The requirement of post-combustion control is an operational and economical deterrent for most projects. In addition, if post-combustion clean-up will be required in any case to achieve the very lowest levels, the effect may be to discourage additional research to reduce the emissions through lower cost combustion modifications. The higher cost associated with the post-combustion technologies will prevent the introduction of new small gas turbine projects in California.

"Brief Overview of Alzeta Products and Technology"
(S. Smith, Alzeta Corporation)

This presentation reviewed Alzeta's business areas (50% VOC abatement; 25% high performance burners; and 25% advanced technology). Of primary interest in this context was Pyromat CSB used on commercial and industrial boilers and process heaters in sizes from 2 to 125 million BTU/hr. (corresponding to power generation plant input requirements for 200 kw to 12.5 MW plant size). NO_x emissions guarantees are < 9 ppm NO_x @ 3% O_2 (equivalent to ~3ppm at 15% O_2). Development work is underway on gas turbine combustors which have achieved < 2ppm @ 15% O_2 with testing underway or planned at both Allied Signal and Solar.

A brief description of the family of products called Effective Destruction of Gaseous Emissions (EDGE) was provided. (See App 3.7).

"The XONON Catalytic Combustion System"
(C. Solt, Catalytica Combustion Systems)

A brief review of the physics and chemistry of both conventional and catalytic combustion illustrated the principle by which low NO_x is achieved in Catalytica's XONON system. The remainder of the presentation focused on the development and demonstration status of the technology. Programs are underway with a number of major manufacturers including General Electric, Kawasaki, Pratt & Whitney Canada, Solar Turbines and Rolls Royce/Allison.

NO_x emissions in the 1 to 3 ppm range are consistently demonstrated in 8 MW burner cans (nominally 100 million Btu/hr). Issues of length of demonstration and number of starts raised in previous presentations were specifically addressed. Test lengths of hundreds to thousands of hours with hundreds of starts have been carried out. Tests were publicly scrutinized by the U. S. Environmental Protection Agency (EPA), ARB and CEC. In shakedown tests at Silicon Valley Power, the unit was connected to the grid and achieved full-time, unattended operation for over 300 hours with over 300 starts. Continuing RAMD tests since then had reached over 1700 cumulative hours, 25 starts and 94% uptime through August of this year and have since reached 3000 hours and 36 starts.

Commercial availability has been achieved for KHI's M1A-13A 1.5 MW unit with adaptation for other turbines underway with the manufacturers.

"SCONOx™ Catalytic Absorption Technology"
(R. Davis, Goal Line Environmental Technologies)

The family of technologies available from goalie Environmental Technologies for simultaneous NO_x, CO, and VOC control on turbines (gas or oil-fired, diesels, natural gas IC engines and direct-fired boilers was presented. Features of the technology include no ammonia, no by-product streams, and no aqueous solutions. A wider operating temperature range (300 to 700ºF) permits operation over more of the transient periods. The ability to provide full capability at 300º F reduces NO_x emissions during start up and shut down. SCONOx has been cited as the basis for Federal EPA LAER and South Coast Air Quality Management District (SCAQMD) BACT standards for gas turbine plants of 2 ppm (3-hour average) and 2.5 ppm (15-minute average) respectively. The Massachusetts Department of Environmental Protection has now established a 2 ppm and zero ammonia standard for gas turbine plants of 50 MW and smaller based on SCONOx performance.

Performance has been monitored at two operating systems; one, a 30 MW unit at a Federal Co-generation Plant in Vernon, California, the other, a 5 MW unit at the Genetics Institute near Boston, Massachusetts.

NO_x levels below 0.8 ppm are reported with CO below detectable limits and ~95% destruction of VOCs at 300°F. Commercial relationships have been established with ABB for gas-fired turbines (exclusive with ABB above 100 MW; non-exclusive from 10 to 100 MW). For distributed generation units of 10 MW and smaller, Goal Line will act directly.

In other applications, the new SCONOx-IB for industrial boilers will be able to limit NO_x emissions to 5 ppm or less with standard burners. SCONOx-ICN for lean burn natural gas internal combustion engines will be installed in February 2000 on three 2000 HP Waukesha engines at Texas Instruments. Cummins Engine is supporting development work on SCONOx for mobile diesel engines.

The incremental cost of achieving the very lowest levels of NO_x was discussed in other presentations. For example, Witherspoon (App 3.6) estimated the cost per ton of NO_x removal in going from 25 ppm to 2 ppm to be in the range of $20,000 per ton. In introductory remarks, Davis addressed reasons that one might choose a higher cost, low NO_x technology even if not specifically required to do so.

For example, the University of California at San Diego's (UCSD) 26 MW co-generation plant, while not originally subject to BACT, chose to go to 2.5 ppm for the purpose of staying below 50 tons/year. By so doing, they can qualify as a "minor source" and therefore not be required to obtain offset credits and will have room for future expansion. In the future, emission credits may be very expensive or even unavailable at any price. Tollstrup (App 3.3), for example, postulated a price range of $11,000 to $28,000 per ton of NO_x. UCSD's choice of SCONOx also enabled them to avoid use of ammonia on campus.

Pacific Gas & Electric (PG&E) Generation is permitting the 510 MW Otay Mesa merchant plant with SCONOx for similar reasons. PG&E Generation has now received permits for their La Paloma project in Kern County with SCONOx selected for one of the 250 MW units.

“Biomass Applications: Emissions and Controls”
(V. Tiangco, California Energy Commission)

The uncontrolled burning of biomass, as in open field burning, wildfire or solid waste burns in California was compared with biomass-fired power generation beginning with a summary of current emissions primarily of NO_x and PM_{10}. Existing technologies for controlled use of biomass emissions include the following:

- NO_x
  - staged combustion, flue gas recirculation, and fluidized bed combustion
  - selective non-catalytic reduction (thermal de-NO_x)
- Particulates
  - cyclones + baghouses for fluidized bed units or
  - cyclones + electrostatic precipitators with stoker units
- SO_2 (controlled as PM_{10} precursors)
  - dolomite injection

Based on data for emissions from a 22 MW California biomass pilot power plant reductions in emissions achievable with respect to open field burns of agricultural residues would be substantial as follows:

- NO_x: to 20 to 45%
- Particulates: 65 to 82%
- CO: 91 to 99%.

A technology development project supported by the CEC-PIER program with Environmental Engineering Research Corporation (EERC) on coupled combustion gasification technology seeks NO_x reductions of 60 to 90%. A summary of benefits of biomass combustion ranged from extending the life of solid waste landfills to improving forest health, reducing wildfire danger, and achieving zero net CO_2 emissions.

3
EMISSION MEASUREMENTS AND RELIABILITY

An assurance of the ability to measure unit emissions at very low levels anticipated in current and future licensing and enforcement actions is an essential element of both the technological, policy and regulatory approaches to air quality control.

Information was presented on a study conducted by the ASME Codes and Standards Gas Turbine Environmental and Fuels Subcommittee, B133-SC2) which addressed the question of whether emission measurements could be made at the 1 to 2 ppm level achievable by advanced control technologies. The study concluded that 4 of 5 measurement instruments reviewed were capable of accurate measurement of NOx in 1 to 5 ppm range" (chemiluminescence, Fourier Transform Infrared Spectroscopy (FTIR), Ultra Violet Dispersion Optical Adsorption Spectroscopy (UVDOAS), and Tunable Diode Laser (TDL).

However, the opinion of many workshop participants and the results of an EPRI/Continuous Emission Monitor (CEM) Working Group survey suggested that measurements could not yet be made reliably and reproducibly on operating equipment with field-capable instruments to sufficient accuracy and precision to be suitable for compliance measurements. It was generally concluded that additional information was needed on:

- The capability of calibrating instruments for NO_2
- The lack of available span gas for protocol mandated calibration procedures
- The representativeness of samples
- The wide variations reported by participants in an EPRI/CEM working group

Suggestions for additional work were:

- The development of instruments that could go to monitoring levels below 1 ppm
- A determination of how low advanced monitoring techniques might go with further improvement and development
- The continuation and completion of the current American Society of Mechanical Engineers (ASME) studies through Phase 2 (CO, NH_3 and VOC measurement practices and capabilities) and Phase 3 (preparation of American National Standards Institute (ANSI) measurement standards)

Participants called for the development of a CEM Technical Assessment Guide (modeled on the EPRI Technology Assessment Guide for alternative generating technologies) and for a national effort to develop common, reliable protocols, preference methods, and CEM techniques.

Presentations from Emissions Measurements and Reliability Session

In his opening remarks, Chuck Dene, EPRI, who chaired this session, posed three questions:

1. Can we measure emissions at the low levels to which we wish to control them?

2. Can we do it on a continuous basis, 24 hours a day, seven days a week, as opposed to a one-time acceptance test?
3. Are our quality, control testing and auditing procedures adequate and, if not, how might they be made so?

There were three presentations:

1. A review of current measurement practice and capability by a Codes and Standards Committee of the ASME.
2. A review of the problems associated with compliance measurements at operating plants.
3. A discussion of the view from the SCAQMD on the validity and reliability of measurement capabilities relative to the monitoring and enforcement job required.

“NO_x Below 5 ppm from Gas Turbines: A Review of Current Measurement Practice”
(J. Vaught, Vaught Engineering Inc.)

The ASME Codes and Standards Subcommittee on Gas Turbines and Fuels (B133-SC2) is carrying out a Low Concentration Measurement Program in the following three phases to assess measurement capability for gas turbine emissions.

Phase 1: NO_x measurement practices and capabilities
Phase 2: CO, NH_3 and VOC measurement practices and capabilities
Phase 3: Preparation of ANSI measurement standards

This presentation focused on Phase 1 and reviewed the results of tests conducted at ten gas turbine plants where NO_x was being controlled. These plants covered a generating range of 23 to 1044 MW. Combustion controls on two plants consisted of dry low NO_x, and water or steam injection on eight plants. Post-combustion controls consisted of SCR at nine plants and SCONOx at one.

The detection principles of five instruments tested consisted of chemiluminescence, electrochemistry, FTIR, UVDOAS, and infrared absorption with TDL.

Getting the measurements to represent actual emissions is subject to the following considerations:

- NO/NO_x ratio is both variable with load and important to measurement accuracy. For example, electrochemiluminescence detects only NO, while NO_2 and other nitrogen compounds [including a fraction of NH_3] are catalytically transformed to NO in a converter preceding the detector with a conversion efficiency dependent on the gas stream being sampled. In current practice, the conversion efficiency is not routinely calibrated.
- Obtaining a representative sample, especially in short stacks, is very problematic because of concentration gradients.
- To ensure compliance with a regulated level of 2 ppm NO_x at an uncertainty in the measurement of +/- 1.5 ppm, the control system would have to be designed for an emission limit of 0.5 ppm.

Plots of measurement variation can be seen in Figures 10 and 11 in App 3.11. The conclusion presented (See Fig. C in App 3.11) is that four of the five instrument types (excluding the electrochemical method) would be capable of measuring accurately in the 1 to 5 ppm range if great care were taken.

"Low Level NO_x Measurements and Other Compliance Issues on Gas Turbine Combined Cycle Units"
(R. McRanie, RMB Consulting & Research, Inc.)

The presentation by R. McRanie focused on the problem of making credible measurements on operating plants for the purpose of demonstrating regulatory compliance. The primary point was that doing so is very hard. The following six issues were addressed:

1. Protocol requirements for span gas
2. Precision of reference measurement
3. Reliability of CEM
4. Effect of NH_3
5. Permitting and enforcement issues
6. User and agency education

EPA's measurement protocol (Part 75) requires that the "majority of the measurements" be at levels which exceed 20% of the span gas concentration. Therefore, to read in the 2 ppm range, a 3 to 10 ppm span gas is required. Accurate span gas in this range is expensive and hard to obtain. Additional protocol requirements, including 0.5% daily zero and span calibration drift specifications, are very difficult to meet.

The accuracy specified in the protocol is given as +/- 0.02 $lbNO_x/10^6$ Btu corresponding to +/- 5.5 ppm @ 15% O_2 which is clearly unacceptable for measurements at 2 to 3 ppm.

Selective catalytic reduction (SCR) units inject ammonia as the reactant to remove NO_x. Excess ammonia is required to drive the reaction to the desired low NO_x levels. This can lead to problems depending on the sampling and monitoring methods used. For in-stack measurements, the instruments will likely measure ammonia as NO leading to an erroneously high NO_x reading. For extractive sampling followed by lab analysis most samplers will remove the NH_3 and much of the NO in the condenser where the water vapor is removed. In this case, NO_x levels can be held to low levels with very high rates of ammonia injection and the discharge of unreacted ammonia (known as "ammonia slip") will escape detection.

Figures 12 and 16 in McRanie's presentation (App 3.12) are from an EPRI Low Level NO_x Survey of five plants, each of which used SCR in combination with DLN or steam or water injection for NOx control and full concentration extractive sampling for monitoring. The data, which show a rigid cap at the permit level with occasional, quickly corrected excursions are consistent with this interpretation.

NO_x emission exceedances during cold start were discussed at some length and deemed unavoidable. Allowable stress levels on plant components limit the rate at which the system can be brought up to operating temperatures. Therefore, the system must necessarily run for some period of time at temperatures below the level at which lean burn conditions can be established and at which SCR operation can be started. During that period, emissions will inevitably exceed steady state permit levels (See again Figures 12 and 16, App 3.12). These operating requirements must be accounted for in permits to avoid violations and to eliminate a basis for future EPA "credible evidence" enforcement actions.

"Comments on Emissions Measurement Accuracy"
(John Higuchi, South Coast Air Quality Management District)

John Higuchi from the SCAQMD gave a brief, unscheduled presentation. No presentation materials were used or made available for inclusion in this report. He addressed three questions:

1. How well can we measure NO_x and NH_3?

He believes that relative accuracy of +/-20% (1 ppm for a 5 ppm cutoff) is achievable with sufficient care and supervision. For ammonia measurement they currently use wet chemistry methods. Relative Accuracy Test Audits (RATA) are performed every six months. Units with SCR are operating below 5 ppm NH_3 slip even though they are not limited that low by permit. (This is inferred from a lack of complaints.)

2. What needs to happen now?

Protocols are required for continuous emission measurements and for how to deal with varying NO/NO_x ratios in plant emissions. The development of reference methods should take priority since they are the methods by which CEM's are graded.

3. How low can we go?

Ambient measurements can be made to the "parts per billion" level. To achieve comparable levels with in- stack measurements we need to deal with the stack environment (matrix effects from other species), better zero and span gases, and the direct measurement of NO_2 combined with a separate instrument for NO.

4
ENVIRONMENTAL LIFE CYCLE IMPLICATION

The discussion in the prior two sessions focussed exclusively on air emissions from single units. It is recognized, however, that there are larger systemic implications of environmental effects of power generation. Flue gas clean-up technologies can in some instances lead to aqueous discharges or solid waste disposal problems. The fabrication and operation of alternative technologies may have different and important environmental consequences. The location and dispersion of the emissions from on-site distributed generators may be more important than the quantities. An integrated evaluation over the expected life of the unit is essential for making informed choices.

The methodology of life cycle assessment is a useful tool for conducting systematic evaluations. Agreed-upon rules of analysis have been developed by international standards organizations including Society of Environmental Toxicology and Chemistry (SETAC) and International Organization for Standardization (ISO). Example analyses of energy production options were displayed including a comparison of biomass and coal fueled power generation.

Information needed to apply the method includes:

- Boundaries of the system to be studied
- Functions of the system
- Allocation procedures
- Types of impact and methodology of impact assessment
- Data and data quality requirements and
- Assumptions and limitations

Three important advances which would improve the capability of this method to deal with the trade-offs between energy and environment are:

- An expanded ability to treat global climate issues that goes beyond the mere accounting of CO_2 emissions and addresses environmental impacts of warming trends
- The integration of economic considerations into the assessment of environmental technologies
- The life cycle design (as opposed to assessment) whereby the methodology would include optimization routines which identified design concepts or modifications for minimizing integrated, life-long impacts (rather than simply computing the impact for a given system)

Presentations from the Life Cycle Assessment Session

It has long been recognized that the true environmental effects of any activity can go well beyond the point and time of the discharge of the single pollutant in question. Consideration must be given to the upstream (extraction, production, transportation, and other activities involved in the creation of the products or processes being controlled) and downstream (use and disposal of the product) as well as secondary or cross-media effects (does air pollution result in water or land impacts). This question was addressed in two presentations; one, a discussion of the implications of this more integrated and comprehensive analysis for the consideration of air pollution control in power generation; the other, a review of analytical approaches and guidance for conducting such life cycle analyses for power generation.

"Life Cycle Implications of Power Generation Technologies"
(B. Vigon, Battelle)

The discussion began with a definition of a life cycle analysis as one that evaluates the consequences of a product, process, or activity at a systems level and in a comprehensive manner throughout its life cycle. In the context of this meeting, the effect was to broaden the discussion beyond air, to move from emissions to impact (with "impact" defined as "an effect on something of consequence") and to consider multi-dimensional environmental issues such as global climate, acid rain, toxics, and the like.

The benefits of such analysis are to point up the interconnectedness of the energy, environment, and economic aspects which the generation technologies operate in. Such analysis also provides a basis for comparing alternate technologies on an equivalent performance platform or equivalent functional basis. Overall, this type of analysis highlights the additional information needed to conduct a comprehensive comparison of options.

Sample flowcharts and preliminary analyses were provided for several generic technologies including fuel cells and photovoltaic arrays. A specific worked example demonstrated the difference in environmental consequences between the use of biomass or coal to fuel an electric power plant. All of the important ancillary inputs and processes were considered, such as:

- For the biomass fueled plant
  - soil productivity
  - fertilizer production and use
  - pesticide production and use
  - irrigation
  - fuel transportation
  - cultivation energy
  - recycle of ash
  - construction of plant and fabrication of equipment
- For the coal fueled plant
  - mining
  - transportation of fuel
  - ash and sludge disposal or reuse
  - plant construction and equipment fabrication

The result illustrated for the same case that was used in the Tiangco presentation, showed a 50-fold increase in net electricity produced per unit of fossil fuel used and a 20-fold reduction in CO_2 emissions per unit of electricity produced (46 g/kwh vs. 1,022 g/kwh).

Life cycle analysis was offered as a method for understanding the far-reaching implications of the introduction of distributed generation in significant amounts. Specifically, the expanded use of distributed, small-scale generation units would bring with it a host of communications and data exchange requirements which would also have impacts to be accounted for.

"Life Cycle Analysis for Assessing New Generation Technologies"
(J. Fava, Five Winds International)

This material was based in large part on the work completed by SETAC and ISO over the last ten years. Decision rules by which life cycle analyses should be carried out have been agreed to. One of the primary issues is how to draw the boundaries of the system under consideration; how to move from the usual "gate-to-gate" analysis of a single plant to a "cradle-to-grave" (or, more appropriately, "cradle-to-cradle" to account for recycling). Items to be considered include the following:

- Boundaries of the system to be studied
- Functions of the system
- Allocation procedures
- Types of impact and methodology of impact assessment
- Data and data quality requirements
- Assumptions and limitations

An example was given of the analysis conducted by the Coca-Cola Company in a comparison of the life-cycle effects of alternative beverage containers, i.e., glass, plastic, or aluminum. With a clear picture in hand of the relative environmental and economic implications of the three choices, they approached the glass, petrochemical, and aluminum industries (for whom Coke containers represented a considerable market) and urged them to minimize the impacts while maintaining the price and quality of the containers.

The application of this methodology to the power generation industry was illustrated with a set of alternative questions including:

- What is the best technology to reduce SO_2 and NO_x at a site?
- What is the best technology to reduce the overall regulated impact over the life cycle?
- What is the best technology to alleviate current and future environmental concerns for the State of California?

Who is responsible and accountable to act on the answer?

5
GAPS AND ANALYSIS

In this final session the participants, led by Scott Samuelsen and Ellen Petrill, re-capped the highlights of the day's presentations and discussions, identified gaps in the coverage of the topics and recommended a set of next steps to be taken as follow-on to the workshop.

Specific items from this discussion were tabulated on flip-charts generated during the session and reproduced here as Appendices A.3.15, "Gaps and Analysis Summary" and A.3.16, "Items from Wrap-up Discussion." The important points have been woven into the summaries of the individual sessions and into the Conclusions and Recommendations for Next Steps sections which follow. Salient points in the two Appendices are summarized here.

"Gaps and Analysis Summary"
(S. Samuelsen, University of California, Irvine)

In addition to the specific technical items covered elsewhere, the summary redirects our attention to some important precepts of the workshop.

- These discussions are only the start of what should be a continuing effort.
- A California perspective should be maintained in shaping the follow-on steps.
- Issues of particular relevance to distributed generation should be given priority.

"Items from Wrap-up Discussion"
(S. Samuelsen, UC, Irvine and E. Petrill, EPRI)

Most of the recommendations for further discussion and research and for follow-on activities for gathering, codifying and disseminating information are covered under specific topic headings in these notes. In addition, a number of comments were relevant to the formulation of policy and the setting and enforcement of rules. General consensus seemed to have been reached on several points.

- Standards designed to protect the environment should be thoroughly science-based.
- Output-based standards (emissions per unit of electricity produced) are preferable to concentration-based standards (ppm's).
- Regulations should encourage, rather than discourage, the development of new, cost-effective approaches to emission control.
- Lack of consistency of approach (referred to as "disconnects") among the several Federal and State agencies should be addressed.
- Sampling and measurement methods have to be improved to enable credible regulation.
- The value of "wringing out the last few ppm's" should be carefully evaluated.

6
CONCLUSIONS

The central issue for discussion at this Workshop was how to provide an adequate supply of electric power to the citizens of California at a cost low enough to encourage economic growth and protect human welfare in a way that enhances the quality of the environment. Regulatory policy and licensing requirements must further these objectives in a balanced way.

In the drive for excellence in environmental protection, regulatory philosophy at both the Federal and State level has been to require applicants and operators to control emissions to as low a level as can be reached. Criteria such as "best available" (BACT) and "lowest achievable" (LAER) have been imposed based on the concept: if it can be done, it must be done.

While current information and understanding was presented at the workshop, the following questions and conflicts were also addressed in the presentations and open discussion leading to the conclusions that follow.

What levels of emission reduction can be achieved with existing technology? Are the technologies with lowest emission levels capable of operating reliably as part of the power generation infrastructure?

Although the current power generation infrastructure now in place in California is a relatively low emission mix, technologies exist, and are commercially available that achieve significant reductions of emissions in comparison to those options available and installed as recently as ten years ago. The workshop presentations focused primarily on NO_x but similar improvements were referred to for other emissions (CO, VOC's, HAP's) as well. Overall, NO_x emissions have gone from 200 to 400 in the late 80's and early 90's to low single-digit levels for the full application of post-combustion clean-up. Specific performance levels are displayed in Table 4.

In addition to performance, issues, questions and issues of reliability, availability, maintainability and durability (the so-called RAMD issues) are being addressed in several demonstrations and extended operating periods (1000's of hours), with numerous (100's) starts and shut downs being recorded. Developers and vendors of the more advanced technologies are entering into commercial partnerships with established traditional vendors, thus creating increased confidence in the availability and operability of the systems.

What technological advances toward further reductions in emission levels are reasonable to expect and by when?

There was little in-depth discussion of expected future advances in technological options. Those alluded to as likely included:

- Continuing development of applications of the innovative burner technologies, such as surface combustion and catalytic combustors
- System development on additional applications of the post-combustion technologies, such as SCR and SCONOx

- R&D on advanced turbines and reciprocating engines underway under DOE and industry sponsorship

Nothing was presented on advanced distributed generation technologies (microturbines or fuel cells) or on renewables. A discussion of biomass was treated as available technology with no imminent performance improvements sought or expected.

The open issues for future attention and discussion are:

- Possible cost reductions for the currently favored advanced approaches, particularly the post-combustion technologies
- The emission characteristics of the next generation distributed generation options when they become economically viable for significant market penetration

How might a shift in the generation mix toward distributed, on-site generation and away from central, grid-connected power plants affect the environmental impact of power generation?

This question was addressed directly by a presentation on the potential effect of distributed generation of the California environment prepared for the ARB. The study reached two main conclusions: 1) in an era of deregulation, the market potential for distributed generation was significant, and 2) the introduction of distributed generation in the amounts deemed likely by the market penetration analysis would result in substantial increases of emissions into the air.

This information was supplemented in the technology presentations by repeated reference to the following points:

- The difficulty of applying combustion modification improvements (such as DLN) to units of the smaller size appropriate for distributed generation
- The relative (per kwh) cost of applying post-combustion NO_x control to small units

This was left as an important open issue with the recommendation that the life cycle assessment methodology might provide an illuminating way to determine what an appropriate regulatory posture might be toward an influx of distributed generation to the California market.

What do the very low emission technologies cost? Specifically, might the cost of required technologies discourage the introduction of environmentally preferred power projects into California and, as a consequence, impede, rather than encourage, environmental improvement?

The widely held view among Workshop participants was that the cost of NO_x reduction to low single-digit levels was very high. There was relatively little quantitative information presented on the costs of the individual technologies, however, in either the presentations or the discussions.

An estimate of the annual nationwide aggregated costs for air pollution control from stationary sources is approximately $13 billion (or 0.2% of the nation's Gross Domestic Product (GDP) for capital equipment and $1.3 billion for measurement, monitoring, and modeling activities.

The results of one analysis were directed at determining the costs of post-combustion clean-up to remove the last few tons of NO_x. The comparison was between the cost of achieving 25 ppm from a gas turbine using dry low NO_x techniques and achieving 3 ppm with SCR or 3 ppm with

SCONOx. The additional removal was achieved but at a cost of over $19,000/ton NO_x for SCR and over $25,000/ton NO_x for SCONOx.

This raised the issue not only of questionable cost-benefit ratios but the larger issue of whether the requirement and use of technologies at these costs might impede rather than encourage environmental improvement in California. If post-combustion clean-up is unavoidable to achieve such low levels, there remains no incentive to continue the improvement of combustion systems which might achieve improved (say in the range of 10 ppm) but still less than achievable with post-combustion technology but at far less cost. Such technologies, if available, might be used in the voluntary retrofit of existing, exempt units to the net benefit of California environment. This was perhaps the most important issue brought forward by the workshop for further consideration by the CEC and other agencies.

Can the emissions performance of these technologies be measured with sufficient accuracy and precision at these very low levels to ensure that the electricity consumers of California are really getting the environmental protection that they are paying for and that compliance with laws and permits is assured?

Emission control technologies exist and are being required that can reduce NOx emissions to the 1 to 2 ppm range. Operational control, monitoring and compliance assurance, therefore require the ability to measure accurately at this level. Can it be done? Nominally, the answer provided at the Workshop was "Yes."

However, the workshop discussions went beyond the simple issue of "can it be measured" to the more complete question of can it be measured reliably and reproducibly on operating equipment with field-capable instruments to sufficient accuracy and precision to be suitable for compliance measurements (where substantial fines or even jail terms may ride on the answer). Here the conclusions were less clear and in some dispute ranging from the belief that "reliable measurement at 1 ppm NO_x is achievable with careful work and appropriate oversight" to a host of reservations regarding the following:

- Capability of calibrating instruments for NO_2
- Lack of available span gas for protocol mandated calibration procedures
- Representativeness of samples
- Wide variations reported by participants in an EPRI/CEM Working Group

Many articulated requests for additional work ranging from research to developing instruments that could go to levels below 1 ppm and to determining the lowest quantifiable limits achievable with further improvement and development. The continuation and completion of the current ASME studies through Phase 2 (CO, NH_3 and VOC measurement practices and capabilities) and Phase 3 (Preparation of ANSI measurement standards) was encouraged. The value of a CEM Technical Assessment Guide (modeled on the EPRI Technology Assessment Guide for alternative generating technologies) was asserted, and a national effort to develop common, reliable protocols, preference methods and CEM techniques was called for.

Are regulations and permit requirements realistic in their treatment of operating realities of technological systems, such as, for example, achievable control during transients? Or might *well-intentioned operators be inadvertently placed at risk of enforcement action for excursions that they have no way to avoid?*

This question was raised in the context of the use of "credible evidence" by the EPA. It refers to EPA's ability to make use of data, such as CEM records or other information which is not a result of formal, licensed compliance monitoring, to levy fines and sanctions on the basis of "credible evidence of permit violations".

The issue was discussed specifically in regard to start-up transients where the generation plant and associated emission control equipment must necessarily operate for certain lengths of time at temperatures that are below those required for pollutant capture or destruction. These conditions lead inevitably to excursions of emission levels beyond the permitted limits. CEM records showing such excursions may be considered "credible evidence" for enforcement purposes.

It was emphasized that no technological means exist to eliminate such excursions, and therefore, they should be accounted for in the permit language. Whether language on this topic would bring state-level permits into conflict with Federal requirements remains to be resolved. The transient operating conditions issues, was cited in support of the workshop's consensus plea to address what were referred to as "disconnects," such as:

- Differences between State and Federal requirements
- Lack of coordination within California among CEC, ARB, AQM Districts, EPRI and all other cognizant organizations
- Control objectives inconsistent with practical realities of limitations in measurement capabilities or equipment performance

Might the quest for ever-lower levels of air pollutant emissions inadvertently create other problems in other media or locations and at other times?

While no direct response to this question was provided, a method to address it was presented and discussed. Life cycle assessment is a process of evaluating the consequences of a product, process, or activity at a systems level and in a comprehensive manner throughout its life cycle. The methodology has been used for a long time to support integrated impact analyses of proposed activities or alternative technologies. Applications have been often directed to the manufacturing and process industries to ensure that all the impacts of materials extraction, conversion, production, product use, and eventual product disposal or recycling were adequately accounted for.

The treatment of life cycle assessment at this Workshop spoke specifically to its application to the assessment of alternative power production/environmental control options. However, much remains to be done to develop this method to cover the range of questions important to energy/environment balance. Some specific advances, requiring research and development effort to obtain, were identified. Three of the most important topics include:

- An expanded ability to treat global climate issues that goes beyond the mere accounting of CO_2 emissions and addresses environmental impacts of warming trends
- The integration of economic considerations into the assessment of environmental technologies

- Life cycle design (as opposed to assessment) whereby the methodology would include optimization routines which identify design concepts or modifications for minimizing integrated, life-long impacts (rather than simply computing the impact for a given system)

7
RECOMMENDATIONS FOR NEXT STEPS

The Workshop discussions provided useful guidance for the next steps in developing the needed information for environmental management of power generation in California.

Technology Assessment Guide

A useful guide for power generation and environmental control technologies should include sections on currently available technologies, emerging technological advances in traditional technologies, potential adaptations of traditional technologies to distributed generation applications, next generation technologies for both central and distributed plant, and renewable options at both the component and system level.

In addition, the concept of "Technology Assessment Guide" should be broadened beyond technologies to include:

- Techniques for reliable measurement capability including instruments, calibration and operating procedures for all categories of measurement such as research, reference methods, compliance measurements, Relative Accuracy Test Audit (RATA) and CEM's
- Methodologies for evaluation of alternative technologies, not only at the individual component or plant level but in the more global context of assessing the effect of major shifts in state-wide generation from a central, grid-connected paradigm to an on-site, distributed one

A Steering Committee with representatives from the research, industrial, generation and regulatory communities should be convened and provided with staff assistance to develop the Table of contents for this expanded, three-part Guide, to generate preliminary annotated outlines for each section, and begin the search for world-class individuals and organizations to assemble the material.

Syllabus

An up-to-date comprehensive compilation of reliable sources of the most current information would be an invaluable contribution. It should include active participants (individuals and organizations), their current activities, data compilations, papers, presentations, conferences and symposia, commercial activities and offerings, regulatory updates, licensing activities and status, new project starts and other relevant information.

Much of the information would be identified and collected as part of the task of developing the contents outline for the assessment guides. The syllabus should be kept current and available on the Information Exchange Website (see next section). Information gathered in the interactive use of the Website should be regularly incorporated. A group should be charged with the responsibility for developing a structure for organizing the syllabus and initially populating the data base with information currently in-hand and available from this Workshop's participants.

Information Exchange Forum

Two approaches were encouraged.

1. Internet-based: An authoritative Website should be designed and launched where active workers on this issue could interact. It would provide a central point for gathering information and testing the quality of the contents outlines for the Technology Assessment Guide and the Syllabus. It would also serve the usual functions of quick response Q&A on fast-breaking issues; keeping track of latest developments prior to the usual presentation/publication cycle and easy access to expert opinion on specialized questions.
2. Annual Workshops: Workshops should be regularly convened to review progress and new developments in the area. To the extent that the Website becomes widely used, the issues, participant lists and presentation topics will emerge to create the best agenda for each Workshop.

Research Plan

Needs were identified in several categories requiring research. Some candidates are the following actions:

- Reduce costs of, or develop lower cost alternatives to, the emerging very low NO_x emission technologies
- Improve efficiency, lower cost, and lower emissions for next-generation distributed technologies
- Articulate measurement protocols, instruments and methods capable of reliable, reproducible measurements in the field on typical flue gas streams
- Include modeling techniques, design of methods, technology comparisons, and economic criteria in extensions of life cycle assessment
- Examine the evolution of alternate regulatory policies under open competition as well as the impact on California's environment, as Statewide models and analyses of how the emergence of alternative advanced technologies might shift in the generation mix

Many elements of these broad areas are currently the subject of research efforts at the DOE, EPA, the National Laboratories, EPRI, numerous commercial organizations and the CEC. Steering groups could identify those topics where critical gaps exist of particular benefits to California, and to direct and coordinate future focused research.

8
REFERENCES

1. California Air Resources Board. 1996. Emissions by Category, 1996 Estimated Annual Average Emissions Statewide. http://www.arb.ca.gov
2. California Energy Commission. 1995. http://www.energy.ca.gov/electricity/electricitygen.html
3. U.S. Department of Energy's Energy Information Agency (EIA). 1997. http://www.eia.doe.gov/emeu/sep/ca/summary.html

Appendix 1: Workshop Agenda

CEC-EPRI Workshop on

Environmental Impacts of New Generation in California
Thursday, October 28, 1999
Hyatt Islandia, San Diego, CA
Provisional Agenda V8.2

8:00 AM **Continental breakfast, registration**

8:30 **Keynote – David Rohy, CEC**

A number of commercial and industrial developers, California air quality districts, Federal agencies, and the public have posed questions regarding the management of emissions from existing and new power generating options for California. Many are manifestations of siting cases that come before the CEC. The objective of CEC on environmental impacts of new generation in California is to provide the market place and regulators with a sound basis for implementing the most environmentally and economically desirable generation mix that meets the electricity needs for the citizens of California. To this end, this Workshop will take steps in creating the tools necessary to identify the emissions of technologies and the options for effectively managing them. Specifically, the workshop will focus on air emissions, the ability to measure them accurately, and the potential integration of all environmental impacts via life-cycle considerations in technology review and selection criteria. The outcomes of this workshop are expected to stimulate the undertaking of several follow-on steps, possibly including:

1. A contents outline for a technology assessment guide
2. A syllabus of the best available information on candidate technologies, their environmental characteristics and their place in the electricity supply spectrum
3. A technical and scientific exchange forum for continual discussions of environmental impacts from a variety of generating technologies, emission measurement technologies, pollutant mitigation technologies, and emerging research findings
4. A plan for public research and development to create products that will enhance practices whereby environmental protection and innovations in generation technology are consistent

8:45 **Generation: emissions and control, Chair: Steve Gehl, EPRI**

What emissions can be expected from either existing or new generating alternatives?

Environmental challenges for new generation, E. J. Honton, Resource Dynamics.
Emissions from distributed generation technologies in 2002 & 2010, Susan Horgan, Distributed Utility Associates
Guidance for power plant siting, Mike Tollstrup, CARB
Environmental control issues, Leonard Angello, Clean Air Technologies
Applications and control of combustion systems, Eric Wong, Caterpillar
Environmental signatures of combustion systems, Leslie Witherspoon, Solar Turbines

10:30 Break

10:45 Very low NO_x combustion technology, Bob Kendall, Alzeta
Catalytic reduction of emissions, Chuck Solt, Catalytica
Catalytic reduction of emissions, Richard Davis, Goal Line
Biomass applications, Val Tiangco, CEC
Non-combustion 5 kw-5 mw applications & waste products, Steve Gehl, EPRI

12:00 Lunch break

1:00 PM **Emission measurement & reliability, Chair: Chuck Dene, EPRI**

How can emissions be measured or supplied to ensure environmental permit compliance and to validate performance requirements? With what certainty can <5 ppm NO_x emissions be measured and quantified with respect to calibration methods, reference methods, etc.? What are the long-term reliability and drift problems for continuous emissions measurements? Questions on regulatory review of low NO_x emissions data and certification will be addressed.

Current measurement practice for NO_x below 5 ppm, John Vaught, ASME.
Recent low NO_x measurement experience, reference methods and certification Issues. Richard McRanie, RMB Consulting & Research.

2:30 Break

2:45 ***Environmental Life Cycle Implications – Bruce Vigon, Battelle***

What are the environmental life-cycle implications of new technologies? This session is to address the spatial and temporal parameters available for comparing life-cycle assessments of technologies ranging from large generating stations to fuel cells.

Life cycle characteristics of different technologies, Bruce Vigon, Battelle.
Life cycle planning and assessment, James Fava, 5 Winds.

3:45 **Gaps and Analysis – Scott Samuelsen, UC Irvine**

This session is intended for the session chairs and others to review the objectives for the workshop and to suggest the next steps in research, development, regulation and permitting on the basis of current knowledge and points made during the workshop.

4:30 **Adjourn**

Appendix 2

CEC-EPRI WORKSHOP ATTENDEES, October 28, 1999

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Appendix 3

Presentation Visuals

3.1 E. J. Honton, Resource Dynamics Corporation
"Environmental Challenges for New Generation"
3.2 S. Horgan, Distributed Utility Associates
"The Potential Impacts of Distributed Generation of California Emissions"
3.3 M. Tollstrup, California Environmental Protection Agency
"Guidance on Power Plant Permitting and BACT"
3.4 L. Angello, Clean Air Technologies
"Gas Turbine Environmental Control Issues"
3.5 J. Burnette, Fairbanks Morse Engine Division
"Applications and Control of Combustion Systems: Reciprocating Internal Combustion Engines"
3.6 L. Witherspoon, Solar Turbines, Inc.
"Environmental Signatures of Mid-range Gas Turbine Systems"
3.7 S. Smith, Alzeta Corporation
"A Brief Overview of Alzeta Products and Technology"
3.8 C. Solt, Catalytica Combustion Systems
"The XONON Catalytic Combustion System"
3.9 R. Davis, Goal Line Environmental Technologies
"SCONOx TM TM Catalytic Absorption Technology"
3.10 V. Tiangco, California Energy Commission
"Biomass Applications: Emissions and Controls"
3.11 J. Vaught, Vaught Engineering Inc.
"NOx Below 5 ppm from Gas Turbines: A Review of Current Measurement Practice"
3.12 R. McRanie, RMB Consulting & Research, Inc.
"Low Level NOx Measurements and Other Compliance Issues on Gas Turbine Combined Cycle Units"
3.13 B. Vigon, Battelle
"Life Cycle Implications of Power Generation Technologies"
3.14 J. Fava, Five Winds International
"LCA for Assessing New Generation Technologies"
3.15 S. Samuelsen, University of California, Irvine
"Gaps and Analysis Summary"
3.16 S. Samuelsen, University of California, Irvine/
"Items from Wrap-up Discussion"
E. Petrill, EPRI

Environmental Challenges for New Generation

CEC-EPRI Workshop
October 28, 1999

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RESOURCE DYNAMICS CORPORATION
...business solutions for energy markets

Overview

1. California is part of an evolving nationwide effort
2. California environmental power generation issues
3. Environmental challenges to consider

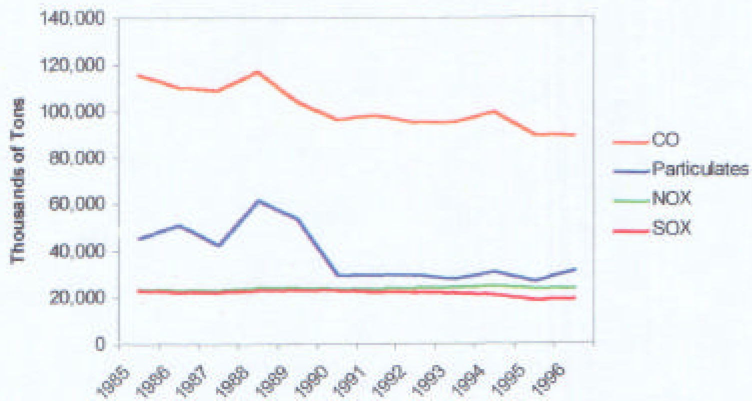
1. California is Part of an Evolving Nationwide Effort

- Clean Air Act standards cover many criteria pollutants
- $13 billion annually for stationary source air abatement (0.2% GDP)
- SIP Call power plant retrofits may cost $2 billion annually
- $1.3 billion annually for air emissions monitoring, measuring, modeling

Emissions Data Widely Collected

- EPA collects data on 6 criteria pollutants and CA collects data on 9 criteria pollutants
- Four major criteria pollutants impact power generation: CO, PM, NO_X, SO_X

U.S. Air Emissions



Source: U.S. EPA, National Acid Precipitation Assessment Program

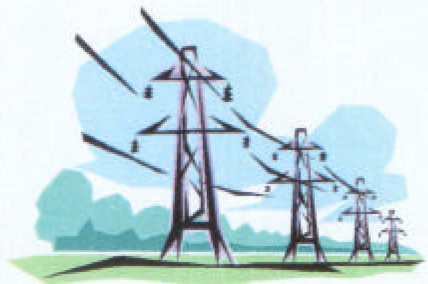
Percent of Emissions Generated by U.S. Electric Industry

Pollutant	1994	1995	1996
CO	0.3	0.4	0.4
Particulates	0.6	1.0	0.9
NO_X	33.0	26.7	25.8
SO_X	70.4	65.1	65.9

Source: U.S. EPA, National Acid Precipitation Assessment Program

2. CA Environmental Power Generation Issues

- Environmental laws affecting power generation
- Emission controls on existing generation
- Future generation
  - Central station
  - DR
  - Renewables



CA Environmental Laws

- Regulations vary across 35 regional/ county air districts and 14 air basins
- From add-on control technologies toward market-based measures
  - RECLAIM trading credits if > 4 tons SO_X or NO_X emitted annually. Fixed but decreasing pool size, cover one year, AQDs run system.
  - If not RECLAIM: Emission reduction credits, privately owned, indefinite life, publicly traded
- Moving emission limit targets

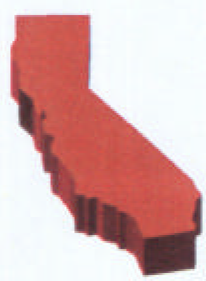
Ambient Air Quality Standards

Pollutant	Averaging Time	Federal Standard	California Standard
CO	8 hour	9 ppm	9 ppm
	1 hour	35 ppm	20 ppm
PM_{10}	Annual geometric mean	-	30 $\mu g/m^3$
	24 hour	150 $\mu g/m^3$	50 $\mu g/m^3$
	Annual arithmetic mean	50 $\mu g/m^3$	-
NO_2	Annual arithmetic mean	0.053 ppm	-
	1 hour	-	0.25 ppm
SO_2	Annual arithmetic mean	0.030 ppm	-
	24 hour	0.14 ppm	0.04 ppm
	1 hour	-	0.25 ppm

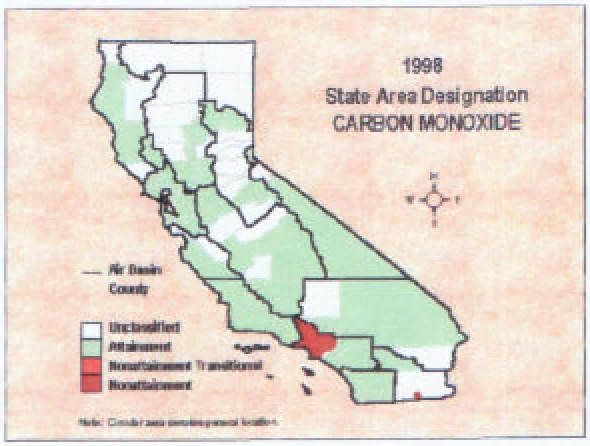
Source: California Air Resources Board

State Implementation Plan

- CA has attained all areas for NO_X and SO_X
- California must bring CO and PM_{10} non-attainment areas into compliance
- Ozone is largely non-attained
- NO_X and VOCs are ozone precursors
- NO_X is carefully controlled, and will affect power generation permits



CO Non-Attainment

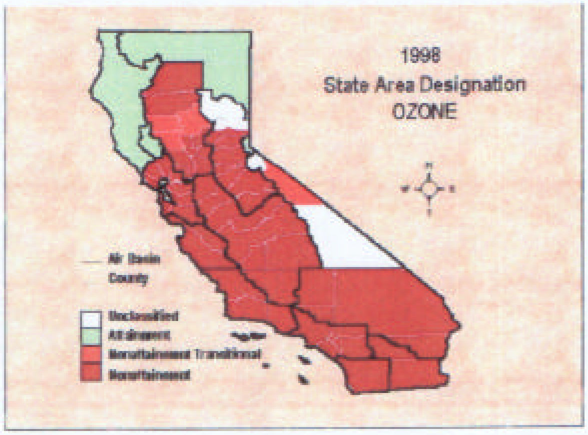


Source: California Air Resources Board

Particulates Non-Attainment

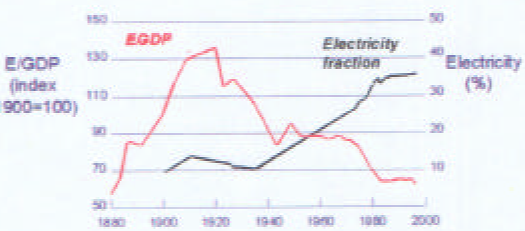
Source: California Air Resources Board

Ozone Non-Attainment



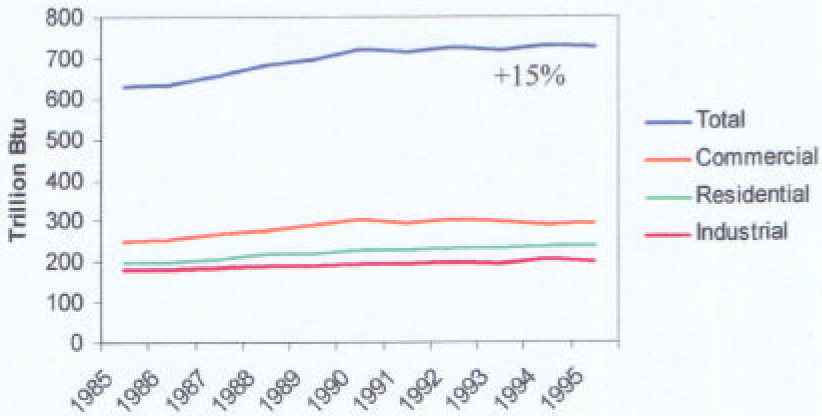
Source: California Air Resources Board

Rising Demand for Electricity



- Energy efficiency up but higher electric share
- California population will increase ~25% and economic activity will increase ~35% by 2020
- Must meet even stricter 2020 emissions standards

CA Electric Consumption



Source: EIA State Energy Data Report 1995

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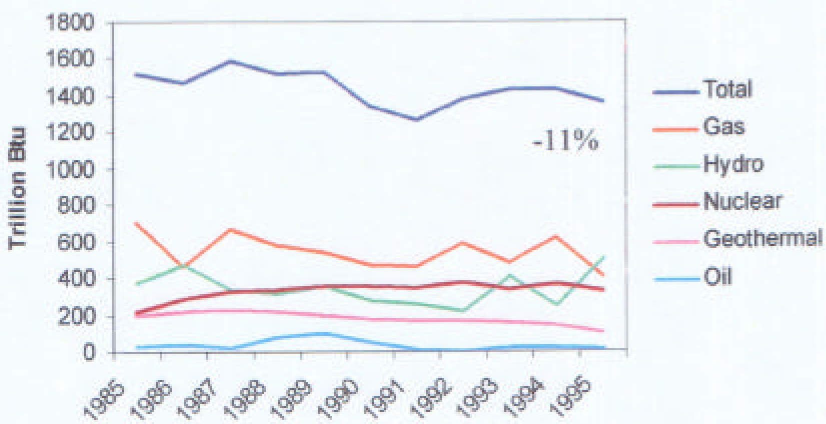
Fuels Used in CA to Generate Electricity



Source: EIA State Energy Data Report 1995

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CA Power Generation Emissions

Tons per Day

Pollutant	Total Stationary Sources	Electric Utilities	Cogeneration
CO	348	36	36
PM_{10}	211	5	3
NO_X	633	69	36
SO_X	138	8	2

Percent of Total Stationary Sources

Pollutant	Electric Utilities	Cogeneration
CO	10.3	10.3
PM_{10}	2.4	1.4
NO_X	10.9	5.7
SO_X	5.8	1.4

Source: California Air Resources Board

Emission Controls

- Best Available Control Technology → Lowest Achievable Emission Rate

BACT	LAER
Rich burn IC engines with NSCR	
Lean burn IC engines	Lean burn IC engines with SCR
Turbines with dry low NO_X or water/steam injection	Turbines with SCR or $SCONO_X$

- Selective Catalytic Reduction (SCR) and Catalytic Absorption ($SCONO_X$) are becoming the norm for large gas units, but a burden for smaller DR units
- DR hampered by case-by-case treatment
- Regulations don't fully account for displaced boiler emissions under CHP

Impacts on Future CA Generation

- Limited new hydro, geothermal, nuclear
- New generation plans must include control technologies
  - Combined cycle
  - DR
  - Renewables
- Import more, presently around 40%

The DR Option

- DR may be applied in large numbers
  - Peak shaving on worst days
  - Retailco backup power
- Widespread DR use may make smaller generators subject to air quality controls
- DR will continue to evolve

Air Emissions by Technology

(lb/kWh)

Generation Technology	CO	PM_{10}	NO_X	SO_X
Distributed Resources				
Recip engines	.004-.006	.0002	.0015-.037	
Small gas turbines	.0006-.003	.0001-.0002	.0001-.004	.00003
Microturbines	.0002-.002	.0001-.0002	.0003-.001	.00003
Fuel cells	.00001	0	.000002-.00006	0-.000003
Photovoltaic	0	0	0	0
Wind turbines	0	0	0	0
Central Station				
Gas steam	.0001	.00001	.0001-.0003	.00003
New coal plant		.0001	.002	.002-.004
Geothermal	0	0	0	0
Hydropower	0	0	0	0
Nuclear	0	0	0	0

Sources: CADER and Resource Dynamics Corporation based on manufacturers' specifications

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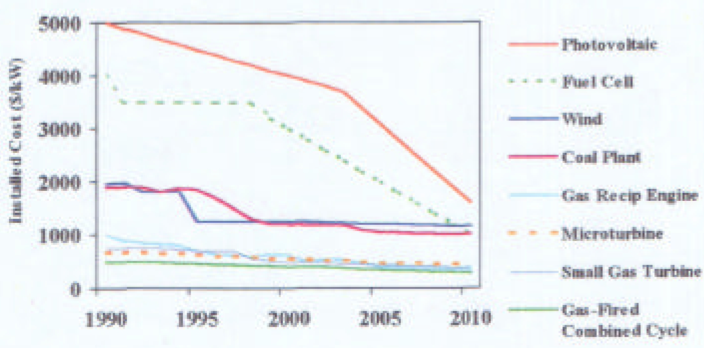
Generation Capital Cost By Technology (98$)



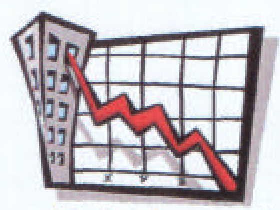
Source: Resource Dynamics Corporation

22

The Renewables Option

- Renewables have few emissions
- Wind and PV can be either DR or central station
- Oct 19 132 kW solar
- Wind economics are comparable to coal
- Green power subsidy to stimulate development?!

Impact on Total Emissions



- Retrofits may reduce emissions a limited amount
- SCR and $SCONO_X$ will reduce new turbine emissions, but at a cost of stalling potential small CHP applications
- RECLAIM trading credits and ERCs will encourage lower emission technologies
- DR could increase or reduce NO_X depending on the technology and controls used
- Microturbines/recips will increase CO emissions

3. Environmental Challenges to Consider

- How will a large transfer of existing reciprocating engines (high NO_X) from emergency to peak shaving use change environmental regulations?
- Will widespread use of microturbines in urban areas (increasing CO and NO_X) result in new permit requirements for smaller generators?
- How will higher priced NO_X emission allowances ($4,000?) affect the use of either control technologies or microturbines?
- Should cogeneration be credited for displaced boiler emissions when measuring emissions per kWh produced?
- Given DR environmental uncertainties, what should the policies be for using DR as part of the generation mix? How should we arrive at such policies?

Environmental Challenges to Consider (continued)

- What would it take to standardize or even simplify air quality regulations across CA, and what would the implications be?
- What would it take to move from a case-by-case assessment method to a) presumptive BACT for the power generation industry, b) standardized siting requirements, and c) type testing and inspection of DR generators?
- Who should sponsor a web site dedicated to exchanging technical and scientific discussions about the environmental impacts of generating technologies, emission measurement technologies, pollution mitigation technologies, and emerging research findings?

Evolving Environmental Challenges

From:
- Regulatory barriers
- Procedural uncertainties
- Varying procedures
- Tight controls
- Low emissions

To:
- Streamlined regulations
- Specific procedures
- Uniform procedures
- Tighter controls
- Lower emissions

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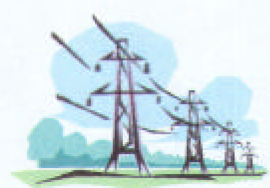
A Glimpse of Future Generation?

- More imports from coal, negatively impacting CA air
- More combined cycle gas with $SCONO_X$
- Distributed fuel cells
- More nuclear central station
- Microturbines if there is a cost-effective breakthrough in control technology



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The Potential Impacts of Distributed Generation on California Emissions

Preliminary Results of A Project sponsored by the California Air Resources Board

CEC-EPRI workshop

October 28, 1999

Susan Horgan

Distributed Utility Associates

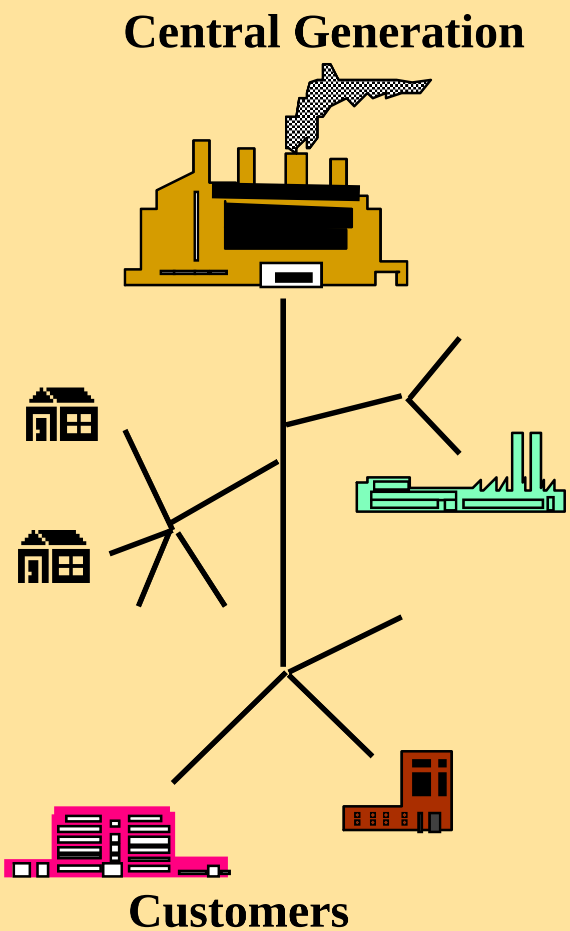
Livermore, CA

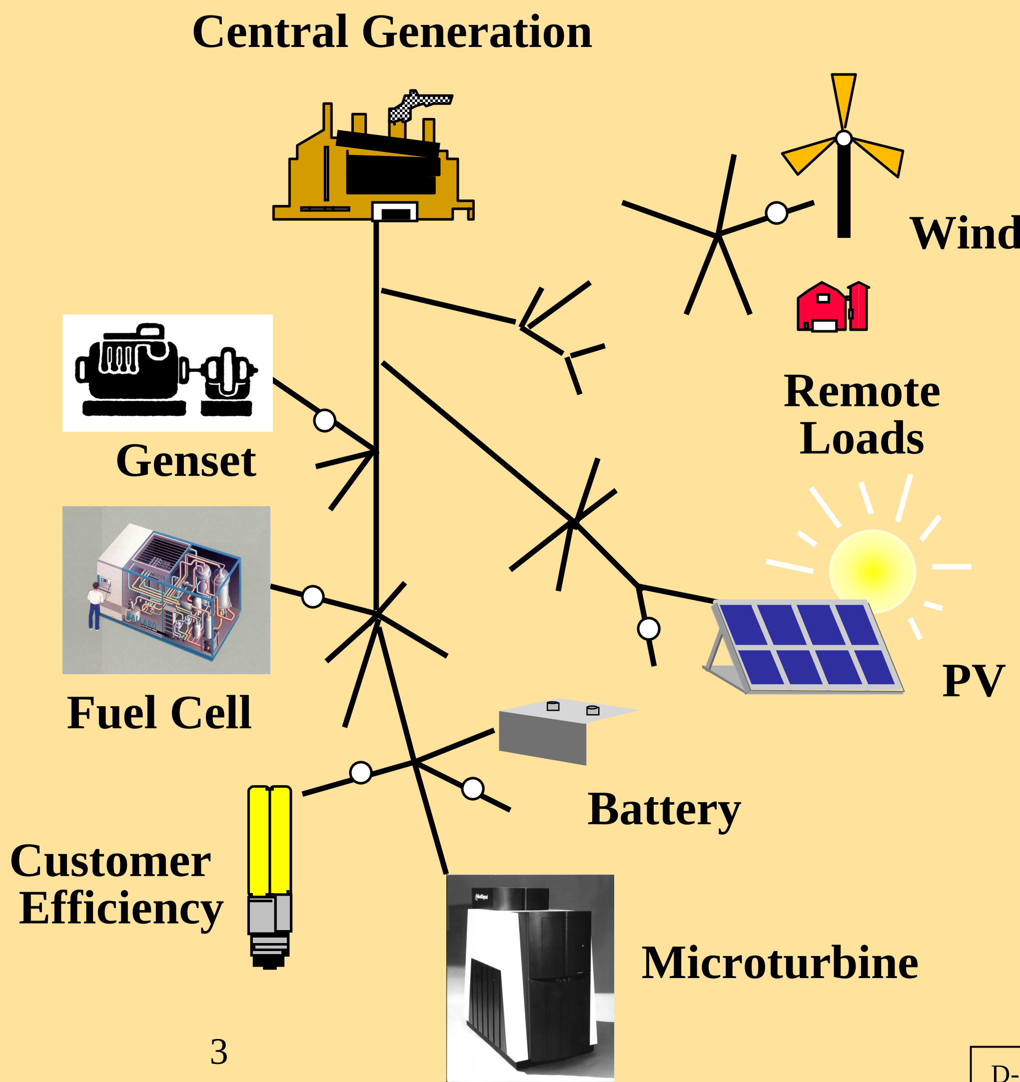
The Questions

- Emissions: absolute or net?
- G vs. g?
- Value environmental externalities?
- Peaking vs baseload vs load following?
- In state vs out of state generation?

Today's Central Utility

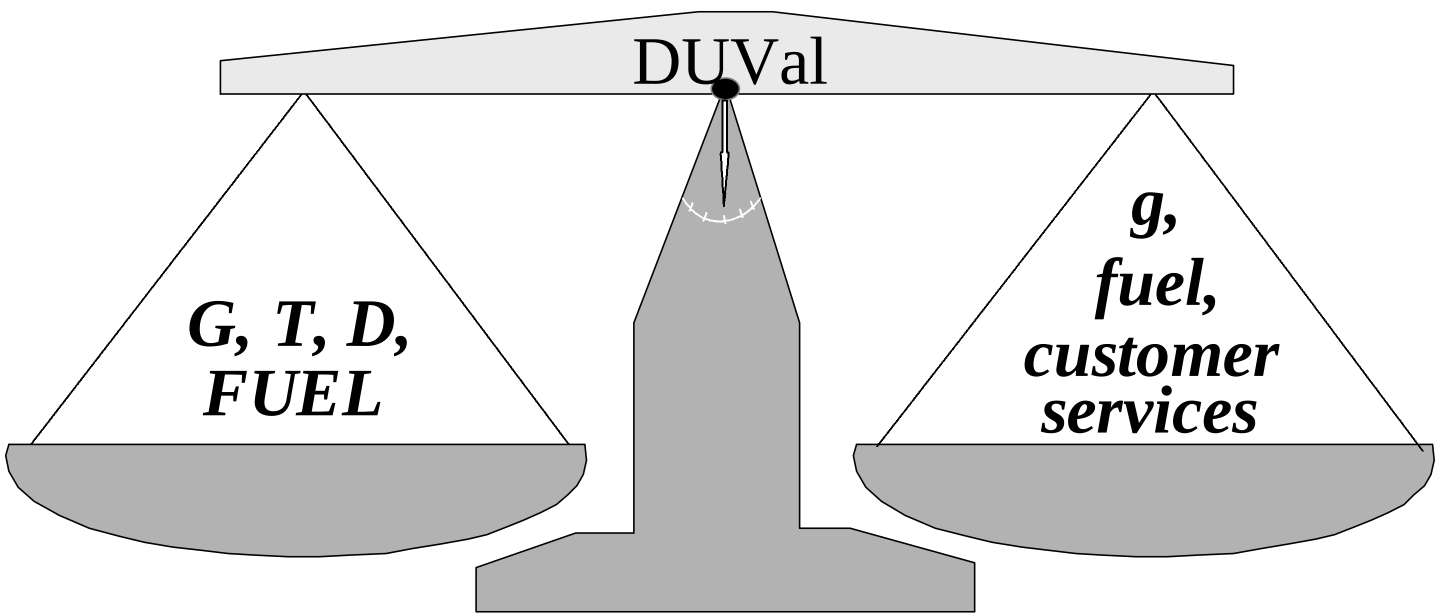
Tomorrow's Distributed Utility?



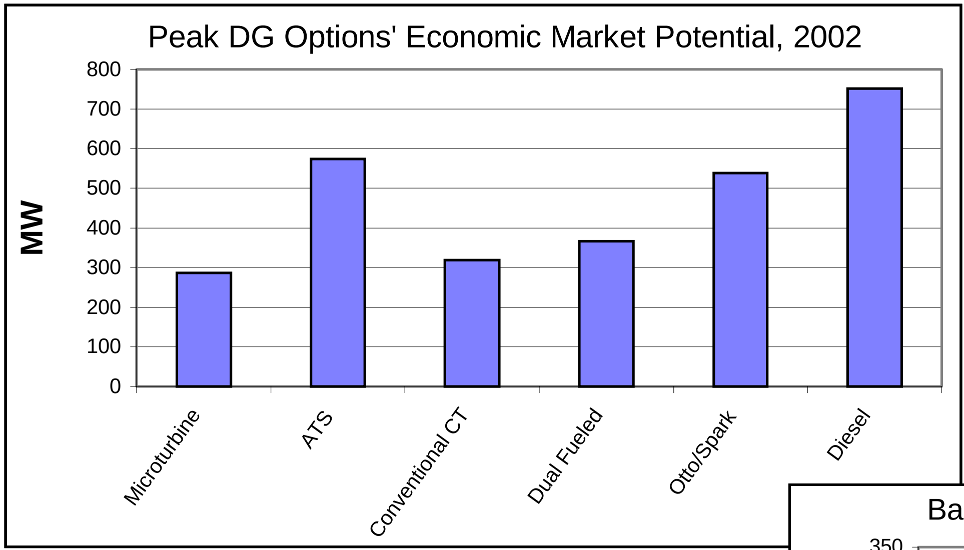


Utility Economics

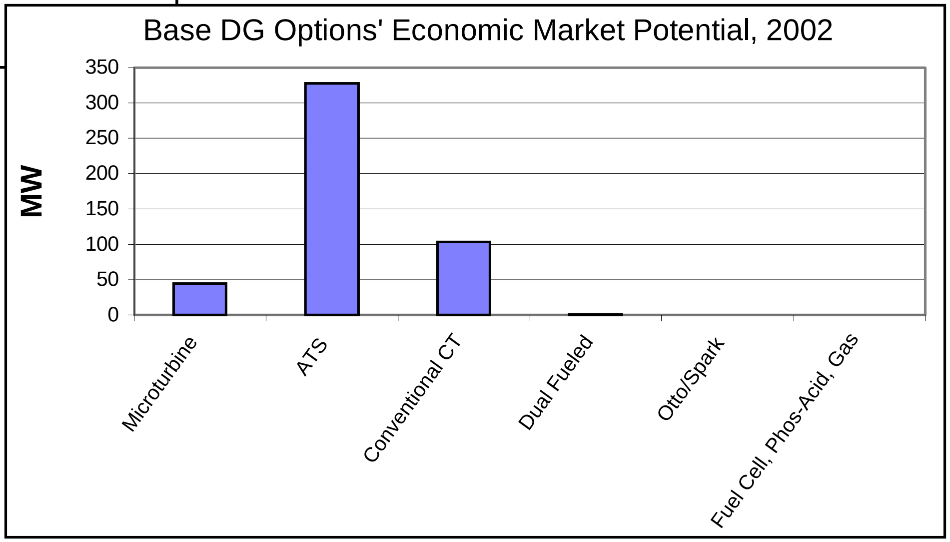
- Lower Cost of Service
  - better asset utilization
  - improved operation



Utility "Economic Market Potential" Preliminary Results, 2002

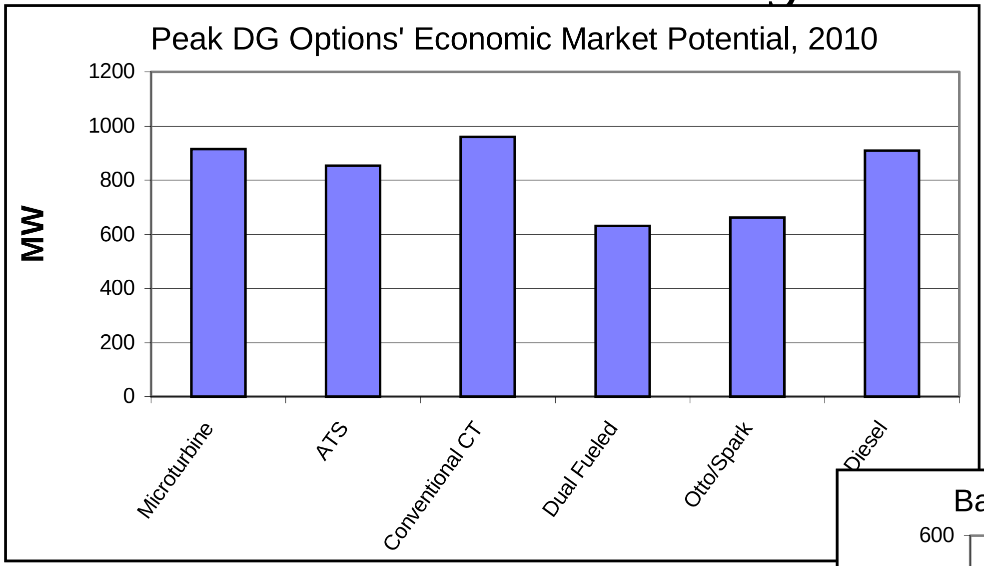


Peak Load



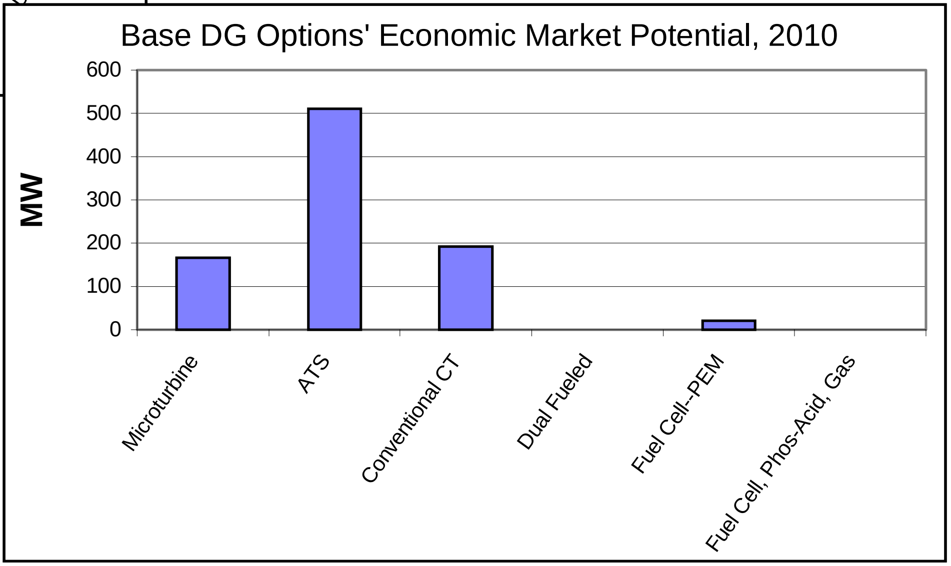
Base Load

Utility "Economic Market Potential" Preliminary Results, 2010



Peak Load

Base Load



Utility Preliminary Results: 2002

2002 *Peaking DG Option*	Market Size (MW/yr): 996			Tons of Emissions (000 tons CO_2)			
	Market %	NOx	SOx	CO	CO2	VOCs	Part
System Only	100%	13.5	2.1	176.4	20.9	2.1	11.4
Microturbine	28.7%	45.3	2.3	201.5	50.6	2.8	10.7
ATS	57.7%	68.1	2.1	224.0	63.4	2.6	8.8
Conventional CT	32.1%	48.8	2.3	168.0	52.6	2.6	10.5
Dual Fueled Engine	36.8%	375.1	5.0	1,211.1	46.9	45.3	46.3
Otto/Spark Engine	54.1%	178.6	1.5	512.0	61.9	92.6	102.2
Diesel Engine	75.5%	1,131.3	23.1	2,299.2	62.3	150.9	198.3

DG + central emissions

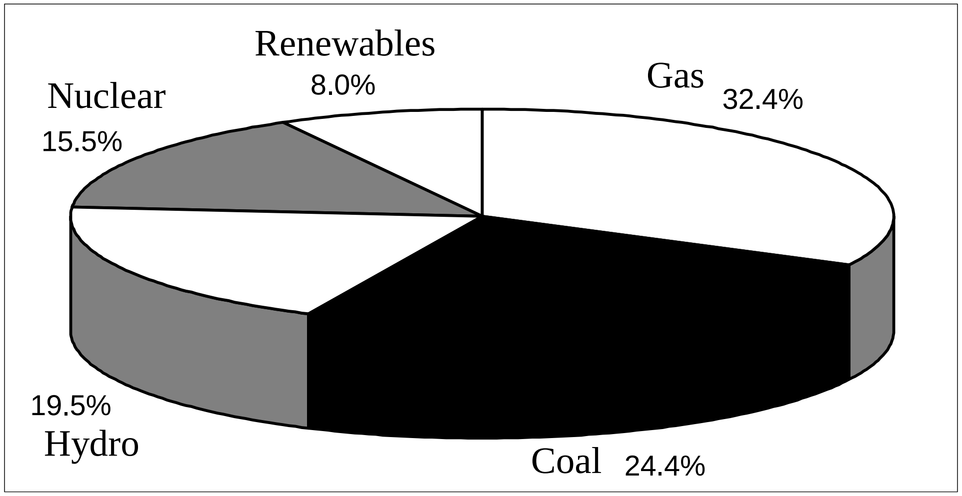
2002 *Baseload DG Option*	Market Size (MW/yr): 996			Tons of Emissions (000 tons CO_2)			
	Market %	NOx	SOx	CO	CO2	VOCs	Part
System Only	100%	322.0	49.5	4,210	499.0	49.5	272.4
Microturbine	4.4%	428.1	75.3	4,302	601.4	51.5	269.5
ATS	32.9%	708.8	50.0	4,859	1,077.9	56.9	236.7
Conventional CT	10.4%	595.1	50.8	4,146	730.2	53.6	264.6
Dual Fuel Engine	0.1%	341.8	49.7	4,284	500.6	51.6	274.0
Fuel Cell--PEM, Gas	0.0%	322.0	49.5	4,210	499.0	49.5	272.4
Fuel Cell--PhosAcid,	0.0%	322.0	49.5	4,210	499.0	49.5	272.4

DG + central emissions

California Electricity

Fuel Type	CA Generation GWh	CA Generation % of CA Gen.	CA Generation % CA Gen.	Imports GWh	Imports % of Imports	Imports % CA Gen.	State Total GWh	State Total % CA Gen.
Gas	79,616	36.1%	29.7%	7,307	15.4%	2.7%	86,923	32.4%
Coal	29,043	13.2%	10.8%	36,361	76.5%	13.6%	65,404	24.4%
Hydro	48,462	22.0%	18.1%	3,891	8.2%	1.5%	52,353	19.5%
Nuclear	41,565	18.8%	15.5%	0	0.0%	0.0%	41,565	15.5%
Non-hydro Renewables	21,537	9.8%	8.0%	0	0.0%	0.0%	21,537	8.0%
Other	353	0.2%	0.1%	0	0.0%	0.0%	353	0.1%
Total	220,576	100%	82.3%	47,559	100%	17.7%	268,135	100%

- 45.9 GW Peak Demand 1999
- 2% Load Growth
- 954 MW Load *Growth* 2002



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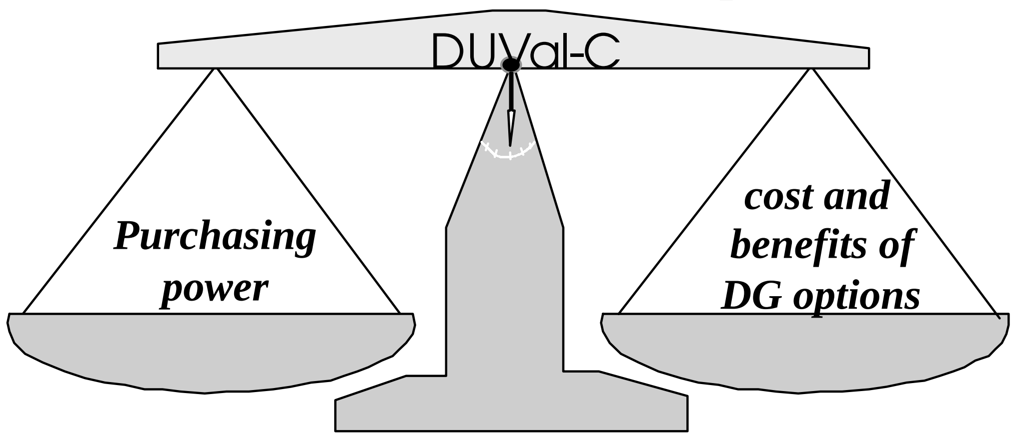
Customer Economics

- Lower Energy Cost
- Better Service--quality, reliability
- Industrial Sector Only

Comparing Central to DU Solutions

Bill and Benefits Comparison



Industrial Customer Results Summary

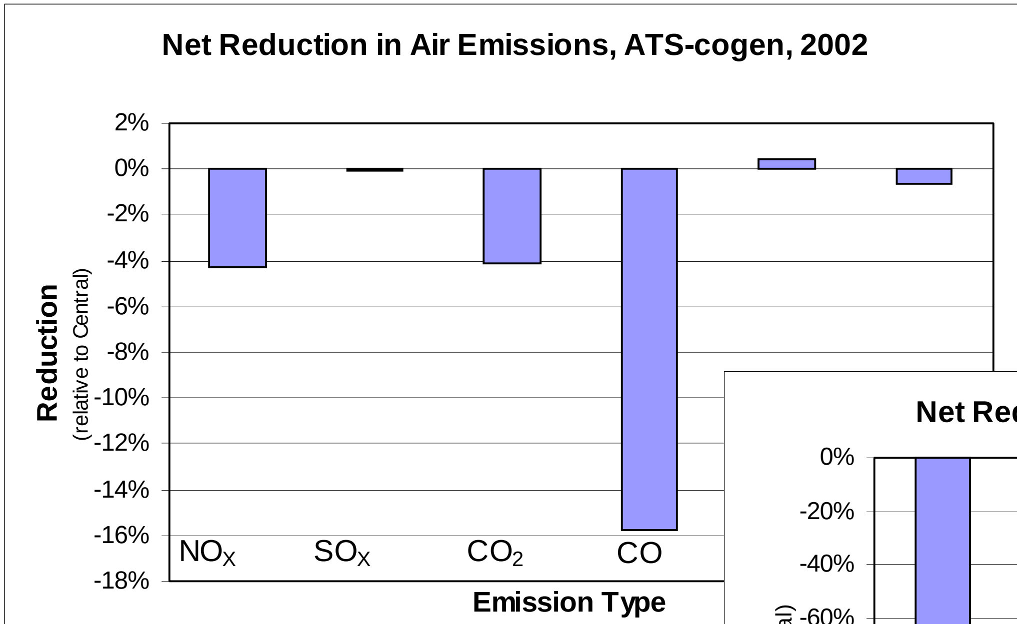
2002

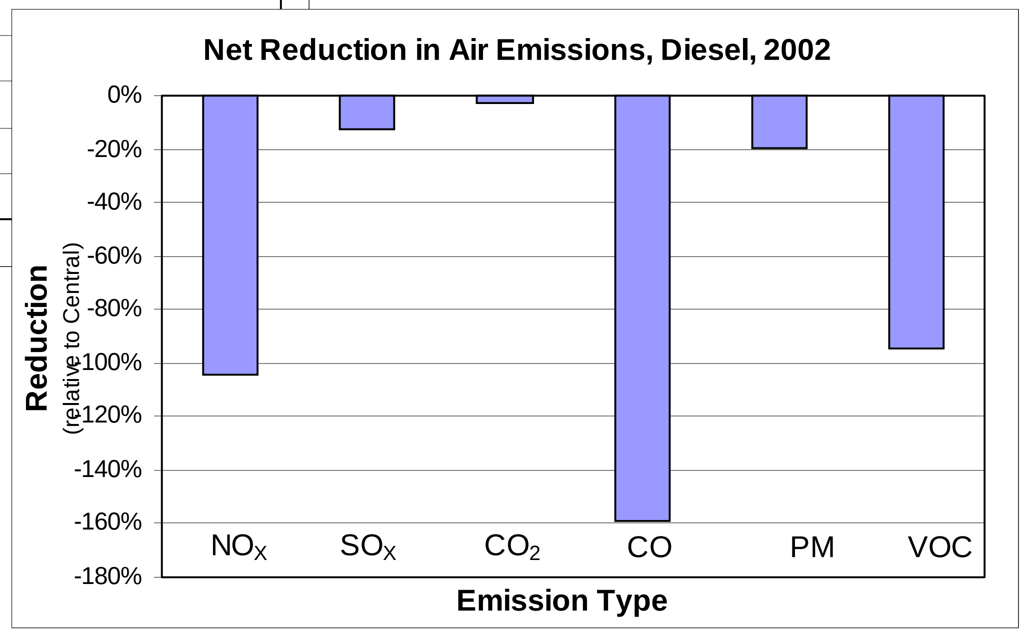
Technology	Optimal Operation Hours Per Year, Incremental Cost Basis	Total B/C Ratio
Micro Turbine	780	0.80
Micro Turbine-Cogen	8759	1.57
Diesel	780	0.91
ATS-cogen	8759	1.74
Gas Spark	780	0.90
Fuel Cell	780	0.25

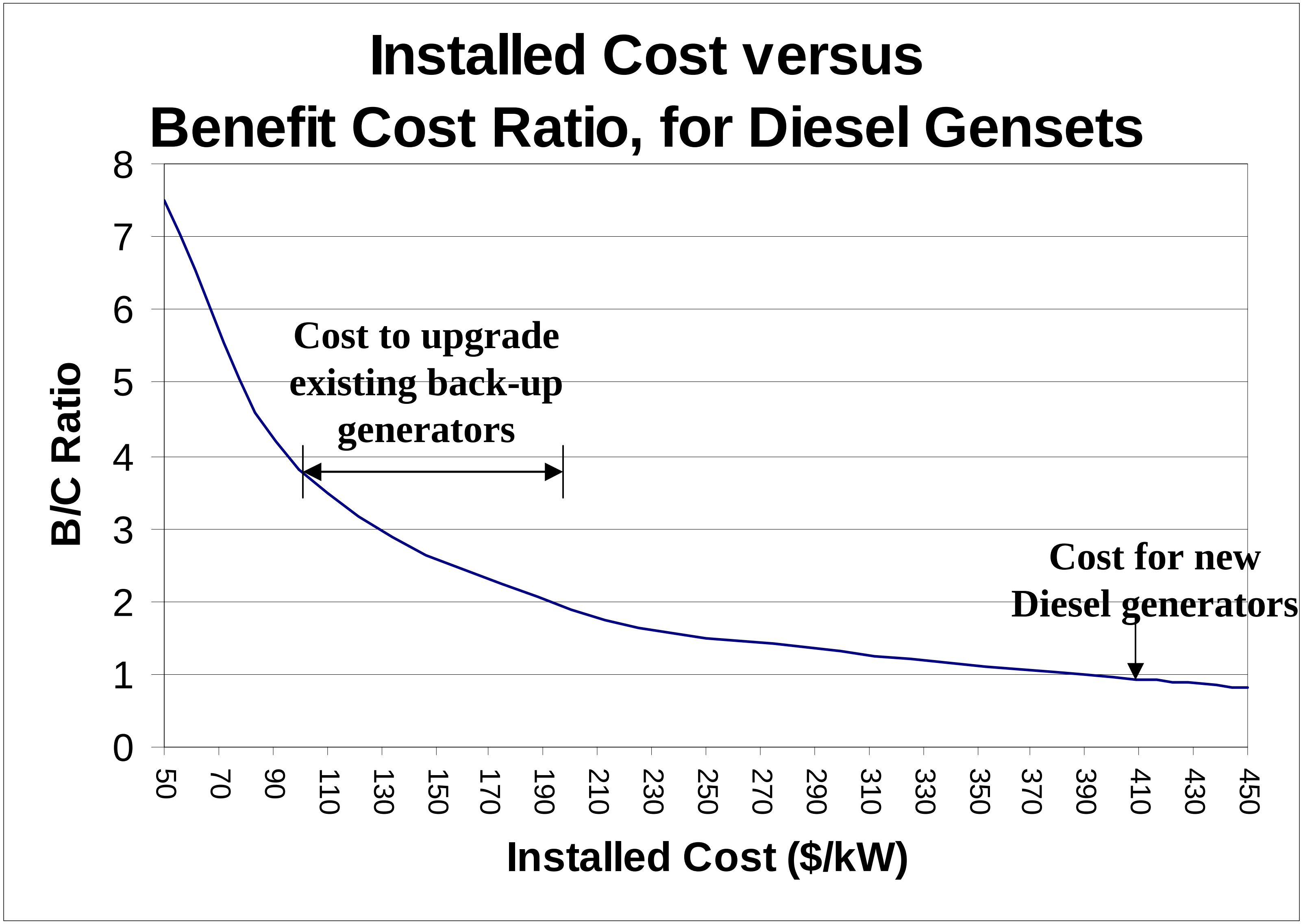
2010

Technology	Optimal Operation Hours Per Year, Incremental Cost Basis	Total B/C Ratio
Micro Turbine	780	0.99
Micro Turbine-Cogen	8759	1.81
Diesel	780	0.92
ATS-cogen	8759	1.81
Gas Spark	780	0.97
Fuel Cell	8160	0.97

Emissions Effects--Selected DRs






Installed Cost versus
Benefit Cost Ratio, for Diesel Gensets
B/C Ratio
0
1
2
3
4
5
6
7
8
Cost to upgrade
existing back-up
generators
Cost for new
Diesel generators
50
70
90
110
130
150
170
190
210
230
250
270
290
310
330
350
370
390
410
430
450
Installed Cost ($/kW)

Summary

- Determine the balance of g vs. G
- Examine hours of operation in hours/year
- Examine markets
- Emission policies

Guidance on Power Plant Permitting and BACT

CEC-EPRI Workshop
October 28, 1999

Michael Tollstrup
Stationary Source Division
California Environmental Protection Agency
Air Resources Board
Sacramento, CA

Purpose of Guidance

- Provide ARB's Perspective on Power Plant Siting and Best Available Control Technology (BACT)
- Assist Districts and Applicants
  - Guidance Only, Not Regulatory
- Encourage uniformity in permitting
- Address difficult permitting issues
  - BACT
  - Offsets

California Regulatory Structure

California Energy Commission
- **Major power plants 50 MW and larger**
- **Provides for local, State, and public participation**

35 Air Pollution Control Districts
- **Stationary sources**
- **Each establish rules and regulations**

California Air Resources Board
- **Mobile sources**
- **Oversight authority**

Deregulation

Establishes free-market for electric power generation

42 Proposed new power plants

- Gas turbines (combined-cycle/cogeneration)
- 100-1000 MW
- Over 25,000 MW total

10 currently in licensing process

2 recently licensed

Guidance

Best Available Control Technology (BACT)

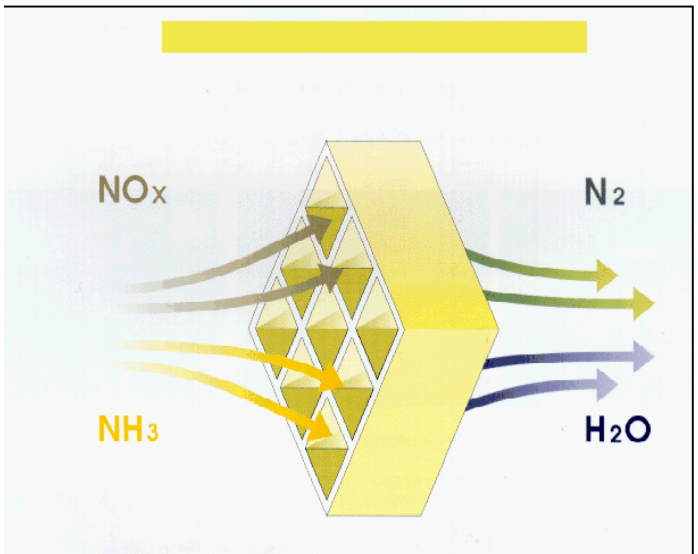
Emission Offsets

Ambient Air Quality Impact Analysis

Health Risk Assessment

Other Permitting Considerations

BACT Technical Review



Stationary Combustion Turbines

– Natural Gas-Fired

– Used for Power Production

– Reviewed Units $\geq$20 MW

Pollutants Evaluated

– NO_X, CO, VOC, PM_{10} and SO_X

Special Considerations

– Equipment Startup/Shutdown

BACT Technical Review
(continued)

---

on District Definition for BACT

- **“Class or Category of Source”**
- **“Achieved in Practice”**
- **SIP Measures and Rules**
- **Based Technologically Feasible**

Case-by-Case Consideration of Project Circumstances

Guidance for BACT:

Achievable Emission Levels for Simple-Cycle Configuration *

5 ppmvd NO_X, 3-hr Rolling Average

6 ppmvd CO, 3-hr Rolling Average

2 ppmvd VOC, 3-hr Rolling Average, or 0.0027 lb/MMBtu

*** at 15% O_2**

Guidance for BACT:

Achievable Emission Levels for Combined-Cycle/Cogeneration Configurations *

2.5 ppmvd NO_X, 1-hr Rolling Average, or 2.0 ppmvd, 3-hr Rolling Average

6 ppmvd CO, 3-hr Rolling Average

2 ppmvd VOC, 1-hr Rolling Average, or 0.0027 lb/MMBtu

Guidance for BACT:

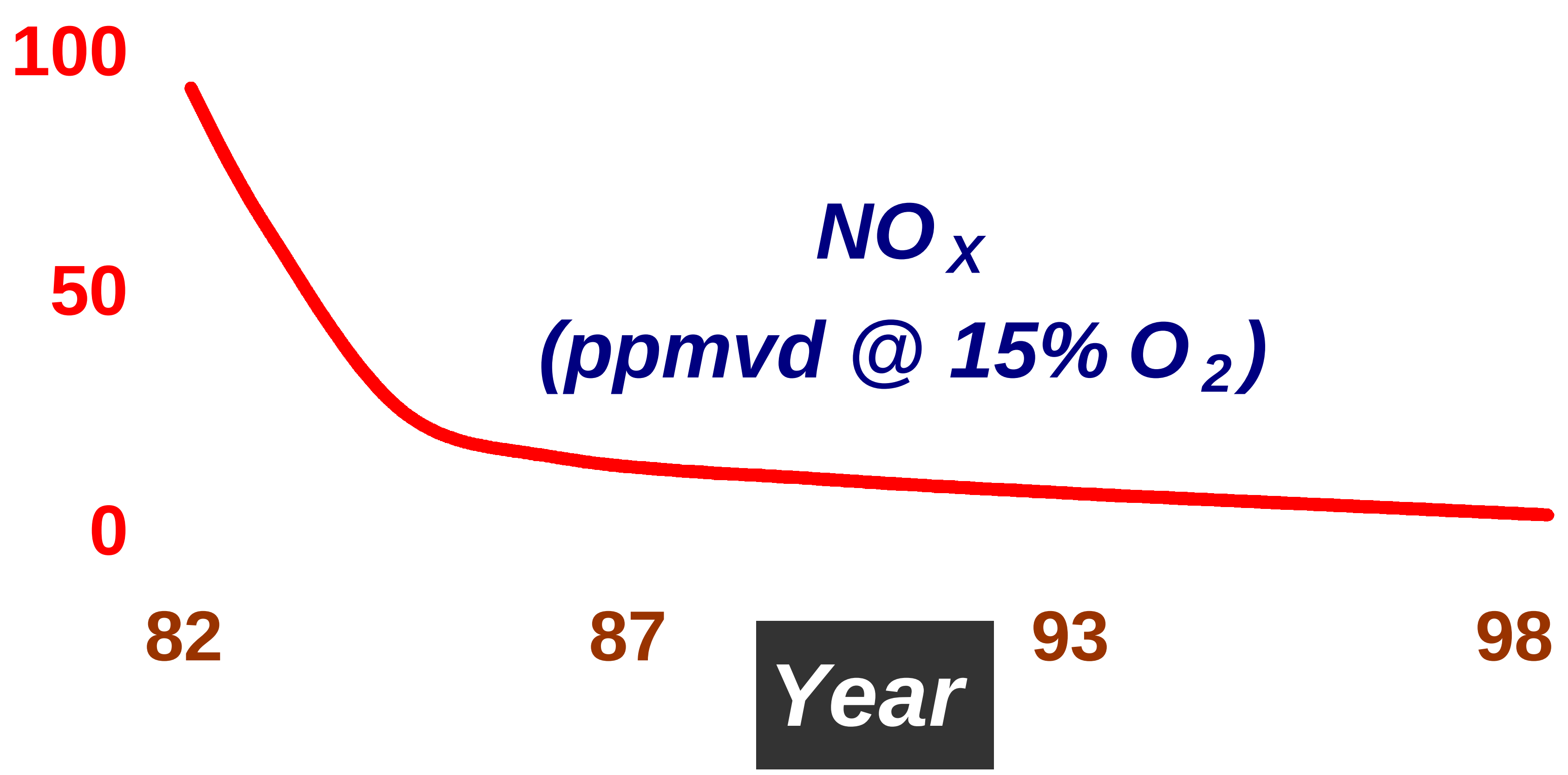
Achievable Emission Levels for SO_X and PM_{10}

For PM_{10} and SO_X, Emission Limits Corresponding to Combustion of Natural Gas with Total Sulfur No More Than 1 grain/100 SCF

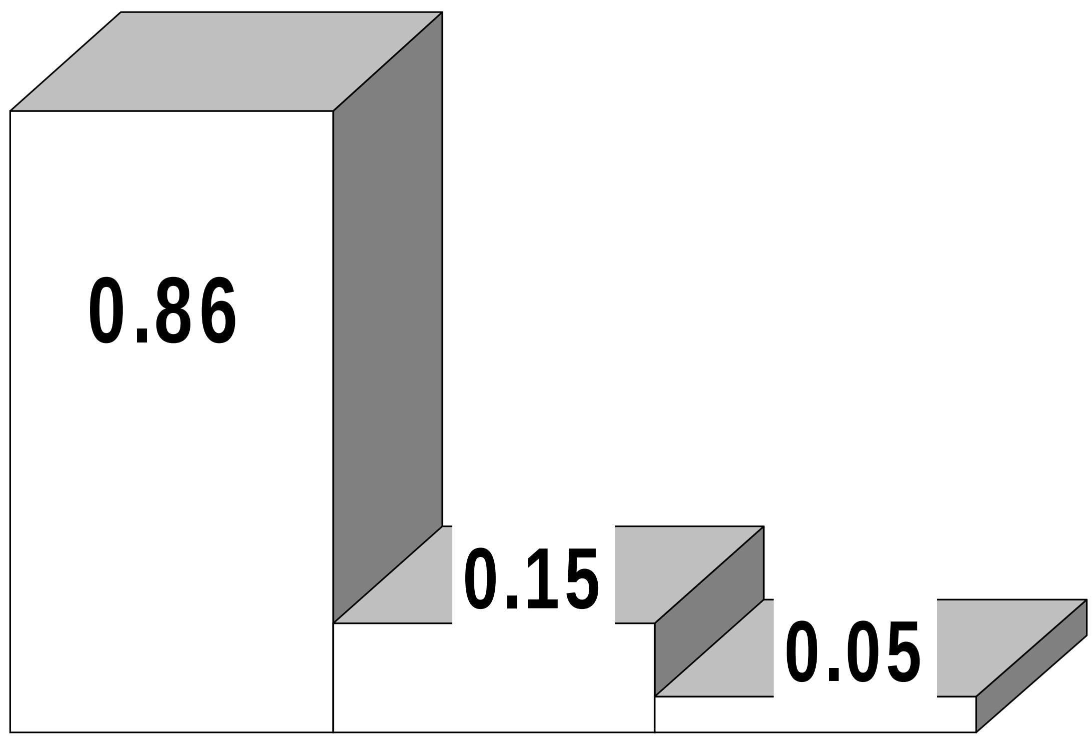
For SO_X, Equivalent to No More than 0.55 ppmvd @ 15% O_2

NO_X BACT Trends in California:

Combined-Cycle/Cogeneration Configurations



Comparative NO_X Emissions: Well-Controlled Power Plants



NO_X (lb/MW-hr)

Typical Project Emissions*

NO_X: 150 to 200 TPY

CO: 480 to 630 TPY

VOC: 20 to 100 TPY

PM_{10}: 90 to 120 TPY

SO_X: 10 to 40 TPY

Guidance for

Interpollutant Emission Offsets

For $PM_{2.5}$, PM_{10} and Precursors (NO_X, VOC and SO_X)

Minimum Offset Ratio of 1.0:1

For Ozone Precursors (NO_X and VOC)

ARB's Basin-Specific Offset Ratios

Alternatively, Determine Case-by-Case with Minimum Offset Ratio 1.0:1

Guidance for

Interbasin Emission Offsets

Allow for Pollutants w/ Regional Impacts

- Ozone Precursors (NO_X and VOC)
- PM_{10} Precursors (NO_X, VOC and SO_X)

Interbasin (Distance) Offset Ratio

- Minimum 2.0:1 for Sources within 50 Miles Distance
- Increase Minimum by One (1.0) for Each

Guidance for

Other Permitting Considerations

Minimize Ammonia Slip when Using SCR

No More Than 5 ppmvd @ 15% O_2

Factors Driving Technology

- SIP commitments
- Technology forcing regulations
- Offsets
  - Increasingly difficult to secure
  - Competition for limited resource
  - Costs

Future

- **Simple-cycle operations**
- **At least two projects proposing 1 ppmv NOx**
- **Need for accurate measurement methods**

Gas Turbine Environment Control Issues

CEC-EPRI Workshop
October 28, 1999

Leonard Angello
Clean Air Technologies
Mountain View, CA

Key Environmental Issues

- Impacts upon health of nearby residents by criteria pollutants, such as NO_x and trace substances, and the impacts upon safety from the use of natural gas and ammonia
  – Zero ammonia technology controversy
- Need for state-of-the-art knowledge and skills to :
  – Address low-level NO_x measurement issues;
  – Independently review/evaluate alternative NO_x, CO, and hydrocarbon control technologies and interpollutant trading.

Purpose of Presentation

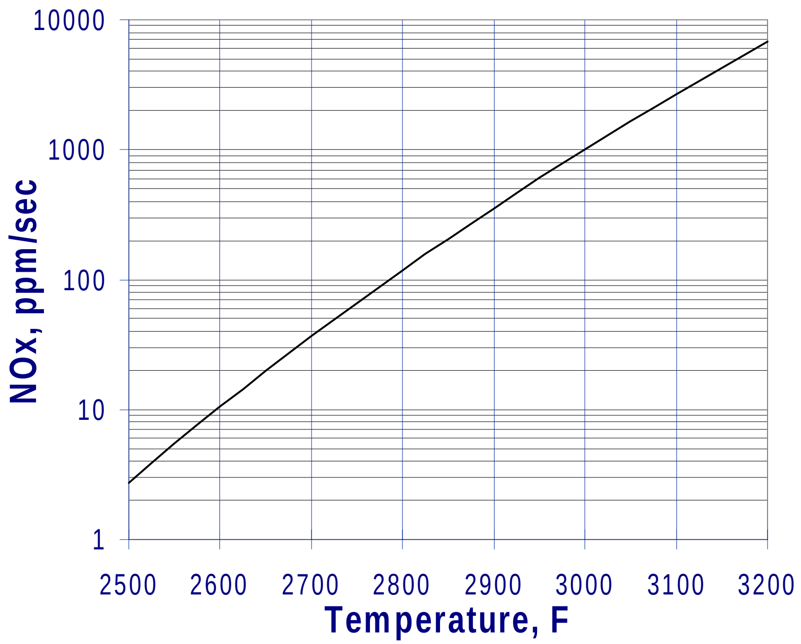
- Identify cost-effective emission control alternatives for combustion turbines and combined cycle units
- Provide perspective on cutting-edge technologies for strategic planning
- Initial focus on ultra-low NOx emission technologies
- Assess near- and mid-term technologies

Ultra Low NOx Control

- Technical Background
- Ultra Low NOx Combustors
  - Catalytic
  - Surface Stabilized
- Post Combustion Solutions
  - Selective Catalytic Reduction
  - SCONOX

Ultra Low NOx Basics

- Minimize Maximum
- Flame Temperature
  - Well Premixed Fuel/Air
  - Less than about 2800F
- High Volumetric Heat Release Rate
  - Residence time less than about 0.01 sec
  - Catalytic Assist
  - Surface Stabilized

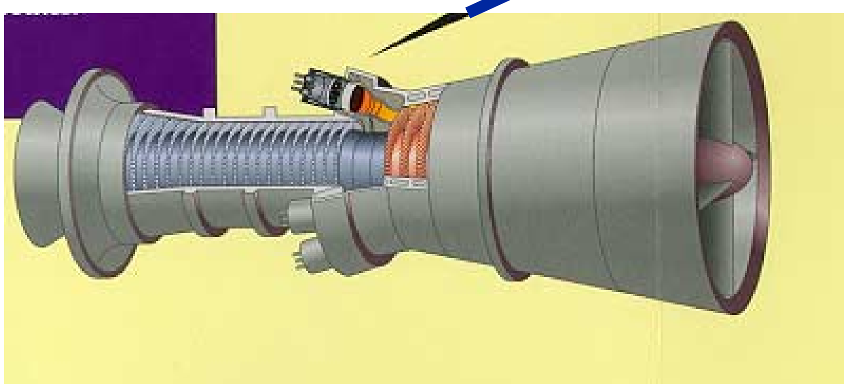


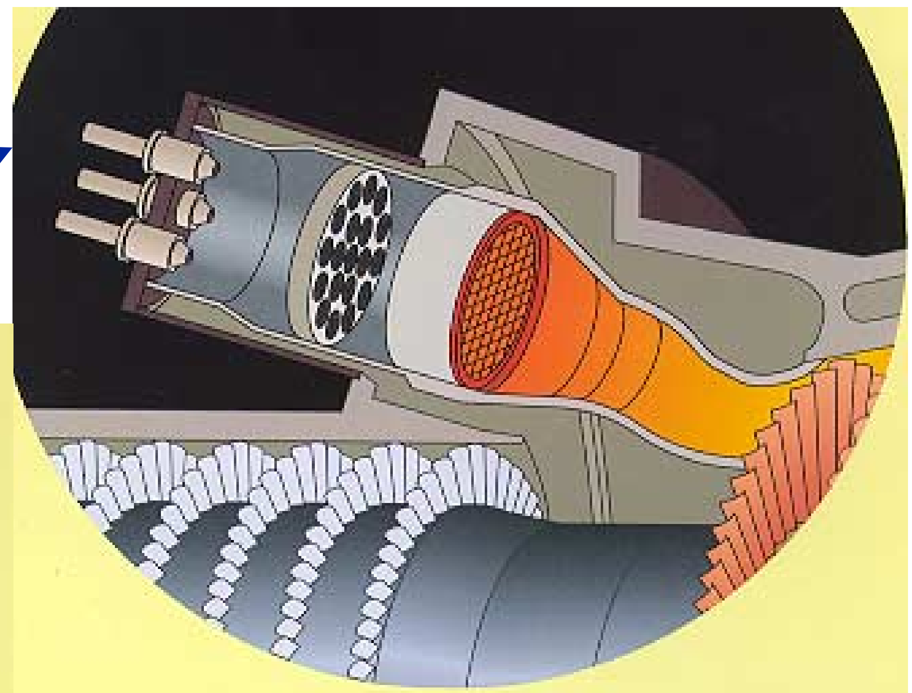
Catalytic Combustion

- Achieves Combustion at Low Temperature
  - Generates Negligible NOx
- Maximum Catalyst Temperature Limited to about 2000F -- More Combustion Needed
- Catalyst Stabilizes Post Catalyst Combustion
- Honeycomb Cells can be Selectively Catalyzed
  - Reduces Catalyst Temperature
  - Provides Efficient and Uniform Mixing for Downstream Combustion
- Downstream Combustion Yields Some NOx

Catalytica Concept

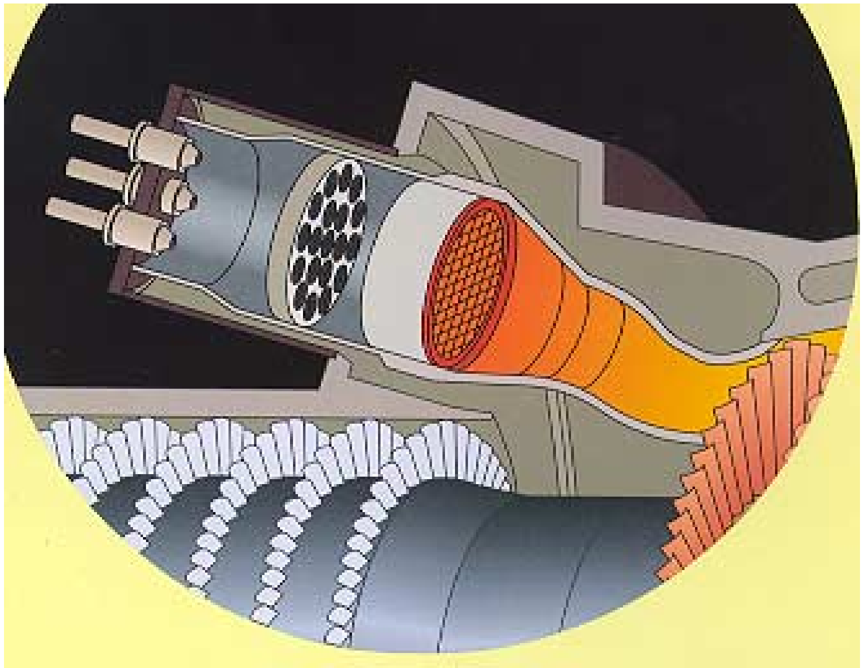
- Schematics from Catalytica Literature
- XONON Catalytic
- Combustor





Catalytic Combustion Technical Concerns

- Materials
  – Performance
  – Durability
- System complexity
  – Pre-burner
  – Fuel/air mixer
  – Catalyst element
  – Control system
- Turndown
- Engine-specific design

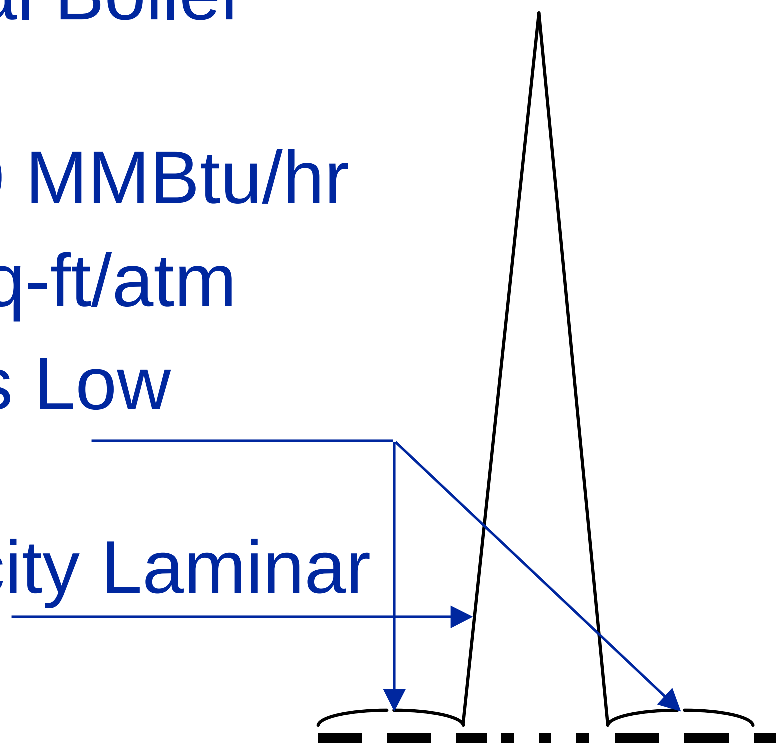


Catalytic Combustion Application Experience

- Single-engine demonstration in progress at Silicon Valley Power
  - Kawasaki turbine
  - 1.5 MW
  - Turbine owned and modified by Catalytica
  - Actual operating hours and starts unreported
- Prior (circa 1998) single-engine, test-stand demonstration
  - 1,100 hours
  - 220 starts

Surface Stabilized Combustion

- Effectively Used for Industrial Boiler Applications
  - Installations from 1 to 180 MMBtu/hr
  - Operates at 1MMBtu/hr/sq-ft/atm
- Dual Porosity Surface Yields Low Velocity Attached Flames
- which Stabilize High Velocity Laminar Wedge Flames
- Stable at Low Flame
- Temperatures and High Intensity



Clean Air Technologies

Industrial Surface Stabilized Combustor

Red surface combustion stabilize hi-intensity laminar blue flame

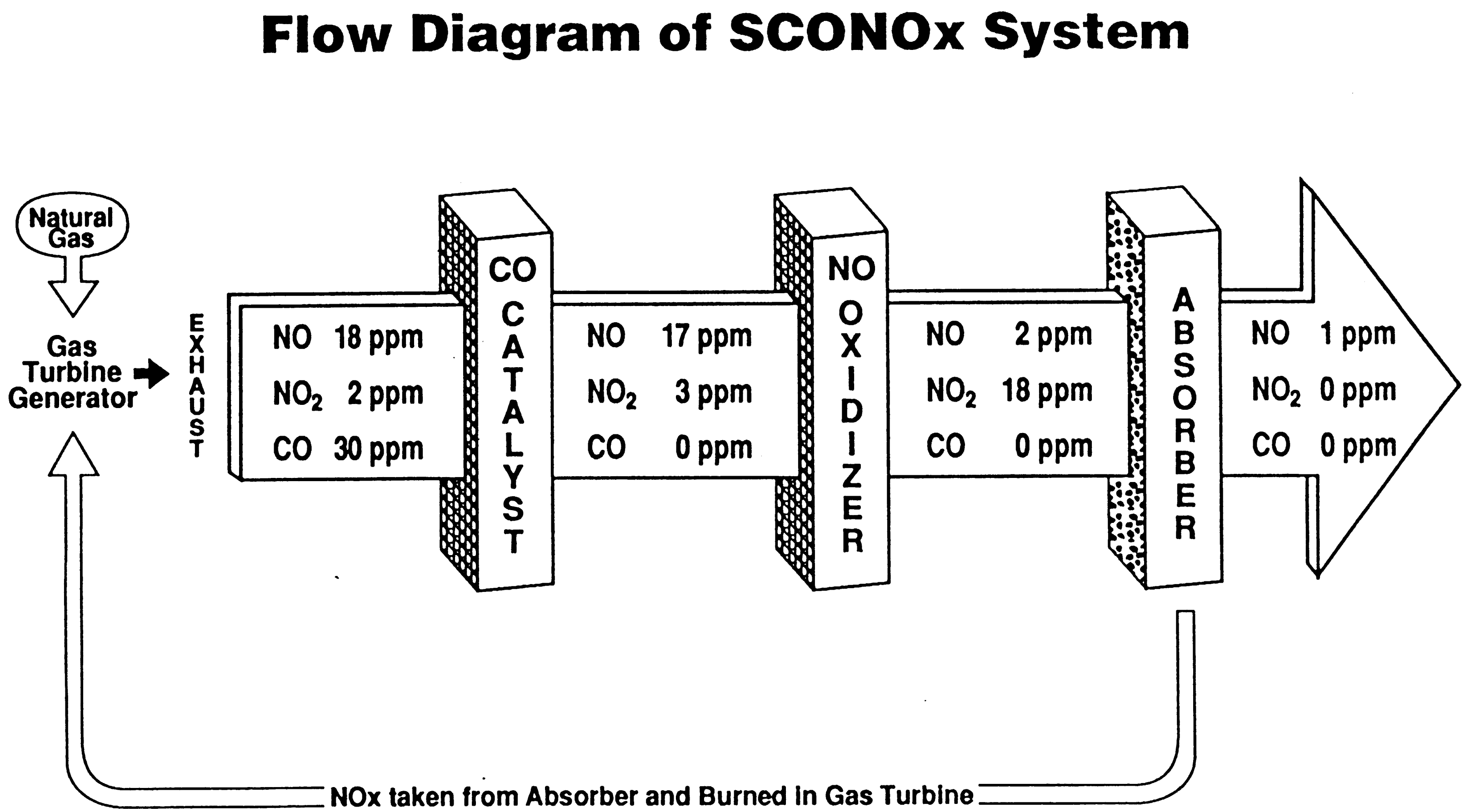
Surface Stabilized Combustion Applied to Gas Turbines

- Demonstrated at High Pressure and High Preheat at:
  - Federal Energy Technology Center in Morgantown
  - Solar Turbines in San Diego
  - Alzeta Corporation in Santa Clara
- Simultaneous Emissions less than 2 ppm of NOx, 5ppm of CO and UHC over broad range
- Simple, Compact, Minimal Cost Premium
- Turbine Tests Planned for 1,000 kW Solar Saturn Engine and 75 kW AlliedSignal TurboGenerator

Post Combustion NOx Control

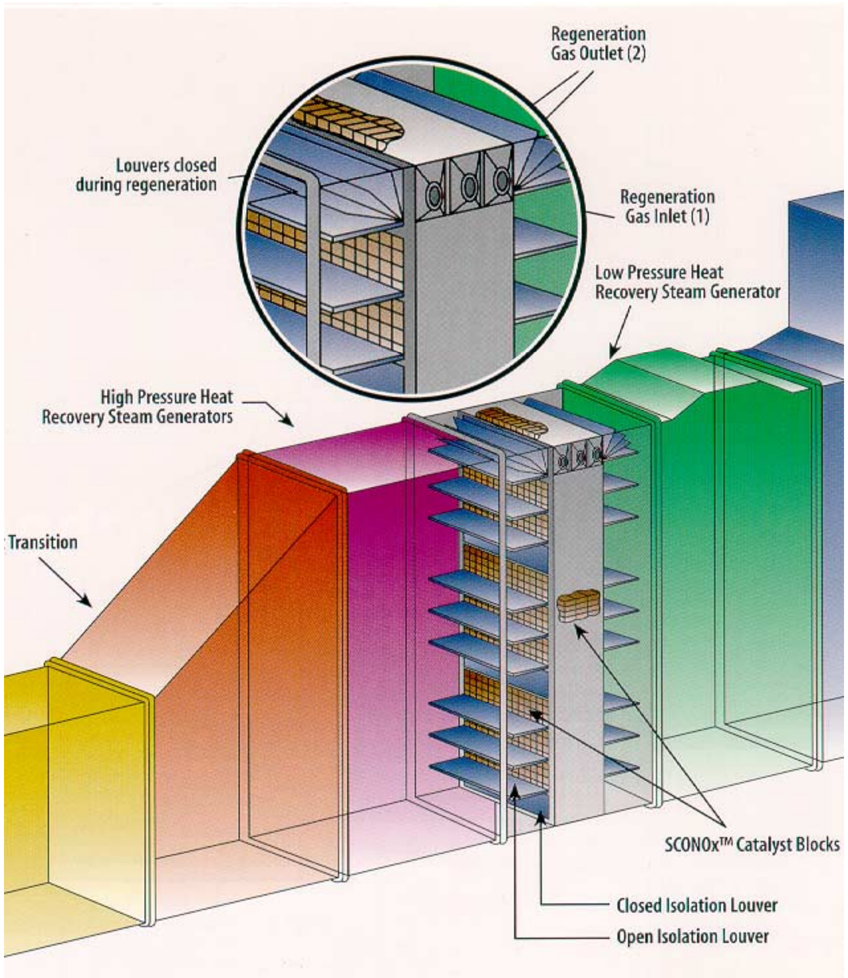
- Selective Catalytic Reduction
  - Requires NH_3, Limited Temperature Range, Large Footprint, Used in Combination with Low NOx, $$
  - 90% Reduction of NOx, Current SCAQMD BACT
- SCONOX
  - Requires H_2, Limited Temperature Range, Large Footprint, Platinum Based Catalyst, Used in Combination with Low NOx, $$$
  - Achieved 2-ppm NOx, SCAQMD considering as BACT

SCONOx Flow Diagram



SCONOx Technical Concerns

- Scale-up to large plant sizes
- Mechanical integrity
  - Louver coordination
  - Seal durability and effectiveness
- Thermal performance
  - Regenerator efficiency
  - Temperature limitations
- Catalyst degradation
- Safety
- N_2O Emissions



SCONOx
Application Experience

- Single-engine demonstration operating since 1996
  - LM2500 co-generation plant
  - 25 MW
  - Plant owned and modified by Sunlaw Energy (developer of SCONOx technology)
- Two future sites planned
  - La Paloma (250 MW near Bakersfield)
  - Sunlaw Los Angeles (840 MW near downtown Los Angeles)

Low-Temperature SCR Application Experience

- Gas-fired CT Experience
  - 4,000 MW capacity worldwide / few operating problems
  - NOx conversion 60-90% / multi-year catalyst life
- Oil-fired CT Experience
  - One operating unit worldwide (Sweden)
  - Inconsistent operating history
  - Significant HRSG plugging with S > 0.2 %

High-Temperature, Simple-cycle SCR Application Experience

- Gas-fired CT Experience
  - Five operating units in US with mixed operating histories
  - Most sites experiencing premature catalyst life (< 2-year guarantee level)
- Oil-fired CT Experience
  - One operating unit in world (Puerto Rico)
  - Catalyst unable to meet NOx emission and ammonia slip guarantees

High-Temperature, Gas-fired SCR Operating Site

- Side view of diverging section of SCR transition duct exiting GE Fame 5 simple-cycle CT

- High-temperature SCR catalyst reduction from 42 ppm to 9 ppm

- Peaking application (~400 hours/year)

Ultra Low NOx Technology Comparison Summary

Feature	Low NOx + SCR	Low NOx + SCONOX	Catalytica
Emissions (ppm)	< 3	< 3	< 3
Environmental/ Safety Impacts	Some	Some	Few
Application Limitations	Some	Many	Many
Cost Impacts	High	Highest	Low
Proven in Practice	Yes	In Process	In Process

Summary

- Key issues identified
- Recent research reviewed
- Seeking perspective on future research activities
  - Content of a technical assessment guide
  - Credible “third party” evaluation of exiting ultra-low NOx technology demonstrations
  - Focused “first use” field demonstration study
  - Workshops, roundtable, focus groups

Application and Control of Combustion Systems Reciprocating Internal Combustion Engines

CEC-EPRI Workshop
October 28, 1999

Jay A. Burnette
Marketing
Fairbanks Morse Engine Division
Chicago, IL

Traditional Technology

Gas and Dual Fuel Engines (Gas/Diesel) - 1988 to 1992

- **Best Available Control Technology (B.A.C.T.)**
  - Air/Fuel ratio adjustment
  - Injection timing retard
  - Air manifold temperature reduction
- **B.A.C.T. Results**
  - NOx emissions reduction - 40%
  - Impact to thermal efficiency - 15 to 30%
- **Commercial Product Capability w/ B.A.C.T.**
  - S.I. Gas - 32 to 38% efficiency (2.5 g/bhp-hr NOx)
  - Dual Fuel - 40 to 43% efficiency (4.5 g/bhp-hr NOx)

Low Emission Technology

Gas and Dual Fuel Engines (Gas/Diesel) - 1992 - 1999

- **Lean Burn Combustion**
  - Pre-combustion chamber technology
  - Advanced turbocharging
  - Ignition system advancements
- **Micro-Pilot Ignition (Dual Fuel)**
  - Pre-combustion chamber technology
  - Reduced pilot diesel charge = LOWER NOx
- **Selective Catalytic Reduction (SCR)**
  - Catalyst (Zeolite) / Reagent (Ammonia)
  - Reduction Efficiencies (R.E.)>90% but **EXPENSIVE**

Current Product Performance

- **Spark Ignited Gas Engines**
  - Brake Thermal Efficiency - up to 40%
  - NOx - 0.7 grams/bhp-hr (~65-70 ppm)
  - SCR's utilized only in critical non-attainment areas
- **Dual Fuel Engines**
  - Brake Thermal Efficiency - up to 43%
  - NOx - 1.0 to 1.5 grams/bhp-hr (~85-90 ppm)
  - SCR's utilized only in critical non-attainment areas

Emissions Measurement
"grams/bhp-hr" vs. "ppm"

- **NOx in Grams/bhp-hr**
  - Representative of permit requirements, i.e. "lbs/hr" or "tons/year"
  - Specific NOx output
- **NOx in Parts per Million (ppm)**
  - PPM figures vary by oxygen content in exhaust stream
  - Higher oxygen content or higher "flow" results in lower ppm figures
  - "<u>Solution to pollution is dilution</u>"

Application Experience - FM

<u>San Francisco State University</u>

Equipment - 1 x 1,300 kW Dual Fuel
Application - Cogeneration
175° F Hot Water
Thermal Efficiency - 41%
NOx Emissions - 1.0 gram/bhp-hr
CO Emissions - 2.0 grams/bhp-hr

Application Experience - FM

Staten Island University Hospital

Equipment - 1 x 2,370 kW Dual Fuel
Application - Cogeneration
175 psig Steam

Thermal Efficiency - 41%
NOx Emissions - 1.0 gram/bhp-hr
(w/o SCR Reduction - Zeolite/NH_3)
90% R.E. - ~0.1 gram/bhp-hr
- or - 10 ppm
CO Emissions - 2.0 grams/bhp-hr

ARES Program

- RD&D Program for Advanced Reciprocating Technology
- Program Participants
  - U.S. Department of Energy
  - Industry - Reciprocating Engine Manufacturers
  - National Laboratories
  - Universities
- Goals Include Major Efficiency Gains and NOx Reduction (>50% Eff. / 0.1 g/kW-hr NOx)
- Specific Program Structure TBD

ARES Program

Engine Manufacturers

ARES

Advanced Reciprocating Engine Systems

DRESSER Waukesha

CAT® Gas Engines

BFGoodrich

Fairbanks Morse
Engine Division

Cummins

COOPER ENERGY SERVICES

ARES Program Technology

- "Knock" Mitigation Model
  - Higher BMEP's required to achieve goals
- Development of "Ultra-Lean" Combustion
- Advanced Micro-Pilot Ignition - Dual Fuel
  - Pre-combustion chamber vs. open chamber
- Exhaust After-Treatment Development
  - SCR for "lean burn" combustion
  - Oxidizing catalyst for "rich burn"
- Other Materials / Technology Advancements?

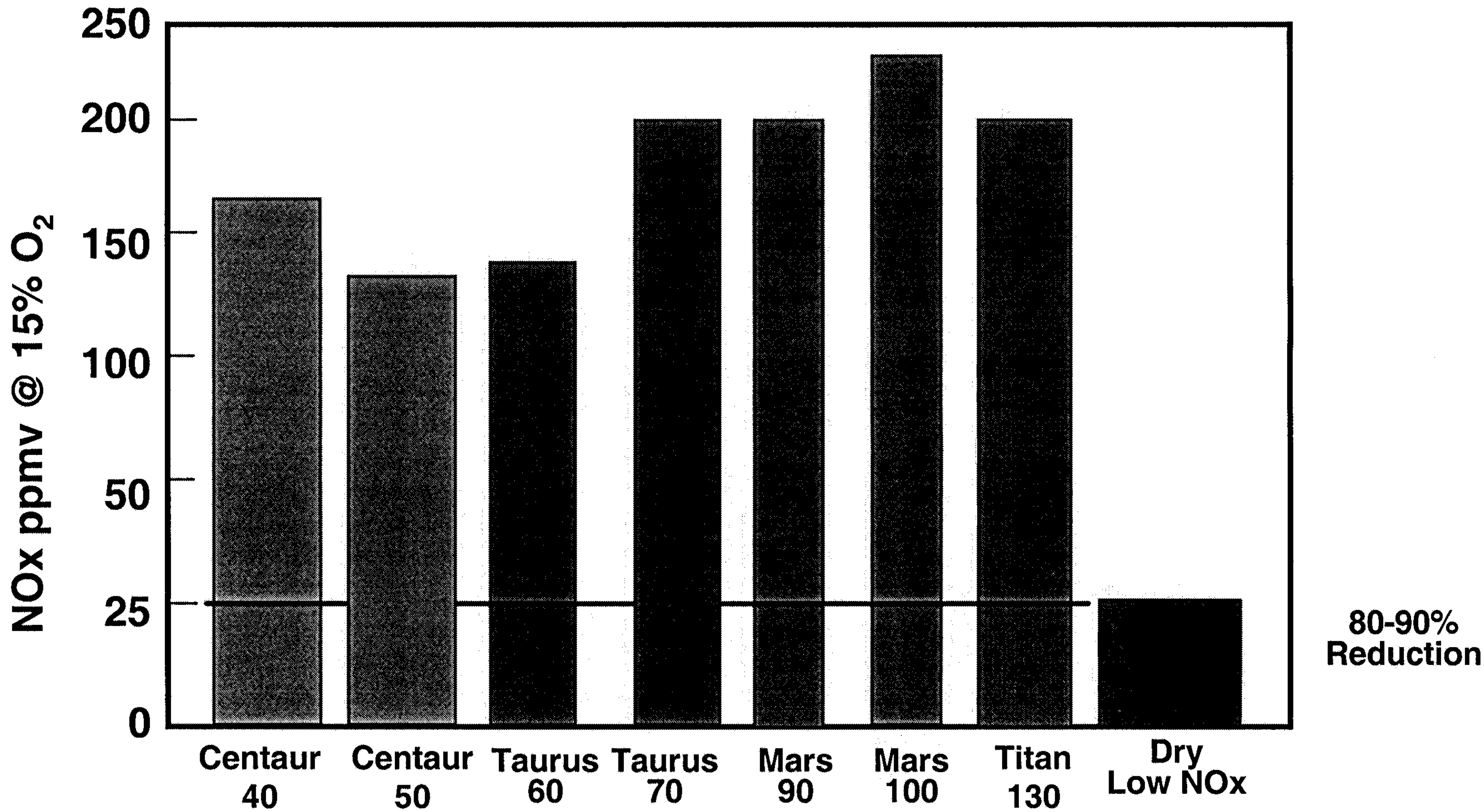
Environmental Signatures of Mid-range Gas Turbine Systems

CEC-EPRI Workshop
October 28, 1999

Leslie Witherspoon
Solar Turbines, Inc.
San Diego, CA 92186

Dry NOx Levels

Natural Gas Fuel



Future Plans of Manufacturer's

- Maintain Focus on RAM-D
- Continue Development of Dual-Fuel Options
- Add Fuel Flexibility

Advanced Combustion Benefits

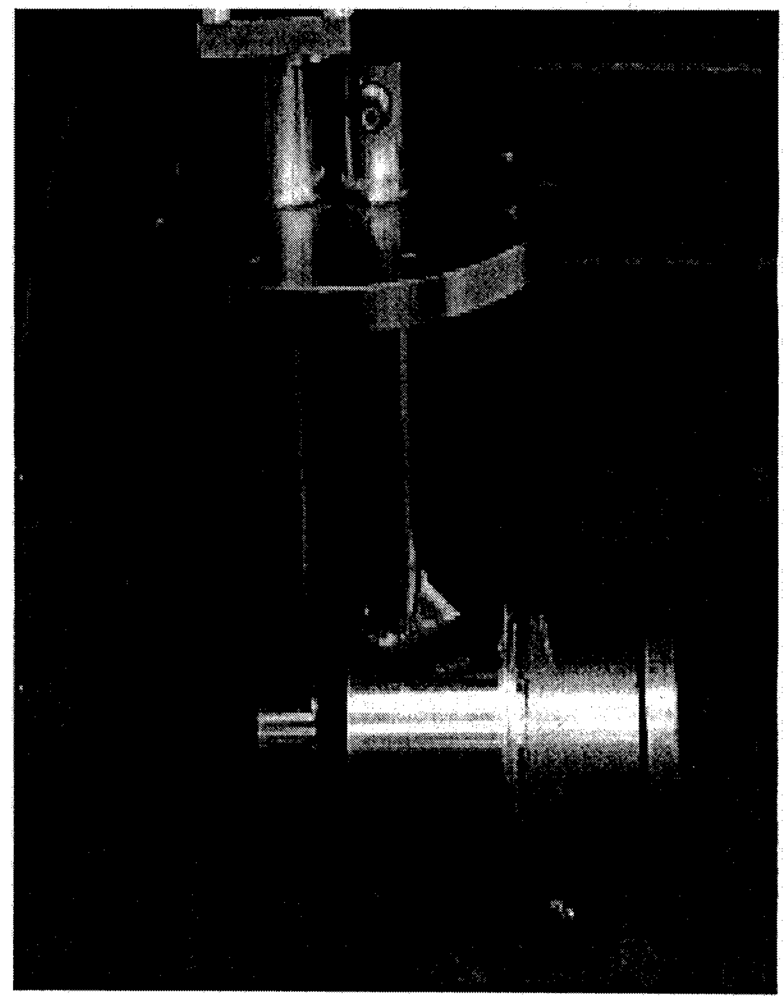
- Lower Emissions
  - NOx
  - CO
- Improved Part-Load Efficiency
- Wider Low Emissions Operating Range

120-024

LW4

Variable Geometry

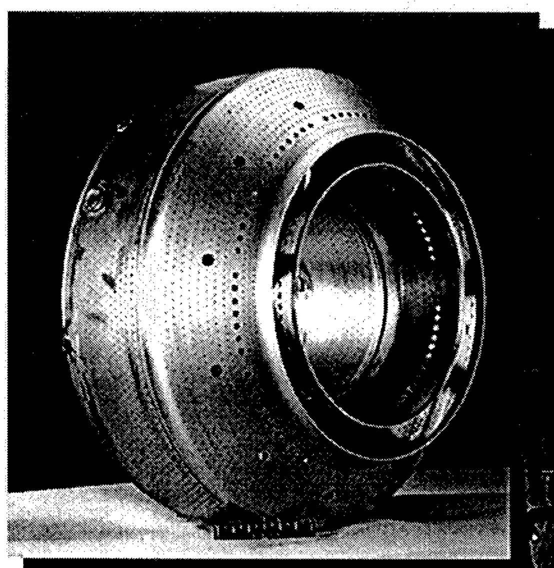
- Definition: Method of Controlling Primary Zone Airflow
- Used to Maintain Constant Flame Temperature
- Extends Low Emissions Operating Range



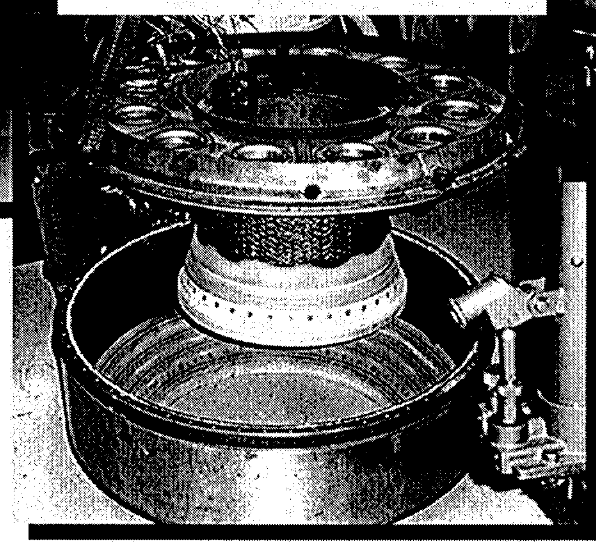
cws

Advanced Hot Wall Combustor Comparison

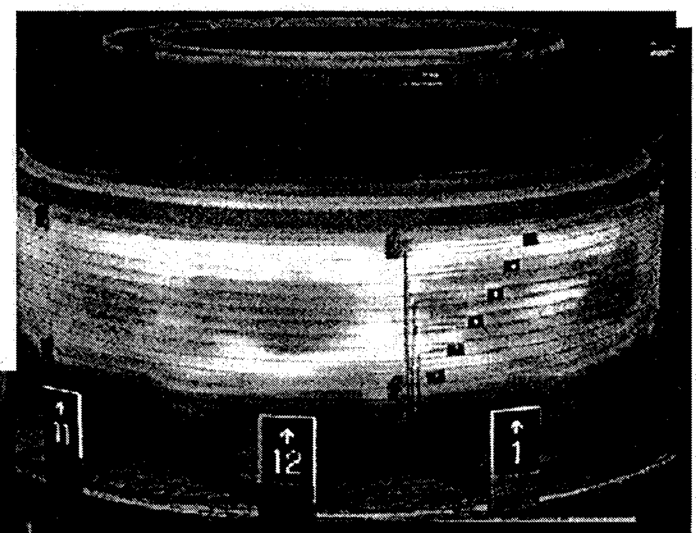
EFFUSION-COOLED



CERAMIC



ABC



120-045

cw 6

Advanced Turbine System Program Goals

- Efficiency - 15% Higher than 1991 Baseline Turbines
- Emissions - Single Digit NOx (ppmv)
- Life-Cycle Cost - 10% Lower Cost of Power
- RAM-D - Improved Reliability, Availability, Maintainability and Durability
- Mercury 50 - first commercial product

CW7

Advanced Technology Development

- Technologies Being Assessed to Further Reduce Emissions
- Challenges to Achieve Reductions
  - Good Durability
  - Acceptable Life-Cycle Cost

120-062

LW8

Selective Catalytic Reduction (SCR)

- In the SCR process, ammonia is injected into the gas turbine exhaust stream as it passes through the HRSG reacts with NO_x in the presence of catalyst to form N_2 and H_2O
- Conventional, Low Temp, and High Temp
- Applied to very small population of small gas turbines - most SCR applications are on standard combustor turbines (90% reduction, 150-190 ppm to 15-19 ppm)
- Not proven for variable loaded applications
- Very expensive for small gas turbines - incremental cost over a DLN, assuming technical feasibility, $15,000-$20,000/ton of NOx removed

LW9

SCONOx

- SCONOx™ catalytic absorption system controls both CO and NO_x without the use of NH_3
  - Oxidizes CO to CO_2 and NO to NO_2
  - CO_2 exhausts to the atmosphere
  - NO_2 is absorbed into a coating applied on top of the oxidation catalyst
- Limited temperature range
- Not demonstrated on variable loaded applications
- Very expensive for small gas turbines - incremental cost over a DLN, assuming technical feasibility, $25,000/ton of NOx removed

CW9

Taurus 60 SoLoNOx Add-on Control Incremental Cost Comparison

	DLN (@25 ppm)	SCR (@ 3ppm)	SCONOx (@ 2 ppm)
Basic Equipment Cost	$165,000	$305,000	$775,000
Total Annual Cost	$ 41,295	$423,337	$590,815
$/ton NOx removed	$369	$ 19,243	$ 25,688
$/kw-hr	0.00095	0.00969	0.01353

- Based on OAQPS cost estimating methodology
- Includes basic equipment cost, auxiliary equipment, instrumentation, monitoring, taxes, freight, direct and indirect costs, installation, operating and maintenance costs (including utilities, monitoring), overhead and administration, insurance, and property tax.

CW 10

Summary

- New technologies must be economically viable in the marketplace
- In the regulatory push for lower and lower emissions the following factors need to be considered
  - Cost of combustion control technology or add-on control system
  - Operating load range and ambient temperature range over which low emissions can be satisfied
  - Fuel flexibility limitations
  - Next generation vs. retrofittable

LW11

A Brief Overview of Alzeta Products and Technology

CEC-EPRI Workshop
October 28, 1999

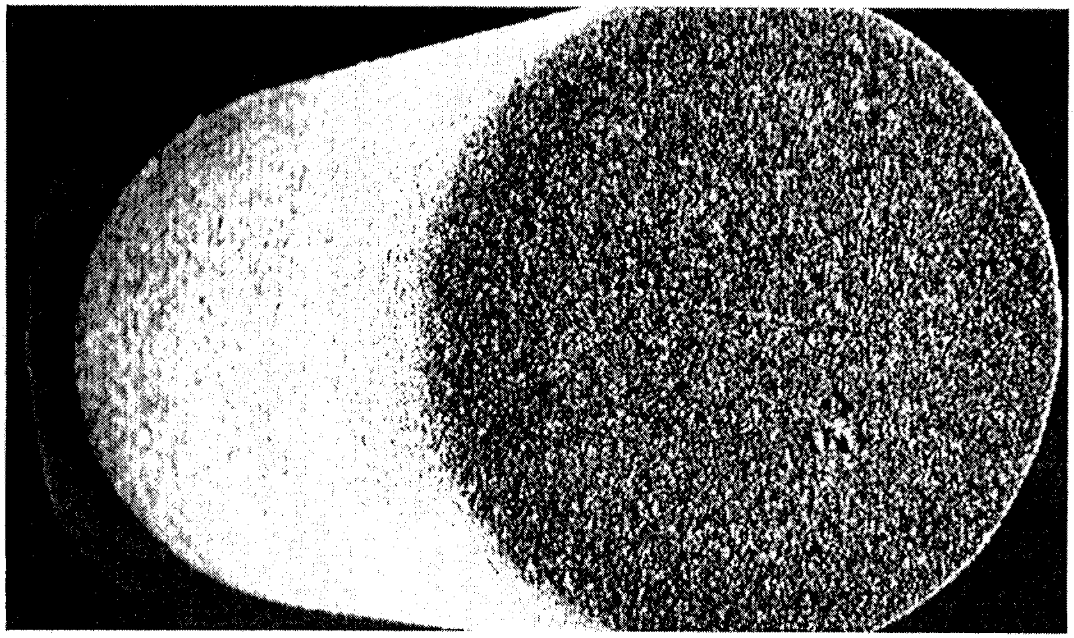
Scott Smith
Alzeta Corporation
Santa Clara, CA

Products and Services

- VOC Abatement Systems (50%)
  - Catalytic and Thermal Oxidizers
  - Turn-key Systems (includes Concentrators, Heat Recovery, Scrubbers, Process Feed Systems etc.)
  - OEM Technology Supply (BOC Edwards)
- High Performance Pre-mix Surface Combustion Burners (25%)
  - OEM Burner Components to Equipment Manufacturers
  - Industrial Burner Systems to End Users
- Technology Development (25%)
  - Commercial, Institutional and Government Contract R&D

Pyrocore

- Pyrocore is a porous ceramic matrix



- 9 ppm NOx at 3% O_2.
- Commercial boilers.
- Plastics Dryers.
- Sizes Range from 30,000 - 2.0 Million Btu/hr

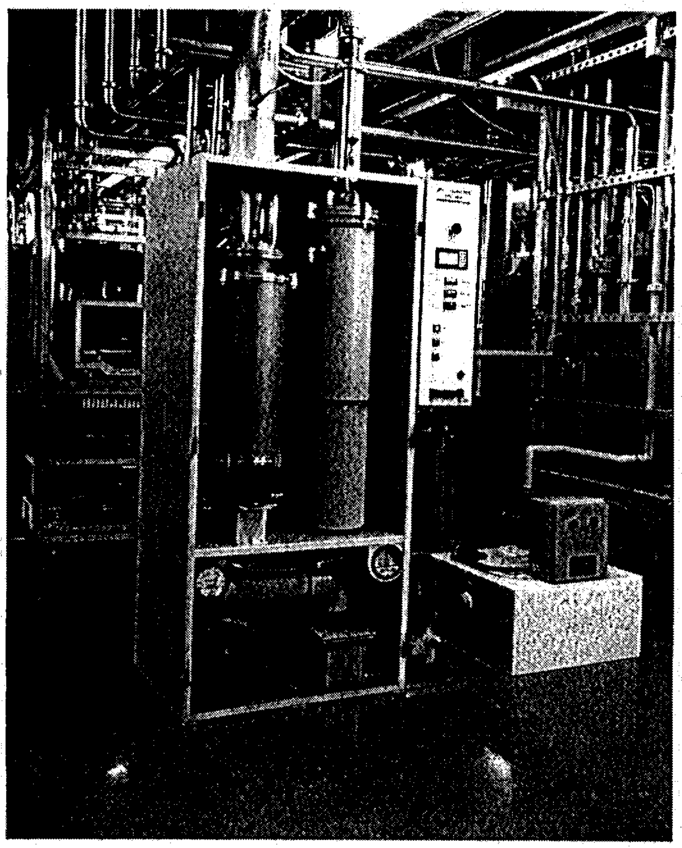
Pyromat CSB

- 9 ppm NO_x guarantee at 3% O_2.

  - Commercial and Industrial Boilers
  - Process Heaters

  - Sizes Range from 2 - 125 Million Btu/hr

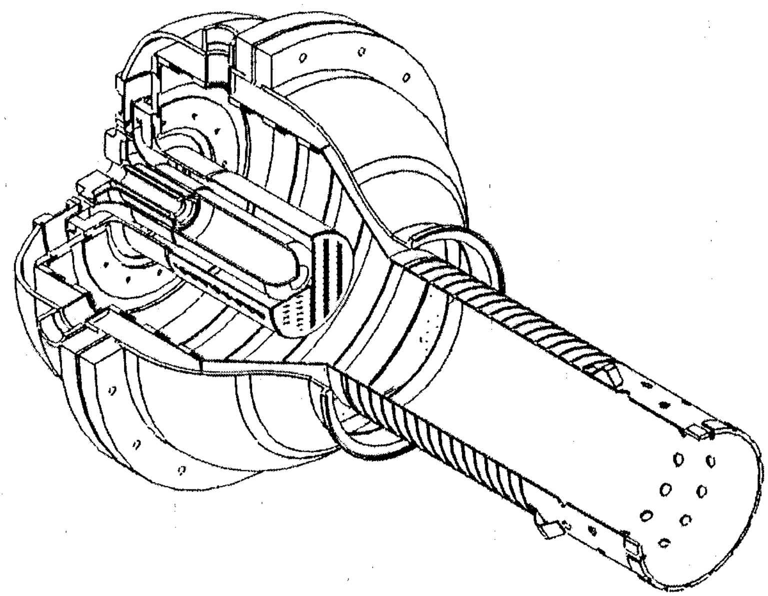
BOC Edwards TPU/TCS



- Point-of-Use CVD/Etch PFC Gas Abatement
- Small Capacity Flows (200 slpm)
- Handles Particulate and Acid Forming Gases (Silane, C_2F_6, NF_3, ClF_3...)
- High DRE, Reliability
- Lower Cost TCS system recently introduced

Gas Turbine Combustors

- Less than 2 ppm NO_x achieved at 15% O_2.



- Prototype testing inside the AlliedSignal TurboGenerator are scheduled for November.
- Two can tests at Solar Turbines have occurred and qualification for engine tests is planned.

Effective Destruction of Gaseous Emissions

ALZETA CORPORATION
Santa Clara, California, USA

The XONON
Catalytic Combustion System

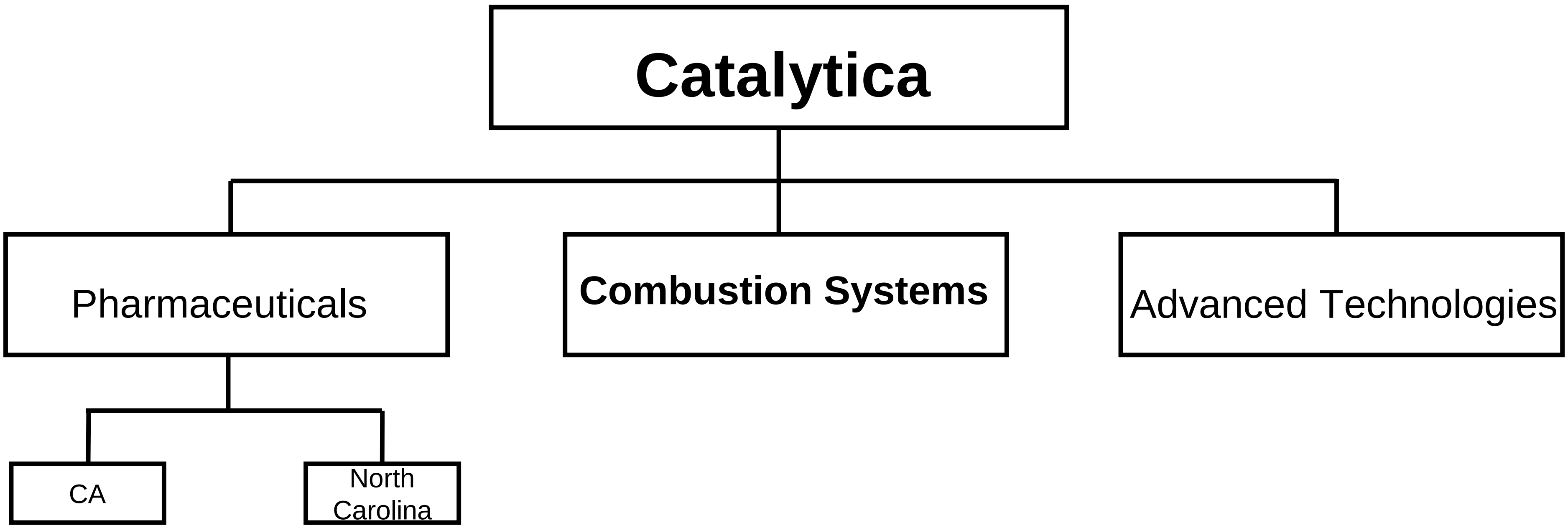
CEC-EPRI Workshop
October 28, 1999

J. Charles Solt
Director of Regulatory Affairs
Catalytica Combustion Systems, Inc

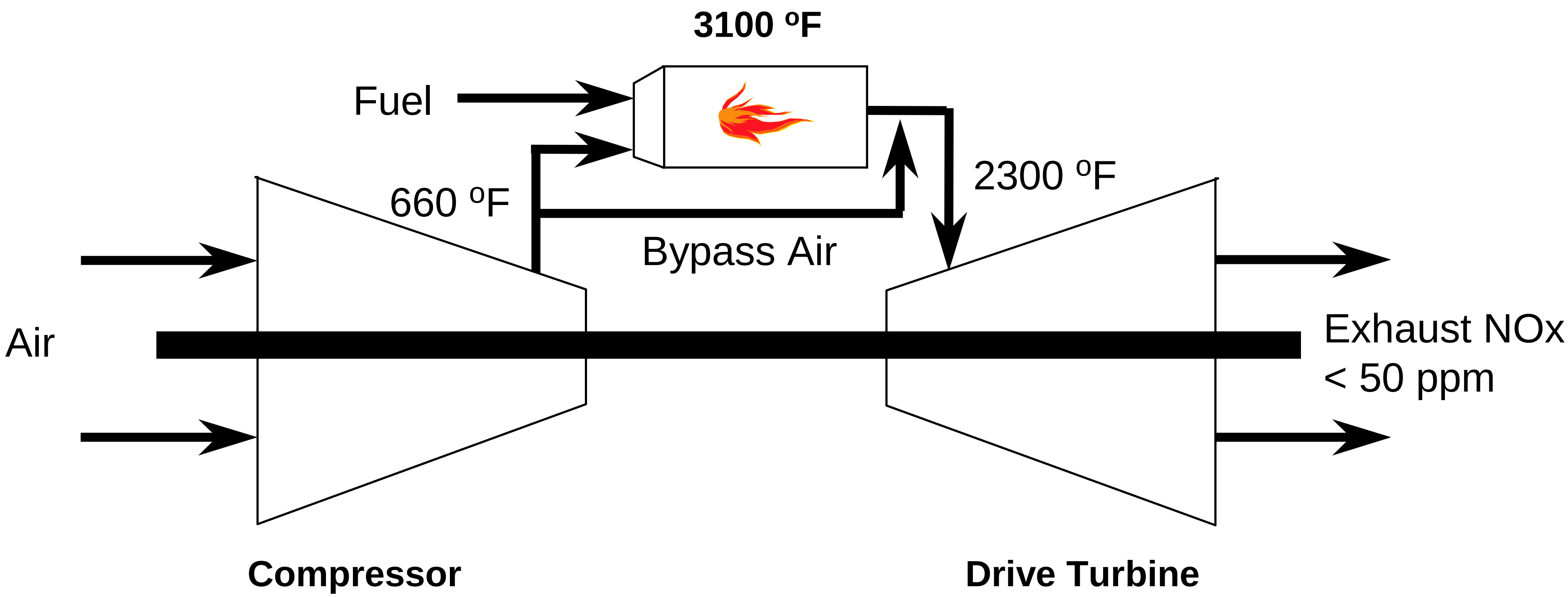
Catalytica
Combustion Systems

Catalytica, Inc.

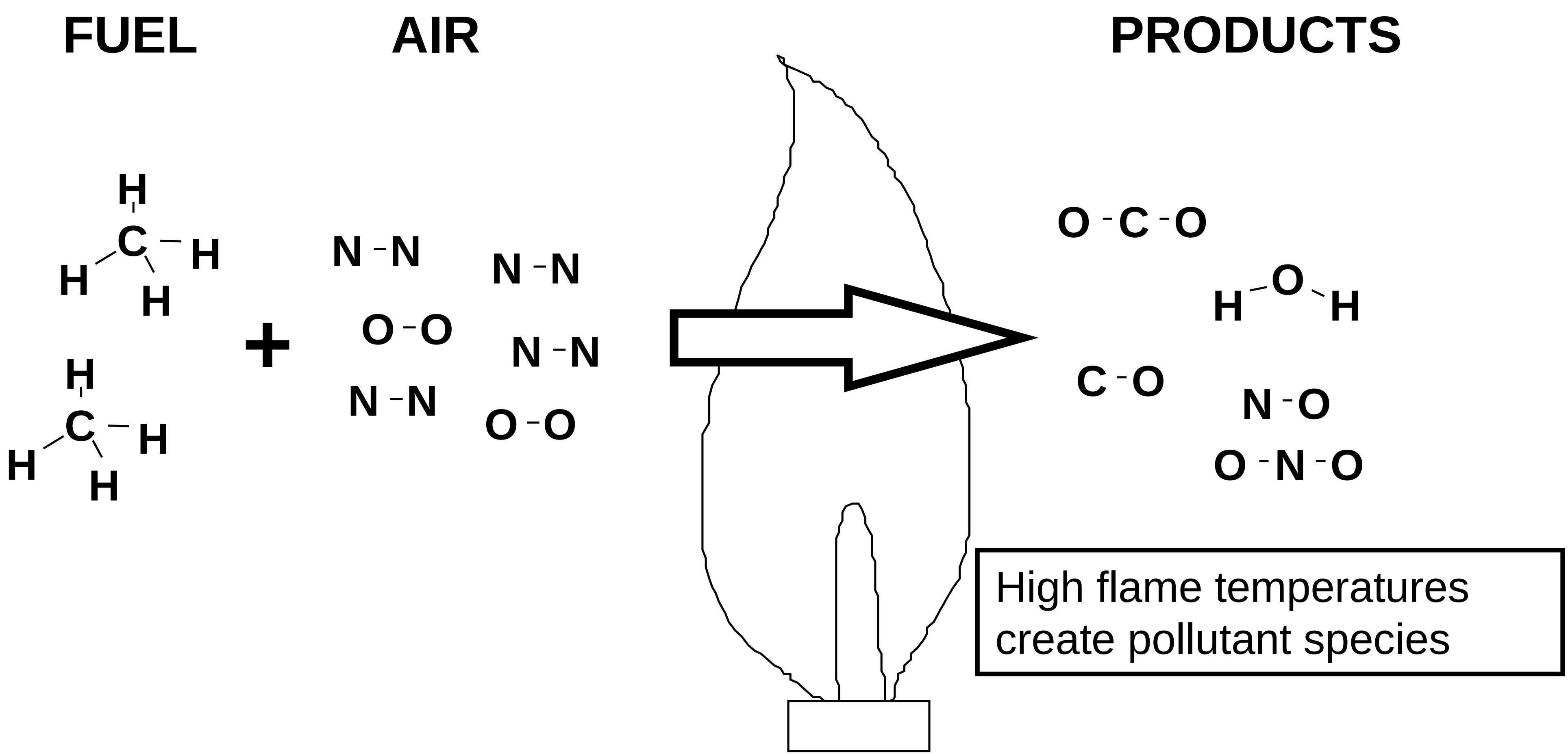
- NASDAQ (CTAL)
- Market capitalization of ~$800 million
- 1,400 employees



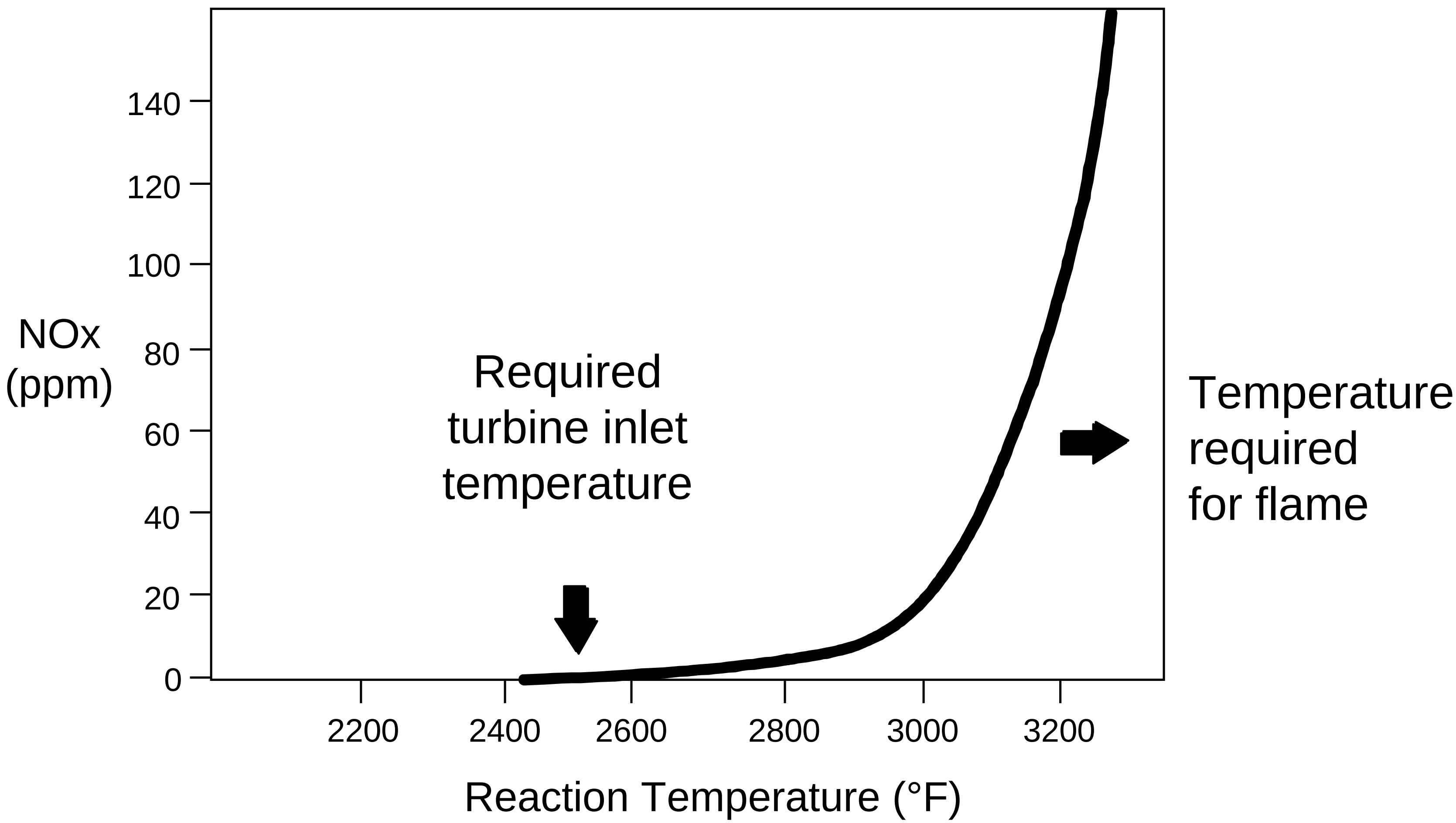
Flame Combustion Generates High NOx



Challenge of flame chemistry



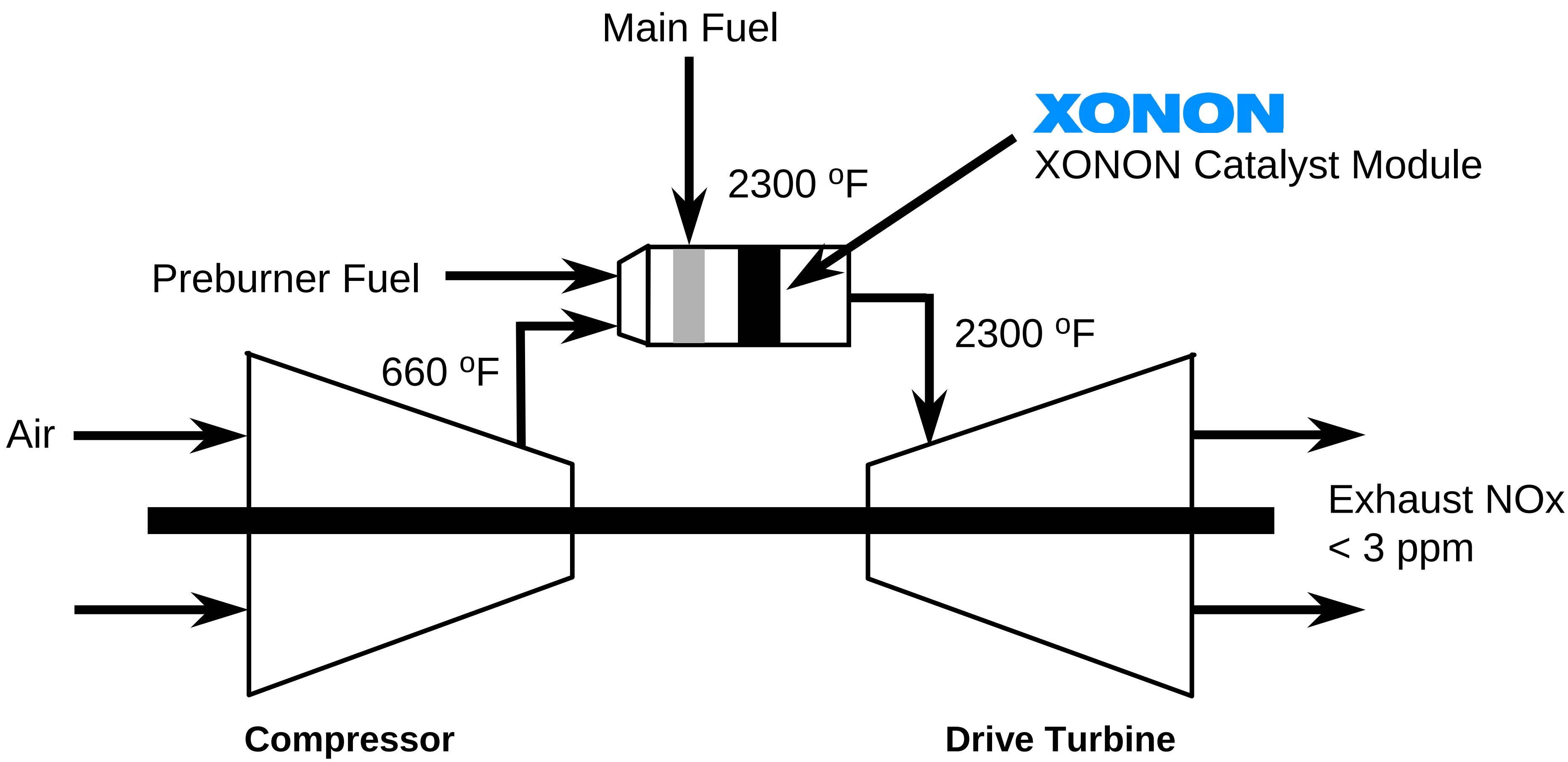
High Temperatures Cause High NOx Levels



Options for Limiting NOx Emissions

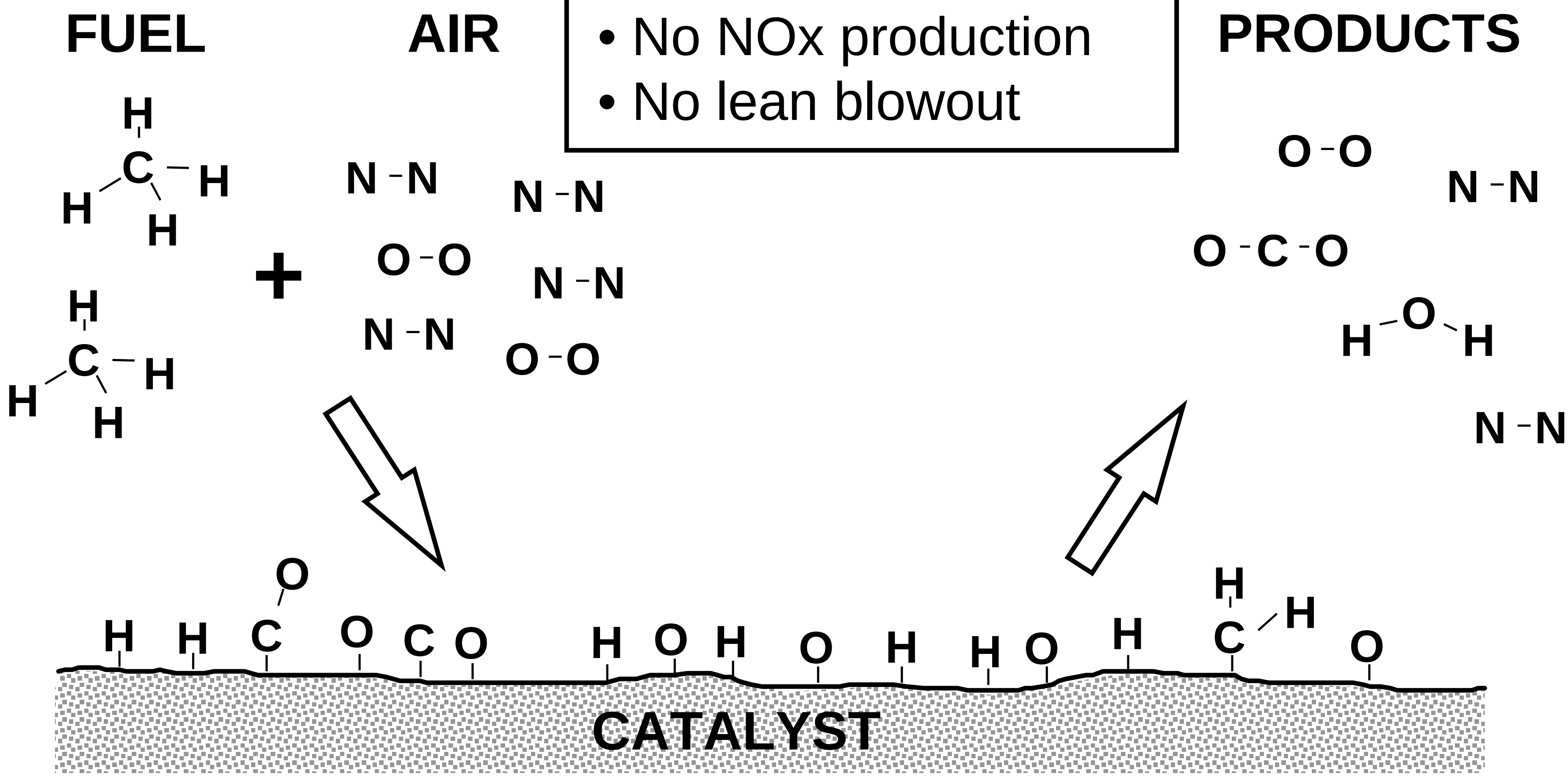
- Inject water or steam diluent to decrease flame temperatures
  - Insufficient impact
  - Expensive water processing
- Operate at lowest possible flame temperature (“lean premix”)
  - Practical limit: ~15 ppm NOx
  - Unstable flame causes machine vibrations
- Remove NOx from exhaust stream
  - Selective Catalytic Reduction (“SCR”) using ammonia
  - Costly to install and operate
  - Requires combustor controls as well
- XONON catalytic combustion

XONON Combustion System



Advantages of catalytic chemistry

- No NOx production
- No lean blowout



XONON Programs

- General Electric
- Kawasaki
- Pratt & Whitney Canada
- Solar Turbines
- Rolls Royce/Allison Engine Company
- Other contracts in progress: to be announced

Results – 7/9E Test Rig

- Full load performance
  - NOx 1.7 ppm
  - CO 1.3 ppm
  - UHC 0.0 ppm

Tulsa

OBJECTIVES

- demonstrate XONON technology on a gas turbine
- develop performance database for further technology development

Tulsa

RESULTS

- 1,057 hours operation
- 206 fired starts to FSNL
- emissions:
  - NOx < 3 ppm
  - CO, UHC < 10 ppm

Silicon Valley Power (shakedown)

OBJECTIVES

prepare facility for extended durability testing

re-establish baseline operation with XONON 1 combustor

establish reliable connection with utility grid

develop control system for unattended operation

design improvements for increased reliability

Silicon Valley Power (shakedown)

RESULTS

- 322 hours, 332 starts
- connection to utility grid
- full-time, unattended operation achieved
- improved XONON 2 combustor

Silicon Valley Power (RAMD)

OBJECTIVES

- run for 8,000 hours to develop prediction for long term reliability
- satisfy contractual funding obligations (DOE, CEC, GRI, others)
- provide a development platform for technology improvements
- provide a showcase for XONON technology
- provide sufficient operation to demonstrate that the XONON technology is *achieved in practice*

Silicon Valley Power (RAMD)

RESULTS (through 8/99)

- Over 1,700 cumulative hours,
- 25 starts
- 94% uptime
- Average emissions:
  - NOx < 1.5 ppm
  - CO, UHC < 2.0 ppm

XONON is Working

- Proven environmental performance
  - $NO_x < 2.5$ ppm
  - CO and UHC < 6 ppm
- Key performance validation
  - Low combustor dynamics/vibration
  - Enhanced pattern factor vs a standard combustor
  - Robust operation—throughout the engine load range and during operating transients
  - Performance and efficiencies comparable to a standard combustor
  - Improved lifecycle costs

XONON Summary

- Major breakthrough reducing NOx emissions
  - < 2.5 ppm NOx
  - < 6 ppm CO and UHC
- No impact on turbine operations
  - Low vibration/noise
- XONON for KHI M1A-13A commercially available.
- Commercial adaptation for other turbines underway.

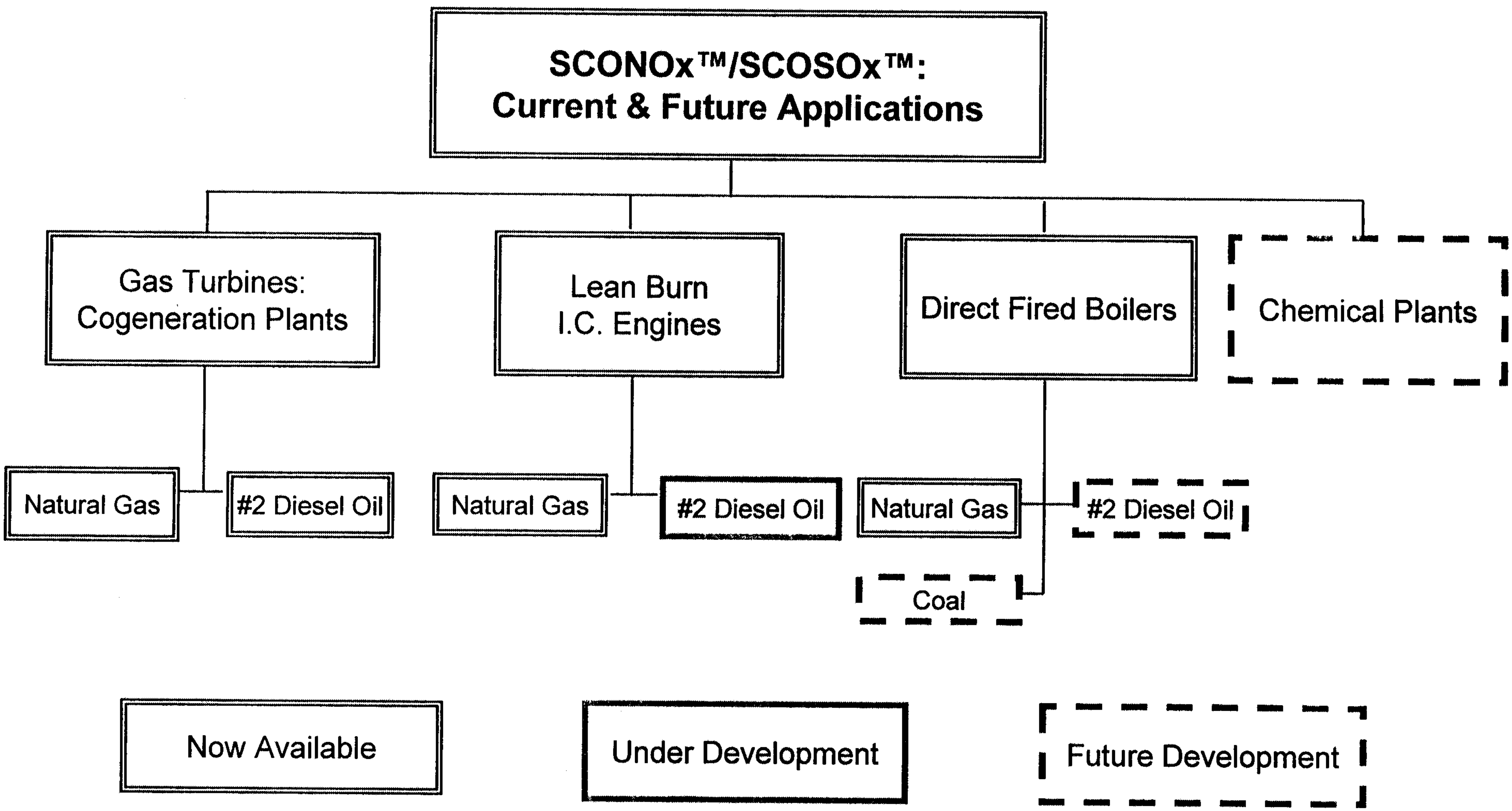
SCONOx™

Catalytic Absorption Technology

CEC-EPRI Workshop
October 28, 1999

Richard Davis
Marketing
GOALLINE Environmental Technologies

SCONOx™ / SCOSOx™ Current & Future Applications



GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ Brand Products

- **SCONOx™ GT** for Gas Turbines
- **SCONOx™ IB** for Industrial Boilers
- **SCONOx™ IC-D** for Diesel IC Engines
- **SCONOx™ IC-N** for Natural Gas IC Engines

GOAL LINE
ENVIRONMENTAL TECHNOLOGIES

SCONOx™ Highlights

- Achieves Very Low Emissions
  - » Less than 2.0 ppm NOx Outlet
  - » Greater than 90% CO, VOC
- Simple Operation
  - » No ammonia is used, thus eliminating ammonia slip and ammonia onsite storage, handling and storage
  - » No byproducts are generated
  - » No aqueous solutions involved
- Wide Operating temperature Range
  - » 300°F to 700 °F
  - » High conversion on cold start and shutdown
  - » High conversions for fluctuating emissions

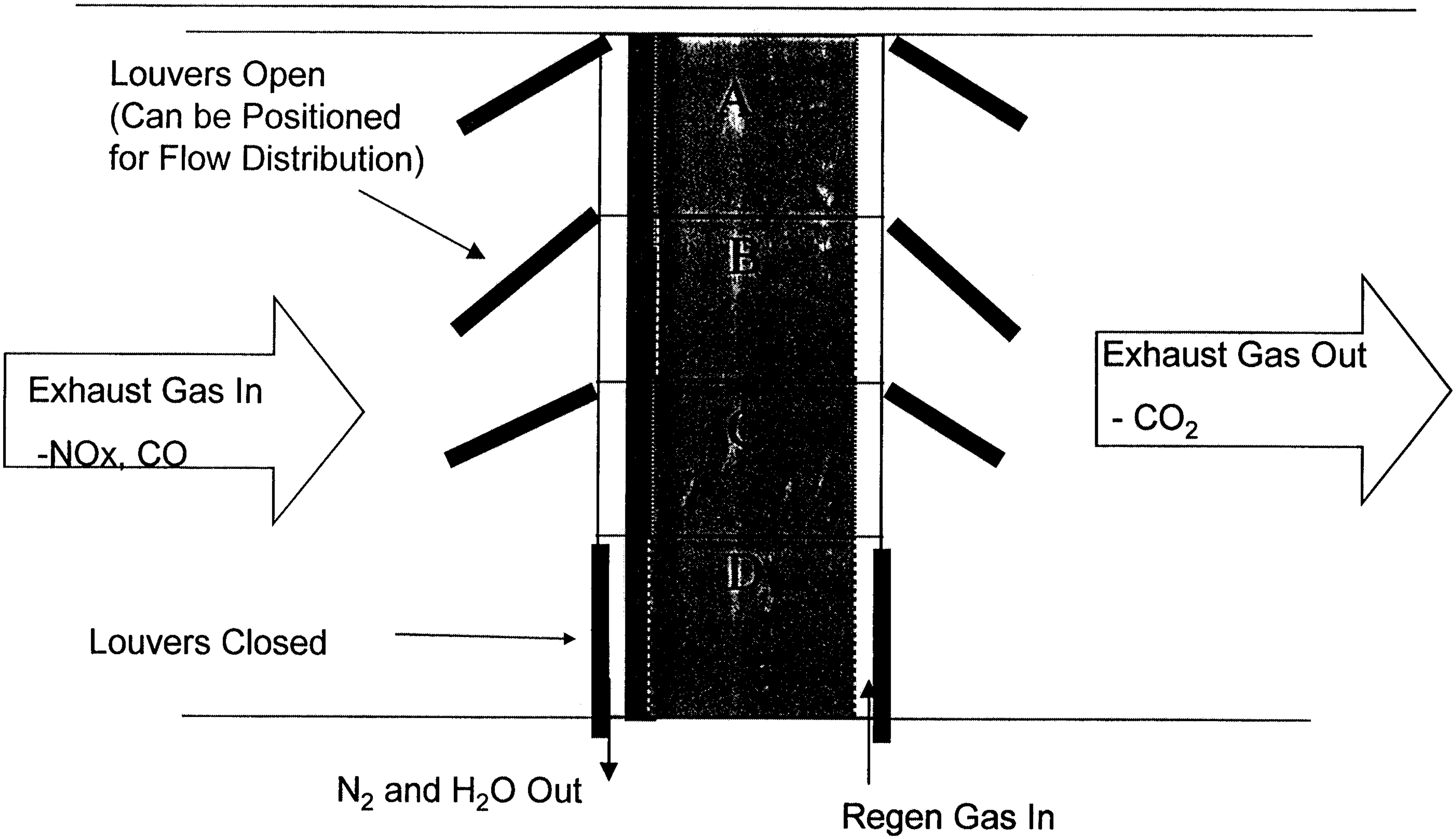
GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ System: General Description

- Single System Emissions Control for NOx, CO, and VOC
  - » Oxidizes CO to CO_2
  - » Oxidizes NO to NO_2
  - » Oxidizes VOC to $CO_2 + H_2O$
  - » Absorbs NO_2 onto its Surface Through Use of Absorber Coating
- Isolation Capability for Regeneration
- Regeneration Gas Reacts With Nitrites and Nitrates to form H_2O and elemental nitrogen, N_2

GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ GT: General Process Flow



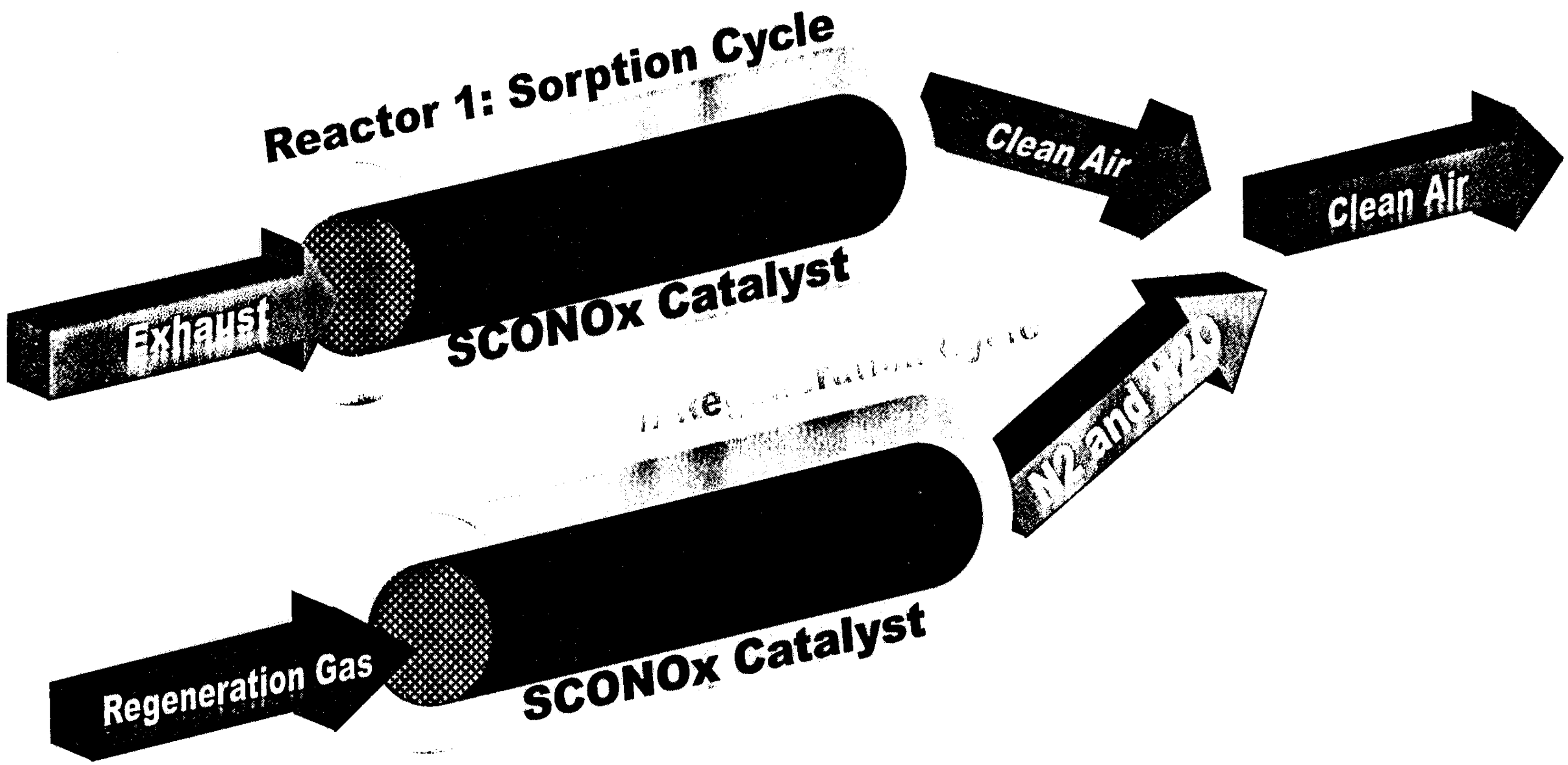
GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ GT: Operating Results

- Two systems in operation
  - » 30 MW Federal Cogeneration Plant
  - » 5 MW Genetics Institute Cogeneration Plant
- NOx — Below 0.8 ppm
- CO — Below Detectable Limits
- VOC
  - » Formaldehyde 97% @ 300°F
  - » Acetaldehyde 94% @ 300°F
- No Lost Plant Availability

GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IB: Industrial Boiler System



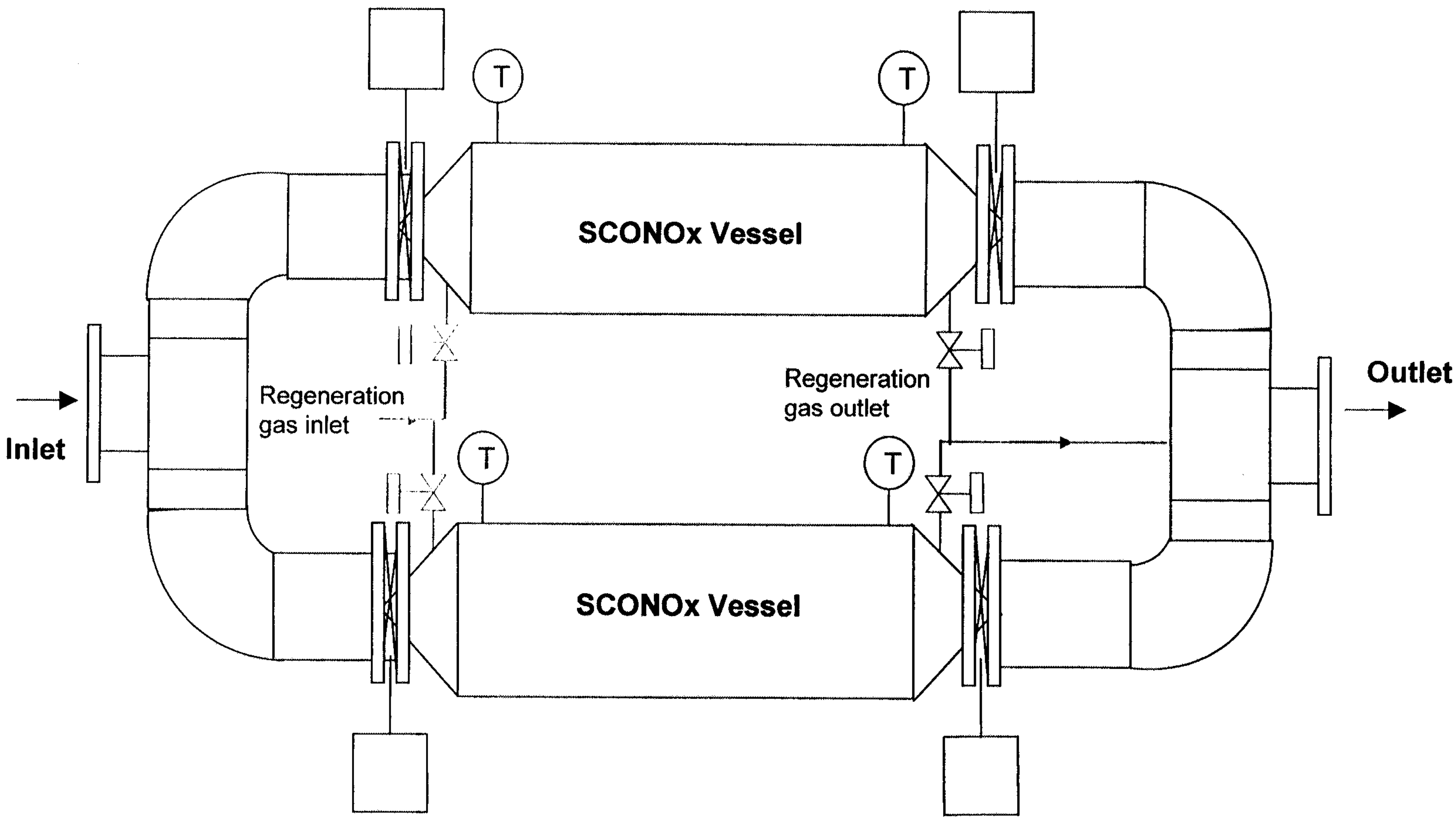
GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IB: Features & Benefits

- Low Capital & Operating Cost
  - » Less Capital Cost than SCR or LTO Technology
  - » Operating cost of 400 HP Boiler
    - > Natural Gas $0.13/hr
    - > Electricity $0.70/hr
- Simple Mechanical Operation
  - » Blower and Valves are only Moving Parts
- Small Equipment Footprint
  - » No Reagent Storage
  - » 400 HP Boiler Skid
    - > 8' long x 7' wide x 7' high
  - » No By-products Generated

GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IC-N: Natural Gas IC Engines



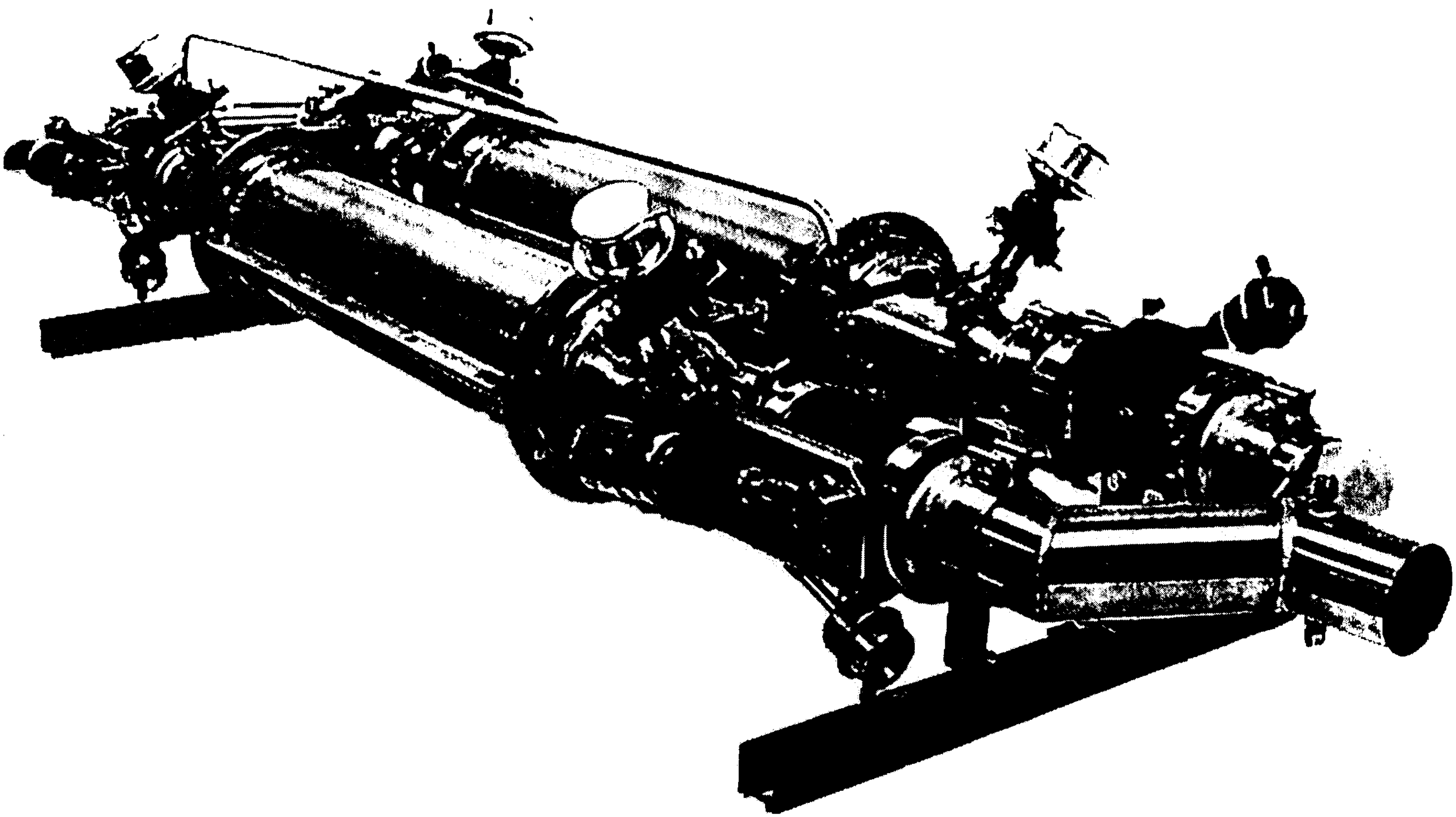
GOAL LINE ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IC-N: Engine Operational Benefits

- Flexibility to tune engine for maximum performance regardless of emission levels.
- Extended engine life due to cooler combustion temperatures compared to rich burn settings.
- Increased fuel savings over rich burn natural gas engines.
- Control of multiple air pollutants with a single catalyst.
- Significantly reduced emissions on cold starts due to low temperature performance.
- Ability to meet existing and future emission standards for any size lean burn engine.

GOAL LINE
ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IC-D: Diesel IC Engines



GOAL LINE
ENVIRONMENTAL TECHNOLOGIES

SCONOx™ IC-D: Diesel IC Engines

- Goal Line has been running its LAER/BACT-setting SCONOx system for gas turbines on a diesel engine for the last eight months.
- The result is a “sulfur-regenerable” SCONOx for diesel engines that reduces NOx 90% to 99% and Hydrocarbons and CO by a similar amount.
- SCONOx is the only diesel emission control system that is not poisoned by sulfur; has less than a 2% fuel penalty; and works over a wide temperature range.

GOAL LINE
ENVIRONMENTAL TECHNOLOGIES

Goal Line Commercial Relationships

- **SCONOx GT: Gas Fired Turbines**
  - » Larger than 100 MW
    - > ABB Environmental Systems - Exclusive
- **SCONOx GT: Gas Fired Turbines**
  - » 10 MW - 100 MW
    - > ABB Environmental Systems - Non Exclusive
    - > Licensing Agreements Available
- **SCONOx GT: Gas Fired Turbines**
  - » <10 MW - Goal Line Direct
- **SCONOx IC-D: Diesel IC Engines**
  - » Test Program Underway for Cummins Engine Co.
- **SCONOx GT: Catalyst Manufacturing**
  - » World Wide Manufacturing Agreement with Sud Chemie/United Catalyst

GOAL LINE
ENVIRONMENTAL TECHNOLOGIES

Biomass Applications: Emissions and Controls

CEC-EPRI Workshop
October 28, 1999

Valentino Tiangco
Renewable Energy Technologies
California Energy Commission
Sacramento, CA

What Emissions Can Be Expected From Existing Biomass Power Plants or New Generating Alternatives?

Wheelabrator biopower plant, California

NREL

Emission Controls for Existing Technologies

NO_x - staged combustion, flu gas recirculation, fluidized combustion

Post combustion strategy

-selective non-catalytic reduction (SNCR), called thermal deNO_x

- generally used in ozone non-attainment areas

Emission Controls for Existing Technologies

SOx - limestone (or dolomite) injection

This control method is generally used in PM_{10} non attainment areas because SOx is precursor to PM_{10}

Emission Controls for Existing Technologies

PM emissions are controlled by a cyclone followed by:

-Baghouses - used on fluidized bed design boilers

-Electrostatic Precipitators (ESP) - used on stoker grate design boilers

Emission Controls for Existing Technologies

CO and ROC - controlled by combustion management.

-Fluidized bed boilers are especially effective in minimizing CO and ROC.

Critical Biomass Issues in CA

Diminishing Waste Disposal Options

-Forest health - catastrophic wildfires

-Agriculture - open field burning phase out by 2000

-Solid waste - divert 50% of waste streams from landfill by the year 2000

Increasing Air Quality Concerns

-Open field burning contributes over 13,000 tons/yr of PM, 130,000 tons/yr of CO and 20,000 tons/yr of ROC

-Wildfires contribute an estimated 600,000 tons/yr of air pollutants

Marginal Economics

Conflicting Regulations

Reducing Air Emissions

Decreasing uncontrolled burn emissions

-Reduced open-field burning

-Reduced wildfires

Better control of biomass power plants

-Increased efficiency and reduced emissions through new technologies and co-firing

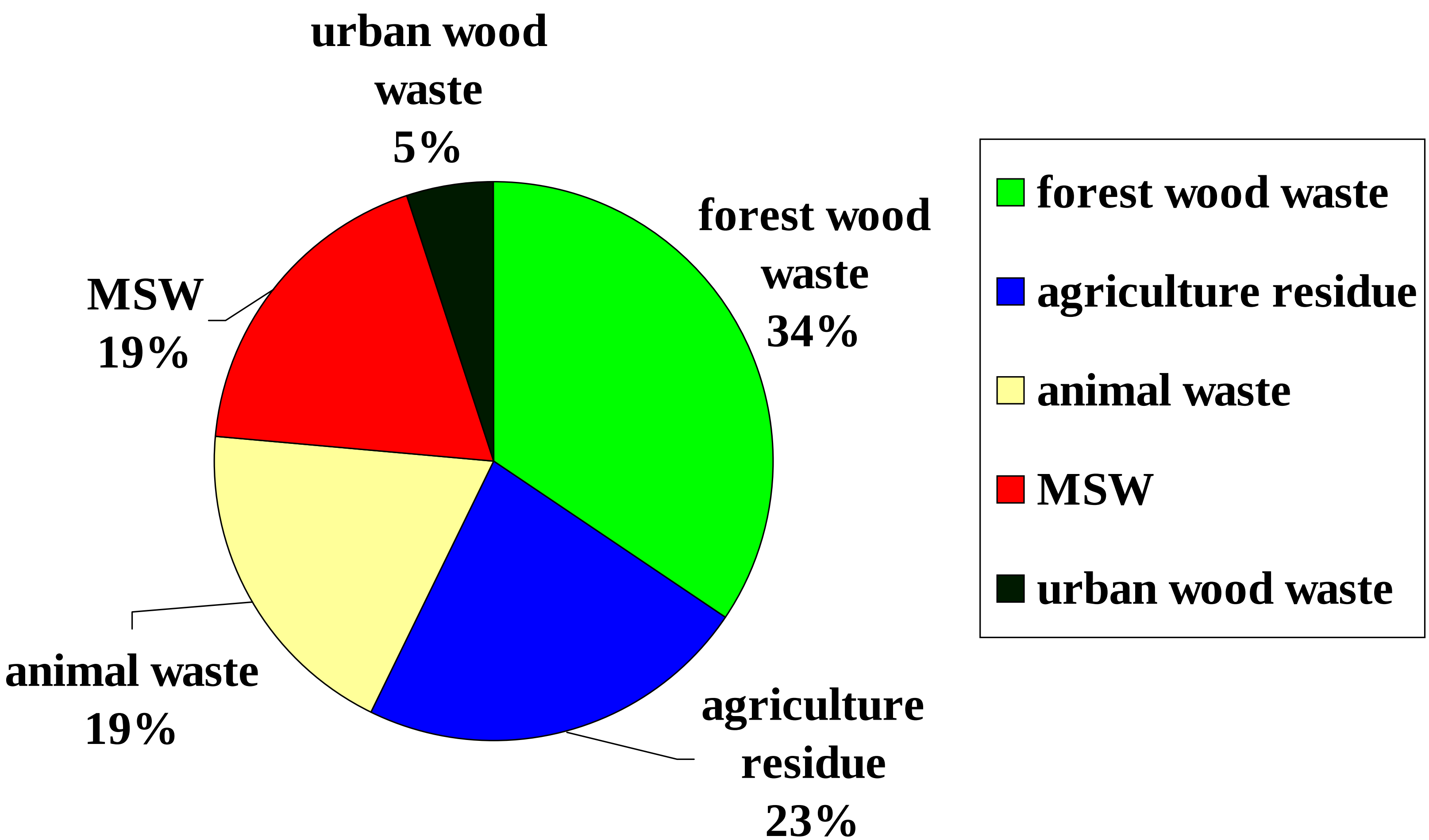
Increasing capture of gases from landfill and livestock manure

Actual Emissions of California Biomass Power Plants

Species	lbs/MWh	tons/yr
NOx	1.9	5,220
SOx	0.3	960
PM_{10}	0.4	1,082
CO	7.6	21,368
ROC	0.58	1,615

All of these plants are able to maintain actual emissions level below permit levels.

Biomass Fuel Supplies
63 Million Tons of Waste Per Year



Emission Reductions for a 21.6MWnet biomass power plant burning offset agricultural residue

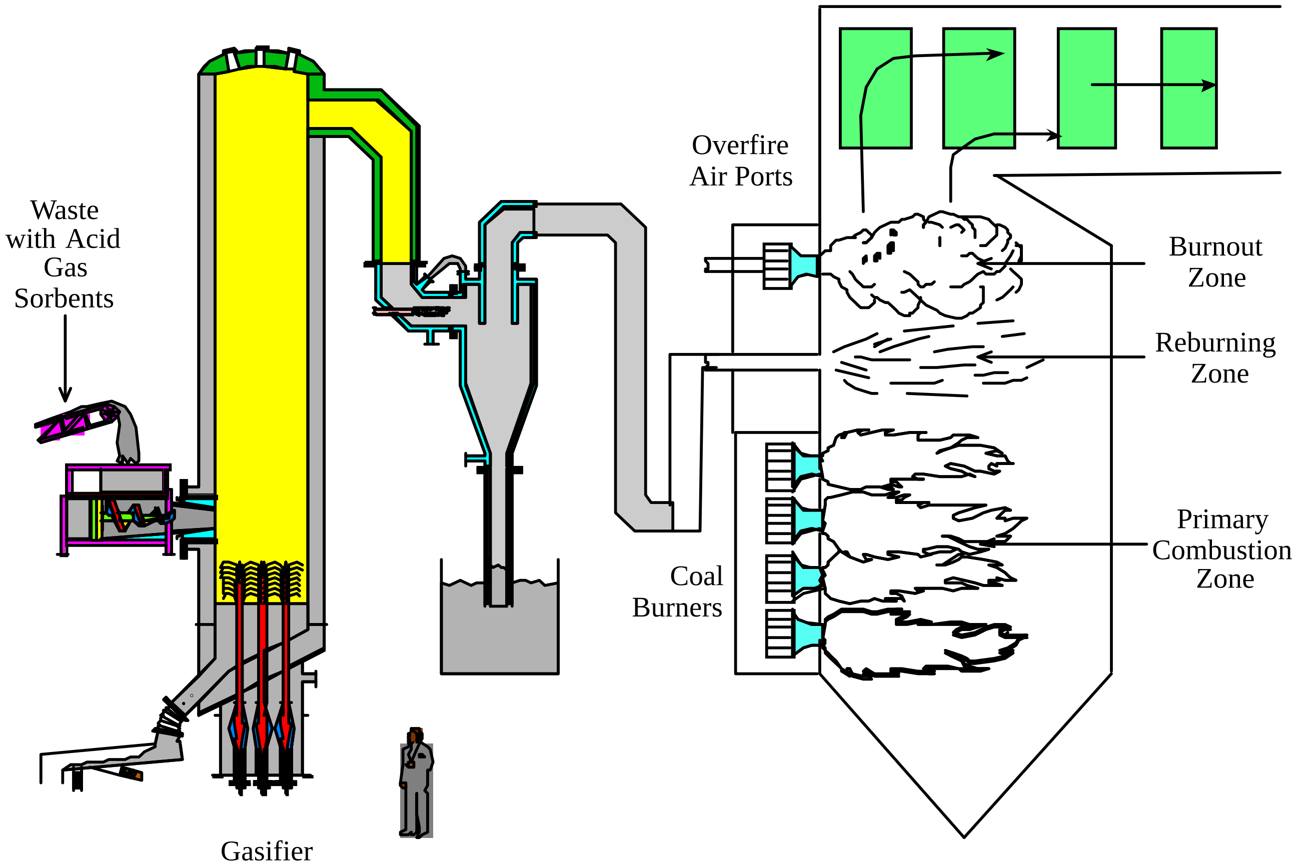
Item	Power Plant		Open Burn		Reductions		
	Permitted Emission (tons/yr)	Source Test (tons/yr)	Emission (tons/yr)	Permit based (tons/yr)	Source Test based (tons/yr)	Permit based (%)	Source Test based (%)
NOx	**98**	**68**	**123**	**25**	**55**	**20**	**45**
SOx	**40**	**0.2**	**62**	**22**	**61.8**	**35**	**99.7**
PM10	**61**	**32**	**174**	**113**	**142**	**65**	**82**
CO	**171**	**22**	**1807**	**1636**	**1785**	**91**	**99**
ROC	**98**	**1**	**199**	**101**	**198**	**51**	**99**

Zero *Net* CO_2 Emissions

Carbon dioxide released by burning biomass is comparable to the amount captured by the vegetation itself while it grows.

When produced and consumed on a sustainable basis, biomass contributes no excess carbon dioxide to the atmosphere.

Coupled Combustion Gasification Technology



PIER-GE EERC project: NOx reduction by 60-90%

Other Technologies

Gas Cofiring in Biomass Boilers

Anaerobic Digestion/Landfill Gas Recovery Systems

Co-location of Biomass-to-ethanol facility to existing biomass boiler

Environmental Benefits of Biomass to Energy

Provides for waste disposal

Extends life of landfill

Reduces open-field agricultural burning

Reduces risk of wildfires

Decreases emissions from ag and forest burning

Improves forest health

Increases diversity of electric generation

NOx Below 5 ppm from Gas Turbines:

A Review of Current Measurement Practice

CEC-EPRI Workshop
October 28, 1999

John Vaught
Principal Consultant
Vaught Engineering Inc.
Scotsdale, AZ

ASME Codes and Standards Gas Turbine Environmental and Fuels Subcommittee B133-SC2

- Writes standards for emission measurement (B133.9)
- Has hands-on measurement experience
- Looked at BACT/LAER determinations
- Decided it was imperative to review measurement practice

Changing NO_x Emissions

Diffusion flame combustors

- Rated load = 95% NO, 5% NO_2
- Low power = 50% NO, 50% NO_2

DLN (lean premix) combustors

- Rated load = 25-40% NO_2
- Low power = 50-90% NO_2
- Future = 90% NO_2 at rated load

Chemiluminescent Instruments

- Only measure NO
- NO_2 is determined indirectly with a NO_2 to NO converter
- Converter is CHECKED for efficiency but not CALIBRATED

NO_2 is not a qualified measurement and is

<u>NOT RIGOROUS</u>

Difficulty of Compliance with Low NO_x Standard

NOx levels, ppm	**Estimated** measurement variation of ± 1.5 ppm	**Estimated** measurement variation of ± 1 ppm
Standard	2.0	2.0
Measurement variability	1.5	1.0
Control level required to ensure compliance	0.5	1.0

Agency Targets for BACT/LAER

	NO_x	CO	VOC	NH_3
California ARB	2-5	6	2	<5?
Massachusetts DEP	2			zero
Texas NRCC	5-9	9	2	7

ASME Low Concentration Measurement Program

Phase I: **NO_x measurement practices and capabilities**

Phase II: *CO, NH_3, and VOC measurement practices and capabilities*

Phase III: *Preparation of ANSI measurement standard*

Phase I: NO_x Measurement

DIRECTION: Steering Committee (EPA, IGTI, ASME CRTD, ASME Codes and Standards)

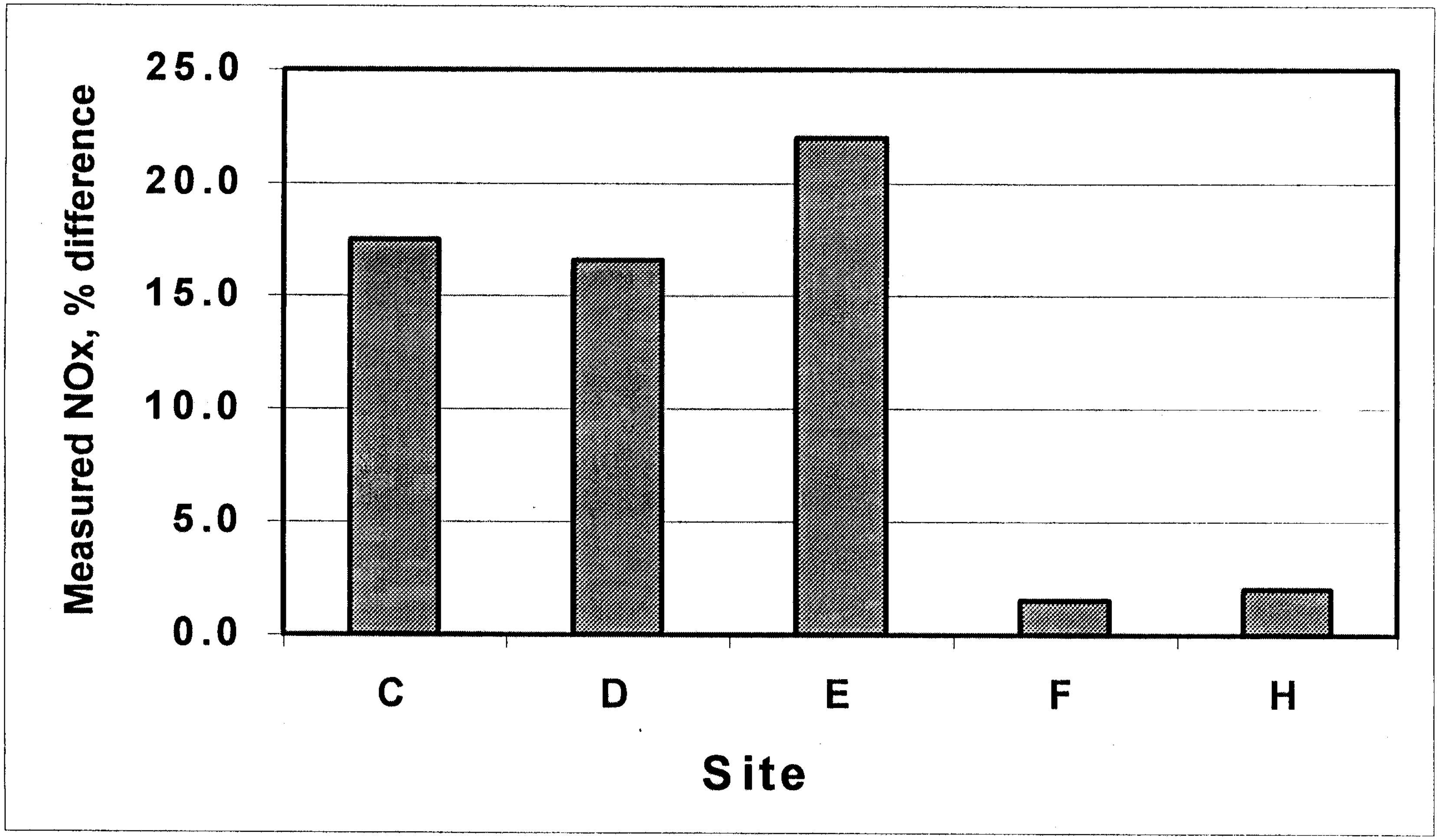
PROGRAM:

1. Review measurement standards
2. Interview agencies, engine manufacturers, engineering and test companies, instrument manufacturers
3. Review instrument specifications (CL, FTIR, electrochemical, UVDOAS, TDL)
4. Review tests of 10 GT plants where NO_x = 1-5 ppm

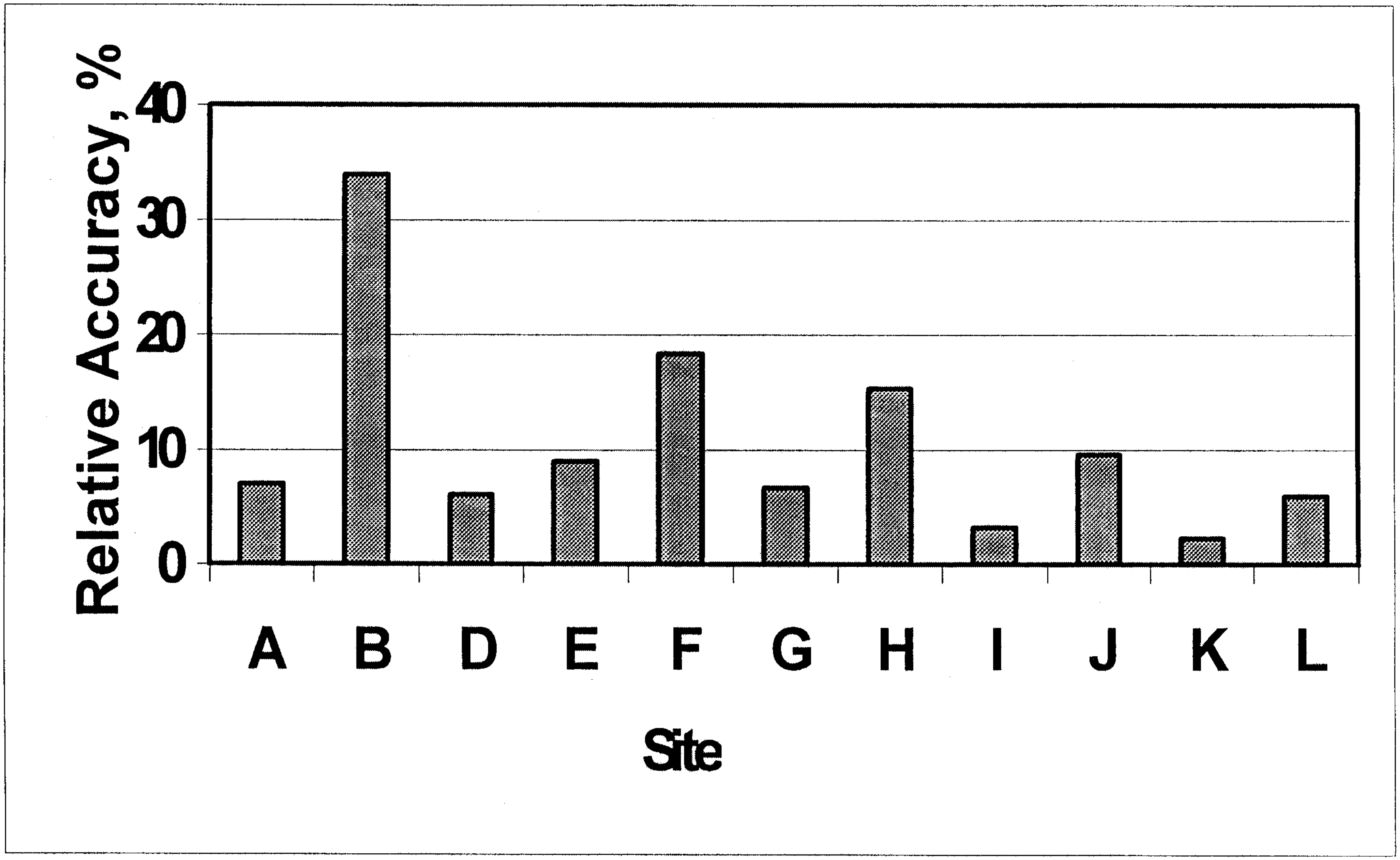
Gas Turbine Site Tests

- 10 sites, most multiple units
- Rated 23-1044 MW
- Permitted at 1-5 ppmdv @ 15% O_2
- Natural gas fuel, combined cycle
- Engine controls (2 DLN, others W/I or S/I)
- After catalyst controls (9 SCR, 1 SCONOX)

NO_x Measurement Variation (Unit-to-Unit)



NO_x Measurement Variation RATA



Measuring Instruments: 1-5 ppm NO_x

Type	Advantages	Disadvantages
Chemilum	Hundreds in use, EPA protocol	Doesn't measure NO_2 directly
Electrochem	Compact, inexpensive	Insufficient accuracy
FTIR	Multi-component	Small experience base for GTE
UVDOAS	Multi-component, meas. at 250°C	Small experience base for GTE
TD Laser	Multi-component, interference free	Small experience base for GTE

Sampling and Sample Conditioning

Representative sample? PROVE IT!

- Tall stacks = normally no problem
- Short stacks = use carbon balance and multi-holed sampling probe
- Lowest 8 O_2 readings aren't always representative

Engine has DLN combustion control

- Exhaust has high NO_2
- Extract moisture without condensation or measure hot and wet

Summary

1. High NO_x measurement variability was observed.
2. DLN engines have high NO_2 emissions and present CL instrument systems are likely to under-measure NO_2.
3. A low concentration measurement protocol is required for NO_x and other pollutants.
4. Traverse and water removal practices need updating.
5. 4 of 5 measurement instruments reviewed were capable of accurate measurement of NO_x in the 1-5 ppm range. (CL, FTIR, UVDOAS, TDL)

Acknowledgement

Our thanks to the sponsors of this program, the US Environmental Protection Agency, the International Gas Turbine Institute, and the many companies and agencies that provided information to us during this review.

Low Level NO_x Measurements And Other Compliance Issues On Gas Turbine Combined Cycle Units

CEC-EPRI Workshop
October 28, 1999

Richard D. McRanie
RMB Consulting & Research, Inc.
Raleigh, NC 27612

Why Are We Here?

- Most Regulatory Agencies Have Determined That New Combined Cycle Gas Turbine Units Should Be Equipped With SCR NO_X Reduction
- Permits Contain NO_X Limits Of 1-5 ppm
- Flue Gas Contains 3-10 ppm NH_3

Accurate Continuous NO_X Measurements Are Difficult To Make At Such Low Levels

The Low Level NO_X Problem

- No Low Level Protocol 1 Span Gases
  - NIST and Gas Vendors are Working on This Problem
  - One Vendor Now Providing Gases
  - To Meet the "Majority of Readings >20% of Span" Requirement in Part 75, Protocol Span gases in the Range of 3-10 ppm are Needed

The Low Level NO_X Problem

- No Low Level Protocol 1 Span Gases
- Precision Of Reference Measurement
- Reliability Of Continuous Monitor Measurement
- Effect Of NH_3 Slip On NO_X Measurements
- Permitting & Enforcement Issues
- User & Agency Education

The Low Level NO_X Problem

- Precision Of Reference Measurement
  - Part 75 Presently has a Low Emitter NO_X Measurement Accuracy Specification of ±0.02 lb. $NO_X/10^6$ Btu
  - This is Equivalent to ±5.5 ppm at Typical Gas Turbine Exhaust Conditions
  - Is This Specification Still Reasonable?

The Low Level NO_X Problem

- Reliability Of Continuous Monitor Measurement and Turbine Controls
  - Drift of Continuous Monitors and Turbine Controls May be a Significant Problem
  - Presently Have Difficulty With 15 ppm Machine
- Effect Of NH_3 Slip On NO_X Measurements
  - Differential Measurements Required for Chemiluminesent Monitors

The Low Level NO_X Problem

- Permitting & Enforcement Issues
  - Are Limits Appropriate Considering Measurement Problems?
  - Start up and Load Changes Cause Excursions
  - How is Compliance Determined?
- User & Agency Education
  - Document and Communicate Measurement Issues

Better Understanding The Problems

- Establish An Interest Group/Working Committee
  - Document The Issues
  - Document Experience
  - Define Present CEM Capabilities
  - Identify Research Needed

EPRI Low Level NO_X Survey

- Sources With Limits Of 5.0 ppm Or Less
- Sources In Operation At Least 1 Year
- Twenty Facilities Contacted
  - CA, NY, MN, OR, PA, NJ, MA
- Five Sources Returned Completed Survey
  - Three, 4-5 ppm Limit; Two, 3-3.5 Limit
  - Specific Source Information Confidential

EPRI Low Level NO_X Survey

- All Five Units Use SCR Combined With DLNB and/or Steam/Water
- Four Have Hourly Average NO_X Limits - One Has 24-Hour Average Limit
- Four Of The Units Have NH_3 Slip Limits of 10-20 ppm
- All Five Units Used Full Concentration Extractive Sampling Rather Than Dilution

EPRI Low Level NO_X Survey

- RATAs Are Virtually Impossible to Pass On A Relative Accuracy Basis
- Difficult To Meet 0.5% Daily Zero And Span Calibrations Drift Spec.
- Low Level Span Gases Very Expensive

EPRI Low Level NO_X Survey

- Steady-State Operation Compliance Measurements OK At 5.0 ppm
  - CEM "Noise" Level ~ 3 ppm
  - Just Crank Up The NH_3
- Startup, Load Changes And Burner Maintenance Cause Emission Limit Exceedences

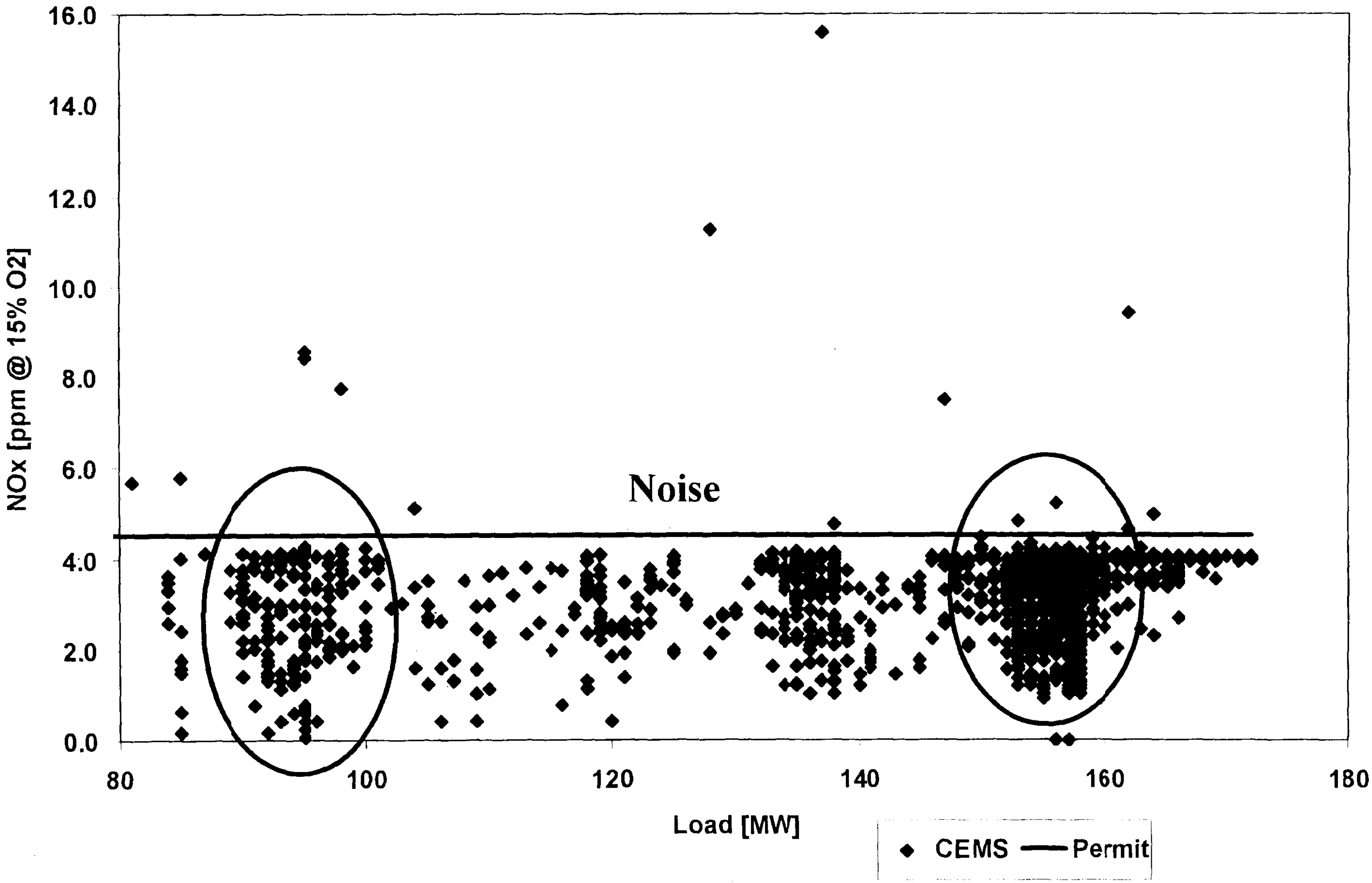
Performance Tests

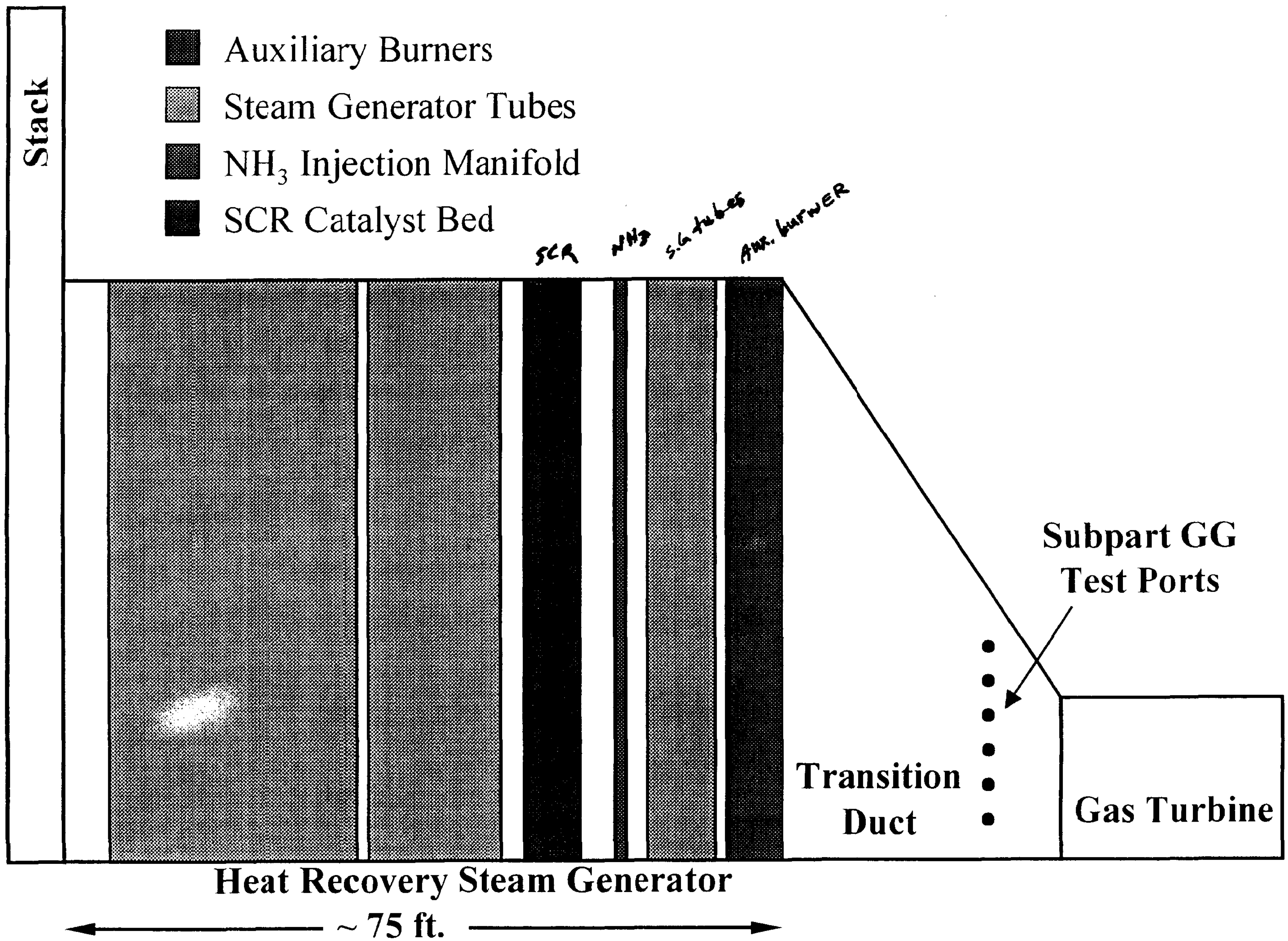
- New Combined Cycle Units With Auxiliary Burners Are Subject To 40 CFR Part 60 Subpart GG And Either Subpart Da or Db
- These Regulations Did Not Contemplate The Unit's Very Low Emission Levels And Are Seriously Flawed Re: Performance Tests

Performance Tests

- Subpart GG Combined With Da/Db Require the Gas Turbine And Auxiliary Burners To Be Tested Independently
- These Tests Can Be Very Dangerous And Are Totally Unnecessary For SCR Equipped Units - ***Negative*** $\boldsymbol{NO_X}$ ***Contribution For Burners***

Combined Cycle NOx Concentration Vs. Load

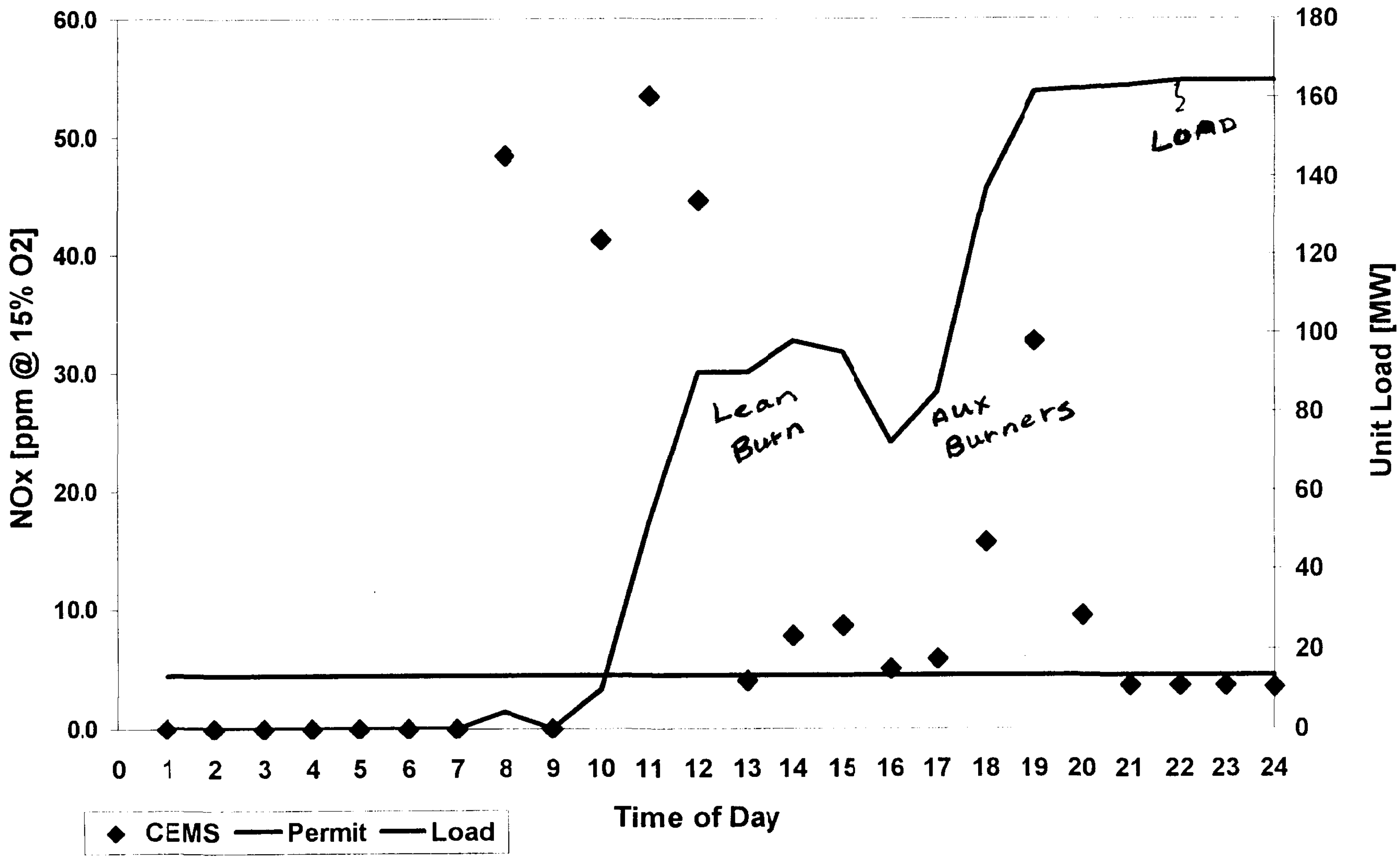



Stack
Auxiliary Burners
Steam Generator Tubes
NH_3 Injection Manifold
SCR Catalyst Bed
SCR
NH3
S.G. tubes
Aux. burner
Subpart GG
Test Ports
Transition
Duct
Gas Turbine
Heat Recovery Steam Generator
~ 75 ft.

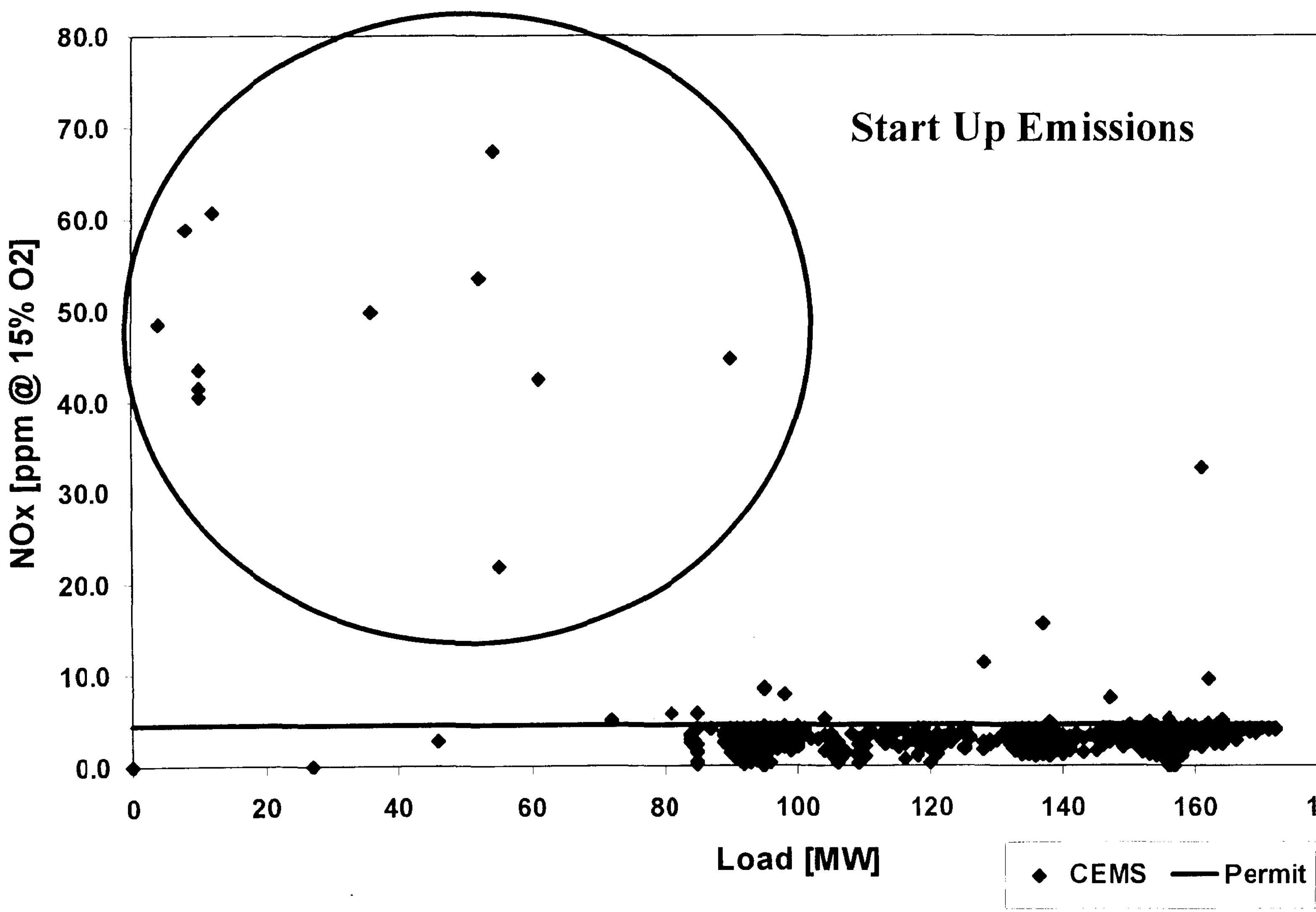
Start Up

- Start Up Without High Emissions Is Technically Impossible
- A Permit Without Start Up Emissions Provisions Is An Invitation To A Future EPA Credible Evidence Enforcement Suit

Combined Cycle Start Up NOx Concentration



Combined Cycle NOx Concentration Vs. Load



God And Mother Nature Are Real Picky About The Laws Of Physics And Chemistry

Therefore:

The Laws Of Physics And Chemistry Cannot Be Changed By A Regulation Or Permit Condition

The Physics & Chemistry Of Startup

- The Turbine Is Cold
- The SCR Is Cold
- The Boiler is Cold

The Emissions Will Be High

Mother Nature Dictates This Fact

The Turbine Is Cold

- A Gas Turbine Is A Precision Piece Of Machinery
  - It Must Be Warmed Up Slowly to Prevent Stress Damage To The Turbine and Casing
- A Gas Turbine With DLNB Must Be At 60-70% Load Before Entering “Lean Burn” Mode
  - Until Then The NO_X Emissions Will Be 50-75 ppm

The SCR Is Cold

- The SCR Catalyst Does Not Work Well Until It Reaches ~700° F
  - Can Plug Catalyst If NH_3 Is Used Below 500-550 ° F
  - NH_3 Slip Will Be Excessive If The Catalyst Is Not Up To Temperature

The Boiler Is Cold

- The Boiler Must Be Heated Slowly To Prevent Stress/Expansion Damage

Summary

The Entire Combustion System Must Be Brought Up To Full Operating Temperature In A Controlled Manner To Prevent Damage

This Takes Several Hours

Life Cycle Implications of Power Generation Technologies

CEC-EPRI Workshop
October 28, 1999

Bruce W. Vigon
Life Cycle Management Group
Battelle
Columbus OH

Life Cycle Implications of Power Generation Technologies

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Research Leader

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Why Life Cycle Assessment???

LCA helps evaluate the environmental consequences of a product, process or activity at a systems level and in a comprehensive manner throughout its life cycle.

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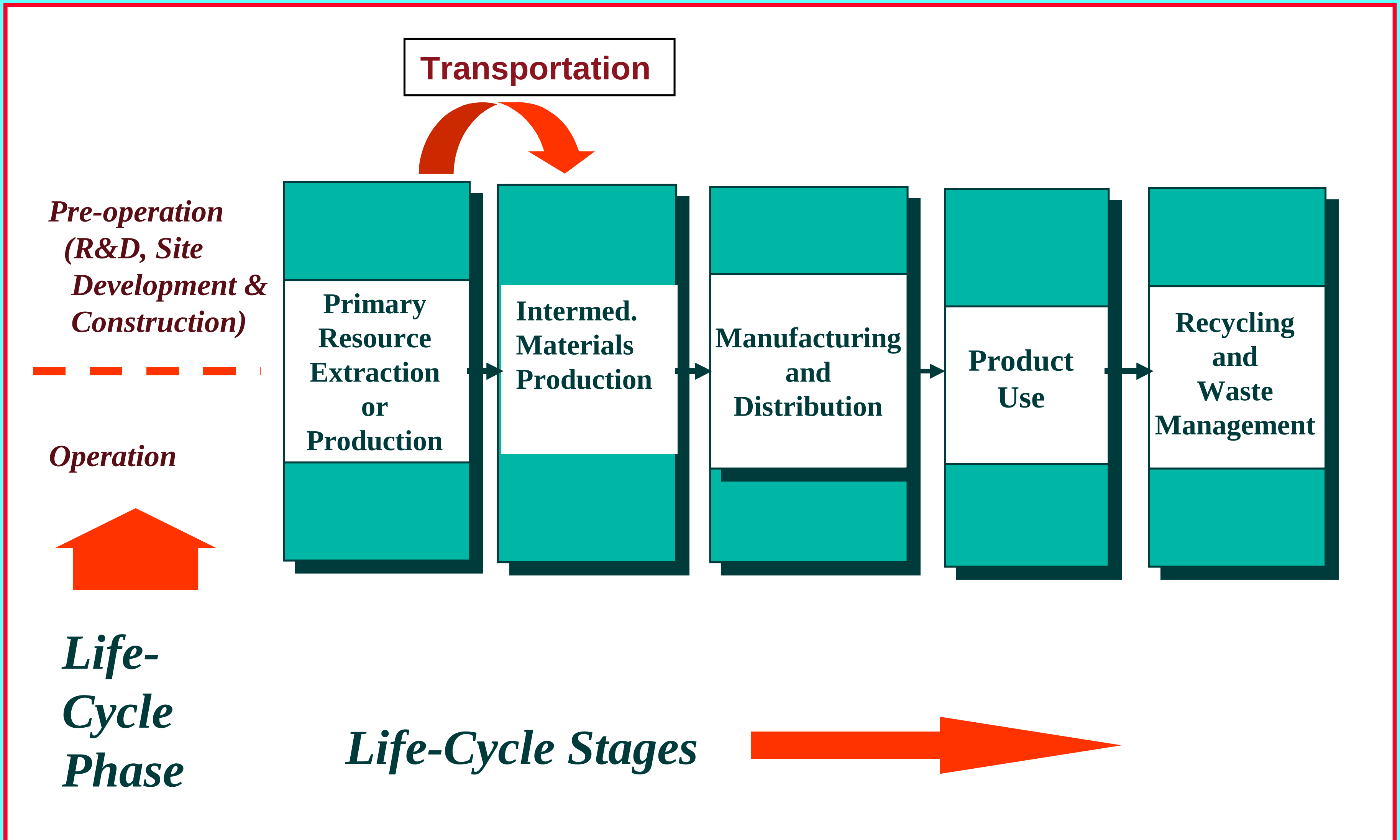
LCA Concept


Transportation
Pre-operation (R&D, Site Development & Construction)
Operation
Primary Resource Extraction or Production
Intermed. Materials Production
Manufacturing and Distribution
Product Use
Recycling and Waste Management
Life-Cycle Phase
Life-Cycle Stages

Beneficial Characteristics of LCA

- Clearly shows interconnections of development and operational activities with supply chain and customers/users
- Provides equivalent performance platform for product or service comparisons
- Assists in identification of other information and analysis needs

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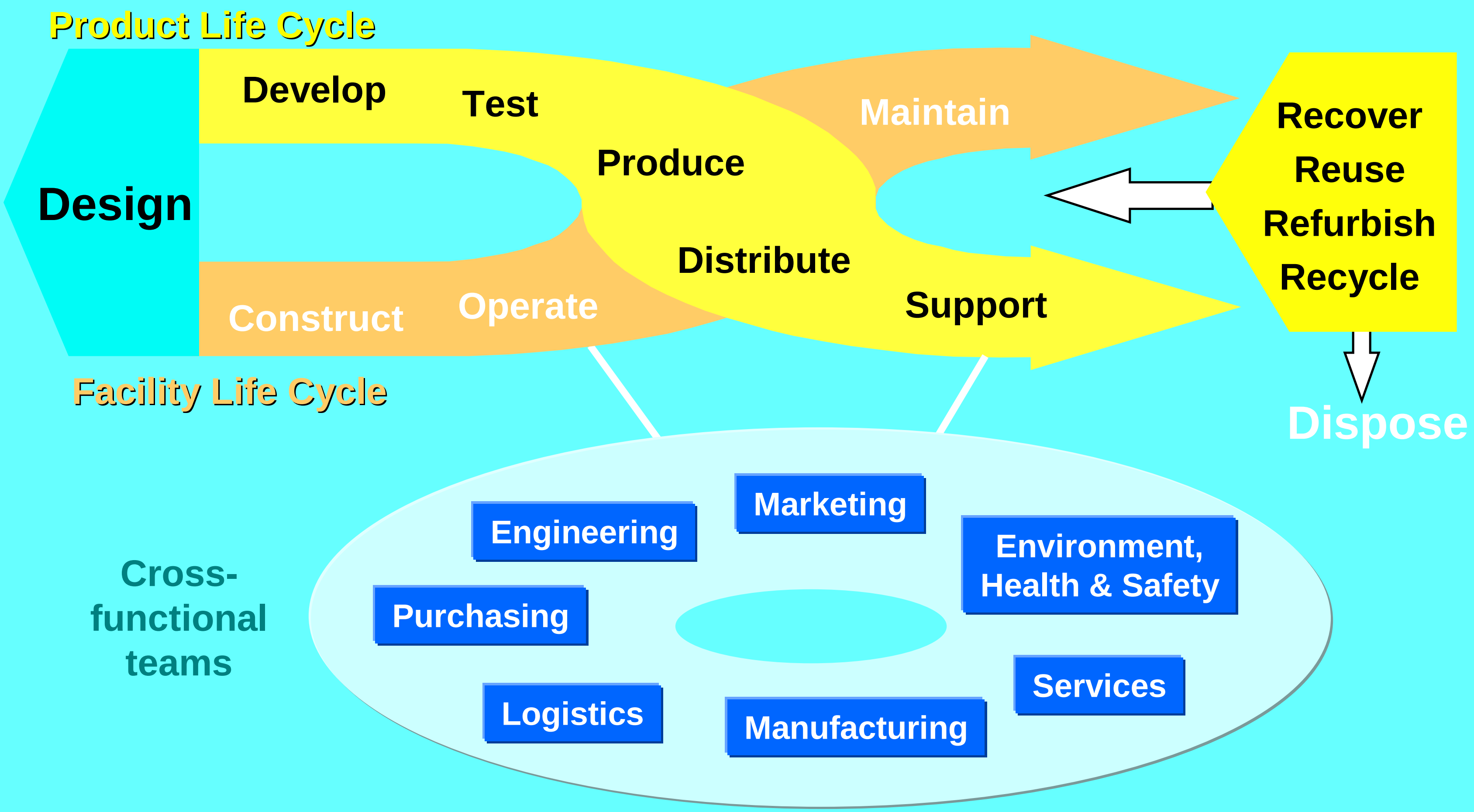
Life Cycle Design



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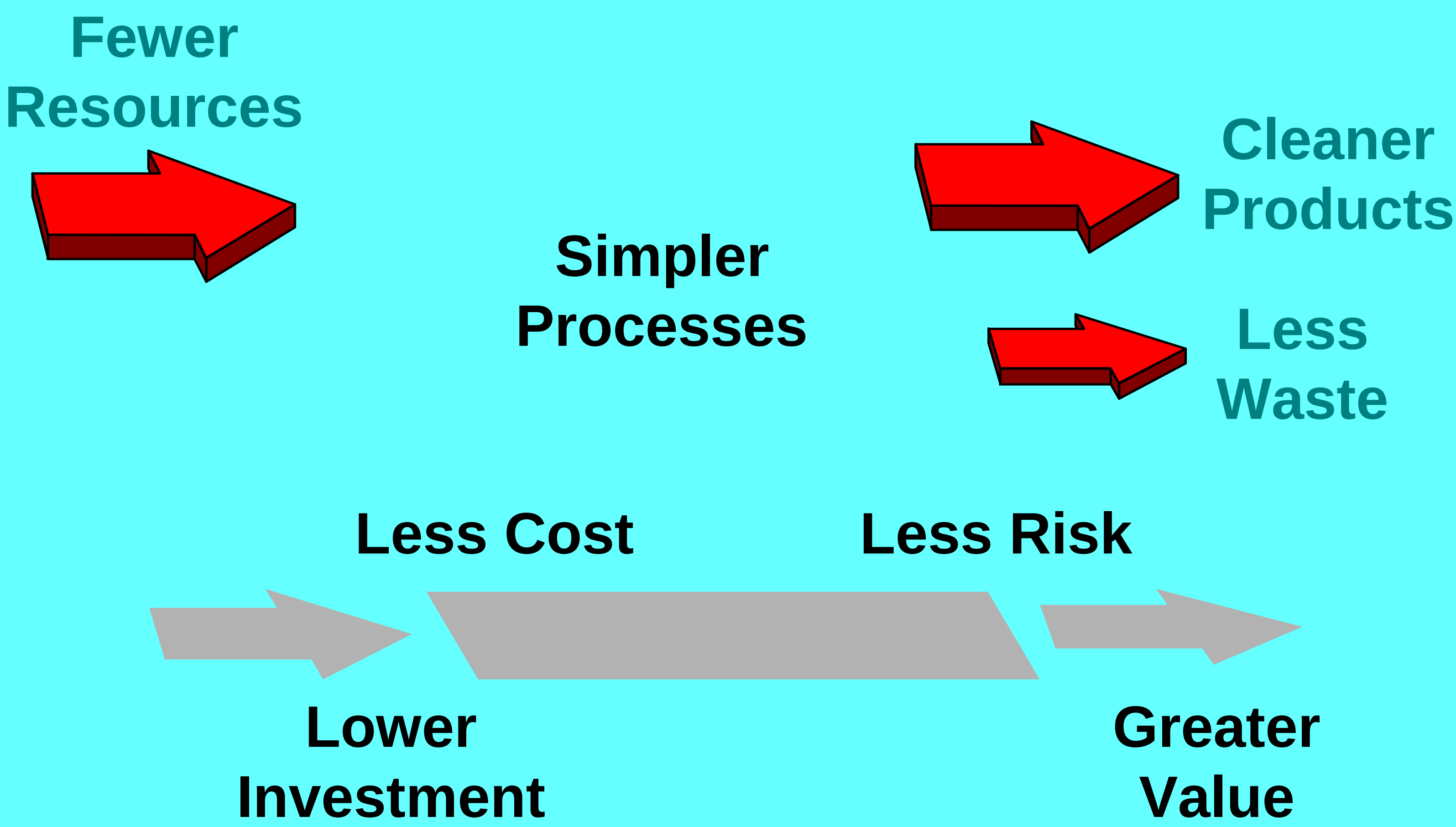
Eco-efficiency Paradigm



Recent LCAs of Power Systems

Life Cycle Assessment of a Biomass Gasification Combined Cycle Power System, Mann, M.K. and Spath, P.L. 1997. NREL/TP-430-23076, National Renewable Energy Laboratory (NREL).

Life Cycle Design of Amorphous Silicon Photovoltaic Modules, Lewis, G. and Keoleian, G.A., 1997. prepared for USEPA National Risk Management Research Laboratory,EPA 600/SR-97/081, prepared by National Pollution Prevention Center, University of Michigan.

Life Cycle Assessment of Coal-Fired Power Production, Spath, P.L, Mann, M.K. and Kerr, D.R. 1999. NREL/TP-570-25119, National Renewable Energy Laboratory.

Life Cycle Analysis of Fossil Power Plant with CO_2 Recovery and Sequestering System, Waku, H., Tamura, I., Inque, M, and Akai, M. 1995. Energy Conversion Mgt. 36 (6-9), 877-880.

Assessment of the Environmental Benefits of Renewables Deployment: A Total Fuel Cycle Analysis of the Greenhouse Gas Impacts of Renewable Generation Technologies in Regional Utility Systems, DyneCorp EENSP, Inc. 1995. Report to NREL, contract DE-AC02-83CH10093.

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Issues in LCA Application to Power Generation

- Boundary Decisions for Technologies and Systems
- Ancillary Inputs and Processes
- Products/Services versus Functions
- Marginal, Average, and Specified Technology Assessments
- Improvements versus Comparisons
- Hidden Impacts - Spatial and Temporal
- Inventory versus Impact Assessment
- DR Integration

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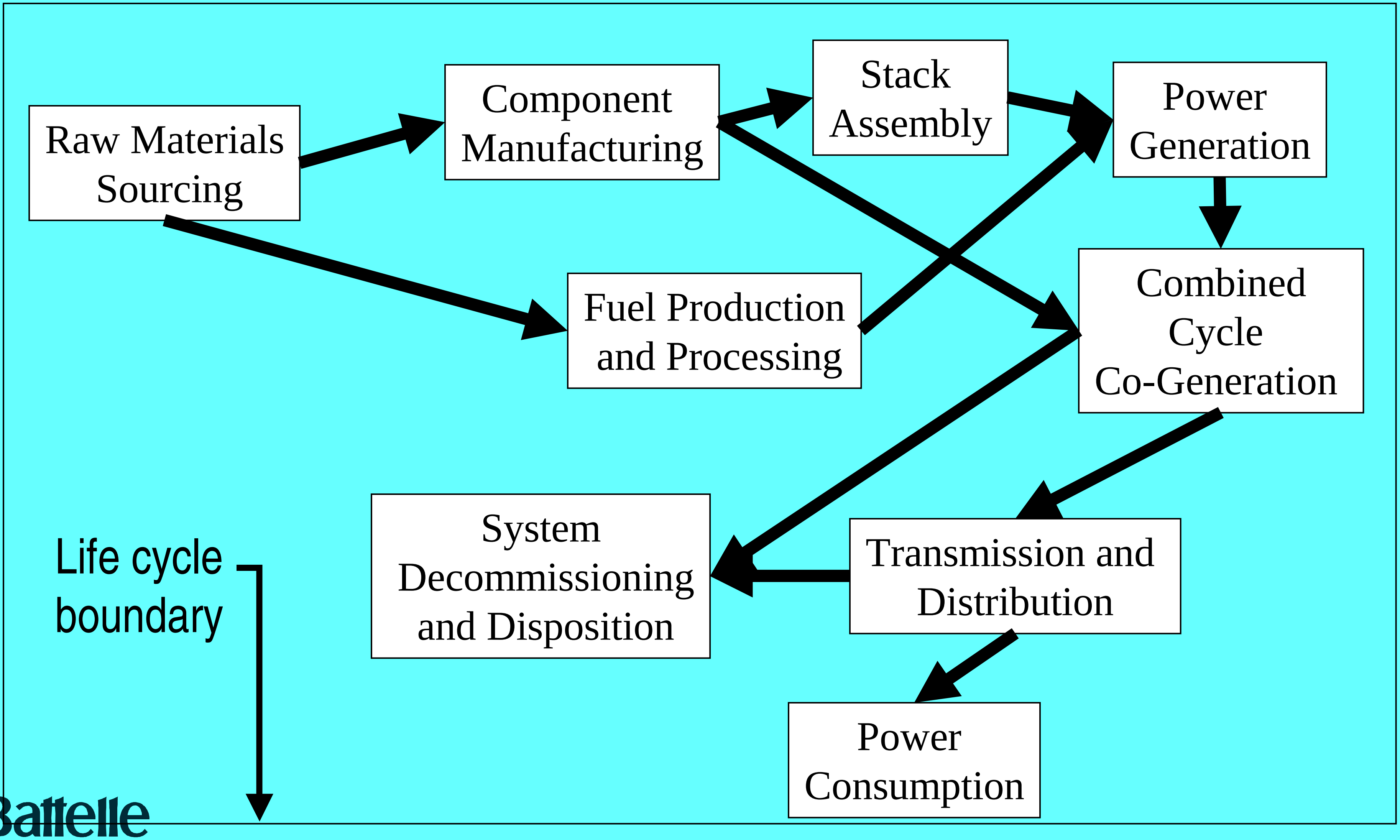
Solid Oxide Fuel Cell Life Cycle



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Life Cycle of a Photovoltaic Array Module

Material Production

Copper ore ➡ Copper

Limestone, Iron Ore, Coal ➡ Steel

Chromium, Nickel ➡ Stainless Steel

Natural gas, Petroleum ➡ EVA

Bauxite, Recycled Al ➡ Aluminum

MG silicon ➡ Silane

Manufacturing

Troy MI

substrate wash
back reflector deposition
amorphous Si deposition
TCO deposition
module slabbing
TCO scribing
short passivation
grid screen print
cell cutting
pack and ship

Tijuana MX

cell interconnection
module laminating
final assembly
final testing
pack and ship

San Diego CA

warehouse
ship to use site

Use and Maintenance

Recovery and Disposal

reuse entire module
reuse part of module (disassemble/recycle)
dispose/energy recover

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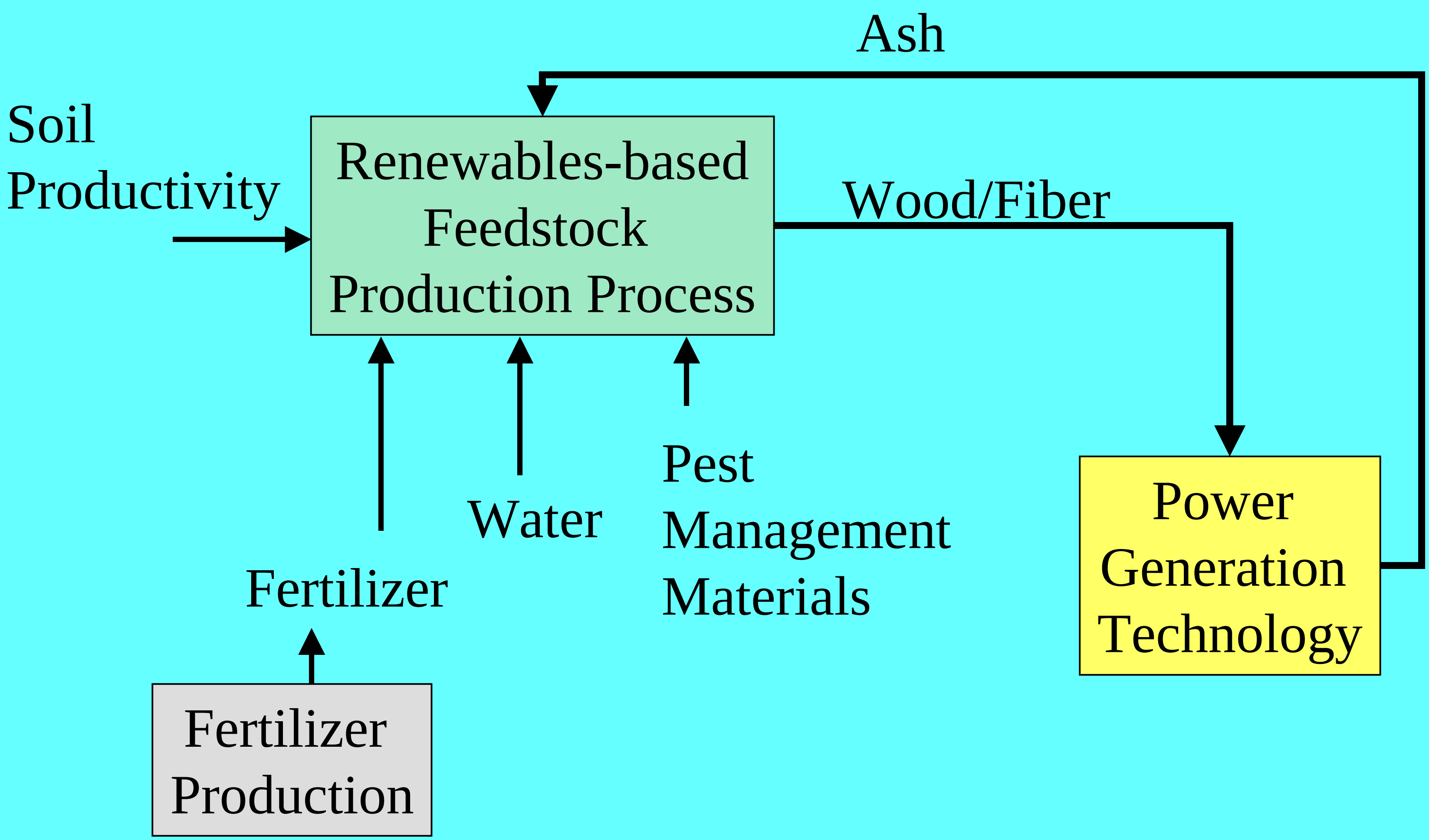
Ancillary Inputs and Processes



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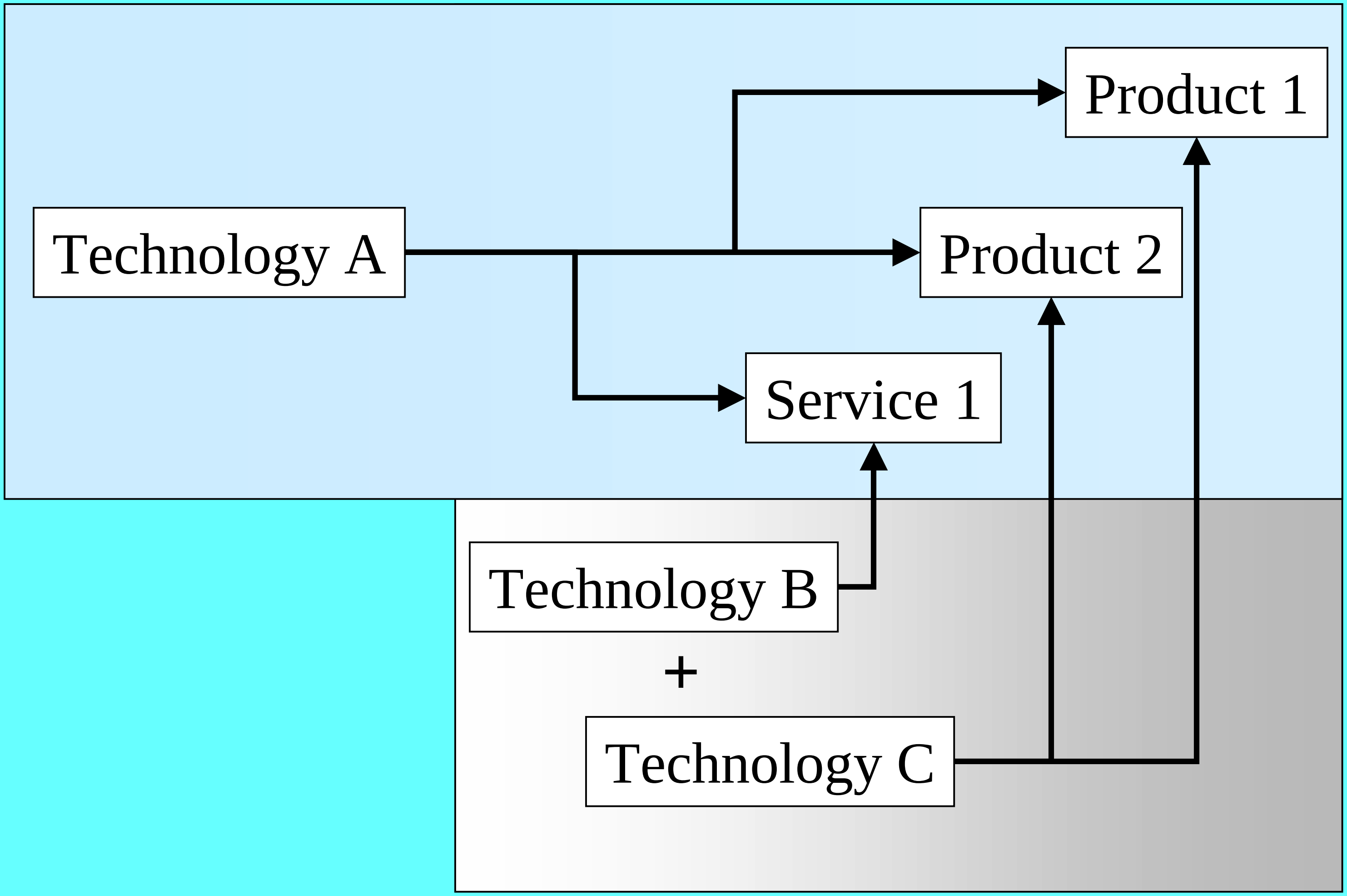
Functions vs. Products/Services



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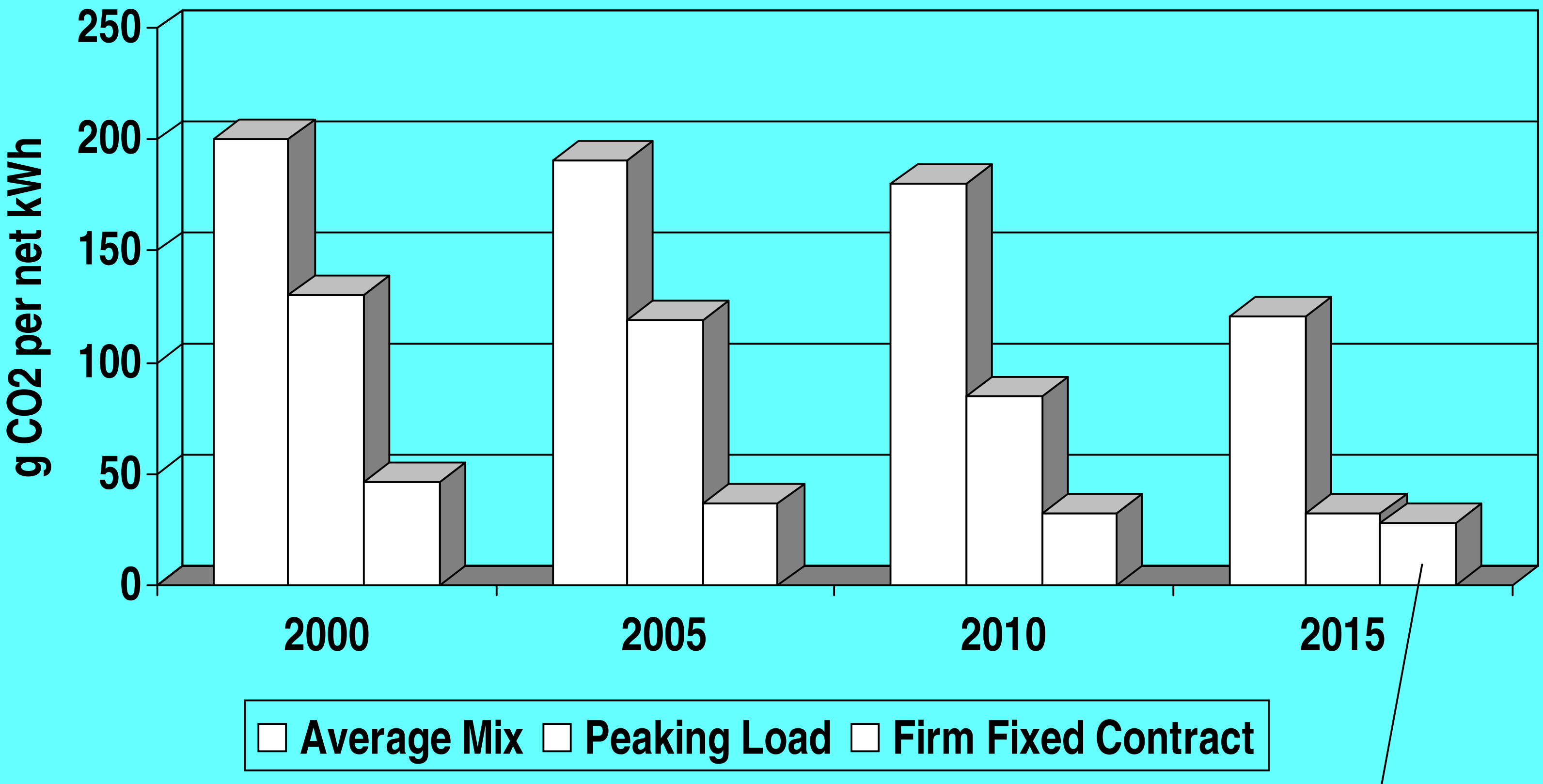
Average, Marginal, and Specified Technology Mixes



Care is needed to properly analyze individual customer versus system impacts

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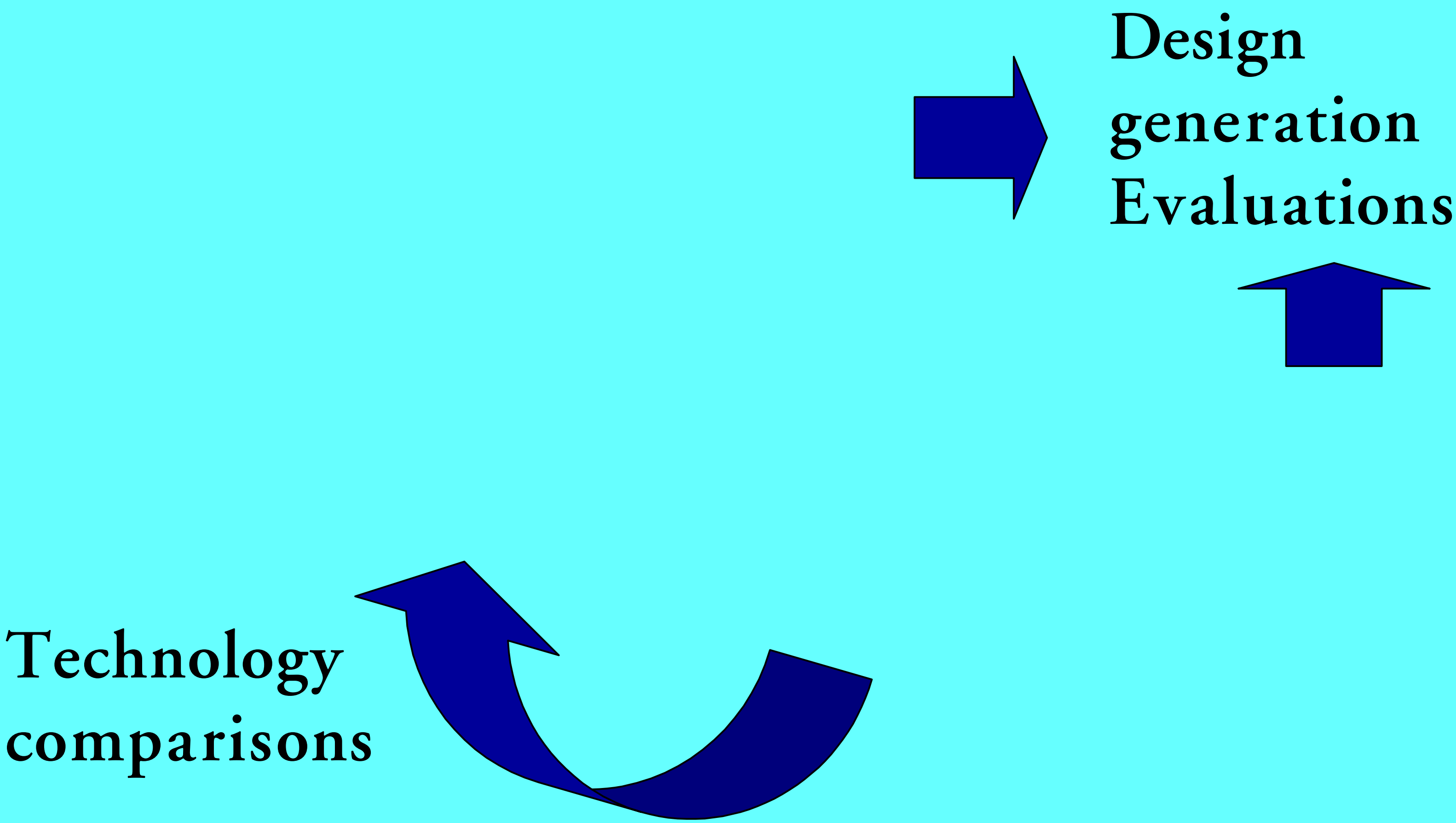
Design Improvements versus Technology Comparisons



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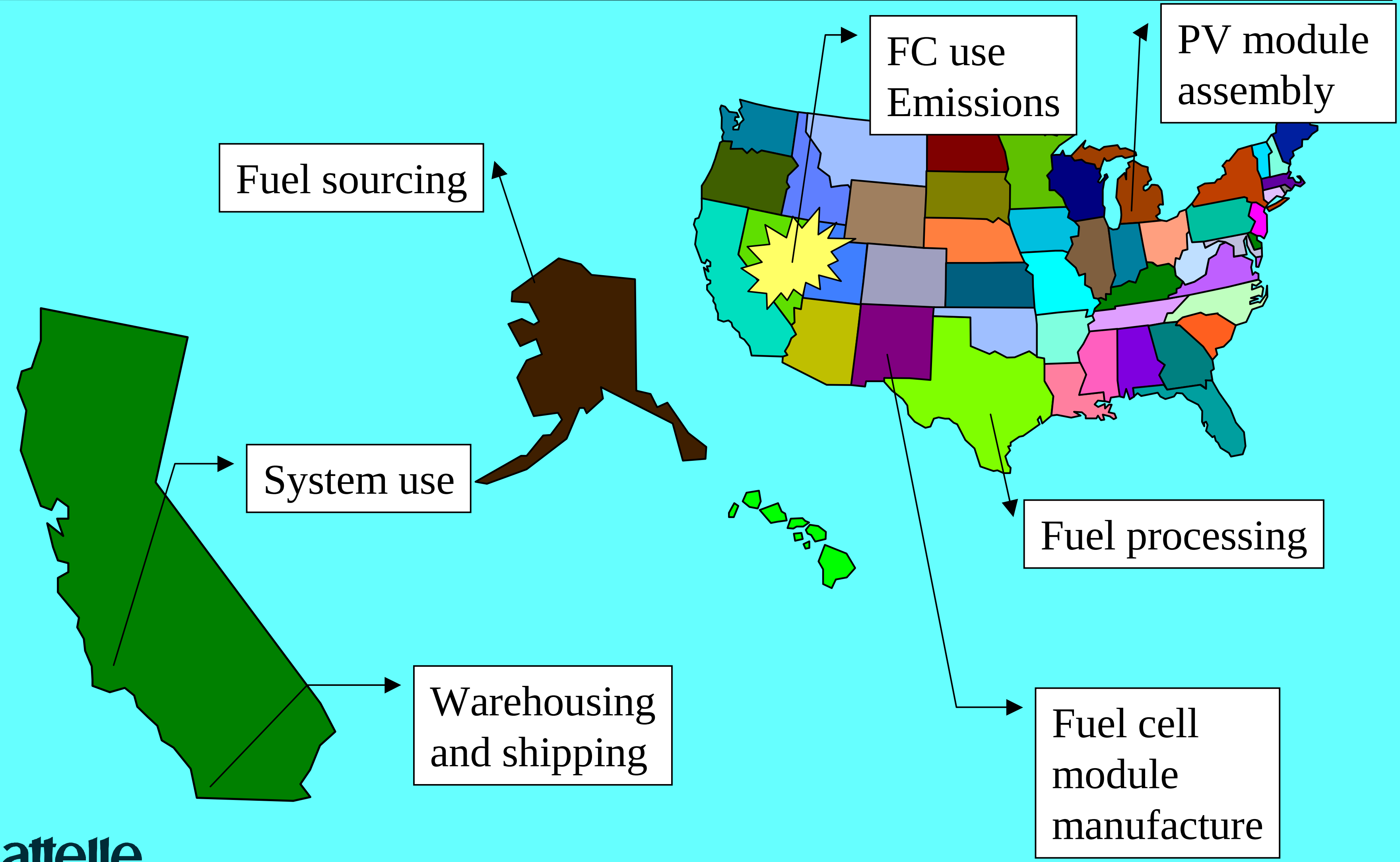
Hidden Impacts - Spatial



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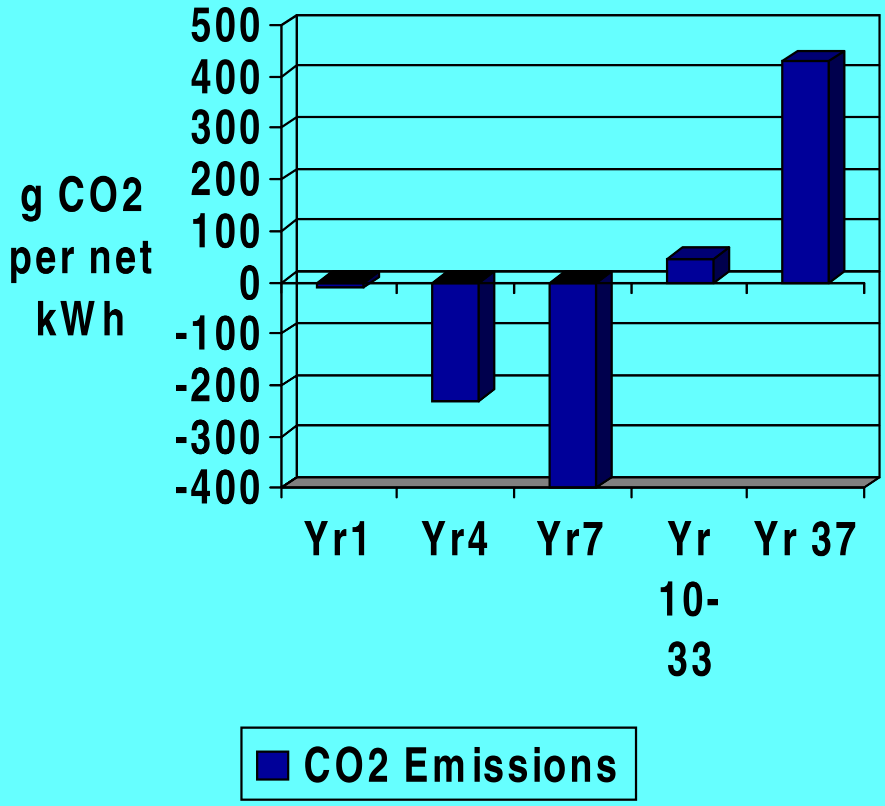
Hidden Impacts - Temporal



Depending on the technology or systems, the **time variability of impacts** may be highly significant!

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Inventory versus Impact-Based Assessments

Life Cycle Inventory

Individual flows of energy, resources, and emissions

Life Cycle Impact Assessment

Classification

Grouped data by issue area, e.g. global warming contributors

Characterization

Category indicators used to aggregate contributions

Normalization

Indicators referenced to benchmark

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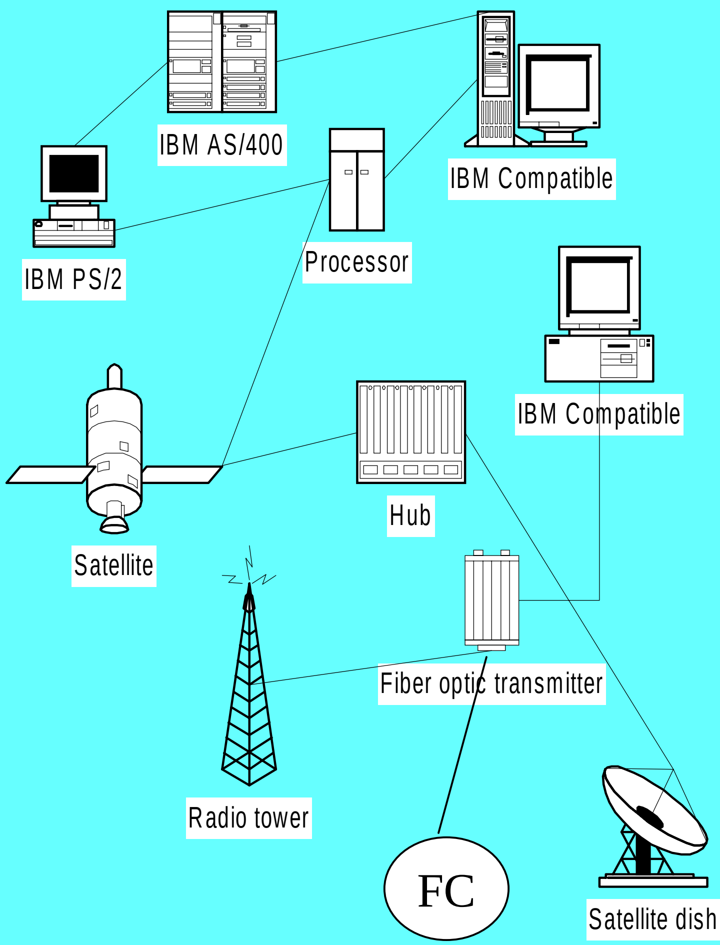
Integration of DRs in Utility Systems

Nature of Distributed Resources and Implications for Grid Technologies

- communications requirements of load balancing and stability
- need for reconfiguration of distribution system
- controllers for two way power flows



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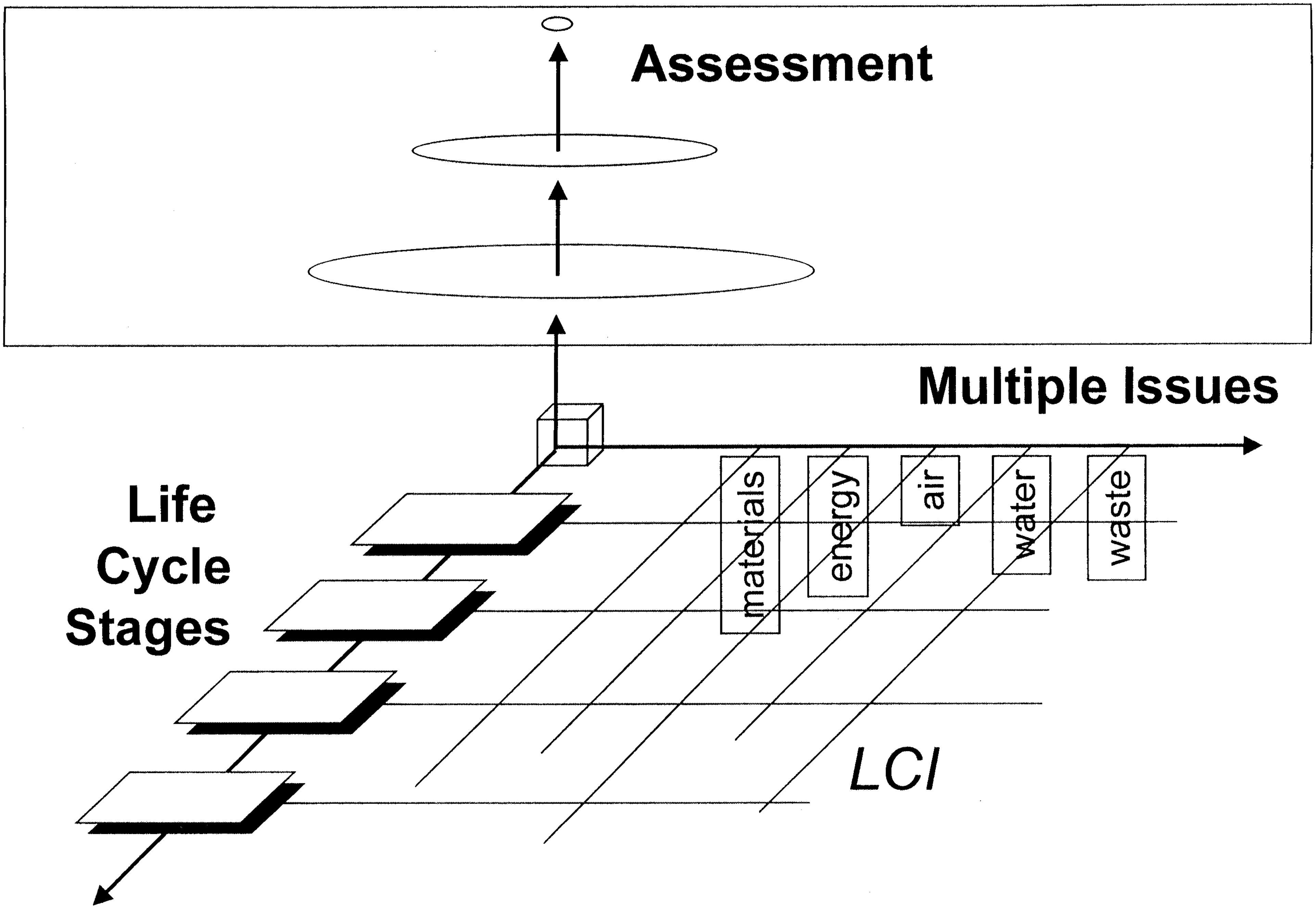
Life Cycle Assessment for NewGeneration Technologies

CEC-EPRI Workshop
October 28, 1999

James Fava
Five Winds International
Canada – USA – Germany


Assessment
Multiple Issues
Life
Cycle
Stages
materials
energy
air
water
waste
LCI

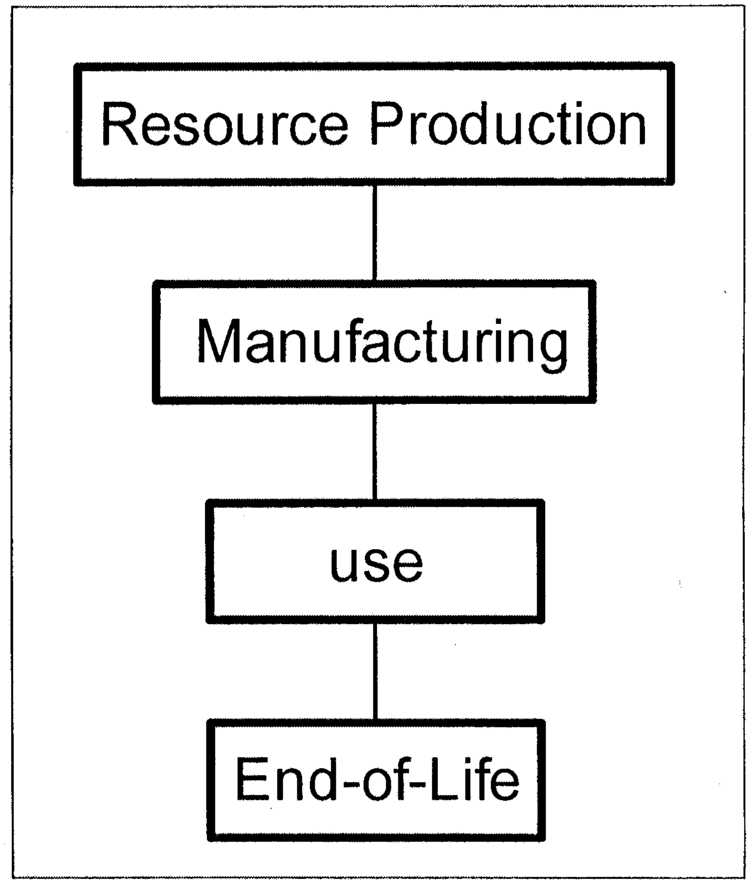
When starting an LCA Consider:

- The system to be studied, system boundaries
- Functions of the system(s), functional unit
- Allocation procedures
- Types of impact and methodology of impact assessment
- Data requirements, initial data quality requirements
- Assumptions, limitations
- Type of critical review, if any
- Type and format of the report

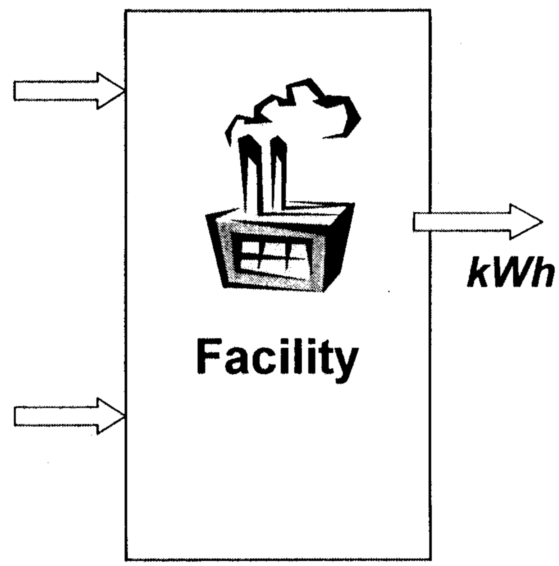
Source: ISO 14040

System boundaries

- Determines which processes are included & excluded
- Function of goals of the study, resources available, application, internal use or external application



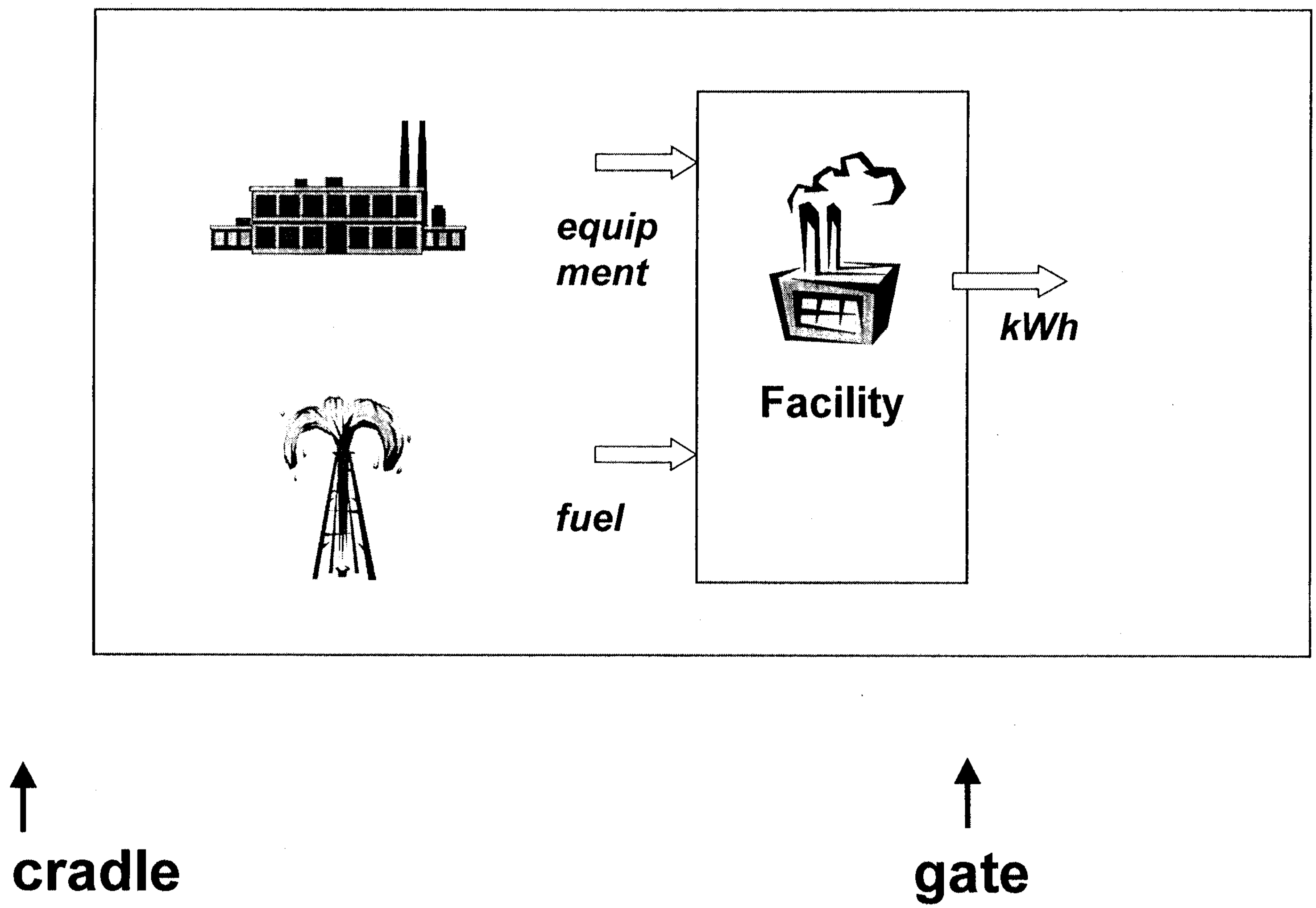
Defining System Boundaries



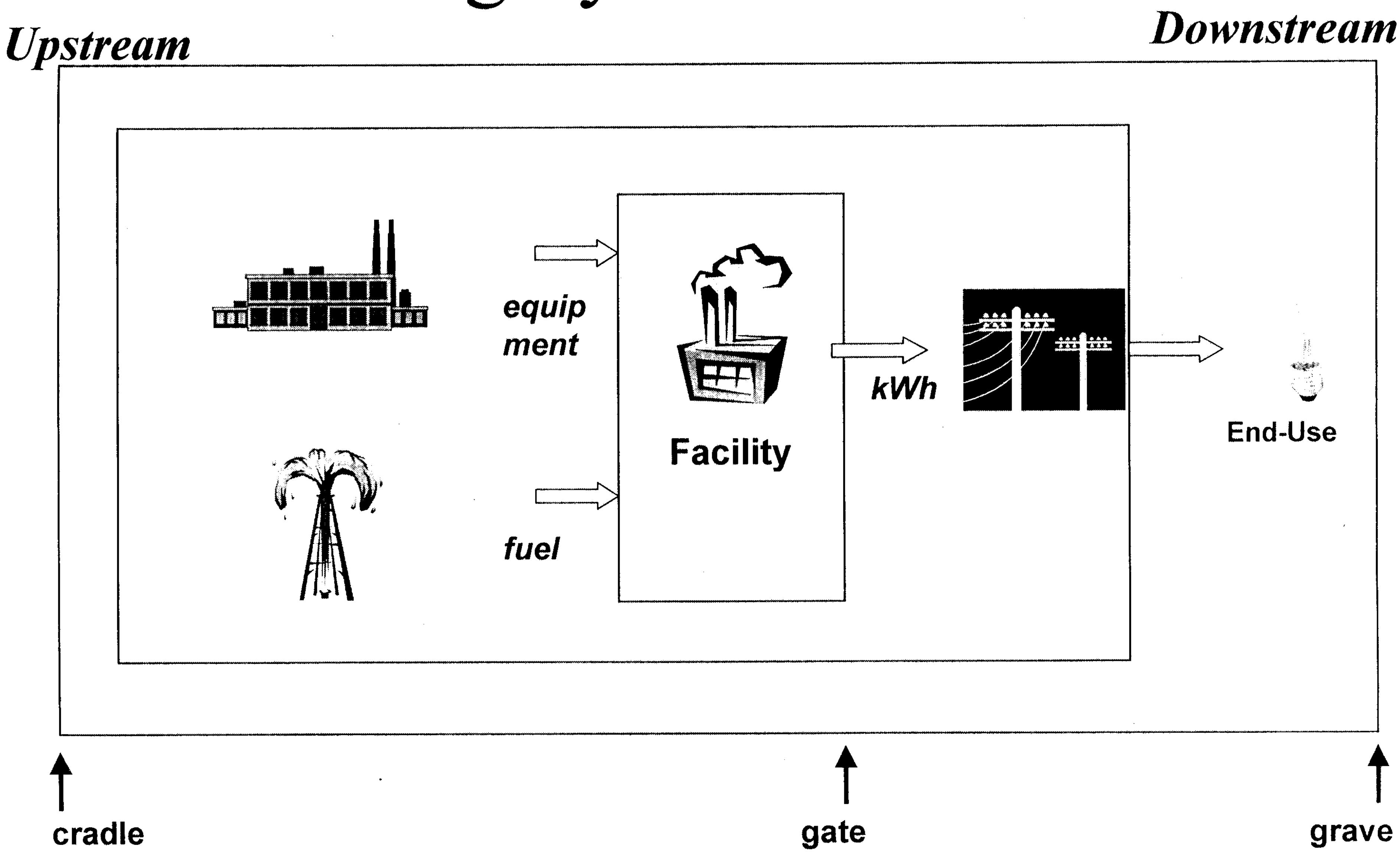
Gate to gate

Defining System Boundaries

Upstream

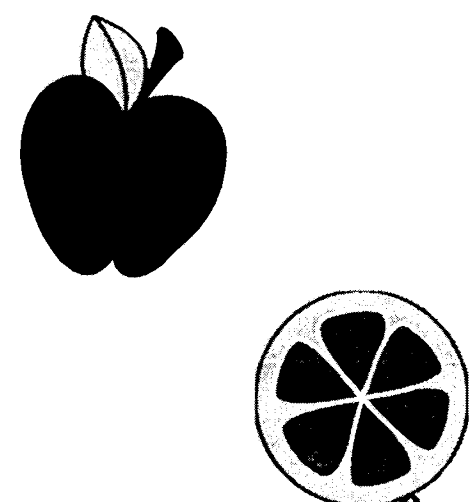


Defining System Boundaries



Functional unit and comparisons

- How do you make a fair comparison between alternative systems?
- *"Functional unit is a measure of the performance of the functional outputs of the product system"*
  - ISO 14040 standard
- kWh ? Apples to oranges?



Typical LCA datasheet/questionnaire

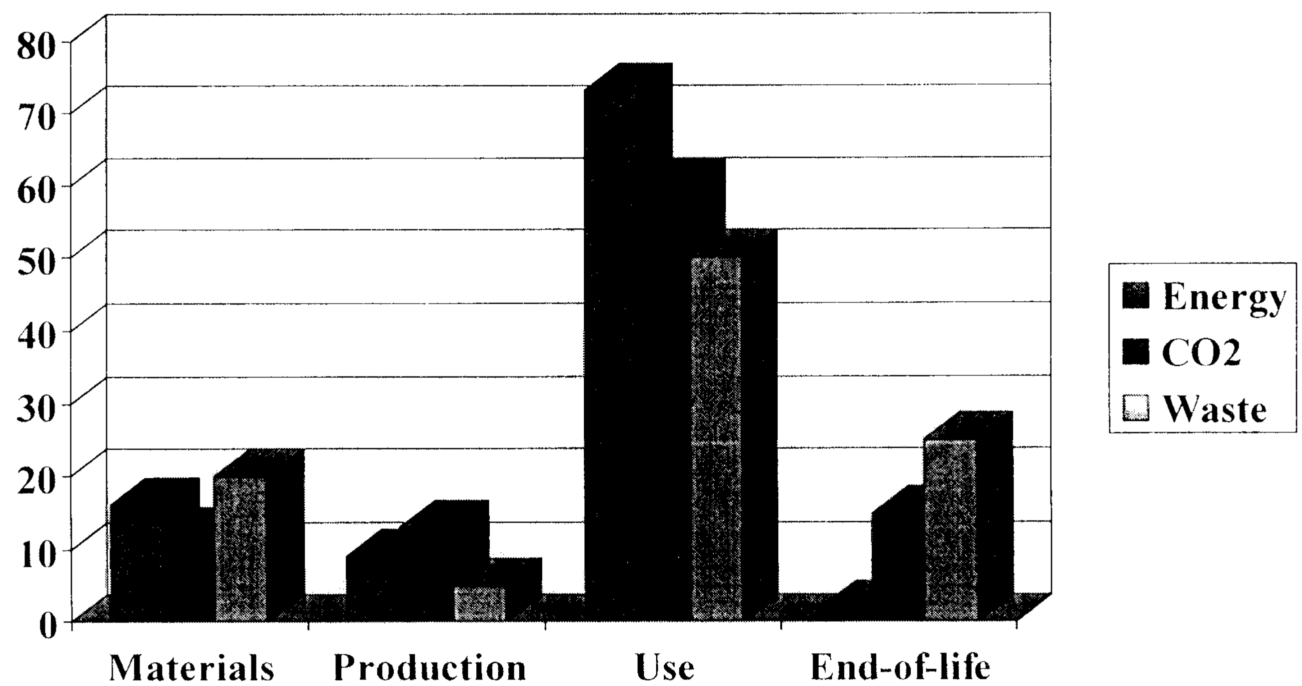
Process:________ **Data source:**_________ **Time period:**___

INPUTS (per unit of process product)	OUTPUTS
Raw Materials extracted from the earth intermediate flows (incl. packaging and transport of intermediate materials)	Main Products By-Products Solid waste to be processed Fluid waste to be processed
Energy fuels, electricity	Environmental outputs emissions to air emissions to water emissions to land
Transport Services	
Other inputs	

Data Quality

- Relevant to goals and scope of the study
  - time-related coverage
  - geographical
  - technology coverage
  - precision, completeness, representativeness
  - consistency and reproducibility
  - sources cited
  - uncertainty

RESULTS: Life-Cycle Profile



Gaps and Analysis Summary

CEC-EPRI Workshop
October 28, 1999

Scott Samuelson
National Fuel Research Center
University of California, Irvine, CA

ENVIRONMENTAL IMPACTS OF NEW GENERATION IN CALIFORNIA

GOAL

- INITIATE THE DIALOG ("*TODAY NOT THE END*")

OBJECTIVES

- IDENTIFY AND UNDERSTAND:
  1) EMISSIONS FROM NEW GENERATION ALTERNATIVES
  2) EMISSIONS MEASUREMENT TECHNIQUES
  3) ENVIRONMENTAL LIFE CYCLE IMPLICATIONS

EMISSIONS FROM DR (I/III)

- CALIFORNIA PERSPECTIVE
  - LOCAL GENERATION IS A CLEAN MIX
  - 20-40% IMPORTED
  - 35 DISTRICTS PERMITTING NEW GENERATION?
  - > 50MW: CEC SOLE AUTHORITY FOR LISCENSING
    - √ 42 PROPOSED, GTE COMBINED CYCLE, CO-GENERATION
    - √ 100-1000MW, 25,000 MW TOTAL
    - √ PEAKING?
  - ARB "BACT GUIDELINES"
    - √ >20MW GTE >50MW EVALUATED GUIDELINES
  - CURIOUS NEW PLAYER: DG
    - √ 1 MW TO 20 MW (?)
    - √ 25 kW TO 500 kW (?)

EMISSIONS FROM DR (II/III)

- EMISSIONS:
  - 100PPM, 50PPM 25PPM, 15PPM, 9PPM, 2-3PPM NOx (15%O2)
    - √ COMBUSTION (LB, CATALYTIC, SURFACE)
    - √ POST-COMBUSTION (SCR, SCONOX)
  - WRINGING OUT THE LAST PPM'S
    - √ ECONOMICALLY VIABLE?"
    - √ FUEL QUALITY
    - √ 50 TON CHALLENGE
  - A REMAINING OPPORTUNITY: DUTY CYCLE
    - √ VARIABLE GEOMETRY
    - √ OPTIMIZATION CONTROL
    - √ START-UP, SHUT-DOWN
    - √ DUAL FUEL

EMISSIONS FROM DR (III/III)

- ISSUES OF DG IMPACT
  - NEXT TO PEOPLE, SHORT STACKS
  - OPPORTUNITIES (DEMANDS?) FOR CO-GENERATION
  - EMISSIONS (POLLUTANT)
    - √ WHAT ARE EMISSIONS: NOx, CO (HAPs, OPs, N2O)
    - √ THERMAL CREDIT, BOILER OFFSET CREDIT
    - √ REGULATED? STATE STANDARDIZED? WAIVERS
    - √ POPULATION, DISTRIBUTION (TYPES AND SPATIAL), DUTY CYCLE (ECONOMIC COST/BENEFIT: CAPITAL/OPERATION)
    - √ DISPLACING IMPORTED, OR LOCAL GENERATION
  - EMISSIONS (ACOUSTIC)
  - EMISSIONS (SEISMIC)
  - WEB SITE: SPONSOR?

MEASUREMENT TECHNIQUES (I/II)

- QUESTIONS
  - CAN WE MEASURE NOx “THAT LOW”?
  - ARE INSTRUMENTS ADEQUATE?
  - DO DISTRICT REGULATIONS CORRECTLY REFLECT?

ISSUE #1: DLN NOx TENDS TO NO2

- PROTOCOL REQUIRED FOR NO2
  - INSTRUMENT
    - √ CAPABLE OF 1 PPM NO2
  - IS THE SAMPLE REPRESENATIVE?
    - √ SPATIALLY, TEMPORALLY, LINE AUGMENTATION
  - NO2 CALIBRATION SPAN GAS

MEASUREMENT TECHNIQUES (II/II)

ISSUE #2: CEMS

- INSTRUMENT RELIABILITY
- SPAN PROTOCOL GAS
- NH3 SLIP
- EPRI/CEM WORKING GROUP
  - DOCUMENT ISSUES, EXPERIENCE, CEM CAPABILITIES
- SCAQMD
  - 1 PPM NOx ACHIEVABLE
  - CAREFUL WORK PLUS OVERSIGHT
  - STANDARD PROTOCOLS APPROPRIATE AND NEEDED
    - √ PROTOCOL SPAN REFERENCE METHOD
    - √ CEMS INSTRUMENT
  - A NATIONAL EFFORT?

LIFE CYCLE ANALYSES (I/I)

- "SPEED CHANGE"

- CRADLE TO GRAVE → CRADLE TO CRADLE
- SYSTEMS PERSPECTIVE
  - ENERGY FLOWS
  - ENVIRONMENTAL IMPACTS
- FOUR STANDARDS FOR LCA
- QUESTION?
  - WHAT QUESTION, HOW FRAMED
  - WHO ASKS
  - WHO RESPONSIBLE
  - DOES LCA HAVE A ROLE IN DR?

Items from Wrap-up Discussion

CEC-EPRI Workshop
October 28, 1999

Scott Samuelson
National Fuel Research Center
University of California, Irvine, CA

Ellen Petrill
Executive Director
EPRI, Palo Alto, CA

GENERATION

GAPS

- Climate change impacts of combustion system

NEXT STEPS

Research

- High effic. @ medium load units

Development

- Certification
- CADER or CEC develop/sponsor website
- Science – based standards – integrated emissions stds; analysis of impacts

Regulation/Permitting

- Commom units – wt /energy
- Ease regulations to allow development of new technologies
- Incorporate energy development by district in socio-economic planning
- Broaden definition of emergency, incl. D6
- Reliability issues with Frame 7 used as peakers – address in permitting
- Output – based standards

MEASUREMENT

GAPS

- Startup/shutdown – ASME study
- Research meas. vs. RATA vs. CEMS different compliance is key, can this meas. be made?
- How docs meas. relate to credible evidence?

NEXT STEPS

Research

- Define how low can existing meas. technologies go?
- Are there other meas. tech. that go lower

Development

- Measurement TAG
- CEC coordinate w/ CARB, districts & EPRI on low NOx measurement issues plus legal issues.

Regulation/permitting

- Address Fed vs. state (district disconnects Fed - ± 5.5.ppm SCAQMD ± 1ppm
  Address disconnect btwn practical approaches & controls being enforced

LIFE CYCLE

GAPS

- Move to Life Cycle Design
- Broaden LCA to <u>all</u> new gen.
- Consideration of alternative technologies

NEXT STEPS

Research

- Perform LCA: renewables & fossil fuels
- LCA for like kind technologies

Development

- LCA protocol as analytical tool
- LCA clearinghouse
- Combine LCA to economic evaluation

Regulation/Permitting

Appendix 4:
Biographical Sketches

Jay Burnette
Director of Marketing
Fairbanks Morse Engine Division
B F Goodrich

Mr. Burnette has been with Fairbanks Morse for 8 years. He currently leads the sales and marketing for a wide range of engines used for commercial applications. Mr. Burnette has prior long-standing operations and maintenance experience with Cummins Engineering Company. Mr. Burnette was educated in mechanical engineering at Purdue University.

Richard Davis
Consultant
Goal Line Environmental Technologies
Pasadena, CA

Mr. Davis markets and sells on the West Coast a line of catalyst systems useful for minimizing NOx and CO emissions from gas turbines, boilers and internal combustion engines. For 25 years prior Mr. Davis promoted a full range of gas and steam turbines, boilers as well as electrical and emissions control systems for ABB Power Generation. His academic training is in business at Loyola Marymont University.

Charles Dene
Project Manager
EPRI
Palo Alto, CA

Mr. Dene manages projects on continuous emissions monitoring and performance of gas and oil fired power plants. The evaluation of many of the current continuous emission measurement methods are based the outcomes of his projects. Mr. Dene has been with EPRI for 21 years working on monitoring and post-combustion emission controls. His academic training is in chemical engineering at Wayne State University.

James Fava
Managing Director
Five Wind International
West Chester, PA

Dr. Fava leads a global management consulting firm specializing in helping clients to understand the competitive opportunities associated with the environmental dimensions of their product, technologies and services. For 23 years Dr. Fava has been integrating environmental and product sustainability with the strategic planning process and business practices. Leading industrial & energy companies and federal agencies are among the clients. Dr. Fava has been active in numerous national efforts including co-chairing the Environmental Management Standards Technical Committee for ISO 14000.

Steve Gehl
Manager of Strategic Planning
EPRI
Palo Alto, CA

Dr. Gehl has been involved in conceptualizing and managing over the last 5 years the development of the electricity technology 25-year roadmap road map in which research and development applicable to distributed resources are prominent. In the prior 10 years, Dr. Gehl managed research and development on many aspects related to steam generation of electricity. His academic training encompassed mechanical engineering and metallurgy at the University of Florida.

John Higuchi
Manager, Monitoring & Source Testing
South Coast Air Quality Management District
El Monte, CA

Mr. Higuchi is responsible for ambient air quality monitoring and emissions testing including certification of CEMs. He has worked with the District and it precursor agencies since 1969. His academic training is in physics at the University of California-Los Angeles and California State University-Los Angeles, and in electrical engineering at the University of Southern California.

E. J. Honton
Director of Strategic Business Development
Resource Dynamics Corporation
San Francisco, CA

Mr. Honton manages the company's operations in the San Francisco office. He has long-standing experience in solving complex business problems with emphasis on analysis of markets, economic impacts of technology on business operations. Most recently he has been exploring factors underpinning successful domestic and international DR business strategies. He received his academic training in civil engineering and economics at Ohio State University.

Susan Horgan
Founding Member
Distributed Utilities Associates
Pleasanton, CA

Ms. Horgan has specialized over the last 13 years in management of research projects, strategic planning, demand side management, regulatory compliance and transfer of technology focused on distributed utility. Ms. Horgan has researched industrial optimization at PG&E, managed environmental communications and training at Lawrence Livermore National Laboratory. Ms. Horgan’s academic training is in political science, economics, business law, marketing and communications.

Richard McRanie
Principal
RMB Consulting and Research, Inc
Raleigh, NC

Mr. McRanie provides consulting services to utilities and other large industries on emissions compliance measurements, permitting, regulatory analysis and particulate control. He also directed utility services at Kilkelly Environmental Associates. For 25 years he managed research on power plant performance at Southern Company Services.

Ellen Petrill
Technical Executive
EPRI
Palo Alto, CA

Ms. Petrill leads EPRI's Client Relations team serving the Western US and Canada, serving EPRI members and recruiting new members to join EPRI's collaborative programs. In 13 years with EPRI, Ms. Petrill has worked as project manager in fluidized-bed combustion systems, fossil power plant performance and as regional manager for transfer of generation technology. Her academic and graduate education is in mechanical engineering from Stanford University in Stanford, CA.

David Rohy
Vice Chair
California Energy Commission
Sacramento, CA

Dr. Rohy, served as Vice Chair of the California Energy Commission from 1995 through 1999. His primary role was to guide the Commission's technology development programs and to facilitate collaborative approaches on issues facing the distributed resources market. Previously he led research and development at Solar Turbines, Inc., bringing new thermodynamic, combustion and material concepts to market reality in the design of combustion turbines. Dr. Rohy's academic education is physics at the University of California at Santa Barbara, and in experimental solid state physics at Cornell University in 1968.

Professor Scott Samuelsen
Director
National Fuel Cell Research Center
UC Irvine
Irvine CA

Dr. Samuelsen has created a comprehensive, realistic approach for integrating advances in science and technology with practical aspects of energy generation and supply ranging from fundamental research to meeting the demand for broadly educated individuals.

Valentino Tiangco
Technical Lead and Project Manager
Renewable Energy Technologies, PIER
California Energy Commission
Sacramento CA

Dr. Tiangco has been with the energy commission for a number of years while also serving as a visiting faculty member advising graduate students in renewable energy resources at UC Davis and Sacramento State University. Dr. Tiangco's academic training is in mechanical engineering, management and energy conversion systems in the Philippines and UC Davis. He serves as technical advisor on several U. S. Department of Energy programs and on the United Nations Development Program through a Transfer of Knowledge. He is the recipient of several technical awards in his field.

Mike Tollstrup
Project Support Section Chief
California Air Resources Board
Sacramento, CA

Mr. Tollstrup has been dealing with permitting and technology issues at ARB for about 10 years. He now manages a project support group. He was instrumental in the development of ARB's guidelines for permitting and licensing large gas fired turbine power generating plants. His academic training is in environmental engineering at the California Polytechnic University, San Luis Obispo.

John Vaught
Principal Consultant
Vaught Engineering, Inc
Scottsdale, AZ

Mr. Vaught leads consulting services on combustion and emissions problems involving the uses of aircraft engines, stationary gas turbines and reciprocating engines. Prior to the consulting, Mr.

Vaught supervised emissions, compliance and alternate fuels at the Allison Division of General Motors for many years. He has contributed his knowledge to professional societies such as ANSI, SAE and ASME. ASME recently released a study on the measurement of low NO_x concentrations from gas fired turbine.

Bruce W. Vigon
Practice Leader of Life Cycle Management
Battelle Columbus
Columbus, OH

Mr. Vigon develops and applies methods for life cycle management. During the past 10 years he has directed numerous analyses of commercial and DoD products and processes. He is senior author of the standard guidance documents on life cycle inventory analysis, and has led a number of industrial and governmental studies on development, application, and evaluation of candidate methodologies for life-cycle impact assessment and total ownership cost. He is a member of the editorial board of the International Journal of Life-Cycle Assessment and has authored more than 30 articles and several book chapters on life cycle methods and tools.

Leslie Witherspoon
Research Engineer
Solar Turbines, Inc
San Diego, CA

Ms. Witherspoon manages environmental programs at Solar. She is responsible for the interpretation of air emission regulations with respect to her company's markets and products. She supports customers with emissions data and permitting strategies. Previously Ms. Witherspoon was manager of consulting services at Trinity Consultants working on industrial permitting and regulatory compliance. Her academic training included chemical engineering at the University of Missouri-Rolla and business administration at the University of Kansas.