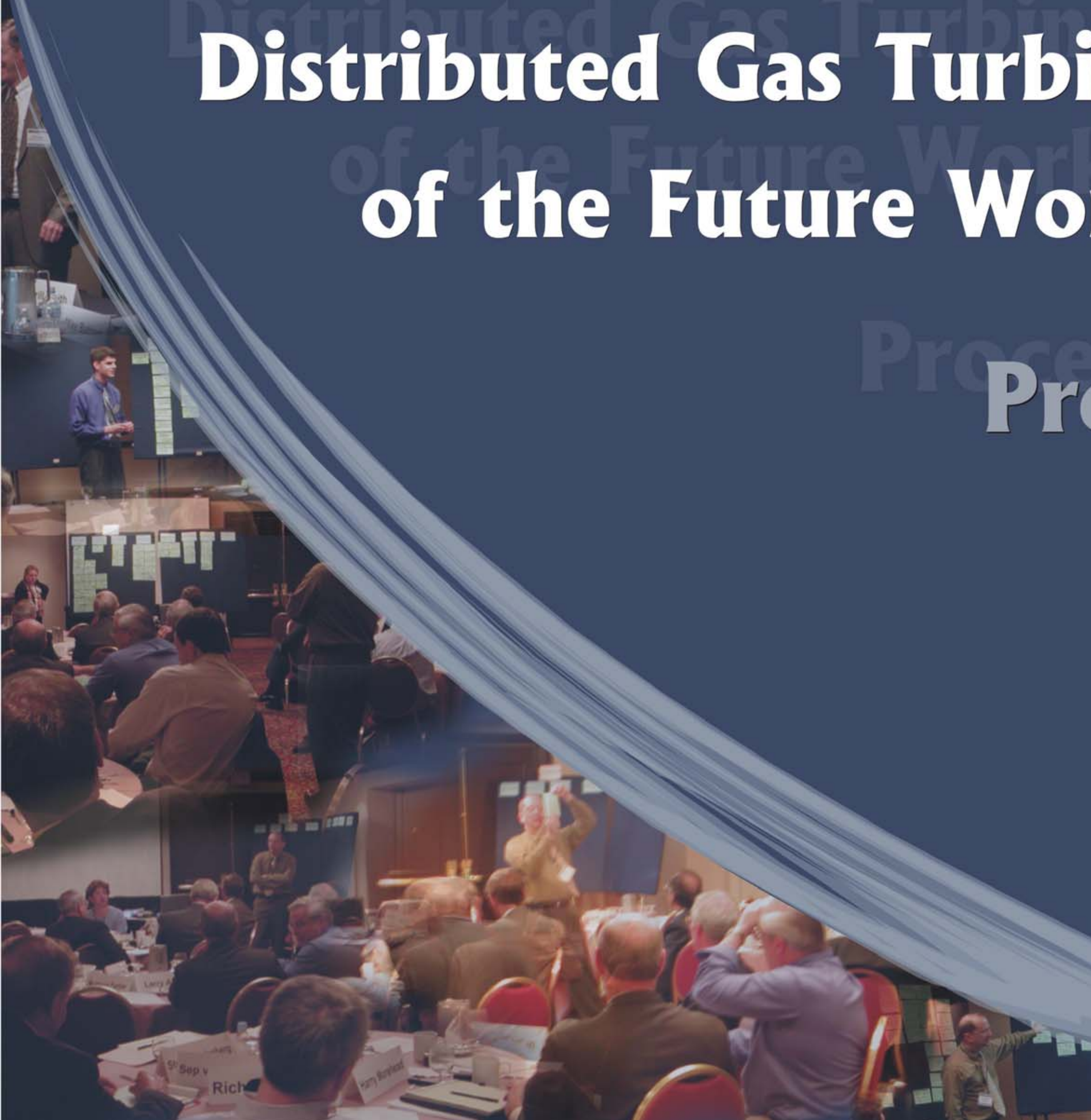
# Distributed Gas Turbine of the Future Workshop

## Proceedings

June 2003



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# Chapter 1. Introduction

On June 4, 2003, more than 30 participants representing the gas turbine industry, federal and state agencies, and National Laboratories participated in the Distributed Gas Turbine of the Future Workshop in Washington, DC. A complete list of attendees can be found in Appendix A. The intent was to develop visionary characteristics and leap frog ideas about the distributed gas turbine of the future. In addition, the workshop addressed the research, development, demonstration, and technology transfer needs for achieving the vision with time frames and the respective roles of industry, government, universities, and National Laboratories. The agenda can be found in Appendix B. Contact Brian Marchionini at bmarch@energeticsinc.com for copies of the presentations.

This document is a summary of the proceedings of this workshop. It captures the comments and ideas that were exchanged, and summarizes the major themes that were expressed throughout the workshop.

Chapter 2 presents the results of a discussion on the design, cost, efficiency, emissions, manufacturing, installation, and/or O&M requirements that distributed turbines will have to satisfy if they are to compete.

Chapters 3-5 present the results of the discussion held in three breakout groups. Each breakout group addressed the following questions:

*"What visionary characteristics and leap-frog ideas do you have about the distributed gas turbine of the future?"*

*"What are the top research, development, demonstration, and technology transfer needs for achieving the vision?"*

*"Who is the primary sponsor for this RD&D need—Government or Industry?"*

*"Who is the primary performer for this need—Industry, National Laboratories, or Universities"*

*"When is a commercial product needed—in the short-term, mid-term, or long-term?"*

Chapter 6 presents the participants' closing remarks.

# Chapter 2. Vision Requirements

There are a number of requirements for distributed turbines to satisfy if they are to compete with other alternative energy conversion devices. To be competitive, turbines must provide over a 20% savings for the total electricity cost compared to grid connected energy services.

Distributed gas turbines must be extremely clean by producing very little or no emissions at all without some form of after-treatment. They not only need to be cleaner than what is going on-line today, but must be competitive with future central station generation and adhere to tightening air regulations. Using blends or pure feed stocks of natural gas, coal gas, oil, propane, biogas, methanol, and hydrogen may support the ultra-clean distributed turbine of the future.

Another requirement is to lower manufacturing costs and increase durability of advanced materials. Advanced alloys, ceramics, and composites are one of the keys to greater efficiency and lower emissions through higher operating temperatures. These materials should be capable of sustaining 2500°F and 40,000 hours of continuous operation while being less than 50% the cost of existing materials.

To realize their full potential distributed gas turbines should be packaged with combined heat and power systems. These systems require easy installation and interchangeable components that can be completed by the customer. These turbine systems will also need to be web operated and notify the customer or operator specifically what maintenance is required and when it needs to occur. These turbines will be required to run for over 100,000 hrs without replacement parts.

Table 2-1 contains additional requirements for the distributed gas turbine of the future.

## Table 2-1. Vision Requirements

| System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Small** | **Both** | **Big** | **Cost** | **Efficiency** | **Emissions** | **Manufacturing** | **Installation** | **O&M** |
| • By 2010, 500-2500 kW turbines integrated with hot fuel cells with turbine inlet temperature of 1000C at $650/kWh<br>• By 2010, accommodate contaminants from biomass<br>• By 2025, hydrogen fueled turbine in 1-5MW CHP packaged turbines<br>• By 2020, recuperator 100,000 hr 98% effective | • By 2010, auto-operated CHP<br>• By 2050, hydrogen 50% energy basis<br>• By 2010, gas turbine technology capable of multi fuel w/o emissions impact in CHP mode<br>• By 2020, clean & efficient & reliable customer transparent<br>• Today, customer value proposition must be a winner e.g.: cost of electricity is a function of efficiency, $/kW, $/MBTU, availability, reliability, emissions, O&M<br>• By 2015, integration of gas turbine fuel/emissions characteristics with fuel processing<br>• By 2015, design robustness sufficient for consistent, lowest manufacturability of the product<br>• Zero CO2 emissions<br>• By 2020, alternative cycles & design optimized to fuel type<br>• By 2010, flexible design to optimize customer benefits of CHP/electricity<br>• By 2020, nuclear fuel gas turbine<br>• By 2020, high temperature materials (2500F) for 40,000 hrs joinable and environmentally stable, <2X $ of existing materials<br>• By 2010, advanced bottoming cycle | • By 2020, fuel cell turbine hybrids 5-500 MW<br>• Hi Speed integrated gas turbine/ generator 5 MW with no gears | • All-in cost >20% less than the grid | • By 2050, electrical efficiency 60%, heat and electric power charged to fuel 95%<br>• By 2015-2020, higher efficiency of gas turbine systems than in plans<br>• By 2050, >40% efficiency LHV for <1MW | • By 2025, zero emissions--period<br>• By 2010, fuel flexibility with low emissions <3ppm NOx<br>• By 2040, a sustainable energy economy<br>• By 2010, zero CO2 turbines with H2<br>• By 2007, <3ppm NOx<br>• By 2012, <2ppm NOx w/o SCR<br>• By 2015, small turbine emissions will need to be as low as cleanest central station technology<br>• By 2015, <3ppm NOx (natural gas)<br>• By 2015, <9ppm NOx (liquid fuel)<br>• 2030-if we are driving a zero energy vehicle is 3ppm sufficient?<br>• By 2015, emissions basis as ability to clean up air coming into turbine<br>• By 2015, <3ppm NOx from broad range of GT sizes<br>• By 2010, near-zero emissions w/o after-treatment—environmentally affirming | • By 2020, integrated packaged CHP systems (1MW-40MW) that capture at least 80% of the energy in the fuel<br>• By 2015, ability to meet manufacturing process & precision requirements consistently and cost effectively<br>• By 2010, fuel flexible 1-5MW portfolio of interconnected packaged CHP turbines<br>• By 2015-2020, lower cost manufacturing of advanced material components | • By 2015, installation all inclusive skid mounted system with easy installation for easy mobility<br>• By 2020, easy installation and interchangeable replacement parts with can be performed by consumer<br>• By 2020, factory shipped product is all inclusive, plug and play, with factory certified emissions and electrical interconnect-like a refrigerator, buy, plug-in, beers cold | • By 2015, 50,000 hr engine<br>• By 2030, 100,000hr engine w/ no replacement parts<br>• By 2007, O&M $0.005/kWh<br>• By 2010, web operated anticipatorily maintained systems<br>• By 2025, turbine will need to be able to tell operator when and what maintenance is needed |

# Chapter 3. Breakout Group #1

Gas turbines are well-known technologies for converting gaseous fuels into electricity and thermal energy. Their principal advantages are relatively low emissions and high-quality heat. These attributes make gas turbines prime options for clean energy generation, particularly through the addition of heat recovery equipment, combined cycle designs, and combined heat and power applications.

Advances in these areas have been obtained in large-frame turbines, but have not yet been adapted to smaller, distributed systems. There are unique technical challenges in the smaller size ranges that have yet to be fully addressed.

In looking to the future of gas turbines, it is expected that the level of competition among alternative energy conversion devices will increase. Reciprocating engines will be a primary competitor, as will fuel cells, and solar and wind energy devices. The public benefits that can be obtained from the increased use of gas turbines – e.g., low emissions and high-energy efficiency – warrant continued efforts to develop advanced designs.

### Group 1 Participants

| Name | Organization |
|---|---|
| Larry Alford | Austin Energy |
| Chuck Berry | Gas Technology Institute |
| Bill Day* | South Carolina Institute for Energy Studies |
| Mike Donovan | Solar Turbines |
| David Godfrey | Manufacturing Resources Inc. |
| Debbie Haught | U.S. Department of Energy |
| Bruce Hedman | Energy and Environmental Analysis, Inc. |
| Jim Kesseli | Ingersoll-Rand |
| Krishan Luthra | General Electric |
| Neil McDougald | Alzeta |
| Dave Richerson | Richerson&Associates |
| Rich Sweetser | Exergy Partners, Inc |

*** Group Spokesperson**

**Facilitator:** Rich Scheer, Energetics Incorporated

The distributed gas turbine system of the future will have a significantly different profile than today's systems. The characteristics of future systems are listed in Table 3-1. For example, future systems will have much smaller environmental impacts, including emissions of nitrogen oxides of less than 3 parts per million (untreated). They will be fuel flexible, with the capability of switching between fossil, renewable, and hydrogen fuels. They will come in user-friendly pre-packaged modules, that customers will be able to custom design to tailor to their specific circumstances, business operations, and energy needs. These packaged systems will feature the seamless integration of thermally activated technologies like absorption chillers for combined heating, cooling, and power applications. The future system will be fully wired and internet-ready for remote monitoring, diagnostics, and on-line maintenance. Through the use of advanced alloys, ceramics, ceramic composites, and nano-ceramics, the future system will achieve significant gains in fuel efficiency in simple cycle mode, and 90%+ fuel efficiency will be common in packaged CHP applications.

There is much research, development, demonstration, and testing that needs to be done to develop clean, efficient, reliable, and affordable distributed gas turbines that can deliver substantial public benefits and compete effectively in the marketplace with

reciprocating engines, fuel cells, solar, and wind energy devices. These needs are outlined in Table 3-2. The primary target of the RD&D is to ensure that the costs of delivered energy services from distributed gas turbines will be 20% less than grid-connected energy services (not including the value of the thermal energy.) Strong government-industry partnerships are needed to accomplish the RD&D and ensure that both public and private benefits are obtained.

The top priority actions to achieve the target include:

- Develop advanced combustion systems to enable ultra-low emissions without after treatment, including such concepts as DLN, catalytic combustion, and trap vortex combustion. These need to have low pattern factors and operations under wet conditions.
- Develop multi-fuel combustor equipment that can use natural gas, coal gas, oil, propane, biogas, methanol, and hydrogen.
- Develop pre-packaged and modular designs that include turbine systems with front-end advanced gas pressurization equipment and back-end thermally activated technologies for maximum fuel efficiency and minimal emissions in combined heating, cooling, and power applications.
- Develop longer life and higher temperature advanced alloys, ceramics, ceramic composites, and nano-ceramic materials for turbines. The manufacturability of these materials on a large scale needs to be built into research plans from the outset to ensure affordable components, sub-systems, and systems.

## TABLE 3-1. CHARACTERISTICS OF THE DISTRIBUTED GAS TURBINE OF THE FUTURE

□= TOP PRIORITY IDEAS

| UTILIZES ADVANCED SYSTEMS DESIGN | INCORPORATES ADVANCED MATERIALS | IS COMPETITIVE IN A WIDE VARIETY OF APPLICATIONS | IS "USER-FRIENDLY" FOR INSTALLATION AND OPERATIONS |
|---|---|---|---|
| • Turbine<br>– Emits <3ppm NOx (untreated)<br>□□□□□□□<br>– Has higher efficiency and performance at competitive costs<br>□□□□□<br>– Uses active clearance control, aero design<br>• Turbine System<br>– Is fuel flexible<br>□□□□□□□<br>– Natural gas, oil, biogas, coal gas, methanol, hydrogen<br>– Is pre-packaged, including CHP variants<br>□□□□<br>– Is easy to connect to the grid<br>□□□<br>– Uses low-cost heat recovery equipment | • Hot Section<br>– Uses monolithic ceramics with improved toughness<br>□□□<br>– Uses nano-ceramics that can withstand higher temperatures, with strength, toughness, and extended life<br>□□<br>– Uses steam resistant components<br>□□<br>– Uses CFCCs with lower cost manufacturing technologies<br>□□<br>– Uses advanced alloys<br>• Recuperators<br>– Uses environmental resistant metals and alloys<br>– Uses environmental resistant ceramics with lower costs<br>• Manufacturability<br>– Uses formable advanced materials<br>□□<br>– Uses joining technologies<br>□ | • Customers can buy modular systems, off-the shelf, with minimal installation costs<br>□□□□□<br>• Customers can buy "custom-designed" systems based on application<br>□□<br>• Have on-site flexible control of electric-to-thermal energy ratio<br>□<br>• Are adaptable to thermally activated devices<br>• Are pre-certified for "plug&play"<br>– Grid interconnection<br>– Environmental siting and permitting<br>– "Appliance rated"<br>• Have net-zero environmental impact (on system basis)<br>• Are fuel flexible<br>• Able to match output to load seamlessly<br>• Maintenance is transparent to customers<br>• Are integrated with energy management systems | • Come pre-packaged for CHP<br>□□<br>• Site maintenance functions moved to factory-based modules<br>□□<br>• Are quick to convert from heating to cooling<br>□<br>• Have remote diagnostics<br>• Have multi-plex system/package functions<br>• Are easy to integrate multiple units<br>• Have modular construction/assembly |

## TABLE 3-2. RD&D NEEDS

### RD&D TARGET: THE COST OF DELIVERED SERVICES FROM DISTRIBUTED GAS TURBINES WILL BE 20% LESS THAN GRID-CONNECTED ENERGY SERVICES (not including the value of the thermal energy)

□= TOP PRIORITY NEEDS

**ROLES**

| **Primary Sponsor:** | | **Primary Performer:** | |
|---|---|---|---|
| G: | Government | g: | government |
| I: | Industry | i: | industry |
| | | u: | universities |
| | | n: | national labs |

| | DESIGN AND MANUFACTURING | MATERIALS | COMBUSTION | SUB-SYSTEMS | PACKAGED SYSTEMS | DEMONSTRATION AND TESTING |
|---|---|---|---|---|---|---|
| **Short-Term (0-3 years)** | • Conduct design studies to determine which alternatives give greatest benefits for various applications in terms of total efficiency (G, i) □□□<br>• Conduct systems studies to breakdown cost drivers of subsystems and components (I, i) □ | | • Develop advanced real-time control algorithms for improved combustion performance (I, i & u)<br>– Emissions<br>– Efficiency | • Develop various recuperator technologies (I, i) | • Develop a portfolio of thermally activated equipment packages for integration with gas turbine exhaust for ultra-efficient CHP (G, i, n, u) □□□□<br>– Absorption chiller package<br>– Water treatment<br>• Choose a few high target opportunity applications<br>• Produce pre-packaged systems (including CHP variants) (I, i) □□□□<br>• Develop low emission supplemental firing technologies (e.g. duct burners) (I, i) □ | • Conduct long term corrosion testing of advanced materials (G&I, i, n) |

| | Design and Manufacturing | Materials | Combustion | Sub-Systems | Packaged Systems | Demonstration and Testing |
|---|---|---|---|---|---|---|
| **Mid-Term (3-10 years)** | • Develop technologies that reduce installation and life-cycle costs of smaller size ranges (G&I, i) □□□□<br>– Including development of advanced manufacturing techniques<br>• Demonstrate low cost fabrication of ceramic components with cooling passages (G&I, i)<br>• Develop protocols to ensure that manufacturability is integrated in all facets of design (G&I, i, near-mid-long term)<br>• Study opportunities for near zero maintenance designs<br>• Research active tip clearance controls | • Develop oxidation/corrosion resistant coatings for high temperature use (G&I/I-N-U) □□<br>• Develop ceramic composites/nano ceramics □□<br>– 1200-1500°C<br>– Stable microstructures<br>– Long life 48,000 hours<br>• Develop abradable coatings (G, i) | • Develop advanced combustion systems to allow < 3 ppm without SCR (G, i, u) □□□□□□□□□<br>– DLN, catalytic, trap vortex<br>– With low pattern factor<br>– Wet cycle technology<br>• Develop multi-fuel combustor equipment (G, i, n) □□□□□□□□□<br>– For fuel flexibility: natural gas, propane, biogas, coal gas, methanol, hydrogen | • Develop recuperators for high pressure ratios and 700-750°C (G&I, i) □□ | • Develop "no worry" gas pressurization systems G, I, n, mid-long term) □□□□<br>• Develop advanced sensors diagnostics and controls for optimizing operations and remote monitoring and maintenance (G&I, i, u) □<br>• Develop advanced and low cost integrated heat recovery systems (I, i) | • Demonstrate system performance and emissions levels of various fuel types, including both high and low Btu (G, i, n) □□□<br>– Create engine testing facility for independent evaluations<br>– Durability<br>– Efficiency<br>– Cost<br>– Operating limitations<br>• Demonstrate ceramics and ceramic composite components (G, i) □□<br>– Characterize materials for testing of advanced ceramics<br>• Test packaged system module to certify subsystems and components (I, i, n) |
| **Long-Term (>10 years)** | • Develop advanced designs that include magnetic bearings (G, n) | • Develop tougher $Si_3N_4$ to >10 Mpa-m$^{1/2}$ (G, i, n, u) □□□<br>– High temperature 1200-1500°C<br>• Long life 48,000 hours<br>• Develop steam resistant alloys for 1500°C environments (G, n, u) | | • Develop direct drive generators and power electronics (G, u) | | |

# Chapter 4. Breakout Group #2

A number of key themes and messages set the stage for discussion about the distributed gas turbine of the future. Government involvement in research, development, and deployment of new gas turbine technologies has been vital to development of the technology thus far, and must continue. Establishment of a true "vision" of the future and accompanying RD&D needs rests on agreed-upon metrics, e.g., cost and efficiency targets, emission levels, and precise markets for these products. In addition, successful RD&D rests on the ability to transfer the technology into the marketplace. State research programs, such as those managed by the California Energy Commission and the New York State Energy Research and Development Agency, rely on technology transfer activities to get new products and systems into real-world environments. The distributed gas turbine of the future will require similar integration into the market to make it competitive with reciprocating engines, and other products fueled by renewables.

**Group 2 Participants**

| NAME | ORGANIZATION |
|---|---|
| Pete Baldwin* | Base-E |
| Mike Batham | California Energy Commission |
| Matt Ferber | Oak Ridge National Laboratory |
| Bob Licht | Saint-Gobain Ceramics |
| Steve Lindenberg | NRECA |
| Bob Oates | Williams International |
| George Touchton | GLT Energy Consultancy |
| Luis Troche | U.S. EPA CHP Partnership |
| Dick Tuthill | Pratt & Whitney |
| Steve Waslo | U.S. Department of Energy |

*** Group Spokesperson**

**FACILITATOR:** JAN BRINCH, INCORPORATED

With these provisos, visionary characteristics of the gas turbine of the future will include:

- Hybrids
- Advanced Heat Exchangers
- Ceramics and other new surfaces and coatings
- Advanced control systems
- Fuel flexibility

Hybrid engines will lead the way in new turbine system designs. In particular, high-pressure nuclear turbines, operated in a combined cycle mode, will capture much of the market. Equally, fuel cell powered hybrids will capture a fair share of the market.

A number of new surfaces and coatings will improve the efficiency and reliability of gas turbines, such as ceramics, "next-generation" composites and alloys.

Advanced control systems will serve an expected "plug & play" marketplace for distributed gas turbines. Other installation and service characteristics will include a move to conditioned maintenance; development of advanced diagnostics and predictive maintenance; real-time pricing; transmission and distribution support for integration distributed generation; reduced emissions; and SCADA systems for managing energy usage.

Fuel flexibility is an important characteristic of the distributed turbine of the future, since reliance solely on gas may jeopardize the cost and availability of this product. Turbines will have to be designed to utilize biofuels, either in gasified or direct-use applications, or other liquid fuels besides gas.

Table 4-1 provides additional detail of Group 2's discussion on the characteristics of the distributed energy turbine of the future.

Research, development, and deployment will rely on continued strong government-industry partnerships that sponsor work in:

- Ceramics
- Catalytic combustions
- Alloy development
- Low-cost sensors
- Low-cost power electronics
- Advanced metallic and ceramic recuperators

For larger gas turbines (>3 MW), RD&D needs to be directed at incremental improvements through better use of materials and processes. Combustion by-products remain a concern, but must be addressed. For smaller machines (<3 MW), RD&D should be focused on fuel flexible cycles, higher temperature metallics, small hybrids, and recuperator materials.

In the short term, research needs to be sponsored on ceramics, Ceramic Matrix Composites (CMCs) and Environmental Barrier Coatings (EBCs) that are reliable and cost-effective. Alloys and other advanced material concepts need to be developed so that they perform at higher temperatures and are cost-competitive. Low cost sensors also need to be designed to further enhance the market competitiveness of turbines for use in distributed generation environments.

In the mid term, the most critical RD&D need is the design of metal, ceramic, and other new recuperator materials. Other important RD&D needs to be done to lower the cost of power electronics, to develop a heat exchanger for small-CHP applications that is reliable and economical, and to design and test biomass-fueled, small gas turbines systems (in the 500-2500 kW range). Finally, basic materials and process research, development, and deployment is still needed in high temperature materials for alternative fuel and combustion conductions.

Table 4-2 provides additional detail on the short-term (0-3 years), mid-term (3-10 years) and long-term (>10 years) RD&D that should be conducted for successful deployment of the distributed turbine of the future.

## TABLE 4-1. CHARACTERISTICS OF THE DISTRIBUTED GAS TURBINE OF THE FUTURE

□= TOP PRIORITY IDEAS

| UTILIZES ADVANCED SYSTEMS DESIGN | INCORPORATES ADVANCED MATERIALS | IS COMPETITIVE IN A WIDE VARIETY OF APPLICATIONS | IS "USER-FRIENDLY" FOR INSTALLATION AND OPERATIONS |
|---|---|---|---|
| • Hybrids<br>□□□□□<br>– High pressure nuclear turbine (comb-cycle)<br>– Fuel cell hybrids (require new turbines)<br>• Develop zero emissions turbine<br>□□<br>– First $CH_4$ and $O_2$ (near term)<br>– $H_2$ and $O_2$ 2030<br>• Develop control system that optimizes customer value (algorithms and control)<br>□□<br>• Advanced bottoming using low quality exhaust heat at low $/kW<br>□<br>• Packaged energy system (electricity, heat, cooling)<br>□<br>– 60% electric efficiency<br>– 95% power and heat and cooling charged to fuel<br>– Factory module assemblies for very rapid installation and maintenance<br>– Design 100,000 hour life turbine core (including recuperator) 2040<br>• Rich or lean catalytic combustion with <3 ppm<br>□<br>• Future<br>– $CO_2$ sequestration<br>– Air separation<br>– $H_2 + O_2$ turbine need Roadmap for 2030<br>• Liquid fuel conditioning to enable fuel heating increase<br>• Develop plug&play small CHP systems<br>• Single shaft design low pressure ratio 1000°C turbine inlet temperature<br>• Develop robust catalytic combustion < 2 ppm without after-treatment | • Prime reliant surfaces (thermal and environment)<br>□□□□<br>– New coating materials<br>– Surface modification technologies<br>– Design methodologies<br>– Remaining life assessments<br>– Repair – techniques (refurbish coatings)<br>• Reduce turbine chargeable cooling air to raise efficiency through ceramics and other advanced materials<br>□□□□<br>– Cooled ceramics<br>– Next generation monolithics and composites<br>• Cost effective manufacturing<br>□<br>• Alloy development<br>□<br>• Materials for power electronics ("inside the box")<br>• Cost effective high temperature high performance heat exchangers<br>– Metal<br>– Ceramic<br>• Cycle development<br>• Materials for tolerance control and internal effects | • Advanced control systems<br>□□□<br>– Control system to help in plug& play application<br>– Move to conditioned maintenance<br>– Develop advanced diagnostic and prediction for maintenance<br>– Real-time price and cost<br>– T&D support to integrated DER<br>– Reduce emissions from turbines in design of hot control units<br>– SCADA to aggregate energy in the system | • Fuel flexible turbines in available settings<br>□□□<br>– Biofueled gasifier or direct fired<br>– Liquid fuel turbines<br>• Match turbine to chemical, petrochemical, aluminum, glass<br>□<br>• Small turbine on trailer to move to service loads<br>• CHP in various settings<br>• Demand response applications<br>– Peaking energy replacement<br>– Respond to frequent thermal cycles<br>• Stand alone residential applications<br>• Power quality applications<br>• Power reliability (replace UPS)<br>• Small sizes and recuperated<br>– Catalytic oxidation development |

## TABLE 4-2. RD&D NEEDS

□= TOP PRIORITY NEEDS

| ROLES | | | |
|---|---|---|---|
| **Primary Sponsor:** | **Primary Performer:** | | |
| G: Government | g: government | u: universities | |
| I: Industry | n: national labs | i: industry | |

| | MATERIALS AND PROCESSES | INTERNAL COMPONENTS | INSTRUMENTATION AND CONTROLS | AUXILIARIES AND BOP | COMBUSTION | SYSTEMS | POLICY |
|---|---|---|---|---|---|---|---|
| **Short-Term (0-3 years)** | • R&D: Ceramics, CMC's, EBC's □□□□□□ (G, u, n, i)<br>– Reliable, robust and cost-effective ceramic processing<br>– Oxide-oxide composites<br>– Next generation monolithic SN & SiC<br>• Alloy development □□□ (G, n, u, i)<br>• Manufacturing process developed for advanced design/material concepts – affordable $ □ (G, u)<br>– Improved high temperature joining of ceramics and metals | • Liquid fuel heating □ (I, i) | • Low cost sensor program □□□ (G, n, u)<br>• Secure SCADA replacement □ (G, i) | | • Catalytic combustion □□□□ (G, I, i)<br>– Catalyst life 30,000 hours<br>• Development and demonstration, higher temperature, longer life, lower cost, $CH_4$ oxidation catalyst | | • Policy<br>– Determine requirements for turbine of the future, then develop it (like Advanced Turbine Systems) (e.g., hybrid that fits large market need)<br>– Develop mission statement<br>– Develop stretch goals that warrant the effort<br>– Expected outcomes<br>o Strategic quality of life<br>o Strong economics<br>o Competitiveness<br>– Market analysis<br>– Quantify Benefits<br>– Justify government involvement |

| | MATERIALS AND PROCESSES | INTERNAL COMPONENTS | INSTRUMENTATION AND CONTROLS | AUXILIARIES AND BOP | COMBUSTION | SYSTEMS | POLICY |
|---|---|---|---|---|---|---|---|
| **Mid-Term (3-10 years)** | • Develop TBC which has thermal conductivity ~ to state-of-the-art $ZrO_2$ but has temp capability → 2800°F □□ (G, I, u, n, i)<br>• Accelerated environmental testing of high temperature materials for alternative fuel and combustion conditions □ (G, n)<br>– RD&D for materials with improved high temperature props in high $H_2O$ gases<br>• GT atmosphere – ceramic surface optimization to increase component life □ (G, i) | • Recuperator materials and design methodology □□□□ (G, n)<br>– Metal<br>– Ceramic<br>– Other<br>• Liquid fuel heating used for cooling components □ (I, i)<br>• Cost effective mag bearing R&D (small sizes) (I, i)<br>• Advanced mag bearings for core engine<br>• High temperature metallic alloy recuperator<br>– Cost effective<br>– High performance | • Neural network development and demonstration for heating/cooling/ electric real time economic dispatch (G, u, n) | • Lower cost power electronics development □□ (I, i)<br>• Develop heat exchanger for small CHP applications that is reliable and economical □□ (I, i)<br>• Advanced bottoming for low quality exhaust heat □□ (I, i, n) | • Advance the control capabilities of turbines to reduce emissions, O&M cost, cost of electricity □□□ (G, i)<br>• Field test zero emission turbine using $O_2 + CH_4$ leading to $H_2$ fuel (collect $CO_2$) □ (G, i) | • Biomass fuel small GT (500-2500 kW) systems □□ (G,i)<br>– Gasified<br>– Direct fired<br>• Small GT coal based fuel concept (500 kW-2500 kW) CHP/powe r quality □□ (G, I, mid-long term) | • Regulatory "How do we get utility to like cogen?<br>• Technology transfer helps utilities and customers understand turbine opportunities by creating analytic tools and tutorials<br>– Transfer results of successful demonstrations via regional application centers (i.e., Midwest CHP Center)<br>– Focus presentations on D&D results to end-user commercialization groups (i.e., CADER, USCHPA, etc.)<br>• Use standard testing protocols, document results via joint demos (ASERTTI)<br>• Technology transfer |

| | MATERIALS AND PROCESSES | INTERNAL COMPONENTS | INSTRUMENTATION AND CONTROLS | AUXILIARIES AND BOP | COMBUSTION | SYSTEMS | POLICY |
|---|---|---|---|---|---|---|---|
| **Long-Term (>10 years)** | | | | | | • Gas turbine for F/C hybrid 500-2500 kW GT, 2000-10,000 kW system SOFC 1000°C unaugmented □□ (G, I, n)<br>• Turbine powered by helium gas-cooled nuclear reactor □□ (G, I, n) | opportunities, conditions in petrochemical industry |

# Chapter 5. Breakout Group #3

The small gas turbine of the future can achieve many public benefits. These benefits include:

- adding value to the grid,
- diversifying and reducing fuel use,
- enhancing energy security and assurance,
- stabilizing the energy economy, and
- achieving near-zero emissions (including carbon).

These public benefits will not be achieved by the small gas turbine of the future without public investment in research, development, demonstration (RD&D) and technology transfer activities.

## Group 3 Participants

| NAME | ORGANIZATION |
|---|---|
| Jeff Abboud | Gas Turbine Association |
| Richard Brent* | Solar Turbines |
| Kevin Burns | Precision Combustion |
| Steve Freedman | Consultant |
| Patricia Hoffman | U.S. Department of Energy |
| Jay Keller | Sandia National Laboratory |
| Harry Morehead | Siemens Westinghouse |
| Dave Stinton | Oak Ridge National Laboratory |
| Sep Van Der Linden | Brulin Associates |

*** Group Spokesperson**

**FACILITATOR:** DAN BREWER, ENERGETICS, INCORPORATED

These RD&D and tech transfer activities involve more than just the Department of Energy, they depend on communication and collaboration between Congress, EPA, FERC and state/local agencies. In addition to intergovernmental synergism, competitors must have pre-commercialization communication- a process that DOE is in a position to facilitate. Transitional R&D is needed to meet the long-term goals of the small gas turbine of the future. There is not going to be one "savior" activity that will achieve the vision of the future. Finally, fundamental research requires national laboratory and university participation.

On these premises, the gas turbine of the future will have integrated sensors, diagnostics, and controls. These electronics will be wireless and smart, interacting with computational models. The gas turbine of the future will also be fuel flexible and have standardized, common interface points with the grid. These overarching characteristics include goals that need to be achieved throughout all aspects of the turbine: from individual component development through system design and operation.

In addition to these overarching characteristics, the small gas turbine of the future will have:

- Ultra-low emissions
- High-temperature composites
- Capability of being fully integrated with the grid

Ultra-low emissions are necessary for the gas turbine to meet the ever-increasingly stringent air emissions. NOx regulations are becoming tighter across the United States and $CO_2$ emissions may become heavily regulated. Turbines can reduce their NOx emissions by catalytic combustion of the fossil fuels. Both NOx and $CO_2$ emissions can be reduced by lean premixed pre-vaporized combustion and by enriching the fuel stream with hydrogen fuel.

Composites that can handle temperatures greater than 1250°C and/or complex shapes will improve the efficiency of the turbine, as well as the operation and maintenance of the turbine

The small gas turbine of the future will be fully integrated with the grid. They may operate in a base load operation. The turbine will serve as a component of a fully integrated CHP unit that has switchable heat and power operations.

Table 5-1 provides additional characteristics identified by Breakout Group 3 of the future small gas turbine.

The top priority research, development, demonstration, and technology transfer needs for achieving the vision for small gas turbines include:

- Research and development on the manufacturability of composites
- Research and development on modeling system integration, through next generation computational fluid dynamics (CFD)
- Research and development on diagnostics, sensors, and controls
- Regulatory incentives for promising new technology
- Government as the 1st, 2nd, and 3rd adopter of new technology

Composites enable turbines to handle higher temperatures, improving the turbine's performance. Composite materials are proven, but are very costly to manufacture. Research and development on the manufacturability of composites sponsored by industry consortia within the next 3-10 years will help make composites more widespread.

Government sponsored research and development on modeling system integration, through the use of next generation CFD is a top priority need. This medium to long-term work will be performed by national laboratories and universities.

R&D on diagnostics, sensors, and controls will help identify potential problems before they occur. In the long-term controls can, not only identify, but correct the problem, reducing operation and maintenance costs.

In the short-term, small gas turbines could use regulatory incentives to help transfer the new technologies from the laboratory to the marketplace. These incentives include tax and/or emission credits, as well as regulatory flexibility for permitting these new, promising technologies.

Also, in the short-term government acting as the 1st, 2nd, and 3rd adopter of new technology will demonstrate the high-performance technologies.

A complete set of priority RD&D and tech transfer needs can be found in Table 5-2.

## TABLE 5-1. CHARACTERISTICS OF THE DISTRIBUTED GAS TURBINE OF THE FUTURE

□ = TOP PRIORITY IDEAS

| UTILIZES ADVANCED SYSTEMS DESIGN | INCORPORATES ADVANCED MATERIALS | IS COMPETITIVE IN A WIDE VARIETY OF APPLICATIONS | IS "USER-FRIENDLY" FOR INSTALLATION AND OPERATIONS | CROSSCUTTING ISSUES |
|---|---|---|---|---|
| • Lean pre-vaporized premixed combustion (LPP) w/ $H_2$ enriched for NOx control and $CO_2$ control □□□<br>• Ultra-low emissions for NOx and $CO_2$ □□□<br>- Possible catalytic combustion of hydrocarbon fuels to reduce NOx<br>• Integrated Sensors and Controls for the turbine and system □□<br>• Hybrid Systems, SOFC and Turbine<br>• An appliance that is transparent, clean, efficient, integrated system, sensors/controls, fuel flexible, higher RAMD and reduced costs | • Composites that can handle temperatures > 1250°C and/or are complex shapes □□□<br>• Recuperator Materials that are cost-effective and can handle temperatures > 800°C □<br>• Monolithic Ceramics that are: environmentally stable, fracture resistant, and have manufacturability □<br>• Improved superalloy/TBC that are capable handling temperatures > 1500°C<br>• Catalyst supports that are better than metal | • Baseload w/ grid- A fully integrated CHP (w/humidity control) with switchable heat and power □□<br>• Demand response- No gear box, remote operations through information technology, ultra-clean, best-value proposition, interconnection onboard certified/tested and utility desired product □<br>• Utility baseload- high efficiency, low emissions, advanced materials, modularity, information technology/sensors □<br>• Intermediate/peak shaving- high efficiency (not necessarily CHP), ultra-clean, on-board controls, management of bulk purpose<br>• Energy security- low cost, mobile, multi-fuel, readiness mode<br>• Power Quality- Take/shed load handle transients, on-board to handle ac-dc-ac, ups<br>• VOC/contaminant destruction- advanced combustion, materials<br>• Cold/ambient conditions, on board fuel reformation, easily transportable, power density, on-roof/odd location, faster response time, IT sensors integrated | • Have a bi-directional standard- systems are pre-approved for permitting and interconnection □□□<br>• Acceptance of DG/CHP by the real estate and new construction community □<br>• Condition based diagnostic systems □<br>• Plug and Play systems (modules) for installation and service<br>• On-line sensors to support engine diagnostic health system<br>• Wireless Sensors and controls (all electronic)<br>• Self-healing- coatings, materials, and controls | • Integrated sensors, diagnostics, and controls<br>• Wireless (smart), interact with computational models<br>• Common interface points (standardization)<br>• Fuel flexibility |

## TABLE 5-2. RD&D NEEDS

**□ = TOP PRIORITY NEEDS**

| | Research and Development | Demonstrations | Government Incentives | Collaborations |
|---|---|---|---|---|
| **Short-Term (0-3 years)** | • Achieve in-engine ultra-low emissions (G, i, n, u) □□<br>• Bridge between design and manufacturing (design to cost to production) (I, i) | • Government is 1st, 2nd, 3rd adopter of new technology (G, g) □□□<br>• Perform a new building demo project with a designed in GT-CHP system integrated into the "building energy management system" and publicize results (I &G, i) □□<br>• Locate demonstration sites willing to accept unproven technology (I, g) □ | • Regulatory flexibility for promising new technologies<br>• Tax/emission credits or permitting for early adopters (G (EPA), i) □□□□<br>• Incentivize advanced sensors and controls (G, i) | • Consortium for small gas turbine design<br>• Clear channel for communication (e.g. Heat Engine Conference)<br>• Internet components (G, u, i) □□ |
| **Mid-Term (3-10 years)** | • Manufacturability of composites (I, consortium, i) □□□□ | | • Gov't-Industry co-funded new technology risk insurance pool (G, i) □□<br>Gov't backed performance bonds for new technology plants (G, g) □ | |
| **Long-Term (>10 years)** | • Modeling System Integration Next Generation CFD (G, u, n) □□□□<br>• Diagnostics to Sensors and Controls (G, n, i) □□□□<br>• Modular Interconnection standard (I, g) □<br>• Complex composites and shapes (G, i, n) □<br>• Development of next generation "Si3N4" (G, u, n) □ | | • Sustained DOE/public financial support for potential GT advances that offer primarily public benefits (G, i, n, u) □□<br>• DOE advocate appropriate depreciation schedule (G, i) □ | |

**ROLES**

| **Primary Sponsor:** | | **Primary Performer:** | |
|---|---|---|---|
| G: | Government | g: | government |
| I: | Industry | i: | industry |
| | | u: | universities |
| | | n: | national labs |

# Chapter 6. Closing Plenary

Final thoughts by the participants included:

- A set of clear and defensible metrics with solid targets and intermediate milestones need to be developed that can be tracked to assure program advancement.
- Revolutionary technologies should be investigated to attain technology goals.
- Gas turbines are competing with technologies, reciprocating engines in particular, that are raising the bar for efficiency, cost, and emissions.
- The Department of Energy should partner with the California Energy Commission, New York Energy Research and Development Agency, and other state agencies in leveraging future gas turbine efforts.
- Manufacturers, utilities, communication and control suppliers, and other stakeholders should team to provide overall value to the advancement of gas turbines.
- Many of the issues with mid-sized turbines also apply to microturbines and large frame turbines.

# Chapter 7. Conclusions

Distributed gas turbines must be extremely clean by producing very little or no emissions at all without some form of after-treatment. They not only need to be cleaner than what is going on-line today, but must be competitive with future central station generation and adhere to tightening air regulations. Using blends or pure feed stocks of natural gas, coal gas, oil, propane, biogas, methanol, and hydrogen may support the ultra-clean distributed turbine of the future.

Another requirement is to lower manufacturing costs and increase durability of advanced materials. Advanced alloys, ceramics, and composites are one of the keys to greater efficiency and lower emissions through higher operating temperatures. These materials should be capable of sustaining 2500°F and 40,000 hours of continuous operation while being less than 50% the cost of existing materials.

To realize their full potential distributed gas turbines should be packaged with combined heat and power systems. These systems require easy installation and interchangeable components that can be completed by the customer. These turbine systems will also need to be web operated and notify the customer or operator specifically what maintenance is required and when it needs to occur. These turbines will be required to run for over 100,000 hrs without replacement parts.

# Appendix A. Participants

Alzeta Corporation
*Neil McDougald*

APPA
*Michael Hyland*

Austin Energy
*Larry Alford*

base e
*Peter Baldwin*

Brulin Assocaites
*Septimus van der Linden*

California Energy Commission
*Mike Batham*

Energetics, Incorporated
*Daniel Brewer, Jeannette Brinch, Brian Marchionini, Richard Scheer*

Energy and Environmental Analysis
*Bruce Hedman*

EXERGY Partners Corp.
*Rich Sweetser*

Steven I. Freedman, Inc.
*Steven Freedman*

Gas Technology Institute
*Charles Berry*

Gas Turbine Association
*Jeff Abboud*

GE Global Research
*Krishan Luthra*

GLT Energy Consultancy
*George Touchton*

Ingersoll-Rand
*James Kesseli*

MRI
*David Godfrey*

NRECA
*Steve Lindenberg*

Oak Ridge National Laboratory
*Mattison K. Ferber, David Stinton*

Pratt & Whitney Power Systems
*Richard S. Tuthill*

Precision Combustion, Inc.
*Kevin Burns*

Richerson and Associates
*Dave Richerson*

Saint-Gobain Ceramics
*Robert Licht*

Sandia National Laboratories
*Jay Keller*

SCIES
*Bill Day*

Siemens Westinghouse Power
*Harry Morehead*

Solar Turbines Incorporated
*Michael Donovan, Richard Brent*

U.S. Department of Energy
*Debbie Haught, Patricia Hoffman, Merrill Smith*

U.S. Department of Energy – Chicago
*Stephen Waslo*

U.S. Environmental Protection Agency
*Luis Troche*

US DOE FE – NETL
*Richard Dennis*

Williams International
*Robert Oates*

# Appendix B. Agenda

## Distributed Gas Turbine of the Future Workshop

Marriott at Metro Center
775 12th Street NW
Washington, DC 20005

June 3-4, 2003
Washington DC

### Purposes

- To expand on the technology characterization for small gas turbines
- To develop visionary and leap-frog ideas for gas turbines in a sustainable energy economy
- To identify RD&D needs for small gas turbines

### Agenda

**June 3**

5:30 pm Reception at Marriott Hotel hosted by Solar Turbines Inc.

**June 4**

7:30 am Continental Breakfast and Registration

8:00 am Opening Plenary
- Welcome and Introduction, *Pat Hoffman, U.S. Department of Energy*
- Review Facilitation Gameplan, *Rich Scheer, Energetics, Inc.*

8:30 am Plenary Session
- Summary of Technology Characterizations, *Bruce Hedman, EEA*
  - Current status of turbine cost and performance
  - Key technology issues
  - Future cost and performance of turbines

- Facilitated group discussion

  Focus question: *"Imagine yourself in the future where a sustainable energy economy exists. Based on the previous presentation, what modifications would you suggest to the technology characterizations for distributed gas turbines to enable them to contribute to the nation's sustainable energy system? Please indicate what date you think this is possible."*

10:45 am Break

11:00 am Breakout Session #1—Characteristics of the Vision

Focus question: *"What visionary characteristics and leap-frog ideas do you have about the distributed gas turbine of the future?"* These ideas will be put into one of these categories 1) novel turbine system designs, 2) novel use of advanced materials, 3) novel applications, 4) novel use of installation and service, or 5) other.

12:00 pm Lunch

1:00 pm Breakout Session #2—RD&D Needs

Focus question: "*What are the top research, development, demonstration, and technology transfer needs for achieving the vision?*"

3:00 pm Break

3:15 pm Breakout Session #2—Continued

Focus questions:

- *"Who is the primary sponsor for this RD&D need—Government or Industry?"*
- *"Who is the primary performer for this need—Industry, National Laboratories, or Universities"*
- *"When is a commercial product needed—in the short-term, mid-term, or long-term?"*

4:00 pm Group Presentation Preparation

4:30 pm Closing Plenary Session

5:30 pm Adjourn